SH THORPEX: ISSUES RELEVANT FOR SOUTHERN HEMISPHERE POLAR LATITUDES AND ANTARCTICA

Ian Simmonds*
School of Earth Sciences, The University of Melbourne, Victoria 3010, Australia

1. INTRODUCTION

The Antarctic and Southern Hemisphere (SH) polar latitude regions host frequent intense weather events. As a typical example Figure 1(a) shows a synoptic map from ERA-40, with open and closed and strong and weak cyclones identified by the Melbourne University cyclone tracking scheme (Simmonds and Keay 2000; Simmonds et al. 2003, 2008). What is immediately apparent is the large number of intense, mobile systems in the very baroclinic subantarctic environment, and how the influence of these systems can be seen to extend into the mid latitudes. The complexity of the tracks of cyclones is indicated in Figure 1(b) which shows every fifth track (for cyclones which last at least 24 hours) from the December – February 1999-2002 from ERA-40.

These cyclonic systems impact in a variety of ways on activities in the Antarctic, on shipping in the southern oceans, and on significant portions of the southern continents. Improvements in the skill of forecasts of these would be of immense benefit, although a number of regionally specific characteristics make difficult the forecasting problem. These aspects include sharp topographic and thermal contrasts, and the complexity of the interactions between the atmosphere, ocean, continental ice and sea ice. These regional aspects also make difficult the task of obtaining trustworthy analyses which adequately reflect the complexity of the thermal properties and circulation of the region. Until recent times the region has been one of very poor data coverage, and hence the initial conditions for forecasting have been known with a high degree of uncertainty.

An ongoing effort addressing Antarctic atmospheric prediction that is particularly relevant to Southern Hemisphere THORPEX is that of the Antarctic Mesoscale Predictions System (AMPS). AMPS is a real-time, experimental numerical weather prediction (NWP) system that supports the forecasting needs of the United States Antarctic Program (USAP) and that has become a resource for a host of nations with scientific and logistical activities in Antarctica and the Southern Ocean (Powers et al. 2003; Bromwich et al. 2005) (http://www.mmm.ucar.edu/rt/mm5/amps/). Since 2000 AMPS has provided twice-daily forecasts for Antarctica and key areas within it primarily for the USAP, but with an eye to offering forecast products and assistance to the international community as requested. The system encompasses implementations of the Polar MM5 (Grell et al. 1995; Bromwich et al. 2001) and the next-generation Weather Research and Forecasting (WRF) model (Skamarock et al. 2008). AMPS currently provides nested grid forecasts over the Southern Ocean at 60-km resolution, the Antarctic continent at 20-km resolution, and targeted regions of Antarctica at 6.7-km (western Ross Sea, Antarctic Peninsula, South Pole) and 2.2-km (Ross Island) resolution.

One of the specific regions focused on in THORPEX is the polar regions. The THORPEX Plan explicitly draws attention to the fact that the polar regions are host to high impact weather events, including spring thaws, sea ice movement, and severe winter cyclones resulting in strong winds, high seas, and heavy precipitation. As indicated above these impact on safety, fisheries and fishery management, and transportation. In addition, climate change in the Antarctic region has the potential to change the distribution of ice cover, with consequences for the frequency, location and intensity of cyclonic storms. Our knowledge of the complex interactions involved with this, and specifically the prediction of intense storms, is in urgent need of enhancement.

2. ANALYSIS VERACITY AND FORECAST SKILL

The prediction of high-impact SH weather events clearly relies on a high quality forecasting system. The skill of operational SH NWP has been showing steady improvement (e.g., Figure 14 of Uppala et al. (2005)). The skill with which extreme weather events are forecast depends to some degree on the biases in the NWP model employed. A historical perspective on the skill of climate models in the high southern latitudes (e.g., Simmonds 1990) is very useful in providing a background for understanding trends in forecast accuracy. For example, climate models of the 1970s exhibited little skill is simulating average mean sea level pressure, as exemplified in Figure 2 with the results of (a) Kasahara and Washington (1971) and (b) Manabe et al. (1975). In these simulations the subtropical ridge is either badly located or non-existent and it is difficult to find any semblance of the midlatitude westerlies or the circumpolar trough. The extent of the vast improvements made over the last few decades can be appreciated from the results presented in many studies (e.g., Turner et al. (2006)).

