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The Influence of the Upwelling Extent upon Fog Incidence at Lüderitz, SWA/Namibia

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Abstract

This paper examines the influence of the horizontal extent of the cold water upwelling on the incidence of fog at Lüderitz, Namibia, during 1983/84. The spatial extent of the upwelling was measured on days with synoptic conditions conducive to fog formation ie. when a coastal low was centred to the south of the study area. A significant relationship was identified, indicating increased fog occurrence with an upwelling extent of less than 200 km and vice-versa. The moisture necessary for fog formation was postulated as originating from the warm water to the seaward side of the upwelling zone. With a narrow upwelling, the circulation around the coastal low extends beyond the cold water mass, whereas when the extent of the upwelling exceeds that of the coastal low circulation, evaporation is limited, resulting in a relatively dry onshore air flow.

THE INFLUENCE OF UPWELLING EXTENT UPON FOG INCIDENCE AT LÜDERITZ.

Jana Olivier and Philip Stockton

The west coast of southern Africa is subject to persistent advection sea fog and low stratus cloud which considerably reduces visibility as well as incoming solar radiation at the surface (Figure 1). This fog serves both as a blessing and as a curse to the region. The precipitable moisture from the fog forms the lifeblood of the region, maintaining a rich diversity of desert flora and fauna (Taljaard, 1970; Schulze, 1974; Nieman et al, 1978), while fishermen specifically seek out areas where the fog takes longer to disperse in order to locate colder water for their fishing activities (Sciocatti, 1984). On the other hand the poor visibility associated with fog disrupts coastal air and sea transport and impedes tactical support and rescue services (Estie, 1984, 1986; Mullan, 1984). For this reason, any improvements in fog forecasting techniques would benefit the region as a whole.

Although the meteorology of advection sea fog occurrence has been studied extensively in California (Noonkester, 1979) and in the United Kingdom (Harrison & Phizacklea,1985), it has been neglected in southern Africa where research has concentrated on the contribution of fog to the precipitation input and its effects on the plants and animals of the area and the local Namib wind regimes (Jackson,1954; Taljaard, 1979; Tyson & Seely, 1980).This paper attempts to redress this shortcoming to some degree by focussing on those meteorological and oceanographic conditions favouring sea fog development.

Sea fog forms when warm air cools to dewpoint over a cold ocean (Lutgens & Tarbuck, 1979). Since a steep sea surface temperature gradient exists along the west coast, with the coldest upwelled water lying adjacent to the coast, air moving onshore traverses a progressively colder surface, causing potential fog conditions (Estie, 1986). However, research by Lutjeharms and Stockton (1987) has shown that the extent of the upwelling is extremely variable. This paper aims to investigate the possible effect of the size of upwelling on the frequency of fog, by comparing linear upwelling extent (in kilometres from the coast) with the occurrence or non-occurrence of fog. The investigation centres on the Lüderitz area because it is a centre of upwelling (Shannon, Walters & Mostert, 1979) as well as being subject to frequent west coast advection sea fogs (Figure 1).

Potential fog days

To facilitate comparison, the analysis was confined to days with similar fog producing atmospheric conditions. For this reason potential fog days (PFD) were identified. These are days on which the meso- and synoptic scale conditions seem conducive to fog formation, whether the fog actually materializes or not.

In the search for a representative PFD situation it was assumed that, for advection fog to form ;

i) the original temperature of the air should exceed the sea surface temperature (SST) of the upwelled water;

ii) a stable temperature lapse rate, with a well defined inversion layer, should exist ; and

iii) onshore winds are neccesary in order to advect the moist airstream over the cold water surface. (Estie, 1986).

Lack of upper air and sea surface temperature data for Lüderitz precluded their direct inclusion in the study. Furthermore, due to paucity of wind data and the extreme variability of the short term wind direction daily synoptic charts were used to supplement surface data in the identification of onshore air trajectories.

An onshore wind component may result from the presence of the South Atlantic High to the west of Lüderitz,a coastal low centered to the south thereof, an approaching cold front and afternoon sea breezes.

Estie (1984) noted that coastal lows are characterised by the presence of low level inversions. It was therefore assumed that potential fog conditions should exist whenever a coastal low occurs to the south of Lüderitz. This assumption was tested by comparing the presence of coastal lows with actual fog occurrence (as extracted from "past weather" Weather Bureau printouts.) In this study, the coastal low was defined as an enclosed low pressure system located to the south of Lüderitz.The lack of upper air data made it impossible to confirm the true nature of these cells. Table 1 reflects the frequency of actual fog occurence with associated synoptic conditions.

