Gravity Waves from Southern Ocean Islands and the Southern Hemisphere Circulation

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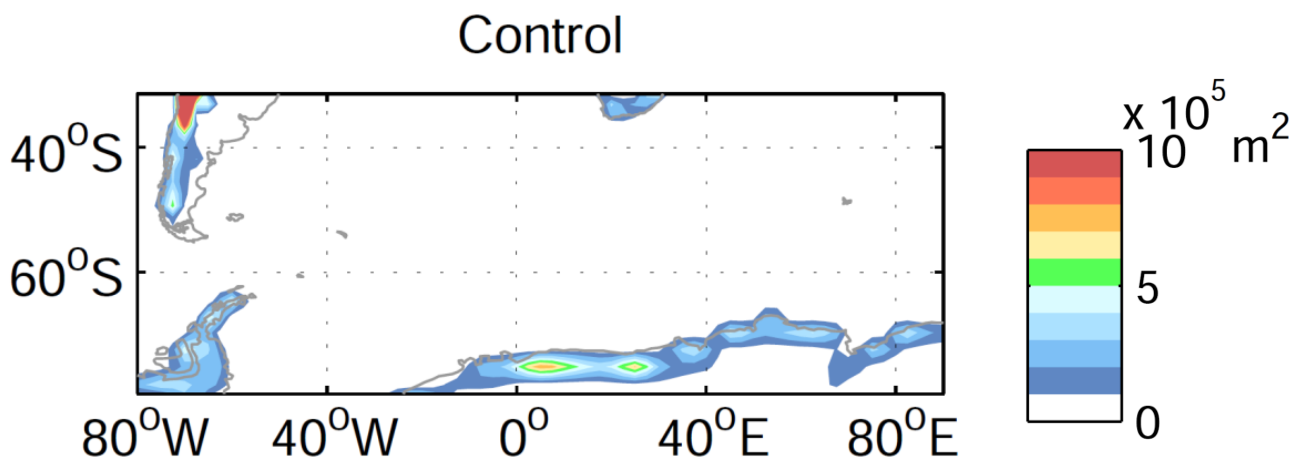
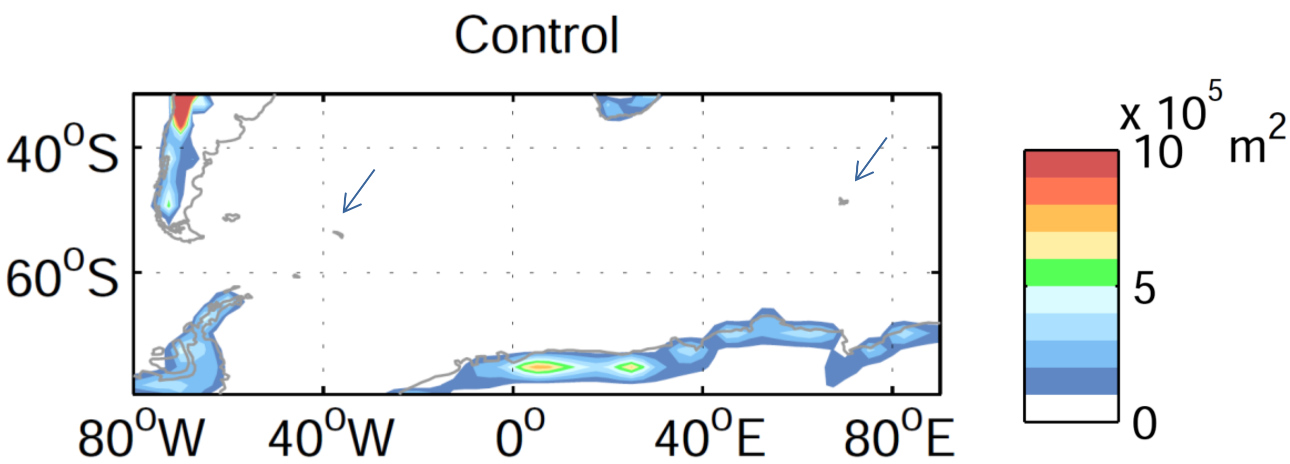
Topographic Variance in SH



Gap in topographic variance in Southern Ocean

Topographic Variance in SH



Gap in topographic variance in Southern Ocean

Kerguelen Island (highest elevation 1,850m, 7,215 km^2)

Photo courtesy Communication TAAF

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South Georgia Island

(highest elevation 2,934m, 3,903 km^2)

Photo courtesy NASA.

Heard Island (highest elevation 2745m, $368km^2$)

Photo courtesy Australian Antarctic Division (A.J. Graff).

