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THE WEATHER OF THE AGULHAS BANK AND THE CAPE SOUTH COAST

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ABSTRACT

Until 1982, when the National Research Institute for Oceanology (NRIO) erected self-contained, automatic weather stations (AWS) on the Cape South Coast, no **continuous coastal** measurements were available. This Institute had erected an AWS on the drilling rig Sedco K in 1978, so that over 3 years of very valuable offshore data was already available on the adjacent Agulhas Bank. Although the weather offices at George and Port Elizabeth have made accurate meteorological observations for over 30 years, this data is shown here to differ significantly from actual coastal measurements. Thus the NRIO AWS network, which operated for just over a year, provided a detailed, short-term data set for the study of coastal weather processes.

In order to acquire **longer term** data from coastal observations, five years of hourly wind observations from lighthouse keepers along the Cape South Coast were also utilised. Although these are estimates, it is shown that a coastal estimate may be more representative of marine conditions than an anemometer reading some distance inland. Voluntary Observing Ship's data (VOS) extracted from SADCO's Marine Climatology database, provided the long-term **offshore** information, whilst also supplying very useful 'present weather' (synoptic code ww) observations for case studies. Observations from synoptic stations for the period that the coastal AWS were deployed (February 1982 - March 1983), were provided by the South African Weather Bureau.

With this unique and comprehensive data set, the various weather systems affecting the region are discussed. Twelve case studies form the main reference for this discussion, which includes relevant oceanographic parameters. The weather systems are considered firstly as individually propagating circulations with the AWS network providing details of propagation speeds and coastwise development.

Secondly the combined 'weather producing' effects of these systems are discussed, with a strong emphasis being placed on man/weather interactions. It is shown that certain operations along the Cape South Coast and over the Agulhas Bank, are extremely weather sensitive, and would benefit considerably from an increased knowledge of weather processes. Recommendations aimed not only at those managing weather sensitive operations, but also at those involved in coastal meteorological measurement and research, complete the thesis.

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The author would like to thank the lighthouse keepers at Cape St. Francis for their help in maintaining the automatic weather station there. The help of Nature Conservation Officers from the Goukamma Nature Reserve in maintaining the weather station at Walker Point was similarly, much appreciated.

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ACRONYMS/ABBREVIATIONS

Any shortened version of a name, unit, process or phenomenon which has been used in the text, figures or tables, is expanded below. Many of the abbreviations apply only to figures or tables where space was limited. Standard abbreviations are not included in this list.

ABS	Agulhas Bank Studies
AC	Agulhas Current
AOA	Atlantic Ocean Anticyclone
AWS	automatic weather station
BH	blocking high
BOH	bud-off high
CAC	cold air cyclone
cf	cold front
CI	Cape Infanta
cl	coastal low
COL	cut-off low
COL-E	COL giving easterly winds
COL-W	COL giving westerly winds
CSC	Cape South Coast
CSF	Cape St. Francis
CSIR	Council for Scientific and Industrial Research
CT	Cape Town
CYCL	mid-late low undergoing rapid cyclogenesis
E AB	eastern Agulhas Bank
ECMWF	European Centre for Medium Range Weather Forecasting
ENSO	El Niño Southern Oscillation
ERC	energy release component
ESW	extreme storm wave
GOSSTCOMP	Global Operational Sea Surface Temperature Computation
H_{mo}	significant wave height
HFV	HF Verwoerd (airport)
IGY	International Geophysical Year
IOA	Indian Ocean Anticyclone
IR	infra-red (satellite imagery)
LB	land-breeze

ACRONYMS/ABBREVIATIONS (cont.)

LSFT	large-scale frontal trough
M Bay	Mossel Bay
MN	R/V Meiring Naudé
NDBO	NOAA Data Buoy Office (USA)
NOAA	National Oceanic and Atmospheric Administration
NRIO	National Research Institute for Oceanology
NSRI	National Sea Rescue Institute
NWP	numerical weather prediction (model)
PE	Port Elizabeth
PWB	PW Botha (airport)
SADCO	South African Data Centre for Oceanography
SAWB	South African Weather Bureau
SB	sea-breeze
SST	sea surface temperature
synop	synoptic weather observation
T_p	peak energy period
VOS	voluntary observing ship
VHRR	very high resolution radiometer
VIS	visual (satellite imagery)
VTPR	vertical temperature profile radiometer
W AB	western Agulhas Bank
WAVE	frontal system plus wave formation
WMO	World Meteorological Organisation
W Pt	Walker Point
WSS	wind speed sensor

1. INTRODUCTION

1.1 HISTORICAL BACKGROUND AND RATIONALE

In 1981 the author started a project on the Cape South Coast to study the marine meteorology of the coastal belt and the adjacent Agulhas Bank. There were three basic reasons for the initiation of this study: Firstly, the Agulhas Bank Studies (ABS) project, which had just been launched, required a meteorological input. Secondly, the marine meteorology of the region had been generally neglected. Thirdly, it was recognised that certain atmospheric processes could significantly affect human activities in the area. Before any advice could be offered on how best to manage these interactions, a greater understanding of the marine meteorology was required.

1.1.1 Previous Work - Gaps in Knowledge

This was the first study of this type to be done on the Agulhas Bank. Furthermore, no similar studies of any **limited region** could be found in the literature. The only comprehensive study of weather conditions along the Southern African coastline was undertaken jointly by the Royal Navy and the South African Air Force (SAAF) during the second World War (the resulting publication is hereafter referred to as RN, 1944). However, relatively little attention was given to the synoptic systems responsible and most of the emphasis was on providing a general **climatological** picture.

Taljaard (1972) produced a very comprehensive study of the synoptic meteorology of the Southern Hemisphere but the South African zone was treated as a whole, on a much larger scale than that presently considered. Studies of synoptic scale conditions affecting a particular region are usually limited to one particular type of system. Thus, Taljaard (1985) has done research on the cut-off low of Southern Africa. Another example of this approach is Gyakum's 1982 study of explosive cyclogenesis. Preston-Whyte (1973, 1975, 1980) undertook a number of studies concerning the character of the coastal low along the Natal coast. Where researchers have gone from the synoptic scale to actual meteorological and then oceanographic conditions, these papers have generally been restricted to a few case studies, for example, Barstow and Lygre's (1985) study of mid-latitude cyclones generating high swell in the North Atlantic. Studies involving specific events (for example, the cut-off low which produced the 1981 Laingsburg flood - Estie, 1981) have appeared from time to time in the South African Weather Bureau (SAWB) Newsletter, but few have alluded to the effect of such events on the coastal ocean.

In studies where specific meteorological and oceanographic phenomena have been linked, there has been a tendency to limit the meteorological component to a particular parameter, usually the wind field. Whilst some attention is given to explaining local wind anomalies, the role played by weather systems on the synoptic scale has been largely neglected. Thus, Kamstra (1985) has presented a comprehensive picture of the wind field off the Cape West Coast, which is followed in the same publication by Jury, who investigated the wind in the same area but at a mesoscale level in a number of case studies. Schumann et al. (1982) used wind estimates from lighthouses to explain upwelling plumes emanating from several South Coast capes. Again, the synoptic scale circulation responsible for producing the necessary wind field, received relatively little attention.

In the light of the above summary, an approach which emphasises the **synoptic scale circulation** in a broad study of both atmospheric and related oceanographic processes on a regional scale, is seen to be unique. Nevertheless, existing, more specialised research has provided a valuable input to this thesis.

1.1.2 Agulhas Bank Studies

The ABS project was envisaged as a multi-disciplinary project involving physical oceanographers, geologists, biologists and chemists from CSIR's National Reasearch Institute for Oceanology (NRIO). It was recognised at an early stage that the atmosphere over the Bank (and even far beyond), had an important role to play in virtually all coastal processes and so a meteorological study was launched within the Physical Oceanography Division at the NRIO. Unfortunately, due to insufficient financial support, the ABS project never really assumed a truly multi-disciplinary character. The meteorological component carried on independently, however, forming the basis of this thesis.

The atmospheric parameter of most interest to the other disciplines involved in ABS was the wind field over the coastal ocean. Whereas most meteorological studies providing support for parallel ocean measurement tend to ignore the synoptic situation, it was felt that there would be all round benefit from a knowledge of the **origins** of particular wind patterns. The synoptic scale system is the linkage between a variety of phenomena, and a particular discipline may well be interested in a combination of meteorological parameters.

1.1.3 Weather Sensitive Operations and Activities

Few human activities are totally independent of atmospheric processes. Extreme wind events, for example, may affect a large proportion of the population depending on their severity. Similarly extreme rainfall events such as the cut-off low of September 1968 (Hayward and Van der Berg, 1968) which caused extensive flooding in Port Elizabeth. Extreme swell events have been shown to affect shipping on the Agulhas Bank in various ways (for example, Hunter, 1979).

But even the day to day atmospheric processes cannot be ignored in certain areas of work: To those combatting an oil spill encroaching on the coast, the everyday **wind field** suddenly assumes immense importance. Wind induced currents have also been shown to be of vital importance to the transportation of anchovy eggs and larvae (Shelton and Kriel, 1980). Sedimentologists, trying to set right man-made imbalances in the flow of sand along the coastline, also need a knowledge of the coastal wind field.

Other areas requiring not only a knowledge of present wind conditions, but also an accurate prediction of future conditions include the Forestry Department, (Siddons et al., 1985), and the tourist industry, (Smith, 1961). Those seeking out suitable sites for wind turbines need long-term wind data (Diab, 1984) and should this means of generation become a reality, predictions will be required for short-term planning purposes. Although the primary parameter required by any ship routing service is waves, the local wind field may also provide an important input, (Mackie, 1981).

Fog may drastically affect many modes of transport, with shipping required to reduce speed and airports sometimes closed. Helicopter support for the offshore industry may be grounded. When the necessary precautions are not taken, considerable loss of life may occur (for example, SA Shipping, September 1972). Other atmospheric phenomena such as **hot berg wind conditions** may encourage combustion, whilst **thunderstorms** may initiate fires on the coast and even possibly offshore where tankers in ballast may contain highly flammable gases if cleaning is not done properly. SOEKOR is involved in offshore drilling operations which are also sensitive to atmospheric phenomena and capable of producing widespread marine pollution in the event of extreme storm damage after a 'strike'.

An area of activity which will require considerable knowledge of local atmospheric processes both present and future is that of **industrial development.** This includes coastal developments which involve industrial processes introducing pollutants to the atmosphere, and developments offshore such as the fixed gas production platform planned by SOEKOR. The Cape South Coast could well be the site of South Africa's next nuclear power station and atmospheric processes will be of both direct and indirect importance. Accurate prediction of the likely path to be followed by any radioactive leak is a very desirable capability. But the ability of the local sea-water to absorb the heat generated by such a plant, is also a function of the local wind field, due to upwelling effects.

When local authorities are considering plans for **new developments** in the coastal zone, it is imperative that various atmospheric and related oceanographic processes be taken into account. These include not only design conditions such as maximum flood, wind speed or sea-water levels, but also day to day processes. For example, prevailing westerly winds will ultimately be the undoing of any building situated in an active dune field, as the dunes inevitably move downwind. This type of impact of atmospheric processes on both industrial and residential developments in the coastal zone, has been depicted in Heydorn and Tinley (1980).

Finally, it should be pointed out that atmospheric processes over the Agulhas Bank may have a significant effect on the weather over much of the sub-continent. The regular passage of migratory or bud-off high pressure cells, is an example. These highs have to cross the Bank as they separate from the Atlantic Ocean Anticyclone (AOA) and gain a considerable amount of moisture from the Agulhas Current as they journey around the coast. Their effects are felt as far north as Zimbabwe where the presence of the high off the east coast results in the influx of a relatively shallow layer of very moist air known locally as the 'Guti'. Thus, it is not only human activities in the immediate vicinity which are affected by atmospheric processes on the Agulhas Bank, but also those much further afield.

1.2 THE AIMS OF THE THESIS

Having justified the initiation of a study of the marine meteorology of the Cape South Coast and its continental shelf waters, the aims of such a study can be defined. Three primary aims were identified:

(a) To identify all the various weather processes which influence the waters of the Agulhas Bank and the adjacent coast. Special emphasis would be placed on linking these processes with synoptic scale systems, where this is justified. New data collected during the ABS Meteorology project, particularly automatic weather station (AWS) data, would provide a major input to this study. It would be augmented by all other existing data.

(b) To show how the synoptic weather systems, through their associated weather processes, may significantly influence various human activities on the Cape South Coast and offshore.

(c) To indicate those areas where the existing knowledge together with the new information uncovered by this study could be of use in various coastal and offshore operations, and make recommendations concerning future data collection programs and applied research.

1.3 THE STRUCTURE OF THE THESIS

The basis for this study has now been presented and its primary aims stated. The next section (1.4) of **Chapter 1,** describes the geographical area covered by the thesis, whereafter the availability of meteorological data is considered. The chapter concludes with an introduction to the synoptic scale systems.

Chapter 2 - Climate. This chapter comprises a discussion of long-term patterns in the atmosphere and coastal ocean of the Agulhas Bank. It uses the longer time scale data to define the mean condition for each parameter as well as its seasonal and in some cases diurnal variation. However, the short-term AWS data also plays a prominent role in this chapter in that it is the only measured data directly applicable to the coastal region. It also had a relatively high sampling rate (every 15 minutes). Apart from providing seasonal wind roses, it is used to give some indication of the range of values experienced on the coast and offshore. Note that **extreme** conditions have also been considered a part of the general climate. VOS data is used extensively to give an indication of the range of values that meteorological parameters may assume offshore.

Chapter 3 - Case Studies. Weather patterns on the Bank are dominated by so-called 'basic cycles', with disruptive perturbations modulating the standard sequences. On this basis the first case study is devoted to looking at a winter weather cycle, whilst the second considers a summer equivalent. The following 10 case studies, each of which is based upon one week's data from one or more automatic weather stations, were selected to portray weather conditions associated with a particular synoptic event. Anomalous weather patterns dominate this selection, although most events were chosen for their impact on human activities in the region. In each case study the role played by **all** the relevant synoptic systems is discussed. Propagation speeds are calculated where possible and cases of coastwise development highlighted. Mesoscale circulations, linked to synoptic scale events, are considered in some detail and oceanographic conditions are also described, where such information is relevant and available.

Chapter 4 - Synoptic Scale Systems. These all-important weather systems are discussed in detail, by drawing upon relevant publications and including the information contained in the case studies. Both the mesoscale circulations and the wide variety of weather conditions associated with each system, are included in the discussions.

Chapter 5 - Man/Weather Interactions. This chapter discusses selected issues focusing on the effects of both atmospheric and coastal ocean processes on certain human activities. In some cases additional data and analyses are introduced in order to enhance the discussion. Thus it is in this chapter that both the first and second aims of the thesis are realised, that is, consolidation of knowledge concerning the relevant natural processes and their impact on human activities.

Chapter 6 - Summary and Recommendations. A number of coastal and offshore operations/activities are chosen to illustrate how many coastal and offshore activites may benefit from the study described in previous chapters.

Chapter 7 - Recommendations for Future Research. This final chapter provides, firstly, recommendations concerning the need for an expanded data collection network. Further recommendations concern those aspects of the synoptic scale systems and their related weather elements which merit further research.

1.4 GEOGRAPHICAL AREA COVERED BY THIS STUDY

The Cape South Coast is taken here as that stretch of coastline from Cape Agulhas (longitude 20°E) to Cape Padrone (26°28'E), at the eastern extremity of Algoa Bay (Fig. 1.0). The Agulhas Bank is that section of the continental shelf which is shown to bulge southward off the Cape South Coast, as far as the 200 m isobath. A major oceanographic feature which is not indicated on Fig. 1.0 but easily located by means of the 200 m isobath, is the Agulhas Current. The core of the current is usually found just seaward of this contour, but satellite imagery shows clear evidence of warm water from the current intruding frequently onto the shelf in the form of surface filaments and separate eddies.

Fig. 1.1 shows the major topographical features and also places the various sources of data in relation to these features. The term 'coastal' will be used here to refer to that strip of land, adjacent to the coastline, extending as far inland as the first major range of mountains. This strip is over 100 km wide in the west where the Langeberg Range marks the coastal limit, whilst the Outeniqua Range restricts the coastal strip to approximately 10 km in the region from George to the eastern extremity of the Tsitsikama Mountains. In the east, the coastal range, now the Kareedouwberge, peters out west of Cape St. Francis. The Groot-winterhoekberge, further inland, terminate approximately 50 km northwest of Port Elizabeth.

The coastal AWS sites, manned lighthouses and the position of the two weather offices operated by the SAWB, have also been indicated in Fig. 1.1 (see legend).

Note that whilst the present study was restricted to the designated area as far as actual weather observations are concerned, the relevant synoptic scale systems were often hundreds of kilometres away. With regard to these systems it was thus necessary to consider a much greater area.

1.5 DATA SOURCES

1.5.1 Automatic Weather Station (AWS) Data

Recognising from the outset that this was a data sparse region, it was decided to erect automatic weather stations both on the coast and offshore. Although an AWS had been in operation on the Sedco-K, drilling mainly south of Mossel Bay for four years, this was the first deployment of such a **coastal network** and the first time that a continuously recording **shipboard AWS** was operated in this region. Apart from the general scarcity of meteorological data, it was found that prior to the deployment of any AWS, most of the available measurements were too far inland to be of any real use, since they reflected landward rather than marine conditions.

Each of the 3 coastal AWS was equipped with an anemometer, wind direction sensor, air pressure sensor and temperature sensor. The air pressure was a particularly accurate sensor (rated net accuracy ± 0,5 mb), which had recently been developed. The AWS at Cape Infanta and Walker Point had an identical configuration with all the sensors mounted on a T piece, 5 m above ground level. This coastal network was in operation from February 1982 to March 1983, and provided the first concurrently **measured** wind data of truly coastal origin.

Cape Infanta. The AWS was actually located at Uiterstepunt which is some 2 km south-west of Cape Infanta (see Fig. 1.2) and approximately 8 km to the south of the Breede River mouth. This AWS location, at the top of a 30 m cliff (actual height of sensors above sea level was 34 m), was subject to considerable turbulence at times. Thus, it was decided not to attempt to reduce wind speeds to the standard 10 m level. To the north-west of the AWS the Potteberg rises to over 240 m. The Langeberg Range is approximately 60 km to the north across the coastal plain - over 1 600 m above sea level in places.

Walker Point. This was an ideal measuring site, being located on a relatively low peninsula 3 km south-east of the Goukamma River Mouth, with prevailing winds reaching the station after only a few metres of overland track (Fig. 1.3). The sensors were 13 m above sea level so no reduction of wind speeds was deemed necessary. The nearest high ground of significance lies approximately 4 km to the north between the Goukamma River and the Knysna Lagoon - reaching up to 227 m above sea level. To the north, the major peaks of the Outeniqua Range rise to over 1 450 m, some 30 km from the AWS site.

Cape St. Francis. With the exception of the pressure sensor which was located in the watchroom, all sensors were mounted at 40 m above sea level, some 2 m above the lighthouse dome. The lighthouse is actually located at Seal Point, 3,5 km south-west of Cape St. Francis (see Fig. 1.4). The mouth of the Kromme

River is approximately 8 km to the north. The surrounding countryside is gently undulating with the nearest mountain range, the Kareedouwberge (an extension of the Tsitsikamma Mountains), having its eastern extremity 35 km to the north-west of the lighthouse. To the north, the Groot Winterhoekberge reach 536 m, some 70 km from the lighthouse.

Wind speeds at Cape St. Francis were reduced using a multiplication factor of 0,86 which resulted from using a roughness length (Z_O), of 0,005 m in the standard logarithmic profile equation (Changery, 1982). (For more details on the choice of Z_O, see Appendix 4).

From the above description, it will be seen that both Walker Point and Cape St. Francis were well exposed sites for the measurement of the coastal atmosphere. The Cape Infanta site was less suitable due to the rugged coastal terrain. In total, the three sites provided for the first time, a continuously recording network for the observation of weather systems traversing the region.

Pressure records from Storms River Mouth. Although not strictly an automatic weather station, a barograph was provided to the National Parks Board at the Tsitsikama Coastal National Park, and barograms were available for the period May 1982 to February 1983. These were used mainly for checking the continuity of coastal pressure systems between Walker Point and Cape St. Francis.

Rig AWS data. This data came initially from Sedco-K which was instrumented in June 1978 and continued to gather data at various well sites on the Bank until April 1984. Instrumentation was virtually identical to that used on the coastal AWS except that air temperature was not measured on the Sedco-K.

The Actinia started drilling on the Bank in mid 1983 but was only equipped with an AWS in January 1984. Temperature and pressure sensors were of Theodor Friedrichs (T.F.) manufacture, but both wind speed and direction sensors were Aanderaa as on the other AWS. A T.F. water temperature sensor gave sea temperatures approximately 15 m below the surface on either a port or starboard caisson.

Wind direction and wind speed sensors were located at 73 m on the Sedco-K, and 84,5 m above sea level on the Actinia. Reduction of these winds to the standard 10 m height, is a problem which is discussed in the Appendix 4. Although both rigs have spent most of their time in an area roughly south of Mossel Bay, data is also available from well sites on the eastern Agulhas Bank.

R/V Meiring Naudé. Since the initial ABS cruises in 1982, the Meiring Naudé collected various data on the Agulhas Bank each summer with an additional winter cruise in August 1982. On each occasion an AWS was mounted on the ship. A tap was taken off the ship's gyro repeater and off the log in order to calculate a true wind vector (in actual fact w.r.t the water). SST was obtained by direct measurement of the water sampler supply and later by also tapping the ship's SST sensor, mounted in the bow. Attempts to measure relative humidity were not very successful, due mainly to salt contamination and early failure of the only humidity sensor available. Apart from air pressure and SST, the sensors were all mounted on a crossbar attached to the after mast, 9,7 m above sea level. On the 1984 cruises, an anemometer and temperature sensor were also mounted on the bow of the vessel. This AWS was often the only source of nearshore data since commercial shipping generally keeps well offshore along most of this coastline.

1.5.2 Other Data Sources

Voluntary observing ship (VOS)-data. The SA Data Centre for Oceanology (SADCO), maintains a comprehensive database of Voluntary Observing Ship (VOS) Data which covers the period 1960 to 1985. The eastern Agulhas Bank is particularly well covered, with the degree square around Cape St. Francis having more reports than any other around SA (13 270). This was the first time that a large volume of VOS data was used in this type of study. A full discussion of the VOS data appears in Appendix 1.

Hourly wind estimates from lighthouses. This data set was extracted from the original logs for the years 1976-1980 inclusive, and made available in edited form on the CSIR Cyber 750 computer. Climate studies in this region had previously been based upon long-term data from George and Port Elizabeth. Despite the drawback of the winds being estimated, this data set was of considerable value as it was the first relatively long-term set of wind data from truly coastal sites. For further details of this data consult Appendix 2.

Hourly wind measurements from the airports. The only real use made of this data was in comparisons with coastal and offshore AWS data. The poor showing of this data as an indicator of coastal conditions (see Appendix 3) did not justify its further usage where an alternative was available.

Coastal synoptic stations. The lighthouse keepers at Cape St. Blaize and Cape St. Francis provide a full synoptic observation (synop) to the Pretoria forecast office every 3 hours except for the 23h00 intermediate synop. Cape Agulhas provided a synop at the following main synoptic times only: 08h00, 14h00 and 20h00. All this synoptic data was obtained for the main study period - that is, February 1982 to March 1983 inclusive. Note that this data was the only source of present weather information such as precipitation or fog, **on the coast.**

Sea-surface temperature (SST) Data. Mr Ben Sciocatti of the D F Malan Meteorological Office has been collecting surf temperatures and quayside water temperatures from various organizations along the South African coastline for over a decade. Data was obtained from him for the following stations for 1982 and 1983 - Stilbaai (1 reading per day), Knysna (1) and Humewood, Port Elizabeth (2).

Daily weather bulletins. Extensive use has been made of this monthly publication from the South African Weather Bureau (SAWB) which includes the daily 14h00 synoptic charts, maximum and minimum temperatures and 24 hour rainfall figures.

Satellite imagery. An incomplete set of visual and thermal infra-red imagery from Meteosat 1 and 2 was obtained from the D F Malan Meteorological Office. Unfortunately coverage was particularly poor in 1982, but the full set was available for viewing in Pretoria, where the imagery coinciding with some of the case studies was consulted.

1.6 INTRODUCTION TO THE SYNOPTIC SCALE SYSTEMS

Considerable emphasis is placed on the various synoptic scale systems which are responsible for the region's weather and thus also its climate. These systems are introduced at an early stage so that they will be familiar elements by the time they are referred to in the next chapter. The standard sequence for synoptic scale systems on the Agulhas Bank is: coastal low - frontal trough (it may pass unnoticed, well to the south) - bud-off high - coastal low, etc. However, as will be seen in the first case study of the next chapter (winter basic cycle), a series of cold fronts may replace the single front in the ideal case; or there may be no well-defined bud-off high in between the coastal lows.

1.6.1 Definitions

A count of the different synoptic scale systems appearing in each month from February 1982 to March 1983 is summarized in Table 1.1. This count is based on the daily 14h00 surface charts of the SAWB and their supporting summaries (inferences). The count should be viewed as a qualitative indication since apart from the large gap between charts (24 hours), no upper air data was available. Nevertheless, counts may be regarded as accurate to within 1-2 systems per month in the case of coastal lows, fronts and bud-off highs, while the less common, dominant systems are not easily missed. Counts included those fronts which passed south of the Bank as well as blocking highs and cut-off lows which, though they may have been geographically distant from the Agulhas Bank, still had a significant effect on its weather. It must be stressed that these definitions were formulated purely to facilitate the identification of synoptic scale systems from the 14h00 surface pressure analyses:

Coastal low. This required a closed low pressure system on the coast or close to the coast if it had recently moved offshore. There must be no mention in the 14h00 inference of upper air support, that is, in the form of an upper air trough or closed upper low. There must be no significant precipitation associated with the system, apart from the normal interior thunderstorms of summer, moving onto the coast. Note that a single coastal low had only to appear **somewhere** on the Bank to be counted; several may never have appeared on the western Agulhas Bank.

Cold fronts. This term was applied very generally to typical frontal troughs, waves and even lows with no analysed front, so long as it was linked to a frontal trough to the south. A frontal trough followed by a wave development on the same front counted as two cold fronts.

Bud-off highs. This category included all migratory highs spawned from the Atlantic Ocean Anticyclone (AOA) which moved around the coast, eventually merging with the Indian Ocean Anticyclone (IOA) in the east. Systems which only appeared on the eastern Agulhas Bank after the AOA had ridged overland were also counted, as were highs passing well south of the Bank but north of 50°S (the southern limit of the published synoptic charts).

Blocking highs. A migratory high, originating in a ridge of the AOA or even moving in from south of Gough Island, which became 'stuck' for more than two days south or southeast of the Bank, was termed a blocking high.

Cut-off lows. This was taken to be a deep system which had its origins in a frontal trough but was now cut off by a ridge to the south. It could have appeared anywhere over the southern parts of the sub-continent or off the west, south or south-east coast and still have had an effect on the Agulhas Bank. To distinguish between a cut-off low (COL) and a coastal low, inferences were checked for mention of the upper air situation. Widespread precipitation also immediately excluded the coastal low.

Deep coastal low. This refers to the case where a coastal low is supported by an upper trough, so that uncharacteristic cloud cover may be observed and even precipitation. However, there must have been no mention of a **closed low** in the upper atmosphere.

1.6.2 Monthy Counts

Coastal Lows. Counts varied from 7 in September and November 1982 to 15 in January 1983. No seasonal pattern was evident. Roughly 10 systems per month appeared on the Agulhas Bank. Compare this with the Natal Coast where a similar study over a five year period (Hunter, 1984) gave an average of only 7 coastal lows per month. This disparity is presumably due to the observed phenomenon of coastal lows filling up or even leaving the coast between Port Elizabeth and Durban (Hunter, 1984).

Cold fronts. On the whole the cold front count was > the coastal low count, since a single coastal low may be linked to more than one front as it moves around the coast. Again, there was no seasonal pattern, the highest count appearing in December (19), with the lowest in October (7). The average was roughly 12 per month.

Bud-off highs. Except for July 1982, the bud-off high count was < the coastal low count. This ties in with the common observation that more than one coastal low passage may occur between bud-off highs. Average frequency was about 6 systems per month.

Blocking highs. In agreement with the long-term pattern (Taljaard, 1972) blocking was most frequent in autumn and spring. April had the highest count, namely 4.

Cut-off lows. These low pressure systems with a deep, cold core circulation, are normally twinned with a blocking high to the south. However, the two do not always go together as the monthly counts testify. As might be expected, maximum counts occur in autumn and spring. Taljaard (1985) found an average of 10,7 cut-off lows per annum for the period 1973 - 1982. His count for 1982 was considerably lower than the present count (13 versus over 21), but still had 1982 with one of the highest counts in the 10 year period. Note that his area was restricted, extending only 5^{o} off the west and east coasts.

Deep coastal lows. There were very few counts in this category, it being intermediate between the shallow coastal low and a cut-off low on the coast. Nevertheless, it was felt necessary to retain this category to distinguish between closed upper low and upper trough cases. The former situation is associated with more severe weather conditions.

2. CLIMATE

2.1 INTRODUCTION

This chapter focuses on mean conditions and the range of values which meteorological and related oceanographic variables may assume on the Agulhas Bank and the adjacent coastal belt. Apart from providing an insight into the long-term meteorological situation, the information also sets the scene for the short-term case studies of day-to-day weather processes discussed in the next chapter.

In order to describe the climate of a particular region, weather observations covering as long a period as possible are accessed, analysed and summarised. This chapter makes use of all available summarised data to describe the climate of the Cape South Coast. This description is structured according to a typical synoptic report from a coastal station or vessel offshore, that is, Winds - Air temperature - Visibility - Cloud (and Sunshine) - Sea-level pressure - Humidity - Precipitation - Sea surface temperature (SST) - Sea and Swell. The intention is to provide the reader with a general idea of meteorological conditions on the Cape South Coast - average and extreme. Where possible, seasonal and even diurnal distributions of certain parameters are given.

2.2 CLIMATE CLASSIFICATION ACCORDING TO KÖPPEN

The symbolic combination Cfb was chosen by Köppen (Haurwitz and Austin, 1944) to designate those regions with a temperate rainy climate (C), moist in all seasons (f), with a warm summer (b). More specifically, this classification requires that the driest month receive more than 30 mm mean rainfall and that the warmest monthly mean temperature be below 22°C. This classification is shown to apply to a broad belt encircling the mid-latitudes of the Southern Hemisphere, though having relatively little representation on the three continents. Most of the Cape South Coast falls into this classification, although parts of the coastal belt west of Mossel Bay must be excluded due to their aridity.

2.3 WIND

The various sources of wind data were identified in Chapter 1. Although the coastal AWS data covered too short a period to provide climatic means, it did give an idea of the range of values to be expected on the coasts.

VOS data provided by far the largest volume of offshore data but in most cases wind is estimated and this data is by no means continuous in time. The drilling rig, Sedco-K, provided the only semi-long-term, continuous, wind recordings offshore. However, wind reduction to a standard 10 m above sea level posed a problem.

2.3.1 Weather Offices

H F Verwoerd Airport (HFV), Port Elizabeth

This weather office has the only long-term data set (over 30 years), which is in any way applicable to coastal wind conditions over the eastern part of the Cape South Coast. It is only 2 km from the coast at an altitude of 60 m, whilst the nearest manned lighthouse is at Cape Recife, approximately 10 km to the south-east of the airport (see Fig. 1.1). Although the lack of instrumentation at Cape Recife precluded a proper comparison of wind speeds, it was clear that coastal wind speeds are generally higher. Confirmation of this fact is contained in the section on extreme winds (5.6), and in examples in Appendix 3. The nearest coastal measurements available were from the AWS on Cape St. Francis lighthouse, approximately 70 km south-west of HFV Airport.

Appendix 3 also shows that the airport can experience extended calm conditions when a fresh wind is blowing on the coast and offshore. Referring to W.B. 38 (1978), maximum percentage calms (hourly average less than 1,3 m/s), are recorded in winter at HFV - 26 per cent. Five years of estimates from Cape Recife give the percentage calms in winter as just under 20 per cent. Note, however, that the lighthouse figure is likely to be an overestimate as low wind speeds are likely to be estimated as calms. No figure for percentage calms is available offshore since wind measurements on the rigs are well above sea level and it is not possible to obtain statistics on calms at 10 m simply by reducing speeds from 73 m or higher. However, with the sea surface showing little diurnal cooling, the frequency should be a lot lower.

According to the airport data, spring is the season for strong winds, but only 0,13 per cent of hourly observations in that season exceed 17,1 m/s. Compare this with Cape St. Francis where in the **winter** of 1982, 4 per cent of all winter (AWS) observations exceeded **18 m/s.** When comparing lighthouse estimates with measured **hourly** averages, bear in mind that the period over which the estimate is 'averaged', is uncertain. Whilst the standard measurement period for synoptic wind observations is 10 minutes, Graham (1982) found that an estimate based on sea state (as at the lighthouses), is closer to an hourly average because of the delayed reaction time of the sea.

Further comparison between Cape Recife lighthouse estimates and long-term statistics at HFV yield the following:

(a) Winds with a westerly component dominate throughout the year at both sites. At the airport the highest frequency of WSW winds occurs in September as opposed to a westerly peak in November at Cape Recife.

(b) At both sites easterly winds attain their highest frequency in summer. HFV recorded no extreme winds (above 17,1 m/s) with an easterly component. Whilst easterly gales were quite common at Cape Recife, in no month do they exceed the westerly gale count.

(c) Both sites have their highest gale count in October. Note that this is the month in which a number of severe Black South-easter events (that is, cut-off lows) have affected this coast. At the same time, intense frontal systems may still affect the Cape South Coast in October, and even later in the year.

P W Botha Airport (PWB), George

This weather office is at 221 m above sea level, with the nearest available lighthouse wind estimates at Mossel Bay (Cape St. Blaize), approximtely 30 km to the south-west. In comparing long-term wind patterns the following points were made:

(a) The dominant westerly component winds at PWB airport are WNW and NNW with the latter very much a winter phenomenon. The increased northerly components compared with the coast are due to increased friction overland, lowest pressure being to the south when the wind is from the west. In summer ESE and south-easterly winds dominate the wind records at George, compared with south-westerly dominance at Cape St. Blaize. However, this last direction is very much the product of local coastline orientation and may be made up of both easterly and westerly components.

(b) As at Port Elizabeth nocturnal stability overland results in a greater percentage calms occurrence inland. The summer westerlies seem to be particularly affected. Percentage calms reach a maximum in April at both sites.

(c) Wind speeds exceeding 17,1 m/s occur most frequently in November at George, but gale counts are considerably less than on the coast. The lack of strong ESE winds and the appearance of strong westerly components places the wind climate at George midway between Cape St. Blaize and Cape St. Francis.

(d) Taking the AWS data into account, an abrupt change in the coastal wind climate is evident between Cape St. Blaize and George, with westerly components enhanced to the east of Cape

St. Blaize. This could well be due to coastal weather systems encountering a coastal mountain range (the Outeniquas) in the vicinity of George.

For a comparison between short-term wind measurements at George and the Walker Point AWS, see Appendix 3.

2.3.2 Seasonal Wind Variation at Cape St. Blaize - Figures 2.1 and 2.2

Prevailing Winds. The marked south-westerly component is assumed to be a local effect since **westerly** winds dominate at Cape Infanta and offshore. The pronounced north-westerlies from May to August are largely the result of an upsurge in land-breeze events, although the stronger north-westerly components probably originate from pre-frontal conditions. The increase in the onshore component in summer reflects the more favourable conditions for sea-breeze development. South-easterlies are at a minimum in June and a maximum in January. South-westerlies have their maximum frequency in December at Cape St. Blaize.

Calms. Greatest percentage calms were recorded in April - 11,6 per cent, with June giving the lowest count (3,5 per cent). Note that the enhanced land-breeze conditions at this location, preclude the presence of a large percentage of calms.

Gales. Gales with an easterly component make **summer** the stormiest season at Cape St. Blaize. Gales with a westerly component are infrequent. The lowest gale count occurred in May. AWS measurements at Cape Infanta, approximately 120 km to the south-west support these observations.

2.3.3 Seasonal Wind Variation at Cape St. Francis - Figures 2.3 and 2.4

Prevailing Winds. The markedly zonal appearance of the Cape St. Francis wind roses is partially due to the lighthouse keepers preference for 8 compass points. **AWS** data from Cape

St. Francis indicates that prevailing winds are actually E-W and WSW-ENE. Westerly winds dominate throughout the year but attain their highest frequency in November. Although an offshore flow appears in May it is much weaker than that at Cape St. Blaize. Easterlies reach their maximum frequency in January, dropping off to a minimum in June.

Calms. As at Cape St. Blaize, April records the highest number of calms. However, probably due to the weaker land-breeze circulation at Cape St. Francis, the percentage calms remains high throughout the winter decreasing through the spring to reach a minimum in January.

Gales. June has by far the highest gale count with the great majority associated with the extreme westerly winds of passing frontal systems.

2.3.4 Seasonal Wind Variation Offshore - Figures 2.5 to 2.8

Approximately five years of wind data have been analysed for the Agulhas Bank from drilling areas roughly 100 km south of Mossel Bay. The following aspects emerged:

(a) Prevailing winds. The lack of channeling by coastal topography is reflected by the wide spread of wind directions offshore. Easterly is the most common direction in summer, but westerlies dominate in all the other seasons.

(b) The high percentage of light to moderate north-westerly winds in winter at Cape St. Blaize is not experienced offshore, as the majority of drill sites seem to be too far offshore to come under the influence of the land-breeze. However, it is also possible that the depth of the land-breeze was shallower than the height of the anemometer.

(c) The greatest number of percentage calms is recorded in winter even though this is the season with the highest gale count.

(d) Easterly gales are more common than westerly gales in summer. This is a characteristic of the western Agulhas Bank.

2.3.5 Coastwise Variation

Although local effects are present at both sites, Cape St. Francis is taken here as representative of the eastern portion of the Cape South Coast, whilst Cape St. Blaize represents the western section:

(a) The pronounced north-westerly circulation in winter at Cape St. Blaize is a local effect. AWS data does not show a marked increase in the land-breeze from east to west, but rather identifies **preferred localities** for an enhanced circulation.

(b) Prevailing westerly component winds (that is, south-west at Cape St. Blaize and westerly at Cape St. Francis), attain their highest frequency in the first half of **summer** at both sites.

(c) The south-easterly wind at Cape St. Blaize and the easterly at Cape St. Francis both attain maximum frequency in January. Even in this month, however, westerly components dominate. This is slightly more noticeable in the east than the west, a fact which is given further attention when looking at the AWS data in detail.

(d) Both stations gave April as the month with the highest percentage of calms. However, Cape St. Blaize with its enhanced land-breeze has its **lowest** count in June, whilst at Cape St. Francis the number of calms remains high throughout the winter.

(e) The biggest discrepency in the wind records representing the eastern and western sections of this coastal region lies in the frequency and distribution of **strong** winds. The gale counts are considerably higher in the east with the stormiest month (June) having 222 hourly gales in the 5 year period. Not only are the counts lower in the west, (maximum count is in December - 49), but summer becomes the stormiest season, with easterly component gales by far the most common. AWS gale counts support this pattern.

2.3.6 <u>AWS Wind Roses</u>

No attempt is made to present the one year of coastal AWS data as typical of all months or seasons. Quite apart from the relatively short period and some severe gaps in the data, 1982 saw the development of an El Niño event which rated as one of the strongest in the past century (Rasmusson, 1983). However, from a climatological point of view, the AWS data is very useful for confirming spatial variations along the coast:

(a) Referring to the seasonal wind roses in Figs. 2.5 to 2.8, the prevailing wind direction varies considerably across the Bank in the summer. Cape St. Francis shows a westerly dominance, Walker Point is fairly balanced and Cape Infanta has an easterly bias.

(b) Just as Cape St. Blaize is the favoured site for winter offshore flow amongst the observing lighthouses, so Walker Point is favoured amongst the AWS sites. Here the northwester is second only in frequency to the prevailing westerly in winter. Time-series show that this is largely due to the contribution of the nocturnal land-breeze (see case studies). Even in summer north-westerlies comprise almost 10 per cent of the total wind observations at Walker Point.

(c) The marked increase in strong westerly components in the east was also evident in the lighthouse estimates. Individual case studies (Chapter 3) show that frontal systems often intensify as they cross the Bank.

(d) Cape St. Francis is by far the stormiest of the three coastal sites. Its gale count is also significantly higher than that recorded on the rig south of Mossel Bay. In September 1978

Sedco-K recorded wind speeds at a position 40 km south of Port Elizabeth, which still hold the record for offshore measurements on the Bank. This gives further support to the idea of more extreme conditions on the eastern Agulhas Bank.

(e) Although autumn is again identified as the calmest season, the possibility of individual severe storms in this season is reflected in the gale count. The record storm of May 1984 (see case study No. 10) is a good example.

(f) At Cape Infanta, easterly wind components dominate in all seasons except winter.

(g) According to Schulze (1983), the 1982/83 summer season, during which the summer rainfall regions experienced severe drought, was characterised by an unusually high frequency of frontal systems with a large negative surface pressure anomaly to the south-west and a positive anomaly to the east. The AWS summer data consisted mainly of 1982/83 summer data, yet when compared with the five summers included in the lighthouse estimates, no definite anomaly can be discerned.

2.4 AIR TEMPERATURE

2.4.1 AWS Data

Cape Infanta. The air temperature ranged from 7,9°C on 18 June (1982) at 06h00 to 32,4°C on 7 May at 15h00. Note that the so-called **berg wind condition** (refer to section on coastal lows, Chapter 4), with subsiding air being heated adiabatically, is responsible for most anomalously high air temperatures along the South African Coast.

In almost all cases where the temperature dropped below 9°C, a light north-westerly wind was blowing, coincident with a pressure maximum indicating that a BOH was rounding the coast. The role played by the land-breeze in transporting cold air from the high interior back to the coast, cannot be over-emphasised. Minimum temperature was recorded after sunrise in the majority of cases.

Walker Point. Minimum temperatures are again dominated by cold offshore flow with the lowest 60 temperatures all having NNW to north-westerly winds, 2-5 m/s. The absolute minimum temperature was 6,9°C recorded at 06h00 on 18 June. These minimums occurred at any time between 23h00 and 08h00 as the LB circulation was sometimes over-run by synoptic scale flow.

The absolute maximum temperature at Walker Point was also on 7 May (at 13h00) - 30,1°C. Berg wind conditions can just as well produce anomalously high temperatures during the night, for example, on 8 May at 05h00 over 25°C was recorded.

Cape St. Francis. An absolute minimum air temperature of 8,8°C was recorded on 3 July at 05h00. As with the other AWS extreme minima were accompanied by light winds in the NNW to westerly sector. However, not all cases were simply land-breeze situations. On 17 June, for example, a low 9,5°C was recorded at **10h00,** probably the result of a cold downdraught from post-frontal cumulus. On 14 August an absolute maximum of 32°C was recorded at 14h00. In general, berg wind conditions were accompanied by north-westerly winds, which gusted to gale force in some cases.

Drilling rigs. The advantage of a continuous recording at a fixed site offshore was clearly depicted on 11 October 1985 when the oil rig, Actinia, was drilling at a position approximately 58 km south-east of Plettenberg Bay. (This rig is the only source of relatively long-term air temperature data at fixed sites offshore). A dry bulb reading of 33,8°C was recorded - well in excess of the VOS maxima (see below). However, it should be remembered that strong inversions occur over the sea during berg wind conditions and the temperature sensor on the rig is over 20 m above sea level, considerably higher than the bridge of most merchant vessels.

2.4.2 Weather Offices

The effect of moving even slightly inland is immediately obvious from air temperature tables provided by Schulze (1974) - both Port Elizabeth and George have recorded temperatures above 40°C, and both have come close to freezing point.

2.4.3 Air Temperature Extremes from VOS

Because of the volume of data involved, VOS data for the Agulhas Bank had to be split into east and west, the dividing line being 23°E. In each data set the dry bulb parameter was ordered and after checking the validity of each report using the daily 14h00 synoptic charts, the following absolute values were obtained:

Western Agulhas Bank	28,5°C maximum	- 23 May 1984
	9,5°C minimum	- 14 August 1975
Eastern Agulhas Bank	29,0°C maximum	- 23 March 1974
	9,5°C minimum	- 1 June 1968

Both absolute maxima occurred under berg wind conditions with the coastal low just to the west of the vessel and subsiding air aloft. Coastal temperatures were above 30°C. Both absolute minima were associated with an influx of cold maritime polar air behind an intense frontal trough with the Atlantic High (AOA) ridging in behind it.

2.4.4 Diurnal and Seasonal Variations in VOS Reporting

The following discussion applies to all the VOS parameters which follow, that is, not just dry bulb:

A search of all reports in the two Agulhas Bank data files, placing each observation according to its month and time of day, resulted in Tables A1.1 and A1.2 in Appendix 1. Total records in the Agulhas Bank West file were 44 367 and in the Agulhas Bank East file 57 373. This disparity as well as the difference in monthly totals and that between the various synoptic times, is taken into account when comparisons are made. Note that there was a significant number of reports which fell outside the main synoptic times - thus the short-fall in absolute totals. For comparing total counts of present weather (ww) phenomena, the ratio of reports which included a present weather observation was 55 588/43 361, that is, 1,28 east versus west. The ratio for total reports was 1,29.

2.4.5 Distribution of Dry Bulb Temperatures from VOS

Temperatures of 25°C and over. Considerably more cases were encountered in the east (689 vs 228), probably because merchant vessels are generally further offshore in the west. However, there is also evidence that the coastal low is better defined in the east (see case studies). The damping effect of sea temperature on any marked rise in air temperature would also be less prominent in the east, due to the greater influence of warm Agulhas current water.

Temperatures less than 12°C. From AWS data it is evident that the nocturnal land-breeze circulation, by advecting air down from the interior, is responsible for most of the very low air temperatures at the coast. There is no marked diurnal heating over the ocean, and the land-breeze is considerably weakened and warmed as it moves offshore. The absolute minimum temperatures in both VOS areas were recorded on the 14h00 synoptic hour, with cold maritime polar (mP) air feeding in behind a deep frontal wave. A further factor which may have contributed to the low temperatures is downdraughts of cold air from convective cloud - both reported precipitation at the time.

2.5 VISIBILITY

Good Visibility. This condition is usually associated with post-frontal weather excluding the effects of low clouds or showers. These conditions usually remain until the following migratory high has passed to the east, since subsidence and stratifiation of the marine air is most noticeable on the western side of these systems. **Land-breezes** are also associated with good visibility in the lower layers (RN, 1944), since they introduce dry, salt free, continental air to the coast and off-shore. However, in the vicinity of concentrations of coastal industry, the land-breeze also transports pollutants seaward.

Haze. This refers to the suspension of dry particles such as dust or salt in the atmosphere, reducing horizontal visibility. Heavy haze is usually indicative of a stable lower atmosphere which is inhibiting mixing and dispersal. Thus, easterly winds blowing into an incoming coastal low, or north-westerly winds ahead of a front are often associated with poor visibility.

Fog. This refers specifically to a condition where horizontal visibility is reduced to less than 1 km by **water droplets** in suspension. According to the World War 2 study (RN, 1944), fog is more common over the western parts of the Agulhas Bank with March having the highest frequency - 42 hours at Cape St. Blaize and 33 hours at Cape Recife. However, a count of fog reports in the Cape St. Blaize and Cape St. Francis synoptic reports for March 1982 found approximately 19 counts for each, with a much higher frequency of **events** at Cape St. Francis, most of the observations from Cape St. Blaize relating to a particular period of 3 days (see Chapter 4). SA Sailing Directions (1975), also supports a high frequency of fog at Cape St. Francis - for example, 5 days on average in March. In Chapter 4 the effect that fog has had on shipping on the Agulhas Bank, is discussed in some detail. Diurnal variation on the coast shows a peak at 06h00 to 08h00 with an afternoon minimum.

Advection fog versus radiation fog. Most of the fog contributing to the above statistics is advection fog which is most common in summer and autumn. Note that these are the seasons in which strong easterly winds are most common and thus coastal upwelling events most frequent. The well-defined inshore front on the Agulhas Current may delineate the edge of the fog bank very clearly with the fog unable to survive over the warm waters of the current. Radiation fog forms in the river valleys mostly in winter, though it may drift out to sea on occasion (RN, 1944).

Fog distribution according to VOS data. Searches were conducted for all reports of fog whatever its further condition or position (for example, at a distance from the vessel). The western Agulhas Bank returned 291 cases in the 26 year period 1960-1985 inclusive. In the eastern portion the count was 459. Note that these are relatively low counts when one considers the total number of reports. The highest frequency of fog observations in both cases occurred in March on the 06h00 synoptic hour. The lowest counts occurred in June in the east, but in December and January in the west.

2.6 CLOUD AND SUNSHINE

Schulze (1974) and RN (1944) were consulted for long-term statistics on these parameters:

Cloud cover. This averages between 40 and 50 per cent along the coast with a winter minimum and a spring maximum, which ties in with a September maximum for percentage diffuse radiation at Port Elizabeth - 40 per cent. In December total radiation varies from 700 cal cm^{-2} day^{-1} in the west to 600 in the east. In winter this parameter is fairly constant along the coast at about 225 cal cm^{-2} day^{-1}.

Diurnal variation of cloud cover. In all seasons cloud cover at Port Elizabeth shows a slight decrease from 08h00 to 14h00. This is a reflection of the relative importance of convective versus stratiform cloud, the latter favouring the early morning.

Clouds offshore. A well-known phenomenon in the vicinity of the Agulhas Current is the extensive line of convective cloud from which showers or even thundershowers may precipitate. With the current closest inshore in the east this is more a phenomenon of the eastern Agulhas Bank.

Reconnaissance aircraft during World War 2 reported this cloud line over the current on 142 out of 230 days (Govett, 1941). Meteosat images confirm this high frequency of occurrence and indicate that these clouds generally show maximum development in the early hours of the morning with a seasonal preference for autumn and winter.

Govett has provided a comprehensive description of the cumulus development over the Agulhas Current. However, his observation that these clouds dissipate under easterly conditions must be questioned after random checks on Meteosat imagery. Several examples were found where the cumulus persisted long after the BOH had crossed the Agulhas Bank, that is, easterly winds had become established on the coast.

On the other hand the cooler inshore waters of the continental shelf generally favour stratiform cloud which may clear over the current, due to the enhanced convective mixing over the warmer water.

2.7 SEA-LEVEL PRESSURE

2.7.1 AWS Data

During the main study period the sea-level pressure varied as follows:

Cape Infanta:	abs. minimum	1 000,4 mb	1 December 1983
	abs. maximum	1 030,0 mb	27 February 1983
Walker Point:	abs. minimum	1 000,8 mb	1 February 1983
	abs. maximum	1 034,0 mb	22 August 1982
Cape St. Francis:	abs. minimum	999,1 mb	26 December 1982
	abs. maximum	1 034,0 mb	22 August 1982
Sedco-K (Oil Rig):	abs. minimum	1 000,0 mb	1 February 1983
	abs. maximum	1 034,0 mb	4 September 1982

The limitations of using one year's data as a climatic indicator are borne out by the record low pressures of May 1984. Air pressure on the Actinia dropped to 980,3 mb whilst the oil rig was drilling south of Mossel Bay and a record low pressure was registered at Port Elizabeth - 988,4 mb. Nevertheless, certain observations may be made concerning the AWS data:

(a) All of the absolute minima occurred in **summer,** and three out of four were the result of deep frontal waves. The fourth, at Cape St. Francis, involved a **coastal low passage.** It is quite common for the coastal low in a coastal low/front pair to produce the lowest pressure on the east or south-east coasts since the front is generally moving with a southerly component at that longitude.

(b) The absolute maxima reflect the more intense bud-off high pressure systems occurring in the winter. The summer maximum at Cape Infanta was due to a blocking system - part of a cut-off low/blocking high pair.

2.7.2 VOS Data

A search through the VOS data rendered the following range of values:

Western Agulhas Bank:	abs. minimum	983,5 mb	16 May 1984
	abs. maximum	1 041,3 mb	14 June 1984
Eastern Agulhas Bank:	abs. minimum	984,2 mb	22 August 1974
	abs. maximum	1 041,0 mb	8 July 1979

The record low pressures of May 1984 are reflected in the western Agulhas Bank minimum. This was due to a case of explosive cyclogenesis in a mid-latitude frontal system. In the east a cut-off low was responsible for the lowest pressure. The intense migratory highs of winter provided the highest pressures in both areas, with the bud-off high of 8 July 1979 eventually becoming part of a cut-off low/blocking high pair.

Note that the temporal coverage of VOS data was insufficient to ensure that every major storm was identified, for example, for the very intense storm of May 1984, there was no VOS data on the eastern Agulhas Bank.

Seasonal/Diurnal Variations. These were considered for the following cases:

(a) Pressure 1 035 mb and greater: The great majority of these intense high pressure systems occurred in the winter months, June to August.

(b) Pressure less than 1 001 mb: 211 observations qualified for this category in the east compared with only 99 over the western Agulhas Bank. This indication that many lows intensify as they cross the Bank, is verified by AWS data. **May** and **December** recorded the highest number of low pressure systems in this category, with the December count in the east being double that in the west. Case Study no. 8 provides a good example of a summer frontal system which had intensified considerably by the time it reached the eastern Agulhas Bank.

2.8 HUMIDITY

Humidity measurements were not attempted at any of the coastal AWS. However, Schulze (1974) has calculated average vapour pressures and saturation deficits for a number of south coast sites:

Water vapour content is shown to reach a peak in February (approximately 20 mb), with a minimum in July (10-12 mb), the annual variation in temperature playing a major role. The 14h00 mean relative humidities for these months are approximately 70 per cent and 60 per cent respectively.

Diurnal variation in vapour pressure at Port Elizabeth in February shows a 19h00 peak (20,7 mb) and an 06h00 minimum (18,6 mb). The diurnal curve is of the oceanic type with an unlimited supply of moisture except during offshore flow conditions. The 06h00 water vapour minimum ties in with minimum temperature and possibly a weak land-breeze. The 19h00 peak is probably due to the moisture influx of the sea-breeze. In July the vapour pressure peak is at 17h00 at Port Elizabeth (12,8 mb) and the minimum is at 07h00 (9,8 mb), with the land-breeze playing a greater role in reducing the latter figure. During berg wind conditions extremely low moisture levels may be recorded at the coast, with relative humidity dropping below 20 per cent.

VOS reports. Humidity measurements by ships of opportunity are, unfortunately, subject to considerable error and are difficult to verify. However, a single (verified) report from a vessel 50 km south of Knysna shows that dry subsided air may extend down almost to the sea surface even at this distance offshore. The vapour pressure in this case was only 6,5 mb (RH 35 per cent). This report came **after** the passage of a coastal low, indicating that general subsidence associated with the high pressure system can be more important than offshore flow in producing berg wind conditions. Alternately, if the frontal system following the coastal low is well developed with a strong northwesterly flow ahead of it, there may be insignificant cooling associated with the passage of the coastal low. This is due to the fact that large scale subsidence continues, keeping warm dry air in circulation at the surface. The possibility of berg wind conditions near the surface, over 50 km offshore, was further verified by the drilling rig, Actinia, on 11 October 1985 (see earlier section on air temperature - drilling rigs).

At the other end of the scale, vapour pressures of over 30 mb have been reported offshore. Note that near-saturated air does not necessarily mean poor visibility. The micro-physics of the atmosphere plays an important role in the condensation process.

2.9 PRECIPITATION

2.9.1 Long-term Coastal Rainfall Figures

Although monthly rainfall means are well distributed throughout the year, autumn and spring have a slight maximum (Schulze, 1974). The coastal orography plays a considerable role in the spatial variation. Coastal rainfall varies from a low of 292 mm at the mouth of the Breede River (WB 29, 1960) to over 1 000 mm east of Plettenberg Bay where the land rises steeply from the sea. Going further east, Cape St. Francis records 674 mm on average whilst at Humewood Beach (Port Elizabeth), the total has decreased to 539 mm. On Bird Island in Algoa Bay the lack of relief results in only 476 mm per annum.

As might be expected, there is a significant increase in rainfall as one gains altitude moving inland, with over 1 200 mm recorded on the seaward slopes of the Outeniqua Mountains.

2.9.2 Precipitation Types

Rain from stratiform cloud is responsible for a large part of the annual precipitation total, but strong convection may occur during certain synoptic situations, sometimes resulting in flooding. On average, only 10 thunderstorm days are recorded per annum, but even these become significant during times of drought when a lightning strike from well developed cumulus cloud may start off a serious forest fire (see Chapter 4).

2.9.3 Precipitation Offshore

Rain or drizzle. On the western Agulhas Bank a search for all cases where vessels reported present weather 'rain or drizzle', produced 896 hits. On the eastern Agulhas Bank 1 472 cases were encountered. Thus, it would seem that the coastal rainfall configuration extends offshore with generally higher rainfall in the east. No actual figure is available for precipitation offshore, but a lack of topography could well result in an annual total lower than the coast. Note that the above counts are relatively low when the total number of observations is taken into account. The enhancing effect of warm Agulhas Current water on convective cloud could well result in increased rainfall further offshore.

Seasonal/diurnal variations. March gave the highest precipitation event count in the east, and July the highest count in the west. Although both areas had their lowest counts in December, it was the western area with the lower December percentage, again reflecting its proximity to the Mediterranean climate of the Southwestern Cape. The diurnal distribution of rainfall shows slight maxima on the 06h00 and 00h00 z synoptic hours.

Showers including hail. A similar search to the above for a present weather 'shower' condition, produced 464 and 792 cases for the western and eastern areas respectively. This imbalance is to be expected since the Agulhas Current which is a preferred location for convective cloud development, diverges from the coast as it flows westwards.

The diurnal distribution indicates that the first half of the morning is the commonest time for showers to fall. This is borne out by satellite observations. Showers are most common in May on the eastern Agulhas Bank and in June in the west. This is the time of year when SST's are still relatively high whilst influxes of cold air have become more common, thus causing decreased stability offshore.

Thundershowers. The thunderstorm count in the west is significantly lower than that in the east (29 versus 80). With the greatest number of observations at 18h00 and 00h00, it would seem that the associated cumulonimbus cloud is not simply an extension of the showery cumulus in the previous section, but that a different process is involved. The seasonal pattern also changes, with February being the preferred month in the east, and August/September in the west.

2.10 SEA-SURFACE TEMPERATURE (SST)

Taking the mean of the months March, June, September and December for 11 years (data includes VOS and coastal surf temperatures), an average temperature of 18°C inshore increasing to over 21°C in the Agulhas Current, was obtained. The Agulhas Current is responsible for injecting large volumes of warm water onto the Bank, in the form of intrusive tongues and eddies.

2.10.1 Coastal Observations

Average monthly SST at Still Bay varies from 13,7°C in August to 21,1°C in January with extremes of 11,5 and 26,0°C in these respective months. At Knysna the respective means are 14,5 and 20,7°C. Absolute minima of 10,3°C in February and April are indicative of upwelling events in summer and autumn. An absolute maximum of 26°C was also recorded in January at Knysna. Port Elizabeth (Humewood Beach) varied from 15,6°C in August to 21°C in January. The absolute minimum of 10,0°C was recorded in May, again underlining the dominant role played by upwelling in producing low SST's.

2.10.2 VOS Reports

To investigate the range of SST variation over the Bank, values were classified into two groups:

SST less than 12°C. Reports in this category were slightly higher in the west (44 in the west, 41 in the east). Unseasonally low SST's occurred in April on the western Agulhas Bank and in February on the eastern Agulhas Bank, indicating upwelling events.

SST 27°C and greater. 127 cases were found on the eastern Agulhas Bank, with only 5 in the west. This is partly due to the fact that the shipping lanes are further removed from the Agulhas Current core in the west. The twenty highest SST values in the east were plotted by position. This resulted in a cluster extending from east of Algoa Bay to Cape St. Francis, indicating that most merchant vessels leave/enter the current to the south of Cape St. Francis. The 5 cases of high SST's on the western Agulhas Bank are considered to be the result of Agulhas Current intrusions in that area.

2.11 SEA AND SWELL

2.11.1 Measured Data

Swell direction. Clinometer data from Cape St. Francis gives a southerly swell as being the most common, followed by SSW and south-west, whilst VOS data has SSW and south-westerly swell dominating in the degree square east of Cape Agulhas (Swart and Serdyn, 1981).

Period. Sedco-K Waverider data has revealed that peak energy wave period (T_p), exceeded 7,8 s 95 per cent of the time and 16,5 s 5 per cent of the time on the Agulhas Bank south of Mossel Bay.

Swell height. According to Sedco-K data the largest waves on the Agulhas Bank occur in spring with summer giving the lowest frequency of high waves. However, a Waverider off Cape St. Blaize gave a **winter** maximum with an H_l^{10} of over 8 m. This value is in agreement with the absolute maximum significant wave height recorded at Sedco-K, where, on 1 September 1978 8,6 m was recorded.

2.11.2 VOS Estimates

By far the largest source of sea state data are the estimates in VOS reports. Laing (1984), has made a comprehensive assessment of sea and swell observations in the southern oceans. He found the best correlations (comparing reports at various distances), for **combined** wave height (see Appendix 1). Swell directions were found to vary by up to 70°.

Swell. According to VOS data, estimated swell height (taken to be roughly equivalent to significant wave-height) reaches a maximum of 12-14 m over the Bank. Although this may seem extreme in comparison with the measured values, Schumann (1976) has published wave recorder data measured both in and out of the current with extreme heights almost double in the current with an opposing swell. Although south-westerly swells dominate the high swell conditions, cut-off low events resulted in a heavy south-easterly swell. The VOS reports give winter as the season for high swell, with summer and autumn having the fewest counts.

Taking all swell heights of 8 m or greater, the total count was 300 on the eastern Agulhas Bank versus 140 in the west. This could be largely due to more observations in the east being taken within the Agulhas Current where a south-westerly swell would be enhanced.

Wind waves. Deck officers are required to separate sea state into swell and wind waves when compiling a synoptic observation. Under high wind conditions this is a difficult process. Wave-heights from SADCO's VOS data were thus also ordered, and all wind waves of 6 m and greater sorted by season. August had the highest count in both areas with 71 cases in the east and 32 in the west.

This completes the discussion of long-term values and patterns within the marine atmosphere over the Agulhas Bank, and in the coastal ocean below.

