Mountain Waves Observed with AIRS above Islands in the Southern Ocean

Seasonal, Interannual and Latitudinal Variations

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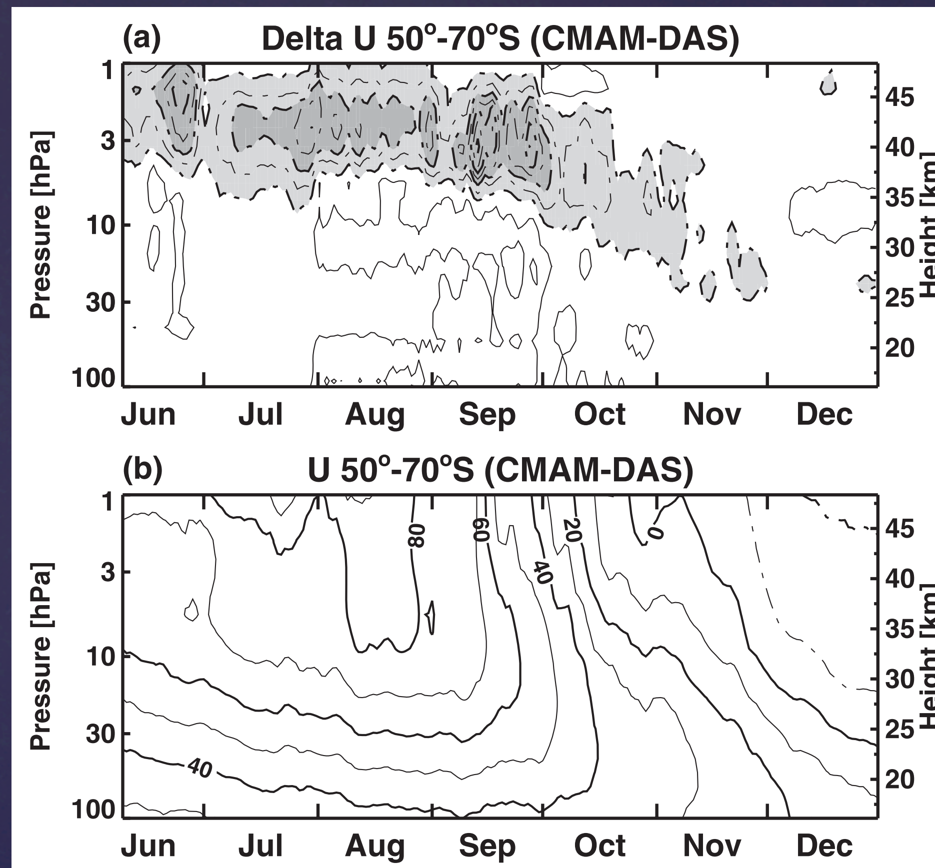
Motivation: "Missing drag" in the SH

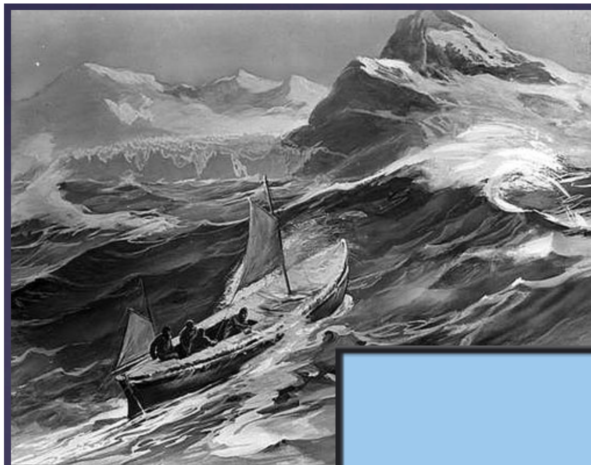
- Butchart et al. [2011] showed common SH biases in CCMVal simulations.

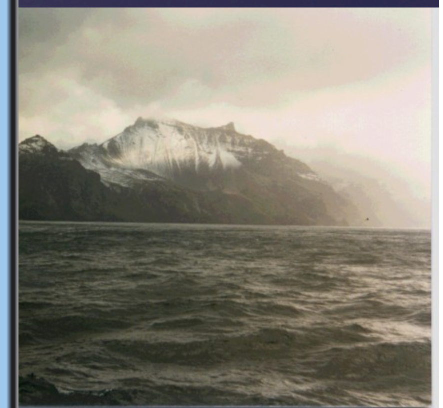
- McLandress et al. [2012] found CMAM wind biases in upper stratosphere compared to data assimilation system; Added artificial band of orographic gravity wave momentum flux near 60ºS to correct bias.

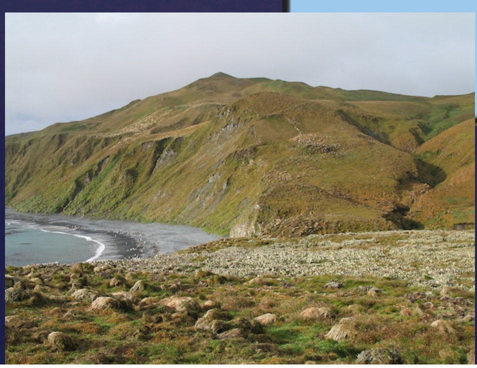
- SH Wind biases affect:

→Vortex temperatures
→Seasonal vortex breakdown timing
→Depth of springtime ozone loss





