Long-duration balloon observation of gravity-wave momentum fluxes and intermittency over Antarctica

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Motivations

- In the atmosphere, gravity waves transport energy and momentum from their source regions (mainly the troposphere) to the middle atmosphere
- Wave breaking in the stratosphere and mesosphere contribute to the driving of the global-scale Brewer-Dobson circulation
- GW scales (10 – 1,000 km in the horizontal, 100 m – 10 km in the vertical) are such that they are only marginally resolved in AGCMs that are used to study climate change
- Their global effects are parameterized in AGCMs, but these parameterizations are based on simplifying assumptions.
  - In particular, a significant part of the momentum flux is put in a generic "non-orographic" GW drag part, for which there is no link with underlying source processes: a constant and homogeneous source is assumed

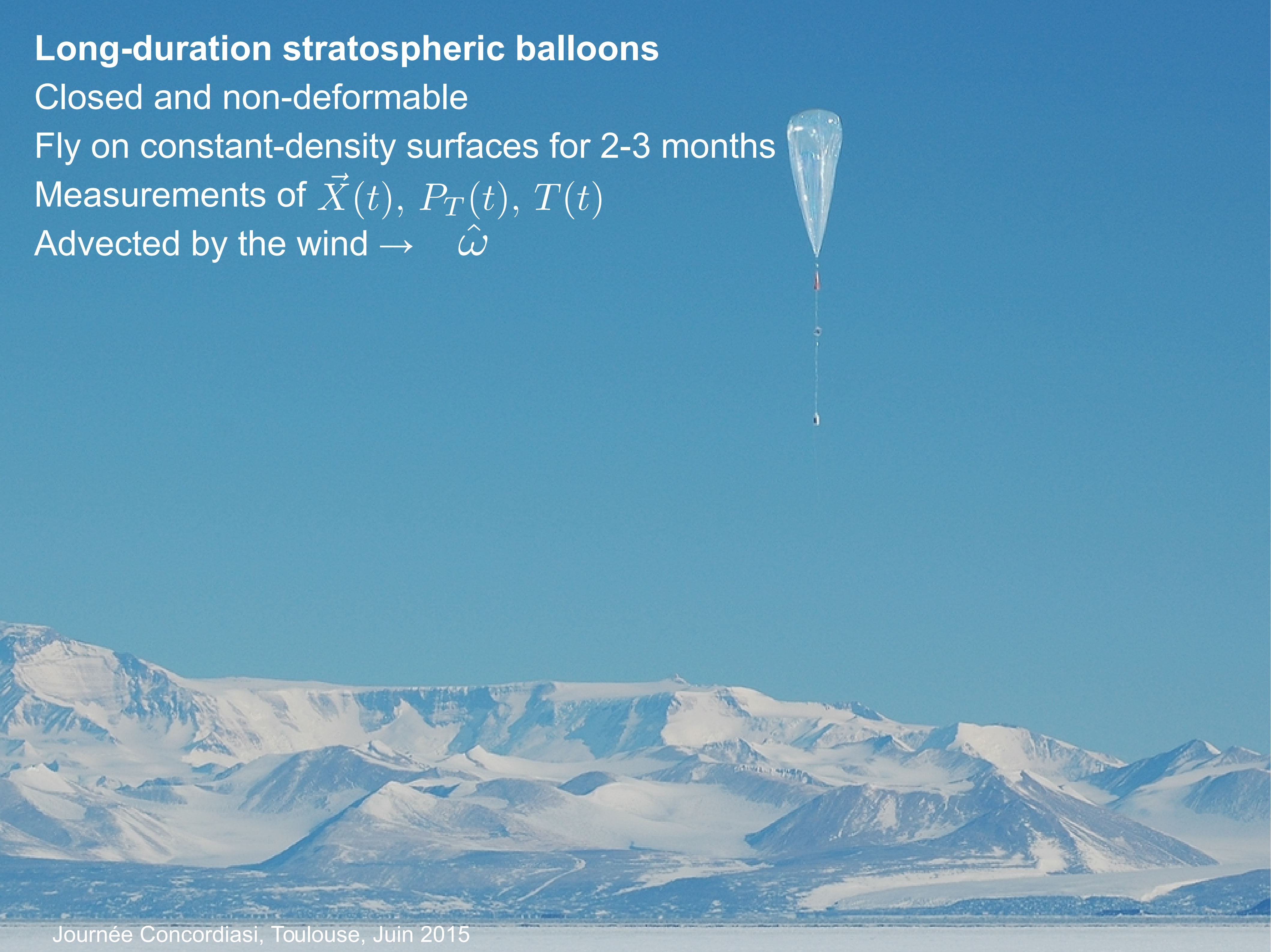
Long-duration stratospheric balloons

Closed and non-deformable

Fly on constant-density surfaces for 2-3 months

Measurements of $\vec{X}(t)$, $P_T(t)$, $T(t)$

Advected by the wind → $\hat{\omega}$



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Vorcore campaign

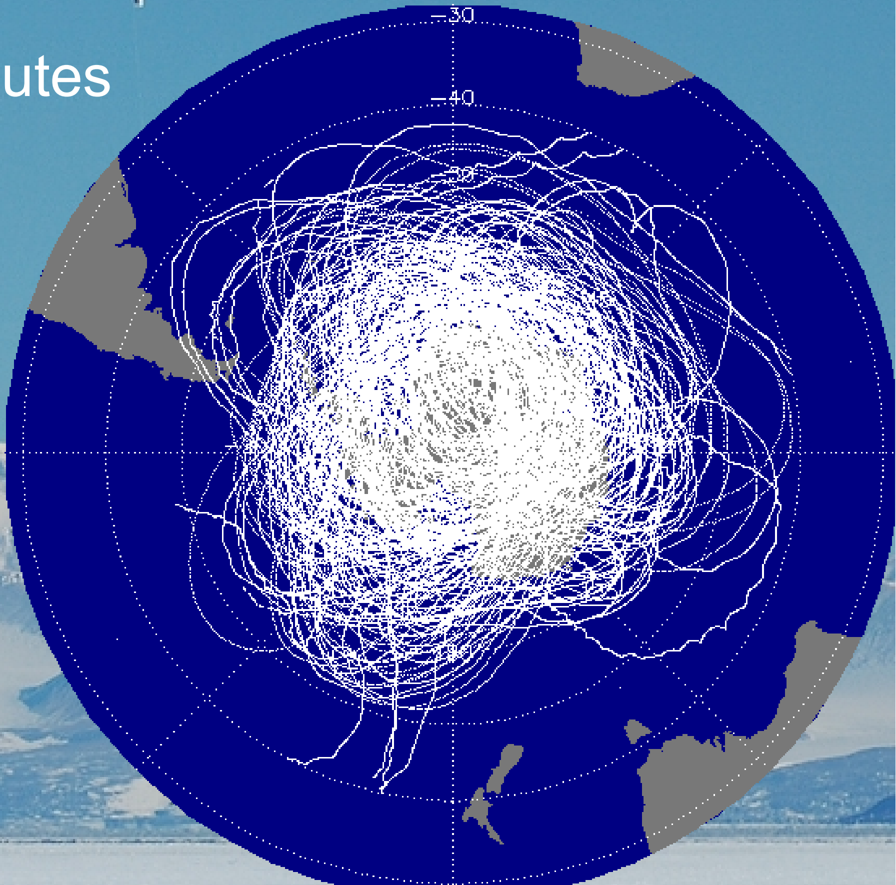
Sep. 2005 – Feb. 2006

27 balloons, 60 and 80 hPa

In-situ measurements of u, v, P every 15 minutes

$\overline{\rho u'w'}$ and $\overline{\rho v'w'}$ from wavelet analysis

150,000 obs



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Concordiasi campaign

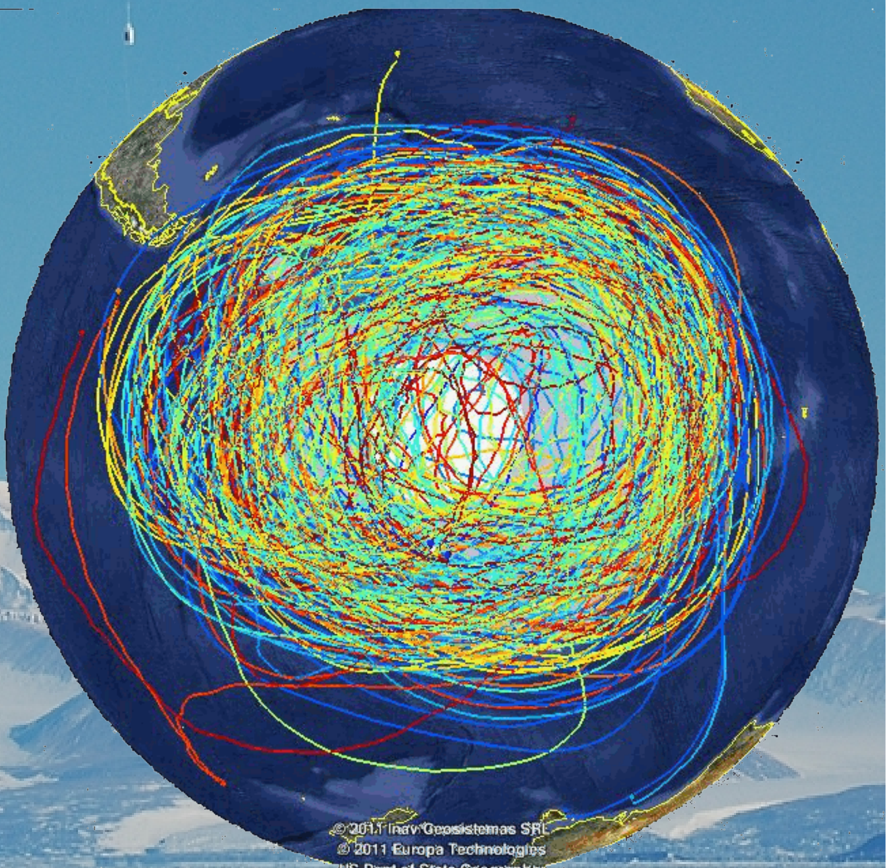
Sep. 2010 – Jan. 2011

19 balloons, 60 hPa

In-situ measurements of u, v, P every 30 s

$\overline{\rho u' w'}$ and $\overline{\rho v' w'}$ from wavelet analysis

2,600,000 obs

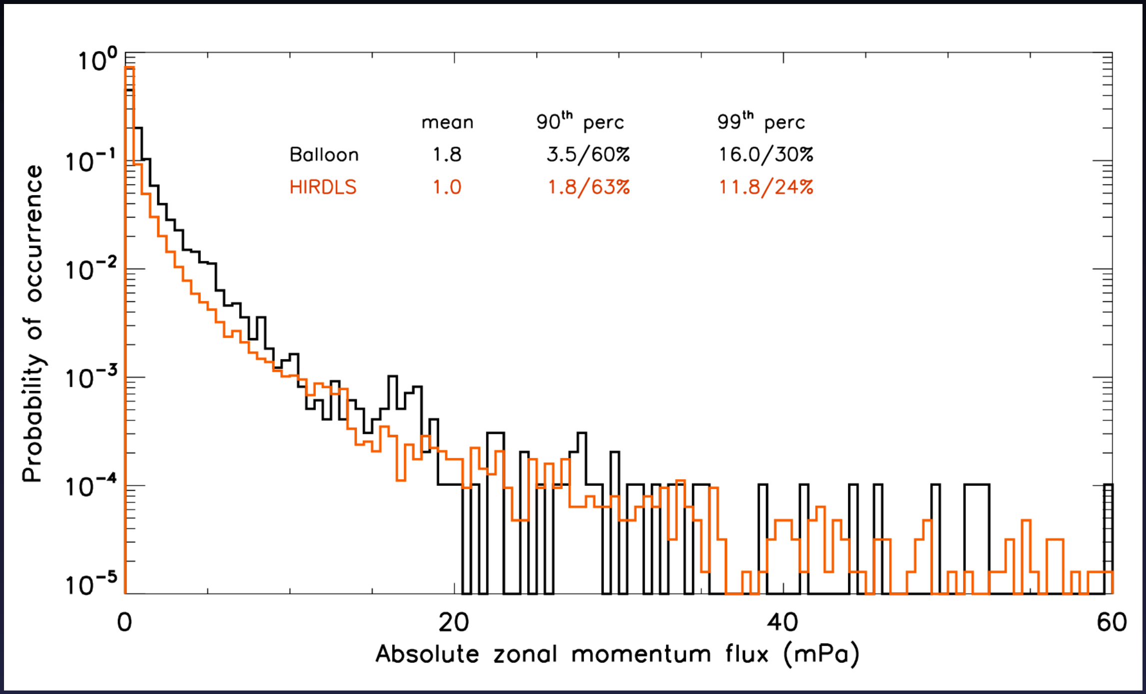


Gravity-wave intermittency
(with Vorcore observations)