3. CASE STUDIES

This chapter presents twelve case studies which include most of the weather situations likely to be encountered on the Agulhas Bank. In order to simplify the general picture of weather patterns in this region a distinction is made between a 'basic cycle' and perturbations which periodically disrupt this basic cycle. This division is justified by the fact that the synoptic scale systems involved in the basic cycle are highly repetitive, as a study of synoptic sequences will soon show. The first two case studies were chosen to portray these basic cycles, one case study for winter, and one for summer, each covering a week on the Agulhas Bank. The next 10 case studies were chosen mainly to depict the impact which atmospheric processes have on human activities on the coast and offshore. This impact is, however, only fully discussed in the next chapter, the aim here being mainly to identify processes.

Whilst data from the coastal AWS forms the mainstay of these studies, AWS data from Sedco-K and R/V Meiring Naudé is also available in some cases. The drilling rig, Actinia, is the only source of continuous data from a fixed site, after the main 1982/3 study period. Voluntary Observing Ship Data (VOS), provided very useful additional offshore information and was the only source of present weather observations (for example, precipitation, fog, etc.). In each of these case studies a description of the major synoptic systems at 14h00 is given on the first time-series. Their passages are arrowed on all the time-series where they were clearly defined. Additional arrows indicate changes in other parameters associated with the passage of the synoptic system. Unless stated, no height reduction of wind speed has been applied. When a wind speed is quoted, this is a 15 minute average, as on the time-series, unless otherwise indicated.

Only 5 of the 12 case studies to follow did not have cut-off low activity appearing at some time during the week. The reasons for the apparent preference for this system are threefold. Firstly, the cut-off low with its attendant blocking high will be shown to play a very significant role in the weather anomalies of the Cape South Coast. Secondly, in some of the case studies a cut-off low just happened to occur in that week - it was not the dominant system, weather wise. Lastly, as Taljaard (1985) has confirmed, 1982 had an unusually high frequency of cut-off lows.

The dominant synoptic scale systems, their propagation and development, and related weather conditions are discussed in detail. Note that all times quoted are SAST, unless GMT is specifically stated, for example, 12h00z implies 14h00 SAST. Details of propagation speeds, time intervals between systems and other features identified in the case studies, are summarized in the next chapter. It is suggested that the relevant SAWB Daily Weather Bulletins containing the 14h00 sea-level pressure analyses for each day, be consulted whilst following the case study descriptions.

3.1 CASE STUDY NO. 1 - WINTER

The week 2 to 8 August 1982 is plotted on the multiple time-series to depict a winter synoptic cycle on the Agulhas Bank (see Figs. 3.1.1 to 3.1.7). Although extreme wind conditions, and extended frontal activity were associated with this cycle, it was no different from a normal winter cycle in its basic pattern. The events of each day are discussed in terms of the dominant synoptic systems and their related weather. In addition to the 3 coastal stations, Sedco-K was approximtely 130 km SSE of Cape Infanta, and the R/V Meiring Naudé started from Port Elizabeth on 2 August to work various lines on the eastern Agulhas Bank.

offshore flow was associated with the second coastal low, with temperatures on 7 and 8 August rising well above normal. The switch from gusty north-westerly winds to less turbulent westerly winds behind the coastal low, is marked by a considerable drop in temperature, for example, at Cape St. Francis an almost instantaneous temperature drop of over 10°C occurred. This drop in temperature also coincided with a gust front at Walker Point and Cape St. Francis, the latter double the intensity of the former, whilst at Cape Infanta and on the Sedco-K, no such feature was recorded.

Although she was 50 km west of Cape St. Francis and over 20 km offshore, the Meiring Naudé recorded little attenuation in the berg wind condition. This would imply that local subsidence and not simply advection of subsided continental air offshore, played the major role. Fig. 3.1.6 shows the sea-level pressure analysis for 05h00 on 8 August and Fig. 3.1.7 the air temperature trace on the Meiring Naudé. The Meiring Naudé also recorded a very turbulent offshore flow ahead of the coastal low. On the inshore leg of the ship's track the wind was gusting to gale force.

3.1.2 Cold Fronts

The cold front of 3 August was first encountered on the rig despite this AWS being east of Cape Infanta's longitude. This system was well defined at Cape Infanta at 06h00 on 3 August, with a 3°C temperature drop, pressure minimum, moderate gust front and wind direction backing from north-west to WSW. Two hours later, the same system passed Walker Point with an enhanced gust front and temperature **rise**. The land-breeze had caused the temperature to drop below 10°C overnight, making the post-frontal WSW wind seem relatively warm.

At 10h00 the front passed Cape St. Francis, where the gust front was enhanced to such an extent that **average** wind speed reached gale force with gusts of almost 30 m/s. Compare this with Cape

Infanta where the maximum gust associated with the front was less than 20 m/s. In contrast with the other AWS, absolute minimum pressure at Cape St. Francis was associated with the coastal low passage and not the cold front. Post-frontal drizzle was reported from Cape St. Blaize and Cape St. Francis.

The second cold front developed in the polar maritime air behind the first, and its associated low pressure system may thus be termed a secondary development or polar low. The abbreviation CAC used on the time-series stands for yet a third term used to describe this phenomenon, namely, **cold air cyclone.** Note that classical frontal theory cannot account for the frontal nature of this low since the frontal zone developed **after** the depression. The frontal passage through Sedco-K was well defined at 18h00 on 4 August with the typical parameter changes. The passage of this front was associated with the highest gust of the week on Sedco-K. On the coast the pressure minima, wind speed maxima and temperature fall associated with the front were all present, but insufficiently sharp to justify the calculation of a propagation speed.

The Meiring Naudé, sheltering in the lee of Cape St. Francis, experienced significantly lower wind speeds although the gust front was sharper than at the nearby lighthouse AWS (see Fig. A4.2). As the front passed over, maximum wind speeds in the east were again significantly higher than those experienced in the west. Post-frontal rain and showers were reported from all three lighthouses.

The last cold front crossed the Bank early on 5 August and was yet another secondary development in the cold mP air. Comparing the pressure traces at Cape Infanta and Walker Point, the front is better defined at the latter station. Using the gust front as a marker the relatively slow speed of 25 km per hour is obtained for the Walker Point - Cape St. Francis leg. As might be expected, frontal temperature contrasts decreased with the passage of each successive system.

Due to the rapid nature of their development, and the fact that no intermediate BOH's crossed the Bank, neither of the secondary frontal systems was associated with a coastal low. The initial front was preceded by the first coastal low by approximately 11 hours at Cape Infanta, 9 hours at Walker Point and 7 hours at Cape St. Francis, that is, the gap was closing meridionally as the two systems diverged latitudinally. The latter comment refers to the normal southward component of movement which frontal systems display in this region. Light precipitation was also associated with this front at Cape St. Blaize and Cape St. Francis.

3.1.3 Bud-off High (BOH)

The pressure maximum which appears on all AWS pressure traces on 5 and 6 August, marks the only BOH to cross the Bank in the week under discussion. Temperature traces indicate that its passage coincided with the lowest air temperatures, both coastal and nearshore. On Sedco-K synoptic reports indicated that the coldest air temperature was recorded behind the last front. VOS reports have also indicated that the land-breeze dominates absolute minimum temperatures only in the nearshore region. Note that the passage of a BOH is marked by a gradual backing of the wind direction from westerly to easterly. However, this tendency is frequently interrupted by the land-breeze depending on the time of day. This is portrayed on all the coastal time-series on the night of 5 to 6 August, and even on the wind direction trace for the Meiring Naudé, despite the vessel being some 20 km off Plettenberg Bay. At the time of the BOH passage, Cape Agulhas reported precipitation which would appear to be linked to the nocturnal land-breeze.

3.1.4 Land and Sea-Breezes

A characteristic of the **land-breeze** is that it produces a well-defined trough in the coastal temperature record. Furthermore, the wind is generally light and lacking in turbulence. It is not necessarily straight offshore since a gradient wind may be superimposed or the land-breeze may be channelled by the local coastal topography, especially deep river valleys. Depending on the size of the circulation, there may also be a Coriolis effect which would tend to give the land-breeze a westerly component on this coast.

Bearing in mind that land-breezes are largely nocturnal and early morning phenomena, they are relatively easy to identify. Walker Point stands out as a preferred location for land-breeze development with land-breezes occurring on 5 out of the 7 days, despite the strong synoptic flow. On the morning of 6 August after the trio of frontal systems had introduced cold mP air into the interior, the presence of the BOH ensured slack pressure gradients. Furthermore, generally subsiding air within the western half of the high pressure cell resulted in a high long-wave radiation heat loss overnight. With sea temperatures remaining high, a well-defined land-breeze circulation developed. Very low temperatures were recorded over the interior during the night of 5 August, with Beaufort West going down to -4,8°C and Oudtshoorn 0°C. Returning to the coast via the land-breeze circulation, this air resulted in a minimum temperature of 7°C at 02h00 on 6 August at Walker Point.

The Meiring Naudé gave some idea of the seaward extension of the land-breeze when she recorded 9°C with an offshore flow at 01h00 on the same day. The vessel was then 20 km south of Plettenberg Bay.

On Sedco-K, over 100 km offshore, the wind veered to westerly at about 02h00 on 6 August, accompanied by a drop in wind speed and a decrease in turbulence. Since there is no synoptic scale explanation for this change, it could well be an extension of the land-breeze, enhanced by the temperature contrast between inshore waters and the Agulhas Current, and turned through 90° by the Coriolos effect.

The only way of recognising the sea-breeze was to look for an onshore tendency in the wind direction since no marked cooling is associated with the sea-breeze in winter. However it is difficult to separate synoptic scale turning of the wind direction from a turning due to the sea-breeze effect. Generally low daytime temperatures overland result in the sea-breeze circulation being weak in the winter. On the afternoon of 5 August, however, there was a significant backing in wind direction from westerly to WSW. This switch occurred at 14h00 in the west and about 16h00 in the east, and the onshore flow kept air temperatures relatively constant until the land-breeze took over at between 20h00 and 22h00. Note that this sea-breeze event coincided with a BOH passage.

3.1.5 Precipitation

Very light precipitation was recorded on the western part of the coast in association with the first two fronts. Cape St. Blaize reported 2,2 mm on 4 August (24 hours ended 08h00) and 0,2 mm on the following day. The only precipitation at Cape St. Francis was associated with the coastal low/front pair of 8 August, when frontal uplift resulted in thunderstorm development - 10,8 mm. In the Plettenberg Bay area considerable damage was done by the gusty conditions associated with thunderstorms, early on 9 August.

3.1.6 Sea-Surface Temperature (SST)

Measurements made each morning at Knysna Heads showed very little variation during the study period, that is, 14-15°C. Gale force westerly winds late on 4 August caused the surf temperature at Humewood Beach (Port Elizabeth) to drop from 16°C to

14^{o}C overnight, presumably the result of mixing. The highest temperature (17^{o}C), was asociated with the passage of the BOH. At Still Bay at the other end of the Bank, a minimum temperature of 12,5^{o}C on 5 August was associated with the passing of the last cold front. At none of the coastal measuring sites did SST change by more than 3^{o}C during the week under study. This is an indication of how well the surface layers over the Agulhas Bank are mixed in winter, since a number of intense frontal systems crossed the Bank.

Sea-surface temperature was measured continuously on board the Meiring Naudé. The two spikes on the temperature trace of 3 August indicate excursions into Agulhas Current water. The continuously low SST's from 4 August 07h00 to 5 August 09h00 mark the period spent sheltering in St. Francis Bay. The ship moved out into the Agulhas Current again on 6 August. It is noticeable that major changes in SST which were prolonged, due to the ship moving into large bodies of significantly warmer or colder water, were generally accompanied by changes in air temperature.

On Sedco-K SST reached a **maximum** of 19^{o}C at 08h00 on 5 August after 24 hours of westerly gales. This again emphasises what little effect even strong winds have on the temperature profile over the Bank, in winter.

3.1.7 Sea State - Waverider Records from Sedco-K

A jump in significant wave-height, H_{mo}, from 2,4 to 5 m occurred on 3 August **after** the initial jump in wind speed associated with the first front. T_p (peak energy period) also changed from 8,1 to 10,7 seconds. With the passing of the second cold front, H_{mo} increased to 6,1 m and T_p to 13,5 s. After the third cold front on 5 August, H_{mo} dropped steadily.

3.1.8 Synoptic Reports from VOS

Eastern Agulhas Bank. On 2 August at 02h00 a merchant vessel south-east of Port Elizabeth reported violent wind and rain showers, presumably from convective cloud over the current. On 6 August at 02h00 a report of light drizzle was received from a ship approximately 50 km SSE of Storms River Mouth. It is significant that the land-breeze was well-defined at both Walker Point and Cape St. Francis, with a BOH moving across the Bank. No synoptic scale event can be linked to this precipitation. It is suggested that this was an example of enhanced convection over the Agulhas Current (cumulus and strato-cumulus cloud was reported) with the land-breeze providing a trigger by undercutting conditionally unstable air over the current.

Western Agulhas Bank. Apart from reports of precipitation on 3 August and 5 August associated with frontal systems, the only VOS observation of significance was on the 3 August at 14h00 when a vessel approximately 100 km south-east of Cape Infanta estimated a wind speed of 26 m/s - considerably stronger than the Cape Infanta AWS value. This may have been a local effect as the ship also reported showers, that is, it could have been associated with a cold air downdraught.

3.2 CASE STUDY NO. 2 - SUMMER

The week 23 February to 1 March 1982 saw 4 coastal lows, 4 frontal systems and 2 BOH's cross the Bank. AWS data was available from Cape Infanta, Walker Point and Cape St. Francis (see Figs. 3.2.1 to 3.2.3).

3.2.1 Coastal Lows

While the passage of a single coastal low with a 5°C temperature drop, pressure minimum, jump in wind speed and almost instantaneous wind switch is clear on 24 February at 13h00 at Cape St. Francis, a pre-coastal low land-breeze at Walker Point makes it difficult to mark the synoptic system's passage there. At Cape Infanta the initial wind switch from north-east to westerly occurred at 10h00, thus giving an average propagation speed to Cape St. Francis of over 120 km/hour. Relatively light winds were associated with the passage of this coastal low.

Moist maritime air behind this coastal low was presumably cooled to saturation as it passed over cold inshore waters since by 17h00 visibility at Cape St. Francis had dropped to 400 m in fog. By 20h00 visibility had further deteriorated to under 100 m. Note that a cut-off low pressure system associated with an extended easterly blow on 20 February, had already brought SST's at Knysna down to 14°C, thus enhancing the 'fog producing potential' of the local ocean. A coastal low was analysed east of East London on the 12h00z chart of 26 February, but none of the AWS recorded its passage, so it must have formed east of Port Elizabeth.

The second coastal low to cross the Bank passed Cape Infanta at 02h00 on 27 February. At Walker Point the post-coastal low pressure jump and wind switch from north-westerly land-breeze to westerly occurred at 06h00. The situation at Cape St. Francis is not easily explained. The wind switch occurred at 02h00, that is, simultaneous with Cape Infanta, and ahead of Walker Point, combined with gust front and pressure minimum. Peak wind speed on 27 February at Cape St. Francis was recorded at 10h00 - almost 20 m/s. This was not only several hours earlier than Cape Infanta and Walker Point, but the wind speed was much higher. The following explanations are offered:

(a) Several years of synoptic analysis of Sedco-K data indicated that not only could an individual front be linked to a specific coastal low, but that if a wave developed on the front, this cyclogenesis could be linked to the formation of a new coastal low.

(b) The premature gust front at Cape St. Francis at 02h00 on 27 February may thus be linked to a new coastal low development ahead of the existing coastal low. Furthermore, the gale force westerlies between 09h00 and 11h00 may be explained in terms of the new wave formation. This system must have developed over the eastern Agulhas Bank, as neither of the other AWS were affected. Interpolation between synoptic charts suggests that the wave development seems to have taken place in the area of Agulhas Current retroflection, that is, 38-40°S 15-20°E. This seems to be a favoured area for frontal wave development. Pandolfo (1985) investigated the role of SST gradients in cases of explosive cyclogenesis in the Northern Hemisphere. However, several other factors including upper air circulation, may play a major role in such development.

(c) Another possible explanation is that the coastal low actually appeared at Walker Point at 02h00 as well, but the land-breeze was at that time dominating the surface circulation and continued to do so until 06h00. This would mean that this system appeared almost simultaneously at all three AWS. This places a question mark over the idea of the coastal low being an independently propagating system, and lends support to the concept proposed by De Wet (1984) who preferred to regard it as one which is continuously being generated.

Cape St. Francis again reported early morning fog behind this coastal low. Note that fog occurrences are nearing their peak at this time of year, March usually achieving the highest count.

The last coastal low, on 1 March, had only temporary south-westerly winds behind it due to an extensive ridge south of the Agulhas Bank. The low arrived at Cape Infanta at approximately 10h00. The land-breeze circulation at Walker Point made the passage of this coastal low indistinct, but it passed Cape St. Francis at about 12h00, giving a propagation speed in excess of 150 km/hour. Significant pre-coastal low warming at Cape St. Francis indicates that subsiding air reached the surface at about 08h00, that is, short-lived berg wind conditions occurred. Extensive fog occurred in association with this coastal low after the fresh easterly winds had moderated; thus the fog formed prior to the passage of the coastal low, with earlier berg wind conditions identifiable.

Note that the post-coastal low westerlies were associated with a slight drop in temperature at Cape St. Francis only. At the other two coastal AWS, there was no immediate cooling with the passage of the coastal low.

3.2.2 Cold Fronts

Although intense frontal depressions may affect the Agulhas Bank even in summer, the only system which is clearly depicted on the AWS plot occurred on 27 February. As suggested earlier the premature westerly gales at Cape St. Francis were probably due to a wave development on this front over the eastern Agulhas Bank. Although the effects of this wave were negligible at the other two AWS, the actual front, coming approximately 11 hours after the coastal low at Cape Infanta caused peak westerly winds at these AWS sites.

There was no significant temperature drop behind this front. Although it was overshadowed by the buster (that is, gust front associated with the coastal low) approximately 8 hours earlier, the cold front was associated with thunderstorm activity as it passed Cape St. Francis.

3.2.3 Bud-off Highs (BOH)

The first BOH passed well south of the Bank on 26 February. Easterly components behind this system were particularly short-lived at Cape St. Francis. The second and last BOH in the study period came in behind the cold front of 27 February and was associated with well-defined land-breeze circulation at Walker

Point on the morning of 28 February. All stations experienced fresh easterly winds behind this system with Cape Infanta reaching near-gale force (15 m/s).

3.2.4 Land and Sea-breezes

Although the **land-breeze** is more of a winter circulation, it is still evident in summer, particularly at Walker Point. The light north-westerly wind and relatively cool air associated with the nocturnal land-breeze were recorded at both Cape Infanta and Walker Point with the passage of the first BOH. A well-defined land-breeze circulation occurred on 6 out of 7 mornings at Walker Point. Early on 25 February, whilst a light land-breeze was blowing at Walker Point, Cape St. Blaize reported light drizzle, yet another example of localised precipitation associated with the land-breeze.

The **sea-breeze** is observed to have the following effects on the various AWS parameters:

(a) By displacing relatively warmer coastal air, a premature drop in temperature may be registered with the onset of the sea-breeze (summer only).

(b) On this coast a pure sea-breeze will be southerly, but due to Coriolis turning, and superimposition of synoptic scale winds, this direction is seldom recorded.

(c) Peak wind speed with a pure sea-breeze should occur any time after the maximum land-sea temperature difference has been reached (14h00-15h00 on the Cape South Coast in summer according to WB 28 1974). The actual time lapse is dependant on surface friction. Preston-Whyte (1969) found this time lapse to be nil in the Durban area.

Unlike the Cape West Coast where low SST and marked heating overland in summer favour a strong sea-breeze circulation, the Cape South Coast is more favourable for land-breeze development.

Looking for premature drops in air temperature not associated with any synoptic scale development, sea-breezes were identified at all three AWS on 26 and 28 February. In each case a sudden drop in air temperature occurred at between 09h00 and 12h00 after initial rapid warming from a cold land-breeze condition. This drop was associated with an onshore wind component and in some cases a temporary peak or sudden jump in wind speed.

It is significant that both sea-breeze days occurred after the passage of BOH's. Peak wind speeds (sea-breeze plus gradient wind), occurred at between 17h00 and 23h00 on these days, but it was difficult to separate synoptic scale and local components.

3.2.5 Precipitation

No significant rainfall was reported from the lighthouses. George recorded very light falls (less than 1 mm) associated with frontal passages on 24 and 27 February.

3.2.6 Sea-Surface Temperature

Very little change in SST was registered at Still Bay or Knysna during the week under study. At Port Elizabeth on 24 February the passage of the coastal low coincided with a temperature rise from 21-24^{o}C. These are surf temperatures at Humewood Beach and this change may therefore reflect a change in sea state. Slight cooling (20-18^{o}C), was associated with the passage of the BOH early on 28 February.

3.2.7 Sea State

Since Sedco-K was in Mossel Bay undergoing her annual maintenance, no Waverider data was available. However, VOS data gives some indication of conditions. Coverage is by no means complete, and for the major development of 27 February in the east there are no wave reports. The frontal system of 25 February, although it had negligible effect on the coastal weather, produced the highest swell amongst the VOS data - south-westerly 6 m on 25 February at 12h00z. This report was roughly 60 km south-east of Cape Infanta. It is significant that the front was followed by a BOH relatively far south. Such a cold front/ BOH combination with its increased pressure gradients and unstable PBL ensuring a better transfer of momentum to the sea surface, seems to provide better wave generation than a single frontal system.

3.2.8 Synoptic Reports from VOS

Eastern Agulhas Bank. Two ships reported fog in the Cape St. Francis region on 25 February. Winds were moderate to fresh westerly associated with relatively weak cold fronts passing by. The most significant synoptic feature associated with the fog was the fresh easterly winds on 23 February and 24 February. It has been shown that such winds are responsible for upwelling at certain capes on the Cape South Coast, Cape St. Francis included (Schumann et al., 1982). A later case study will show that westerly winds (the coastal low came through at 13h00 on 24 February), may push the upwelled water eastwards, thus providing a cold water body downwind of the source of upwelled water for the formation of advection fog.

Thick fog with visibility less than 200 m was reported on 1 March at 18h00z by a vessel in St. Francis Bay. Note that this was again after a moderate to fresh easterly wind followed by the passage of a coastal low at 12h00. Although the vessel reported an SST of 18°C, much colder water was recorded in St. Francis Bay in March 1984 after prolonged, strong easterlies, for example, on 10 March 1984, the SST recorded on board the Meiring Naudé dropped to 11°C (see Section 5.4.2 on upwelling).

Western Agulhas Bank. Two reports of low SST's were received after the strong easterlies of 23 February, with 16°C off Cape Agulhas and 15,5°C off Cape Baracouta.

3.3 CASE STUDY NO. 3: 27 AUGUST - 2 SEPTEMBER 1978 (Figure 3.3.1)

Dominant feature: Repeated, intense Cold Air Cyclone developments around a semi-stationary parent low.

This represents the stormiest period on record since offshore measurements began in 1978. Neither the maximum wind speed nor the maximum wave-height, have been exceeded in the past 8 years on the Bank. At approximately 06h00 on 2 September, an absolute maximum gust of 45,5 m/s was recorded at the top of the derrick on Sedco-K (73 m asl.). The maximum hourly average wind speed (04h00 to 05h00), was 33,1 m/s which reduces to 26,1 m/s at 10 m. At the time of the storm, the rig was approximately 40 km south of Port Elizabeth.

Weather systems prior to 30 August 12h00. On 27 August a cold front passed south of the rig. Behind this system there was a sudden drop in speed of over 20 m/s as the wind backed to south-westerly then easterly. There is evidence of a brief land-breeze early on 28 August, after which a coastal low passed through. A cold front with a wave which had developed to the south-west of the Bank, arrived approximately 10 hours after the coastal low and the maximum 15 minute wind speed of almost 25 m/s occurred approximately 4 hours after the frontal passage.

The AOA ridged in behind this front, mainly overland, and a brief land-breeze was experienced offshore, from 19h00 to midnight on 29 August, peaking at 21h00 when it reached 6 m/s. Early on 30 August, a coastal low passed the rig, heralding the beginning of a relentless frontal onslaught, with 5 intense frontal systems passing over the rig in the next 4 days.

Frontal systems starting 30 August 15h00. The first system, coming approximately 12 hours after the last coastal low, was associated with a jump in wind speed at 15h00. This also coincided with a definite switch in wind direction and a pressure minimum. Early on 31 August the second cold front, which had developed a wave, passed over the rig. During the next 60 hours, wind speed seldom dropped below 20 m/s. The frontal passages are well-marked by peaks in wind speed and troughs in the air pressure trace. These systems were continually being developed in the mP air behind the previous front - **cold air cyclones.** Note that the change in wind direction associated with each frontal passage was less than 20^{o}, although the general tendency to back is clear.

The last frontal system passed the rig at 05h00 on 2 September, bringing with it a record 2 second gust of 45,5 m/s. Though this value was measured at 73 m above sea level, conditions were so unstable and turbulent that a similar extreme probably applied to lower levels. The hourly average between 04h00 and 05h00 (33,1 reduces to 26,1 m/s at 10 m), also holds the record for measured data on the Agulhas Bank. Note that the above reduction is, if anything, too severe, that is, the hourly average at 10 m may well have been closer to 30 m/s.

The highest estimated wind speed from VOS reports on the eastern Agulhas Bank was 33,4 m/s (02h00). Graham (1982) has suggested that VOS estimates be taken as hourly averages, but if this is treated as a standard 10 minute average, it compares very well with the unreduced 15 minute average from the rig (34,1 m/s). Maximum estimated wind speed at Cape St. Francis was 30 m/s.

An important feature of this case study is that it highlights the inadequacy of a wind record such as that from Port Elizabeth's H F Verwoerd Airport, only 2 km from the coast, when it comes to estimating offshore conditions (see Fig. A.3.2 Appendix 3). The stable PBL overland kept Port Elizabeth's average hourly wind below 10 m/s until 09h00 on 1 September, whilst

Sedco-K, 40 km to the south, was averaging well over 20 m/s. The following day, the airport recorded its maximum hourly average between 09h00 and 10h00 - 19 m/s (south-westerly) - well below that recorded earlier on the rig.

Pressures rose rapidly behind the last front as the AOA ridged overland. This is regarded as an important factor in the generation of post-frontal winds and swell.

Swell. This storm also ranks as one of the most severe to hit the Agulhas Bank, from the point of view of sea state, in the last decade. The 8,6 H_{mo}, at 20h00 on 1 September, is the highest to be measured on the Agulhas Bank thus far. Note that Waverider records at the rig were sampled 6 hours apart, with no record being available for 02h00 on 2 September - so actual H_{mo} could well have been higher. The highest swell estimate from eastern Agulhas Bank VOS was 9 m - from a vessel south-west of Cape St. Francis at 14h00. However, Shillington (1979) reports that wave-heights of 12-15 m were estimated off the east coast. The vessel responsible for this observation was riding the Agulhas Current, which would have strongly opposed the swell. It seems quite likely that an H_{max} (trough to crest) of over 20 m may have been encountered on the seaward side of the eastern Agulhas Bank.

It is significant that a vessel in the vicinity of Cape St. Francis at 20h00 on 1 September, reported thunderstorm activity. Early the following morning in Port Elizabeth, intense thunderstorm activity was also reported. Hamilton (1980) studied the synoptic conditions during which 4 NDBO data buoys had capsized, and found that in each case cold polar air associated with intense convective activity, was present. He postulated that the squally, unstable conditions associated with thunderstorms were imparting additional high frequency energy to the sea surface. Shillington (1979) noted that the local generation of waves played a significant role in producing the extreme wave-heights of this period.

3.4 CASE STUDY NO. 4: 16-22 FEBRUARY 1982 (Figures 3.4.1-3.4.3)

Dominant feature: Cut-off low/blocking high pair with the associated surface low situated over the interior.

The main synoptic pattern in this case study was a COL/BH pair on 17 and 18 February which, although associated with a relatively weak Black Southeaster, caused heavy rain locally on the eastern Cape South Coast. Following upon a frequently observed pattern in COL situations, a second low developed on the Cape West Coast on 19 February. This system was associated with gale force easterly winds on the Agulhas Bank which resulted in selective coastal upwelling.

Primary cold front - 16 February. The passage of this front through the 3 coastal AWS is marked on the time-series. Propagation speeds were roughly 40 km/hour in the west and over 90 km/hour in the east. This turned out to be the 'primary cold front' as prescribed by Taljaard (1985) for COL development. Note that in this case the passage of the front was associated with a marked gust front at Walker Point, whereas Cape St. Francis had a wind speed discontinuity of only 3 m/s. Nevertheless, this gust front provided the means to accurately time the frontal system along the coast. Post-frontal rain was reported from all 3 lighthouses.

COL/BH. The warm blocking high was east of Gough Island on 16 February providing the essential warm air advection southwards over the island and relatively cold air advection northwards behind the primary cold front (Taljaard, 1985). By 17 February this system had ridged in south of Cape Agulhas, cutting off a low over the central interior. This situation was very short-lived with the COL moving out to sea the following day, but Cape St. Francis had received 58 mm of rain in typical Black Southeasterly conditions by 08h00 on 18 February. Early on the same morning a merchant vessel south of Mossel Bay reported visibility down to 4 km in driving rain (VOS report). The heaviest rain at Cape St. Francis and Cape St. Blaize was reported on the morning of 18 February , as the low moved seaward. The high rainfall figure at Cape St. Francis was very localised, for example Swartkops, east of Port Elizabeth, recorded only 5,8 mm. The COL remained well-defined offshore as it moved north-east into the Mozambique Channel.

Deep coastal low. A second low developed on the west coast on 19 February. Although not associated with a closed upper circulation, an upper trough is mentioned in the 14h00 inference. It would be incorrect to regard this as a normal, shallow coastal low, since both Cape St. Blaize and Cape St. Francis reported precipitation early on 19 February. The BH was still south of the Agulhas Bank and the tight pressure gradient between these two systems resulted in easterly winds which averaged approximately 20 m/s for over 12 hours at Cape Infanta.

Coastal SST measurement showed that significant upwelling had taken place. Between 08h30 on 19 February and 09h00 on 20 February SST readings at Knysna Heads dropped from 21 to 14°C. VOS reports of SST offshore remained relatively constant throughout the period. Cold upwelled water only reached Humewood (Port Elizabeth) on the morning of 22 February after the switch to strong westerly components the previous evening. The surf temperature dropped from 22 to 15°C. Presumably the westerly components were necessary to transport water upwelled off Cape Recife (a preferred location - Schumann, 1982) into Algoa Bay. No change in SST was recorded at Still Bay, presumably because of its position relative to sources of upwelling.

Strong easterly winds continued on 20 February, especially in the east. On 21 February a coastal low formed east of Cape Infanta as a result of the deep offshore flow around the COL and moved eastwards along the coast. The latter system followed the coastal low less than 5 hours later averaging approximately

35 km/hour between Cape Infanta and Walker Point. It then accelerated to more than double this speed on the leg to Cape St. Francis where a well-defined gust front marked its passage. Just prior to this gust front, advection fog at Cape St. Francis reduced visibility to 800 m. This fog was probably linked to anomalously low SST values.

Mesoscale circulations. Even in February the land-breeze circulation was very much in evidence, particularly at Walker Point where it undercut even the strong synoptic circulations (see mornings of 17 and 19 February). Characteristic 'notches' in the overnight wind speed envelopes of the other AWS are also present, as cold air flowed down from the interior setting up a very stable PBL and isolating the surface layer from supplies of high momentum air above.

3.5 CASE STUDY NO. 5: 15-21 APRIL 1982 (Figures 3.5.1-3.5.3)

Dominant feature: Marked cyclogenesis south of Port Elizabeth associated with an offshore cut-off low development.

A rapid succession of cold fronts followed by a case of marked cyclogenesis south of Port Elizabeth on 17 April preceded the development of a COL offshore the following day. The cyclogenesis on 17 April provided Cape St. Francis with the absolute maximum wind speed for the whole 1982/3 study period. Significant wave heights of over 5 m were also reported.

Pre-coastal low conditions. On 15 April at 14h00, Sedco-K, approximately 100 km south of Mossel Bay, reported thick fog with visibility down to 1 km. Both Cape Agulhas and Cape St. Francis had reported fog earlier. At 02h00 the following day a vessel approximately 100 km to the east of Sedco-K was also reporting fog with only 500 m visibility. A COL/BH pair earlier in the month were associated with strong easterly winds which caused SST's to drop markedly on the coast.

The primary cold front(s). The coastal low associated with this system passed along the Bank on the morning of 16 April but its passage was masked at all 3 AWS by local land-breeze circulations. Once east of Cape St. Francis the coastal low deepened rapidly with central pressure dropping almost 10 mb, a sure indication of cyclogenesis in the associated frontal system(s).

Two frontal systems were associated with the initial coastal low, the second a secondary development in the cold air. The surface layer of this cold air mass would have drawn considerable heat energy from the Agulhas Current as it moved towards the coast. The coastal AWS thus depicted a very turbulent, unstable air mass on 17 April. Light precipitation was recorded at both Cape Agulhas and Cape St. Blaize in association with these fronts.

This secondary development may be linked to the eventual explosive cyclogenesis as a wave formed on the original front. Such developments have been studied in detail by Mullen (1983) who referred to the frontal wave as being 'induced' by the following cold air cyclone. Although the development of cold air cyclones (secondary lows) behind the main front is a common occurrence south of the Agulhas Bank, with such systems often playing the major role in a series of frontal passages, their development is not well handled by current numerical models (Akyildiz, 1985).

The intense wave formation south of Port Elizabeth on 17 April resulted in Cape St. Francis recording an hourly average wind speed of 24,3 m/s (westerly) at 11h00 - the highest value to be recorded on the Bank in the main study period. This hourly mean should be compared with the absolute maximum for all rig data (26,1 m/s) which was measured by Sedco-K 40 km south of Cape Recife on 2 September 1978. Note that both values have been reduced to 10 m (see Section 5.6 on extreme winds), but the time-series for Cape St. Francis depicts average wind speed measured at the top of the lighthouse.

By 11h00 Cape St. Francis was already reporting continuous heavy rain which amounted to 44 mm by the following morning. At 14h00 H F Verwoerd Airport reported a thunderstorm, which was possibly associated with the deep COL forming offshore.

By 02h00 on 17 April a VOS report estimated swell height at 4,5 m in the vicinity of Cape St. Francis. This compares very well with the Waverider measurement at Sedco-K of 4,76 m. The rig measurements peaked at 06h00 on 18 April - 5,12 m as the blocking high ridged in south of the low.

COL/BH. An intense high was situated in the Gough Island region on 16 April. This warm, blocking system had moved east and cut off the original frontal wave by 18 April. On the evening of 17 April at 20h00 a vessel south of Knysna was already reporting reduced visibility in heavy showers. Continuous rain fell all along the Cape South Coast on 18 April with Cape St. Francis reporting a thunderstorm at 05h00. By 19 April the BH had merged with the Indian Ocean Anticyclone (IOA). Note that the COL formed offshore and stayed offshore so that the extreme winds on the Agulhas Bank were **westerly.** There was no coastal upwelling.

It is possible that a secondary low developed on the eastern Agulhas Bank on the morning of 19 April reinforcing the COL which moved **westwards** according to the SAWB analyses. This could explain the fact that wind speeds at Cape St. Francis again rose to over 25 m/s giving 19 April the second highest hourly values of the entire recording period. Heavy rain was again reported from Cape St. Francis early on 19 April, reducing visibility to under 5 km.

Weak ridge followed by cold front. On 20 April the COL moved off to the south-east followed by a weak ridge over the Agulhas Bank. Associated with this ridge was a particularly interesting land-breeze case at Cape Infanta. Late on 19 April, the land-breeze reached almost 10 m/s. It commenced at 22h00 and reached its peak within an hour. This peak (flow directly offshore) coincided exactly with the minimum air temperature recorded that night. The land-breeze continued intermittently until 09h00 the following morning, when a north-easterly wind took over, and the temperature jumped almost 4°C.

The cold front referred to by Taljaard (1985) as the 'disruptive cold front', was associated with a wave development south-west of Cape Town. This system and its attendant coastal low were never in evidence at Cape Infanta where easterly winds blew from 20 April onwards. At the other two coastal AWS, the pair were vaguely identifiable. At 20h00 on 21 April a vessel south-east of Algoa Bay was reporting lightning. This convection may well have been related to the above cold front which passed Cape St. Francis at about 19h00. Strong horizontal wind shear was associated with this front with wind direction backing directly from west to easterly.

Persistence of blocking. By 22 April yet another BH was in position south of the Agulhas Bank, indicating how a situation with high meridional flow index may be quickly re-established.

3.6 CASE STUDY NO. 6: 26 JULY - 1 AUGUST 1982 (Figures 3.6.1-3.6.3)

Dominant feature: Frontogenesis associated with a series of cut-off lows.

A series of COL systems affected the Agulhas Bank during this 7 day period, the third COL being associated with a double frontal system on 29 July which produced the highest wind speeds. At Cape St. Francis the gust front associated with the second front caused **average** wind speed to jump from 10 m/s to over 20 m/s (both the quoted averages and the average wind speed on the Cape St. Francis time-series have been reduced to 10 m).

Coastal low. The wind direction traces suggest that the initial coastal low which passed Cape Infanta on 26 July, never reached the other two AWS, both of which recorded an **earlier** passage.

Both Walker Point and Cape St. Francis recorded pre-coastal low north-westerlies which became westerly in the early afternoon. This is presumed to be a land-breeze condition, which persisted when the land mass remained cool relative to the sea, but with flow turned through 90^o by the Coriolis effect.

COL moves out. On 27 July the COL moved out over the eastern Agulhas Bank. This system is discussed by Taljaard (1985). It had formed in the wake of an earlier COL which tracked south of the country on 22 and 23 July. This second COL caused near-gale force (15 m/s) westerlies over the eastern Agulhas Bank early on 27 July.

BOH. The switch from westerly to easterly wind components on 27 July marks the passage of a BOH. At Walker Point there is evidence of a sea-breeze at about 12h00, with a premature drop in air temperature coinciding with a marked increase in onshore flow.

COL No. 3. On 28 July a third COL which had appeared north of Gough Island on 26 July started to influence Agulhas Bank weather. With a deep layer of offshore flow, a coastal low formed and passed over the AWS network at 06h30 (Cape Infanta), 10h30 (Walker Point) and 13h00 (Cape St. Francis). These times give rough propagation speeds of 50 km/hour and 70 km/hour over the western and eastern Agulhas Bank respectively. Both Cape Infanta and Walker Point had light **westerly** winds ahead of this system; presumably this was the local land-breeze turned anticlockwise by the Coriolis force. All 3 lighthouses reported precipitation associated with this COL.

Note that the absolute minimum on the pressure trace at Cape St. Francis at 13h00 was associated with this coastal low whilst at Cape Infanta absolute minimum pressure was associated with the following cold front.

Frontogenesis associated with COL. Although the above COL had no frontal origins, the dynamics of the system caused a double front to form. This pair was particularly well-defined at Cape St. Francis where it was marked by two intense gust fronts at 03h30 and 08h30 on 29 July. Just prior to the first gust front, Cape St. Francis reported lightning in the vicinity - possibly cumulonimbus triggered by the front. Hourly average speeds behind the second front reached 25,5 m/s (21,9 m/s at 10 m). The gap between these two fronts narrowed from 10 hours at Cape Infanta to 7 hours at Walker Point, and only 5 hours separated them at Cape St. Francis. Propagation speeds increased dramatically from west to east - 18 to 70 km/hour for the first front, and 25 to over 150 km/hour for the second. As usual wind speeds also increased from west to east - from a 13 m/s peak at Cape Infanta and Walker Point to 21,9 m/s at Cape St. Francis.

The gust fronts associated with this COL and the subsequent strong westerly winds which blew for almost 24 hours, had dire results at the Ruiterbos Forestry Station approximately 30 km north of Mossel Bay where over 2 500 ha were burnt in a fire which began before the upsurge in wind speed (see Section 4.2.6 on forest fires).

AOA/BOH. The AOA moved in behind the COL late on 29 July, but as the ridge was initially overland, coastal wind remained westerly. A cell of high pressure appeared off the east coast on 30 July, followed by a BOH moving around the coast and causing winds to go easterly. At Walker Point with optimum conditions for the land-breeze, cold offshore flow continued until 10h00 on 30 July. Coastal air temperatures which had dropped below 10°C started rising again at about sunrise. Note also the characteristic wind speed and direction traces indicating very little turbulence. At Cape St. Francis the start of the land-breeze coincided with a sudden drop in wind speed at 05h30. This same effect was observed at Walker Point at 03h00 on 31 July. The lighthouse keeper at Cape St. Blaize reported early morning rain, possibly linked to the onset of the land-breeze.

COL No. 4. A fourth COL appeared south-west of Cape Town on 31 July. At 14h30 the associated coastal low passed Cape Infanta. It averaged approximatly 40 km/hour as it passed along the coast. The phenomenon of westerlies **ahead** of the coastal low is again apparent at Walker Point - presumably a local circulation.

The last COL produced westerly winds which attained their maximum speed in the east, Cape St. Francis recording an hourly average of 24,8 m/s (21,3) at 00h00 on 1 August. Apart from the suspected role played by the local topography in enhancing wind speeds at Cape St. Francis the surface low moved with a slight northward component as it passed eastwards south of the Bank.

3.7 CASE STUDY NO. 7: 6-12 OCTOBER 1982 (Figures 3.7.1-3.7.4)

Dominant feature: A cut-off low situated off the Cape West Coast resulted in an extended period of strong easterly winds on the Agulhas Bank.

The dominant synoptic pattern is again a COL/BH pair which resulted in VOS reports of high waves and heavy rain offshore. There was also evidence of coastal upwelling. A VOS report of thick fog coincided with berg wind conditions on the coast on 6 October.

Initial coastal lows. A gust front which caused average wind speed to jump almost 15 m/s at 01h00 on 6 October at Cape St. Francis was associated with a coastal low which had already passed through the other AWS. A second coastal low only 6 hours behind the first caused temporary berg wind conditions at Walker Point and Cape St. Francis with early morning temperatures well over 20°C. The passage of this system (04h00 at Walker Point, 06h00 at Cape St. Francis), resulted in rapid cooling.

The pre-coastal low berg wind conditions on the coast coincided with thick fog on the coast and offshore - a VOS report from south of Cape Seal at 02h00 gave visibility at only **50 m.** Presumably this was a case of berg winds soaking up moisture as they moved over the ocean, only to be cooled to condensation by lower SST's. An additional factor would be the very marked stratification associated with berg winds. Precoastal low fog was also reported from Cape St. Blaize.

Extended thunderstorm activity on the coast, associated with the second coastal low, did not seem to be a case of interior thunderstorms moving onto the coast ahead of the coastal low, as no precipitation was reported from the adjacent interior. It would seem to be rather a 'deep coastal low' situation with an upper trough to the west. The combination of fog followed by thunderstorms, indicates a stable surface layer, with unstable 'middle layers'.

Cold fronts 1 and 2. Anomalous north-easterly winds occurred at Cape Infanta on the morning of 6 October. Presumably the easterly components were a reflection of the rapidly changing pressure field. The cold front associated with the first of a pair of mid-latitude lows passed Cape Infanta at 15h30. Half an hour later it passed over Sedco-K with a well-defined gust front. The rig was drilling approximately 100 km south of Cape Infanta during this period. This cold front did not show up well at Walker Point or Cape St. Francis, probably due to a strong southward component in the system's track. However, on 7 October with a single deep low analysed south of Port Elizabeth at 14h00, VOS estimates of swell height were over 6 m on the eastern Agulhas Bank. The second low making up the original pair passed south of the Bank on 7 October. Although a cold front was not placed in the trough on the 14h00 analysis, the passage of a front is discernable on the time-series, especially at Cape Infanta.

Cold front No. 3. The third mid-latitude low, a new development in the cold air (CAC), passed eastward south of the Bank on 8 October. This system was still developing and tracking in more of an easterly direction, so that peak winds were experienced in the east (for example, Cape St. Francis maximum gust

33,7 m/s at 08h00). Post-frontal rain occurred at both Cape St. Blaize and Cape St. Francis.

Yet another low developed in the cold air on 8 October keeping Cape St. Francis winds at gale force until mid-afternoon. Several VOS reports with swell height estimated at over 6 m were received from the eastern Agulhas Bank. VOS estimates of wind speed were suprisingly consistent, and compared well with the measured values for Cape St. Francis. This system did not show up well on the western Agulhas Bank.

COL/BH. The AOA, well south of its normal position as required for COL development, intensified to approximately 1 040 mb on 9 October as it ridged in over the Agulhas Bank. All 3 coastal AWS experienced an enhanced land-breeze circulation associated with this ridge. Both Cape St. Blaize and Cape St. Francis reported overnight rain during the period that the land-breeze was blowing. By 14h00 a low was being analysed over the central interior, and 24 hours later it had shifted to the Cape West Coast. Taljaard (1985) followed the track of this COL on the upper air charts. At both 700 and 300 mb the low was displaced north-west initially, turning to the south-east late on 11 October. This is roughly reflected in the surface pattern although more than one centre was analysed on 12 October (excluding the associated coastal low).

Uninterrupted easterly winds occurred at Infanta and on the rig on 10 and 11 October with coastal speeds comparable with those offshore (approximately 15 m/s - note that Sedco-K winds have not been reduced). SST dropped from 17°C on 9 October at Knysna Heads to 12°C the following day as a result of coastal upwelling. VHRR data from NOAA satellites has shown Cape Seal to be at the base of an upwelling plume under such conditions and with continued easterly winds this is the most likely source of the cold water at Knysna. The cold water thus had approximately 30 km to travel from source to observation point, which would imply that upwelling was initiated soon after the upsurge of easterly winds. At 14h00 on 10 October a vessel south of Cape Barracouta gave an easterly swell of 5,5 m.

The 'coastal low' associated with the COL passed along the coast on 12 October and effectively switched off the strong easterlies. Just ahead of this low a VOS report from a ship well south of Cape Infanta, gave heavy continuous rain at 02h00. Cape St. Blaize also reported heavy precipitation associated with the passage of this low - 25,3 mm was recorded. The first of the two surface lows associated with the upper COL brought very gusty westerly winds to the western Agulhas Bank within a few hours of the easterlies dying down. On this occasion the rig, with wind speed averaging over 20 m/s, had far stormier conditions than Infanta, whilst at Walker Point the wind speed never rose above 5 m/s. Cape St. Francis also recorded relatively mild westerly conditions as this system moved out. This comparison should serve as a warning that conditions offshore - even within 100 km of the coast - may differ considerably from coastal weather conditions.

Land-breeze. At the other two coastal AWS the ability of the land-breeze to disrupt even a major synoptic condition is well portrayed. Considering the wind speed/gust envelope on 10 and 11 October, the COL easterlies were markedly attenuated by the land-breeze at Walker Point and Cape St. Francis on both mornings. This effect was far less noticeable at Cape Infanta. Early on 9 October at Walker Point the land-breeze introduced very cold air to the coast ($8^{\circ}C$) resulting in a highly stable PBL and effectively stifling the transfer of high east wind momentum from above.

At Cape St. Blaize, light rain occurred again early on 10 October in association with the land-breeze. The following evening the lighthouse keeper reported 800 m visibility in fog - probably due to advection over cold upwelled water.

3.8 CASE STUDY NO. 8: 9-15 DECEMBER 1982 (Figures 3.8.1-3.8.4)

Dominant feature: Intense cyclogenesis in summer.

This 7 day period illustrates how the eastern Agulhas Bank may be subjected to stormy frontal conditions with gale force westerly winds even in summer. Drought conditions were well established by 9 December with Port Elizabeth receiving less than 50 per cent of its normal combined November/December rainfall. Thus a bushfire went rapidly out of control on 10 December when the passage of a cold front caused Cape St. Francis winds to reach 25 m/s and remain at gale force for over 24 hours. Extensive fire damage occurred on the campus of the University of Port Elizabeth.

Sedco-K was still drilling in the same position as for the previous case study, that is, approximately 100 km south-east of Cape Infanta. The wind trace at Cape Infanta will be seen to have somewhat less resolution than normal. This is due to a 30 minute recording interval in place of the usual 15 minutes.

Coastal low No. 1. This system passed along the Bank on 9 December. Using the wind switch as a marker, a propagation speed of approximately 60 km/hour was obtained for the Walker Point/ Cape St. Francis leg. It is significant that only on the rig did the wind switch tie up with the pressure minimum. At Walker Point and Cape St. Francis, the pressure minimum occurred almost 6 hours ahead of the wind switch.

Frontal systems. Two intense cold fronts followed the initial coastal low. The first averaged well over 100 km/hour between Infanta and Walker Point. The associated gust front was not nearly as well-defined offshore as on the coast. Rapid development of a wave on this front south of the Agulhas Bank, led to its slowing down, with an average speed to Cape St. Francis of only 44 km/hour. This sudden cyclogenesis resulted in wind speeds reaching 25 m/s at approximately 17h00 at Cape St. Francis. It was these winds which caused an earlier fire at Seaview (PE) to flare up and spread rapidly eastwards. At 14h00 on 10 December a VOS report from east of Algoa Bay gave a waveheight of **7,5 m.** Both Cape Agulhas and Cape St. Francis reported precipitation associated with this front. The second cold front moved across the Bank on 11 December. The associated CAC must have developed significantly as it moved eastwards judging by the anemometer traces at Cape St. Francis relative to the other AWS.

BOH - 11/12 December. This system followed the last front across the Bank late on 11 December. As is commonly the case the land-breeze circulation was enhanced during the passage of this BOH, even though the latter was relatively weak. At 02h00 a merchant vessel approximately 50 km south of Cape St. Francis reported continuous heavy rain with a 2 km visibility. SST was a relatively warm 19,8^{o}C. There can be little doubt that this precipitation was due to enhanced convection over the Agulhas Current, since no synoptic system can be held responsible. Furthermore it is very tempting to choose the land-breeze circulation which was clearly evident at Cape St. Francis at the time, as a possible trigger mechanism for offshore thunderstorms.

Coastal low No. 2. With the passage of this coastal low on 12 December westerly components were retained at the rig indicating that this system had unusually little offshore extent. It averaged over 40 km/hour from Infanta to Walker Point and roughly 60 km/hour on the second leg to Cape St. Francis.

Front plus wave, 13 December. The development of a wave on the cold front associated with coastal low No. 2, took place on 12 December. As is frequently the case, this cyclogenesis took place in an area south-west of Cape Town where Agulhas rings (Olson, 1986) may be present.

The cold front which was well-defined at all 4 AWS, took approximately one hour to cover the 200 km between Infanta and Walker Point. On the rig the gust front was recorded at 02h00, the same time as at Cape Infanta, inidicating a surface front sloping to the west at lower latitudes. Between Walker Point and Cape St. Francis it slowed down considerably, averaging under 50 km/hour.

The time interval between coastal low and cold front narrowed from 11 hours at Cape Infanta to 8 hours at Cape St. Francis as the pair crossed the Bank. As usual, highest wind speeds were recorded at Cape St. Francis with an hourly wind speed of 25,5 m/s (21,9 reduced), at 07h00 on 13 December. Both Cape St. Blaize and Cape St. Francis reported rain just to the rear of this system.

BOH, 13 and 14 December. As the rapid rise in pressure at all 4 AWS testifies, a fast-moving BOH crossed the Bank on the night of 13/14 December. With temporarily slack pressure gradients and clear skies, favourable land-breeze conditions were established at all 3 coastal AWS. The cold offshore flow brought coastal air temperatures down to under 15°C. Even at the rig, a light north-westerly wind was experienced on the morning of 14 December.

Coastal low No. 3. A coastal low/cold front pair crossed the Bank on 15 December. However, the front was only discernable at Cape Infanta and the rig, as it only reached Walker Point on 16 December. A VOS report from roughly the centre of the coastal low at 14h00, gave a dry bulb temperature of 25,5°C, which was higher than any of the AWS. This phenomenon has been noted previously, that is, that the subsidence inversion associated with a coastal low may descend lower offshore than on the coast.

3.9 CASE STUDY NO. 9: 11-17 FEBRUARY 1983 (Figure 3.9.1)

Dominant features: Offshore measurements of a land-breeze during cut-off low easterlies. Also a major wave-generating frontal system in summer.

On 11 and 12 February 1983, the R/V Meiring Naudé ventured south of Mossel Bay as far as the Agulhas Current in order to retrieve a current meter mooring. She spent 13 and 14 February in Mossel Bay harbour and the last 3 days depicted on the time-series were spent close inshore between Mossel Bay and Gericke Point. The AWS on board was able to record the effects of a wave development south of the Bank on 11 February and land-breeze undercutting of COL easterlies, from 14 to 16 February 1983.

Frontal wave. The synoptic analysis of 11 February indicated a single deep low at about 45 S, 21 E (14h00). The subsequent analysis (24 hours later) indicated that a wave had developed on the front, inducing coastal pressures to drop to almost 1 000 mb. Near gale force winds were recorded by the Meiring Naudé for over 24 hours. Navigation officers estimated swell heights of 8-10 m on 12 February, and had to abort operations due to the heavy swell. It is assumed that swell heights were considerably enhanced in the Agulhas Current. Observers on Sedco-K, drilling well inshore of the current, estimated swell height at 6 m.

This cannot be regarded as the primary front for the subsequent COL events since a COL was only identified on the Cape West Coast on 16 February. All 3 lighthouses giving synoptic reports recorded precipitation associated with this frontal wave.

BOH. Late on 12 February the AOA started to ridge in behind the above frontal system so that an almost continuous ridge existed south of the Bank from 13 February onwards. This resulted in an extended period of easterly winds on the Bank. Frontal systems continued to pass south of the Bank after the ridge had been established. At Cape St. Blaize early morning precipitation on 13 February may have been associated with the land-breeze.

COL. Although a surface low was maintained off the west coast from 15-17 February, causing winds on the Agulhas Bank to remain easterly, these winds seemed to be of insufficient strength to generate upwelling at the Capes. Alternately the coastal waters were insufficiently stratified. There was little change in SST at either Port Elizabeth or Knysna and the SST channel on the shipboard AWS showed very little variation during this week.

However, a report of thick fog from Cape Agulhas at 08h00 on 17 February indicated probable upwelling in the extreme west of the Agulhas Bank, with the moist, post-coastal low air being cooled to saturation through contact with the sea surface.

Coastal low. On 17 February a coastal low formed in association with the main COL north-west of Cape Town. This system 'switched off' the easterly flow on the Agulhas Bank as it passed along the coast. Fresh southerly winds were recorded behind this system on the Meiring Naudé which was by then in the Great Brak region, within 15 km of the shore.

Land-breezes. A major feature of this time-series is the way in which it showed the land-breeze circulation consistently undercutting the synoptic scale easterlies. This was particularly clear when the vessel was at anchor in Mossel Bay (13-15 February). The anomalous direction of the land-breeze at this location is probably due to the combination of Coriolis turning and the local topography. Cape St. Francis reported rain very early on 15 February, possibly associated with the land-breeze.

On 16 and 17 February the Meiring Naudé was working a grid between Mossel Bay and Gericke Point, but remaining within 15 km of the coast. Even offshore, the land-breeze is seen to undercut the easterlies associated with the COL. Wind speeds thus dropped dramatically in the early morning, as the PBL stabilized. Note, however, that the land-breeze was clearly warmer by the time it reached the Meiring Naudé offshore, compared with the mornings in port.

3.10 CASE STUDY NO. 10: 12-18 MAY 1984 (Figures 3.10.1-3.10.2)

Dominant feature: Explosive cyclogenesis - a Southern Hemisphere 'bomb'.

During the 7 day period covered by this time-series, several intense frontal systems crossed the Bank with their associated low pressure systems deep and relatively far north. Pandolfo (1985), has suggested that steep SST gradients may play an important role in cases of rapid cyclogenesis, and it is thus significant that the GOSSTCOMP means for the week ended 15 May 1984, showed Agulhas Current water of over 20^{o}C as far west as the 17^{o}E meridian, with strong gradients to the west and particularly to the south of this. The anomaly in this area for April 1984 was over 4^{o}C (NOAA).

On 16 May a low pressure system which more than justified the label 'bomb' (see Section 4.3.5), passed south of the Bank after causing millions of rands damage along the Southwest Cape Coast. Although Sedco-K has recorded higher wind speeds on this section of the Agulhas Bank, the Actinia recorded by far the lowest air pressure since continuous offshore measurements began in 1978. At the time of the storm she was drilling at a position approximately 110 km south of Still Bay.

Initial frontal systems. On 12 May the passages of two fronts are visible on the time-series, both marked by a pressure minimum and a jump in wind speed at 06h30 and 19h00 respectively. No major systems are discernable on 13 May, but no less than 3 cold fronts passed over the rig on 14 May, the last of which moved rapidly north-east to produce a maximum gust of 33,7 m/s at 23h00 on the rig. It is possible that this was related to the downdraught from a thunderstorm triggered by the front, as average wind speed was only 22,3 m/s and air temperature also dropped temporarily.

The 'bomb'. The original low passed just south of Gough Island on the evening of 14 May 1984. It was relatively weak, with a central pressure of approximately 994 mb. By 20h00 on 15 May central pressure had dropped to 962 mb, that is, 32 mb in 24 hours. Fortunately for the sea-level synoptic analyst, a drifting buoy equipped with an accurate pressure sensor lay almost directly in the path of the storm.

This explosive case of cyclogenesis, placed this system in the category of a 'bomb' as defined by Sanders and Gyakum (1980), that is, it had averaged a pressure fall of over 1 mb/hour for over 24 hours. Note, however, that this system was considerably closer to the equator than most Northern Hemisphere 'bombs'. At its peak the storm centre was a mere 600 km SSW of Cape Town.

The track chart of this mid-latitude low (Fig. 3.10.1), shows that the system veered rapidly to the south soon after reaching maximum intensity (02h00 on 16 May). This factor probably saved the Cape South Coast from considerably more damage than was experienced.

Just prior to the dramatic fall in pressure on 15 May two systems affected the Bank in rapid succession. At approximately 10h00 a cold front passed the Actinia causing temperatures to drop to a low 13°C in the middle of the day. Immediately behind this system a weak BOH formed which was associated with the later development of a coastal low in the vicinity of Plettenberg Bay, that evening. Both of these systems only came into prominence over the eastern Agulhas Bank. The coastal low was associated with berg wind conditions in the Port Elizabeth area where a ship in Algoa Bay gave dry bulb 23,4°C and dewpoint 4,9°C at 06h00 on 16 May.

The anomalous north-easterly wind at the rig on the afternoon of 15 May is significant in that it indicated a rapidly changing pressure field in which the geostrophic assumption failed and surface winds blew almost directly across the isobars.

The main front associated with the 'bomb' passed over the rig at 02h00. Consider the marked temperature fall of over 5°C, over 10 m/s jump in wind speed, and a definite backing in direction which all coincided at this time - a text-book cold front. A sharp pressure rise followed as the AOA ridged in overland. On 17 May at 19h00 a secondary frontal system passed the rig and it was only on 18 May that a BOH started moving around the coast.

Propagation speed. The main cold front on 16 May took approximately 2 hours to cover the distance between Cape Town and Actinia, giving a zonal propagation speed of about 100 km/hour (front orientation as per Scholtz, 1984).

Wind. The maximum gust of 39,7 m/s (84,5 m above sea level), was not a record on this section of the Agulhas Bank, where Sedco-K has measured 44,2 m/s. However, as portrayed in the time-series, average wind speed on the rig exceeded 20 m/s for over 12 hours, and this resulted in a very heavy sea being generated locally, superimposed on the large swell arriving from the west. The gust front arrived at East London at 20h00 causing considerable damage yet at Port Elizabeth hourly wind never exceeded 8 m/s. It is possible that the topography of Port Elizabeth's hinterland played a major role in this anomaly.

Air pressure. The low of 16 May provided Port Elizabeth with a record low pressure of 988,4 mb. The minimum rig pressure of 980,3 mb was also well below any previous minimum, which gives some indication of the pressure gradients across the Agulhas Bank. Although the extremely tight pressure gradients would have caused a difference in sea-level of over 20 cm between storm centre and the Cape South Coast, the low pressure centre was over 600 km offshore with its track diverging rapidly from the coast. The effect of wind drag was probably more important, but fortunately this was not associated with an onshore surge.

Air temperature. The berg wind conditions on the eastern Agulhas Bank associated with the coastal low of 15/16 May did not cease after its passage. This was due to the strong offshore flow ahead of the front. Thus early on 16 May, Cape St. Francis was still reporting over 23°C. With the passage of the cold front on 16 May, major temperature falls were recorded overland and even well offshore (see Actinia time-series). On the rig, temperatures continued to decline steadily after the initial drop, to as low as 10°C at times.

To the south of the rig this maritime polar (mP) air mass would have been crossing Agulhas Current water which was over 10°C warmer. The resulting extremely unstable PBL, coupled with an already favourable synoptic situation, caused heavy convective activity over the southern Agulhas Bank. These conditions extended over the rig early on 17 May, and the very unusual report of offshore **hail** was received.

Sea temperatures: These are measured at a depth of approximately 15 m on the Actinia. Temperatures fell from about 16°C to 13°C from 15 to 18 May, the main fall occurring just prior to the secondary frontal system on 17 May. Presumably the surface waters of the Bank were already sufficiently mixed to prevent any major change in temperature.

Sea state: On the Actinia the **estimated** wave height (no Waverider data was available) at 06h00 on 16 May was 8,5 m. A VOS estimate approximately at 50 km to the north of the rig gave 9 m. Both compare well with the maximum measured H_{mo} at Slangkop, south of Cape Town, of 10,8 m.

Prediction: Although this storm will probably rank as one of the major frontal systems to affect the **Southwest Cape** this century, it did not provide design wind conditions on the Agulhas Bank. It was, however, very unique as an extreme case of cyclogenesis. Because of their rapidity of development, such systems may be of greater danger than tropical cyclones and it is thus imperative that all physical processes involved be correctly modelled. The ECMWF numerical model, which is operated at Reading, UK, predicted the 16 May 02h00 position correctly, 48 hours ahead, but had central pressure 28 mb too high (Scholtz, 1984).

3.11 CASE STUDY NO. 11: 22-28 SEPTEMBER 1984 (Figure 3.11.1)

Dominant feature: Heavy easterly swell associated with a cut-off low.