The diagnosis and prediction of extreme events at high southern latitudes also depends strongly on the quality of analyses. These have improved dramatically in recent years (Bromwich and Fogt 2004; Uppala et al. 2005; Jones and Lister 2007). Much of this improvement has come as a result of the innovative and optimum use of available observations, and of profile information from a range of satellites. It should be pointed out, however, that profile information is of most use when data at a reference level is available. High quality sea level information are now being provided by the latest generation of scatterometer data. In his review Liu (2002) discussed the many aspects in which scatterometer data can be applied, including the study of

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* *Corresponding author address:* Ian Simmonds, School of Earth Sciences, The University of Melbourne, Victoria, 3010, Australia; e-mail: simmonds@unimelb.edu.au.

weather and marine storms (of particular relevance in the Southern Ocean) and in the sea ice and weather interaction. The latest generation of these instruments is the SeaWinds-on-QuikSCAT (QS) which was launched on 19 July 1999 and has provided an almost continuous set of surface wind measurements over most of the world's oceans. The resolution and swath of this instrument (25 km and 1800 km, respectively) has provided an invaluable source of data. Of relevance to obtaining surface pressure fields (of immense value in their own right, but also important as a reference field), Patoux et al. (2003) have inverted the QS data to obtain global surface pressure fields, and concluded their derived fields were of a quality at least comparable to the ECMWF analyses. Making further use of these high quality and high resolution QS data Patoux et al. (2005) were able to study in extraordinary detail the evolution of their sample of three fronts and frontal waves over the Southern Ocean. Many recent studies (e.g., Patoux et al. 2009; Yuan et al. 2009) have further demonstrated the great value of scatterometer retrievals for detecting and diagnosing storms in the high southern latitudes.

These scatterometer data have also been used to explore, and better understand, the near-surface structure of intense midlatitude cyclones in southern waters (e.g., Buckley and Leslie 2004; Leslie et al. 2005). A range of creative uses of these data is being followed up under SH THORPEX.

3. CYCLONIC SYSTEMS AND THEIR ROLE IN HIGH SOUTHERN LATITUDE INTERACTIONS

Cyclonic systems in the subantarctic region play a central role in determining the weather and climate of the high southern latitudes (e.g., Simmonds et al. 2005; Pezza et al. 2007). In recent times our understanding of these systems, in what had been a data sparse region of the globe, has progressively increased, as our theoretical understanding and the quality of subantarctic analyses has improved. As contributions to SH THORPEX investigations by our group have comprehensively quantified the vertical structure and tilt of cyclonic systems in the high southern latitudes (Lim and Simmonds 2007). We are also exploring how the mean spatial structure of cyclone eddies relates to that of measures of baroclinic instability, such as the maximum Eady growth rate. Under this very commonly-used framework the maximum growth rate of eddies is proportional to the ratio of the meridional temperature gradient and the Brunt-Väisälä frequency. Because this expression for the growth rates is nonlinear it is clear that a true appreciation of the mean Eady growth rate cannot strictly be determined from the mean atmospheric state, but rather the mean rate should be determined from the mean of the instantaneous growth rates calculated over some extended period. Figure 3 (a) shows the mean maximum Eady growth rate at 500 hPa in JJA calculated with the traditional method which uses the time-mean flow, while part (b) shows the change to the mean maximum Eady growth rate when the mean rate is calculated from the individual 6 hourly maximum growth rates. It is seen that much larger mean growth rates are diagnosed with the synoptic approach, particularly around the Antarctic coast. The axis of greatest growth rate is moved to the south (Simmonds and Lim 2009). These findings are of significance to THORPEX in that they present a more consistent approach to understanding the distribution of high southern latitude cyclone behavior.

