Southern Hemisphere Wind Biases in Climate Models and Missing Gravity Waves:

What can AIRS observations tell us?

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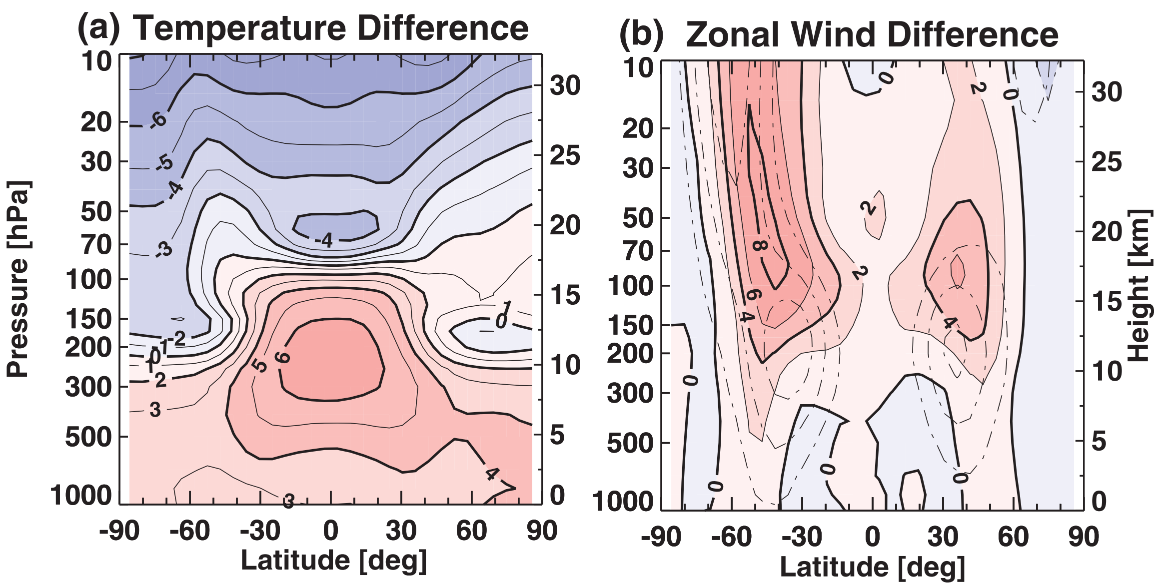
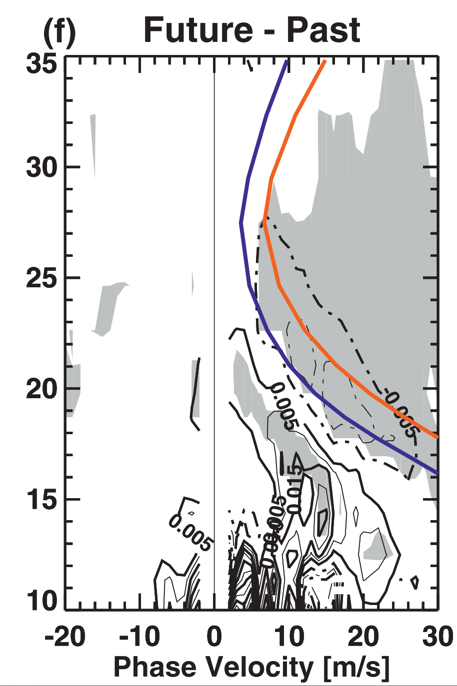
Introduction: Stratospheric Winds and Climate Change

Greenhouse Gas Increases → Tropospheric Warming and Stratospheric Cooling

Future (2080-99) – Past (1960-79)



~ Geostrophic Balance
-dT/dy ~ du/dz



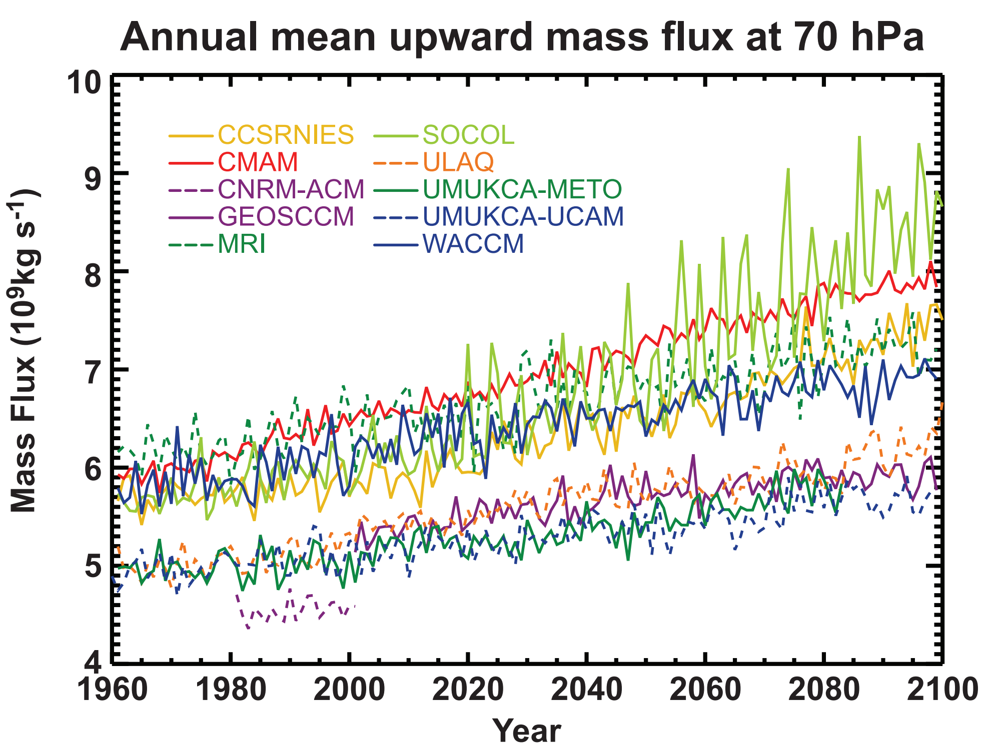
Shepherd and McLandress [2011]:
showed how anticipated future zonal wind changes lead to higher critical levels for synoptic scale waves (right) → and stronger stratospheric wave drag at higher altitudes.

Note ΔU < 10 m/s !

Introduction: Stratospheric Winds and Climate Change

Small changes in zonal-mean winds affect Rossby wave and gravity wave propagation, with wide ranging impacts on climate and weather processes.

Example: GHG increases and small changes in the upper-level winds lead to an increasing trend in the strength of the global equator-to-pole stratospheric transport circulation in most chemistry-climate models:



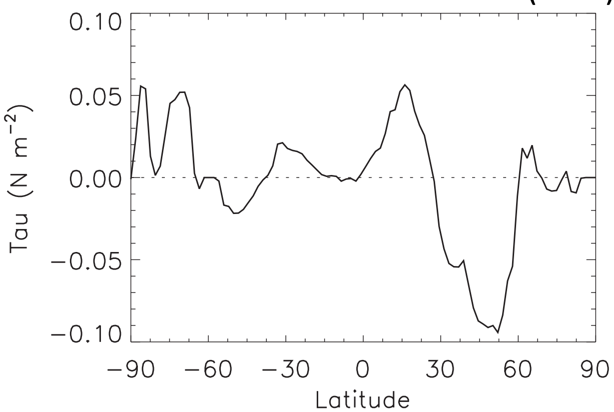
From SPARC CCMVal Report 2010

These wave-driven circulation trends will affect global water vapor and ozone concentrations with associated radiative effects and feedbacks.

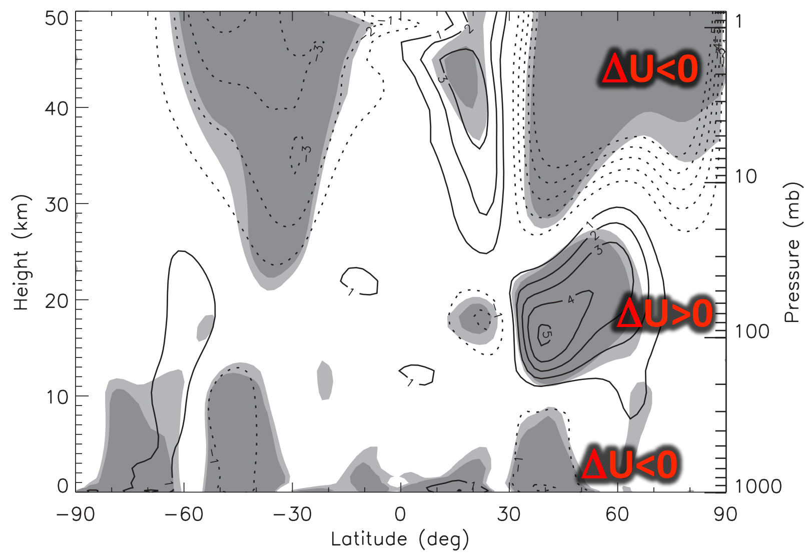
GWD Indirect Effects: Interactions between surface drag and waves

Richter et al. [2010]: Interactions between surface drag, gravity waves, planetary waves

