Changes on barotropic planetary waves associated with changes in the northern hemisphere stratospheric polar vortex

J. M. Castanheira[1], M. L. R. Liberato[2], L. de la Torre[1], H.-F Graf[3] and C. C. DaCamara[4]
(1) CESAM, Department of Physics, University of Aveiro, Portugal, (2) UTAD, Department of Physics, Portugal,
(3) CAS, Department of Geography, University of Cambridge, UK, (4) CGUL, IDL, University of Lisbon, Portugal
jcast@ua.pt, mlr@utad.pt, ltr@uvigo.es, hfg21@cam.ac.uk, cdcamara@fc.ul.pt

1. The Problem

It is well known from observation and theory that the stratospheric circulation is forced by the planetary waves generated in the troposphere by the topographic and heat forcing fields.

There is an issue not yet completely understood 'Is the tropospheric wave generation sensitive to the strength of the polar stratospheric vortex?'

2. Data and Method

Data were obtained from the NCEP/NCAR reanalysis dataset. November to April daily means of the horizontal wind components (u, v) and of the geopotential height, available at 17 standard pressure levels from 1000 to 10 hPa, with a horizontal grid resolution of 2.5º lat 2.5º long, covering the period 1959-2006, were used.

The data were projected onto the normal modes of an atmosphere at rest (see details in *Liberato et al.*, JAS, 2007).

$$\begin{bmatrix} u \\ v \\ \phi \end{bmatrix} = \sum_{m=0}^{\infty}\sum_{s=-\infty}^{\infty}\sum_{l=0}^{\infty}\sum_{\alpha=1}^{3} w_{msl}^{\alpha}(t)G_m(p)\exp(is\lambda)C_m \cdot \begin{bmatrix} U(\theta) \\ iV(\theta) \\ Z(\theta) \end{bmatrix}$$

where, $G_m(p)$ are the vertical structure functions and $(U,\ iV,\ Z)^T$ are the Hough vectors.