To study GW intermittency,
we directly look into the GW momentum-flux PDFs

Comparison with momentum flux
derived from HIRDLS observations

Balloons/HIRDLS
October, PDF of $\rho|\overline{u'w'}|$

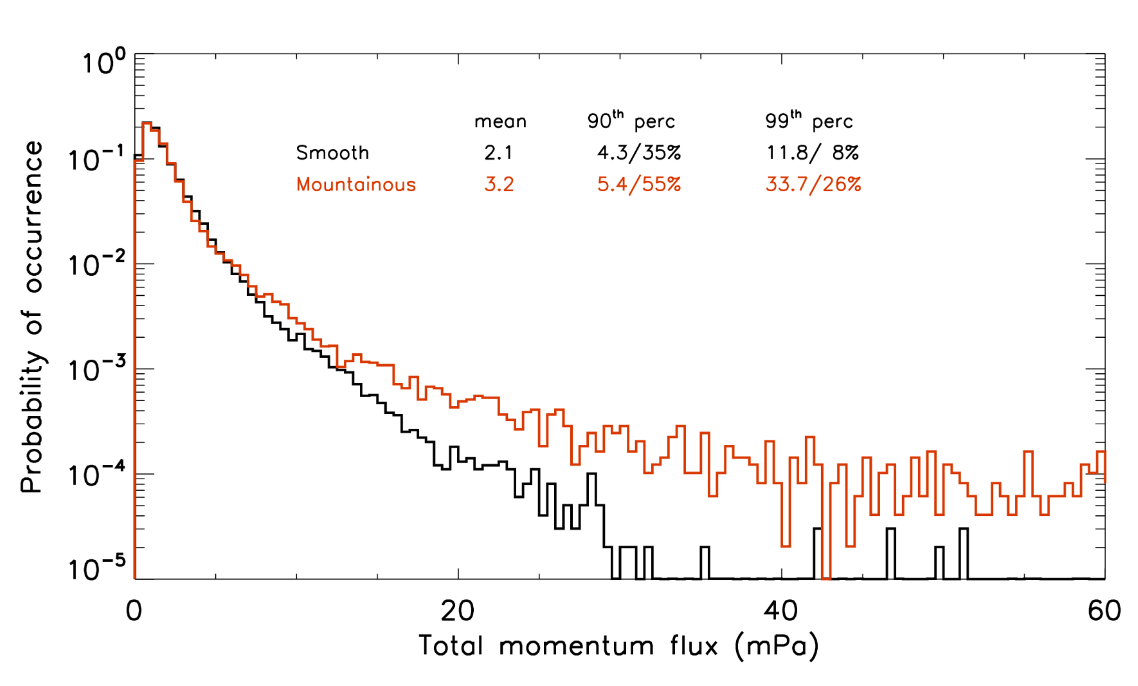


Hertzog et al., 2012

Good agreement between both kind of observations.
The major part of the momentum flux is due to rare, large amplitude events.

Mountains/flat areas

Balloons, PDF of $\rho\langle u'_{//}w'\rangle$



Wave momentum fluxes are as expected higher over mountain than over flat areas, but wave intermittency is also increased.

Similar "background" wave activity (@ small momentum fluxes)

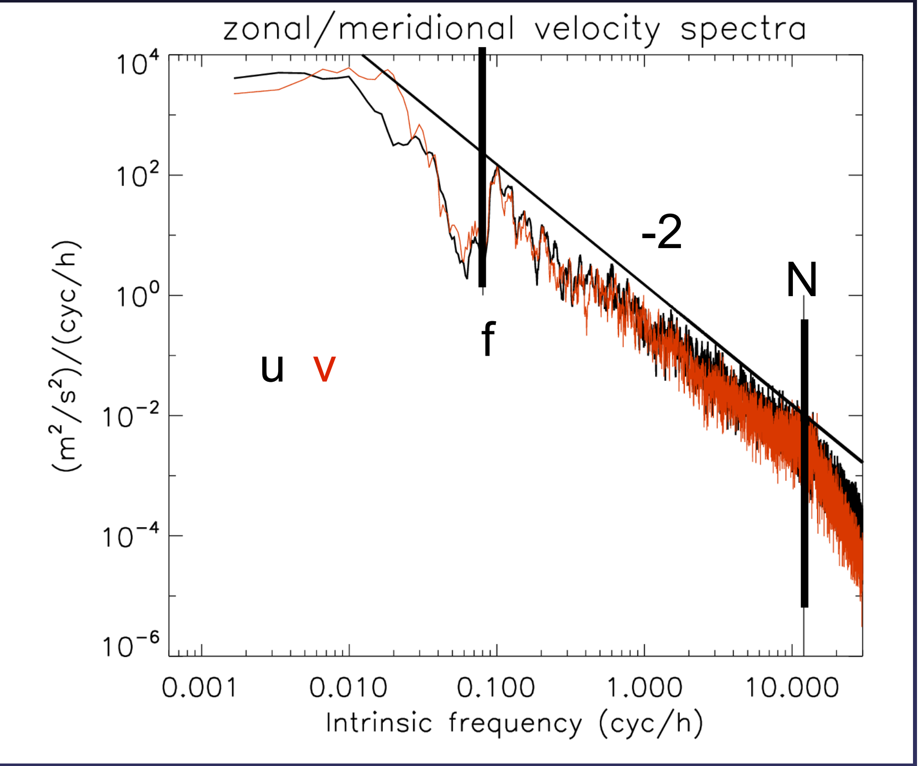
Full gravity-wave characteristics
(with Concordiasi observations)

With respect to the previous Vorcore campaign, there were two major improvements during Concordiasi:

- higher time resolution (30 s) along the balloon trajectories
  → whole gravity-wave spectrum is resolved
- higher precision of GPS altitude and pressure measurements
  → Eulerian P disturbance

$$P_e' = P_l' - \zeta' \frac{\partial \bar{P}}{\partial z}$$

and wave parameters: $\hat{c}, c, m$ ...

