Observations of gravity-wave momentum fluxes and intermittency over Antarctica from long-duration balloon flights in the stratosphere

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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, especially the "non-orographic" one (e.g., homogeneous source).

Long-duration stratospheric balloons

Fly on constant-density surfaces

For 2-3 months

Advected by the wind → $\hat{\omega}$

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Concordiasi campaign

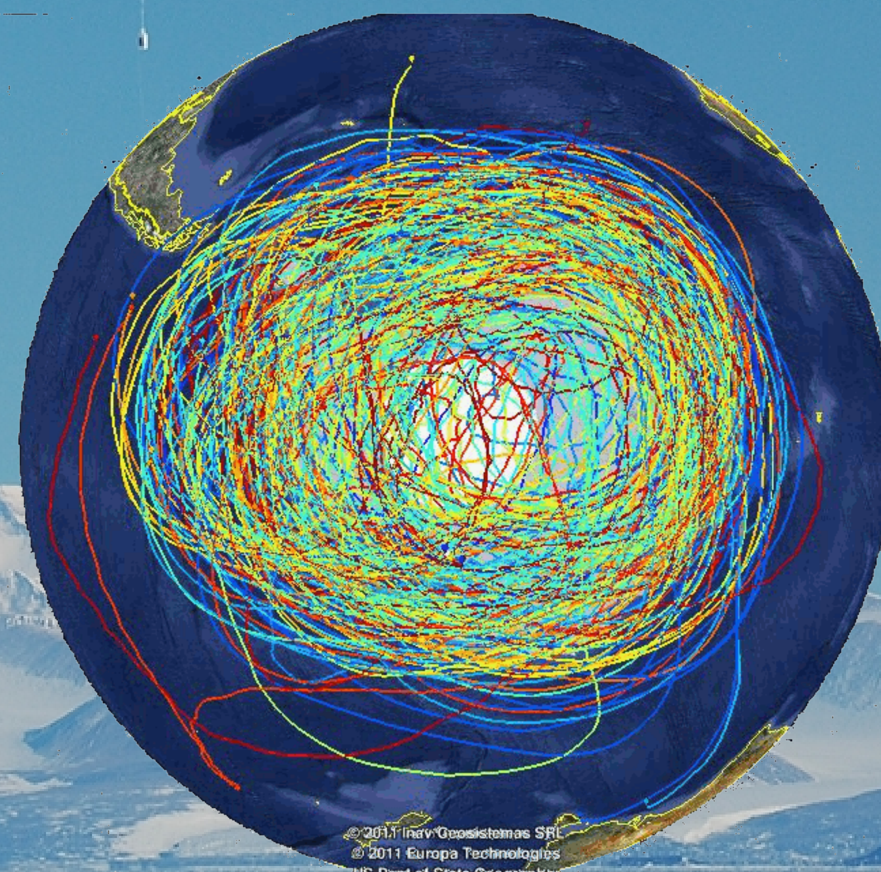