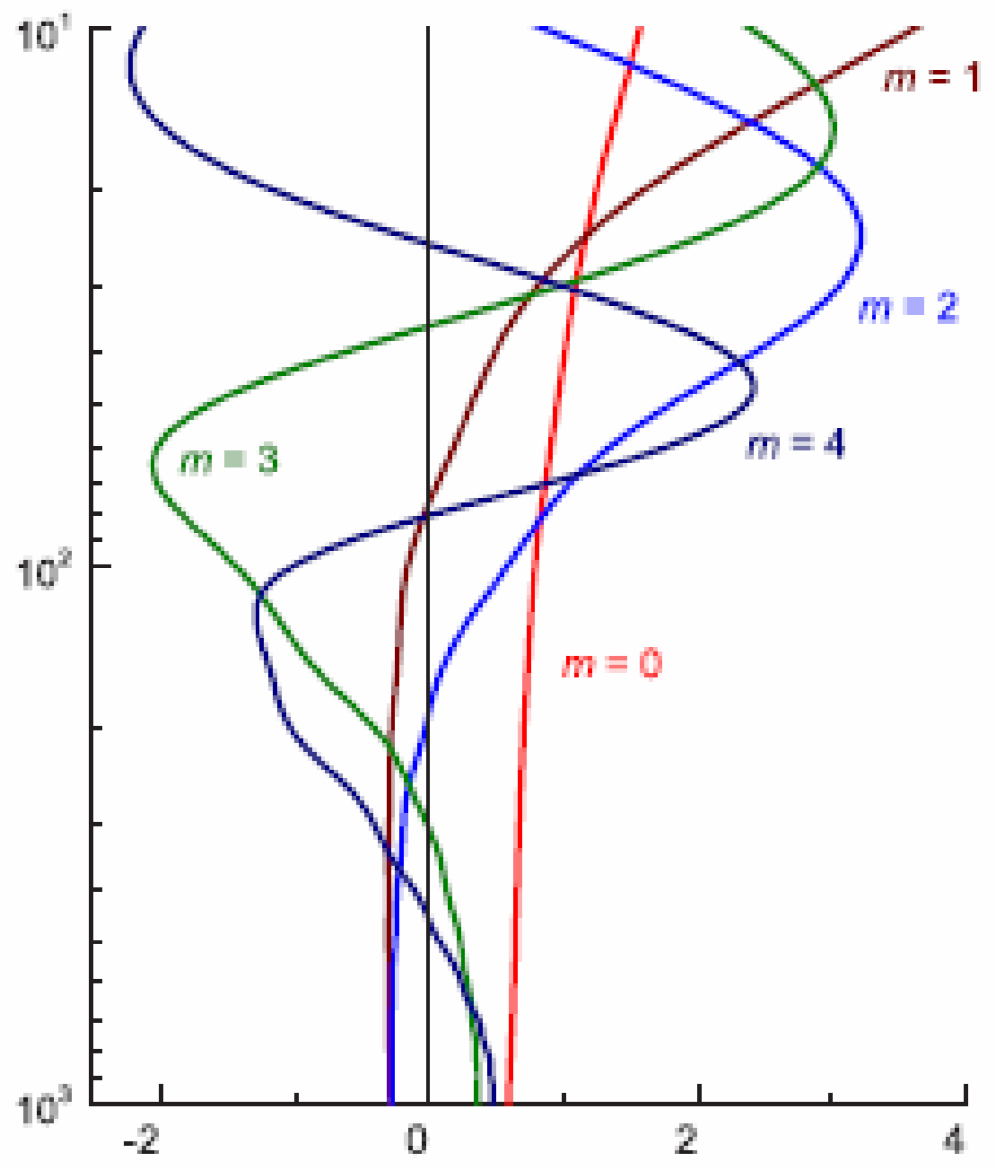

Figure 1: The first five vertical structures of the normal modes of the NCEP atmosphere are shown.

The energy associated with each wave is given by

$$E_{msl}^{\alpha}(t) = \frac{p_s h}{c_s}\left|w_{msl}^{\alpha}(t)\right|^2$$

where w is the complex wave amplitude, p_s is a constant near surface pressure and h is the equivalent height. Here only the energy of planetary Rossby (α = 2) is analyzed.

3. Results

3.1 Forcing of vortex variability

Periods of strong vortex accelerations and strong vortex decelerations are identified computing the slope of a 15-day running mean of the 50-hPa NAM index. The accelerations and the decelerations periods are grouped according to the initial and final vortex strengths. For each group, the composites of the energy anomalies associated with the baroclinic (m=1, 2, 3, 4, 5) planetary waves were computed.

