Dynamical Studies of the Stratosphere with VORCORE SPBs

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References

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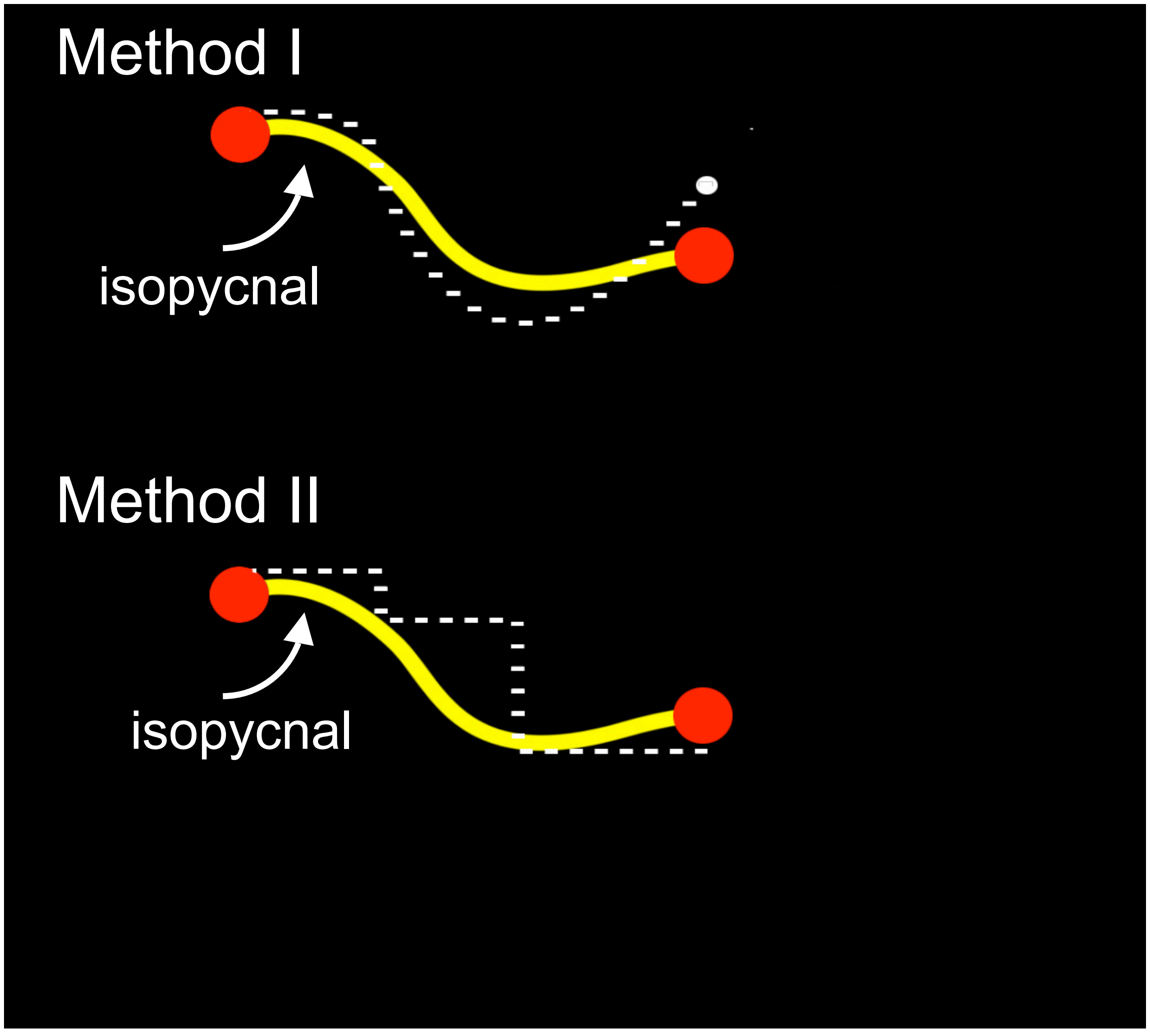
Simulated Trajectories by a Model of the Middle Atmosphere



UKMO Stratosphere-Mesosphere Model (SMM) with geopotential height prescribed at the lower boundary set at 100 hPa

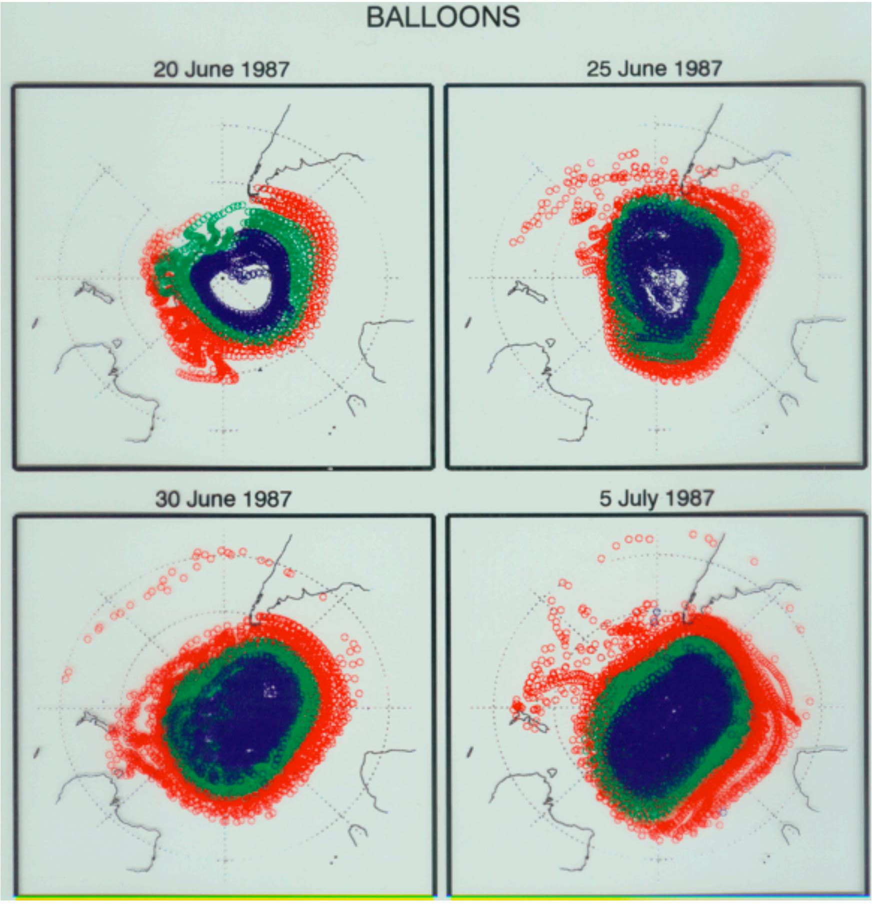
Options: On-line* / Off-line**

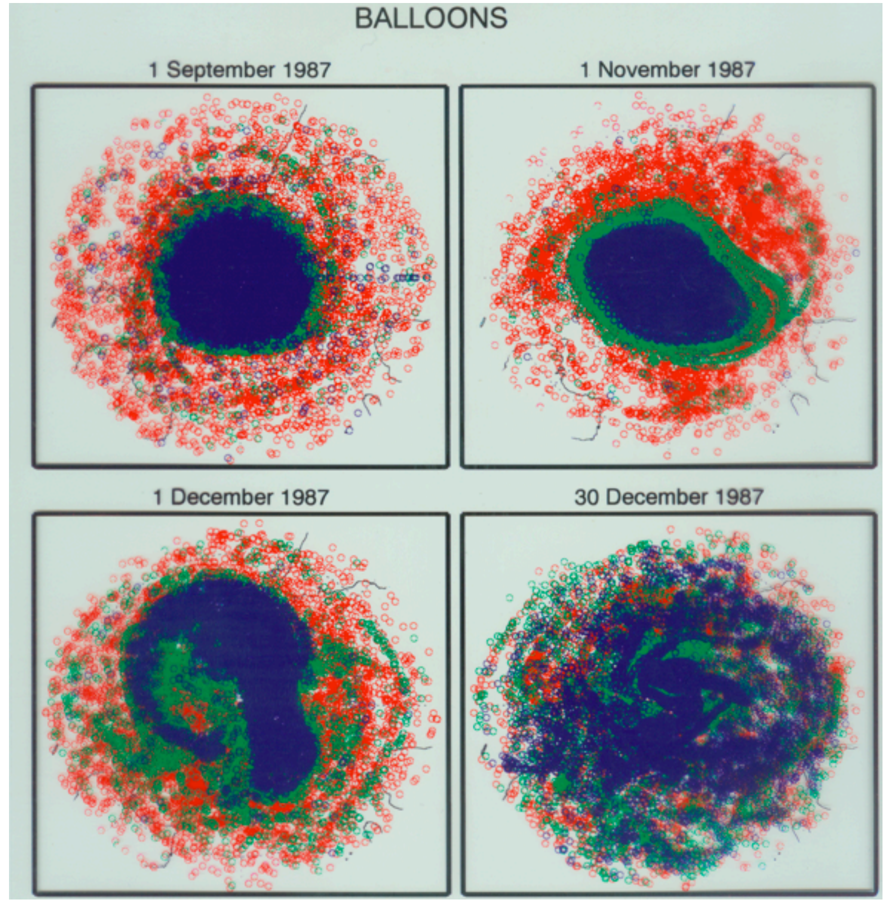
* Data available every 20 minutes

** Data available every 24 hours

Trounday et al. *JGR* 1995

Simulated Trajectories and Dispersion Laws





Dispersion Law		Length Scale (km)	Time Scale (days)
$\langle D^2 \rangle = ke^{lt}$	$k = 687,\ l=0.035$	90-150	1.5-4
$\langle D^2 \rangle = ht^3$	$h = 6.45\ 10^{-3}$	180-640	7-18
$\langle D^2 \rangle = Ft$	$F = 1.68$	700-1200	20-40

Pre-VORCORE Campaigns

3 technological campaigns aimed at preparing the Vorcore campaign:

- Ecuador 1998: 3 LD flights (21, 47, 24 days)
- Kiruna 2001: 3 LD flights (24, 70(?), 19 days)
- Kiruna 2002: 6 LD flights (11, 29, 14, 8, 11, 43 days)

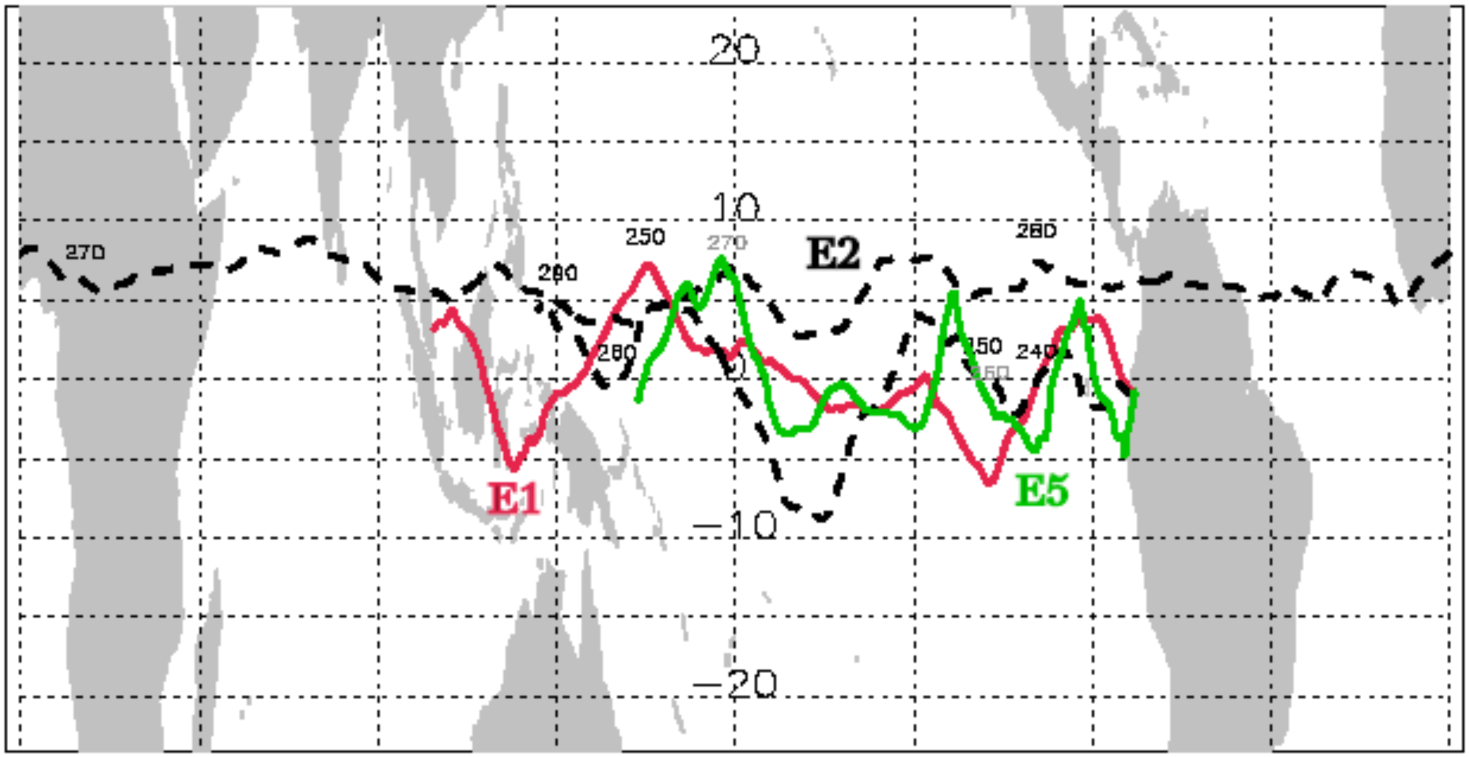
with meteorological gondolas:

- temperature, pressure, wind
- 12/15 minutes

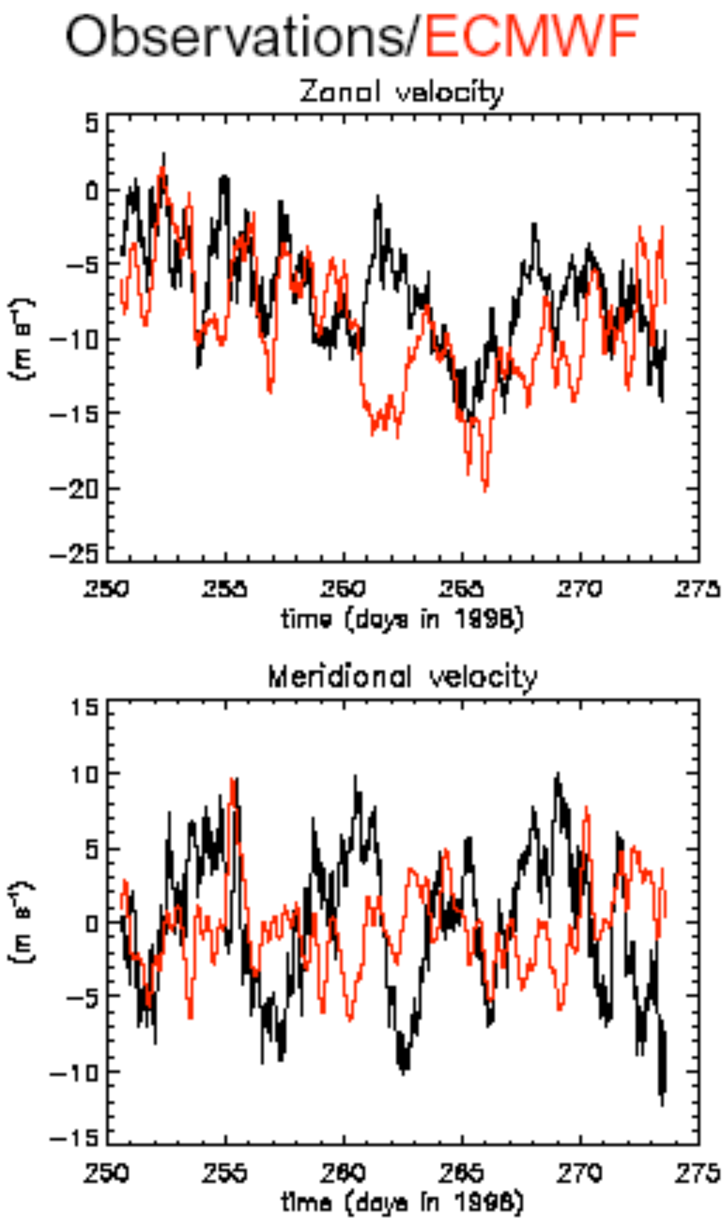
Vial et al. *JGR* 2001

Trajectories of SPBs in the Ecuador Campaign

(Labels indicate days in 1998)



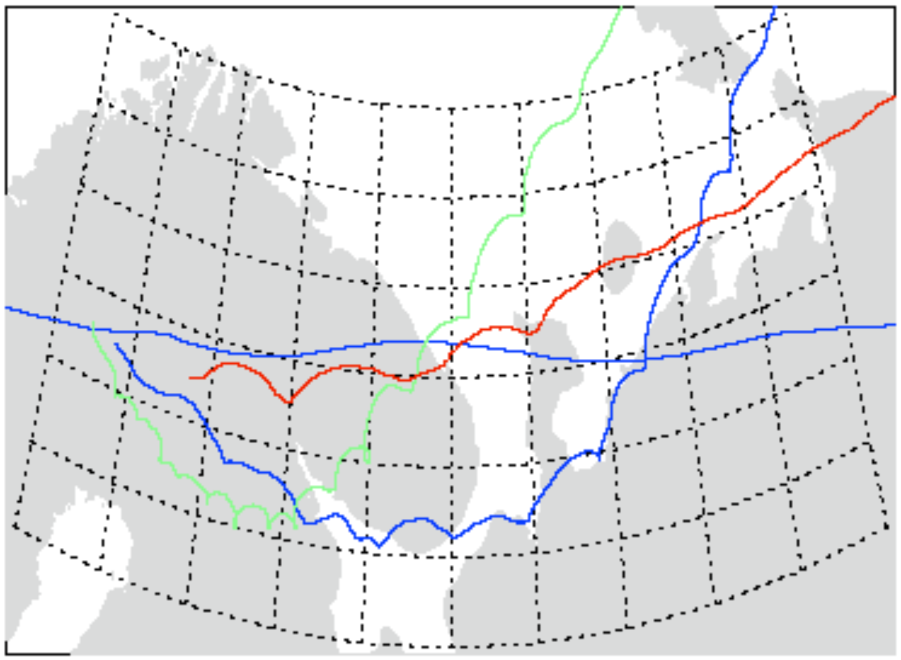
Behaviors can be interpreted as the zonal-mean flow and a mixed Rossby-gravity (Yanai) wave with an apparent period of about four days and zonal wavenumber 4. There is also evidence of a Kelvin wave with an apparent period of about 10 days and zonal wavenumber 1.