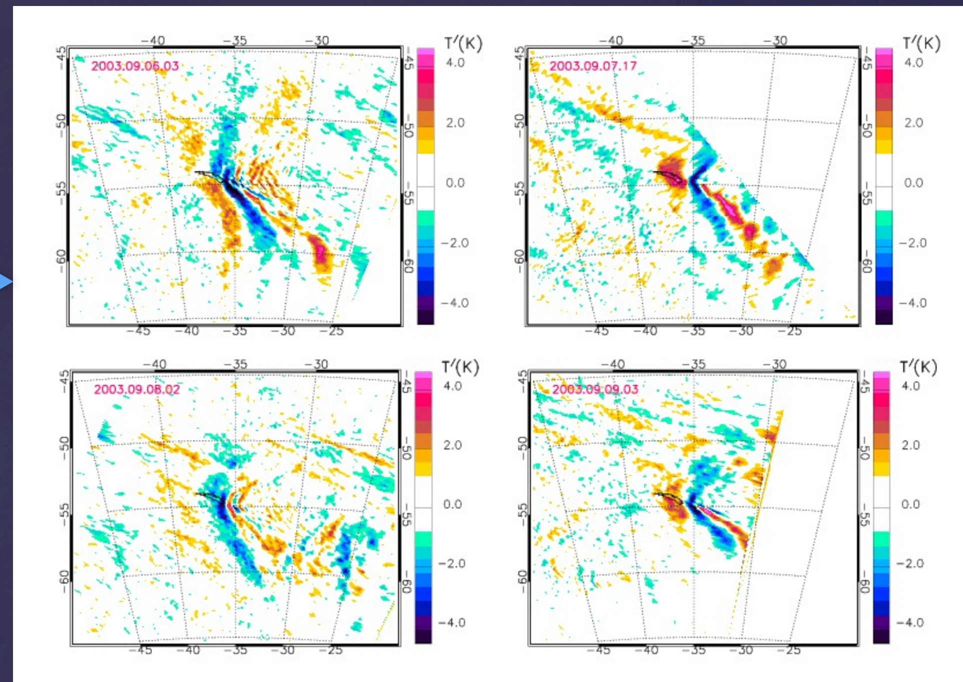




Island orographic wave drag?

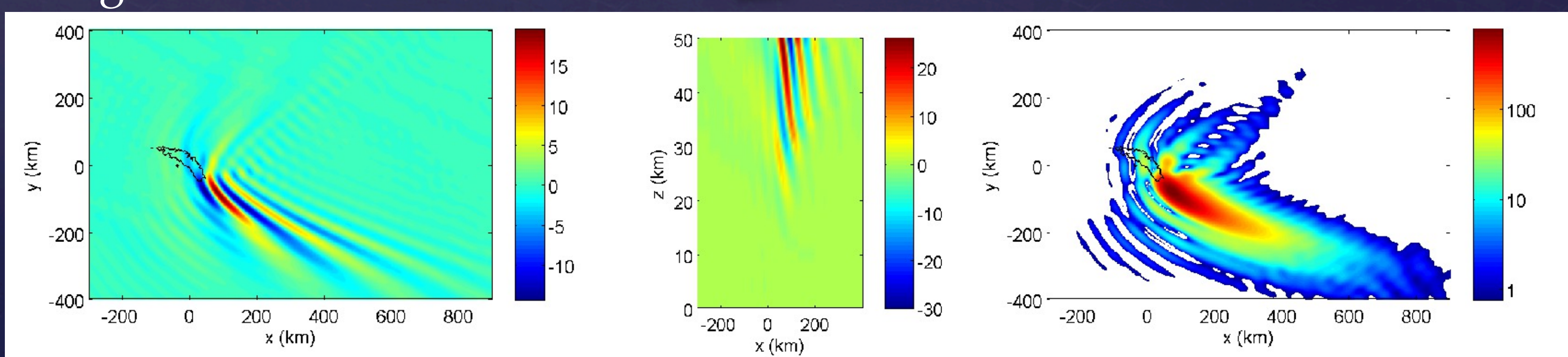
Remote islands provide some missing drag

Alexander et al [2009]:
Orographic gravity waves above South Georgia Island in **AIRS** measurements.



IR channel w/peak at 3hPa~40km

Fourier-ray model comparison confirmed vertically propagating gravity waves with substantial momentum flux and inferred drag.



New Study: 14 Islands Examined

- Latitudes 37-61°S
- Peak altitudes 400-3000m
- Survey of the data found no wave events for Gough, Macquarie, Amsterdam, Bouvet. Auckland often obscured by NZ.

Name:	Peak Altitude	Latitude	Longitude
MacQuarie	410m	54.5°S	159°E
Auckland	705m	50.7°S	166°E
Amsterdam	867m	37.8°	77.5°E
Gough	910m	40.3°S	9.9°W
Bouvet	935m	54.4°S	3.4°E
Crozet	1090m	46.4°S	51°E
Prince Edward	1242m	46.9°S	37.7°E
South Orkney	1266m	60.6°S	45.5°W
South Sandwich	1370m	58.4°S	26.4°W
Tasmania	1617m	42°S	146°E
Kerguelen	1850m	49.3°S	69.6°E
Tristan da Cunha	2062m	37.1°S	12.3°W
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South Georgia	2934m	54.2°S	36.8°W

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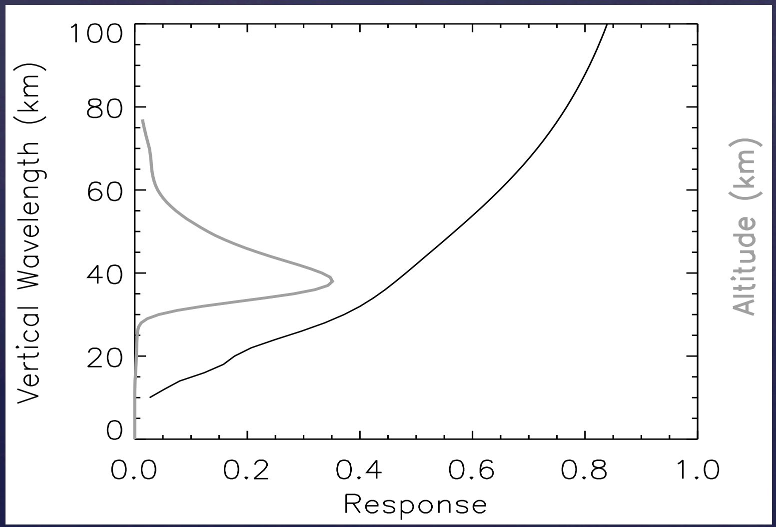
Focus on island peaks > 1000m