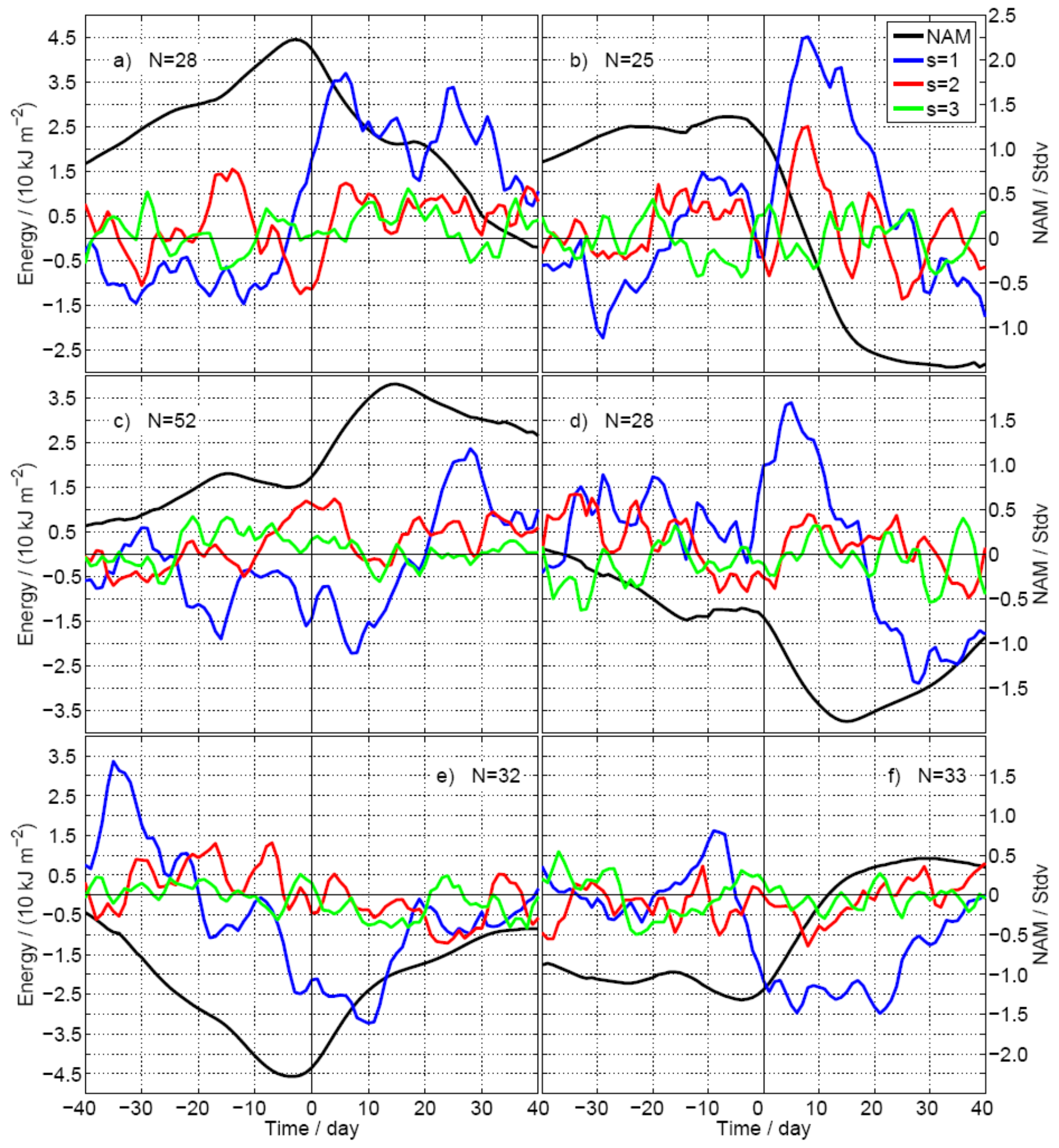

Figure 2: Composites of the energy anomalies associated with baroclinic (m=1,2,3,4,5) planetary Rossby waves with wave numbers s =1,2,3. Black curves show the composites of smoothed NAM at 50 hPa. Day zero refers to the beginning of the acceleration or deceleration periods. The values of N are the numbers of events of each type.

It is quite evident the strong energy peaks associated with wave number s=1, during rapid vortex decelerations. During vortex acceleration, negative energy anomalies associated with wave number s=1 are observed.

3.2 Sensitivity of barotropic planetary waves to the vortex strength

Strong (SVR) and weak (WVR) vortex regimes were identified, considering the periods when the 11-day running average of the vortex strength was one standard deviation above or below the seasonal cycle, respectively. The vortex anomalies must remain 15 days at least.