Sep. 2010 – Jan. 2011

19 balloons, 60 hPa

In-situ measurements of u, v, P

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

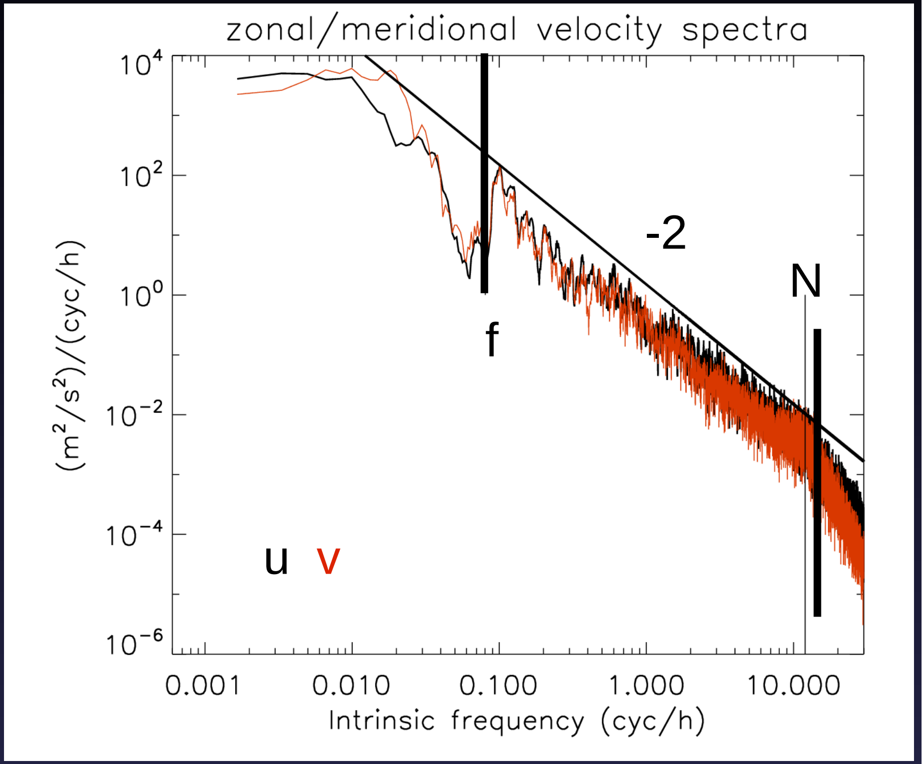
2,600,000 obs



Gravity-wave momentum flux

Recent improvements:

- higher time resolution (30 s) along the balloon trajectories
  → whole gravity-wave spectrum



- higher precision of GPS altitude and pressure measurements
  → Eulerian P disturbance

$$P'_e = P'_l - \zeta' \frac{\partial \bar{P}}{\partial z}$$

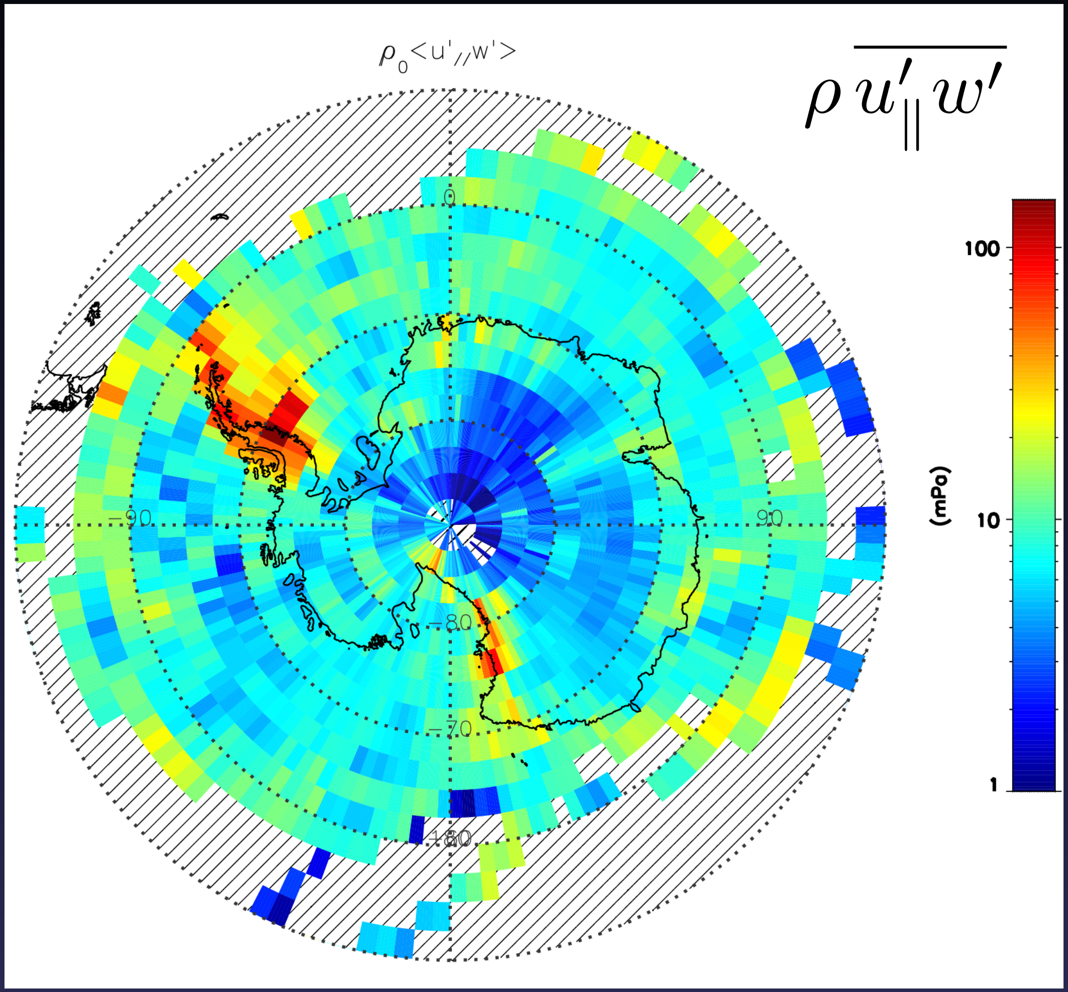
and wave parameters: $\hat{c}, c, m$ ...