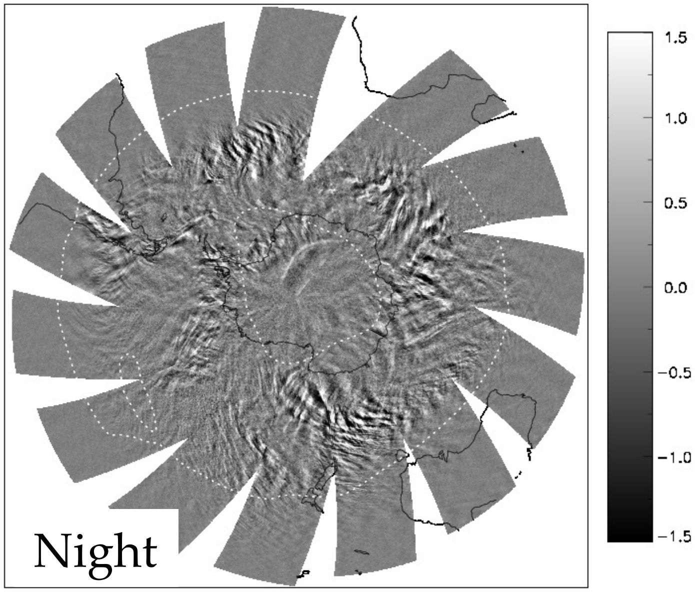
AIRS Sampling

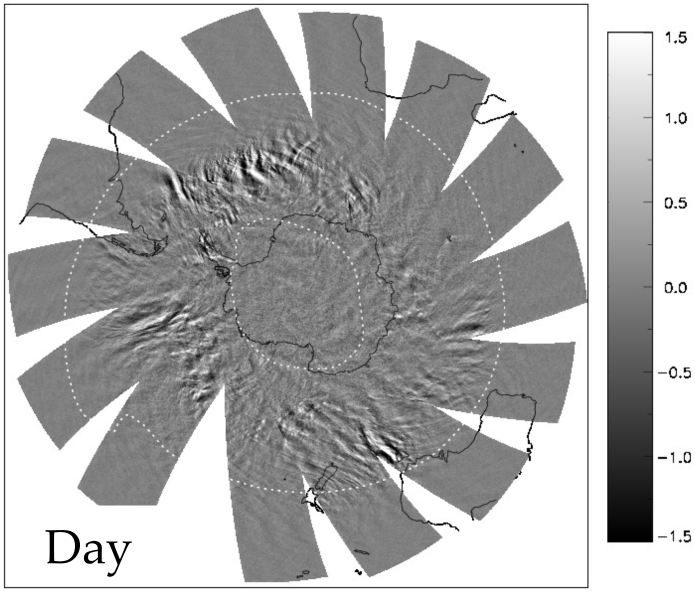
- Typically 2-3 measurement swaths daily above each island.

- Winter season has westerly stratospheric winds favorable for vertical propagation of mountain waves.

- AIRS kernel function depth means only long vertical wavelength waves > 12 km are visible.







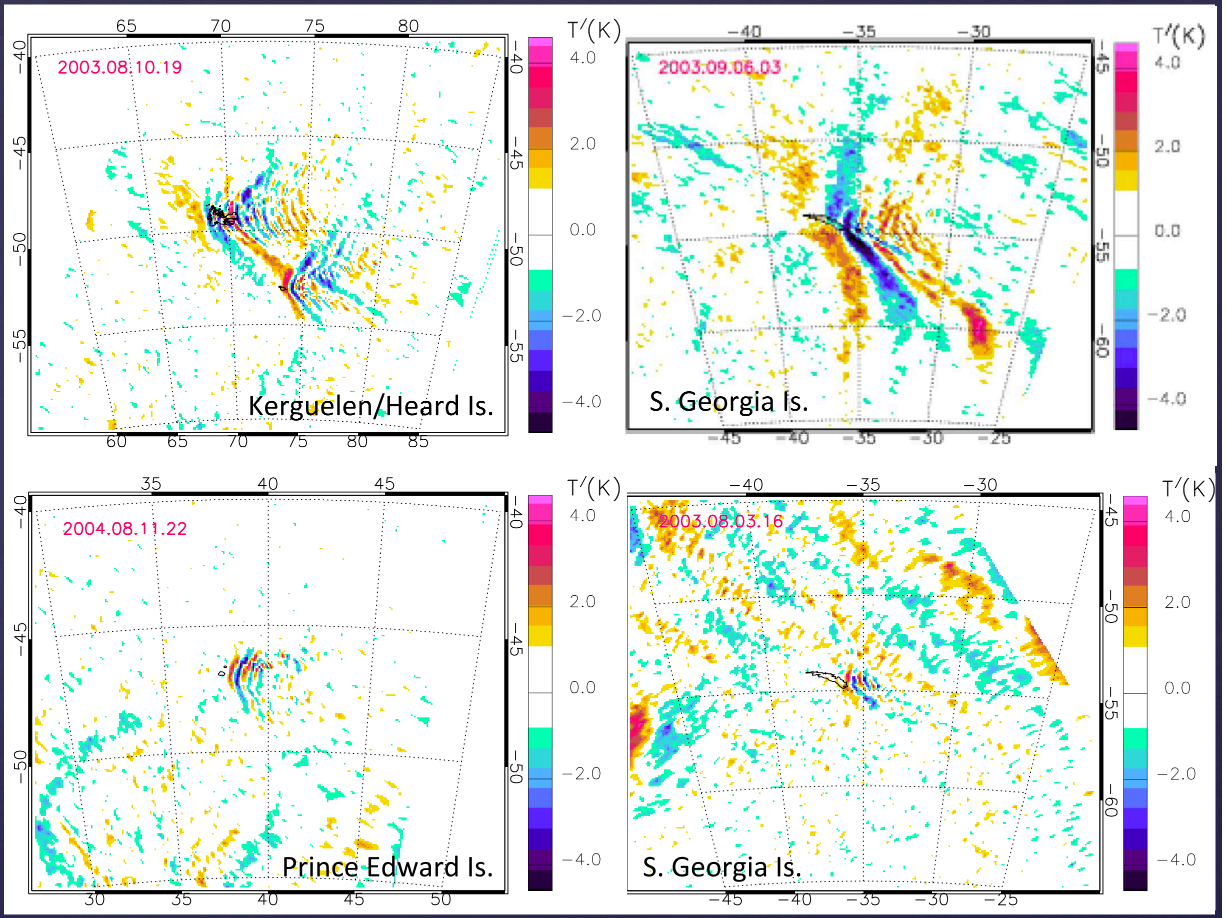
Method: Wave event identification

Identify island waves in data via distinct arc or v-shaped patterns, connected to island, extending eastward.

