

Surfing Tropical Waves in the Lower Stratosphere: Inferences on Waves and Winds from Long-Duration Super-Pressure Balloons and Balloon-borne Radio Occultation Profiles

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BACKGROUND

Motivation: Short Vertical Wavelength Tropical Waves

...have important climate influences:

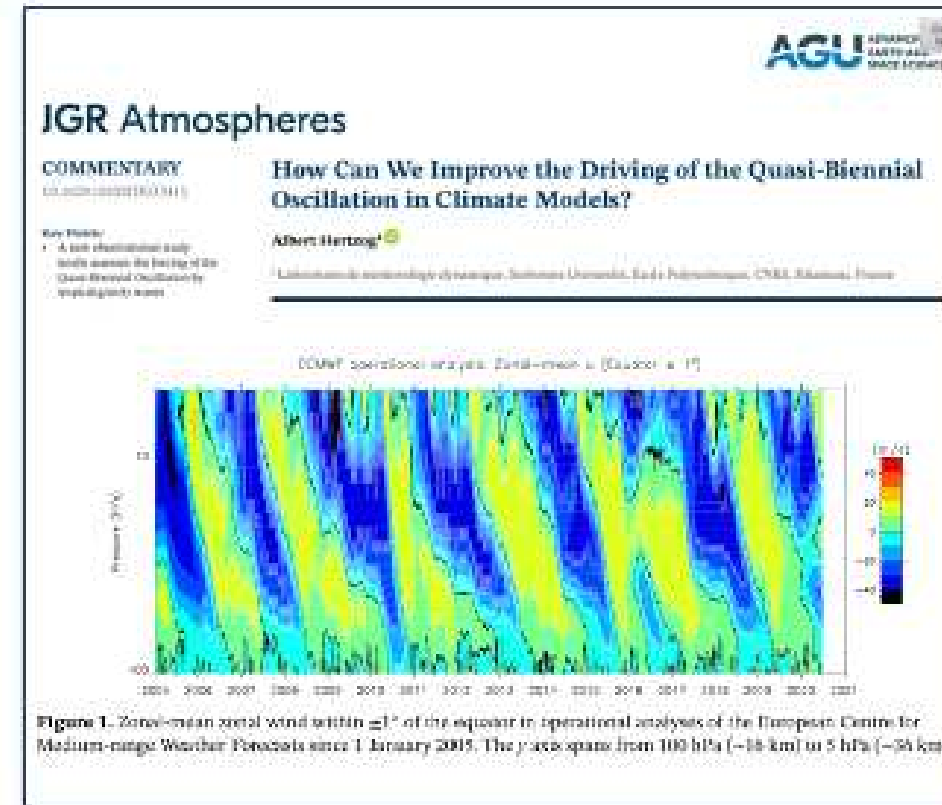
- Quasi-Biennial Oscillation (QBO) teleconnections modulate tropical precipitation and Northern winter weather patterns [e.g. Gray et al. 2018]

Recent results highlight:

- Large-scale tropical gravity waves drive the lower stratospheric QBO near wave critical levels where $\lambda_z \rightarrow 0$ [Vincent & Alexander 2020; Hertzog 2020]
- Dissipation closer to critical levels gives larger forces:

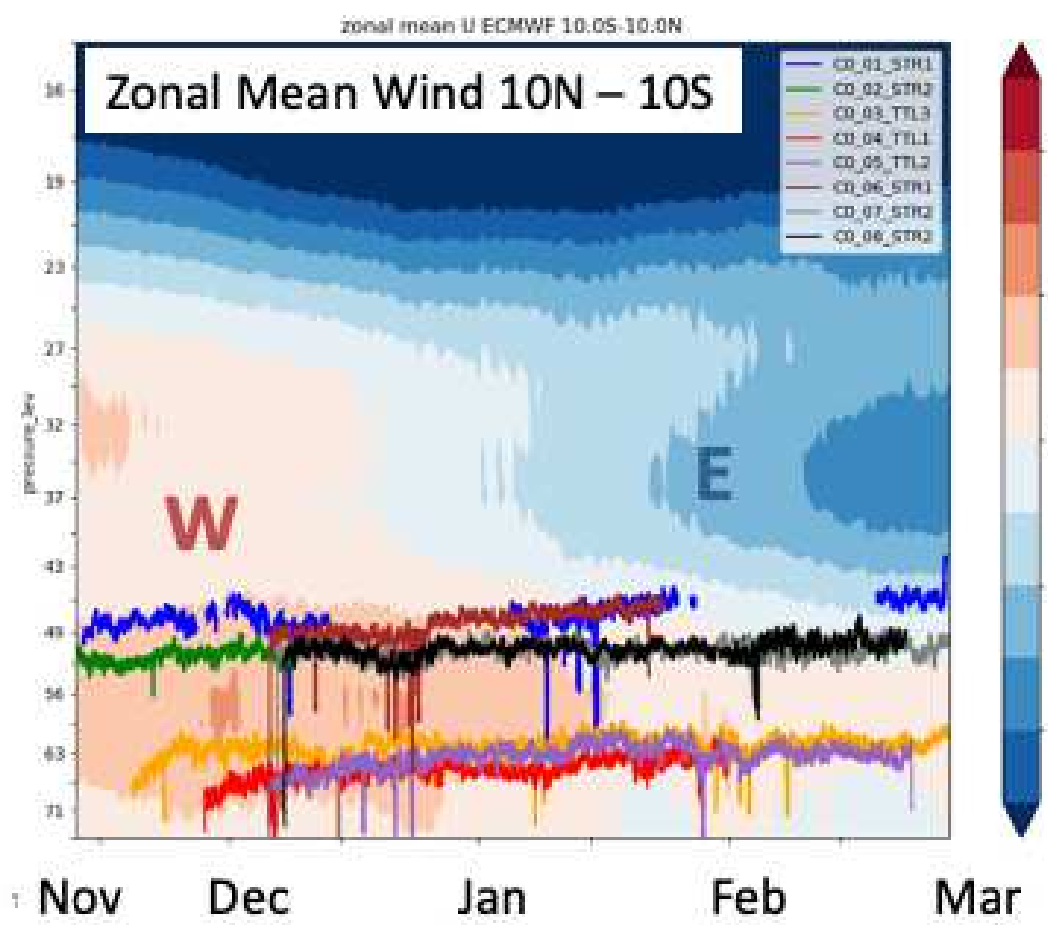
$$Force = -\frac{1}{\rho} \frac{\delta Flux}{\delta z}$$