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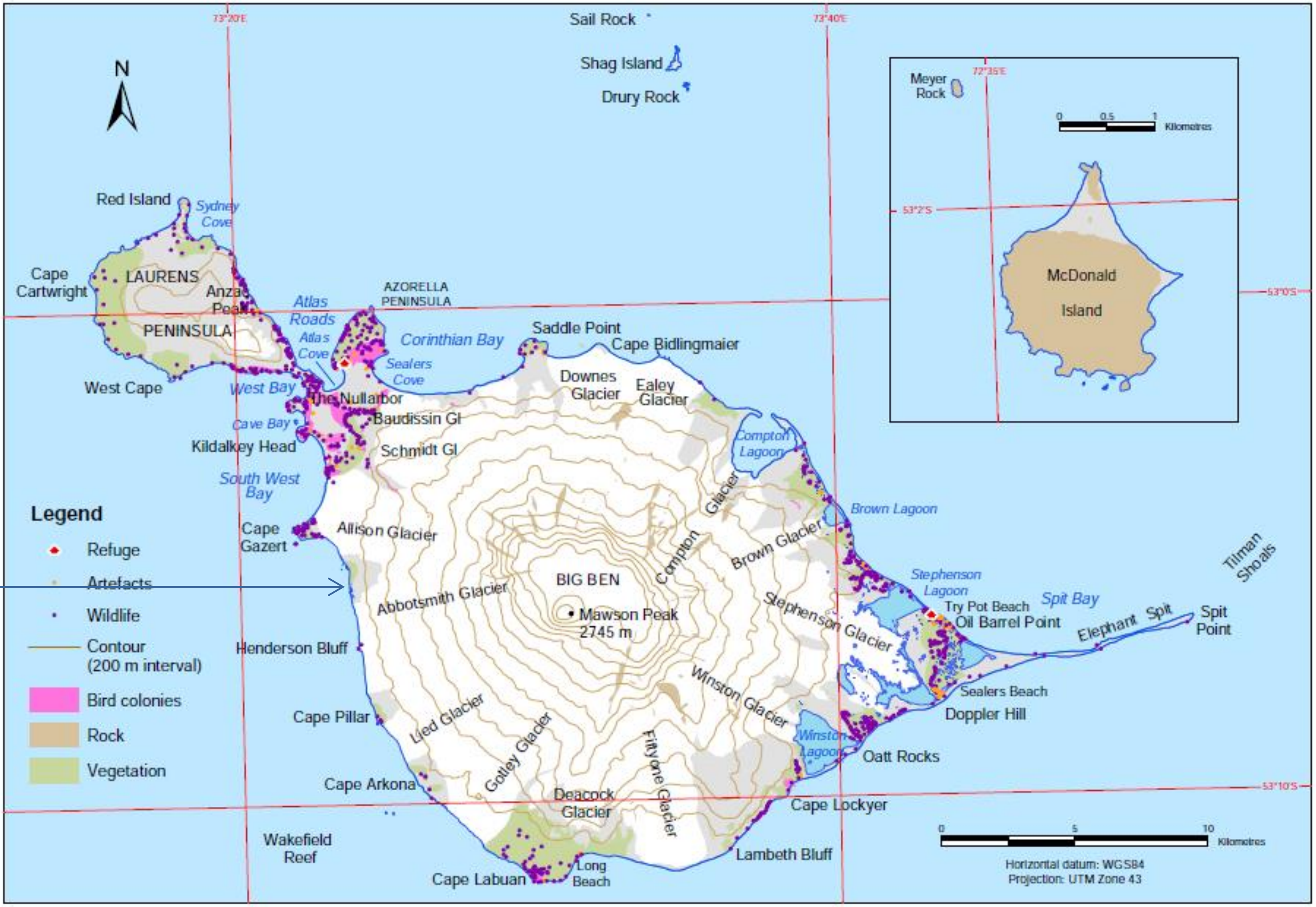
Heard Island (highest elevation 2745m, 368km^2)