Surface Wind Tendency from Turbulent Mountain Stress (TMS)



DJF wind changes due to this surface TMS



Occurrence Frequencies of Sudden Warmings are much higher with surface TMS:

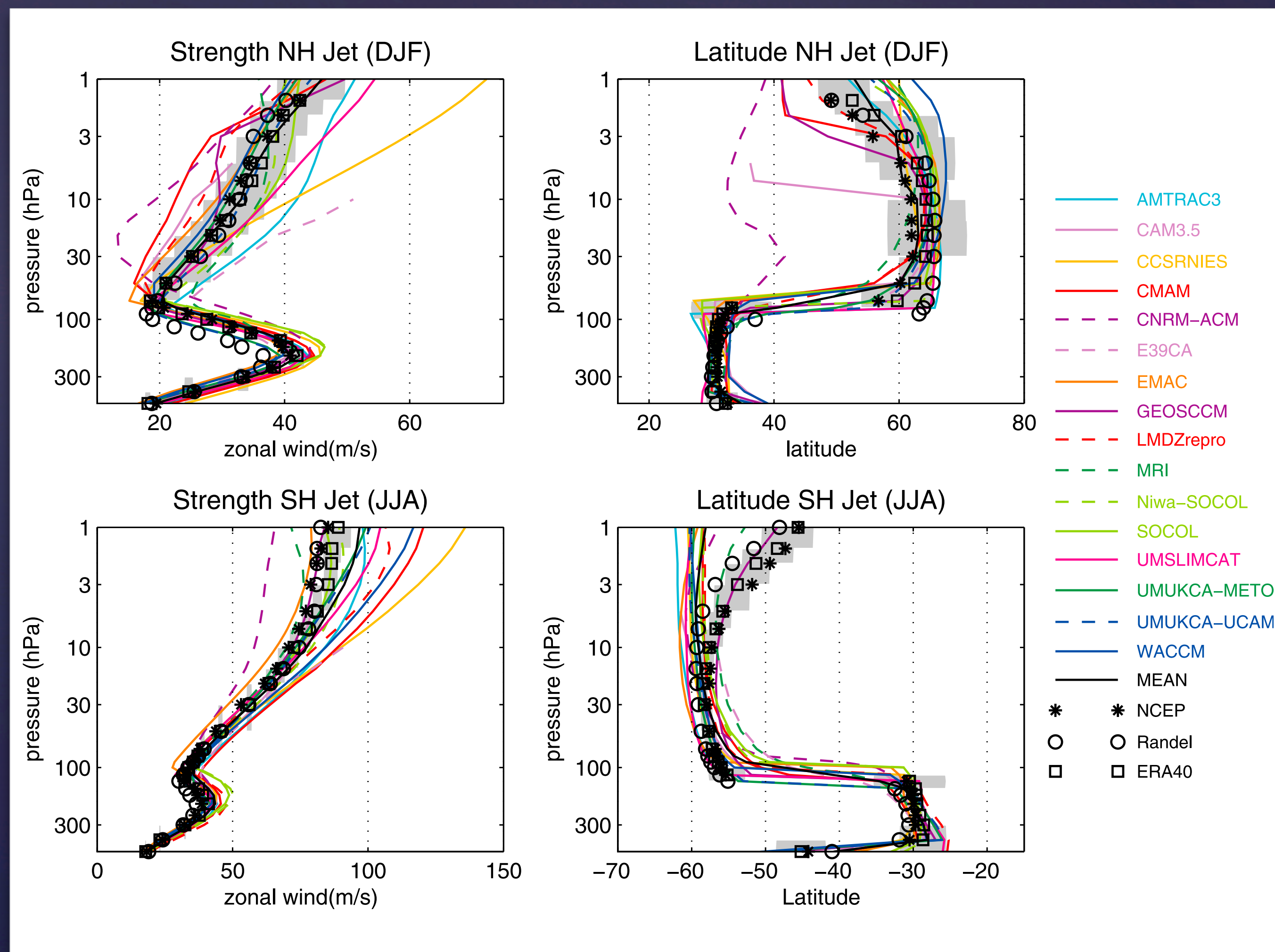
Warming type	ERA-40	WACCM3.5 (With TMS)	WACCM3.5ntms (No TMS)
Major midwinter (NDJF)	0.5	0.4	0.1
Major midwinter (NDJFM)	0.6	0.6	0.25
Minor (NDJF)	0.9	1.0	0.4
Minor (NDJFM)	1.4	1.4	0.65

Common Model Biases

Wind biases in the Southern Hemisphere are common.
Butchart et al. [2011]

Zonal
Winds

Southern Hemisphere wind strength remains too large and the latitude of the jet maximum too far poleward in most models.

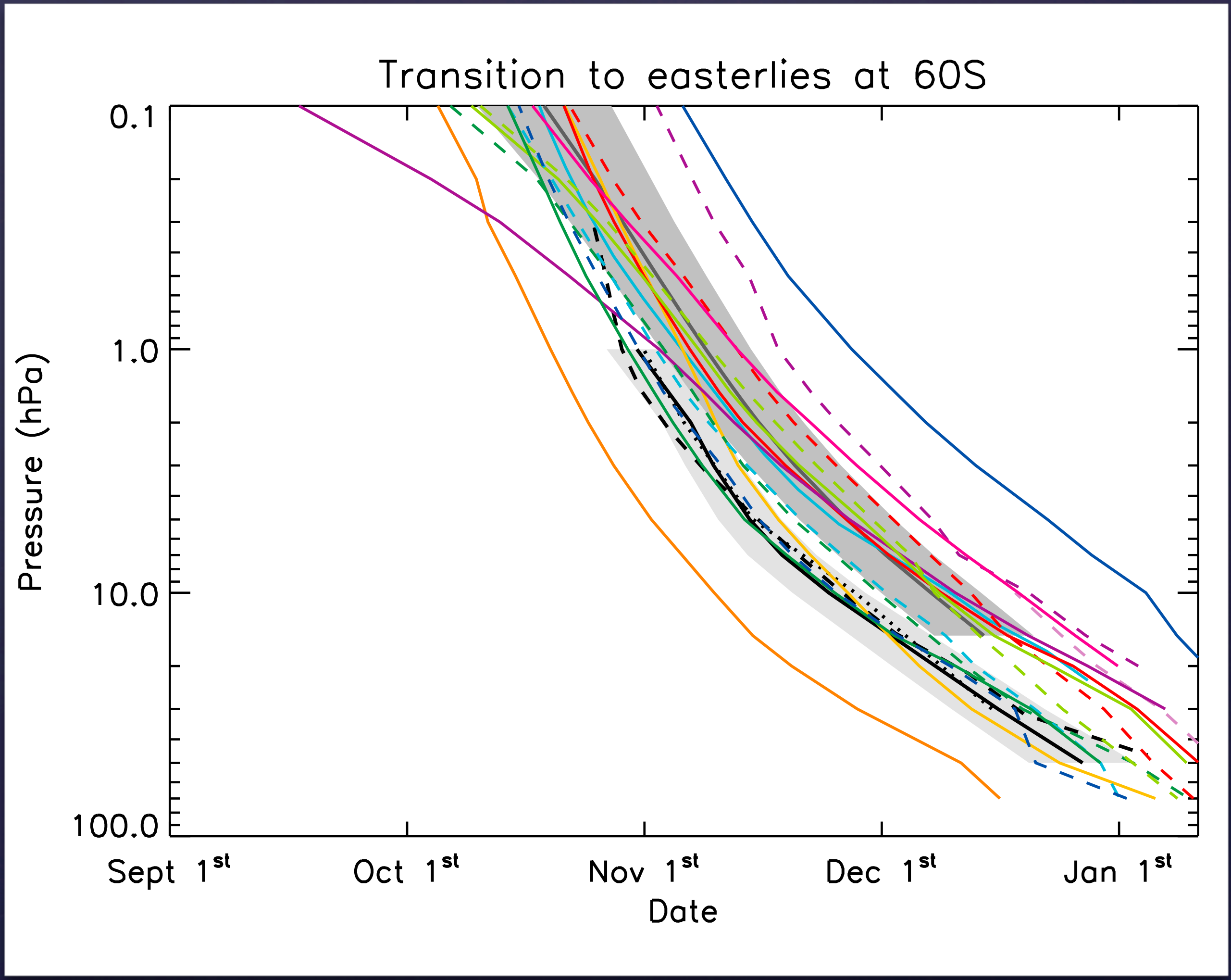


Common Model Biases

Seasonal transition of the winds occurs too late in the Southern Hemisphere
Butchart et al. [2011]

Altitude of the zero wind line during the transition from winter westerlies to summer easterlies.