- QBOs in models are too weak at 50hPa [Bushell et al. 2020]



2019-2020 Strateole-2:

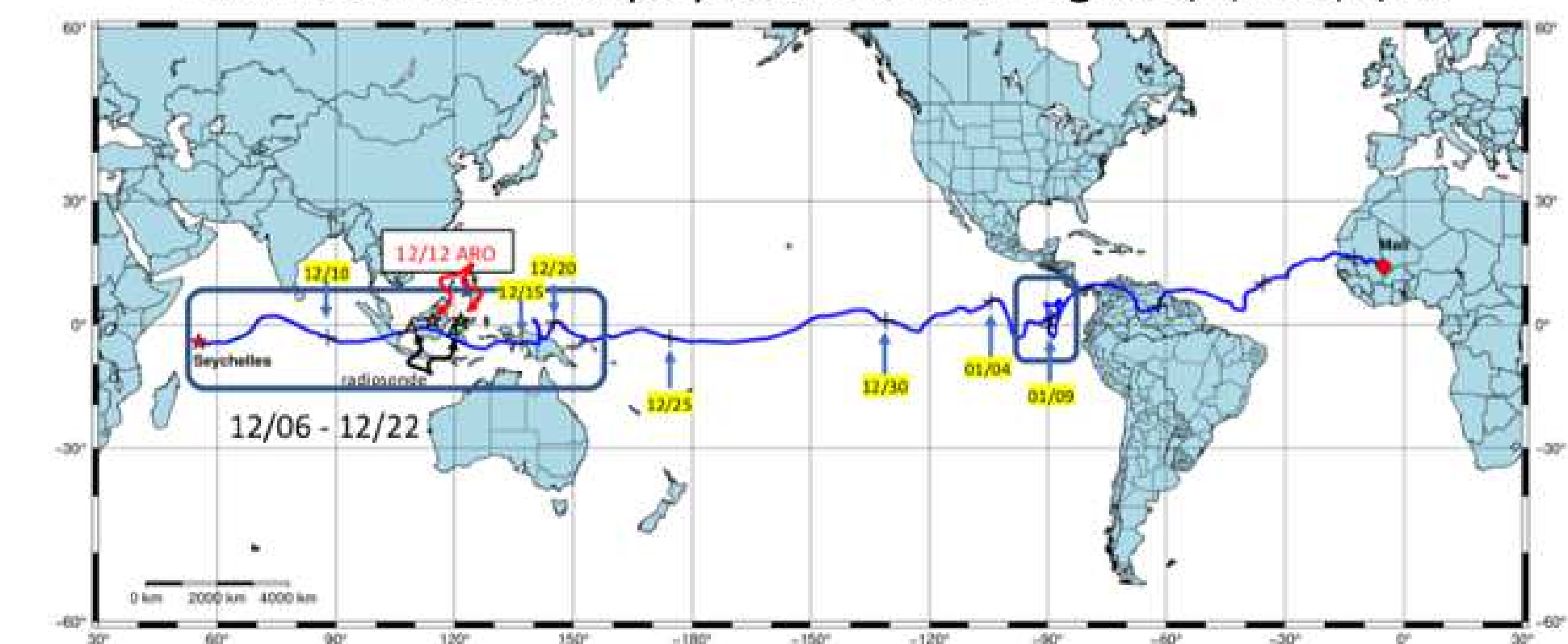
8 Balloon Flights in the lower stratosphere



