Full gravity-wave characteristics inferred from long-duration balloon flights in the tropics and over Antarctica

Albert Hertzog, V. Jewtoukoff, A. Podglajen, R. Plougonven
LMD, Palaiseau, France

R. A. Vincent
University of Adelaide, Adelaide, Australia

http://www.tinyurl.com/strateole

Outline

- Motivations
- Superpressure balloons and balloon flights
- Techniques to retrieve gravity-wave characteristics
- Wave characteristics
  - In the southern hemisphere polar region
  - In the tropics
- Conclusions

Motivations

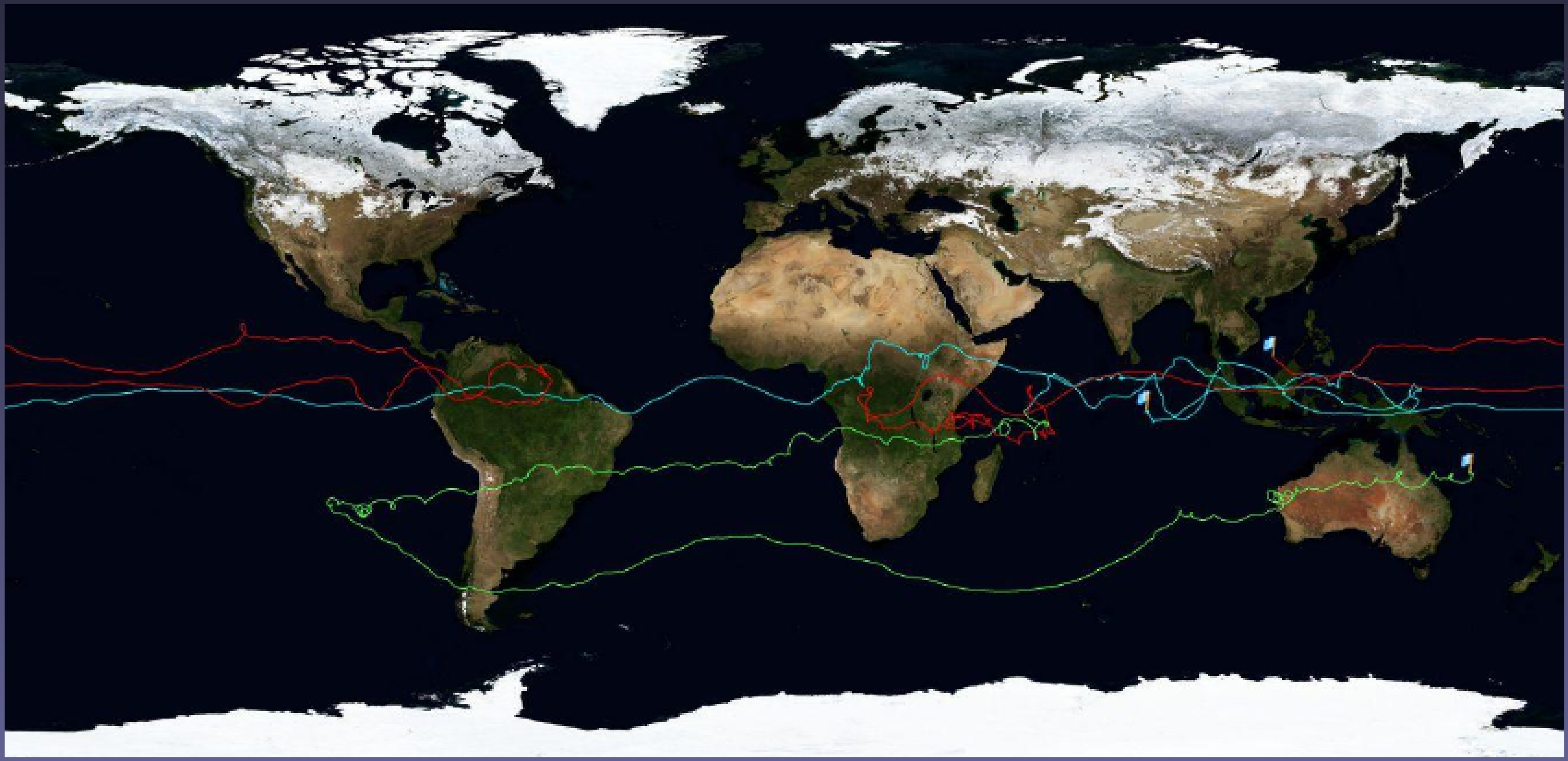
- Gravity waves contribute to the driving of middle-atmosphere large-scale circulations
  - Brewer-Dobson circulations in the extratropics
  - QBO and SAO in the tropics
- Gravity waves remain subgrid-scale processes in climate models
  - Their forcing of the background flow needs to be parameterized in those models
    - Source, propagation, breaking
- Gravity-wave observations can provide constraints to GWD parameterizations
  - Increase our confidence in climate projections

Superpressure stratospheric balloons

- (first order) Fly on constant-density surfaces in the lower stratosphere (~ 19 km/60 hPa)
  - Flight duration ~ 2-3 months
- Measurements of $\vec{X}(t), P_T(t), T(t)$
- Balloons are advected by the wind
  - u, v are deduced from successive balloon positions
  - Measurements provide intrinsic periods/frequencies ($\hat{\omega}$) of wave disturbances

Balloon flights

- Pre-Concordiasi (Tropics)
  - 3 flights
  - Feb. – May 2010
- Concordiasi (South Pole)
  - 19 flights
  - Sept. 2010 – Feb. 2011



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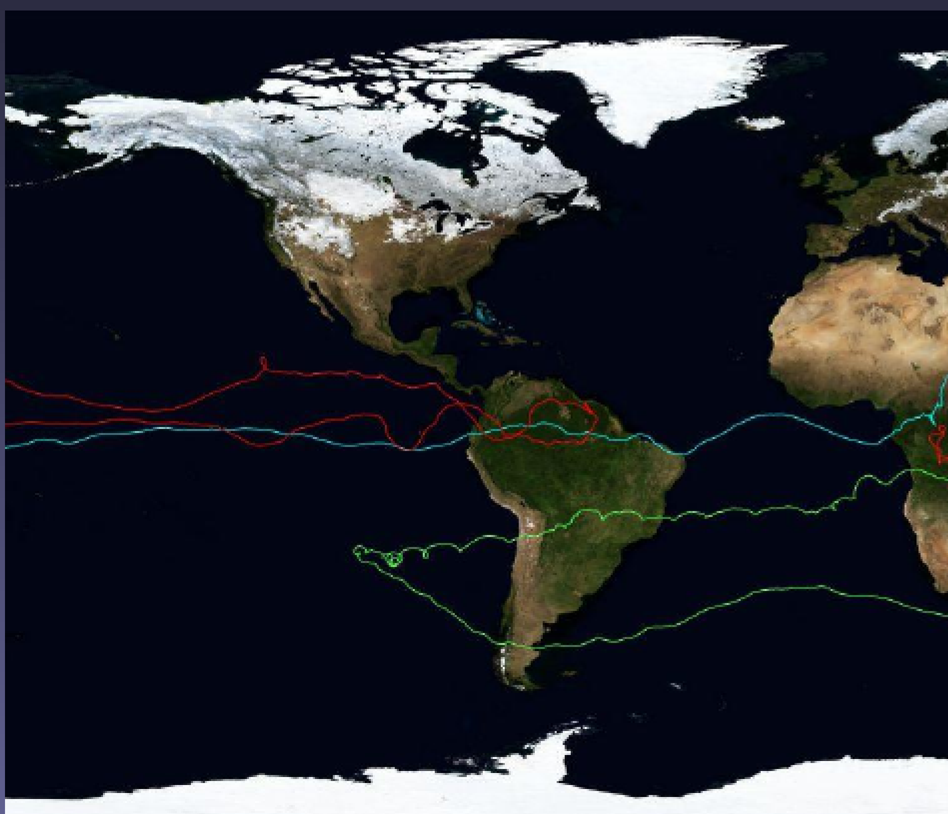
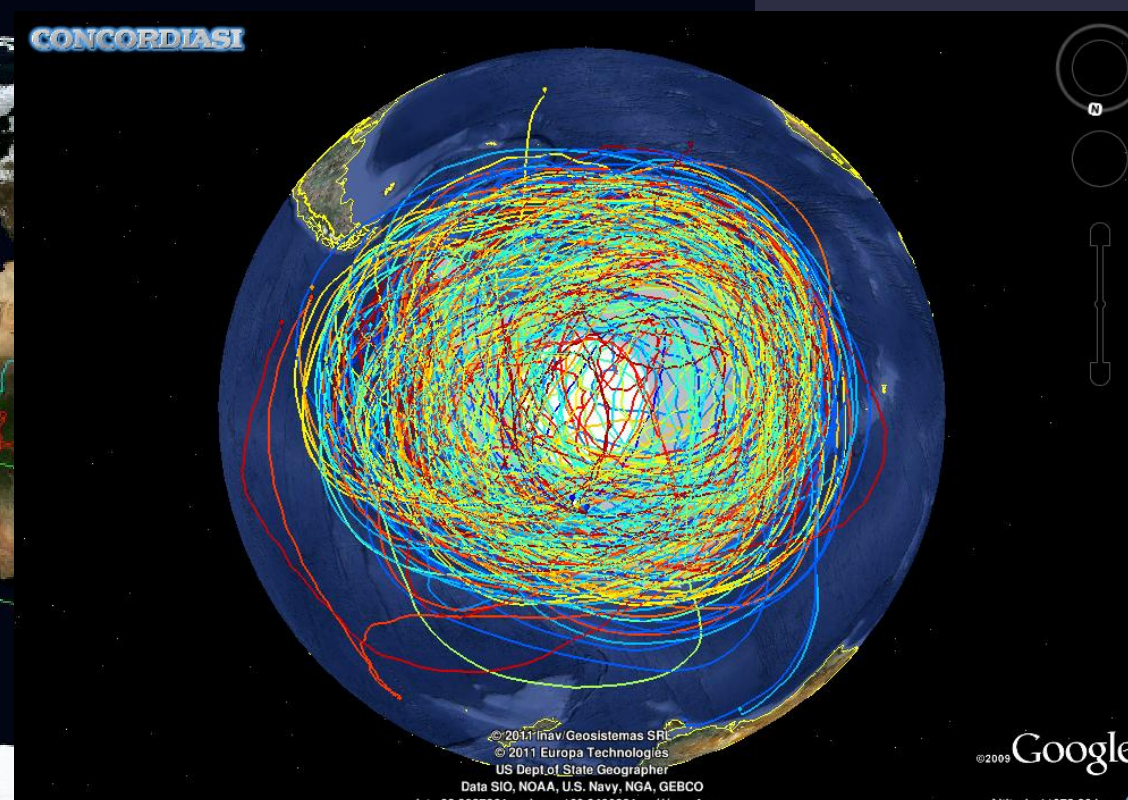
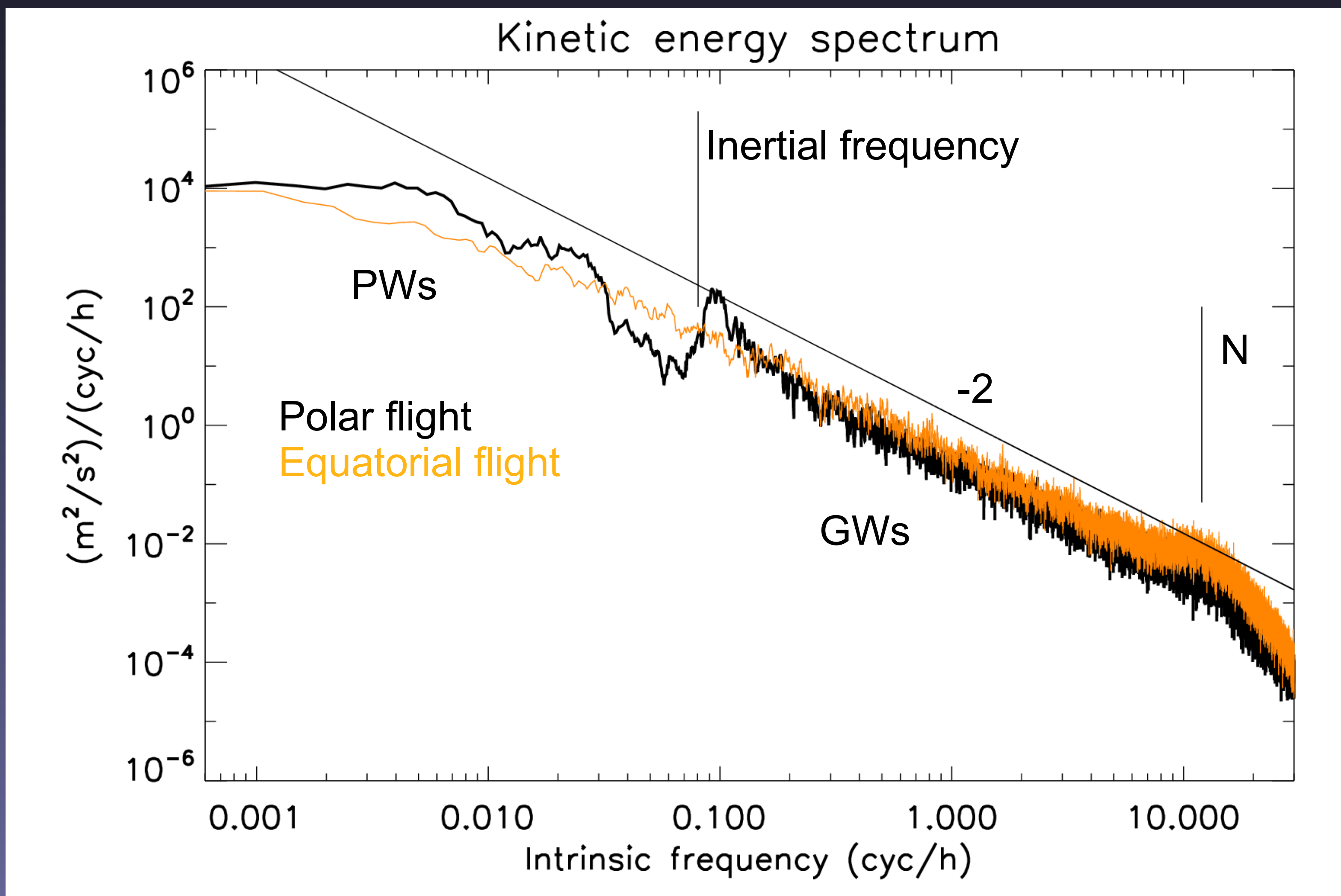