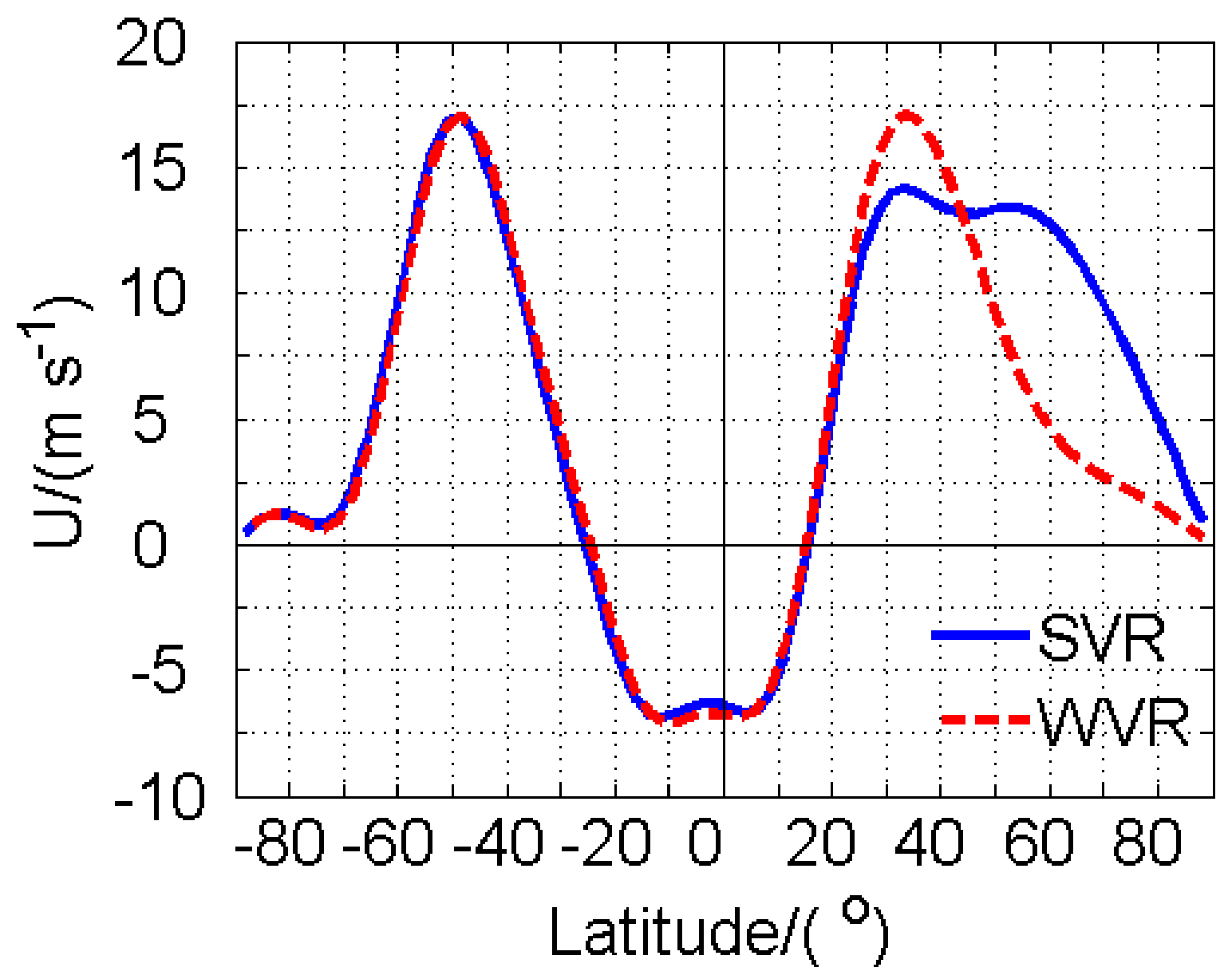

Figure 3: Zonal mean zonal wind component associated with the barotropic vertical structure (m=0). The projection onto the barotropic structure was normalized to correspond to the vertical average weighted by $G_0(p)$.