The only two ports on the Cape South Coast, Mossel Bay and Port Elizabeth, are well situated as far as the normal westerly components of swell are concerned. But a heavy swell with an easterly component can cause port closures and even damage coastal structures. On 27 September 1984, considerable damage was done to coastal fences and railway lines at Port Elizabeth. As might be expected, a COL situation was responsible for the easterly fetch. Only AWS data from the Actinia, drilling on the western Agulhas Bank, was available for this period. Although this time-series does not portray the high wind speeds over the eastern Agulhas Bank, it does not indicate clearly the passage of the various systems.

COL/BH. With the COL/BH pair initially well to the west of the country, fresh to strong easterly winds blew continuouly over the Bank from 22 to 24 September 1984. At 18h00 on 24 September, the passage of a coastal low heralded a brief period of west to south-westerly winds. The BH then moved in south of the Bank causing gale force easterlies to blow. Although these winds were of relatively short duration at the rig due to the passage of two surface lows on 26 and 27 September, the tight pressure gradients between the BH and these lows, continued for the next 3 days, south-east of the Bank.

A VOS report coinciding with the passage of the first low, gave thunderstorm conditions south-west of Kynsna at 02h00 on 26 September. At 06h00 the following day another report indicated that fog had formed behind the second COL. Another VOS report of fog was received from the Port Elizabeth area on 28 September. Visibility offshore remained down to 500 m locally, even by the early afternoon. These fog reports may well be related to coastal upwelling as a result of the extended period of strong easterly winds.

Swell. The easterly fetch region east of the Bank on 26 and 27 September resulted in a heavy swell over the eastern Agulhas Bank. On 27 September at 06h00 a vessel in Algoa Bay reported an easterly swell of 6 m. Damage to coastal works in Port Elizabeth has already been mentioned. Thus a COL/BH situation may generate heavy easterly swell on the Agulhas Bank, that is, swell from a direction which is not well catered for by harbour and other coastal works on the Cape South Coast.

3.12 CASE STUDY NO. 12: 5-11 FEBRUARY 1985 (Figure 3.12.1)

Dominant feature: Extended easterlies associated with a blocking high, after the passage of the cut-off low.

This period is very similar to the previous case study in that a COL/BH event was again associated with reports of strong easterly winds followed by reduced visibility in fog. However, in the present case, 2 surface lows associated with the upper COL passed over the rig prior to the long easterly blow.

COL/BH. This COL/BH pair were situated half way between Gough Island and Cape Town at 14h00 on 5 February 1985. After a complex pattern of lows had passed across the Bank on 6 and 7 February, near-gale force easterlies were established, with the BH almost stationary for the next 3 days. On 6 February at 14h00, a VOS report gave reduced visiblity due to heavy rain in the vicinity of Cape Recife. This was just to rear of the initial coastal low. Note that the strong easterly winds were switched off by the passage of a coastal low early on 11 February. The BH had finally shifted eastwards.

The other drilling platform on the Agulhas Bank, Sedco-K, approximately 40 km south-east of Cape St. Francis, experienced a drop in SST to 12°C at 08h00 on 10 February. Presumably this was due to the generation of an upwelling plume south-west from Cape Recife. By 14h00, Sedco-K was reporting fog with minimum visibility 1 km - advection fog formed after air had traversed the cold upwelled water. At 02h00 the following day, a VOS report from a vessel south-west of the rig, indicated thick fog with 500 m visibility. This was just ahead of an incoming coastal low.

Swell. Sedco-K reported a south-easterly swell of approximately 5 m on the afternoon of 8 February 1985. However, swell height measurements from the Actinia were generally low, giving some indication of attenuation from east to west.

4. SYNOPTIC SCALE WEATHER SYSTEMS

4.1 INTRODUCTION

Due to the very broad area of marine meteorology being covered in this thesis, **discussions, conclusions** and **recommendations** are generally structured around the individual phenomena. In this chapter the various characteristics of the synoptic scale systems are summarized. Although the discussion draws largely upon the atmospheric and related oceanographic processes identified in previous chapters, AWS and other information outside of the case studies has also been utilised.

Chapter 1 introduced the synoptic scale pressure systems in terms of the role that they play in deciding long-term weather conditions. The case studies then gave day-to-day examples of how these systems dictate the weather of the Agulhas Bank. Each of these systems will now be considered in more detail. The case studies provide an important source of **new** information about particular systems, as well as consolidating existing ideas.

4.2 THE COASTAL LOW

As Table 1.1 showed, this is the most dominant synoptic system on the coast. It has counterparts in South America and Australia, but it is the Southern African system which is best defined thanks to the marked escarpment bordering much of the coastline.

4.2.1 Formation and Dissipation

This system owes its existence to the interaction between synoptic scale flow at the level of the escarpment (1 - 1,5 km), and the sharp drop in altitude towards the coast. It is essentially a lee-side low. De Wet (1984) has suggested that the South

Coast system is generated by the north-westerly flow ahead of eastward propagating west wind troughs. It was shown in the previous chapter that a single coastal low may form on the eastern Agulhas Bank whilst surface winds in the west remain easterly. That the frequency of occurrence is highest in the east is supported by the coastal wind roses, with a higher frequency of westerly winds indicating that some coastal lows start their track on the eastern Bank. This is particularly the case in summer when the AOA may keep a ridge over the western Agulhas Bank for several days. Case study No. 5, 21 April 1982, gives an example of continued easterlies at Cape Infanta, whilst a coastal low and its attendant cold front are clearly seen to pass through the other two AWS.

It is also possible for a coastal low which was clearly visible over the western Bank, to dissipate in the central Bank area. This occurred on 26 July 1982 (case study No. 6), when only Cape Infanta saw the characteristic east-west wind switch. It is possible, however, that the coastal low moved offshore, since both AWS to the east reported westerly winds. Estie (1984) reported that coastal lows may move offshore on the northern Natal Coast. This is, strictly speaking, no longer a coastal low, since the major influence of the topography is now removed. The low must develop a new dynamic balance in order to survive. Sometimes such a development is seen to coincide with the formation of a wave on an incoming front.

4.2.2 Propagation Path and Periodicity

Propagation path. From the above it is evident that the coastal lows may leave the coast over the central part of the Cape South Coast. Its path over the **western** section still needs a clarification which extends to the whole question of the continuity of the coastal low from the Cape West Coast system to the South Coast system. Since the coastal low is dependent on an escarpment for its existence, it seems probable that those systems which move from the west to the southern coast, follow the coastal mountain ranges. Over the extreme western parts, this would imply a path tracking well inland (see Fig. 1.1).

Periodicity. The time between two consecutive coastal lows may vary from less than 24 hours to a maximum of approximately 1 week. For example, on 6 October 1982 (case study No. 7), Cape St. Francis experienced two coastal low passages in 6 hours. This period varies to such an extent that it would be misleading to talk of an average frequency. However, there are times when coastal lows may pass through with great regularity for several weeks (Hunter, 1984).

4.2.3 Propagation Speed

The siting of the 3 coastal AWS provided a unique opportunity for calculating propagation speeds. However, two factors made such calculations difficult at times. Firstly, it was often difficult to put a definite time mark on the coastal low passage. Due to the effects of atmospheric tides and local topography, the pressure trace was largely unsuitable. The local pressure minimum associated with the coastal low often did not coincide with the change in wind direction, especially on the coast. The wind switch was also often poorly defined due to undercutting by the local land/sea-breeze circulation.

Secondly, the sometimes high propagation speeds (> 100 km/hour) lead to relatively short time intervals between stations which were often comparable with the accuracy of the time marks.

Where a coastal low passage of moderate speed (say 70 km/hour) was accompanied by a well-defined wind switch or gust front at all 3 coastal AWS, the calculated propagation speed was regarded as accurate to within roughly 20 km/hour. Table 4.1 lists those coastal lows from which it was able to calculate speeds to within this limit:

(a) If the excessively high speeds (150 km/hour and over) are to be rejected, three possible reasons for an error may be put forward. Firstly, the time of passage may have been incorrectly identified. Secondly, the whole idea of regarding this as a continuously propagating independent system (Gill, 1977), as opposed to one which requires continual generation (De Wet, 1984), may be questioned. Lastly, this may not have been the same system all the way through. Case study No. 2, 27 February 1982, gives an example of a coastal low seemingly moving from **east to west.** In actual fact the system which passed through Cape Infanta dissipated, whilst a **new** system developed in the west.

(b) Speeds are seen to range from 25 km/hour to 90 km/hour, excluding the outlyers. With this small sample it would not be justified to link propagation speed to other characteristics. However, it may be said that those coastal lows which preceded cut-off lows did not display anomalous speeds.

(c) As regards coastwise changes in propagation speed, this could only be determined in 9 out of the 12 cases. In 3 cases there was little change, 5 showed a distinct acceleration, whilst the only deceleration was associated with a cut-off low.

(d) A common problem in trying to mark the time of passage on the time-series was anomalous westerly winds **ahead** of the coastal low, so that no wind switch was available. A possible explanation is that an earlier land-breeze had been turned by Coriolis action - or there had been an earlier passage of a system which only formed on the eastern Agulhas Bank.

4.2.4 Depth of Circulation

A subsidence inversion marks the upper limit of the coastal low circulation. This inversion separates the warm subsided offshore flow from the surface maritime air. It is usually situated at about escarpment level, but drops with the approach of the coastal low, minimum mixed-layer depth coinciding with the passage of the coastal low. When this subsidence inversion extends down to the surface, hot berg wind conditions are experienced on the coast.

Wind direction is often reversed above the inversion with a characteristic wind shear at the inversion top. The weak cyclonic circulation is replaced by an anti-cyclonic circulation above, so that any precipitation **directly** associated with the coastal low is likely to be confined to a light drizzle dependant on orographic enhancement.

4.2.5 Offshore Extent

From Sedco-K data it would seem that most coastal lows on the Cape South Coast extend beyond 100 km offshore, that is, their passage is clearly marked on the rig time-series, with pressure minimum, wind switch and increased wind speed coinciding. Examples of coastal low passages offshore are presented in Table 4.2. Of the 10 passages, only 2 did not have easterly components offshore, ahead of the coastal low. On 17 February 1983 (case study No. 9), the Meiring Naudé was close enough inshore to pick up the land-breeze, and in the second case, the Sedco-K experienced continuous north-westerly winds, whilst the coastal low passed inshore.

It is interesting to note that in 7 out of 10 passages, the wind veered from north-easterly (NE) or NNE through northerly to post-coastal low westerlies, that is, if one regards the coastal low as a closed circulation, the centre must be over 100 km offshore. However, the seasonal wind roses (Section 2.1.1), indicate that easterly winds are more common offshore than on the coast in summer. This would indicate that several coastal lows pass inshore of the rig, a fact which has been observed in routine rig wind analysis. In comparison, AWS observations from Sedco 708, a similar distance off the Cape West Coast, imply that many more coastal lows may pass inshore there without affecting the prevailing south-easterly winds.

4.2.6 Leader Front

Taljaard (1961), proposed the existence of a 'leader front', marking the transition between tropical continental (cT) and tropical maritime (mT) air masses. The western edge of the coastal low is placed at the intersection between this front and the coastline. The coastal low is thus envisaged as a part of a much more extensive **pre-frontal** system. This concept is supported by the front-like changes often associated with coastal low passages, both inland and offshore.

4.2.7 Relationship Between Coastal Low and Following Frontal Trough

Continuous AWS data from the Sedco-K, drilling since 1978 on the Agulhas Bank south of Mossel Bay, has suggested a strong link between coastal low and following frontal system. This is to be expected since the large scale trough associated with the latter also provides the north-westerly forcing function for coastal low formation. Table 4.3 was compiled from the case studies to indicate the range of time intervals between coastal low and **the first** frontal system to follow (bearing in mind that a series of cold fronts may follow a single coastal low passage). Note that all systems following behind coastal lows which displayed frontal features, were considered. Thus, a deep coastal low and several fronts which developed in cut-off low circulations, were included. The following points emerged:

(a) The enhanced land-breeze circulation at Walker Point again lead to uncertainties in the time of passage. There were signs of a maritime flow overriding the land-breeze when the coastal low was due, but it was felt that using this phenomenon as a time mark could not be justified.

(b) Although this is a small sample, the eastward reduction in the time interval is clear in two cases, whilst only one case had an increase, and this was a cut-off low.

(c) Where concurrent offshore measurements were available, 2 cases occurred where the time interval between coastal low and front was 2 to 3 hours **longer** offshore, compared with the nearest coastal AWS. This is difficult to explain, as the case studies have shown that the coastal low passage is generally later offshore, whilst the cold front arrives earlier.

(d) Considering the only two 'pure' frontal pairs, the interval varied from 13 to 7 hours across the Bank. This is in good agreement with larger samples taken from Sedco-K AWS data.

(e) As the counts in Section 1.6 showed, a single coastal low may be linked to more than one front at different stages of its journey along the coast. For example, a new wave development on the front may initiate the formation of a new coastal low. This is illustrated in case study No. 2, 27 February 1982.

(f) Rapidly falling coastal pressure associated with an intensifying coastal low is usually linked to an intensifying frontal system. A good example of this occurred during the intense storm of May 1984 (case study No. 10). There were also several examples of how absolute minimum pressure shifts from the frontal system to the coastal low as the pair pass eastwards, for example, 2 -3 August 1982, case study No. 1.

4.2.8 Weather Conditions Associated with the Coastal Low

Wind direction. The characteristic switch in wind direction (E-W) associated with a coastal low passage is not always abrupt. If the passage occurs at night there is a good chance that the local land-breeze or simply the radiative stabilisation of the PBL, may 'decouple' the large scale flow. On the other hand, a slow-moving, elongated coastal low with a strong ridge to the south will result in a slow veering of the wind which may never go further than southerly (for example 17 February 1983, case study No. 9). The coastal low has also been identified as the 'switch' which marks the end of a long spell of easterly winds associated with a COL/BH episode (for example case study No. 7, 12 October 1982 and case study No. 12, 10 February 1985).

Wind speed. Pre-coastal low easterlies may reach gale force but they are generally far steadier than the turbulent westerlies behind the system. It is thus generally possible to distinguish pre-coastal low conditions from post-coastal low conditions without recourse to wind direction, but by simply looking at the average speed/gust envelope. The previous chapter showed that post-coastal low westerlies often increase considerably in strength as the system moves east. This is not the case with the easterlies which may be just as strong or stronger in the west. Case study No. 4, 19 February 1982 gives an example where the easterlies at Cape Infanta were the strongest on the coast. Most of the case studies contain proof of the enhanced post-coastal low **westerlies** at Cape St. Francis.

Buster. When the post-coastal low wind takes the form of a sudden jump in wind speed from near calm to over 10 m/s, it is known as a 'buster'. This phenomenon is clearly more common on the eastern Agulhas Bank. Some coastal low models (for example Gill, 1977) predict a rapid decrease in the intensity of this gust front as one moves offshore. However, a coastal low passage on 24 October 1973 coincided with a VOS report of a series of line squalls 75 km south of Mossel Bay (**Marine Observer,** October 1974). As a further contradiction of this theory, busters are also apparent on the rigs, although their frequency is lower than on the coast (for example 12 October 1982, case study No. 7). These observations support the concept of an intense leader front extending well offshore.

Case study No. 2, 8 August 1982, is a good example of a buster which reached its peak at Cape St. Francis. In that case the 2 second gust jumped from 10 m/s (pre-coastal low berg winds) to over 25 m/s. Despite high speeds attained during buster conditions, especially in the east, highest wind speeds on the coast are not associated with the coastal low but rather with frontal systems or cut-off lows - see Section 5.6 on extreme winds.

Air pressure. As might be expected, the passage of a coastal low is associated with a local minimum on the air pressure record. However, this pressure minimum may be displaced from the wind switch by several hours at coastal stations. This is presumably due to atmospheric tidal effects and interaction between the coastal low circulation and the local topography. Offshore the two events usually coincide.

The summer case study No. 2 showed how absolute minimum pressure in a specific coastal low/cold front sequence may shift from the frontal system to the coastal low as the pair cross the Bank. This reflects the tendency for fronts to track south-easterly. On the south-east and east coasts absolute pressure minima are nearly always associated with the coastal low.

Air temperature. In general the passage of a coastal low is associated with a cooling as warm offshore flow is replaced by an influx of cooler maritime air. This cooling is enhanced when pre-coastal low berg winds occur. However, should a landbreeze dominate at the time of the coastal low passage, there may well be a **rise** in temperature due to low land-breeze temperatures. Thus on 3 August 1982 (case study No. 1), Cape St. Francis warmed abruptly by over $5^{\circ}C$, as the coastal low brought in maritime air to displace the continental land-breeze air of under $10^{\circ}C$.

Berg wind conditions. Extremely high temperatures on the Cape South Coast are nearly always associated with pre-coastal low berg wind conditions. Should a strong offshore flow be maintained **behind** the coastal low, such as occurs when a well-defined frontal system follows, temperatures may remain relatively high (see May 1984 storm, case study No. 10).

Some indication of the offshore extent of berg winds is contained in Fig. 3.1.7, with the Meiring Naudé experiencing a peak of $27^{\circ}C$ 22 km offshore. This was equal to the peak value at Walker Point indicating that there was no attenuation offshore. This observation is supported by the VOS report on 15 December 1982 (case study No. 8). This lack of attenuation may indicate that the warming is more due to subsidence extending over the sea than hot continental air advecting offshore.

Note that the wind direction during a berg wind event (the term 'berg wind' is taken here simply to indicate abnormally high temperatures) need not necessarily be directly offshore, although the majority of events in the case studies had this parameter between north-east and north-west. In case study No. 8, 15 December 1982, Walker Point had a **southerly** component associated with peak temperatures. This highlights the role of subsidence as against simple advection, but it is important to remember that these are **circulations,** that is, a southerly wind locally is not necessarily a source of maritime air.

It will be noted that berg wind conditions were accompanied by a very turbulent flow offshore on 8 August 1982 (Meiring Naudé). This phenomenon has been noted elsewhere (RN, 1944), and is probably the result of the mountainous coastal topography. Several of the berg wind conditions in the case studies were associated with busters, especially at Cape St. Francis.

It is important to remember that anomalously high temperatures associated with the lowered inversion level above a coastal low may never reach the surface. Yet the layer of warm to hot air with its related high density gradients may present a significant hazard to descending or ascending aircraft. The July-September 1984 issue of Comair News relates the experiences of a light aircraft pilot descending for H F Verwoerd Airport. His aircraft registered a fall of almost 1 000 m/minute above the coastal low, only to rise at almost 2 000 m/minute soon afterwards, as air density changed rapidly over short distances.

4.3 MID-LATITUDE DEPRESSIONS, TROUGHS AND FRONTS

4.3.1 Simple Models and Problems of Frontal Analysis

The link between the mid-latitude depressions and the polar front (boundary between tropical and polar air masses), was first explained by the so-called Norwegian or classical frontal model. This theory, which still survives in many modern text books, proposes that a mid-latitude low starts as a wave on a pre-existing air mass discontinuity.

However, in the 1950's, with upper air soundings becoming more numerous, it became generally accepted that the formation of a mid-latitude low is not dependent on having a frontal zone already present (Taljaard, 1961). Leading synoptic analysts suggested that the dynamics of a baroclinic atmosphere would be sufficient to develop a mid-latitude low, and that frontogenesis could, in actual fact, **follow** cyclogenesis. Thus, low pressure systems developing completely within post-frontal polar maritime (mP) air, may develop frontal characteristics (for example, 31 August to 2 September 1978, case study No. 3). Similarly, the surface low associated with the upper COL of 28 July 1982 (case study No. 6) developed a double front as it rounded Cape Agulhas, both of which were clearly discernable on the AWS time-series.

Taljaard's definition of a front implies the use of upper air information, but most systems pass well south of the sub-continent, where the only two radiosonde stations are some 4 000 km apart. Whilst thicknesses obtained from the NOAA satellites' vertical temperature profile radiometer (VTPR) sounder are invaluable for large scale analysis, coverage is not of a sufficient density to accurately position individual fronts.

Thus, in the Southern African region, the positioning of fronts offshore is almost wholly dependent upon a rather subjective interpretation of visual, infra-red and water vapour images from the geostationary satellite METEOSAT II. Frontal analysis has, in a way, gone the full circle. The Norwegians placed much emphasis on cloud type and sequence, and now we look largely to cloud patterns in frontal analysis. Yet Hunter (1986), illustrates the inability of satellite imagery to identify and position even prominent vortices, at times.

A split cold front model. Browning and Monk (1982) concentrated on the so-called 'katafront', that is, a cold front in which there is a general subsidence except for the lowest few kilometres. In the anafront there is a general ascent of warm air up the frontal slope. Frontal activity is more marked in the latter case with clear temperature, wind and precipitation zones. However Browning and Monk, looking at occurrences of cold fronts over England and Wales for the period January to March 1981, classified 8 out of the 14 well-defined fronts as katafronts, all 8 of which conformed to their 'split' model. Judging by the generally low rainfall associated with fronts passing over the Cape South Coast, the percentage of katafronts is probably even higher here.

Although this model differs in some ways significantly from the average cold front in the South African zone, it also has important similarities. One of these is the recognition that many cold fronts are humidity and not temperature discontinuities. The South African analyst is generally much more dependant on dew-point than dry bulb temperature when trying to place the cold front on the surface synoptic chart. This is a much easier task when the front penetrates well into the interior since coastal stations are often very resistant to changes in temperature or moisture. A check on temperature changes during cold front passages in the case studies shows that the marked discontinuity of 16 May 1984 (case study No. 10), was an exception. In fact most cold fronts do not display a clear temperature discontinuity, with such changes much more likely to be associated with the coastal low.

Another feature of this model which may find favour with South African analysts is the so-called 'conveyor belt' concept. This is a zone limited to a few kilometres in depth extending ahead of the surface cold front which is characterised by high potential wet bulb temperature (θw), and sometimes a low level jet.

4.3.2 Historical Studies of Frontal Systems in the South African Zone

Taljaard et al. (1961), saw the necessity for a clear definition of a front, particularly when it came to the analysis of the International Geophysical Year (IGY) data of 1957/8. Thus, it was decided that a horizontal temperature gradient of $3^{\circ}C$ through the frontal zone would be the minimum requirement. Furthermore this temperature change must extend at least 3 km into the atmosphere. These requirements are too stringent to be applied in the present study and would exclude many frontal systems which significantly affected the weather on the Bank. However, some of their findings, using the above defintion, are of interest:

(a) Frontal zones were observed as far north as $15^{\circ}S$ in winter and $25^{\circ}S$ in summer.

(b) Referring specifically to fronts in the sub-tropical zone ($20-40^{\circ}S$), the intense subsidence inversion is contrasted with incoming frontal conditions. A warning is sounded to analysts not to mistake changes in the inversion for frontal changes. Wet bulb potential temperature is a very useful distinguishing characteristic, since it is conserved during subsidence. It is again emphasised that on the South African Coast, the major temperature and humidity changes are usually not frontal but prefrontal, that is, associated with the passage of a coastal low.

(c) In contrast to the model of Browing and Monk where a **mid-tropospheric** zone of saturated air extends well ahead of the cold front, Taljaard found the incidence of such a feature at the latitude of the Cape South Coast as being infrequent.

Fronts in the sub-tropical region. Following upon their detailed investigations, Taljaard et al. presented a frontal model for the sub-tropics, the essential features of which were as follows:

(a) Occluded fronts were considered to be a rarity north of 35°S.

(b) The important 'leader front' concept was described (see coastal low section, above).

(c) A layer of middle cloud was included in the model, beneath the high level inversion (approximately 500 mb) which preceeds the cold front. In the sub-tropics this has nothing to do with an occlusion or warm front.

(d) To the rear of the cold front a subsidence inversion is soon established and except in the case where a post-frontal cold trough (secondary development) is present, the inversion steadily descends and intensifies. This would fit in with the observation in the case studies that most fronts deposited relatively little precipitation.

4.3.3 Movement of Mid-latitude Cyclones

The average direction of movement of mid-latitude cyclones affecting the Southern African zone was found to be ESE in study by Taljaard (1967). Van Loon (1967) calculated propagation speeds for cyclones in the zone 30-40 S, 60-140 E. He calculated that the average speed in summer 1958, was approximately 10,5 m/s. In winter 1957 this value was just over 11 m/s (40 km/hour). These speeds are markedly lower than the average speed calculated from the case studies (Table 4.4). The discrepancy may be due to the front rotating about the parent low imparting an extra velocity component to the front. However, in his frequency distributions Van Loon does indicate that speeds of up to 25 m/s were encountered.

Fig. 3.10.1 (case study No. 10), depicts the track followed by the 'bomb' of May 1984. Note that the deep low pressure system associated with the cold front of 16 May, had a propagation speed of 33 m/s between 02h00 and 08h00 on 15 May. Similarly, the intensifying low of March 1986 (Hunter, 1986) travelled at speeds of up to 32 m/s. As the above paper shows, the propagation speed of a frontal system may be critical for swell generation.

4.3.4 Cyclogenesis

The distribution of cyclogenesis in the Southern African zone for the 18 month I.G.Y. period July 1957 to December 1958, shows a significant summer concentration near 45°S, 0-10°E (Taljaard, 1967). Olson (1986), used satellite imagery to identify highly energetic rings separating in the Agulhas Current retroflection zone some 10°E of the above area. Pandolfo (1985), showed that such cold-core features favoured enhanced generation of cyclonic potential vorticity. It is thus possible that high SST gradients to the south-west of the country are playing a major role in the cyclogenesis.

In winter the distribution was much more scattered, with more systems developing close to the coast. Note that the term 'mid-latitude cyclone' was applied to all low pressure systems with the same basic structure, even those which developed north of 40°S.

Even in the summer months of the above period, there were two cases of cyclogenesis just south of the Agulhas Bank. A brief look at any set of summer Daily Weather Bulletins will show that this was not unique to the I.G.Y. Case study No. 10 depicts a case of extreme cyclogenesis which produced record low pressures on the Agulhas Bank. The area of most rapid central pressure fall had a marked warm water anomaly to the east, that is, SST gradients would have been high in the region of cyclogenesis. Frontal systems are frequently observed to undergo rapid development to the west of the retroflection zone (for example the wave development of 12 December 1982 - case study No. 8). Further east, the Agulhas Current itself represents a source of intense SST gradients (on its inshore edge), which may play a major role in cases of frontal wave intensification closer to the coast.

4.3.5 Explosive Cyclogenesis and the 'Bomb'

Several Nothern Hemisphere researchers (for example, Roebber, 1984), have recently given attention to the phenomenon of explosive cyclogenesis. As case study No. 10 demonstrates, explosive cyclogenesis may occur at relatively low latitudes with disastrous results. As explained in the previous chapter, the term 'bomb' refers to a low pressure system which averages a central pressure drop of 1 mb/hour for 24 hours (Sanders and Gyakum, 19-80).

Apart from the May 1984 bomb, several cases of explosive cyclogenesis occur each year south of the Agulhas Bank. Although not of the same intensity, they may nevertheless be associated with destructive wind and high sea conditions. The frontal low of 4 December 1976 is an example:

December 1976 storm. In a 24 hour period this low pressure system deepened to such an extent that coastal pressures dropped to below 994 mb, giving Port Elizabeth its lowest pressure in almost a decade and its highest gust in almost 20 years (35,6 m/s). Considerable wind damage occurred in the city on the afternoon of 4 December.

No AWS data is available for this storm, but hourly lighthouse observations indicate that a gust front estimated to peak at about 30 m/s (hourly estimate) crossed the eastern Agulhas Bank in approximately 2 hours on 4 December. VOS estimates are in good agreement with those from the lighthouses. At 14h00 on 4 December a ship south-west of Cape St. Francis reported a westerly wind of about 30 m/s as the cold front passed. Visibility was reduced in heavy rain and swell was estimated at **10 m.** This swell estimate was supported by several other vessels including the minesweeper 'Windhoek', involved in a rescue operation in Algoa Bay. Note that this extreme swell occurred in the middle of summer. Furthermore it was generated in a relatively short space of time.

This further example of rapid frontal development shows that this potentially destructive phenomenon occurs sufficiently frequently to warrant detailed study. Such study is even more justified by the fact that present numerical weather prediction (NWP) models handle this type of development with the least success (Gyakum, 1983; Jager, 1984 and Akyildiz, 1985).

The QE 2 storm. This was a case of explosive cyclogenesis in the western North Atlantic during which an initially shallow surface low deepened by almost 60 mb in 24 hours. The name of the storm derives from the fact that the passenger liner, Queen Elizabeth 2, passed south of the centre early on 11 September 1978 where she received extensive damage due to the high swell. James (1979), has estimated that wave heights of over 20 m (H_{max}) occurred near the centre of the storm. Such extremes could well occur in the Agulhas Current on the edge of the eastern Agulhas Bank during storms such as the December 1976 storm.

As was the case in May 1984, NWP models successfully located the centre of the storm in the prognoses, but drastically underforecast the central pressure. Another parallel with the May 1984 storm, is that the QE 2 storm was associated with intense convective activity. Gyakum (1983), has suggested that convective processes which may be poorly simulated in present NWP models, are largely responsible for the rapid development of the system.

Note that the QE 2 storm also developed in a region of intense SST gradients where warm Gulf Stream water contrasts strongly with the cold Labrador Current. Pandolfo (1985) has found that in theory cyclonic potential vorticity may be generated at a sufficiently high rate for 'bomb' formation over the Gulf Stream - under certain surface wind conditions.

Baroclinic leaf. A case of rapid cyclogenesis in the eastern Pacific is discussed by Jager (1984). National Weather Service prognostics for this storm, which had its origins in a weak frontal wave, were out by 50 mb at the storm centre. Jager claimed that the appearance of a so-called 'baroclinic leaf' pattern in the clouds on satellite imagery, is a reliable indication of rapid surface cyclogenesis. He linked the rear edge of this leaf pattern to a strong upper air jet stream curving cyclonically equatorward. It is of interest that the upper winds at 400 mb during the May 1984 storm (see Section 3.10) were measured at 100 m/s at approximately 06h00 on 16 May.

It is possible that some cases of rapid cyclogenesis affecting the Agulhas Bank are similar to the above, but unfortunately, data coverage would again be insufficient to verify the initial wave, whilst the subsequent development of a deep vortex may not be discovered from satellite imagery until a relatively late stage.

Fastnet yacht race, 1979. This is the final example of an explosive cyclogenesis which caused considerable loss of life amongst competitors in the 1979 Fastnet yacht race, off the south-west and southern coast of England. One vessel recorded a pressure fall of 22 mb in a three hour period. Adlard Coles (1980), described the winds, estimated to gust at over 33 m/s, as extremely turbulent, whilst the high seas were described as exceptionally steep and confused. A total of 302 boats started the race, 217 retired, 18 were abandoned and 5 were sunk. There were 15 fatalities amongst the crews. Of particular significance is the fact that this was a **summer** development, the responsible low deepening suddenly on 14 August 1979 in the Fastnet sea area.

4.3.6 Cold Air Cyclones and the Intensification of Frontal Waves

Apart from the intensification of an existing frontal low, high winds and heavy seas on the Agulhas Bank may also be caused by the development and rapid intensification of a secondary low in the mP air behind an initial front - known alternately as a 'polar low' or 'cold air cyclone' (CAC). The development of a deep wave on an existing front may also result in high winds over a significant fetch region. Since the first system may interact with the second they will be considered together:

In direct contravention of the classic Norwegian cyclone model, the cold air cyclone (CAC) is a vortex which forms in the homogeneous cold mP air mass behind an initial front. Even a relatively brief study of surface synoptic charts south of South Africa will show that this is a very common type of frontal development. The third case study (Sedco-K, 1978) shows a series of these secondary developments crossing the Bank. Case study No. 1 also depicts a series of cold air cyclones.

Mullen (1983) points out that a CAC development may induce the formation of a wave on the preceding cold front. A study of satellite images showed the CAC to be associated with a comma shaped cloud pattern in the post-frontal cumulus field (inverted in the Southern Hemisphere). This is sometimes seen to merge with the preceding frontal band as both systems join to become a single occluded low pressure system.

Forbes *et al.* (1984) used satellite imagery to study mesoscale cloud vortices in the north-east Atlantic. 133 vortices were classified according to cloud pattern and a comprehensive set of meteorological data obtained for each case study. They made the following conclusions concerning those vortices which later developed into full blown polar lows:

(a) Polar lows had a definite preference for over-water development with those systems which moved over land usually weakening rapidly.

(b) The development of **Atlantic** polar lows was found to be the result of both moist baroclinicity and the CISK (Conditional Instability of the Second Kind) mechanism. Thus, significant gradients of horizontal virtual temperature T_v are required, together with a cumulus convection interacting with the large scale motion to cause unstable growth on the latter scale (Holton, 1973).

(c) Large differences in air-sea temperatures causing convection and the formation of the mesoscale vortex patterns were responsible for both developing and nondeveloping vortices. But it was the **position** of the vortex relative to upper height and thermal troughs and ridge axes which decided whether the disturbance would amplify. Advection of absolute and thermal vorticity must be positive over the disturbance.

Note that the above study was based on NOAA 6 and 7 imagery which has not been used operationally in South Africa since the advent of the geostationary satellite products (Meteosat 1 and 2). The latter imagery has a significantly poorer resolution (4 versus 1 km), which is important when the scale of the system being studied is considered (approximately 250 km). Furthermore, the accuracy with which the 500 mb trough axis can be located south of the country, is far less than that attainable in the north-east Atlantic. Thus, the possibility of manually predicting polar low development in our region is at present rather limited, whilst prediction by current numerical models is still subject to inaccuracies (Akyildiz, 1985).

Induction. Mullen (1983), gives an example of so-called 'instant occlusion' when a polar low induced a wave to form on the preceding front and the two systems both displayed explosive development. He suggests that a significant proportion of the intense winter storms over the North Pacific have their origins in cold air cyclone development. A study of synoptic sequences to the south and south-west of South Africa, indicates that this may also apply to intense frontal systems affecting the Agulhas Bank.

Local example of induction. Early on 26 April 1984, a CAC induced a wave to form on the preceding front as it crossed the Agulhas Bank. By 27 April at 14h00, a single deep wave was being analysed well to the south-east of the Bank. The initial frontal system with the wave developing rapidly as it crossed the Bank, was associated with gusts of over 25 m/s on the night of 25 April. Air temperature dropped from 20°C to under 12°C behind this system (Actinia AWS data). Air-sea temperature difference would thus have been over 10°C over the Agulhas Current.

On the evening of 26 April, winds freshened as the cold air system passed south of the rig. However, most of the development seemed to be concentrated in the preceding wave. As the two merged further up the coast, wind speeds of 35 m/s were estimated off the east coast. The Da Gama yacht race which had recently started from Durban, suffered 3 vessels sunk, and the entire crew of the yacht Rubicon, lost without trace.

4.3.7 Frontal Systems Affecting the Agulhas Bank During 1982/3

Table 4.4 lists those frontal systems for which it was possible to calculate coastwise propagation speeds. Attention is drawn to the following points:

(a) These speeds ranged form 18 km/hour to what appeared to be infinity. In actual fact, the calculation for very fast systems is highly inaccurate due to the small time interval between AWS. However, some fronts certainly crossed the Bank at speeds well in excess of 100 km/hour.

(b) Excluding the higher speeds, frontal propagation speeds are of the same order as those calculated for the coastal lows. The coastwise deceleration in 3 out of the 10 cases probably reflects the tendency for fronts to slip southwards. As for coastal lows, speeds generally increased across the Bank.

(c) Gust fronts associated with the frontal passage were the most accurate form of marker. As with the coastal lows, this feature was usually enhanced in the Cape St. Francis area.

(d) An increase in wind speeds roughly 8-15 hours after the passage of a coastal low, was often the only indication of a cold front passage. Garrat and Physick (1983), have discussed the occurrence of gust fronts over south-eastern Australia. A characteristic of such discontinuities in wind speed is the rapid change in air pressure in the frontal region. This is well-defined on the Agulhas Bank AWS time-series (see for example the May 1984 storm, case study No. 10). The Australian study depicted clearly the folly of using steady state approximations in such a frontal zone.

(e) Wind direction did not necessarily have to show a definite backing although this was well-defined with intense frontal systems.

(f) Well-defined frontal systems gave a marked change in curvature on the pressure record with sometimes a pressure jump of a few millibars. In the east, the coastal low was often better defined on the pressure record than the cold front.

(g) Whilst the more intense systems showed well-defined temperature contrasts (for example, May 1984), the majority did not.

(h) Several examples appear in the case studies of enhanced convection associated with thunderstorms being triggered by the passage of a cold front. In the April 1974 edition of the **Marine Observer,** the vessel 'Armadale' reports the sighting of two waterspouts off Cape Recife. From the weather reports and relevant surface pressure analysis it is evident that a passing cold front was enhancing the cumulonimbus cloud already present over the Agulhas Current. The VOS data contained only 9 sightings of funnel cloud in over 25 years, so the above was presumably a rare observation. There were no summer sightings which is probably an indication of the importance of a large air-sea temperature difference in the generation of these mesoscale features.

(i) A good example of a frontal passage is given in case study No. 10. It will be seen that temperature drop, jump in wind speed, and the backing of wind direction, all coincided. Local wind peaks associated with the front are normally within about 4 hours of the other changes.

Table 1.1 (Chapter 1), showed that there were generally more frontal systems crossing or passing south of the Bank than coastal lows moving along the coast. In addition to the observed phenomenon of a single coastal low being associated with more than one cold front during its lifetime, the winter basic cycle showed how a single coastal low could be followed by a series of cold fronts.

4.4 HIGH PRESSURE SYSTEMS

4.4.1 Bud-off Highs (BOH)

The migratory or bud-off high appears initially as an eastward extension of the AOA. The latter is then said to be 'ridging'. This ridging can take place over land (usually more common in winter when the AOA is some 5^{o} further north on average), in which case a separate cell may make its first appearance on the extreme eastern Agulhas Bank. In the west the winds would then remain westerly despite the passing of a pressure maximum, since the centre of the high is to the north of them. However, it is more common for the AOA to ridge south of Cape Agulhas and over the Agulhas Bank. Such a ridge becomes progressively elongated until eventually a separate bud-off high (BOH) forms and moves up the coast. This process may be extremely rapid at times - a BOH may replace a frontal system in less than 12 hours (for example, case study No. 1, 5 August 1982). Similar migratory systems are seen to track south of Australia whilst others cross the southern Andes (Taljaard, 1972).

It is incorrect to ascribe the sharp drop-off in easterly winds on the Cape South Coast in winter, to a similarly drastic reduction in BOH's coming around the coast. Table 1.1 does not support this; on the contrary July had one of the highest counts. The difference is that in winter separate cells may only appear off the eastern Cape Coast for the first time (for example case study No. 6, 30 July, 1982). It is also suggested that residence times for such highs is much shorter in the winter. Summer synoptic analyses show the AOA keeping a ridge over the western Agulhas Bank, in particular, for several days at a time (for example case study No. 9, 13 and 14 February 1983). Note that in case study No. 6 referenced above, the initial overland ridging was followed by a separate cell forming off the east coast, with a BOH finally coming around the coast on 30 July, as well.

The importance of this BOH in the weather cycle of the Agulhas Bank cannot be overstressed. Although it is cold-cored and thus relatively shallow it is directly linked with much of the precipitation of the Cape South Coast and is often a major ingredient whenever extremes of wind, SST or swell are encountered. With its centre well offshore and no definite feature suitable as a time mark, no attempt was made to calculate propagation speeds for this system.

As Table 1.1 indicates, there are usually considerably more coastal lows in a single month than BOH's. Once a BOH has moved right up the east coast it is usually associated with the establishment or intensification of a high over the north-eastern interior. This process has been linked with the formation of coastal lows on the **west** coast (De Wet, 1984), the frequency of which is much lower than that of coastal lows on the Agulhas Bank. Thus, the higher frequency of coastal lows versus BOH's on the Agulhas Bank is to be expected.

Table 4.5 indicates the general circulation associated with the passages of bud-off highs during the case studies:

(a) Maximum pressure associated with the BOH at each coastal AWS is also indicated in the table. Note that there was very little coastwise pressure change and also that the winter systems were associated with higher central pressures.

(b) All 7 of the migratory highs depicted in the table were associated with an enhanced land/sea-breeze. At least 2 of the 3 coastal AWS depicted this feature. The land-breeze, in particular, seemed to benefit from a BOH passage, as slack pressure gradients followed the initial influx of cold air, and clear skies ensured rapid nocturnal cooling overland.

(c) In order to affect the land-breeze the BOH had to arrive at the right time of day. For example, on 27 February 1982, Cape St. Francis experienced no land-breeze enhancement, but the BOH was associated with a marked sea-breeze at that station.

4.4.2 The Blocking High (BH)

This system will also receive attention in the section on COL's since the **warm-cored** high moving in south of the COL is usually a good example of a blocking high. Whilst blocking highs and COLs usually go in pairs, the former does not always imply the existence of the latter.

Van Loon (1956), used three criteria to identify blocking highs in the Southern Hemisphere. Firstly, the blocking pattern must persist for a minimum of 6 days. Secondly, in the above period the system must not be displaced more than 25° longitude, and finally, the high must be at least 10° south of the mean position of the STHP belt. He continued to show that blocking was most frequent in late winter and early spring and that there was a high frequency of blocking in the vicinity of Marion Island.

As can be seen in Table 1.1, the criteria used in Section 1.6 for identifying a high as a blocking system were not nearly as stringent as the above. The highest number of blocking systems was counted in April (4), and even March had 3 counts. However, it is clear from Taljaard's (1985) COL study that 1982 was not a typical year.

Good examples of prolonged blocking situations occur in case studies 7 and 9. In both cases a blocking high was positioned south of the Agulhas Bank, cutting off a low (that is, COL) to the north-west, so that fresh to strong easterly winds blew on the coast for over 48 hours. Assuming a well-defined thermocline in the coastal waters, upwelling could be expected. Should the COL move south-east and become trapped again by a ridging high (see case study No. 11), the increased fetch associated with the easterly winds will result in a heavy swell from that direction.

Note that in both the case studies mentioned above, there is a characteristic pressure trace, with pressure falling gradually over a 3 to 4 day period from the initial maximum. Case study No. 12 gives yet another example of a blocking high south of the Agulhas Bank. However, in this case the long period of strong easterly winds occurred after the surface lows associated with the COL had passed, that is, the pressure gradient was between BH and the following coastal low.

Thus, the case studies have shown that any migratory high which is particularly slow of movement (and not just those conforming to the stringent limits set above), is worthy of attention, both from oceanographer and meteorologist.

4.5 THE CUT-OFF LOW (COL)

Taljaard (1985), has produced a comprehensive publication covering all aspects of the COL from development to decay. For both the physical oceanographer and coastal engineer this is a very important system since it may be responsible for both intense upwelling on the Cape South Coast as well as a high easterly swell on the Agulhas Bank. As pointed out in the discussion of

Table 1.1, 1982 had a particularly high count of COLs and Taljaard has included several of these in his case studies. Unfortunately none of those selected were of major oceanographic significance. A summary of COL circulations during the case studies is given in Table 4.6.

4.5.1 Formation

The following conditions for the formation of a COL were prescribed by Taljaard:

(a) A cold front must be approaching the land mass with the axis of an upper trough several hundred kilometres to the west. This 'primary' front has been indicated, where possible, in the relevant case studies, for example 16 February 1982, case study No. 4.

(b) A high pressure system which is markedly warm cored, that is, intensifies with height, must be in the vicinity of Gough Island. Note that this is well south of the normal sub-tropical high pressure (STHP) belt.

(c) There must be a well-defined trough in the 1 000 - 300 mb thickness field between the above-mentioned front and high. This represents a zone of relatively cold mid-tropospheric air.

(d) On the western side of the high, warm air advection from the north-west is essential for the building of the ridge. The northward advection of cold air towards the sub-continent and the southward advection of warm air to the west of this, results in an S-formation in the upper air thermal pattern. The cold trough is associated with cyclogenesis whilst in the warm ridge subsidence and an intensification of the surface high occurs. In case study No. 5, an extreme example of such cyclogenesis occurred south-east of Cape St. Francis, on 18 April 1982. This was unusually far east.

(e) Taljaard emphasises that the ridge must be well-defined in the upper air, with a closed circulation up to 300 mb as it moves eastward, cutting off a pool of cold air to the north.

(f) The position of the upper cut-off system depends on the longitude at which warm air advection takes place. If it occurs midway between Gough Island and the sub-continent, the COL should appear west or south-west of the country. A deep influx of warm air further east would imply COL development overland or to the south.

(g) The distance between the mid-tropospheric ridge and the following trough axis was required to be relatively small so that there would be a rapid switch from cold to warm advection.

(h) Taljaard points out that the initial cold front, (see a), need never have passed Gough Island where a warm high may already have been present for some time. Thus the front may have formed east of Gough Island.

(i) The St. Helena area is identified as a possible source region for upper air troughs or even closed circulations which may interact with trough/ridge systems further south to produce a COL in the vicinity of the Cape.

4.5.2 Movement

From the tracks of 10 COLs, Taljaard concludes that a COL which forms overland is most likely to move in a south-easterly direction, but displacment in any direction is possible as the 'Laingsburg' system of January 1981, showed. A system forming west of the Cape, could move south-east and miss the land completely, or it could move overland. The direction taken by the COL seems to be dictated by the dominant middle and upper tropospheric flow.

The cases depicted in Table 4.6 have 2 out of the total of 7 COLs moving out from the interior; the rest are associated with surface lows that moved east, south of Cape Agulhas, that is, giving **westerly** winds on the Cape South Coast. The actual speed of propagation (which may be different at different levels), may be sluggish for several days initially, but eventually there is a sudden increase in speed as, for example, when a COL moves seaward from the interior.

4.5.3 Rainfall

(a) The most favourable zone is 300 to 1 000 km east of the upper low centre and in a direction roughly between north-east and south-east of this centre.

(b) The situation where a COL is associated with the formation of a 'coastal low' on the south or south-east coasts is singled out as a potential flood-producer on the Cape South Coast. In this case, there is a strong influx of maritime air behind the 'coastal low' (note that this is actually a 'deep low' on the coast - not a true coastal low), which is forced to rise, giving heavy orographic rain. This is the so-called 'Black Southeasterly' condition. The case studies indicated that a COL passing south of the Bank would generate a coastal low in just the same way as a frontal trough does, for example, case study No. 6, 31 July 1982.

(c) A typical example of intense COL rainfall appears in case study No. 4, with Cape St. Francis receiving 58 mm on 17/18 February. The wind went from south-west behind the primary cold front to south-east with heavy rain - a Black Southeaster. In this case the COL was over the interior, and there was no sign of an associated coastal low. Being of a convective nature, the rainfall was very unevenly spread.

4.5.4 Further Comments

Based on Table 4.6 and the relevant case studies, the following more generalized comments apply:

(a) Some of the strongest winds recorded by the coastal AWS were associated with COL conditions, for example, Cape St. Francis on 19 April 1982, case study No. 5. When the surface low was overland, the strong easterly components, blowing for relatively long periods, resulted in very low SST's in certain localities. Examples of this appear in case studies 4, 7 and 12. The phenomenon of south coast upwelling at certain capes is discussed later.

Gale force **westerly** winds occurred when the surface low appeared west or south of the Bank. In this case there was no change in the coastal SST's (see case study No. 5).

(b) The COL may provide the coastal engineer with a problem in that the area between the surface low and the blocking high may provide a fetch region for the generation of heavy easterly swell; for example, case study No. 11, 27 September 1984. Most coastal structures and particularly the harbours of the Cape South Coast have been constructed taking mainly extreme swell with a **westerly** component into account.

(c) The idea that once a COL has formed in a particular area, the probablity of another forming there is increased. This was voiced by Taljaard (1985), and is strongly supported in the case studies. In July 1982, 4 successive COLs affected the Agulhas Bank. Only the second had its surface low overland at any stage of development.

5. MAN/WEATHER INTERACTIONS

5.1 INTRODUCTION

The previous chapter summarised the main features of the synoptic scale systems and their associated weather processes. The present chapter consolidates the available information concerning those atmospheric phenomena of greatest relevance to human activities in the study region. In addition to the knowledge presented in previous chapters, new data sets are referred to, as well as additional research material relevant to the particular weather situation. Note that these discussions have been extended to include oceanographic phenomena largely brought about by atmospheric circulations (for example, sea state and low sea temperatures on the coast).

The subject of interaction between certain human activities and the atmosphere may be approached in two ways. Where a particular weather situation such as poor visibility in fog, affects a wide variety of activities, the starting point is taken as the atmospheric condition. On the other hand, where an activity is affected by a variety of weather conditions (for example, coastal fire control or commercial shipping), the discussion is structured to radiate from the activity.

Note that only **selected** interactions are considered here, that is, those which were considered of major importance and for which considerable additional information was available. No advice is offered in this chapter on how such interactions may best be managed. That is left to the next chapter, where a broader range of interactions is again considered.

5.2 THE LAND-BREEZE

5.2.1 New Features Uncovered by this Study

Discoveries concerning the land-breeze circulation are considered to be amongst the most important new findings in this study, namely:

(a) The land-breeze is an important circulation at certain localities, even in summer. For example, case study No. 2 shows Walker Point with a well-defined land-breeze circulation on 6 out of 7 days in **February** 1982. Although Walker Point is well situated with the coastal mountain range in close proximity and the Goukamma River nearby to channel the gravitating cold air, the other two AWS also frequently measured a land-breeze. The effect of this circulation on the wind **climatology** of the region, is indicated on the long-term wind roses (Figures 2.1 to 2.4). From May to August, Cape St. Blaize has the north-west sector with most of the lowest wind speeds (< 5 m/s). The much lower frequency of winter land-breezes recorded by the Cape St. Francis lighthouse keepers, was supported by the later AWS measurements.

(b) By **undercutting**, the land-breeze may cause a marked reduction in surface wind speed, even under storm conditions. Examples of this undercutting occurred in case studies No. 4 (17 and 19 February 1982), No. 7 (10 and 11 October) and No. 9 (13 to 17 February 1983). It had generally been considered that a strong gradient wind would overwhelm the land-breeze but evidently the influx of cold air from the interior creates a PBL condition that is sufficiently stable to inhibit any downward transfer of momentum.

(c) Evidence has been presented that suggests that this same process of undercutting may be responsible for the triggering of convective cloud offshore. Consider, for example, the VOS report of 12 December 1982, in case study No. 8, where heavy showers were experienced offshore, but no precipitation occurred on the coast. A possible explanation is thus provided for the diurnal variation of 'Agulhas Current' cumulus lines. Several cases linking coastal precipitation with the land-breeze are also presented, for example, anomalous precipitation events at Cape St. Blaize on 31 July 1982 (case study No. 6), and 10 October 1982 (case study No. 7).

(d) The land-breeze has also been identified as being largely responsible for low minimum temperatures on the coast. The AWS minima (Section 2.4.1) strongly support this observation. Case study No. 7 provides a good example with the air temperature at Walker Point dropping to $8^{o}C$ as late as 9 October in 1982.

(e) The enhancing effect which the passage of a bud-off high (BOH) has on the land-breeze circulation has been clearly demonstrated and explained in the previous section. Table 4.5 presents a land-breeze event at at least 2 of the 3 coastal AWS for all 7 BOH passages. It is suspected that the BOH plays a multiple role in that it is responsible for the initial introduction of cold air which is followed by rapid radiative heat loss due to the vertical temperature structure brought about by subsidence. The BOH also ensures slack pressure gradients as maximum pressure passes the station, allowing the relatively weak local circulation to dominate the wind record.

(f) Contrary to most conceptions of the land-breeze, that which occurs on the Agulhas Bank can reach up to 10 m/s and extend over 40 km offshore (see Appendix 3, Fig. A.3.3 and case study No. 3, 29 August 1978). The land-breeze in the former reference was sufficiently strong to raise half-metre waves in Algoa Bay.

5.2.2 Implications for Man/Weather Interactions

Because the extent of this circulation has been greatly underestimated, the variety of coastal activities it may affect have also been largely unrecognised. For example, the land-breeze could play an important role in the transport of coastal air pollution. It could provide the means to keep an oil slick offshore whilst also having sufficient strength to provide essential wave mixing, under 'synoptically' calm conditions.

From both a recreational and safety point of view the ability of the land-breeze to provide yachtsmen with an inshore wind under otherwise calm conditions, and all craft with a relatively calm zone under storm conditions, make it a circulation feature that coastal management cannot afford to ignore.

The possibility that the land-breeze triggers precipitation both on the coast and offshore has important implications for all those affected by anomalous rainfall events. This subject is considered further in the next section on Coastal Precipitation.

5.3 COASTAL PRECIPITATION

5.3.1 Main Synoptic Systems Responsible for Precipitation

Cut-off lows. Taljaard (1985), has emphasised the role played by COLs in the rainfall over South Africa. This observation applies particularly to the Cape South Coast, where the highest daily figure in the 13 month study period (that is, Cape St. Francis 58 mm on 18 February 1982), resulted from a COL. Note that this single system was largely responsible for Cape St. Francis recording almost double the normal rainfall for February/March. It also gave Mossel Bay its highest daily rainfall in the two summer months. Thus, in time of drought, the COL may well provide rainfall of critical value. The Southern Oscillation Index, an indication of the El Niño Southern Oscillation (ENSO) intensity, was showing a large deviation by mid-1982 (Rasmussen and Hall, 1983). Although there were large negative deviations in the summer rainfall at Cape Agulhas and Cape St. Blaize, the single COL of 18 February ensured that at least part of the coastal belt recorded above normal rainfall.

Considerable damage has been caused by COL situations in the past:

(a) During a COL/Black Southeaster situation in May 1977, many rivers came down in flood, with a pipeline being washed away at Van Staden's River Mouth, and the Langkloof railway line was submerged by the rising Gamtoos River.

(b) The COL which partially destroyed the Karoo town of Laingsburg (25 January 1981), and which was associated with severe Black Southeasterly conditions on the Cape South Coast, was an anomaly in that January is the month least likely to produce a COL (Taljaard, 1985). Mossel Bay received 159 mm in total, but even neglecting the high coastal rainfall, a vast volume of silt-laden river water would have reached the western Agulhas Bank from the interior.

(c) There is no doubt that this system has the most flood producing potential of any weather system on the Cape South Coast. On 1 September 1968, during a COL event, parts of Port Elizabeth recorded over 500 mm at a rate of over 100 mm/hour (SAWB Newsletter, September 1968). This rates as one of the highest and most prolonged rainfall rates in South Africa, and the eastern Cape South Coast is particularly prone to such flooding. In agreement with Taljaard's (1985) observations, the heavy precipitation early on 12 October 1982 (Cape St. Blaize recorded 25,3 mm) occurred just ahead of a 'coastal low' which had formed in association with an upper COL.

Numerous examples of coastal stations or merchant vessels reporting **reduced visibility** in heavy convective showers, may be traced to COL situations.

Frontal systems and the Atlantic Ocean Anticyclone (AOA). Convergence and the upward currents in the frontal zone of mid-latitude troughs seem to play a relatively minor role in the total precipitation of the Cape South Coast, unless there is a deep wave on the front, close to the coast. An example of such a wave appears in case study No. 9, 12 February 1983, when all three lighthouses recorded substantial rainfall. Frontal precipitation may also come in the form of a thunderstorm triggered by uplift in the frontal zone. For example, on 8 August 1982 (case study No. 1), a frontal thunderstorm resulted in 10,8 mm at Cape St. Francis.

The **ridging** process behind a coastal front is associated with much of the Cape South Coast rainfall. For example, at Cape St. Francis, all rainfall events resulting in over 20 mm of rain during the period February 1982 to March 1983, which were not linked to a COL, were found to be associated with a frontal wave followed by a ridge of the AOA.

5.3.2 Other Factors Affecting Rainfall

Orographic Influence. The very dominant role played by the topography in deciding the mean isohyets has already been emphasised in the section on climate. Orographic enhancement should be far less noticeable where the synoptic scale system is itself associated with vigorous updraughts (for example, COLs). However, since the majority of precipitation events result from the onshore flow ahead of a ridging AOA, with large scale but generally weak upward motion, the orographic influence is well imprinted on the annual isohyets.

Land-breezes. In a number of the case studies precipitation was reported on the coast and offshore at a time when no synoptic scale system could be held responsible although a land-breeze circulation was well-defined. Examples appear in case studies 1, 2, 7, 8 and 9, mostly at Cape St. Blaize where the land-breeze is particularly well-defined, but also in the VOS reports. Preston-Whyte (1980), has suggested that the land-breeze may trigger nocturnal precipitation by undercutting the maritime air. Anderson (1979), gives an example of cumulus formation off the west coast of Africa in association with a land-breeze (NOAA VHRR visible image). Neumann (1951) placed great emphasis on the shape of the coastline, requiring convergent land-breezes for thunderstorm activity to be initiated. However, the land-breeze may simply act as a wedge to lift conditionally unstable air sufficiently to make it unstable. The warmer air over the Agulhas Current would naturally require less impetus for convection to be started.

It is possible that the eastern extremity of the Cape South Coast, with the Agulhas Current relatively close inshore, may periodically receive showers from large cumulus originating over the Agulhas Current. Hunter (1986a) has pointed out that such seaward initiated showers are not uncommon along the northern Natal Coast, in the vicinity of Richard's Bay, where the Agulhas Current is close inshore.

5.3.3 The Effect of Precipitation on Human Activities

Apart from the absolute dependance of virtually all Cape South Coast activities on adequate precipitation for water supply, unpredicted rainfall, extreme rainfall events or prolonged rain, may adversely affect many human activities. For example, intense convective precipitation of several hours duration, such as may be found during a COL may, apart from causing severe structural damage and possible loss of life due to flooding, result in very restricted horizontal visibility (consider the VOS report of 18 February 1982, case study No. 4). Thus, shipping may be forced to reduce speed, whilst continuous, heavy convective showers have resulted in the closure of H F Verwoerd Airport in the past. Coastal road traffic may also be severely affected by such conditions.

There are many outdoor activities, both commercial and leisure-related which may by affected by **untimely** rain. The unloading of certain bulk cargoes has to be postponed, and if the rain is prolonged the ship's schedule will be disrupted resulting in a large financial loss. Similarly, the building industry, tourism, sport and certain agricultural activities on the coast may be adversely affected by prolonged rainfall. Even the forestry industry is dependant on dry periods to provide suitable conditions for controlled burning.

5.4 SEA TEMPERATURES ON THE CAPE SOUTH COAST

5.4.1 Coastal SST Measurements

Schumann *et al*. (1982) put forward a possible mechanism for Cape South Coast upwelling involving easterly wind components and a characteristic bottom topography at the capes. In the earlier case studies, several examples of verified upwelling were emphasised. The following points may be regarded as additional to the study by Schumann *et al*.:

(a) Whilst the importance of a strong, sustained easterly wind component had already been established, the present study has shown that certain synoptic conditions, that is, a COL/BH pair with the former to the north of the Bank, provide the optimum upwelling situation, since the strength and duration of the easterly wind is then maximised.

(b) Sudden falls in SST in Algoa Bay associated with a **westerly** wind were previously thought to be the result of wind mixing. However, the present study has shown that this may occur soon after the passage of a coastal low. Prolonged easterly winds ahead of the coastal low cause upwelling at the capes (including Cape Recife), whilst the post-coastal low westerlies serve merely to transport the cold water into Algoa Bay. There is no indication of westerlies producing similarly low temperatures independently.

(c) Major upwelling events occurred in case study numbers 4, 7 and 12. Note that in all three cases a BH/COL pair was present, with an extended easterly flow over the Cape South Coast. The months represented are February 1982, October 1982 and February 1985 respectively. A marked fall in SST followed within 1-2 days of the upsurge in easterly winds but SST measurement points were sparsely distributed, so much of this time may represent the advection of the cold water from identified generation sites.

5.4.2 SST Measurements on Board the **Meiring Naudé**, February/March 1984

In addition to the upwelling events included in the case studies, the 1984 summer cruise of the R/V Meiring Naudé on the Agulhas Bank provided some very interesting data on coastal upwelling:

(a) On the morning of 25 February, SST dropped over $8^{o}C$ to $13^{o}C$ as the vessel moved inshore just east of Cape Agulhas. Successive lines across the Bank revealed upwelled water on each inshore excursion, all along the coast eastwards as far as Cape Infanta. The cold water extended over 8 km offshore. Fresh to strong easterly winds had sprung up on 24 February behind a well-developed ridge. These winds blew until 26 February when a coastal low moved along the coast. On the morning of 25 February, Cape Point was reporting a 60 knot southeaster as the AOA ridged strongly eastwards.

(b) On 9 March 1984 at 08h00, the R/V Meiring Naudé found relatively cold inshore water off Tsitsikamma Point ($15^{o}C$). Coming inshore again at approximately 22h00, to a point east of Cape St. Francis in St. Francis Bay, SST dropped to almost $11^{o}C$, indicating upwelled water. Successive tracks across the Bank ending in shallow water in St. Francis Bay on 10 and 11 March, all showed evidence of upwelled water there.

In the second case above (9-11 March) the north-easterly wind started to pick up on 8 March, and averaged 15 m/s (near-gale force), for most of the following day. Assuming that the water in St. Francis Bay originated in the upwelling plume linked to Cape Recife, it must have been transported rapidly westwards.

The above examples indicate that upwelled water may be located some distance from the generating points less than 24 hours after the initiation of upwelling. Coastal currents may not be sufficiently strong to provide this rate of advection and thus, the idea of a limited number of upwelling generation points must be questioned, despite the evidence of satellite imagery.

5.4.3 SST Measurements on Board the Oil Rigs

A search through SST data from the oil rig Sedco-K, south of Mossel Bay, failed to indicate any link between synoptic scale wind and SST changes **offshore.** It is significant that cases of marked surface cooling due to wind mixing were also not apparent. On the other hand, when Sedco-K was drilling closer inshore, for example, 40 km south-east of Cape St. Francis on 10 February 1985, the effects of an extended easterly wind were clear - SST dropped to 12°C at 08h00. Note that near gale force easterlies had already been blowing for over 48 hours.

Data from the oil rig Actinia gathered at the drilling sites on the eastern Agulhas Bank showed a definite drop in SST behind several well-defined **frontal systems.** For example, on 16 June 1983, with the rig drilling south-west of Cape Recife, and a COL with several surface lows **offshore** (that is, rig winds westerly), SST dropped from 19,4 to 11,3°C. Note that 'SST' on the Actinia is actually measured at a depth of 15,5 m. This 8°C fall in temperature, was associated with the passage of a front which had developed in the circulation of the first low pressure system (that is, a cold air cyclone (CAC)).