Wind direction



Closest thing to an isolated Gaussian mountain

Waves from Sandwich Islands

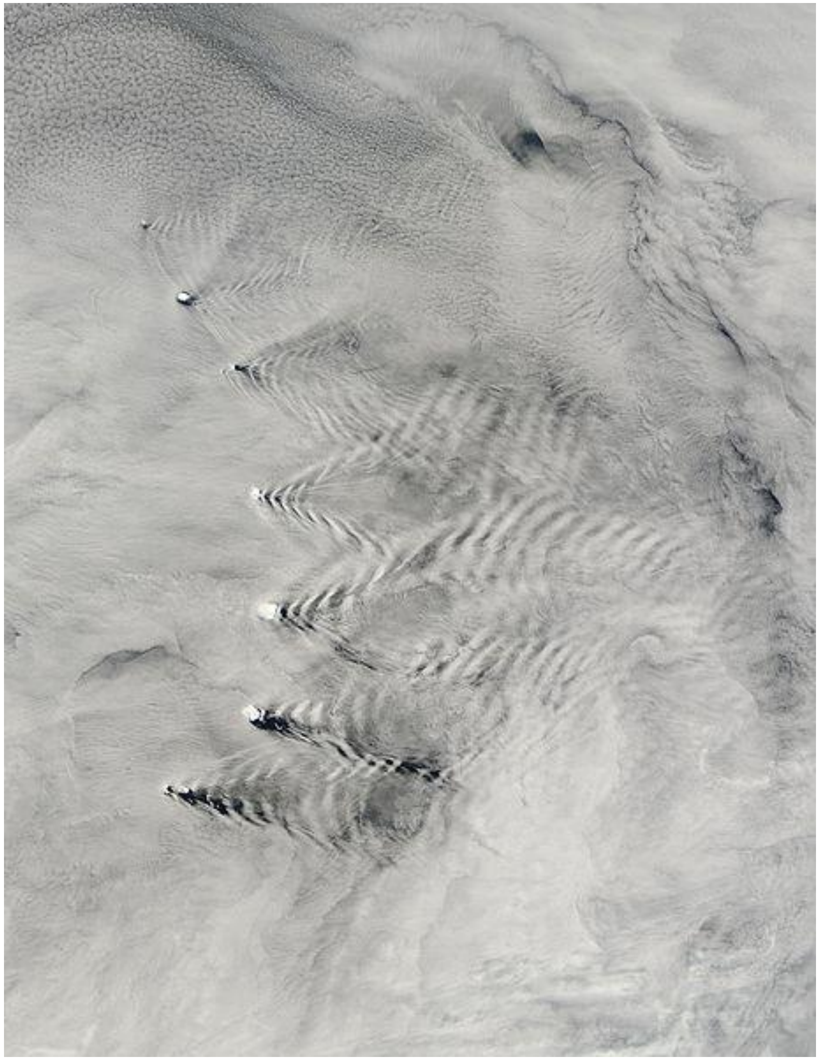
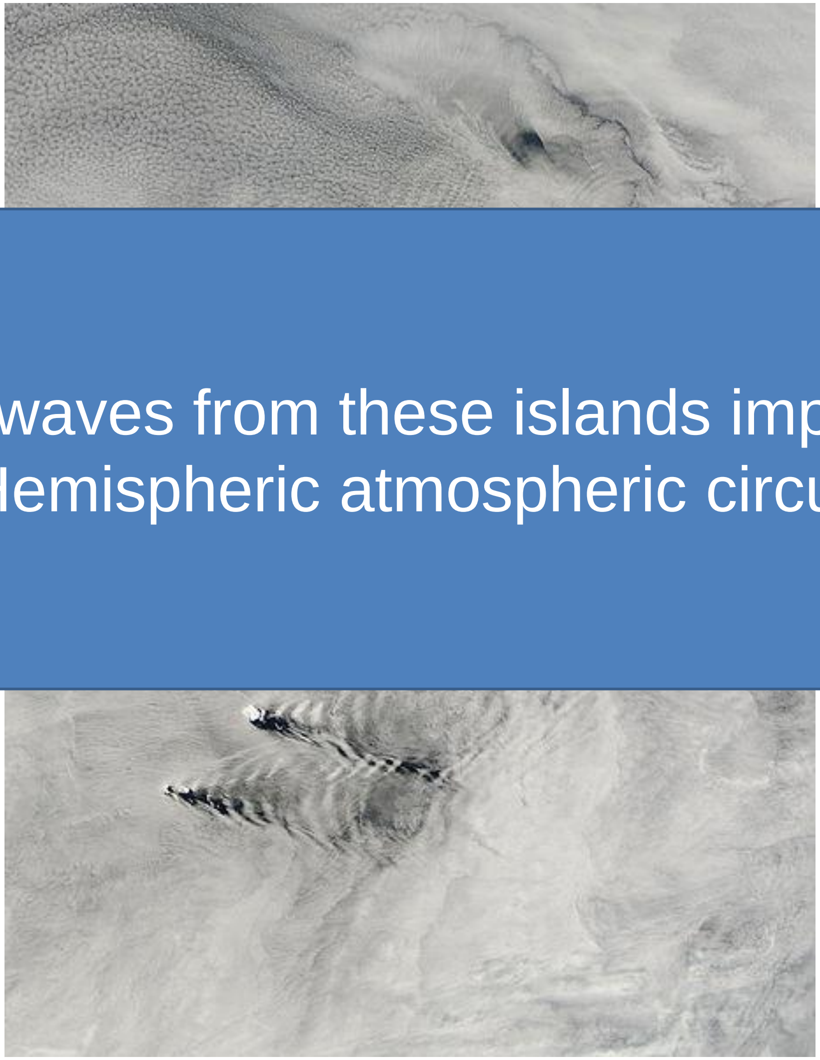


Photo courtesy NASA (MODIS on TERRA).

Waves from Sandwich Islands



Do gravity waves from these islands impact the Southern Hemispheric atmospheric circulation?

Photo courtesy NASA (MODIS on TERRA).

