transport has been shown to occur over entire oceans and continents (Prospero *et al.*, 1981; Muhs *et al.*, 1990; Swap *et al.*, 1993) and has implications for global climate change (Garstang *et al.*, 1996; Tyson *et al.*, 1995; Tyson *et al*, 1996). Moreover, since the layering acts as a vertical barrier, convective rainfall over the subcontinent will be regulated to some degree by the physical structure of the discontinuities.

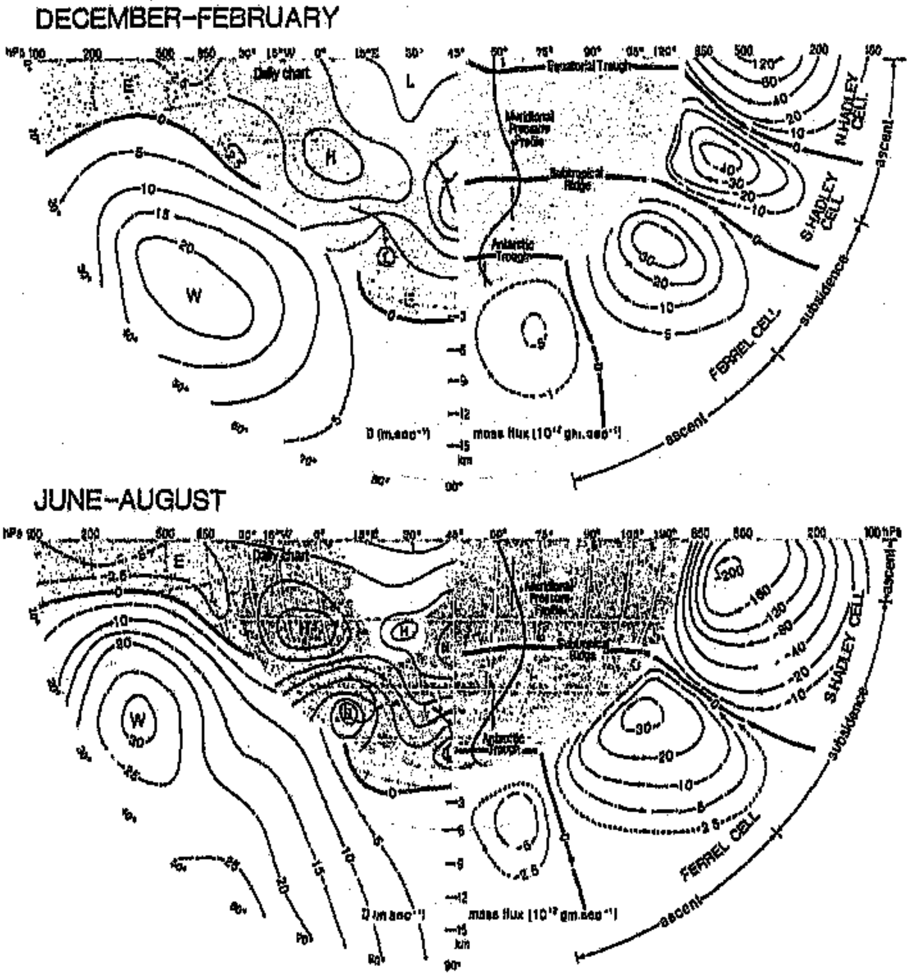

Figure 1.2 The Hadley and Ferrel Cells in relation to southern Africa (after Newell *et al.*, 1972)

In as much as elevated absolutely stable layers control pollution transport and mixing in the vertical, they are in turn controlled by prevailing synoptic circulation (Taljaard, 1955; Diab, 1975; Preston-Whyte and Tyson, 1989; Tyson *et al.*, 1995). A predominant belt of subtropical

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Elevated absolutely stable layers were identified at various altitudes over southern Africa during the Southern Africa Fire Research Initiative (SAFARI) (Garstang *et al.*, 1996). They were found to be both temporally persistent and structurally continuous over the subcontinent. The presence of these layers has obvious implications for local as well as global pollution transport, since stable discontinuities trap pollutants below their bases by inhibiting mixing in the vertical and acting as upper air boundaries (Fig. 1.1) (Munn, 1966; Diab, 1975; Hobbs, 1980; Oke, 1987; Tyson *et al.*, 1988; Preston-Whyte and Tyson, 1989).

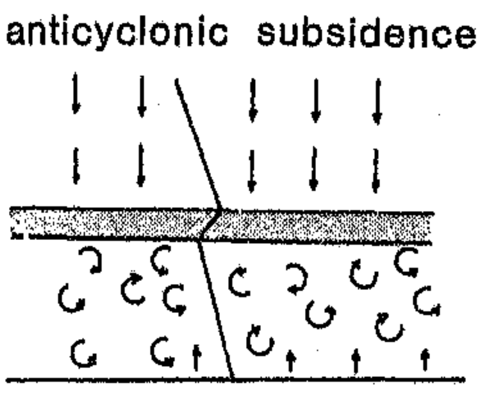

Figure 1.1 Subsiding air creating an elevated absolutely stable layer, which suppresses turbulence (after Preston-Whyte and Tyson, 1989)

Whereas both surface- and elevated absolutely stable layers may lead to local high concentrations of pollution in the troposphere, it is the elevated layers which play an important role in controlling long-range transport and recirculation of aerosols and trace gases (Taljaard, 1955; Preston-Whyte and Tyson, 1989; Garstang *et al.*, 1996; Tyson *et al.*, 1995). Such

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CONTENTS

CHAPTER

(iv) determine daily variability of elevated absolutely stable layers over the subcontinent, and

(v) establish to what extent the results found during SAFARI are representative of South Africa's general climate.

The dissertation is divided into six chapters. In **Chapter 1** absolutely stable layers are defined and the literature reviewed. Applications of the research are alluded to. **Chapter 2** describes data sources as well as the statistical and empirical methodologies which are employed. A climatology of elevated absolutely stable layers by synoptic type is presented in **Chapter 3**. **Chapter 4** presents a synthesis of the climatology where the general structure of the discontinuities is expounded. The results for all the synoptic circulation types are averaged giving a climatology for the entire year. In **Chapter 5** the elevated absolutely stable layers are analyzed for the month of July, where atmospheric stability is at a maximum. Results of this chapter are compared with previous research and the climatology for archetypal synoptic types. The daily persistence of discontinuities is also examined. Results are summarised in the **Chapter 6**.

Data used in the analyses were provided by the South African Weather Bureau. Mention must be made of Mr M. Edwards and Mr D. Waldie for their always eager assistance in obtaining the data. Thanks is extended to Dr S. Mason, for his contribution on the programming side. I am grateful for the collective input of Dr P. D'Abreton, Mr S. Crimp, Mr J. Hamilton and Mr A. Joubert who have helped out with their general comments on the work and their assistance with many computer hassles. Miss L. Harris contributed to the research in the first chapter. The cartographic work of Mr P. Stickler is acknowledged, and the assistance of Mr O. Kritzinger with the diagrams is greatly appreciated. I am indebted to Mrs S. Cosijn for her invaluable support and hard work on many of the diagrams and her help in collating the document. The supervision and continuous encouragement of Prof. P. Tyson is acknowledged with gratitude.

PREFACE

Numerous temporally persistent and spatially continuous elevated absolutely stable layers were identified throughout the vertical profile of the troposphere over southern Africa during the Southern Africa Fire Research Initiative (SAFARI). Stability over the subcontinent is attributed to anticyclonic circulation and upper air subsidence associated with the Hadley and Ferrel cells. Thus the structure and characteristics of the layers are determined, to a large degree, by prevailing synoptic circulation.

The physical structure and temporal persistence of stable discontinuities have a significant impact on convective rainfall and pollution dispersion. Pollutants tend to accumulate below the layer bases, since stability inhibits turbulent mixing in the vertical and acts as an upper air boundary. Stable discontinuities thereby control both the vertical and horizontal circulation of aerosols and trace gases. Such regulation of the distribution of these pollutants on a macroscale level and in the free-air has implications for global climate change. In order to gain greater insights into long-range transport mechanisms over southern Africa and South Africa's contribution toward global warming, a climatology of elevated absolutely stable layers based on synoptic circulation is required.

In this dissertation, spatial and temporal structures of elevated absolutely stable layers are examined over the subcontinent. More specifically, the objectives of the research are to:

(i) determine the horizontal and vertical structure of elevated absolutely stable layers for different synoptic circulation types.

(ii) ascertain the temporal persistence of elevated absolutely stable layers by synoptic circulation type.

(iii) examine the most extreme stability conditions associated with anticyclonic circulation in July.

To

Sue and Wendy

ABSTRACT

Recent research has highlighted the lack of information on elevated absolutely stable layers *per se* throughout the troposphere over the southern African subcontinent. Hence a climatology of elevated absolutely stable layers is derived for each of four predominant synoptic circulation types over southern Africa; namely semi-permanent continental anticyclones, transient mid-latitude ridging anticyclones, westerly wave baroclinic disturbances and barotropic quasi-stationary easterly waves. The horizontal and vertical structures as well as the temporal persistence of elevated absolutely stable layers are analysed using radiosonde data from nine South African aerological stations from the period 1986-1993. In addition, a climatology is derived for the mid-winter stability maximum, during the month of July from 1989-1993, in order to gain greater insights into the influence of anticyclonic circulation on the elevated absolutely stable layers. Four non-surface stable layers are identified over the country, at approximately the 800 hPa, 700 hPa, 500 hPa and 300 hPa levels. The lower of these layer occurs only over the coastal regions. All of the discontinuities exhibit a high degree of persistence and appear to be rapidly reconstructed subsequent to synoptic scale disturbances. The presence of these layers has obvious implications for local as well as global pollution transport, since stable discontinuities trap pollutants below their bases and act as upper air boundaries. As a consequence, global-scale transport of aerosols and trace gases in the free air is controlled to a large degree by these discontinuities. Greater insights into the mechanisms controlling such large-scale transport are essential in ascertaining southern Africa's contribution to greenhouse gas concentrations. Moreover, the persistence and strength of the discontinuities have implications for rainfall over the subcontinent, with the lower layers in particular acting as a vertical boundary to turbulence and mixing, and thus hindering the development of convective precipitation.

I declare that this thesis is my own, unaided work,
and that it has not been submitted previously
as a dissertation or thesis for any degree
at any other University

CRAIG COSIJN C. Cosijn

University of the Witwatersrand, 1996

STABLE DISCONTINUITIES IN THE ATMOSPHERE OVER SOUTH AFRICA

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University of the Witwatersrand, Johannesburg
Department of Geography and
Environmental Studies

Degree awarded with distinction on 25 June 1996.

Dissertation submitted to the Faculty of Science,
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for the Degree of Master of Science

stable layer for six hours before the arrival of the front. Von Gough and Tyson (1977) note that it is possible for elevated stable layers to be rapidly reconstructed once the front has passed.

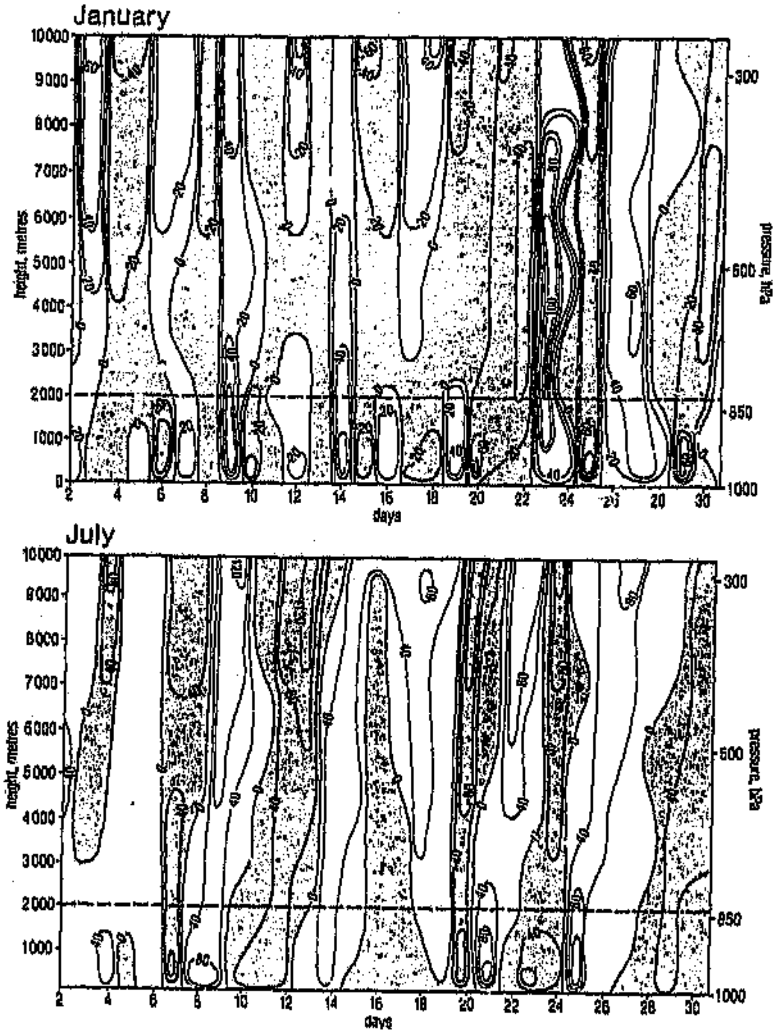


Figure 1.13 Thirty-day time-height sections during January and July to show the effect of passing weather disturbances on pressure departures (hPa) from monthly means at Durban (after Preston-Whyte and Tyson, 1989)

1.3.4 *Coastal Lows*

Although coastal lows are not one of the four predominant circulation types upon which the stable layer climatology in this dissertation is based, it is considered necessary to mention their effect on absolute stability as their influence on the coastal regions is marked and frequent. Spectral analysis of surface pressure fluctuations along the coast indicate disturbances influencing the region

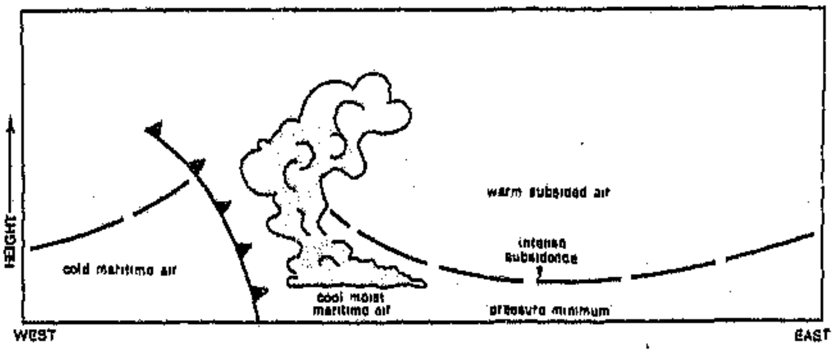


Figure 1.11 Schematic diagram to show subsidence inversion height variation with the passage of a cold front and attendant coastal low along the southern and eastern coasts of southern Africa (after Diab, 1975)

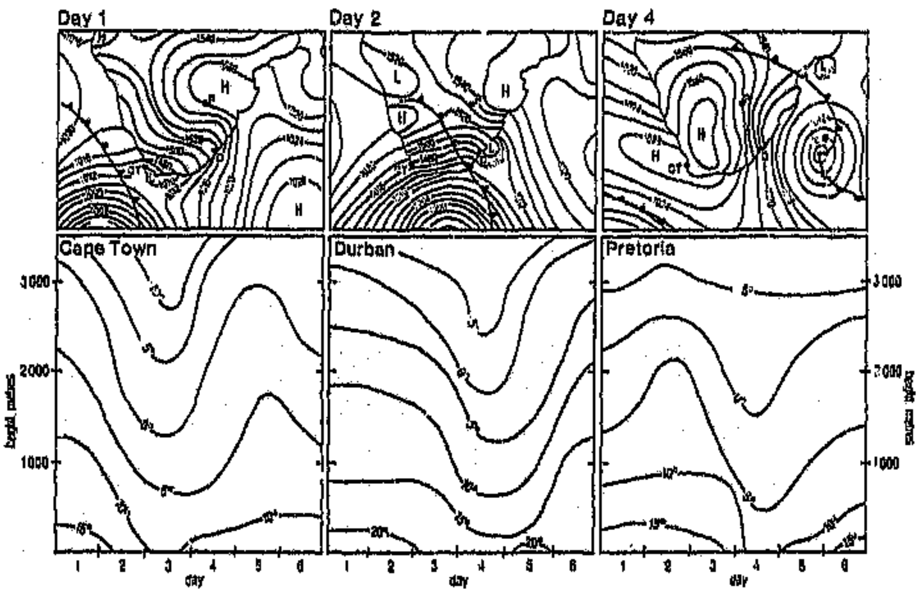


Figure 1.12 A six-day sequence to show the effect of a westerly low and cold front on the vertical distribution of temperature (after Preston-Whyte and Tyson, 1989)

The influence of westerly waves may be either shallow or may penetrate through the entire troposphere. As is shown by Figures 1.12 and 1.13 the passage of cold fronts exert their control throughout the troposphere with little time lag. There is uncertainty as to exactly when stable layers are lifted or eroded, with the approach of a front. Lamb (1972) suggests that it is immediately prior to the arrival of the front. In a similar study, Elliott (1958) observed that there is no indication of a

1.3.3 *Westerly Waves*

Transient baroclinic westerly waves influence predominantly the southern parts of the country during the winter months. During the austral summer they occur well to the south of the subcontinent exerting little direct influence on South African weather. During winter, the westerly waves migrate northwards with the Southern Hemispheric high pressure belt and may penetrate inland if the disturbance is deep and intense, and if the first non-surface inversion is weak. This typically occurs during the transitional seasons (Jackson, 1933; Preston-Whyte and Tyson, 1989).

Westerly disturbances are associated with rainfall between April and October along the south-western, southern and eastern coastal regions of the country. Near-surface divergence to the east of the trough promotes favourable conditions for stable layer development. Near-surface convergence develops to the west of the trough (Fig. 1.10d), with the consequence that the eastward moving wave destroys, weakens or forces the lifting of any stable discontinuities that were present with pre-frontal conditions (Fig. 1.11) (Taljaard, 1955; Taljaard *et al.*, 1961; Byers 1974; Preston-Whyte, 1975; Tyson *et al.*, 1976; Tyson *et al.*, 1988).

WESTERLY WAVE

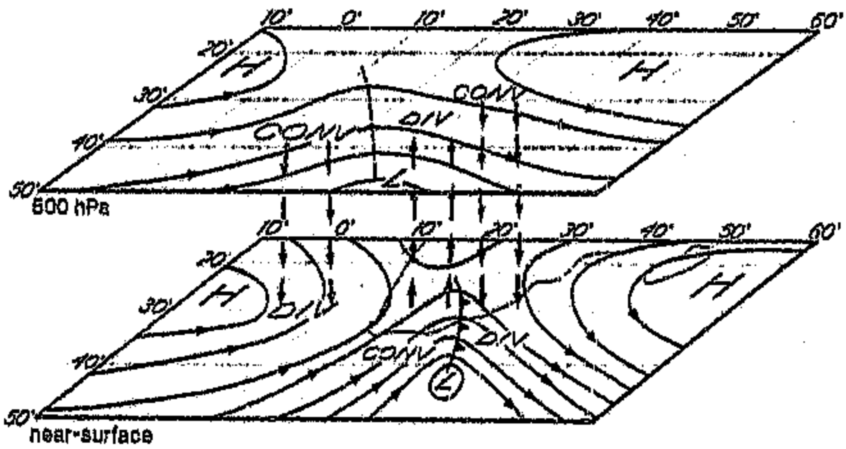


Figure 1.10d A schematic representation of near-surface and 500 hPa circulation associated with a westerly wave (after Preston-Whyte and Tyson, 1989)

discontinuities (Taljaard, 1955; Preston-Whyte and Tyson, 1989); and secondly, anticyclonic recirculation over the subcontinent has the potential to compound atmospheric pollution accumulation under the stable layer bases (Annegarn *et al.*, 1993; Garstang *et al.*, 1996; Held *et al.*, 1994; Tyson *et al.*, 1995, 1996).

1.3.2 *Easterly Waves*

Quasi-stationary easterly waves are tropical disturbances occurring over the north of the country during the austral summer. They migrate northwards during winter, exerting little direct influence on South Africa during these months. Typically, they are shallow systems which are experienced weakly at the 500 hPa surface, and are overlain in the upper air by warm-cored anticyclonic circulation (Preston-Whyte and Tyson, 1989).

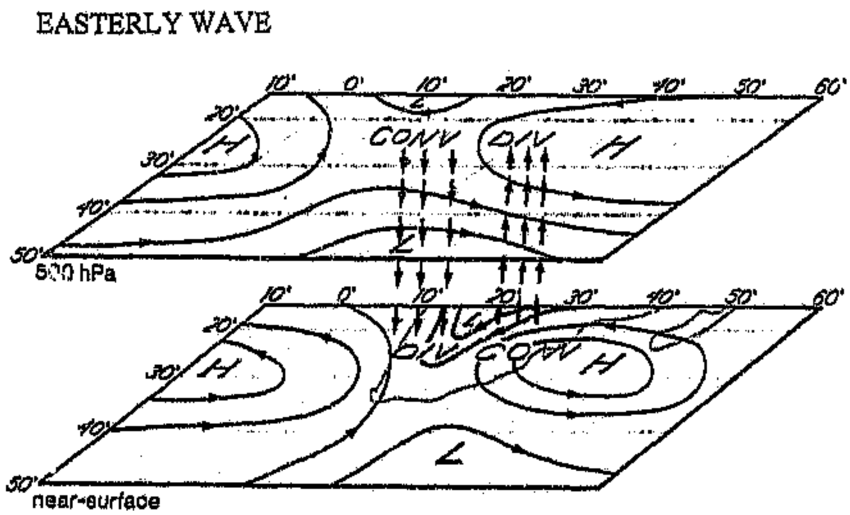


Figure 1.10c A schematic representation of near-surface and 500 hPa circulation associated with an easterly wave (after Preston-Whyte and Tyson, 1989)

Near-surface convergent activity develops to the east of the trough, with near-surface divergence to the west (Fig. 1.10c) (Preston-Whyte and Tyson, 1989). Under such conditions, stable layer development is favoured to the west, but not to the east where convective activity destroys the layers or forces them to higher altitudes (Byers, 1974; Tyson, 1976; Tyson *et al.*, 1988). Above 500 hPa subsiding air from the overlying anticyclone promotes the formation of absolutely stable layers.

CONTINENTAL ANTICYCLONE

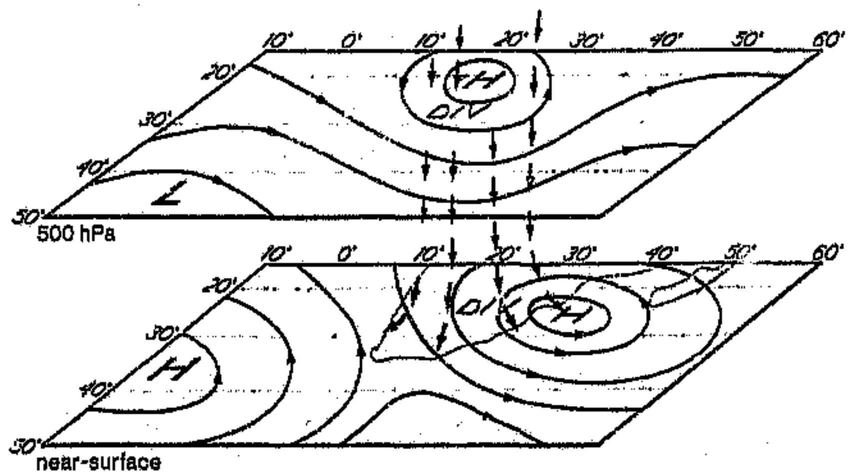


Figure 1.10a A schematic representation of near-surface and 500 hPa circulation associated with a ridging anticyclone (after Preston-Whyte and Tyson, 1989)

RIDGING ANTICYCLONE

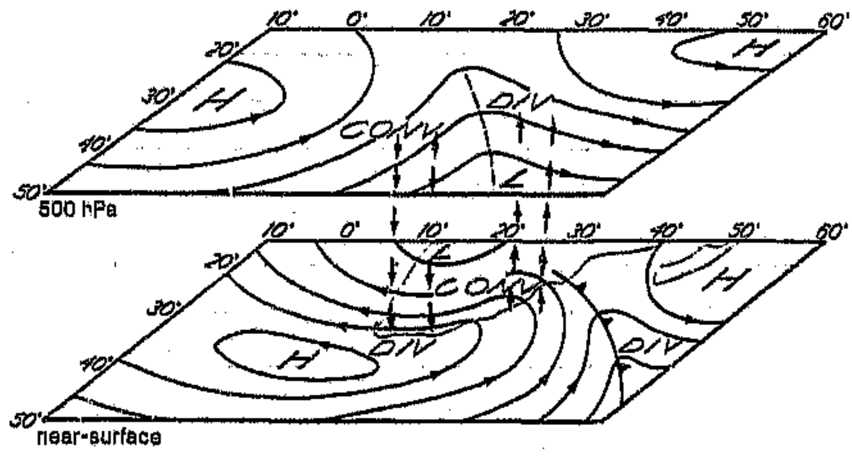


Figure 1.10b A schematic representation of near-surface and 500 hPa circulation associated with a continental high pressure system over southern Africa (after Preston-Whyte and Tyson, 1989)

than any other anticyclone over the oceans (Vowinckel, 1955a), and therefore exerts a significant control upon the stability regime over the east coast (Diab, 1975).

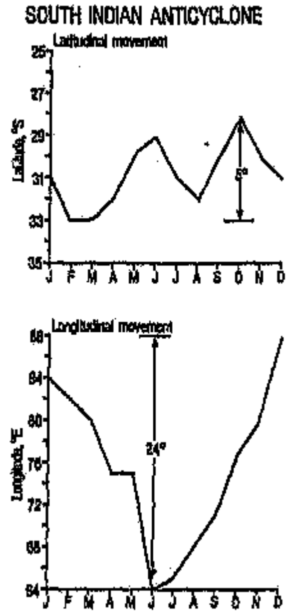


Figure 1.9 Annual variation in the position of the South Indian Anticyclone (modified after Vowinckel, 1955; McGee and Hastenrath, 1966)

The continental anticyclone is persistent over the plateau for the majority of the year, but is particularly deep, intense and frequent during the winter months. It is characterised by near-surface divergence and upper tropospheric convergence together with subsidence through the 500 hPa surface into the lower atmosphere (Fig. 1.10b). These factors provide atmospheric conditions which particularly favour the development of both elevated and surface-based stable layers. The north-westward displacement of the continental anticyclone with altitude (Fig. 1.10b), from its near-surface position over Mpumalanga, Gauteng and the Northern Province promotes favourable conditions for upper air stability over Botswana and northern Namibia (Preston-Whyte *et al*, 1977; Preston-Whyte and Tyson, 1989).

The influence of anticyclonic circulation over the subcontinent is two-fold. First, large-scale subsidence associated with anticyclonic conditions promotes the occurrence of multiple stable

The interaction between the South Atlantic Anticyclone and local sea-breezes induces strong low-level inversion conditions over the west coast of South Africa during the austral summer (Taljaard, 1955). The mean seasonal displacements of this synoptic system are shown in Figure 1.8 (Vowinckel, 1955b). Over a period of days, however, the anticyclone may ridge around the south of the subcontinent in the lee of westerly waves. This ridging activity has a bimodal maximum frequency during February and October, and may bring rainfall to the south-eastern parts of the country (Fig. 1.10a), particularly the coastal regions. Over the south-western parts of the country, near-surface divergence and fine, hot weather are associated with enhanced stable layer development. The ridging anticyclone system may vary in depth from below the escarpment to above the 500 hPa surface (Preston-Whyte and Tyson, 1989).

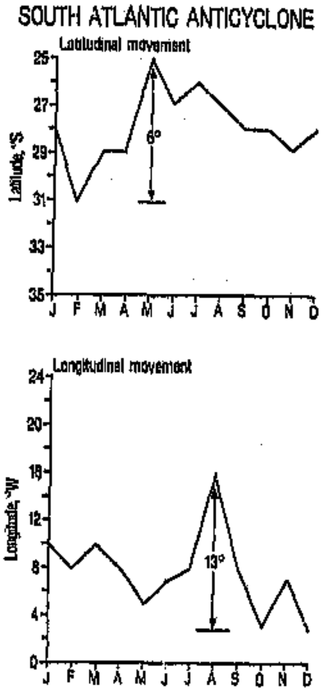


Figure 1.8 Annual variation in the position of the South Atlantic Anticyclone (modified after Vowinckel, 1955; McGee and Hastenrath, 1966)

According to Diab (1975), the annual east-west oscillation of the South Indian Ocean Anticyclone (Fig. 1.9) plays a large role in controlling the weather on the east coast of the country. The anticyclonic influence is most strongly felt during June, when it is at its western-most location, and is least experienced during the summer months (Diab, 1975). The intensity of the cell is greater

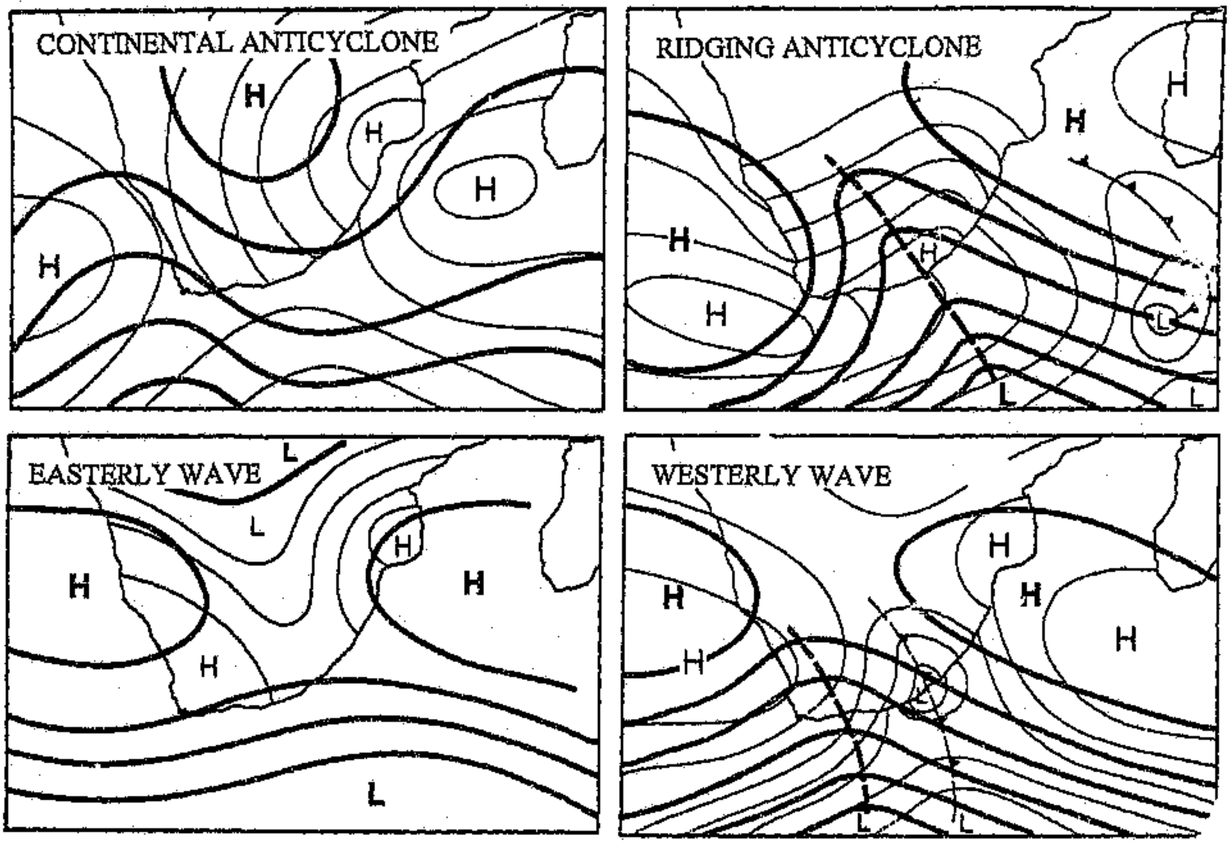


Figure 1.6 Four predominant synoptic circulation types over southern Africa (after Preston-Whyte and Tyson, 1989)

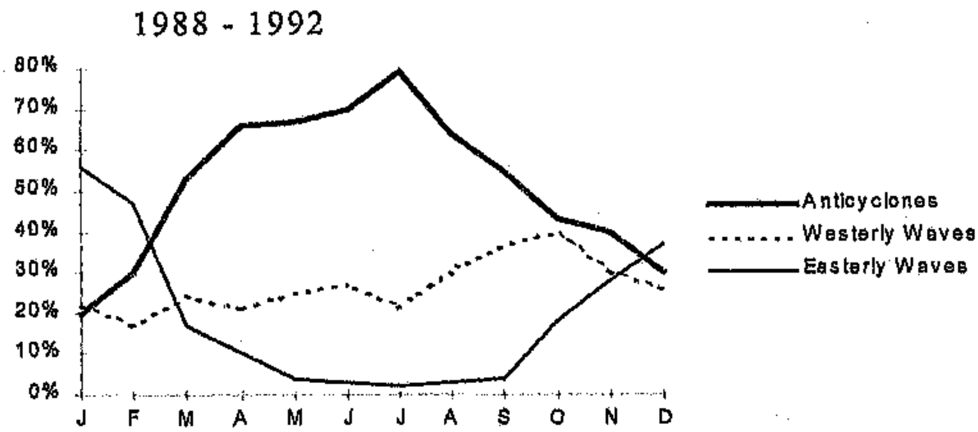


Figure 1.7 Frequency occurrence of predominant circulation types over southern Africa (after Preston-Whyte and Tyson, 1989). (Abscissa represents months of the year)

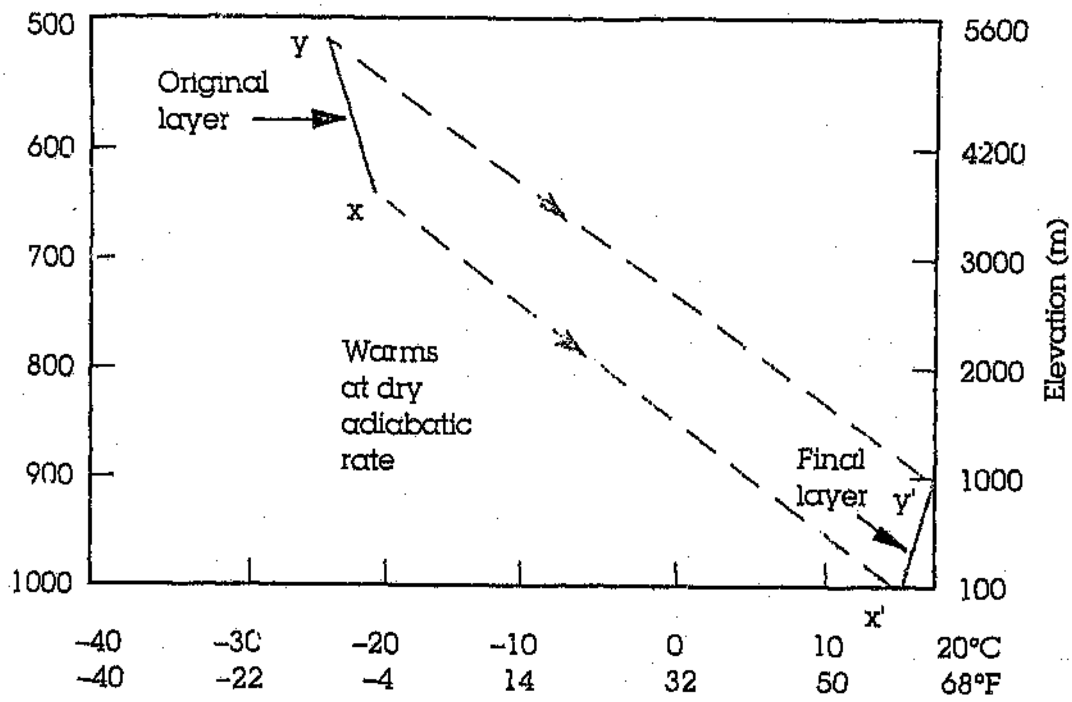


Figure 1.5 Elevated absolutely stable layer caused by upper air subsidence under anticyclonic circulation (after Ahrens, 1993)

upward movement of air, which penetrates the stable air, and erodes the base. The stable layer is weakened by the mixing, is lifted to higher altitudes and the base height variability is increased (Preston-Whyte and Tyson, 1989).

1.3.1 *Anticyclonic Circulation*

As South Africa is situated in a subtropical belt of high pressures (Newell, *et al.*, 1972; Preston-Whyte and Tyson, 1989) the predominant circulation over the majority of the subcontinent is anticyclonic, occurring with a maximum frequency during the austral winter (Fig 1.7) (Jackson, 1952; Taljaard, 1953; Tyson, 1976, 1987). Three semi-permanent anticyclones are observed to influence the climate over the subcontinent; namely, the South Atlantic Anticyclone, the South Indian Ocean Anticyclone and the continental anticyclone.