Given the nature of the labor involved with compiling statistics on cyclones, in recent times a number of groups have designed computer algorithms to detect and track cyclones from digital analyses. Those who designed schemes which had a specific focus on SH synoptics were Murray and Simmonds (1991), Sinclair (1994, 1995, 1997), Simmonds and Murray (1999), Simmonds et al. (1999) and Simmonds and Keay (2000). An important outcome of SH THORPEX is the availability of a user interface to compile cyclone statistics for a given event or epoch (see below). THORPEX will also provide an environment conducive to the further refinement of these automatic identification schemes, and their application to new data sets, for example, to eddies in the Southern Ocean circulation revealed from satellite altimeter data (e.g., Jason and Envisat), and vortices in Antarctic sea ice (Wassermann et al. 2006) .

4. EXPLOSIVELY DEVELOPING CYCLONES (OR 'BOMBS')

Explosively developing cyclones (or 'bombs') are characterized by rapid central pressure reduction and dramatic increase in intensity. Such characteristics are associated with difficulty of prediction and also with serious threats to human life and property when these cyclones occur off coastal regions, or in shipping lanes. Until recent years most of the research on these weather phenomena has been conducted on NH events. However, the availability of reanalysis products and the improvement of analysis quality in the high southern latitudes has meant that these features can be now be realistically studied in the subantarctic region. For example, Lim and Simmonds (2002) and Simmonds et al. (2003) explored the distribution and seasonality of these features. They also indicated how the criteria for a bomb must be generalized to account for the strong westerly environment at high southern latitudes. Leslie et al. (2005) used this methodology to discuss two bombs. One of their cases was a "supercyclone" bomb that developed to the southwest of New Zealand region during May 29 to 31, 2004, and was well-captured by the QS scatterometer instrument. Improvements in analysis quality and forecast accuracy are a key aspect in predicting the likelihood and evolution of 'bombs', and the potential they represent for harm and destruction.

5. COLD OUTBREAKS

The Antarctic continent and its surroundings influence greatly the weather and climate over the mid latitudes of the SH continents. One of the most dramatic examples of this influence in the occurrence of 'cold outbreaks'. The most severe of these involve the meridional or near-meridional transport of cold air from the subantarctic or Antarctica itself. These are usually of short duration (2-3 days) and tend to be associated with specific synoptic patterns. They impact significantly on many economic and social aspects in the affected regions.

Cold outbreaks are relatively frequent over southern parts of the Australian and South American continents. Given this frequency, it is perhaps surprising that the mechanisms associated with these events (and their remote forcing) have been investigated only in a handful of studies. For Australia we can mention, among the more the recent investigations, those of Perrin and Simmonds (1995), Simmonds and Rashid (2001), Jones (2003) and Ashcroft et al. (2009). For the South American case the papers of Marengo et al. (1997, 2002), Garreaud (1999, 2000), Vera and Vigliarolo (2000), Lupo et al. (2001), and Pezza and Ambrizzi (2005a, b) are particularly worthy of mention. Overall, these papers reflect a steady increase in the understanding and ability to model these extreme SH events. The events have great impacts on many aspects of human activities and are an important focus for SH THORPEX. It has become clear that these events are associated with significant hemispheric organization, but their regional consequences differ (e.g., through the presence of the Andes). The strong anticyclonic component of the dipole which is present in virtually all outbreaks is seen to travel vast distances, and in the southern Australian case usually originate in the western Indian or even the Atlantic Oceans. Recent work of Ashcroft et al. (2009) has shown significant negative sea surface temperature anomalies in the southern Indian Ocean in the week prior to southern Australian outbreak events (see Figure 4), suggesting that largescale air-sea interaction plays a role in the longevity and strength of highs associated with cold outbreaks. An enhancement of international collaboration in this area of meteorology, and specifically the role Antarctica and its environs play in these very influential episodes, would be an ideal deliverable from THORPEX on the diagnosis and forecasting of these extreme events.