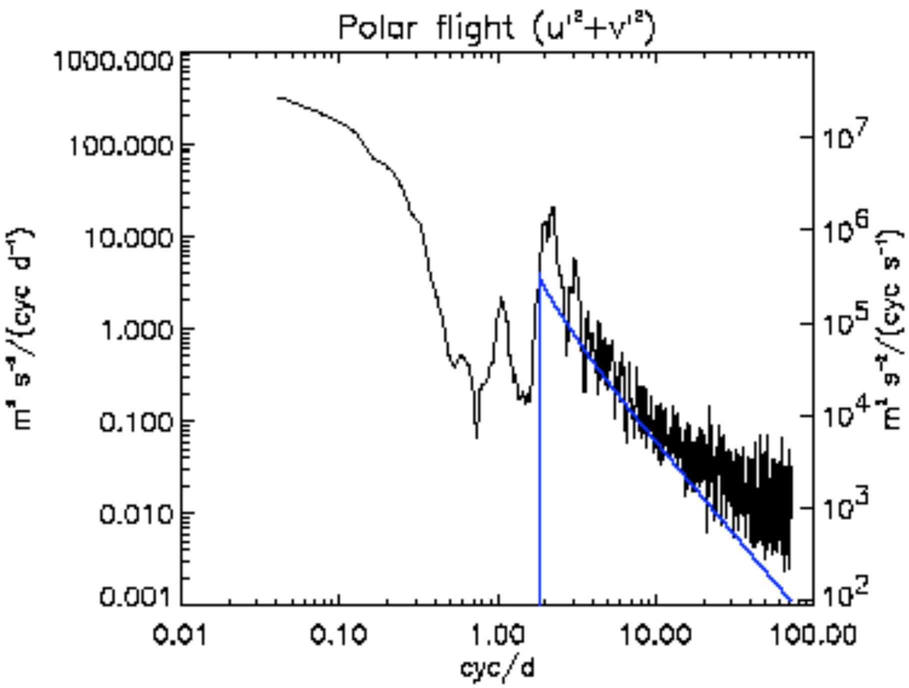


Large differences were found between instantaneous SPB velocities and those in the ECMWF analysis for the corresponding flight periods.

Trajectories of SPBs in the Kiruna Campaign

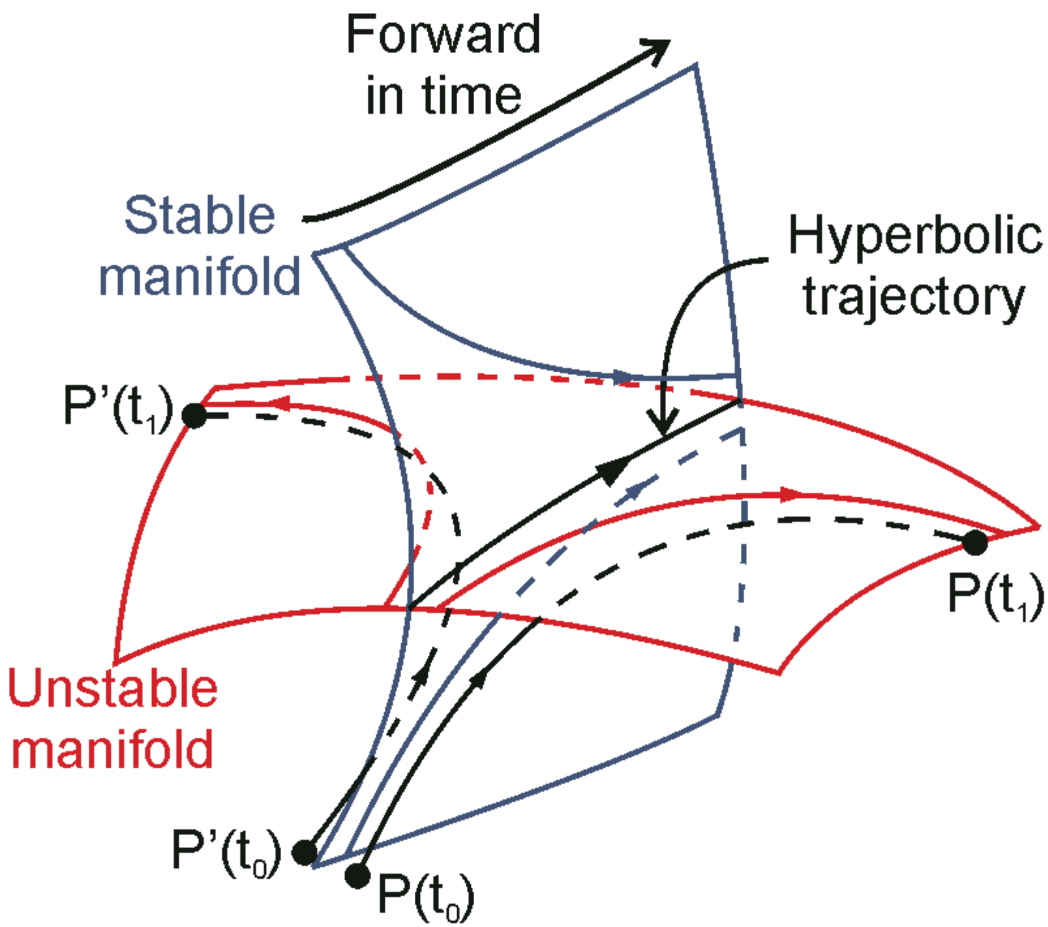
Zoom on the Kiruna campaign trajectories over northern Scandanavia and northwestern Russia





Kiruna SPBs spectra show a peak at periods close to 1 day. No comparable peak was found in the Ecuador SPBs.

Hertzog et al. *GRL* 2002



Behaviour of the hyperbolic trajectory and the trajectories on and near the stable and unstable manifolds.

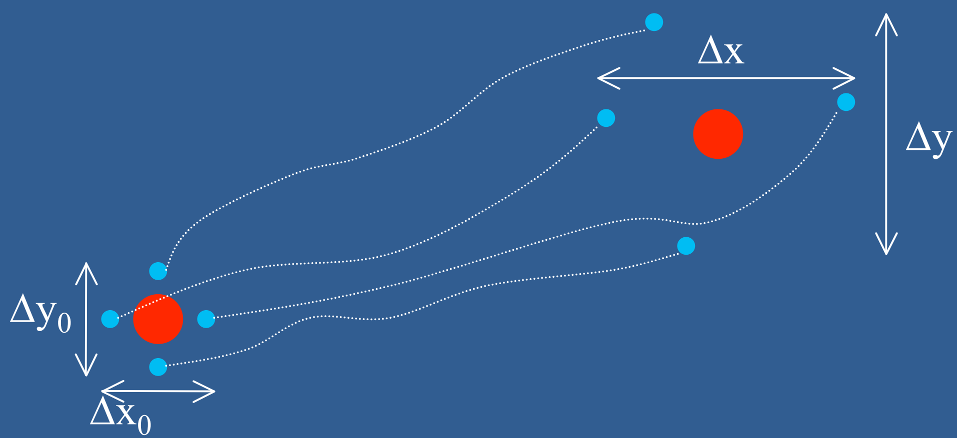
Two trajectories starting from nearby initial conditions across the stable manifolds will diverge after a sufficient time period.

De la Camara et al. *Clim. Dyn.* 2009

Finite – Time Lyapunov Exponents (FTLE)

FTLE are used to identify areas with maximum expansion rates

between fluid particles initially close to each other.



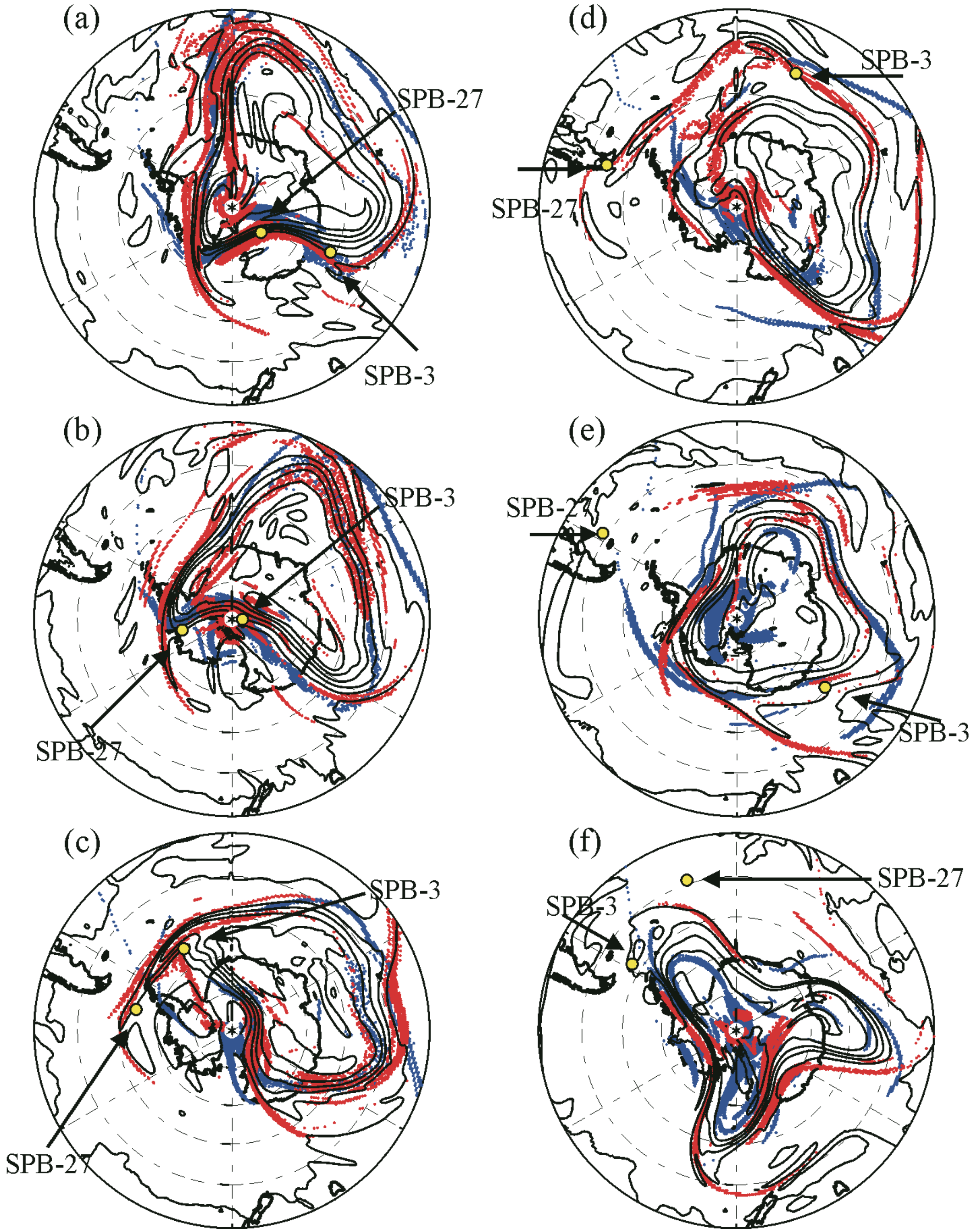
$$G = \begin{bmatrix} \frac{\Delta x}{\Delta x_0} & \frac{\Delta x}{\Delta y_0} \\ \frac{\Delta y}{\Delta x_0} & \frac{\Delta y}{\Delta y_0} \end{bmatrix}$$

Maximum eigenvalue of G*G

$$LE = \frac{1}{\Delta t} \ln\left(\sqrt{\lambda_{max}}\right)$$

Each particle is advected, forward and backward in time, during 4 days (Δt = 4days) with a 2nd-order Runge-Kutta-Hein algorithm integrating horizontal velocity field data at 2 different isopycnic levels (GEOS-5 reanalysis with VORCORE balloons).