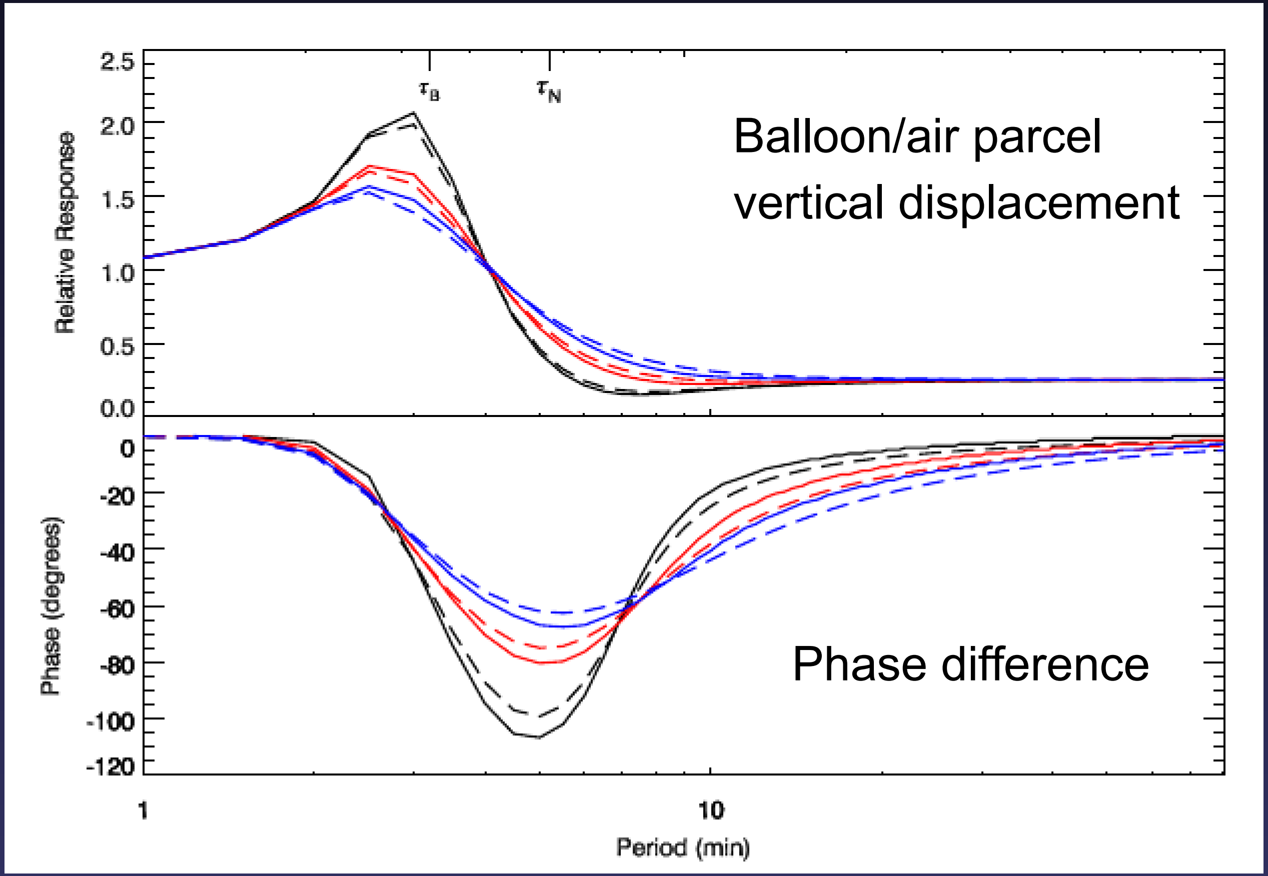


Retrievals of gravity-wave characteristics (1)

- Wavelet decomposition of observed timeseries $\rightarrow (t, \hat{\omega})$ space
- Working out linear GW polarization relations, and assuming perfect isopycnic balloon...
  - Momentum flux $\mathrm{Im}(\tilde{p}_T \tilde{u}_\parallel^\star) = -\bar{\rho} H \frac{N^2}{\hat{\omega}} \mathrm{Re}(\tilde{u}_\parallel^\star \tilde{w})$
  - Phase speed $\hat{c} = \frac{1}{\bar{\rho}\delta_-} \frac{\mathrm{Re}(\tilde{p}\tilde{u}_\parallel^\star)}{\tilde{u}_\parallel^2}$, where $P' = P'_T - \zeta' \, dp_0/dz$
  - Vertical wave number $m = -\bar{\rho}^2 \hat{c} \delta_- \left(\frac{N^2 - \hat{\omega}^2}{\hat{\omega}} \right) \frac{\mathrm{Re}(\tilde{u}_\parallel^\star \tilde{w})}{\tilde{p}^2}$
  - Horizontal wave number through the GW polarization relation
  - Ground-based frequency/phase speed through Doppler-shift equation

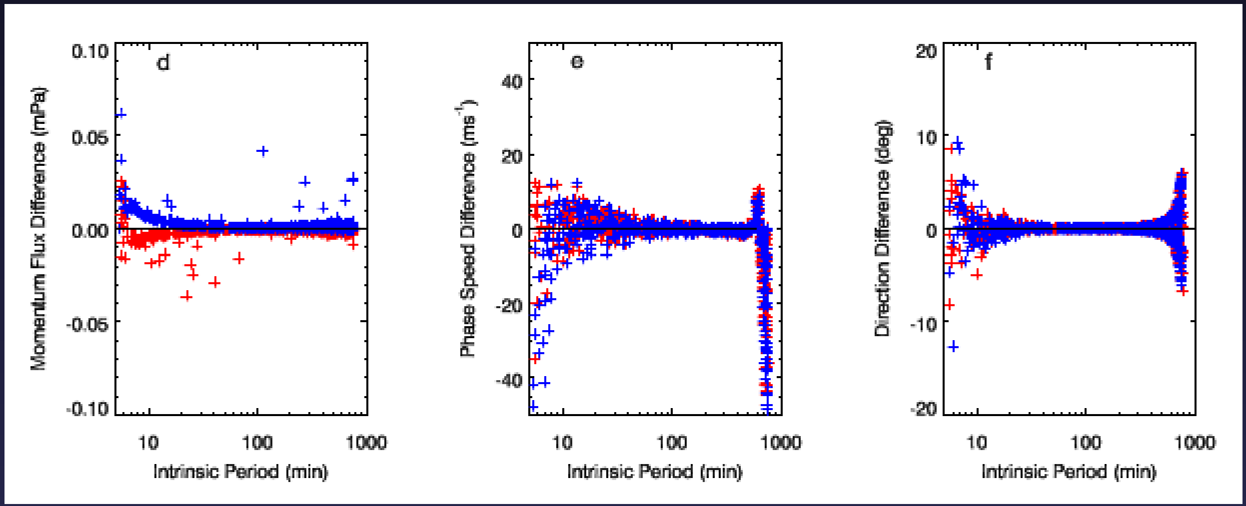
Retrievals of gravity-wave characteristics (2)