Balloons drifted in westerly QBO winds at two levels: ~65 and ~50 hPa

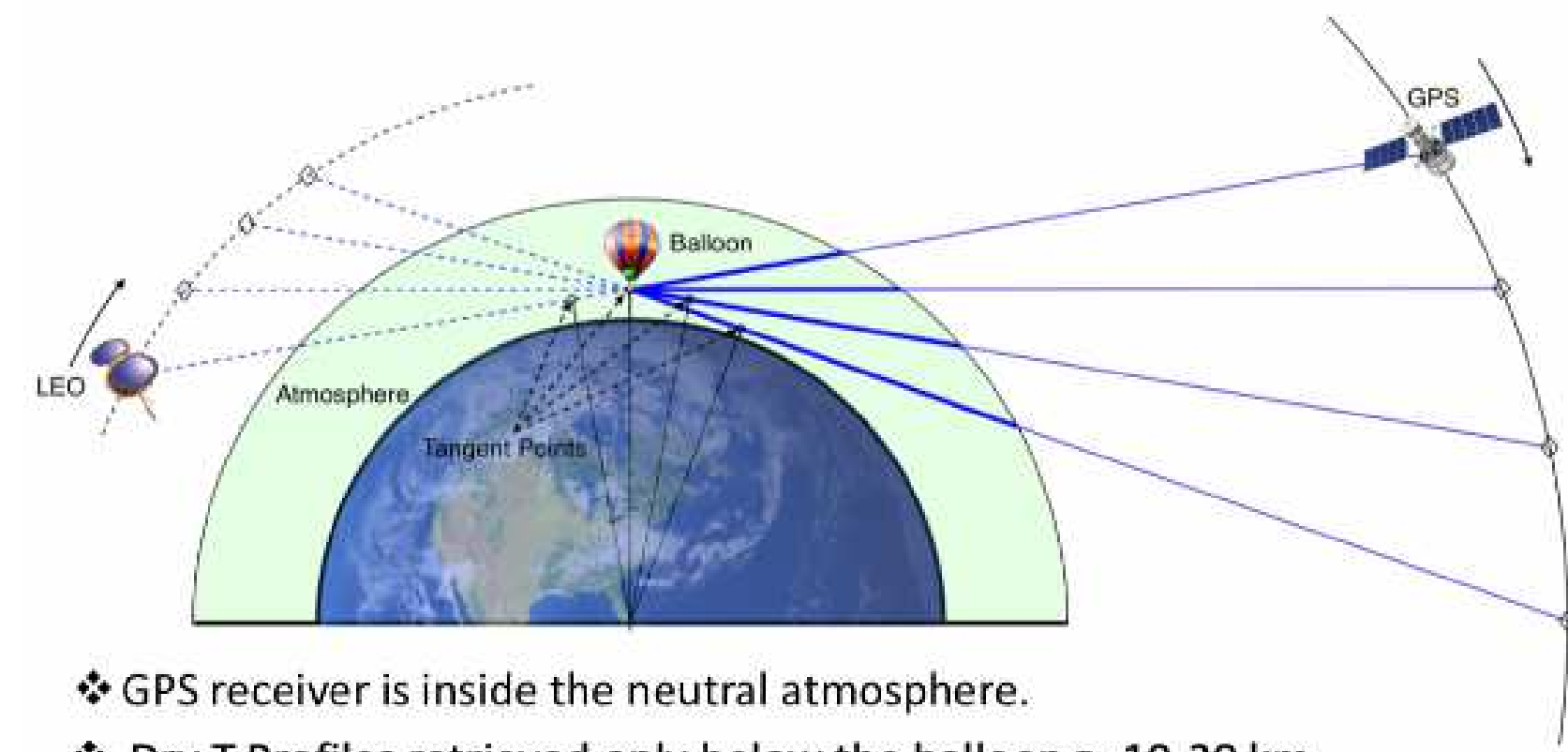
- Bramberger et al. [2020]: TTL3 balloon observed Kelvin wave critical layer interactions below the westerly wind peak.
- This talk: STR1 balloon carrying "ROC" Radio-Occultation profiler observations of tropical waves.

Radio-Occultation ("ROC") Temperature Profiles from the Strateole-2 Superpressure Balloon Flight 12/6/19-2/1/20



- Data recovered from Iridium link is mostly from the area in boxes, 17-day continuous part in Indian Ocean/SW Asia, some from East Pacific near South America.