Time step = 3h



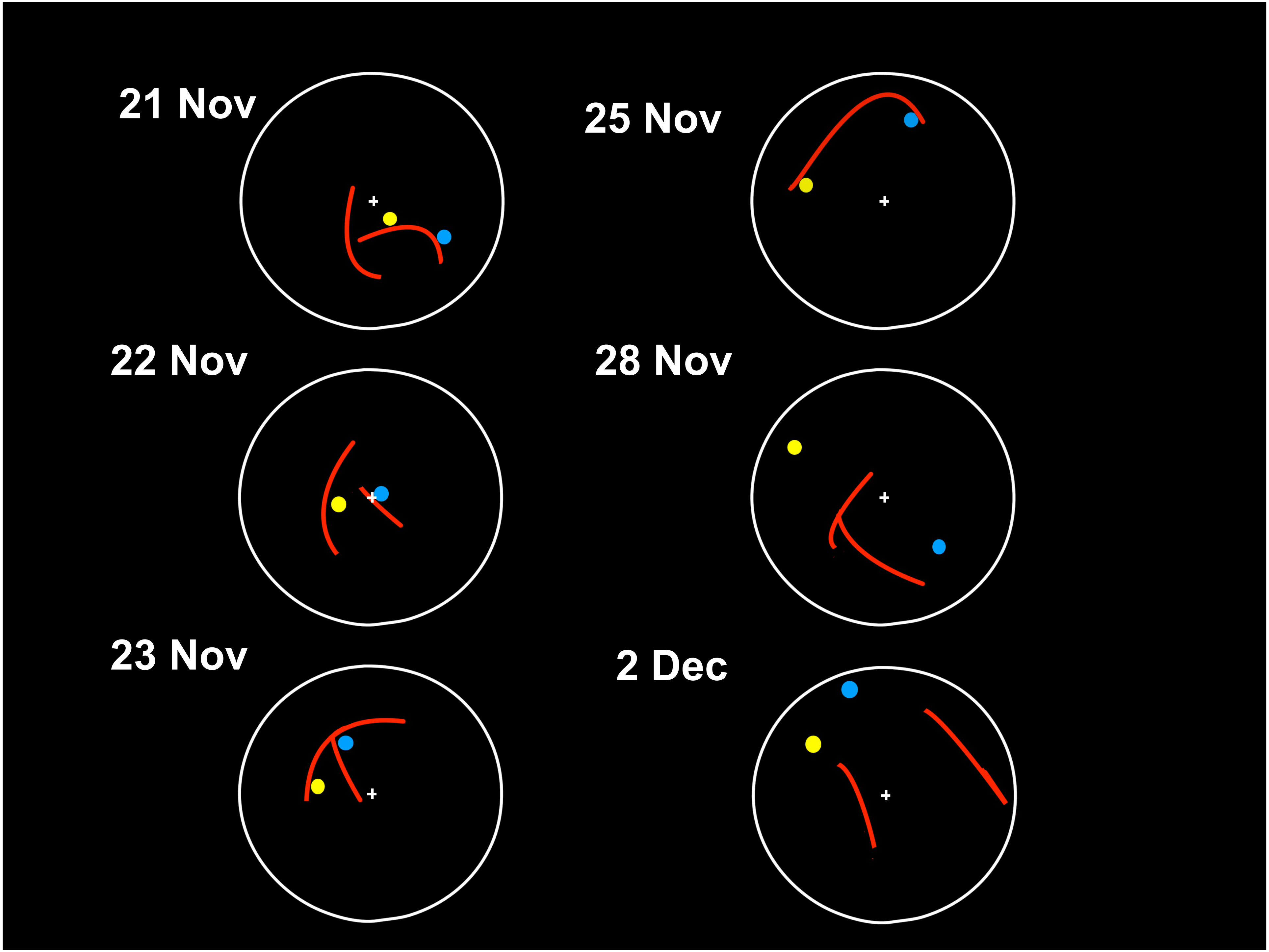
Contours: Potential Vorticity maps on the isopycnic level ρ = 0.0916 kg m-3.

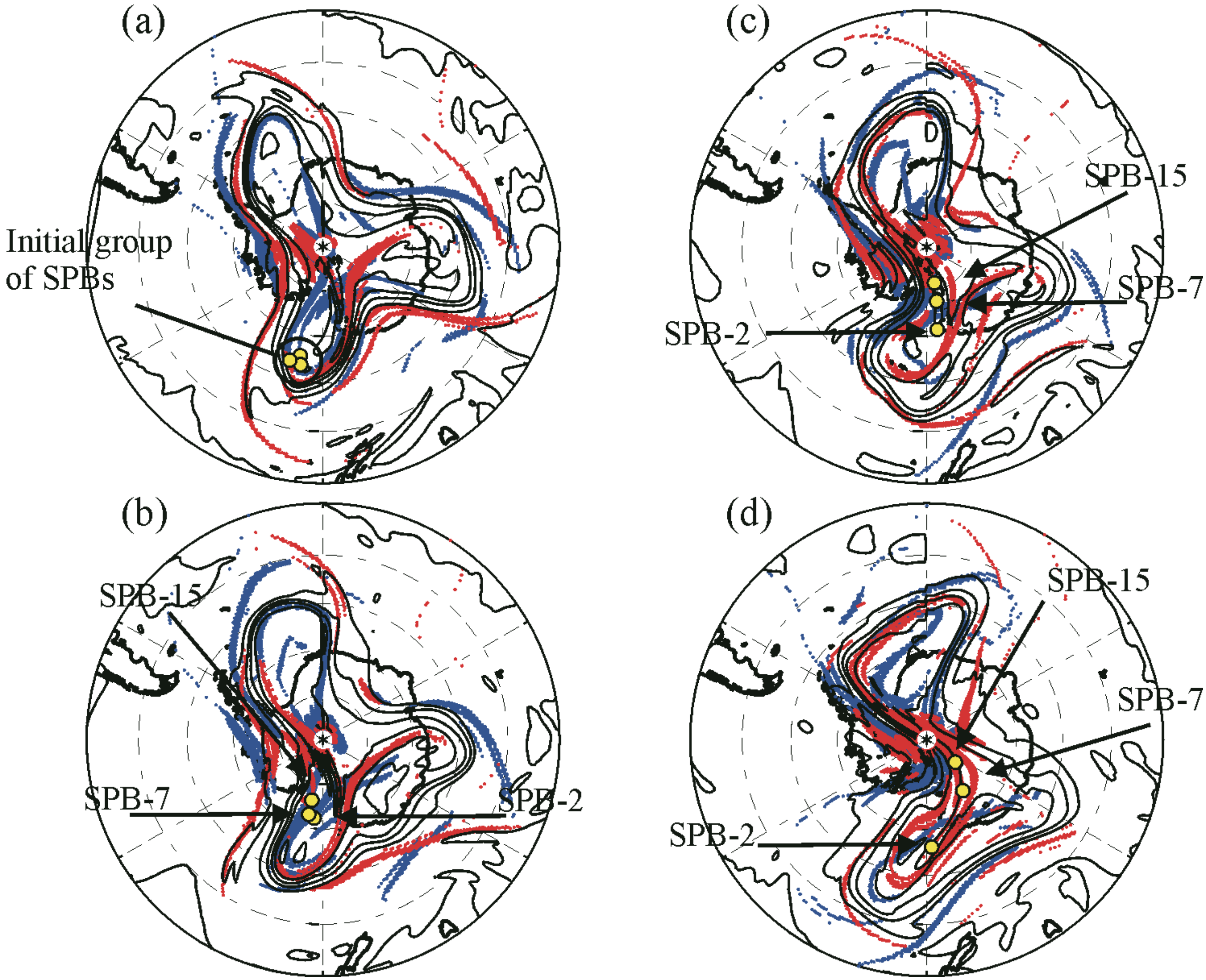
Contour interval 8 PVU (1 PVU = 10-6 m2 s-1 kg-1 K).
Shaded Central initial location of set of particles with FTLE values above 0.033 h-1 for the forward (blue) and backward (red) integrations at the same isopycnic level.

Yellow dots

Location of SPB-3 and SPB-27

(a) 21 November at 06 UTC,
(b) 22 November at 06 UTC,
(c) 23 November at 18 UTC,
(d) 25 November at 18 UTC,
(e) 28 November at 09 UTC,
(f) 2 December at 00 UTC


21 Nov
25 Nov
22 Nov
28 Nov
23 Nov
2 Dec



Location of SPB2, SPB7 and SPB15. (a) 3 Dec at 00 UTC, (b) 4 Dec at 00 UTC, (c) 5 Dec at 00 UTC, and (d) 6 Dec at 00 UTC.