- But the balloon is not perfectly isopycnic...
- We study the response of superpressure balloons to gravity-wave disturbances *(Vincent & Hertzog, AMT, 2014)*



Retrievals of gravity-wave characteristics (3)

- Tests based on (random) choice of GW characteristics, synthetic timeseries of balloon observations (including observation noise), and retrieval analysis



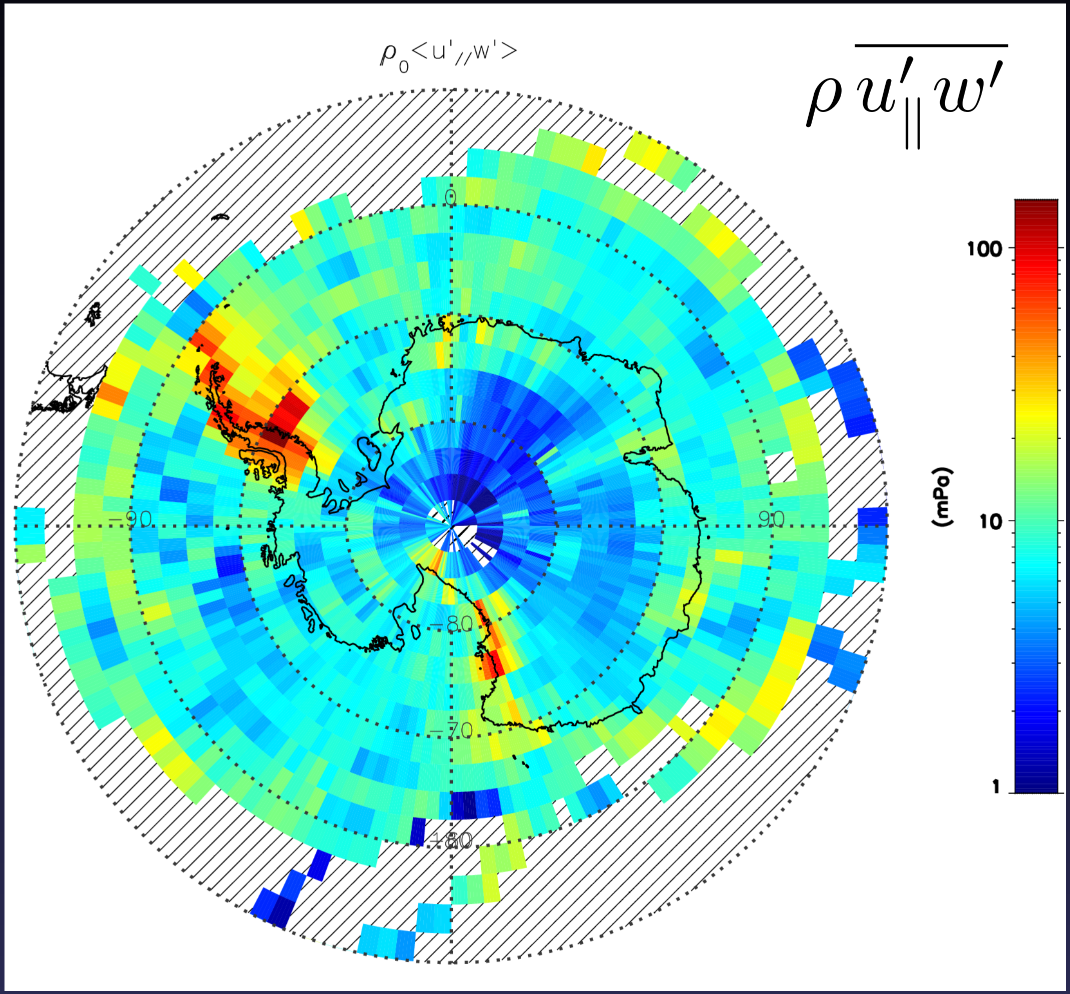
$$2f < \hat{\omega} < N/2$$

Map of absolute momentum flux

(Sep.-Jan. average)

2.5° x 2.5° boxes

Mean = 9.0 mPa



Enhanced activity over Peninsula, Drake passage and Transantarctic mountains, as well as along the continental coast