Energy spectrum with balloon obs.

GPS measurements performed every minute during the 2010 flights
=> Long-duration balloons can resolve the whole spectrum of atmospheric waves



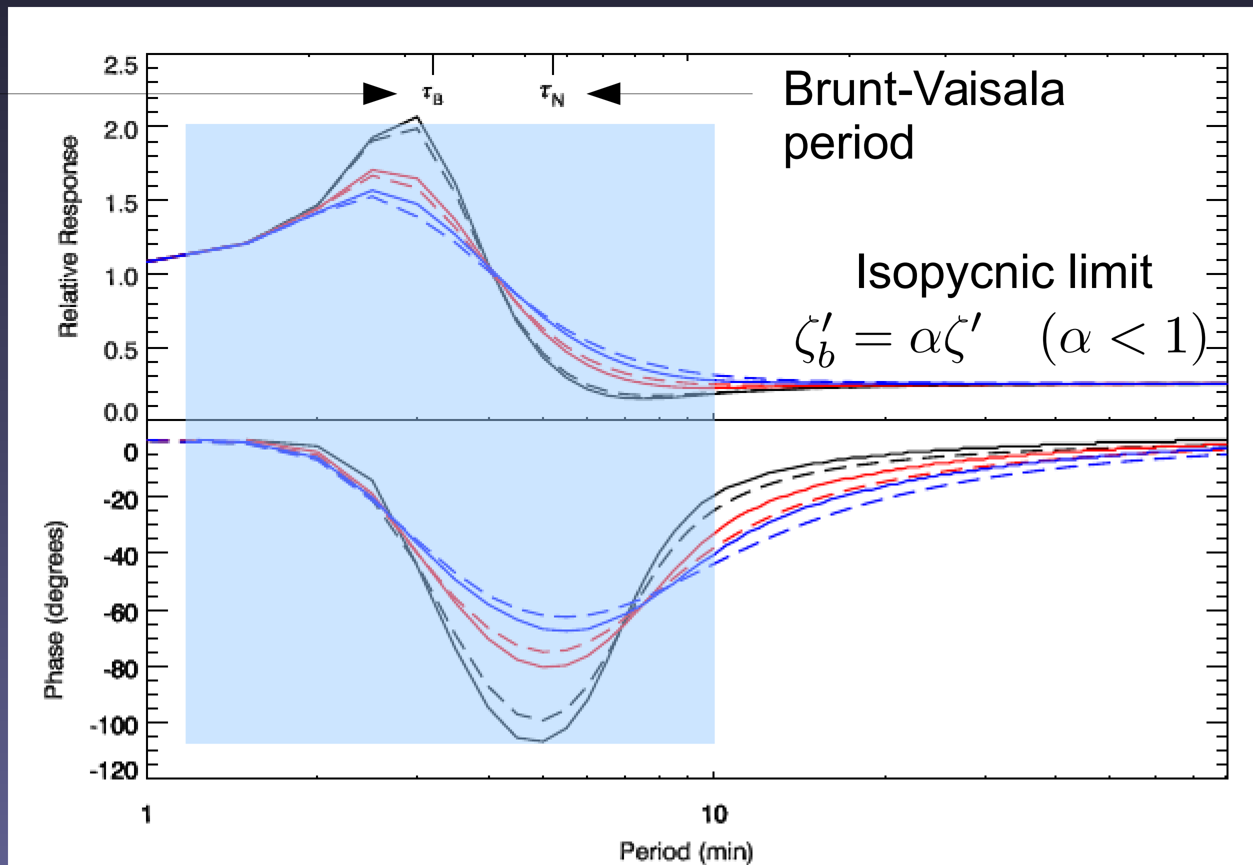
Retrievals of gravity-wave characteristics (1)

- Wavelet decomposition of observed timeseries → $(t, \hat{\omega})$ space
- Working out linear GW polarization relations, and assuming perfect isopycnic balloon...
  - Momentum flux $\mathrm{Im}(\tilde{p}_T \tilde{u}_{\parallel}^{*}) = -\bar{\rho} H \frac{N^2}{\hat{\omega}} \mathrm{Re}(\tilde{u}_{\parallel}^{*} \tilde{w})$ and wave direction of propagation
  - Phase speed $\hat{c} = \frac{1}{\bar{\rho}\delta_-} \frac{\mathrm{Re}(\tilde{p}\tilde{u}_{\parallel}^{*})}{\tilde{u}_{\parallel}^{2}}$, where $P_T' = P' + \zeta_b' \frac{\partial \overline{P}}{\partial z}$
  - Vertical wave number $m = -\bar{\rho}^2 \hat{c} \delta_- \left(\frac{N^2 - \hat{\omega}^2}{\hat{\omega}} \right) \frac{\mathrm{Re}(\tilde{u}_{\parallel}^{*} \tilde{w})}{\tilde{p}^2}$
  - 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 balloons are not perfectly isopycnic...
- We looked at the response of superpressure balloons to gravity-wave disturbances *(Vincent & Hertzog, AMT, 2014)*

Balloon neutral oscillation period

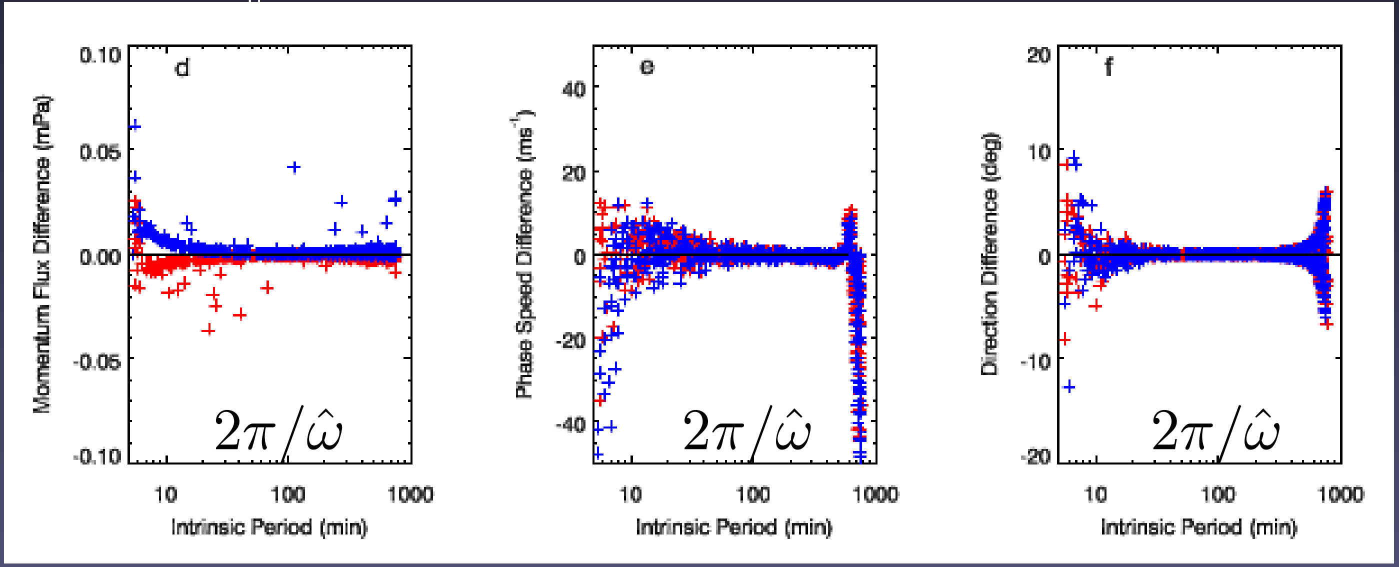


Intrinsic period (min)

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

$\overline{u'_{\parallel} w'}$ $\hat{c}_h$ θ



$2\pi/\hat{\omega}$ $2\pi/\hat{\omega}$ $2\pi/\hat{\omega}$

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

Vincent and Hertzog (2014)