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

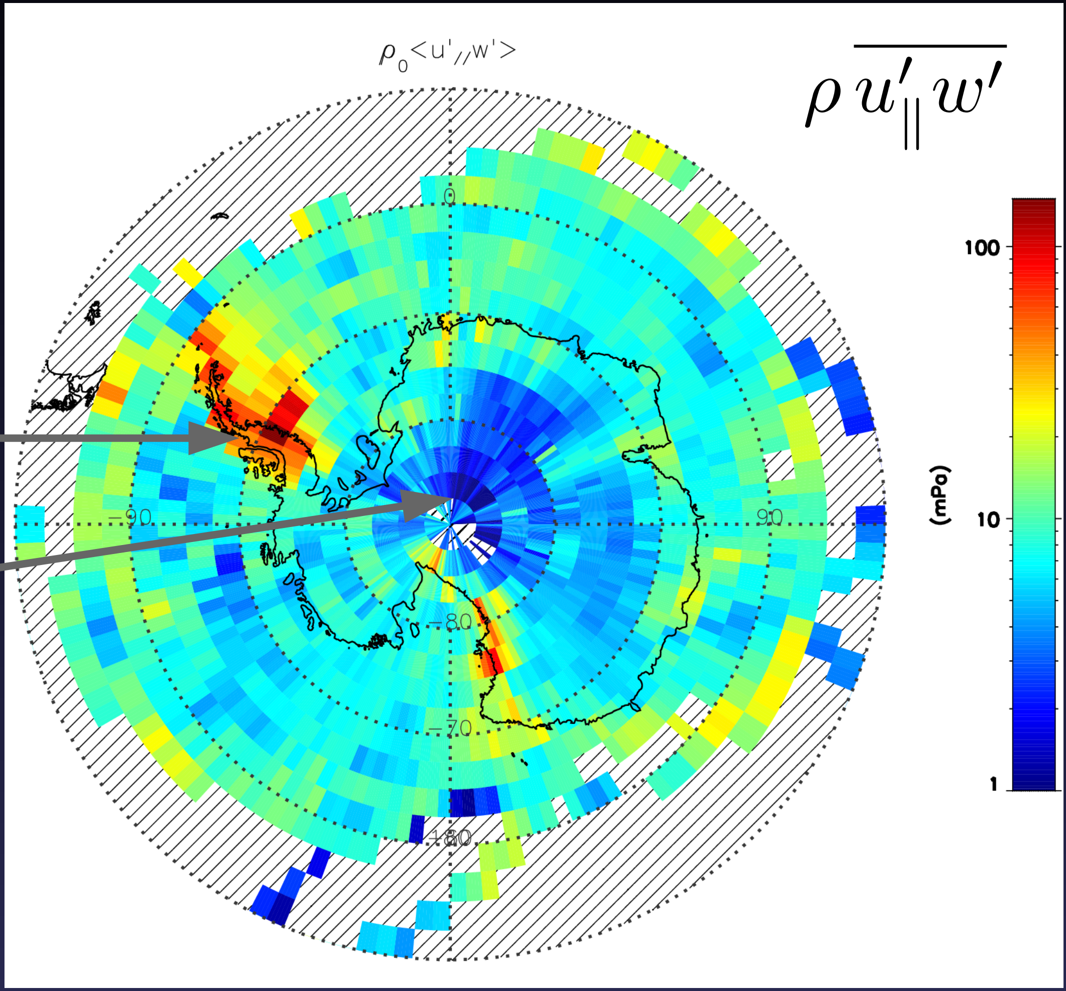
(Sep.-Jan. average)