Higher activity above Austral Ocean than above the Plateau

Map of absolute momentum flux

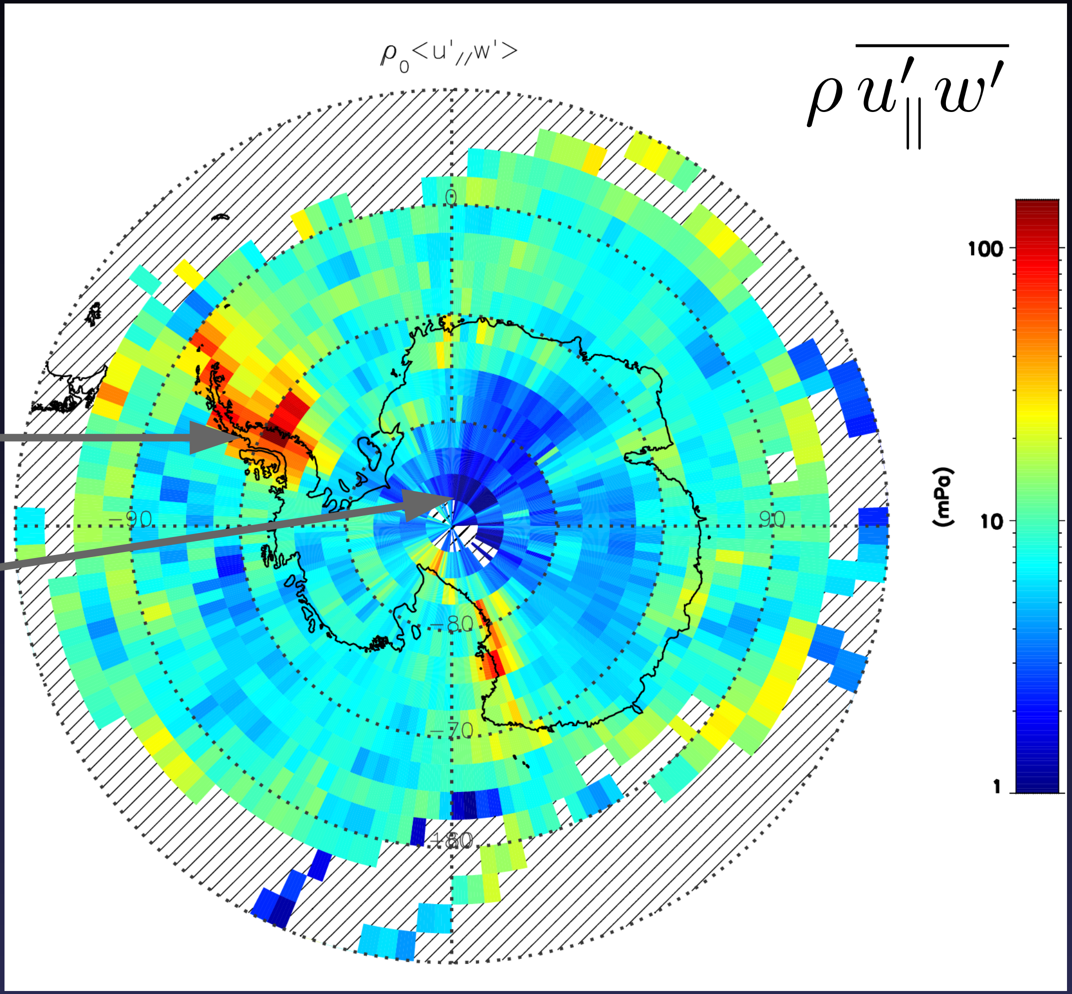
(Sep.-Jan. average)

2.5° x 2.5° boxes

Mean = 9.0 mPa

160 mPa

0.6 mPa



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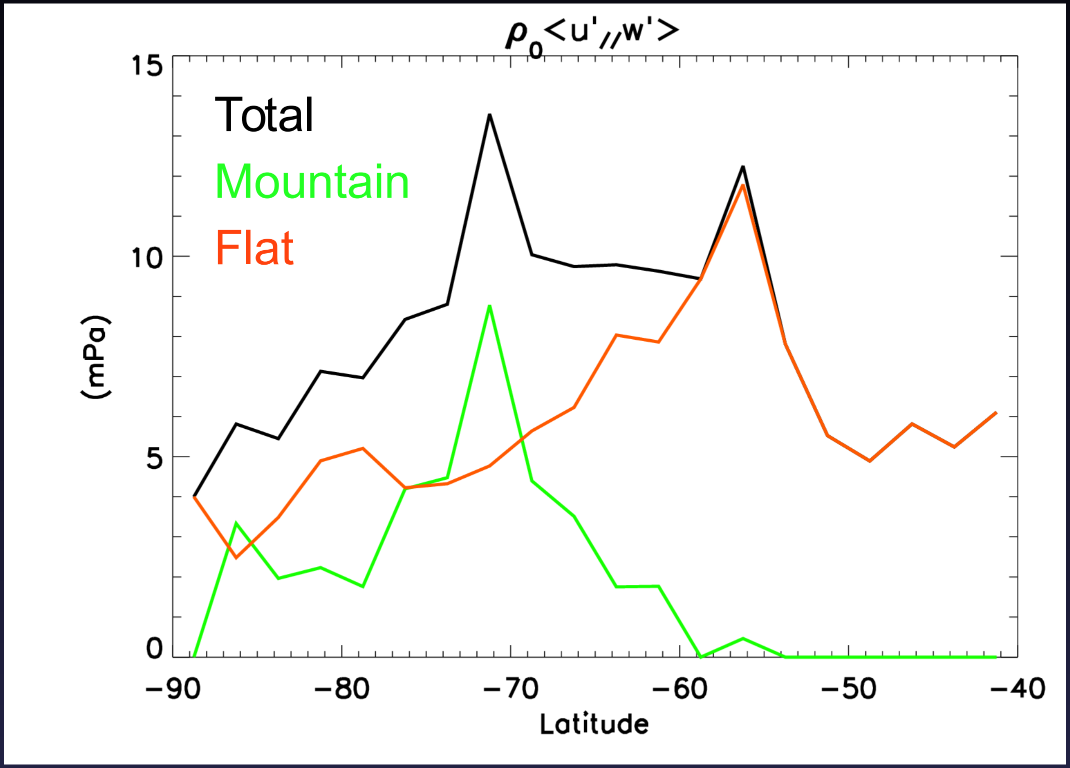
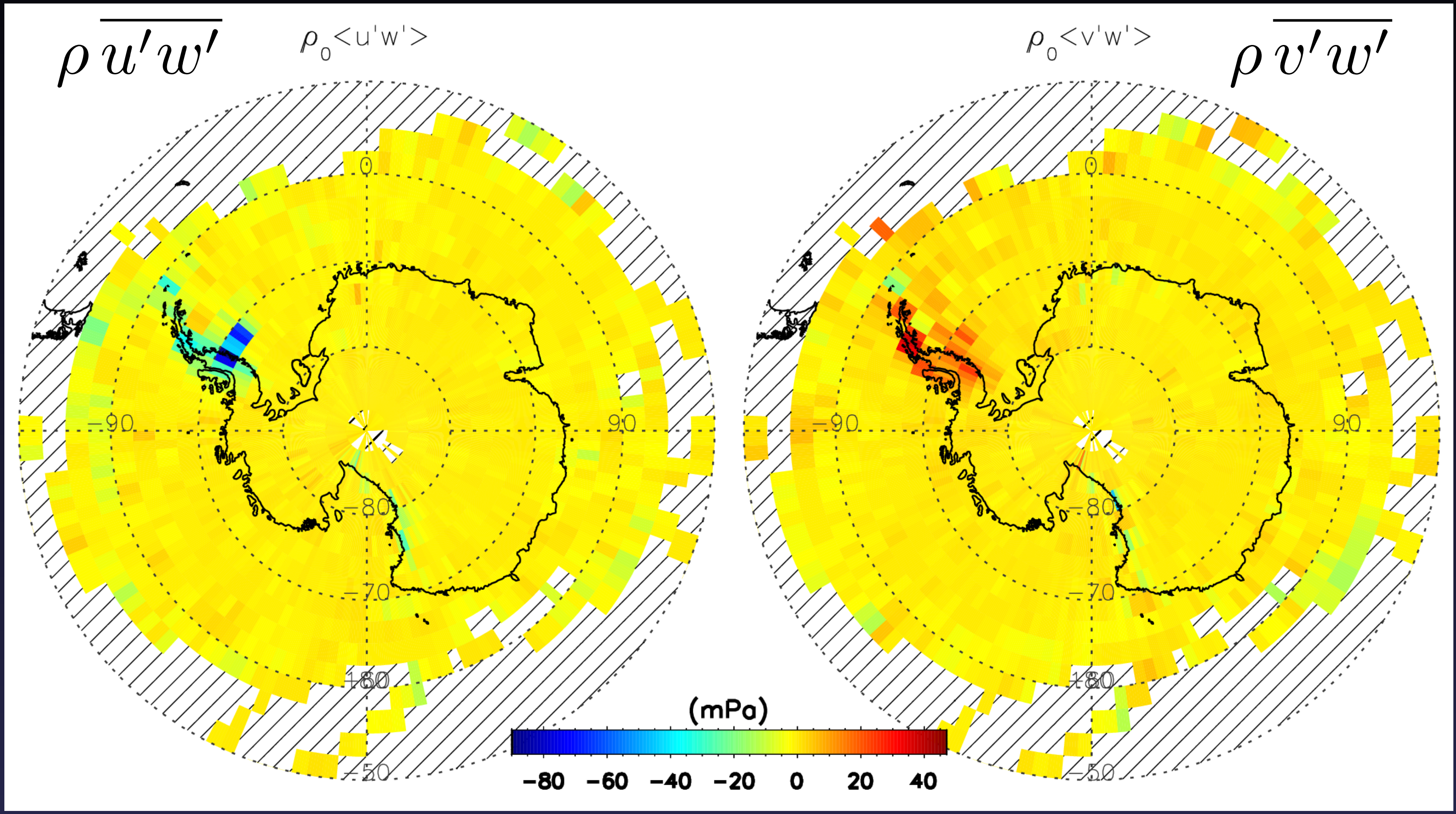
Zonal average of absolute momentum flux