Gravity-wave momentum fluxes

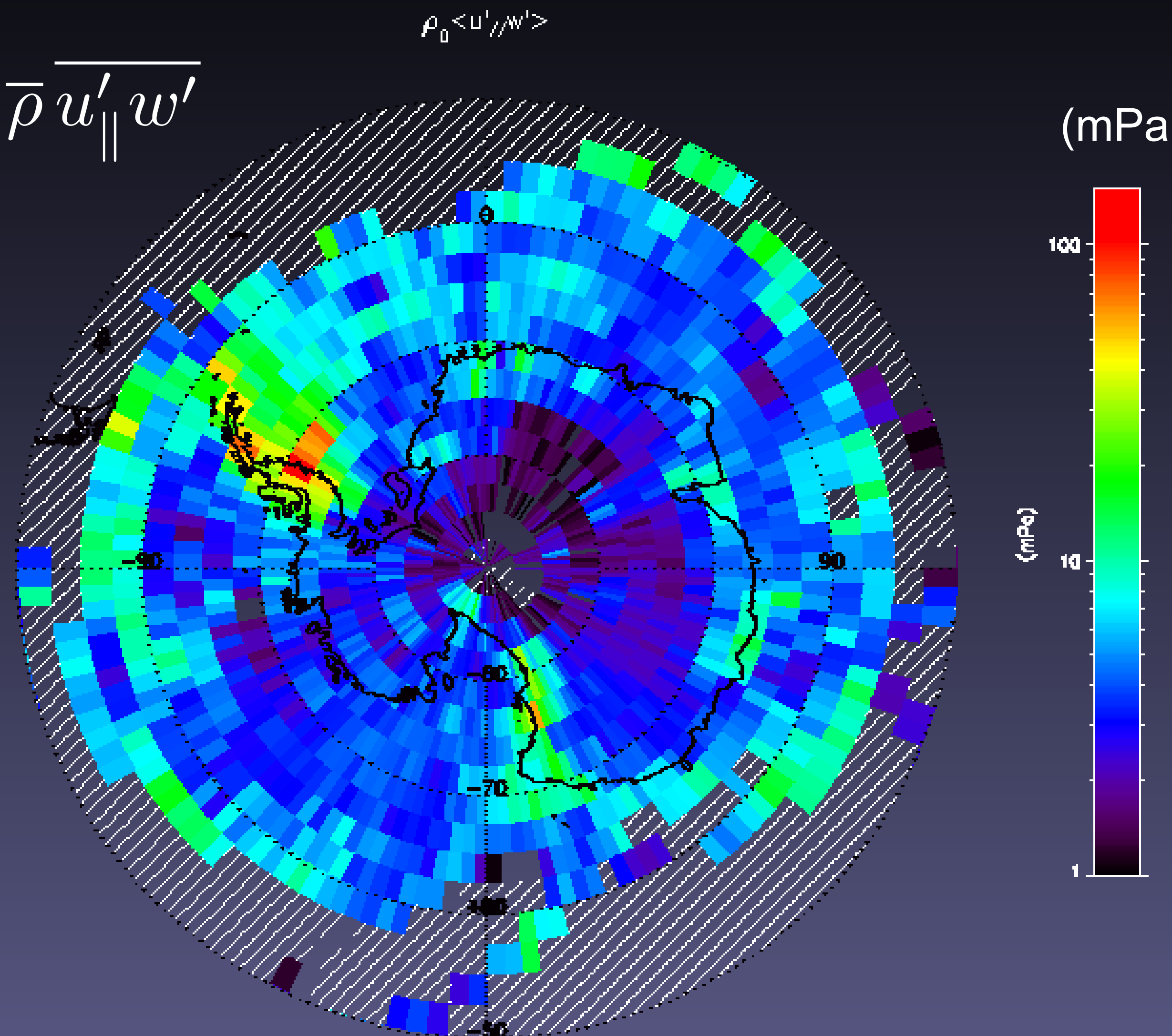
$$\overline{\rho}\,\overline{u'_{\|}w'}$$

Campaign mean: 8.8 mPa

Largest values over Peninsula and Transantarctic mountains (maximum: 180 mPa)

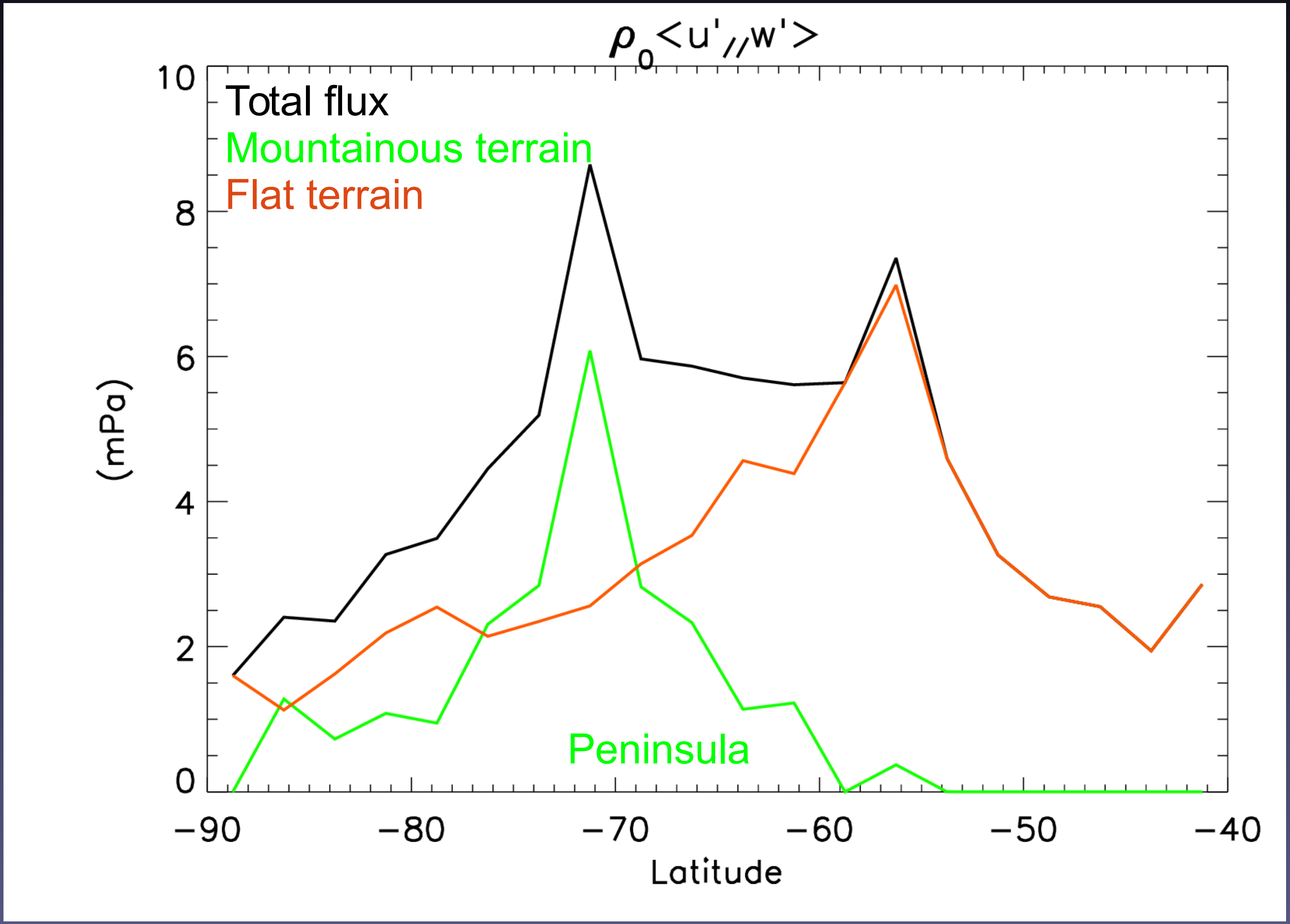
Lowest values over the Plateau

Ring of 8-10 mPa fluxes at 60°S over the ocean



Absolute momentum fluxes
(Concordiasi 2010)

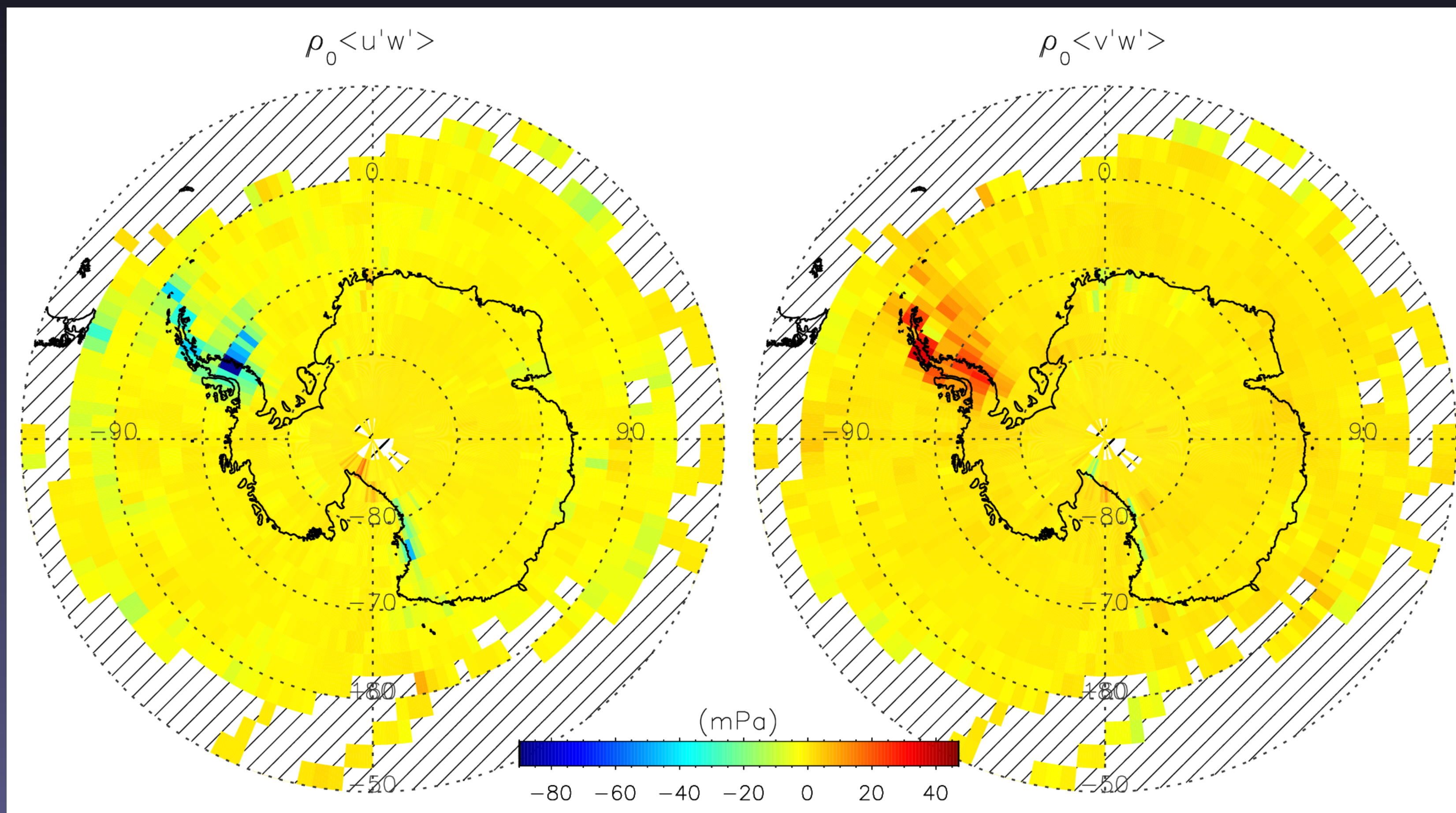
Zonal-mean flux distribution



Zonal-mean momentum fluxes exhibit a secondary peak at 55°S, which seems to be associated with non-orographic gravity waves in the balloon data: Jet/front waves in the SH storm track

Zonal and meridional momentum fluxes

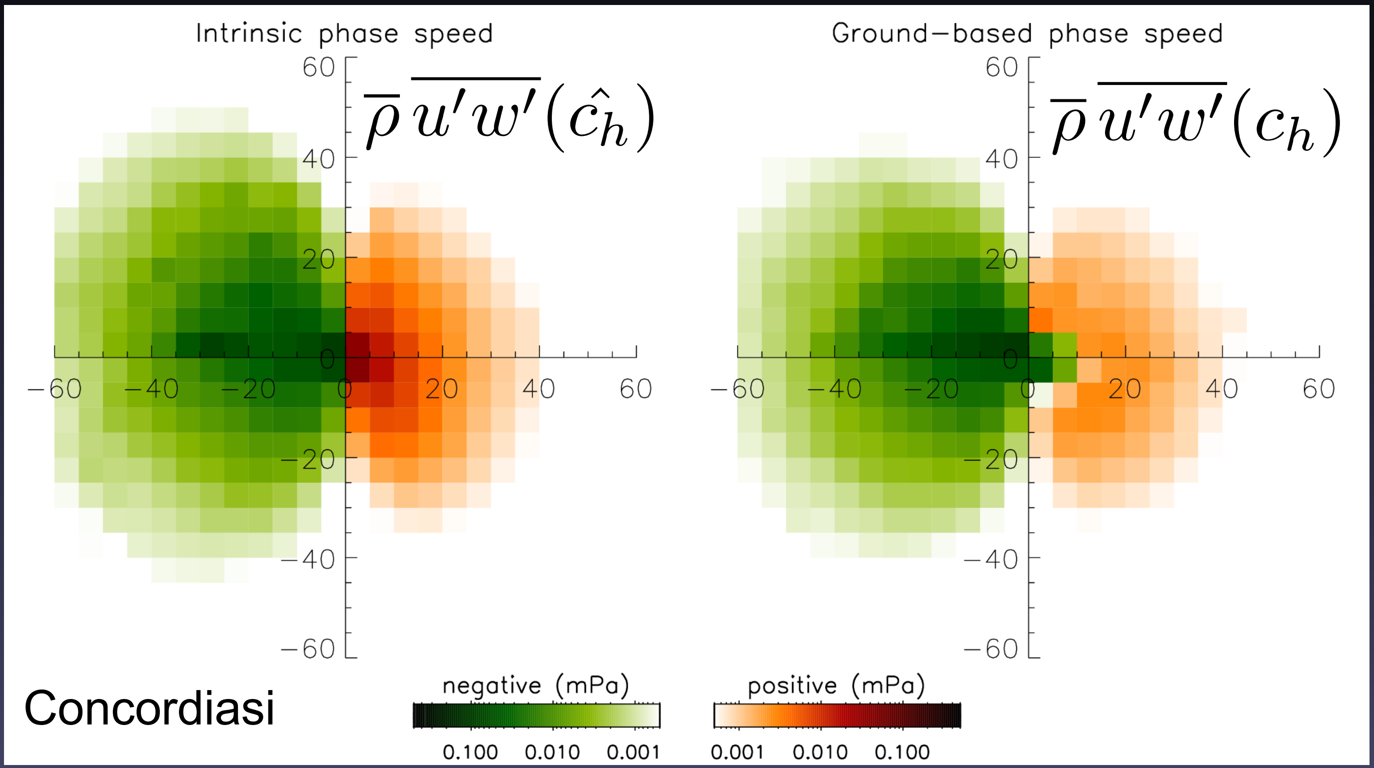
$\overline{\rho}\,\overline{u'w'}$ $\overline{\rho}\,\overline{v'w'}$



