Climatology and Interannual Variability of Upward and Downward Propagation of Rossby Wave Activity Across the Tropopause

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INTRODUCTION

The climatology and interannual variability of upward and downward propagation of Rossby wave activity across the tropopause associated with submonthly fluctuations are studied in the Southern Hemisphere late winter, by using a phase-independent wave-activity flux and an index for waveguide structures, both of which are suited for diagnosing stationary Rossby wave propagation on a zonally-asymmetric time-mean flow. This study is based on NCEP/NCAR reanalysis data from 1979 to 2003. Submonthly fluctuations are defined by applying 8-day low-pass filter and subtracting its 31-day moving averaged field. This is a new aspect of dynamical linkage between the stratosphere and troposphere in the wintertime extra-tropics.

A case study in August 1997

Before discussion of climatology of vertical wave-activity flux, a typical example of this linkage is shown. There, a particular event of large-scale, quasi-stationary cyclogenesis was observed in the troposphere of the Southern Hemisphere (SH) in August 1997 (Fig. 1). In the cyclogenesis (blue suares in Fig. 1), downward wave-activity injection from anticyclonic anomalies upstream that had developed in the exit region of the lower-stratospheric polar-night jet (PNJ) contributed to it substantially . Consistent with that downward injection, phase lines of observed streamfunction anomalies exhibited a distinct eastward tilt with height. The development of the anticyclonic anomalies occurred at the leading edge of a quasi-stationary Rossby wave train propagating along the PNJ that had originated from a tropospheric blocking ridge farther upstream (denoted by red circles in Fig. 1).

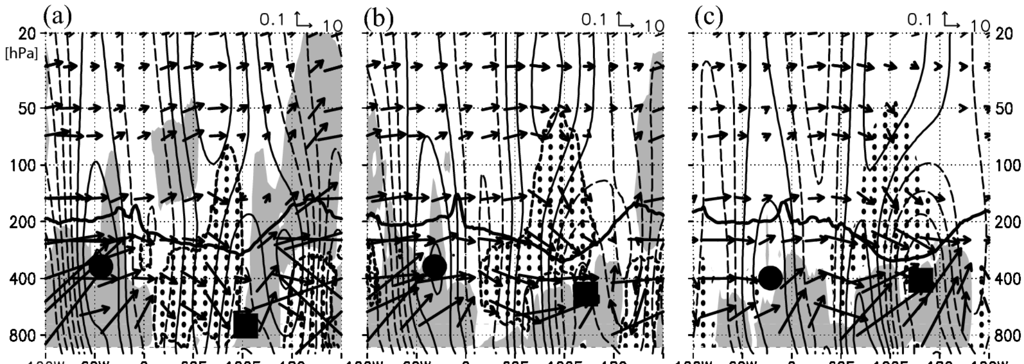


Figure 1 Zonal sections for 60°S of geopotential height anomalies (contoured for ±30, ±90, ±150 and ±210 m) and an associated wave-activity flux (arrows) on 8, 10 and 12 August 1997. Scaling for the arrows is given near the upper-right corner of each panel [Unit: $m^2 s^{-2}$]. Shading and stippling indicate the upward and downward components, respectively, of the wave-activity flux whose magnitude

exceeds 0.03 [m^2 s^{-2}]. The anomalies have been normalized with pressure. The 5-day mean tropopause defined by the NCEP is indicated with a thick solid line.

Though less often than upward wave-activity injection across the tropopause, similar events of downward wave-activity injection occurred several times during late winter of 1997, primarily in the regions south of Australia and over the central South Pacific, over each of which the PNJ exit overlapped with a tropospheric subpolar jet (SPJ) to form a vertical waveguide locally. It is argued that the downward wave-activity propagation is essentially due to refraction in the vertically sheared westerlies, and the zonal asymmetries in the time-mean flow are a likely factor for the observed geographical preference of the downward wave-activity injection.

Climatology of upward and downward propagation across the troposphere

The climatology of the upward and downward wave-activity propagation across the tropopause is studied in the SH late winter. To elucidate upward and downward propagation, we took only positive or negative value of 100-hPa vertical component of wave-activity flux for each day on each grid. Then averaged them within a month. The upward and downward wave-activity propagation is prominent over the Southeastern Pacific and South Atlantic (Fig. 2b and e) , where the axes of the climatological-mean PNJ and SPJ are meridionally close to one another (Fig. 2a and d) and submonthly circulation fluctuations are active both in the lower stratosphere and troposphere (Fig. 2c and f). The above results can be obtained based on other renalaysis data of ERA-40 (Uppla et al. 2005) and JRA-25 (Onogi et al. 2007).