Biases in SH stratospheric circulation

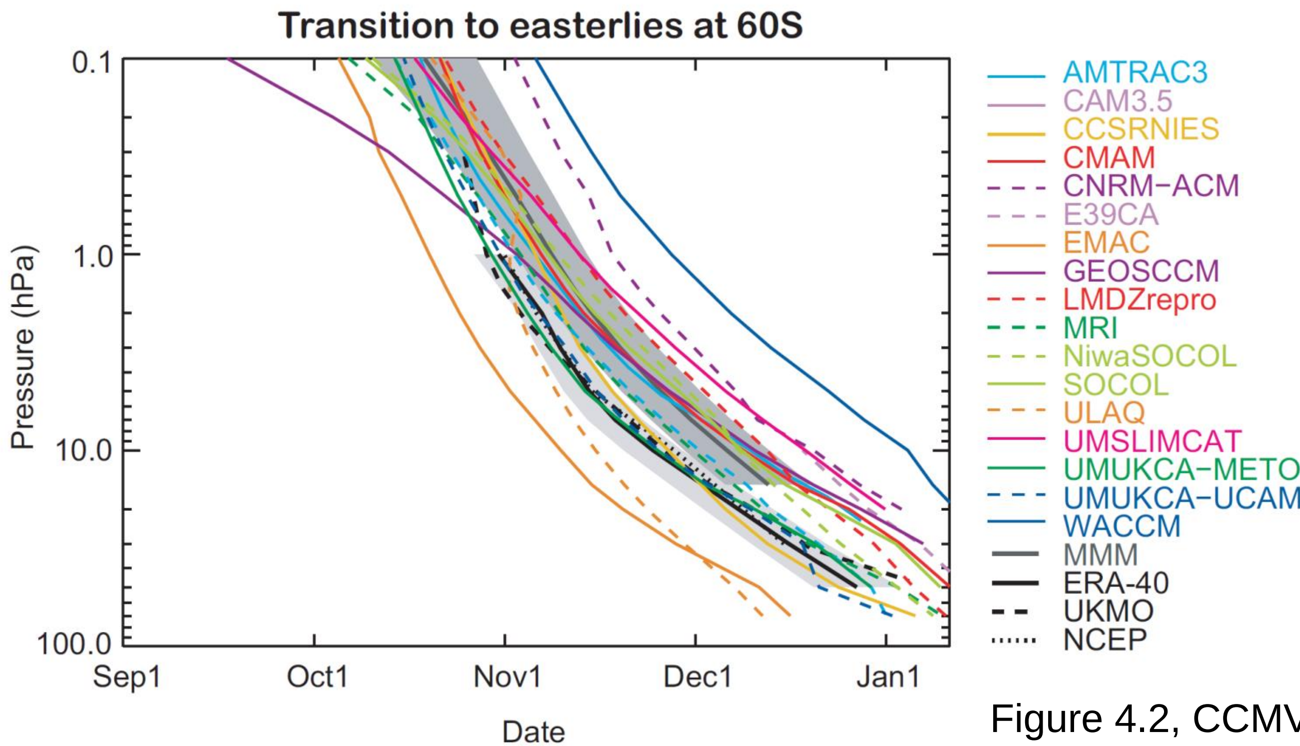
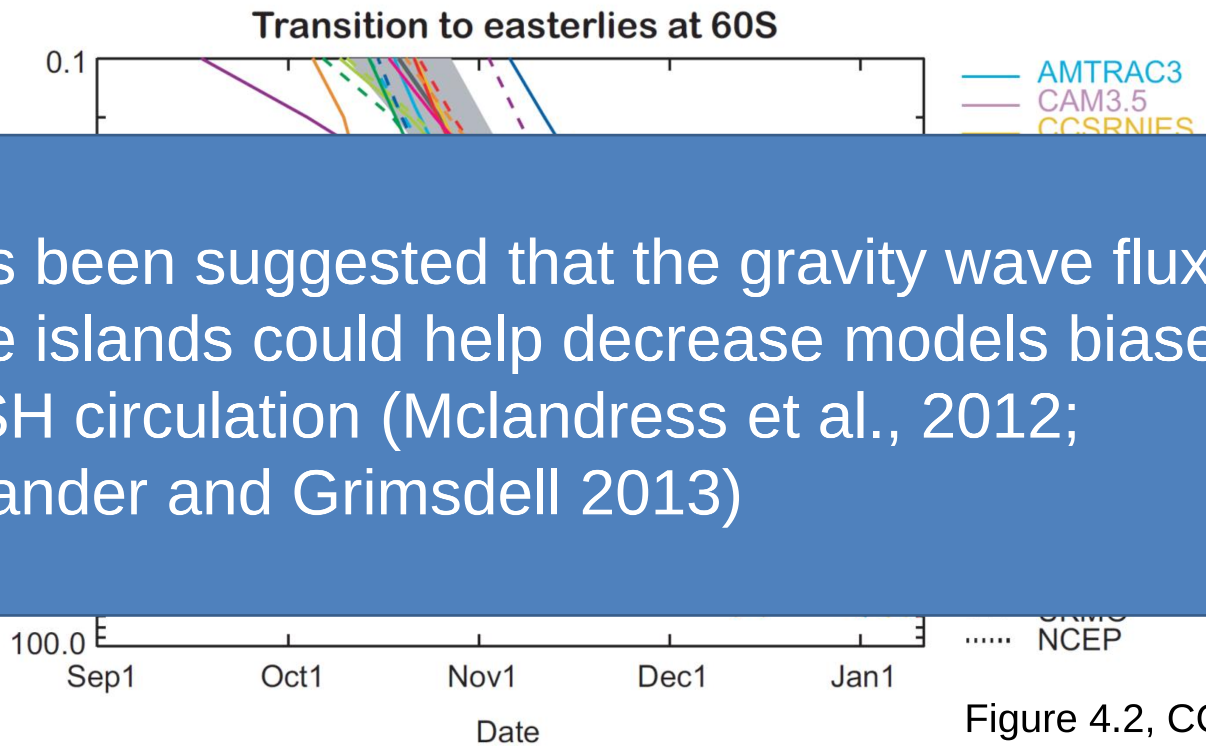