Wave Fluxes in Geometric Coordinates

- The problem is to infer the wave fluxes in geometric coordinates using data on isopycnal surfaces
- Wave fluxes have two contributions
  - *Flux through constant density surfaces*
  - *Flux induced by mean flow over constant density surfaces*
- Need to infer vertical velocity in geometric height coordinates associated with each

$$\hat{w}' = \hat{w}'_{\varphi} + \bar{H}w'$$

Flux induced by mean flow over wave-deformed surfaces

Flux through constant density surfaces

$$\hat{w}'_{\phi} = \left[\frac{\partial}{\partial t} + \bar{u}\frac{\partial}{\partial x}\right]\frac{\phi'}{g} = i\omega_I \frac{\phi'}{g}$$

$$w' = -i\omega_I \frac{g\bar{H}}{\bar{S}} \frac{p'}{\bar{p}}$$

Momentum Flux Relations

$$\overline{\hat{w}'u'} = -i\omega_I \bar{H}\overline{\left(\frac{\varphi'}{g\bar{H}} - \frac{g\bar{H}}{\bar{S}}\frac{p'}{\bar{p}}\right)u'}$$

$$\overline{\hat{w}'v'} = -i\omega_I \bar{H}\overline{\left(\frac{\varphi'}{g\bar{H}} - \frac{g\bar{H}}{\bar{S}}\frac{p'}{\bar{p}}\right)v'}$$

The values of φ', p', u' *and* v' are provided by the SPBs

- Wavelet analysis of wave power versus time and intrinsic frequency
- For selected frequency bands
  - Reconstructed velocity, pressure and contour height
  - Derived vertical velocity fluctuations
  - Vertical momentum flux

Methodology for computing GW momentum fluxes

<u>*Boccara et al. (2008), Hertzog et al. (2008)*</u>

- **Bandwidth: 1 – 24hr**
- **Calculations in wavelet space (rotations to orient the x-axis along the wavenumber vector)**
- **Identification of gravity wave packets**

$$\Re(w' u_{\parallel}'^{*}) = -\frac{\hat{\omega}}{\bar{\rho} H N^2} \Im(p_l' u_{\parallel}'^{*})$$

<u>*This work*</u>

- **Bandwidth: 1 – 12hr**
- **Use of the wavelet analysis to bandpass the data**
- **Flux relations applied in wavelet space**

$$\overline{\hat{w}'\vec{v}'} = -i\omega_I \bar{H} \overline{\left(\frac{\varphi'}{g\bar{H}} - \frac{g\bar{H}}{\bar{S}} \frac{p'}{\bar{p}} \right) \vec{v}'}$$

$$\overline{\hat{w}' u'} = -\omega_I \frac{g\bar{H}^2}{\bar{p}\bar{S}} \overline{p' u'^{*}} \quad if \quad u' \sim e^{i(kx - \omega t)}$$

Hertzog et al. (JAS, 2008)

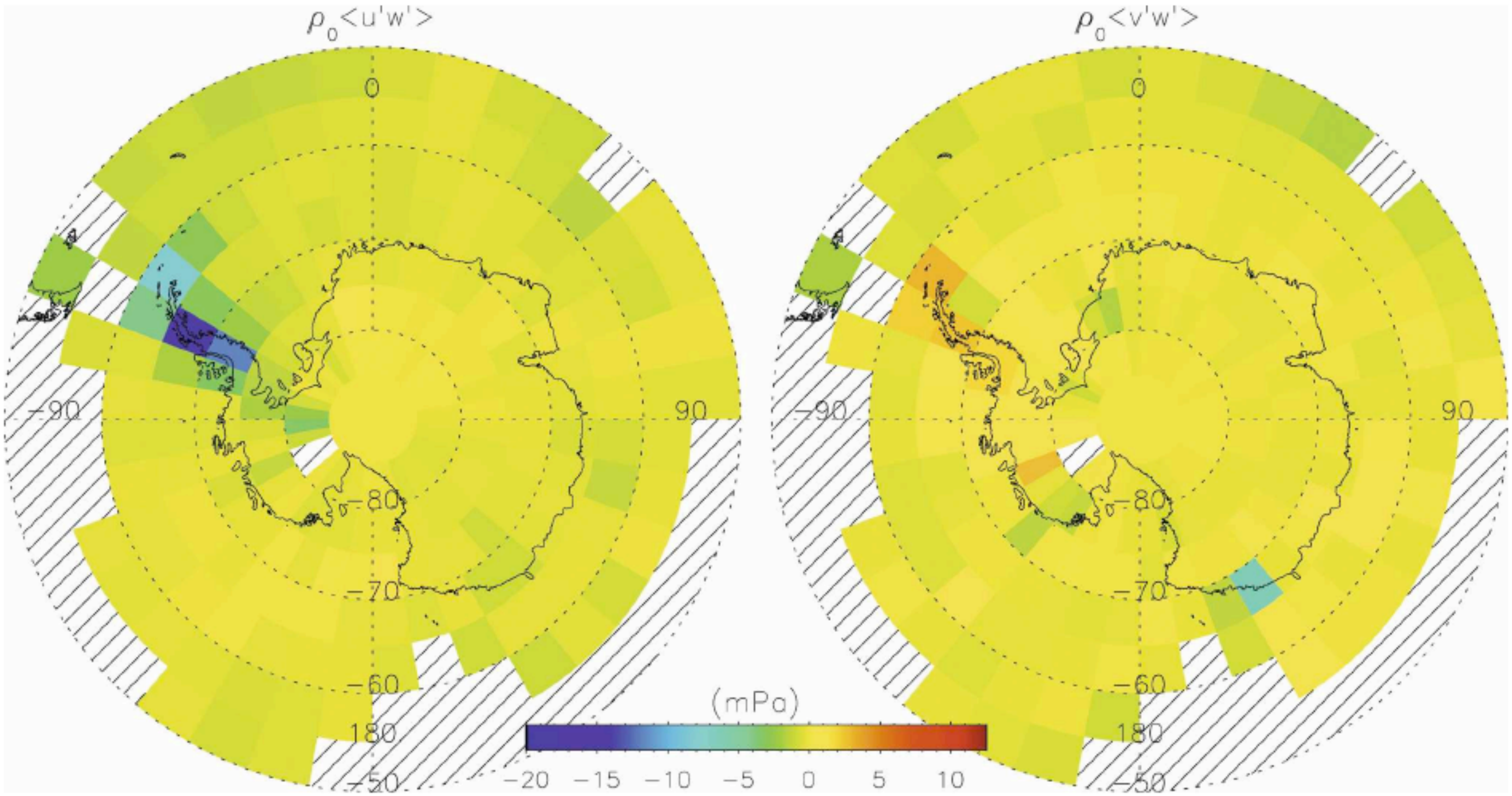
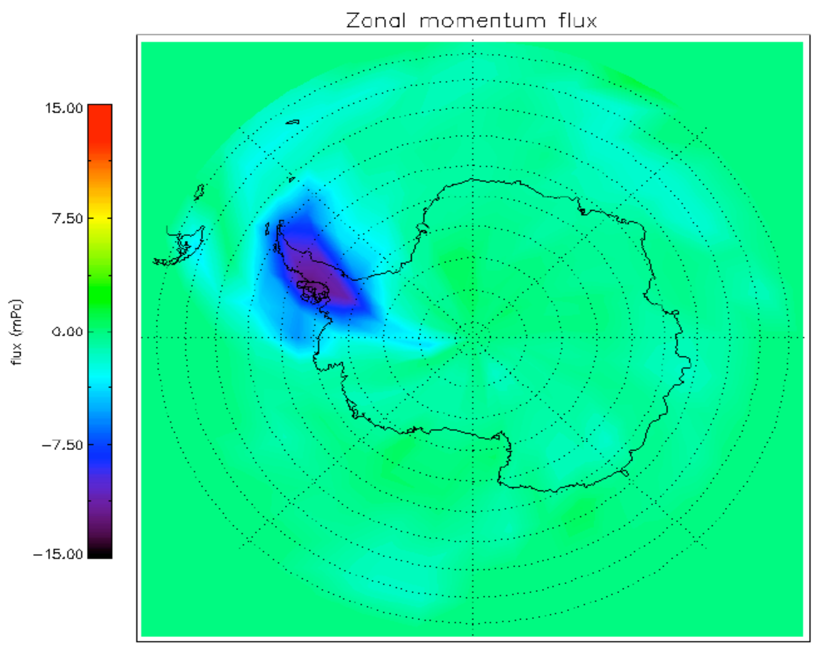


FIG. 4. As in Fig. 3 but for (left) zonal and (right) meridional momentum flux.