Zonal momemtum fluxes are negative almost everywhere
Campaign mean: -1.2 mPa

Insignificant bias on meridional momemtum fluxes
Campaign mean: 0.1 mPa

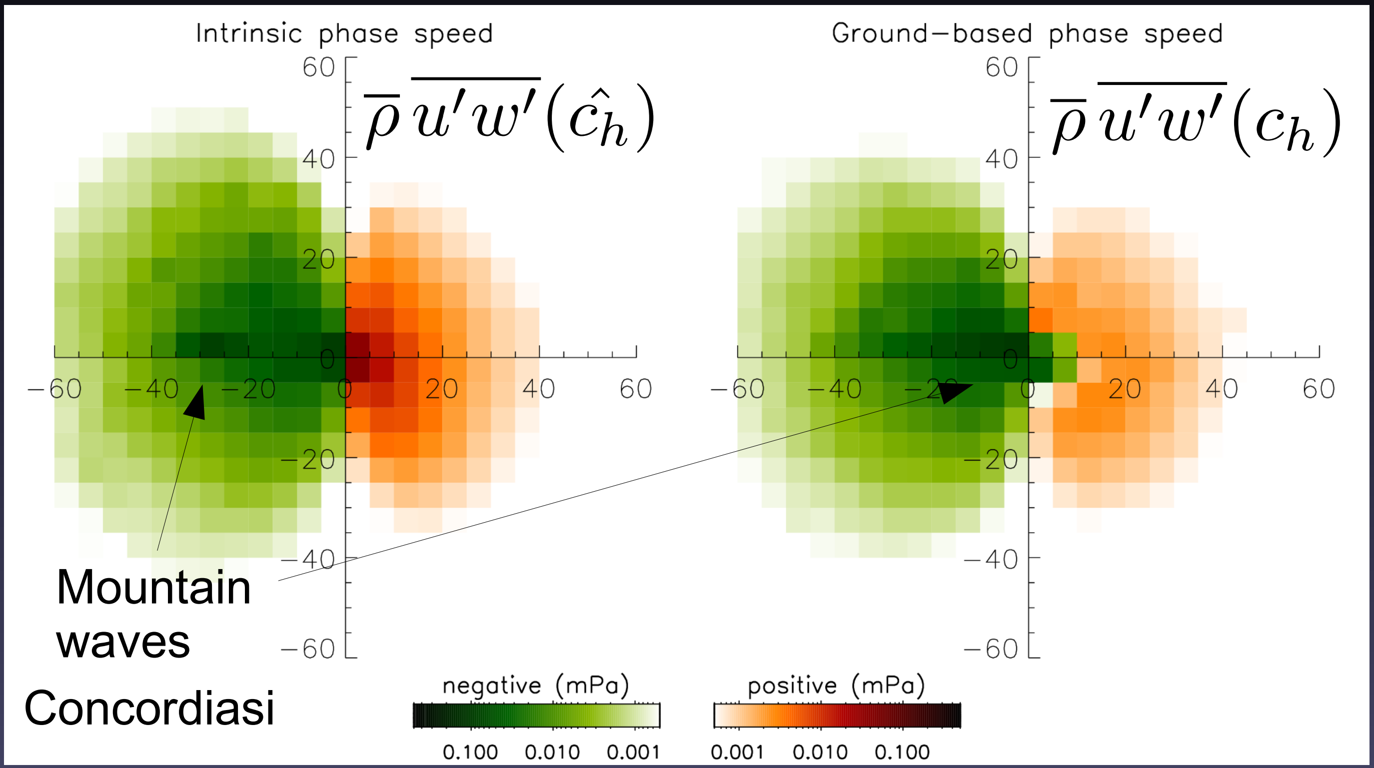
Phase-speed momentum-flux spectrum



Polar flights indicates a predominance of westward-propagating waves in the LS

Waves with zero ground-based phase speeds are associated with westward fluxes, i.e. mountain waves

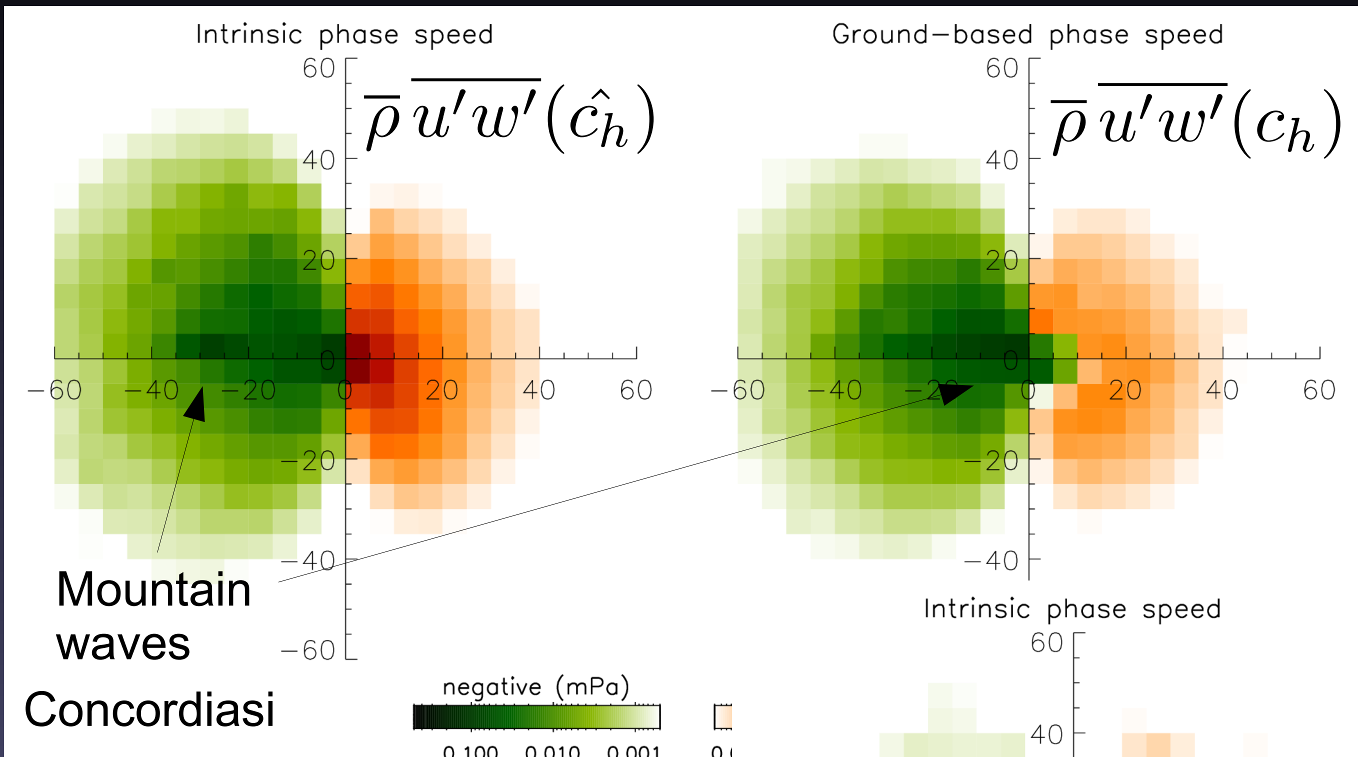
Phase-speed momentum-flux spectrum



Polar flights indicate the predominance of westward-propagating waves in the LS

Waves with small ground-based phase speeds are associated with westward fluxes, i.e. mountain waves