2.5° x 2.5° boxes

Mean = 9.0 mPa

160 mPa

0.6 mPa



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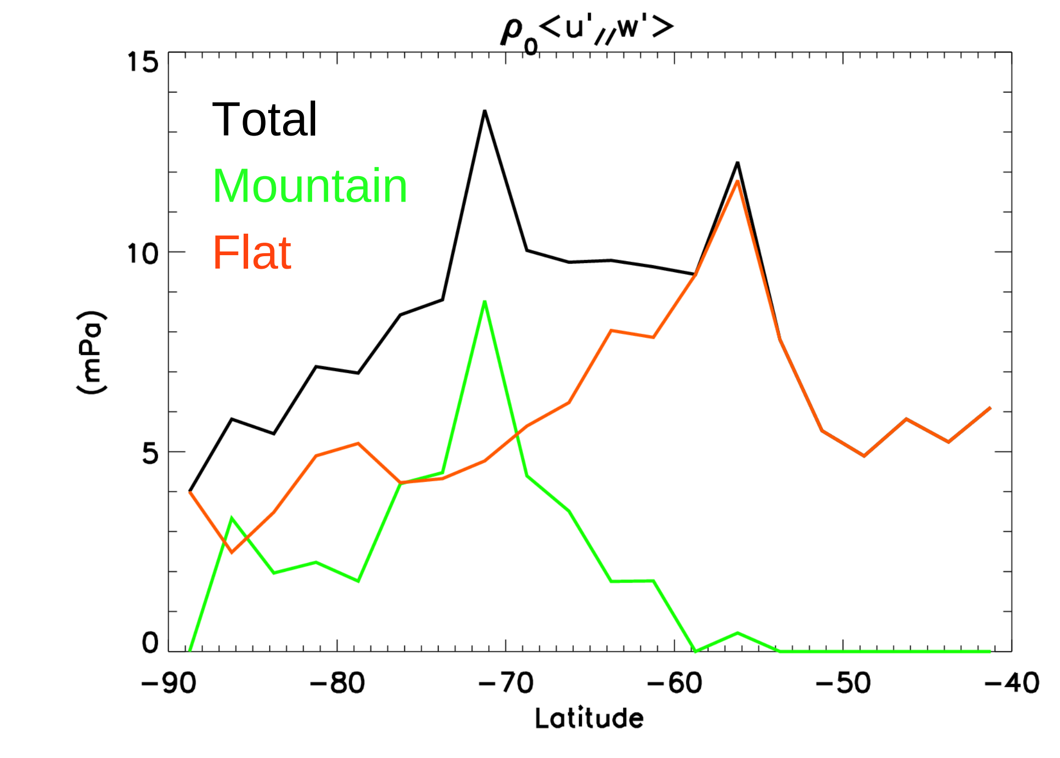
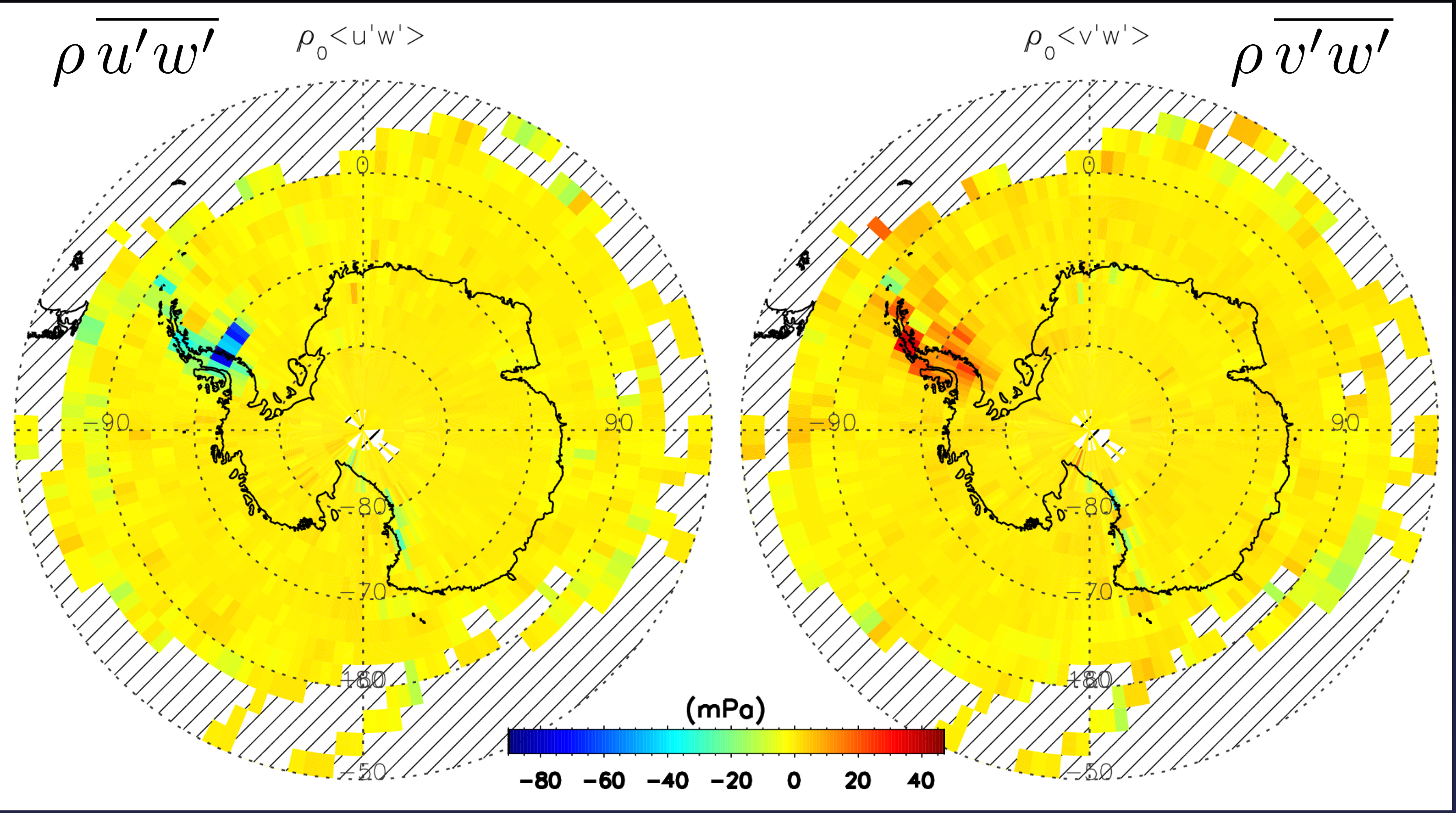
Zonal mean absolute momentum flux