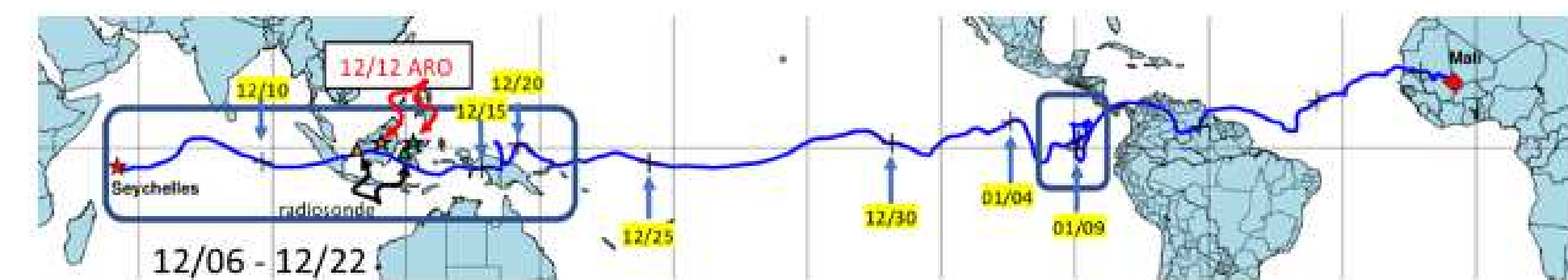
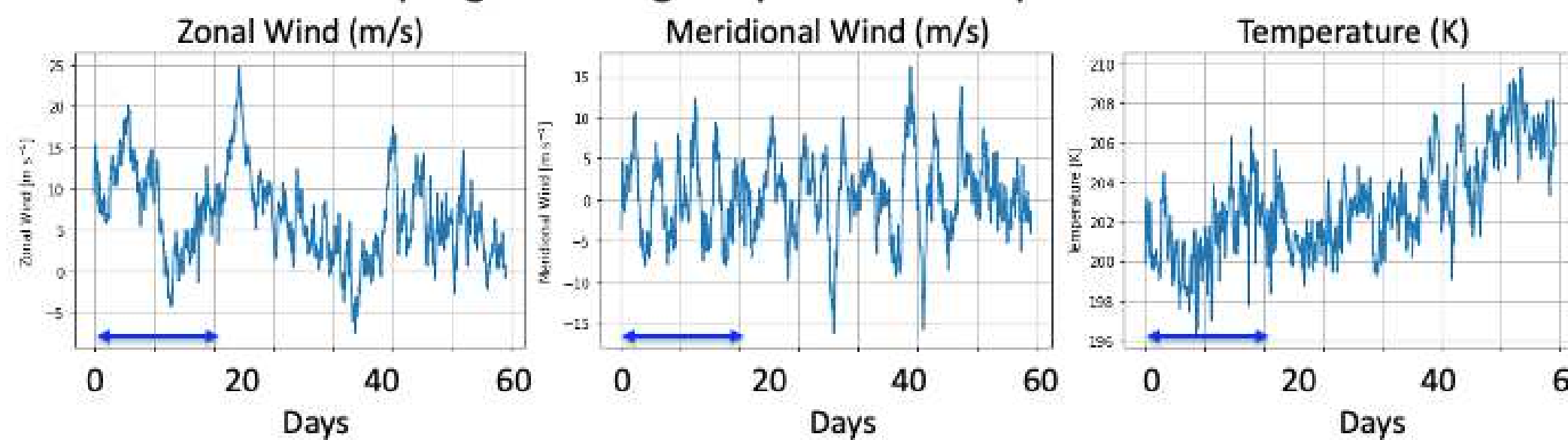
Balloon-borne RO



- GPS receiver is inside the neutral atmosphere.
- Dry T Profiles retrieved only below the balloon z~10-20 km
- Tangent point drifts horizontally with altitude up to ~300km