Models (colors) remain late compared to the observations (black)



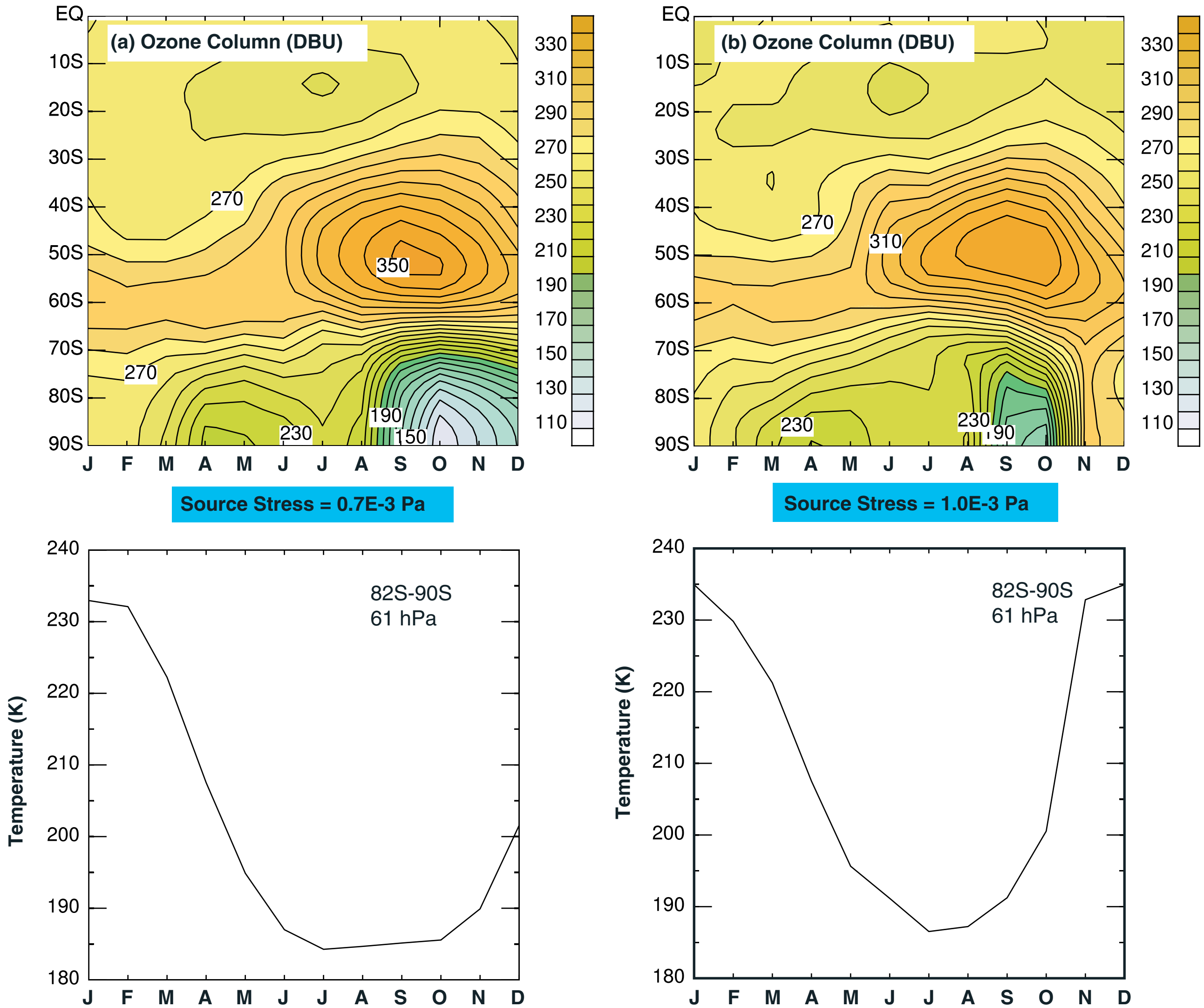
Gravity Wave Drag can reduce common model biases

Improving Southern Hemisphere vortex biases and effects on ozone loss

Alexander et al. [2010]

Plots from WACCM from Fabrizio Sassi:

Changing the parameterized gravity wave momentum flux can change the timing of the summer transition, give warmer spring temperatures, and result in dramatically less ozone loss.



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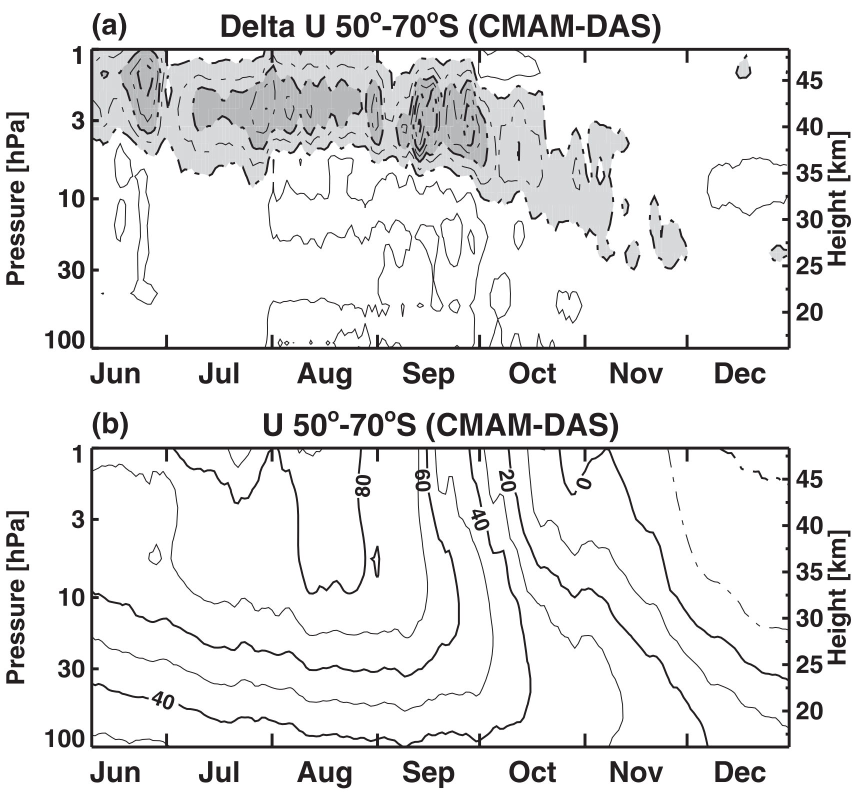
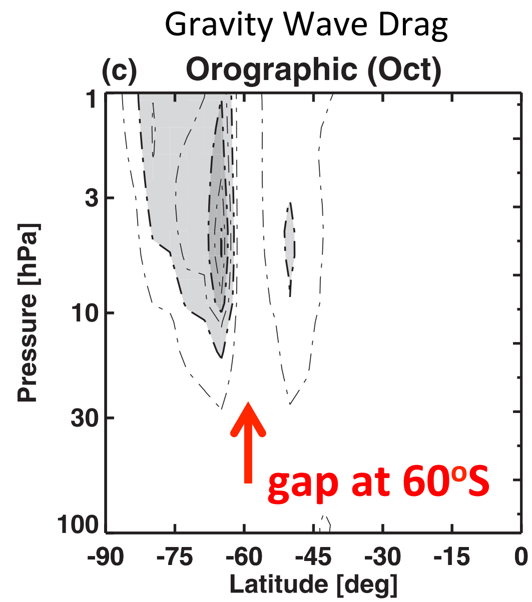
Improving Southern Hemisphere vortex biases and effects on ozone loss

McLandress et al. [2012]: CMAM wind biases in the stratosphere compared To Data Assimilation System. Attributed to missing Gravity Wave Drag.





Experimented with adding gravity wave momentum flux in a band at 60°S to "fill the gap" and correct the bias.

Gravity Wave Drag can reduce common biases

Improving Southern Hemisphere vortex biases and effects on ozone loss

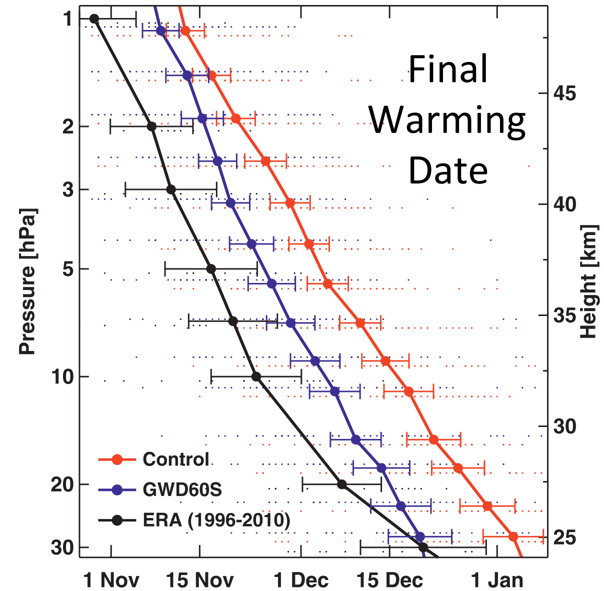
McLandress et al. [2012]:

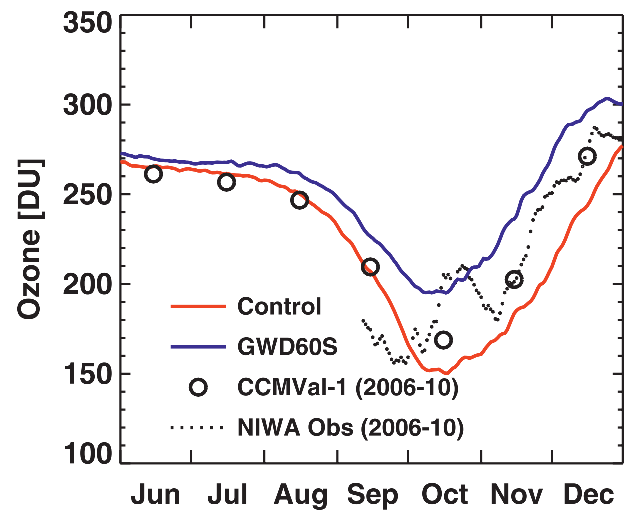
Correcting the SH Stratospheric Wind biases affects:

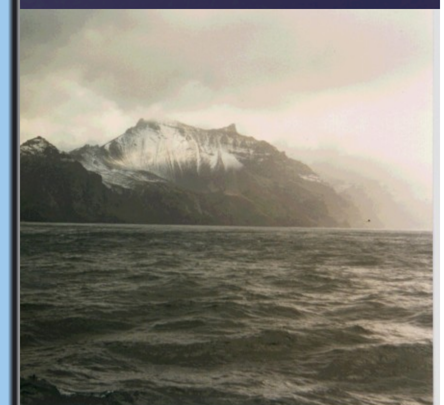
➔Vortex temperatures

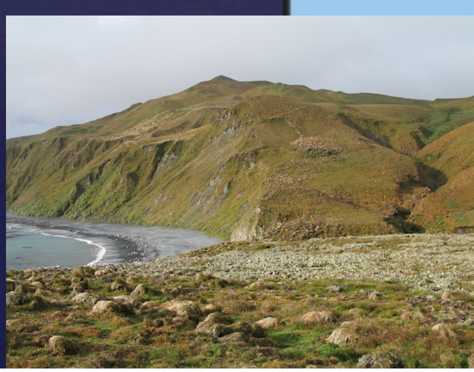
➔Seasonal vortex breakdown timing

➔Depth of springtime ozone loss









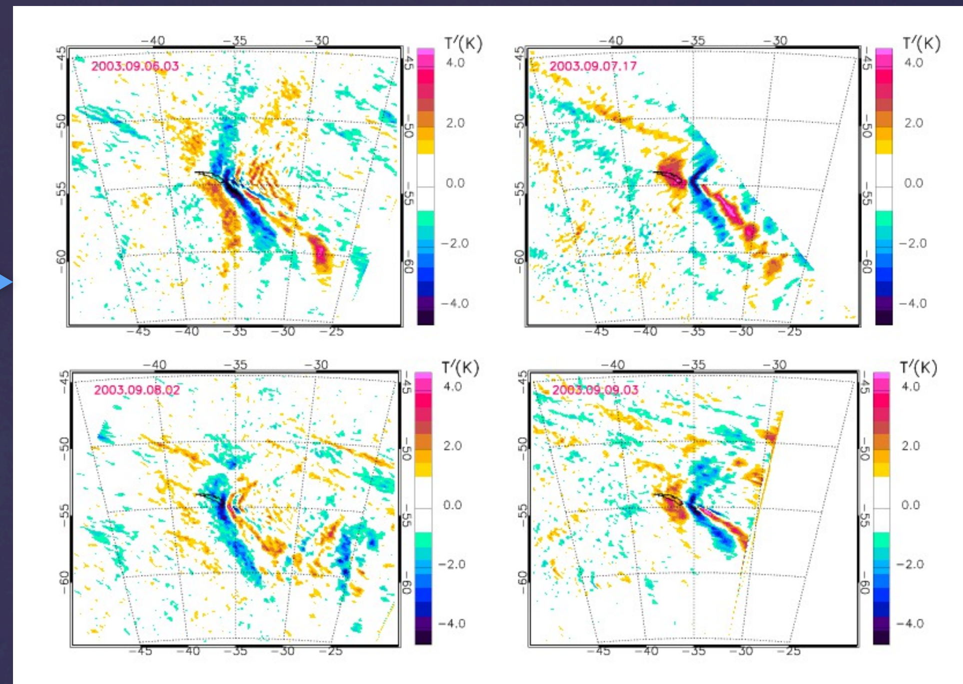
Island orographic wave drag?

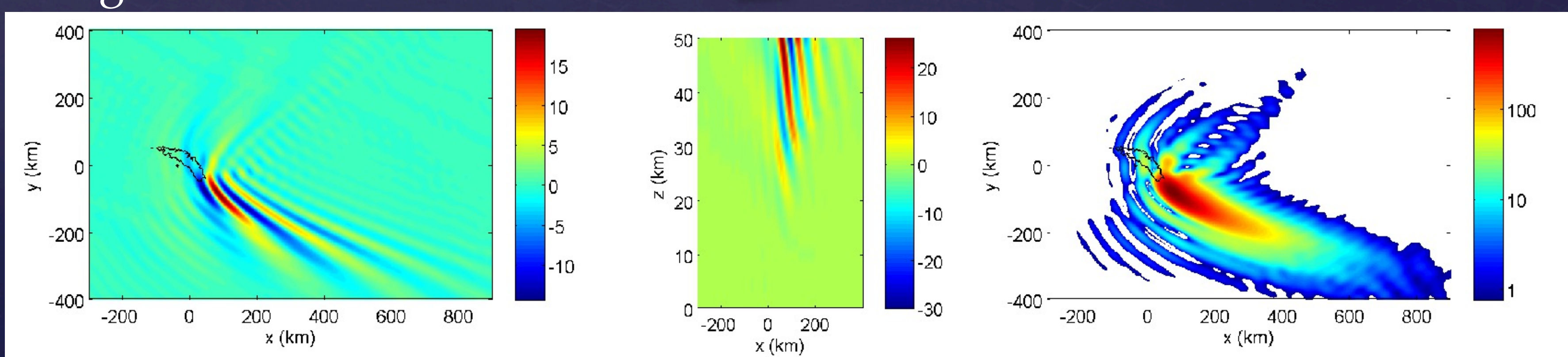
Remote islands provide some missing drag

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.

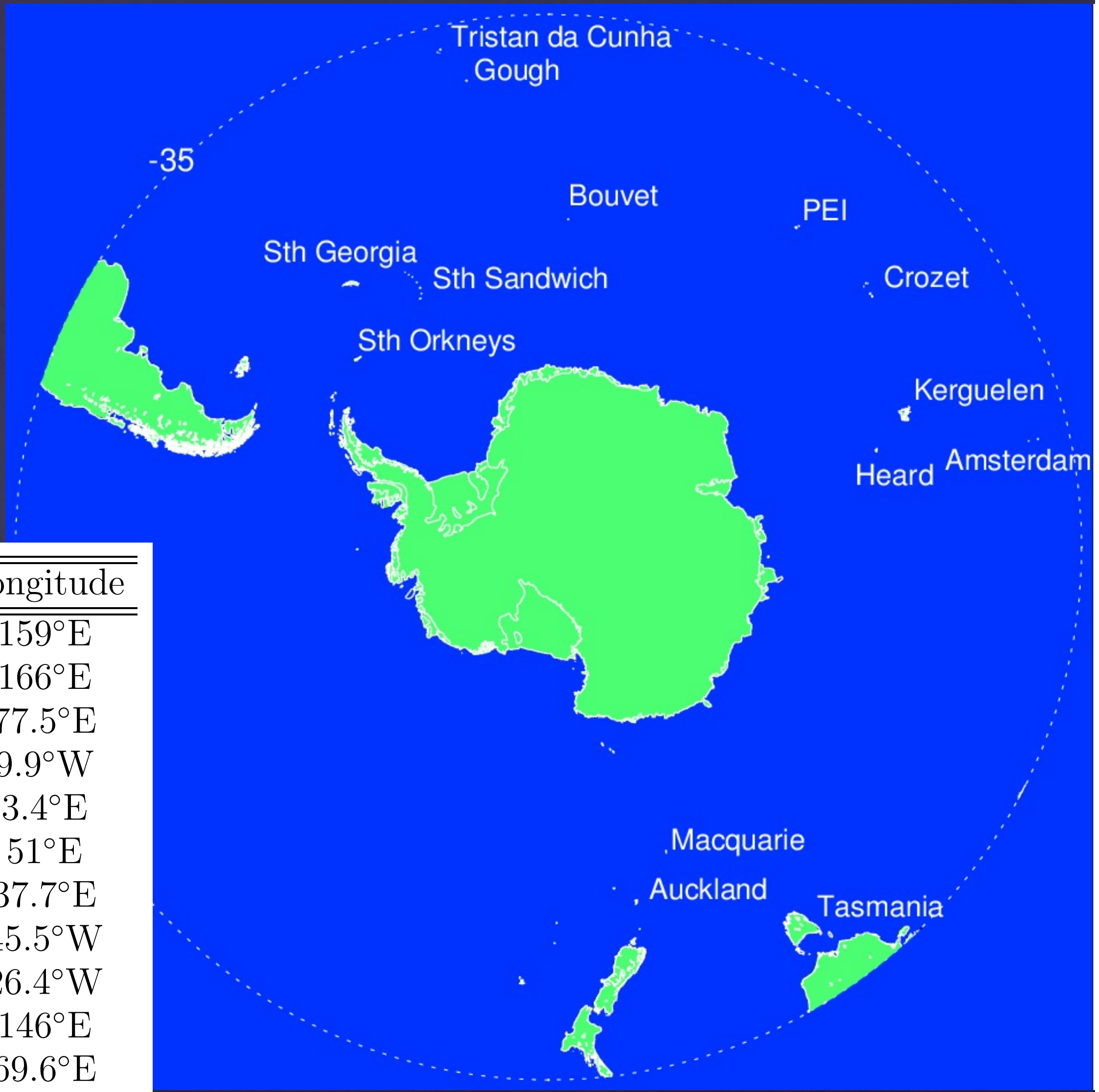




New Study: 14 Islands Examined

- Latitudes 37-61^{o}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
Heard	2745m	53.1°S	72.5°E
South Georgia	2934m	54.2°S	36.8°W