Monthly statistics:

$$\text{occurrence frequency} = \frac{\#\ \text{events}}{\#\ \text{overpass}}$$

Island waves may be obscured by background waves from other sources:



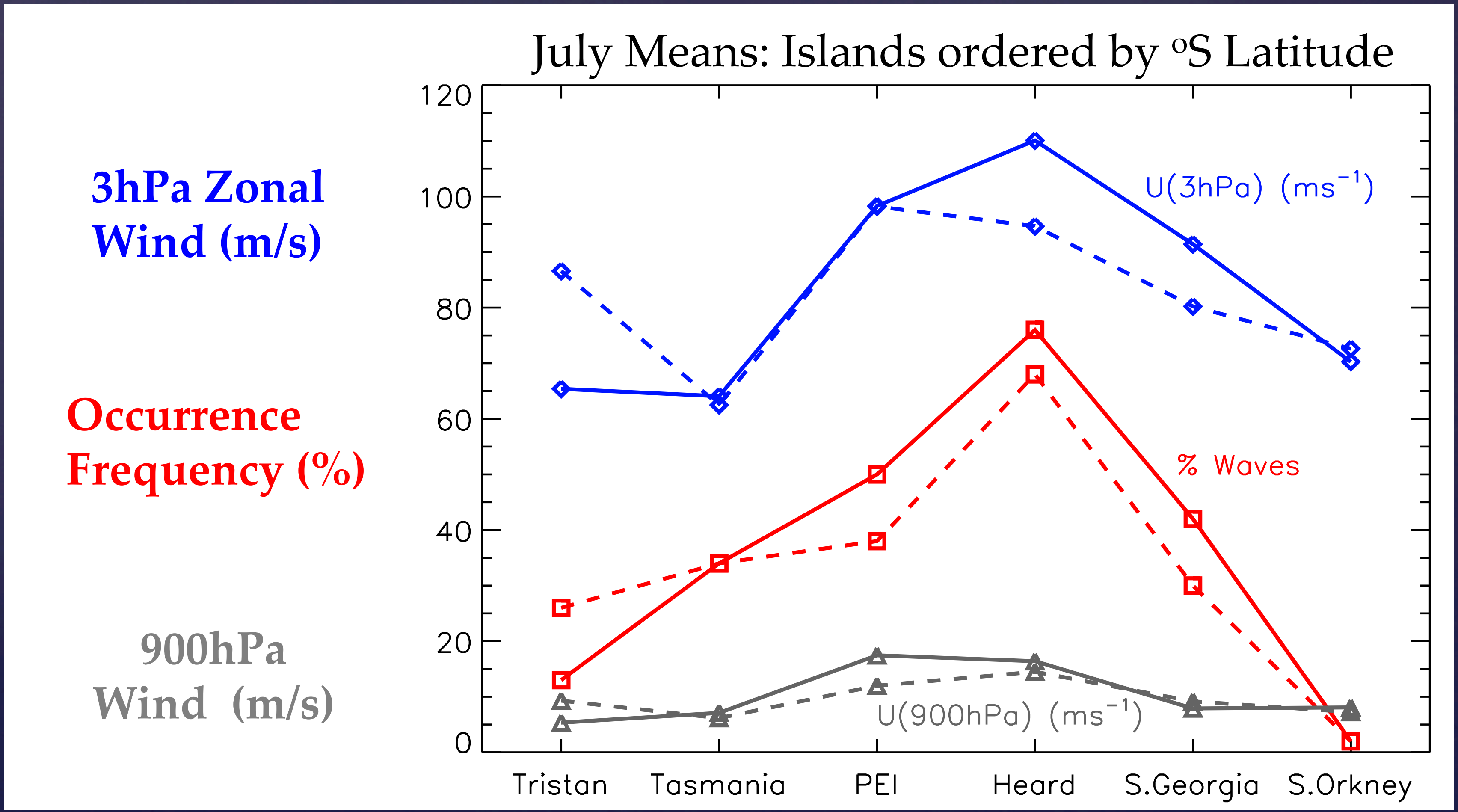
Uncertain cases give estimate of occurrence frequency uncertainty +/-8%

Results: July Occurrence Frequencies

Wave occurrence varies with latitude and in rough proportion to wind at the observation level.