Figure 4.2, CCMVal2 report

Leads to overly persistent ozone hole

Most of these models do not explicitly represent these islands.

Biases in SH stratospheric circulation



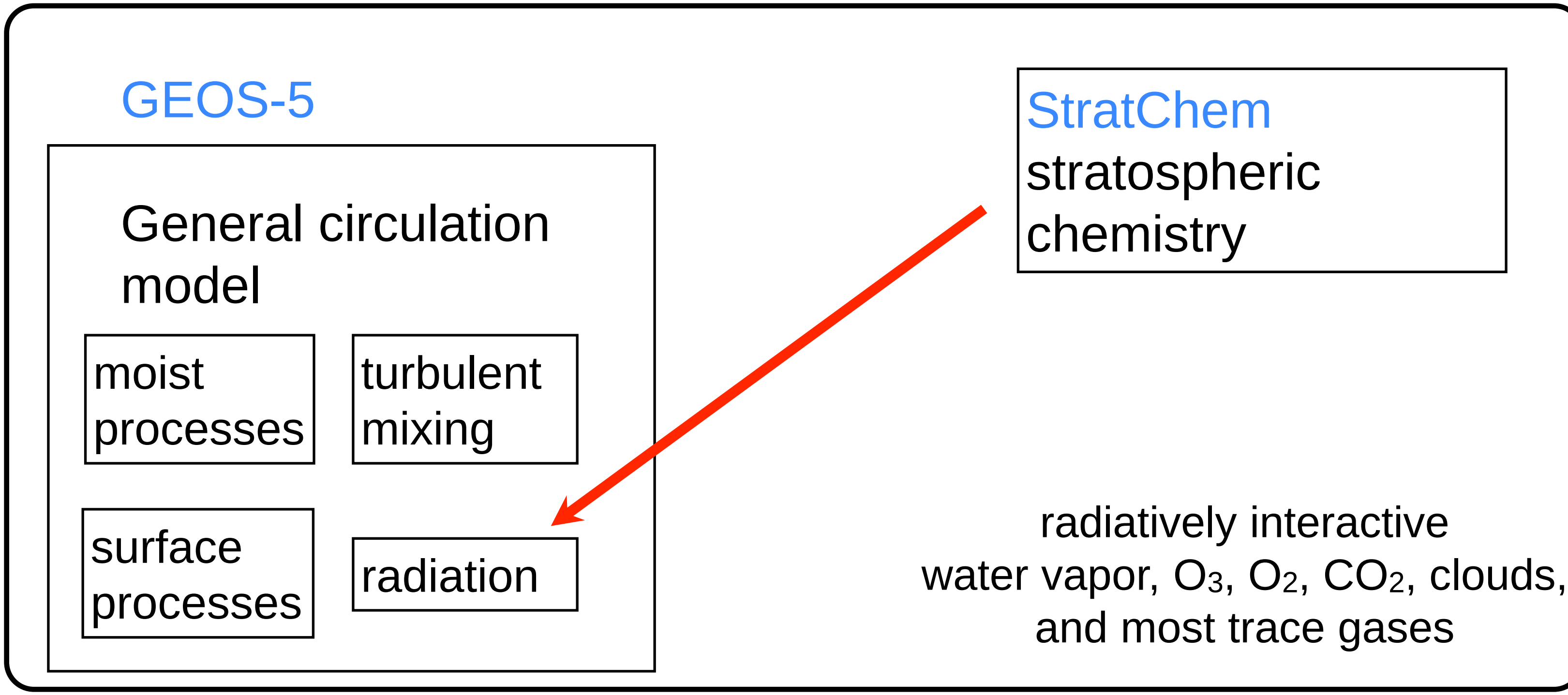
It has been suggested that the gravity wave flux fom these islands could help decrease models biases in the SH circulation (Mclandress et al., 2012; Alexander and Grimsdell 2013)

Figure 4.2, CCMVal2 report

Leads to overly persistent ozone hole

Most of these models do not explicitly represent these islands.