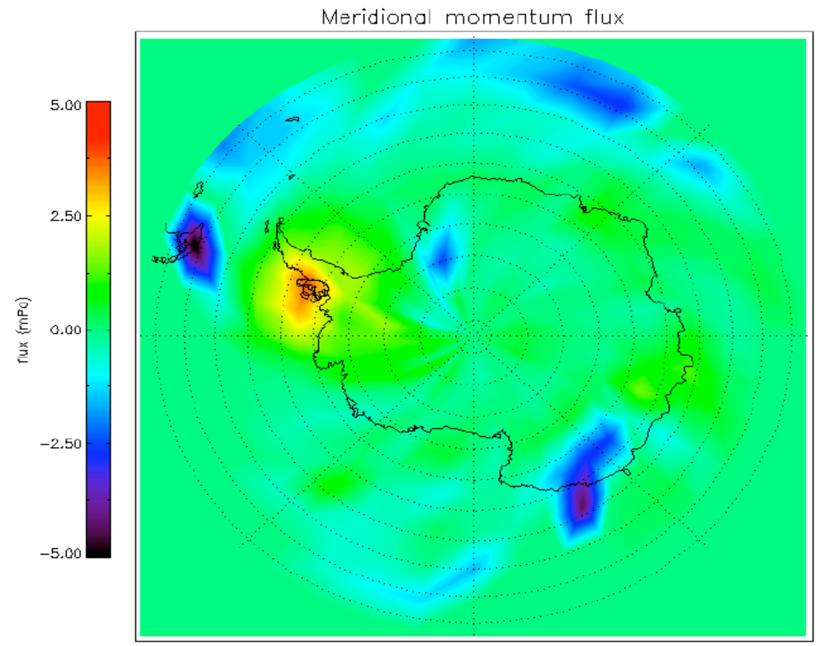
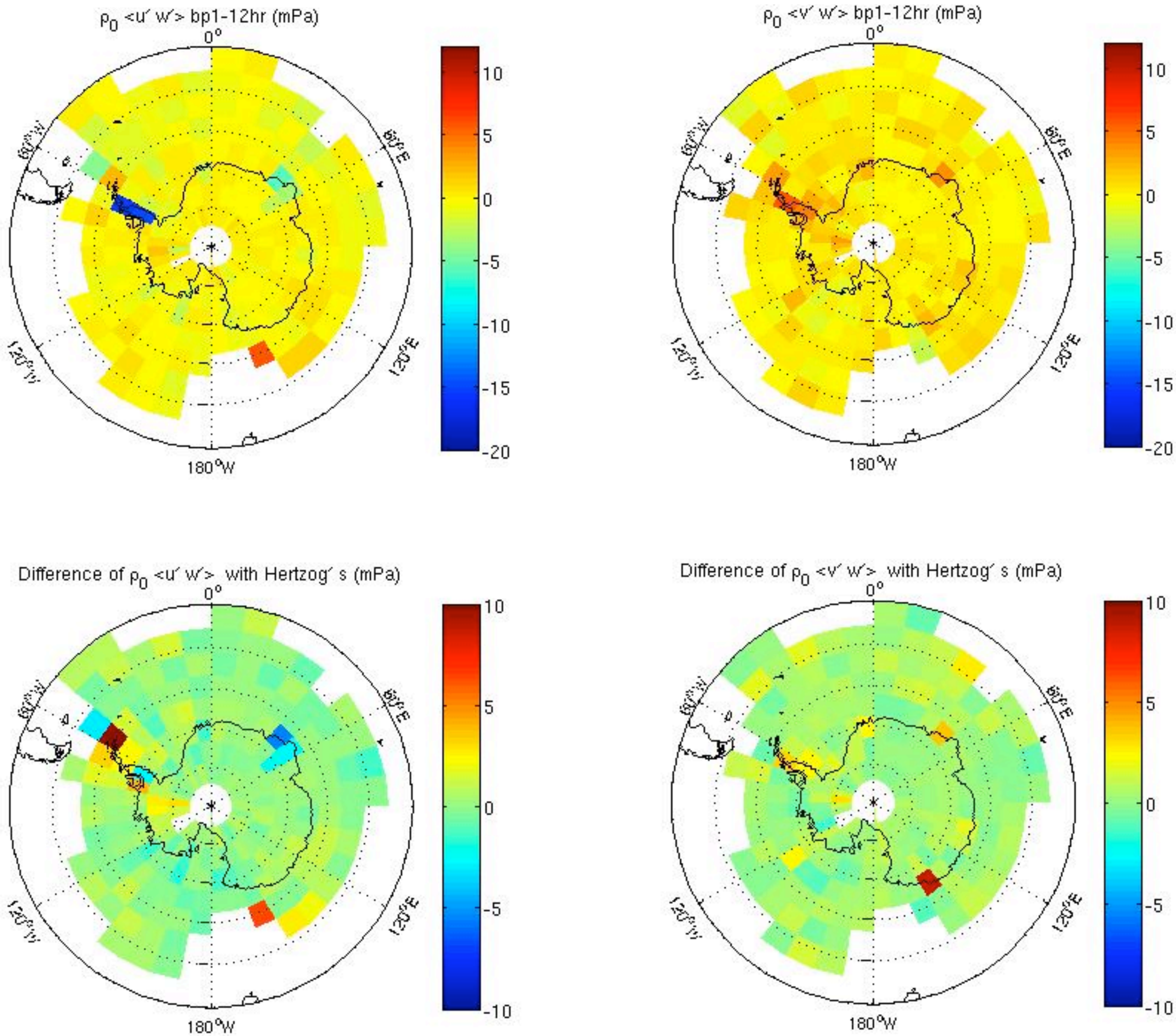


Figure 1. Wavelet-space calculation of zonal momentum flux, 1-12 hour bandpass.

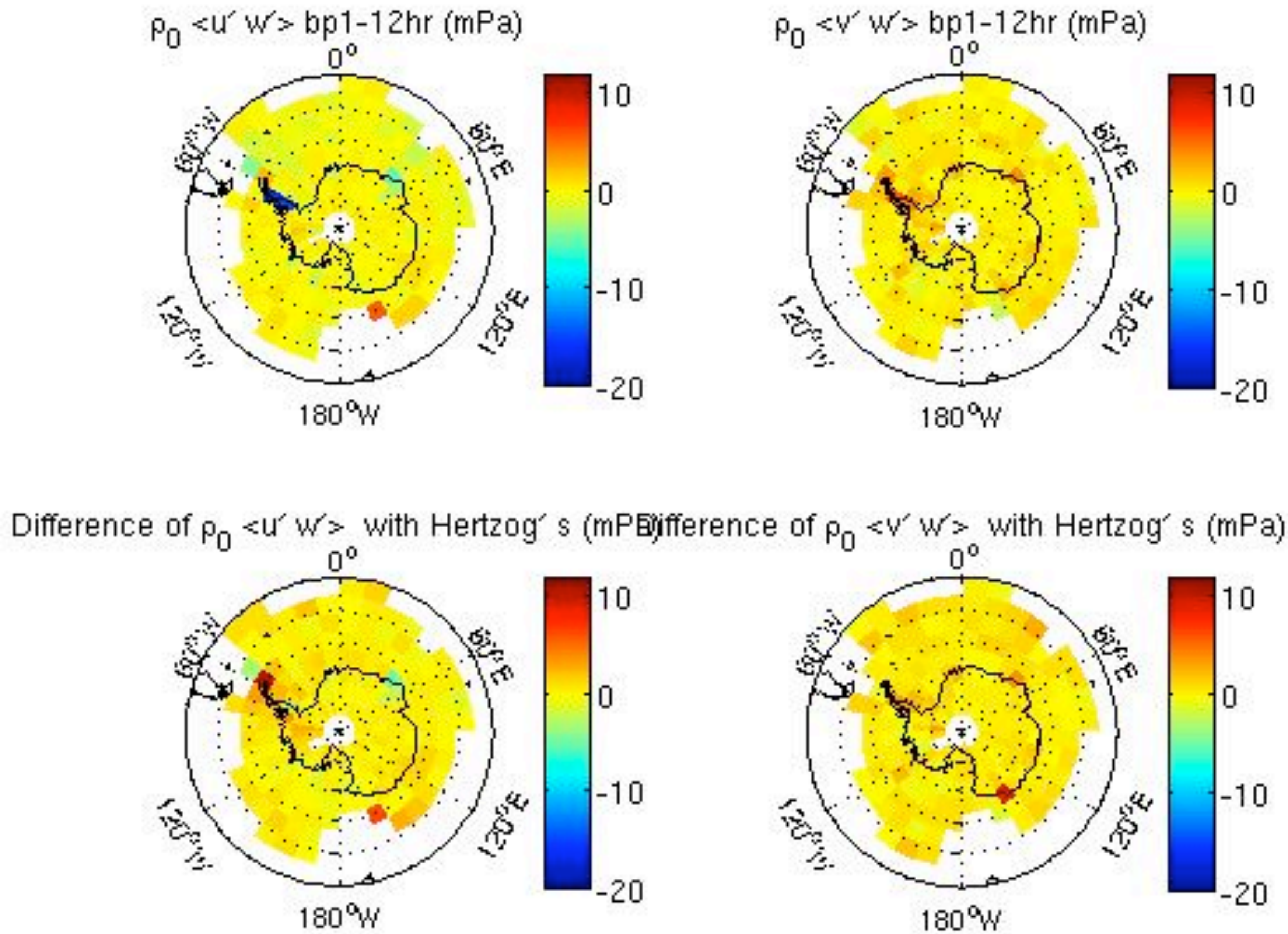
Figure 2. Wavelet-space calculation of meridional momentum flux, 1-12 hour bandpass.

$$\overline{\hat{w}'\vec{v}'} = \overline{\sum_w -\frac{d\varphi_w}{dt}\vec{v}_w^* + i\omega_w \frac{g\overline{H}^2}{\overline{S}} \frac{p_w}{\overline{p}} \vec{v}_w^*}$$