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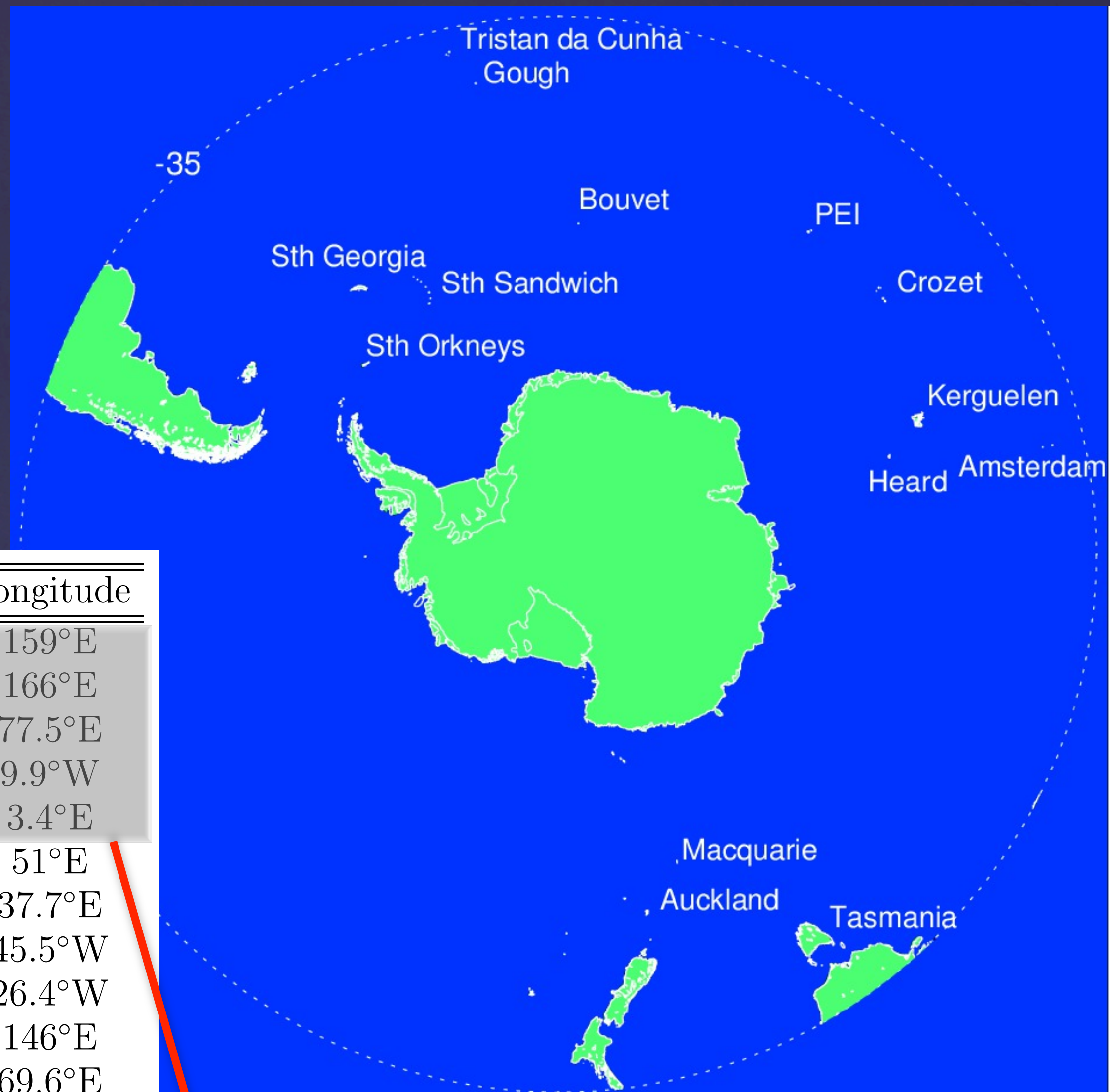

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Focus on island peaks > 1000m

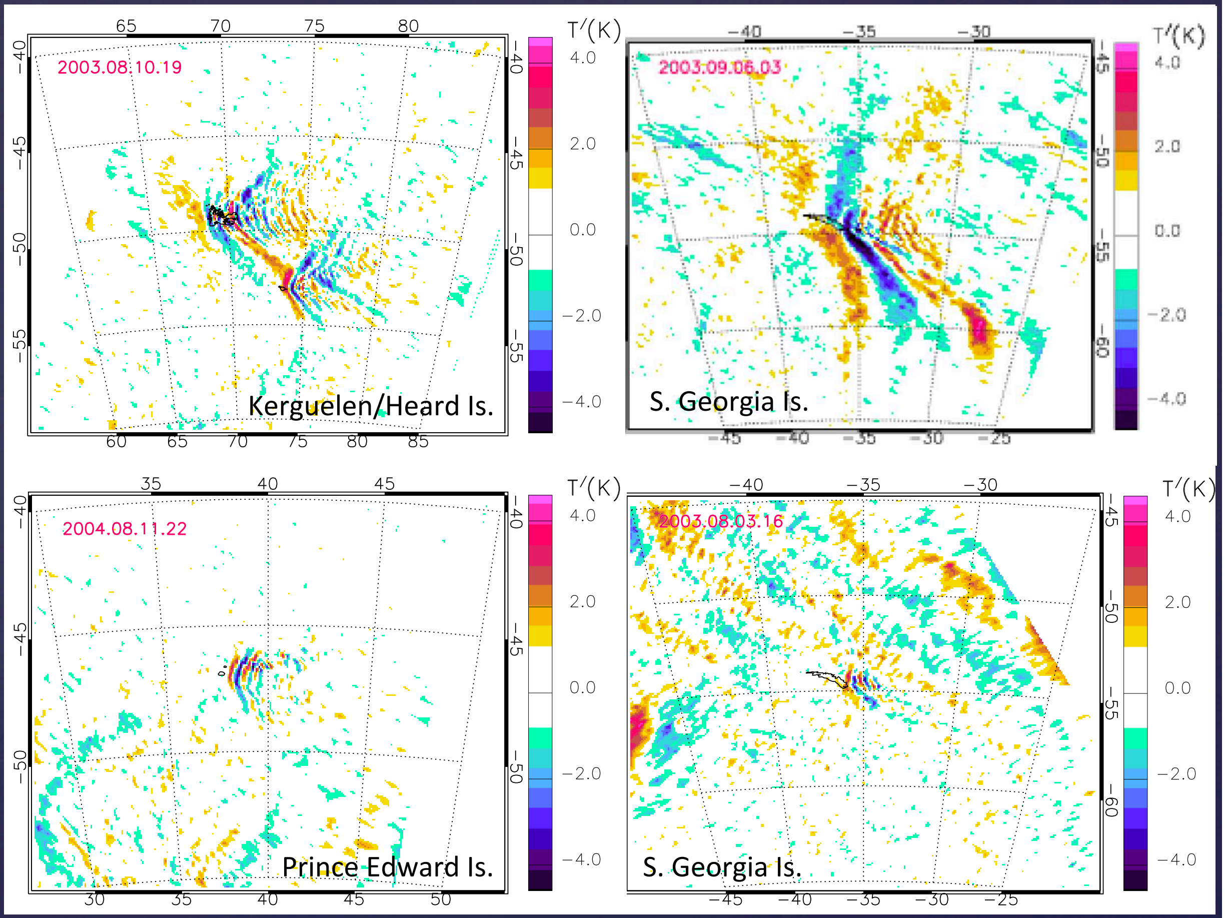
Method: Wave event identification

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:



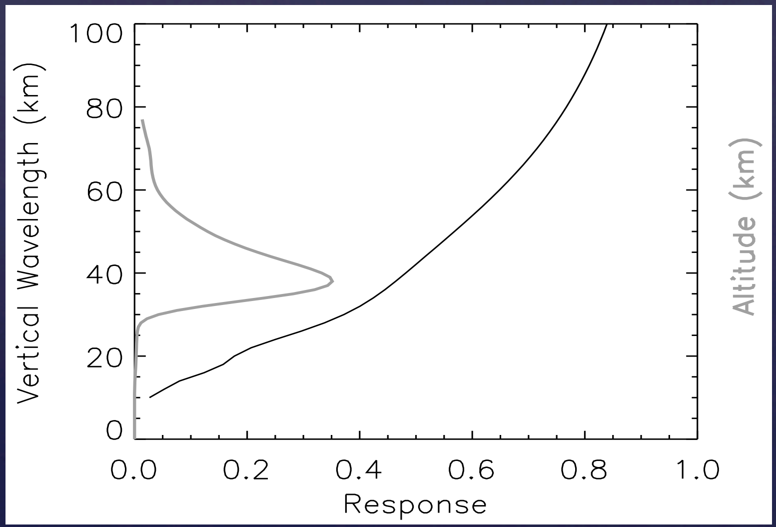
Uncertain cases give estimate of occurrence frequency uncertainty +/-8%

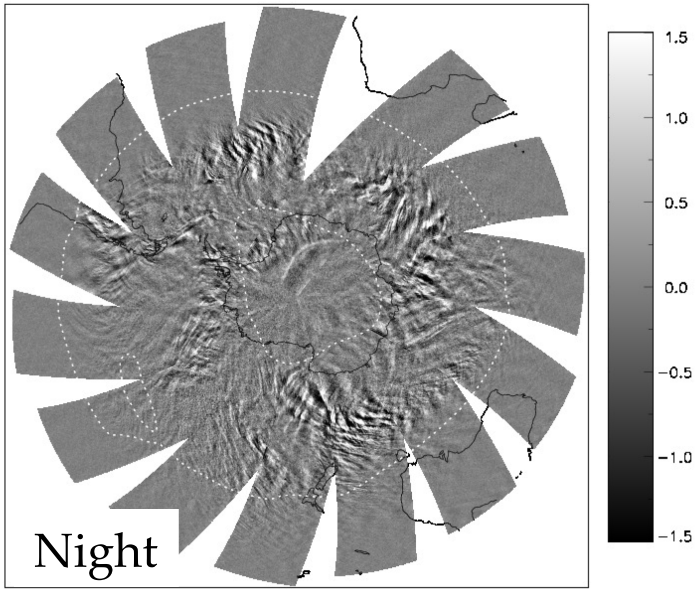
AIRS Sampling

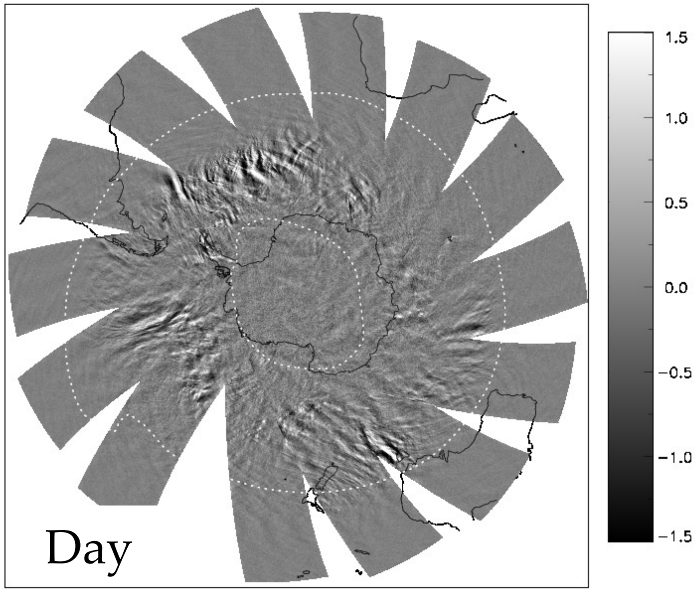
- Typically 2-3 measurement swaths daily above each island.

- 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.