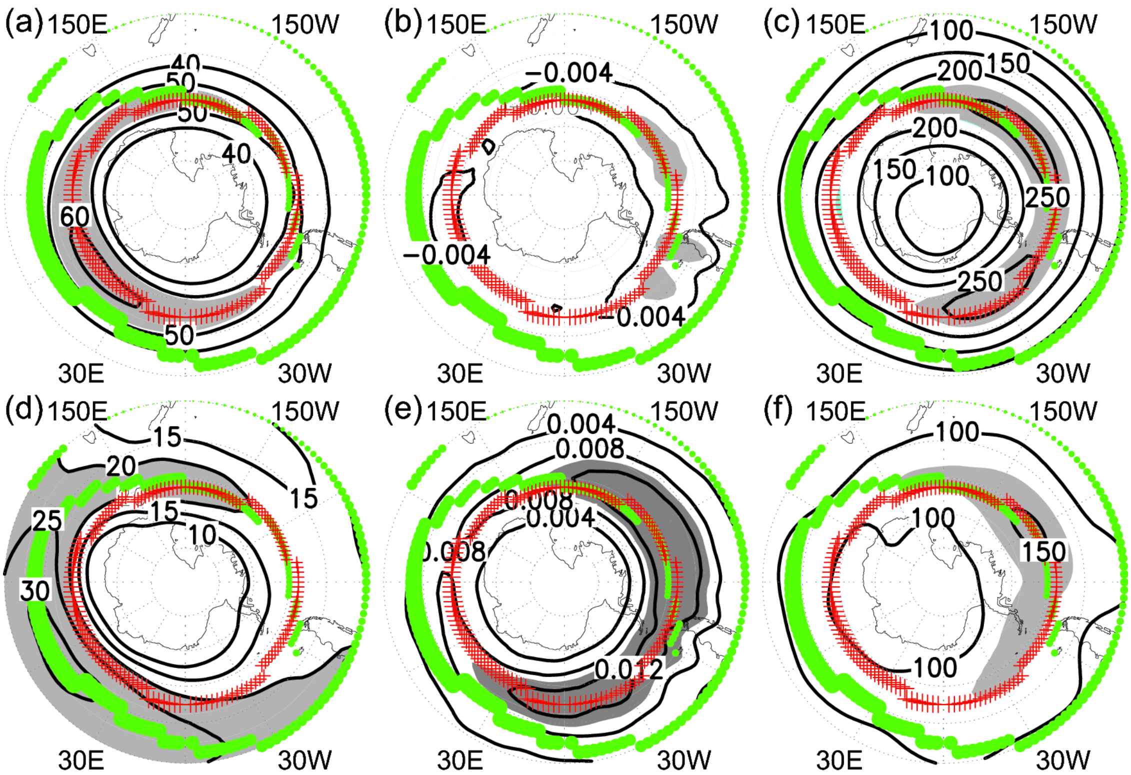
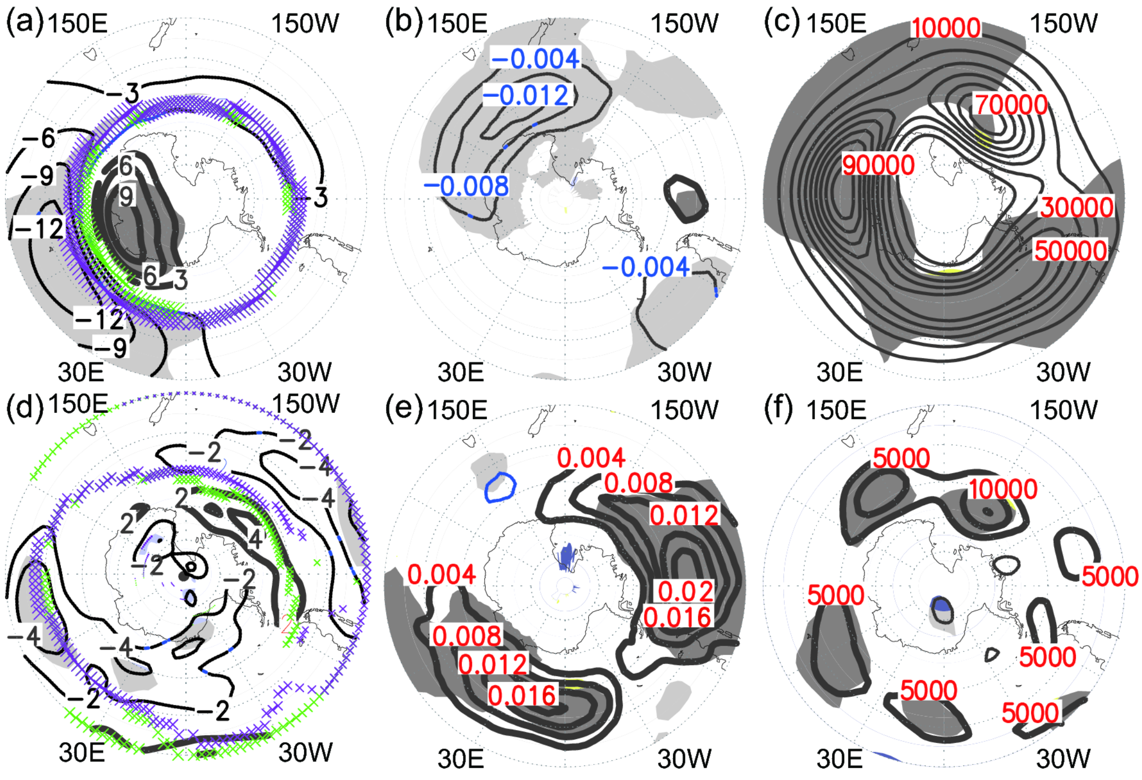