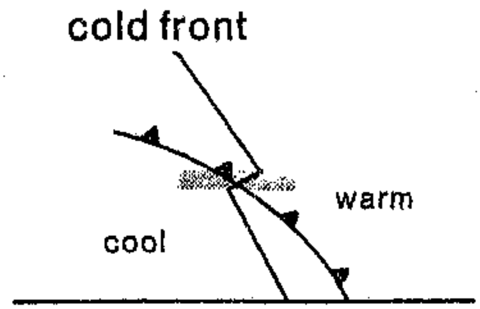


Figure 1.4 Elevated Inversion layers induced through frontal activity (after Preston-Whyte and Tyson, 1989)

cause the layer to become more stable (Fig. 1.5). This phenomenon is most likely to occur aloft during anticyclonic circulation, but may occasionally occur at the surface (Oke, 1987; Ahrens, 1993). The induced stability would usually act to inhibit convective mixing in the vertical. Alternatively, if the convection is strongly forced, the layer would be eroded and/or forced to higher altitudes (Preston-Whyte and Tyson, 1989).

1.3 THE INFLUENCE OF SYNOPTIC SCALE CIRCULATION ON THE OCCURRENCE OF ABSOLUTELY STABLE LAYERS

The structure and distribution of stable discontinuities are influenced significantly by prevailing synoptic conditions. The four most frequently occurring synoptic scale circulation types over South Africa are semi-permanent continental anticyclones, transient mid-latitude ridging anticyclones, quasi-stationary easterly waves, and westerly wave baroclinic disturbances (Fig. 1.6) (Tyson, 1987; Preston-Whyte *et al.*, 1989). These provide the basis for studying the stratigraphy and distribution of absolutely stable layers over the country.

Synoptic circulation is instrumental in controlling vertical divergence and convergence, which in turn directly control the temporal and physical structures of stable layers. Subsiding air is associated with surface divergence and initiates conditions which are favourable for the formation of stable layers. The layers themselves tend to be shallow and intense, exhibiting low base level fluctuations. Vertical convergence, on the other hand, is associated with surface turbulence and the

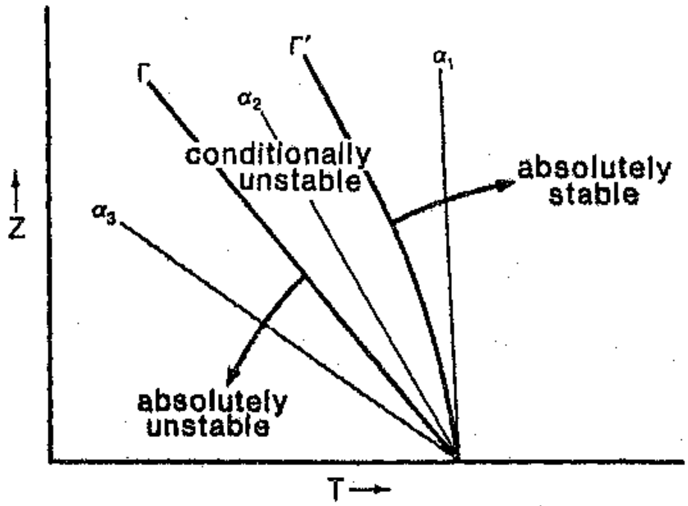


Figure 1.3 Absolute stability, conditional stability and absolute instability, where T is temperature, Z is height, Γ is the dry adiabatic lapse rate (DALR), Γ' is the saturated adiabatic lapse rate and α_1, α_2 and α_3 are three hypothetical environmental lapse rates (ELR) (after Preston-Whyte and Tyson, 1989)

air, or adiabatic warming from upper air subsidence, usually associated with anticyclonic conditions (Munn, 1966; Longley, 1970; Oke, 1987; Preston-Whyte and Tyson, 1989; Ahrens, 1993). Radiative cooling generally accompanies the formation of inversions and stable layers which are surface-base. These fall beyond the scope of this study and will not be considered further. Cold air advection and subsidence will be discussed in more detail as they typically result in the development of elevated absolutely stable layers in the free air.

When katabatic flows or cold fronts advect cool air into an area, the dense cold air undercuts the warmer ambient air, resulting in an inversion layer at the interface between the two air masses (Oke, 1987; Preston-Whyte and Tyson, 1989) (Fig. 1.4). In contrast, the development of subsidence inversions can be best understood if an example is taken of a thick layer of unsaturated air covering a large area. Assuming that this layer were to undergo subsidence, induced by upper air convergence and surface divergence (as typically occurs in anticyclonic conditions), the layer would be compressed under the increasing weight of the atmosphere as it descends. The top of the layer would therefore descend further from its original position than would the base, experience greater warming and consequently high pressures over South Africa is caused by the descending limb of the Ferrel and Hadley Cells in the southern hemisphere (Fig. 1.2) (Newell, *et al.*, 1972; Preston-Whyte and Tyson, 1989). The resultant dominance in anticyclonic circulation with its associated upper air subsidence, promotes the formation of persistent absolutely stable discontinuities throughout the vertical profile of the troposphere (Taljaard, 1955; Preston-Whyte and Tyson, 1989).

Until their identification during SAFARI, southern African elevated absolutely stable layers *per se*, throughout the troposphere have not received much research attention. Numerous questions concerning their temporal and structural nature remain as yet unanswered. This dissertation therefore attempts to:

(i) determine the vertical a[illegible]ntal structure of elevated absolutely stable layers for different synoptic circulation types.

(ii) ascertain the temporal persistence of elevated absolutely stable layers by synoptic circulation type.

(iii) examine the most extreme stability conditions associated with anticyclonic circulation in July.

(iv) determine daily variability of elevated absolutely stable layers over the subcontinent, and

(v) establish to what extent the results found during SAFARI are representative of South Africa's general climate.

1.2 DEFINITION OF AN ELEVATED ABSOLUTELY STABLE LAYER

An absolutely stable layer is defined as having an environmental lapse rate (ELR) which is less than the saturated adiabatic lapse rate (SALR) (Fig. 1.3) (Berry et al., 1945; McIlveen, 1986; Preston-Whyte and Tyson, 1989). Temperature inversions are an extreme form of absolute stability where temperature increases with height (Berry *et al.*, 1945; Oke, 1987; Preston-Whyte and Tyson, 1989).

The formation of both absolutely stable layers and temperature inversions may occur as a result of radiative cooling from the earth's surface, horizontal advection of warmer or cooler

CHAPTER 2

DATA AND METHODOLOGY

2.1 PHYSICAL CHARACTERISTICS OF THE SUBCONTINENT

South Africa lies in the region between 15° and 35° East and 22° and 35° South. For the purpose of this study the area is broadly divided into two regions, namely, the plateau and the coastal region (Fig. 2.1). The regions are separated by the escarpment which varies significantly in height, reaching its highest elevation of 3000 meters in Lesotho. The plateau generally stands above 1000 meters and has an average altitude of about 1500 meters. The escarpment constitutes a major climatological and meteorological barrier (Jackson, 1947), and is likely to exert a significant impact upon the occurrence of stable discontinuities in the lower troposphere.

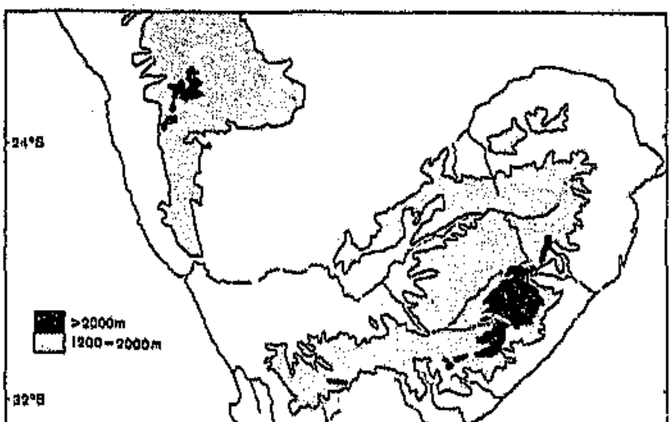


Figure 2.1 Generalised relief of southern Africa (after Cole, 1961)

1.6 CONCLUSIONS

It is apparent that the majority of the earlier research has been concerned with the most extreme case of absolutely stable layers, namely temperature inversions. No research, except that of SAFARI, has focused on absolute stability *per se*, throughout the troposphere. Of the free-air inversion studies, most work has focused on the first non-surface inversion. The work of Garstang *et al.* (1996) has clearly shown the importance of researching not only temperature inversions, but all absolutely stable conditions. Moreover, attention should be given to elevated absolutely stable layers throughout the vertical profile of the troposphere, and not just to the first elevated inversion.

* * * * * * *

The fundamental concepts of elevated absolutely stable layers have been introduced in this chapter. Previous research has been reviewed and the influence of synoptic scale circulation features on stable layers have been discussed. Data and methodology to be used are discussed in Chapter 2.

minimum sea-surface temperatures in the Agulhas (Grundlingh, 1987) occur simultaneously with highest and lowest inversion bases at Durban, but not at Port Elizabeth (Harrison, 1993). Factors influencing inversion development over the coastal regions are not yet fully understood, and require further research.

1.5.2.3 The West Coast

The South Atlantic Anticyclone is typically quoted as being the predominant mechanism controlling inversion frequencies over the west coast (Diab, 1975; Preston-Whyte *et al*, 1977). Although the South Atlantic Anticyclone is at its eastern-most position when inversions are strongest and inversion bases are lowest, the core of the circulation system lies west of the Greenwich Meridian (Fig. 1.8) (Vowinckel, 1955b), and this is the time of year when anticyclonic circulation is weakest. Low-level diabatic control is rejected as an influence, since the highest bases occur close to the period of minimum surface temperatures (Harrison, 1993). Consequently, Harrison (1993) proposes two factors to control west coast inversions. The first is upper air subsidence associated with outflow from convection over the interior. During winter the outflow is associated with the Asian summer monsoon and thus subsidence is limited, causing higher inversion bases. The second, and probably more important factor, is the influence of heat fluxes from the Benguela Current. During summer, maximum atmospheric cooling (Hastenrath and Lamb, 1978) is coincident with maximum inversion frequency and intensity.

1.5.2.4 The Southern African Subcontinent

Theron and Harrison (1991) found that the inversions are dynamic and thermodynamic interfaces demarcating the three levels at which air flow directions reverse. The coastal inversion lies within the boundary zone, which has its upper limit at the plateau inversion, near 700 hPa. Decoupling generally occurs between the surface layers up to the coastal inversion, and the layers between the coastal and plateau inversions. Above the boundary layer lies the barotropic zone, and above that the jet-stream zone. The boundary between these latter two layers is also marked by a temperature inversion at approximately 200 hPa. This inversion may be associated with both the jet-stream (Harrison and Theron, 1991) and the tropopause (van Loon *et al.*, 1968; Labitzke and van Loon, 1972; Newell *et al.*, 1974).

motion over the Indian Ocean is 1000 km (Stefanick, 1980). Hence, it is suggested that the anticyclonic circulation over the subcontinent forms independently from the South Indian Ocean Anticyclone (Streten, 1980).

A suggested process maintaining strong low-level inversions, given the above conditions, is sub-inversion diabatic cooling via long-wave radiation escape through a dry atmosphere (Harrison, 1986). Turbulent mixing of cooled air below the nocturnal surface inversion, in addition to an upper radiational surface of particulate matter trapped below the inversion, will help to preserve the relative coldness of near-surface air (Harrison, 1993). The fact that the inversions are maintained by strong local diabatic controls is indicated by lowest inversion levels being coincident with lowest temperatures (Diab, 1977; Harrison, 1993).

Whereas inversion heights are a function of low-level diabatic processes, inversion depths appear not to fit into this cycle. To suggest, however, that the depths may therefore be dependant on subsidence intensity would imply that subsidence intensity is spatially and temporally restricted across the plateau, which is unlikely to be the case. A possible alternative interpretation is that the results of the research may be data dependant rather than indicative of process changes, due to the fact that the depths fluctuate very little during the year (Harrison, 1993).

1.5.2.2 The Eastern and Southern Coasts

Over all of the coastal regions, except Durban, maximum surface pressures are synchronous with maximum inversion frequencies, strengths and lowest base heights, indicating that low-level diabatic processes are involved in the inversion formation (Harrison, 1993). An alternate hypothesis to one of low-level diabatic control is upper air subsidence, not through the influence of the South Indian Ocean Anticyclone (as is discussed above), but possibly due to outflow from the interior associated with summer convection, causing suppression around the coastal regions. This process would explain the phase reversals between the coast and the interior (Harrison, 1993).

Over Durban, however, maximum inversion frequencies are associated with minimum base-levels and minimum temperatures, during July (Theron and Harrison, 1991) pointing to the lack of low-level diabatic control. Possible alternative inversion controls over the east coast are ocean to atmosphere heat fluxes over the Agulhas Current, which are at a maximum in December (Walker and Mey, 1988, Harrison, 1993), and sea-breezes (Preston-Whyte, 1977). The maximum and occurs at this height during mid-summer and for the latter, during September. Base heights decrease during mid-winter to minimum values of 1600 meters for Pretoria and 1730 meters for Bloemfontein, under the influence of stronger subsidence closer to the core of the continental high (Diab, 1975). Taljaard (1955) observes winter inversions at a mean height of 1760 meters over Pretoria.

Interior stations experience peak frequencies during the winter months, and minima during summer (Fig. 1.17e, 1.17f) (Preston-Whyte *et al.*, 1977; Harrison, 1993). During the winter months anticyclonic circulation is more intense over the plateau causing non-surface inversions to be even more pronounced and frequent. Over Pretoria, first elevated inversion frequencies range from 68-16% during June and February respectively (Diab, 1975; Preston-Whyte *et al*, 1977). The frequencies over Bloemfontein are 40% in June and fall to 3% in December. Taljaard (1955), however, observed much higher inversion frequencies over the plateau, in the order of three out of every four days (75%) during winter, and one out of every two days (50%) in summer.

In summary, all the stations except Cape Town appear to follow a dominant annual frequency cycle (Harrison, 1993). Furthermore, a country-wide semi-annual cycle is evident with the interior experiencing maxima during December and January, and the coastal stations experiencing maxima during February and March. A prominent antiphase relationship exists between Pretoria and Durban (Harrison, 1993).

1.5.2 *Recent Developments in Understanding the Controls of Non-Surface Inversions*

Harrison (1993) comments on some of the possibly simplistic explanations put forward concerning the mechanisms controlling non-surface inversions, in earlier studies. He suggests that in some instances synoptic features may have been attributed with more influence than is tenable, and that there may be other influences involved which are not necessarily synoptic in nature.

1.5.2.1 The Plateau

It has been suggested that the western limb of the South Indian Ocean Anticyclone is responsible for maximum inversion frequencies over the interior during winter (McGee and Hastenrath, 1966; Diab, 1975; Preston-Whyte *et al.*, 1977). Harrison (1993) suggests that this is unlikely as the mean western-most extent of the South Indian Ocean Anticyclone is only 64°E (Fig. 1.9) (Vowinckel, 1955b; Streten and Pike, 1980), and the characteristic scale of transient system and Harrison, 1991), whilst the lower inversion is most frequent in spring. It is likely that these two inversions have been confused to some degree by including the data for both inversions in the analysis by Diab (1975) and Preston-Whyte *et al.* (1977) (Harrison, 1993).

The lower of the two layers is observed at 1000 meters over Durban and Maputo during the winter and rises to between 1200 and 2000 meters during the summer months (Taljaard, 1955). Diab (1975) and Preston-Whyte *et al.* (1977) suggest that the first elevated inversion height ranges between 1360 and 1675 meters (Fig. 1.16d), with the base of the inversion lying closest to the surface during July and August. This winter decrease in inversion height is attributed to the influence of the South Indian Ocean Anticyclone (Diab, 1975; Preston Whyte *et al.*, 1977). In comparison with the west coast, the east coast inversion generally occurs at higher altitudes (Diab, 1975; Preston-Whyte and Tyson, 1977).

Lowest inversion frequencies (40%) over the east coast occur during early winter, and highest frequencies (84%) during spring (Fig. 1.17d). However, unlike the layers over Port Elizabeth, the period of low frequencies does not coincide with an increase in inversion height (Diab, 1975). Diab (1975) contends that the macroscale influence of the South Indian Ocean Anticyclone serves to explain the seasonal trends over Durban, but that fluctuations over a short time frame are associated with the passage of depressions along the coastal regions.

1.5.1.5 The Plateau

During summer, inversions over the plateau are weaker than during winter, and occur at higher altitudes due to easterly wave convective activity (Taljaard, 1955; Preston-Whyte *et al.*, 1977). Moreover, the greater altitude of the plateau and frequent diurnal convective mixing over the plateau typically cause stable layers to occur at higher altitudes over the interior than over the coastal regions (Taljaard, 1955; Preston-Whyte et al., 1977). In contrast to the coastal stations, there is an absence of free-air inversions below 500 meters altitude over the interior (Diab, 1975). Harmonic analysis indicates that at most of the stations there is a dominant annual cycle in inversion base levels (Harrison, 1993), with highest levels over the interior occur during the summer months in the region of 600-700 hPa.

The mean maximum height of the first elevated inversion over Pretoria and Bloemfontein are 2495 meters and 3185 meters, respectively (Figs. 1.16e and 1.16f). For the former the layer

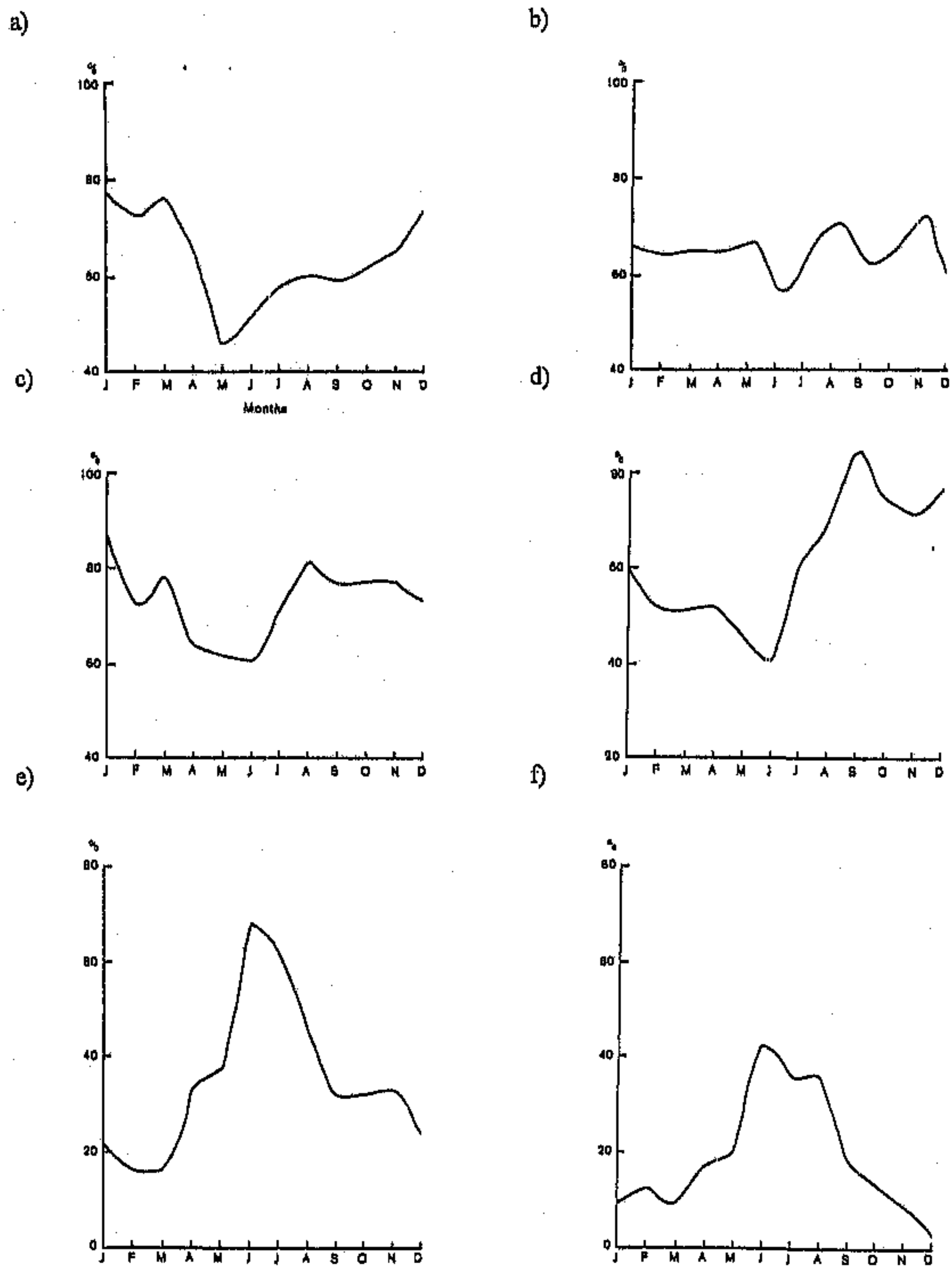


Figure 1.17 Monthly mean non-surface inversion frequency over (a) Alexander Bay, (b) Cape Town, (c) Port Elizabeth, (d) Durban, (e) Pretoria and (f) Bloemfontein (after Diab, 1975)

the mean monthly altitude of the inversion base has an annual range of 1120-1485 meters (Fig. 1.16b). The discrepancy between the findings is most probably due to the use of different data over different time periods. In addition, the layers are highly variable during summer, with factors such as strong southerly winds causing the inversions to rise more than 4000 meters, thus, possibly giving exaggerated results (Diab, 1975). Concurrent with the increased height of the layer during winter is a weakening of inversion strength to a quasi-isothermal layer, denoting the strong influence of the westerly wave disturbances (Taljaard, 1955).

The south-west coast has significantly lower inversion frequencies than does the west coast (Fig. 1.17b). With a winter minimum of 56% and a summer maximum of 73%, the south-west coast follows the same seasonal trend as the west coast, but with a lower inter-seasonal frequency variability (Diab, 1975).

1.5.1.3 The South Coast

Late autumn shows a relative decrease in both the first elevated inversion height and frequency over Port Elizabeth, due to the northward migration of the high pressure belt and the passage of westerly waves (Diab, 1975). A maximum frequency is apparent during January (86%) and a minimum during June (60%). Relative to the west and south-west coasts inversion frequencies over Port Elizabeth are lower than Alexander Bay, but slightly higher than Cape Town. The magnitude of the annual frequency variation is similar to that of Cape Town (Fig. 1.17c) (Diab, 1975).

During summer there appears to be less variability about the mean inversion height than over the west and south-west coasts, which may be attributed to the ridging of high pressure systems around the south of the subcontinent during this time of year (Diab, 1975). Otherwise, the inversion regime is, on the whole, similar to that of the south-west coast, with mean inversion heights ranging between 780-1490 meters for March and September respectively (Fig. 1.16c) (Diab, 1975).

1.5.1.4 The East Coast

Over the east coast two elevated absolutely stable layers are apparent, which are seemingly formed by different processes (Taljaard, 1955; Diab, 1975; Harrison, 1993). The upper layer is most frequent in winter and is most probably an extension from the inversion over the interior (Theron

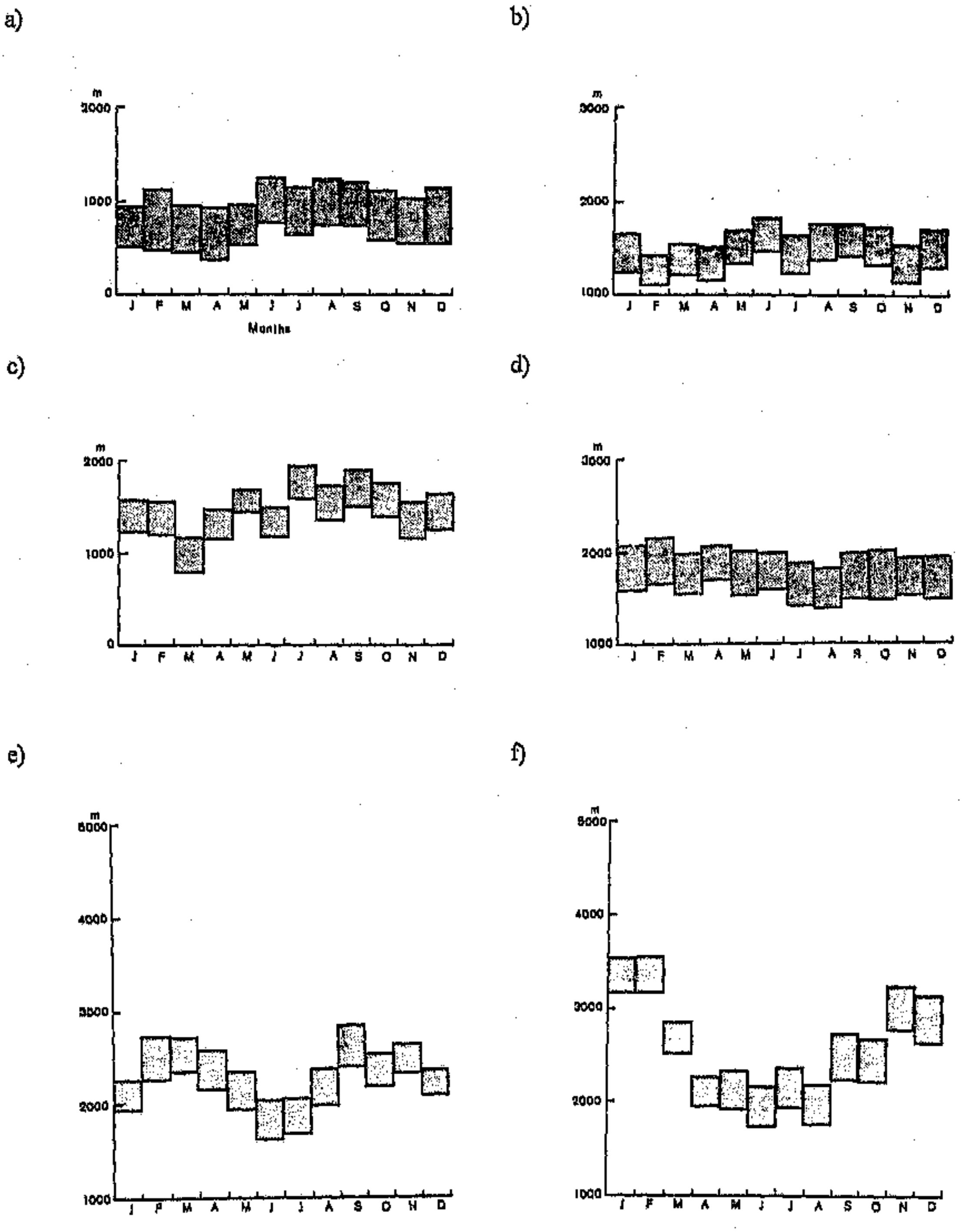


Figure 1.16 Monthly mean non-surface inversion base heights over (a) Alexander Bay, (b) Cape Town, (c) Port Elizabeth, (d) Durban, (e) Pretoria and (f) Bloemfontein (after Diab, 1975)

Tyson, 1977; Von Gough, 1978, 1979). What is known of elevated inversions is due mainly to the work of Taljaard (1955), Diab (1975), Preston-Whyte *et al.* (1977) and Harrison (1993).

1.5.1 Spatial and Temporal Distribution

1.5.1.1 The West Coast

The west coast is characterised by relatively low-level non-surface inversions, which are regulated by pressure fluctuations and the cold Benguela Current (Taljaard, 1955; Diab, 1975). The inversions occur at approximately 500 meters altitude throughout the year and seldom rise above 800 meters (Fig. 1.16a) (Taljaard, 1955; Diab, 1975; Preston-Whyte *et al.*, 1977). Maximum inversion frequencies of 98% are experienced during summer, under the influence of the South Atlantic Anticyclone, and a minimum of 66% during winter. The layer shows extreme persistence on an annual basis, with frequencies of below 70% during only one month of the year, and often exceeding 80% (Fig. 1.17a) (Taljaard, 1955; Diab, 1975; Preston-Whyte *et al.*, 1977).

A separate, weaker inversion layer, is identified at approximately 2500 meters. It is presumed to be separate from the lower inversion as it has a maximum frequency during winter and a minimum during summer (Diab, 1978). The shallow first elevated inversion demarcates the boundary between moist, cool maritime air and the overlying warm, dry continental air (Taljaard, 1955; Diab, 1975).

1.5.1.2 The South-West Coast

Although the west and south-west coasts both fall under the influence of the South Atlantic Anticyclone and the Benguela Current, and have similar stability regimes, the inversion heights for Cape Town are greater than those over Alexander Bay (Fig. 1.16b) (Diab, 1975). The additional influence of ocean to atmosphere heat fluxes from the warm Agulhas current may contribute towards the development of these higher layers.

Taljaard (1955) identifies the first elevated stable discontinuity at approximately 500 meters along the south-west coast during summer. It increases to 1000 meters altitude during winter, due to the passage of westerly wave disturbances, and the fact that maritime subtropical and polar air masses are deeper during winter. Diab (1975) and Preston-Whyte *et al.* (1977), however, show that

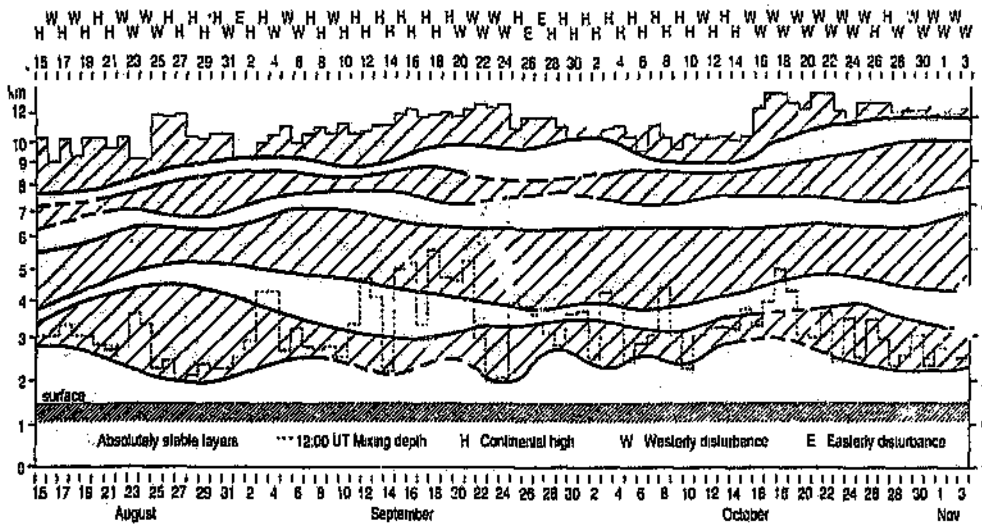


Figure 1.15 Stable discontinuities at Pretoria during the 1992 SAFARI field experiment (after Garstang *et al.*, 1996)

The 550-500 hPa layer was more persistent than the 700 hPa layer which was broken occasionally by the passage of a westerly wave disturbances. The former layer occurred for a maximum run of 53 consecutive days with only one break, despite the passage of westerly wave disturbances, whereas the latter had a longest period of occurrence of 7 consecutive days. Anticyclonic circulation was present on 55% of the days, with westerly disturbances exhibiting a frequency of 41%, and easterlies occurring 4% of the time. All of the layers were observed to be not only temporally persistent, but spatially continuous as well (Garstang *et al.*, 1996), and were found to influence air transport significantly. North of 15°S the layers were found to rise in altitude and ultimately to disap he regions of enhanced convection over the tropics.

1.5 PREVIOUS INVERSION STUDIES

To date relatively little research has been done on the structure and occurrence of stable discontinuities and elevated absolutely stable layers over southern Africa. Most of the research has focused on boundary layer inversions (Tyson, 1963; Hart, 1971; Keen, 1971; Diab, 1975; Boegman *et al.*, 1975; Tyson *et al.*, 1976; Langenberg, 1976; Von Gough and Tyson, 1977; Diab 1977, 1978a, 1978b; Tyson *et al.*, 1988) and urban he it islands (Hart, 1971; Tyson *et al.*, 1973; Von Gough and every three to six days (Fig. 1.14) (Preston-Whyte and Tyson, 1973). While macroscale synoptic features influence the subcontinent as a whole, these coastally-trapped Kelvin wave disturbances are local features influencing the sub-escarpment region only (Tyson, 1987).

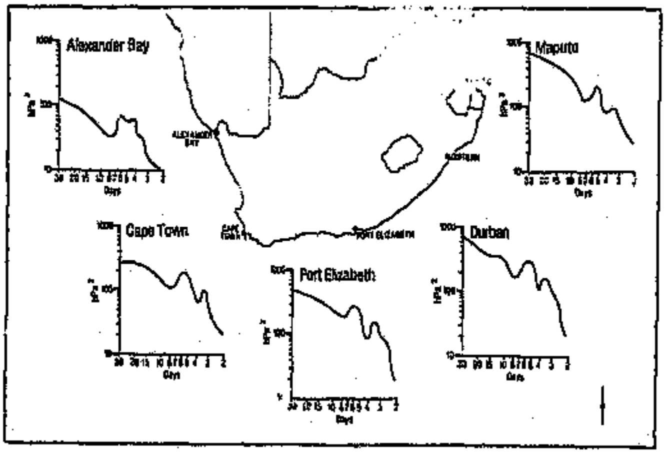


Figure 1.14 Spectra of surface pressure fluctuations at stations around southern Africa. Ninety-five percent confidence limits are included (after Preston-Whyte and Tyson, 1973)

Cooler air behind the coastal low is usually separated from the drier subsiding air above it by an inversion layer. The influence of the system extends to an altitude of approximately 1000 meters, with inversions occurring at sea-level on the leading edge of the low, and anywhere between surface-level and just below the escarpment on the trailing edge of the low. If a subsidence inversion is not present in the low, the system is most probably a surface reflection of a mid- or upper-level trough or low (..stie, 1984).

1.4 PREVIOUS RESEARCH ON ABSOLUTELY STABLE LAYERS

During the SAFARI field observation period from August 15 to October 31 1992, four persistent elevated absolutely stable layers were identified over Pretoria (Fig. 1.15). The first was associated with the top of the mixing layer at 700 hPa (approximately 3000 meters), the second was associated with the main subsidence inversion at 550-500 hPa (approximately 5000 meters), the third layer occurred at approximately 350 hPa (approximately 8500 mete..) and the fourth layer was always associated with the tropopause (Fig. 1.15) (Garstang *et al.*, 1996).

CHAPTER 3

SYNOPTIC CIRCULATION AND THE OCCURRENCE OF ELEVATED ABSOLUTELY STABLE LAYERS

3.1 INTRODUCTION

During the SAFARI field observation period of spring four persistent stable layers were identified at Pretoria over a three month period (Garstang *et al.*, 1996). It is not known, however, how representative this layering is of the general circulation over the subcontinent throughout the year. This chapter is therefore aimed at determining the physical and temporal characteristics of stable discontinuities over South Africa.

Four predominant synoptic circulation types explain much of the circulation variance over southern Africa (Preston-Whyte and Tyson, 1989; Garstang *et al.*, 1996); namely, semi-permanent continental anticyclones, transient mid-latitude ridging anticyclones, quasi-stationary easterly waves and westerly wave baroclinic disturbances. Event days have been identified where each of these circulation types are archetypal and persistent for five-day time periods between 1986 to 1993. The elevated absolutely stable layers associated with them have been analysed.

Three persistent elevated absolutely stable layers are identified over the interior and four layers are observed over the coastal regions with all four of the synoptic circulation types. The three layers are evident over the interior and occur persistently in the region of the 700 hPa, 500 hPa and 300 hPa levels across the entire country. They are spatially continuous over the plateau and extend out over the coastal regions. The additional layer is present only over coastal areas and occurs at 800 hPa, below the mean level of the escarpment. The structures of these elevated absolutely stable layers are discussed below with regard to their horizontal and vertical characteristics as well as their temporal persistence.

The 95% confidence interval (CI) is determined from the difference between the upper and lower 95% confidence limits.

It should be noted that sometimes the 300 hPa stable layer coincides with the tropopause. When this happens the stable layer extends upwards indefinitely into the stratosphere. A value for the top of the tropospheric layer cannot therefore be ascertained and a limit must be assigned. An arbitrary value of 200 hPa is assigned is such cases as the uppermost limit. This has the effect of distorting the depth of the 300 hPa layer, but has little affect on the values for the basal heights of the layers.

2.5 MAXIMUM ABSOLUTE STABILITY OVER SOUTH AFRICA

As anticyclonic circulation predominates over southern Africa and associated subsidence is the primary mechanism in the formation of the elevated absolutely stable layers, a more detailed analysis of the layers during the mid-winter stability maximum (July) is considered necessary. Radiosonde data for five consecutive years from 1989-1993 is used for this purpose.

* * * * * * *

The research has been placed in context of the physiography of South Africa and data, methodologies and statistical techniques have been explained. The analysis of elevated absolutely stable layers for archetypal synoptic circulation over South Africa is undertaken in the following chapter.

$$\bar{x} = \frac{\sum v}{n}$$

where $\bar{x}$ is the mean, $\sum v$ is the sum of the values being analysed and n is the number of stable layer events.

It is important that the terms height and depth are not confused. Height refers to altitude of the base or top of the layer above ground, whereas depth refers to the difference between the upper and lower limits of the discontinuity.

Percentage frequencies (f) are given by:

$$f = \frac{100n}{N}$$

where n is the number of stable layer event days within data set, and N is the total number of days constituting the data set.

The variability between stations may be determined from the standard deviation (σ) given by:

$$\sigma = \sqrt{\frac{\sum (x-\bar{x})^2}{n}}$$

where x is an individual value, and $\bar{x}$ is the mean for all of the individual values.