Table 1 Synoptic conditions associated with fog occurrence at Lüderitz(1984).

	Number of fog days and the associated, dominant, synoptic event.				
Month	**Coastal low**	**Other** cold fronts	Bergwinds	Unidentified	**Total**
January	7			1	8
February	10				10
March	12			2	14
April	5	1		1	7
May	6	1			7
June	1	2	1		4
July	2	4	1	1	8
August	2	3		2	7
September	6	2		2	10
October	3				3
November	12				12
December	8				8
Total	74 (75,5%)	13 +	2 +	9=24 (24,5%)	98

From Table 1 it can be seen that 75,5% of the fog days appear to be directly linked to the presence of coastal lows along the west coast, confirming the dominant role played by this phenomenon in fog formation. Of the remaining 24,5% of the fog events the approach of a cold front was observed in 13% of the cases and a temperature jump associated with berg winds (a hot dry wind from the interior), in 2%. In the other 9% of the episodes no dominant or obviously clear-cut underlying synoptic event was apparent. Since the coastal low system often precedes the passage of a cold front (Taljaard, 1972 ;Kamstra, 1985) and antecedes bergwinds, it may be assumed that the coastal low was present, but unobserved, during these conditions. This implies that 89% of fog occurrence could well be directly or indirectly linked to the presence of coastal lows. The synoptic situation existing during a PFD at Lüderitz is shown in Figure 2.

West Coast upwelling

Like the advection fog, the coastal upwelling off the west coast of southern Africa is a wind induced event (Shannon, et al, 1985; Lutjeharms et al, 1986). The prevailing winds resulting from the juxtaposition of the South Atlantic high pressure system and pressure fields over the adjacent subcontinent are predominantly southerly, and are favourable for upwelling. These winds drive the surface coastal water away from the coast and draw the cooler, underlying water to the surface (Figure 3). This results in the near coastal waters being 5°C to 7°C colder than those associated with the the South Atlantic Ocean Basin waters (Shannon, et al, 1985).

Until recently the measurement of the extent of the upwelling zone was possible only with ship and airborne sensors. In 1981 Lutjeharms showed the potential of using infrared satellite imagery to delimit the position of the upwelling boundary. A gauge of the temperature of the water is possible from these images because the colder water is lighter in tone on the Meteosat photograph due to the reduced infrared radiance from colder bodies.

For this study daily infrared images monitoring the 10,5 - 12,5 micrometer waveband from the Meteosat II satellite were used. Using the line of maximum grey scale contrast as the surface expression of the boundary between the upwelled water and the warmer South Atlantic oceanic water the daily horizontal extent of the upwelled zone was measured for 1983 and 1984 (Table 2). No measurements could be made for those periods where cloud obscured the underlying sea surface.

Upwelling extent and fog frequency

At Lüderitz fog occurs most frequently between midnight and 08h00 (Figure 4). The Meteosat imagery used, however, was sensed at 14h00 and hence the linear upwelling distance from the coastline, for the date prior to that identified as a potential fog day was measured. These distances, in 75 kilometre class intervals, were tabulated against the occurrence or non-occurrence of fog days.(Table 2)

Table 2: Upwelling extent and occurrence of fog on PFD at Lüderitz(1983,84)

Linear distance (km) of upwelling front from coastline	Number of PFD on which ;	
	Fog was Present	Fog was Absent
< 125	4	2
126 - 200	7	3
201 - 275	7	8
276 - 350	5	9
351 - 475	3	1
> 475	2	5

Using the Chi-squared measure of expected values for each cell an apparent clustering of deviations occurred, suggesting an inverse relationship between the extent of upwelling and the occurrence of fog on a potential fog day. The regrouping of the distance intervals into two classes, of less than or greater than 200 kilometres, accentuated this relationship (Table 3).

Table 3: The relationship between upwelling extents of less than and more than 200 km and fog occurrence at Lüderitz for 1983,84.

Linear distance of upwelling front (km) from coastline	Potential Fog Days on which Fog present	Fog absent	Total
< 200 km Actual	11	5	16
Chi^2 Expected	8	8	
> 200 Actual	17	23	40
Chi^2 Expected	20	20	

actual > expected

The null hypothesis, that of the pattern being a chance occurrence, was rejected at the 95% level of significance using both the Chi-squared and the Wilcoxon's-U tests.

Discussion

A possible explanation of the inverse relationship between fog and upwelling extent is postulated schematically in Figure 5.