6. SH THORPEX WEB PAGE FORUM

An important component of SH THORPEX Implementation Plan is the set up of a web page forum. The purpose of this, in part, is to '… establish an ongoing sense of community and shared purpose between Southern Hemisphere researchers and forecasters' (http://thorpex.cptec.inpe.br/). As a contribution to this the group at The University of Melbourne have further developed their on-line cyclone resource. The University of Melbourne Automatic Cyclone Tracking web access allows the calculation (and presentation) of a range of up-to-date cyclone statistics for the user-specified time and space domain. These calculations can be performed on the four reanalysis products NCEP (Kalnay et al. 1996), NCEP2 (Kanamitsu et al. 2002), ERA-40 (Uppala et al. 2005), and JRA-25 (Onogi et al. 2007) (http://www.earthsci.unimelb.edu.au/tracks/cychome.htm).

7. CONCLUDING REMARKS

The Antarctic and high southern latitudes present significant challenges for the diagnosis and prediction of high impact weather forecasts. Already SH THORPEX can be seen to be making significant contributions to these matters from a number of points of view. Particularly pleasing is the level of cooperation across the three SH continents.

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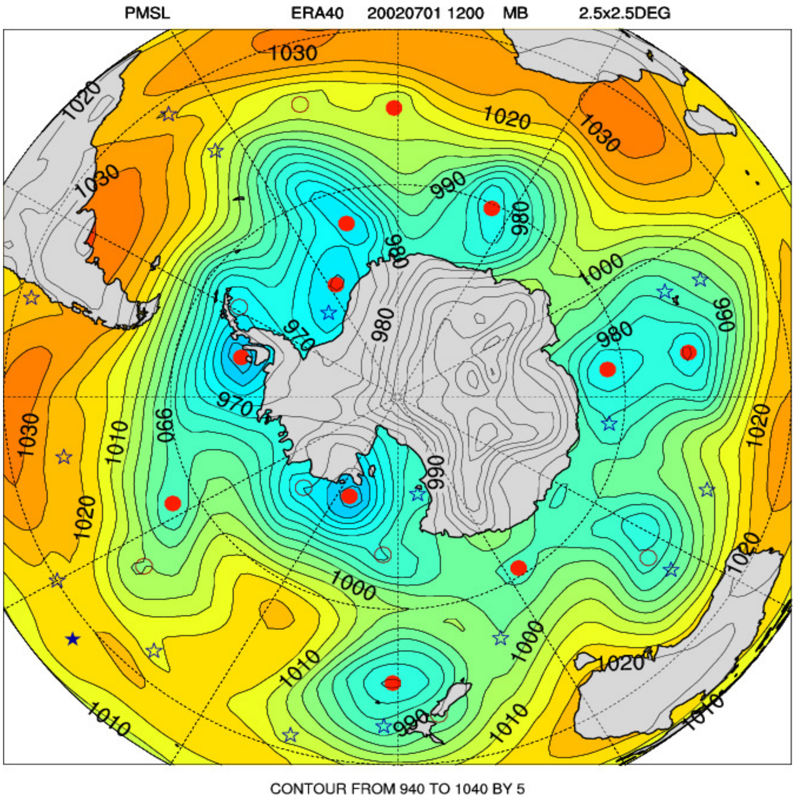


Figure 1(a): 'Satellite' view of the ERA-40 mean sea level pressure analysis at 1200 UTC on 1 July 2002. The contour interval is 5 hPa, and the centre of intense, closed cyclones is indicated with a red dot.

