SENSITIVITY OF THE MAXIMUM EADY GROWTH RATE TO THE TIME SCALE OF THE BASIC FLOW

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1. INTRODUCTION

An estimate of baroclinic instability is very commonly presented with the maximum Eady growth rate (σ; Eady 1949) which is expressed by the ratio of vertical shear (meridional temperature gradient) to static stability. It is a common practice in the climate research community that the time-mean σ is calculated from the time-mean flow. However, this way of calculating the mean σ overlooks the nonlinearities between the vertical shear and static stability and also due to the absolute operator, and therefore, can be misleading in understanding the interplay of baroclinic eddies and the background flow. Therefore, this study is aimed to quantify and explain the bias in calculating Eady growth rates using a time-mean state.

2. Data and Methods

For this study, we analyzed the Japanese 25-year reanalysis (JRA-25) 6-hourly data for the period of 1979-2007 (Onogi et al. 2007). The JRA-25 assimilation model has a resolution of T106L40, but the data are available on a global 2.5°x2.5° latitude-longitude grid, which are used for the current study.

The maximum Eady growth rate is given by

$$\sigma = 0.3098 \frac{|f| \left| \frac{\partial U(z)}{\partial z} \right|}{N} \qquad (1)$$

(Vallis 2006) where N is the Brunt-Väisälä frequency (where $N^2 = \frac{g}{\theta}\frac{\partial \theta}{\partial z}$, g being the acceleration due to gravity, z the vertical coordinate, and θ the potential temperature) and f is the Coriolis parameter. $U(z)$ is the vertical profile of the eastward wind component. In order to examine the sensitivity of the mean σ to the different time scales of basic flow, we calculated the climatology of σ with the following two methods: Firstly, seasonal average of σ was computed with the seasonal averages of vertical shear and static stability in each year, and the climatology was calculated from them (σ_{savg}),

$$\sigma_{savg} = \sum_{y=1}^{29} 0.3098 \frac{|f| \left| \frac{\partial \sum_{m=1}^{3}\sum_{d=1}^{ND}\sum_{t=1}^{4} U(z)}{\partial z} \right|}{\sum_{m=1}^{3}\sum_{d=1}^{ND}\sum_{t=1}^{4} N} \qquad (2)$$

In the second approach, we calculated the instantaneous σ from each of the 6 hourly data, and calculated the long term average of these (σ_{tran}),

$$\sigma_{tran} = \sum_{y=1}^{29}\sum_{m=1}^{3}\sum_{d=1}^{ND}\sum_{t=1}^{4} 0.3098 \frac{|f| \left| \frac{\partial U(z)}{\partial z} \right|}{N} \qquad (3)$$

For this study, we examined σ at the 500 and 850 hPa levels. The σ at the 500 (850) hPa level was obtained from the vertical shear and Brunt-Väisälä frequency estimated with the potential temperatures at the 300, 500, and 700 (700, 850, and 1000) hPa levels in the austral winter (June-July-August, JJA) when baroclinicity is great and synoptic activity is the most vigorous.

3. Results

Figure 1 displays the 29 year climatology of σ_{savg} and σ_{tran} and the difference between them at the 850 and 500 hPa levels. The distribution of large σ_{savg} over the SH extratropics at the 850 hPa level is consistent with other studies (e.g. Berbery and Vera, 1996), having greater than 0.4 day^{-1} over a broad region spiraling from the east of South America to the Drake Passage. A local maximum of σ_{savg} is found over the Pacific Ocean in the midlatitudes. This overall pattern of strong baroclinicity is very similar to the pattern of strong vertical shear associated with the subpolar and subtropical jets in JJA (Lim and Simmonds 2007).

We get a similar pattern in the climatology of σ_{tran}. However, the difference map shows that there is more than 10% increase (> 0.03 day^{-1}) by σ_{tran} in the Eady growth rate over most of the extratropics (Fig 1c). Differences in excess of 0.06 day^{-1} are seen in the sub-Antarctic region.

The Eady growth rates at the 500 hPa level have similar spatial structure to those at the 850 hPa level but have more zonal symmetry and large-scale structure (Figs. 1d-1f). It is apparent in Fig 1f that the baroclinicity obtained from the seasonal mean vertical shear and static stability is significantly underestimated at this level as well at the lower level. Calculating the climatology of σ from the 6 hourly Eady growth rates results in significantly greater growth rates over the circumpolar region. This enhanced estimate of baroclinicity in these high latitudes is consistent with the high rates of cyclogenesis observed there (Turner et al. 1998, Simmonds et al. 2003).