Intra-station variation, indicating the degree of variability about the mean base height, is defined by the 95% confidence limits (CL) from:

$$CL = \frac{1.95\sigma}{\sqrt{n}} \pm \bar{x}$$

individual five-day sequences (Fig. 2.4), from which mean conditions for all events have been derived over the entire time-period.

The layers so evaluated fall into one of four broad categories: the lowest layer which occurs at about the 800 hPa level, the second at approximately 700 hPa, the next in the region of 500 hPa and the final one at the 300 hPa level. In the above example, the lowest layer identified over the five days is assigned to the 700 hPa layer as it occurs in the region of the 700 hPa surface. The next layer up is assigned to the 500 hPa layer and the one above that to the 300 hPa layer. It is seldom that a layer is assigned to the 800 hPa layer for a station over the interior, as the 800 hPa stable layer is a feature which occurs almost exclusively over the coastal regions. Absolutely stable layers which occur below the 700 hPa layer over the interior, or which occur within 100 hPa of the surface are generally considered to be surface inversions or surface-bound absolutely stable layers. Only non-surface absolutely stable layers are considered for analysis.

The layers do not always conform to this categorisation scheme. The third day of the above sequence is a case in point where a weak layer occurs with its base at 500 hPa above the second layer, (Fig. 2.3c). The problem of how to classify such a layer is generally resolved by an examination of the pseudoadiabatic diagram. On investigation of the ascents made during the previous and subsequent days, if there is evidence that the so-called problem layer has split away from or joined together with one of the categorised layers, it is included in the categorised layer. It is evident that layer 2 in Figure 2.3 has split into layers 2a and 2c in Figure 2.3c. Alternatively, if the stable layer approximates the saturated adiabatic lapse rate (e.g. between the 400 hPa and 300 hPa heights in Figure 2.3b) it may be considered to be neutral, and is ignored

2.4 STATISTICAL ANALYSIS

Once the layers have been categorised, statistical analyses are performed on each layer over each individual station. For all of the calculations the population distributions are assumed to be normal.

Mean base heights and upper limits of the stable layers are calculated from:

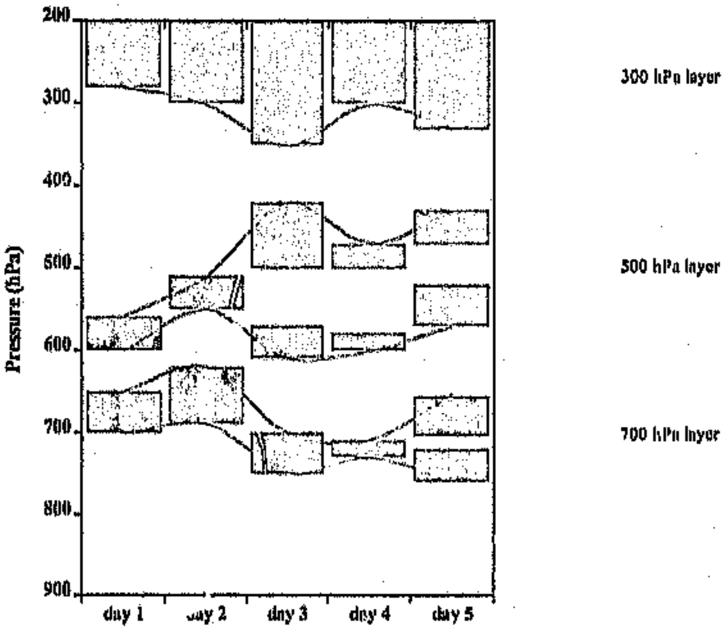


Figure 2.4 Time-height sequence depicting a vertical cross-section of the layers over Pietersburg over a five day time period

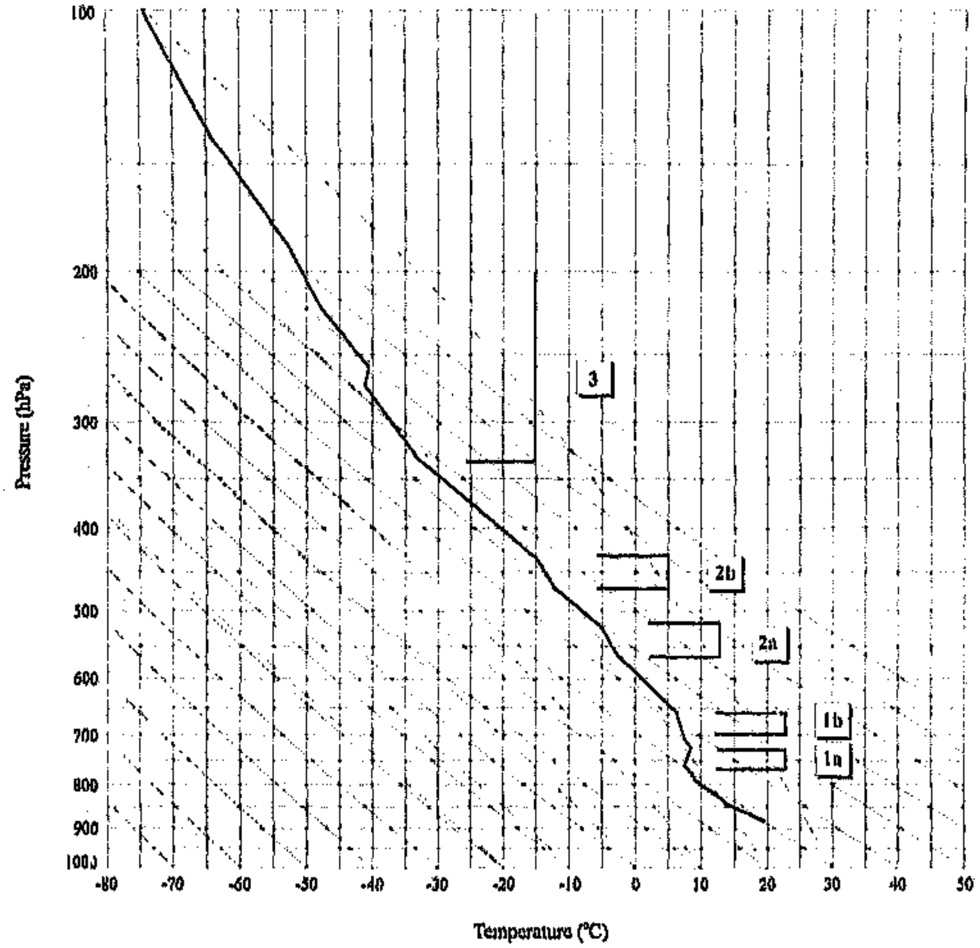


Figure 2.3(e) Pseudoadiabatic diagram showing midday ascents at Pietersburg on May 5 1990

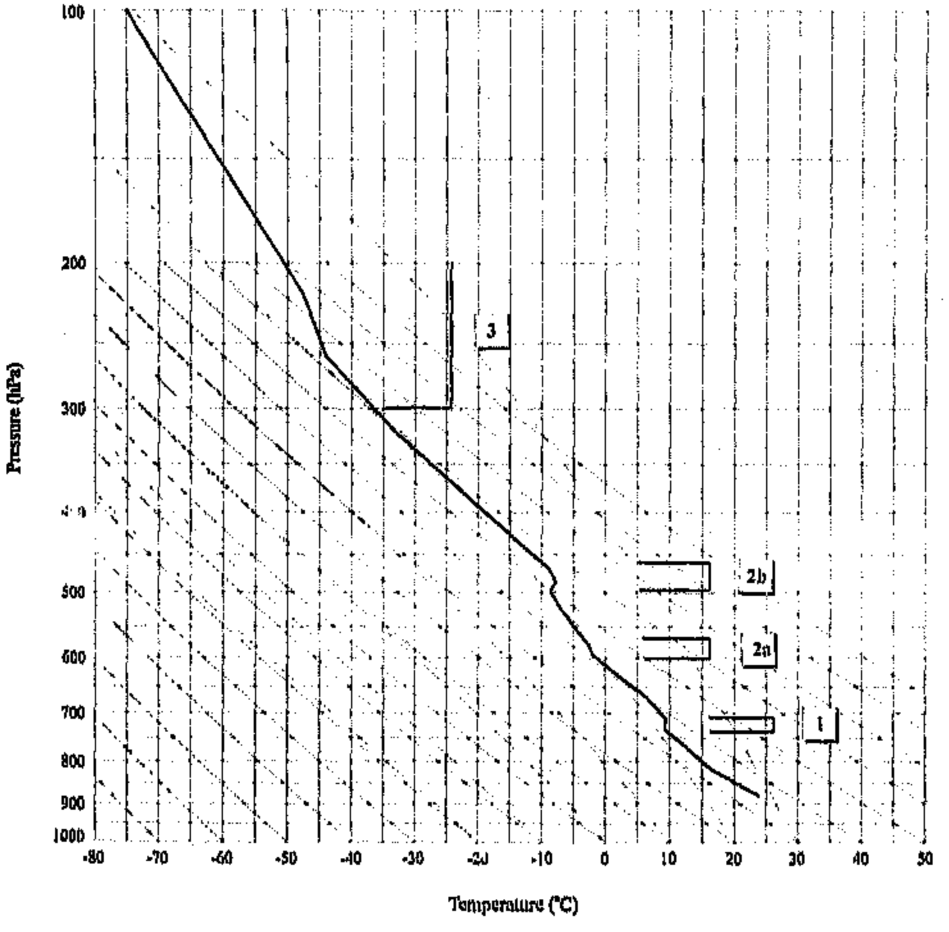


Figure 2.3(d) Pseudoadiabatic diagram showing midday ascents at Pietersburg on May 4 1990

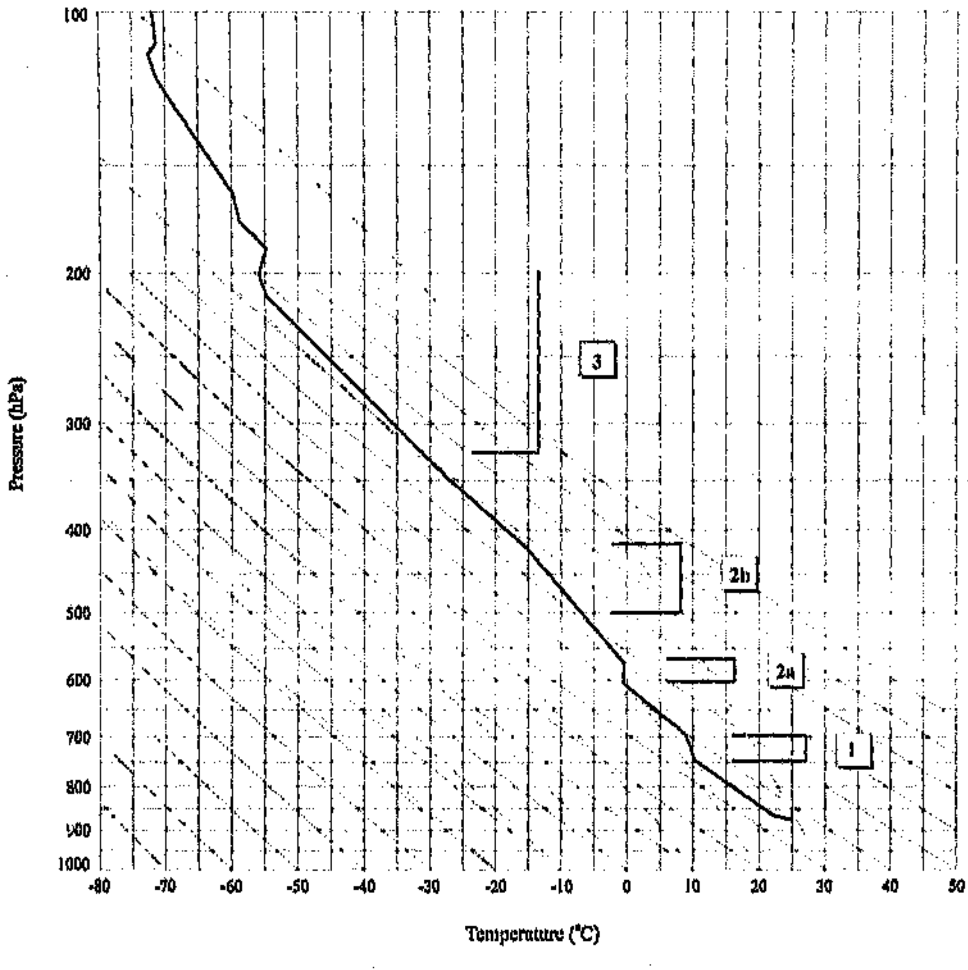


Figure 2.3(c) Pseudoadiabatic diagram showing midday ascents at Pietersburg on May 3 1990

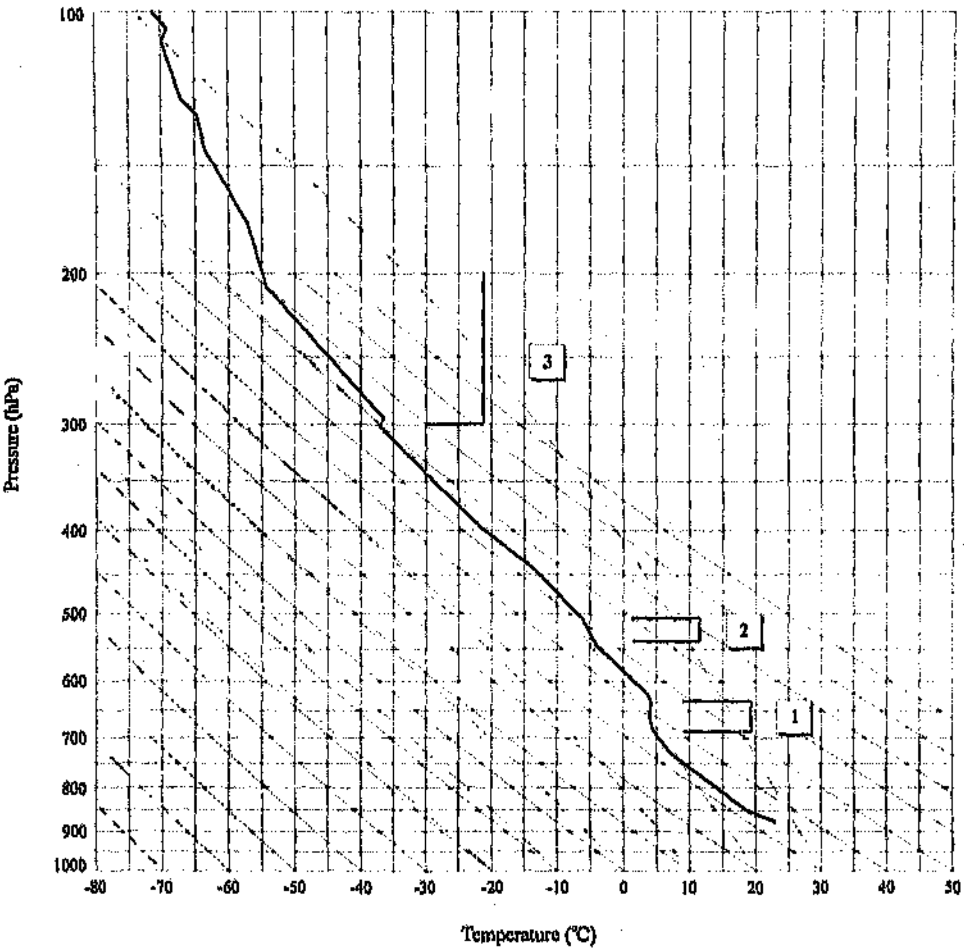


Figure 2.3(b) Pseudoadiabatic diagram showing midday ascents at Pietersburg on May 2 1990

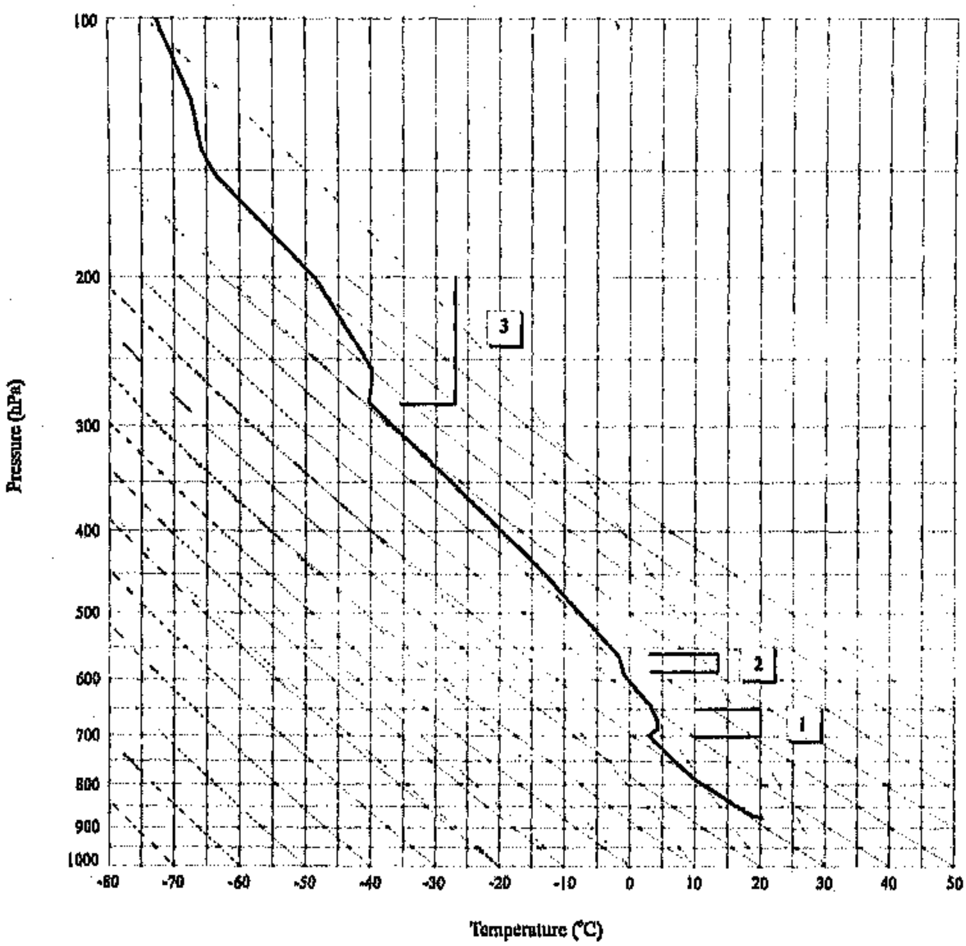


Figure 2.3(a) Pseudoadiabatic diagram showing midday ascents at Pietersburg on May 1 1990 (Horizontal lines are pressure, vertical lines are temperature, diagonal solid lines are dry adiabats, diagonal stippled lines are saturated adiabats and the dark line is the environmental lapse rate)

coarse horizontal resolution of the data it is not unreasonable to use these stations for ascertaining trends in upper level absolute stability.

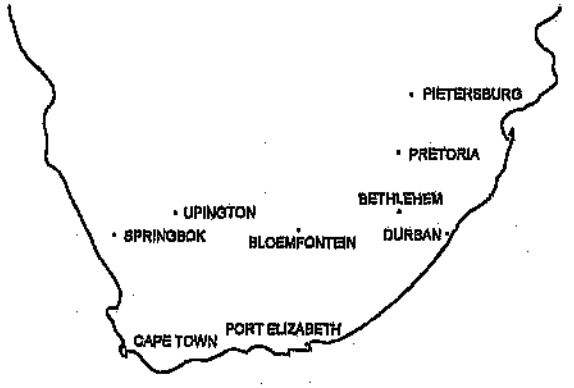


Figure 2.2 Location of aerological stations (modified after Diab, 1975)

In 1987 the meteorological station at Alexander Bay was discontinued and was moved to Springbok. Although Alexander Bay is a coastal station and Springbok occurs slightly inland, the two stations occur within the same immediate geographical location and should exhibit elevated absolute stability characteristics similar enough to be considered as one station. Thus, henceforth they will be considered as one station and will be referred to only as Springbok.

In terms of the future applications of this research, it would have been beneficial to include neighbouring countries such as Mozambique, Namibia, Botswana, and Zimbabwe, so that a climatology could be derived for the whole of southern Africa. However, the data for many of these stations is sparse and incoherent. Grootfontein, Windhoek and Maun would have been particularly valuable in the study of easterly waves. Radiosonde data for Bulawayo and Harare are more readily available, but only early morning ascents are done and therefore have been excluded on the basis that the they may give misleading results.

Radiosonde data is plotted on pseudoadiabatic diagrams (Figs. 2.3a-e). Stable layers are defined where the gradient of the environmental lapse rate is less than the gradient of the saturated adiabatic lapse rate. The daily occurrence of the layers have been determined for

2.2 SYNOPTIC CONDITIONS

The four predominant synoptic circulation types identified by Garstang *et al.* (1995) have been selected for analysis. They are semi-permanent continental anticyclones, transient mid-latitude ridging anticyclones, quasi-stationary easterly waves and westerly wave baroclinic disturbances (cf. Fig. 1.8).

The time frame for the investigation is the eight year period 1986-1993. During this interval events have been identified when the above-mentioned synoptic types were archetypal and persistent over a period of five consecutive days. The identification of the event dates is based on South African Weather Bureau surface and 850 hPa synoptic charts. The dates for the observed events are listed according to synoptic type in Table 2.1.

Continental High	Ridging High	Easterly Wave	Westerly Wave
1987/06/29 - 1987/07/03	1986/09/22 - 1986/09/26	1988/02/14 - 1988/02/18	1986/11/07 - 1986/11/11
1988/05/01 - 1988/05/05	1987/02/24 - 1987/02/28	1989/01/09 - 1989/01/13	1987/07/18 - 1987/07/22
1988/07/14 - 1988/07/18	1987/06/18 - 1987/06/22	1989/12/07 - 1989/12/11	1988/09/13 - 1988/09/17
1990/05/01 - 1990/05/05	1988/10/10 - 1988/10/14	1990/05/15 - 1990/05/19	1989/08/15 - 1989/08/19
1990/07/10 - 1990/07/14	1988/11/09 - 1988/11/13	1991/01/15 - 1991/01/19	1989/10/10 - 1989/10/14
1991/04/17 - 1991/04/21	1988/11/15 - 1988/11/19	1993/02/28 - 1993/03/04	1990/06/02 - 1990/06/06
1992/05/05 - 1992/05/09	1990/08/10 - 1990/08/14		1990/06/25 - 1990/06/29
1992/07/04 - 1992/07/08	1990/08/30 - 1990/09/03		1990/10/02 - 1990/10/06
1992/07/02 - 1992/07/06	1991/08/10 - 1991/08/14		1991/07/02 - 1991/07/06
1993/05/05 - 1993/05/09			1992/02/11 - 1992/02/15

Table 2.1 Inclusive dates of events analyzed according to circulation type

2.3 RADIOSONDE ANALYSIS

Data for midday radiosonde ascents were obtained for nine aerological stations in South Africa for the dates of the individual synoptic events. In total, 1575 radiosonde ascents were analysed for the stable layers by synoptic type, and 1350 ascents were analysed for the mid-summer maximum, giving a total of 2925 analysed ascents. The stations used are Pietersburg, Pretoria, Bethlehem, Bloemfontein, Upington, Springbok or Alexander Bay, Cape Town, Port Elizabeth and Durban. Their geographical locations are indicated in Figure 2.2. Despite the

3.3 STABLE LAYERS ASSOCIATED WITH RIDGING ANTICYCLONES

The four persistent layers during continental anticyclonic circulation are present during ridging anticyclonic events. The statistics for these layers are presented in Tables 3.4, 3.5 and 3.6.

3.3.1 *The sub-escarpment 800 hPa layer*

The base height of the coastal 800 hPa layer is relatively constant over the coastal regions (Fig. 3.6) and is marginally higher during ridging anticyclonic circulation (843 hPa) than it is during the continental anticyclonic events (876 hPa). The maximum mean base height occurs over Upington at 781 hPa and decreases to a minimum of 876 hPa over Cape Town. The base height varies little between coastal stations, exhibiting a standard deviation of 12 hPa, if the data for Upington are excluded. It rises to 33 hPa if Upington is included. (For reasons discussed below, the Upington elevated absolutely stable layers during ridging anticyclonic conditions appear to be an anomalous).

The base of the layer has a maximum 95% confidence interval of 48 hPa over Upington and 46 hPa over Port Elizabeth (Fig. 3.6). This maximum is only in the region of 15 hPa greater than the minimum over Cape Town, resulting in a standard deviation of only 6 hPa for the layer over the entire country. The stable layer for all intents occurs at a constant altitude over the sub-escarpment regions. The values compare favourably with those of Diab (1975) for Durban, Port Elizabeth and Cape Town during the months of maximum ridging frequency (February and October). However, the present study indicates a much higher layer over the west coast than was previously observed. Because there is so little country-wide variation in the confidence interval it can be assumed that local boundary layer influences do not have a significant control over the fluctuations of the 800 hPa stable layer base associated with the ridging high.

Although the mean depth of the stable layer over the country (Fig. 3.6) is fairly similar to those observed during continental anticyclonic circulation, the depth standard deviation of 14 hPa is substantially greater during ridging high events. This greater inter-station variation is due to the influence of both surface convergence and divergence over the country during ridging highs. Surface convergence increases the stable layer depths as turbulence and uplift weakens the structure of the layer; surface divergence and subsidence enhance stability and compress the

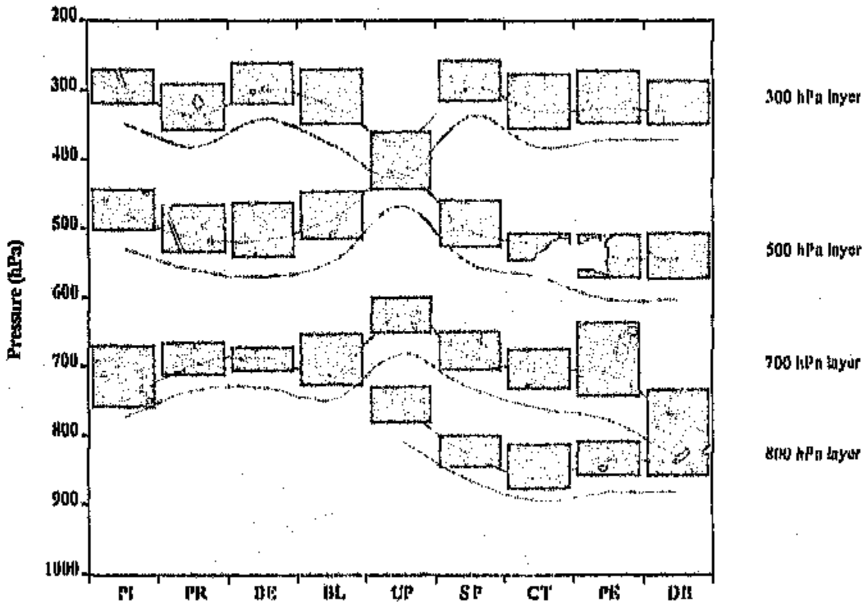


Figure 3.6 Stable layers (shaded) for ridging anticyclones over Pietersburg (PI), Pretoria (PR), Bethlehem (BE), Bloemfontein (BL), Upington (UP), Springbok (SP), Cape Town (CT), Port Elizabeth (PE) and Durban (DB). Upper and lower 95% confidence limits for the base heights of the layers as well as the continental surface are shown in each case

The greatest depths of approximately 50 hPa occur over Pretoria and Bethlehem and decrease with distance from this area (Figs. 3.1, 3.4c). Pietersburg has the shallowest layer of 38 hPa. Although the depths do not vary significantly over the subcontinent, with the standard deviation being only 4 hPa it should be noted that these values may be misleading due to the upper cut-off level of 200 hPa, employed in the analysis.

STATION	800 hPa	700 hPa	500 hPa	300 hPa
PLATEAU				
PI		90	66	88
PR		93	80	91
BE		88	72	90
BL		96	84	90
UP		80	88	90
mean		*89*	*78*	*90*
std dev		*5*	*8*	*1*
COAST				
SP	76	70	62	80
CT	92	74	86	80
PE	48	73	78	80
DB	60	94	78	78
mean	*69*	*78*	*76*	*80*
std dev	*17*	*9*	*9*	*1*
total mean	*69*	*84*	*77*	*85*
total std dev	*17*	*11*	*9*	*6*

Table 3.3 Continental anticyclone stable layer mean frequencies

The 300 hPa layer exhibits a high degree of persistence at this altitude. The lowest frequency of occurrence occurs over Durban (78%). The rest of the stations have frequencies above 80% and over the interior the layer persists 90% of the time. Thus a general south to north frequency increase is evident (Fig. 3.5c).

a)

b)

c)

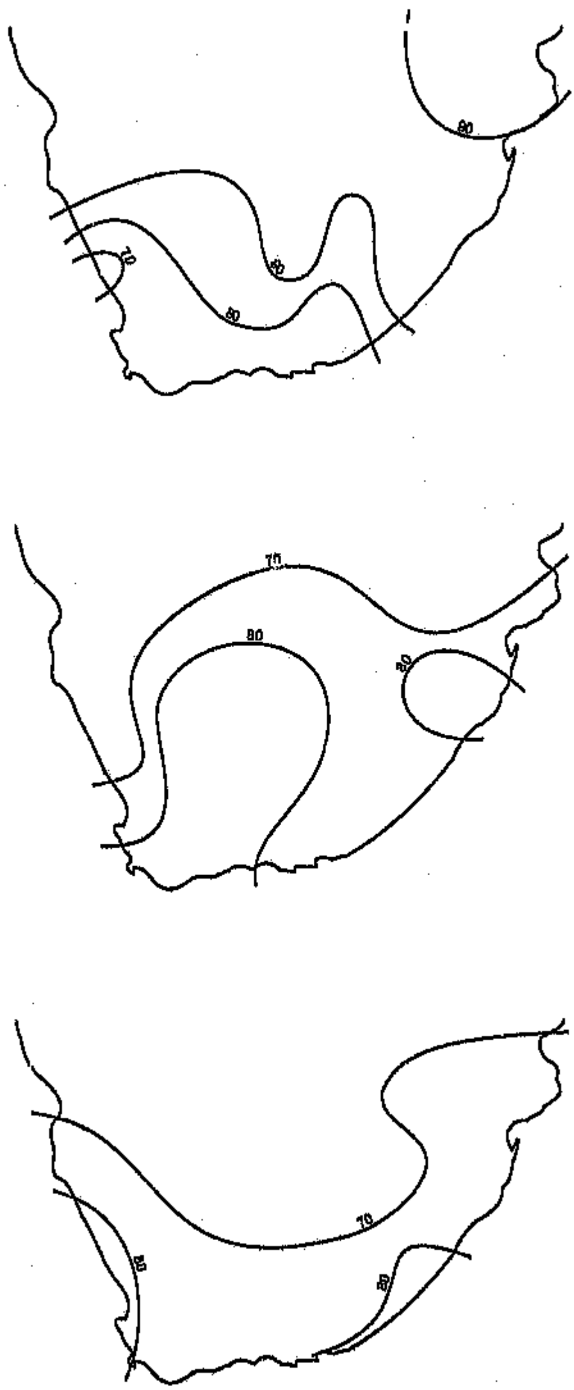


Figure 3.5 Mean frequencies for continental anticyclone (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

over Pretoria and Upington at 67 hPa and minimum values over Springbok at 41 hPa. The layer occurs with a mean value of 59 hPa across the subcontinent.

The mean country-wide frequency of occurrence of the 500 hPa layer is 77% with the prevalence of anticyclonic conditions. Highest frequencies ranging from 80% to 88%, occur in a ridge from Cape Town up the centre of the country, (Fig. 3.5b). Pietersburg and Springbok have the lowest frequency of stable layers, of between 60% and 70%.

STATION	800 hPa			700 hPa			500 hPa			300 hPa		
	Lower Limit	Upper Limit	CI	Lower Limit	Upper Limit	CI	Lower Limit	Upper Limit	CI	Lower Limit	Upper Limit	CI
PLATEAU												
PI				775	751	24	617	569	48	341	301	40
PR				751	727	24	573	513	60	324	292	32
BB				728	702	26	549	501	48	357	311	46
BL				756	720	36	577	529	48	338	298	40
UP				800	760	40	602	554	48	356	318	38
mean				*762*	*732*	*30*	*584*	*533*	*50*	*343*	*304*	*39*
std dev				*24*	*21*	*7*	*24*	*25*	*5*	*12*	*9*	*4*
COAST												
SP	863	837	26	753	705	48	558	510	48	341	289	52
CT	895	859	36	783	733	50	583	541	42	349	303	46
PE	908	864	44	761	699	62	587	543	44	389	361	28
DB	911	873	38	726	686	40	560	510	50	332	288	44
mean	*894*	*858*	*36*	*756*	*706*	*50*	*572*	*526*	*46*	*353*	*310*	*43*
std dev	*19*	*13*	*6*	*20*	*17*	*8*	*13*	*16*	*3*	*22*	*30*	*9*
total mean	*894*	*858*	*36*	*759*	*720*	*39*	*578*	*530*	*48*	*347*	*307*	*41*
total std dev	*19*	*13*	*6*	*23*	*23*	*12*	*21*	*22*	*5*	*18*	*21*	*7*

Table 3.2 Continental anticyclone stable layer 95% confidence limits and intervals (CI)

3.2.4 *The 300 hPa layer*

The 300 hPa layer base has a different general topography over the country from the underlying layers, and appears not to be influenced significantly by the continental anticyclone (Figs. 3.1, 3.2c). The exact causes and controls of the 300 hPa layer have yet to be ascertained. The altitude of the layer decreases concentrically outwards from Port Elizabeth. With a base height standard deviation of only 19 hPa over the subcontinent, the base of the layer varies as little as the three lower layers. The mean 95% confidence interval for the layer base over the country is 41 hPa with a standard deviation of only 7 hPa (Figs. 3.1, 3.3c). There is no significant difference between the mean plateau (39 hPa) and coastal (43 hPa) intra-station base height variation.

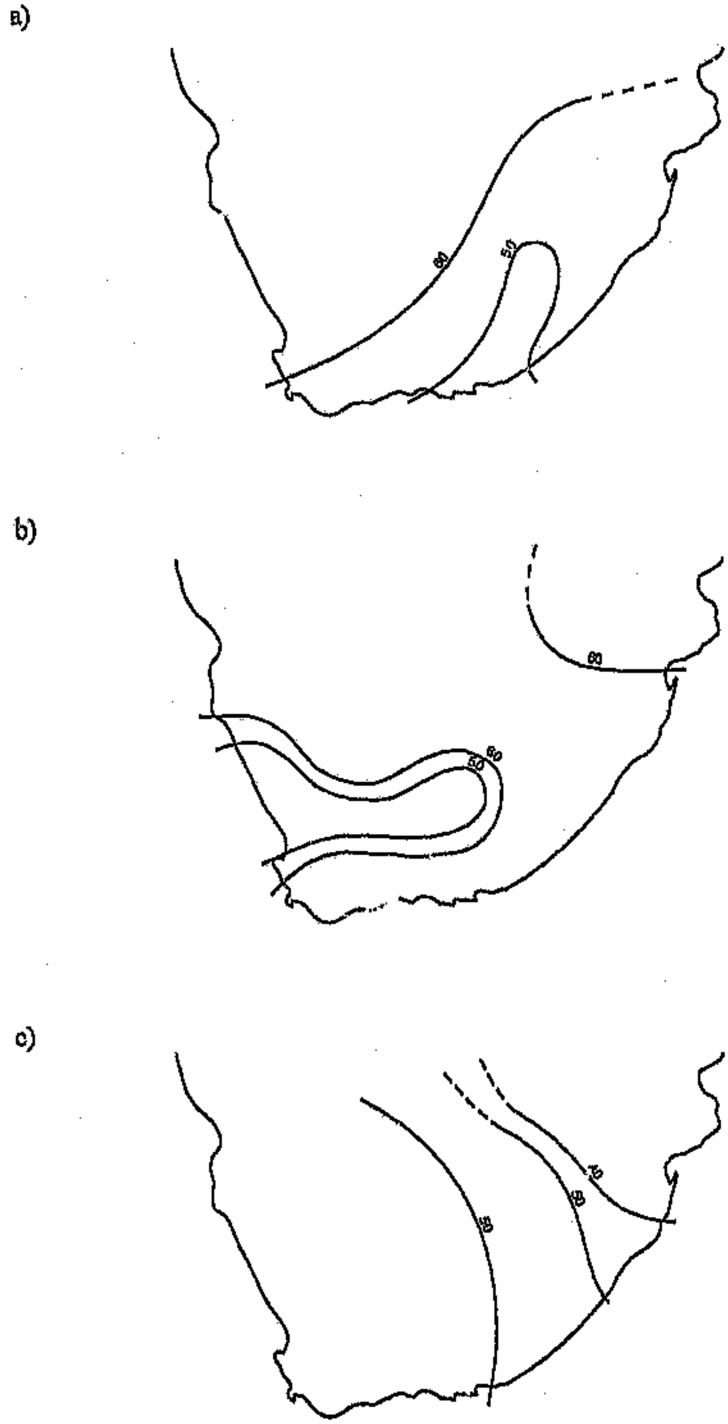


Figure 3.4 Mean depths (hPa) for continental anticyclone (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

continental anticyclones prevail (Fig. 3.5a). Frequencies decrease with distance from the core of the anticyclone and reach a minimum of 70% over Springbok.