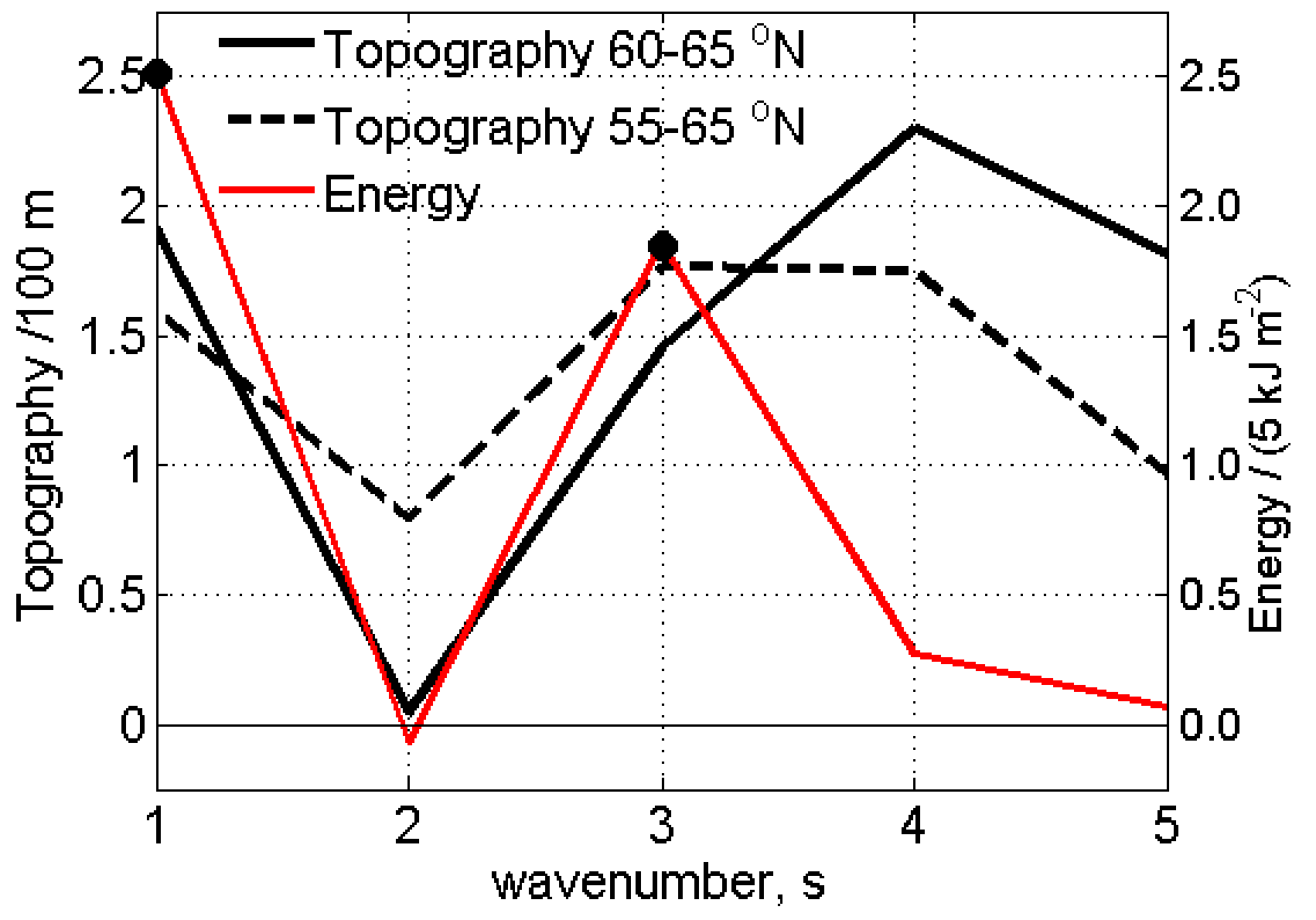

Figure 4: Composite spectra of the energy anomalies associated with barotropic (m=0) planetary Rossby waves. The red curve represents the differences between the means of the energy anomalies during SVR and WVR (SVR minus WVR).
The solid and dashed black curves represent the Fourier components of the mean topography in the latitude bands 55 – 65º N and 60 – 65º N. The dots indicate energy differences which are statistically significant at the 99% level.