GEOSCCM (Goddard Earth Observing System Chemistry Climate Model)



- Resolution: 2˚ latitude x 2.5˚ longitude, 72 vertical layers from surface to 0.01 hPa
- Suffers from late breakdown bias
- Note that default version of model includes some orographic GW drag from these islands.
- McFarlane 1987 scheme for orographic gravity waves, with turbulent PBL drag similar to that in Beljaars et al 2004.

Methodology

We have modified the topography variance to artificially enhance the wave flux from these islands.

Two classes of experiments:

1. Identify the maximum topographic variance from a model resolution used for NWP (1/4 degree x 5/16 degree) for each island, and use this value at the gridpoint corresponding to each island at climate model resolution (2degree x 2.5 degree).
2. Same as 1, but multiply the magnitude of the topographic variance by 5.

For limited experiments, we change the topographic variance only for the GW but not for turbulent drag (following Beljaars et al 2004)

Same experiments performed for two different model versions

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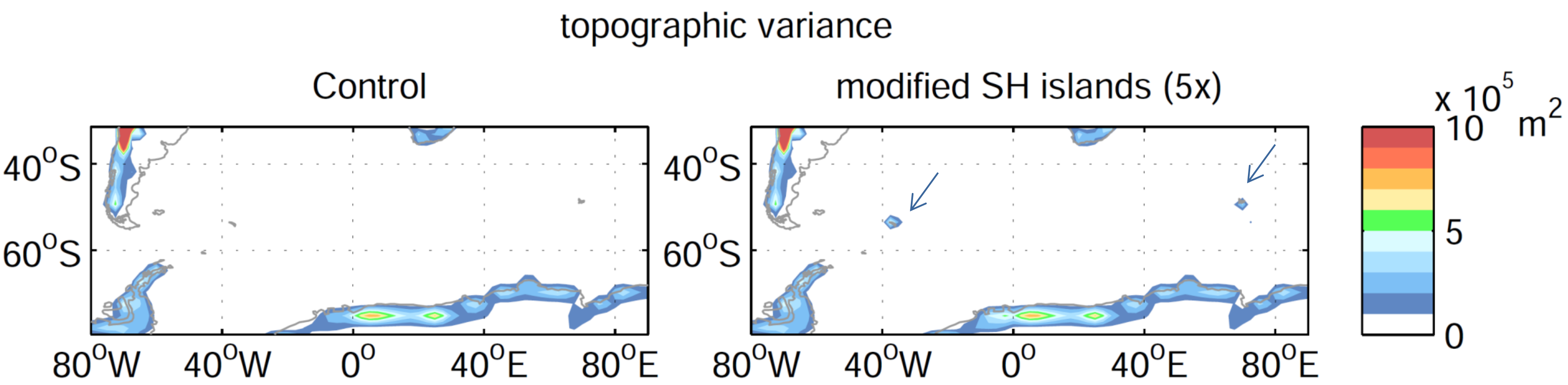
Net Effect of this Change



Large changes for South Georgia, Kerguelen, and Heard Islands (Alexander and Grimsdell 2013).