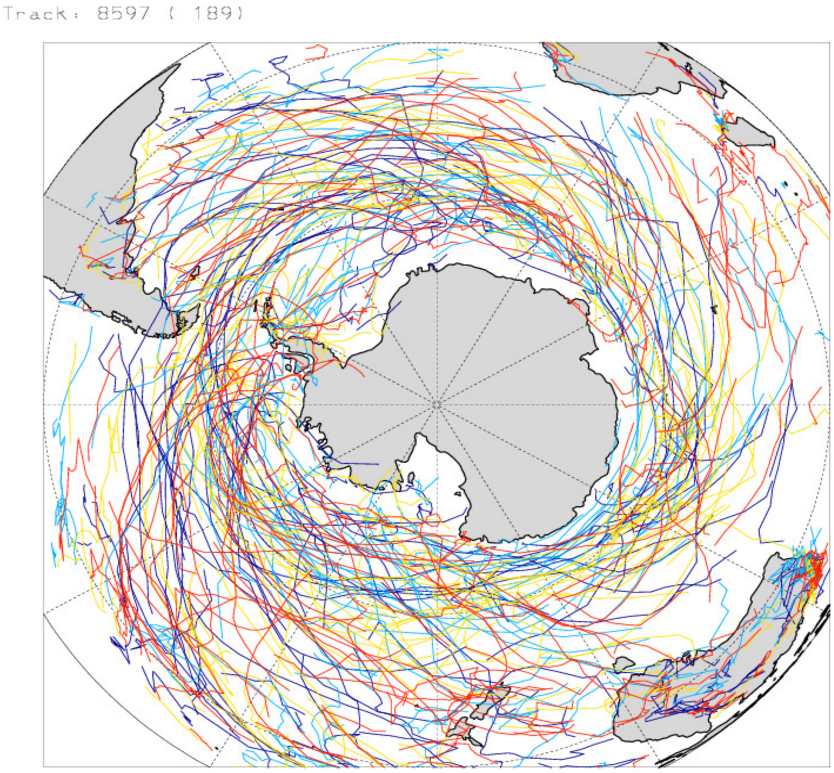


Figure 1(b): 'Satellite' view of mean sea level pressure cyclone tracks derived from the ERA-40 reanalysis. Only every fifth track for cyclones which last at least 24 hours is shown for the period December – February 1999-2002. The tracks in each of the four years are shown in different colors.