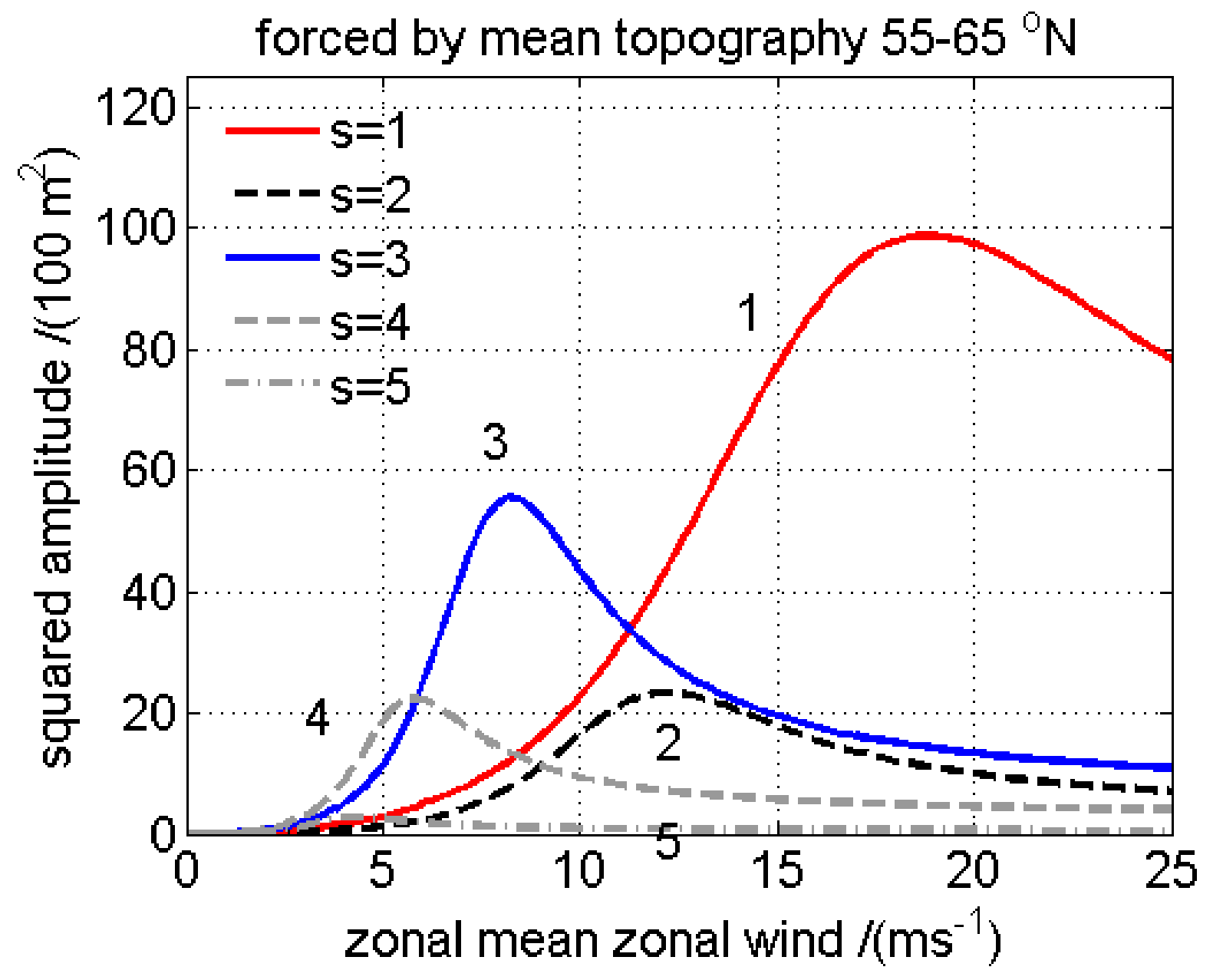

Figure 5: Squared wave amplitude calculated using the topographic Rossby wave model of Charney and Eliassen. The model was forced by the mean topography in the 55 – 65º N channel, and the model parameters are the same as those used by Charney and Eliassen.