Over virtually all regions of the plots we have shown, the climatology of σ_{tran} exceeds that of σ_{savg} in both levels. This is in part due to that the time mean of

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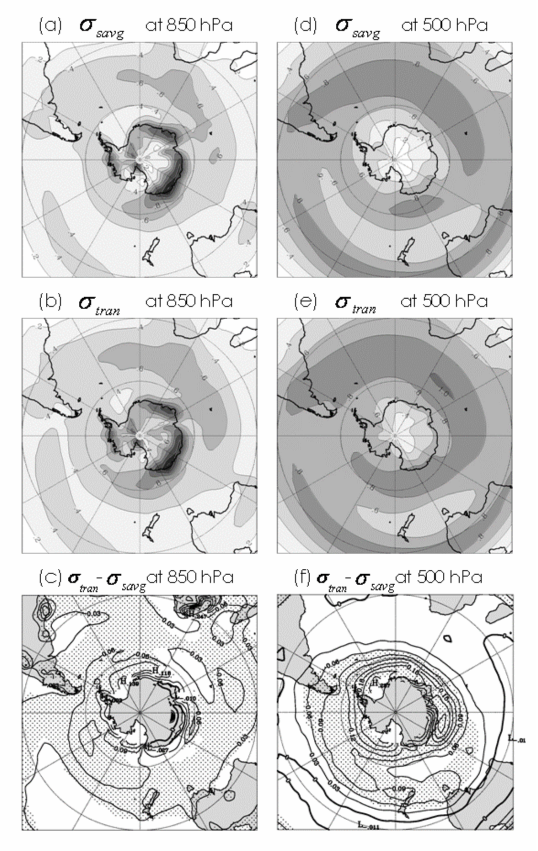

Fig 1: Climatology of the maximum Eady growth rate calculated with (a), (d) seasonal mean vertical shear and N and (b), (e) 6 hourly vertical shear and N, and (c), (f) the difference at 850 hPa (left panel) and at 500 hPa (right panel) in JJA. The contour interval is 0.2 day^{-1} in (a), (b), (d) and (e) and 0.03 day^{-1} in (c) and (f). The stippled area in (c) and (f) indicates that the difference between (a) and (b) and between (d) and (e) is statistically significant at the 95% confidence level. The data poleward of 75°S are masked in (c) and (f).

the absolute values of the vertical shear in eq. (3) is always greater than the absolute value of the shear of the time-mean zonal wind in eq. (2). Also, the mean of the Brunt-Väisälä period, $\overline{\frac{1}{N}}$ is always greater than the Brunt-Väisälä period calculated from the mean Brunt-Väisälä frequency, $\frac{1}{\overline{N}}$. The temporal covariance of the anomalies of vertical shear and static stability also contributes to the differences between σ_{tran} and σ_{savg} (Simmonds and Lim 2009). In addition, Figure 2 shows that the autocorrelation of σ_{tran} becomes insignificant (< 0.5) within a day. This short decorrelation time also suggests that it is inappropriate to compute the mean baroclinicity from the time-mean basic flow, but rather one should obtain the Eady growth rates at all relevant synoptic times and average them.

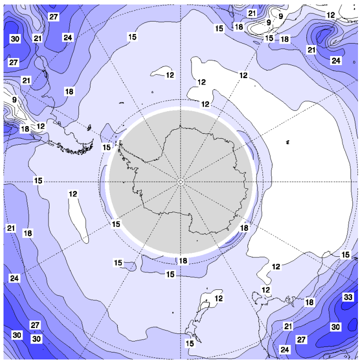

Fig 2: Temporal decorrelation time scale (time to fall to 0.5) (in hours) at the 850 hPa level. The contour interval is 3 hours. The correlation coefficients greater than 0.2 are statistically significant at the 95% confidence level.

4. Concluding remarks

In this study, we have shown that the SH mean maximum Eady growth rate demonstrates considerable sensitivity to the method by which it is calculated, and significant bias occurs in the traditional method of calculating the growth rate from the time-mean basic flow because of nonlinearities and covariances especially over the SH high latitudes. We propose that the mean maximum Eady growth rate should be the average of instantaneous maximum growth rates.

5. References

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