STATION	800 hPa			700 hPa			500 hPa			300 hPa		
	Base Height	Upper Limit	Depth	Base Height	Upper Limit	Depth	Base Height	Upper Limit	Depth	Base Height	Upper Limit	Depth
PLATEAU												
PI				763	710	53	593	540	53	321	283	38
PR				739	687	52	543	476	67	308	257	51
BE				715	666	49	525	461	64	334	282	52
BL				738	680	58	553	505	48	318	276	42
UP				780	715	65	578	511	67	337	291	46
mean				*747*	*692*	*55*	*558*	*499*	*60*	*324*	*278*	*46*
std dev				*22*	*18*	*6*	*24*	*28*	*8*	*11*	*11*	*5*
COAST												
SP	850	803	47	729	667	62	534	493	41	315	269	46
CT	877	823	54	758	700	58	562	500	62	326	284	42
PE	886	832	54	730	688	42	565	501	64	375	327	48
DB	892	842	50	706	653	53	535	469	66	310	260	50
mean	*876*	*825*	*51*	*731*	*677*	*54*	*549*	*491*	*58*	*332*	*285*	*47*
std dev	*16*	*14*	*3*	*18*	*18*	*7*	*15*	*13*	*10*	*26*	*26*	*3*
total mean	*876*	*825*	*51*	*740*	*685*	*55*	*554*	*495*	*59*	*327*	*281*	*46*
total std dev	*16*	*14*	*3*	*22*	*20*	*7*	*21*	*23*	*9*	*19*	*19*	*4*

Table 3.1 Continental anticyclone stable layer mean base and upper limit altitudes, and depths

3.2.3 *The 500 hPa layer*

The 500 hPa layer base has a similar topography over the country to the 700 hPa layer (Figs. 3.1, 3.2a, 3.2b). As the displacement of the centre of the continental high occurs to the north-west with height, one would expect the topography of the layer to move correspondingly in relation to the 700 hPa layer. This is not the case. The north-east plateau again experiences the lowest base levels (593 hPa). Over the eastern and western margins of the country the base level increases to a maximum of approximately 535 hPa. Similar to the underlying layer the 500 hPa layer exhibits very little base height variation over the country, with a standard deviation of 21 hPa.

Ninety-five percent of the time the basal variation about the mean for the country is 48 hPa (Figs. 3.1, 3.3b). The plateau and coast both yield similar values to the country average. The depth structure is relatively homogenous over the subcontinent, exhibiting a depth standard deviation of 9 hPa. Two troughs of comparatively shallower layers are apparent over the eastern plateau and from Springbok to Bloemfontein (Figs. 3.1, 3.4b). Maximum depths occur

a)

b)

c)

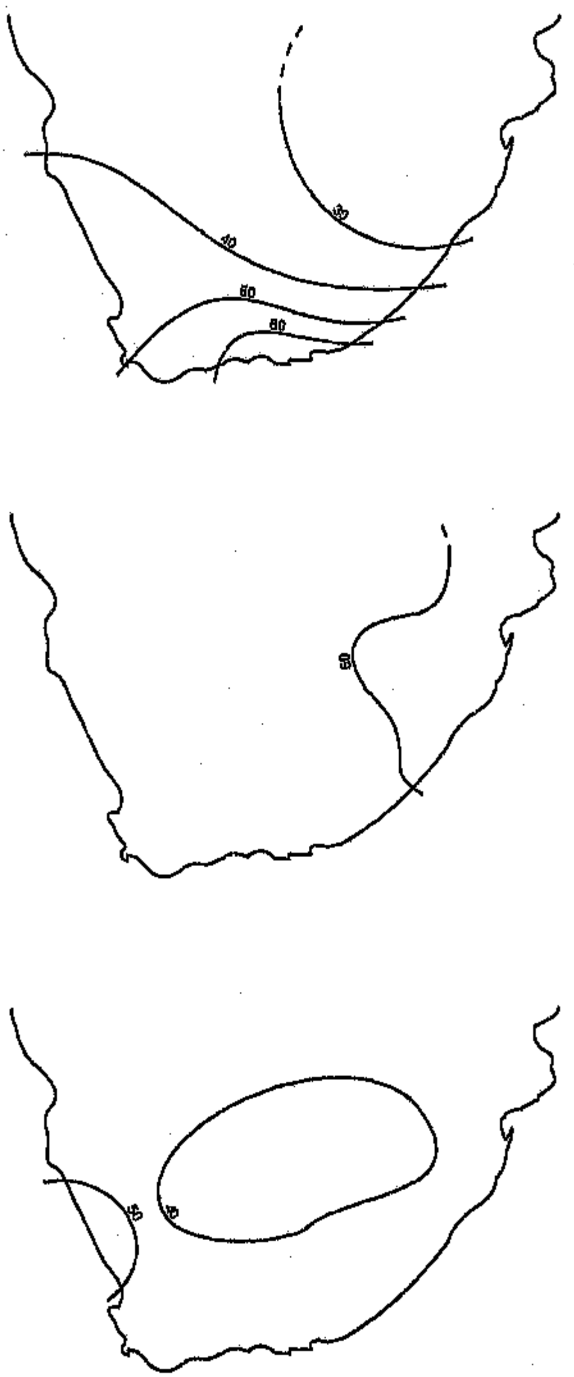


Figure 3.3 95% confidence intervals (hPa) for continental anticyclone (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

3.2.2 *The 700 hPa layer*

The 700 hPa layer is evident as a spatially continuous surface across the entire country with the occurrence of continental anticyclones. The mean variation in base height over the country is relatively small (Figs. 3.1, 3.2a), but is slightly greater than the overlying layers, owing to the influence of diabatic heating and boundary layer mixing.

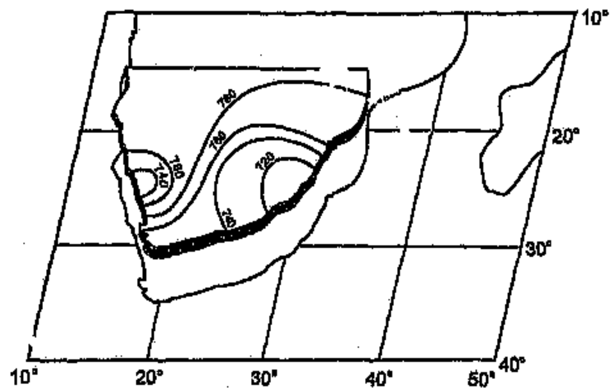
Lowest base levels occur over the interior at Upington (780 hPa). The layer increases in altitude with distance away from the core of the continental anticyclone, as the controlling subsidence intensity decreases (Figs. 3.1, 3.2a). Durban has the highest layer at 706 hPa and may be influenced by the same mechanisms which cause the layer over Bethlehem to have a similarly high altitude (715 hPa). Over the south-west coast, where one would expect the layer to occur at a relatively higher altitude due to the passage of westerly and coastal disturbances during this time of year, it decreases to 758 hPa. Over the country as a whole, however, the layer base varies little, with a standard deviation of 22 hPa.

The layer base has little intra-station variation, with a mean country-wide 95% confidence interval of 39 hPa and standard deviation of only 12 hPa. The maximum fluctuation about the mean base height is 62 hPa over Port Elizabeth. The minimum confidence interval occurs over the eastern plateau in the region of 25 hPa, clearly indicating the strong influence of the continental anticyclone (Figs. 3.1, 3.3a). The layer base deviates about the mean slightly more over the coastal stations (50 hPa) than over the interior (30 hPa), due to the passage of coastally-trapped disturbances.

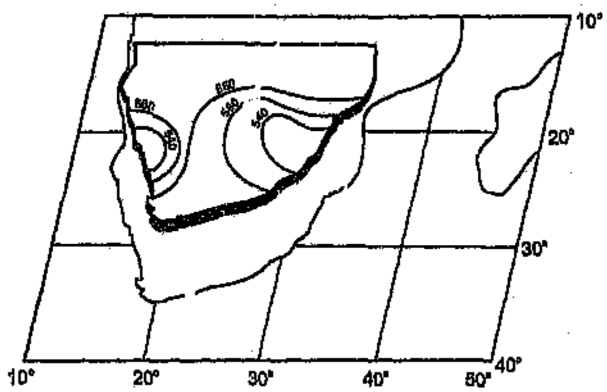
The depth of the 700 hPa layer appears to have a general spatial coherence conforming to the control of the continental anticyclone. The discontinuity exhibits deepest layers over the western parts of the country where the influence of subsidence is not as marked (Figs. 3.1, 3.4a). The layer is shallower over the eastern plateau under increased anticyclonic subsidence. Over the Western and Northern Cape the layer has a similar depth to that of the central plateau. As is the case with the discontinuity base heights, depths do not vary significantly across the country (Figs. 3.1, 3.4a), yielding a country-wide standard deviation of only 7 hPa. The difference between the maximum and minimum depths is only 23 hPa.

The influence of synoptic controls on the 700 hPa layer is clearly evident over the eastern parts of the country, with the layer occurring in the region of 90% of the time while

a)



b)



c)

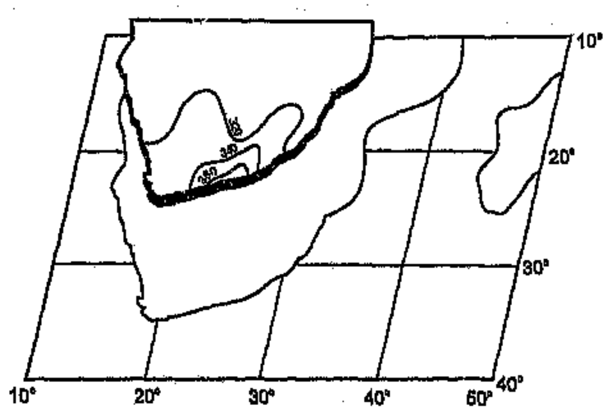


Figure 3.2 Mean base levels (hPa) for continental anticyclone (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

3.2 STABLE LAYERS ASSOCIATED WITH CONTINENTAL ANTICYCLONES

When anticyclonic circulation prevails four elevated absolutely stable layers occur preferentially; three over the plateau and four over the coastal regions. Details are presented in Tables 3.1, 3.2 and 3.3.

3.2.1 *The sub-escarpment 800 hPa layer*

The mean base of the coastal 800 hPa layer is observed to occur at a relatively constant altitude over the coastal regions, decreasing in altitude from 850 hPa over the west coast to 892 hPa over the east coast (Fig. 3.1). Although this appears to contradict the results of Taljaard (1955) and Diab (1975) who observe that the first non-surface inversion decreases in height from the west coast to the east coast during winter, two points should be noted. First, the results of a study of the seasonal trends in inversion heights irrespective of synoptic circulation, are not necessarily directly comparable with the results of a stable layer analysis based upon a single synoptic circulation type. Secondly, of greater significance than the geography of the fluctuation in base height is the magnitude of the fluctuation. Across all the stations the standard deviation of the mean base height exhibits a value of only 16 hPa, which is so slight as to be insignificant. Consequently, it can safely be deduced that the layer height is invariant over the coastal regions around South Africa.

Not only do the mean base heights of the discontinuities occur at approximately the same altitude across the subcontinent, but the intra-station base height variations about the mean are also very small. The 95% confidence interval of the base altitude ranges between a minimum of 26 hPa over Springbok and a maximum of 44 hPa over Port Elizabeth (Fig. 3.1), with a standard deviation over all stations of only 6 hPa.

The layer is deepest over the south and south-west coast and decreases in depth over the east and west coasts, yielding a mean base depth over the country of 51 hPa (Fig. 3.1). The stable layer over the south and south-west coasts experience slightly greater depths due to the turbulent influence of coastal breezes, oceanic influences and coastally-trapped disturbances. Furthermore, maritime subtropical and polar air is deeper during the winter months causing a basal height increase. Durban on the other hand falls under the influence of the continental high with its associated subsidence causing the layer to be compressed over this location.

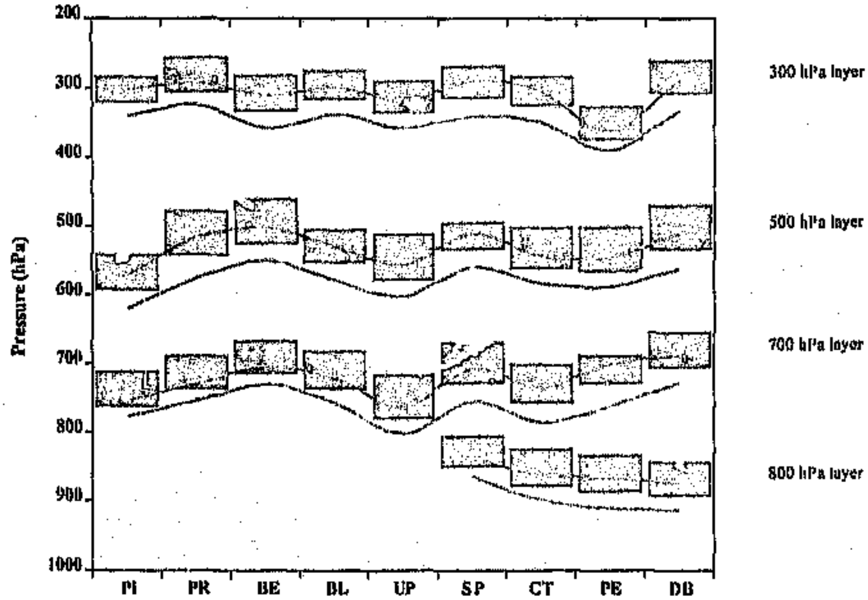
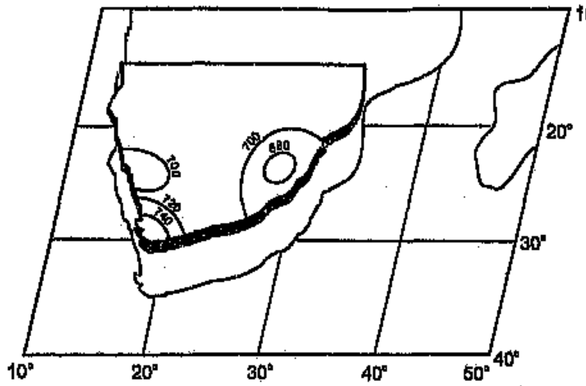
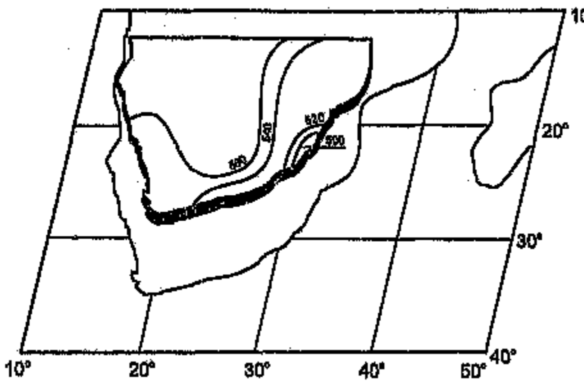


Figure 3.1 Stable layers (shaded) for continental anticyclones over Pietersburg (PI), Pretoria (PR), Bethlehem (BE), Bloemfontein (BL), Upington (UP), Springbok (SP), Cape Town (CT), Port Elizabeth (PE) and Durban (DB). Upper and lower 95% confidence limits for the base heights of the layers as well as the continental surface are shown in each case

a)



b)



c)

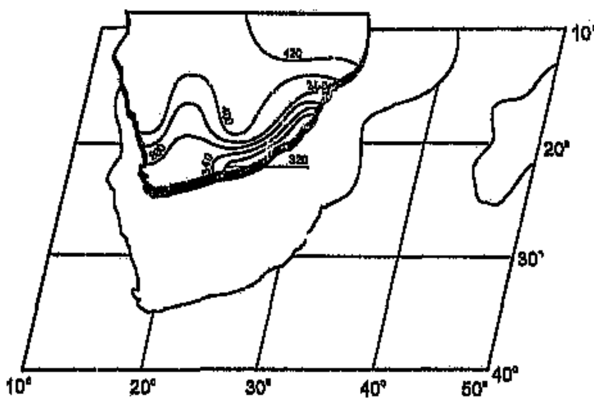


Figure 3.12 Mean base levels (hPa) for easterly wave (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

likely to have little control over the 800 hPa layer, except over Springbok. The base of the coastal 800 hPa layer has a standard deviation of 36 hPa, which is markedly similar to the equivalent value for the ridging high. It is significantly greater than the 700 hPa and the 500 hPa layers for this circulation type. The layer base occurs at a minimum altitude of 891 hPa over Cape Town and a maximum of 801 hPa over Springbok, which is significantly higher than the rest of the stations (Fig. 3.11). The stable layer altitude difference between the west coast and the rest of the coastal regions clearly indicates that Springbok is influenced by different circulation; namely the easterly wave. Again all stations except Springbok compare well with the typical results found by Diab (1975) for summer non-surface inversions.

Ninety-five percent of the time the layer over the country has a base level fluctuation about the mean of 46 hPa (Fig. 3.11), which is slightly greater than the equivalent value during anticyclonic circulation. Maximum intra-station variability is apparent at Port Elizabeth (52 hPa) and minimum values occur at Durban (38 hPa).

The layer maintains a mean depth of approximately 51 hPa and a standard deviation of 12 hPa. The deepest part of the layer is found over Port Elizabeth and the shallowest over Springbok (37 hPa) (Fig. 3.11). The greatest frequency of occurrence of 79% is evident over the east coast, with a progressive decrease to 62% over the south-west and west coasts (Table 3.9).

3.4.2 *The 700 hPa layer*

The 700 hPa layer base occurs persistently at similar altitudes across the entire subcontinent (Figs. 3.11, 3.12a), yielding a standard deviation of 19 hPa. Averaged over all the stations, the layer occurs with a greater base altitude (708 hPa) than those of the equivalent layer during both anticyclonic circulations. Base levels are lowest over the south-west coast (746 hPa), where the influence of the easterly wave is not felt, and rise in altitude in a south-west to north-east axis across the country as they increasingly fall under the influence of surface convergence in the lee of the easterly wave.

Convective activity and mixing to the east of the trough results in turbulence penetrating, weakening and eroding the stable layers. As a consequence the layer over the north-eastern plateau is deeper (approximately 55 hPa) and presumably weaker (Figs. 3.11, 3.14a). Surprisingly, the intra-station base level variation is lower over the eastern plateau than

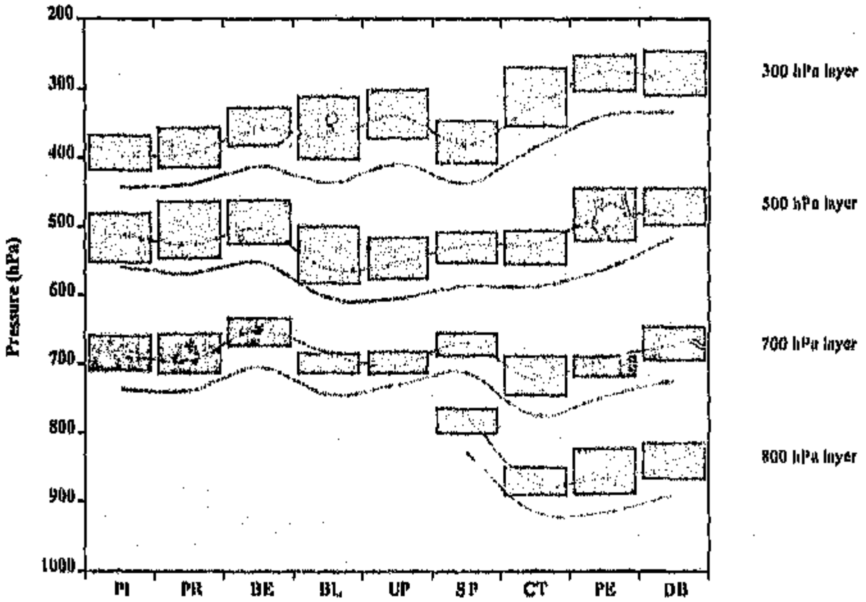


Figure 3.11 Stable layers (shaded) for easterly waves over Pietersburg (PI), Pretoria (PR), Bethlehem (BE), Bloemfontein (BL), Upington (UP), Springbok (SP), Cape Town (CT), Port Elizabeth (PE) and Durban (DB). Upper and lower 95% confidence limits for the base heights of the layers as well as the continental surface are shown in each case

the same height as the 500 hPa layer's upper limit. The mechanisms controlling the development of elevated absolutely stable layer bases over the Northern Cape are obviously different to those for the rest of the country. They are almost certain to be a ociated with easterly waves occurring simultaneously over the region whilst ridging highs occur over the eastern parts of the country.

STATION	800 hPa	700 hPa	500 hPa	300 hPa
PLATEAU				
PI		76	71	89
PR		76	91	93
BE		73	93	93
BL		88	88	90
UP	73	87	88	95
mean	*73*	*80*	*86*	*92*
std dev	*0*	*6*	*8*	*2*
COAST				
SP	78	64	71	93
CT	72	70	44	78
PE	65	55	73	90
DB	53	64	68	96
mean	*67*	*63*	*64*	*89*
std dev	*9*	*5*	*12*	*7*
total mean	*58*	*73*	*76*	*91*
total std dev	*9*	*11*	*17*	*7*

Table 3.6 Ridging anticyclone stable layer mean frequencies

3.4 STABLE LAYERS ASSOCIATED WITH EASTERLY WAVES

Easterly waves influence the northern parts of South Africa. Four elevated absolutely stable layers are observed with the easterly wave circulation. In many respects they have similar characteristics to those of the continental and ridging anticyclonic circulation types. Details of these layers are given in Tables 3.7, 3.8 and 3.9.

3.4.1 *The sub-escarpment 800 hPa layer*

Since the easterly wave influences only the northern parts of the country, the wave is

The 500 hPa layer displays a similar frequency regime to that of the layer below. The frequency of the layer decreases in a north to south trend (Fig. 3.10b). A ridge of highest frequencies exceeding 90% occur from the north-western to the south eastern plateau, with the lowest frequency of 44% over Cape Town. Inter-station frequency variability over the country is highest at this level for ridging highs (17 hPa).

3.3.4 *The 300 hPa layer*

The base of the 300 hPa layer, averaged over all of the stations is higher during continental anticyclonic circulation (327 hPa) than it is during ridging anticyclones (346 hPa). An undulating north-south gradient of base heights is observed, with the base heights generally increasing from south to north (Figs. 3.6, 3.7c). The base of the 300 hPa layer exhibits a standard deviation of 24 hPa, indicating a reduced variation over the country in comparison to the underlying layers. The mean 95% confidence interval (Figs. 3.6, 3.8c) is 48 hPa and the country-wide standard deviation for the confidence interval is 6 hPa, showing very similar values to the equivalent layer for continental anticyclones. Maximum confidence interval values occur at the north-eastern and south-western extremes of the country.

The depth structure for the 300 hPa layer is the reverse of the underlying layers (Figs. 3.6, 3.9c). The deeper parts of the layer occurs over the south-western and central portions of the country, becoming shallower to the east and north. Maximum depth measuring 79 hPa occur over both Bloemfontein and Cape Town. Shallowest values are evident over Upington, where a depth of 40 hPa is evident.

The frequency occurrence of the 300 hPa layer ranges from 78% over Cape Town to 96% over Durban (Fig. 3.10c). A frequency standard deviation of only 7% indicates that the inter-station frequency varies significantly less than the layers below it. An area of higher frequencies in the range of 95% extends across the country in a north-west to south-east ridge.

For ridging anticyclonic circulations conditions the elevated absolutely stable layers at Upington are anomalous throughout the troposphere in comparison with the rest of the country. The coastal 800 hPa layer is present over Upington only during ridging anticyclones and occurs at a higher altitude relative to the rest of the stations. The 700 hPa layer base also occurs at a comparatively higher altitude, the 500 hPa layer is anomalously high in comparison to the rest of the plateau stations and the mean base of the 300 hPa layer is anomalously low, occurring at

a) b) c)

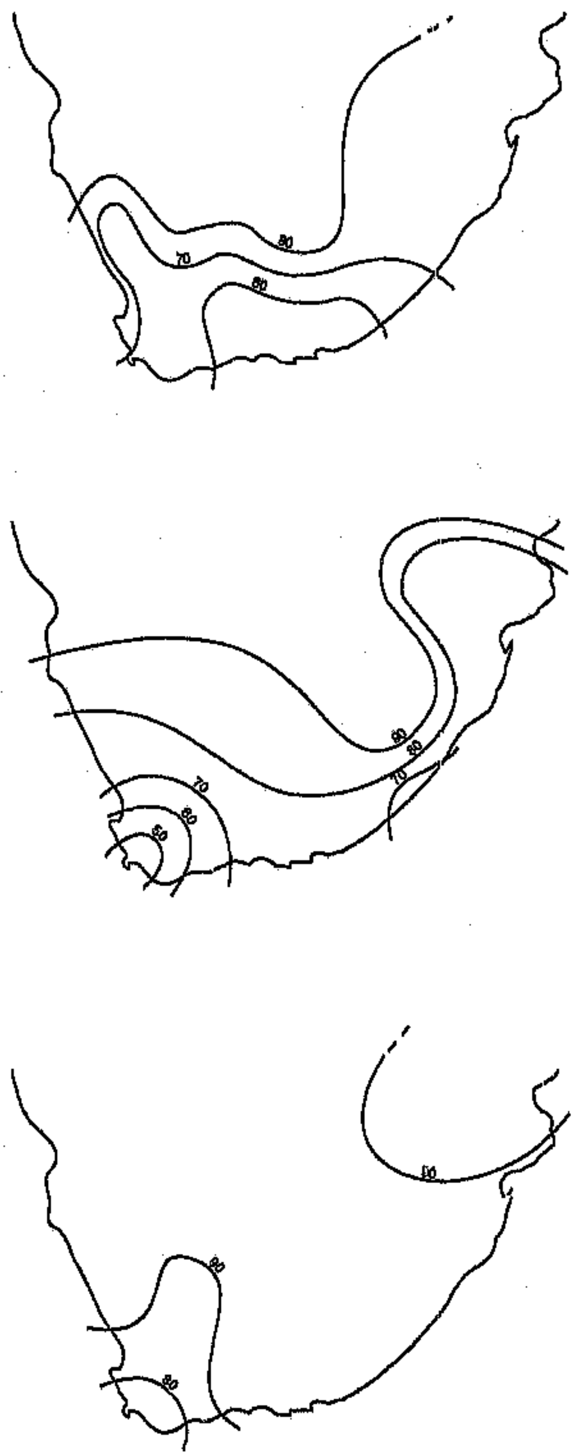


Figure 3.10 Mean frequencies for ridging anticyclone (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

3.3.3 *The 500 hPa layer*

The stable layer base heights for the 500 hPa layer vary little over the subcontinent, exhibiting a standard deviation of 37 hPa (Figs. 3.6, 3.7b). Lowest bases occur over the southern coastal (570 hPa) and eastern coastal regions (572 hPa). The layer increases in height in a south to north gradient, in contrast to the south-east to north-west gradient which is apparent for the 700 hPa layer.

A mean 95% confidence interval of 52 hPa for the entire subcontinent indicates a greater base level deviation about the mean than is evident for the 700 hPa layer (46 hPa). It is also slightly greater than the corresponding value for continental anticyclones (48 hPa) (Figs. 3.6, 3.8b). Intra-station variance increases concentrically with distance from Durban when ridging anticyclones are prevalent.

The general depth structure of the 500 hPa layer is fairly similar to that of the 700 hPa layer in that the shallowest layers occur over the western portions of the country (43 hPa and 40 hPa for Upington and Cape Town respectively) and deepest layers over the east (82 hPa for Bethlehem) (Figs. 3.6, 3.9b). Depth standard deviation averages at 13 hPa over the entire country.

STATION	800 hPa			700 hPa			500 hPa			300 hPa		
	Lower Limit	Upper Limit	CI	Lower Limit	Upper Limit	CI	Lower Limit	Upper Limit	CI	Lower Limit	Upper Limit	CI
PLATEAU												
PI				771	747	24	527	479	48	346	294	52
PR				732	694	38	559	511	48	381	335	46
BE				728	684	44	568	514	54	341	297	44
BL				746	710	36	545	485	60	378	320	58
UP	805	757	48	679	623	56	465	419	46	425	373	52
mean	*805*	*757*	*48*	*731*	*692*	*40*	*533*	*482*	*51*	*374*	*324*	*50*
std dev	*0*	*0*	*0*	*30*	*40*	*10*	*37*	*34*	*5*	*30*	*29*	*5*
COAST												
SP	862	824	38	728	682	46	549	501	48	336	296	40
CT	892	860	32	758	706	52	567	521	46	381	329	52
PE	879	833	46	776	708	68	601	539	62	370	326	44
DB	878	836	42	826	776	50	602	542	60	370	330	40
mean	*878*	*838*	*40*	*772*	*718*	*54*	*580*	*526*	*54*	*364*	*320*	*44*
std dev	*11*	*13*	*5*	*36*	*35*	*8*	*23*	*16*	*7*	*17*	*14*	*5*
total mean	*863*	*822*	*41*	*749*	*703*	*46*	*554*	*501*	*52*	*370*	*322*	*48*
total std dev	*31*	*35*	*6*	[illegible]	*40*	*12*	*39*	*35*	*6*	*26*	*24*	*6*

Table 3.5 Ridging anticyclone stable layer 95% confidence limits and intervals (CI)

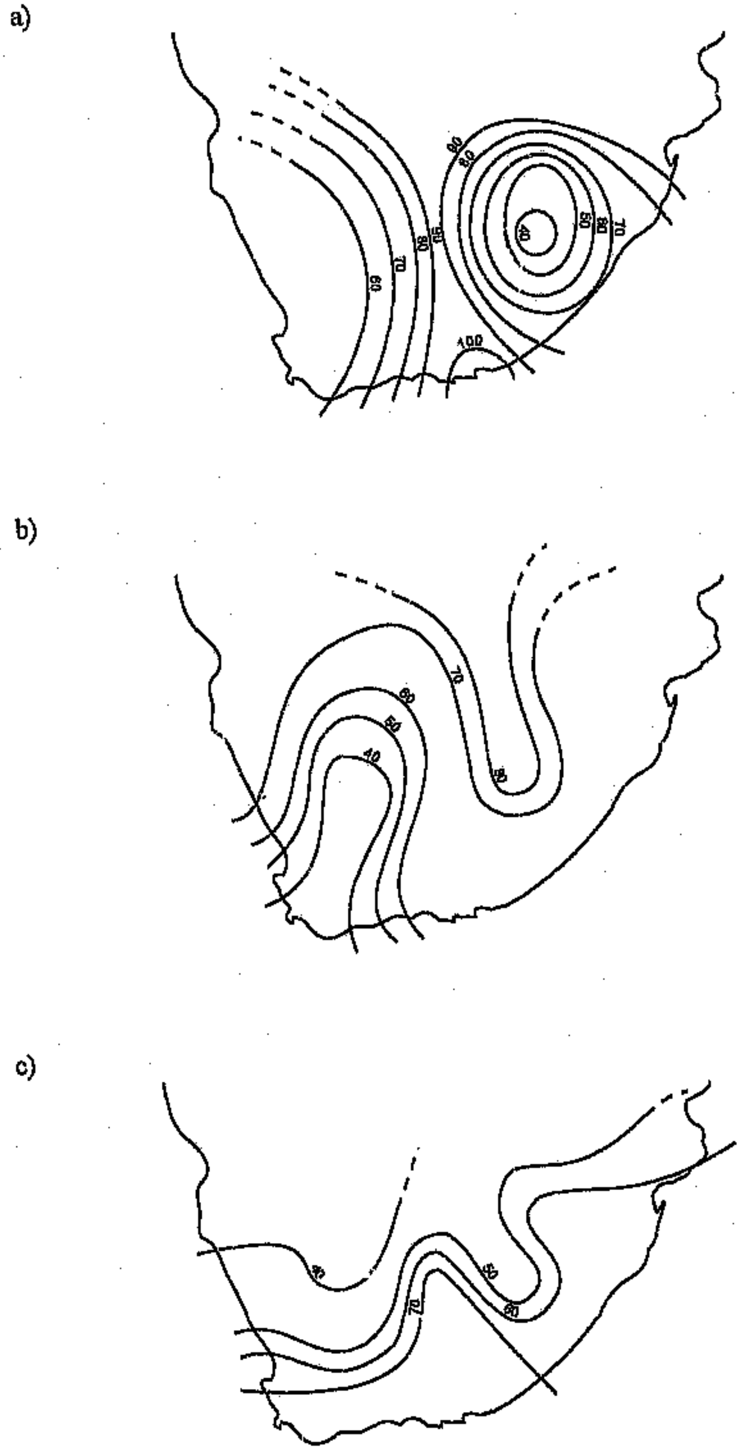


Figure 3.9 Mean depths (hPa) for ridging anticyclone (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

exhibiting a general north to south increase (Figs. 3.6, 3.8a). The coastal stations experience a greater mean confidence interval than do the interior stations.

STATION	800 hPa			700 hPa			500 hPa			300 hPa		
	Base Height	Upper Limit	Depth	Base Height	Upper Limit	Depth	Base Height	Upper Limit	Depth	Base Height	Upper Limit	Depth
PLATEAU												
PI				759	668	91	503	441	62	320	270	50
PR				713	664	49	535	465	70	358	291	67
BE				706	669	37	541	459	82	319	260	59
BL				728	651	77	515	445	70	349	270	79
UP	781	727	54	651	597	54	442	399	43	399	359	40
mean	*781*	*727*	*54*	*711*	*650*	*62*	*507*	*442*	*65*	*349*	*290*	*59*
std dev	*0*	*0*	*0*	*35*	*27*	*20*	*35*	*23*	*13*	*29*	*36*	*13*
COAST												
SP	843	797	46	705	646	59	525	458	67	316	257	59
CT	876	811	65	732	673	59	544	504	40	355	276	79
PE	856	805	51	742	635	107	570	507	63	348	272	76
DB	857	772	85	801	731	70	572	505	67	350	285	65
mean	*858*	*796*	*62*	*745*	*671*	*74*	*553*	*494*	*59*	*342*	*273*	*70*
std dev	*12*	*15*	*15*	*35*	*37*	*20*	*19*	*21*	*11*	*15*	*10*	*8*
total mean	*843*	*782*	*60*	*726*	*659*	*67*	*527*	*465*	*63*	*346*	*282*	*64*
total std dev	*33*	*31*	*14*	*39*	*34*	*21*	*37*	*34*	*13*	*24*	*29*	*13*

Table 3.4 Ridging anticyclone stable layer mean base and upper limit altitudes, and depths

On the whole the 700 hPa layer has a mean depth structure which conforms well to the mean synoptic controls (Figs. 3.6, 3.9a). Although anomalously shallow layers occur over Bethlehem and Pretoria, the majority of stations over the eastern parts of the country are weakened and deepened to 60-90 hPa by surface convergence. The layer over the west is compressed to a depth of 50-60 hPa.

The layer over the north-eastern and eastern parts of the plateau occurs with frequencies in the region of 75%, when ridging anticyclones are prevalent. This is high for an area under the influence of surface convergence. Durban has lower frequencies in the region of 65%. Bloemfontein and Upington have the highest frequencies (88% and 87% respectively) and the Eastern Cape coastal region experiences the lowest frequencies with a minimum of 55% over Port Elizabeth. There is a general north to south decrease in stable layer frequency, with a mean frequency over the interior (80%) far exceeding the mean frequency for the coast (63%) (Fig. 3.10a).

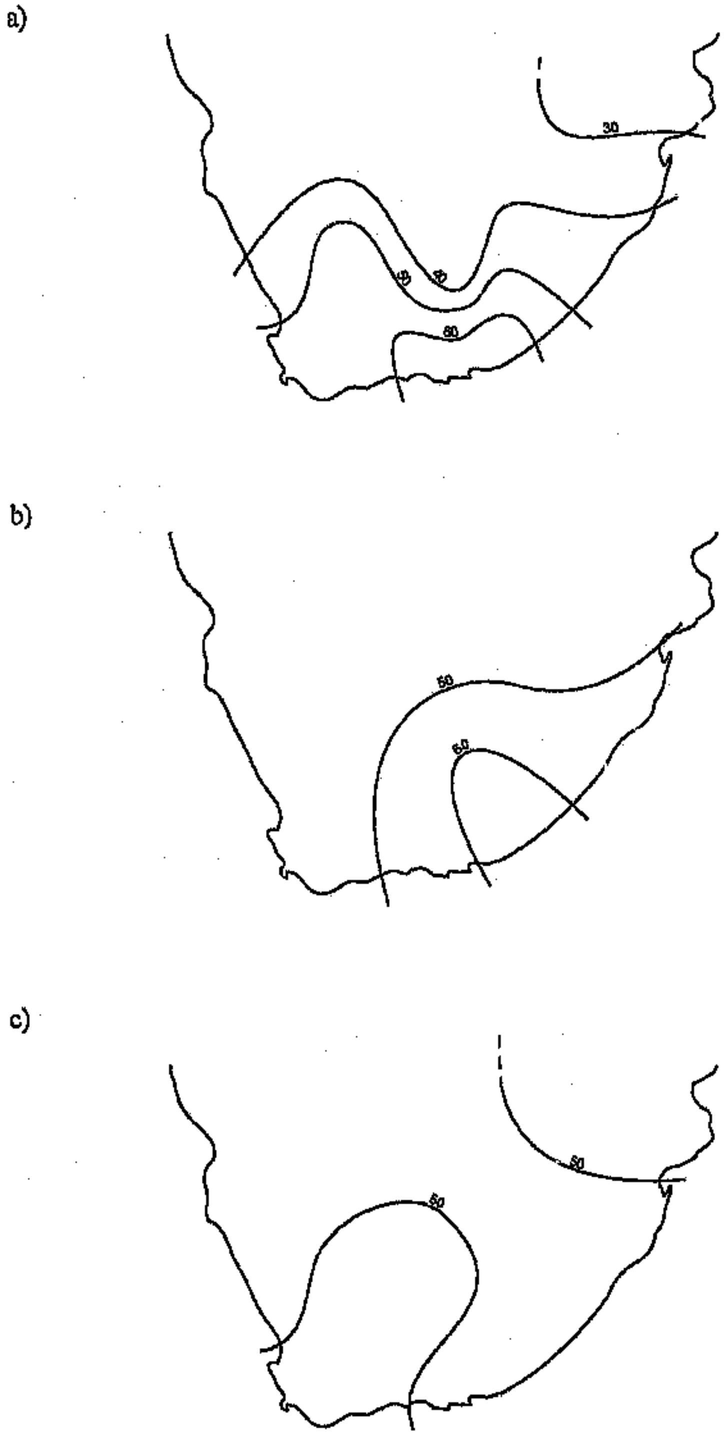


Figure 3.8 95% confidence intervals (hPa) for ridging anticyclone (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

layer. In comparison the continental high exerts only a divergent influence over the country at surface level and consequently mean depths vary less over the subcontinent.