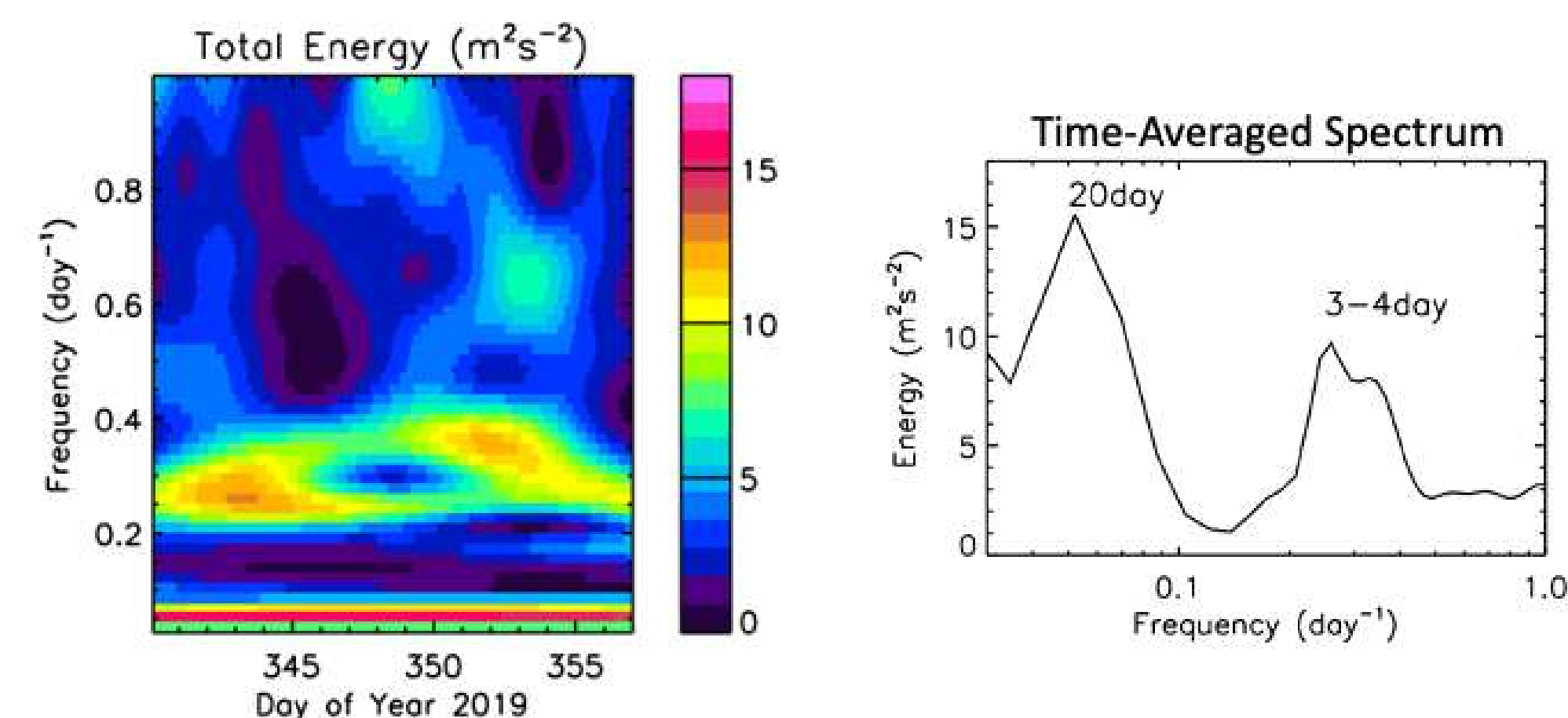
Balloon in situ measurements

30 sec sampling resolves gravity waves and equatorial wave modes



S-Transform KE+PE Spectrum

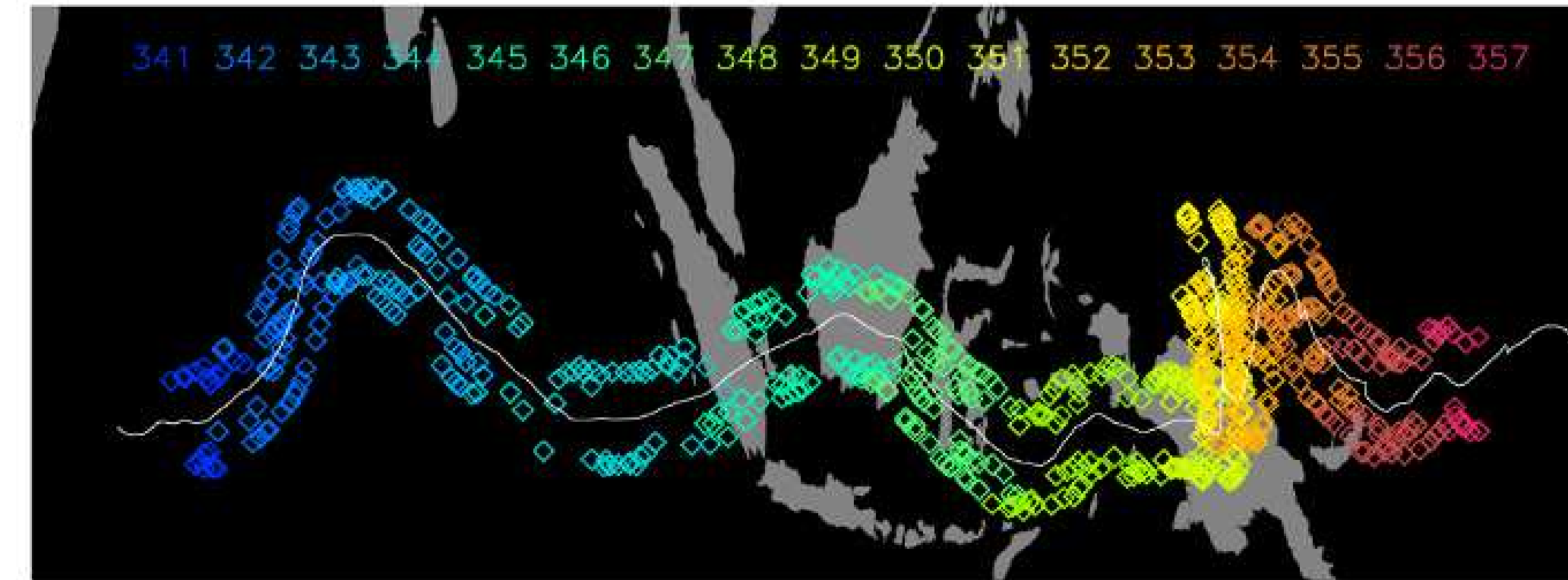
20day Kelvin Wave and 3-4day Inertia-Gravity Wave