Mork (1972), emphasises the fact that the wind circulation around a low pressure system, or even that associated with a frontal trough, is such that upwelling is induced at the sea-surface, that is, the above cooling may not be simple wind-induced mixing of the surface layers. Jensen (1983), considered the effects of storms on vertical mixing through the action of **inertial oscillations** and **internal waves.** He found that the response would be maximised if the duration of the wind pulse equalled one half the inertial period. On the Agulhas Bank this is approximately 10,5 hours. Alternatively, if the wind rotates anti-clockwise with the inertial frequency, or at least undergoes a 180^{o} directional shift, after half an inertial period, the sea-surface will show greatest response. All of these conditions can occur on the Agulhas Bank.

Both Pugh (1982) and Fedorov (1981), have emphasised the resistance that hydrostatically stable surface water (temperature or salinity stratification), will have to turbulent mixing. Pugh suggests that this is a major factor in restricting the ability of summer winds to erode the marked thermocline on the Agulhas Bank. Certainly, the seasonal wind data are insufficient to explain the disparity in mixed layer depth. As the section on extreme wind testifies, major storms may occur in summer, yet their effect seems to be blunted by the stronger solar input. Another factor favouring the ability of autumn or early winter storms to impart more energy to the sea-surface, is that the lower PBL is likely to be more unstable, allowing the wind to get a better 'grip' on the ocean surface.

5.4.4 Upwelling Associated with the Agulhas Current

This mechanism, whereby cold water is upwelled on the inshore boundary of the current, is most evident on the extreme eastern Agulhas Bank. Although the primary generation has nothing to do with the atmosphere, the cold water is probably advected by coastal winds. SST's from Humewood Beach, Port Elizabeth, indicated that cold water on the western side of Algoa Bay was more likely to be linked with wind induced upwelling, and that this Agulhas Current upwelling seldom reaches Port Elizabeth.

5.4.5 Forecasting of Conditions in the Ocean Mixed Layer

In a paper by Clancy and Martin (1981), the importance of the mixed layer to various activities including weather prediction and those making use of acoustic equipment in the sea, is stressed. The important role played by synoptic scale weather patterns is recognised. Fortunately there has been a vast improvement in the prediction of these weather systems in the last 10 years. Note that on the Agulhas Bank, such an upper ocean forecast model could have no hope of success unless it could adequately handle the effects of bathymetry, coastal topography and the Agulhas Current.

5.4.6 Intrusion of Warm Agulhas Current Water onto the Agulhas Bank

Proof that Agulhas Current water is continually being intruded onto the continental shelf, is frequently provided by cloud-free satellite IR pictures. These intrusions occur in the form of unstable tongues of warm water which may eventually detach themselves from the main body of the current and form independent eddies. No attempt was made to link these shelf edge phenomena with atmospheric events, although it is possible that such a link exists.

Remote Sensing. One of the major drawbacks in attempting to link atmospheric processes with changes in SST, is the poor synoptic coverage presently available for the latter parameter. The Very High Resolution Radiometer (VHRR) on operational NOAA satellites cannot provide proper coverage because of cloud-cover, and SST sensors operating in the microwave portion of the spectrum, show poor resolution and suffer from coastal contamination.

5.4.7 Human Activities and SST

Sea-surface temperature has a direct influence on the fishing industry of the Agulhas Bank, due to the dependence of many biological processes on ambient temperature. Similarly the tourist industry may be affected by prolonged upwelling as occurred during the Easter long-weekend in 1982, when low temperatures kept many bathers out of the water at Plettenberg Bay. SST also affects any coastal industry using sea-water as a cooling agent - this includes both existing, conventional power stations and any proposed nuclear plants.

Indirectly, SST anomalies over the Bank may influence the development of certain weather conditions which may then directly affect many human activites. Thus, fog has been shown to form in association with cold upwelled water; for example, all three major upwelling events mentioned above were associated with reports of coastal fog. On the other hand, the intrusion of Agulhas Current water onto the Bank may well extend the area associated with post-frontal convective showers.

5.5 FOG

Fog occurrences on the Cape South Coast and offshore have been discussed in a general way in Section 2.5. Several occurrences of fog were pointed out in the case studies, the majority being linked to upwelling events.

5.5.1 General Comments on the Synoptic Situation Normally Associated with Fog

(a) Fog formation on this coast has in the past been strongly linked with the passage of a coastal low bringing moist maritime air over the cooler inshore waters (RN, 1944). However, case studies 2, 5 and 12 all contain examples of fog which occurred **ahead** of the coastal low, implying that wind direction does not play a major role.

(b) An aspect of fog formation which has been largely underestimated is that of vertical air temperature stability. Laevastu (1973), has emphasised the importance of an inversion layer in trapping moisture and inhibiting mixing. Thus, strong subsidence inversions have been observed to provide a 'lid' for prolonged fog conditions. This may explain the role played by the coastal low in fog formation, since this system is associated with a lowered subsidence inversion level.

(c) The relationship between fog and **upwelling** on the Cape South Coast has also been underrated. Of the ten 'fog events' in the case studies, nine could be linked to an earlier period of extended easterlies, that is, probable upwelling. Note that winds were sometimes fresh (exceeding 10 m/s), during occurrences of fog, indicating that the sea-surface was sufficiently cold to override the effect of the wind mixing the air column.

In addition to the various examples in the case studies, Figs. 5.5.1 and 5.5.2 show the R/V Meiring Naudé traversing cold water on 25 January 1984 as she approached Algoa Bay from the north-east. The passage of a coastal low had introduced moist maritime air earlier that morning, and the presence of upwelled water was sufficient to produce fog patches over eastern Algoa Bay. A fresh north-easterly wind had been blowing the previous day, but this is also an area subject to dynamic upwelling on the edge of the Agulhas Current. Note the rapid response of the air temperature to cooling from below. Fog patches were again encountered on 28 January after another period of easterly winds and the passage of another coastal low. The ship was then south of Cape Infanta.

(d) The case studies have identifed yet another factor which may be important in fog formation. The extremely dry subsiding air associated with berg wind conditions, may soak up a considerable amount of moisture as it moves offshore. Subsequent evaporation of water from the sea-surface will also produce cooling, but it is usually mixing with maritime air behind the coastal low which finally brings the air to dew-point, and fog results.

In case study No. 7 mention is made of a VOS report which gave 50 m visibility in fog with coastal berg wind conditions. Presumably the dry offshore flow absorbed enough moisture to cause a considerable rise in dew-point, whereafter cooling due to a traverse across relatively cold water saturated the air. The stable PBL associated with the approaching coastal low, would also favour fog formation by inhibiting mixing.

5.5.2 Fog Reported by Sedco-K During 1982

Synoptic weather reports at 08h00 and 14h00 from Sedco-K indicate that conditions under which fog forms offshore are somewhat different from those on the coast:

(a) Out of several **pre-coastal** low fog reports, two were associated with berg wind conditions prevailing on the coast at the time (for example, on 7 May 1982 the rig reported 1 km visibility in fog with the wind NNE 10 m/s). These berg wind cases are almost like sea fogs except that it is a dry, initially **hot** wind instead of a dry, cold wind which is causing considerable evaporation at the sea-surface.

(b) It is to be expected that a low SST may sometimes play the major role in fog formation, both on the coast and offshore, in which case the link between fog and a particular synoptic situation, may be lacking. An example of this occurred on 15 April 1982 when Sedco-K reported a reduced visibility of 1 km in fog. No significant synoptic pattern was present but SST was a low 14,4^{o}C.

5.5.3 Fog as seen on Meteosat Imagery - 29 and 30 March 1984

Cape St. Blaize reported fog on both of the above days. It extended well offshore and to the west. The role of the Agulhas Current in dispersing this fog further offshore, was clearly depicted on the geostationary satellite visible images. Typical intrusive tongue patterns were discernable on the southern boundary of the fog. The fog dispersed overland first, as diurnal heating eventually broke down the protective inversion. The last area to clear was offshore in the west. Presumably this was an indication of where the remaining cold water resided.

5.5.4 Fog and Coastal Air Traffic

Although the frequency of fog on the Cape South Coast does not rival that of the Cape West Coast, it is responsible for a significant financial loss as a result of the disruption of air traffic. For example, air traffic was disrupted by fog for two days on 6 and 7 July 1982 at H F Verwoerd Airport, Port Elizabeth. Similarly helicopter services essential to the offshore industry may be disrupted. Under conditions of extremely poor visibility, helicopters may have to return to base. The cost of such an exercise both in terms of the unsuccessful mission and the financial outlay, is considerable.

5.5.5 Favoured Sites for Coastal Fog Formation

From satellite imagery it is apparent that the capes on the Cape South Coast are favoured sites for upwelling to take place. However, once brought to the surface, the cold upwelled water may be advected by coastal winds. Thus, a drop in surf temperature at Humewood, Port Elizabeth may not be experienced until after the passage of the coastal low. It has been shown that, after fresh easterly winds have generated an upwelling plume with its base at Cape Recife, the westerly wind behind the coastal low may push the cold upwelled around Cape Recife into Algoa Bay (for example, 22 February 1982, case study No. 4). There are numerous examples of this type of advection of upwelled water. Knysna regularly receives cold water from the Cape Seal upwelling plume (for example, 20 February 1982, case study No. 4), but here it is the same easterly wind which is responsible for the upwelling, that advects the cold water westwards.

It is significant that the St. Francis Bay region, which is prominent as a fog zone both historically and in the case studies, has capes on either side which have both been identified as sources of upwelled water.

5.5.6 Shipping Collisions in Fog on the Agulhas Bank

The generally low incidence of fog on the Agulhas Bank seems to have lulled seamen into a false sense of security for there have been several serious collisions in the past decade. Although the frequency of fog is low offshore (see Section 2.5), strong gradients in SST ensure that inshore waters are frequently cold enough to generate an advection fog. Although both Cape St. Blaize and Cape St. Francis are credited with only 25 and 26 days of fog respectively, per annum, it is quite possible that the fog occurrence is much higher at localities such as St. Francis Bay, where cold upwelled waters may reside for some time. Of the four cases of ships colliding in fog, discussed below, note that all were in coastal waters, with three of the four in the Cape St. Francis area:

Oswego Guardian/Texanita Collision. One of the most devastating collisions in recent times, was that between two tankers, the Oswego Guardian, and the Texanita, both approximately 100 000 tons dwt. The collision took place in thick fog about 100 km south-west of Mossel Bay, at 06h00 on 21 August 1972. VOS reports showed that the fog was associated with a relatively weak coastal low. Visibilities of 500 m or less were experienced both ahead and behind the coastal low. It is probable that pre-coastal low easterlies caused upwelling on the coast. One observation, taken at 02h00 in roughly the same area as the collision, gave a visibility of less than 50 m. Note that August has, on average, a relatively low incidence of fog on this coast.

The Texanita was broken in half by the resulting explosion and sank within minutes, taking all but 3 of her crew with her. An estimated 10 000 tons of oil spilled into the sea, but pollution was minimal, thanks to a generally offshore circulation (**SA Shipping**, September 1972).

Tekton/Obo Queen collision. On 10 October 1974, the 25 000 ton dwt tanker, Tekton, was almost cut in half in a collision with the 100 000 ton Obo Queen off Cape St. Francis. The synoptic charts indicate that a very weak coastal low was moving along the Cape South Coast at the time. A VOS report confirmed thick fog in the area early the following morning.

Beihai Career/Sunnex Star collision. Yet again in the Cape St. Francis region, the Beihai Career and the Sunnex Star collided in thick fog in February 1981.

Botany Triad/Lu Shan collision. On 6 December 1985 a 6 000 ton tanker, the Botany Triad, collided with a Taiwanese freighter, the Lu Shan, off Cape St. Francis. The thick fog was associated with the passage of a coastal low, but an important feature a few days earlier, was a COL/BH pair with the surface low northwest of Cape Town. Fresh south-easterly to easterly winds on the Cape South Coast could well have caused upwelling.

The reason for the concentration of collisions in the Cape St. Francis area is not simply due to a relatively high frequency of fog. There is also a very high concentration of shipping in that area (see Figure A1.1).

5.5.7 Recovery of Moorings

Dense fog poses special problems for a research vessel recovering moorings which have recently been released from the seabed. Although electronic homing is available, final contact once the mooring is floating on the surface, is visual. A vessel may be travelling a great distance in order to make such a pick-up, so it is essential not to arrive on site in prolonged conditions of dense fog.

5.5.8 Grounding of Vessels in Fog on the Cape South Coast

In recent years there have been several cases of trawlers going aground in the Cape Agulhas area during fog. Further east the Pati ran aground in thick fog on Thunderbolt Reef (Port Elizabeth) early on 29 February 1976. A coastal low had recently moved through, but the wind swung back to easterly as a deep low formed over Cape Town. The ship was not refloated, and her bunker oil caused extensive coastal pollution.

5.6 EXTREME WIND CONDITIONS AND THE PREDICTION OF RETURN VALUES

Prior to the first deployment of automatic weather stations offshore (in 1978, on the oil rig Sedco-K), no accurate wind measurements were available there. It was thus impossible to attempt the calculation of design winds for the Agulhas Bank. Even on the coast, the only long-term, accurate wind measurements were at the major airports. Appendix 3 shows, however, that these data are unsuitable for calculating design winds for structures on the coast.

The erection of three AWS at Cape Infanta, Walker Point and Cape St. Francis, provided accurate data suitable for the calculation of extreme coastal winds for the first time. Although the period of 13 months (February 1982 - March 1983), is rather short for the calculation of 10 to 50 year return winds, Louw and Katsiambertas (1975) describe a method using a Fisher-Tippet Type 2 distribution (Thom, 1966) which has proved successful. They extracted yearly subsets of wind recordings from long-term stations, to show that the return period gusts based on the yearly data were mostly within 3 m/s of that obtained from the long-term data set.

According to the above method, the highest 36 gusts and hourly averages were extracted from each station and arranged chronologically. Six subsets of six, with each subset arranged according to size, were then subjected to the statistical analysis outlined by Thom. The results appear in Tables 5.1 to 5.4. Initially only the set of highest daily values was considered, but as the return values based on this set did not differ significantly from those obtained using the full data set, the latter was used.

5.6.1 Measured Hourly Averages (Table 5.1)

The highest actually measured hourly average at Cape St. Francis has been reduced using Z_O (roughness length) = 0,005 m in the log profile law. As is discussed in Appendix 4, this reduction may be too severe under very unstable conditions. Yet the extreme hourly average at Cape St. Francis is still well above the AWS values further west. Note that Sedco-K, after only 4 months on the eastern Agulhas Bank in 1978, had experienced a wind speed which has yet to be exceeded after over 8 years of measurement south of Mossel Bay. The general increase in wind speed associated with an intensification of weather systems crossing the Bank is a phenomenon well supported by the other data sets, for example, consider the dramatic intensification of the frontal system in case study No. 6, 29 July 1982. The inadequacy of H F Verwoerd Airport data is clearly portrayed in Table 5.1. In a single year, the AWS at Cape St. Francis recorded an hourly wind speed significantly higher than the **50 year return wind** for Port Elizabeth (see Table 5.2).

In the cases where a height reduction was applied, the unreduced speed is included in the table in brackets. It is again emphasised that under extremely unstable conditions, for example, with cold mP air crossing the Agulhas Current, the **unreduced** figure would probably be more applicable, for example, the September 1978 storm may well have produced an hourly average of over 30 m/s over the Agulhas Current.

It is significant that at all locations except Cape Infanta the maximum winds were roughly westerly, being associated with intense frontal systems or COLs passing to the south. At Cape

Infanta the responsible COL was overland resulting in an easterly maximum. Section 2.3 indicates that strong easterly components and relatively weaker westerly components are a feature of the western Agulhas Bank.

5.6.2 Design Hourly Wind Speeds (Table 5.2)

Note that the 1 in 50 year average hourly return speed for Cape St. Francis is higher than that for Sedco-K. Remember, however, that the rig return values are based only on the data collected south of Mossel Bay. If no height reductions were applied, Sedco-K would have the higher value (unreduced speeds in brackets). However, even a 50 year hourly speed of approximately 33 m/s, would not compare with similar calculations for the North Atlantic, where the 50 year maximum hourly wind speed is shown to exceed 40 m/s (UK Department of Energy, 1977).

5.6.3 Measured Gusts (Table 5.3)

No gust values have been reduced for height. This decision was based upon the wind comparisons done on Sedco-K (Appendix 4). It will be seen that the ratio between extreme hourly average and gust is between 1,3 and 1,5 on the coast, and about 1,8 inland. This is to be expected since aerodynamic roughness length is greater overland. However, if reduced hourly averages are used at the rig, the ratios are unrealistically high (1,7), implying that height reductions may be too severe offshore.

5.6.4 Design Gust Values (Table 5.4)

The 50 year gust for the offshore drilling area south of Mossel Bay (45,5 m/s), is precisely the value **measured** off Cape Recife in 1978. This serves to underline the severity of conditions on the eastern Agulhas Bank. Note that Cape St. Francis has a value that is considerably higher than the automatic weather stations to the west, but comparable with the more turbulent conditions inland.

5.6.5 The Synoptic Systems Associated with Extreme Wind Events

Hourly wind estimates from lighthouses. Even though these data were estimated, it is the only continuous, long-term coastal coverage available, which was thus suitable for identifying the weather systems associated with extreme wind events. Only those storms which were estimated to have wind speeds exceeding 25 m/s, were considered. Note that only Cape Recife and Cape St. Francis had such extremes, that is, the wind climate at Cape St. Blaize was considerably milder. This trend for extreme wind events to be less frequent on the western Agulhas Bank, is supported by the AWS data. It is significant that no single event occurred at **both** Cape Recife and Cape St. Francis. Whilst this may in part be attributed to the inaccuracies of the estimates, it must also be regarded as an indication that the same storm will not necessarily produce the same conditions at two adjacent capes, even if they are, as in the above case, less than 100 km apart.

Table 5.5 lists the storm days according to the responsible synoptic scale weather system. COL - E refers to a cut-off low pressure system with its surface low either off the west ocast or overland, so that the extreme winds observed were **easterly** to **south-easterly.** Similarly, COL - W refers to a situation where the surface system is to the south and winds on the Cape South Coast had a strong westerly component.

CAC refers to a Cold Air Cyclone which has developed into an intense low pressure system associated with gale force winds. The term 'cold air cyclone' comes from the fact that these systems develop in the cold mP air behind an earlier frontal system. They are thus also known as 'polar lows' or 'secondary developments'.

CYCL implies rapid cyclogenesis of a mid-latitude low, that is, intensification of an independant, pre-existing low pressure system - not just a frontal wave or CAC. The major storm of May 1984 (case study No. 10), is an example.

LSFT is the acronym used here for a large scale frontal trough.

Note that the counts in Table 5.5 are of systems and not storm days, for example, the large scale trough of 25 and 26 July 1977 only counts as one. The dominant role played by cold air cyclones in producing extreme wind conditions along the eastern portion of the Cape South Coast, is clear. The fact that only the two easternmost lighthouses recorded winds in excess of 25 m/s must be re-emphasised. There were only 3 cases of extreme easterly winds - all could be attributed to COLs.

Extreme hourly averages from AWS. Table 5.6 indicates again, a significant difference in the wind field as one traverses the Cape South Coast from west to east. Whilst all 5 top storms at Cape Infanta involved easterly components, westerly winds completely dominated at Cape St. Francis. Although some major westerly storms were missed at Cape Infanta due to instrument failure, there is no doubt that extreme westerly components were not favoured at this site. Several cases of frontal waves developing as they move across the Bank, support this observation (see for example, case study No. 5, 17 April 1982). The fact that 3 out of 5 Cape St. Francis storms were secondary developments (CAC), fits in with the general picture of frontal systems developing and intensifying as they move eastwards.

Only at Cape Infanta was the relatively common situation of a BOH passing east followed by a coastal low moving down the west coast, able to provide one of the highest wind speeds at the station. This is not to say that the same situation did not produce equally high easterly winds at Cape St. Francis. But, at the latter site, much more intense westerly storms dominated the top five.

Case study No. 4 includes the COL of 19 February 1982 which gave Cape Infanta its highest hourly average wind speed in the 13 month study period. Note that this was an easterly wind. The same system also accounted for one of the top 5 hourly averages at Walker Point. An example of a **frontal wave development** which gave Walker Point another of its top 5 wind speeds appears in case study No. 9, 12 February 1983. In case study No. 5, on 17 April 1982, a cold air cyclone or secondary development is depicted which gave Cape St. Francis its highest hourly average. The same case study includes the second highest speed to be recorded at Cape St. Francis - this time a COL to the south, giving westerly winds with a maximum speed of 28,3 m/s (24,3 m/s reduced). The record-breaking secondary developments of September 1978 are discussed in case study No. 3.

Note that the buster, that is, the gust front specifically associated with the coastal low (for example, 15 December 1982, case study No. 8), although representing a dramatic jump in wind speed, does not result in the coastal low occupying a position in the above tables.

5.6.6 Estimates of Extreme Wind Speed from VOS Reports

Table 5.7 portrays the **seasonal and diurnal distribution** of all wind estimates ≥ 20 m/s, for both the eastern and western Agulhas Bank. Bearing in mind the distribution of total reports (see Appendix 1), the following comments may be made:

(a) The ratio of total reports western to eastern Agulhas Bank was 0,77. Yet in Table 5.7 the ratio of extreme wind reports is only 0,54. This is in agreement with previous conclusions (AWS and lighthouse data), that extreme wind events are significantly more frequent on the eastern side of the Bank.

(b) Both areas show an upsurge in occurrences in May, lasting through the winter and decreasing in November.

(c) There is a relatively high count in December in the east. Both the AWS data and the lighthouse data revealed major storms occurring in December.

(d) Apart from December, the summer months showed the least disparity in storm counts between east and west. In fact, if these counts are normalised the western Agulhas Bank records more storms in February and March, most of them easterlies.

(e) The number of wind estimates exceeding 20 m/s at 14h00 is significantly higher than at any other of the main synoptic hours, even after the counts have been normalised. Although diurnal heating over the ocean is limited, it may still play an important role in destabilising the marine boundary layer, so that vertical momentum exchange is more effective at this time.

(f) Although the months January to March (even April on the western Agulhas Bank) had the lowest counts, the case studies identified major storms even in this 'calm' period, for example, case study No. 9, February 1983.

5.6.7 Human Activities Affected by Extreme Wind Conditions

Obviously the extent to which an extreme wind event may disrupt normal coastal activity would depend on its severity, with major storms such as that of September 1978 affecting the majority of human activities to some degree. However, certain activities are particularly wind sensitive. Ships such as large **container vessels** with considerable surface area above the water line, may be difficult to manoeuvre within the confines of a harbour if winds are too strong. Considerable wind damage may be done to certain coastal **crops**, for example, the wheat fields in the extreme west of the region.

Most activites and structures have an upper wind limit. Architects are required to design **coastal structures** to withstand extreme wind events. Thunderstorms have been associated with extreme downdraughts on the coast that have lifted roofs off houses (for example, case study No. 1, 9 August 1982 - in the Plettenberg Bay area). There is also an example of an anomalous gust, also probably a cumulonimbus downdraught, in case study No. 10, 14 May 1984. Such local effects need to be taken into account when estimating extremes.

In May 1977 a Black Southeasterly/COL situation resulted in shipping movements in Port Elizabeth harbour being severly disrupted. Several vessels broke their moorings (one of which ran aground), and a fishing boat sank.

Gust fronts, whether associated with the passage of a coastal low or cold front, may create extremely hazardous conditions for small craft in inshore waters. Many rescue operations launched by the National Sea Rescue Institute (NSRI) along this coast are related to these sudden escalations in wind speed. Case study No. 8, 13 December 1982, gives a good example of a gust front associated with the passage of a cold front. The almost 15 m/s jump in wind speed had the potential to create havoc amongst the unprepared.

On 4 December 1976, the intense gust front which less than an hour earlier had caused considerable damage in Port Elizabeth, led to a major rescue operation off East London. An offshore dinghy race was being held, and dozens of yachts had to be abandoned as the sudden upsurge in wind occurred. The same weather system caused the sinking of the deep-sea yacht, 'Cloud Nine'.

Finally, the effect of the Agulhas Current on surface wind speeds cannot be ignored. Sweet _et al_. (1981) measured sudden marked increases in wind speed when flying seaward across the north wall of the Gulf Stream, and attributed this to cold slope water stabilising the air column and thus inhibiting the vertical tranfser of momentum inshore of the current core. Vessels moving out into the Agulhas Current can expect similar changes as some of the time-series from the _Meiring Naudé_ testify (for example, case study No. 1, 6 August 1982).

5.7 COASTAL WEATHER AND FIRE

Writing about the long-term effect of weather conditions on fire potential, van Wilgen (1984), defined five fire climatic zones in the Southern and Western Cape, with his "South-eastern coastal zone" extending from Mossel Bay to just west of Humansdorp and inland to the ridge of the coastal mountain ranges. The "South-western coastal zone' extended from Cape Town to Mossel Bay. The ERC (Energy Release Component), which is basically an inverse function of the moisture content of the vegetation, was found to change very little during the year in the eastern zone. In his western region, much of which falls into the winter rainfall area, fire potential is highest in summer. But, it is the **short-term** berg wind conditions which play probably the most dominant role in producing high fire potential.

5.7.1 Fire Reports - February 1982 to March 1983

These were obtained from the forestry regional office in Knysna. These reports cover only the Outeniqua district. The following discussions are centred mainly around these fire reports:

Long-term rainfall. 1982 was the beginning of a long period of general drought in Southern Africa which Schulze (1984) has linked to the El Niño/Southern Oscillation phenomenon of 1982/83. At Port Elizabeth only 3 months, that is, February, April and October, recorded above average rainfall with May 1982 receiving only 21 per cent of the average figure. Thus it may be expected that the winter ERC value for the Cape South Coast was well above the average of 10-30. Note that these values apply specifically to the **fynbos biome.**

Fire initiation. Of the 19 reported fires, only one was linked to a lightning strike. Note that Schulze (1974) gives this coast a thunderstorm frequency of 5-10 per year. The lightning strike fire occurred at approximately 05h00 on 2 March 1983 on the Bergplaas Forestry Reserve about 15 km north-west of Sedgefield. The AWS at Walker Point recorded an anomalous gust just after midnight, indicating a possible thunderstorm downdraught. A coastal low which was moving through at the time appeared to have some support from an upper air trough, so that the thunderstorms could well have developed in the vicinity. A cold front with a well-developed wave relatively close to the coast, passed through that afternoon, bringing welcome rain to extinguish an uncontrollable fire. 200 Ha were burnt.

Berg wind conditions. Whilst it is impossible to predict a single lightning strike, berg wind conditions which cause ERC figures to spiral are generally well predicted on a large scale. However, the relationship between berg winds and the location of the coastal low is not simple, and high temperature with low relative humidity may persist after the coastal low has passed. Furthermore many berg wind conditions never reach the surface, being kept at bay by a thin layer of maritime air.

5.7.2 The Role Played by the Coastal Low in Fire Initiation and Spreading

On 7 January 1983, a fire started at Ruiterbos Forestry Station under highly dangerous weather conditions and resulted in a total of 3 350 Ha being burnt. The weather report from the forestry station (approximately 30 km north of Mossel Bay) gave a dry bulb temperature of 37°C, and relative humidity of only 14 per cent. Wind was north-westerly switching to a south-westerly buster soon after the fire was reported. On the coast, the coastal low went through Cape Infanta at approximately 14h00 and reached Walker Point about 2 hours later, giving a coastwise propagation speed of roughly 100 km/hour. The gust front associated with the coastal low was better defined in the west, but the fire report indicates that winds on the slopes of the Outeniquas were significantly stronger. Post-coastal low winds continued at near gale strength for over 7 hours, and the fire went out of control.

Thus, the coastal low, capable of providing not only high temperatures to aid ignition, but also strong winds to fan any fire which is started during the berg wind conditions, may rightly be termed the 'fire monger' of South African weather systems. Those combatting such fires are often unprepared for the sudden wind switch as the coastal low passes. A strong easterly wind blowing into the system may suddenly change to a westerly buster with wind soon gusting over gale force.

5.7.3 Ventilation Associated with a Cold Front - Forewarning

Case study No. 6 provides a good example of a fire where the damage may have been drastically reduced had greater attention been paid to the current synoptic situation. On 28 July at 16h00, with a coastal low already through, but relative humidity remaining a low 40 per cent on the coast, a fire was reported on privately owned land bordering on the Ruiterbos Forestry Station. **Present** weather conditions were mild and so no **action was taken.** Meanwhile (see Fig. 3.6.1), a marked gust front associated with the following frontal system had already passed through Cape Infanta at about 15h00. The sudden increase in wind speed coincided with a well-defined pressure minimum, as a deep low pressure system passed south of the Agulhas Bank. The synoptic analysis for 14h00 on 28 July gave a double front associated with this system, the first of which was responsible for the 15h00 gust front. This low had developed as a cut-off system on 26 July, north of Gough Island. The forester at Ruiterbos reported a wind switch at 17h00, with a 'strong south-westerly' causing the fire to change direction, and spread rapidly downwind.

Not only would the forester have benefitted greatly from a forewarning of the initial buster, but he might have been able to plan more effectively had he known that worse was still to come. There is evidence of a second cold front moving across the Bank early the following morning (29 July), causing westerly winds to gust to over gale force at Walker Point. At Cape St. Francis a very marked gust front at 08h30 resulted in a maximum gust of 32,3 m/s. Thereafter coastal winds averaged over 20 m/s for more than 6 hours. Hourly average wind speeds at George's P W Botha Airport did not exceed 7 m/s during this whole event. This emphasises the importance of acquiring on-site weather reports.

5.7.4 Further Examples of Strong Winds Fanning Coastal Fires

Two further examples of strong coastal winds ventilating fires to the point that they became uncontrollable, both in December: On 4 December 1976, rapid cyclogenesis associated with a frontal system crossing the Bank, caused near record coastal wind speeds which were largely responsible for a sawmill near George being burnt to the ground. The main gust front was associated with a rapidly developing coastal low which covered the 550 km between Cape St. Blaize and Hood Point (East London) at an average speed of 50 km/hour. The cold front, following approximately 6 hours behind the coastal low, was associated with a maximum gust of 35,6 m/s at H F Verwoerd Airport - the highest since 1957.

The last example of a fire rendered uncontrollable by the sudden increase in wind speed associated with a coastal low/cold front pair, is given in case study No. 8, 10 December 1982. The synoptic situation was very similar to that above, that is, rapid deepening of the coastal low reflecting the presence of an intensifying frontal wave close to the coast. Extensive fire damage was caused on the campus of the University of Port Elizabeth.

5.7.5 Planned Burning

The forestry industry and the agriucltural sector need to have advance knowledge of optimum conditions for planned burning operations. Although it is a short-term forecast that is required, an accurate longer term prediction would also be of great benefit. Optimum conditions for burning, that is, hot, dry conditions may be rapidly turned into a very hazardous situation should a sudden, unexpected increase in wind speed occur.

5.7.6 Summary

The above few examples have highlighted several points concerning Cape South Coast weather, which are of importance to the forester or anyone else involved in the burning or combatting of fires:

(a) The **coastal low** must not be underestimated as far as its ability to produce high fire potential is concerned. Just as important are the strong winds and the switch in wind direction associated with this system.

(b) Sudden escalations in wind speed may also occur with the passage of a **frontal system.** The high temperatures and low humidities associated with certain pre-coastal low berg wind conditions may persist after the passage of the coastal low, until the following frontal system has passed. The last two examples show how a coastal low/cold front pair can combine their 'fire potential' to produce conditions under which many a Cape South Coast fire has thrived.

(c) Local weather effects may often dominate a particular event. For instance the passage of a coastal low may be relatively mild at one location yet associated with a violent buster at another. It is imperative that **on-site weather reports** be obtained for later analysis, and that the forecaster be aware of local anomalies when providing a prediction.

5.8 WEATHER EFFECTS OFFSHORE

Since this study went well beyond the boundaries of the Agulhas Bank when considering the synoptic scale systems affecting the Bank, it was decided to include the **swell** generated by distant systems in this section. However, there is a tendency for those dealing with wave data on the Cape South Coast, to ignore the important role played by locally generated waves. Numerous examples are given in the text of low pressure systems (frontal or COLs), which have shown rapid development in the vicinity of the Bank and produced seas as big as any long-term, large scale frontal system. Thus, the relatively limited fetch, and short duration are more than made up for by the rapidity and intensity of development. The December 1976 storm and the so-called 'QE-2 storm', both described in Section 4.3.5, are good examples of this.

5.8.1 Investigation of Short Period Swell, 1982

SADCO provided significant wave-heights (H_{mo}) and peak energy periods (T_p) from a Waverider buoy moored near the oil rig, Sedco-K, south of Mossel Bay. Looking at all H_{mo} values in excess of 3,3 m with the additional requirement that T_p be less than 9 seconds, 6 out of the 11 hits had an easterly component, and 5 of these were associated with a COL situation. Thus, it may be assumed that the COL plays a major role in the generation of large amplitude, high frequency swell.

5.8.2 Waverider Records, 1982 - All Periods

An analysis of all observations where H_{mo} exceeded 5 m, revealed that **frontal wave** developments were the dominant generators of high swell conditions. The major frontal systems as far as wave generation was concerned, were the cold air cyclones of 4 and 5 August 1982 (see case study No. 1, Chapter 3). However, the absolute maximum wave-height was not associated with a frontal system at all, but an escaping **COL.** As was pointed out earlier, these systems may intensify considerably as they move seawards after a period of residence overland. On 7 October the Waverider recorded an H_{mo} of 6,72 m, the highest in the 12 month period. Direction was south-west. Case study No. 7 gives the time-series associated with this event. It is also significant that one of the highest H_{mo}s in 1982 was recorded on 2 January, that is, in the middle of summer.

5.8.3 Synoptic Conditions Associated with Extreme Swell Height Estimates from VOS

Looking at the 8 highest swell estimates for both the eastern and western Agulhas Bank, the following observations were made:

(a) In a number of cases the fetch region was well south-west of the Bank. However, there were some cases of extreme swell where a system developed markedly, relatively close to the Bank, for example, on 8 May 1970, the frontal wave had its central pressure drop to approximately 985 mb as it passed south of Cape Agulhas. The secondary development of 2 September 1978 (see case study No. 3), also accounted for one of the highest swell height estimates in the VOS data set.

(b) A frontal system which was followed by a **strong ridge** of the AOA, seemed to be associated with a higher swell, presumably due to the increased surface pressure gradient and the fact that it is usually behind this last system that the coldest air temperatures are found, the air originating from far south. Hamilton (1980), has stressed the importance of the stability of the marine boundary layer in allowing the wind to get a good 'grip' on the ocean surface, that is, the easier it is to displace air vertically, the better momentum transfer between atmosphere and ocean. He also found that unstable conditions in the lower planetary boundary layer (PBL) were partly responsible for the capsizing of 5 NDBO moored weather buoys, mainly due to the extra energy input locally - at the high frequency end of the spectrum.

(c) It is highly significant that COL situations produced some of the highest swell reports on the whole Bank. On 21 August 1974, a vessel south-east of Cape Agulhas reported a south-easterly swell of 14 m, associated with a COL situation. Yet there is a tendency to disregard swell with an easterly component when considering extreme wave-heights on the Agulhas Bank.

(d) Not having long-term wave measurements, it is difficult to specify the system most likely to generate design wave-heights. The highest **measurement** on the Bank so far (8,6 m on 2 September 1978), was the result of a series of intense secondary developments around a parent low well to the south. But it is probably the **'bomb'** situation (see case study No. 10) which has the most swell generating potential. Had the May 1984 system continued in an easterly direction, the swell estimates of 9 m may well have been higher. Rossouw (1984) has calculated a design wave height (approximately 1 in 10 years) using Sedco-K data, of over 11 m. Note that his data included the September 1978 storm.

Extreme H_{mo} values from VOS vary between 12 and 15 m - a good comparison when it is considered that none of the rig measurements were taken in the current, where wave/current interaction may considerably amplify the swell. In addition to the effect of the current on swell, local wave generation is likely to be enhanced considerably over the warmer water, due to increased transfer of vertical momentum. Sweet et al. (1981) noted a marked deterioration in sea state across the north wall of the Gulf Stream, similar to that portrayed by Schumann (1976) in the Agulhas Current.

As for tropical cyclones, the Agulhas Bank is too far south and west to come under their influence - even the high swell seldom reaches further than the coast of Natal.

5.8.4 Seasonal Distribution of High Swell Reports from VOS

Looking at swell height estimates which exceeded 8 m, both areas on the Bank showed a **winter** maximum. The western Agulhas Bank had an anomalous minimum count in September, whilst in the east January had the lowest count of high waves.

5.8.5 Extreme Wave Heights According to VOS

Because of the inaccuracies introduced when the mariner is forced to split sea state into sea and swell, so-called 'wind waves' were also considered. Looking at wind wave heights which exceeded 6 m, the dominance of **winter** storms was again apparent. In the east there was a relatively high count in December which ties in with an anomalously high count of extreme wind events in that month (see Section 5.6).

5.8.6 The Effect of Swell Characteristics

It must be stressed that the way in which a **particular** vessel reacts to the swell is also very much a function of the distribution of wave energy with respect to period. This is particularly true in the case of the oil rigs which may resonate if there is significant energy at long periods. For example, in March 1986 financial loss of the order of millions of rands was incurred by SOEKOR when high energy, long period swell caused one of the rigs drilling south of Mossel Bay to resonate. Although wave-heights were not exceptional (estimates of up to 10 m were received), heave amplitudes exceeded 10 m (Hunter, 1986b). Maximum T_p measured at Gouriqua west of Mossel Bay was 18,3 sec at 14h00 on 30 March 1986. Compare this with the long-term wave statistics from Sedco-K which showed that only 5 per cent of all waves had a peak energy period exceeding 16,5 seconds, and the great majority of these were associated with relatively little energy. The number of interacting wave-trains is also an important factor. Most vessels can handle a high, uni-directional swell, but a **confused** sea presents a much greater danger.

5.8.7 Vessels which were Deliberately Grounded in Heavy Seas

Two examples are given below. Although the seaworthiness of the two vessels may be questioned, sea state was nevertheless severe and played a major role in the loss of the vessels:

Oriental Pioneer. In July 1974, a well developed frontal trough was followed by an intense AOA resulting in a broad south-westerly fetch region. The resulting heavy swell on the Bank caused the ore carrier, Oriental Pioneer, to spring a leak. Her master headed for Struis Bay, but the high seas affected the manoeuvreability of the vessel, and she ran aground in the Agulhas area. The resulting oil spillage had adverse affects on coastal flora and fauna.

Evdokia. On 10 June 1979, a deep low with central pressure approximately 980 mb passed relatively close to the Bank. This relatively slow moving system was followed by an intense and developing AOA (approximately 1 040 mbs). The Evdokia started to take water that evening due to the heavy seas. Her master eventually decided to beach the vessel, but chose an extremely hostile coastline within the Tsitsikamma Coastal National Park, with the result that there was only one survivor.

5.8.8 Weather-related Offshore Sinkings or Hull Damage including Loss of Containers and Parting of Tow Cables

One case of a vessel floundering in heavy weather, another of tugs losing their tows, and a third of container loss, are presented here. Relevant additional material is also presented:

Sinking of the Smit Lloyd 102. On 31 December 1970 at 06h30, the Smit Lloyd 102 capsized and sank off Storm's River Mouth. She was a service vessel involved in the search for oil off Plettenberg Bay. Five of the seven crew were lost. The synoptic charts show the classic pattern associated with heavy seas along much of the South African Coastline - a cold front curling into a deep frontal wave, with the AOA ridging in behind. A tight south-westerly pressure gradient produced high swell conditions over the Agulhas Bank, and it appears to have been a particularly large rogue wave which capsized the tug. Consider the discussion on extreme storm waves (ESW) which appeared in the Fall edition of Mariner's Weather Log:

These outsized waves were found to occur mostly when a storm is intensifying rapidly. It has been shown in the case studies that such intensification is fairly common just to the south of the Agulhas Bank, or even on the Bank.

ESW usually develop in the high wind area which in the Southern Hemisphere is north and west of the storm centre. Their main characteristics include a long level crest, a steep, high face, which may be breaking, and a very deep trough. Such waves have been detected on radar. The report emphasises that one of the biggest dangers of an ESW is that the direction from which it appears may make a considerable angle with the general seaway - over 50^{o} in some cases. This angle is mostly to the right of the seaway, probably because when the pressure field is changing rapidly, the geostrophic assumption no longer applies, and winds tend to cross the isobars at a much greater angle.

Thus, a vessel encountering heavy seas on the Agulhas Bank should be on the look out for a freak beam sea under extreme conditions behind a rapidly developing frontal system. This seems to have been the fate of the Smit Lloyd 102.

It must be emphasised that the above discussions do not include the so-called **freak waves** which have received much attention in the literature (for example, Schumann, 1976 and Mallory, 1974). Such incidents have generally been limited to the more northern reaches of the Agulhas Current, where the current opposing the high swell, is more concentrated, reaching up to 8 knots. Note that most vessels rounding the Cape leave the Agulhas Current in the vicinity of Cape St. Francis.

Parting of tow cables in rough seas. In late June 1977, two tugs lost their charges after tow ropes parted. Between 22 and 24 June, a series of frontal systems crossed the Agulhas Bank, their centres relatively close to the coast. On 25 June, the AOA ridged in behind the previous cold front, but no BOH was observed to round the coast, and the flow of frontal systems was soon resumed. One VOS report on the eastern Agulhas Bank on 26 June estimated swell height at 10,5 m. Note that the storm displaced both charges **eastward** at 4 to 6 knots before they were relocated and towing resumed.

Loss of containers. On 30 November 1981, the vessel, Pagnet, lost 23 containers off Cape Agulhas. The synoptic systems responsible for the high seas were a deep frontal wave which traversed the southern Agulhas Bank trailing a tight south-westerly gradient behind it. A feature of this system was the extremely cold air which it introduced offshore - 9°C was measured. This made for a very unstable surface layer which meant much improved coupling between the gale force winds and the sea-surface. Further to the east, Sedco 708 measured south-westerly winds of 20 m/s, and swell heights of almost 10 m were estimated.

It is of interest that a prolonged COL situation just prior to this, caused an easterly swell of up to 7 m to appear on the Bank on 25 and 26 November. The containers lost from the Pagnet, were transported rapidly **northwards** by the current, and several were recovered off Cape Point.

Buckley (1983) has also emphasised the importance of local wind in the generation of extreme waves, especially where the wind is subject to sudden changes in speed and direction. Looking at damage incurred by shipping due to extreme weather conditions, the US Coast Guard found that **localised wave loads** were the most common cause. With the upsurge in container traffic, damage to, or loss of, such containers has also become a strong possibility during heavy swell conditions.

Again with respect to containerised traffic, Buckley also warns against the sudden appearance of a 'misaligned', large, swell train. Such 'episodic waves', may cause a vessel to roll to such a degree that containers or equipment on deck may break free.

5.8.9 Groundings as a Result of a Loss of Power and Onshore Winds

In recent years there have been numerous cases of vessels suffering total power failures off the South African Coast. With a strong onshore wind component, such as may be experienced during a COL situation, a vessel without power could well be driven ashore:

(a) On 31 August 1902, a COL situation associated with gale force south-easterly winds, and heavy rain, resulted in the grounding of 21 ships along a 3 km stretch of coastline at Port Elizabeth (Burman, 1967). Thus it is that vessels sheltering from the normal 'westerly' weather have been caught unawares by the sudden development of a Black Southeaster. It has been shown in Chapter 3 how rapidly a frontal wave situation with fresh westerly winds can change into a COL with a sudden change in wind direction (for example, case study No. 7, 8-10 October

1982). There are also examples of vessels being driven ashore during Black Southeasterly conditions after seeking shelter behind the Robberg (Plettenberg Bay) from earlier westerly storms.

(b) Ironically enough, it was also during a COL situation that the powerless Wafra grounded off Cape Agulhas in February 1971. But on this occasion, the vessel was drifting on the western side of a low that was centred offshore, giving the Agulhas area strong south-westerly winds. After two unsuccessful attempts to tow her away from the coast, she grounded on a reef 11 km off Cape Agulhas. Although later refloated, and sunk offshore, the Wafra still ranks as the worst coastal oil pollution to have hit the South African coastline thus far.

5.8.10 Transhipment of Oil

August 1982 saw the transhipment of 120 000 tons of crude oil in Algoa Bay after the tanker Marofa had developed cracks in her hull. This is an example of a shipping operation which is particularly weather sensitive, requiring accurate predictions for several days ahead. With the heavy tanker traffic around the Cape, more such transfers may be expected in the future. In the same month, over 280 000 tons of oil had to be transhipped from the supertanker Antonios G in False Bay.

5.8.11 Wave Prediction on the Agulhas Bank

The only wave prediction model to have been run operationally in the South African region was the wave model run by the SAWB. This model uses the wind field from an atmospheric prediction model as input for the wave growth equations. No long-term verification was ever attempted with this model, but it was shown to be capable of significant inaccuracies (Shillington, 1978). This is not suprising since the model used wind fields computed by the 6 level primitive equation model run by the Weather Bureau. This model was not capable of consistently accurate sea-level pressure prognoses.

Francis (1985), has described in some detail the wave and storm surge models run by the UK Meteorological Office. Whilst surge prediction is not in much demand along the South African coastline, an accurate swell forecast on the Agulhas Bank could be of considerable use to the offshore industry south of Mossel Bay, and to shipping in general. The Meteorological Office envisages a global forecast facility in the near future.

Any swell prediction model covering the Agulhas Bank would have to take into account the Agulhas Current. Furthermore, as has been pointed out above, the effect of intense local developments may be considerable, and such systems would have to be well-defined by the atmospheric model providing the input to the wave model. Francis notes that the boundary layer transfer processes whereby the wind imparts kinetic energy to the sea-surface, are not completely understood. Many researchers have stressed the importance of the stability of the lower PBL in deciding how well the two media are going to be coupled.

5.8.12 Syledis Positioning System

This is a UHF radio positioning system used by SOEKOR to ensure accurate well-site location. This system had an adverse affect on the AWS on the rig in that its operation was linked to severe signal corruption, especially on the wind speed channel. Fortunately, periods of operation were usually short, at the beginning and end of a well-site.

However, the effect of certain atmospheric phenomena on the operation of this instrument may not be so unimportant: Janes et al. (1985) testing a similar system on the Nova Scotia coast, found it to be very weather sensitive when used at longer ranges. Fog or heavy precipitation attenuated signal strength, and frontal conditions affected ranging accuracies. Although frontal intensities may be nowhere as severe on the Agulhas Bank, frequent inversion conditions associated with the coastal low could adversely affect signal strength.

6. SUMMARY AND RECOMMENDATIONS

The first aim of this thesis as stated in the introductory chapter, was to describe meteorologial and related oceanographic conditions on the Cape South Coast and over the adjacent Agulhas Bank. Considerable emphasis was to be placed on the role of the synoptic scale systems as producers of various weather and sea conditions, and newly accessed data sources were to be used extensively. The information resulting from this study was then to be used to discuss man/weather interactions in this region. All this has now been achieved. It remains to summarise the findings of the study, with respect to both the weather systems and weather sensitive activities, and finally to suggest the direction which future research in this field might take.

Since the final aim of this thesis was to provide information of practical value to those managing weather sensitive operations, both coastal and offshore, the summary is structured according to possible users of this information.

6.1 THE SHIPPING INDUSTRY

6.1.1 Waves

It is the wave-generating capability of weather systems which is probably of greatest interest to ship operators. The so-called 'bomb' associated with explosive cyclogenesis, and the more common cold air cyclones which develop in maritime polar air masses, have been identified as major swell generating systems. So, too, the frontal wave which develops close to the coast. The Atlantic Ocean Anticyclone has been identified as another important ingredient in heavy swell events.

Numerous examples of enhanced wave generation due to an unstable lower boundary layer (that is, post-frontal air of polar origin crossing warm Agulhas Current water) have provided confirmation of a previously underestimated factor. An example of possible rogue wave generation due to a rapidly changing surface pressure field, should sound a warning to all ship operators that explosive cyclogenesis may pose a special threat to deck cargo such as containers.

The section on climate gave winter and spring as the seasons with the highest frequency of heavy swell. Maximum VOS estimates of 12 to 14 m **in the current** did not appear far-fetched when compared with Waverider measurements. Apart from the weather systems mentioned above, the cut-off low situation which provides extended gale force easterly winds, has been shown to be a major generator of extreme **easterly** swell. Furthermore, such swell may approach the large amplitude attained by the more common westerly component swell of frontal origin.

The classic recipe for heavy swell, that is, long duration of strong winds blowing over an extended fetch region, has been shown to be unnecesary if the responsible weather system shows rapid development close to the coast. The relatively short period waves produced may make an important contribution to the total wave energy, even when a major fetch region also exists further south.

6.1.2 Wind

This parameter is most important to shipping as a generator of swell as discussed above. However, extreme wind does place a large load on the superstructure of a vessel, so that a head wind may result in a significant loss of speed and so disrupt schedules. This loading is of particular importance when manoeuvring a large vessel such as a container carrier within the confines of a harbour. All the findings related to extreme wind events should thus be of interest to ship operators - the intense gust fronts associated with certain coastal lows and frontal systems in particular. It has been shown that these sudden upsurges in wind speed are far more likely to occur on the eastern Agulhas Bank, and, contrary to theory, may also occur offshore. Furthermore, although extreme wind events are most common between May and November, a vessel crossing the Agulhas Bank must be prepared for gale force winds at any time of the year. December showed up as an unusually stormy month on all data sets.

As far as actual extreme values are concerned, the Agulhas Bank, with a 1 in 50 year hourly average of under 30 m/s, does not compare with extreme conditions in the North Atlantic (40 m/s for the same return period). However, the seasonal contrast is markedly less over the Bank.

6.1.3 Fog

Considerable attention was given to this phenomenon, and it was shown that the incidence of vessels colliding in fog was unusually high, considering the documented frequencies of fog occurrence on the Agulhas Bank. The role of easterly winds, particularly the extended easterlies associated with a cut-off low, in initiating coastal upwelling and thus providing cold water for advection fog formation, has been clearly shown. Furthermore, the Cape St. Francis region has been identified as a major source of such cold water. It is suggested that the frequency of fog in St. Francis Bay may well exceed the 26 days per annum recorded at Cape St. Francis lighthouse.

An unusual discovery was the fact that several offshore fog reports coincided with berg wind conditions on the coast. Thus, far from ensuring a vessel with clear, dry conditions, the offshore flow may soak up sufficient moisture to make saturation easily attainable through later cooling. Apart from its link with berg wind conditions, the coastal low may also provide a very important 'lid' to inhibit the vertical mixing of moisture, thus favouring fog conditions.

The solution for any vessel which has had to reduce speed in fog, is to move into warmer waters offshore - assuming this does not mean a major diversion. Such a move is particularly feasible over the eastern Bank, where the Agulhas Current is closer inshore. The initial climate study showed that March is the favoured month for fog formation on the Agulhas Bank. Note that absolute minimum sea temperatures on the Agulhas Bank occur in **autumn**, when average temperatures are still relatively high. The dominant effect of upwelling in this season is thus clear. VOS reports indicate that the diurnal fog cycle peaks in the early morning, when the atmosphere is most stably stratified.

6.1.4 Precipitation

Although of little importance to the vessel at sea, rain may severely disrupt the schedule of vessels trying to unload certain cargoes in harbour. The land-breeze has been identified as a probable culprit for triggering unforeseen coastal rain.

6.2 THE OFFSHORE INDUSTRY

Whereas most of the merchant vessels crossing the Agulhas Bank have to deal with extreme conditions all over the globe, the exploration rigs adjust their operation to local conditions. It is thus imperative that they are completely aware of the range of values which the sea and atmosphere may present on the Agulhas Bank.

6.2.1 Waves

As with their mobile counterparts, the drilling rigs are more affected by the waves generated by extreme winds than the winds themselves - particularly wave fields with an energy distribution concentrated close to the natural heave frequency of the rig. It is contended that the mid-latitude cyclone responsible for such a distribution enhances the longer period waves by following a longer north-easterly track at anomalously high speeds. It is the rapidity with which sea state deteriorates that threatens rig operations. If drilling is in progress, the drill string has to be decoupled. Furthermore, because of rapidly increasing rig heave, the riser has to be pulled well clear of the well-head. All these operations become increasingly hazardous as the sea state deteriorates. Despite documented evidence of rapid wave height increases, the standard interval between swell recordings is 6 hours.

Remarks relating to the seasonal and spatial distribution of high wave events should be of interest to drilling operators for long-term scheduling. They should also take note of the major swell generating systems identified earlier. Both VOS and measured wave data suggest that wave conditions are likely to be more severe over eastern Agulhas Bank well sites than those south of Mossel Bay. The frequent intensification of weather systems as they approach the eastern Agulhas Bank, would also support this.

6.2.2 Wind

The derrick provides the most wind resistance on a semi-submersible, so that deck loads may have to be redistributed under extreme conditions, to reduce the overturning moment. Probably the most sensitive operation to wind is the landing of the helicopter on the helipad. It has been shown that rapid increases in wind speed may occur during the passage of a front or coastal low, whilst downdraughts from convective cloud may also provide extremely dangerous conditions for landing.

During gas testing, a continuous check on wind conditions is necessary to ensure that the gas flare is not blown inboard. This study has shown that 180° directional switches may be associated with a coastal low passage, whilst sudden changes may also be associated with thunderstorm conditions.

Table 4.3 gives some indication of the range of time intervals to be expected between the passage of a coastal low and its associated frontal system. The former passage is usually clearly defined on the rig (see case studies), so it is possible to predict roughly the arrival time of peak wind conditions associated with the front. Alternatively, the tabulated propagation speeds (Table 4.1) may be used to predict the time of arrival of a particular system, if another rig is well upstream, and in radio contact.

6.2.3 Fog

Findings concerning this particular weather situation should be of interest to the helicopter pilots flying to and from the rigs. A delivery flight or crew change which has to be aborted because dense fog makes landing hazardous, constitutes a significant financial loss. Fog frequency increases inshore, away from the fog-dispersing waters of the Agulhas Current, and closer to the upwelling plumes anchored to the major capes. Helicopter operators should thus be prepared to encounter more fog at well sites on the eastern Agulhas Bank, particularly after an extended period of strong easterly winds or even during coastal berg wind conditions. It may be beneficial to monitor sea temperatures as well as the position of the next coastal low.

6.2.4 Lightning

Post-frontal convective cloud development may be of such an intensity that deep cumulonimbus clouds form in the region of the rig. This is more likely in the east where the proximity of the Agulhas Current is an important additional factor. The extremely unstable conditions usually associated with a cut-off low situation, or even the transitory trigger action provided by a passing front should be taken into account when gas is being brought up from beneath the sea-bed.

6.2.5 Temperature

Various sources of offshore air temperature data have shown that berg wind conditions may extend well offshore. The more eastern well-sites are particularly susceptible, being closer inshore. Having travelled over water for up to 50 km, the air reaching the rig may be markedly humid, and thus present a health hazard to those engaged in heavy labour on the drill floor. The effect of temperatures in excess of 30°C on the operation of certain equipment must also be considered.

6.3 THE COASTAL FORESTRY INDUSTRY

The interaction between this industry and certain coastal weather systems was considered in some detail. The coastal low with its associated frontal system was shown to present a formidable combination for those trying to combat an accidental fire on the coast. Thus, berg wind conditions ahead of the coastal low may provide hot, dry conditions for easy ignition whilst the wind maxima associated with both this system and the following front may ventilate the fire out of control. Recognising the important role played by the coastal low, those combatting an existing fire or planning a controlled burn, may benefit from the detailed study of this system. Again, some idea of the time interval between the buster (if it exists, which is much more likely in the east), and the peak frontal winds, may be of use in deciding how best to combat the fire.

It may also benefit the forester to take note of the specific type of frontal situation and consider the findings on coastal precipitation. A front with a well-developed wave close to the coast, or one which is being followed by a well-defined ridge of the Atlantic High, is more likely to provide precipitation to help extinguish the fire. On the other hand an intense front may mean that hot, dry offshore flow is maintained, even after the passage of the associated coastal low.

Although thunderstorm conditions occur only 5-10 times per year in this region, lightning may still initiate fires here. Attention is thus drawn to the thunderstorm-triggering potential of the coastal low and cold fronts, with cut-off lows being associated with particularly unstable conditions.

Finally this study has highlighted the tendency for sudden escalations in wind speed associated with frontal or coastal low passages, to be enhanced in the eastern section of the region. Nevertheless, such features as gust front intensity or adiabatic warming appear to be highly localised, and the importance of on-the-spot weather observations has been emphasised.

6.4 THE FISHING INDUSTRY

Comments here are directed at both the larger vessels operating out of ports such as Mossel Bay or Port Elizabeth, as well as the ski boat fishermen launching from a great variety of sites all along the Cape South Coast. Whilst numerous examples of merchant cargo vessels encountering difficulty in heavy weather have been given, little mention of the casualties amongst these smaller craft has been made. However, a brief look at past issues of the National Sea Rescue Institute's Quarterly Journal, 'Sea Rescue', will show that casualties are much higher amongst this group. This is to be expected, since even the larger fishing vessels are not as capable of riding out severe weather as the larger merchant ships. For ski boats launching from an open beach, there is the added danger of traversing the surf zone, and many accidents have occurred there.

Thus, all the information on wind, waves and fog which was drawn to the attention of those operating ships on the Agulhas Bank, should also be of interest to those in charge of smaller vessels. However, being considerably smaller, warnings re gust fronts, explosive cyclogenesis and rogue wave conditions, are even more applicable. Most of these vessels rely on being close enough to home to outrun deteriorating weather and sea conditions. But the case studies include several examples where weather systems crossed the whole Agulhas Bank in a matter of hours. It is thus essential that these vessels obtain detailed prognoses before departure, and that every attempt be made to improve the accuracy of these forecasts.

Certain fish species are very sensitive to ambient water temperature. Quite apart from the phenomenon of large-scale fish kills during upwelling events, fishermen usually stand to benefit from a detailed knowledge of SST patterns. More detailed SST information is needed. Present 10 day means are probably smoothing out most of the short-period events on the Bank.

6.5 OIL POLLUTION

Although average wind conditions in the long-term were presented in the earlier section on climate, it is envisaged that this information would serve merely as a guideline, should a major oil spill occur on the Agulhas Bank. On a synoptic scale, global numerical weather prediction models such as the ECMWF model are showing a high degree of skill over several days. It is felt that the present study may well be of use in helping the forecaster reduce the large scale wind predictions down to a more local prediction. The land-breeze circulation, for example, has been shown to dominate the winter wind rose at certain localities. Furthermore, case studies show that it may be strong enough to affect the state of the sea, thus aiding mixing.

Similarly, other local effects such as the intense gust fronts which may occur with the passage of coastal lows and cold fronts, particularly over the eastern Agulhas Bank. Note that features such as the coastal low are too small to be resolved by most NWP model output. Yet the circulation around this system may play a major role in deciding the trajectory of an oil spill.

An operation which is particularly weather sensitive is that of transhipping oil from one tanker to another. This has been necessary on a number of occasions recently, after vessels have grounded or suffered hull damage.

6.6 COASTAL MANUFACTURING INDUSTRY

Apart from the threat posed by extreme conditions which may similarly threaten many Cape South Coast operations, that is, wind damage, flooding and even wave damage for any structure near the sea, industry which is responsible for emmission into the atmosphere, has an added problem. The coastal low with its inversion 'lid' provides conditions with high pollution potential, whilst the land-breeze, evident throughout the year, may provide a very useful dispersing mechanism.

Any organisation which is involved in the generation of electricity on the coast, whether it be a conventional power station or nuclear, may be interested in a cold water source such as that provided by upwelling events. A prediction capability may well be required in order to assess the impact of a warm water outfall on the environment. The link between easterly winds on the coasts, particularly those associated with a cut-off low event, and upwelling, was exposed in the case studies.

6.7 YACHTING

The above term is taken to include all yachts from sailboards to deep-sea keelboats. Obviously all have considerably more interest in local wind conditions than the motorised craft considered up till now. Whilst dependant upon the wind for propulsion, these craft, particularly the smaller ones, are also much more sensitive to extreme wind conditions. This sensitivity is well portrayed in the example of rapid frontal wave development cited in the previous chapter (Section 5.6.6). All aspects of extreme wind events as considered in Section 5.6 should be of interest to the yachting fraternity.

To those yachtsmen who are as yet not fully aware of its benefits, the land-breeze circulation discussed earlier should prove useful. Not only can the land-breeze provide a means of propulsion during synoptically calm conditions, but as several of the case studies showed, it may undercut even a strong synoptic flow up to 10 km offshore, thus providing a temporary haven under stormy conditions. The enhancing effect of the BOH on the land-breeze has been clearly proven, and this knowledge may be used to considerable advantage by the yachtsman.

Fog poses just as much a danger to deep-sea yachts as to other larger craft, particularly in regions of heavy traffic such as off Cape St. Francis. But the section on upwelling is also of importance to all yachtsmen, particularly those most likely to find themselves in the water. Survivability is greatly reduced when water temperature drops to under 12°C, as may occur on the Cape South Coast. The wind conditions associated with upwelling, and the advection of cold water into Algoa Bay have been described.

6.8 ERECTION OF COASTAL STRUCTURES

Cut-off low events have been identified as being generators of extreme easterly swell which has damaged coastal structures. Those involved in the design and positioning of such structures, should be aware of the causative factors, since the same synoptic scale system may be associated with extreme wind and/or extreme rainfall, earlier in its lifetime. The design engineer is thus also referred to sections on precipitation and extreme wind.

Apart from taking into account weather extremes such as gale force wind or flooding, those involved in the planning of residential sites on the coast need to consider long-term effects. These include aeolian sand transport, as well as that associated with wave action, if the houses are very close to the beach. For example, Port Elizabeth in common with many other coastal sites, is faced with a beach erosion problem as a result of interference to the coastal flow of sand. Note that a single storm may cause a beach face to migrate rapidly landward. If the storm sand flow is in the direction of long-term transport, replacement may take many months.

6.9 MISCELLANEOUS

There are many other coastal activities which are weather sensitive to some degree, and may thus benefit from this study. These include many leisure activities such as hang-gliding, skin diving and surfing. Whether the activity be primarily affected by sea state or wind, the synoptic scale pattern will be playing a dominant role. The major attempt in this study has been to portray the various roles played by synoptic scale systems in producing the weather which affects so many activities on the Cape South Coast and the Agulhas Bank.

7. RECOMMENDATIONS FOR FUTURE RESEARCH

This final chapter is aimed at the scientific community as well as others involved in data collection and/or research in the field of marine meteorology. The recommendations all stem from the experience gained in the collection and analysis of data for this study.