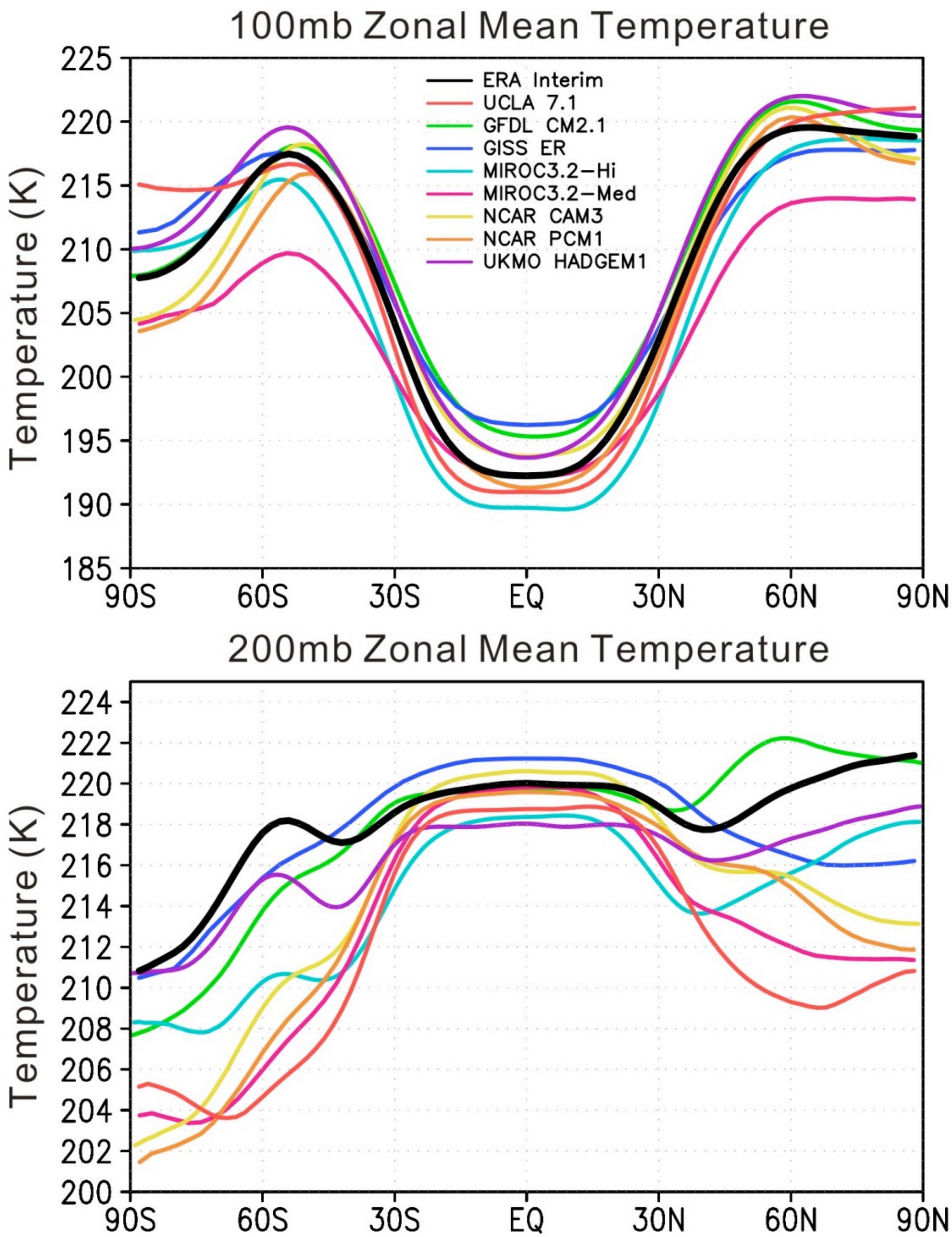
L. Gelinas 2010



ρ0 <u′ w′> bp1-12hr (mPa)
ρ0 <v′ w′> bp1-12hr (mPa)
Difference of ρ0 <u′ w′> with Hertzog′ s (mPa)
Difference of ρ0 <v′ w′> with Hertzog′ s (mPa)
0°
60°E
120°E
180°W
120°W
60°W
10
5
0
-5
-10
-15
-20



De la Camara 2010



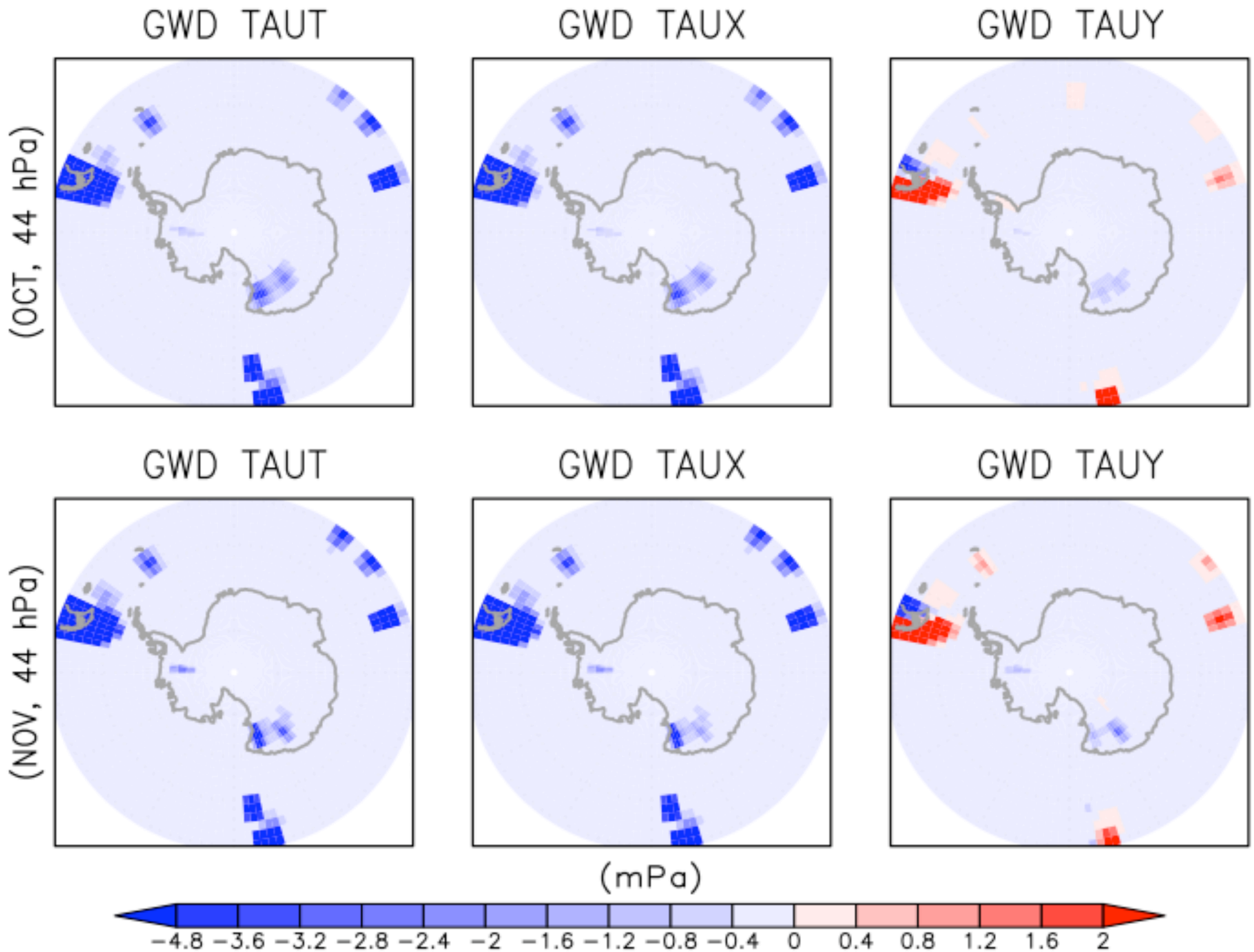
The cold pole bias of AGCMs

(WCRP-CMIP3)

