Baroclinic Life-Cycles from GPS Radio-Occultation Measurements

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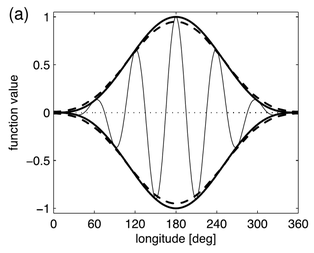
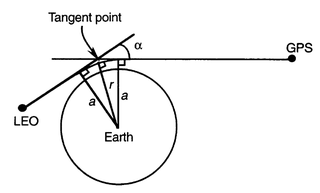
1) Motivation

- Rossby wave packets (RWPs) are sub-planetary and transient undulations of mid-latitude zonal flow. Organized succession of troughs-ridges.
- Tropospheric phenomenon with important role of tropopause (TP) dynamics
- **There are no observational studies about the fine-scale structures of RWPs across the UTLS. Data for this only available recently (GPS-RO)**
- **Atmospheric models lack vertical resolution around UTLS**
- **Little research about stratospheric signals related to RWPs**
- **Implications for predictability, as forecast errors grow together with RWPs envelopes!**



Wolf and Wirth (2015): idealized representation of a zonally-constrained wave packed (thin line) and its envelope (thick line).

2) Data and Methods



Kursinski et al. (1996): sketch of the GPS radio occultation measurement technique.

Data:

- Temperature and pressure profiles from GPS-RO missions: CHAMP, COSMIC, GRACE, Metop-A, Metop-B, SAC-C, TerraSAR-X ('wetPrf' product). ~2500 profiles/day globally on a 100 m vertical grid. 2007-2016
- GPS-RO gridded on 5° by 5° longitude-latitude grid following Pilch Kedzierski et al. (2017)
- ERA-Interim winds

Method to detect RWPs:

- Filter the gridded GPS-RO with a 2-D Fast Fourier Transform. Wavenumbers 4-10 separately (periods 2-20 days). **See section 3**
- Reconstruct the RWP envelope (zonally constrain filtered signals) with novel technique **See section 4**

3) Carrier Wave Activity

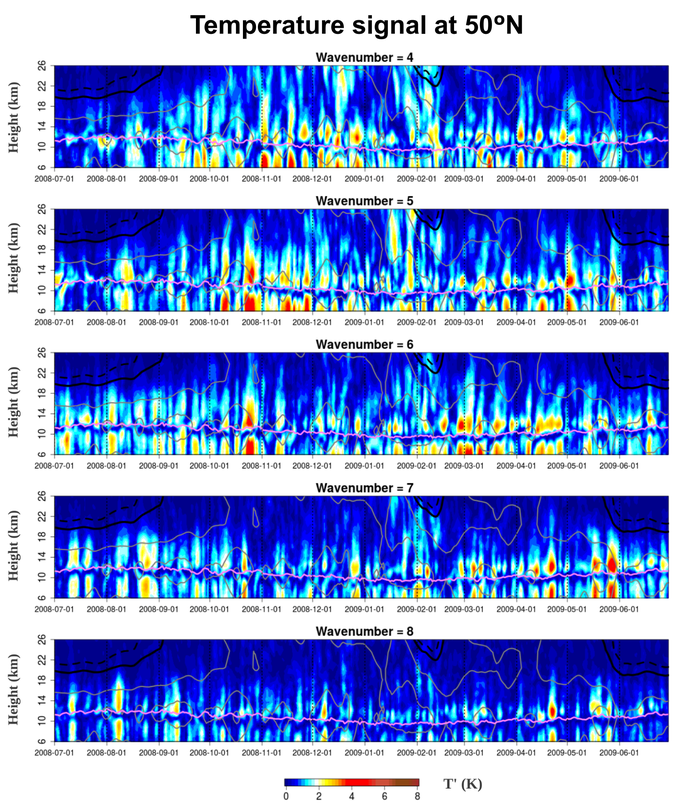


Fig. 1: Time-height sections of wave activity in terms of temperature. Magenta line denotes the zonal-mean tropopause height. Grey solid lines denote westerly zonal winds, with 10 ms^{-1} separation. Thick black solid and dashed lines denote 0 ms^{-1} and -3 ms^{-1}, respectively.