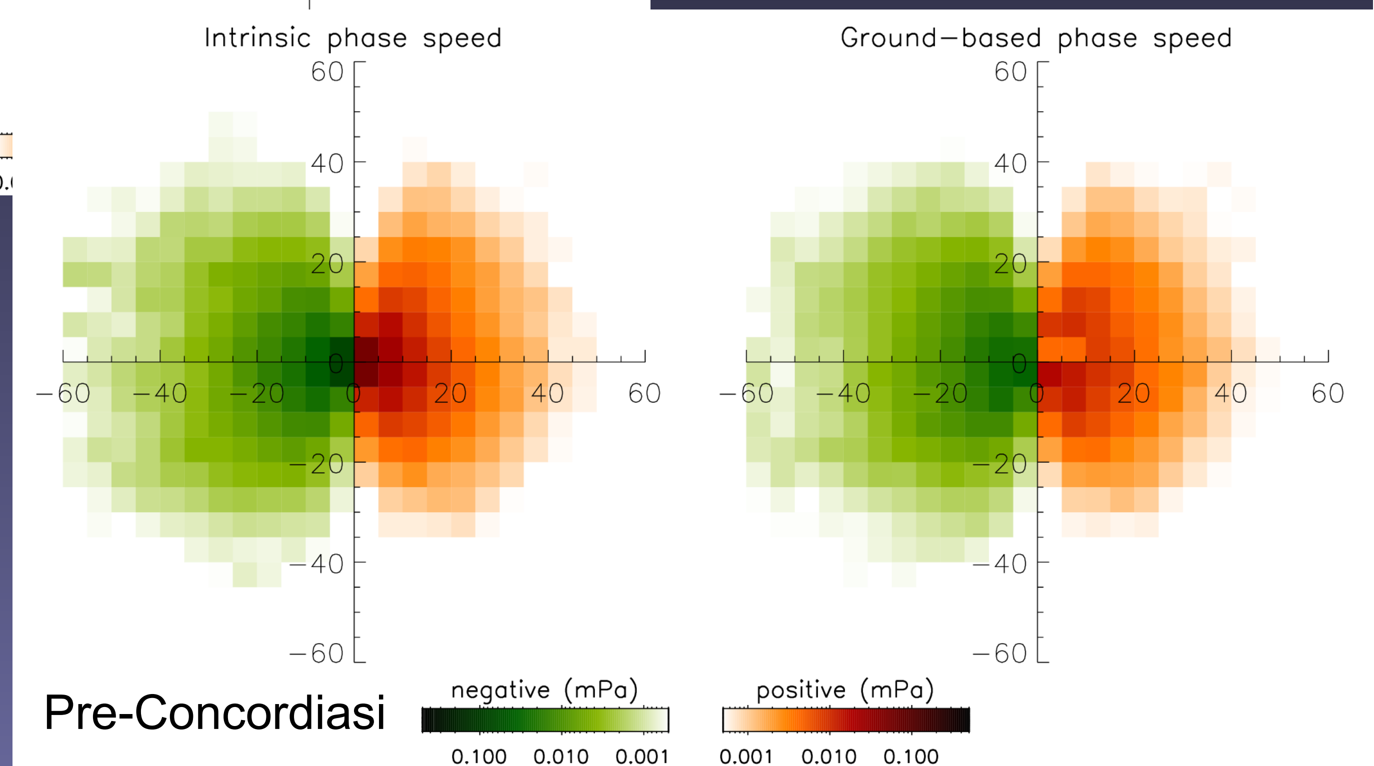
Phase-speed momentum-flux spectrum



Polar flights indicates the predominance of westward-propagating waves in the LS

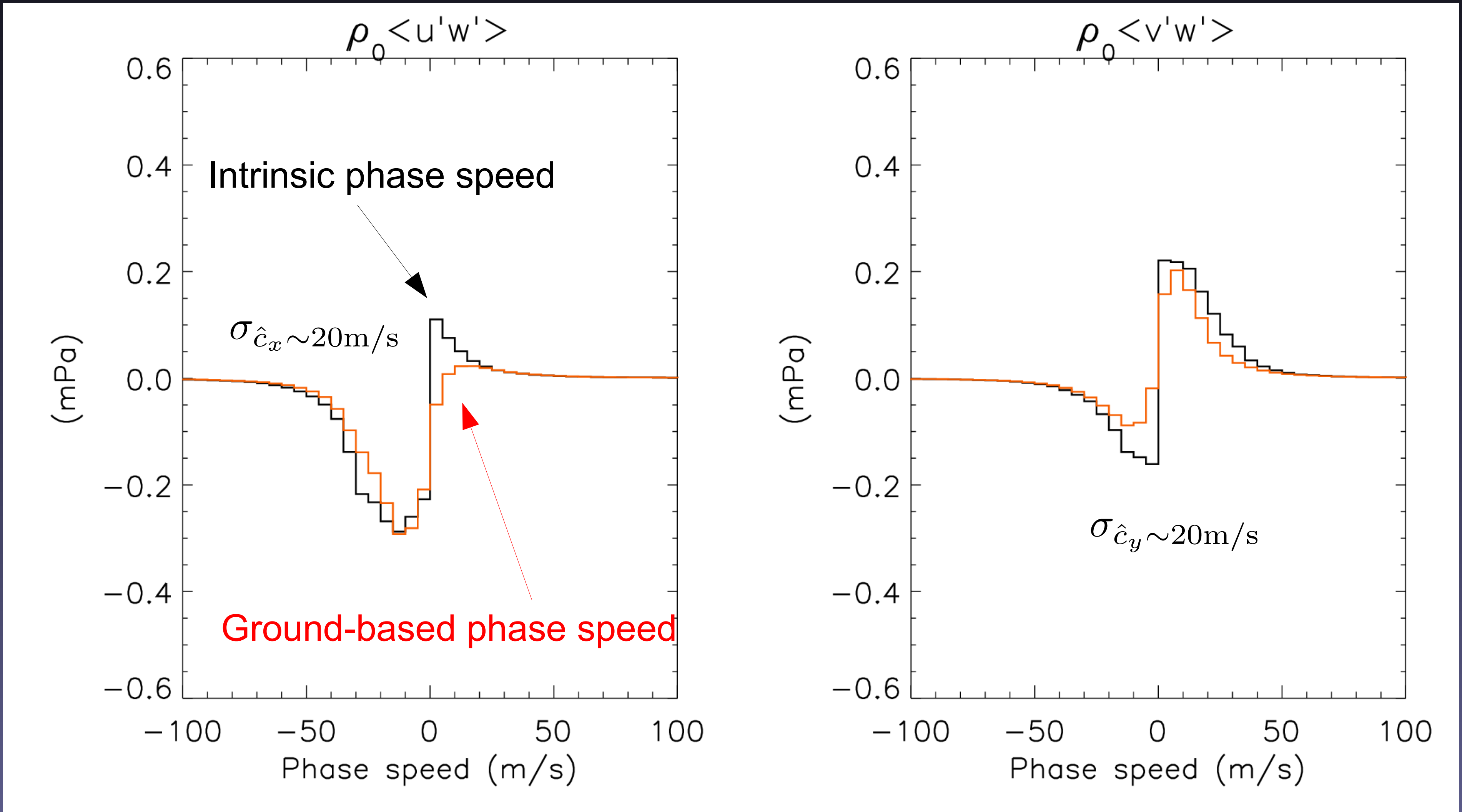
Waves with small ground-based phase speeds are associated with westward fluxes, i.e. mountain waves

Tropical flights do not show any preferential direction of propagation (isotropic sources + balloons experienced both QBO phases)



1D phase-speed spectrum

Concordiasi flights

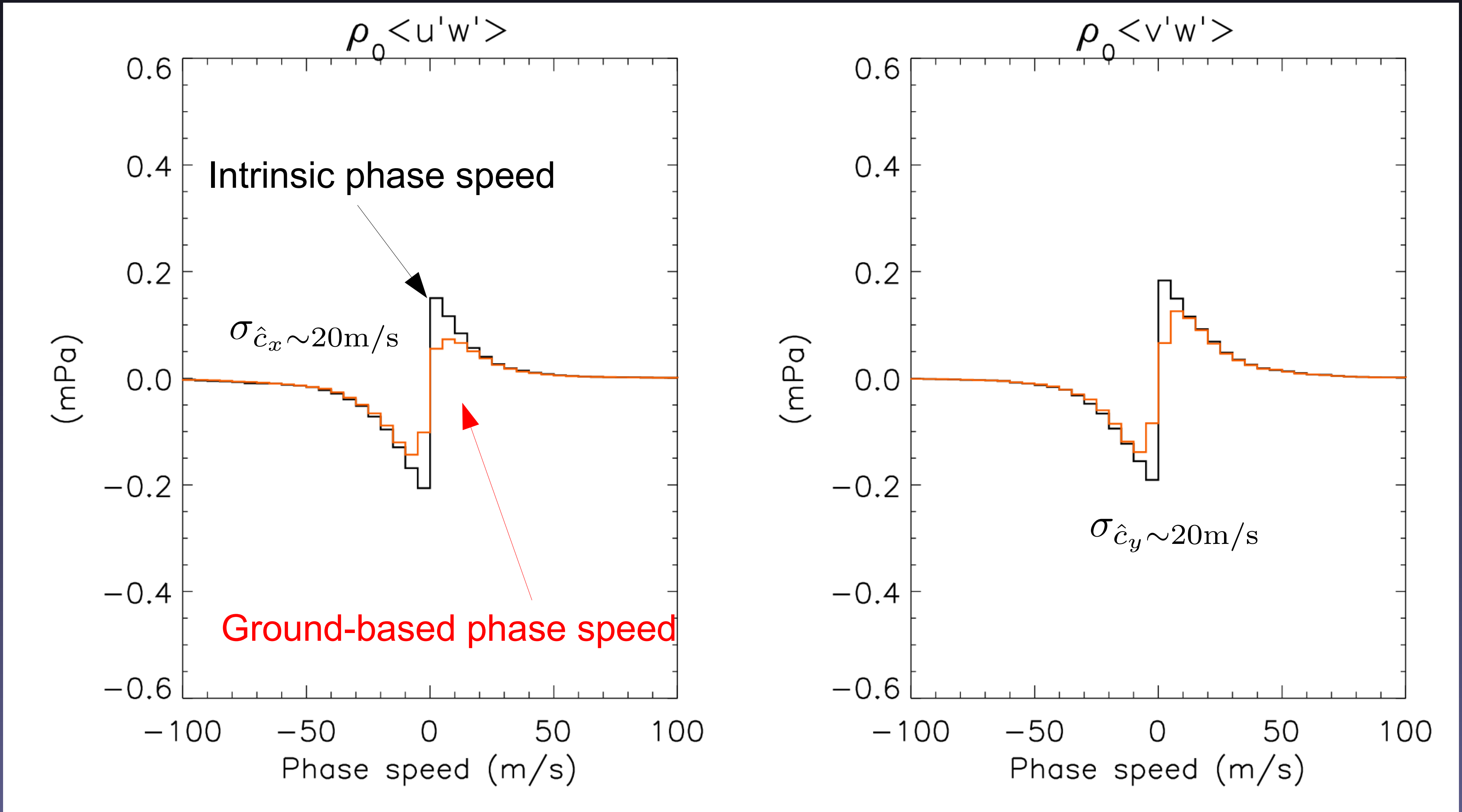


Most of the flux associated with |c| < 50 m/s

Ground-based phase-speed spectrum narrower than the intrinsic phase-speed spectrum

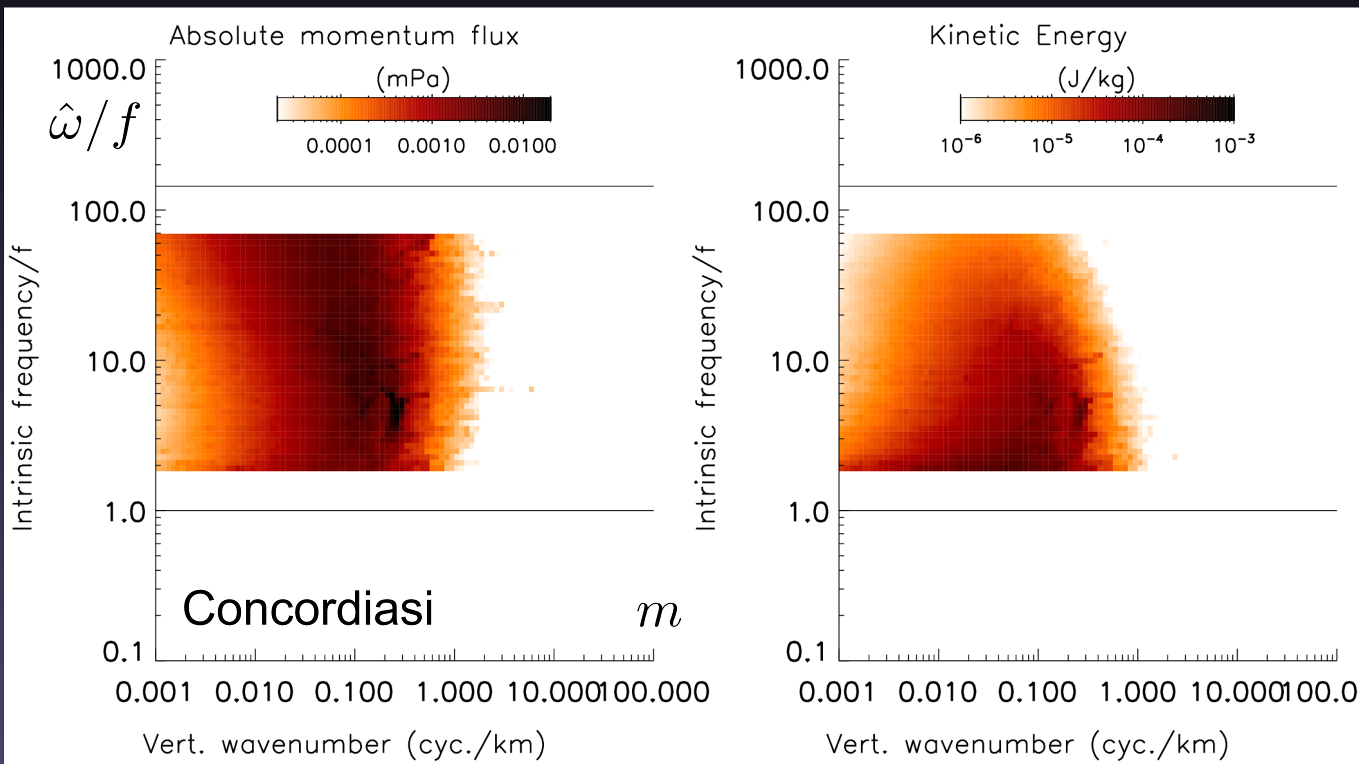
1D phase-speed spectrum

Pre-Concordiasi flights



Phase-speed spectrum in the tropics are more symmetric than over the Pole
Isotropy of convective source and wind filtering