GW momentum fluxes maximize between 55S and 75S.

Fluxes are segregated according to the underlying topography (flat/sloppy terrain)
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

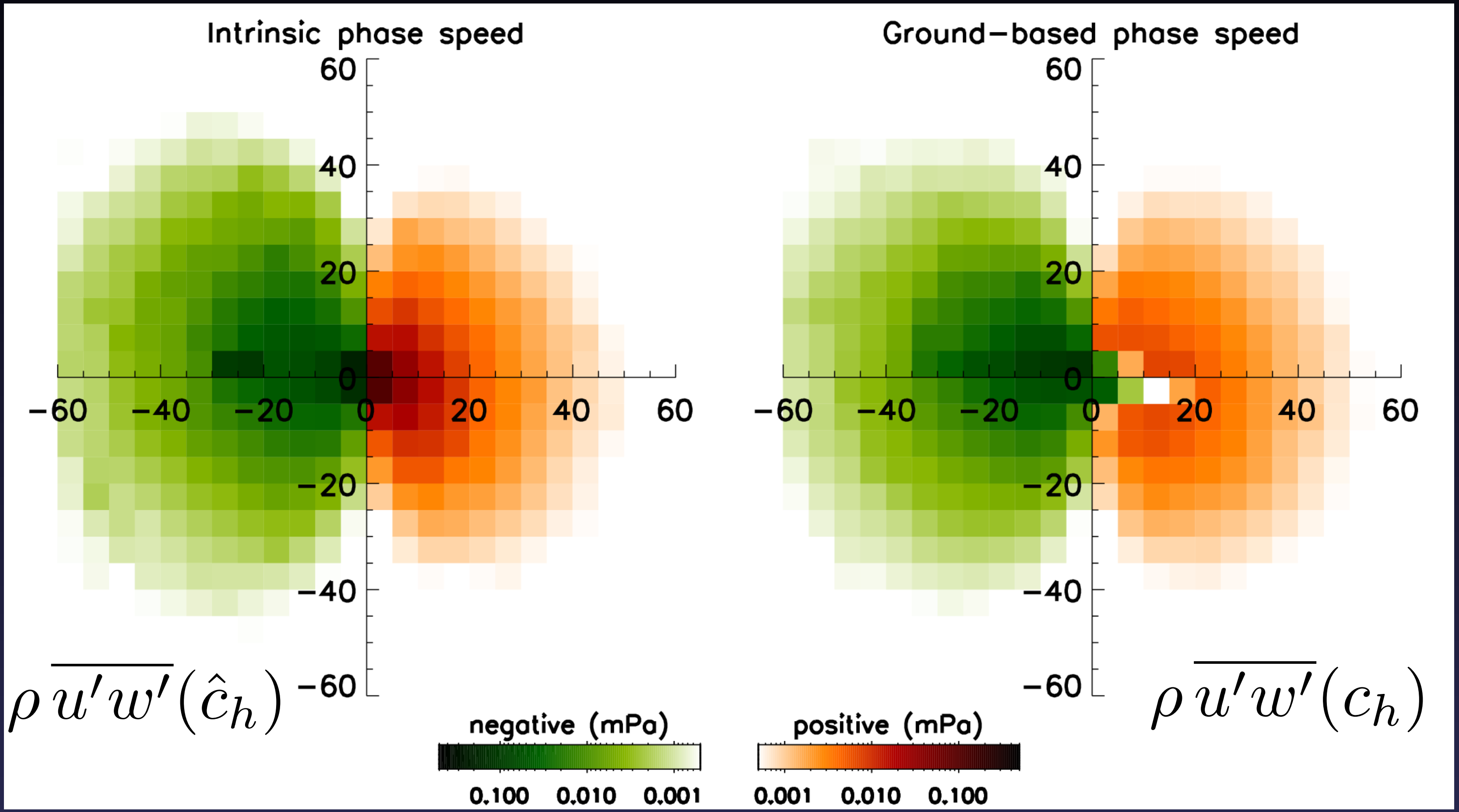


Zonal momentum fluxes are almost everywhere negative (mountains & ocean), whereas both positive and negatives meridional fluxes are found.