The coastal low which causes fog is a relatively small, local phenomenon. For fog to be produced it is essential that air movement around the low pressure cell traverses a warm water body in order to gain moisture which is then condensed to form fog in the NE quadrant of the circulation cell.
These conditions are met when the extent of the upwelling is less than the diameter of the coastal low (Figure 5a). However, if the upwelled extent exceeds the diameter of the coastal low, the air circulates over a homogeneously cold surface, remains relatively dry, thus precluding the formation of fog (figure 5b).

This hypothesis was tested by comparing the dew point temperature on days with upwelling extents of less than 200 km with those days when it exceeded this distance. The Wilcoxon's-U test indicated that the dew point was significantly (95% level) higher on days when the cold water extended less than 200 km from the coastline and vice-versa, thus lending further credence to the above hypothesis.

Conclusion

The aim of this paper was to determine the relationship between the extent of cold water upwelling at Lüderitz with the occurrence or non-occurrence of fog. The analysis was limited to the days on which atmospheric conditions were similar and conducive to fog formation. Such potential fog conditions were found to exist when a coastal low was centred to the south of Lüderitz.Satellite imagery was used to find the distance from the coast to the outer limits of the cold water. A significant relationship was identified, indicating that fog was less likely to occur when the upwelling extended beyond 200 kilometres and, vice versa. This was postulated as being due to the relative dryness of the air above an extensive upwelling region and the inability of a local scale phenomenon such as a coastal low to import moist air from beyond the upwelling front. Coversely, with a narrow upwelling region, the warm water lying to the seaward side of the cold, supplies the overlying air mass with enough moisture to increase the likelihood of fog formation when such air is advected across the inshore upwelling.

Traditionally fog prediction models have included variables relating to the presence of inversions, sea surface temperatures and wind direction.This study has shown that, for the study area, the horizontal extent of the cold water mass plays a significant role in fog formation. It is therefore strongly recommended that the extent of the upwelling should be included in any fog prediction model for the west coast of southern Africa

References

1. Estie, K E 1984. "Forecasting the Formation and Movement of Coastal Lows", Paper presented at the Coastal Low workshop held at the *Institute of Marine Technology*, Simonstown, 15 & 16 March 1984, 17-27.

2. Estie, K E 1986. " Fog in the Namib" (Unpublished).

3. Harrison, S J & A P Phizacklea, 1985. " Tide and the Climatology of Fog occurennce in the Forth Estuary", *Scottish Geographical Magazine*, **101** (1), 28-36.

4. Jackson, S P 1954. " Sea Breezes in South Africa", *S.A. Geographical Journal*, **26**, 13-23.

5. Kamstra, F, 1985. "Environmental Features of the Southern Benguela with special reference to the Wind Stress". In : *South African Ocean Coloour and Upwelling Experiment*, (editor : L V Shannon), Sea Fisheries Research Institute, Cape Town, 13 - 27.

6. Lutjeharms, J R E 1981. "Satellite studies of the South Atlantic upwelling system". In : Oceanography from Space, (editor : J F R Gower), *Marine Science*, 13, Plenum Press, New York, 195-199.

7. Lutjeharms, J R E & P L Stockton 1987. "Kinematics of the Upwelling Front of Southern Africa", (In Press), *S.A. Journal of Oceanology*.

8. Lutgens, F K & E J Tarbuck 1979. *The Atmosphere - an Introduction to Meteorology*, Prentice Hall, Inc., New Jersey, p 111.

9. Mullan, D S 1984. "Low stratus and Sea Fog in the North Irish Sea", *Weather*, **39**, No. 8, 235 - 238.

10. Nieman, W A, Heyns, C & Seely, N J 1978. "A Note on Precipitation at Swakopmund", *Madaqua*, **11**, No. 1, 69 - 73.

11. Noonkester, V R 1979. "Coastal Marine Fog in Southern California", *Monthly Weather Review*, **107**, 830 - 851.

12. Sciocatti, B 1984. "The Effect of Sea Surface Temperatures on the Formation or Disposal of Advection Fog with the Passage of a Coastal Low", Paper presented at the Coastal Low workshop, held at the Institute of Marine Technology, Simonstown, 15 & 16 March 1984, 51 - 52.

13. Schulze, B R 1974. *Climate of South Africa, Part 8, General Survey*. South African Weather Bureau. Dept Environmental Affairs, Pretoria.