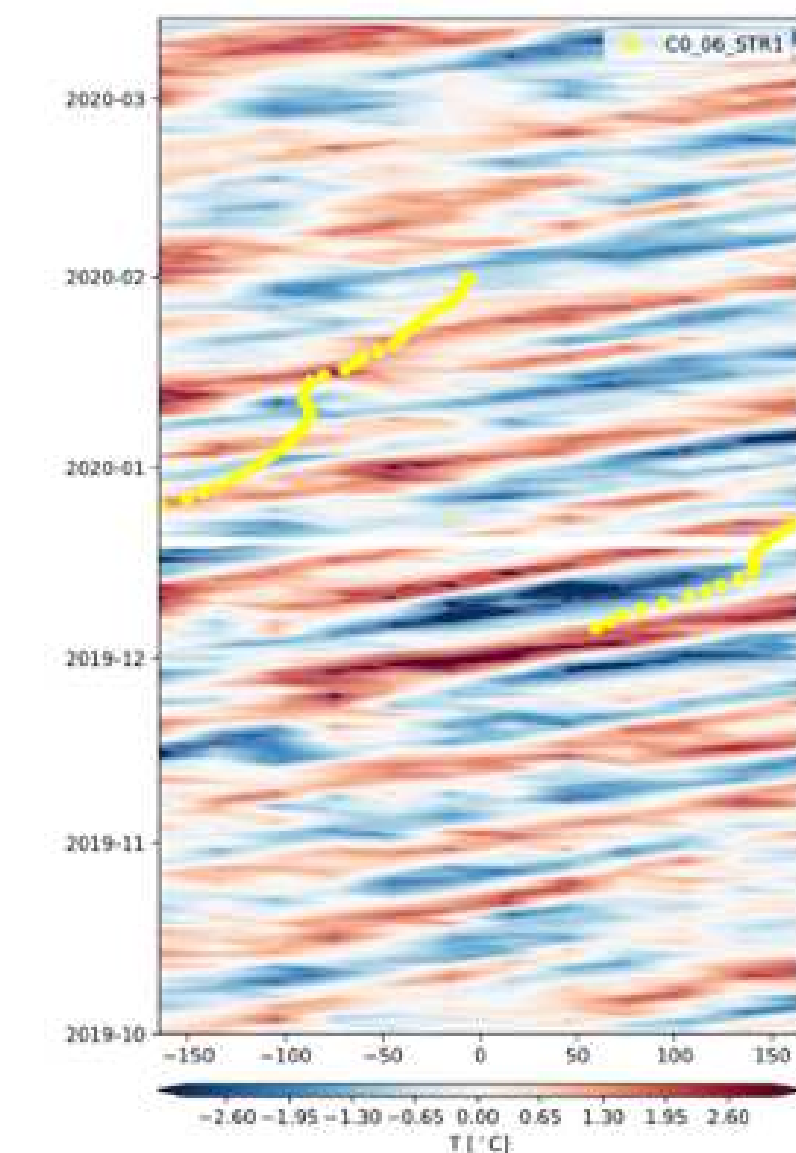
ROC Tropopause Tangent Points

DOY: 340-357 = Dec 6-23, 2019

> 40 profiles/day



COSMIC-2 Hoevmoeller diagram of symmetric T' at the equator

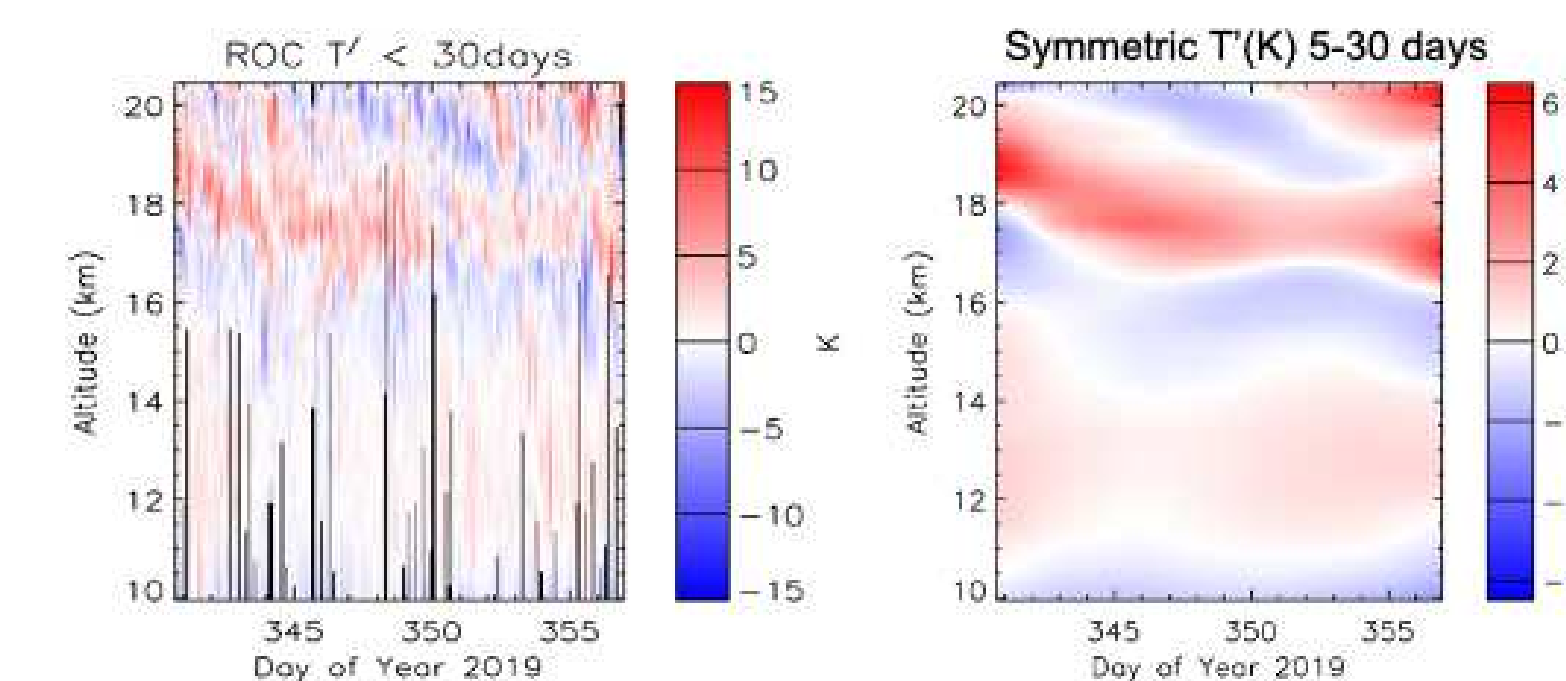


COSMIC-2 Temperature anomalies 5°S-5°N at balloon flight altitude

