19.13 CHANGES TO THE VERTICAL STRUCTURE OF CYCLONES UNDER GLOBAL WARMING

Eun-Pa Lim* and Ian Simmonds
The University of Melbourne, Victoria, Australia

1. INTRODUCTION

Baroclinicity is known as the major mechanism driving extratropical cyclones. Therefore, it is an important issue to determine how baroclinicity will change in the troposphere as the globe warms up. A number of studies using GCMs seem to agree with a general reduction of lower troposphere baroclinicity and an increase of upper troposphere baroclinicity (Hall et al. 1994, Zhang and Wang 1997, Carnell and Senior 1998, Sinclair and Watterson 1999, Knippertz et al. 2000). However, there are still discrepancies in detail about how these changes will influence surface cyclone frequency and features. To explore this, we investigate vertical organization over surface cyclones by tracking low pressure systems vertically so that the changes of cyclone properties like system density, intensity, scale and depth might be able to be shown with respect to the changes of their upper level counterparts. In this paper, we focus on the climatology of Southern Hemisphere (SH) winter cyclone vertical organization.

2. DATA AND METHODOLOGY

We use the National Centers for Environmental Prediction-Department of Energy (NCEP-DOE) reanalysis-II data set (Kanamitsu et al. 2000, 2002). The data include mean sea level pressure (mslp), 925, 850, 700, 600 and 500 hPa geopotential heights (hereafter, Z*height*) in June-July-August (JJA) from 1979 to 2000.

In order to detect cyclones at each level, the Melbourne University cyclone finding and tracking scheme (Simmonds and Keay 2000a, Keable et al. 2002) is used.

The vertical organization over surface cyclones is obtained as follows: first, we find the location and time of maximum depth of a surface cyclone. In a circle of 4° latitude radius centered on the location and time found, we search for the vertical extension of the cyclone at the next data level. This tracking is continued to Z500.

3. RESULTS

Table 1 summarizes the features of SH cyclones at six levels treated separately occurring in JJA 1979-2000. mslp cyclones show smaller scale but greater intensity than upper level cyclones. An interesting fact found in this table is that the mean cyclone properties show decrease in their values from the surface to Z850 or Z700, but then start to increase again at higher elevations. These characteristics probably reflect the influence for topography, boundary conditions, more wave-like patterns in the upper atmosphere and the presence of the jet stream in the upper troposphere.

	System Density (cyclones $(°lat)^{-2}10^{-3}$ analysis^{-1})	Radius $(°lat)^{-2}$	Intensity $(\nabla^2 Z)$ $(m(°lat)^{-2})$	Depth (m)
Z500	1.00	6.02	4.10	46.9
Z600	0.97	5.96	3.53	40.3
Z700	0.96	5.84	3.28	35.9
Z850	0.98	5.78	3.52	35.3
Z925	1.10	5.92	3.69	36.5
msl	1.19	5.13	5.78	31.8

Table 1 mean SH winter cyclone properties in 1979-2000

We find from our "vertical tracking" that about 47% of surface SH extratropical cyclones have well organized vertical structure which can be traced all

Corresponding author address: Eun-Pa Lim, School of Earth Sciences, The University of Melbourne, Victoria 3010, Australia;
e-mail: eplim@earthsci.unimelb.edu.au

the way to Z500 in winter. Furthermore, this percentage has increased significantly (99% confidence level) over our 22 years of record (Fig.1). Much of this increase is associated with the increase of the ratio of mslp-Z500 structured cyclones at high latitudes south 60°S (99% confidence level). The enhancement of vertical organization of cyclones might be strongly related to the increase of mean depth of SH extratropical cyclones in the SH (Simmonds and Keay 2000b) and particularly to the increase of high latitude cyclone mean depth (Simmonds et al. 2003).

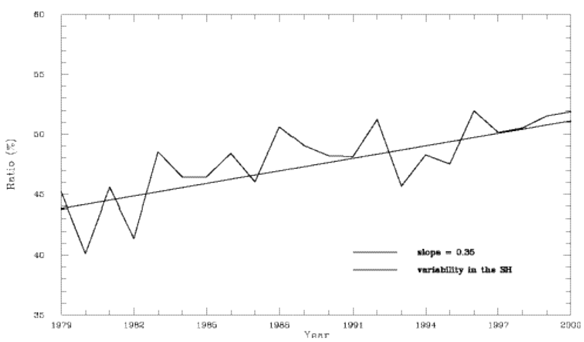

Figure 1 Time series of the ratio of the number of well-organized cyclones to the entire mslp extratropical cyclones in the SH in JJA 1979-2000