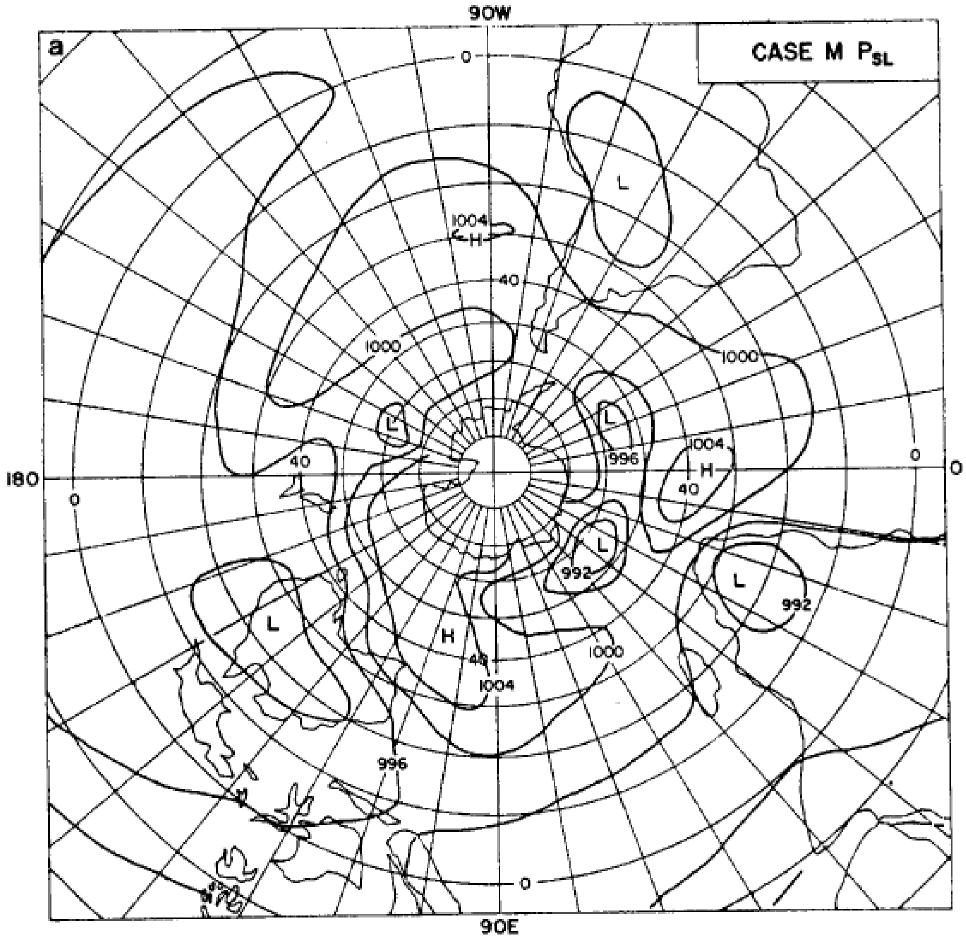


Figure 2(a): Mean January MSLP as simulated by Kasahara and Washington (1971)