7.1 THE DATA COLLECTION NETWORK

A comprehensive network of coastal and offshore automatic weather stations, capable of providing real-time data through telephone links, would be of considerable benefit. Those involved in coastal weather prediction would then be capable of compiling a more accurate 'first guess' field on a regional scale, and thus be in a better position to predict future events. The data from such a network would also be of great benefit to those interested in **present** weather conditions - forestry has been given as an example. It is important to bear in mind that at present forecasts are issued 3 times a day - based on the 0500, 08h00 and 14h00 synoptic analyses. Thus, there is a 15 hour gap between 14h00 and 05h00, during which no updates are made. Yet a coastal low or cold front may cover the entire Cape South Coast in a matter of hours. For those requiring precise forecasts for just a few hours ahead, such a network would hold great promise.

South African Weather Bureau AWS Program. The Weather Bureau is presently involved in a large scale AWS erection program throughout the country. One of the findings of this study which must be stressed here, is that an AWS which is to measure **marine** conditions, must be sited as close to the sea as possible. Walker Point, for instance, is considered an ideal site for a marine AWS as it consists of a low-lying, narrow peninsular. It also has telephone and mains power close at hand. As regards increased corrosion due to salt spray, this can be can be overcome through correct choice of materials. Neither the masts nor the sensors deployed for the 13 month coastal AWS measurement period in 1982/3, suffered any marked corrosion, despite close proximity to the sea.

Sea-surface temperature measurement. Correct siting of marine AWS also makes possible the addition of an extra channel which would be of considerable benfit to many organisations, that is, SST. However, the actual placing of the sensor in an environment with suitable water circulation and no sand accumulation, may be difficult at some sites. Adequate protection of cabling through the breaking wave zone is also a major problem.

Humidity. It is imperative that humidity be measured in the marine environment, despite the practical problems associated with remote measurement. AWS operators in the UK and elsewhere claim to have solved the major problem of salt contamination, through use of a suitable membrane.

Moored buoys. The ideal platform for the unobstructed measurement of **offshore conditions** would be a moored buoy such as those operated by the NOAA Data Buoy Office (NDBO) in the United States or the meteorological buoys funded mainly by offshore operators in the North Sea and North Atlantic. However, an attempt in 1982/3 to construct and deploy a moored buoy off Mossel Bay with very limited funds, showed that it is an impractical venture without the necesary expertise and adequate funding. It should also be borne in mind that the apparently high initial capital outlay will eventually be far exceeded by maintainance costs if the buoy is moored any distance offshore. High running costs should also be adequately catered for.

Continuous link with rig AWS. Fortunately the semi-submersible oil rigs presently involved in drilling on the Agulhas Bank provide readily available, even if not ideal AWS platforms. However, it is recommended that VHF or Meteosat links would make this AWS data continuously available, and provide immediate warning of equipment failure. Once the first fixed gas production platform has been installed, it will provide a better AWS site.

Wind measurement on oil rigs and production platforms. A continual problem associated with the measurement of wind on these platforms, it to find a suitably exposed site for the anemometer. Usually this is at a great height above the sea-surface, yet wind reduction to the standard 10 m level is often inaccurate or totally ignored. The calculation of wind at lower levels is a complicated matter involving a knowledge of temperature stratification and other processes. One of the rig tender vessels could possibly be instrumented to provide an indication of the various wind profiles.

7.2 SYNOPTIC SCALE SYSTEMS

7.2.1 The Coastal Low

Very little is known about the offshore configuration of this system. A permanent AWS on one of the workboats plying between Mossel Bay and the rigs could, in time, build up useful information about the coastal low circulation offshore. More information is also needed about the trajectory followed by this system over the western parts of the Cape South Coast, and the relationship between the gust front (buster) and local topography. Furthermore, the appearance of a weak low offshore, associated with the disappearance of the coastal system, has received little or no attention. A common feature of the multiple time-series based on coastal AWS data was the time lag between minimum pressure and the wind switch as the coastal low passed through. This also needs a clearer explanation.

7.2.2 Mid-latitude Lows, Fronts and Waves

Cyclogenesis associated with SST anomalies. It is recommended that particular attention be given to the possible link between cyclogenesis and those areas south and south-west of the country, where anomalously high sea temperatures are associated with the Agulhas Current, its retroflection zone, and so-called 'Agulhas Rings'. This will require a comprehensive data set of SST which, unfortunately, remote sensing cannot supply continuously due to the problem of cloud cover. Operational microwave sensors may provide a partial solution in the future. As for the sea-level pressure analyses, these would preferably be available at 3-hourly intervals in order to resolve cases of explosive cyclogenesis in better detail. Note that sea-level pressure is not routinely available through remote sensing, but free-drifting buoys equipped with pressure sensors may play a very important role in helping deliniate the sea-level isobars. Pressure and wind observations from the rigs, although they emanate from sites only about 100 km offshore may be of great benefit to the shipping forecaster, for example, in helping to identify a newly-formed wave on a front. It is therefore imperative that the quality of these observations be ensured. The research needed into vertical wind profiles has already been mentioned.

Coastal low/cold front link. The link between coastal low and cold front needs further clarification. Rig wind and pressure data first indicated that the time interval between the passage of a coastal low and its associated cold front, was fixed in a relatively narrow range. So too, the time lapse between frontal pressure minimum and maximum wind speed.

7.2.3 Cut-off Low

Whilst this system has received considerable attention as a major source of precipitation overland, its offshore circulation and the effects thereof on shipping and coastal activities, has been largely ignored. The identification of this system is important even when it is well offshore, since it has been shown to be responsible for some unique and important atmospheric and oceanographic phenomena. It is therefore suggested that the work of Taljaard be extended to cover the effects of cut-off low pressure systems offshore.

7.2.4 Mesoscale Circulations - The Land-breeze

This circulation has been shown to influence many activities, yet relatively little is known about its extent, especially offshore. Both its vertical structure and its diurnal cycle need further clarification. So too, the important 'undercutting' process whereby the landbreeze may create a relatively calm, stable, coastal zone as it flows in underneath the marine air.

7.2.5 Cumulus Lines Offshore

A possible link between enhanced convection and the land-breeze, needs to be investigated. If such a link is confirmed, it would considerably improve the prediction of anomalous rainfall events. Vertical soundings of temperature and wind will be required offshore if the full extent of the land-breeze is to be measured.

Oceanographers could also benefit from such a study, since a more definite link between the observed lines of convective cloud and the Agulhas Current core would enable them to use such cloud as an indication of SST patterns when no satellite infrared imagery is available.

7.3 METEOROLOGICAL AND RELATED OCEANOGRAPHIC PARAMETERS

7.3.1 Wind

Extreme wind events. With the erection of more permanent AWS on the coast, it will be possible to calculate design winds based on an increasingly longer data set. These same AWS will also provide actual **measured** coastal wind speeds upon which the shipping forecaster can base his forecast. The lack of wind in the Port Elizabeth region during the major storm of 16 May 1984, led to a large overforecast of wind speed. This phenomenon, presumably due to interaction between the large scale circulation and local topography, must be explained if forecasts of extreme events are to be improved.

Estimated winds. Since the majority of wind observations, coastal and offshore, are at present estimates, it is imperative that the accuracy of these estimates be statistically checked. This requires the availability of measurements nearby, and is particularly easy to do when an AWS is to be installed at a manned lighthouse.

7.3.2 Temperature

Berg winds. In order to predict the onset and termination of this condition at a particular site, the exact relationship between air of anomalously high temperature, and both large scale and local circulation, must be determined. This applies particularly at an offshore site.

Minimum temperatures. Prediction of minimum temperatures at certain coastal sites is heavily dependent on an understanding of the local land-breeze circulation, since the case studies have shown conclusively that minimum coastal temperatures are dominated by nocturnal offshore flow.

7.3.3 Visibility

Moderate to good conditions. Prediction of visibility in the range moderate to good, cannot at present be done on a quantitive, scientific basis. Activities such as aerial photography are dependant on good visibility and this should justify a more scientific approach, based upon a knowledge of circulation, suspended matter and ventilation.

Poor visibility - mist and fog. This is a condition which can be predicted on a rough time and space scale, but if local predictions are to improve, a greater understanding of the processes is needed. If the recommendation for real time SST measurements at coastal and offshore sites is heeded, this would also have benefits for fog prediction locally.

7.3.4 Precipitation

Rainfall figures away from the coast are non-existent, yet the semi-submersible Sedco-K has provided a potential platform for almost a decade. It is suggested that an automatic recording rain gauge on board one of the rigs would provide information of interest to marine biologists, chemists and climatologists.

7.3.5 Sea-surface Temperature

Prediction of upwelling. A quantitative model, capable of accounting for coastal upwelling in terms of wind, ocean stratification and coastal bathymetry, is required if coastal SST changes are to be predicted. In order to formulate and test such a model, comprehensive and well-placed AWS data will be needed. Such a model would require an accurate wind field prognosis from an operational atmospheric model on a fine mesh grid.

Agulhas Current intrusions. The relationship, if any, between atmospheric events and intrusions of warm Agulhas Current water onto the bank, needs to be investigated. Furthermore, the effect that such intrusions have on **atmospheric** processes, have received no attention until now, despite the fact that vast amounts of heat energy are invovled.

7.3.6 Sea State

Although global swell forecasts have been promised by the UK Meteorological Office, it is unlikely that their wave model will take into account local effects such as the Agulhas Current. If swell predictions are to be produced locally, an accurate surface wind prognosis, marine boundary layer prediction and realistic modelling of local effects, will be needed.

The rig damage of 30 March 1986, has highlighted the need for research into enhancement of long period swell by anomalous propagation of the generating synoptic scale system.

OVERALL CONCLUSION

This thesis has utilized a comprehensive and essentially unique set of marine meteorological data, most of which was collected, processed and analysed by the author, to investigate atmospheric processes over the Agulhas Bank and the adjacent Cape South Coast. For the first time a network comprising three coastal and one offshore AWS was set up, enabling previously unattainable, yet essential features of coastal weather systems, to be described. This is also the first time that a large data bank of VOS data has been used to provide individual reports.

The investigation has been largely centred around the synoptic scale systems responsible for the region's weather as well as for certain aspects of the physical oceanography on the Bank. The structuring of the general description of weather processes has benefitted considerably from this somewhat revolutionary approach.

In the analysis of the above data, it has been possible to clarify several processes previously misunderstood whilst many totally new relationships were also uncovered. The more standard requirements of certain sectors have also been catered for, such as the design wind speeds and gusts for the coast and offshore, previously non-existant.

This thesis has not only presented an updated description of the weather and climate of the region. It has identified the many areas where man's activities are particularly sensitive to atmospheric processes and shown clearly the advantages to be had from a greater understanding of such processes.

The importance of local effects in determining weather conditions at a particular site, has been stressed repeatedly. If high resolution prognoses are to become a reality in this region, a comprehensive mesoscale model will be required. Hopefully the present study will be of some benefit in the construction of such a model.

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TABLE 1.1: Synoptic Systems affecting the Agulhas Bank 1982/3

	Coastal lows	Cold fronts	Bud-off highs	Blocking highs	Cut-off lows	Deep coastal lows
1982						
FEBRUARY	12	11	5	1	3	0
MARCH	8	10	5	3	3	2
APRIL	8	8	2	4	5	1
MAY	11	11	7	0	0	0
JUNE	14	10	4	2	0	0
JULY	8	11	9	3	2	0
AUGUST	11	13	4	1	1	1
SEPTEMBER	7	14	6	3	1	0
OCTOBER	8	7	5	2	2	0
NOVEMBER	7	14	7	2	3	0
DECEMBER	12	19	9	1	0	0
1983						
JANUARY	15	11	8	0	0	0
FEBRUARY	9	9	7	0	1	0
MARCH	14	16	8	0	0	0
TOTAL	144	164	86	22	21	4
MONTHLY	10,3	11,7	6,1			

TABLE 4.1: Coastal Low Propagation Speeds

Date	Speed (km/hour) Western Agulhas Bank	Speed (km/hour) Eastern Agulhas Bank	Comments
21/02/82	35	90	Deep c.l. preceded by c.l. over E AB
24/02/82	-150-		Land-breeze at Walker Point
01/03/82	-150-		Indistinct at Walker Point - earlier LB
16/04/82	35	90	Pre-c.l. westerlies at Cape St. Francis
28/07/82	50	70	COL - Pre-c.l. westerlies
31/07/82	40	45	COL - Pre-c.l. westerlies
02/08/82	50	90	Precursor of intense frontal activity
08/08/82	25	45	Associated with berg wind conditions
06/10/82	-	40	Second of a pair of closely-spaced c.l.'s
12/10/82	135	30	Cut-off low (COL) in the upper air
12/12/82	45	60	Associated with intense frontal wave
15/12/82	30	175	Berg wind conditions offshore

TABLE 4.2: Coastal Low Passages - Time-series from Offshore AWS

Date	Position	Comment
28/08/78	Sedco K 40 km S of PE	NE - N (land-breeze) - WNW
30/08/78	Sedco K 40 km S of PE	NNE - N (land-breeze) - SW
02/08/82	Sedco K 130 km SSE of C. Infanta	Light NW ahead of c.l.
08/08/82	Sedco K 130 km SSE of C. Infanta	NE - N - W Coastal berg winds
03/08/82	Meiring Naudé 80 km SSE of CSF	NE - N - W
12/10/82	Sedco K 100 km S of C. Infanta	NE - VAR. - SW. Marked gust front
15/12/82	Sedco K 100 km S of C. Infanta	NE - N - SW gust front
17/02/83	Meiring Naudé 15 km off Gt. Brak	Land-breeze (NW) - westerly
24/09/84	Actinia 90 km S of Mossel Bay	pre-COL wind E-S
06/02/85	Actinia 80 km SSW of Mossel Bay	pre-COL NE - N - W

TABLE 4.3: Time Interval (hours) between Coastal Low and the following Frontal System

Date	CI	W Pt	CSF	Offshore	Comment
21/02/82	-	-	6	-	c.l. to 'deep c.l.'
27/02/82	11	LB	f wave	-	wave forms - new c.l. at CSF
28/07/82	8	LB	15	-	c.f. associated with COL offshore
02/08/82	11	9	7	10 - Sedco K 130 km SSE of CI 10 - MN 80 km SSE of CSF	Start of intense frontal activity
10/12/82	13	11	10	15 - Sedco K 100 km S of CI	Marked gust front with c.f.
24/09/84	-	-	-	11 - Actinia 90 km S of M Bay	cf associated with COL
06/02/85	-	-	-	7 - Actinia 80 km SSW of M Bay	cf associated with COL

TABLE 4.4: Coastwise Propagation Speeds of Cold Fronts

Date	Speed (km/hour)		Comments
	Western Agulhas Bank	Eastern Agulhas Bank	
16/02/82	36	117	Gust front used clearly defined at CSF
27/02/82	(200+)	f wave	Possible non-continuous gust front - new wave formed
16/04/82	80	43	Used temperature drop as marker
28/07/82	18	70	Double front associated with COL
29/07/82	25	175	Double front associated with COL
03/08/82	67	88	Gust front most intense at CSF
05/08/82	-	25	Cold Air Cyclone - last of a series
06/10/82	36	58	Cold front into double low
07/10/82	44	70	-
08/10/82	200	88	Gust front only at CSF - CAC
10/12/82	200	44	Gust front at Walker Pt. and CSF

TABLE 4.5: Summary of Bud-off High (BOH) Pressure Systems occurring during Case Studies 1 to 8

Date	C. Infanta	Walker Pt.	C. St. Francis	Comment
26-27/02/82	WSW-LB-NNE 1 016 mb	SW-LB-NNE 1 016 mb	W-SB-E 1 016 mb	BOH later at CSF - enhances sea-breeze
28/02-01/03/82	SW-S-SB 1 019 mb	SW-LB-SB 1 020 mb	W-LB-SB 1 020 mb	Offshore component of LB rel. weak at CSF
20/04/82	Var.-LB-SB no pressure	WSW-LB-E 1 022 mb	LB-W 1 022 mb	no easterlies at CSF
27/07/82	W-LB-E 1 021 mb	LB-SB 1 021 mb	W-NE 1 021 mb	CSF too late for LB
30/07/82	WNW-LB-E 1 026 mb	LB-E 1 026 mb	W-LB-NNE 1 027 mb	LB associated with drop in wind speed
06/08/82	LB-NE 1 030 mb	LB-NE 1 030 mb	LB(WNW)-NE 1 030 mb	Sedco K - possible LB-E 100 km offshore
11-12/12/82	SW-LB-SB 1 013 mb	LB-SB 1 012 mb	LB-SB 1 012 mb	Sedco K 100 km offshore remains westerly

TABLE 4.6: Summary of Cut-off Low (COL) Pressure Systems occurring during Case Studies 1 to 8

Date	C. Infanta	Walker Pt.	C. St. Francis	Comment
17-18/02/82	NE-S-E 1 016 mb	E-NW-SE 1 014 mb	SE-E-S 1 015 mb	Surface low over interior - moves seaward W of Walker Point
18-19/04/82	SW-LB-SW nil pres- sure	W-NW-W 1 013 mb	gale force W 1 011 mb	Deep surface low cut-off SE of Port Elizabeth
26-27/07/82	Westerly 1 019 mb	W-LB 1 018 mb	Westerly 1 017 mb	COL preceded by c.l.
28-29/07/82	WNW-W 1 011 mb	NW-W 1 013 mb	NW-W 1 013 mb	COL associated with double front - passed south
31/07-01/08/82	WNW-SW 1 020 mb	WNW-WSW 1 019 mb	Westerly 1 020 mb	COL preceded by c.l., passes south
09-12/10/82	E-W-WSW 1 004 mb	E-W-Var. 1 004 mb	E-Var-W 1 006 mb	Sedco K, 100 km off-shore, E-gale force SSW. suspect COL passed over

TABLE 5.1: Maximum Measured Wind Speeds - Hourly Averages

Actually **measured extremes:**	m/s			
Cape Infanta	20,5	easterly	19/02/82	15h00
Walker Point	20,5	westerly	29/04/82	03h00
Cape St. Francis	28,3 (24,3)	westerly	17/04/82	10h00
Sedco K (1978) - S of Cape Recife	33,6 (26,5)	WSW	02/09/78	04h00
Sedco K (1978-1984) - S of Mossel Bay	31,5 (24,9)	WNW	10/06/79	08h00
HFW Airport (1951-1970) - Port Elizabeth	21,0	westerly	-	-
PWB Airport (1951-1964) - George	21,0	WNW	-	-

TABLE 5.2: Design Wind Speeds - Hourly Averages

Calculated **return values** - return period in years: m/s					
	2	5	10	20	50
Cape Infanta	20,9	21,5	21,8	22,1	22,6
Walker Point	18,5	19,4	20,1	20,7	21,6
Cape St. Francis	25,0	25,8	26,4	26,9	27,6 (32,1)
Sedco K (1978-1984) - S of Mossel Bay	24,1	24,9	25,4	26,0	26,7 (33,8)
HFW Airport	-	-	-	-	22,3
PWB Airport	-	-	-	-	22,2

TABLE 5.3: Maximum Measured Gusts

Actually **measured extremes:**	m/s			
Cape Infanta	26,9	WNW	10/08/82	14h00
Walker Point	30,2	westerly	29/04/82	03h00
Cape St. Francis	37,1	westerly	12/02/83	10h00
Sedco K (1978) - S of Cape Recife	45,5	WSW	02/09/78	04h00
Sedco K (1978-1984) - S of Mossel Bay	44,2	WNW	10/06/79	08h00
HFW Airport (1951-1970) - Port Elizabeth	38,0	WSW	-	-
PWB Airport (1951-1964) - George	35,0	WNW	-	-

TABLE 5.4: Design Gusts

Calculated **return values** - return period in years: m/s					
	2	5	10	20	50
Cape Infanta	26,8	27,7	28,3	28,9	29,7
Walker Point	27,3	28,4	29,1	29,8	30,8
Cape St. Francis	37,3	38,4	39,2	40,0	41,0
Sedco K (1978-1984) - S of Mossel Bay	39,8	41,6	42,7	43,9	45,5
HFW Airport	-	-	-	-	40,7
PWB Airport	-	-	-	-	41,3

TABLE 5.5: Synoptic Systems associated with Extreme Wind Events - Lighthouse Data, 1976 - 1980

WAVE	COL - W	COL - E	LSFT	CAC	CYCL
08/06/76	06/11/80	08/05/77	25+	09/06/76	23/07/76
14/11/80		24/09/80	26/06/77	15/07/76	4+
		03/11/80		31/08/78	05/12/76
				01/09/78	
				02/09/78	
				19/11/80	
2	1	3	1	6	2

TABLE 5.6: Synoptic Systems associated with the 5 Top Storms at AWS Sites on the Agulhas Bank

	CAC	WAVE	COL - E	COL - W	BOH - E	LSFT
Cape Infanta	0	0	3	0	2	0
Walker Point	1	2	1	1	0	0
Cape St. Francis	3	1	0	1	0	0
Sedco K	1	1	-	-	-	3

TABLE 5.7: Seasonal and Diurnal Distribution of VOS Reports with Wind Speed > 20 m/s - eastern Agulhas Bank

TIME	MONTH:	1	2	3	4	5	6	7	8	9	10	11	12	Total
02h00		2	5	7	6	22	18	21	17	21	11	6	6	142
08h00		5	13	9	14	14	36	37	41	36	21	12	11	249
14h00		14	7	5	22	28	37	41	38	32	34	18	26	302
20h00		11	8	12	5	29	25	25	18	24	17	9	9	192
Total		32	33	33	47	93	116	124	114	113	83	45	52	885

Seasonal and Diurnal Distribution of VOS Reports with Wind Speed > 20 m/s - western Agulhas Bank

TIME	MONTH:	1	2	3	4	5	6	7	8	9	10	11	12	Total
02h00		4	6	7	2	7	7	10	15	7	7	6	6	84
08h00		5	5	2	5	21	15	19	16	19	10	6	7	130
14h00		6	12	6	8	15	12	19	27	21	18	8	11	163
20h00		12	8	6	6	5	5	17	13	8	9	6	5	100
Total		27	31	21	21	48	39	65	71	55	44	26	29	477

TABLE A1.1: Distribution of VOS Reports over the western Agulhas Bank: 1960 - 1985

	02h00	08h00	14h00	20h00	TOTAL
January	825	992	973	856	3 646 (0,93)
February	723	893	855	701	3 172 (1,07)
March	857	1 045	972	817	3 691 (0,92)
April	769	919	860	721	3 269 (1,03)
May	761	965	864	683	3 273 (1,03)
June	742	958	848	704	3 252 (1,04)
July	787	957	915	789	3 448 (0,98)
August	815	903	869	800	3 387 (1,00)
September	745	959	900	730	3 334 (1,01)
October	803	943	902	761	3 409 (0,99)
November	819	974	906	765	3 464 (0,98)
December	770	851	842	764	3 227 (1,05)
TOTAL	9 416	11 359	10 706	9 091	40 572
	(1,08)	(0,89)	(0,95)	(1,16)	

TABLE A1.2: Distribution of VOS Reports over the eastern Agulhas Bank: 1960 - 1985

	02h00	08h00	14h00	20h00	TOTAL
January	1 075	1 146	1 191	1 130	4 542 (0,96)
February	883	933	986	967	3 769 (1,16)
March	1 023	1 007	1 135	1 086	4 251 (1,03)
April	1 053	1 077	1 135	1 072	4 337 (1,01)
May	1 031	1 035	1 161	1 127	4 354 (1,01)
June	1 022	1 029	1 152	1 082	4 285 (1,02)
July	1 113	1 168	1 211	1 136	4 628 (0,94)
August	1 035	1 143	1 226	1 056	4 460 (0,98)
September	1 060	1 090	1 168	1 117	4 435 (0,98)
October	1 050	1 089	1 158	1 066	4 363 (1,00)
November	1 051	1 163	1 209	1 160	4 583 (1,05)
December	1 006	1 115	1 153	1 047	4 321 (0,99)
TOTAL	12 402	12 995	13 885	13 046	52 328
	(1,05)	(1,01)	(0,94)	(1,00)	

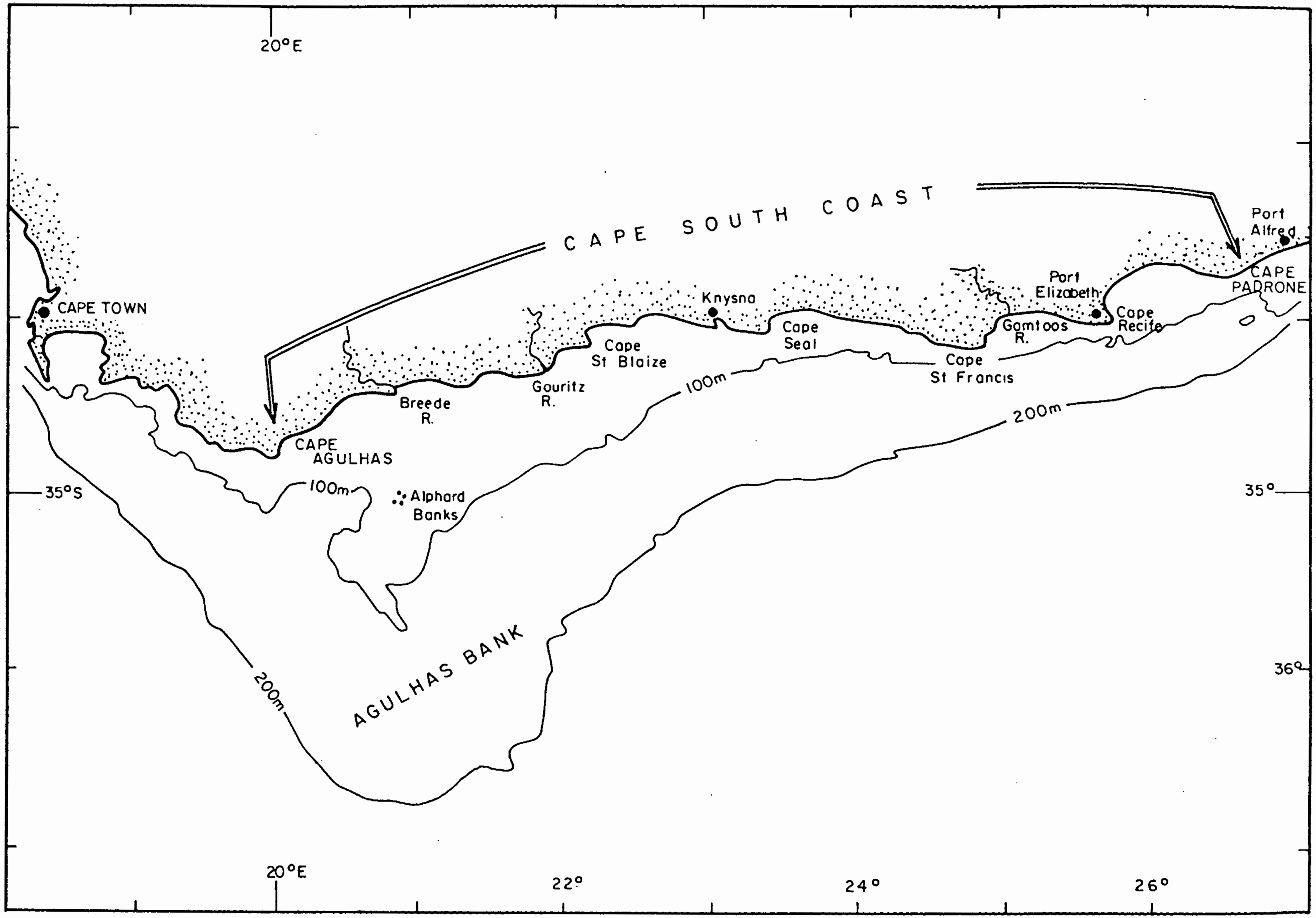

Fig. 1.0 Major features of the Cape South Coast and adjoining Agulhas Bank.

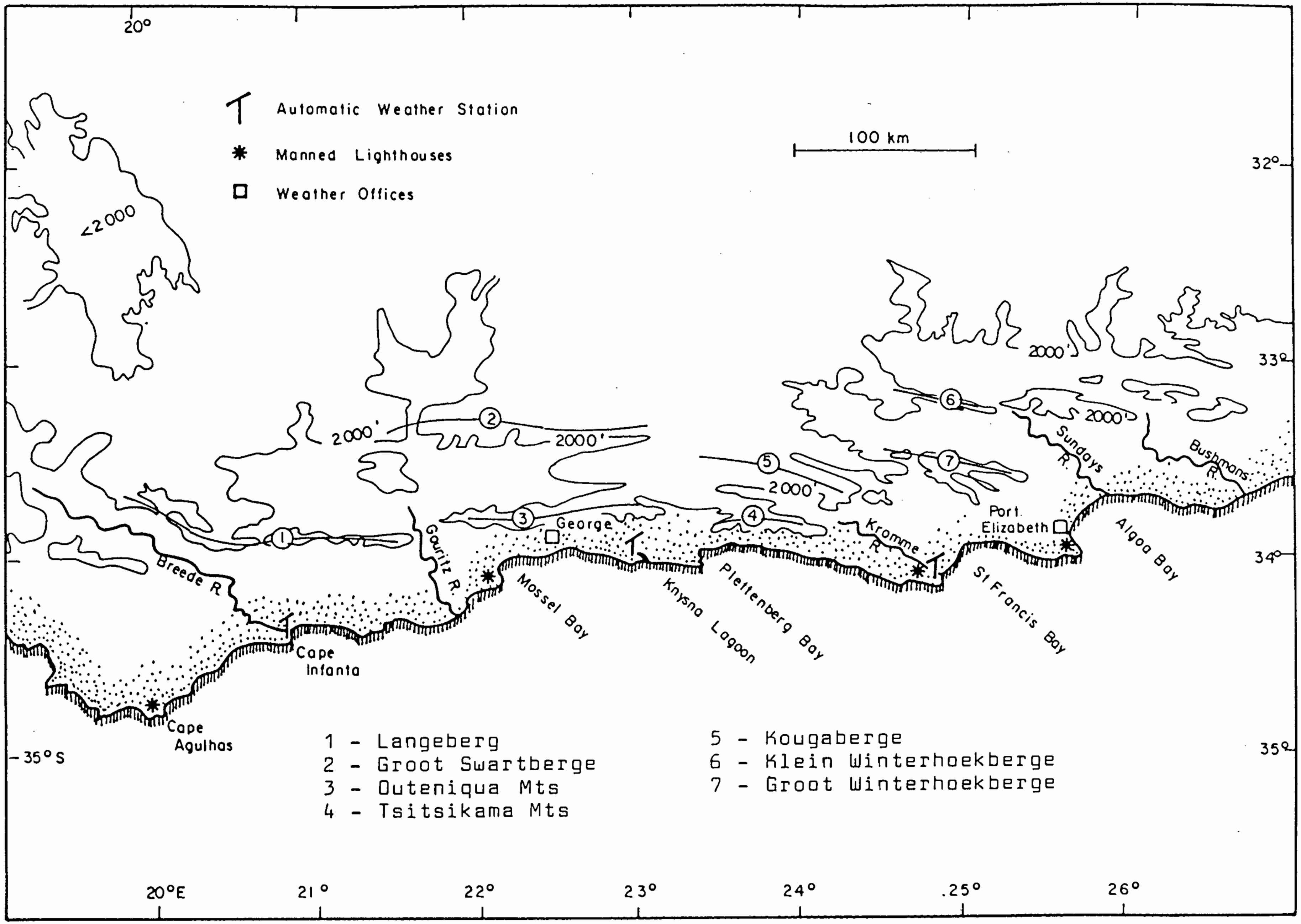

Fig. 1.1 Location of various meteorological observation sites on the Cape South Coast. The 2 000 ft contour delineates the major topographical features.

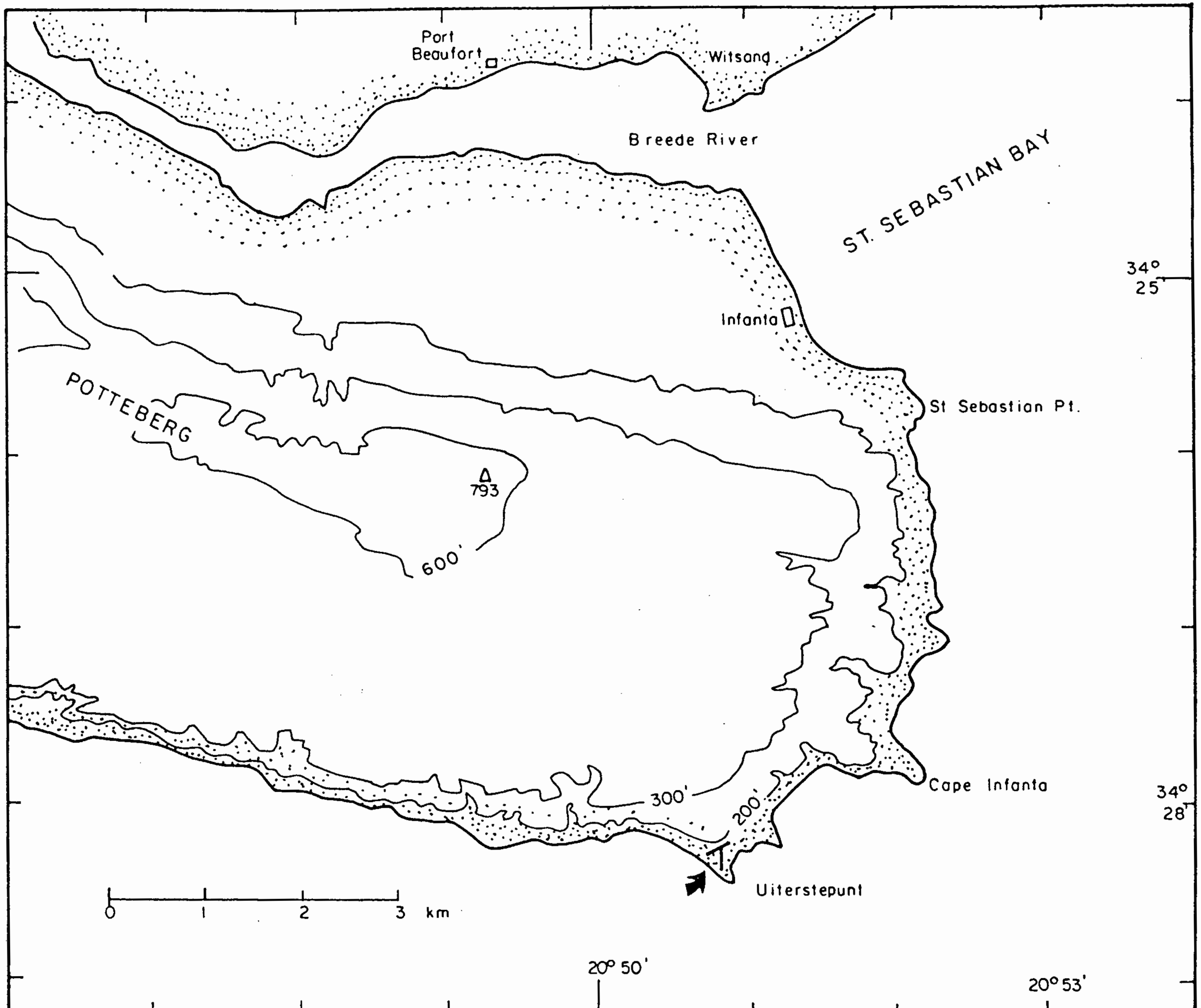

Fig. 1.2 Location map for the automatic weather station near Cape Infanta. Note that contour heights are in **feet**.

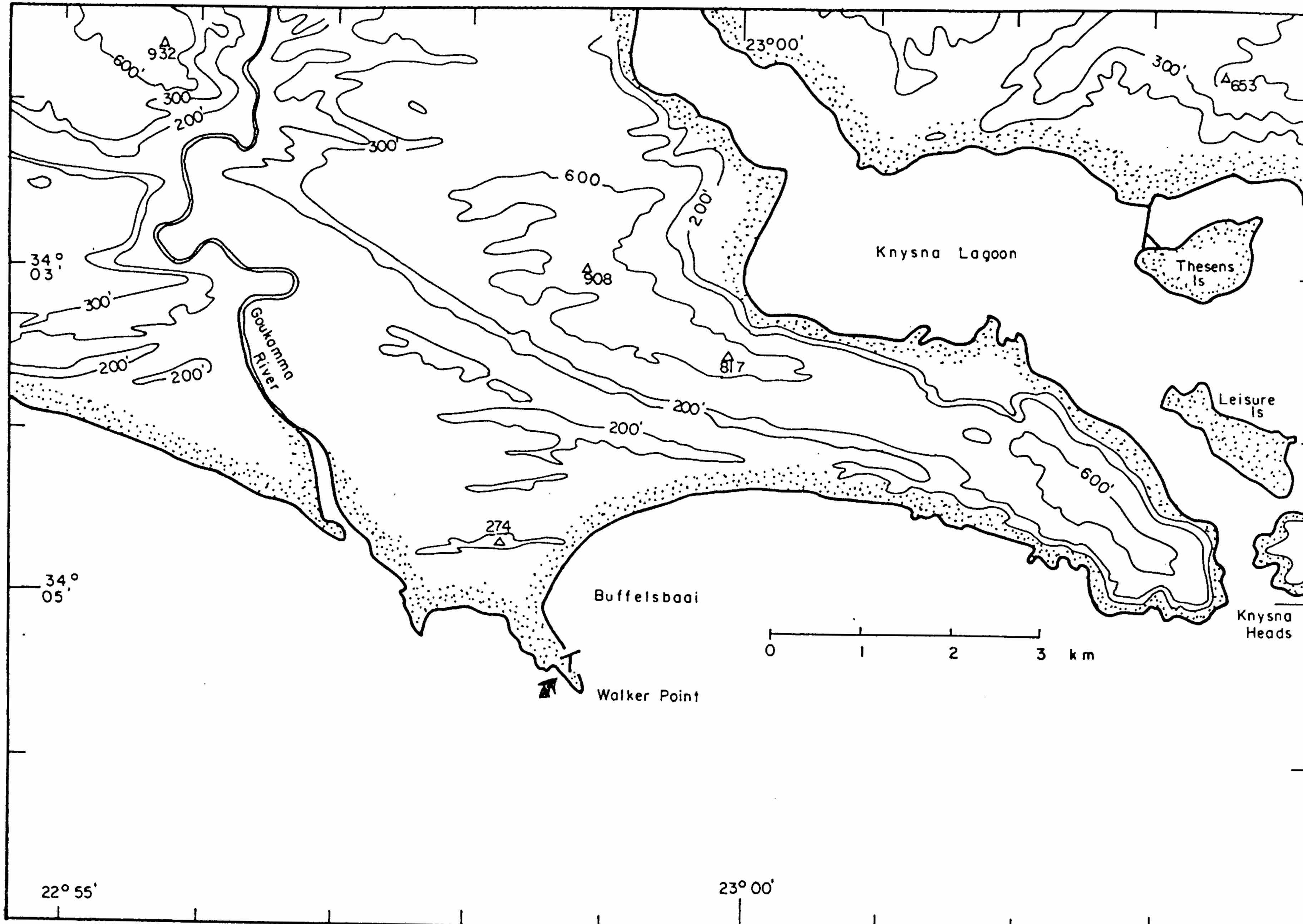

Fig. 1.3 Location map for the automatic weather station at Walker Pt. Note that contour heights are in feet.

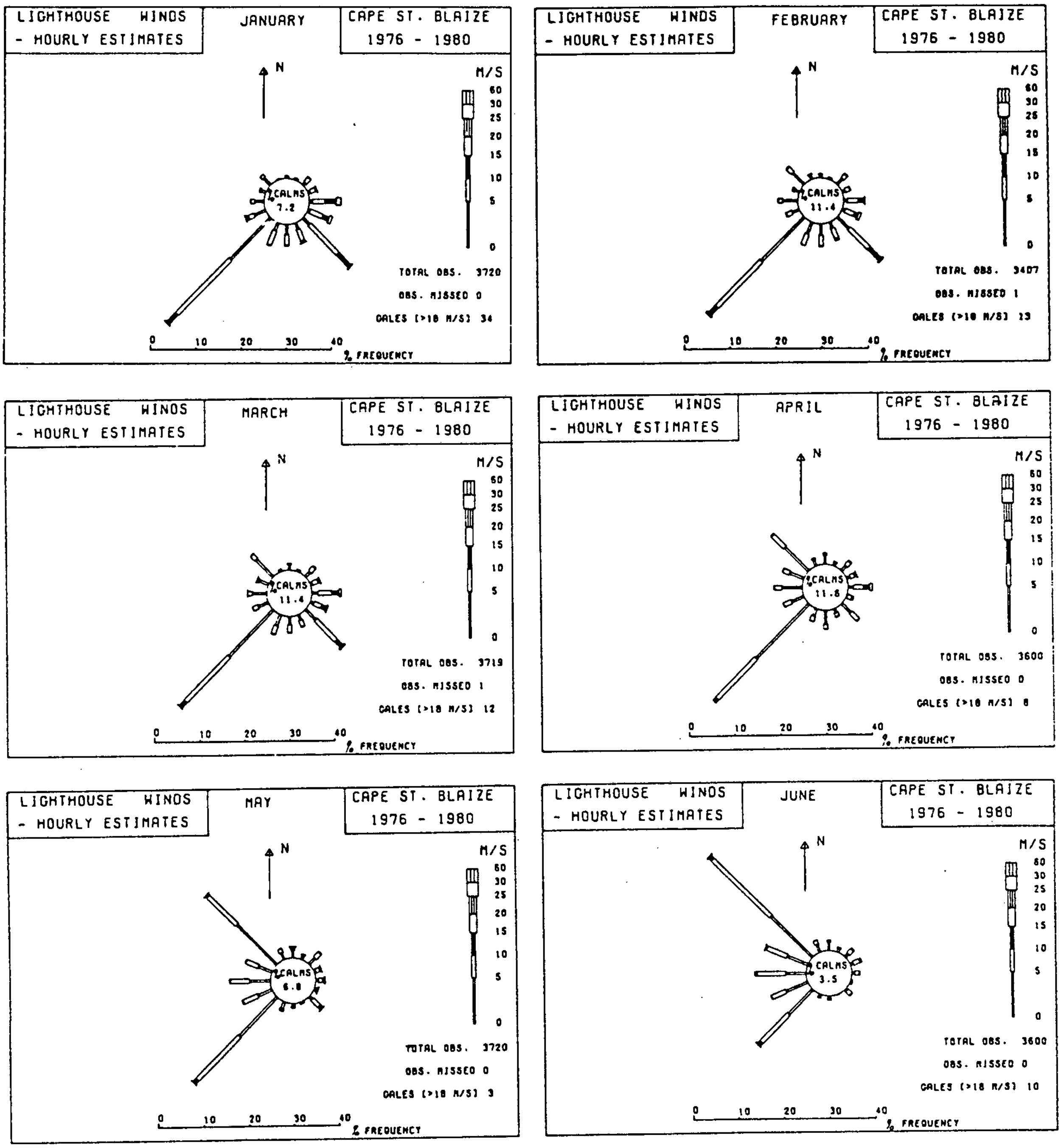

Fig. 2.1 Mean monthly wind roses for Cape St. Blaize based on hourly estimates from 1976 to 1980. January to June.

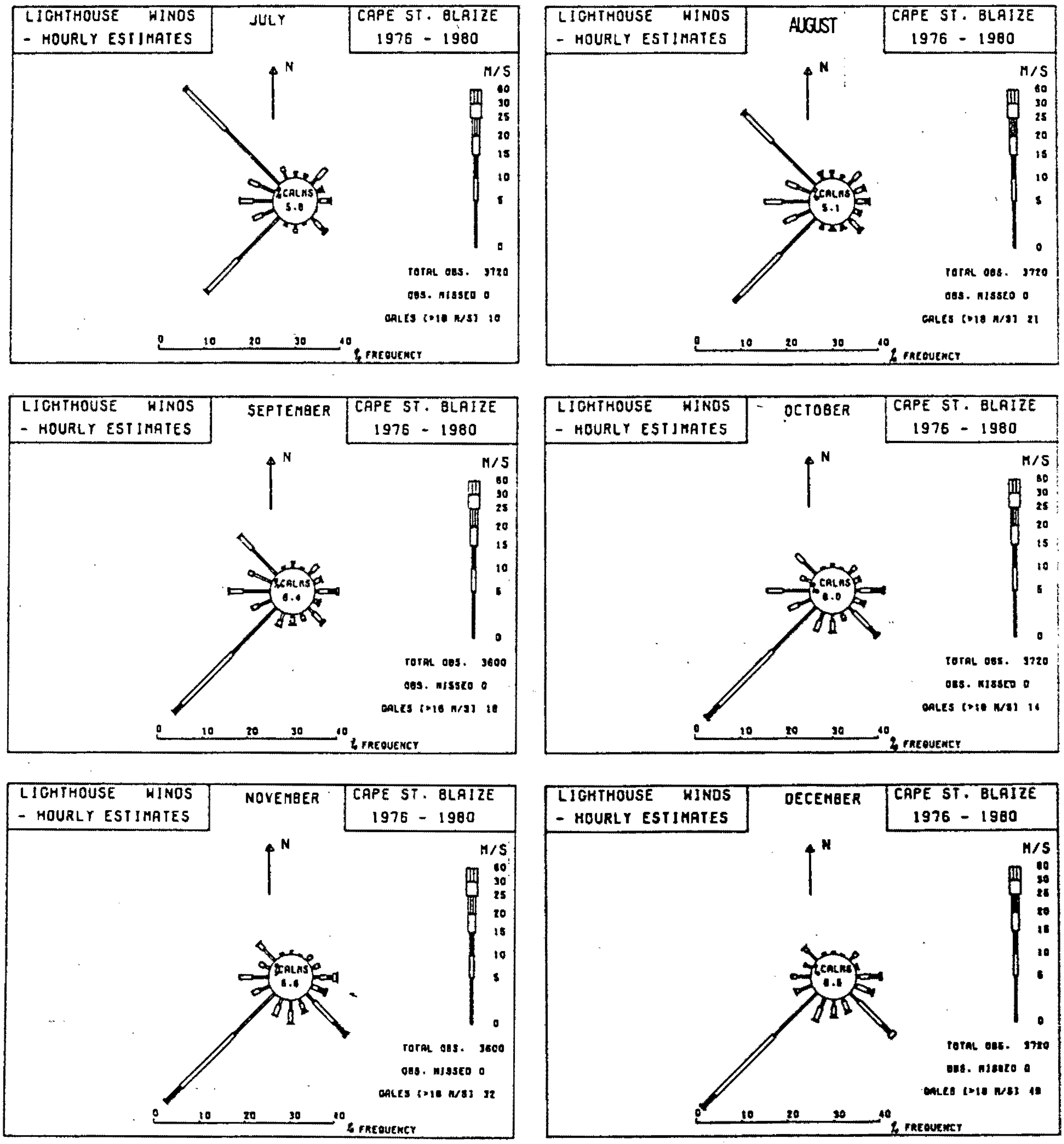

Fig. 2.2 Mean monthly wind roses for Cape St. Blaize based on hourly estimates from 1976 to 1980. July to December.

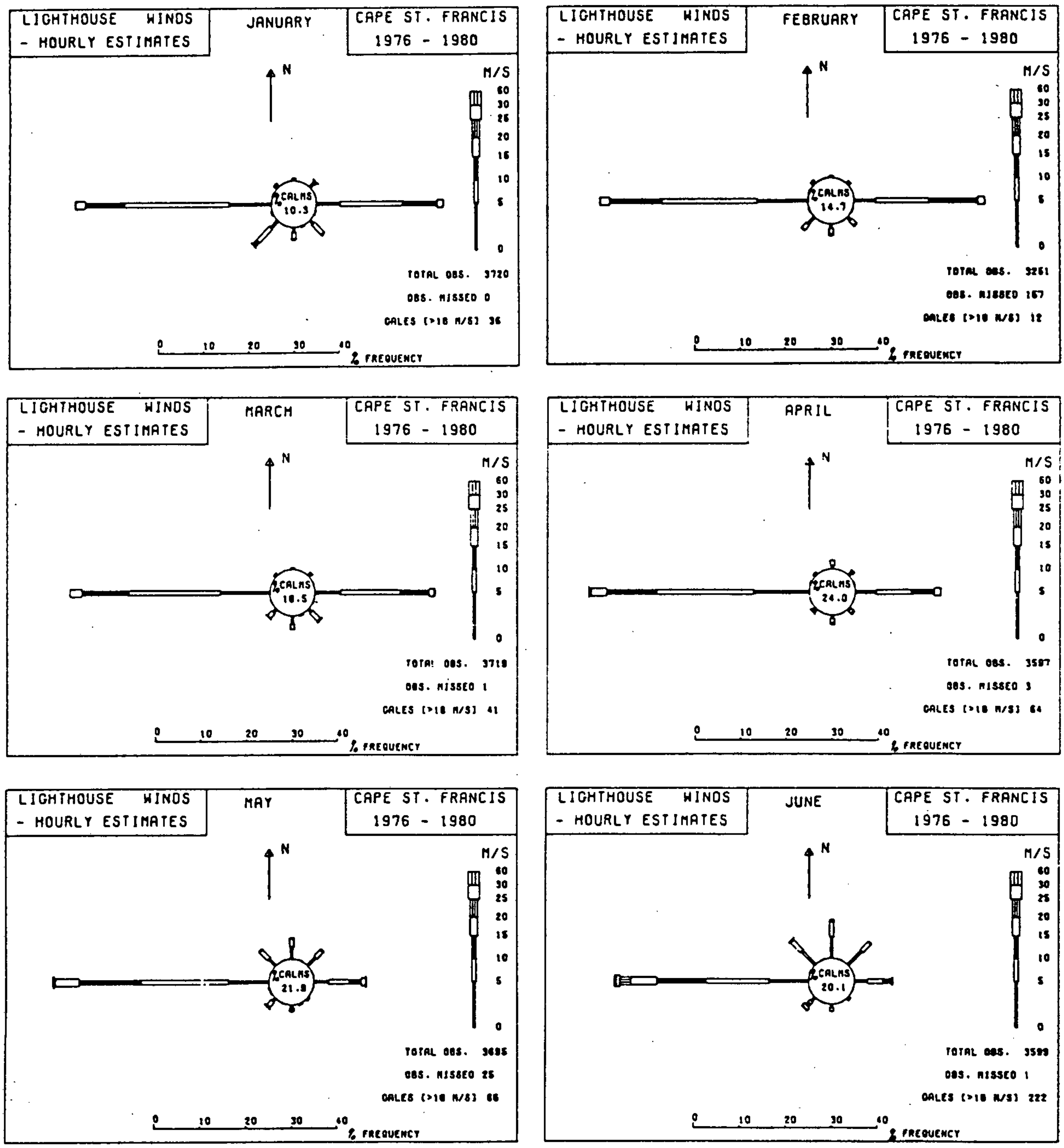

Fig. 2.3 Mean monthly wind roses for Cape St. Francis based on hourly estimates from 1976 to 1980. January to June.

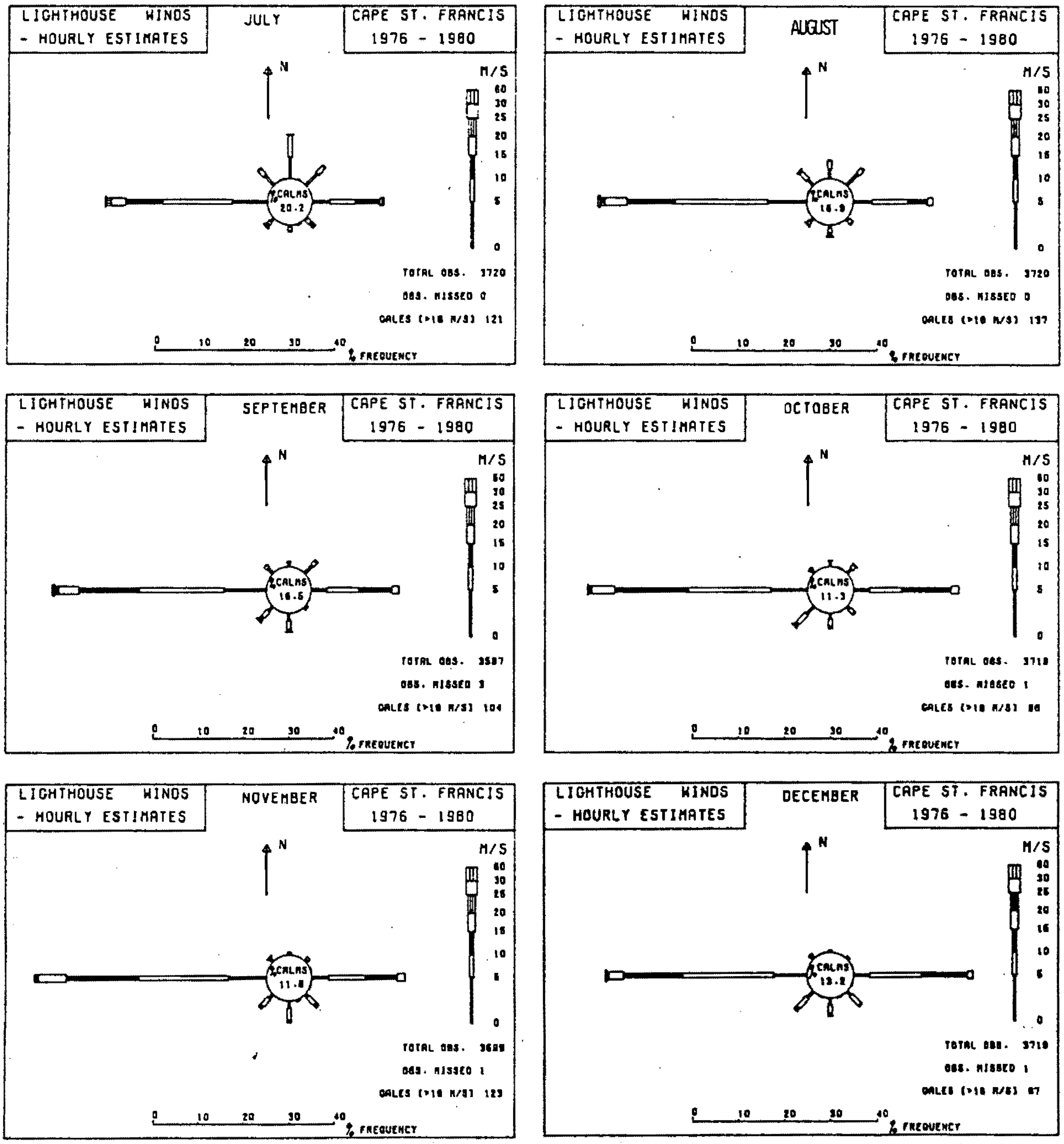

Fig. 2.4 Mean monthly wind roses for Cape St. Francis based on hourly estimates from 1976 to 1980. July to December.

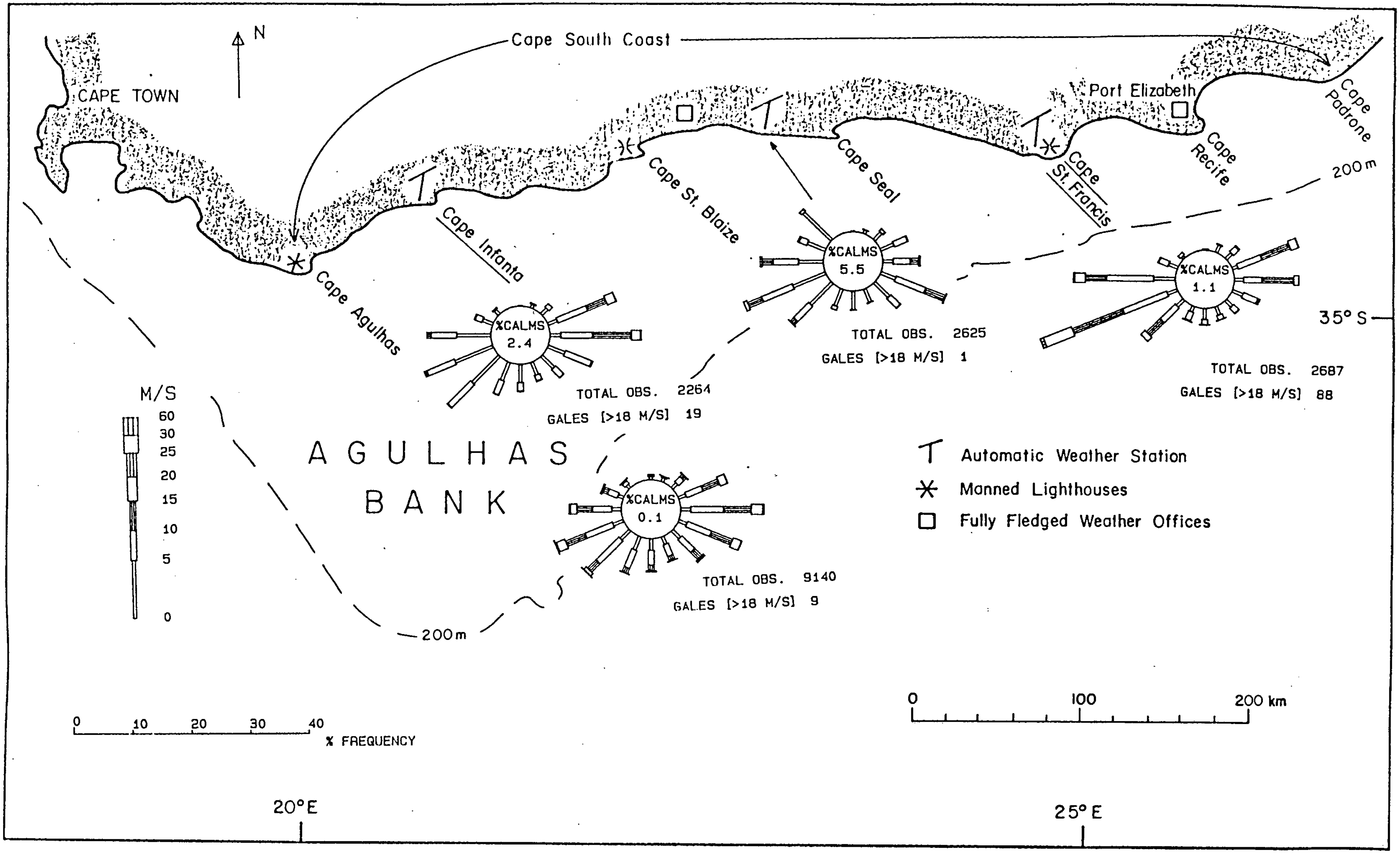

Fig. 2.5 Seasonal wind roses based on hourly AWS measurements 1982/1983 - **Summer** (December, January, February).

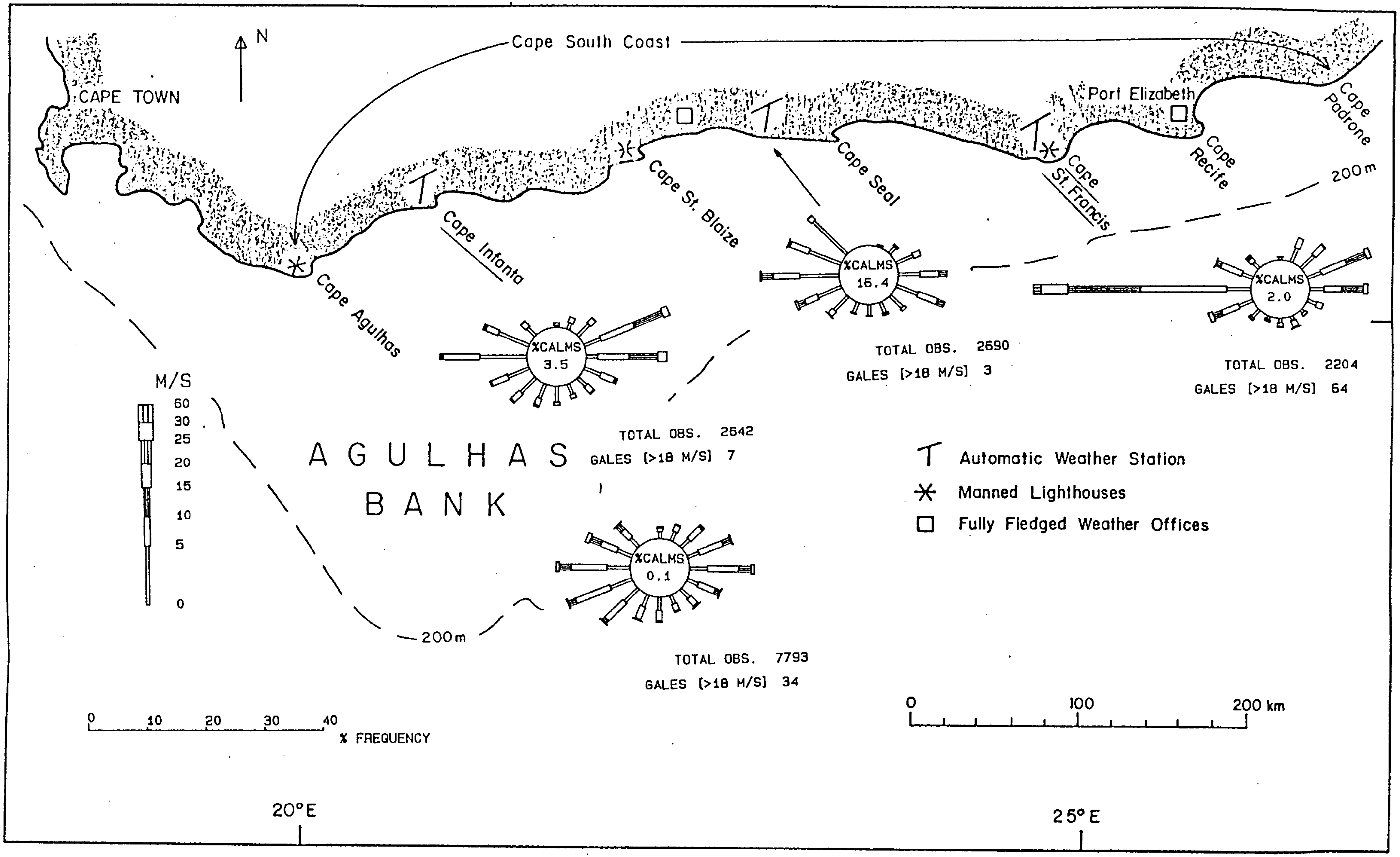

Fig. 2.6 Seasonal wind roses based on hourly AWS measurements 1982/1983 - **Autumn** (March, April, May).