The surface cyclone features show clear differences according to whether or not surface cyclones are vertically well organized. Table 2 suggests that the surface cyclones having a Z500 cyclone partner are more intense, larger and deeper than those ending their connection at Z700 or lower. Moreover, the mslp-Z500 coupled cyclones appear to have twice the lifespan of the others. Overall, the results shown in Fig. 1 and Table 2 are consistent with the

	Mslp-Z500	No further connection than Z700
System density	0.59	0.31
Radius	5.65	5.02
Intensity	0.98	0.72
Depth	5.82	3.80
Lifespan (days)	4.25	2.25

Table 2 Comparison of cyclone properties of the cases of mslp-Z500 and no further connection than Z700.

Increase of explosive cyclones for the same period in the SH (Lim and Simmonds 2002).

When surface cyclones experience their deepest stages, the average distance between Z500 and mslp cyclone centers is about 398 km. This distance has reduced significantly for the last two decades (99% confidence level) (Fig. 2).

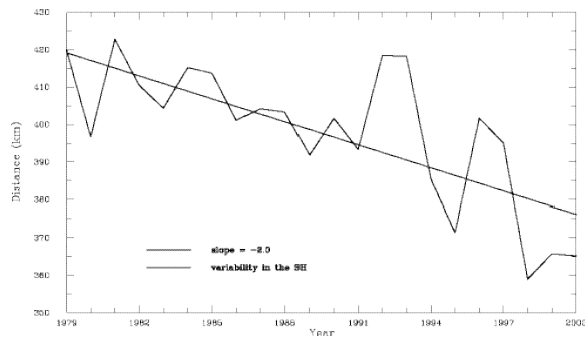

Figure 2 Time series of the average distance between coupled Z500 and mslp cyclone centers in the SH in JJA 1979-2000

Figure 3 presents a summary of the positions of Z500 cyclones relative to their surface counterparts and the number of couples in each direction (all directions are divided by 45° sectors). The couples of the surface cyclone and Z500 cyclone are counted in each 10° latitude longitude box and distributed according to the relative direction of the Z500 cyclone to the surface one. The arrows point in 8 directions of the compass and their length represents the number of pairs in each direction. Most of the Z500 cyclones coupled with surface cyclones are positioned westward of the surface feature. The relative positions of Z500 cyclones to the surface counterparts seem to distribute evenly at all western directions. Nevertheless, it is shown that a number of cyclones occurring along the coast of East Antarctica have a strong component of southward tilt, which is different from the cyclones at the coast of West Antarctica. Also, it appears that there are more preferred directions for Z500 cyclones to interact with their surface counterparts over the Southern Ocean south of Australia and New Zealand and the southern Pacific Ocean.

In addition, we document the times at which Z500 cyclones are associated with the surface cyclone deepest stages. As expected from above results, a number of Z500 cyclones have their maximum development at the same time as the surface cyclones. Also, it is interesting to note that the deepest stages of Z500 cyclones do not show any particular preference to pre- or post-stage of those of surface counterparts.

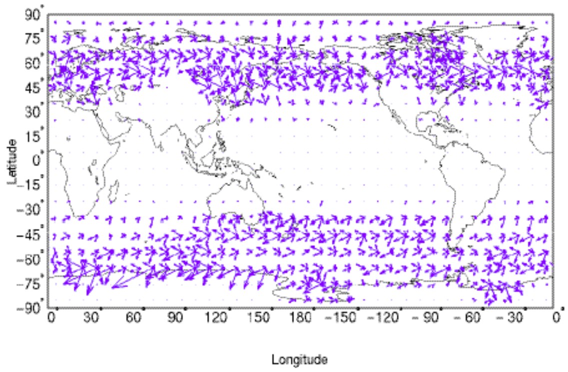

Figure 3 Relative positions of Z500 cyclones to their partners at mean sea level in JJA 1979-2000 (the length of arrows is proportional to the number of pairs)

Overall, the results from the Northern Hemisphere (NH) winter cyclones are similar to those of the SH. In terms of the vertical organization mslp-Z500 structured cyclones occupy about 50% of the entire population of NH winter mslp cyclones. However, their percentage does not show any particular trend for the last two decades in contrast with the increase for the SH case. In the average distance between Z500 and mslp cyclone centers, there has been a decrease, but the slope is less steep than that of the SH. Hence, SH cyclone vertical structure appears to have changed much more than that in the NH during the recent period of warming.

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