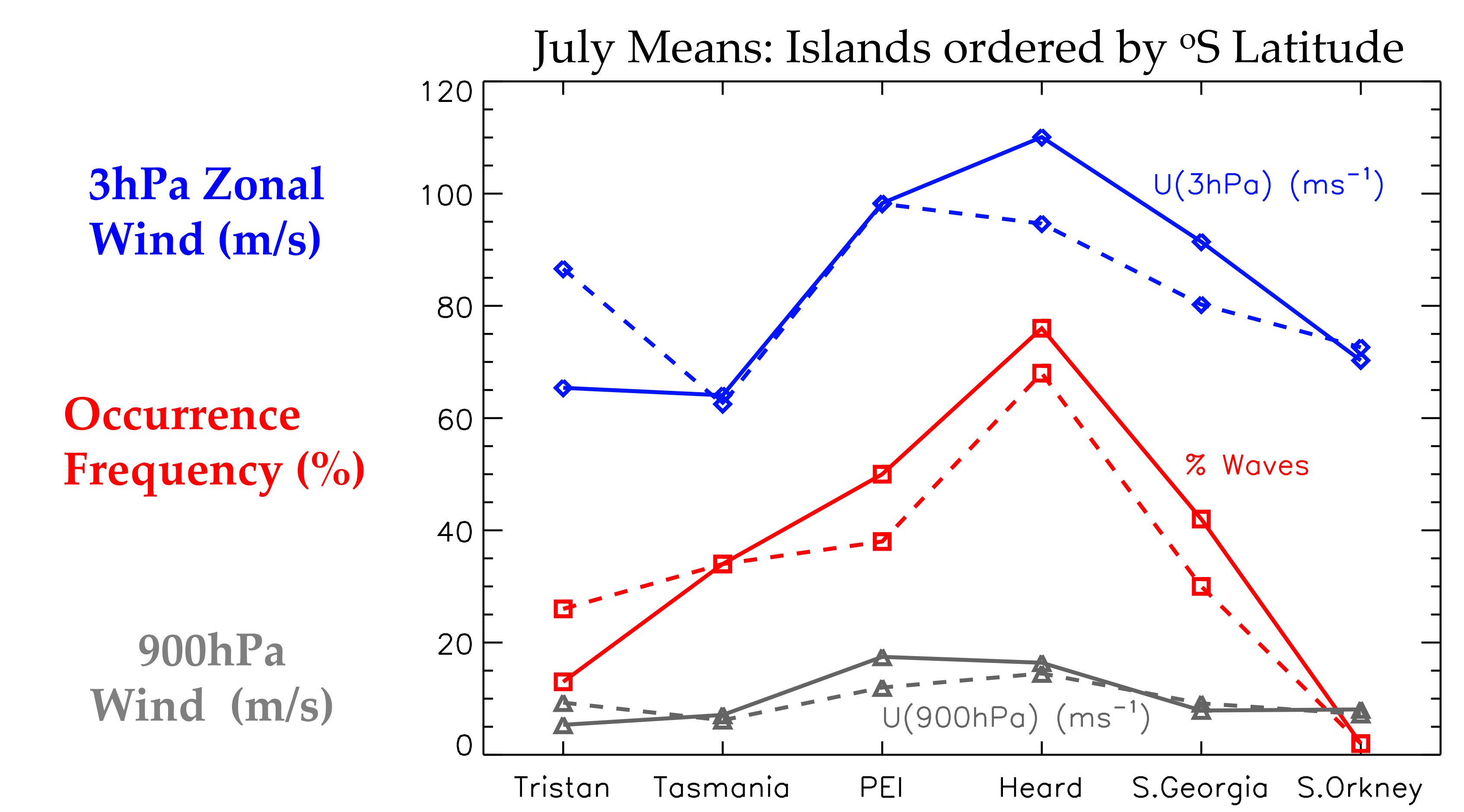


Results: July Occurrence Frequencies

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.**

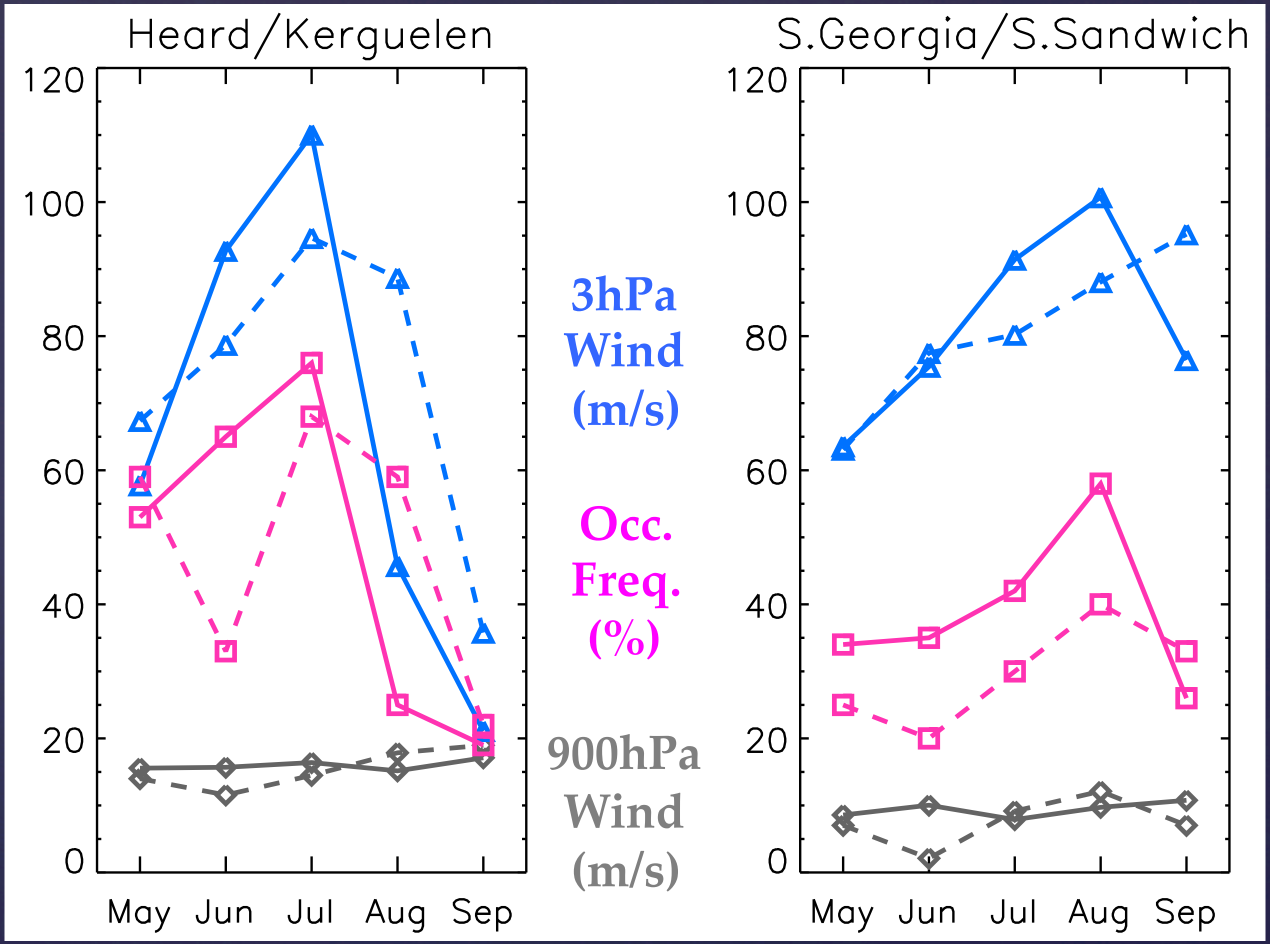
This further suggests wave events may be far more common than observed.



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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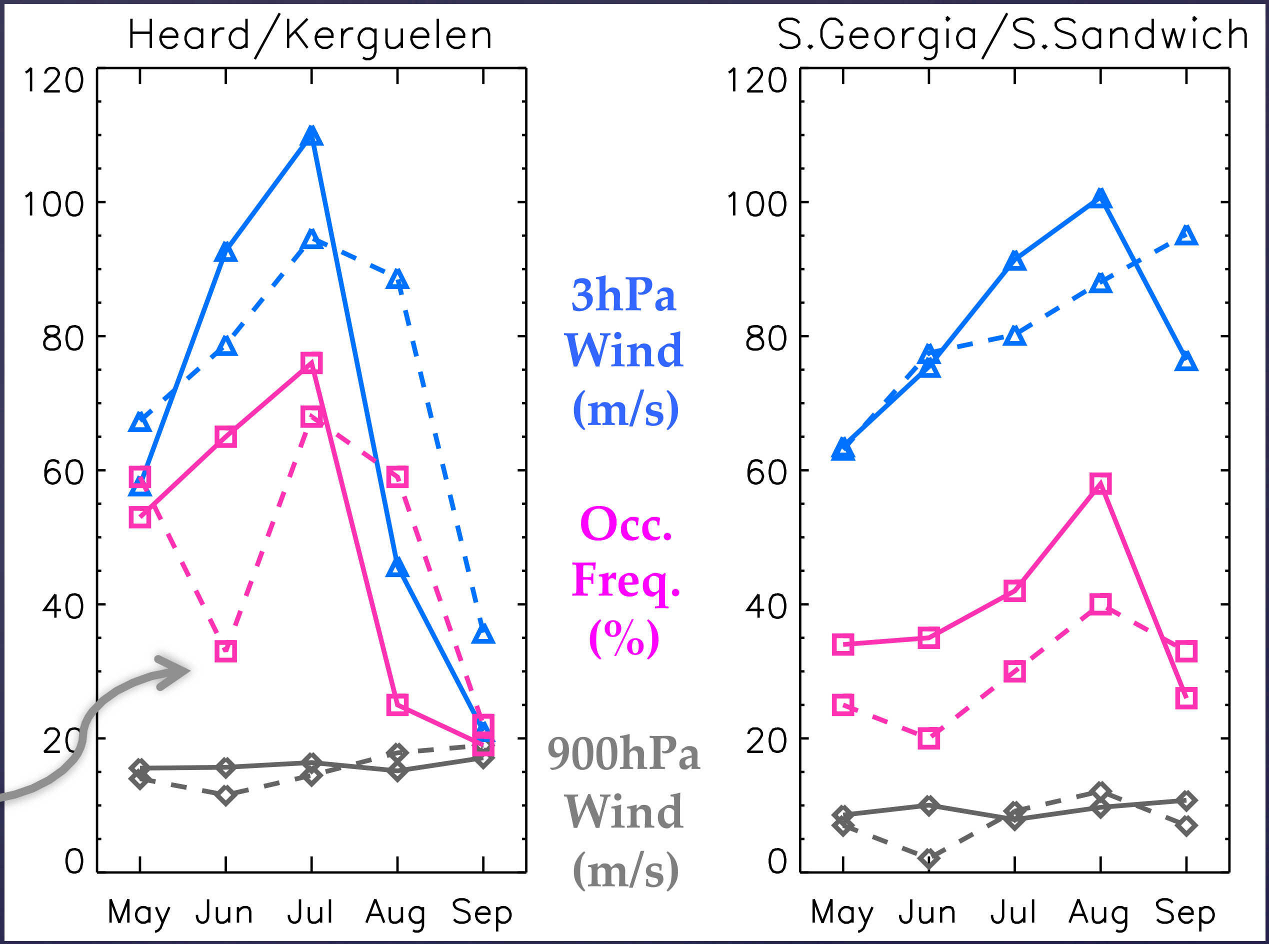


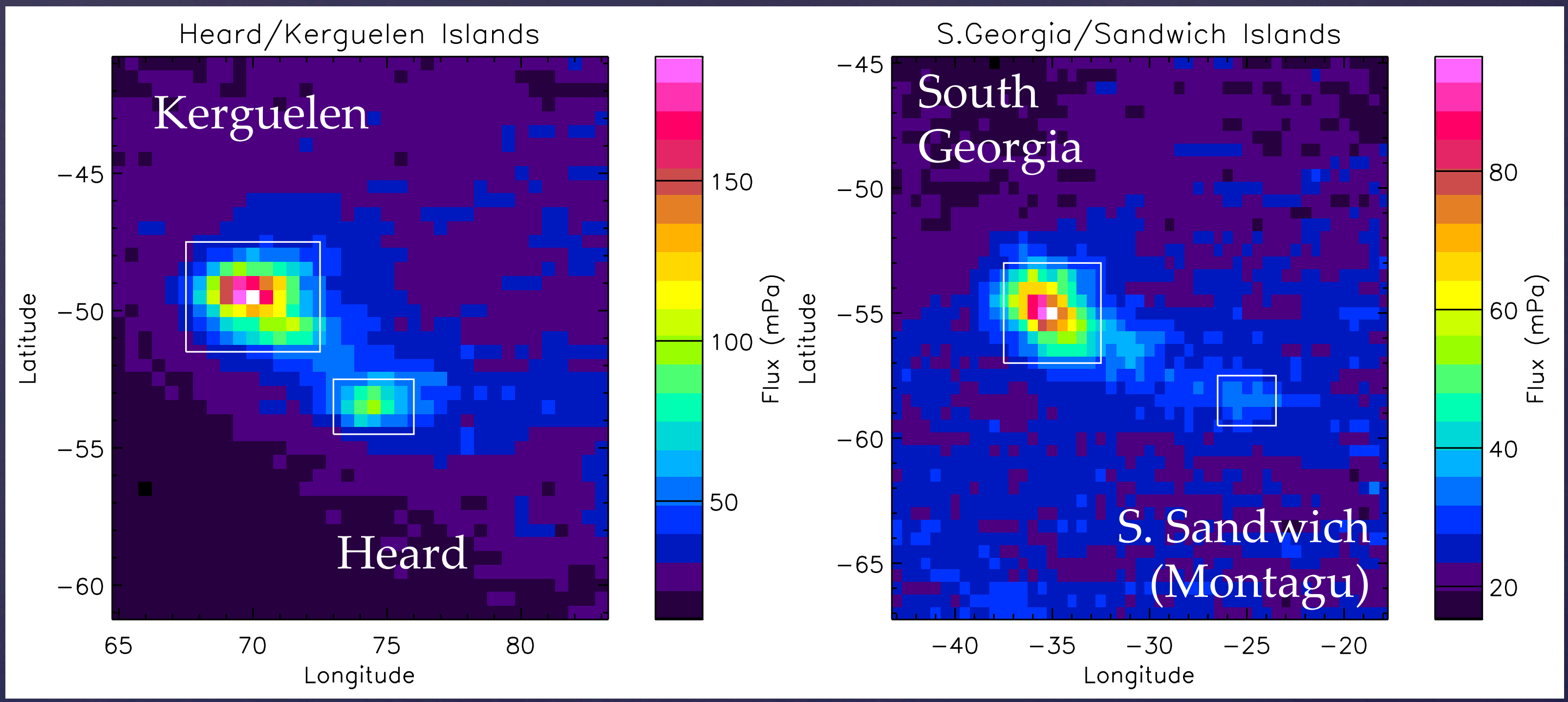
Anomaly in June 2003 at Kerguelen/ Heard:

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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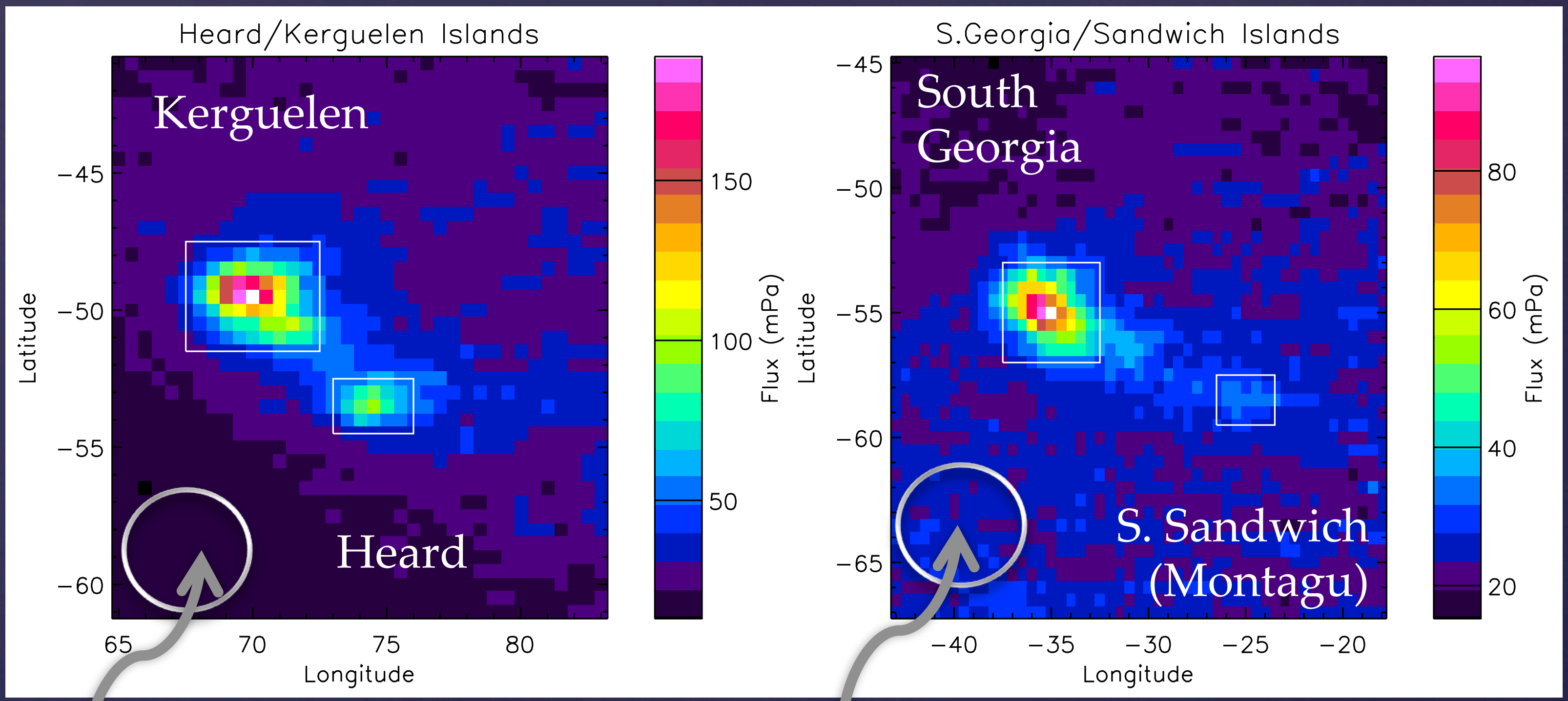


Error due to AIRS measurement noise = 4 mPa

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

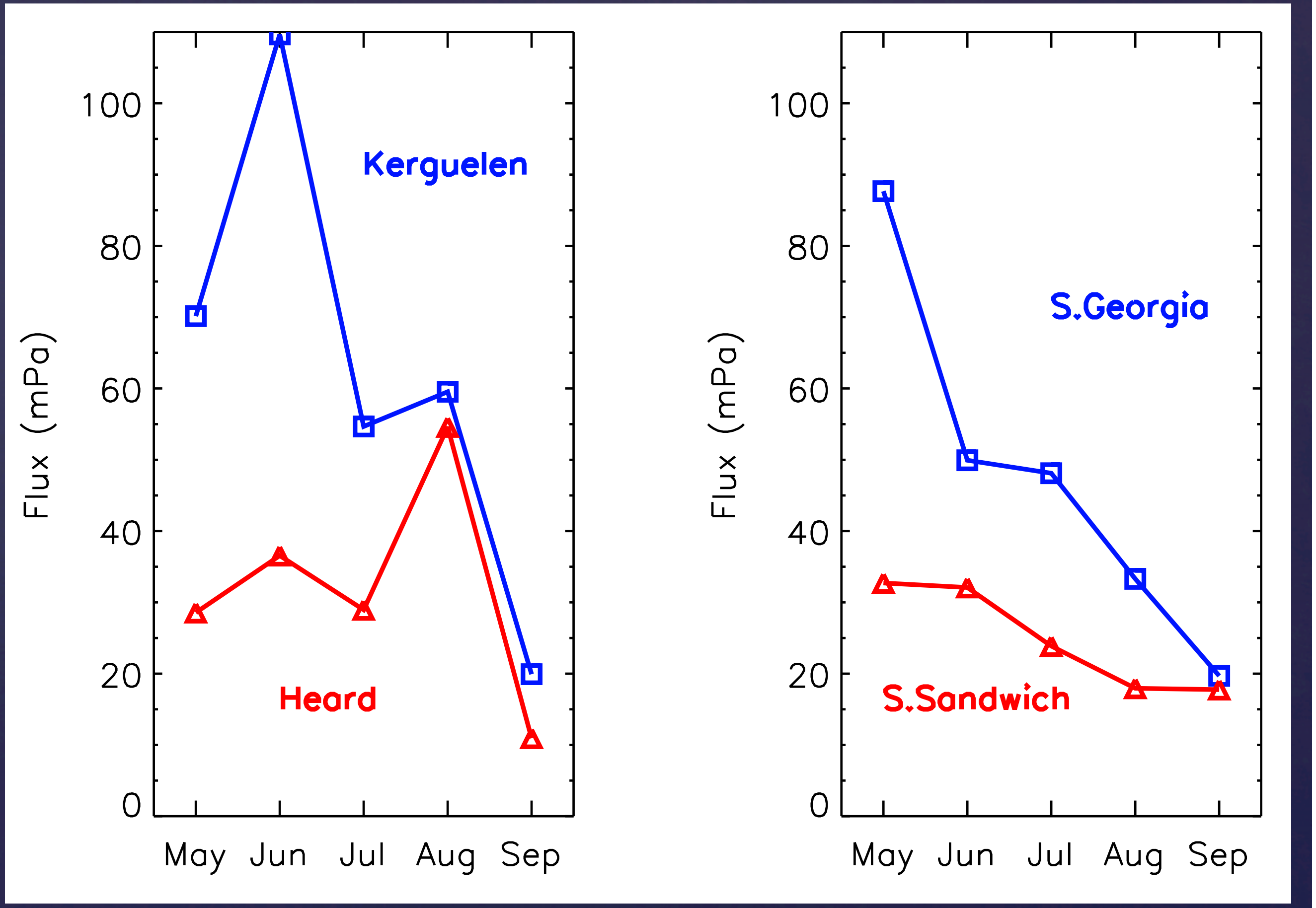
Momentum Flux: Seasonal Variation

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

- Note wave fluxes typically decay with z.

- Might max monthly mean momentum fluxes (~100mPa) and occurrence frequencies (~75%) 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^ox4^o area
3. Event momentum flux for small Islands with topography >2000m= 50 mPa per 3^ox2^o area
4. Event momentum flux for small Islands 1000-1500 m = 30 mPa per 3^ox2^o area

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➔Substantial zonal-mean contributions from these island wave events.

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

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.

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Reference in JGR: Alexander, M.J. and A.W. Grimsdell, 2013: Seasonal cycle of orographic gravity wave occurrence above small islands in the Southern Hemisphere: Implications for effects on the general circulation. *J. Geophys. Res.*, **118**, 11,589–11,599 doi:10.1002/2013JD020526.