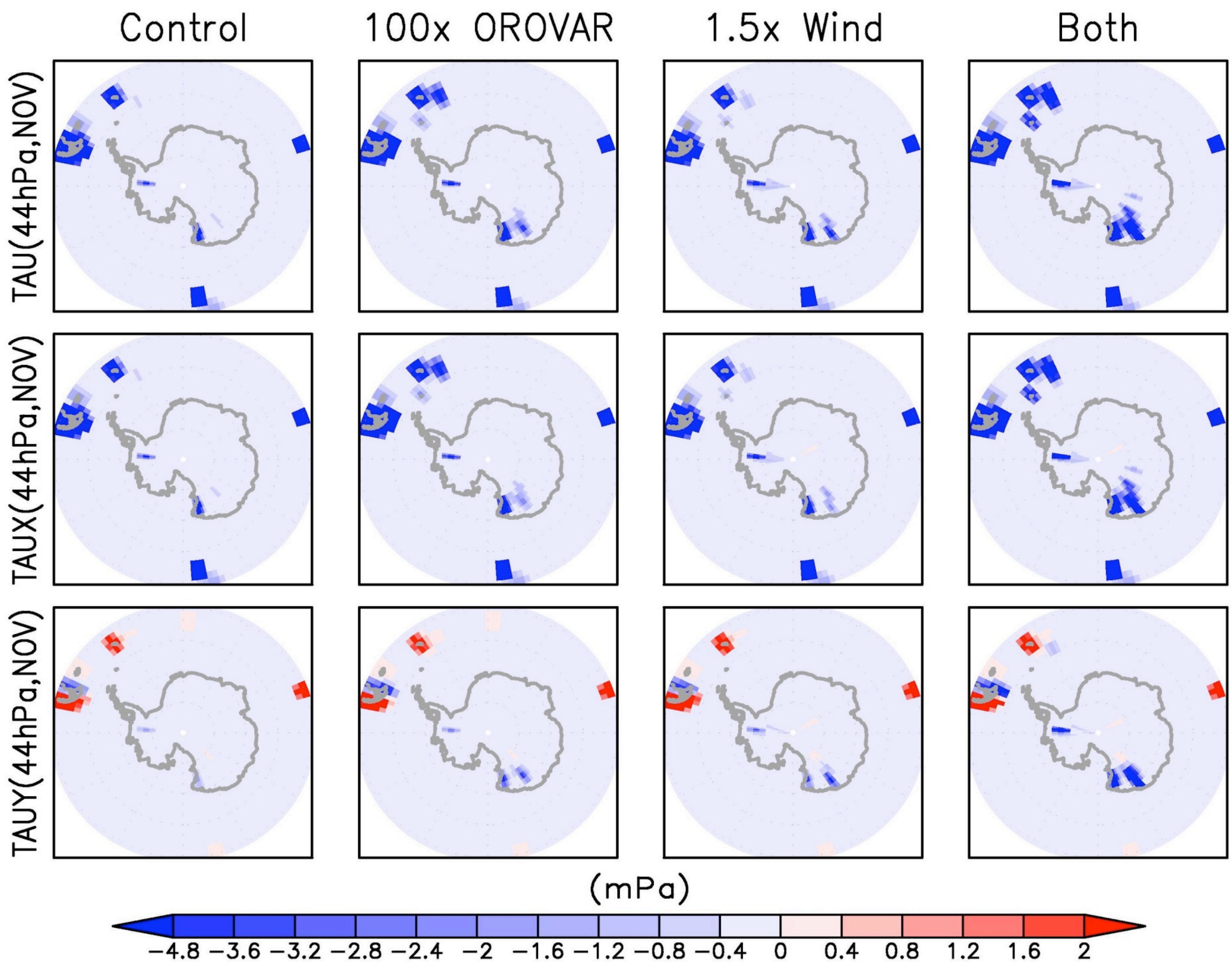
Ma 2010

OGW Flux from UCLA AGCM parameterization

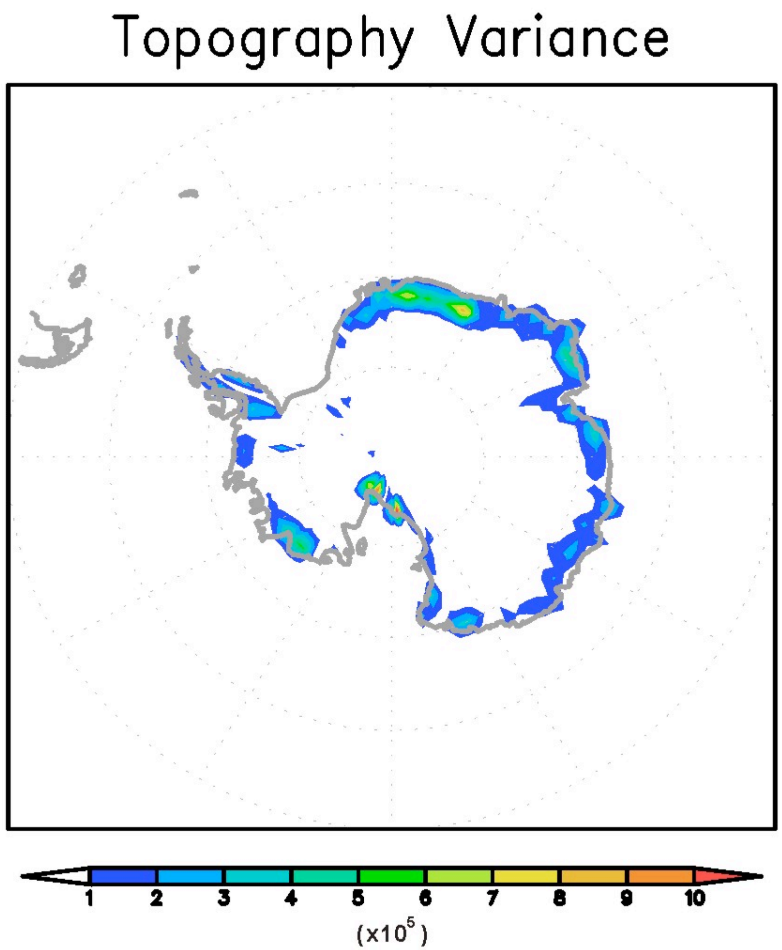
(Off-line, October, 44 hPa; Kim and Arakawa 1995)

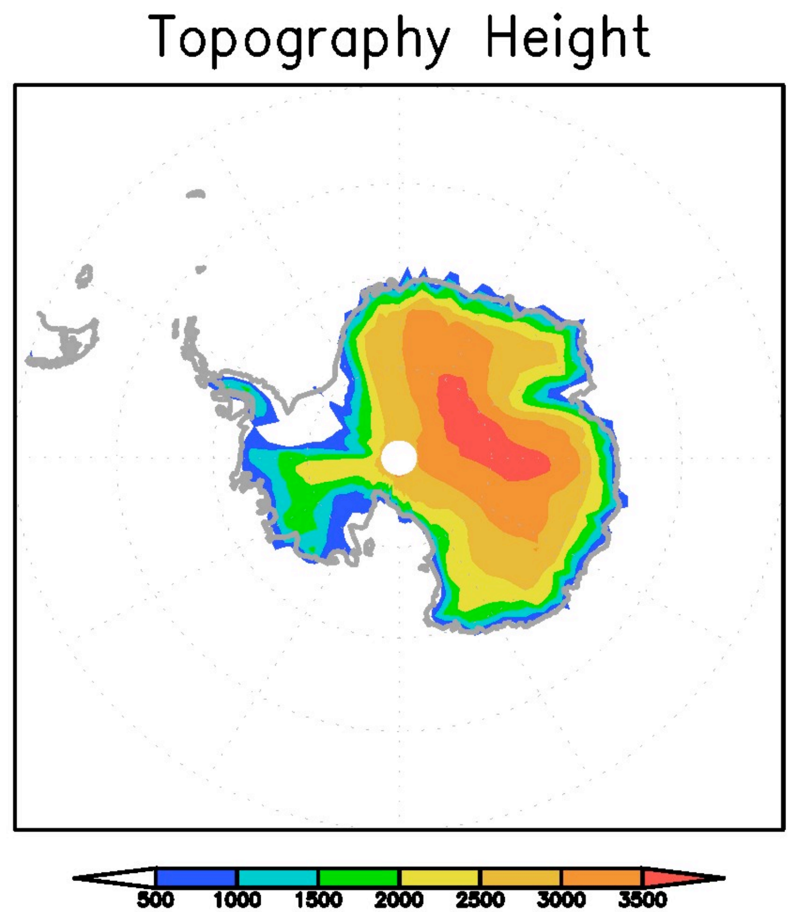


Sensitivity Experiments with UCLA AGCM



Sensitivity Experiments with UCLA AGCM





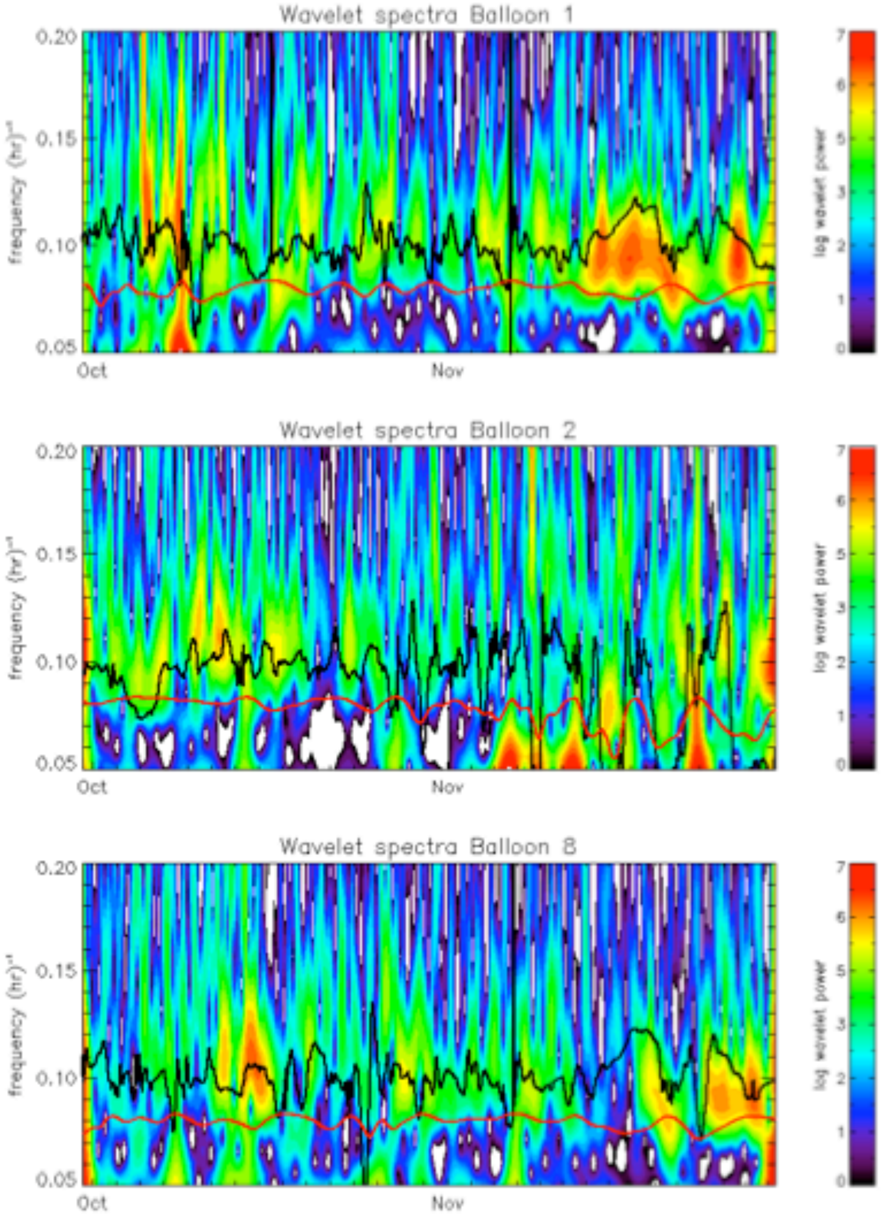


Figure 2. Wavelet spectra for balloons 1, 2 and 8, released near 50 hPa. Inertial frequency (a function only of latitude) is shown in red for each balloon trajectory. The effective inertial frequency (a function of latitude and relative vorticity) is shown as a solid black line.

The inertial peak obtained from data provided by balloons drifting with the wind should be found where

$$f_{eff} = f + \bar{\zeta}$$

in which f is the inertial frequency (Coriolis param.) and $\bar{\zeta}$ is relative vorticity.

We have interpreted f_{eff} as the inertial frequency in a coordinate frame moving with the basic flow.

Gelinas et al. 2010

Summary

- We have derived a set of dynamical equations for isopycnic coordinates. This allows the use of height data and makes derived quantities (e.g., fluxes and vertical velocity) less dependent on intermediate quantities.
- Applied relations to waves using wavelet analysis, derived vertical velocity fluctuations, and calculated vertical momentum flux.
- Compared fluxes from those calculated by an AGCM parameterization during a model run.
- Suggested that the inertial peak inside the Antarctic vortex is shifted to near ten hours by the rotational effect of the background flow.

Plans for CONCORDIASI

- Use more advanced Lagrangian techniques for better understanding of the polar vortex evolution.
- Continue investigation of the waves in the Antarctic atmosphere, with an emphasis on inertial and orographically induced waves.
- Assess behavior of GWD parameterization in GCMs.
- Establish collaboration with very-high resolution models to further study the gravity wave field.
- Establish collaboration with data assimilation teams to help with validation.

List of Symbols

ψ = general dependent variable

$\mathbf{u} = (\mathrm{u,v})$ = horizontal velocity

p = pressure

ρ = density

$\phi = gz$

$w = \dot{\zeta}$

$\hat{w} = \dot{z}$

$W = RT + \phi$

$(\ )'$ = wave quantity

$\overline{(\ )}$ = horizontal average

z = altitude

$\zeta = -\log(\rho/\rho_0)$

$\omega_I = \omega - k\bar{u}$

$c_I = c - \bar{u}$

$\theta = T(p_0/p)^\kappa$

$\kappa = R/c_p$

$\bar{S} = \gamma R\bar{T}\,\partial\log\bar{\theta}/\partial\zeta$

γ = ratio of specific heats (c_p/c_v)

Q = heating rate per unit mass

$\bar{H}$ = scale height