Surface convection and turbulence over the south-eastern parts of the country, frequently associated with ridging highs, causes the layer to occur less frequently and the mean depth of the 800 hPa stable layer to be significantly greater than it is over the rest of the coastal areas. The stable layers over the Eastern and Western Cape coastal regions all have similar depths (Table 3.6) and are all controlled by vertical subsidence. This surface divergence over the western regions leads to favourable conditions for the formation of stable layers, and consequently the layer occurs with greater frequency over these areas. Springbok has the greatest frequency (78%).

3.3.2 *The 700 hPa layer*

The mean altitude of the 700 hPa layer base (726 hPa) is slightly greater than it is during continental anticyclonic events (740 hPa) (Figs. 3.6, 3.7a). Over Upington the layer occurs at a maximum altitude of 651 hPa. It is likely that local controls exerted by the easterly wave cause this anomaly. Pietersburg, with its low base (759 hPa) is too far north to fall under the regular control of ridging anticyclonic circulations, and the layer is somewhat anomalous in this locality as well. Relatively higher bases ranging from 706-728 hPa occur over the eastern parts of the country under the influence of surface convergence, with lower values over the southern and south-western parts of the Western Cape in the range of 732-742 hPa due to vertical subsidence associated with surface divergence. Durban has the lowest base of 801 hPa, and is obviously influenced by local mechanism other than surface turbulence and mixing.

The mean base of the 700 hPa layer has a greater base height standard deviation for the ridging anticyclone (39 hPa) than it does for the continental anticyclone (22 hPa). Nevertheless the standard deviation for this layer across the country emphasises, rather the lack of variation of the discontinuity base heights than the fact that in the eastern parts of the subcontinent the layers are higher than the rest of the country (Figs. 3.6, 3.7a).

Averaged over the country the mean 95% confidence interval for the 700 hPa layer base (46 hPa) is approximately the same as it is for the 800 hPa layer (41 hPa). The confidence interval exhibits an inter-station variability of 12 hPa (double that of the 800 hPa layer). The intra-station base variation ranges from 68 hPa at Port Elizabeth to 24 hPa at Pietersburg,

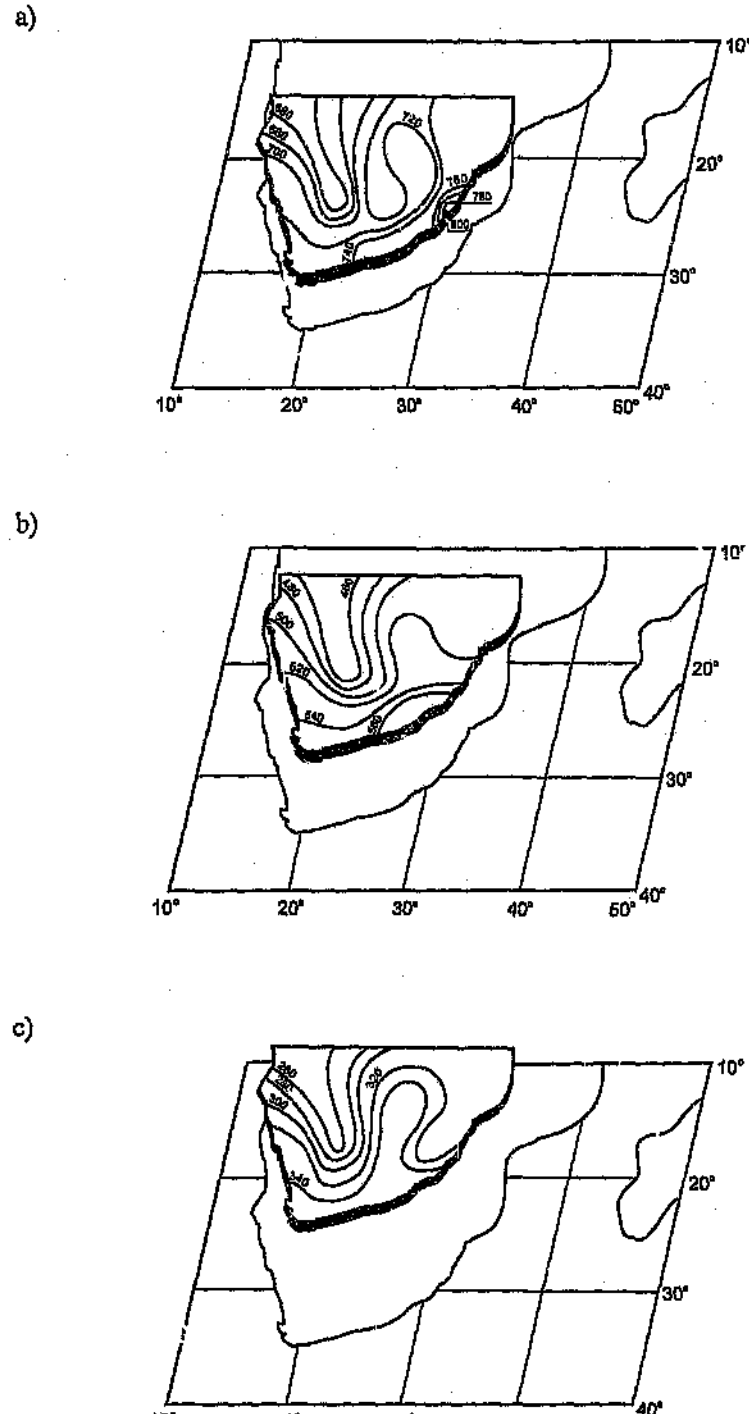


Figure 3.7 Mean base levels (hPa) for ridging anticyclone (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

a)

b)

c)

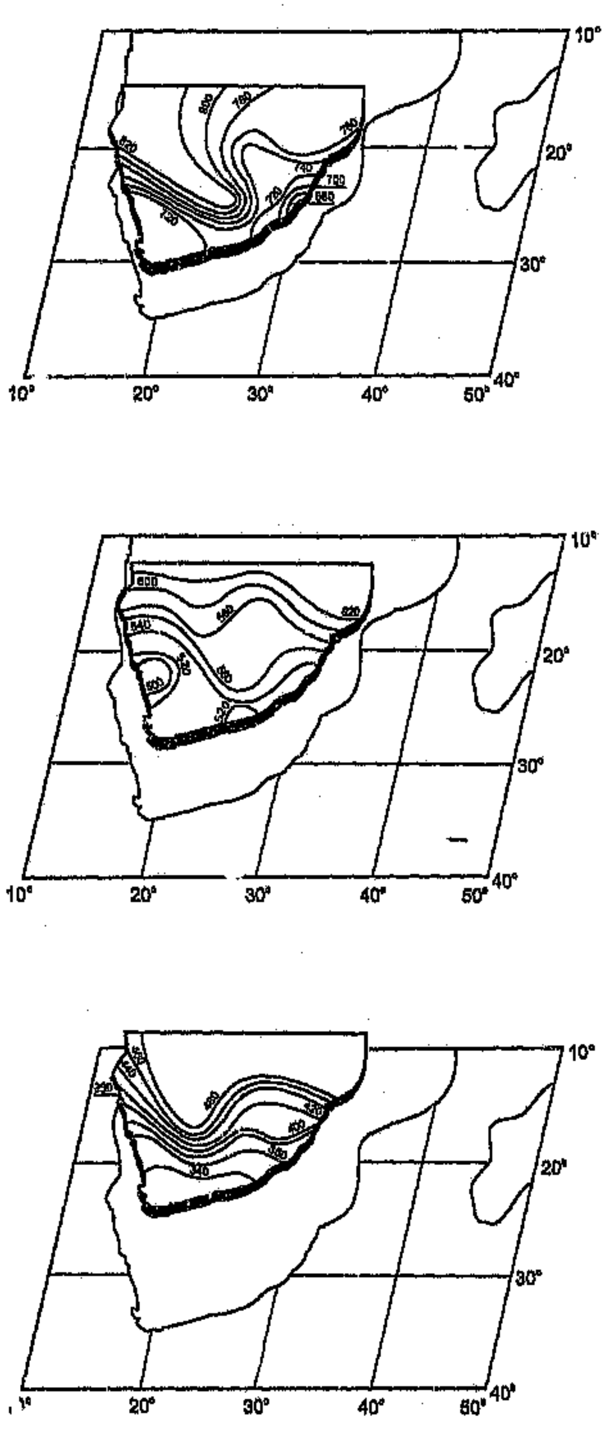


Figure 3.18 Mean base levels (hPa) for pre-frontal (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

STATION	800 hPa			700 hPa			500 hPa			300 hPa		
	Base Height	Upper Limit	Depth	Base Height	Upper Limit	Depth	Base Height	Upper Limit	Depth	Base Height	Upper Limit	Depth
PLATEAU												
PI				770	700	70	612	577	35	493	420	73
PR				745	709	36	576	520	56	422	375	47
BE				721	674	47	555	488	67	411	342	69
BL				810	732	78	576	513	63	374	321	53
UP				823	693	130			0	460	400	60
mean				*774*	*702*	*72*	*580*	*525*	*44*	*432*	*372*	*60*
std dev				*38*	*19*	*33*	*20*	*33*	*25*	*41*	*36*	*10*
COAST												
SP	805	772	33	701	647	54	480	377	103	353	242	111
CT	848	780	68	703	686	17	523	473	50	335	260	75
PE	892	840	52	728	665	63	515	455	60	326	264	62
DB	846	796	50	668	620	48	526	444	82	368	298	70
mean	*848*	*797*	*51*	*700*	*655*	*46*	*511*	*437*	*74*	*346*	*266*	*80*
std dev	*31*	*26*	*12*	*21*	*24*	*17*	*18*	*56*	*20*	*16*	*20*	*19*
total mean	*848*	*797*	*51*	*741*	*681*	*60*	*545*	*481*	*57*	*394*	*325*	*69*
total std dev	*31*	*26*	*12*	*46*	*36*	*23*	*39*	*57*	*26*	*51*	*62*	*22*

Table 3.10 Pre-frontal stable layer mean base and upper limit altitudes, and depths

STATION	800 hPa			700 hPa			500 hPa			300 hPa		
	Base Height	Upper Limit	Depth	Base Height	Upper Limit	Depth	Base Height	Upper Limit	Depth	Base Height	Upper Limit	Depth
PLATEAU												
PI				797	730	67	696	626	70	500	382	118
PR				755	697	58	596	508	88	451	364	87
BE				745	708	37	604	546	58	401	314	87
BL				766	726	40	582	503	79	392	302	90
UP				773	735	38	610	545	65	454	403	51
mean				*767*	*719*	*48*	*618*	*546*	*72*	*440*	*353*	*87*
std dev				*18*	*14*	*12*	*40*	*44*	*11*	*39*	*39*	*21*
COAST												
SP	853	810	43	745	681	64	543	467	76	350	297	53
CT	840	813	27	714	599	115	575	467	108	350	244	106
PE	836	779	57	757	673	84	523	467	56	373	290	83
DB	850	820	30	708	675	33	532	465	67	325	263	62
mean	*845*	*806*	*39*	*731*	*657*	*74*	*543*	*467*	*77*	*350*	*274*	*76*
std dev	*7*	*16*	*12*	*31*	*34*	*30*	*20*	*1*	*19*	*17*	*21*	*20*
total mean	*845*	*806*	*39*	*751*	*692*	*60*	*585*	*510*	*74*	*400*	[illegible]	*82*
total std dev	*7*	*16*	*12*	*26*	*40*	*25*	*49*	*51*	*15*	*58*	[illegible]	*22*

Table 3.11 Post-frontal stable layer mean base and upper limit altitudes, and depths

occurrence of the coastal 800 hPa layer is approximately 85% over Port Elizabeth during both conditions (Tables 3.14, 3.15). As in all the previous situations the layer is absent over the interior.

3.5.2 *The 700 hPa layer*

The general structure of the 700 hPa layer mean base height is similar during both pre-frontal and post-frontal circulation conditions with a base height decrease from south to north (Figs. 3.16, 3.17, 3.18a, 3.19a). Greater inter-station variation in height occurs over the interior during pre-frontal conditions, yielding a standard deviation (38 hPa) twice that of the post-frontal standard deviation (18 hPa). The layer over the coast decreases in altitude after the front has passed, but remains fairly constant over the interior, increasing only 7 hPa with the transition. The 95% confidence intervals indicate that the variability about the mean over each station is greater during pre-frontal conditions (74 hPa) than they are for the post-frontal (51 hPa). With the exception of Springbok and Upington, base height variability decreases after the wave has passed over the stations, with both circulation types exhibiting similar intra-station base height structures across the country (Figs. 3.16, 3.17, 3.20a, 3.21a).

The mean depth of the layer over the entire country is the same for both conditions (60 hPa) (Figs. 3.16, 3.17, 3.22a, 3.23a). However, the depth structures for the two circulation types are markedly different across all the stations. The pre-frontal layers over the coast and interior have a mean depth of 72 hPa and 46 hPa respectively, whereas the post-frontal equivalent appears to be the exact opposite (48 hPa and 74 hPa for the interior and coast respectively). The layer over the western and southern coastal regions becomes deeper after the front has passed, owing to post-frontal mixing. The same is true of Pretoria. The rest of the stations in an east-west band across the country experience a decrease in the 700 hPa stable layer depth under post-frontal conditions. Upington experiences exceptionally deep layers during pre-frontal circulation (130 hPa). The same applies to Cape Town during post-frontal conditions (115 hPa). No coherent picture emerges.

Contrary to expectation, the frequency of the layer increases from 65% to 77% with the passage of frontal disturbances over the country (Figs. 3.24a, 3.25a). One would expect surface convergence associated with post-frontal conditions to lead to a significant decrease in the stable layer frequency. The layer is not apparent over Upington during pre-frontal circulation. This is most likely a function the data rather than the station experiencing a genuine absence.

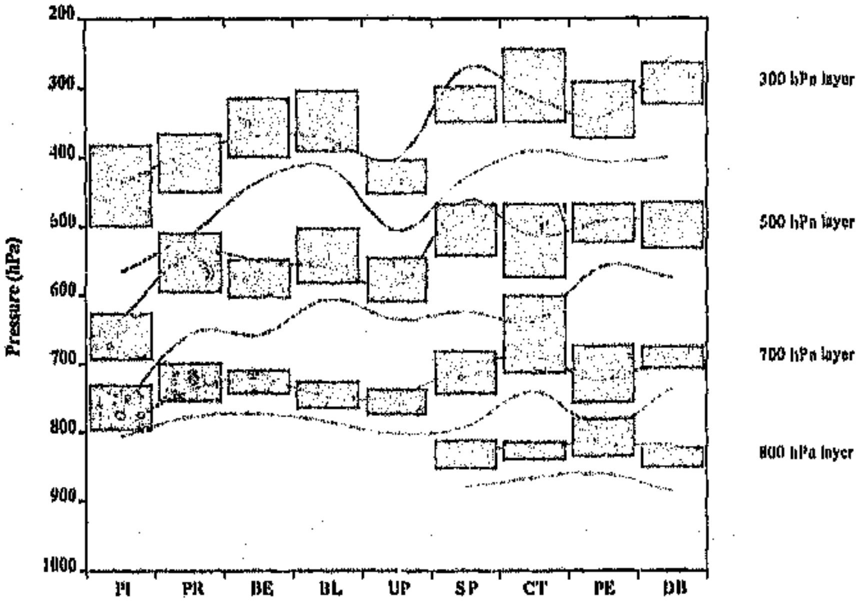


Figure 3.17 Stable layers (shaded) for post-frontal conditions over Pietersburg (PI), Pretoria (PR), Bethlehem (BE), Bloemfontein (BL), Upington (UP), Springbok (SP), Cape Town (CT), Port Elizabeth (PE) and Durban (DB). Upper and lower 95% confidence limits for the base heights of the layers as well as the continental surface are shown in each case

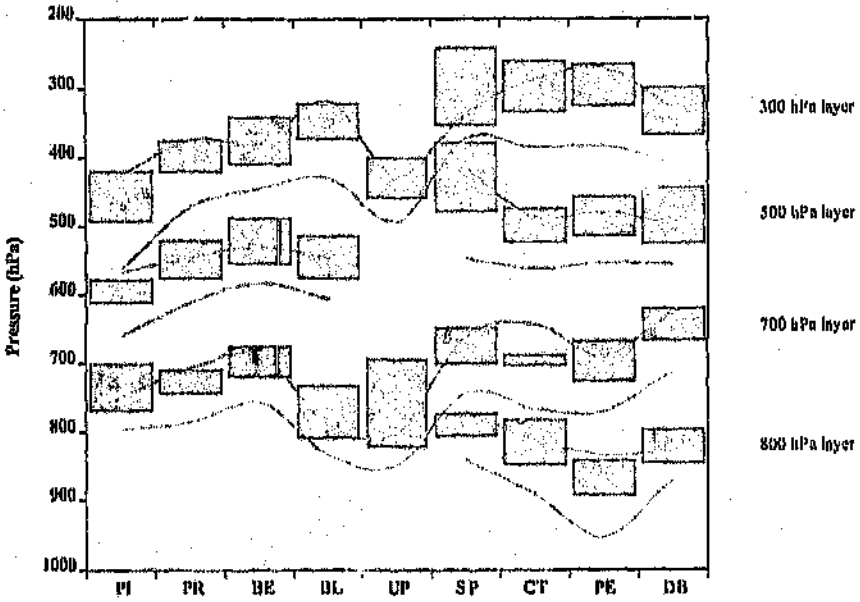


Figure 3.16 Stable layers (shaded) for pre-frontal conditions over Pietersburg (PI), Pretoria (PR), Bethlehem (BE), Bloemfontein (BL), Upington (UP), Springbok (SP), Cape Town (CT), Port Elizabeth (PE) and Durban (DB). Upper and lower 95% confidence limits for the base heights of the layers as well as the continental surface are shown in each case

The stable layer occurs with extreme persistence at 300 hPa, reaching highest frequencies of 97% over Pretoria, and lowest frequencies of 79% over Springbok. The general structure shows that the layer occurs with relatively greater frequency over the eastern parts of the country and decreases in frequency over the western coastal regions and Northern Cape (Fig. 3.15c).

3.5 STABLE LAYERS ASSOCIATED WITH WESTERLY WAVES

Westerly waves are transient, fast-moving synoptic systems, making the determination of mean areas influenced by surface divergence and vergence problematic. Consequently, each day is analysed individually in order to ascertain where the areas of convergence and divergence occur at the specific time of the radiosonde ascent. The structures of the layers for pre-frontal and post-frontal conditions are thus dealt with separately. Details are presented in Tables 3.10 to 3.15.

3.5.1 *The sub-escarpment 800 hPa layer*

Although the coastal 800 hPa stable layer has a similar mean height over the entire country during both the pre-frontal (848 hPa) and post-frontal conditions (845 hPa) (Figs. 3.16, 3.17), significantly greater between station deviations in the layer height occur during pre-frontal circulation period. Contrary to expectation the standard deviation of the layer is 31 hPa before the front and only 7 hPa after the front has passed. This decreased base variation is also observed in the 95% confidence interval, where the pre-frontal value is 78 hPa and the post-frontal value is 51 hPa. The cause of the exceptionally high pre-frontal inter- and intra-station base height variance lies in a few outlier values; namely an anomalously low Port Elizabeth base height (892 hPa), a high Springbok base height (805 hPa) and a high Port Elizabeth base height confidence interval of 120 hPa. Should these figures be excluded the mean values for each condition would be more similar. The depth of the layer to the west of the moving wave (51 hPa) is slightly greater than it is to the east (39 hPa). One would expect the layer depth to increase under conditions of uplift and convection behind the front (Figs. 3.16, 3.17).

The layer is present with a slightly greater mean frequency before the wave passes over the stations, due to the mixing and uplift of the post-frontal conditions. Nevertheless, the fact that the layer is present 67% of the time during post-frontal conditions is an indication of the persistence and strength of the layer despite synoptic controls. The maximum frequency of

a)

b)

c)

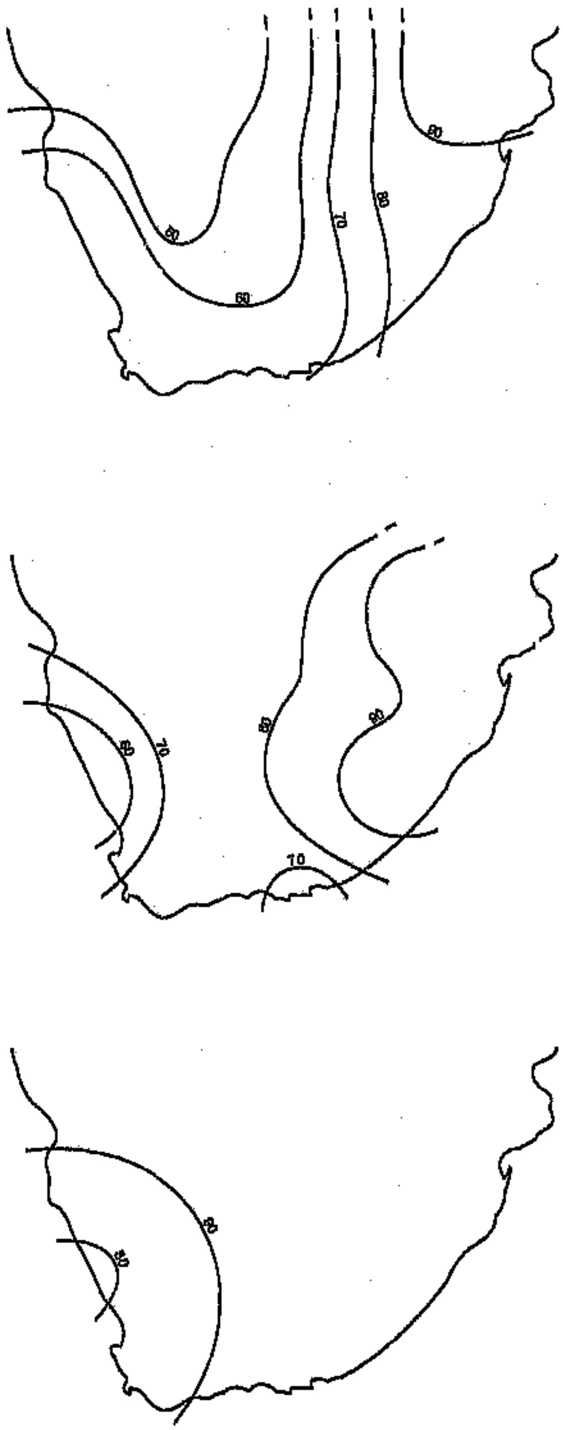


Figure 3.15 Mean frequencies for easterly wave (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

3.4.4 *The 300 hPa layer*

The 300 hPa layer is too high to be influenced by surface-induced easterly waves. Nevertheless, the structure of the base heights across the subcontinent appears to be the same as the 500 hPa layer in that the layer decreases in altitude in a south to north direction (Figs. 3.11, 3.12b, 3.12c). A base height standard deviation of 41 hPa shows that the variation in base height over the country is much greater in the cases of the underlying layers.

Deeper layers as well as lower base heights are observed over the northern central parts of the country, with a maximum depth occurring over Bloemfontein (91 hPa) (Figs. 3.11, 3.14c). The shallowest part of the layer occurs over Pietersburg and Port Elizabeth (54 hPa and 55 hPa respectively). The mean 95% confidence interval is 56 hPa with a standard deviation of 10 hPa (Figs. 3.11, 3.13c), indicating the same degree of base height variability over all of the stations. There is a general east to west increase in confidence intervals across the country, much the same as the underlying layer. The layer exhibits maximum intra-station variability at Upington (70 hPa) and minimum over the eastern parts of the country (approximately 45 hPa).

STATION	800 hPa	700 hPa	500 hPa	300 hPa
PLATEAU				
PI		90	93	93
PR		83	90	97
BE		76	97	93
BL		59	86	93
UP		45	79	86
mean		*71*	*89*	*92*
std dev		*16*	*6*	*4*
COAST				
SP	62	62	59	79
CT	62	66	72	83
PE	75	63	63	92
DB	79	86	100	93
mean	*70*	*69*	*74*	*87*
std dev	*8*	*10*	*16*	*6*
total mean	*70*	*70*	*82*	*90*
total std dev	*8*	*10*	*18*	*7*

Table 3.9 Easterly wave stable layer mean frequencies

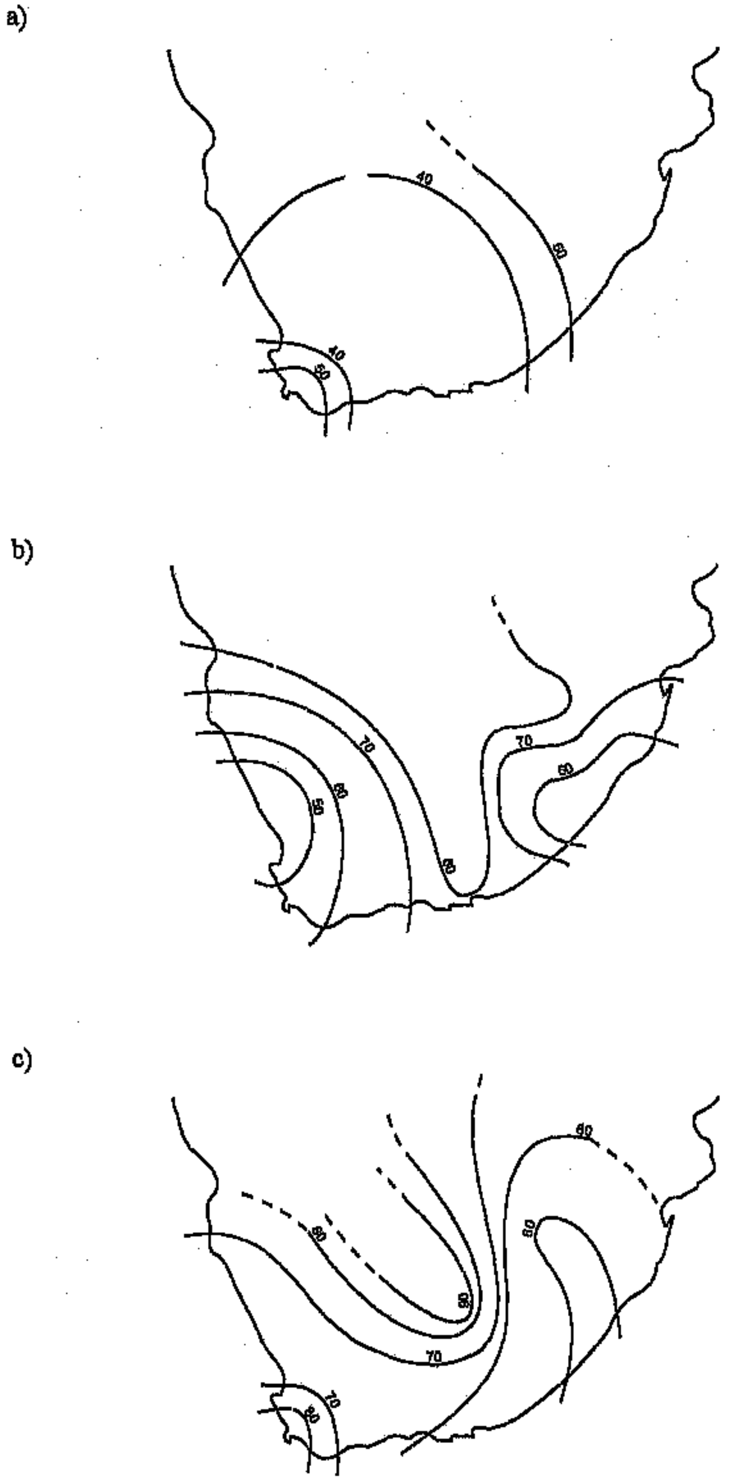


Figure 3.14 Mean depths (hPa) for easterly wave (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

hPa) (Figs. 3.11, 3.13b). Neither of the above-mentioned stations are located within the control of the easterly wave. Again the synoptic control is evident with relatively less deviation about the mean base height over the eastern plateau under the influence of anticyclonic flow, and the variation increasing over the central parts of the country just to the east of the wave. One would, however, expect greater standard deviations across the country for the layers under strong convective systems such as the easterly wave.

STATION	800 hPa			700 hPa			500 hPa			300 hPa		
	Lower Limit	Upper Limit	CI	Lower Limit	Upper Limit	CI	Lower Limit	Upper Limit	CI	Lower Limit	Upper Limit	CI
PLATEAU												
PI				734	686	48	556	510	46	442	398	44
PR				736	692	44	568	526	42	438	394	44
BE				703	647	56	550	502	48	412	356	56
BL				744	684	60	603	561	42	436	370	66
UP				729	701	28	603	551	52	408	338	70
mean				*729*	*682*	*47*	*576*	*530*	*46*	*427*	*371*	*56*
std dev				*14*	*18*	*11*	*23*	*23*	*4*	*14*	*23*	*11*
COAST												
SP	826	776	50	712	666	46	584	524	60	436	380	56
CT	912	870	42	773	719	54	586	524	62	385	325	60
PE	914	862	52	746	690	56	561	483	78	338	274	64
DB	887	849	38	721	669	52	514	482	32	333	291	42
mean	*885*	*839*	*46*	*738*	*686*	*52*	*561*	*503*	*58*	*373*	*318*	*56*
std dev	*36*	*37*	*6*	*24*	*21*	*4*	*29*	*21*	*17*	*42*	*40*	*8*
total mean	*885*	*839*	*46*	*733*	*684*	*49*	*569*	*518*	*51*	*403*	*347*	*56*
total std dev	*36*	*37*	*6*	*19*	*20*	*9*	*27*	*26*	*13*	*40*	*42*	*10*

Table 3.8 Easterly wave stable layer 95% confidence limits and intervals (CI)

The 500 hPa layer has a mean depth (67 hPa) which is somewhat greater than the 700 hPa layer (44 hPa). The layer is deepest in a north to south ridge over the central parts of the country due to the uplift of air immediately to the rear of the wave (Figs. 3.11, 3.14b). Layer depths decrease over Upington and Springbok under the influence of upper air subsidence to the west of the wave.

The layer occurs with a frequency of 90% over the eastern parts of the country and decrease to 60-70% over the western parts of the country (Fig. 3.15b). A comparison of the layer frequencies to the east and west clearly indicates a significant difference in the influence of the regimes on either side of the wave.

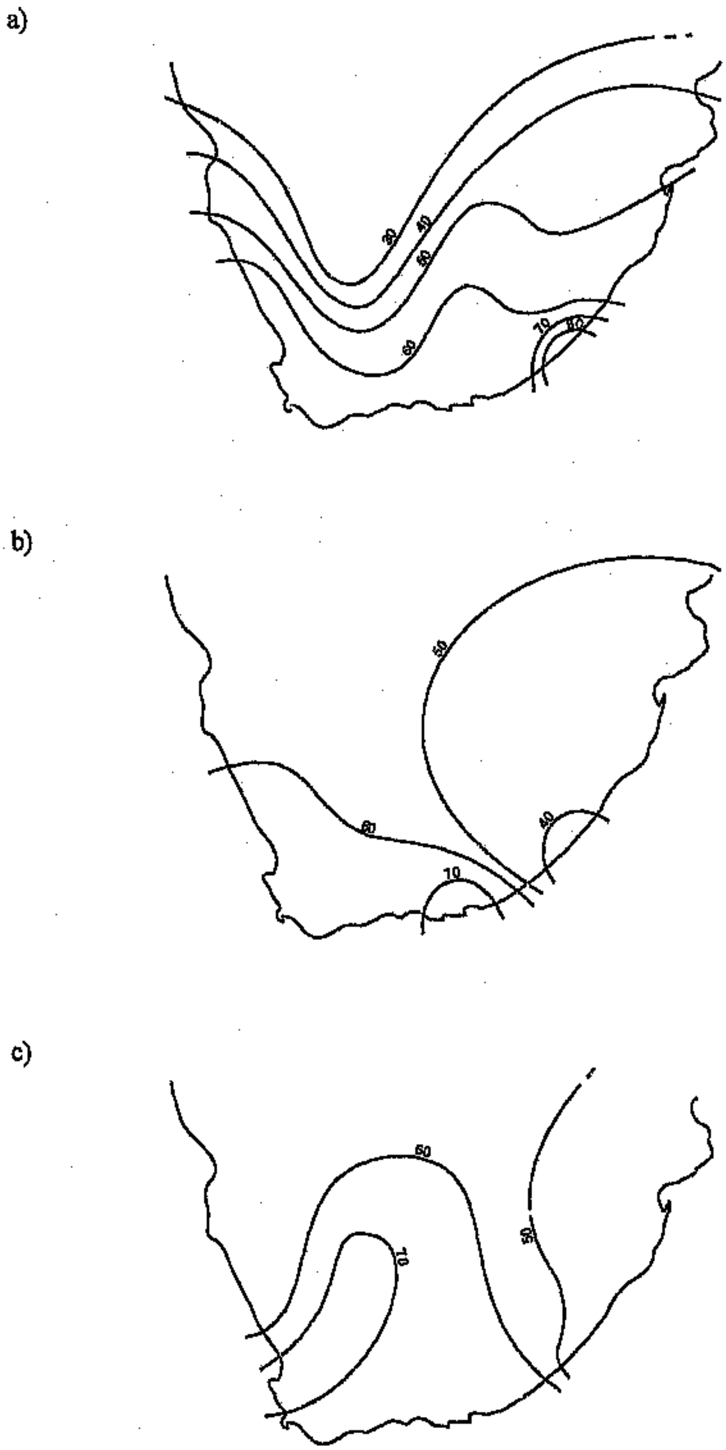


Figure 3.13 95% confidence intervals (hPa) for easterly wave (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

it is for the majority of the country. To the west of the trough, subsidence compresses the layer, resulting in a shallower, but stronger layer over Upington (37 hPa) and Springbok (35 hPa) which exhibits far less base height variability, especially over Upington (28 hPa) (Figs. 3.11, 3.13a, 3.14a)

The structure of the stable layer frequencies conform well to the synoptic controls at this altitude. Highest frequencies occur in the high pressure areas to the rear of the trough, in the range of 80-90% (Fig. 3.15a). Upington has a lower frequency of occurrence of 45%.

STATION	800 hPa			700 hPa			500 hPa			300 hPa		
	Base Height	Upper Limit	[illegible]	[illegible] Height	Upper Limit	Depth	Base Height	Upper Limit	Depth	Base Height	Upper Limit	Depth
PLATEAU												
PI				710	657	53	553	480	73	420	366	54
PR				714	656	58	547	462	85	416	355	61
BE				675	632	43	526	459	67	384	326	58
BL				714	682	32	582	499	83	403	312	91
UP				715	680	35	577	516	61	373	300	73
mean				*706*	*661*	*44*	*557*	*483*	*74*	*399*	*332*	*67*
std dev				*15*	*18*	*10*	*21*	*22*	*9*	*18*	*25*	*13*
COAST												
SP	801	764	37	689	652	37	554	506	48	408	346	62
CT	891	848	43	746	687	59	555	504	51	355	270	85
PE	888	821	67	718	686	32	522	442	80	306	251	55
DB	868	812	56	695	644	51	498	442	56	312	246	66
mean	*862*	*811*	*51*	*712*	*667*	*45*	*532*	*474*	*59*	*345*	*278*	*67*
std dev	*36*	*30*	*12*	*22*	*19*	*11*	*24*	*32*	*13*	*41*	*40*	*11*
total mean	*862*	*811*	*51*	*708*	*664*	*44*	*546*	*479*	*67*	*375*	*308*	*67*
total std dev	*36*	*30*	*12*	*19*	*19*	*10*	*25*	*27*	*13*	*41*	*42*	*12*

Table 3.7 Easterly wave stable layer mean base and upper limit altitudes, and depths

3.4.3 *The 500 hPa layer*

Base heights for the 500 hPa layer decrease from a maximum of 498 hPa over Durban to a minimum of 582 hPa over Bloemfontein. The mean base height for all stations is 546 hPa and the control of the easterly wave is evident even at this height. However, contrary to expectation, the wave over the northern central part of the country induces a trough of relatively lower base heights (Figs. 3.11, 3.12b). A comparatively small base height variation occurs across the country, with the layer exhibiting a standard deviation of 25 hPa.