GW momentum fluxes maximize between 55S and 75S
Zonally averaged non-orographic gravity-wave activity above the Austral ocean is as important as orographic activity above the continents

Zonal and meridional momentum fluxes

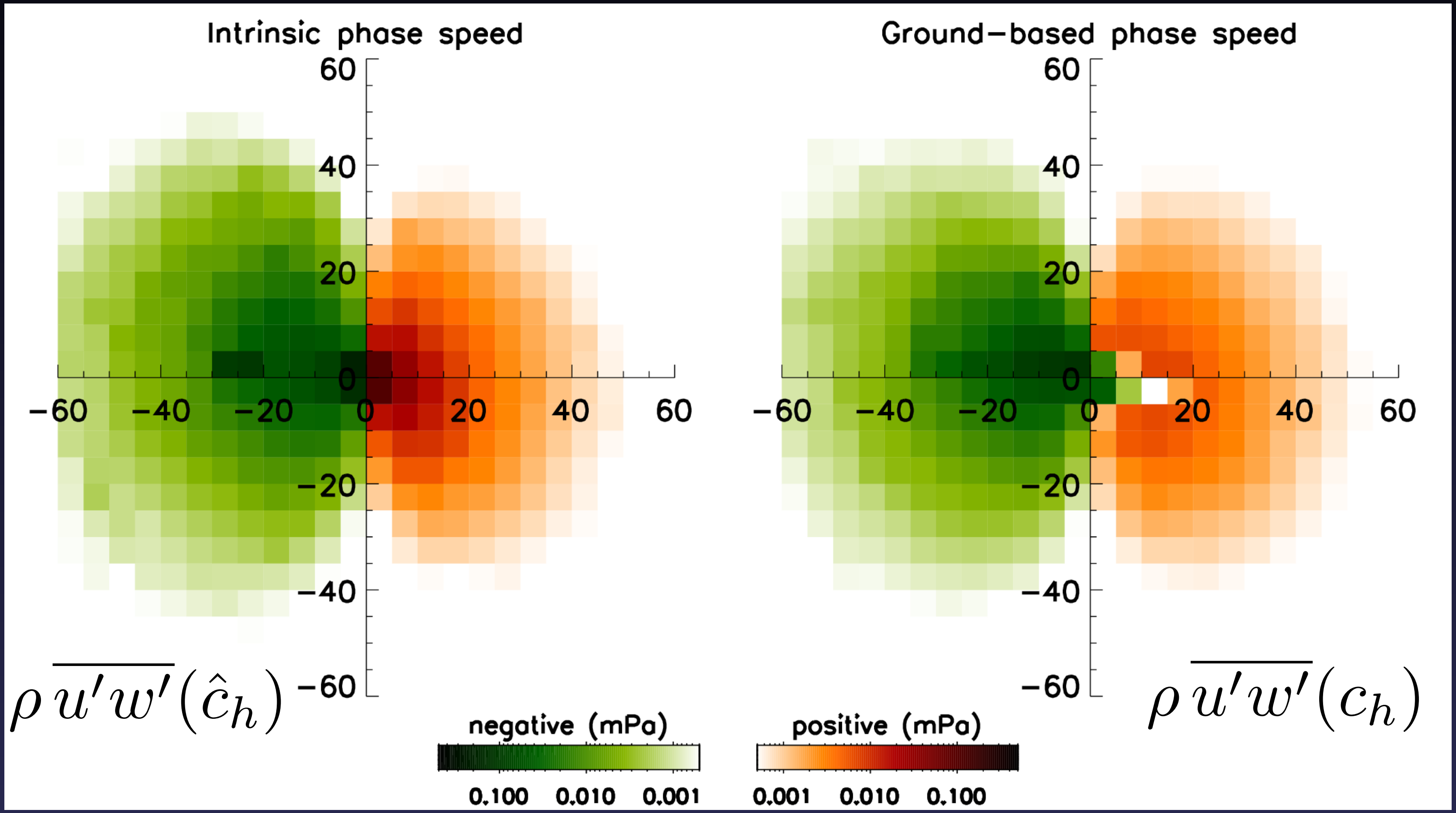


Zonal momentum fluxes are almost everywhere negative (mountains & ocean), whereas both positive and negatives meridional fluxes are found.