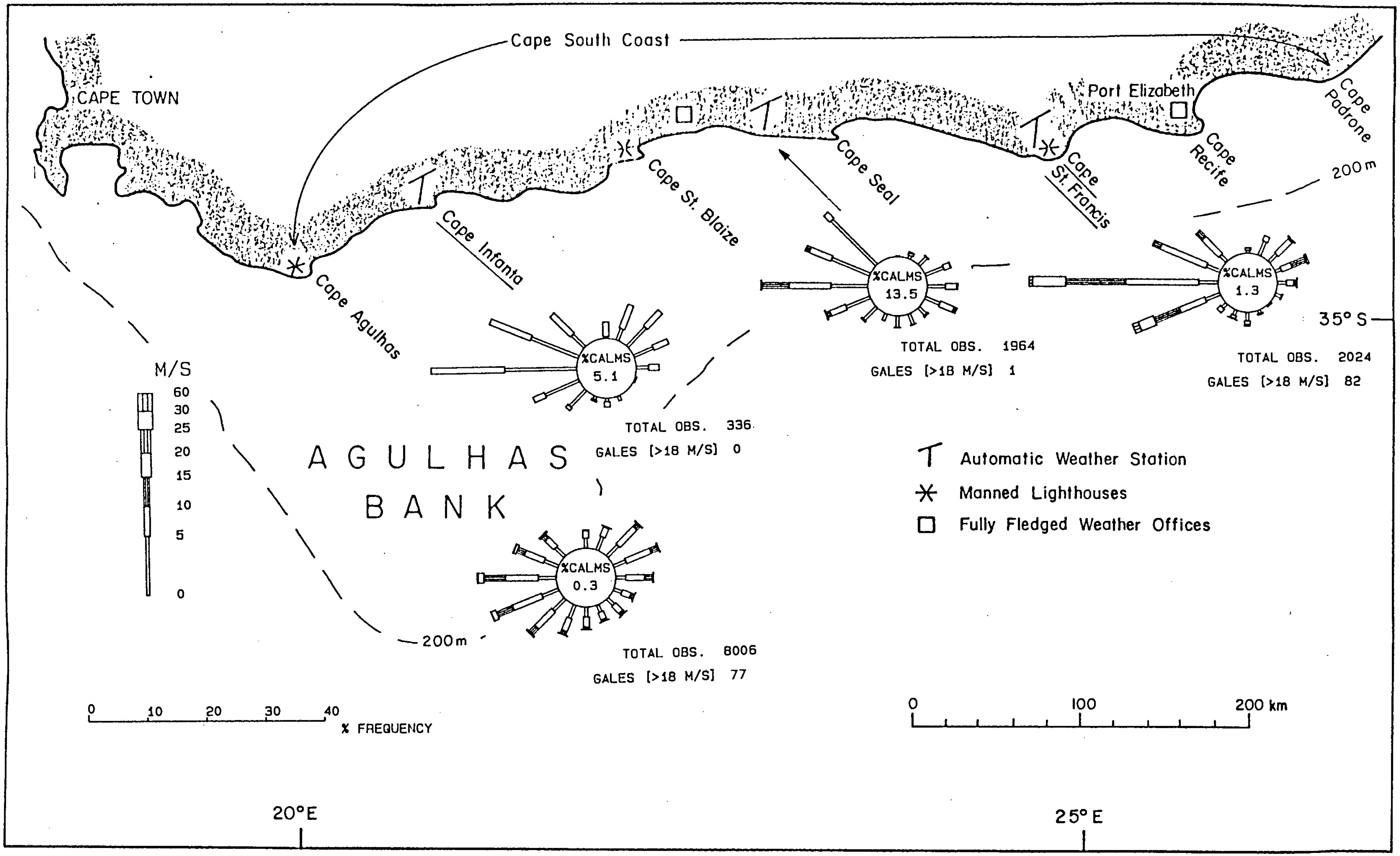

Fig. 2.7 Seasonal wind roses based on hourly AWS measurements 1982/1983 - **Winter** (June, July, August).

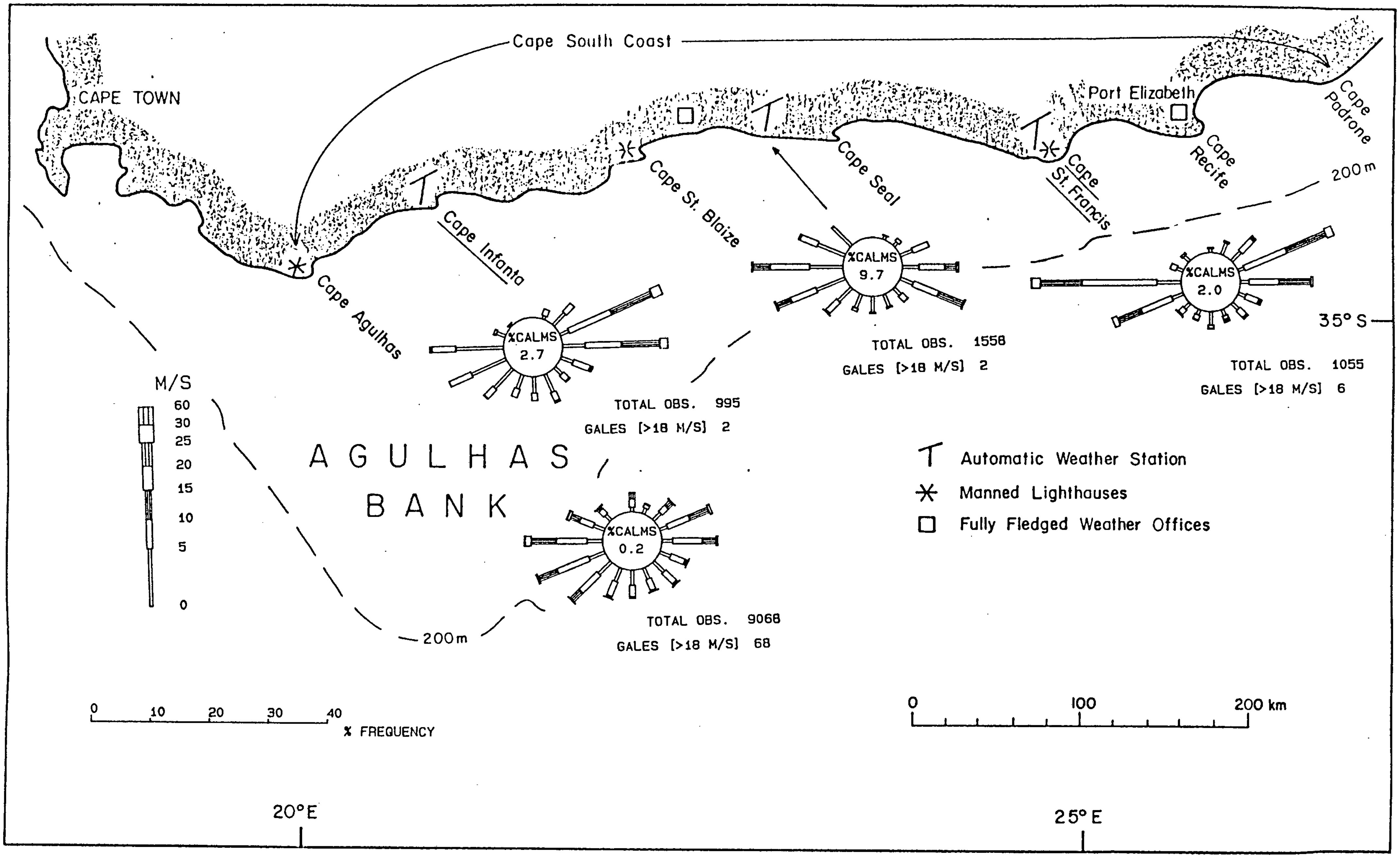

Fig. 2.8 Seasonal wind roses based on hourly AWS measurements 1982/1983 - **Spring** (September, October, November).

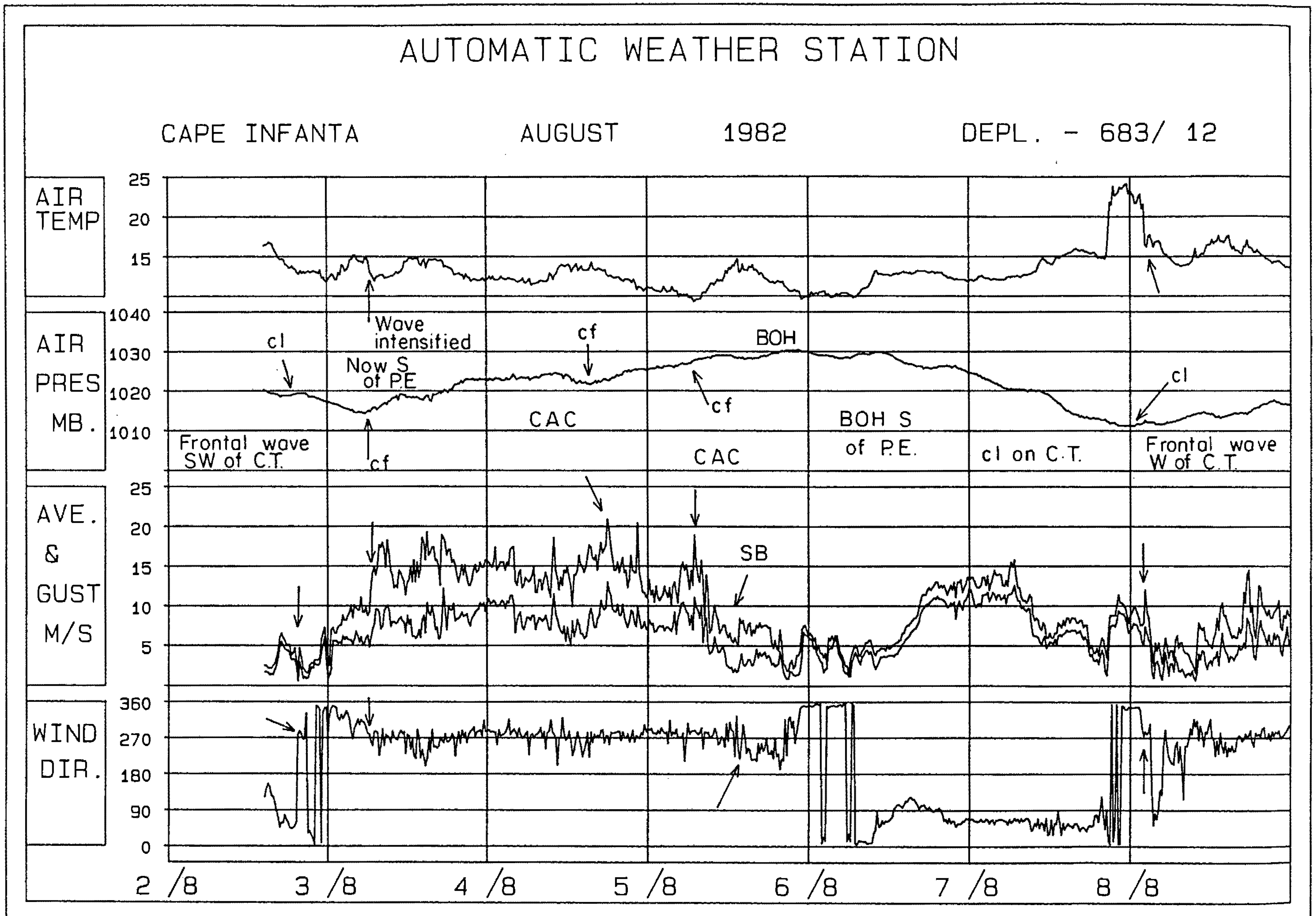

Fig. 3.1.1 Basic cycle in winter - Cape Infanta.

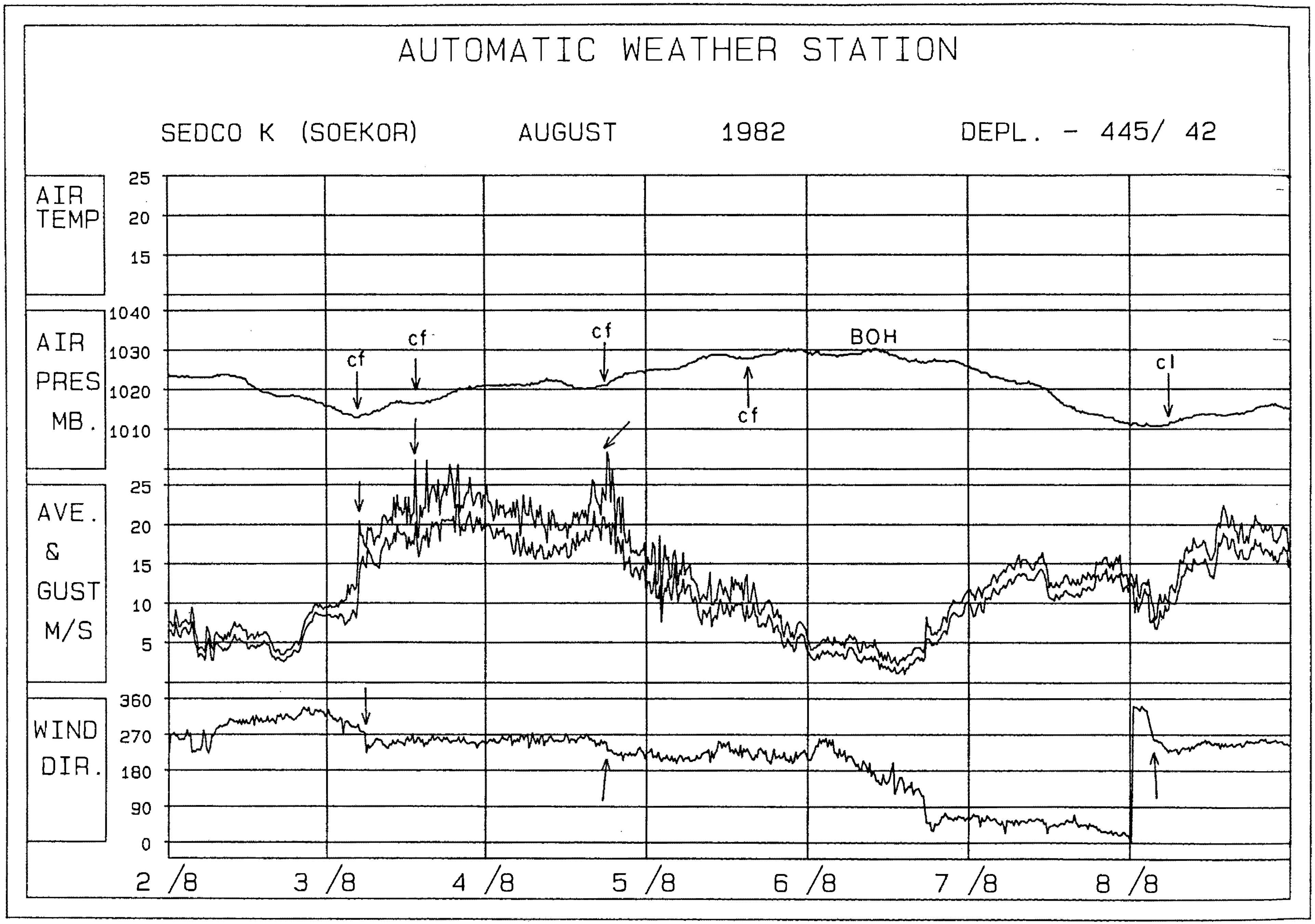

Fig. 3.1.2 Basic cycle in winter - Sedco-K.

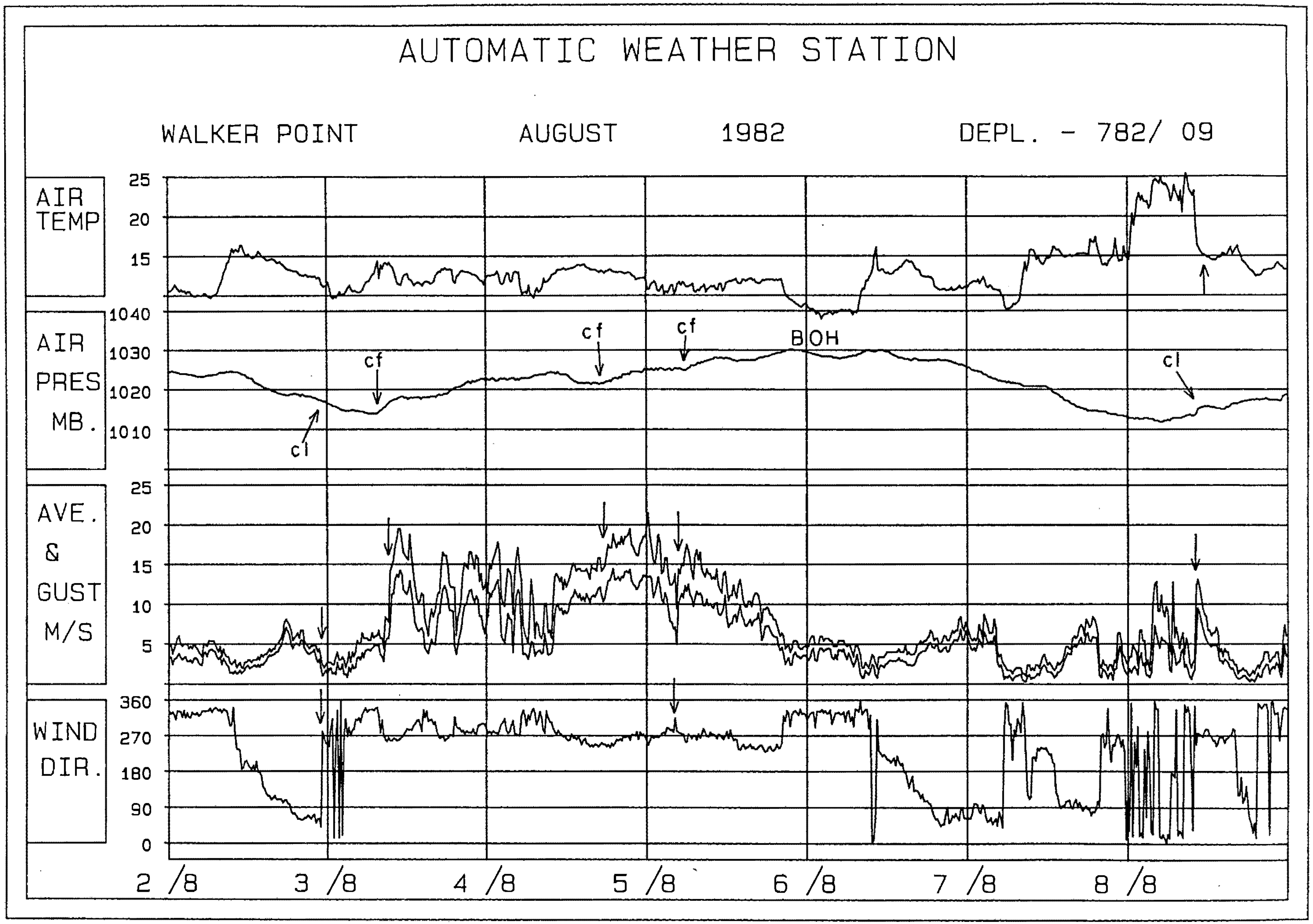

Fig. 3.1.3 Basic cycle in winter - Walker Point.

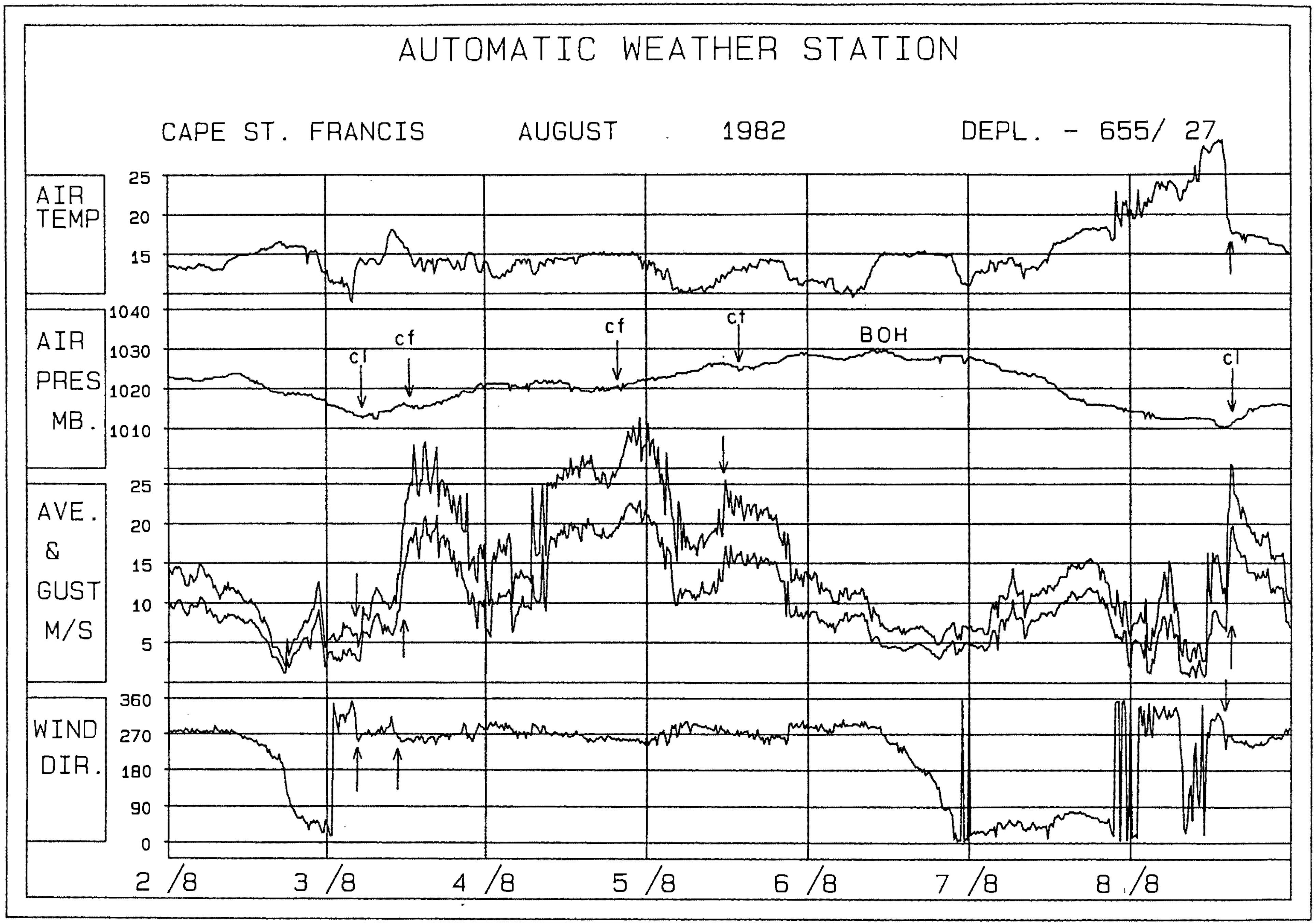

Fig. 3.1.4 Basic cycle in winter - Cape St. Francis.

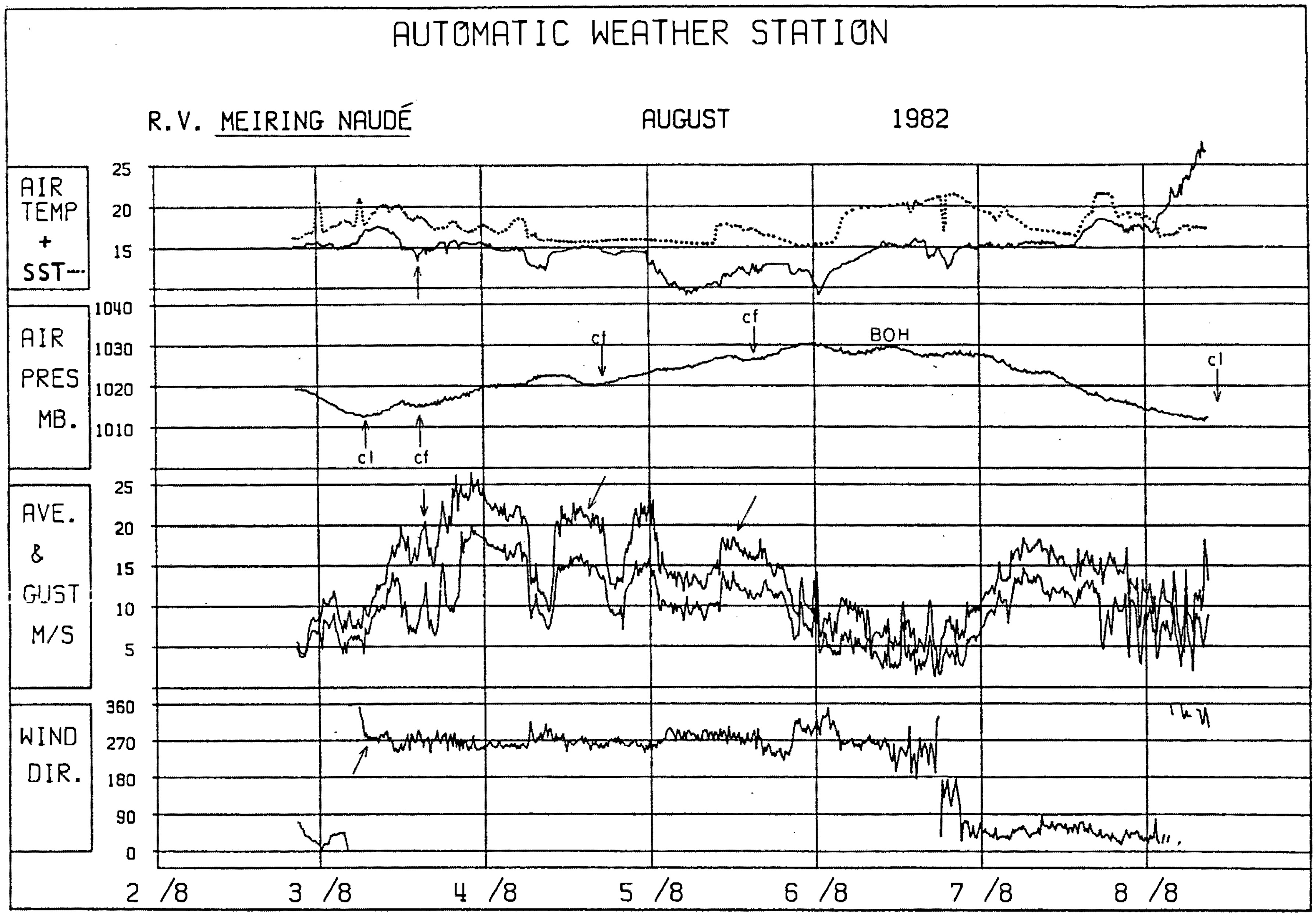

Fig. 3.1.5 Basic cycle in winter - *Meiring Naudé*.

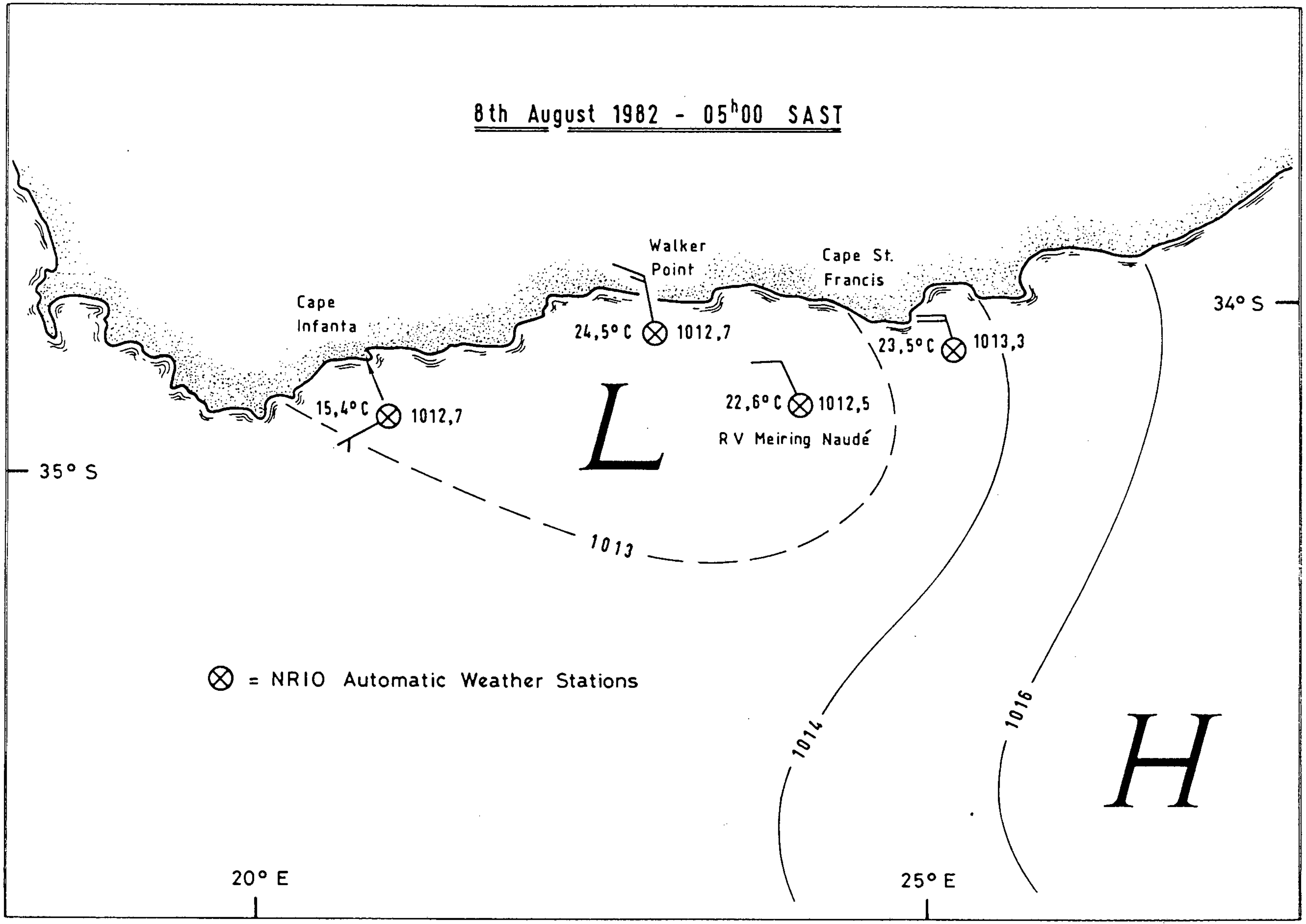

Fig. 3.1.6 Sea-level pressure analysis associated with pre-coastal low berg winds.

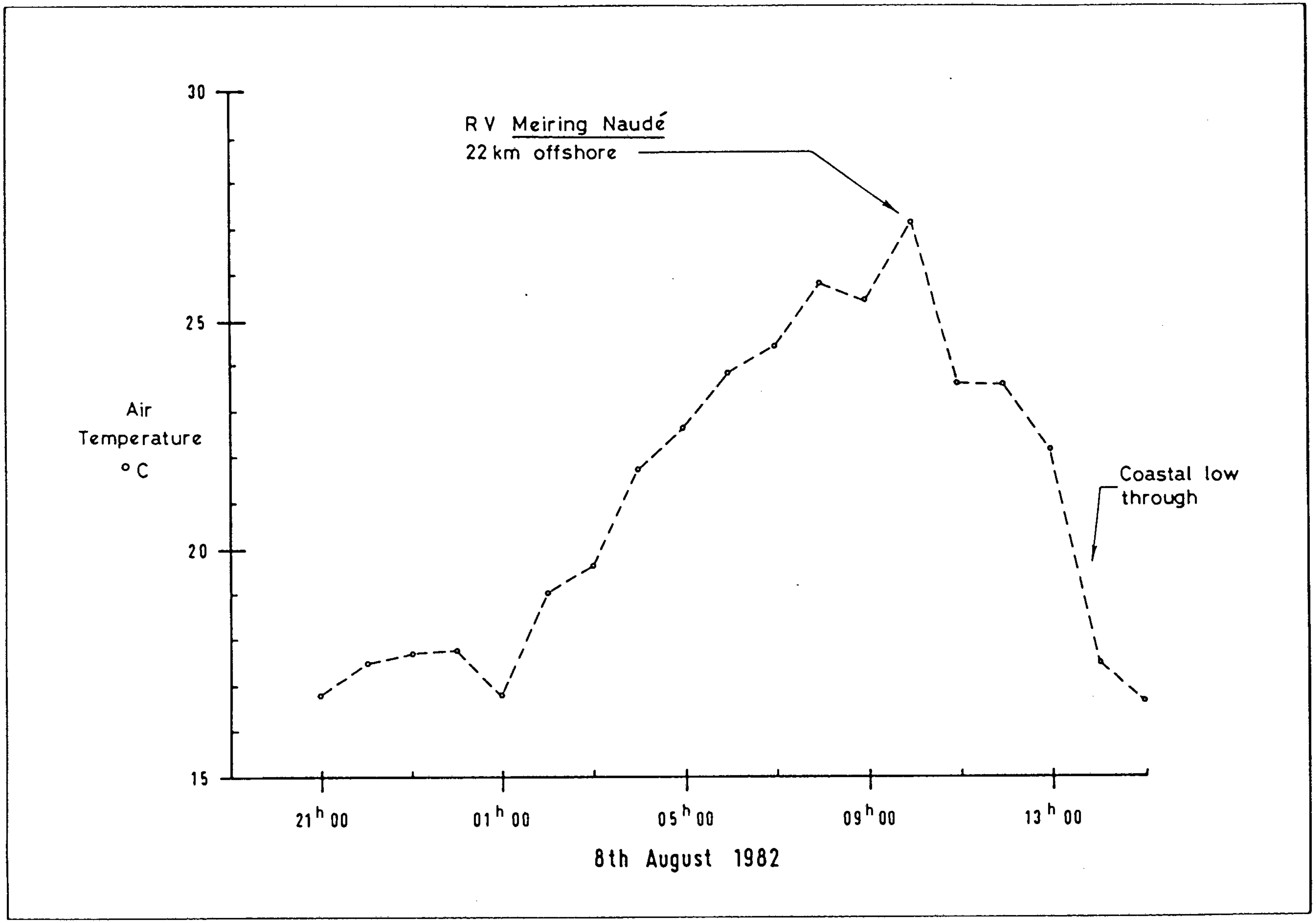

Fig. 3.1.7 Basic cycle in winter - extent of berg winds offshore.

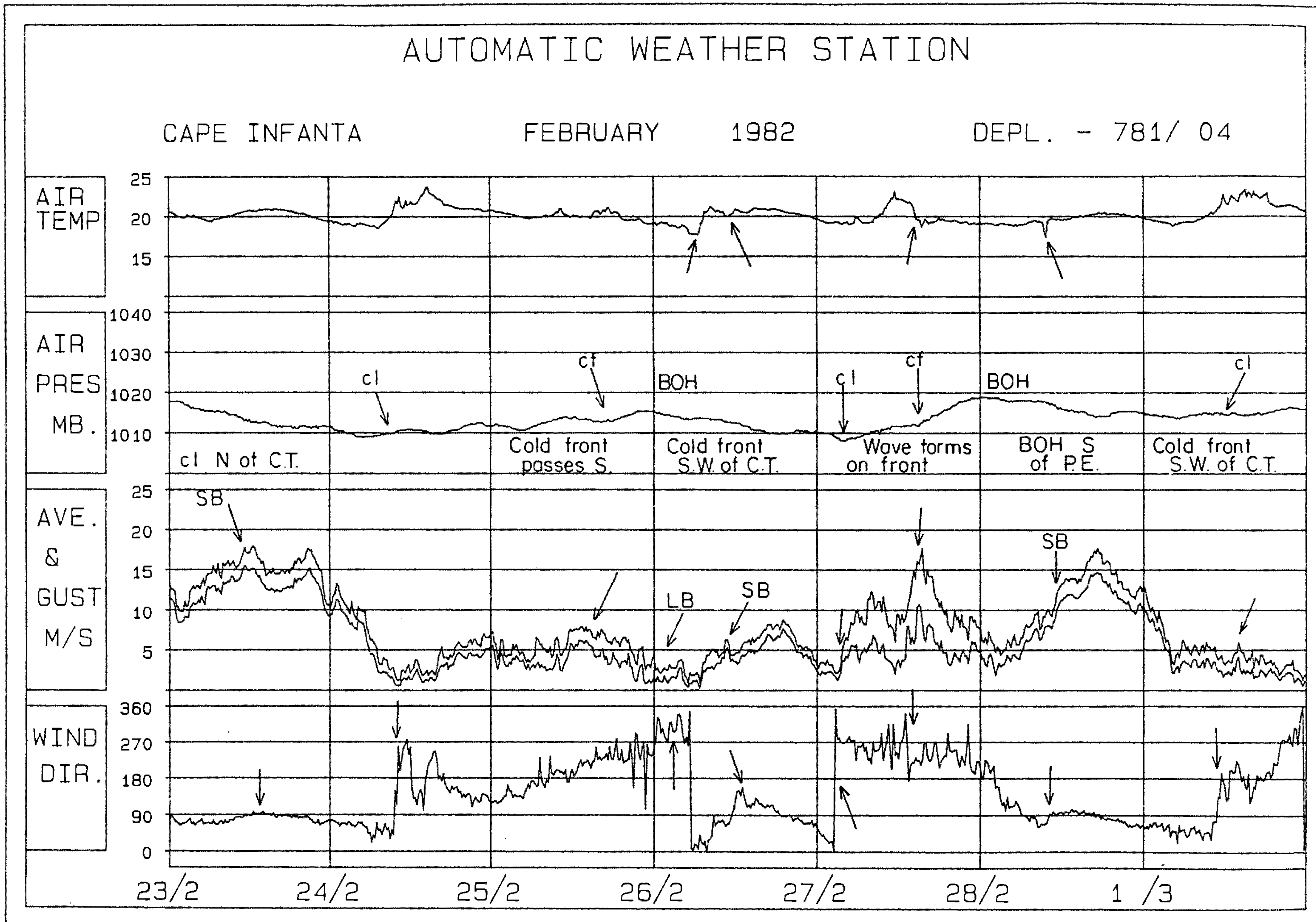

Fig. 3.2.1 Basic cycle in summer - Cape Infanta.

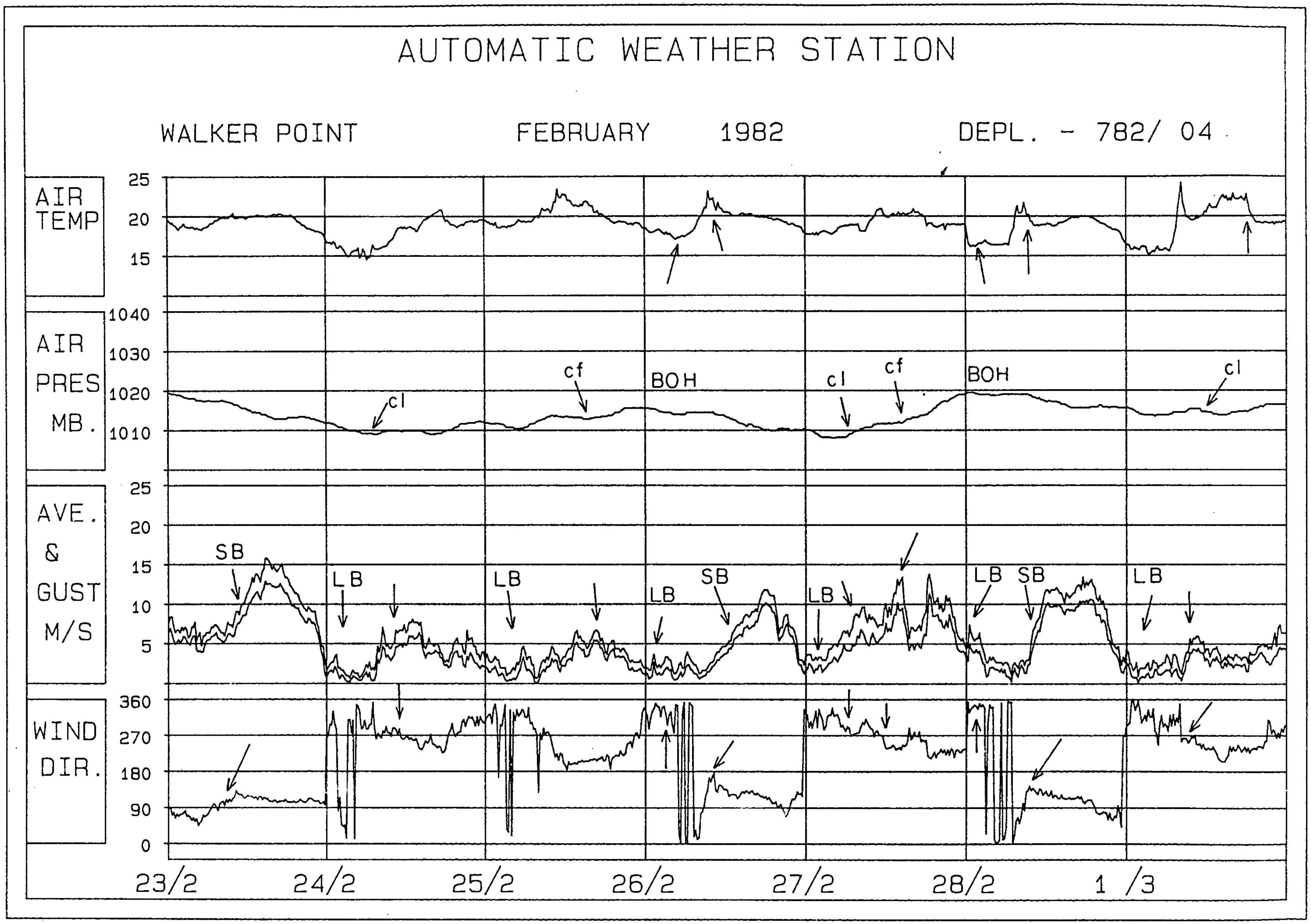

Fig. 3.2.2 Basic cycle in summer - Walker Point.

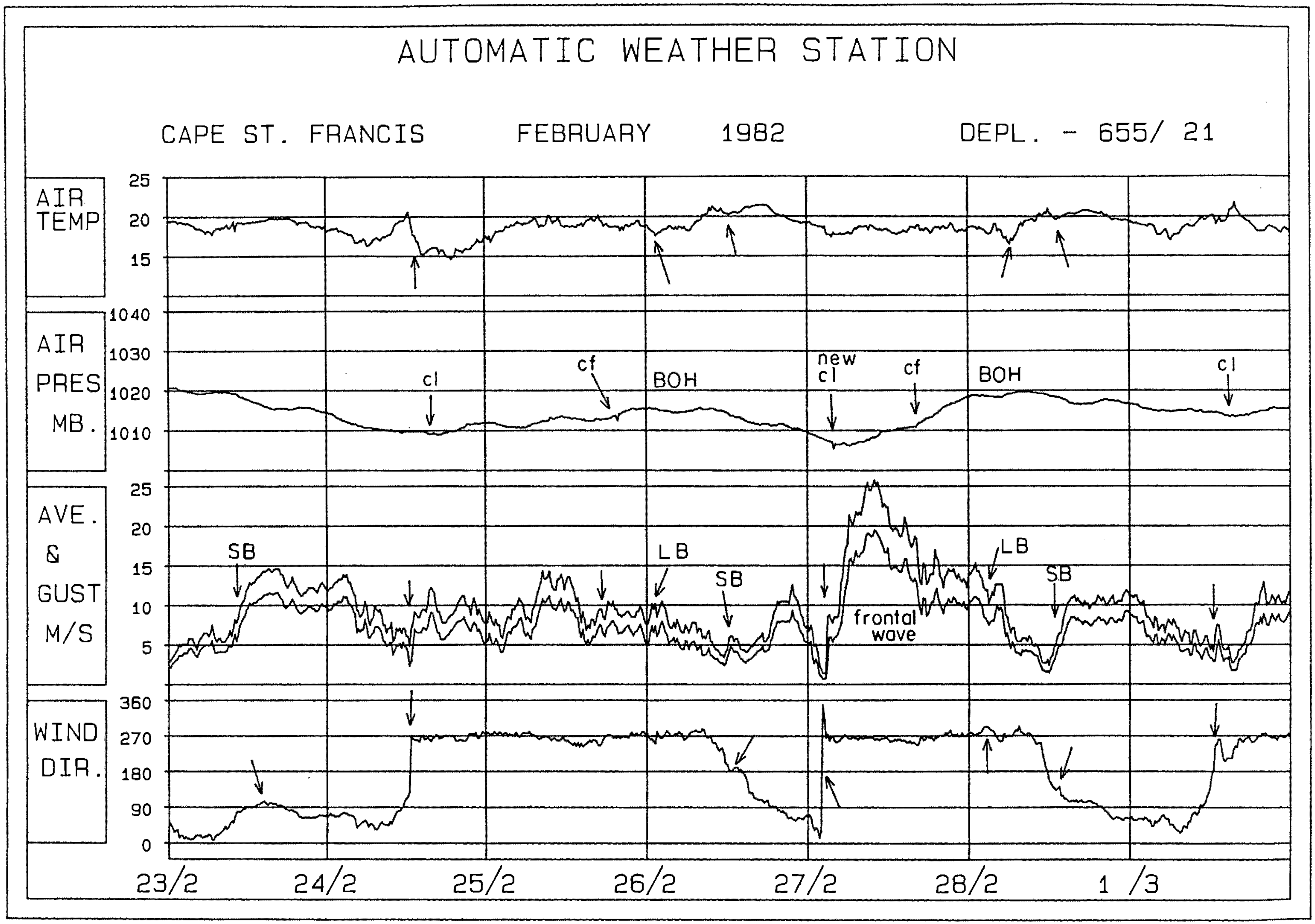

Fig. 3.2.3 Basic cycle in summer - Cape St. Francis.

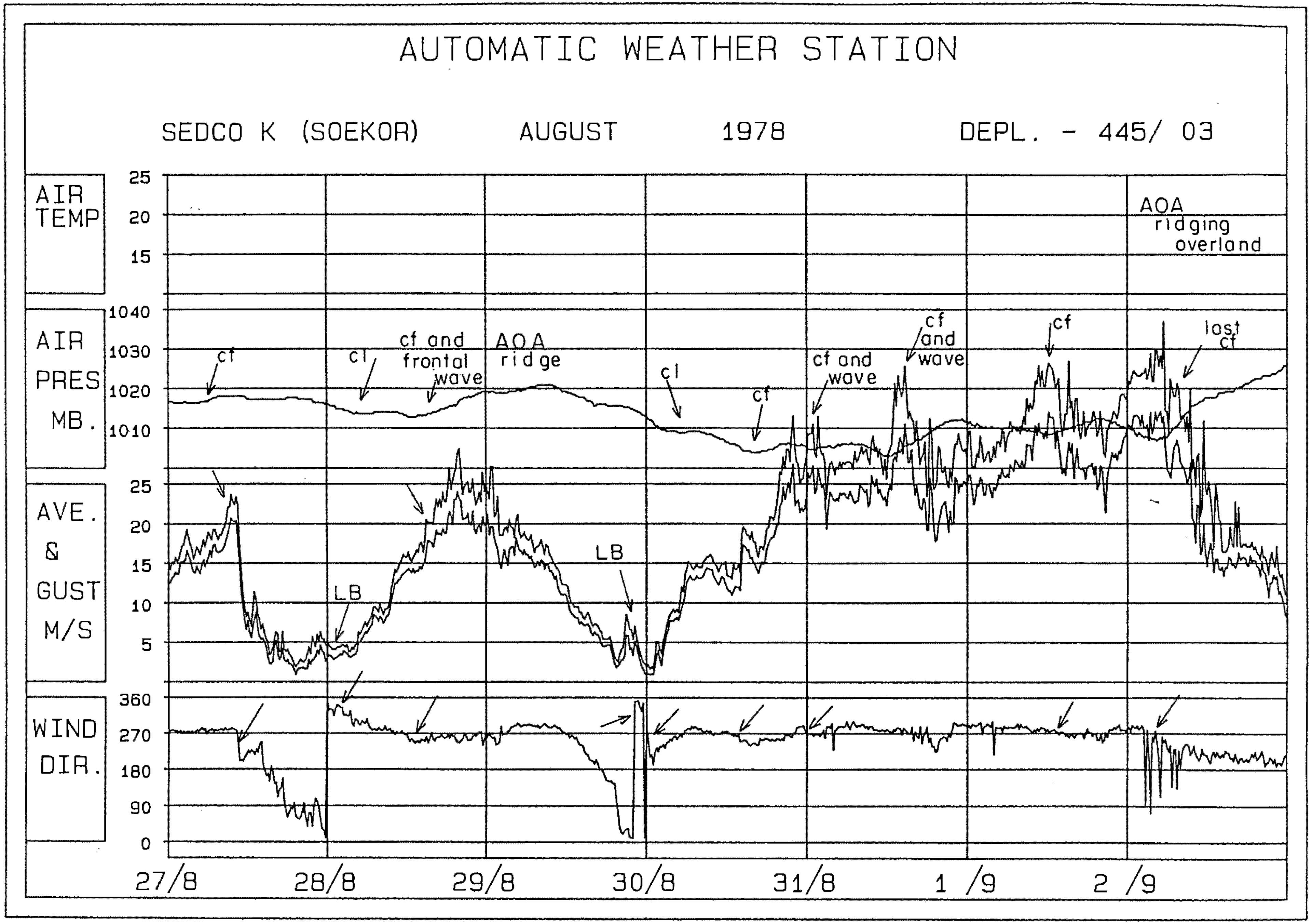

Fig. 3.3.1 Case Study No. 3 - Sedco-K.

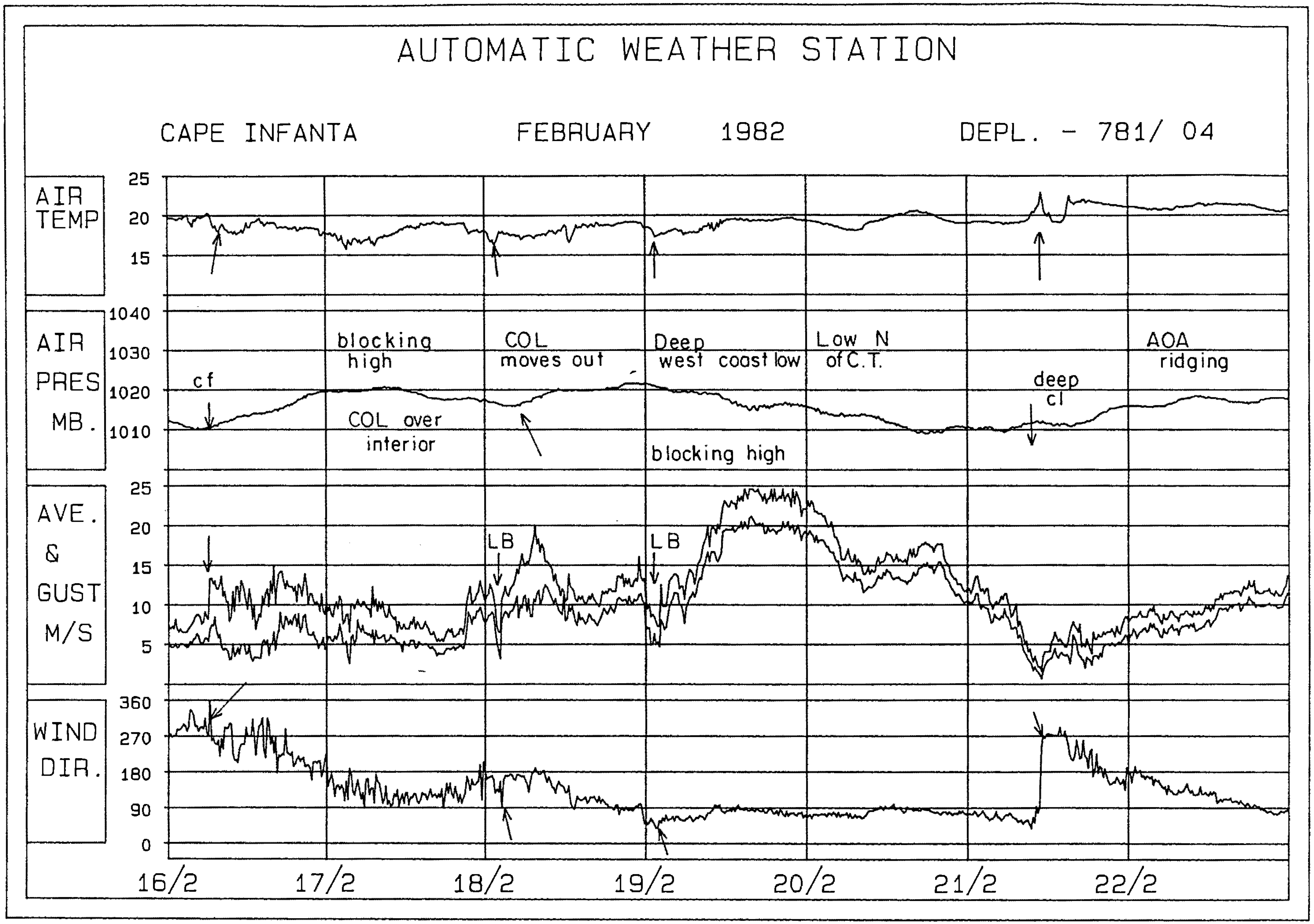

Fig. 3.4.1 Case Study No. 4 - Cape Infanta.

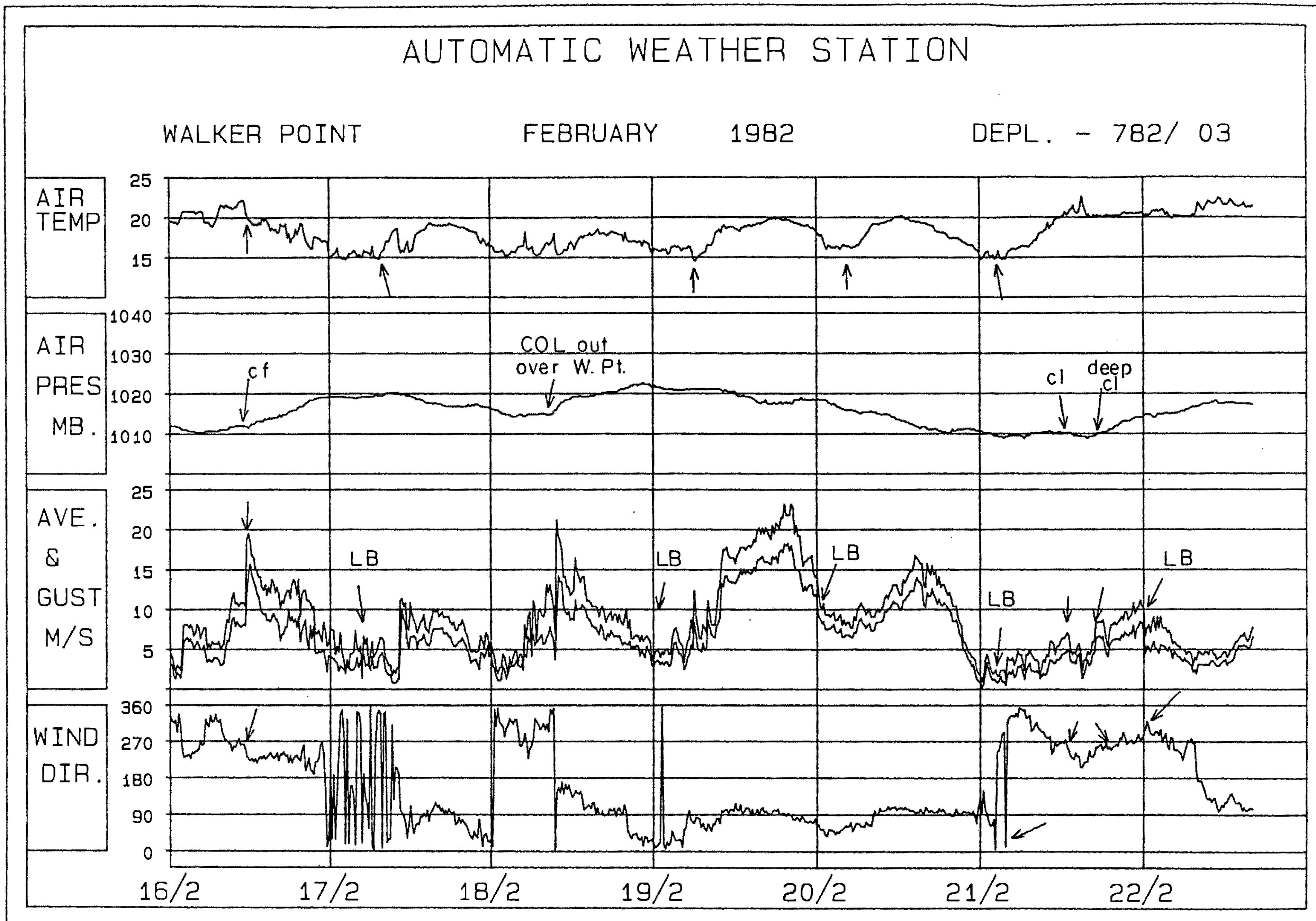

Fig. 3.4.2 Case Study No. 4 - Walker Point.

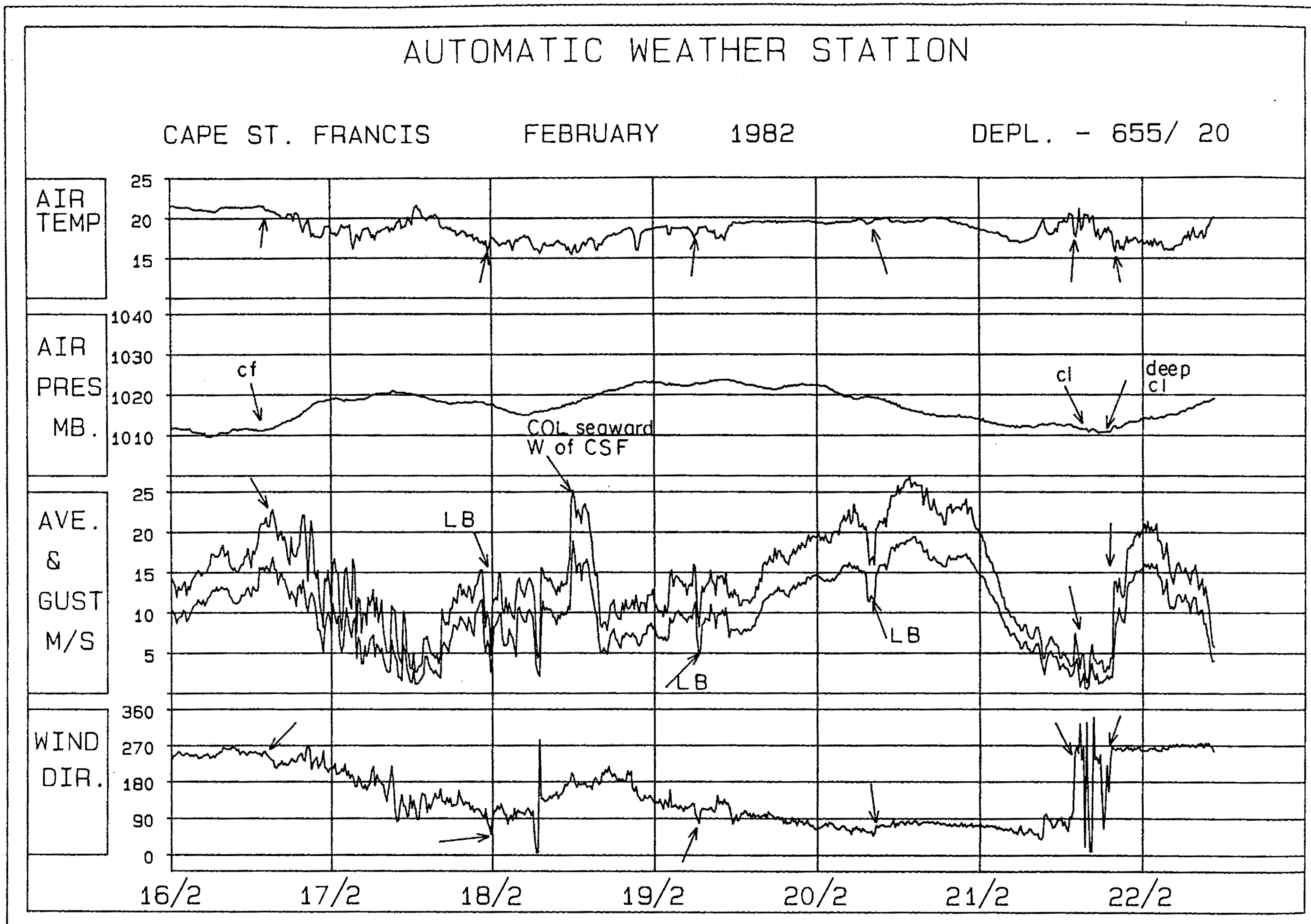

Fig. 3.4.3 Case Study No. 4 - Cape St. Francis.