$(m, \hat{\omega})$ 2D spectra

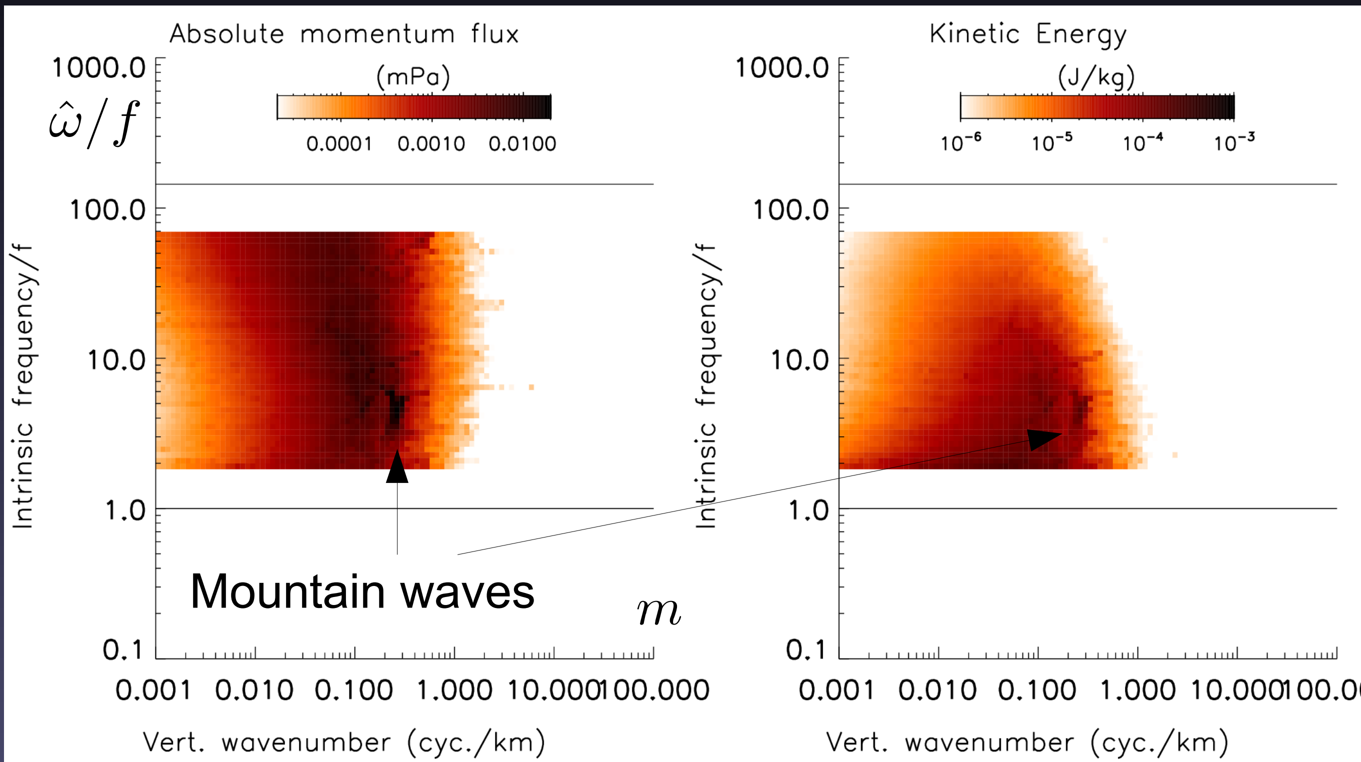


Momentum fluxes almost separable in m and $\hat{\omega}$
Largest fluxes associated with 3-10 km

(Kinetic-) energy associated with mostly long-period waves

Mountain waves show up at λ_z=3 km, $\hat{T}$= 1-4 hr
Corresponding to λ_h=100-200 km

$(m, \hat{\omega})$ 2D spectra



Momentum fluxes almost separable in m and $\hat{\omega}$

Largest fluxes associated with 3-10 km

(Kinetic-) energy associated with mostly long-period waves

Mountain waves show up at λ_z=3 km, $\hat{T}$= 1-4 hr

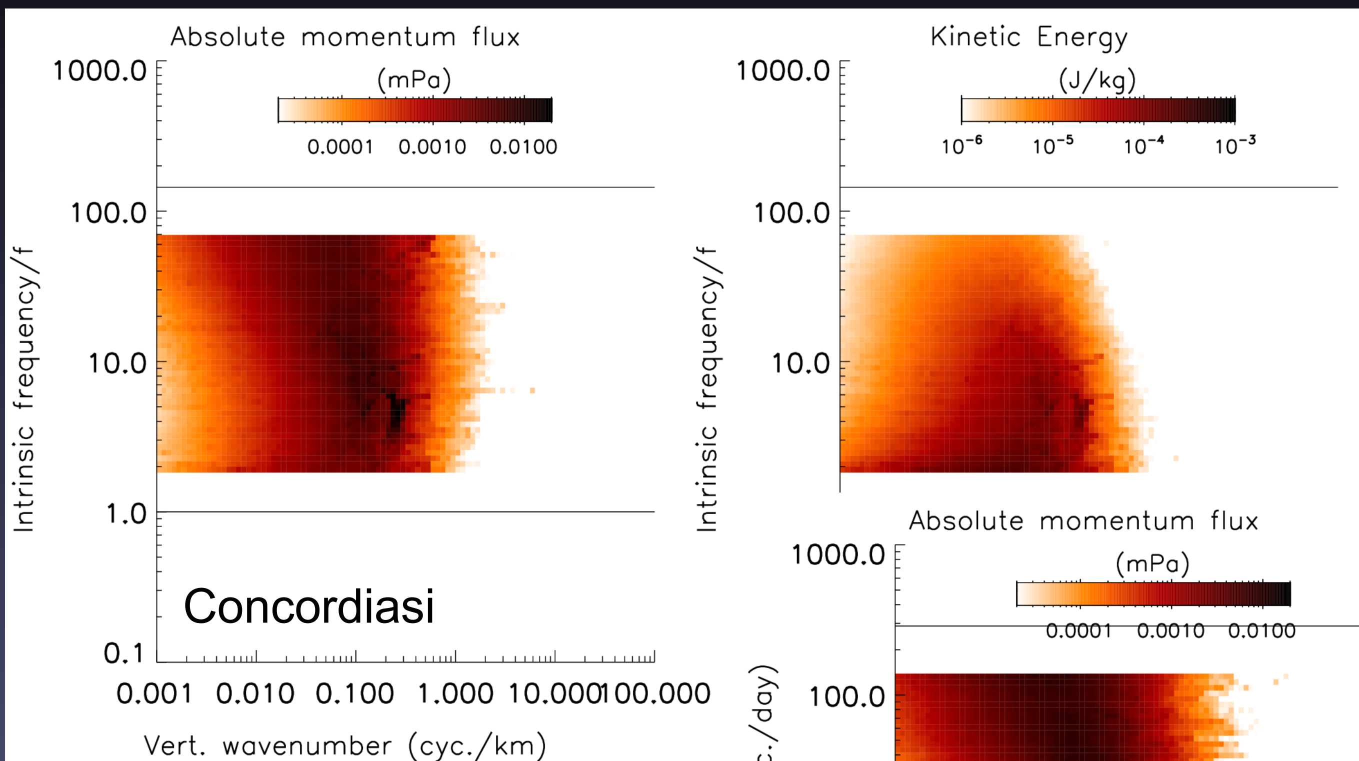
Corresponding to λ_h=30-150 km

$(m, \hat{\omega})$ 2D spectra

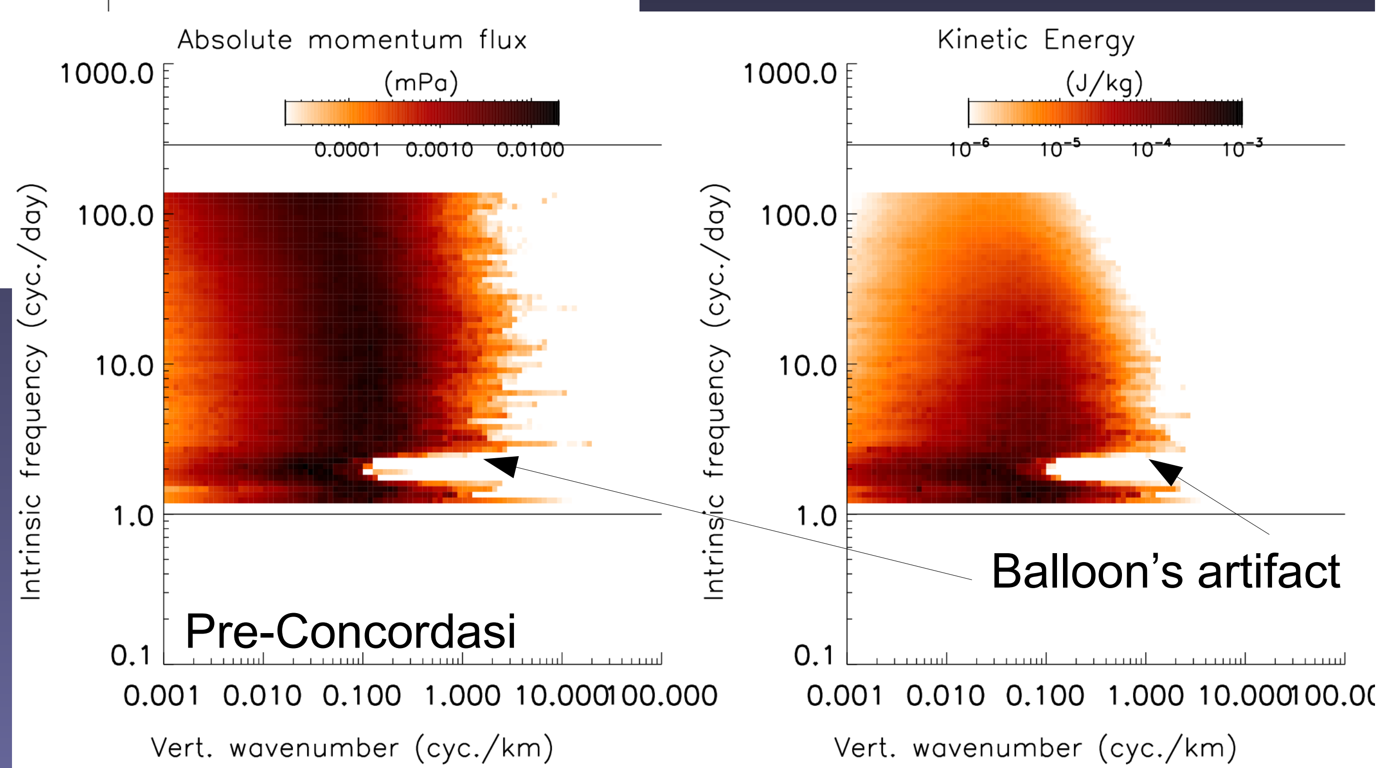
Momentum fluxes almost separable in m and $\hat{\omega}$
Largest fluxes associated with 3-10 km