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

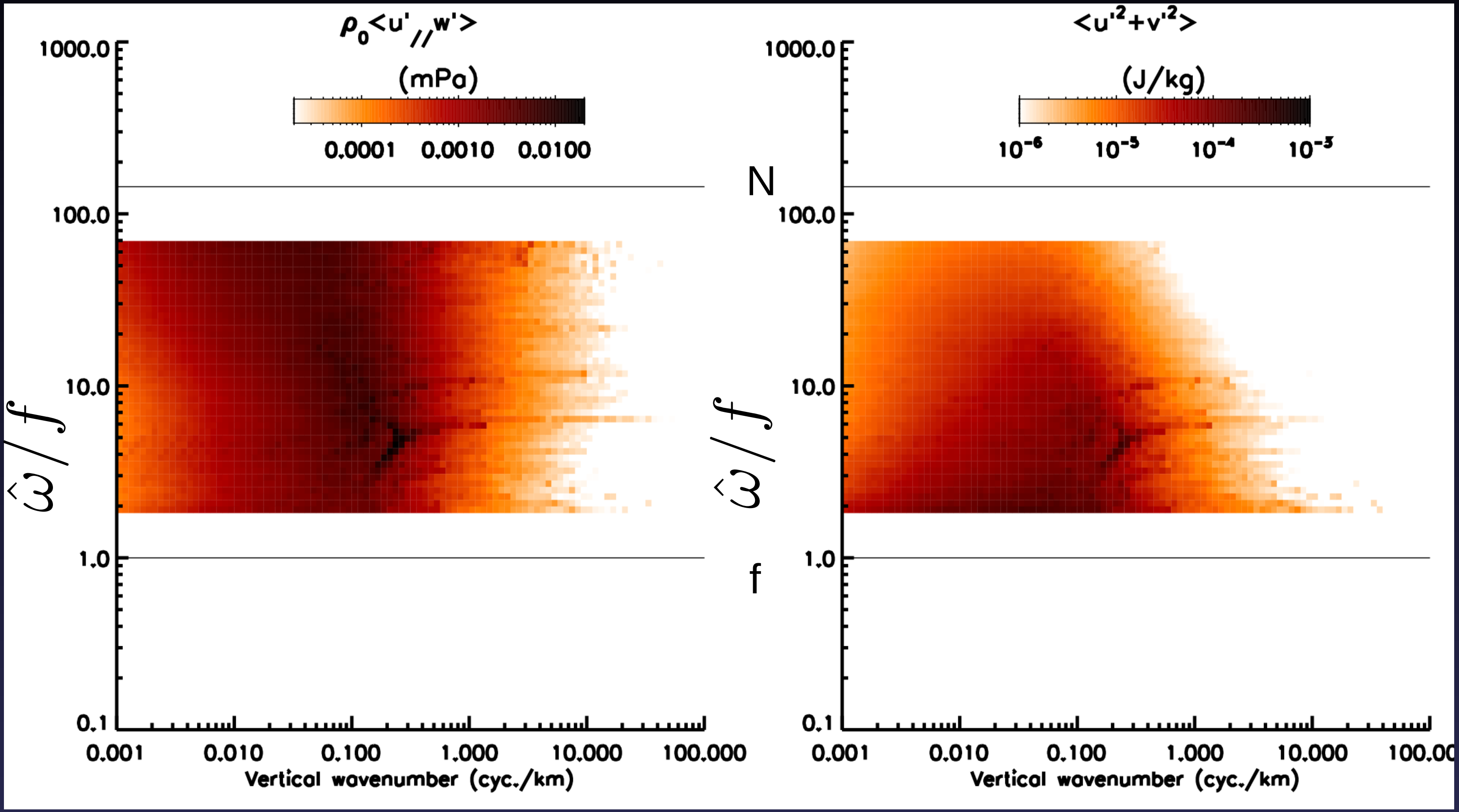


Most of the westward flux is found between 0-40 m/s, while eastward fluxes are in 0-20 m/s