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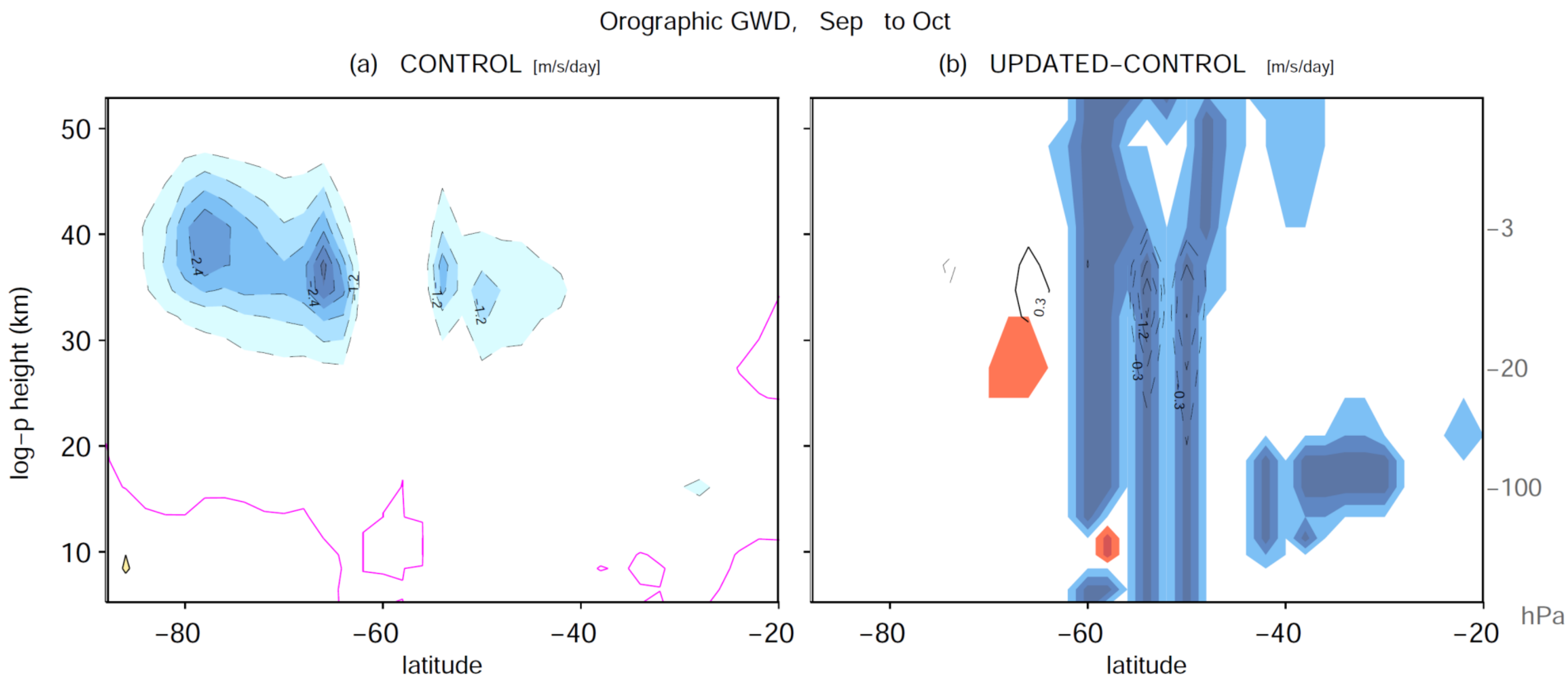
Change in Orographic GW Drag



Including this change partially fills in the GW hole near 55S-60S

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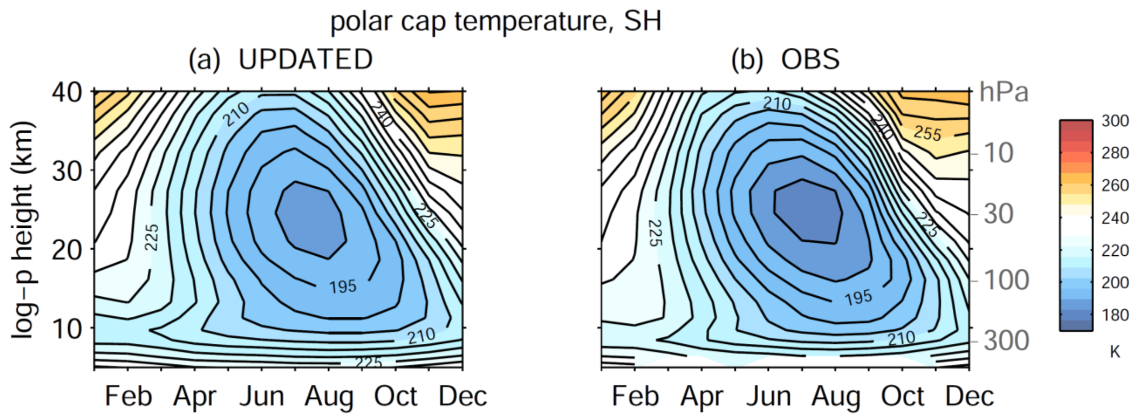
Change in Polar Cap Temperature