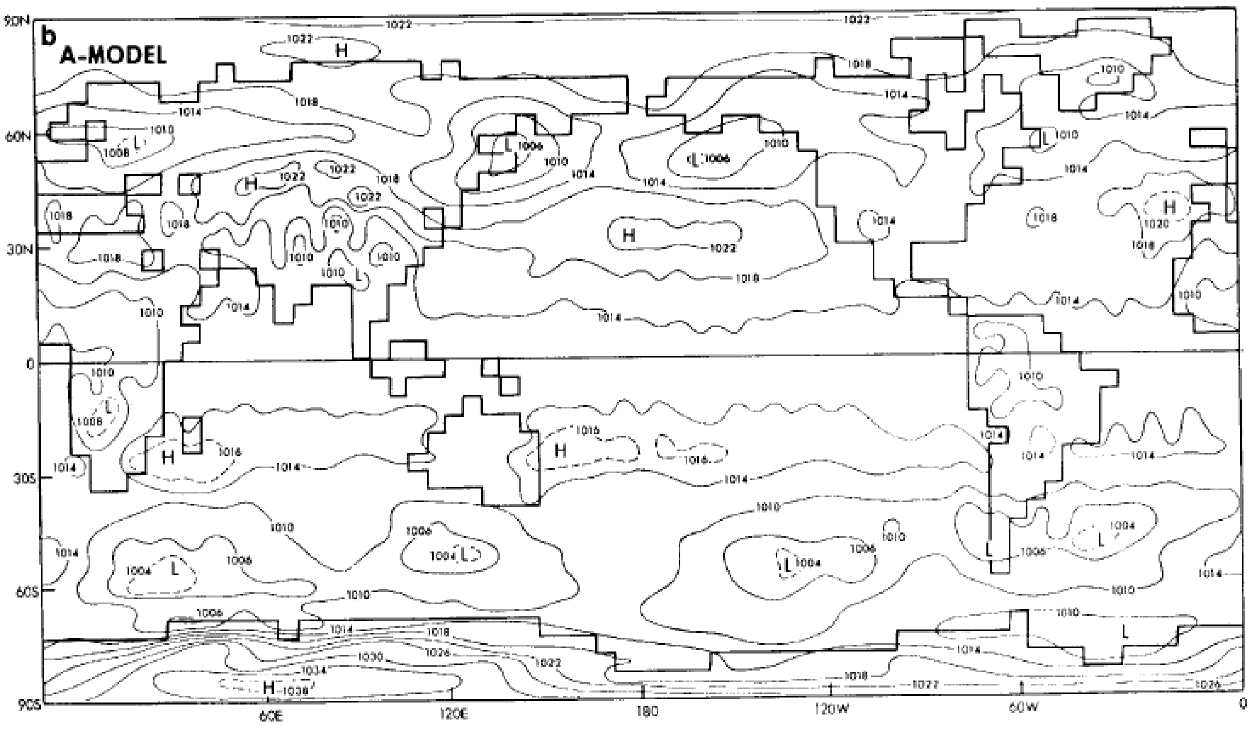
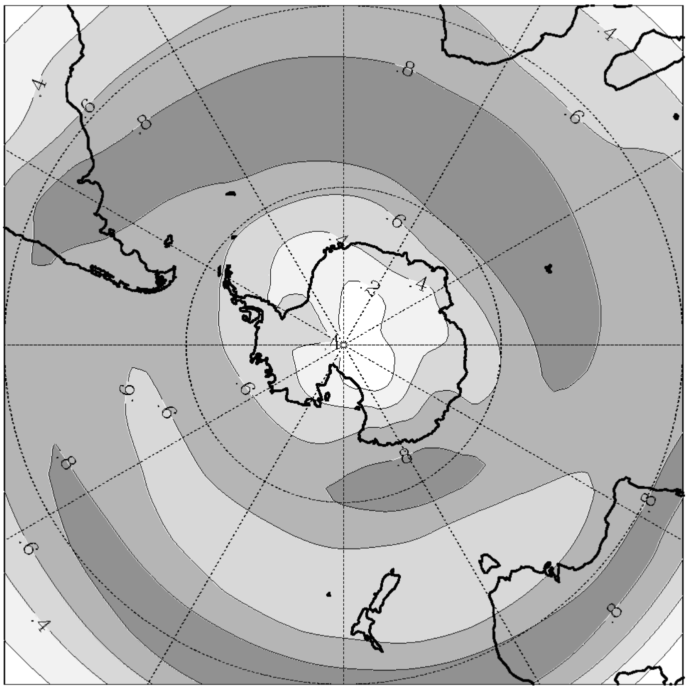
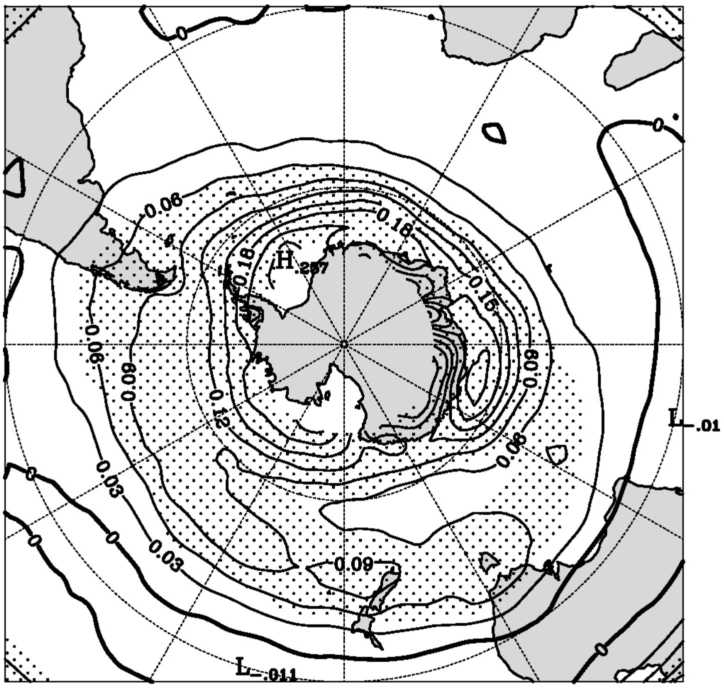


Figure 2(b): Mean January MSLP as simulated by Manabe et al. (1975).



(a) σ_{savg}



(b) $\sigma_{tran} - \sigma_{savg}$

Figure 3: (a) Climatology of the maximum Eady growth rate calculated with seasonal mean vertical shear and *N* at 500 hPa in JJA. Part (b) shows the change to the mean maximum Eady growth rate when the mean rate is calculated from 6 hourly maximum growth rates. The contour interval is 0.2 day^{-1} in (a) and 0.03 day^{-1} in (b). The stippled area in (b) indicates that the change is statistically significant at the 95% confidence level. (The data poleward of 75°S are masked in (b).)