➔ **First order control: stratospheric wind on wave visibility in AIRS.**

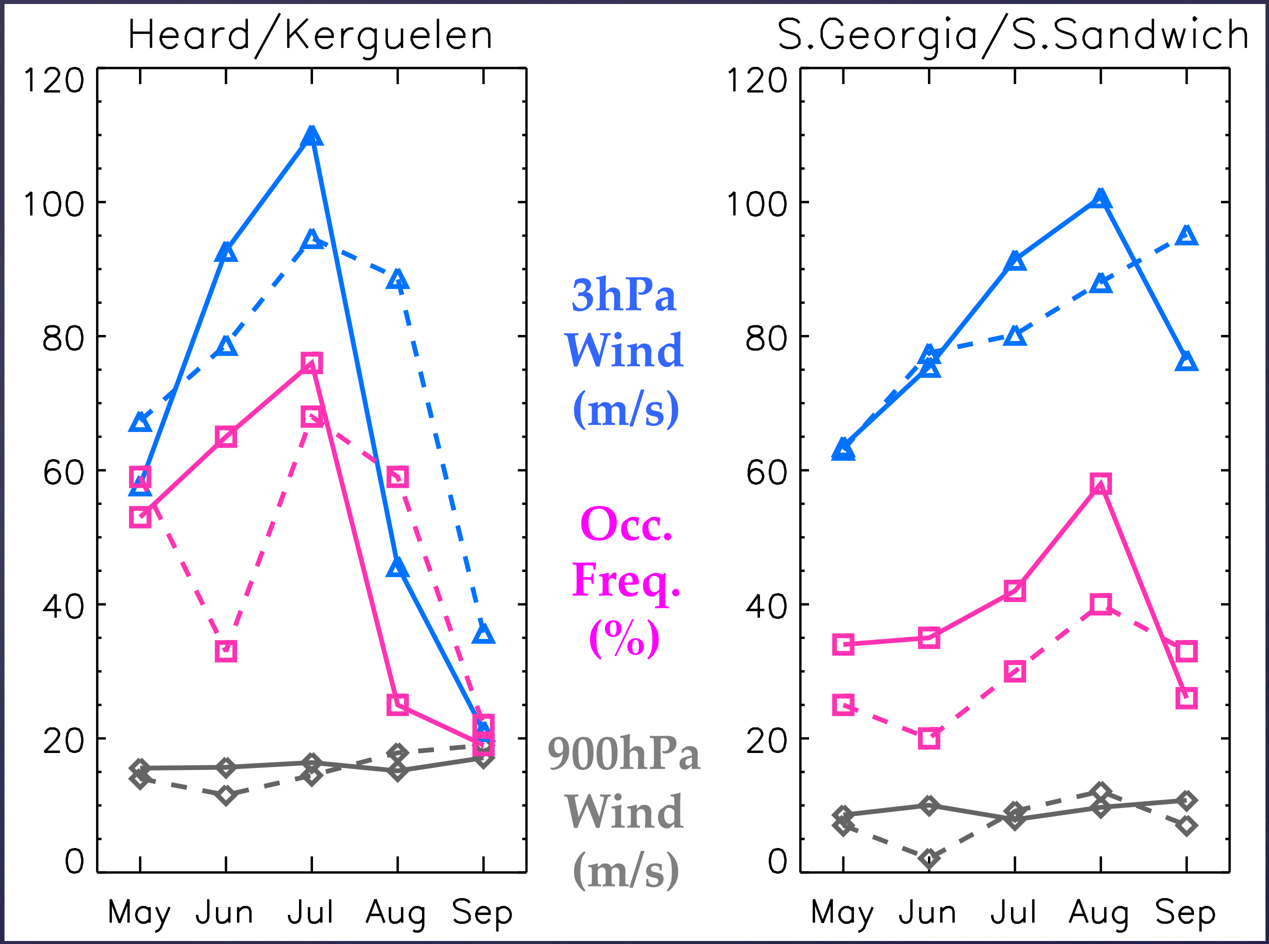
This further suggests wave events may be far more common than observed.



Results: Seasonal and interannual variations

May-September
- - - - 2003
——— 2004

Seasonal variation in **occurrence frequency** also follows the **zonal wind speed** at the observation level.



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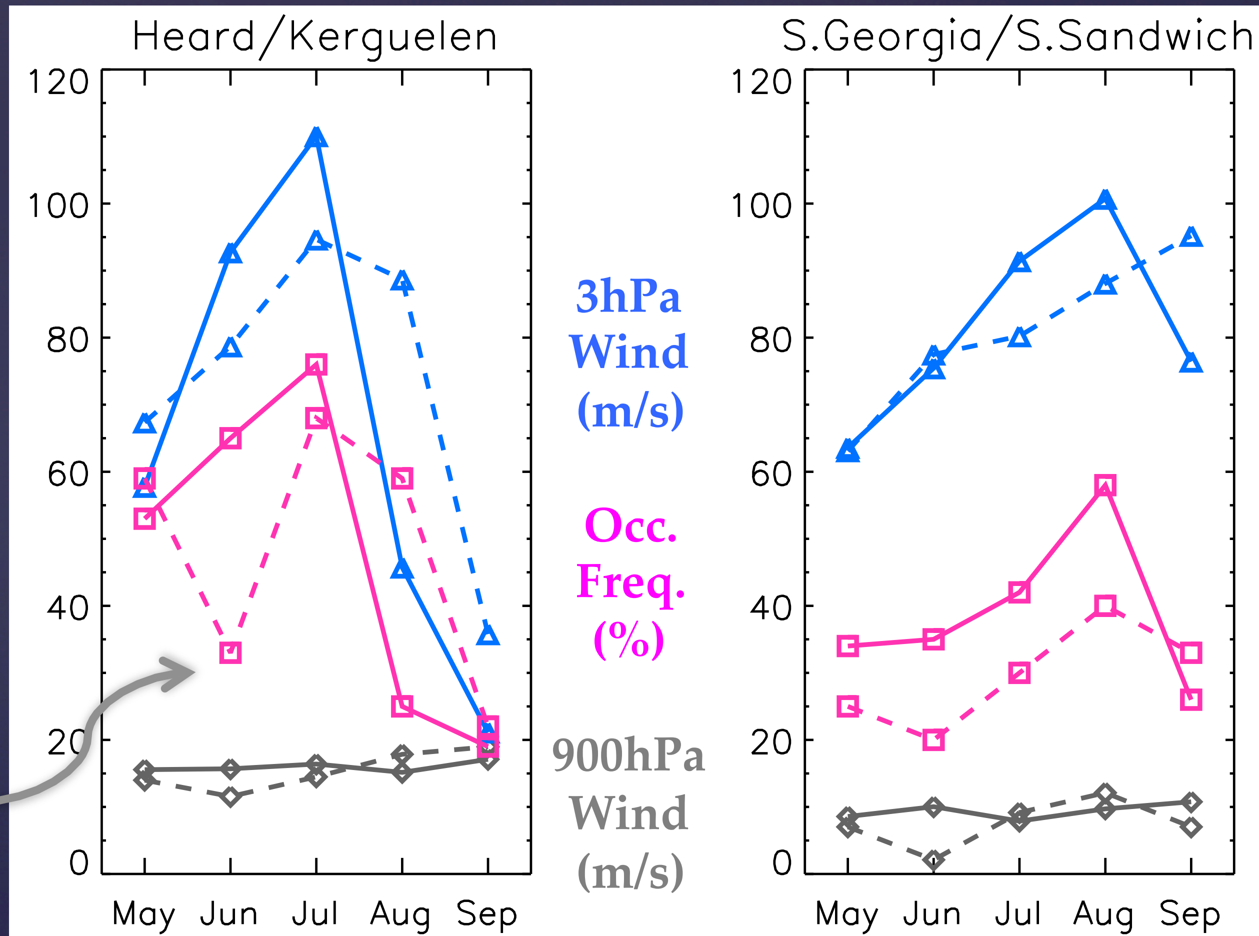