14. Shannon, L V, N M Walters & S A Mostert 1985. "Satellite Observations of Surface Temperature and Near-surface Chlorophyll - the Southern Benguela Region", In: *South African Ocean Colour and Upwelling Experiment*, (editor: L V Shannon), Sea Fisheries Research Institute, Cape Town, 183 - 210.

15. Taljaard, J J 1970. "The Water Context of the Atmosphere over Southern Africa", Paper read at the Convention on Water for the Future, Pretoria.

16. Taljaard, J J 1972. "Synoptic meteorology of the southern hemisphere". In : *Meteorology of the Southern Hemisphere*, (editor: C W Newton) Boston; American Meteorological Society, 139 - 213

17. Taljaard, J J 1979. "Low-level Atmospheric Circulation over the Namib", *W B News Letter*, 361, pp. 65 - 67.

18. Taljaard, J J & T E W Schumann 1940. "Upper-air Temperatures and Humidities at Walvis Bay, South West Africa", *Bull. Amer. Meteor. Soc.*, 21, 293 - 296.

19. Tyson, P D & M K Seely 1980. "Local Winds over the Central Namib", *S.A. Geographical Journal*, 62 (2), 135 - 150.

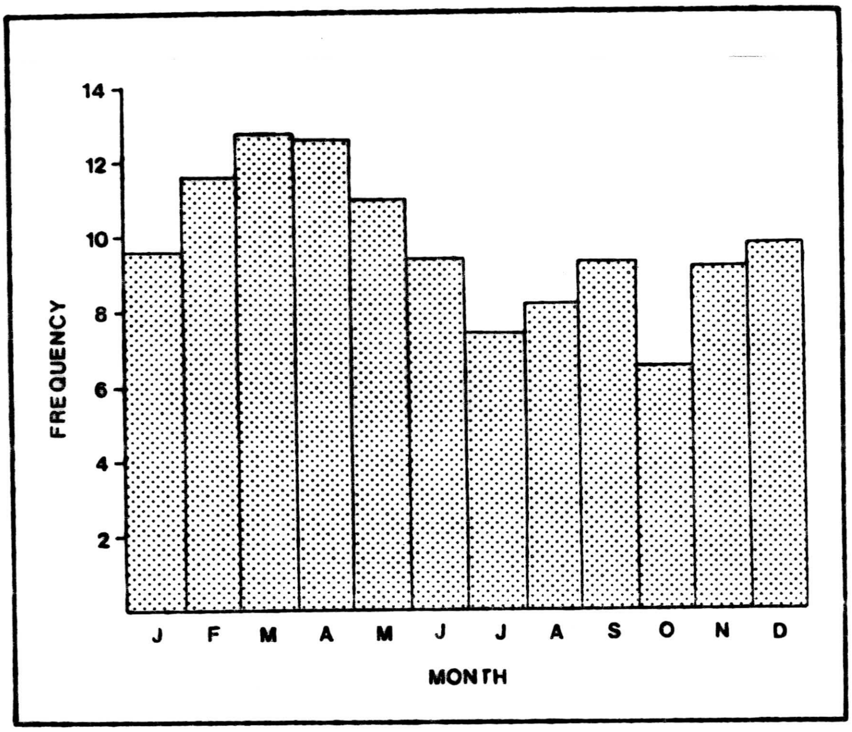

FIGURE 1 : % Frequency of fog days per month at Lüderitz (1984).