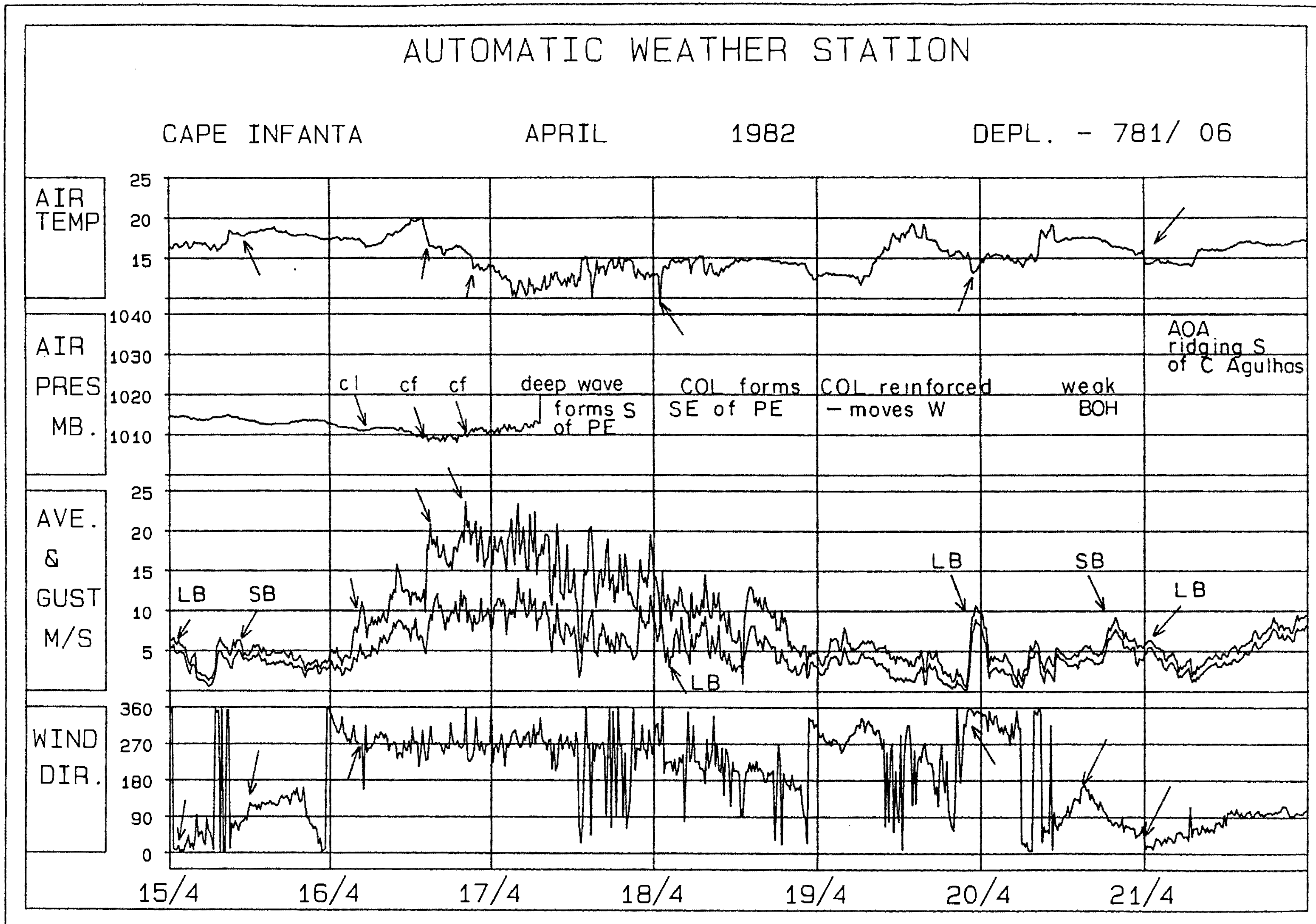

Fig. 3.5.1 Case Study No. 5 - Cape Infanta.

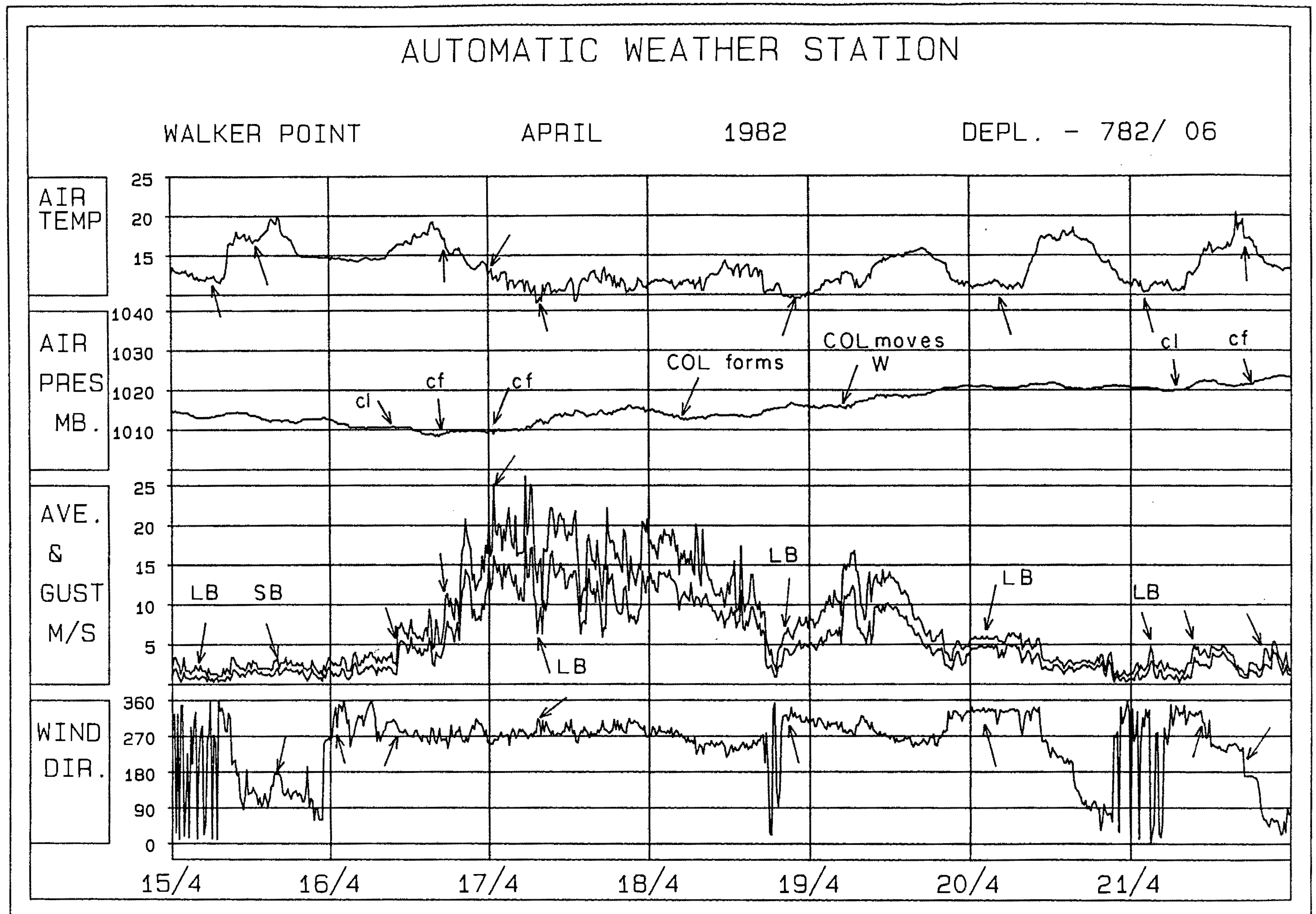

Fig. 3.5.2 Case Study No. 5 - Walker Point.

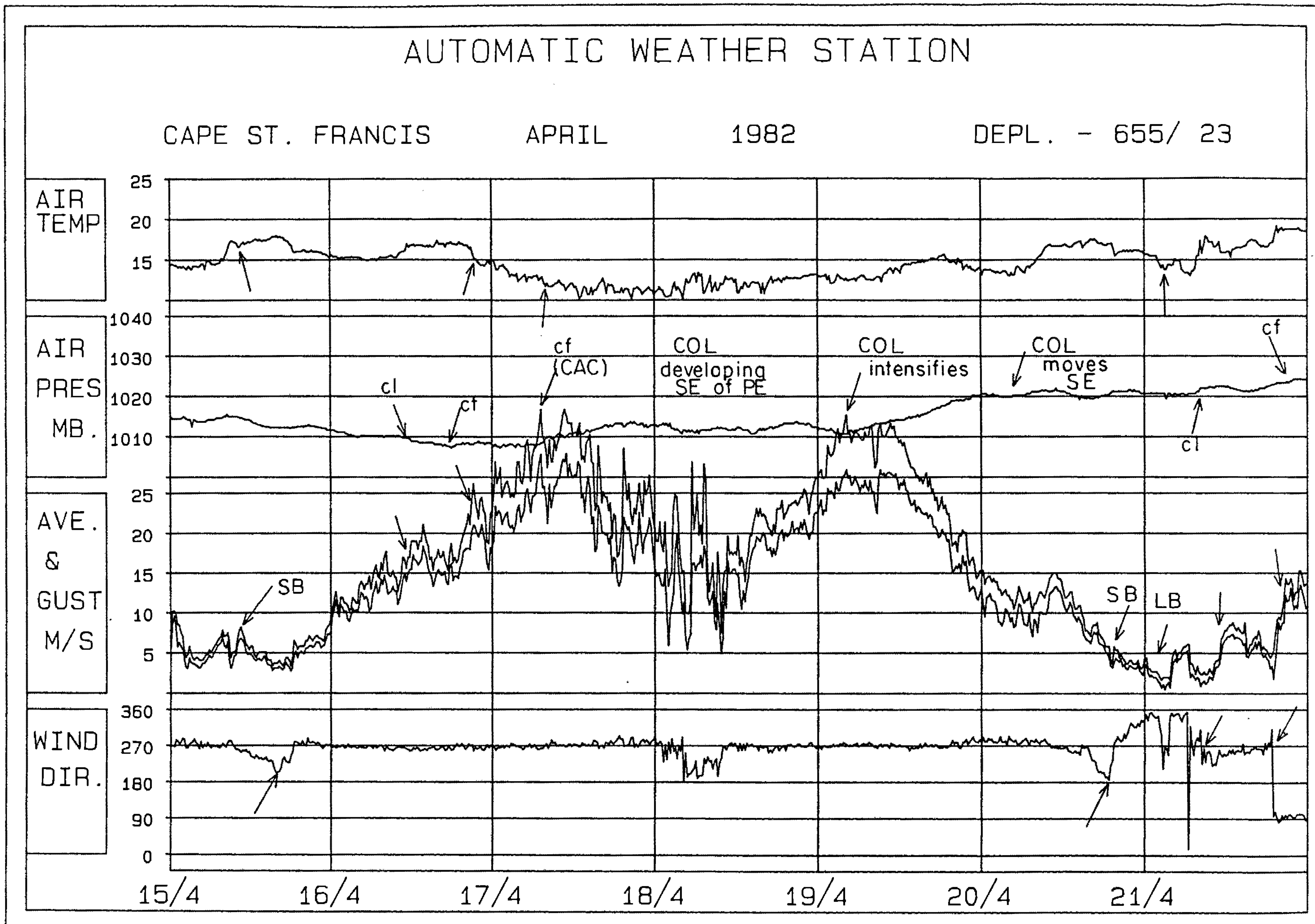

Fig. 3.5.3 Case Study No. 5 - Cape St. Francis.

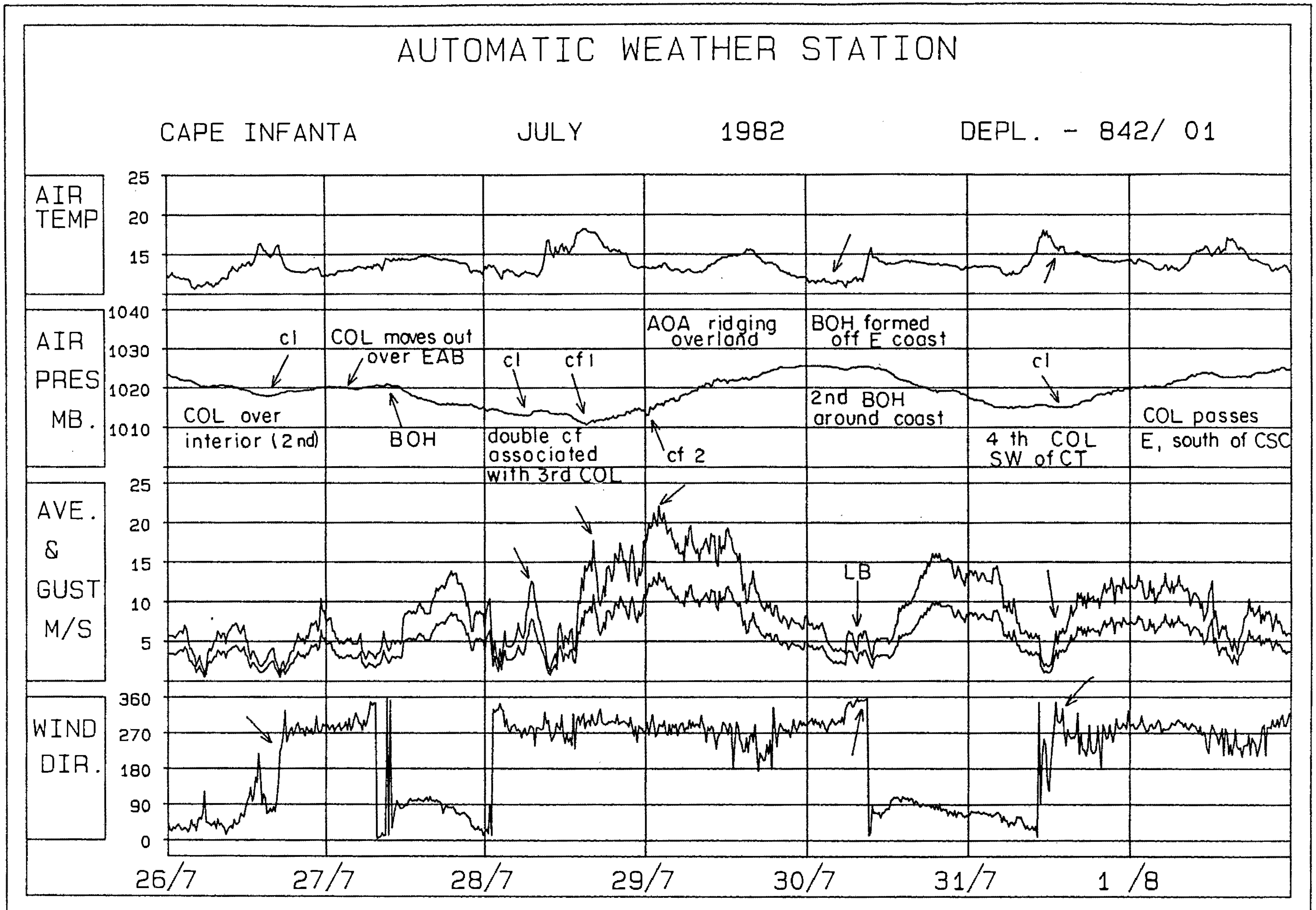

Fig. 3.6.1 Case Study No. 6 - Cape Infanta.

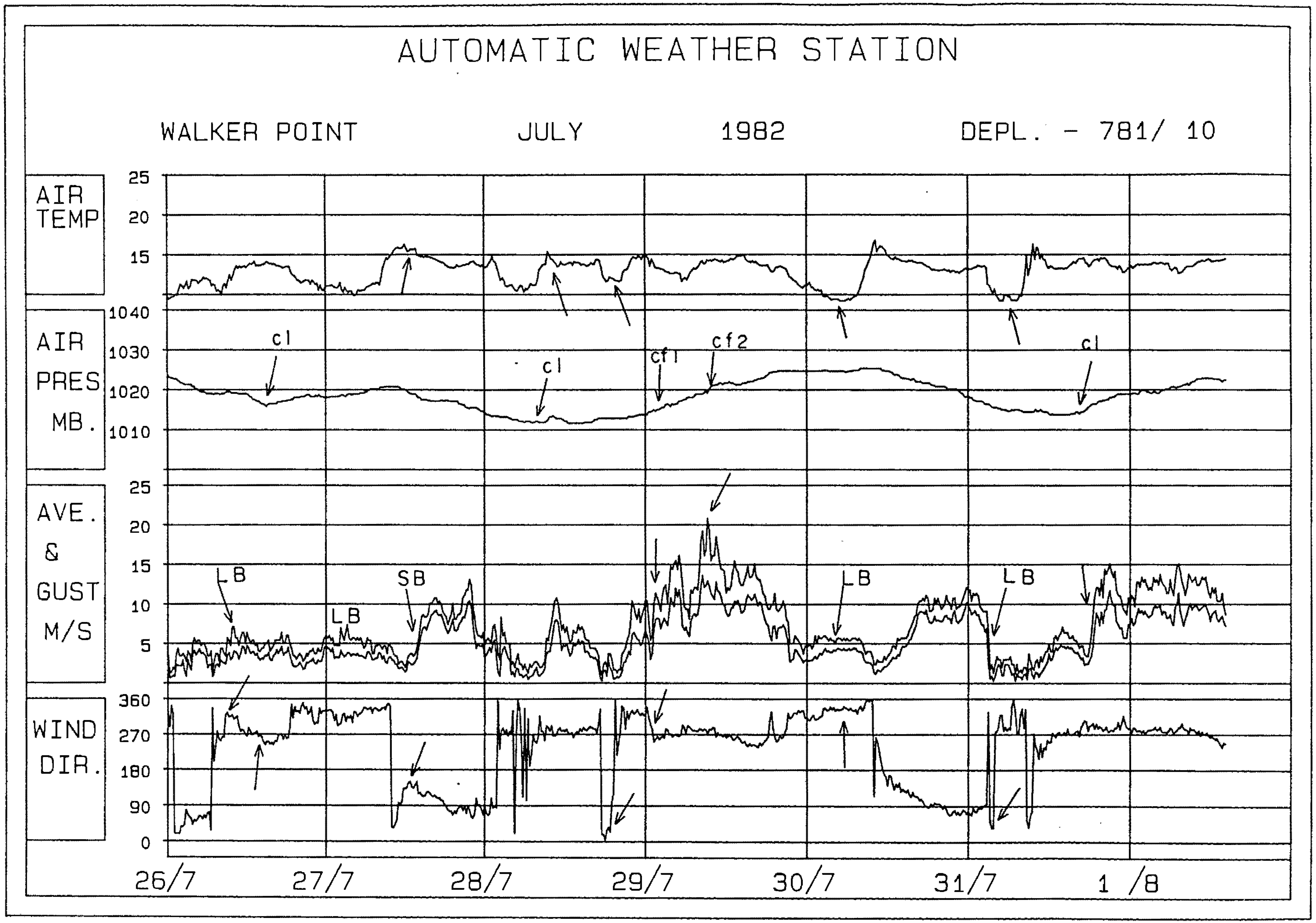

Fig. 3.6.2 Case Study No. 6 - Walker Point.

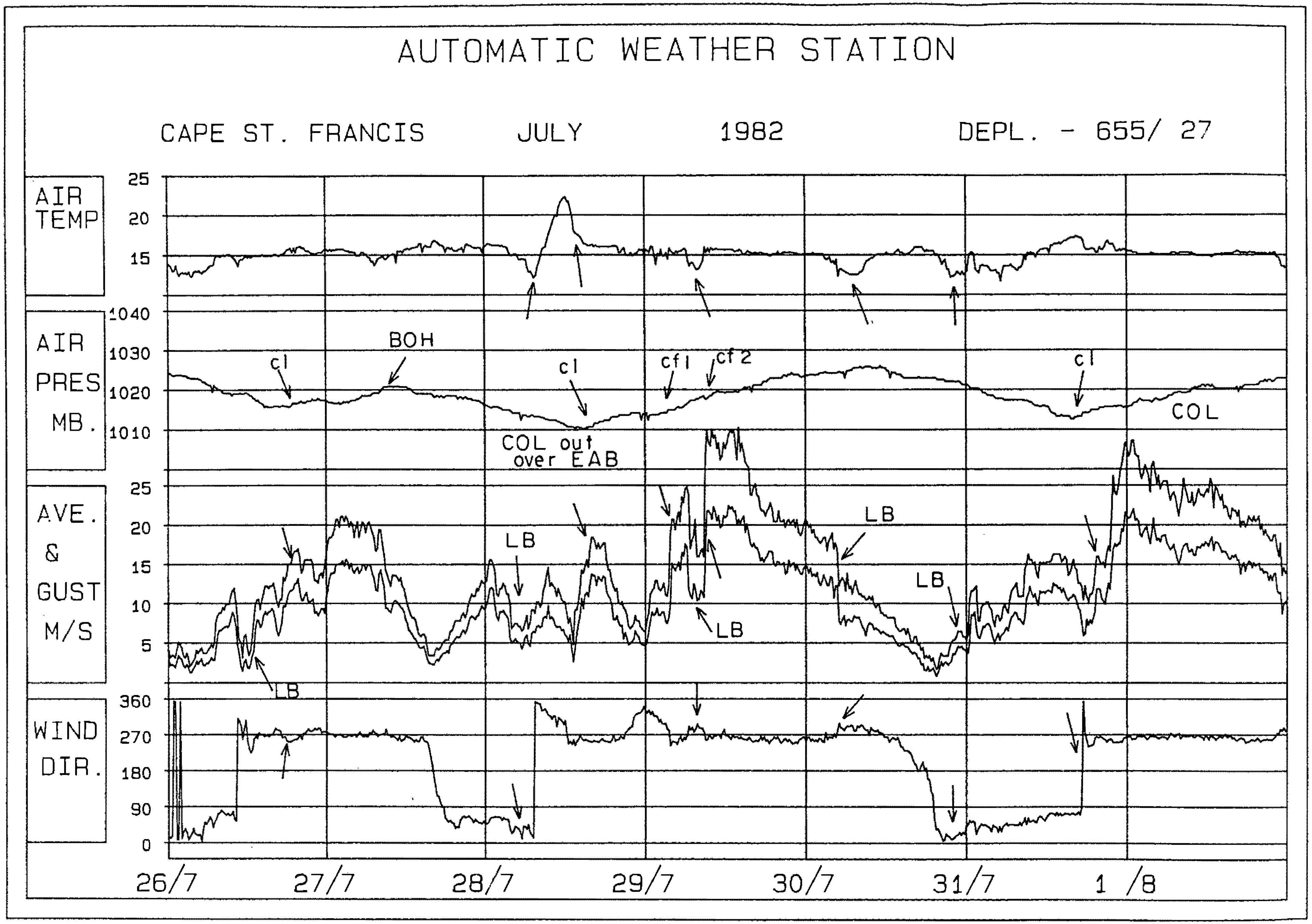

Fig. 3.6.3 Case Study No. 6 - Cape St. Francis - wind speed reduced to 10 m.

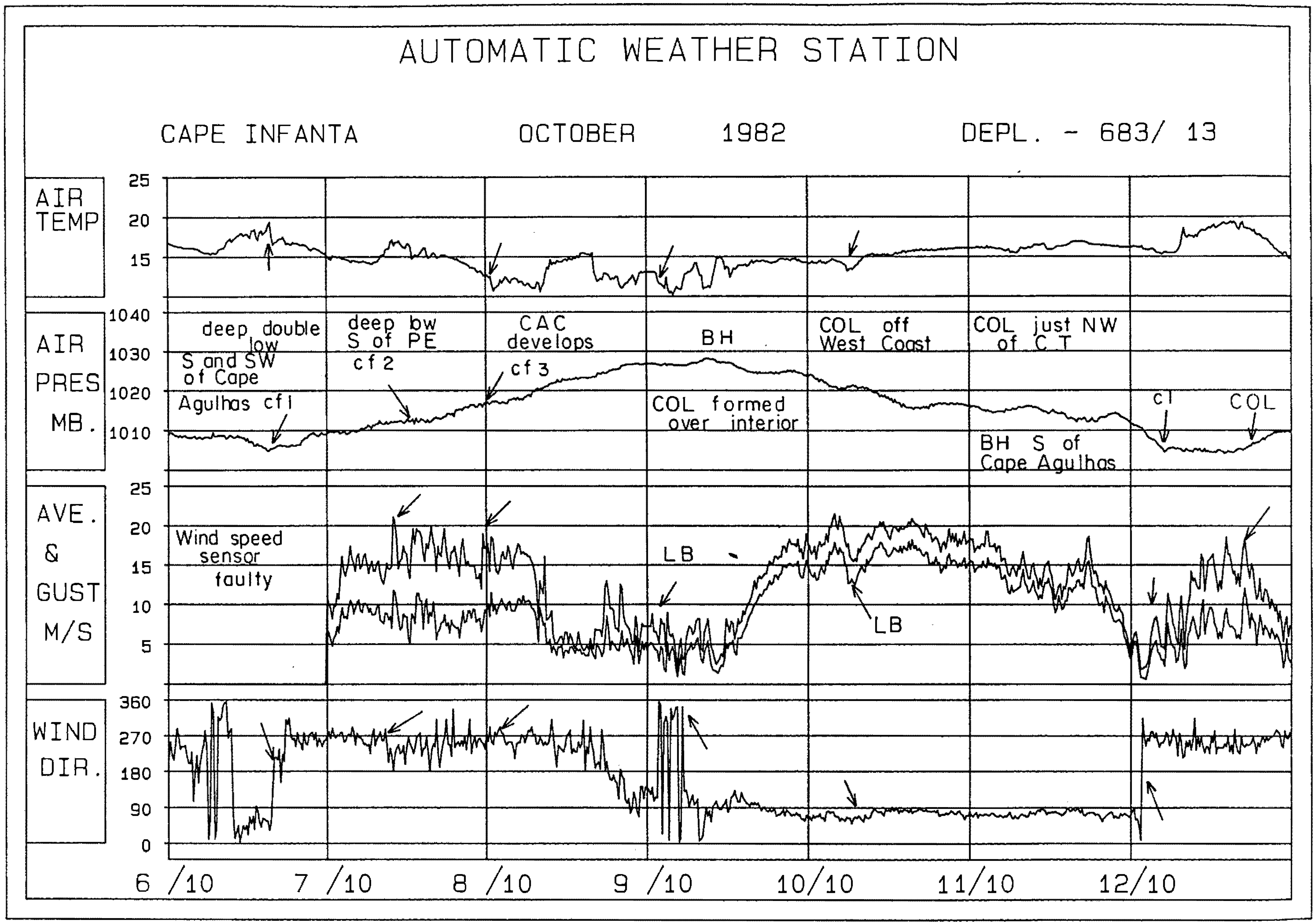

Fig. 3.7.1 Case Study No. 7 - Cape Infanta.

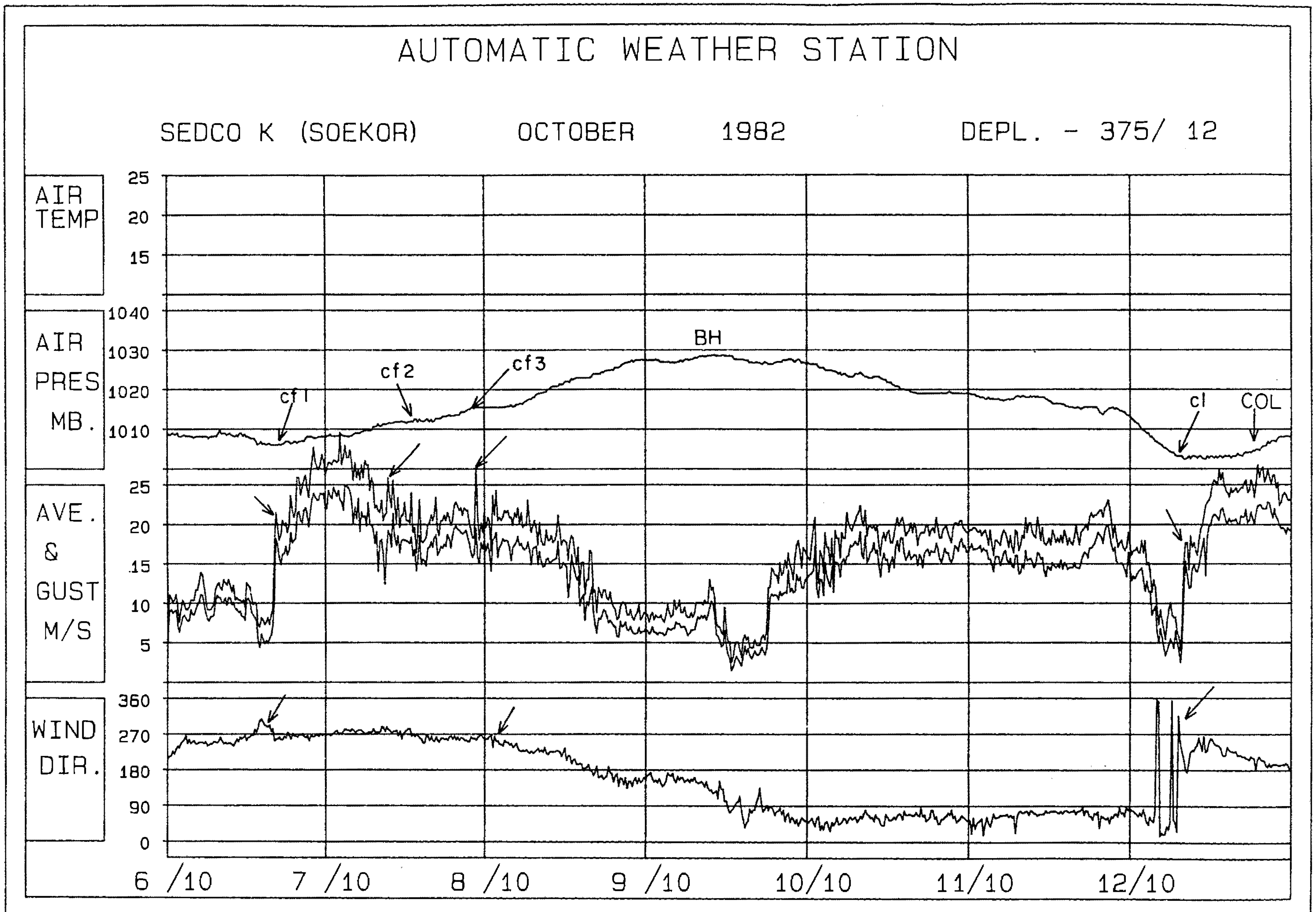

Fig. 3.7.2 Case Study No. 7 - Sedco-K.

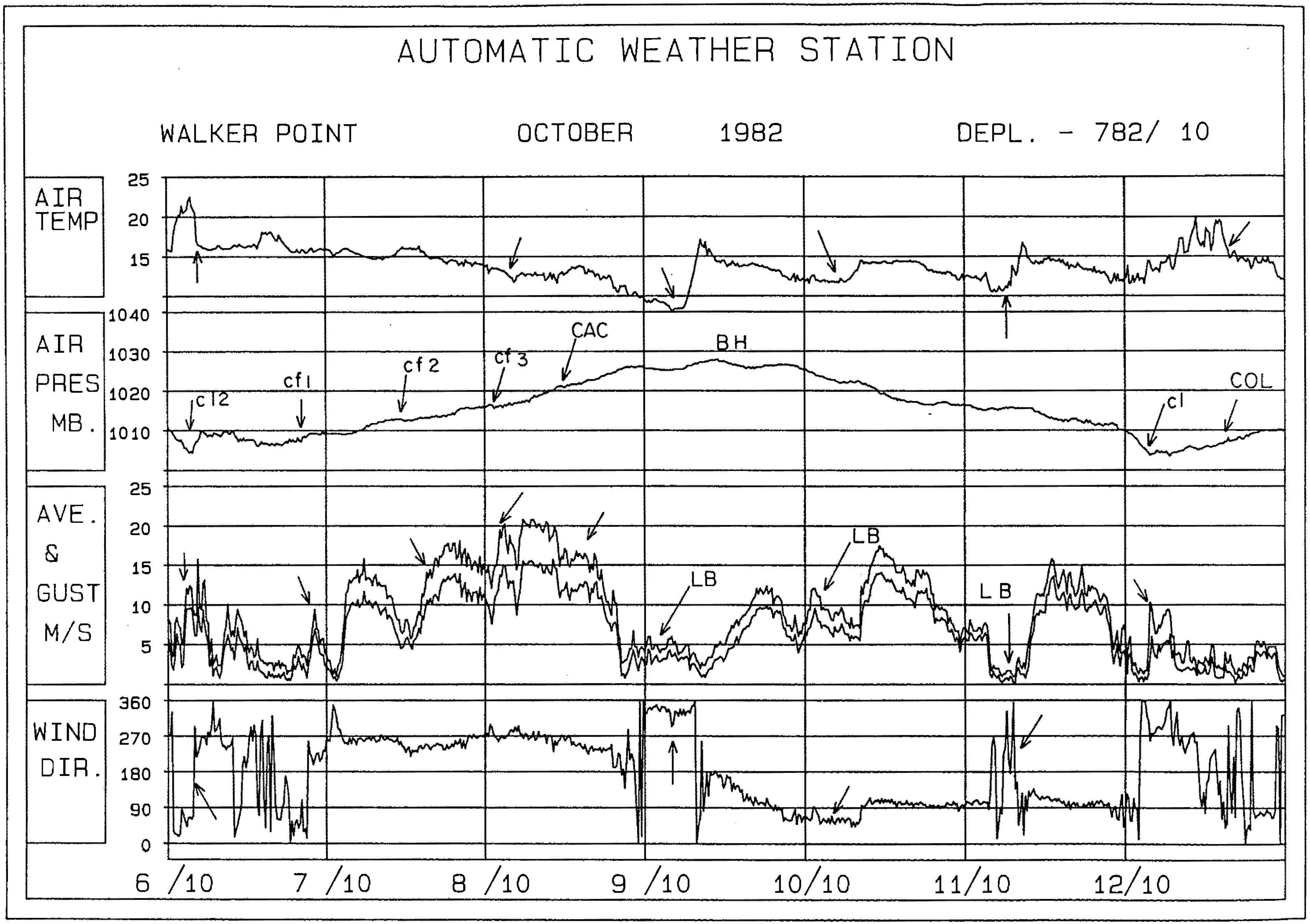

Fig. 3.7.3 Case Study No. 7 - Walker Point.

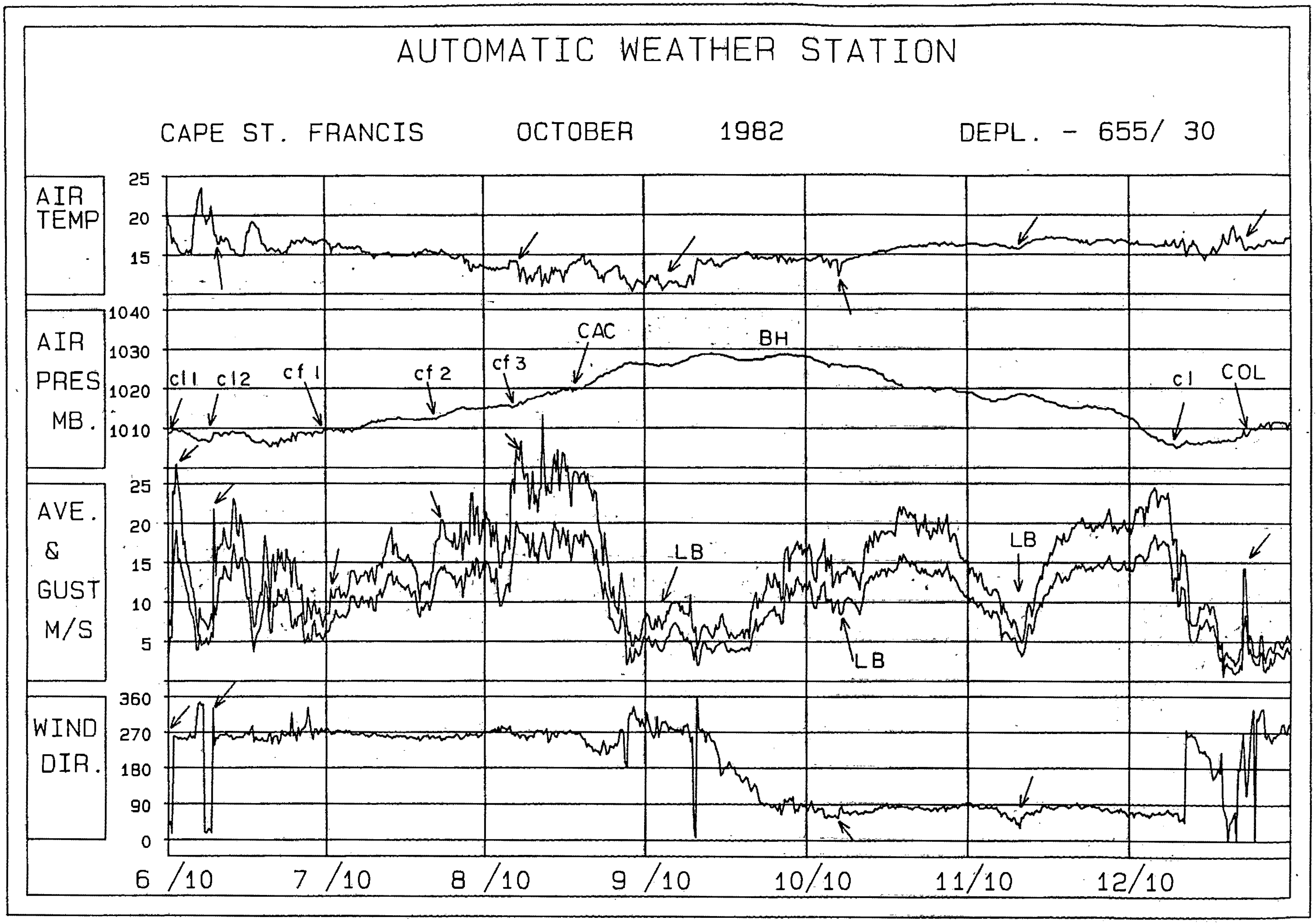

Fig. 3.7.4 Case Study No. 7 - Cape St. Francis.

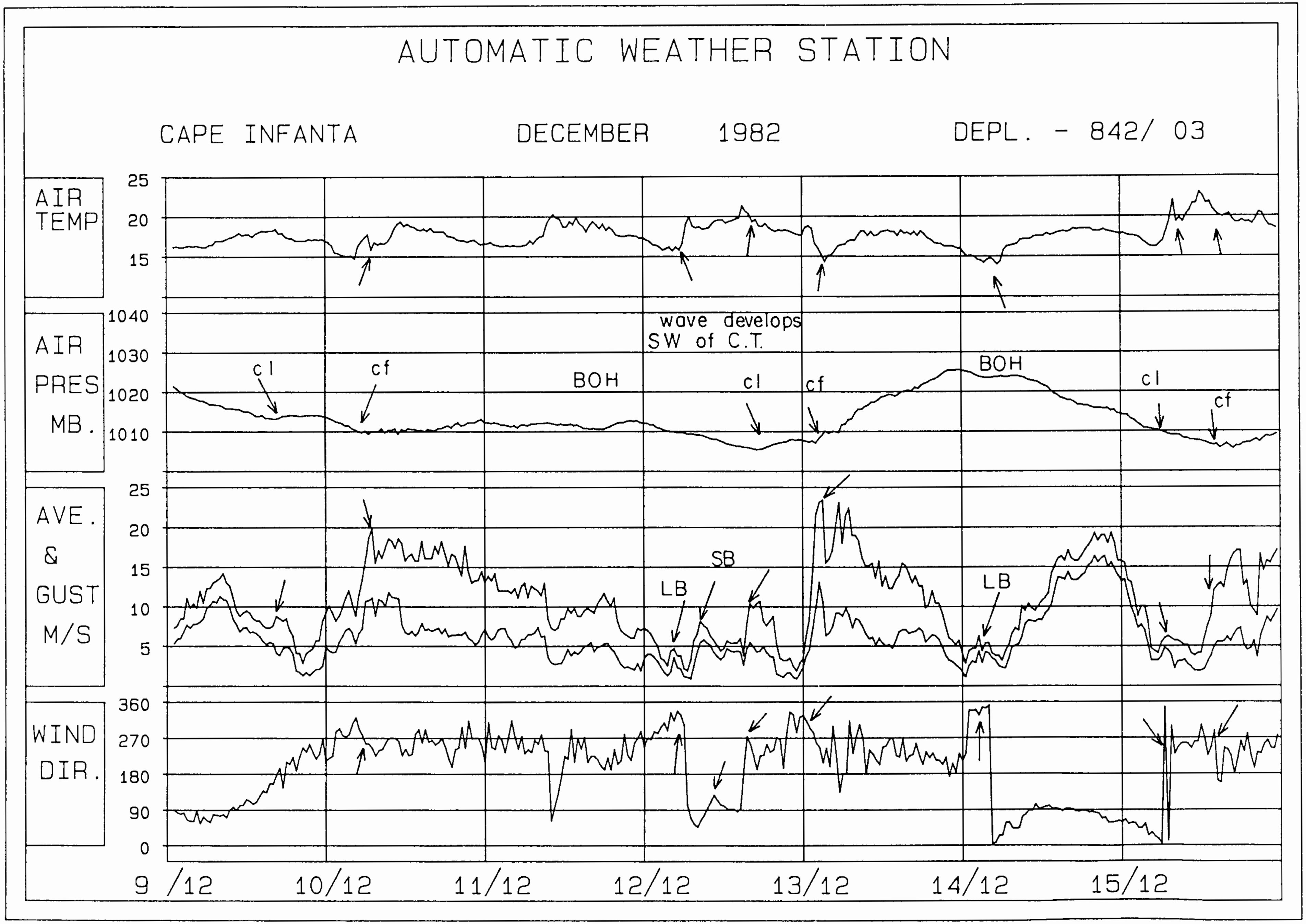

Fig. 3.8.1 Case Study No. 8 - Cape Infanta.

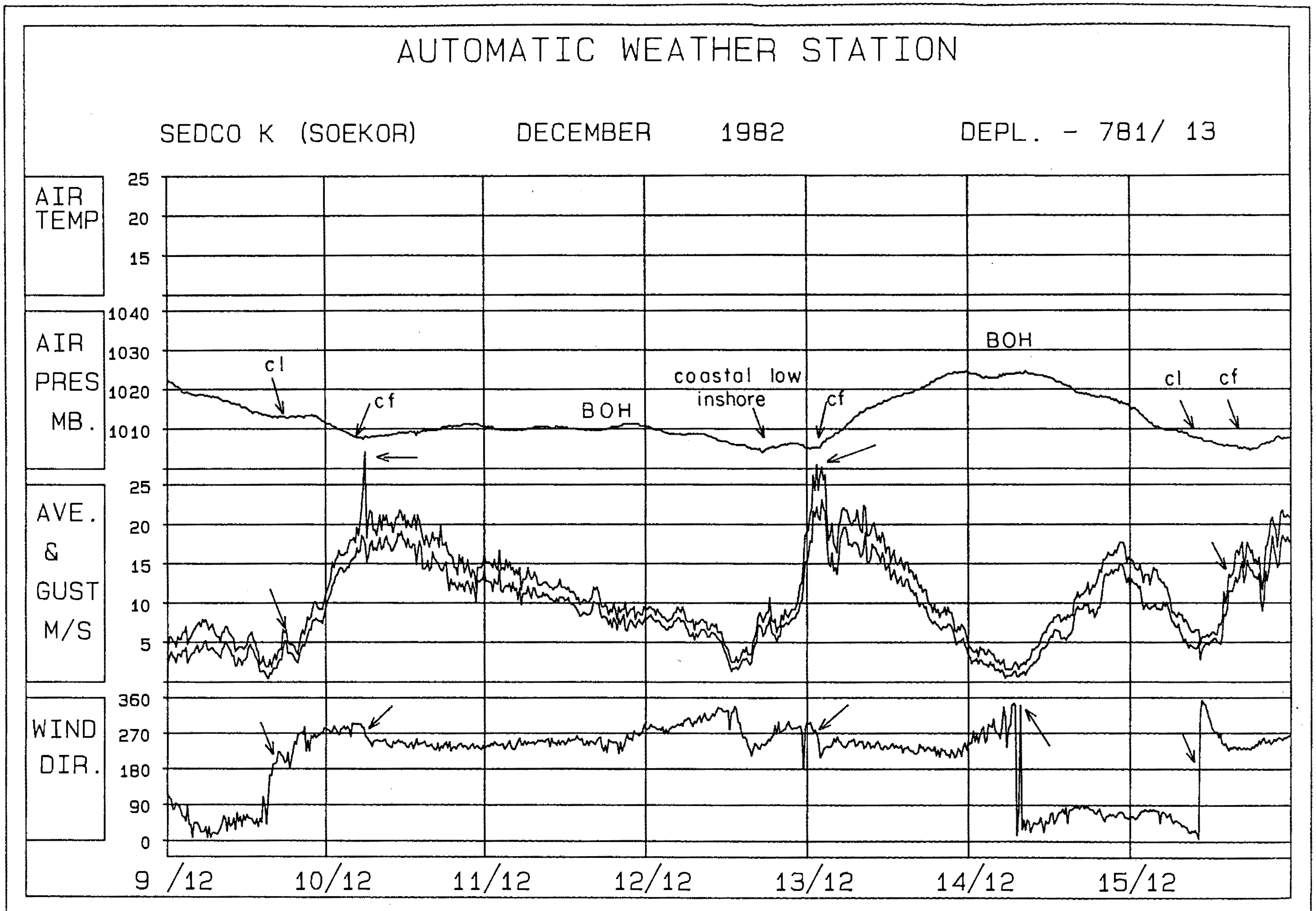

Fig. 3.8.2 Case Study No. 8 - Sedco-K.

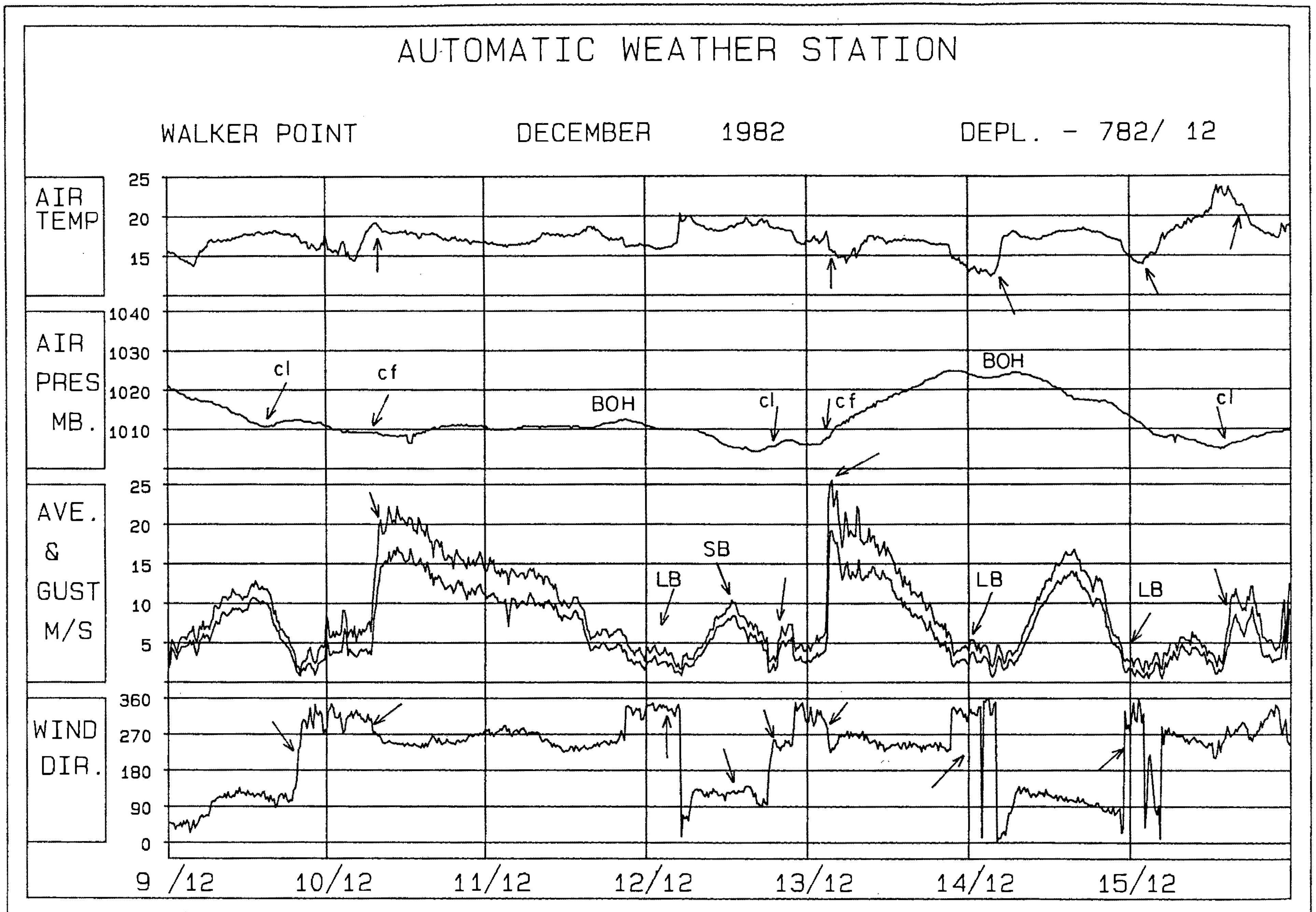

Fig. 3.8.3 Case Study No. 8 - Walker Point.

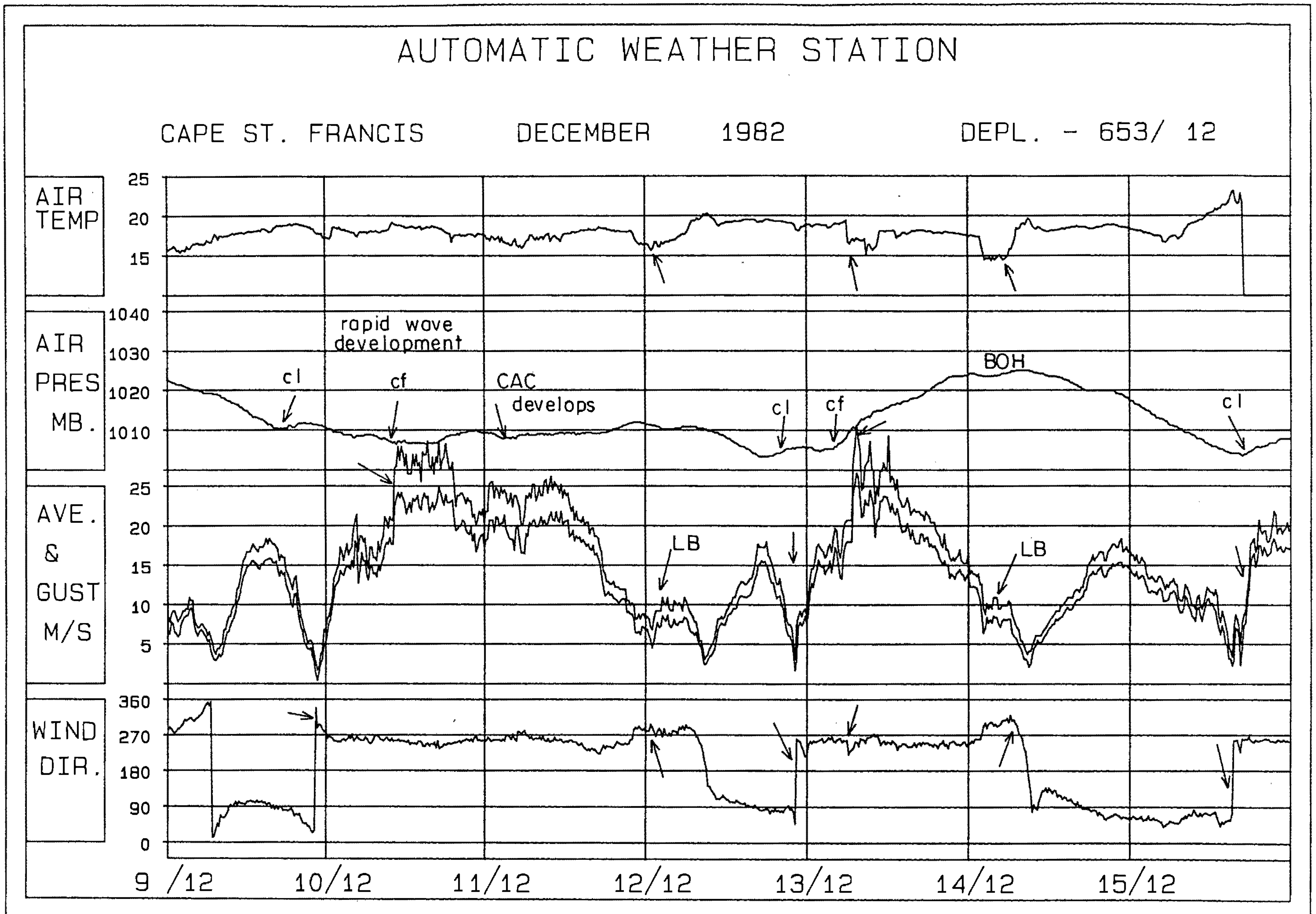

Fig. 3.8.4 Case Study No. 8 - Cape St. Francis.

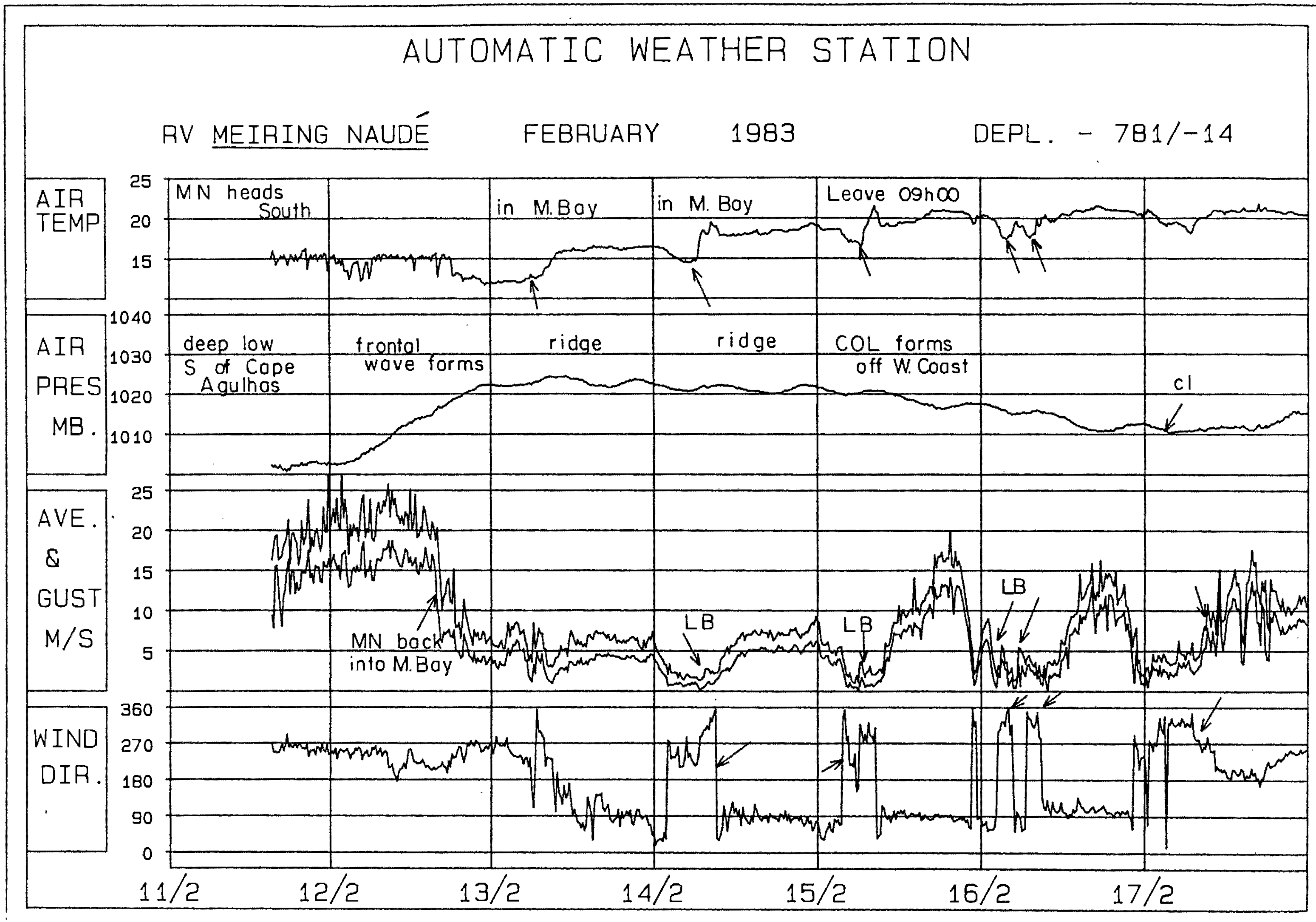

Fig. 3.9.1 Case Study No. 9 - Meiring Naudé.

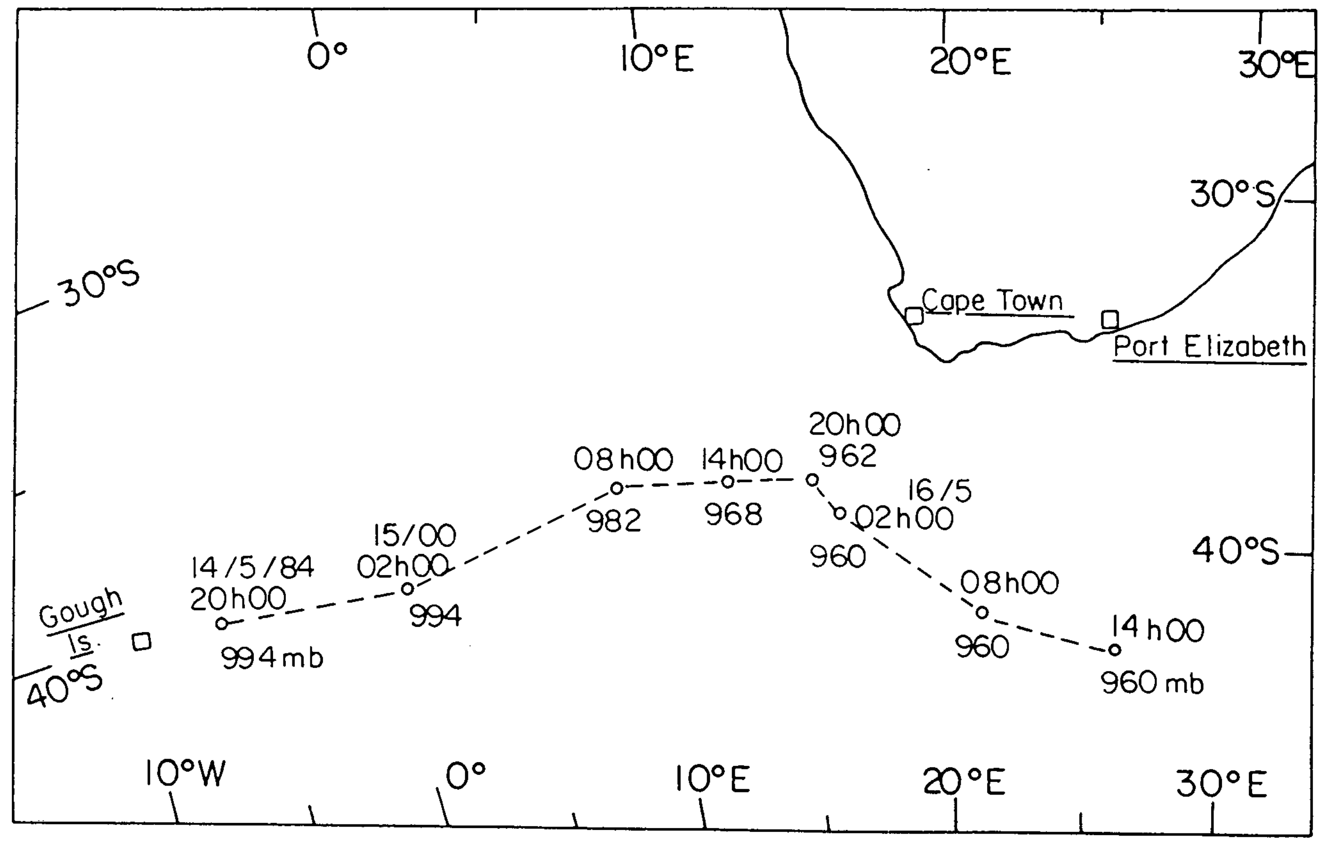

Fig. 3.10.1 Case Study No. 10 - track followed by 'bomb'.

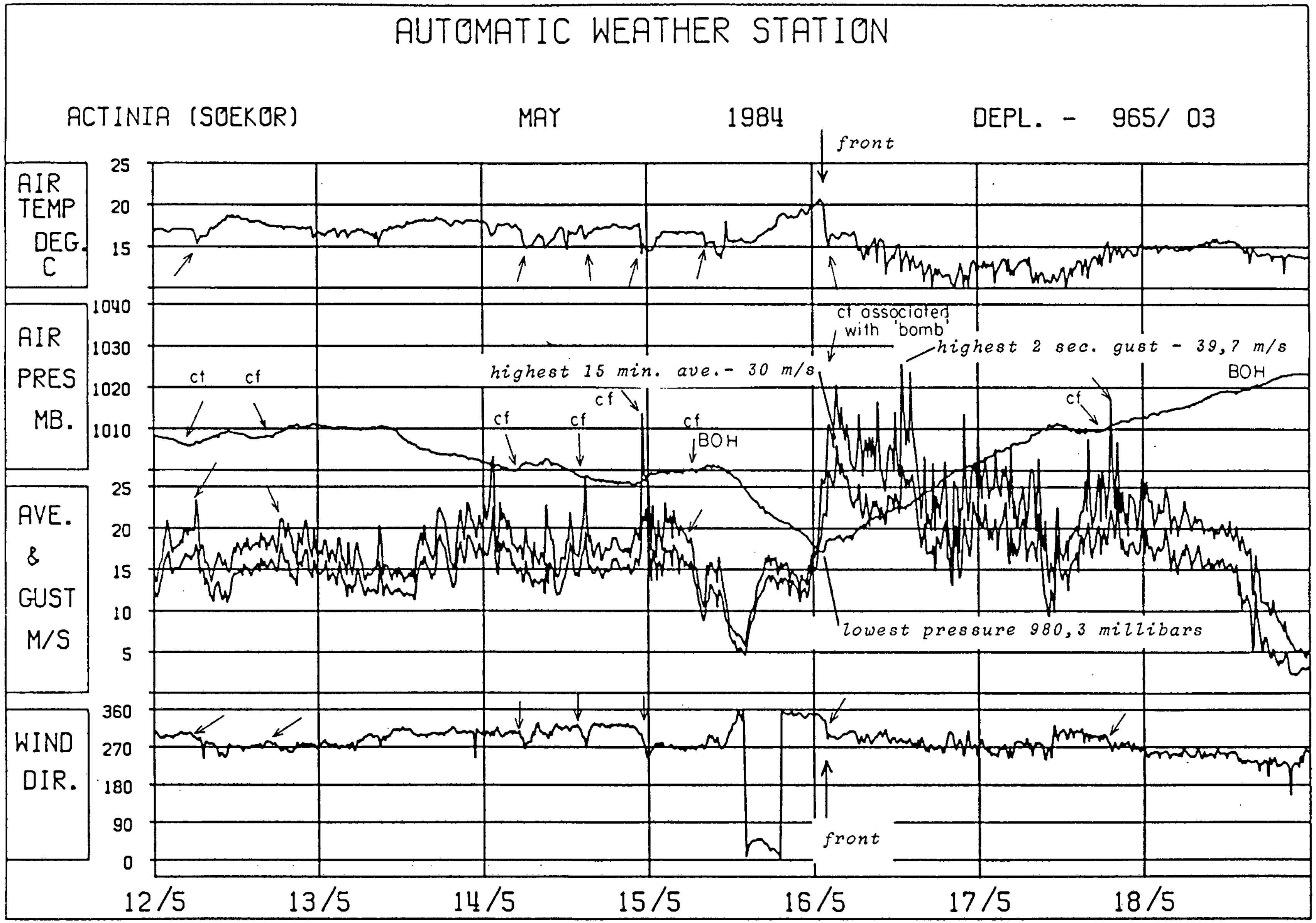

Fig. 3.10.2 Case Study No. 10 - Actinia.