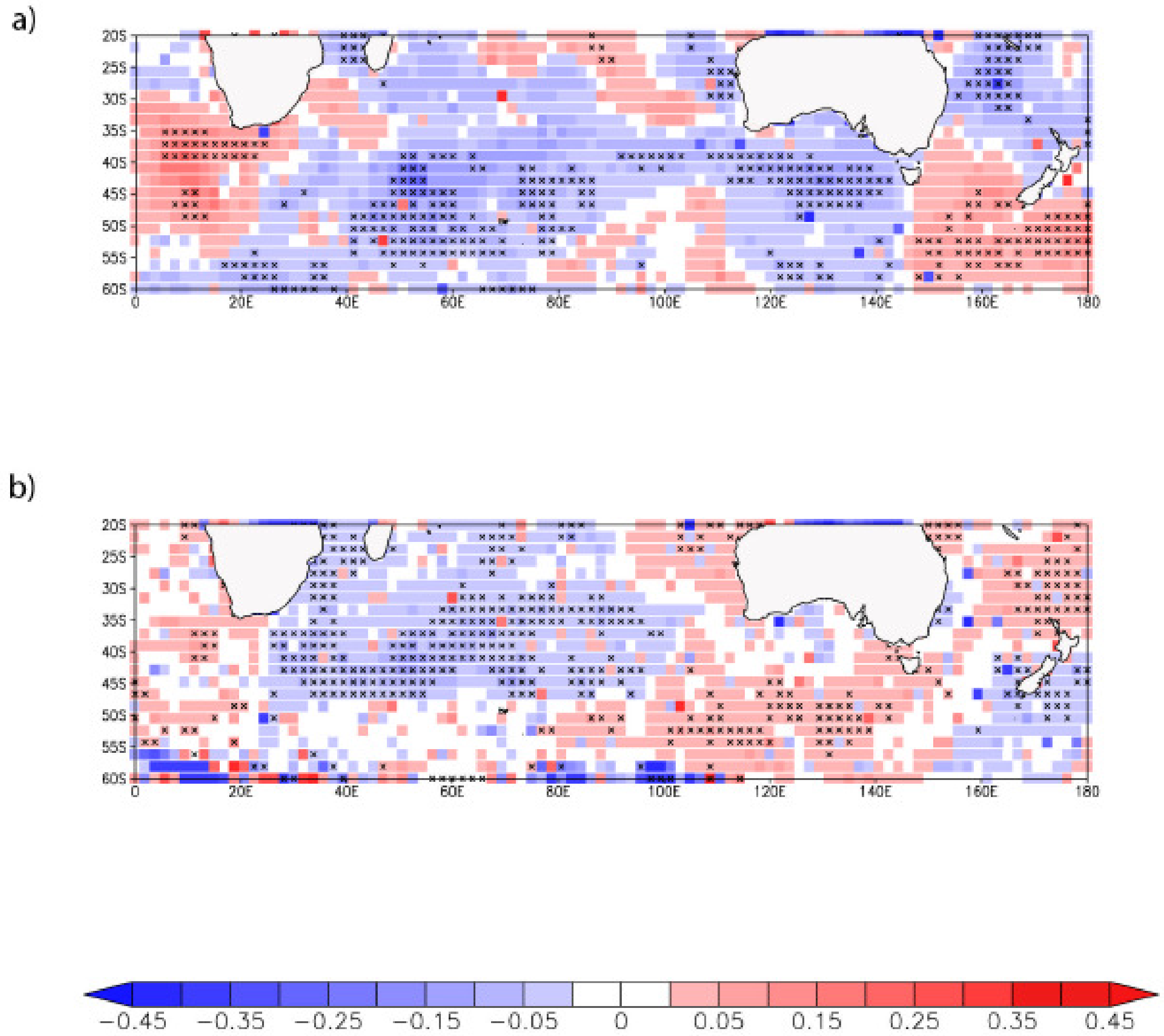


Figure 4: Average surface skin temperature anomalies (℃) over ocean for the seven days before Cold Outbreaks summer in Melbourne (a) and winter in Perth (b). Areas marked with a cross indicate regions over which the anomalies differ significantly at the 90% confidence level. (From Ashcroft et al. (2009).)