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.

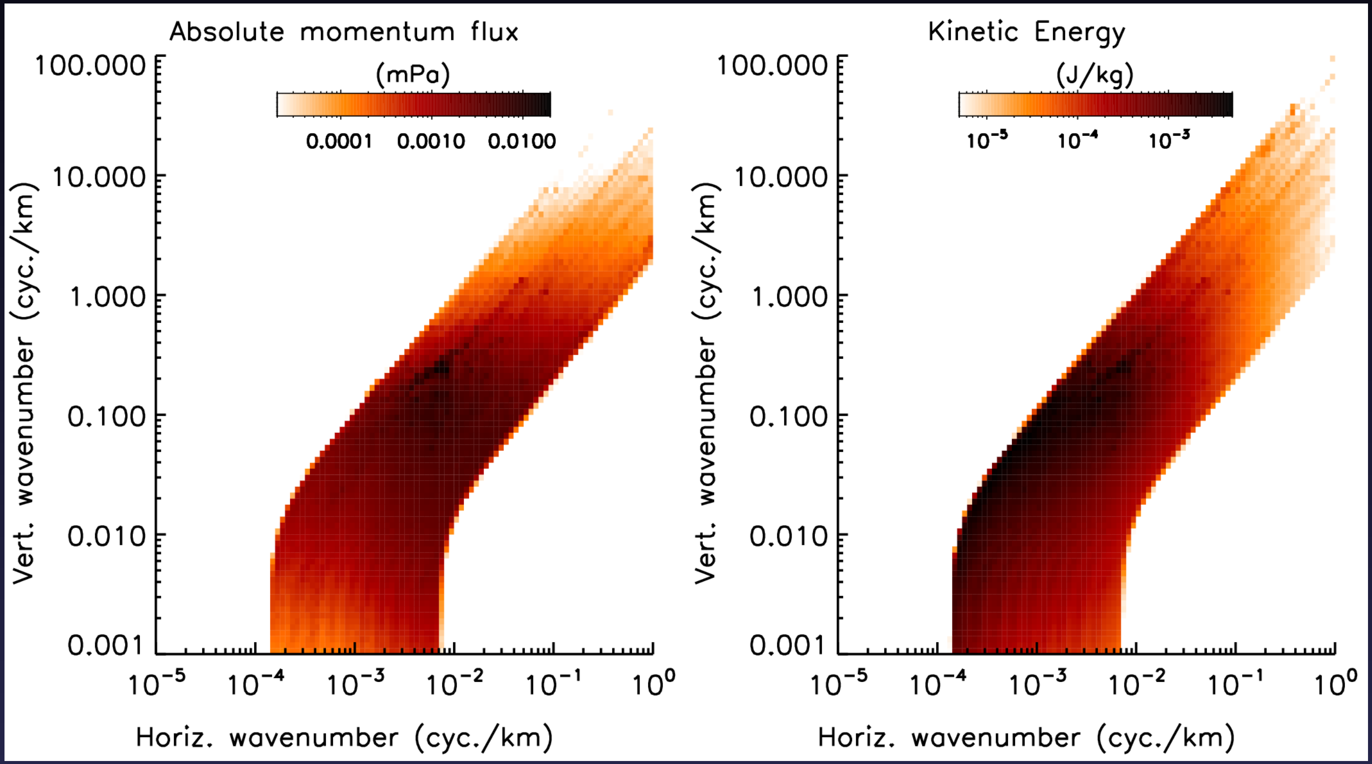
The ground-based phase speed distribution exhibits “intro waves”, i.e. waves with $c_h < \mathbf{u}\cos\theta$