Figure 2 (a) Climatological mean of zonal wind at the 50-hPa level in August and September from 1979 to 2003 (contoured for 40, 50 and 60 m/s). Southward from 40°S is shown. Crosses and dots show axes of 50-hPa and 400-hPa westerlies jets, respectively. (b) Downward component of time-mean wave-activity flux at 100-hPa level (contoured for -0.004 m^2 s^{-2}). Shading indicates regions where the flux is less than

-0.006 [m^2 s^{-2}]. Crosses and green dots are the same as in (a). (c) Standard deviation of submonthly low-pass-filtered fluctuations in 50-hPa geopotential height (contoured for 100, 150, 200 and 250 [m]). Shading denotes regions where the standard deviation is more than 220 [m]. (d) Same as (a) but for 400-hPa level (contoured for 15, 20, 25 and 30 m/s). (e) Same as (b) but for upward component (contoured for 0.004, 0.008 and 0.0012 m^2 s^{-2}). Shading indicates regions where the flux is larger than 0.006 [m^2 s^{-2}]. (f) Same as (c) but for 400-hPa geopotential height (contoured for 100 and 150 m). Shading denotes regions where the standard deviation is more than 120 [m].

Interannual variability of the downward propagation

By taking active and inactive months of 100-hPa downward wave-activity flux over particular regions and making composite maps, we investigated interannual enhancement in local downward wave-activity injection into the troposphere from the stratosphere. To the south of Australia, enhancement of downward flux (Fig. 3b) tends to be associated with a poleward shift of the stratospheric PNJ axis upstream (Fig. 3a) and the strengthened SPJ in the troposphere underneath (Fig. 3d). These wind structure changes influence the formation of local waveguides across the tropopause through the meridional and vertical curvature changes in the time-mean flow. Downstream of enhanced regions of prominent downward wave-activity injection, tropospheric submonthly fluctuations also tends to be enhanced (Fig. 3f). Similar changes associated with enhancement of downwrad flux over the South Pacific is observed.



(a) Difference of composite map for the 50-hPa monthly-mean westerlies between active and inactive downward wave-activity propagation months to the south of Australia. Green and purple crosses denote westerly axes for the active downward months and inactive downward months, respectively. Heavy and light shading denotes the difference is positively and negatively significant at 90% level. (b) The same as in (a) but for monthly-mean downward wave-activity flux. Thick and thin line denote positive and negative, respectively (contour interval is 0.004 [m^2 s^{-2}] and a zero line is omitted).

Enhanced downward wave activity is indicated by the thin line. (c) The same as in (a) but for variance of 50-hPa anomalous geopotential height defined in each months between active and inactive downward injection months. (d) The same as in (a) but for 400-hPa level. (e) The same as in (b) but for 400-hPa level. (f) The same as in (c) but for 400-hPa level.

Influence of interannual variability associated with the SH annular mode (SAM) and El Nino/Southern Oscillation (ENSO) on downward wave-activity injection is also examined. In association with the above-mentioned wind structure changes, downward wave-activity injection does enhance significantly, but only slightly over certain regions in most cases. Their influence on the tropospheric submonthly fluctuations is also limited.

Conclusion

These results are obtained on the basis of a particular framework in which a planetary-scale wave in the lower stratosphere is considered as a zonally-confined "wave packet" propagating zonally as well as vertically on a zonally-asymmetric time-mean flow. Such a framework is rarely used in the previous studies on the stratospheric planetary-scale waves, most of which do not take propagation in the zonal direction and dependence on a zonally-asymmetric basic state of wave propagation into consideration.

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