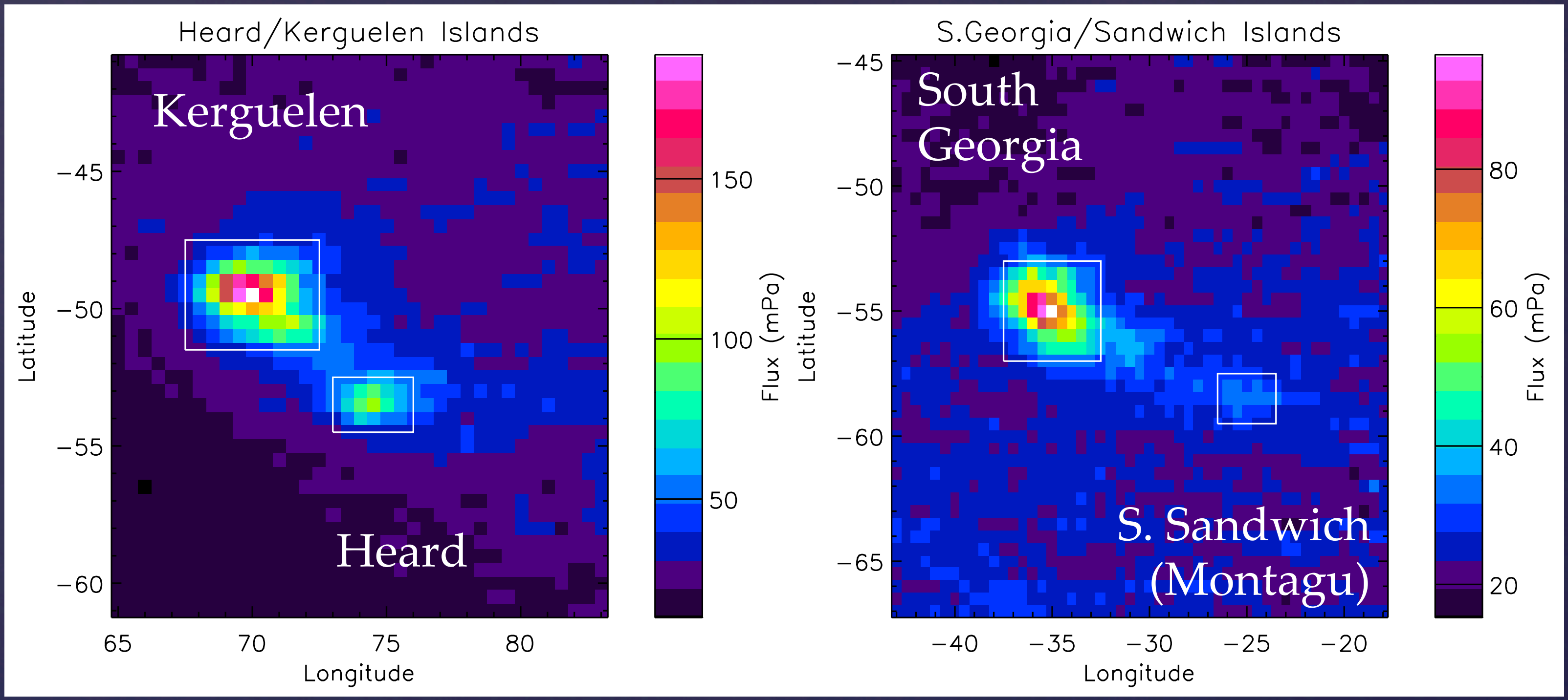
Anomaly in June 2003 at Kerguelen/ Heard:

Details reveal no waves observed during a 6-day period of easterly surface winds, when orographic waves were effectively shut off.

➔ **Additional effects of surface conditions on wave generation.**

Significance to General Circulation

Event-mean momentum fluxes estimated directly from AIRS data with wavelet method [Alexander et al, 2009]: All events May-Sep 2003-4