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



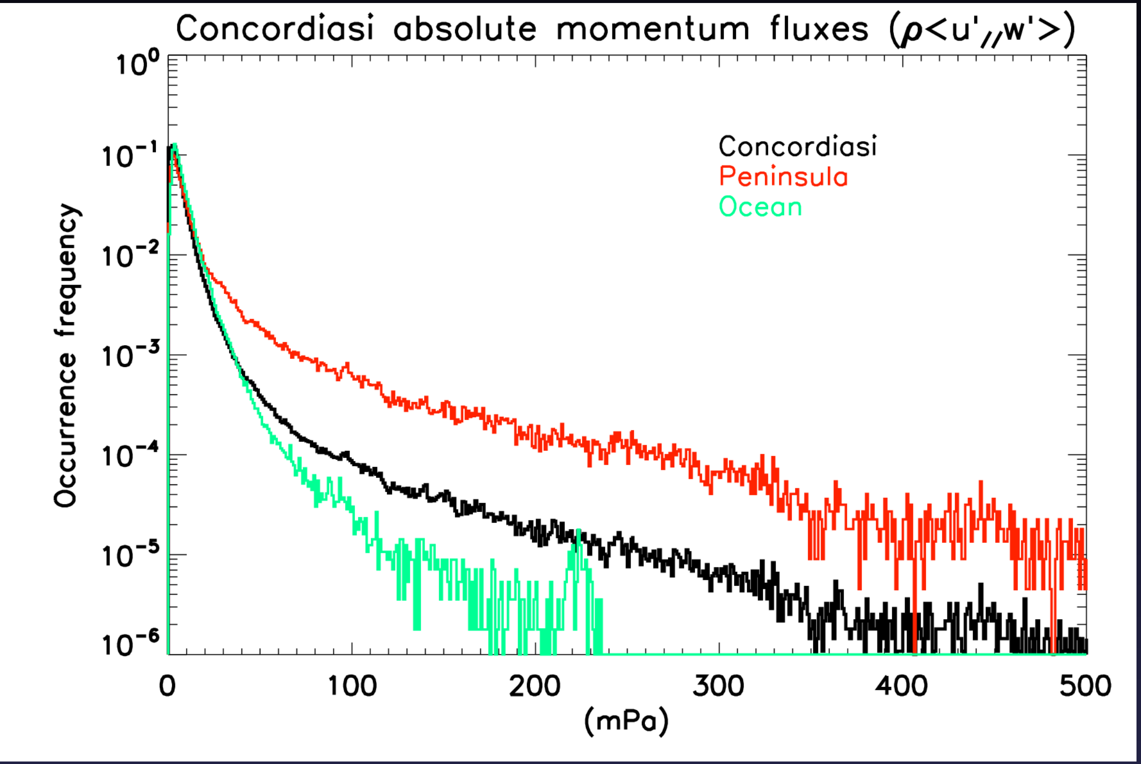
Momentum fluxes and kinetic energy maximize for vertical wavelengths between 2-30 km.
Yet, the momentum flux distribution is broader than the kinetic energy one:
in particular higher frequency waves contribute more significantly to the flux than to the energy.
Mountain waves induce the enhancement observed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

(k_h, m) distributions of momentum fluxes and kinetic energy



Momentum fluxes are mainly associated with waves with horizontal wavelengths shorter than 500 km, unlike kinetic energy.

Momentum-flux pdfs



	90th percentile	$F(f > f_{90})/F_{tot}$
Concordias	15 mPa	50 %
Peninsula	50 mPa	65 %
Ocean	15 mPa	35 %

Conclusions

- Long-duration balloon flights can provide a full characterization of GWs in the lower stratosphere (MF, phase speeds, wavelengths, etc.)
- The Antarctic Peninsula is the major GW hotspot in the SH high latitudes...
- … yet, non-orographic gravity waves are as important when zonal means are considered
- Momentum fluxes are predominantly associated with high-frequency, short horizontal wavelength waves (unlike KE)
- Observations show that GW activity is very intermittent