- Yellow dots show balloon carrying ROC
- COSMIC-2 also shows presence of both wn=1 and wn=2 Kelvin waves in the Eastern Hemisphere at this time.

Temperature anomalies T'(K)

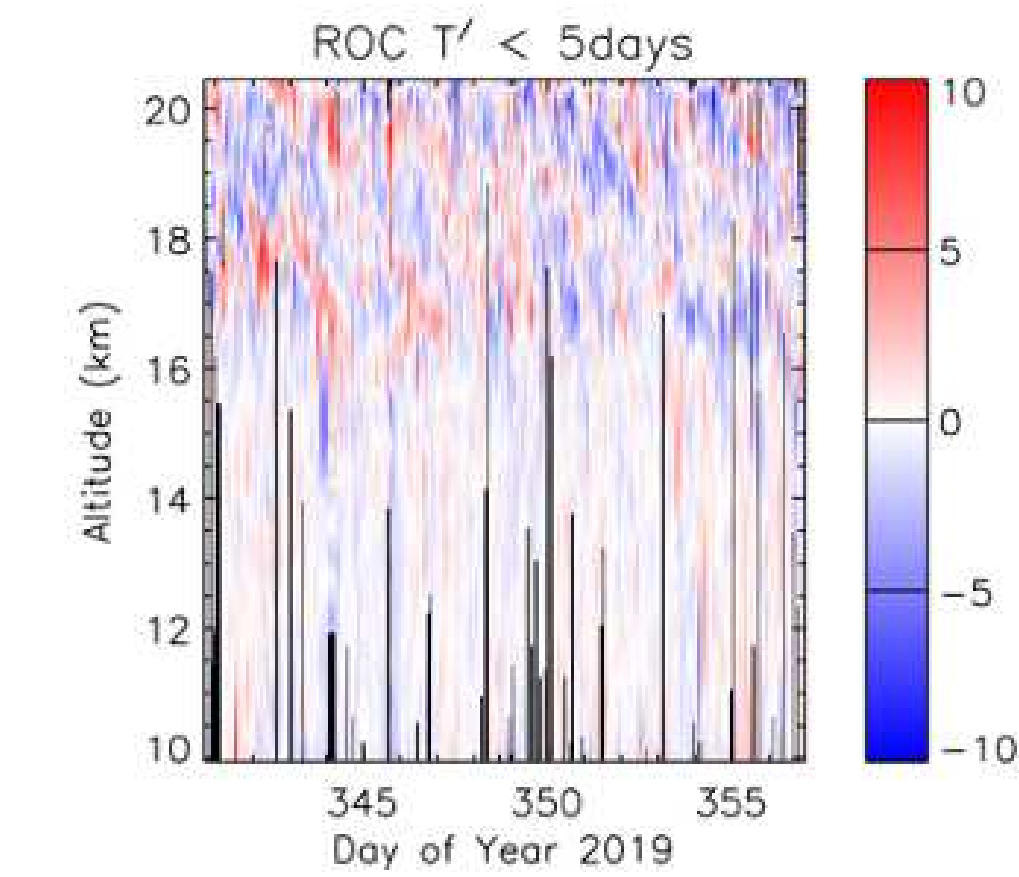
anomalies from 30-day 10°x5° avg COSMIC-2 RO profiles