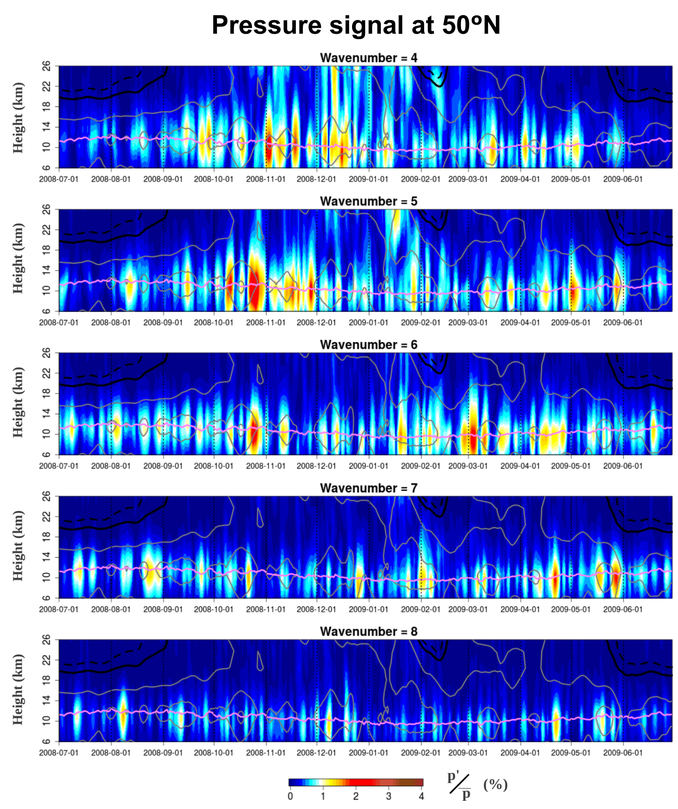


Fig. 2: Same as Fig.1 but for pressure wave anomalies, relative to the mean pressure of each vertical level.

Temperature signal (Fig. 1):

- Temperature signal maximizes above TP
- Co-amplification of LS and UT temperature signals across TP: time evolution nearly identical

Pressure signal (Fig. 2):

- Pressure signal (≈ geostrophic) maximizes at TP, weakens upward and downward
- **Signals extend up to 20km height!**

Global statistics

- Co-amplification maximizes in mid-latitudes and for intermediate wavenumbers (Fig. 3b)
- Wave activity too, with tendency for longer wavenumbers at higher latitudes: maintains horizontal scale of wave packets (Fig. 3a)

- All agrees very well with previous literature and theory about scale and structure of RWPs (e.g., Hoskins et al., 1985; Andrews et al., 1987)
- **LS temperature signal new!**

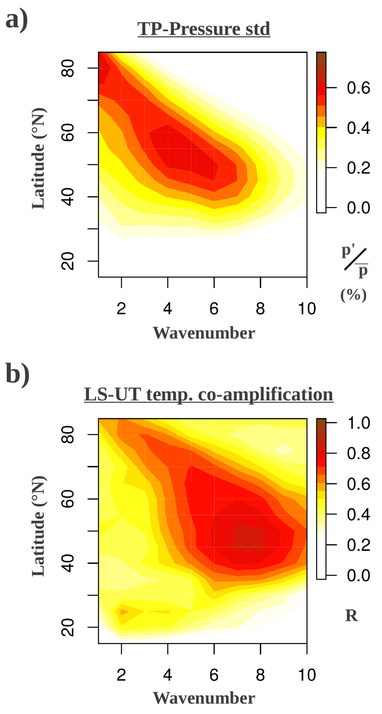


Fig. 3: (a) Wave activity spectrum, as standard deviation of pressure anomalies at the zonal-mean tropopause level. (b) Co-amplification of the LS and UT temperature signals, calculated as the correlation of their amplitude time-series.

4) Wave Packet Envelope Reconstruction

Local phase regression to define the envelope:

- **1)** At every longitude: one phase of filtered wave is fitted to observations (taking out offset and slope): regression coefficient R^2 and amplitude define the envelope's shape. This avoids distortion by long waves (e.g., presence of wavenumbers 1 or 2 with superposed RWP)
- **2)** Scaling: variances of filtered carrier wave and obtained RWP have to be equal (see Fig. 5). This avoids artifacts from stationary components or from coefficients.

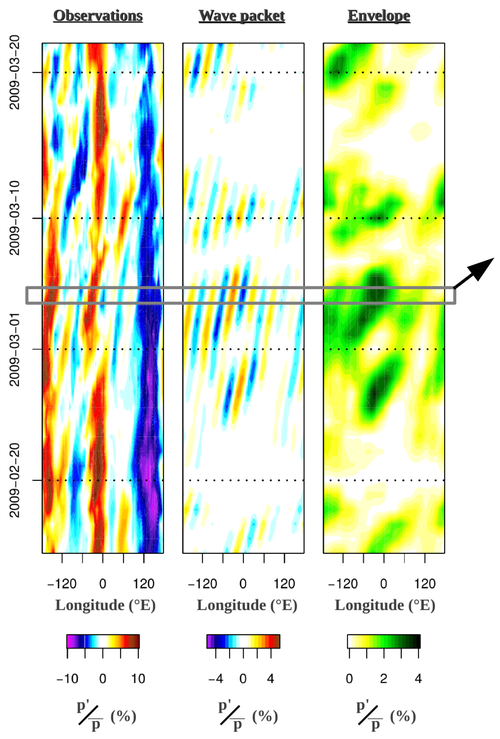


Fig. 4: Comparison of observed pressure anomalies, the filtered and zonally constrained wave packets, and the reconstructed envelope at 10 km height and 50°N for a selected case with carrier wavenumber 6.