Variation about the mean base height is at its maximum over Port Elizabeth where a 95% confidence interval of 78 hPa is apparent. Minimum variation occurs over Durban (32 waves occurs 45% of the time, the 700 hPa layer over Bethlehem occurs 48% of the time for pre-frontal westerly waves and Springbok during post-frontal circulation has frequencies of 33% and 44% for the 300 hPa and 800 hPa layers respectively. It is evident that the layers usually occur with these low frequencies in geographical locations which are not directly influenced by the individual synoptic circulation type being examined. Hence, the low persistence may generally be ascribed to other controlling mechanisms, and is not necessarily representative of the archetypal synoptic situation being investigated. Alternatively it occurs in regions of strong convergence where the layers are clearly destroyed.

* * * * * * *

The structural and temporal characteristics of four elevated absolutely stable discontinuities have been presented for different circulation types. In Chapter 4 the results are summarised and discussed. In addition, mean conditions for generally fair-weather events, irrespective of synoptic type, will be considered.

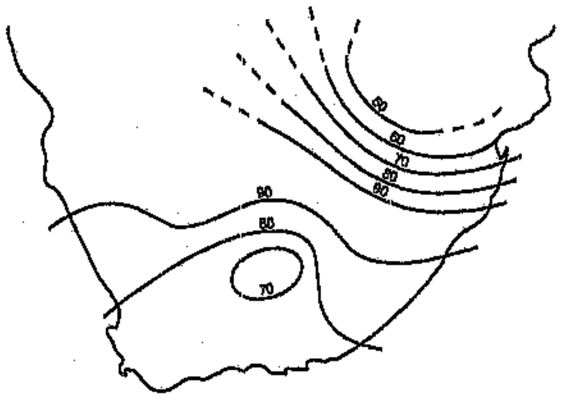
central parts of the country experience a slight decrease in the layer frequency after the front has passed over, but the stations to the east and west of this area experience an increase in frequency. During pre-frontal conditions the layer occurs 100% of the time over Bloemfontein and Upington. The frequencies decrease concentrically outwards from this ridge. During post-frontal conditions the layer occurs with frequencies in the region of 90% over the most stations, with the notable exception of 33% for Springbok which is the lowest frequency observed for any layer in the analysis.

STATION	800 hPa	700 hPa	500 hPa	300 hPa
PLATEAU				
PI		50	83	67
PR		80	50	90
BE		91	82	91
BL		70	96	93
UP		90	80	90
mean		*76*	*78*	*86*
std dev		*15*	*15*	*10*
COAST				
SP	44	88	88	33
CT	73	73	73	93
PE	88	72	52	64
DB	63	82	82	91
mean	*67*	*79*	*74*	*70*
std dev	*16*	*7*	*14*	*24*
total mean	*67*	*77*	*76*	*79*
total std dev	*16*	*7*	*14*	*26*

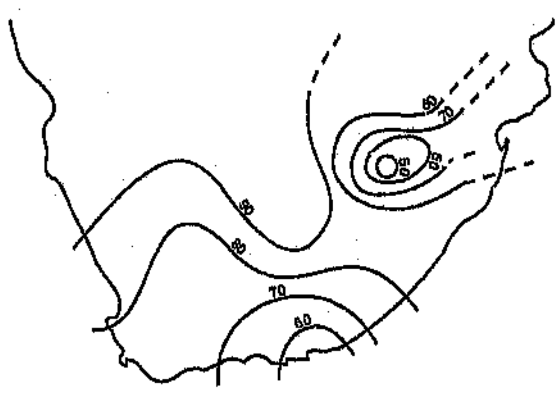
Table 3.15 Post-frontal stable layer mean frequencies

Since all of the post-frontal layers exhibit frequencies significantly greater than would be expected under strongly convective conditions, the implication is that elevated absolutely stable layers over the subcontinent are rapidly reconstructed after the passage of the front. Von Gough and Tyson (1977) have alluded to this rapid reconstruction over Johannesburg. The layers seldom decrease in frequency occurrence to below 50%, regardless of synoptic circulation type. However, it is found that at least one of the values occurs less than 50% of the time for each individual synoptic circulation investigated. For the continental anticyclone, the 800 hPa layer over Port Elizabeth occurs with a frequency of 48%, for the ridging anticyclone the 500 hPa layer over Cape Town is present 44%, the 700 hPa layer over Upington for easterly

a)



b)



c)

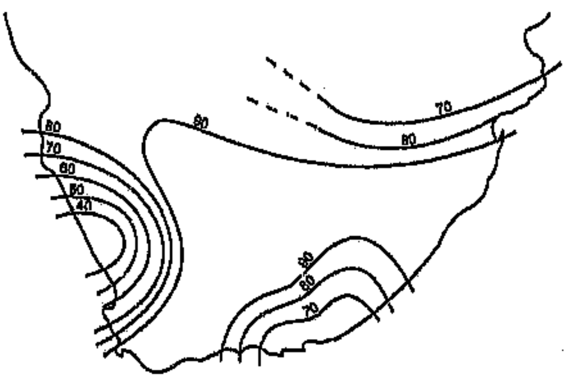


Figure 3.25 Mean frequencies for post-frontal (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

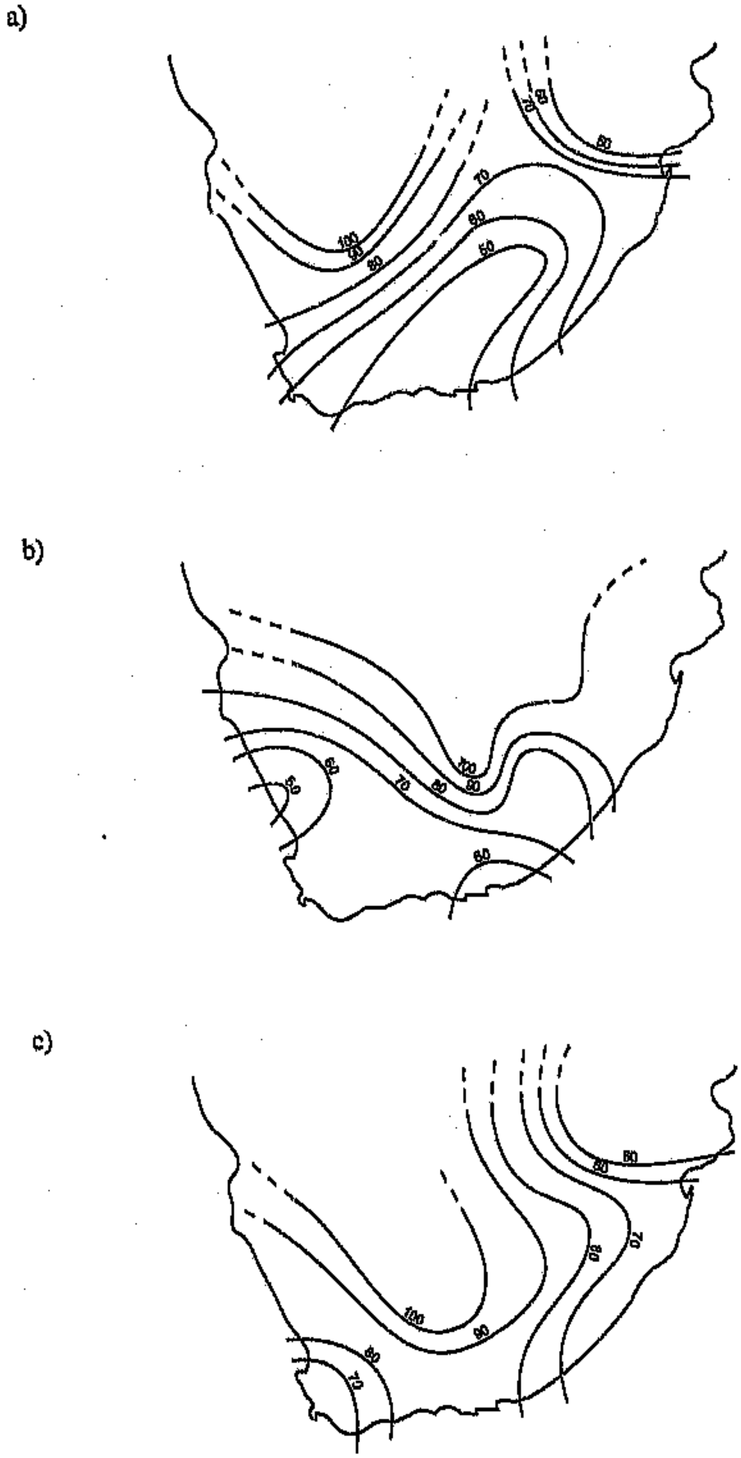


Figure 3.24 Mean frequencies for pre-frontal (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

peripheral regions of this band, over Durban, Pretoria and Springbok (Figs. 3.16, 3.17, 3.20c, 3.21c). Generally, the synoptic controls on the layers are evident over the country.

Mean depths over the country are 69 hPa during pre-frontal circulation and 82 hPa during post-frontal. Over the eastern plateau the depth increases from a range of 47-73 hPa during pre-frontal conditions to 87-118 hPa at the trailing edge of the wave. Shallow layers lie over the central plateau and increase with distance from this core during pre-frontal conditions. After the passage of the wave the shallowest layers lie on the east and west coasts, with the deepest layers occurring on the north-east and south-west extremities of the country (Figs. 3.16, 3.17, 3.22c, 3.23c)

STATION	800 hPa	700 hPa	500 hPa	300 hPa
PLATEAU				
PI		50	100	50
PR		69	100	80
BE		48	76	90
BL		50	100	100
UP		100		100
mean		*63*	*94*	*84*
std dev		*20*	*10*	*19*
COAST				
SP	75	88	50	88
CT	67	50	67	67
PE	86	57	57	71
DB	67	71	71	63
mean	*74*	*67*	*61*	*72*
std dev	*8*	*15*	*8*	*10*
total mean	*74*	*65*	*78*	*79*
total std dev	*8*	*15*	*18*	*12*

Table 3.14 Pre-frontal stable layer mean frequencies

Mean frequencies of the layer over the coastal and inland stations do not alter significantly from pre-frontal to post-frontal conditions (Figs. 3.24c, 3.25c). The standard deviation of the layer frequency does, however, increase significantly from pre-frontal to post-frontal conditions over the coastal regions, and decreases over the interior. The stations in the

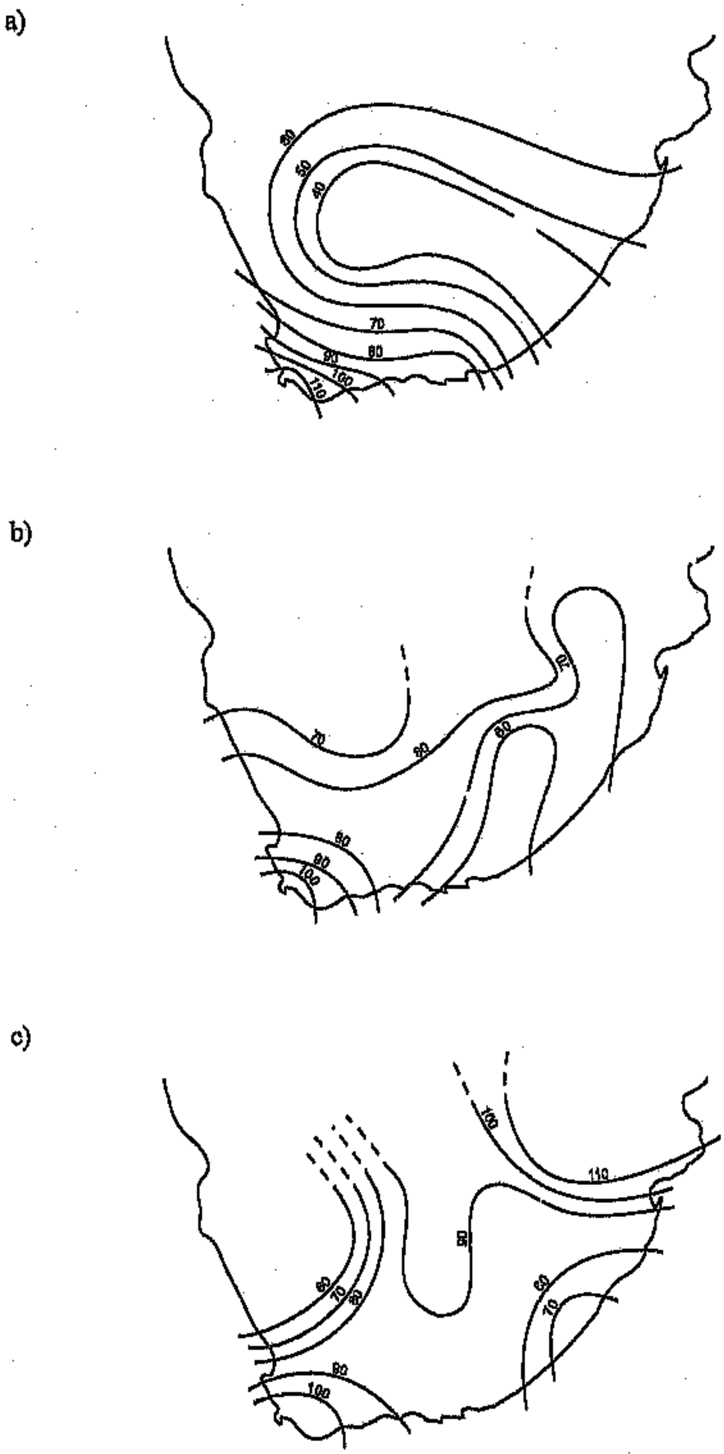


Figure 3.23 Mean depths (hPa) for post-frontal (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

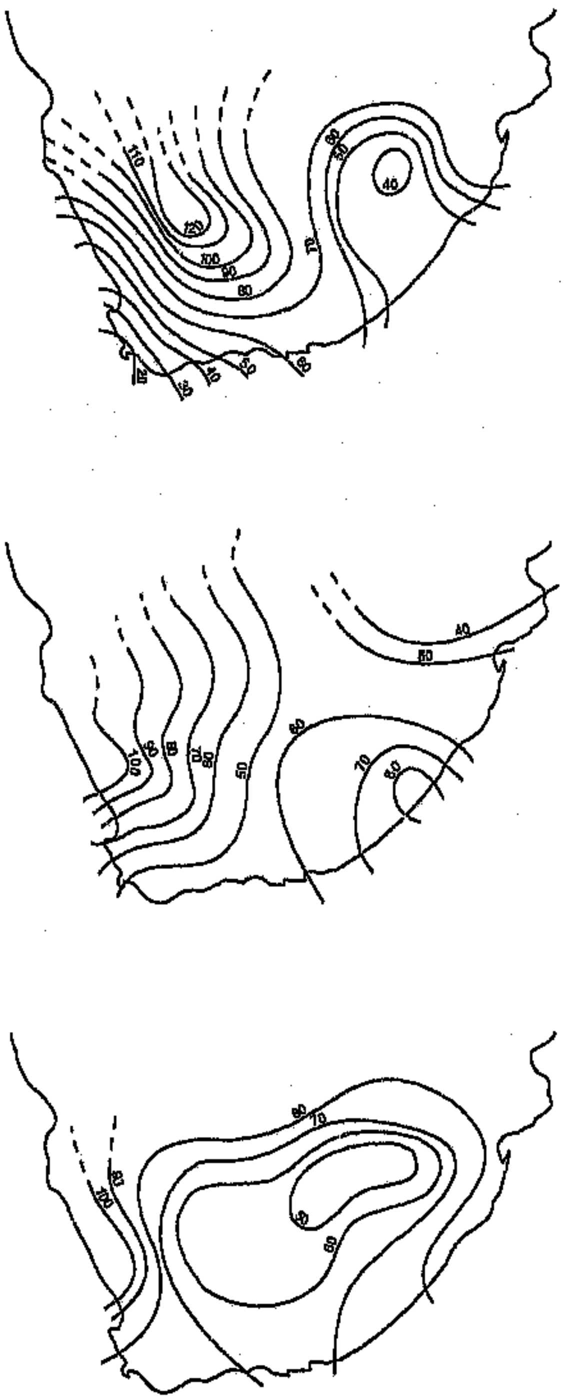


Figure 3.22 Mean depths (hPa) for pre-frontal (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

which is very similar to that of the pre-frontal layer (78%). A minimum frequency of 50% is evident over Pretoria and a maximum frequency of 96% occurs over Bloemfontein. Again there is a general north to south increase, with the exception of Pretoria which has a relatively lower value (Fig. 3.25b).

STATION	800 hPa			700 hPa			500 hPa			300 hPa		
	Lower Limit	Upper Limit	CI	Lower Limit	Upper Limit	CI	Lower Limit	Upper Limit	CI	Lower Limit	Upper Limit	CI
PLATEAU												
PI				802	792	10	760	632	128	565	435	130
PR				776	734	42	655	537	118	510	392	118
BE				770	720	50	657	551	106	434	368	66
BL				784	748	36	606	558	48	412	372	40
UP				801	745	56	636	584	52	506	402	104
mean				*787*	*748*	*39*	*663*	*572*	*90*	*485*	*394*	*92*
std dev				*13*	*24*	*16*	*52*	*33*	*34*	*55*	*24*	*34*
COAST												
SP	877	829	48	790	700	90	623	463	160	430	270	160
CT	864	816	48	740	688	52	637	513	124	388	312	76
PE	857	815	42	792	722	70	556	490	66	405	341	64
DB	883	817	66	734	682	52	574	490	84	397	253	144
mean	*870*	*819*	*51*	*764*	*698*	*66*	*598*	*489*	*109*	*405*	[illegible]	*111*
std dev	*10*	*6*	*9*	*27*	*15*	*16*	*33*	*18*	*36*	*16*	[illegible]	*42*
total mean	*870*	*819*	*51*	*777*	*726*	*51*	*634*	*535*	*98*	*450*	*349*	*100*
total std dev	*10*	*6*	*9*	*23*	*32*	*21*	*55*	*50*	*36*	*58*	*58*	*39*

Table 3.13 Post-frontal stable layer 95% confidence limits and intervals (CI)

3.5.4 *The 300 hPa layer*

The base of the 300 hPa layer remains fairly constant under both pre-frontal and post-frontal circulation types, with a mean base height over the country of 394 hPa for the former and 400 hPa for the latter (Figs. 3.16, 3.17, 3.18c, 3.19c). The general structure of the layer base remains similar under both conditions over the country, with the higher basses occurring over the southern areas and a sharply decreasing gradient to the northern interior.

Under pre-frontal conditions the 95% confidence interval of the layer ranges from 36-136 hPa over the subcontinent, over Springbok and Pietersburg respectively, with a mean of 89 hPa. The post-frontal conditions have a greater range, from 40 hPa to 160 hPa at Bloemfontein and Springbok respectively. Variation about the mean base height decreases in an area from Cape Town to Bloemfontein and Upington after the front has passed, but increases on the

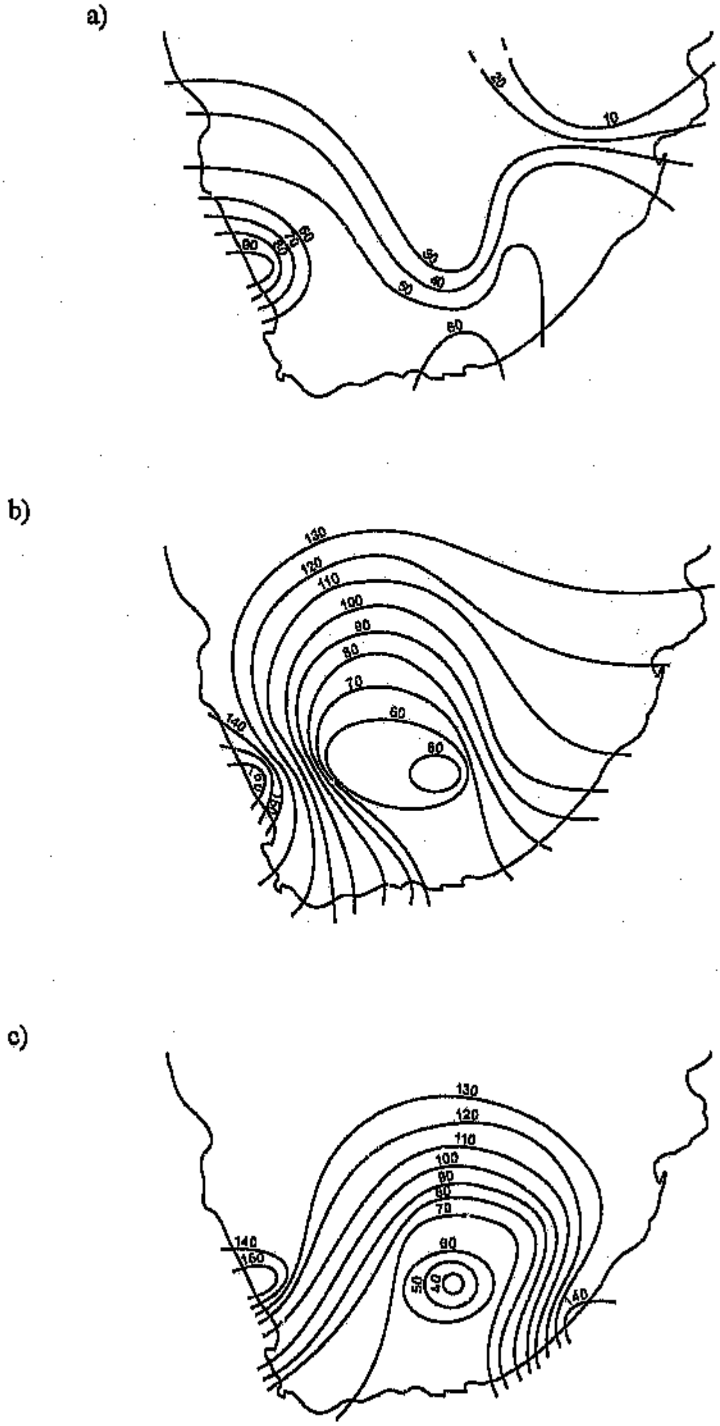


Figure 3.21 95% confidence intervals (hPa) for post-frontal (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

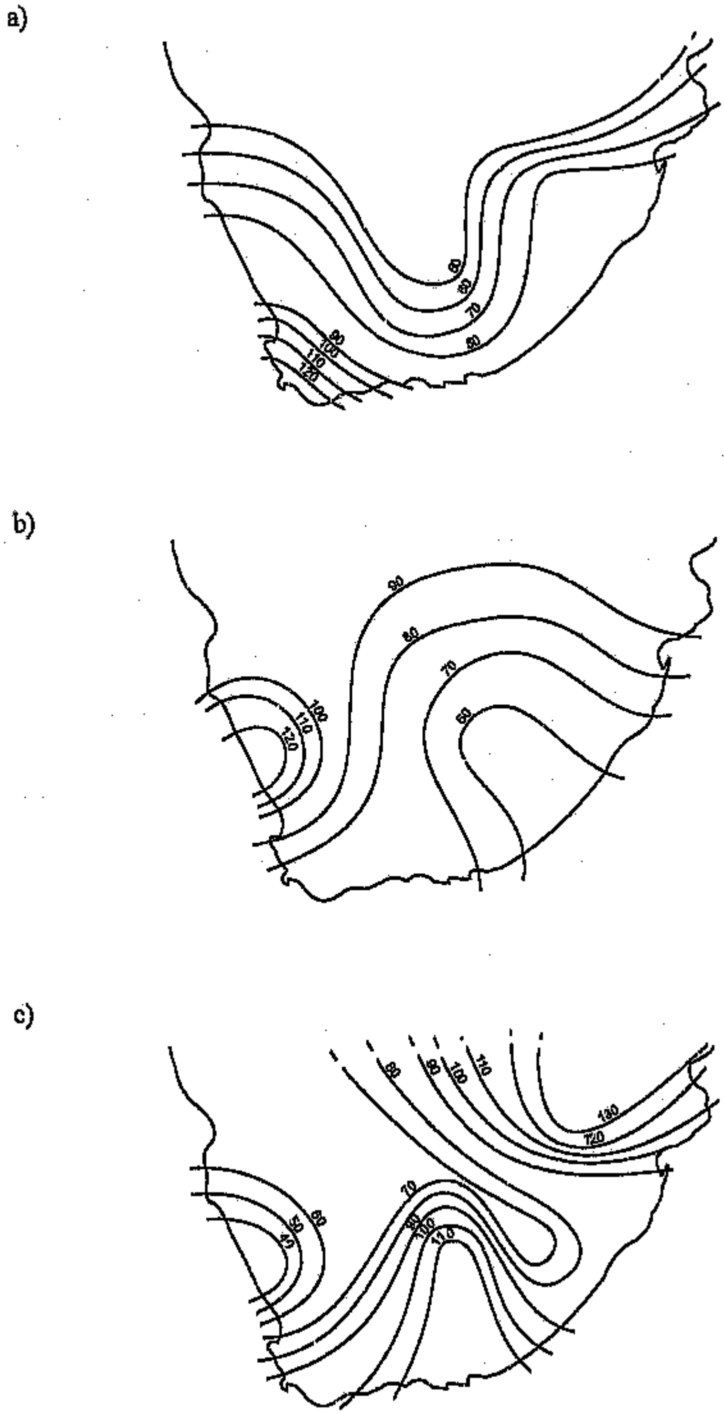


Figure 3.20 95% confidence intervals (hPa) for pre-frontal (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

3.5.3 *The 500 hPa layer*

The general country-wide structure of this layer's base height remains similar over the subcontinent both before and after the passage of westerly wave disturbances (Figs. 3.16, 3.17, 3.18b, 3.19b). The mean base of the layer decreases from 545 hPa for pre-frontal conditions to 585 hPa under post-frontal conditions. In general the layer appears to be lower over the plateau than over the coastal areas.

Intra-station base height fluctuations about the mean increase during post-frontal conditions, except over a small area of the southern coast and Bloemfontein (Figs. 3.16, 3.17, 3.20b, 3.21b). Averaged over all the stations the mean confidence interval is in the region of 100 hPa during post-frontal and 70 hPa during pre-frontal conditions. Depths in the region of 45 hPa over the interior increase to 72 hPa with post-frontal conditions. Coastal layer depths vary little in the transition (Figs. 3.16, 3.17, 3.22b, 3.23b).

STATION	800 hPa			700 hPa			500 hPa			300 hPa		
	Lower Limit	Upper Limit	CI	Lower Limit	Upper Limit	CI	Lower Limit	Upper Limit	CI	Lower Limit	Upper Limit	CI
PLATEAU												
PI				794	746	48	658	566	92	561	425	136
PR				784	706	78	609	543	66	470	374	96
BE				755	687	68	582	528	54	443	379	64
BL				833	787	46	606	546	60	430	318	112
UP				847	799	48			0	493	427	66
mean				*803*	*745*	*58*	*614*	*546*	*54*	*479*	*385*	*95*
std dev				*33*	*44*	*13*	*28*	*14*	*30*	*46*	*40*	*27*
COAST												
SP	339	77[illegible]		742	660	82	545	415	130	371	335	36
CT	887	809	[illegible]	765	641	124	561	485	76	384	286	98
PE	952	832	120	769	687	82	553	477	76	382	270	112
DB	868	824	44	711	625	86	555	497	58	409	327	82
mean	*887*	*809*	*78*	*747*	*653*	*94*	*554*	*469*	*85*	*387*	*305*	*82*
std dev	*42*	*23*	*27*	*23*	*23*	*18*	*6*	*32*	*27*	*14*	*27*	*29*
total mean	*887*	*809*	*78*	*778*	*704*	*74*	*584*	*507*	*68*	*438*	*349*	*89*
total std dev	*42*	*23*	*27*	*39*	*56*	*27*	*31*	*50*	*32*	*53*	*52*	[illegible]

Table 3.12 Pre-frontal stable layer 95% confidence limits and intervals (CI)

The 500 hPa layer frequency increases from 50% over Springbok to 100% over Bloemfontein, Pietersburg and Pretoria. There is a general south to north increase in frequency (Fig. 3.24b). Under post-frontal conditions the layer occurs with a mean frequency of 76%,

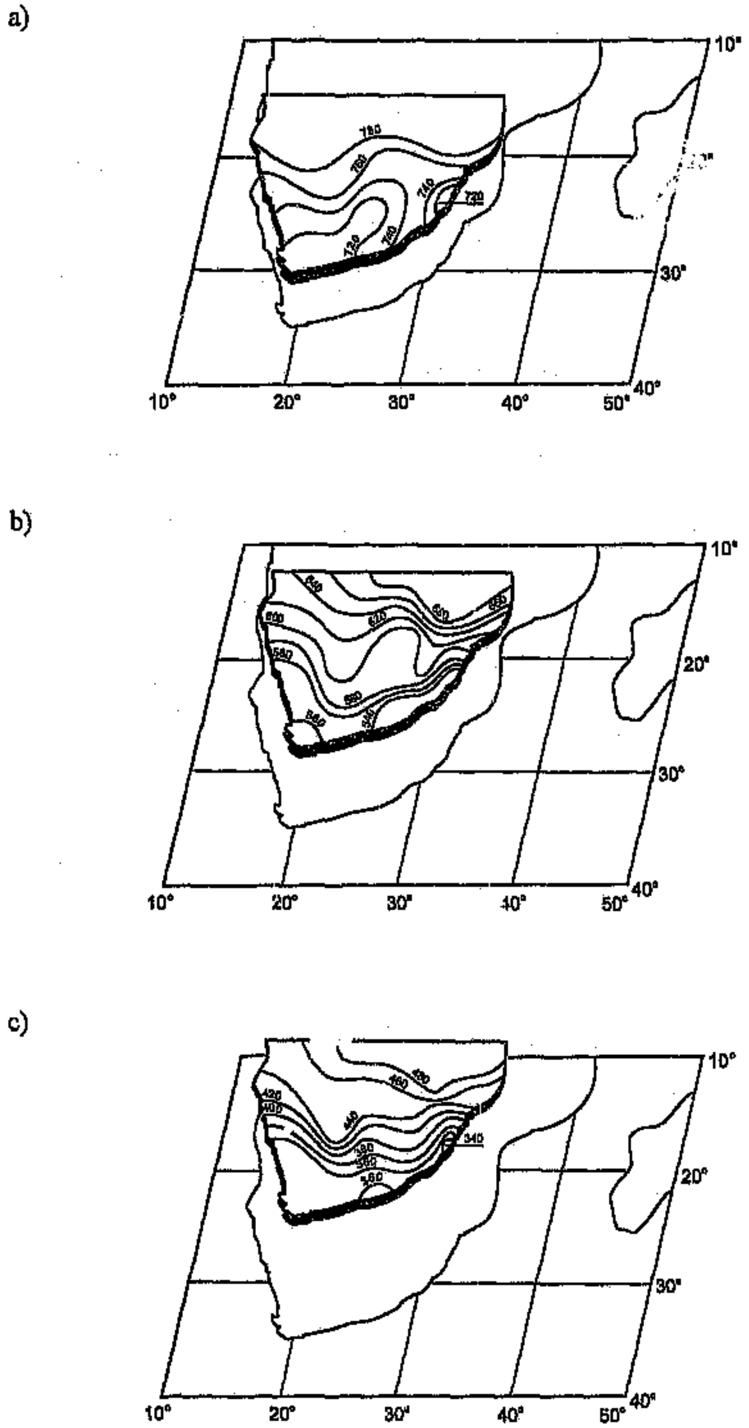


Figure 3.19 Mean base levels (hPa) for post-frontal (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

STATION	800 hPa			700 hPa			500 hPa			300 hPa		
	Lower Limit	Upper Limit	CI	Lower Limit	Upper Limit	CI	Lower Limit	Upper Limit	CI	Lower Limit	Upper Limit	CI
PLATEAU												
PI				775	744	31	624	551	72	451	371	80
PR				756	711	45	593	526	67	425	357	67
BE				737	688	49	581	519	62	397	342	55
BL				773	730	43	587	536	52	399	336	63
UP	805	757	48	771	726	46	577	527	50	438	372	66
mean	*805*	*757*	*48*	*762*	*720*	*43*	*592*	*532*	*60*	*422*	*355*	*66*
std dev	*0*	*0*	*0*	*14*	*19*	*6*	*17*	*11*	*9*	*21*	*15*	*8*
COAST												
SP	853	807	46	745	683	62	572	483	89	383	314	69
CT	890	843	47	764	697	66	587	517	70	377	311	66
PE	902	841	61	769	701	68	572	506	65	377	314	62
DB	885	840	46	744	688	56	561	504	57	368	298	70
mean	*883*	*833*	*50*	*755*	*692*	*63*	*573*	*503*	*70*	*376*	*309*	*67*
std dev	*18*	*15*	*6*	*11*	*7*	*5*	*9*	*12*	*12*	*5*	*7*	*3*
total mean	*867*	*818*	*50*	*759*	*707*	*52*	*584*	*519*	*65*	*402*	[illegible]	*67*
total std dev	*24*	*21*	*6*	*12*	*17*	*12*	*14*	*21*	*13*	*26*	[illegible]	*3*

Table 4.2 Annual stable layer 95% confidence limits and intervals (CI)

STATION	800 hPa	700 hPa	500 hPa	300 hPa
PLATEAU				
PI		71	83	77
PR		80	82	90
BE		75	84	91
BL		73	91	94
UP	73	80	84	91
mean	*73*	*76*	*85*	*89*
std dev	*0*	*4*	*3*	*6*
COAST				
SP	67	74	66	75
CT	73	67	68	80
PE	72	64	65	79
DB	64	79	82	84
mean	*69*	*71*	*70*	*80*
std dev	*4*	*6*	*7*	*3*
total mean	*70*	*74*	*78*	*85*
total std dev	*4*	*6*	*11*	*6*

Table 4.3 Annual stable layer mean frequencies

and minimum persistence of 75% occurs at Springbok. It is during ridging anticyclones and easterly waves that the layer occurs with the greatest frequencies (91% and 90% respectively), and during westerly wave disturbances that it has the least persistence of 79%.

As of yet, the causes of the 300 hPa layer remain somewhat unclear. There is little doubt that it is a subsidence feature. Other causal mechanisms may be dynamical in nature as the layer most likely coincides with the interface between the jet-stream and barotropic zones (Harrison and Theron, 1991; Theron and Harrison, 1991; Harrison, 1993). A more in-depth study of the controls on this discontinuity is required, but is beyond the scope of this dissertation.

STATION	800 hPa			700 hPa			500 hPa			300 hPa		
	Base Height	Upper Limit	Depth	Base Height	Upper Limit	Depth	Base Height	Upper Limit	Depth	Base Height	Upper Limit	Depth
PLATEAU												
PI				760	693	67	591	533	59	411	344	67
PR				733	683	51	559	486	73	391	328	63
BB				712	670	43	550	483	68	370	305	65
BL				751	694	57	562	493	69	367	296	71
UP	781	727	54	748	684	64	552	493	59	405	351	54
mean	*781*	*727*	*54*	*741*	*685*	*56*	*563*	*497*	*65*	*389*	*325*	*64*
std dev	*0*	*0*	*0*	*17*	*9*	*9*	*15*	*18*	*6*	*18*	*21*	*6*
COAST												
SP	830	789	41	714	659	55	527	460	67	348	282	66
CT	866	815	51	731	669	62	552	490	62	344	267	77
PE	872	815	56	735	669	66	539	474	65	346	281	65
DB	863	808	54	716	665	51	533	465	68	333	270	63
mean	*858*	*807*	*51*	*724*	*665*	*58*	*538*	*472*	*65*	*343*	*275*	*68*
std dev	*16*	*11*	*6*	*9*	*4*	*6*	*9*	*11*	*2*	*6*	*7*	*6*
total mean	*843*	*791*	*51*	*733*	*676*	*57*	*552*	*486*	*65*	*368*	*303*	*66*
total std dev	*22*	*19*	*6*	*13*	*12*	*6*	*17*	*18*	*2*	*26*	*28*	*6*

Table 4.1 Annual stable layer mean base and upper limit altitudes, and depths

4.2 SYNTHESIS

The layers increase in frequency with height, exhibiting lowest frequencies at the 800 hPa level (70%) and highest frequencies (85%) at the 300 hPa level. All of the layers are more persistent over the plateau than they are over the coastal regions, sometimes by as much as 15%. Between station base height variability is greatest at the 300 hPa layer, exhibiting a

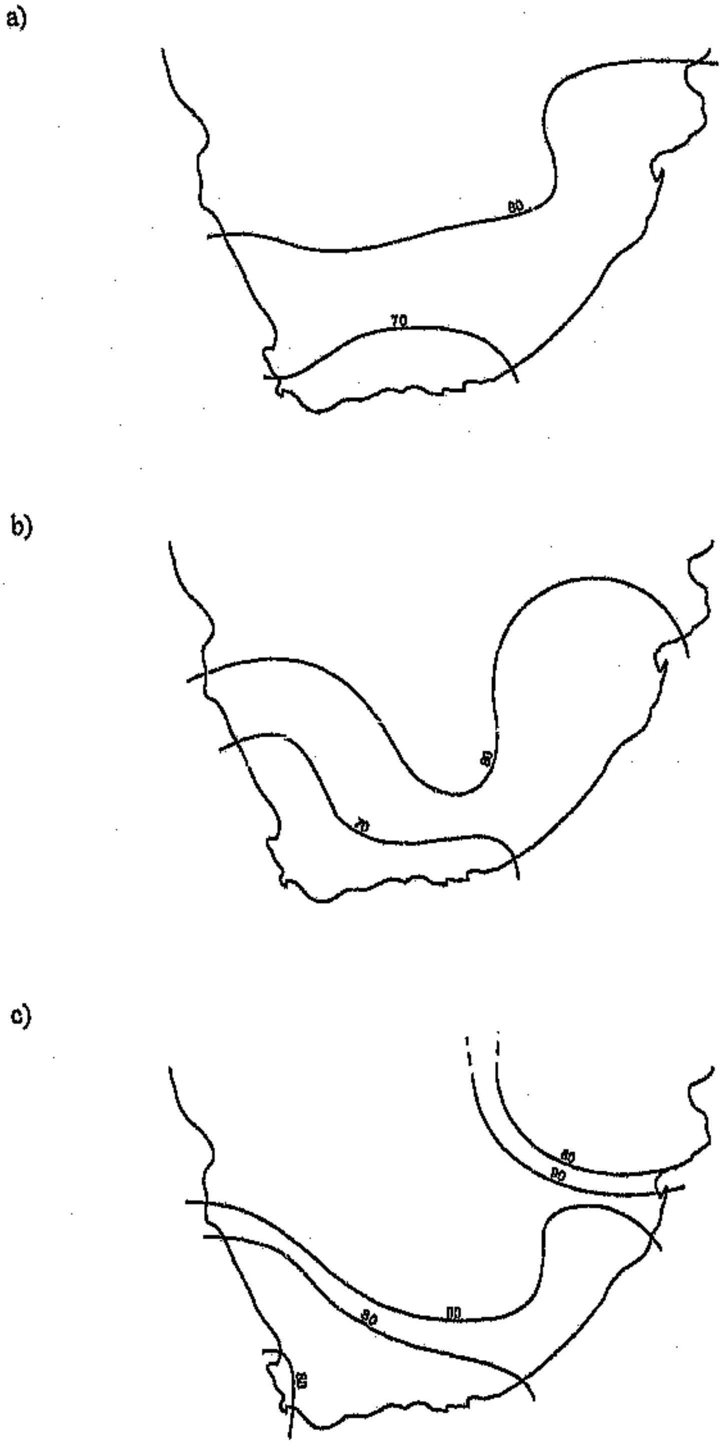


Figure 4.5 Annual mean frequencies for the (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

The 500 hPa stable discontinuity is maintained by descending air associated with the anticyclonic curvature of airstreams, the generation of anticyclonic vorticity and large-scale subsidence. It is mostly associated with the main subsidence inversion.