(Kinetic-) energy associated with mostly long-period waves

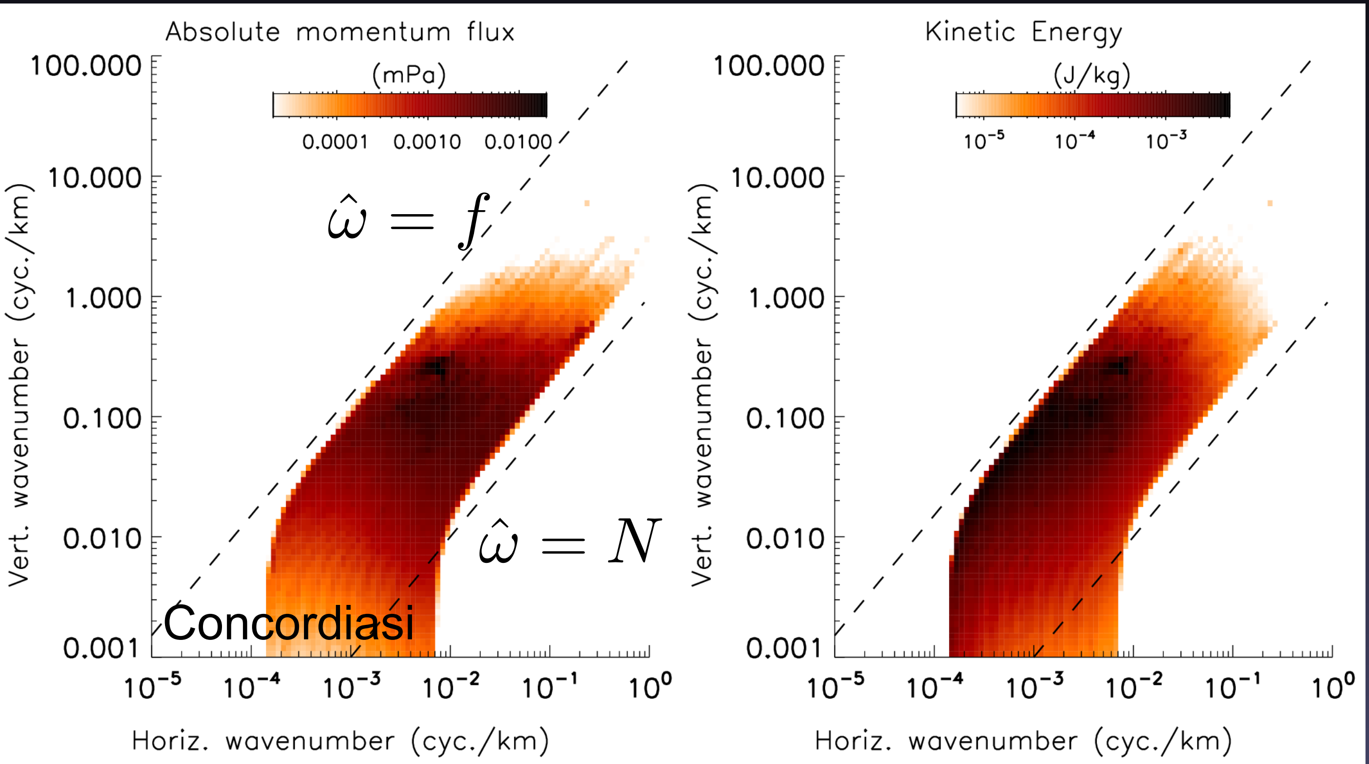
Mountain waves show up at λ_z=3 km, $\hat{T}$ = 1-4 hr



Equatorial 2D spectra much like the polar ones, but extend to lower intrinsic frequencies (and we did not explore the even longer-period waves)

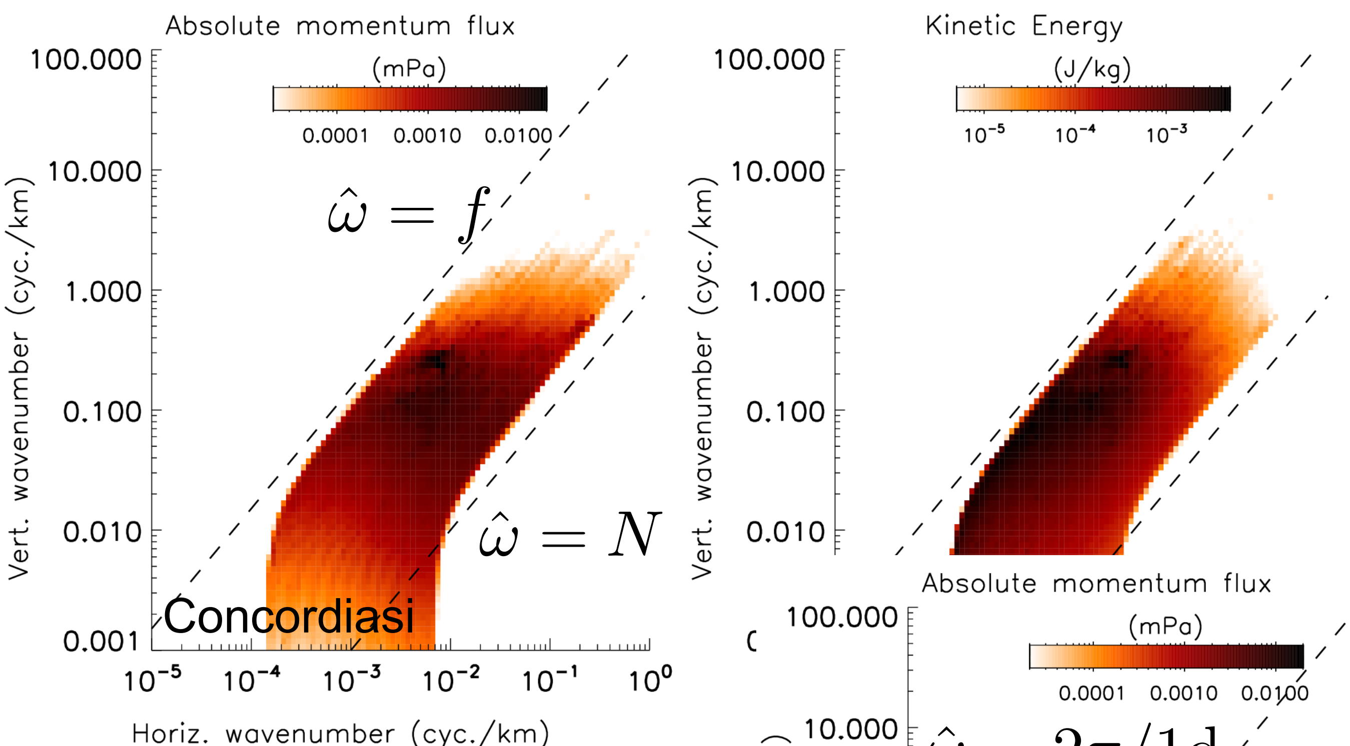


(k_h, m) 2D spectra



Waves with small horizontal scales (down to 10 km) contribute more to the momentum fluxes than to the kinetic energy

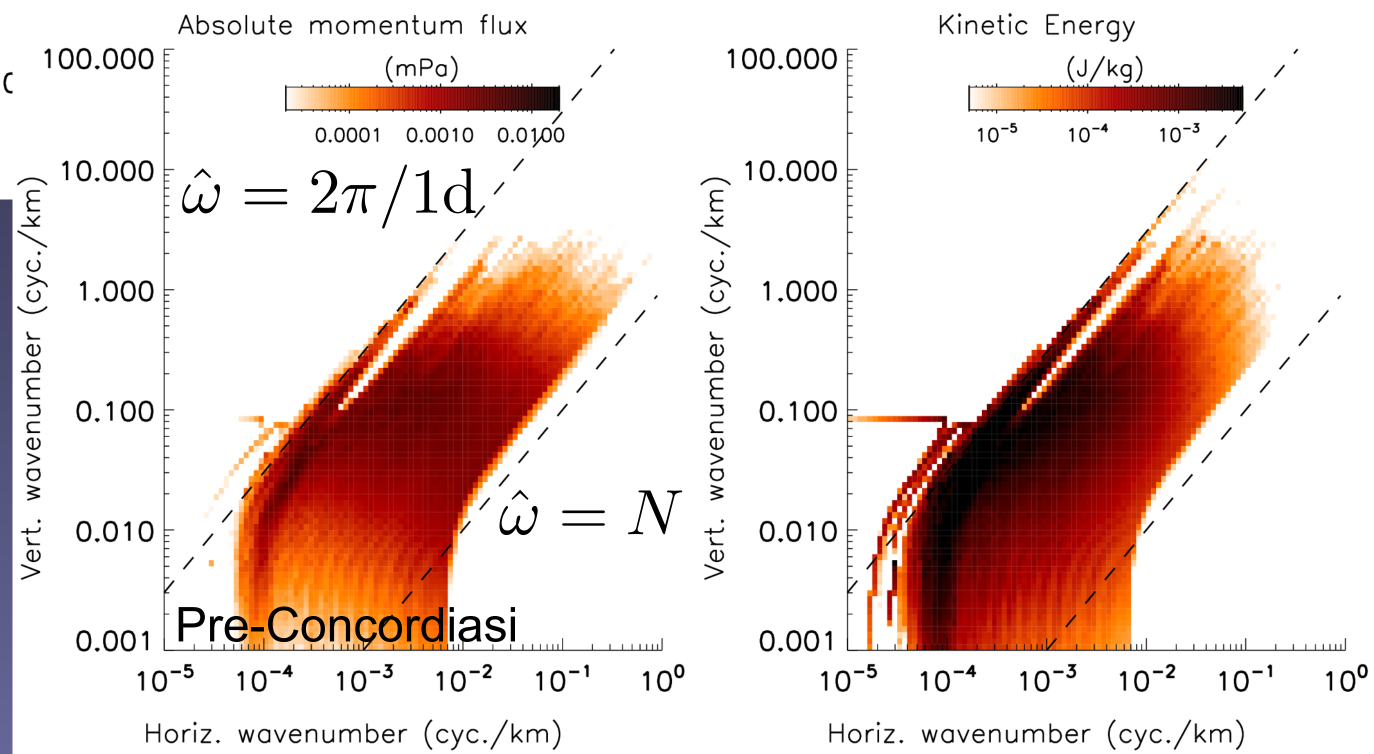
(k_h, m) 2D spectra



Waves with small horizontal scales (down to 10 km) contribute more to the momentum fluxes than to the kinetic energy

Kinetic-energy dominated by long-horizontal, long-period waves in the tropics

Momentum flux spectrum broader
(shallower spectral slopes)



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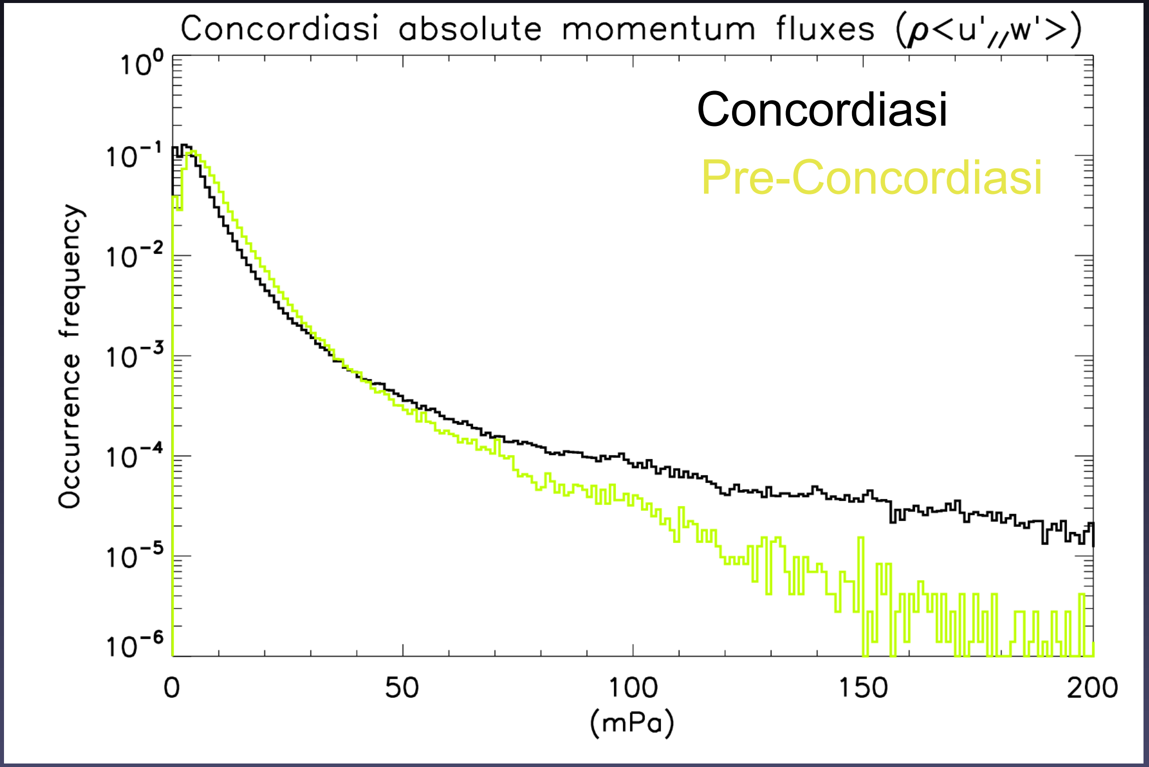