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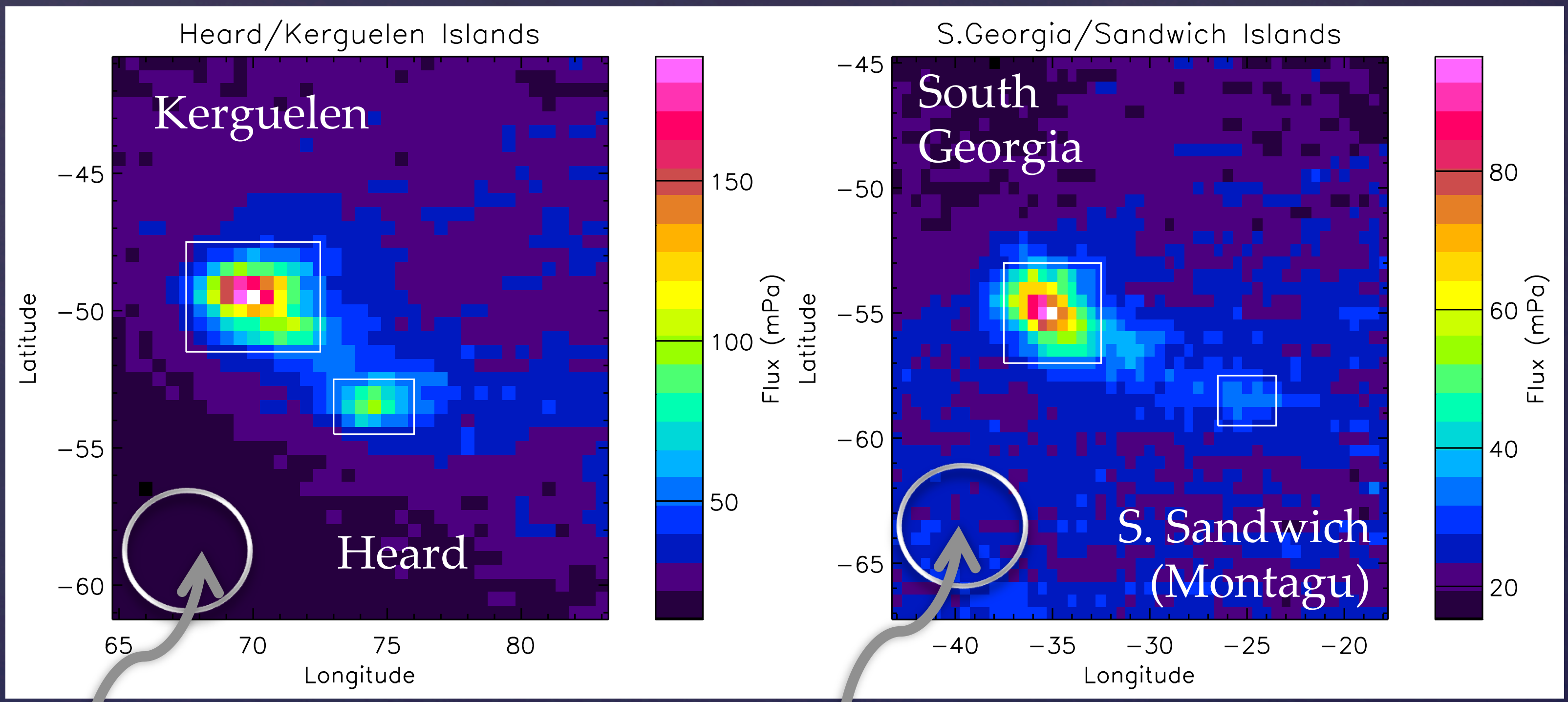

Error due to AIRS measurement noise = 4 mPa

Larger "background values" due to non-orographic waves. (Method assumes c=0) These do not affect local wavelet results.

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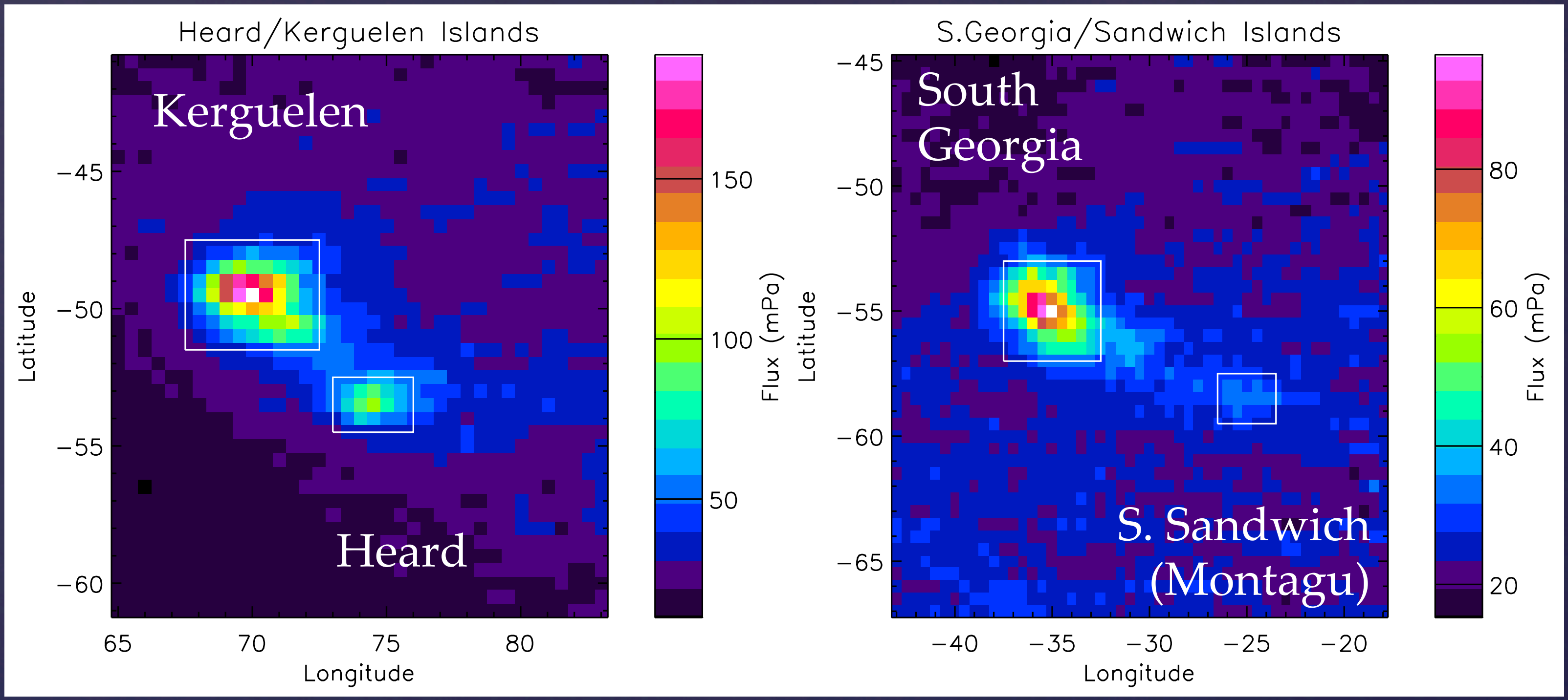


McLandress et al [2012] study estimated 10 mPa zonal mean flux needed to alleviate their climate model wind bias.