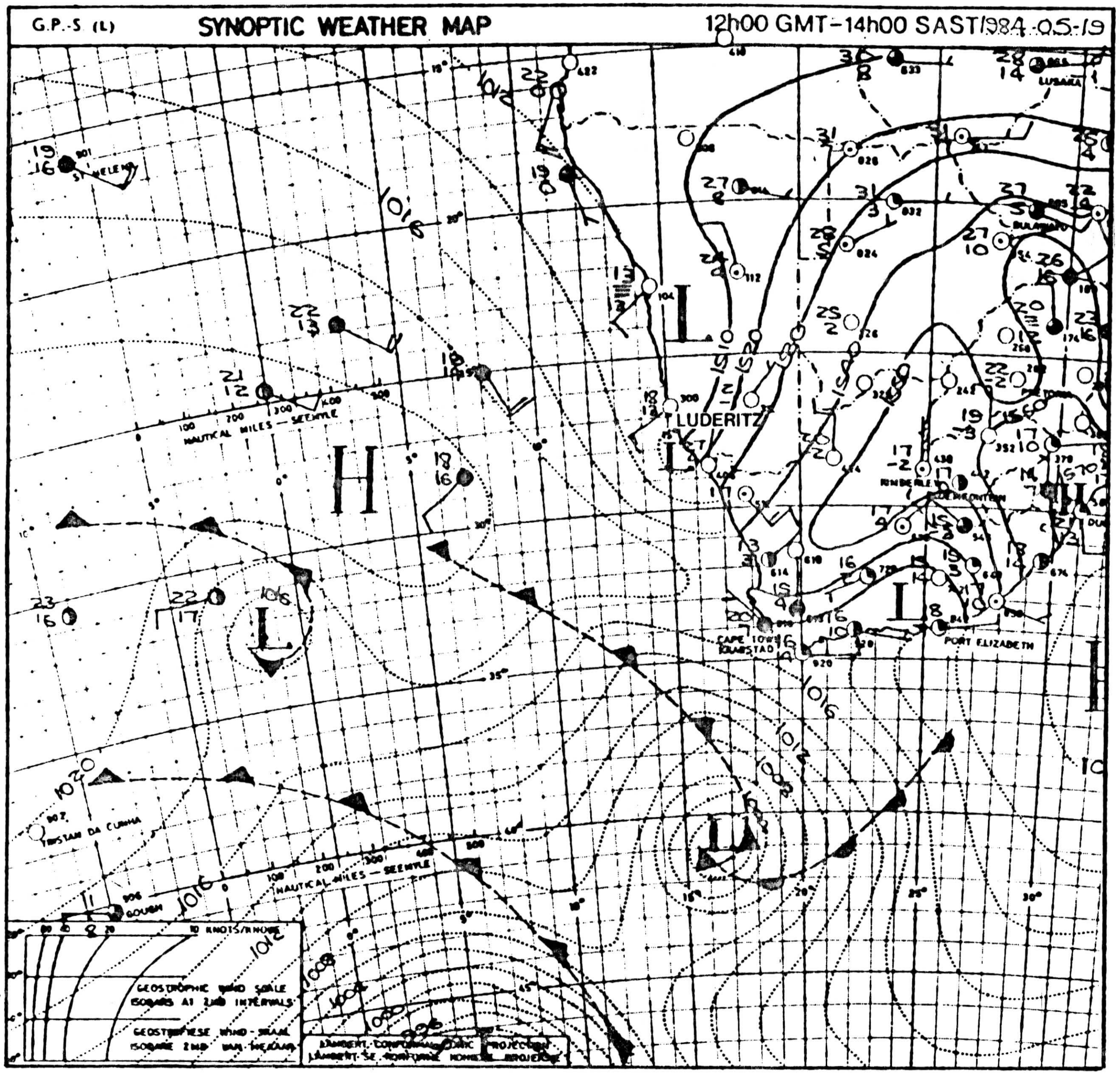

FIGURE 2 : Synoptic situation during fog occurrence at Lüderitz. The coastal low centred to the south of Lüderitz advects moist air over the cold upwelled water, possibly produ= cing fog at Lüderitz. (Source: Daily weather charts, Weather Bureau, Pretoria).

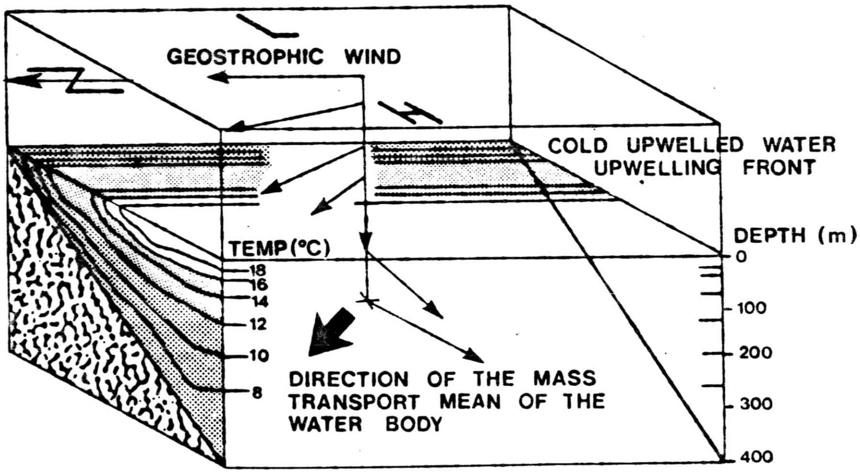

FIGURE 3 : Schematic representation of the mechanics of the coastal upwelling as it occurs along the west coast of southern Africa.