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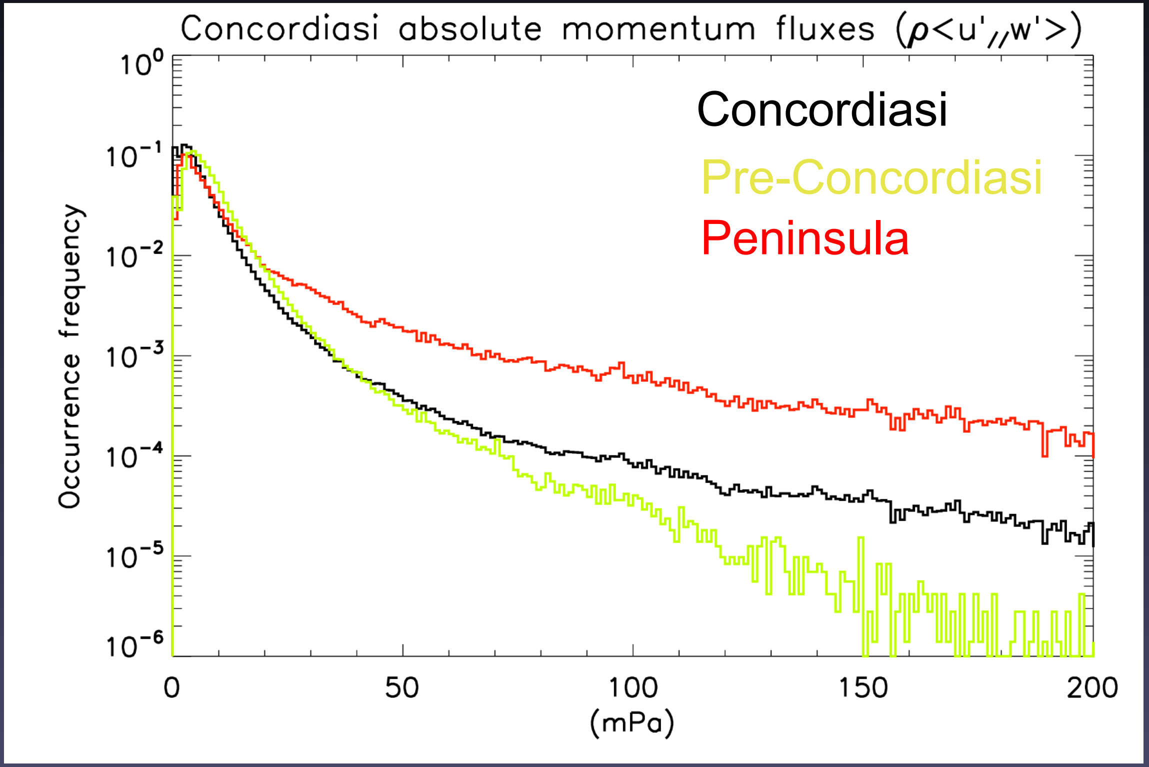

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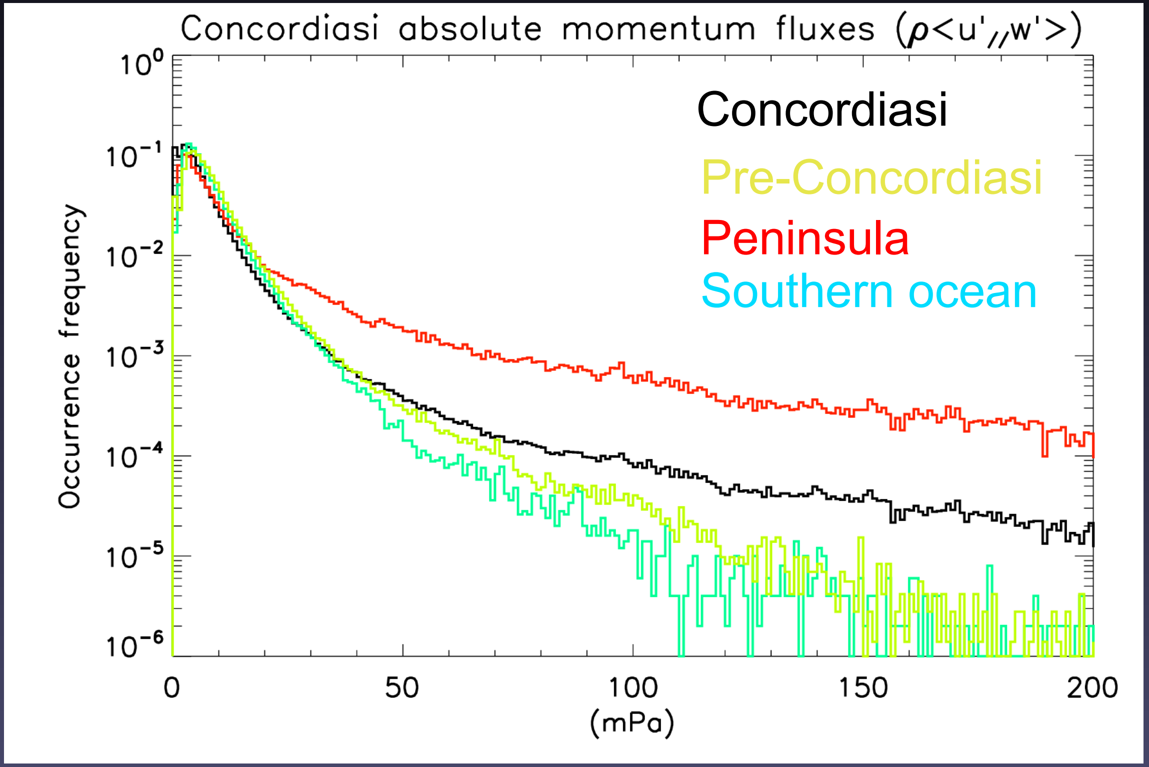

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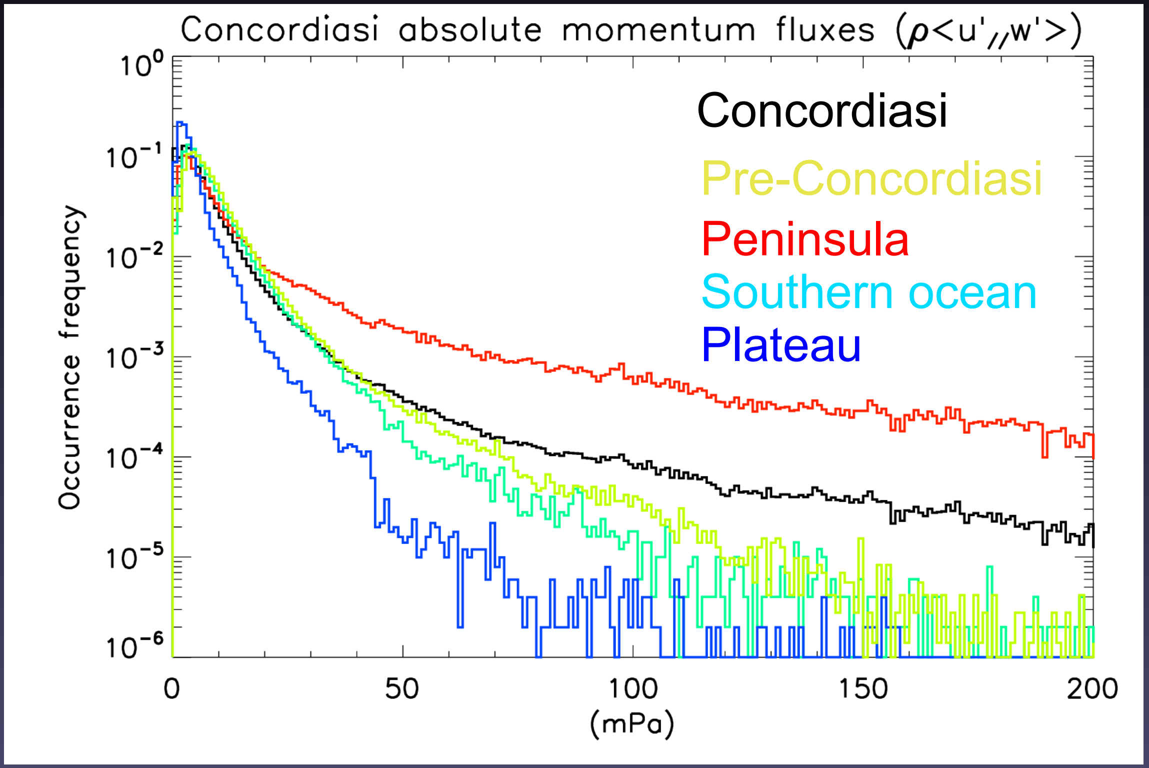

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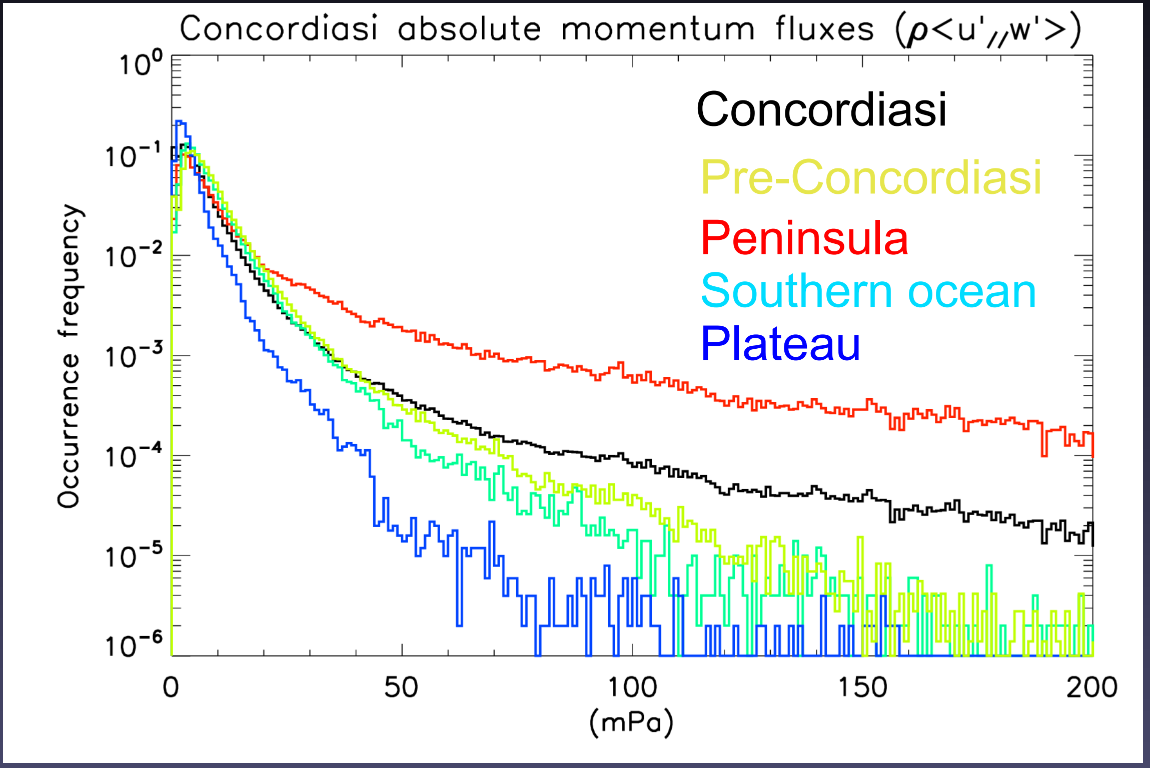

Contribution of the 10% largest wave events to the total flux
Pre-Concordiasi: 32%
Southern Ocean: 32%
Plateau: 37%
Concordiasi: 49%
Peninsula: 84%

Conclusions

- Long-duration balloons provide a unique description of the whole gravity-wave field in the lower stratosphere
  - Quantitative assessment of momentum fluxes in the lower stratosphere
    - Peninsula mountain wave hotspot
    - Importance of non-orographic GW on the zonal-mean MF at 50-60°S
  - Insights into phase-speed spectrum and horizontal/vertical wavelenghts
  - Highlight gravity-wave intermittency

- Strateole 2 (2018-2023) will study wave processes at global scale in the deep tropics
  - 45 balloon flights in total
  - Generation by convection
  - Forcing of the QBO/SAO
  - Transport through the CPT
  - Interaction with microphysics


Thank you for
your attention!