The campaign-averaged net fluxes are significantly smaller than the absolute fluxes:

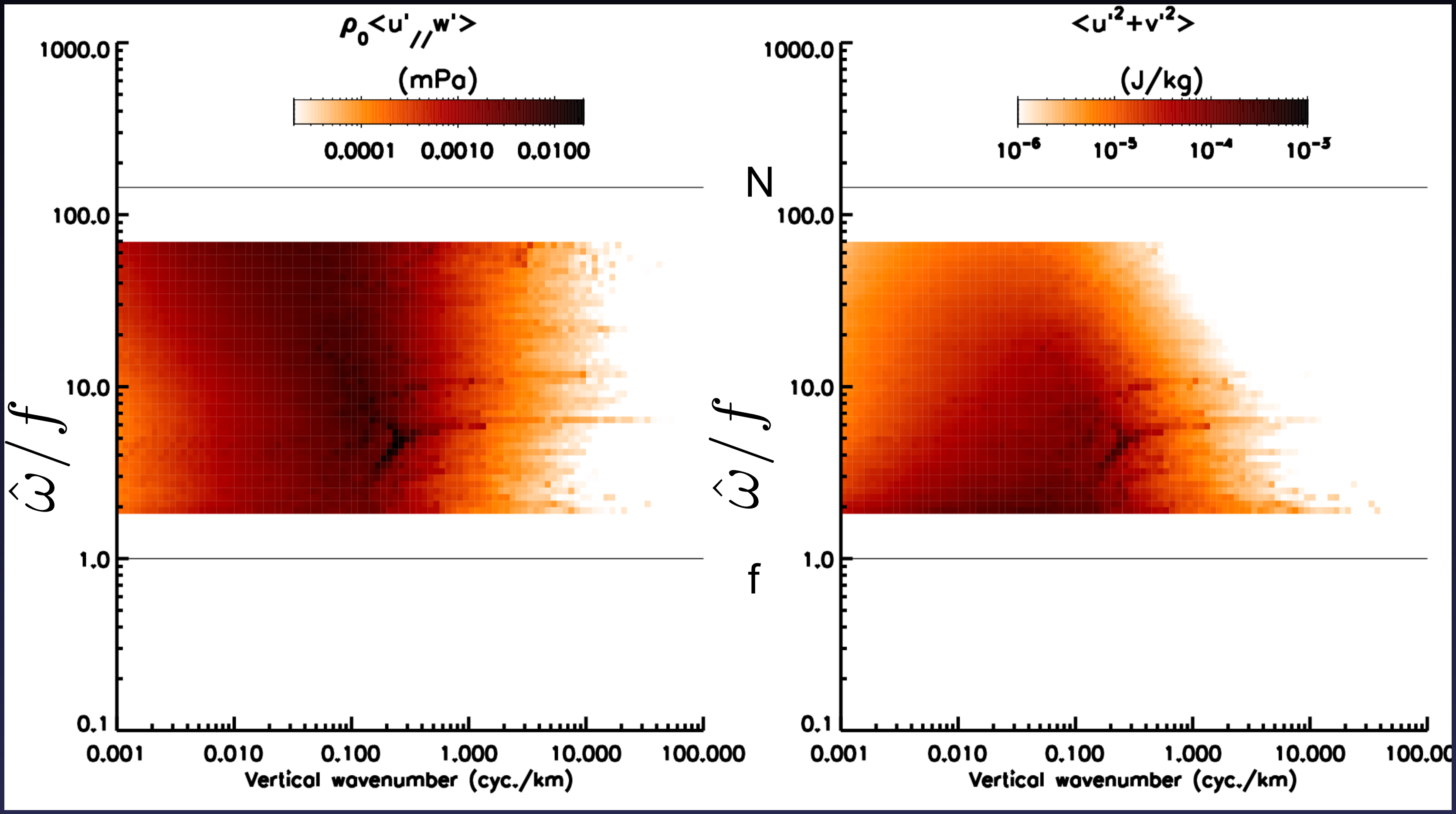
$$\rho\,\overline{u'w'} = -1.4\,\mathrm{mPa} \qquad \rho\,\overline{v'w'} = 0.2\,\mathrm{mPa}$$

Phase speed distribution of zonal momentum fluxes



Most of the westward flux is found between 0-40 m/s, while eastward fluxes are in 0-20 m/s
A secondary maximum in the intrinsic phase speed distribution is found between 20-30 m/s, and corresponds to mountain waves. It is shifted toward ground-based c < 10 m/s.
The ground-based phase speed distribution exhibits “intro waves”, i.e. waves with $c_h < \mathbf{u}\cos\theta$

$(m, \hat{\omega})$ distributions of momentum fluxes and kinetic energy



Momentum fluxes and kinetic energy maximize for vertical wavelengths between 2-30 km.
Yet, the momentum flux distribution is broader than the kinetic energy one:
in particular higher frequency waves contribute more significantly to the flux than to the energy.
Mountain waves induce the enhancement observed between 2-5 km, and 2-4 hr.

Conclusions

- Gravity waves characteristics inferred from long-duration balloon flights are considered as reference datasets (Geller et al., 2013)
- The high-resolution (30 s) achieved during Concordiasi, as well as the high precision on the pressure/altitude records enable us to characterize the full characteristics of gravity waves in the lower stratosphere, and therefore to provide constraints for GWD parameterizations.
- We plan to continue this effort with equatorial flights during Strateole 2!