- 20 day Kelvin Wave $\lambda_z \sim 3-6$ km in stratosphere
- Kelvin wave analysis suggests global scale, horizontal wn=1+2
- Fast intrinsic phase speeds, 23 and 11.6 m/s
- Also seen globally in COSMIC-2 at these altitudes

Temperature anomalies T'(K)

Residual after removal of 5-30 day signals

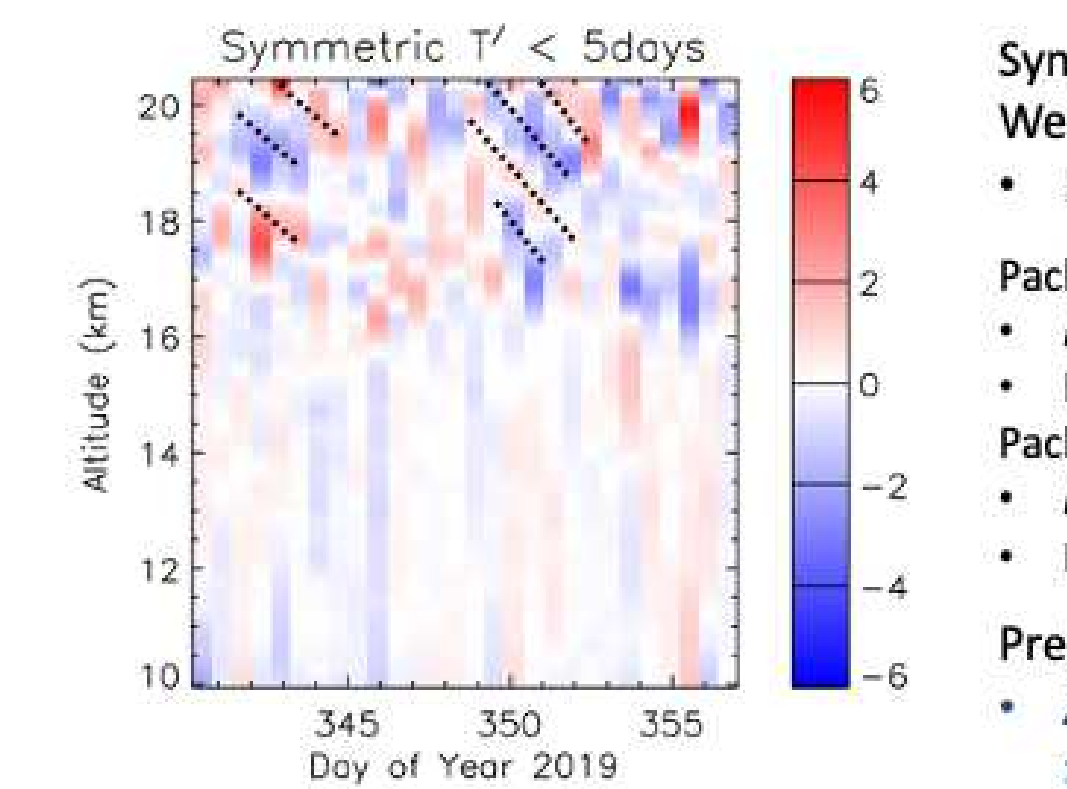


- Reveals shorter period wave structures
- "Profiles" here also vary in lat and lon
- Complex 4-dimensional problem

- Bin data in (lat, z, t) to study structure and evolution of 3-4 day waves

Temperature anomalies T'(K)

Analysis of Inertia-Gravity Wave 3-4 day signals



Symmetric temperature structure suggests n=1 Westward Inertia-Gravity waves

- Dispersion Relation: $\omega=Nk/m$

- Packet 1, DOY 341-345: 4-day wave, $\lambda_z=3$ km
- $k = wn$ 10 (~4000 km), $c=12$ m/s
- Momentum flux ~ 3mPa
- Packet 2, DOY 349-352: 3-day wave, $\lambda_z=2$ km
- $k = wn$ 20 (~2000 km), $c=8$ m/s
- Momentum flux ~ 4mPa

- Preliminary estimate: Dissipation near ~20hPa.
- Zonal mean forces ~0.5m/s/day, roughly half the total needed to drive descent of the QBO.

Summary

- ROC temperature profiles reveal Kelvin and Inertia-Gravity waves with vertical wavelengths as short as 2km and large-to-global horizontal scales.
- Super-pressure balloon data are providing new evidence for wave-mean flow interactions very close to critical levels ($\lambda_z \rightarrow 0$), giving large momentum forces on the QBO. [Vincent & Alexander 2020; Hertzog 2020; Bramberger et al. 2020]
- Global atmospheric models under-resolve these stratospheric critical level interactions. Waves dissipate at lower altitudes, giving smaller momentum forces, and misrepresentation of the QBO.