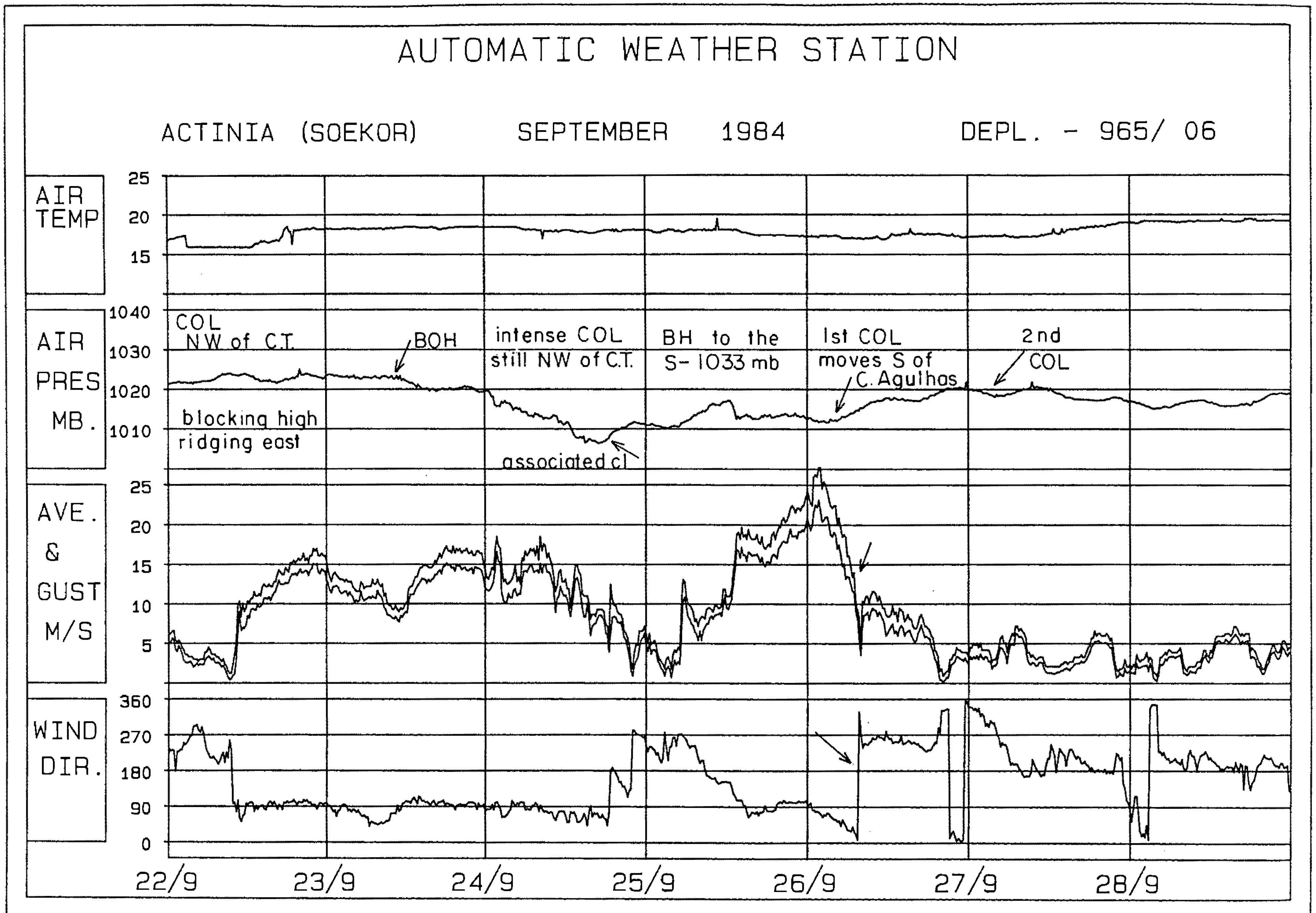

Fig. 3.11.1 Case Study No. 11 - Actinia.

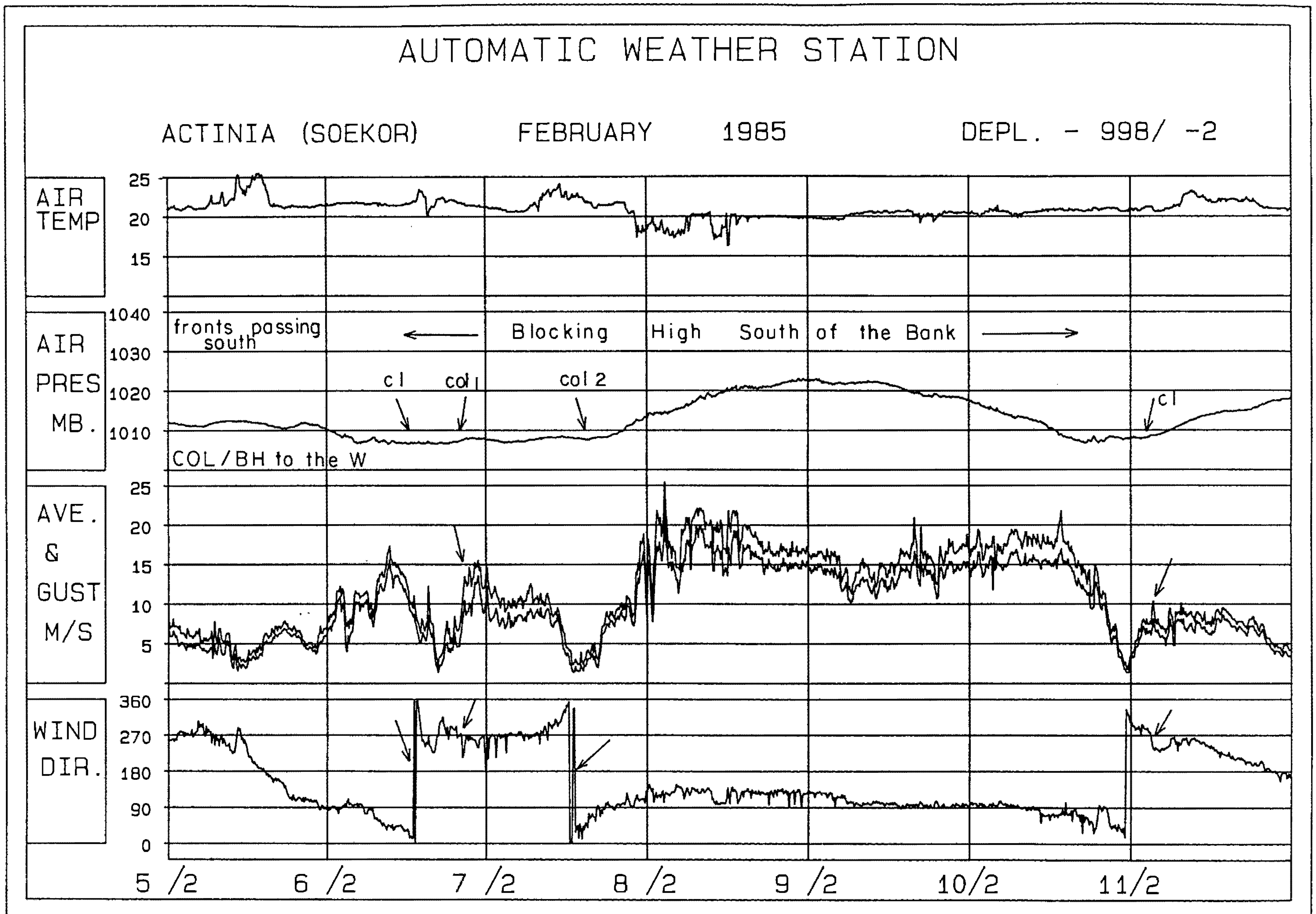

Fig. 3.12.1 Case Study No. 12 - Actinia.

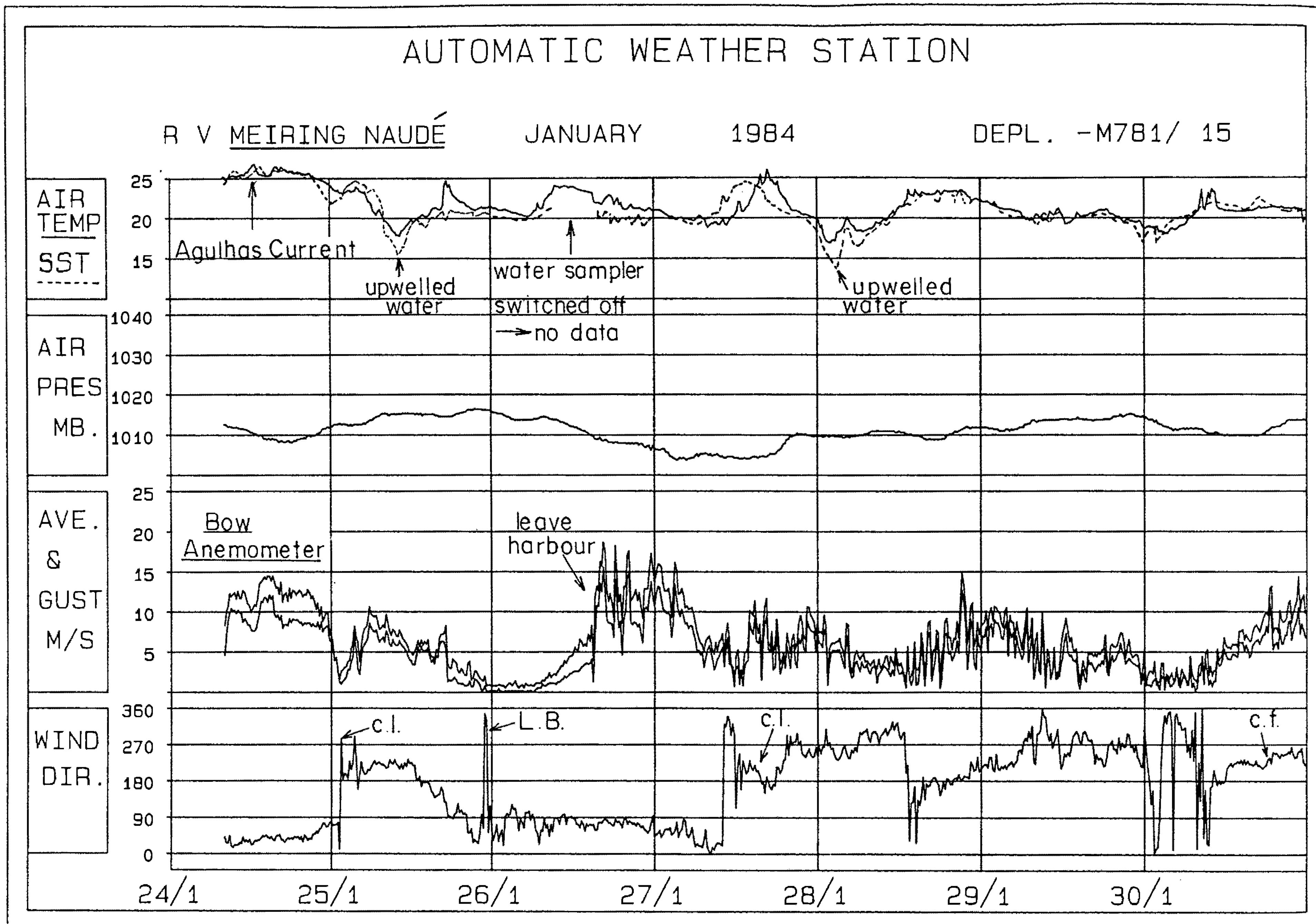

Fig. 5.5.1 R/V Meiring Naudé from Durban to Port Elizabeth, then on to Agulhas Bank.

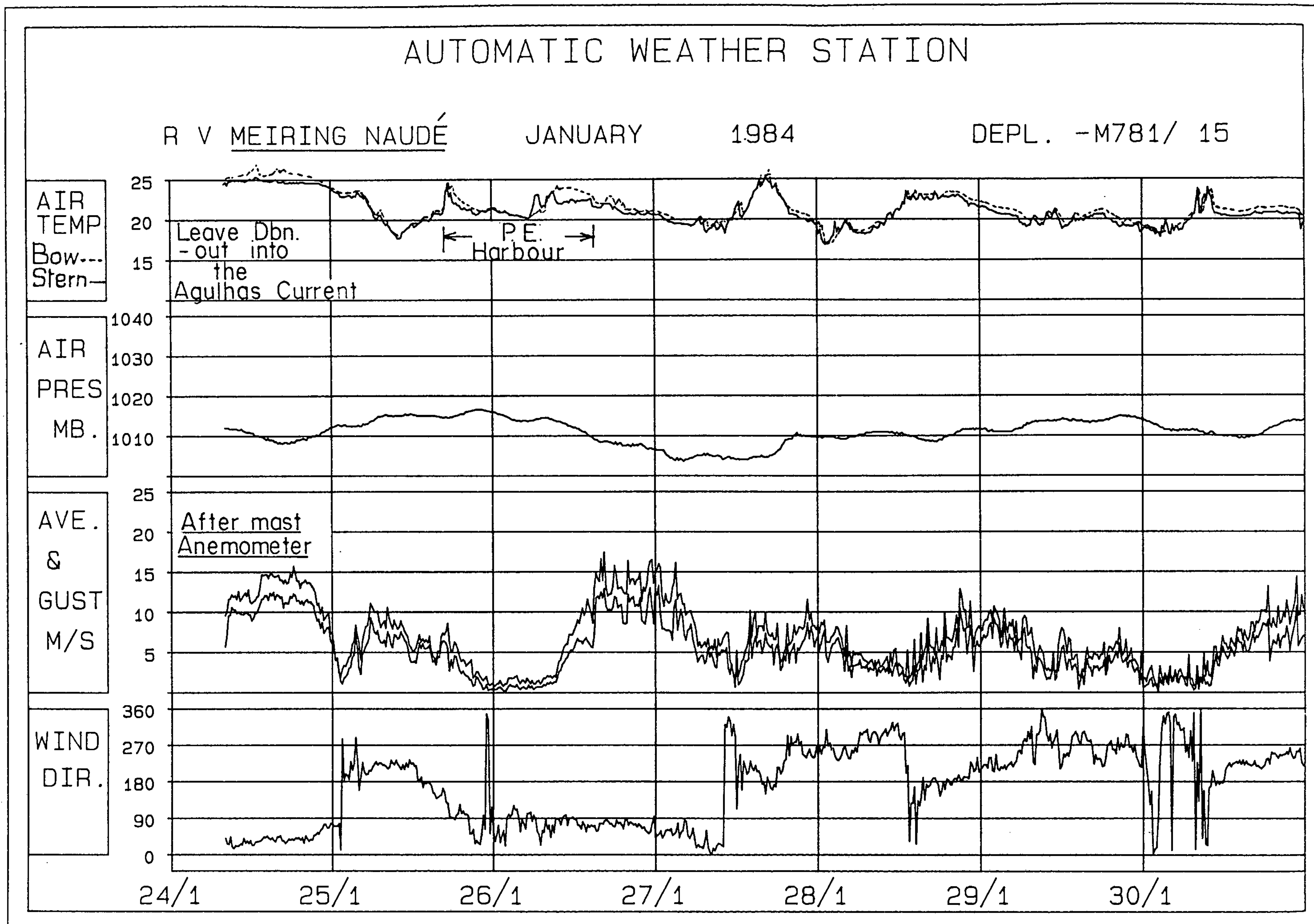

Fig. 5.5.2 R/V Meiring Naudé. Same period as in Fig. 5.5.1 but different sensor channels.

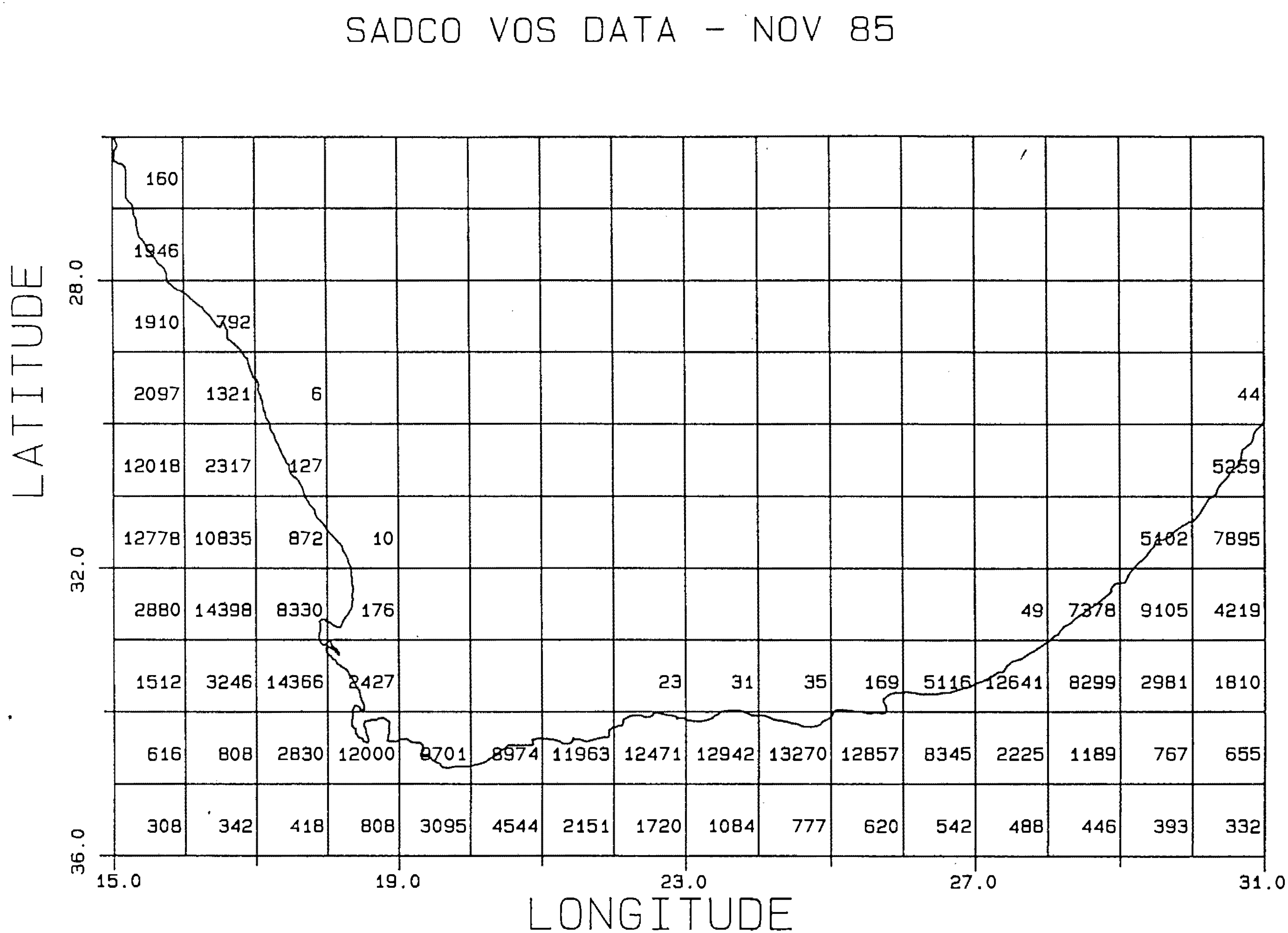

Fig. A1.1 Distribution of SADCO VOS reports around the SA coastline.

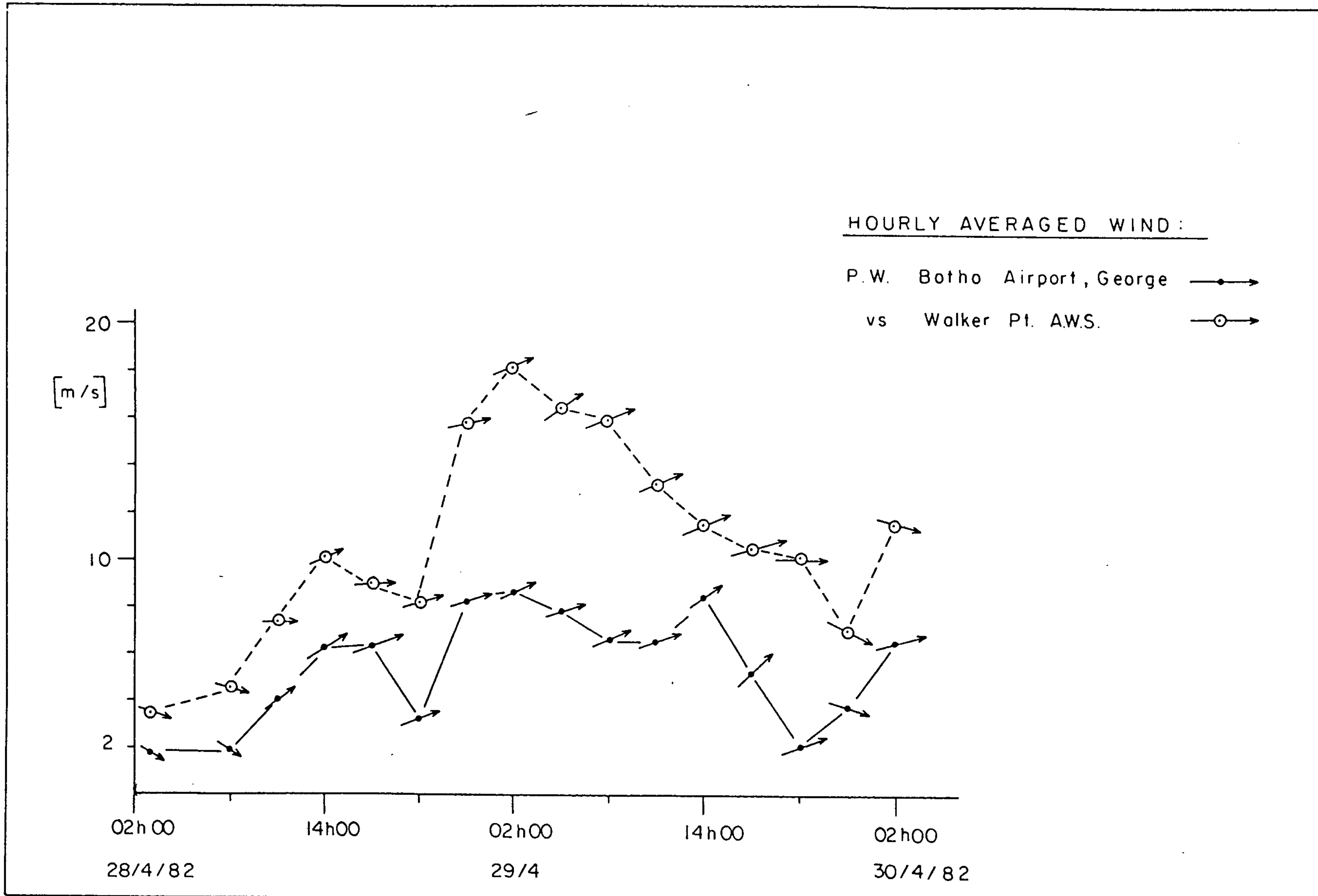

Fig. A3.1 P W Botha Airport vs Walker Point AWS - hourly averaged wind speed.

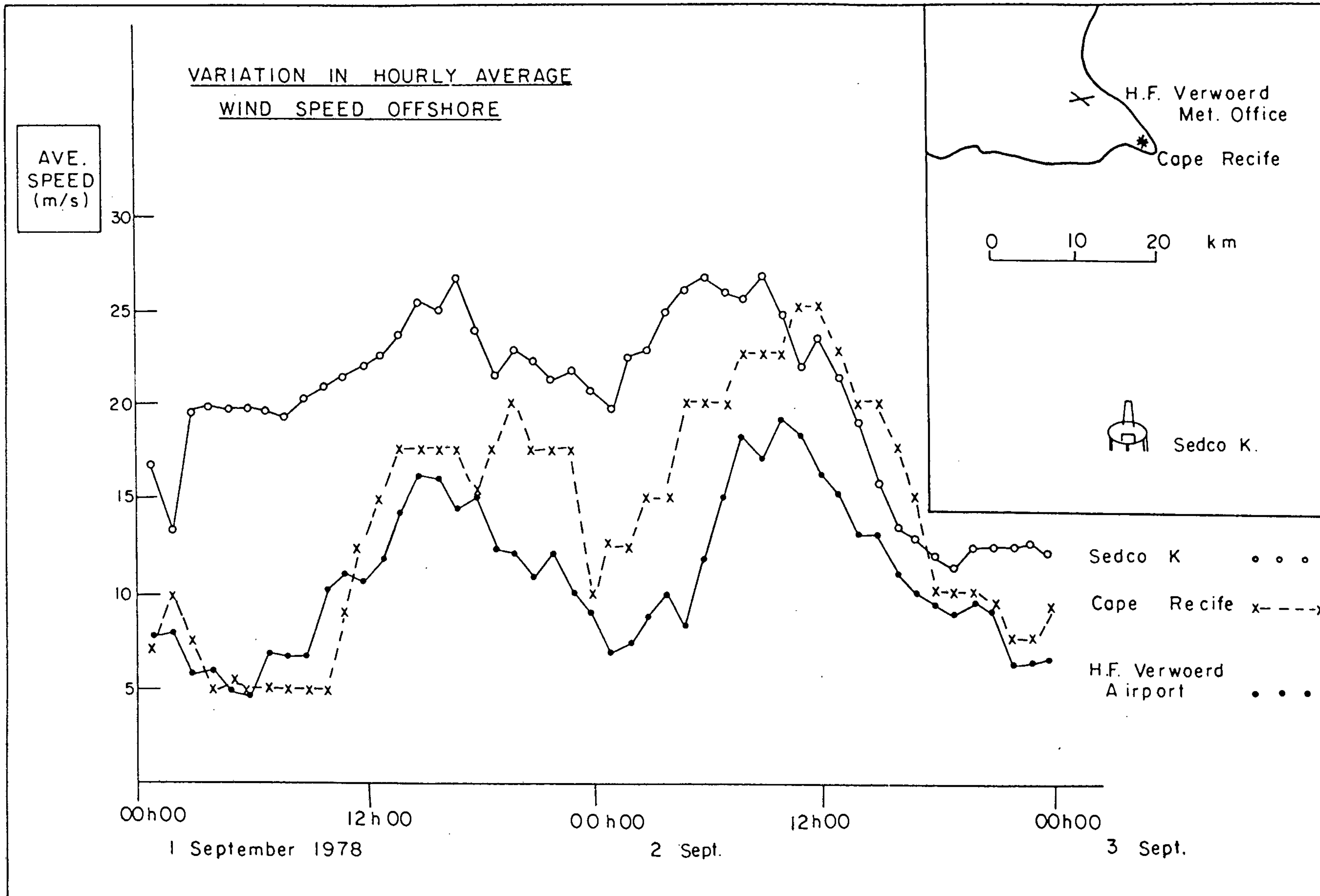

Fig. A3.2 Wind speed on Sedco-K vs land-based anemometers - September 1978 storm.

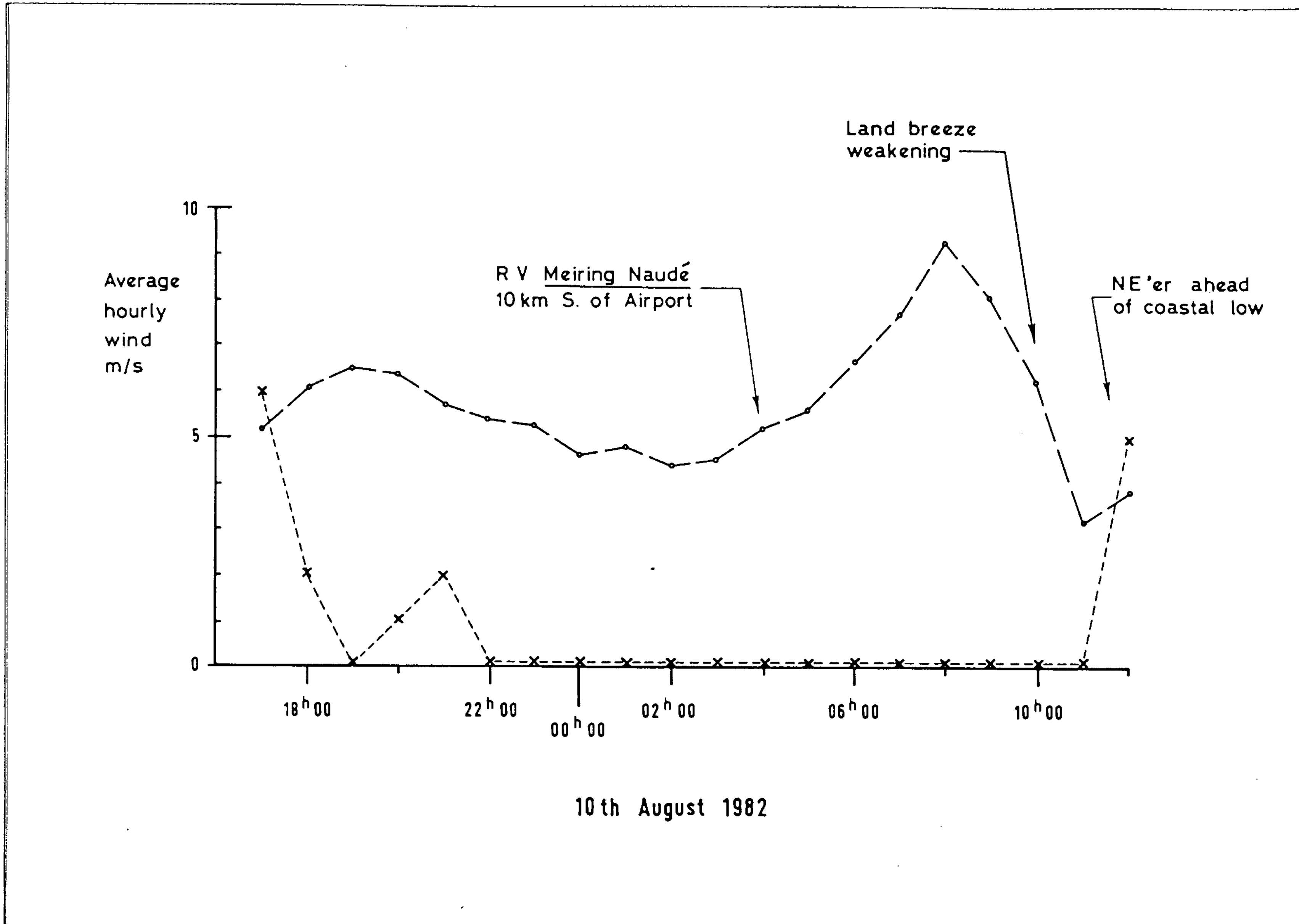

Fig. A3.3 H F Verwoerd Airport vs R/V Meiring Naudé - hourly averaged wind speed.

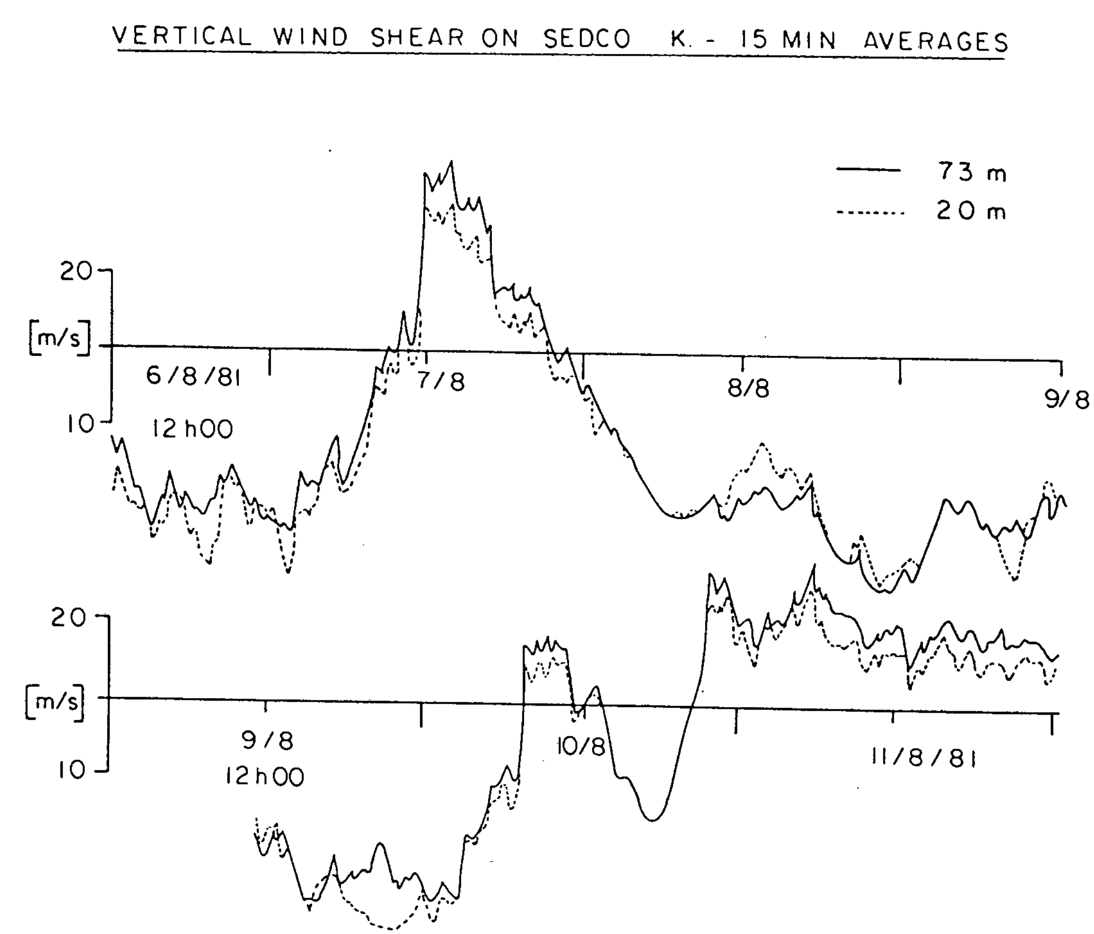

Fig. A4.1 Sedco-K : wind speed at 73m vs 20m wind

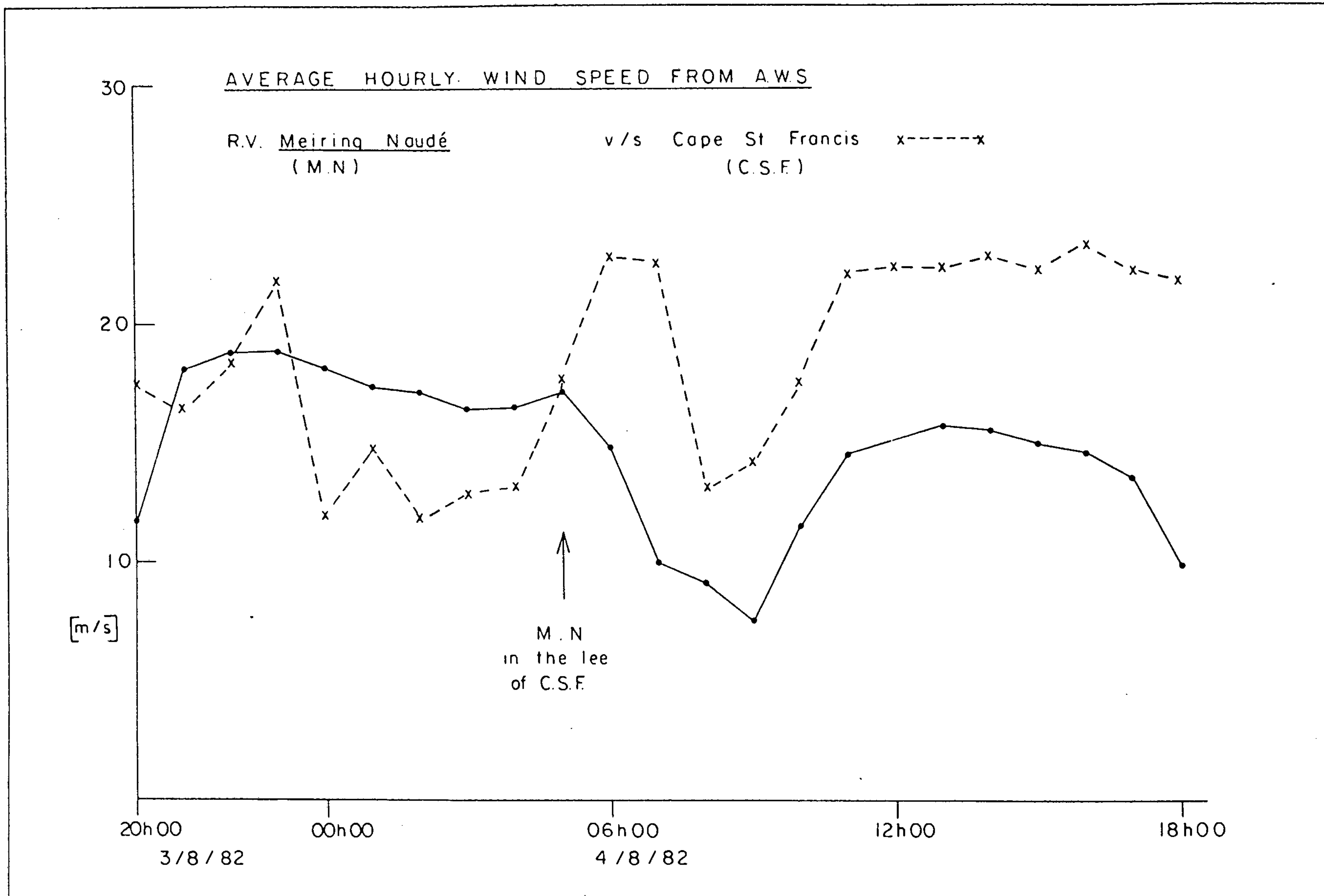

Fig. A4.2 Meiring Naudé vs Cape St. Francis.

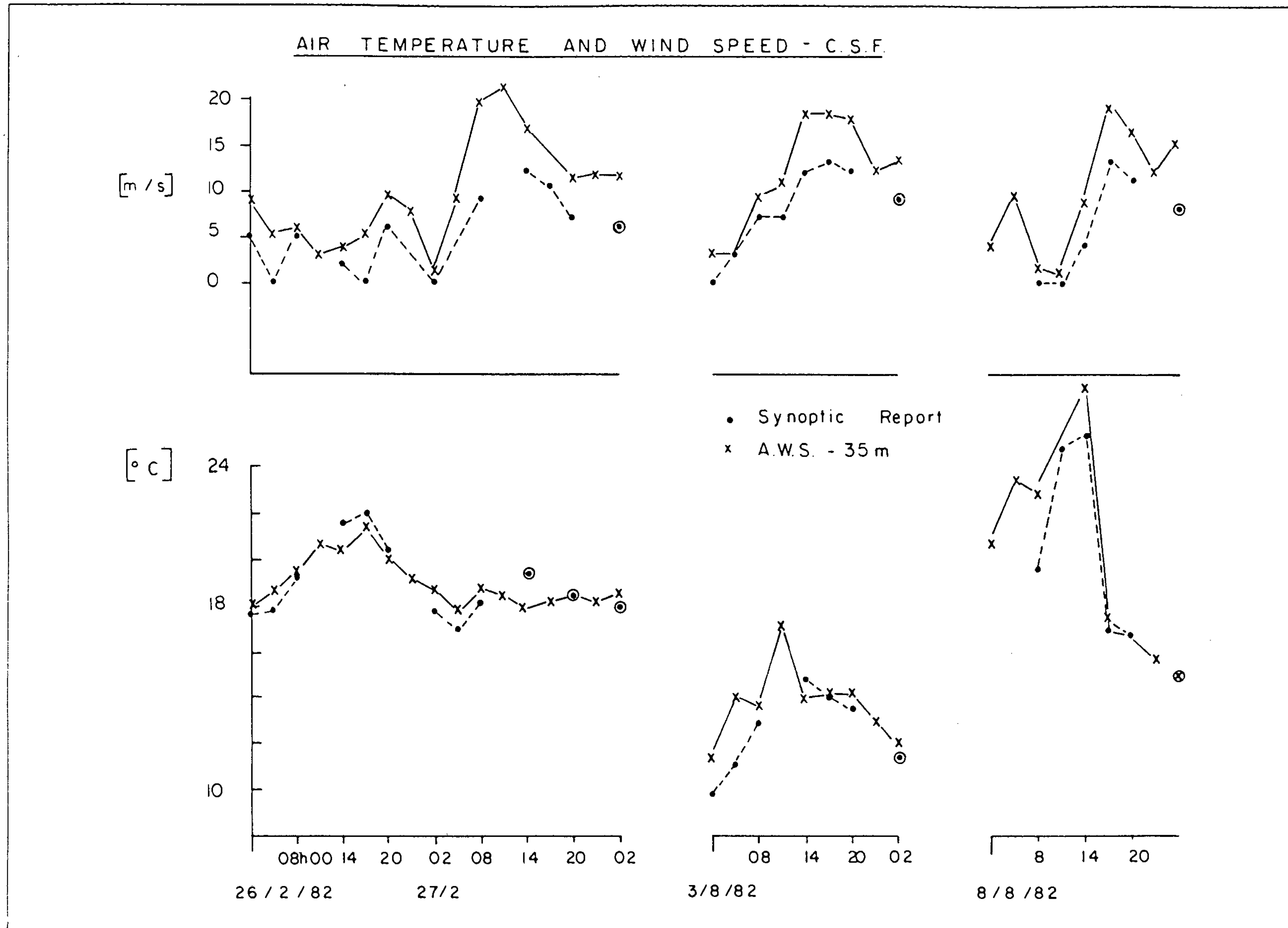

Fig. A4.3 Cape St. Francis: wind speed and air temperature - ground level vs 35 m.

APPENDIX 1

VOLUNTARY OBSERVING SHIP DATA (VOS)

VOS data comprises the only long-term offshore data available to either meteorologist or oceanographer. It is extensively used in both disciplines, but users are not always aware of the origins or limitations of this data. This appendix discusses the way in which the various VOS parameters are obtained, as well as recent attempts to adjudge the accuracy of such data.

SADCO. The SA Data Centre for Oceanology has established two VOS databases utilising mainly data obtained from the UK Meteorological Office at Bracknell. The 'coastal' database which includes the whole continental shelf area around Southern Africa (0 - 70°S, 0 - 50°E), consists of approximately 1,5 million observations from 1960 to 1985. After February 1984, only VOS reports obtained directly from the SAWB, (that is, only SA-recruited ships), were available so that the number of reports drops off drastically after this time. This 'coastal' database, which is permanently on line, has been used extensively in this thesis.

Even the Bracknell data which had been rigorously checked was found to have some obvious errors. The SAWB data had a much higher error content. In most cases erroneous data could be identified by looking at surrounding observations or referring to the relevant 14h00 synoptic chart.

A1.1 SADCO VOS-data on the Agulhas Bank

Due to the vast amount of data available, Agulhas Bank VOS data had to be extracted upon two separate files:

Agulhas Bank West	33 - 36°S, 20 - 23°E	-	44 367 records
Agulhas Bank East	33 - 36°S, 23 - 27°E	-	57 373 records

Figure A1.1 shows the total VOS data inventory on SADCO's coastal database at the time that the data were extracted. Note that although the southern boundary of the rectangular search areas above extends south of the Bank in places, the great majority of reports are on the Bank.

Seasonal and diurnal distribution of reports. By summing the number of observations for each month and each synoptic hour, Tables A1.1 and A1.2 were obtained. As can be seen there was no major biasing, although the 14h00 reports were most numerous in the east and the 08h00 in the west. No clear pattern of seasonality emerged. Note that the total records from these tables will be less than the totals given above, since some reports were not made at the main synoptic times.

In order to be able to compare frequencies in different months or at different times of the day, normalisation factors were calculated (in brackets). When comparing the frequency of a particular phenomenon between eastern and western Agulhas Bank, the ratio of total reports was taken into account, that is, 44 367/57 373 = 0,77.

Present weather observations. The two data files were sorted according to the present weather code (ww), in order to look at frequencies of occurrence and daily/seasonal distributions. No ww report was available for 2-3 per cent of observations.

Other parameters. Most of the parameters in the VOS reports such as wind speed, dry bulb temperature and pressure, were also ordered and extreme values selected for the discussion on climate. From each set of extreme values a daily/seasonal frequency distribution was created. Apart from their collective value in delineating the climatic boundaries offshore, individual VOS reports were extracted to provide offshore data in the case studies.

A1.2 Accuracy of VOS data

Assuming that the deck officer takes such precautions as placing both wet and dry bulb thermometers in a free airflow, and regularly checking on the calibration of the barometer, it is the accuracy of the wind, sea state and SST which is most suspect.

Wind speed. Graham (1982) compared VOS wind estimates with nearby measurements for Ocean Weather Ships and Light Vessels. She concluded that:

(a) The presence of the anemometer on a Voluntary Observing Ship did not necessarily mean a more accurate wind speed. Recognising the problems involved, for example, height reduction, correct exposure and vector addition of ship's velocity, many countries including the UK and RSA, have deliberately **not** equipped their vessels with anemometers.

(b) Graham found that VOS estimates tended, if anything, to be **underestimates** at extreme speeds. In the case studies in Chapter 2, isolated VOS estimates of wind speed are compared with measured winds on the Agulhas Bank. Their accuracy is often quite remarkable considering that they are mere estimates based on an often very confused sea state.

A general look at extreme wind speed estimates on the Bank, showed VOS values tending towards a maximum of approximately 35 m/s. Compare this with an absolute hourly maximum of 33,6 m/s measured at 73 m above sea level on Sedco K. If it is borne in mind that this latter value would probably have required relatively little reduction had it been measured over the current and that the rig data covers only 5 years as against 26 years of VOS data, a 35 m/s maximum seems quite plausible.

The estimate of wind speed using sea state does have its drawbacks, however. Verploegh (1967), makes the point that phytoplankton concentration will affect foam generation, while the actual transfer of momentum to the sea surface is heavily dependant on the stability of the lower PBL.

Sea state. Shearman (1983), noted that the practice of separating sea state into wind and swell waves in the VOS report is for the benefit of the forecaster. For the purpose of comparing VOS swell heights with **measured** H_{mo} he suggested that the two estimates be added.

Verploegh (1967), after comparing VOS reports, found that the standard deviation of a single wave height estimate varied from 0,3 m at 1,5 m, to 1 m at a wave height of 6 m. Verploegh also found standard errors in wave direction of 10-13 degrees, and in wave period of 1,8 seconds. In contrast with these findings Laing (1984) found a particularly poor correlation between VOS estimates of period, and he declared the data of qualitative value only.

In the case studies, however, several comparisons are made between VOS estimates of wave height and Waverider records. Under extreme conditions the VOS estimates were often remarkably accurate - consider, for example, the section on extreme swell in case study No. 3. Note that the H_{mo} value calculated from measured wave data was specifically defined so that it would be comparable with the characteristic wave height Hc, observed visually.

It is quite possible that a navigation officer might report H_{max}, that is, the maximum deviation between two consecutive trough/ridges instead of Hc, under extreme conditions. Nelson (1974), found that in a wave record of 17 minutes durations, H_{max} is typically 30 per cent higher than the H_{mo}. In the extreme case, H_{max} may be double the significant wave height. Note that Laing found a general **overestimation** of wave heights in his study.

Looking at all the VOS reports on the Agulhas Bank, swell heights tended towards a maximum of approximately 15 m. Bearing in mind that the maximum measured H_{mo} of 8,6 m was taken well out of the current, whereas the highest values from VOS would most probably be from vessels riding the Agulhas Current southwards, this value is not unreasonable. Note, however, that for the calculation of design wave-heights much more use is made of wind estimates (and hindcast wave models), than estimates of wave height.

Comparing adjacent VOS estimates of swell direction, Laing found a characteristic 70° spread angle. However, it should be borne in mind that sea state is usually a very complicated combination of swell arriving from a number of fetch areas, with locally generated wind waves making estimates even more difficult. The World Meteorological Organisation, in changing the real time 'SHIP' code in 1982, added the option of reporting more than one swell train. Thus, when comparisons are made, it is essential that height estimates of the same swell trains be compared.

Sea surface temperature (SST). The great majority of vessels obtain 'SST' from a temperature sensor in the engine room intake. This means that for deep draught vessels, such as supertankers, 'SST' is actually 10 m or more below the surface. Very few observations of VOS sea temperatures are in actual fact anywhere near the surface so that under conditions of extreme surface layer stratification, the VOS report may deviate significantly from the actual SST. Another source of error is the warming which is dependant upon the distance between the intake point and the sensing element.

APPENDIX 2

HOURLY WIND ESTIMATES BY LIGHTHOUSE KEEPERS

These data were processed for all manned lighthouses on the Cape south and south-east coasts for the years 1976 to 1980 inclusive. The data were extracted from the original logs stored at Greenpoint (Cape Town) and punched directly onto 9 track tape. An interactive program was written to edit the data on the terminal. Various plot programs were written to present these data in the form of wind roses, progressive vector diagrams (pvd's) and time-series. These data and the analyses have been used extensively in drift card studies at UPE, and also in the study of upwelling along the Cape South Coast.

A2.1 Accuracy of the Data

Although regarded with some contempt by the scientific community, this data set represents the only fixed location, long-term wind data which is truly coastal in origin. Furthermore as Figure A3.2 in Appendix 3 shows, estimates by lighthouse keepers are not to be summarily dismissed. Referring to the above figure, the Cape Recife trace initially followed HFV with the wind WNW, but was slower to succumb to the stabilising effect of nocturnal cooling overland.

Some lighthouses, for example, Cape St. Francis, have been equipped with pressure plate anemometers, but these are only of use up to approximately 15 m/s, whereafter the plate is horizontal. The lighthouse keeper, like his VOS counterpart is thus mainly dependant on the state of the sea for his wind speed estimates. Being some distance from the open sea across a turbulent surf zone, he is at some disadvantage. Nevertheless, the absolute maximum lighthouse estimate of approximately 30 m/s is not unreasonable when it is considered that a 15 minute average of 28,3 m/s (unreduced) was measured at Cape St. Francis in a single year of measurement.

A2.2 Average Monthly Mean Estimates versus Measured Offshore Wind Speeds

Hsu (1980a), established a general formula for converting land-based wind data for use offshore. (Note that monthly means are referred to here):

$U_{sea} = 3\ U_{land}$ ** 2/3

Whilst it was appreciated that cross-coast processes are neither constant with time, nor so simple that one relationship be applicable to any coastline, the above formula was applied to the three Cape south coast lighthouses with 24 hour coverage for 3 months in 1979:

1979	Sedco K	CSB	CSF	Cape Recife
	73 m - 10 m			
July	9,9 - 7,8	4,4 - 8,0	7,4 - 11,4	6,6 - 10,5
September	12,1 - 9,6	4,8 - 8,5	7,5 - 11,5	7,8 - 11,8
October	11,9 - 9,5	5,6 - 9,4	9,1 - 13,1	9,9 - 13,8

The comparison with Cape St. Blaize (CSB) appears to be very good. Note that a roughness length of 0,005 m was used in reducing the rig winds. During these three months, the rig was positioned approximately 150 km south of Mossel Bay. The significantly higher monthly averages on the eastern Agulhas Bank are supported by AWS measurements.

A2.3 Wind Direction

Although the pressure plate anemometer is fitted with a wind vane, most lighthouse keepers do not have this facility, and tend to favour the eight major points of the compass. This becomes evident when the lighthouse wind roses (see Chapter 2), are compared with relevant AWS wind roses. For example, Cape St. Francis has a very zonal appearance which is not nearly as marked on the AWS wind roses for that site.

APPENDIX 3

WIND VARIATION IN THE COASTAL ZONE

The question of whether wind observations from Port Elizabeth's H F Verwoerd Airport (HFV) or George's P W Botha Airport (PWB) are representative of conditions over the nearby coastal waters, is a very pertinent one. The HFV anemometer is situated only 3 km from the coast, 60 m above sea level, whilst at the PWB Airport the wind measurements are 10 km inland and 221 m above sea level. Both weather offices are equipped with accurate Dynes pressure tube anemometers. However, the data are recorded on strip charts and manually reduced and averaged so that the net accuracy is probably lower than the AWS data.

These two stations represent the only **long-term,** accurate wind measurements in the coastal zone of the Southern Cape. The following 3 figures show that this wind-data is often not representative of conditions over the coastal ocean:

Figure A3.1: On 27 April a COL formed offshore, and by 29 April had given the AWS at Walker Point its highest hourly average wind speed in the whole recording period. Wind speed and direction were plotted at 3 hourly synoptic intervals for both Walker Point and George:

(a) The general increase in wind speed at the coast is largely a function of aerodynamic roughness length, Z_O. Hsu (1980b), used a value of 0,01 cm over the sea, whereas Z_O at the airport is probably over 1 000 times this value (that is, over 10 cm). Note that the Walker Point AWS was almost surrounded by the sea, some 50 km ESE of the airport.

(b) A much greater frictional drag is exerted when nocturnal cooling overland causes a stable stratification, inhibiting the vertical exchange of momentum. This is clearly in evidence during the night of 28/29 April 1982. At 20h00, the wind at George showed a sharp decrease, then increased as the mechanical turbulence overcame the temperature stratification to some extent. Nevertheless, the peak hourly wind speed at the AWS site was almost double that at the airport (20,5 versus 10,6 m/s). Note, however, that the ratio between maximum gusts for this storm was not as high (30,2 versus 18,5), due to flow being generally much more turbulent overland.

Although the highest hourly wind speed ever recorded at George is relatively high (WNW 21 m/s) when compared with the above AWS maximum, note that this record wind was directed offshore, with possible funneling or other acceleration due to the high surrounding mountains, and represents a much longer period of measurement. As the time-series shows, a peak wind occurring overnight is likely to be severly underestimated if wind data from George are used to represent coastal conditions.

(c) Although a well-placed coastal AWS will not suffer the effects of nocturnal stratification (Hsu, 1980b expands on the choice of such a site), even Walker Point was markedly affected by a strong land-breeze circulation locally. Even under high wind conditions the undercutting by a cold stable surface land-breeze flow was evident in the form of 'notches' in the wind speed envelope which coincided with a sudden drop in temperature, and wind direction swinging offshore (see case study No. 7, Chapter 3).

Figure A3.2: Consider the wind speed traces for Sedco K and HFV Airport (measured), and the hourly **estimates** from Cape Recife lighthouse, in between these two sites. The airport data are seen to suffer from the same deficiences as those from George:

(a) The rig and the airport are initially totally decoupled. Even on the coast the estimates from Cape Recife indicate a stable nocturnal stratification remaining until late morning on 1 September. This could also be a land-breeze effect, however.

Note that the airport was underestimating offshore wind speeds by 75 per cent.

(b) Even once the airflow at the airport had been fully 'coupled' with the main synoptic flow, greater surface friction and thermodynamic stability meant that the mean hourly wind speed offshore (26,1 m/s at 10 m), greatly exceeded even the 100 year design wind for Port Elizabeth (23,0 m/s - SAWB, 1975).

Note that although the wind speeds from Cape Recife are only estimates based on sea state, they are generally between the onshore and offshore values.

Figure A3.3: This time-series shows how, even under moderate conditions, an anemometer site slightly inland may fail to reflect marine conditions:

(a) The R/V Meiring Naudé was heading towards Bird Island at the eastern end of Algoa Bay, passing south of Port Elizabeth at about 04h00 on 10 August 1982. She experienced a land breeze of between 5 and 10 m/s, whilst HFV Airport remained calm under the nocturnal inversion right up until 11h00.

(b) Whilst such an underestimate of moderate conditions has little importance for the structural engineer, the fact that this flow was offshore makes it of importance to those combatting air pollution.

The above figures have thus shown that wind data from the two weather offices on the Cape South Coast cannot be relied upon to reflect marine conditions, either during normal or extreme conditions.

APPENDIX 4

THE REDUCTION OF COASTAL WINDS TO THE STANDARD 10 m LEVEL

In order to be able to compare wind observations from different AWS sites on the Cape South Coast, it was necessary to reduce all speeds to a standard height of 10 m. This was not done at Cape Infanta since the site was at the top of a cliff face with considerable turbulence. Wind speeds from both Cape St. Francis and the oil rig, Sedco-K, were reduced for the purpose of comparing extreme wind conditions. Note, however, that a reduction factor was not applied on all the time-series. At Walker Point the anemometer was well placed at 13 m above sea level.

A4.1 Vertical Wind Profile

Sedco-K. Only on the oil rig, Sedco-K, was wind speed available at two levels to give some indication of the vertical wind shear offshore. Although the lower anemometer, placed 3 m above the roof of the starboard winch control housing (approximately 20 m above sea-level), had no obstructions upwind under prevailing westerly wind conditions, the superstructure of the rig would still have had some upstream influence. The upper anemometer was mounted on top of the drilling tower, 73 m above sea level, with the crown block approximately 2 m below. Figure A4.1 compares the two wind speed traces:

(a) The lower anemometer was unobstructed for all cases where the speed exceeded 15 m/s, that is, the wind direction had a strong westerly component. For these higher speeds, mechanical and thermodynamic turbulence ensured good coupling between the airflows at the two levels. Note that being offshore, with relatively little diurnal change in stability, no diurnal pattern is discernable in this coupling.

(b) Making use of hourly averages calculated for both levels for peak wind conditions, the speed ratios varied from 0,91 to 0,94. Hsu (1980b), recommended a roughness length of 0,01 cm for the open sea. This gives a ratio between 73 m and 20 m of 0,90 when inserted in the log profile equation:

$$V(73) = \left[\log(Z/Z_o)/\log(20/Z_o)\right] * V(20)$$

Note that the greater the roughness length (Z_o), the greater the wind shear.

Due to an uncertainty in the actual effect of the rig superstructure, a more conservative Z_o of 0,5 cm (0,005 m), was used to reduce extreme values of hourly wind speed to 10 m. This corresponds to a reduction factor of 0,86 to the 20 m level, and 0,79 to the 10 m level. Whilst all the extreme wind speeds from Sedco-K and Cape St. Francis have been reduced using Z_o = 0,5 cm, it must be emphasised that under very unstable conditions, very little speed reduction may be necessary.

(c) Extreme **gust** values differed very little between the two anemometers on the Sedco-K, so it was decided not to apply any height reduction to gust. It might be expected that such transient peaks in wind speed would be communicated downward by the turbulence.

Cape St. Francis. Figure A4.2 presents a comparison over a short period between the anemometer on Meiring Naudé at 10 m above sea level with that of Cape St. Francis (35 m above sea level), as the research vessel came inshore to shelter in the lee of Cape St. Francis (05h00). Note that the Cape St. Francis values have not been reduced. Despite being 25 m below the lighthouse anemometer, the Meiring Naudé speeds were approximately 1,3 times higher as she approached the shore. Even if zero wind shear is assumed, there must have been a significant reduction in the flow at 35 m as the maritime air crossed the coast to reach the lighthouse anemometer - a distance of only a few hundred metres.

A4.2 Cape St. Francis - Temperature Profile and the Choice of Roughness Length

Figure A4.3 gives some indication of the range of temperature differences between the AWS sensor on the top of the lighthouse and the screen temperature 34 m below. Measured wind speed at 35 m above ground, as well as estimated surface wind are also plotted:

(a) It will be seen that high wind speeds do not necessarily mean a neutral lapse rate. At 14h00 on 27 February 1982 with a westerly gale blowing, the lapse rate was superadiabatic, whilst on 8 August at 17h00 with another westerly gale, inversion conditions were present.

(b) Lapse rates varied from +3,4°C (in 34 m) with berg wind conditions present above a shallow marine layer, to a superadiabatic -1,5°C associated with maximum heating in the early afternoon.

(c) Although only **estimates** of surface wind speed were available, it was obvious that there existed no simple relationship between temperature and wind profiles.

(d) An identical profile to that assumed for Sedco-K (that is, Z_O 0,5 cm) was eventually applied to Cape St. Francis. This gave a reduction of 0,86 from 35 m to 10 m. Justification for this choice is simply the fact that prevailing winds had very little overland track before reaching the anemometer. But the fact that Figure A4.3 clearly shows a strong diurnal signal indicates that the marine air is rapidly heated. Thus, this reduction may be too severe under conditions of strong surface heating. It may also be too **lenient** under strong inversion conditions.

A4.3 The Power Law Profile

This is a simplification of the log law:

V(z) = (Z/10)**P * V(10)

Hsu (1982) showed that P would vary considerably for different stability classes, with the smallest value (0,151) corresponding to a very unstable PBL. Note, however, that even this so-called extreme value would give too much reduction on the Sedco-K (that is, 0,74).

Dixon and Swift (1984), calculated P over the sea to be 0,08 which would give a 0,85 reduction on the rig (73-10 m). This seems to be the more suitable index for use on the Agulhas Bank.

A4.4 Spray Entrainment

This is a phenomenon which has received very little attention from researchers looking at wind profiles offshore. With the entrainment of large amounts of sea spray under gale force conditions, momentum transfer from the air to the water drops results in a modification of the vertical wind profile. Macha and Norton (1981), used a high speed wind/wave channel to show that an additional surface roughness term should be introduced into the log law. Unfortunately the results of this study could not be used on the larger height scale of the AWS. But they do indicate that the final factor chosen for the reduction of wind speeds at Cape St. Francis and on the rig, may not be too severe under conditions of heavy wind-blown spray.