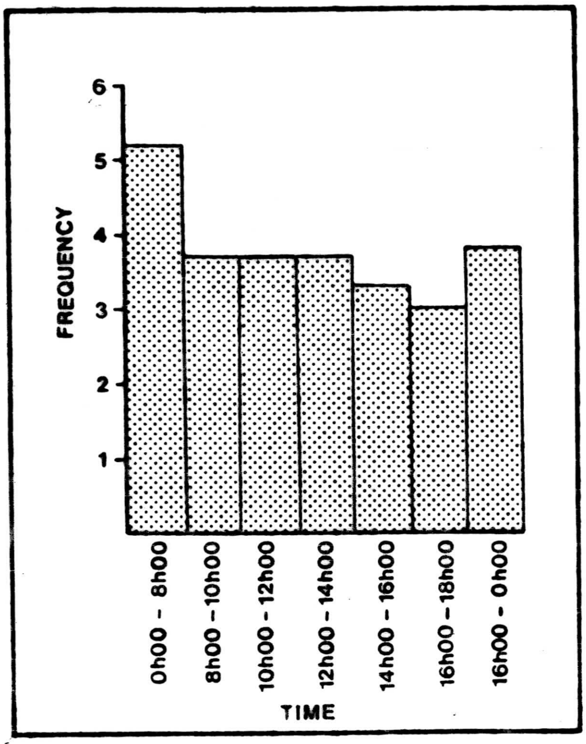

FIGURE 4 : Mean monthly frequency of fog occurrence at Lüderitz (1983, 84) during different time periods.

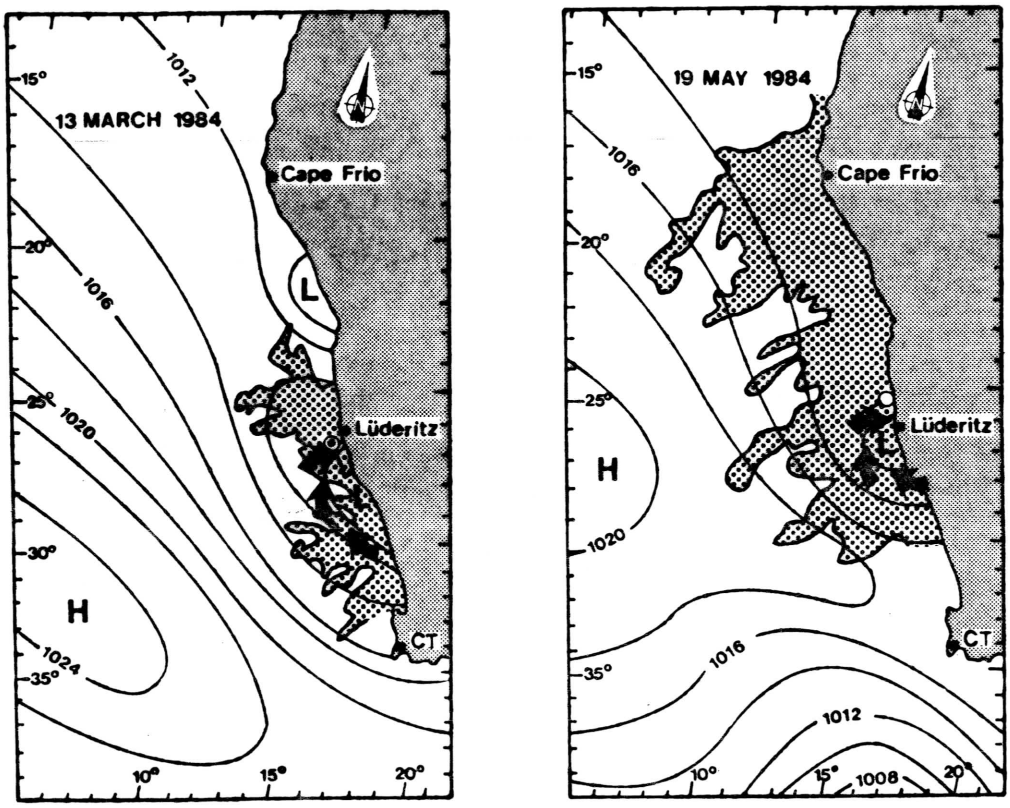

FIGURE 5 : The synoptic and upwelling situations prevailing during a fog day (13 March 1984) and a non fog day (19 May 1984) showing the location of the coastal low and its rela= tionship to upwelling extent in the formation of fog.