4.1.4 *The 300 hPa layer*

The average base of the 300 hPa layer occurs at 368 hPa, with a standard deviation of only 6 hPa over the coastal areas and 18 hPa over the plateau. The mean height of the layer over the subcontinent ranges from 333 hPa to 411 hPa at Durban and Pietersburg respectively, again depicting the south to north base height decrease (Figs. 4.1, 4.2c). Highest base levels occur for continental anticyclonic circulation (327 hPa) and lowest for pre- and post-frontal conditions (394 hPa and 400 hPa respectively).

The depth of the layer decreases slightly in an equatorward direction. A mean value of 66 hPa and a standard deviation of only 6 hPa are observed. A maximum mean depth of 77 hPa occurs at Cape Town and a minimum of 54 hPa over Upington (Figs. 4.1, 4.4c). Post-frontal conditions induce the 300 hPa layer to occur a maximum depth (82 hPa), which is almost double that of the shallowest layer (46 hPa) which occurs during continental highs. Again it should be noted that an upper threshold of 200 hPa altitude is used in the analysis, causing the 300 hPa layer to appear somewhat shallower.

Ninety-five percent of the time the layer has a mean confidence interval of 67 hPa. The mean confidence interval only increases above 70 hPa over the east coast and extreme north-eastern parts of the country (Figs. 4.1, 4.3c). Again maximum values occur during post-frontal conditions (100 hPa) and minimum values are found for continental anticyclones (41 hPa). The layer base has a much greater intra-station variability averaged over the country and a standard deviation for the 95% confidence interval during westerly wave disturbances than it does during anticyclonic circulation and easterly waves. Depths are similarly influenced by these disturbances.

The layer consistently exhibits mean frequencies in the range of 80-95% over the subcontinent, with a ridge of maximum frequencies exceeding 90% in a north-west to south-east axis across the country (Fig. 4.5c). Maximum persistence of 94% occurs at Bloemfontein

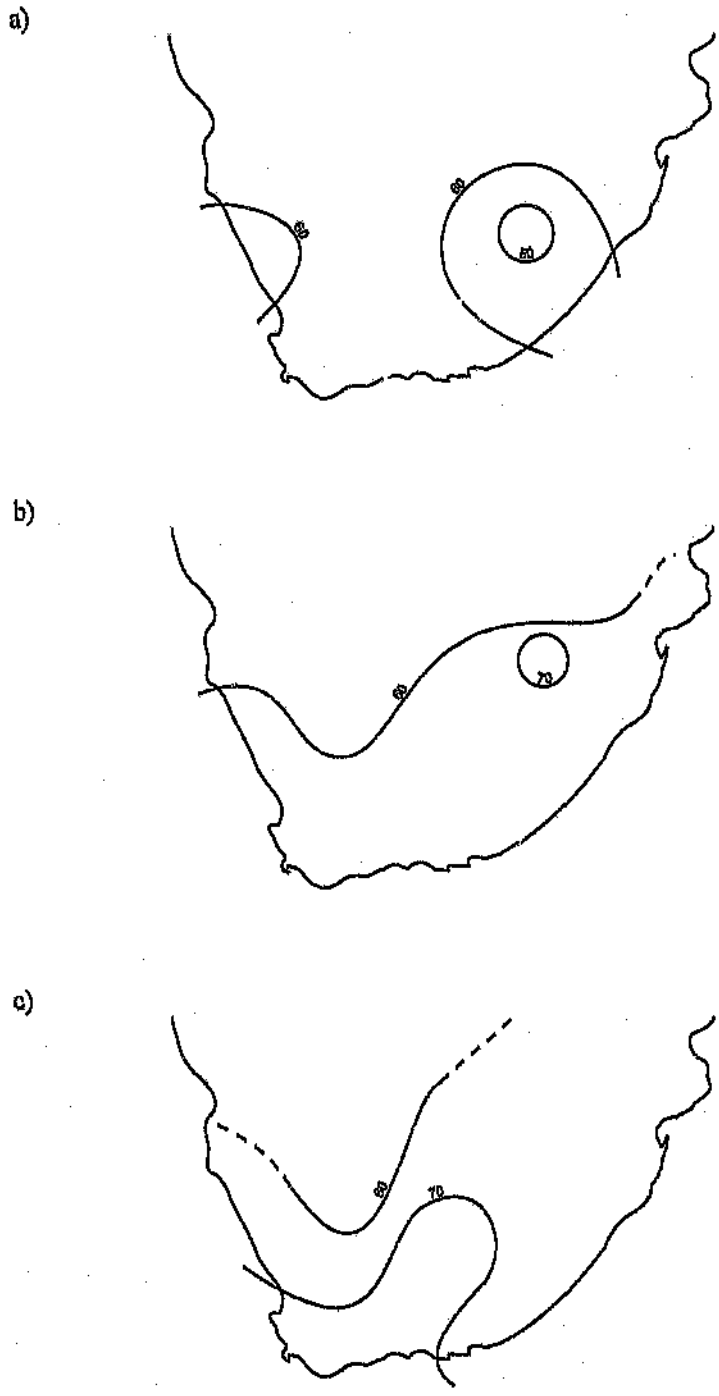


Figure 4.4 Annual mean depths (hPa) for the (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

4.1.3 *The 500 hPa layer*

The mean base of the 500 hPa stable layer is little affected by different synoptic types and maintains a markedly similar topography to the underlying layer. The layer occurs at slightly higher altitudes over the coastal regions (538 hPa) than over the interior (563 hPa), with a maximum height over Springbok (527 hPa) and a minimum over Pietersburg (591 hPa). The annual base height standard deviation is 17 hPa for the entire subcontinent. Ridging highs induce highest basal heights of 527 hPa and post-frontal conditions result in lowest base levels of 585 hPa averaged over all stations. Greatest inter-station base height variations across the country occur with post-frontal westerly wave circulations (49 hPa) and least for continental anticylcones (21 hPa) (Figs. 4.1, 4.2b).

The annual mean 95% confidence interval for the country as a whole is 65 hPa. The annual intra-station variability maximum and minimum are juxtaposed next to each other at Springbok (89 hPa) and Upington (50 hPa) (Figs. 4.1, 4.3b). With the prevalence of post-frontal westerly waves the mean 95% confidence interval averaged over the country is notably largest (98 hPa), exhibiting the highest value of 160 hPa for the entire analysis at Springbok. The lowest mean 95% confidence interval of 48 hPa occurs with continental highs. Annually the topography for this layer shows an east to west trough of low confidence intervals from the east coast to Upington. The values increase concentrically outwards from this trough.

The depth of the layer appears not to be influenced significantly by changing synoptic circulation (Figs. 4.1, 4.4b). The average annual depth of all stations is 65 hPa, with a country-wide standard deviation of only 2 hPa. Annually, Pietersburg has the minimum depth of 59 hPa and Pretoria has the maximum of 73 hPa. The mean depth of the layer is least for continental anticyclones (59 hPa) and greatest for post-frontal disturbances (74 hPa).

The layer occurs with a mean annual country-wide frequency of 78% for all synoptic types, showing a maximum mean frequency over Bloemfontein (91%) and a minimum range of frequencies from 65-68% over the west, south-west and southern coastal regions (Fig. 4.5b). As with the underlying layer this layer's frequency distribution clearly shows the influence of continental anticyclonic circulation. The layer occurs with a maximum mean persistence of 82% for easterly waves and between 76% and 78% for the rest of the circulation types.

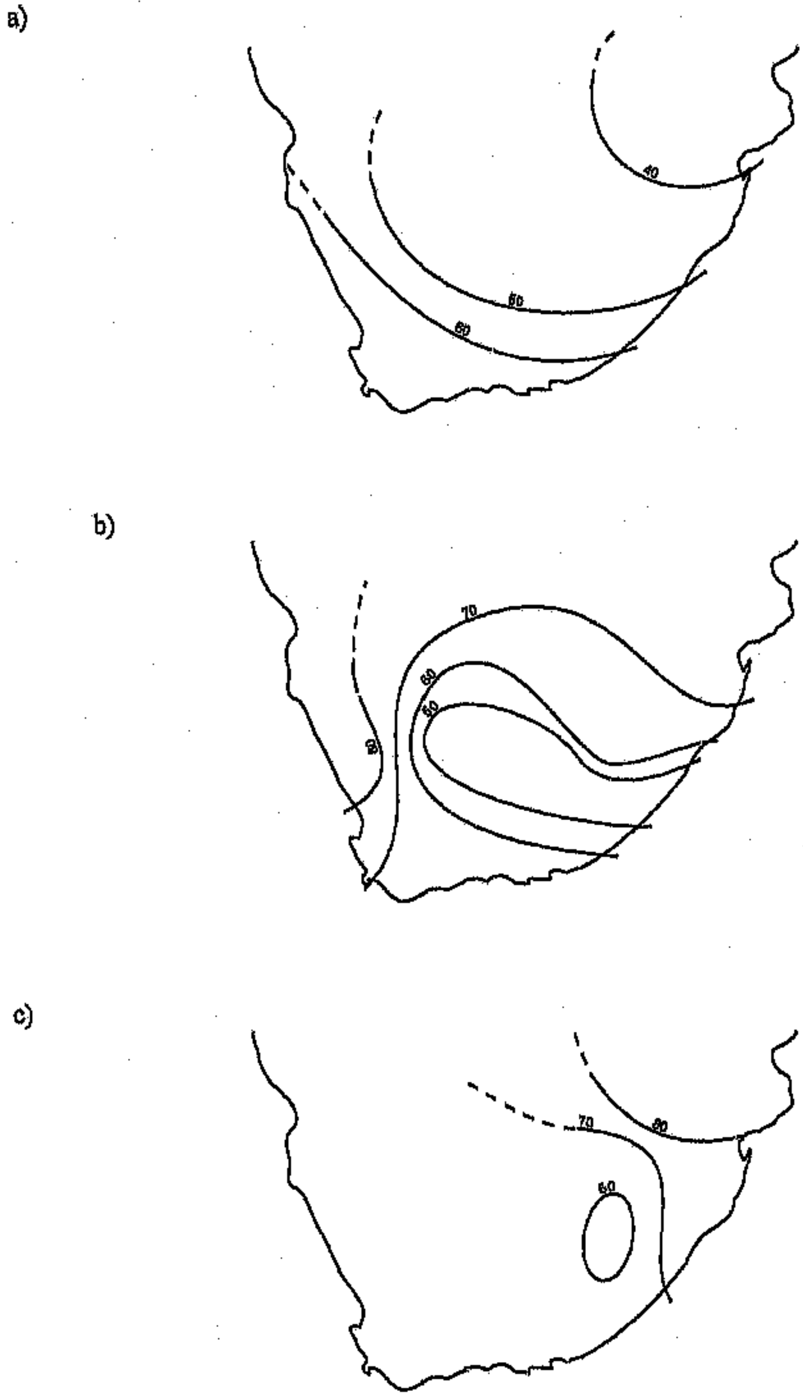


Figure 4.3 Annual 95% confidence intervals (hPa) for the (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

The layer's mean annual frequency of occurrence and standard deviation of frequency are 74% and 6% respectively (Fig. 4.5a). Anticyclonic circulation conditions lead to the layer occurring with greatest frequencies (84%), and westerly wave pre-frontal conditions cause lowest frequencies (65%). Geographically the layer increases in frequency from south to north, on an annual basis.

The discontinuity exhibits similar depths over the plateau to those over the coastal regions (Figs. 4.1, 4.4a), with a mean depth of 57 hPa and a negligible standard deviation of 6 hPa. Ridging highs induce deepest layers (67 hPa) and, surprisingly, easterly waves the shallowest layers (44 hPa). Annually the layer maintains a fairly constant depth over the subcontinent, with the deepest part of the layer occurring over Pietersburg (67 hPa) and shallowest over Bethlehem (43 hPa).

Annual intra-station base height variability across South Africa averages at 52 hPa and exhibits a standard deviation of 12 hPa. Both the 800 hPa and 700 hPa layer mean 95% confidence intervals are somewhat lower than the overlying two layers. A minimum base level variation of 39 hPa occurs under continental anticyclonic circulation and a maximum of 74 hPa is evident under pre-frontal conditions. The mean annual base height variability shows a clear decrease to the south as the layer is influenced less by anticyclonic controls (Figs. 4.1, 4.3a). Highest mean annual intra-station base level fluctuations occur over the coastal regions with a mean coastal value of 63 hPa. By comparison the interior yields a mean variability of 43 hPa.

The 700 hPa layer is usually associated with the top of the midday mixing layer over the plateau. The fact that the layer extends out over the coastal areas suggests that mechanisms other than boundary layer processes are responsible for its maintenance. Subsidence with its associated adiabatic heating is without doubt a major sustaining mechanism. The layer is likely to be synonymous with the interface between the barotropic and boundary zones (Harrison and Theron, 1991; Theron and Harrison, 1991; Harrison, 1993), suggesting that additional thermodynamic mechanisms play a role in its development.

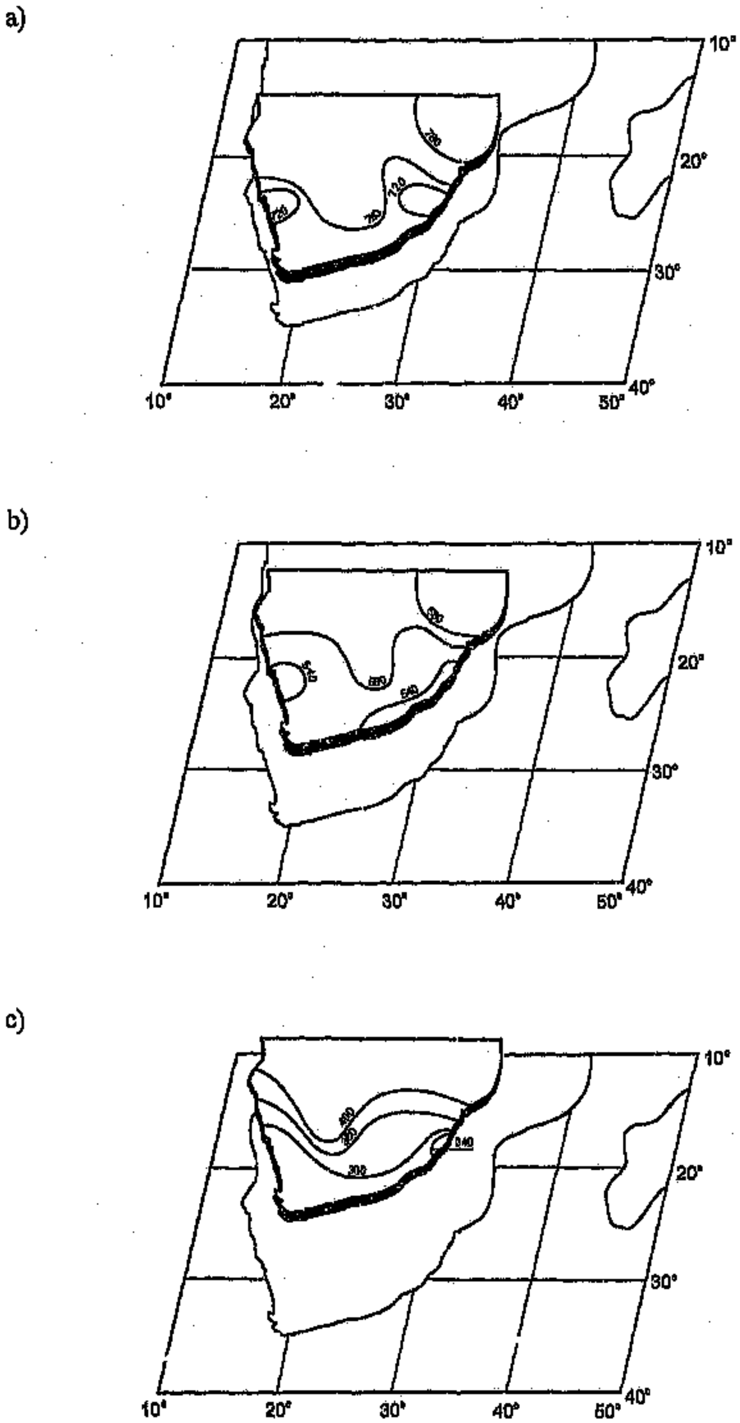


Figure 4.2 Mean annual base levels (hPa) for the (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers

The persistence of the layer appears to vary minimally with changes in synoptic ci. ulation, ranging from a frequency maximum of 74% under pre-frontal conditions to a minimum of 67% and 68% for post-frontal and ridging anticyclonic conditions respectively. Under generally fine-weather circulation conditions the layer occurs in a frequency range over the country of 64% at Durban to 73% at Upington and Cape Town (Table 4.3).

The mean annual intra-station variation about the mean base altitude is small (50 hPa). The layer has a 46-48 hPa deviation about the mean base for all stations except for Port Elizabeth where the fluctuation reaches 61 hPa (Fig. 4.1). The maximum 95% confidence interval, averaged over all coastal stations occurs during pre-frontal conditions (78 hPa), owing to anomalously high values at Port Elizabeth (130 hPa). The minimum confidence interval occurs during continental highs (36 hPa).

The discontinuity has an annual average depth of 51 hPa, with an inter-station variation over the country of 6 hPa (Fig. 4.1). An annual maximum depth at Port Elizabeth (57 hPa) and a minimum at Springbok (41 hPa) are identified, indicating a low inter-station layer depth variability (Fig. 4.1). Post-frontal westerly waves experience the shallowest layer averaged over the entire country (39 hPa) and ridging anticyclones exhibit the deepest mean layer (60 hPa) with the rest of the stations occurring with identical depths of 51 hPa.

The coastal 800 hP stable layer is maintained predominantly by anticyclone associated subsidence. Coastal boundary layer mechanisms such as ocean to atmosphere heat fluxes, diabatic controls, topographical influences and sea breezes may also contribute towards the development of stability at this altitude.

4.1.2 *The 700 hPa layer*

The basal level of the 700 hPa stable layer varies little over the country (Figs. 4.1, 4.2a), yielding an annual country-wide standard deviation of only 13 hPa. The discontinuity base level is highest over the east coast (714 hPa) and west coast (716 hPa) and generally decreases in height in an equatorward direction. A mean base height of 733 hPa is observed. The layer occurs at a maximum mean altitude of 708 hPa for easterly waves and a minimum of 751 hPa for post-frontal circulation over the subcontinent.

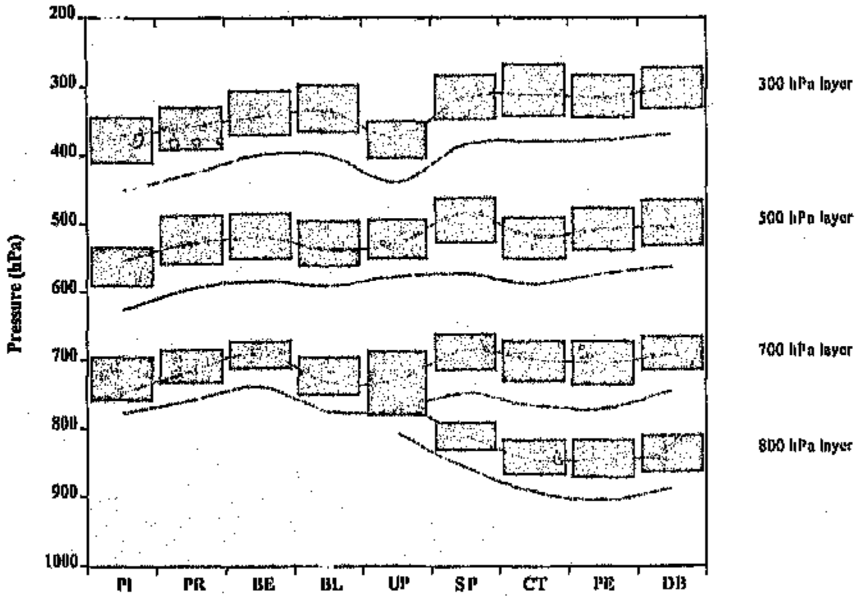


Figure 4.1 Mean annual stable layers (shaded) over Pietersburg (PI), Pretoria (PR), Bethlehem (BE), Bloemfontein (BL), Upington (UP), Springbok (SP), Cape Town (CT), Port Elizabeth (PE) and Durban (DB). Upper and lower 95% confidence limits for the base heights of the layers as well as the continental surface are shown in each case

CHAPTER 4

THE DOMINANCE OF STABLE DISCONTINUITIES

Elevated absolutely stable discontinuities generally maintain remarkably constant heights, depths, 95% confidence intervals and frequencies, regardless of the synoptic controls placed upon them. Combining the samples to give conditions more representative of the circulation as a whole is thus not unreasonable. The combined data based on radiosonde ascents, thus give results which are representative of mean annual simple circulation types. They are not typical of complex situations involving a variety of combined circulation types and unclassifiable situations. It should also be borne in mind that the events analysed have, by and large, been chosen to represent fair-weather conditions. Had rain producing situations been chosen instead, the outcome would have been markedly different. Details of the results are given in Tables 4.1, 4.2 and 4.3.

4.1 THE STABLE LAYERS

4.1.1 *The sub-escarpment 800 hPa layer*

The 800 hPa stable layer is identified only over coastal regions, except at Upington where it occurs with the prevalence of ridging anticyclonic circulation. The base height of the layer occurs on average at 842 hPa over the entire country, with a standard deviation of 22 hPa and an altitude range of 830 hPa (Springbok) to 872 hPa (Port Elizabeth) over the coastal region as a whole (Fig. 4.1). The mean layer base is, not surprisingly, lowest for continental anticyclonic circulation (876 hPa). Highest mean bases occur at 843 hPa for ridging highs and 848-845 hPa for pre- and post-frontal conditions respectively. The easterly wave influences only a small portion of the 800 hPa layer, with the rest falling under predominantly anticyclonic influences. As a consequence the layer has a base altitude very similar to the equivalent layer during continental anticyclones (862 hPa).

5.4 DAILY PERSISTENCE OF THE STABLE DISCONTINUITIES

During SAFARI, layered stable discontinuities were found to persist for extended periods of time. The 500 hPa layer on one occasion was present for 53 consecutive days with only one break between mid-September and early November 1992 (Garstang, *et al.*, 1996; Tyson *et al.*, 1996). By way of comparison, two specific cases from the present study will be presented, in order to illustrate the daily persistence of the layers. Both will be taken from the month of July only.

An example which best illustrates, not only the persistence of the stable layers *per se*, but also the consistent layered structure under strong mid-winter anticyclonic conditions is given for Pietersburg during July 1990 (Fig. 5.6). All three layers at 700, 500 and 300 hPa are clearly identified irrespective of the changing synoptic situation. The 500 hPa layer is absent for only one day, on the 22nd, during the month and is not broken by the passage westerly waves. It occurs with the greatest persistence (96%) of the three layer and is found to be similar to the layers identified during the SAFARI field observation period. In contrast the 700 hPa layer is destroyed on the 8th, two days after the passage of the first cold front. The second westerly wave disturbance on 13 and 14 July was neither strong enough nor deep enough to have any effect on the 700 hPa stable layer, but the layer is absent again on the 18th and from the 29th-31st, yielding a persistence of 84%. The 300 hPa layer was present on only 24 days out of 31 over Pietersburg. The 500 hPa layer occurs with the greatest persistence and is found to be similar to the layer identified during the SAFARI field observation period.

The example for Pretoria during July 1990 illustrates conditions where the 700 hPa layer was absent for only 2 days of the month (Fig. 5.7) and was not disrupte by any of the four westerly wave disturbances passing through during the month. In contrast, the 500 hPa layer occurred 71% of the time during the month, and the 300 hPa layer for 90% of the time. Yet, as was mentioned above, over the period mid-September to early November 1992, during SAFARI, the 500 hPa layer has its persistence maximum of 53 days of continuous occurrence over Pretoria, undulating up and down in position. The 700 hPa layer over the same time period during SAFARI seldom persisted for more than 7 days at a time without being disrupted (Garstang, *et al.*, 1996; Tyson *et al.*, 1996). It is thus evident that although under complex

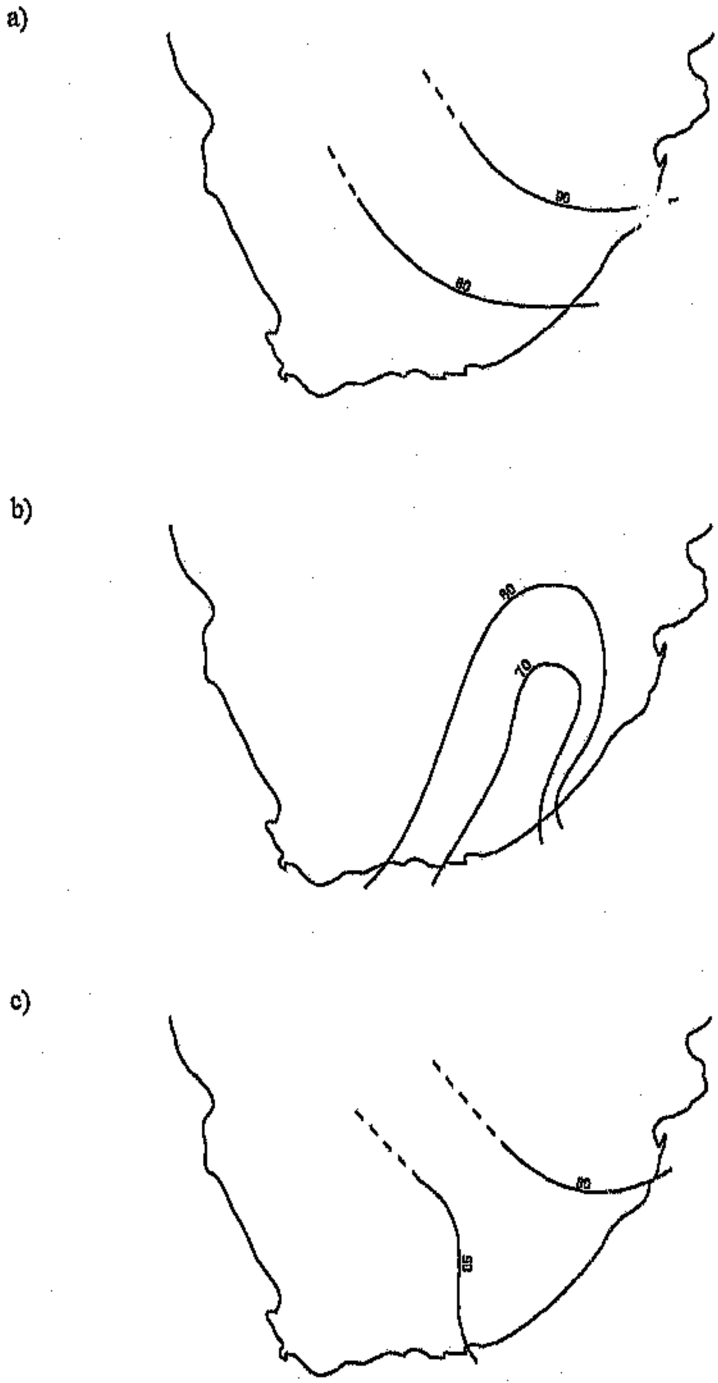
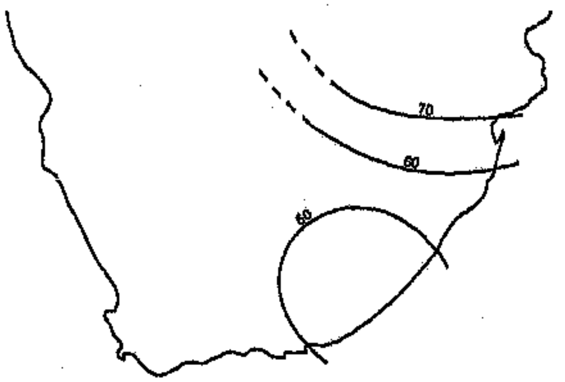
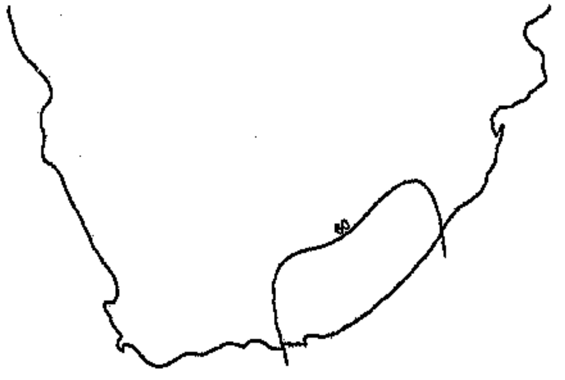


Figure 5.5 Mean frequencies for the (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers for the July months from 1989-1993

a)



b)



c)

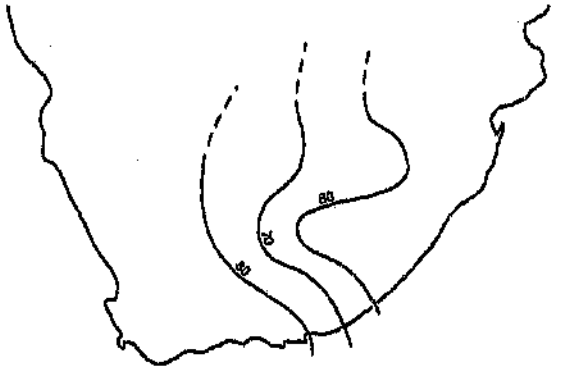


Figure 5.4 Mean depths (hPa) for the (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers for the July months from 1989-1993

STATION	800 hPa			700 hPa			500 hPa			300 hPa		
	Base Height	Upper Limit	Depth	Base Height	Upper Limit	Depth	Base Height	Upper Limit	Depth	Base Height	Upper Limit	Depth
PLATEAU												
PI				752	680	72	530	461	69	297	244	53
PR				735	675	60	541	472	69	318	254	64
BL				756	706	50	546	477	69	288	228	60
PB	863	803	60	696	646	50	561	508	53	306	222	84
DB	838	789	49	651	600	51	478	426	52	269	218	51
mean	*851*	*796*	*55*	*718*	*661*	*57*	*531*	*469*	*62*	*296*	*233*	*62*
std dev	*13*	*7*	*6*	*40*	*36*	*9*	*28*	*26*	*8*	*17*	*14*	*12*

Table 5.1 Stable layer mean base and upper limit altitudes, and depths for the July months from 1989-1993

STATION	800 hPa			700 hPa			500 hPa			300 hPa		
	Lower Limit	Upper Limit	CI	Lower Limit	Upper Limit	CI	Lower Limit	Upper Limit	CI	Lower Limit	Upper Limit	CI
PLATEAU												
PI				761	743	18	545	515	30	305	289	16
PR				743	727	16	556	526	30	329	307	22
BL				766	746	20	557	535	22	298	278	20
PB	874	852	22	710	682	28	574	548	26	319	293	26
DB	849	827	22	[illegible]	635	32	495	[illegible]	34	276	262	14
mean	*862*	*840*	*22*	*729*	*707*	*23*	*545*	*517*	*28*	*305*	*286*	*20*
std dev	*13*	*13*	*0*	*37*	*42*	*6*	*27*	*30*	*4*	*18*	*15*	*4*

Table 5.2 Stable layer 95% confidence limits and intervals (CI) for the July months from 1989-1993

STATION	800 hPa	700 hPa	500 hPa	300 hPa
PI		92	81	77
PR		91	70	79
BL		81	86	90
PB	61	72	77	90
DB	70	80	95	85
mean	*66*	*83*	*82*	*84*
std dev	*5*	*7*	*8*	*5*

Table 5.3 Stable layer mean frequencies for the July months from 1989-1993

with a trough of relatively lower values extending from Port Elizabeth to the eastern interior. This structure is evident only for this layer. The layer is relatively invariant over the country with a standard deviation of 28 hPa.

The mean depth of the layer (62 hPa) is similar to those of both the two underlying layers (55 hPa and 57 hPa for the 800 hPa and 700 hPa layers respectively), and the depth of the 500 hPa layer for continental anticyclones throughout the year (59 hPa). The greatest depths of approximately 70 hPa occur over all of the interior stations, and decrease to just greater than 50 hPa over coastal areas (Fig. 5.4b).

5.3.4 *The 300 hPa layer*

The 300 hPa layer base height for most stations is observed close to the mean value of 296 hPa, except for Pretoria where it falls to 318 hPa (Figs. 5.1, 5.2c). The standard deviation of the base height is 17 hPa. The form and spatial distribution of the base height of the layer (Fig. 5.2c) the confidence interval (Fig. 5.3c), depth (Fig. 5.4c) and the frequency occurrence of the layer (Fig. 5.5c) all suggest that upper air subsidence is the primary mechanism sustaining the stable air. The base of the layer is almost invariant with a maximum 95% confidence interval of 26 hPa over Durban.

The layer is deepest (84 hPa) over the south coast (Figs. 5.1, 5.4c). The discontinuity mean depth is 62 hPa which is approximately 15 hPa greater than during continental anticyclonic circulations throughout the year. This increase in depth may be attributed to the influence of westerly wave disturbances which penetrate even to this altitude.

The mean frequency over the subcontinent (84%) is almost identical to the 300 hPa layer during the continental anticyclonic circulation (85%). The layer occurs with highest frequencies over the southern coastal and southern plateau regions (90%) (Fig. 5.5c), and is always present greater than 75% of the time.