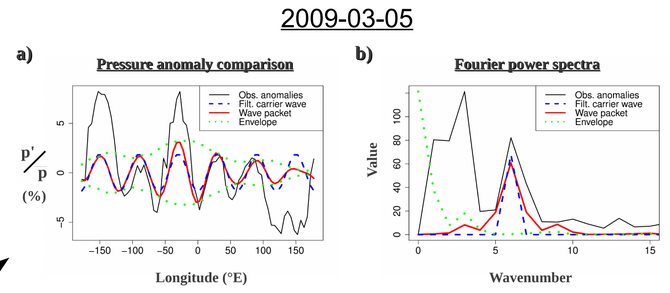


Fig. 5: (a) Comparison of observed pressure anomalies, the filtered and zonally constrained wave packet, and the reconstructed envelope at 10 km height and 50°N on 2009-03-05 from Fig. 4. (b) Their corresponding Fourier spectra.

Key results

- Coherent RWP structures, phase and group propagation (Fig. 4)
- Envelopes easy to track

- Obtained RWP very similar to idealized representations, its Fourier spectrum as well (Fig. 5)
- No distortion by stationary signals
- No small scale structures (higher harmonics) in envelope
- **Similar results compared to Complex Demodulation (Lee and Held, 1993)**

5) Structure and 3D-Evolution

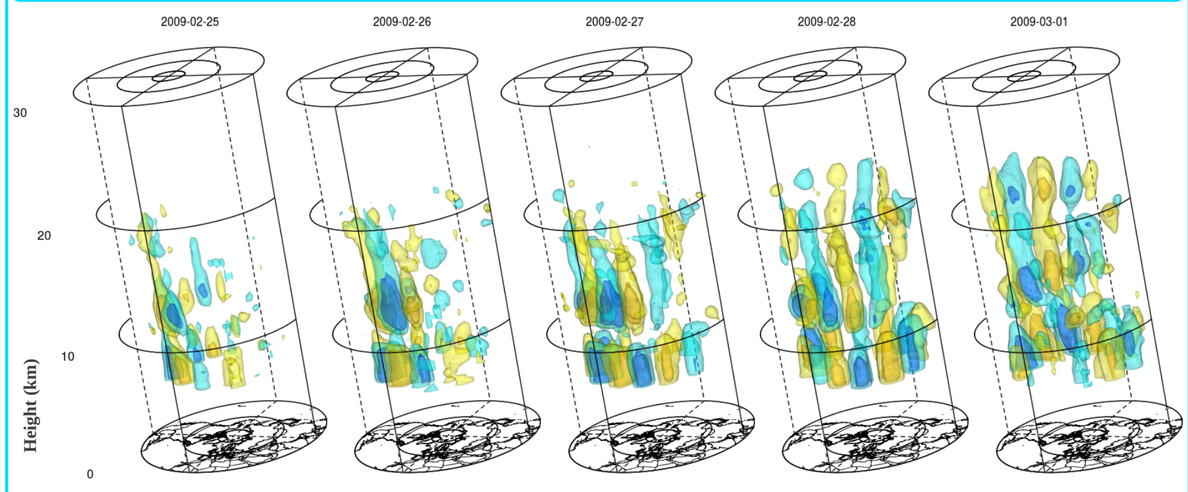


Fig. 6: Evolution of the 3D temperature structure of a wave packet with carrier wavenumber 6, for selected dates from Fig. 4. Blue surfaces represent temperature anomalies of -1.5°C and -3°C while yellow surfaces are +1.5°C and +3°C.

- Downstream development and amplitude growth of the RWP over the North Atlantic (25, 26, 27 Feb. 2018)
- Mature stage (28 Feb.) and dissipation (1 Mar.) near Europe
  Meanwhile another RWP forms over the Pacific Ocean

- **Note opposite phases of tropospheric and LS temperature signals at all times!**
- Temperature signal maximizes above TP
- No signal around TP

- Structure can be explained by advection and meridional temperature gradients (which change sign across TP), **but not the amplified LS temperature signal** → Vertical motion? Diabatic processes (radiation, clouds)?

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Role of Atmospheric Dynamics for Climate Variability and Change (Theme 3.8)

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