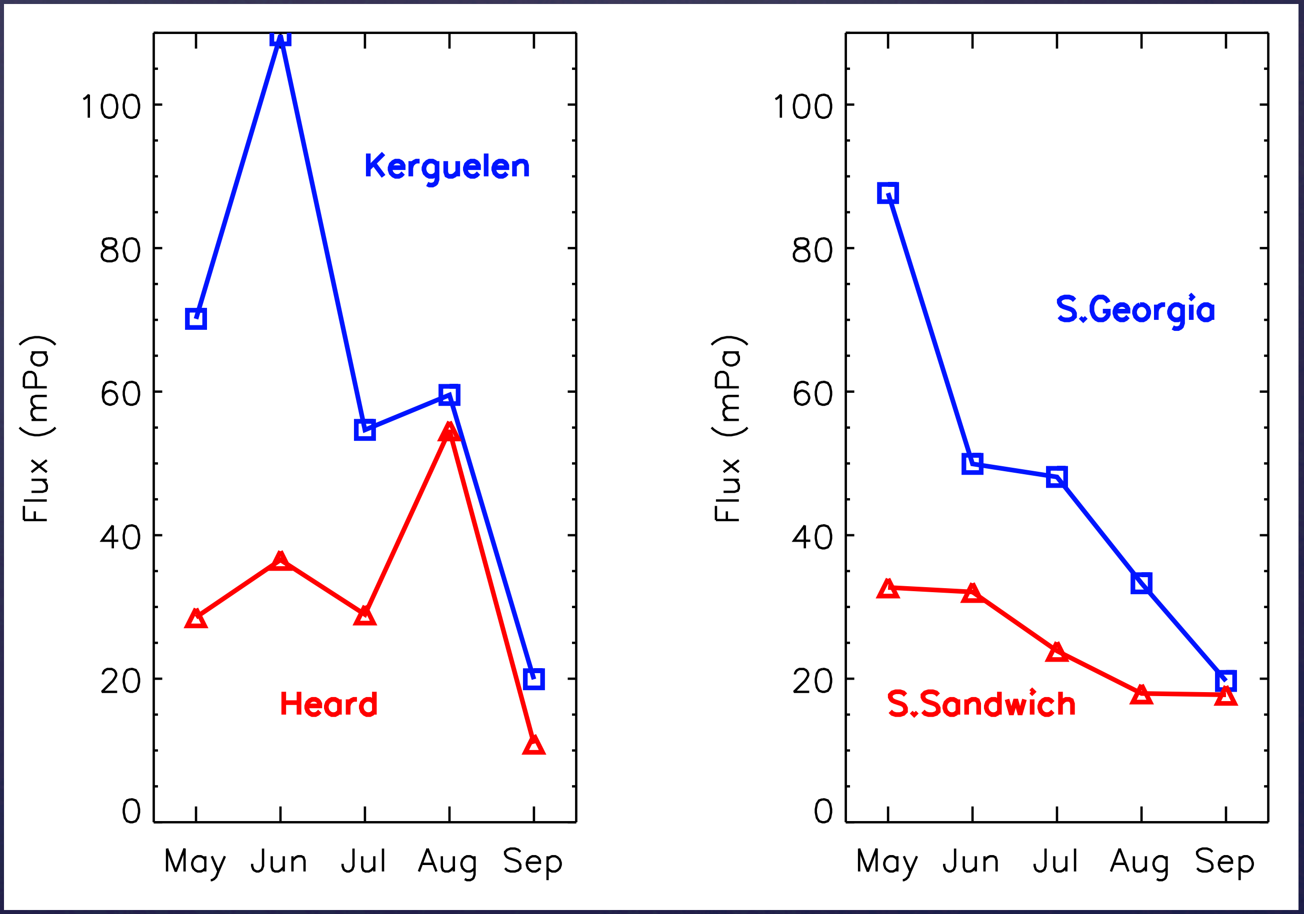
➔ **Substantial momentum fluxes for these island wave events.**

Momentum Flux: Seasonal Variation

Monthly-mean May thru September momentum fluxes for 4 islands.

- Note wave fluxes typically decay with height.
- Might maximum monthly mean momentum fluxes and occurrence frequencies be common at lower altitudes?

Use this scenario to evaluate a potential impact of island orographic waves on the stratospheric circulation…



Potential Impact on General Circulation

Assumptions:

1. Occurrence frequencies in the lower stratosphere = 75%
2. Event momentum flux for larger Islands with topography > 1500 m = 100 mPa per 5°x4° area
3. Event momentum flux for small Islands with topography >2000m= 50 mPa per 3°x2° area
4. Event momentum flux for small Islands 1000-1500 m = 30 mPa per 3°x2° area

Name:	Peak Altitude	Latitude	Contribution to zonal mean flux:
Crozet	1090m	46.4°S	0.2 mPa
Prince Edward	1242m	46.9°S	0.2 mPa
South Orkney	1266m	60.6°S	0.2 mPa
South Sandwich	1370m	58.4°S	0.2 mPa
Tasmania	1617m	42°S	1 mPa
Kerguelen	1850m	49.3°S	1 mPa
Tristan da Cunha	2062m	37.1°S	0.3 mPa
Heard	2745m	53.1°S	0.3 mPa
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Summary & Conclusions

- Orographic waves above small SH islands occur commonly in the fall-thru-spring stratosphere.
- Occurrence frequencies in AIRS are primarily limited by stratospheric winds.
- Momentum fluxes can be large, and mean values >100 mPa (10x zonal mean at other latitudes).
- Small area of island wave events will limit their impact on SH circulation, but collectively they may fill a fraction of the "gap" in SH drag.