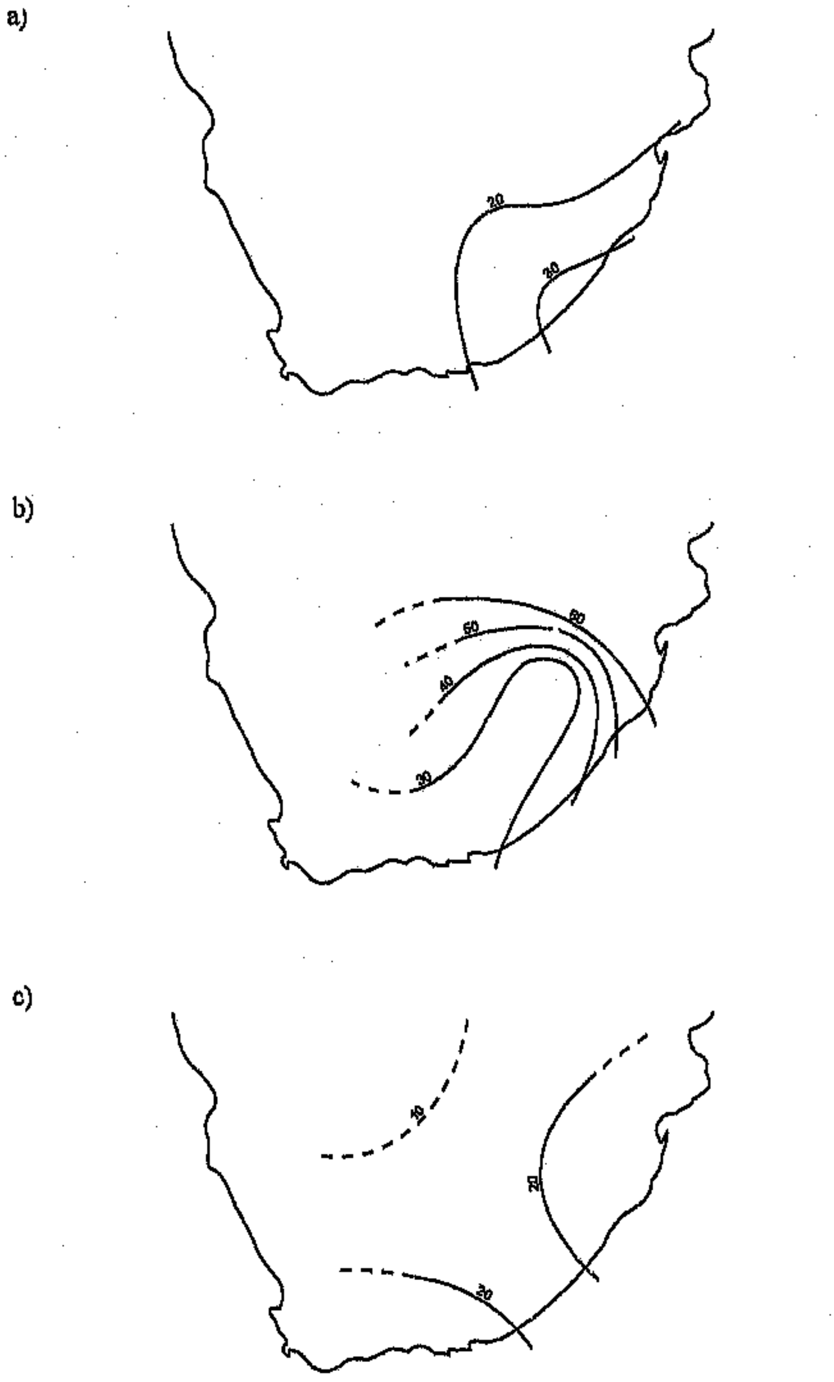


Figure 5.3 95% confidence intervals (hPa) for the (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers for the July months from 1989-1993

Interestingly, for the previous study the layers were found to occur with a 71% and 61% persistence for Port Elizabeth and Durban respectively, and for the current findings the reverse has been found with the layer yielding a persistence of 61% for Port Elizabeth and 70% for Durban.

5.3.2 *The 700 hPa layer*

Both the base height and the 95% confidence interval of the 700 hPa stable layer are lowest over the interior (Figs. 5.1, 5.2a, 5.3a), with a minimum base height of 756 hPa at Bloemfontein and a minimum 95% confidence interval of 16 hPa at Pretoria. Mean base height and base height variability about the mean increase with distance towards the east coast reaching a maximum of 651 hPa and 32 hPa respectively over Durban. The increased variability and height of the base over the coastal regions is attributed to the passage of coastal disturbances. The base height of the 700 hPa layer has the greatest inter-station variability of all the discontinuities during July, with a standard deviation of 40 hPa. This value is substantially higher than that of the equivalent layer for archetypal continental anticyclone (22 hPa) throughout the year.

Contrary to expectation the depth of the layer is greatest closer to the core of the anticyclone (Fig. 5.4a). A maximum depth of 72 hPa occurs over Pietersburg and minimum depths in the region of 50 hPa are evident over Bloemfontein, Durban and Port Elizabeth. The topography of the layer depth over the country is thus the reverse of the equivalent layer depth during archetypal anticyclonic circulation.

Highest frequencies for this layer are evident over the eastern plateau (91% for Pretoria and 92% for Pietersburg) giving an indication of the strong continental anticyclonic controls (Fig. 5.5a). Port Elizabeth yields the lowest frequency of 72%.

5.3.3 *The 500 hPa layer*

The 500 hPa stable layer is similar in its general structure to the 700 hPa layer with the stable layer base height decreasing and the depth increasing with distance from Durban (Figs. 5.1, 5.2b, 5.4b). The maximum base height (478 hPa) and frequency (95%) occur over Durban, and the lowest base (561 hPa) is evident over Port Elizabeth. A minimum frequency of 70% is observed over Pretoria. The 95% confidence intervals and frequencies have a curious structure,

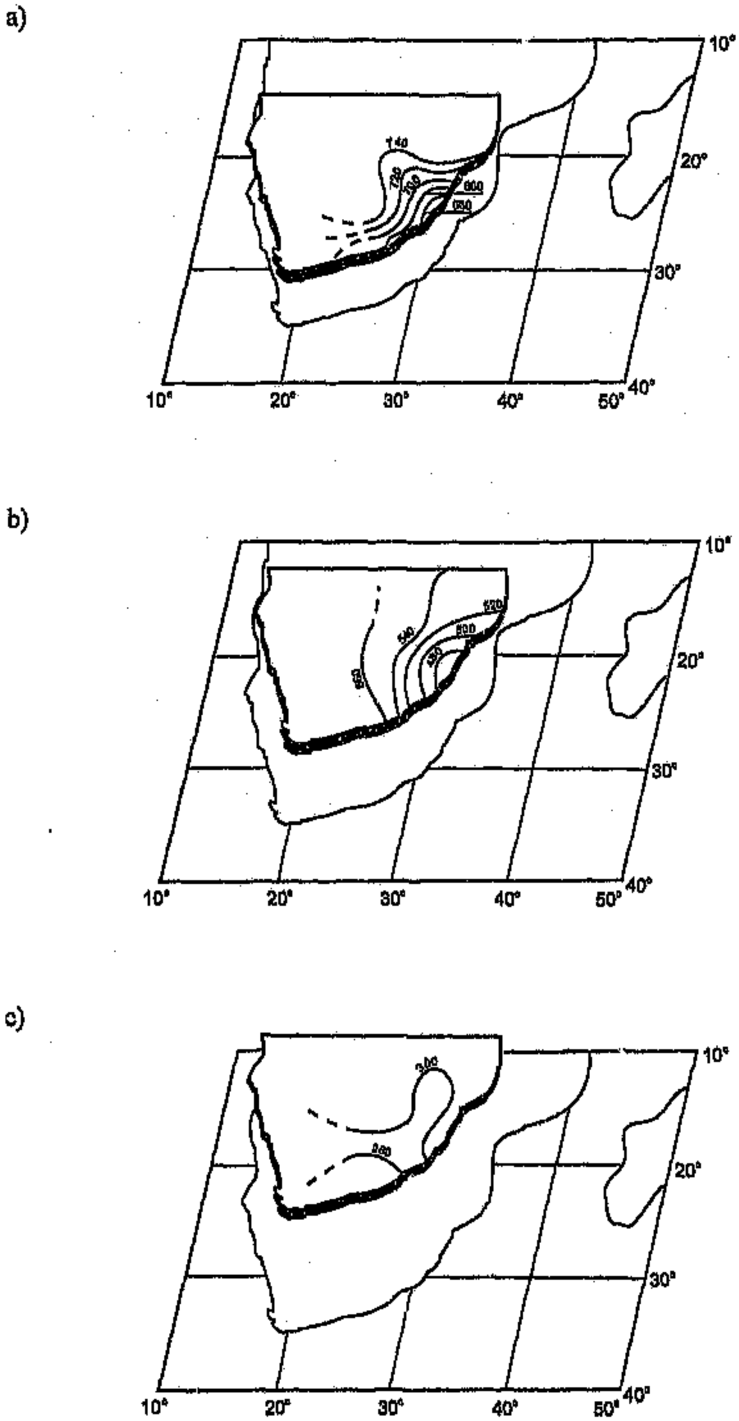


Figure 5.2 Mean base levels (hPa) for the (a) 700 hPa, (b) 500 hPa and (c) 300 hPa stable layers for the July months from 1989-1993

5.2 THE SYNOPTIC CIRCULATION DURING JULY 1989-1993

Over the five July's during the time-period 1989-1993, continental highs were present 77% of the time and 40 westerly waves passed over the country, influencing mainly the coastal regions. Of these 14 were strong enough to penetrate into the interior. Ridging highs prevailed with a frequency of 10% over the subcontinent, and no easterly waves were present. The synoptic situations thus depicted were by no means archetypal as they were in the pervious two chapters. Rather they were complex situations where more than one synoptic circulation type was concurrently present over the subcontinent.

5.3 MEAN JULY ELEVATED ABSOLUTELY STABLE LAYERS

Four elevated absolutely stable layers are identified over the subcontinent during July, corresponding to those present throughout the year. Details are presented in Tables 5.1, 5.2 and 5.3.

5.3.1 *The sub-escarpment 800 hPa layer*

The coastal 800 hPa absolutely stable layer can be identified over both Durban and Port Elizabeth at the 838 hPa and 863 hPa respectively (Fig. 5.1). By comparison with the anticyclonic circulations throughout the year, the mean base height for the two stations is higher at 851 hPa (Fig. 5.1). The layer base over both coastal stations fluctuates very little around the mean altitude, exhibiting a mean country-wide 95% confidence interval of 22 hPa. Contrary to expectation this deviation about the mean base height is less than it is for continental highs. Likewise, the depth of the layer does not vary significantly between the east and south coasts, with a mean value of 55 hPa (Fig. 5.1). With a mean frequency occurrence of 66%, the 800 hPa layer occurs less often than the overlying layers (Table 5.3). The passage of westerly wave disturbances and local boundary layer mechanisms such as diurnal mixing over land, ocean to atmosphere heat fluxes over the sea and the occurrence of thermo-topographic winds and sea-breezes control the frequency of the layer.

The results in general are similar to those of Diab (1975), with the first non-surface inversion occurring at 1570 meters and 1[illegible]80 meters for Port Elizabeth and Durban respectively during July, and yielding depths of 360 meters over Port Elizabeth and 460 meters over Durban.

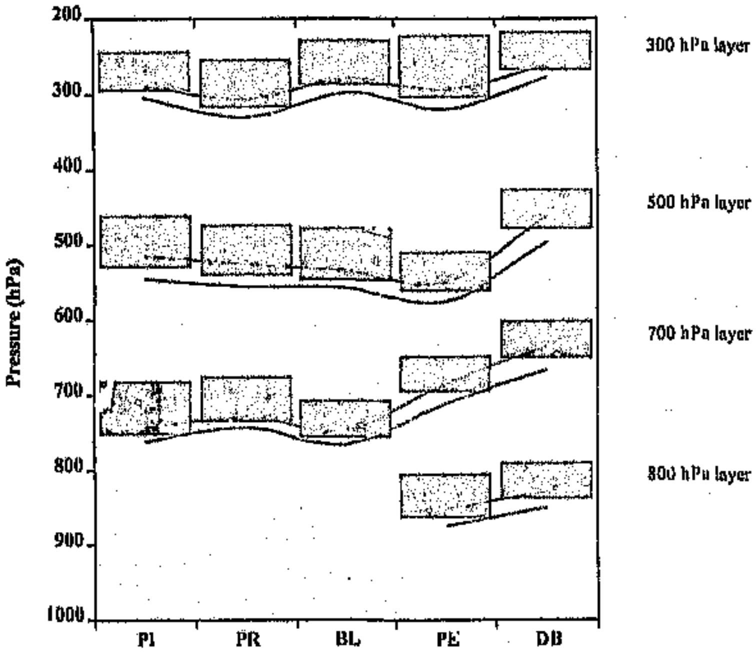


Figure 5.1 Stable layers (shaded) for the July months from 1989-1993 over Pietersburg (PI), Pretoria (PR), Bethlehem (BE), Bloemfontein (BL), Upington (UP), Springbok (SP), Cape Town (CT), Port Elizabeth (PE) and Durban (DB). Upper and lower 95% confidence limits for the base heights of the layers as well as the continental surface are shown in each case

CHAPTER 5

MID-WINTER MAXIMUM ABSOLUTE STABILITY IN THE TROPOSPHERE

5.1 INTRODUCTION

The climatology presented in the previous chapters gives an indication as to the occurrence of absolute stability in the free-air throughout the year as a whole. It considers both individual archetypal synoptic circulation types and the combined averages of those circulation types, giving an annual representation. In this chapter the strongest stability conditions in the annual cycle, namely those in mid-winter, will be considered for all 155 days during the July months from the period 1989-1993, irrespective of synoptic type. July is the month during which anticyclonic circulation is at its maximum frequency (cf. Fig. 1.7) (Preston-Whyte and Tyson, 1989). The influence of anticyclonic air flow on the development of elevated absolutely stable layers is important for two reasons. First, it is the predominant circulation type over southern Africa and as a consequence has a major impact upon the general circulation; and secondly, it is anticyclonic circulation which is the most instrumental in the formation of non-surface stable layers. This aspect of the study is directly comparable to the previous research (Taljaard, 1955; Diab, 1975; Preston-Whyte *et al.*, 1977; Harrison, 1993) which has been undertaken on non-surface inversions.

Only five of the nine aerological stations around the country are considered in this analysis, based on their proximity to the eastern portions of the country, since these are the areas most influenced by surface continental anticyclonic circulation. The five stations are Pietersburg, Pretoria, Bloemfontein, Port Elizabeth and Durban.

country-wide standard deviation of 26 hPa; it is least variable at the 700 hPa layer with a standard deviation of 13 hPa. For most of the layers the base height inter-station fluctuations is greater over the interior than the coast. Intra-station base height deviation about the mean for the country as a whole is greater at the 300 hPa level (67 hPa) and least at the 800 hPa level (50 hPa). Confidence intervals are lower over the interior than over the coast. The deepest layers are those at the 500 hPa and 300 hPa levels (65 hPa and 66 hPa respectively); the shallowest are the 800 hPa and 700 hPa layers (55 hPa and 57 hPa respectively). The layer depths are typically the same over both coastal and plateau regions.

Over the central and eastern plateau the average number of non-rain days per year varies from 225-245 days per year, i.e. 61-67% of the time (Preston-Whyte and Tyson, 1989). The 500 hPa layer has an 85% frequency occurrence and the 300 hPa occurs close to 90% of the time over the plateau throughout the year. The 800 hPa and 700 hPa have slightly lower frequencies of occurrence of 73% and 76% respectively. It would appear that the layers are only absent with active cumulus convection or widespread, strong and deep uplift associated with near-surface convergence in rain-bearing systems. The lower layers are evidently influenced to a greater degree by convection and turbulent mixing. In addition it should be noted that the analysis time period was a dry spell over the subcontinent, which may account to some degree for the high persistence.

* * * * * * *

The mean conditions for predominantly fair-weather events have been discussed, and the stable discontinuities for predominant synoptic circulation types have been compared. In the next chapter mid-summer maximum absolute stability is considered.

7.4 The average depth across all stations of the shallowest layer is 55 hPa at the 800 hPa layer and is deepest at 62 hPa for the 500 hPa and 300 hPa layers. The standard deviation of the depths ranges from a minimum of 6 hPa at the 800 hPa layer to a maximum of 12 hPa for the 300 hPa layer.

7.5 The daily persistence of the discontinuities varies significantly and is not necessarily dependant upon the prevailing synoptic circulation.

8. The representativity of the SAFARI findings:

8.1 Four elevated absolutely stable layers were identified over the plateau during the SAFARI project at mean altitudes of approximately 700 hPa, 550-500 hPa, 350 hPa and the final was associated with the tropopause. These base heights are verified by the current research as being typical of general circulation over South Africa.

8.2 The discontinuities during SAFARI were spatially coherent and temporally persistent over the entire subcontinent. This is shown to be case in the current findings.

9. Sustaining processes:

9.1 The sub-escarpment 800 hPa layer is maintained predominantly by subsidence. Coastal boundary layer mechanisms such as ocean to atmosphere heat fluxes, diabatic controls, topographical influences and sea-breezes may also play a role in the development of stability at this altitude.

9.2 The 700 hPa layer is sustained by upper air subsidence over both the coastal and plateau regions. Boundary layer mechanism such as mixing and turbulence are prominent over the interior and influence the development of the layer. In addition, this layer over the coast frequently forms a dynamic and thermodynamic interface between the underlying boundary layer maritime air and the overlying subsiding air.

6.2 Post-frontal circulation:

6.2.1 The most frequently occurring discontinuity, averaged across the country as a whole, is the 300 hPa layer (79%) and the least frequent is the 800 hPa layer (67%).

6.2.2 The mean base heights across the country, of the four layers are at 845 hPa, 751 hPa, 585 hPa and 400 hPa, with a minimum standard deviation of all base heights of 7 hPa for the 800 hPa layer and a maximum of 55 hPa for the 300 hPa layer.

6.2.3 Averaged across all stations, the 95% confidence interval for base heights is lowest at 51 hPa for both the 800 hPa and 700 hPa layers and highest at 98 hPa and 100 hPa for the 500 hPa and 300 hPa layers respectively.

6.2.4 The shallowest layer averaged across all stations is found at the 800 hPa level (39 hPa), and deepest at 300 hPa (82 hPa) which is the greatest mean depth value observed for the entire analysis. The standard deviation of the depths ranges from a minimum of 12 hPa at the 800 hPa layer to a maximum of 25 hPa for the 700 hPa layer.

6.2.5 The 300 hPa layer over Springbok occurs with 33% persistence which is the lowest observed for the analysis and is notably anomalous.

7. Discontinuities at the time of mid-winter maximum stability:

7.1 Stable layers, averaged across all stations, occur with frequencies ranging from 66% at the 800 hPa layer to 84% at the 300 hPa layer.

7.2 Mean base heights of 800 hPa, 700 hPa, 500 hPa and 300 hPa stable layers are 851 hPa, 718 hPa, 531 hPa and 296 hPa. The standard deviation of base heights over the country varies between 13 hPa for the 800 hPa layer and 40 hPa for the 700 hPa layer.

7.3 Averaged across all stations, the 95% confidence interval for base heights is lowest at 20 hPa for the 300 hPa layers and highest at 28 hPa for the 500 hPa layer.

5.2 The respective base heights of each layer over all stations occur at 862 hPa, 708 hPa, 546 hPa and 375 hPa. The maximum standard deviation of base level is 41 hPa for the 300 hPa layer and the minimum is 19 hPa for the 700 hPa.

5.3 Averaged over the country, the base height intra-station variability of the 300 hPa layer is greatest with a 95% confidence interval of 56 hPa; that of the 800 hPa layer is the least with 46 hPa.

5.4 The deepest layers are found at the 500 hPa and 300 hPa levels (67 hPa), and shallowest at the 700 hPa (44 hPa). Averaged over the whole country, the standard deviation of the depth of all layers ranges from 10-13 hPa for the three upper layers.

6. Stable discontinuities associated with westerly waves:

6.1 Pre-frontal circulation:

6.1.1 The most frequently occurring discontinuities, averaged across the country as a whole, are the 300 hPa layer (79%) and the 500 hPa layer (78%). The least frequent is the 700 hPa layer (65%).

6.1.2 The mean base heights across the country of the four layers are at 848 hPa, 741 hPa, 545 hPa and 394 hPa, with a minimum standard deviation of all base heights of 31 hPa for the 800 hPa layer and a maximum of 51 hPa for the 300 hPa layer.

6.1.3 Averaged across all stations, the 95% confidence interval for base heights is lowest at 68 hPa for the 500 hPa layer and highest at 89 hPa for the 300 hPa layer.

6.1.4 The deepest layer averaged across all stations is found at the 300 hPa level (69 hPa), and shallowest at 800 hPa (51 hPa). The standard deviation of the depths ranges from a minimum of 12 hPa at the 800 hPa layer to a maximum of 26 hPa for the 500 hPa layer.

6.1.5 The 500 hPa layer is not present over Upington when post-frontal circulation is prevalent.

The standard deviation of the depths ranges from a maximum of 21 hPa for the 700 hPa layer to 13-14 hPa for the rest of the layers.

4.5 Only with ridging highs does the 800 hPa layer not occur exclusively over the coast. With such circulation the 800 hPa stable layer is identified over Upington 73% of the time, with a base height of 781 hPa, a 95% confidence interval about the base level of 48 hPa and a depth of 54 hPa.

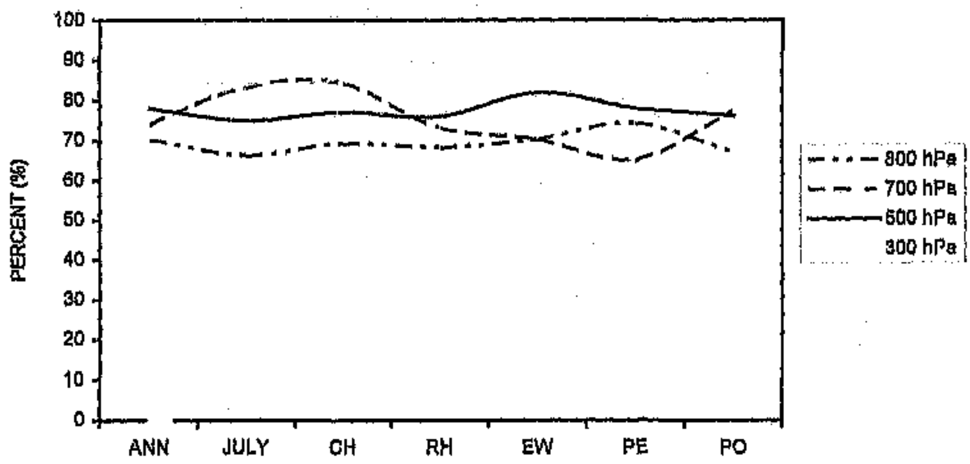


Figure 6.2 Stable layer mean frequencies for continental anticyclones (CH), ridging anticyclones (RH), easterly waves (EW), pre-frontal westerly waves (PE), post-frontal westerly waves (PO) and annual circulation comprising the average of all of the above (ANN) for the time period 1986-1993, and for the July months from 1989-1993

5. Stable discontinuities associated with easterly waves:

5.1 The 800 hPa and 700 hPa layers both have a frequency occurrence of 70% for the country as a whole, whereas the 500 hPa and 300 hPa layers occur with higher frequencies of 82% and 90% respectively.

3. Stable discontinuities associated with continental anticyclones:

3.1 Stable layers occur with mean frequencies across the country ranging from 69% to 85%; the 800 hPa has the lowest frequency and the 300 hPa layer has the highest.

3.2 Across all stations mean base heights of the 800 hPa, 700 hPa, 500 hPa and 300 hPa stable layers are 876 hPa, 740 hPa, 554 hPa and 327 hPa. The standard deviation of base heights over the country varies between 16 hPa for the 800 hPa layer and 22 hPa for the 700 hPa layer.

3.3 Averaged across all stations, the mean 95% confidence interval for base heights is lowest at 36 hPa for the 800 hPa layer and highest at 48 hPa for the 500 hPa layers.

3.4 The average depth over the country of the shallowest layer is 46 hPa at the 300 hPa layer and is deepest at 59 hPa for the 500 hPa layer. The standard deviation of the depths ranges from a minimum of 3 hPa at the 800 hPa layer to a maximum of 9 hPa for the 500 hPa layer.

4. Stable discontinuities associated with ridging anticyclones:

4.1 The three lowest layers, the 800 hPa, 700 hPa and 500 hPa layers, have mean frequencies of occurrence of 63%, 73% and 76%. In contrast the 300 hPa layer occurs 91% of the time.

4.2 Mean base heights across the country of the 800 hPa, 700 hPa, 500 hPa and 300 hPa layers are 843 hPa, 726 hPa, 527 hPa and 346 hPa. The standard deviation of base height over the country varies between 24 hPa for the 300 hPa layer and 39 hPa for the 700 hPa layer.

4.3 Averaged across all stations, the 95% confidence interval for base heights is lowest at 41 hPa for the 800 hPa layer and highest at 52 hPa for the 500 hPa layer.

4.4 Over the whole country the average depth of the shallowest layer is 60 hPa at the 800 hPa layer and is deepest at 67 hPa for the 700 hPa layer.

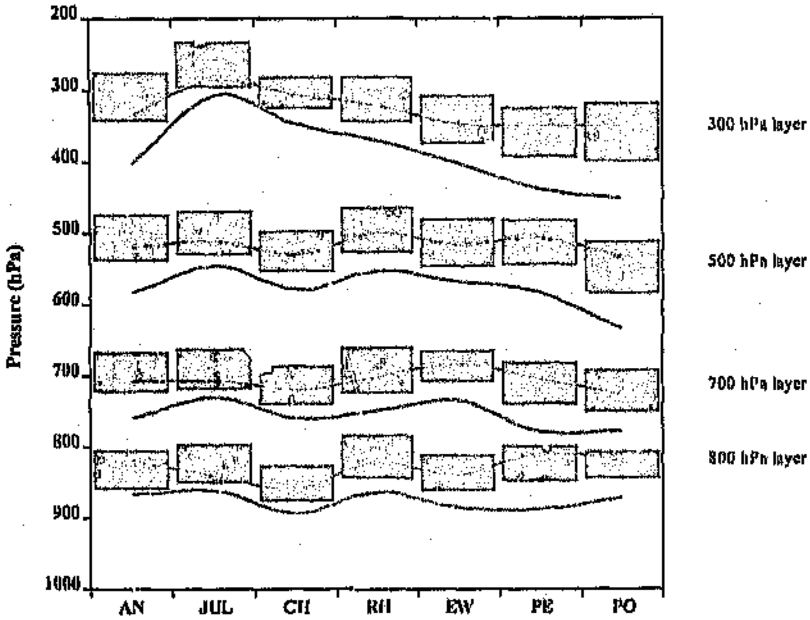


Figure 6.1 Stable layers (shaded) for continental anticyclones (CH), ridging anticyclones (RH), easterly waves (EW), pre-frontal westerly waves (PE), post-frontal westerly waves (PO) and annual circulation comprising the average of all of the above (AN) for the time period 1986-1993, and for the July months from 1989-1993 (JUL). Upper and lower 95% confidence limits for the base heights of the layers are shown in each case

1. General characteristics of stable discontinuities over South Africa:

1.1 Four persistent elevated absolutely stable discontinuities have been identified over South Africa at the 800 hPa, 700 hPa, 500 hPa and 300 hPa levels.

1.2 The lowest discontinuity occurs below the mean height of the escarpment at approximately 800 hPa over the coastal regions.

1.3 Three overlying layers have been identified at the 700 hPa, 500 hPa and 300 hPa surfaces. They occur both over the plateau and coastal regions.

1.4 The base height, depth, 95% confidence interval and frequency structures of the stable discontinuities remain fairly constant irrespective prevailing synoptic circulation.

2. Mean annual stable discontinuities:

2.1 For the year as a whole the 800 hPa layer occurs with a 70% frequency, the 700 hPa layer with a 74% frequency, the 500 hPa layer with a 78% frequency and the 300 hPa layer with a 85% frequency.

2.2 Annual mean base heights of 800 hPa, 700 hPa, 500 hPa and 300 hPa stable layers are 842 hPa, 733 hPa, 552 hPa and 368 hPa respectively. The standard deviation of base heights varies between 13 hPa and 26 hPa over the country.

2.3 Averaged across all stations, the annual 95% confidence interval for base heights is highest at 67 hPa for the 300 hPa layers and lowest at 50 hPa for the 800 hPa layer.

2.4 The average annual depth across the country of the shallowest layer is 51 hPa at the 800 hPa layer and is deepest at 66 hPa for the 300 hPa layer. The standard deviation of the depths ranges from a minimum of 2 hPa at the 500 hPa layer to a maximum of 6 hPa for the rest of the layers.

CHAPTER 6

CONCLUSIONS

Stable discontinuities act as vertical barriers to mixing and convection, inhibiting the development of convective rainfall. The layers trap aerosols and trace gases below their bases, constraining vertical dispersion and limiting transport to the horizontal. Consequently, elevated absolutely stable layers play a large role in controlling the transport of greenhouse gases over extensive distances.

The occurrence of inversions and stable discontinuities have long been recognised to be of importance over southern Africa. Only recently, however, has it been realised how persistent elevated absolutely stable layers might be and how stable the layering structure may be throughout the troposphere. In this dissertation the issue of the occurrence and characteristics of absolutely stable layers throughout the troposphere over South Africa have been addressed by synoptic circulation type. These circulation types have been chosen to represent simple circulation patterns that have persisted at any one time for periods of up to five days at time. Complex synoptic circulation types have not been incorporated in the study, except when mid-winter conditions have been examined irrespective of synoptic type. A total of 2925 radiosonde ascents were analysed to provide the climatology presented. It must be borne in mind that the results obtained apply mainly to fair-weather conditions under which stable discontinuities are most likely to form. No attempt has been made to determine the stability structure of the atmosphere on rain days.

The main findings of the research may be summarised in Figures 6.1 and 6.2 and are reviewed as follows:

* * * * * * *

Absolute stability has been analysed for complex synoptic circulation during mid-winter. The daily persistence of the stable discontinuities have been discussed and compared with mean conditions for fair-weather events and previous findings.

synoptic situations the elevated absolutely stable layers persist to varying degrees, they nonetheless remain prevalent tropospheric features over the subcontinent.

5.5 SYNTHESIS

The structure of stable discontinuities in the troposphere over South Africa, comprising four layers over the coastal regions and three layers over the interior plateau, dominate the mid-winter maximum conditions. With a greater degree of subsidence in anticyclonic conditions at the time of the mid-winter maximum, stable layering of the atmosphere over the subcontinent might be expected to increase. This is found not to be the case. The mean frequencies of the discontinuities for all stations are almost identical to those for stable layers with continental anticyclonic circulation, yielding values of 66%, 83%, 82% and 84% for the 800, 700, 500 and 300 hPa layers respectively during July.

The mean intra-station variability for all stations, as determined by the 95% confidence interval is significantly lower for all of the discontinuities during July than for any of the individual synoptic circulation types. One might have expect it to be greater because of the increased frequency of westerly wave disturbances affecting the country during winter with the poleward migration of circumpolar westerlies.

The depths of the 800, 700 and 500 hPa mid-summer stable layers are similar to those for all-year continental circulation conditions. The 300 hPa layer has a depth similar to the mean depth of layers associated with easterly waves and ridging anticyclones. Mean base heights for all layers, during July occur at similar heights to those for ridging anticyclone circulation types. The 300 hPa layer base height does however appear to be slightly higher than the rest of the circulation types.

A final and important point is that the SAFARI observations appear to have been highly representative of conditions identified during mid-winter and indeed throughout much of the year for non-rain days. Elevated absolutely stable discontinuities over southern Africa are persistent features of the troposphere with continental and ridging highs, easterly waves and westerly waves. They maintain fairly constant heights and depths over vast areas of the subcontinent much of the time.

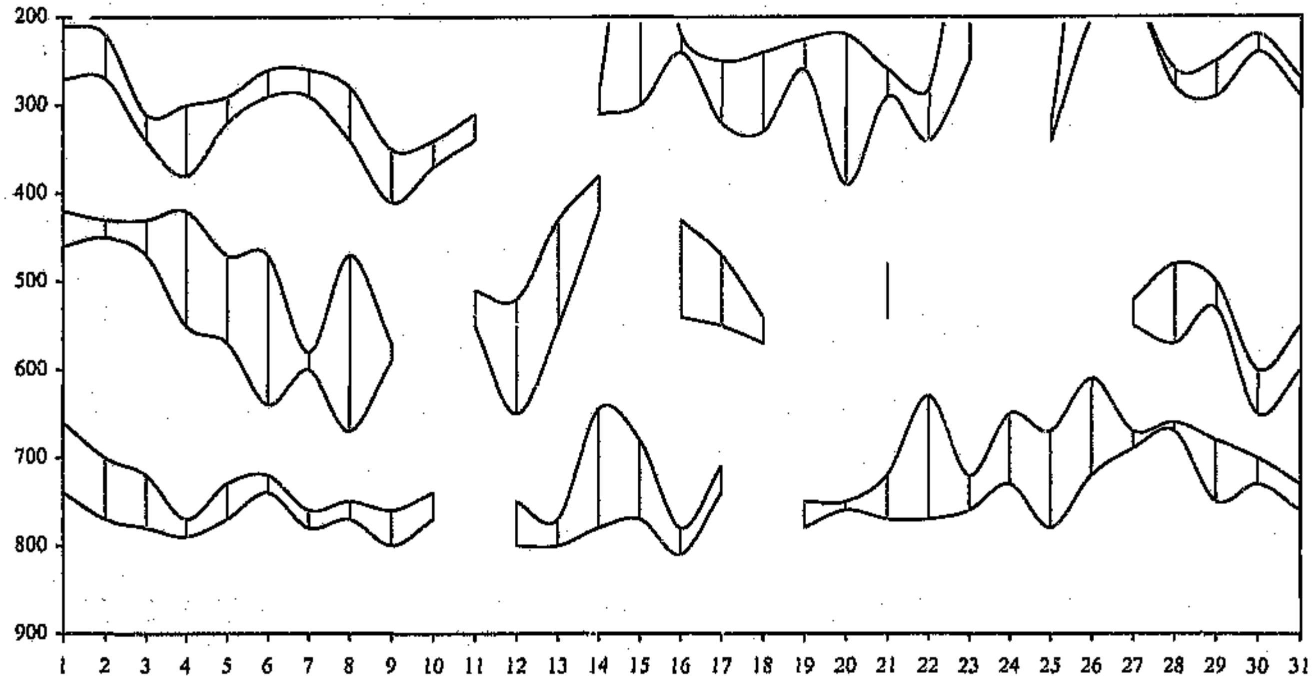


Figure 5.7 Stable discontinuities over Pretoria during July 1990

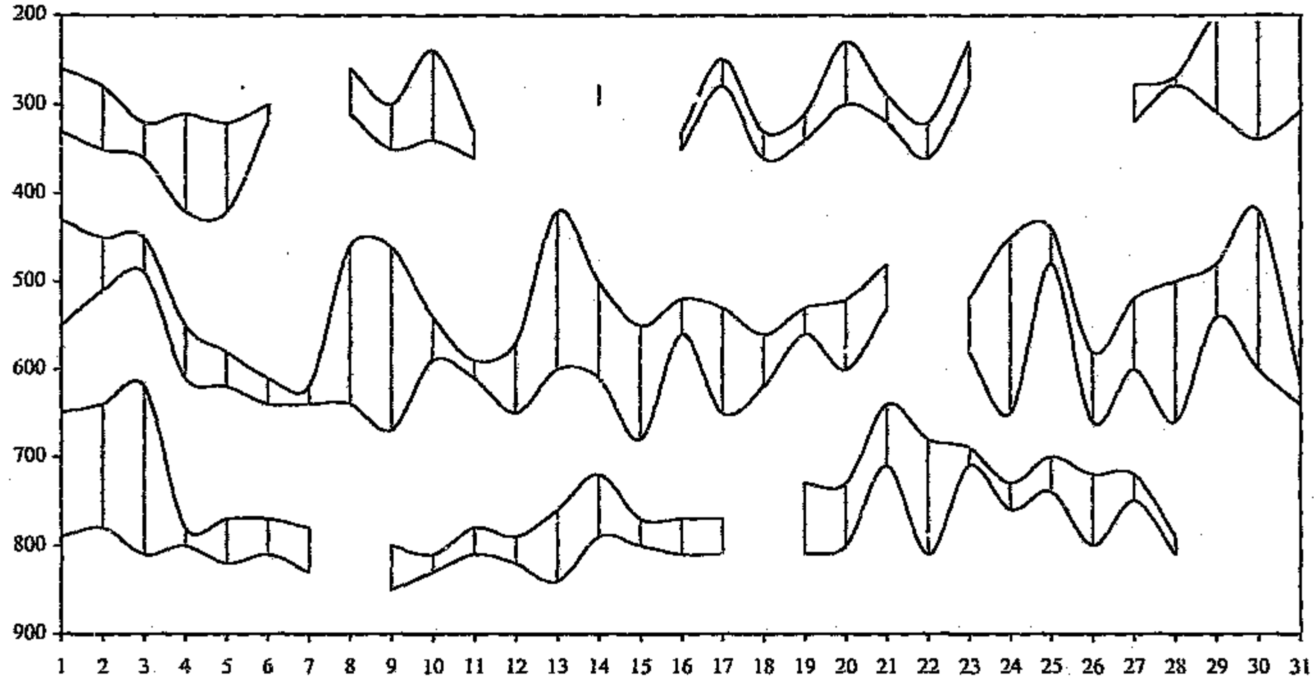


Figure 5.6 Stable discontinuities over Pietersburg during July 1990

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suggesting that thermodynamic mechanisms may contribute to its development.

9.3 The 500 hPa layer frequently coincides with the main subsidence inversion, and is maintained by thermodynamic heating and persistently descending air.

9 4 The 300 hPa layer is a subsidence feature, possibly associated with the jet-stream and the tropopause. Its exact cause remains to be determined.

In conclusion, absolutely stability in the free-air of the troposphere over South Africa occurs in a distinctly three-layered structure over the plateau and a four-layered structure over the coastal areas. It is a pervasive feature of the regional atmosphere throughout the year and the layers are remarkably persistent at all four levels.

The consequences of the layering for rainfall as well as the accumulation of anthropogenic and biogenic products in not only the lower atmosphere, but also throughout the troposphere are considerable. With regard to the former, the persistence and strength of the discontinuities contribute towards the regulation of convective rainfall, as the layers act as vertical barriers to turbulence and mixing. Concerning pollution accumulation the vertical transport of aerosols and trace gases is controlled by the layers both from the surface up and from the stratosphere down. Once pollution has penetrated through one layer, accumulation will occur below the next and so on. The effects of the accumulation are evident to the naked eye at 700 hPa and 500 hPa over interior of South Africa, particularly in winter. Frequently distinct dust and haze belts are clearly apparent at these two levels. Once accumulation beneath a discontinuity has occurred, horizontal transport occurs preferentially at that height and tends to be capped by the layer above. Vast amounts of aerosols and trace gases are recirculated over the country as well as being transported out of South Africa in this way. Hence, the implications for pollution dispersion and global change are considerable.