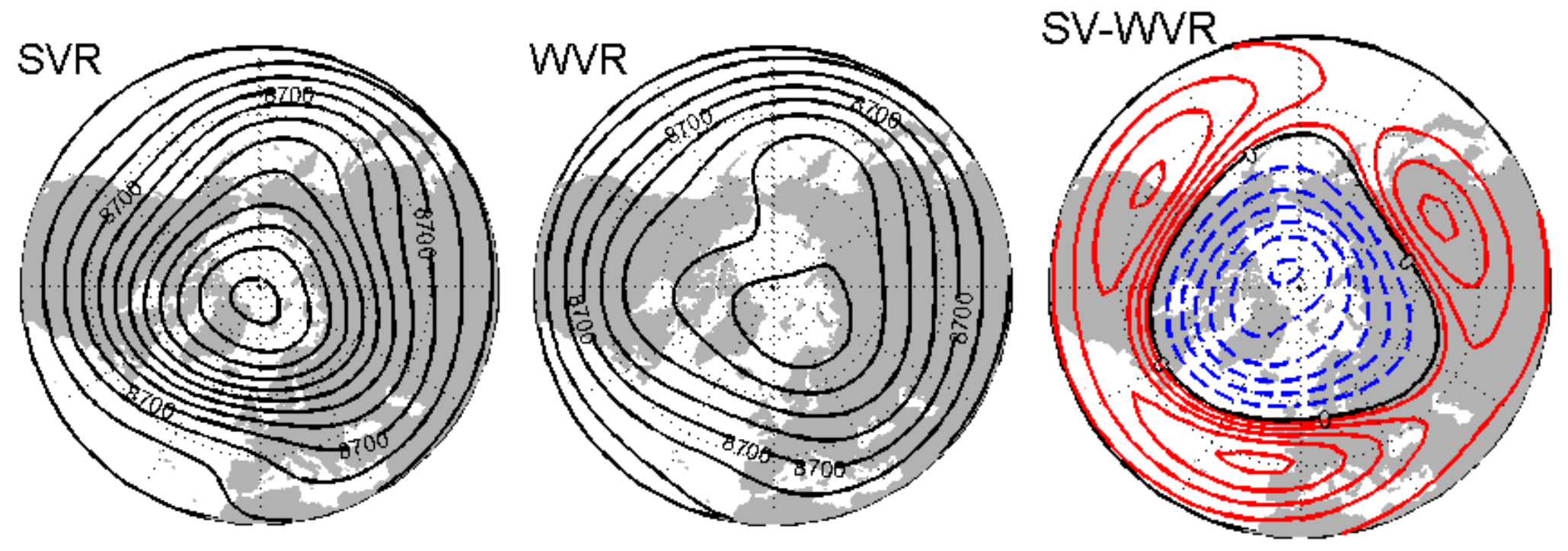

Figure 6: Composites of geopotential fields of barotropic waves (s = 0,1,3) during strong vortex regime (SVR), weak vortex regime (WVR) and their difference (SV-WVR). Contour interval is 75 gpm in SVR and WVR patterns. For the difference pattern, contour intervals are 15 gpm (starting at 10 gpm) for the positive contours, and 50 gpm for the negative contours.

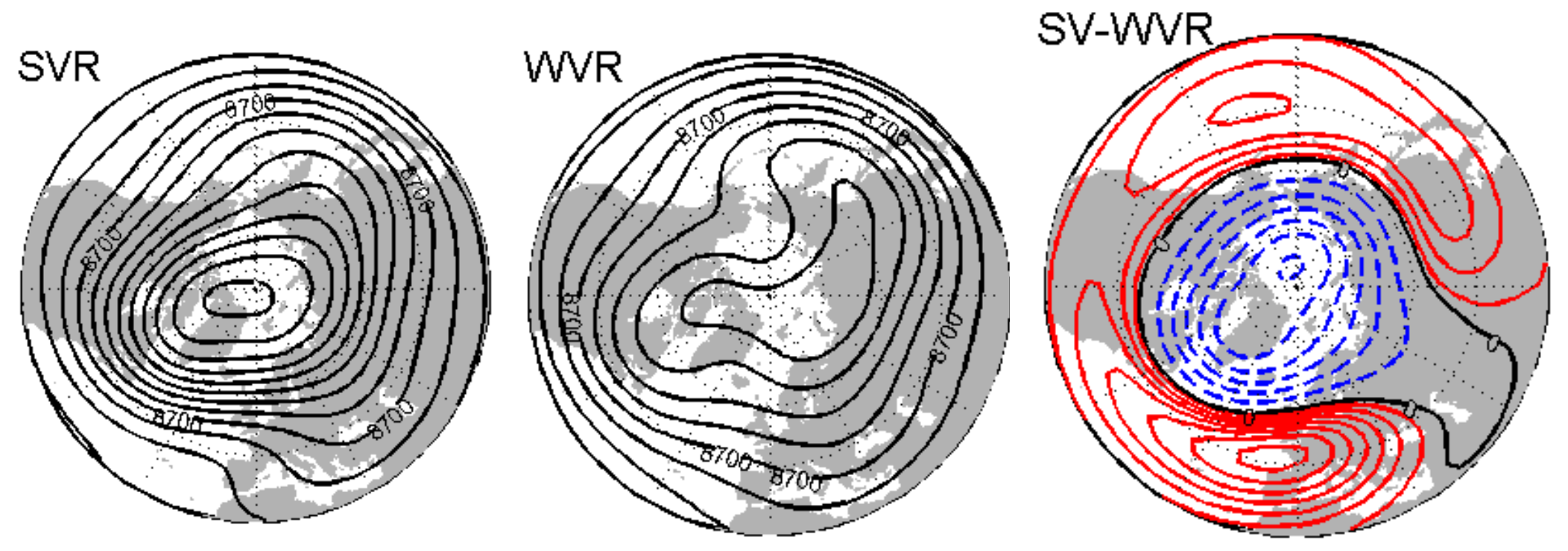

Figure 7: As in Figure 6 but for wave numbers (s=0,1,2,3,4).

4. Conclusions

- Decelerations (accelerations) of vortex strength are associated with positive (negative) energy anomalies of planetary baroclinic waves.
- The planetary barotropic waves of wave numbers s=1 and s=3 are sensitive to the vortex strength. Results suggest that this sensitivity is mediated by the topographic forcing.
- The SVR – WVR composite difference of the geopotential fields of barotropic waves (s = 0,1,3) show high zonal symmetry at high latitude. At midlatitudes it is dominated by a wavy structure with a meridional dipole over the Atlantic basin remembering the NAO.