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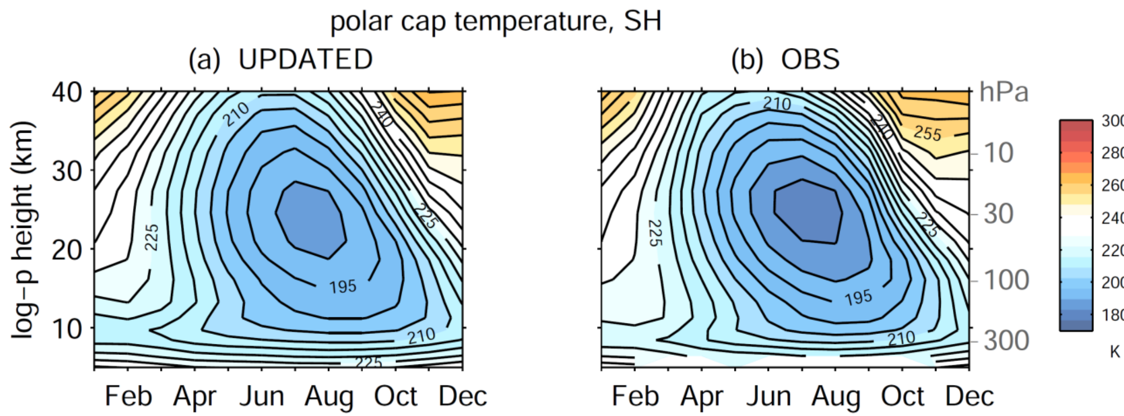
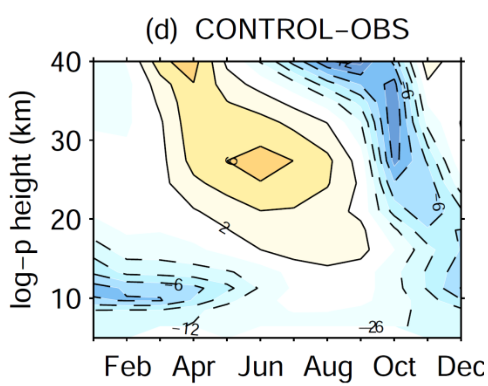
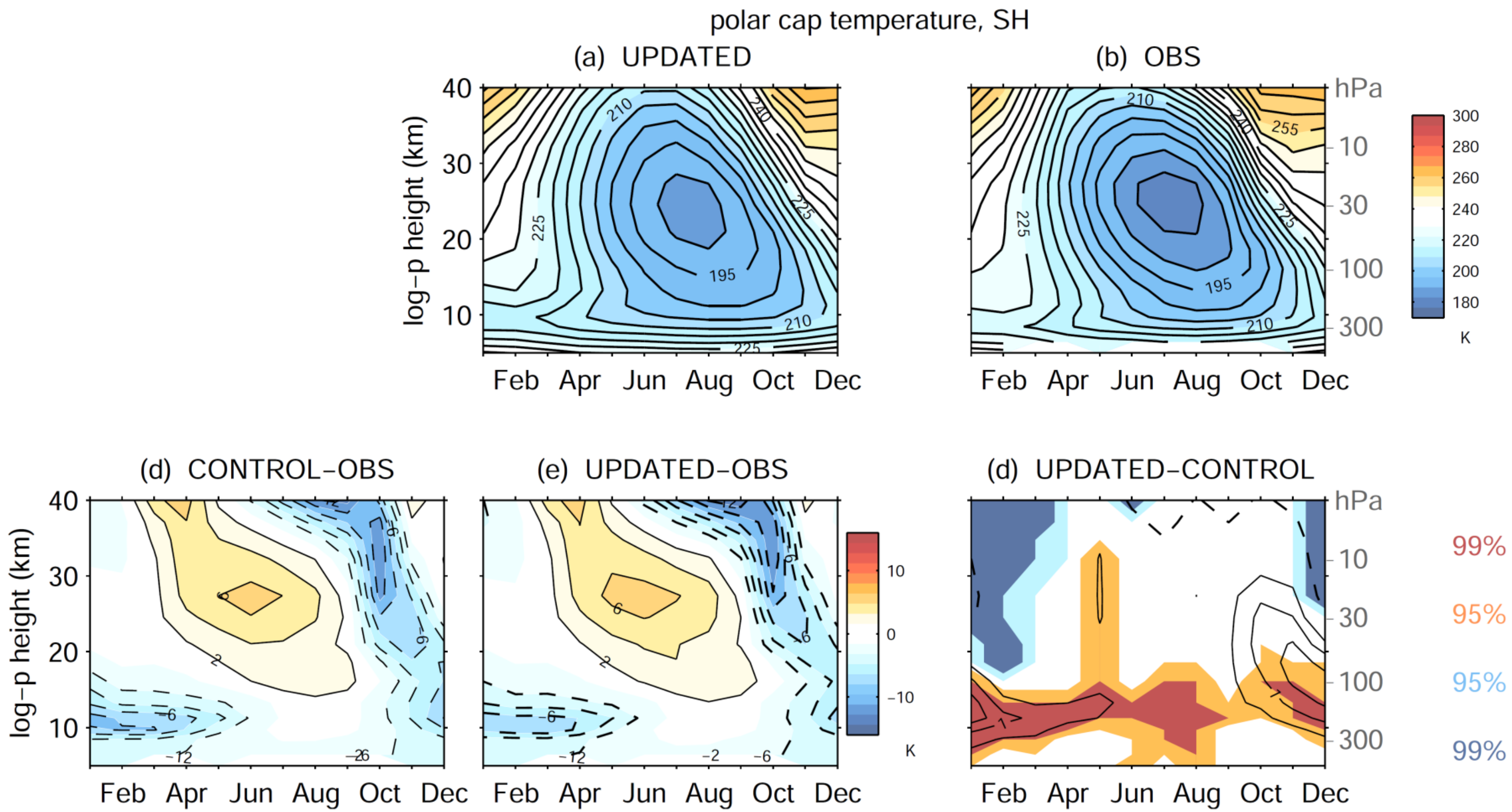




Cold spring pole bias

Change in Polar Cap Temperature



Cold spring pole bias partially ameliorated

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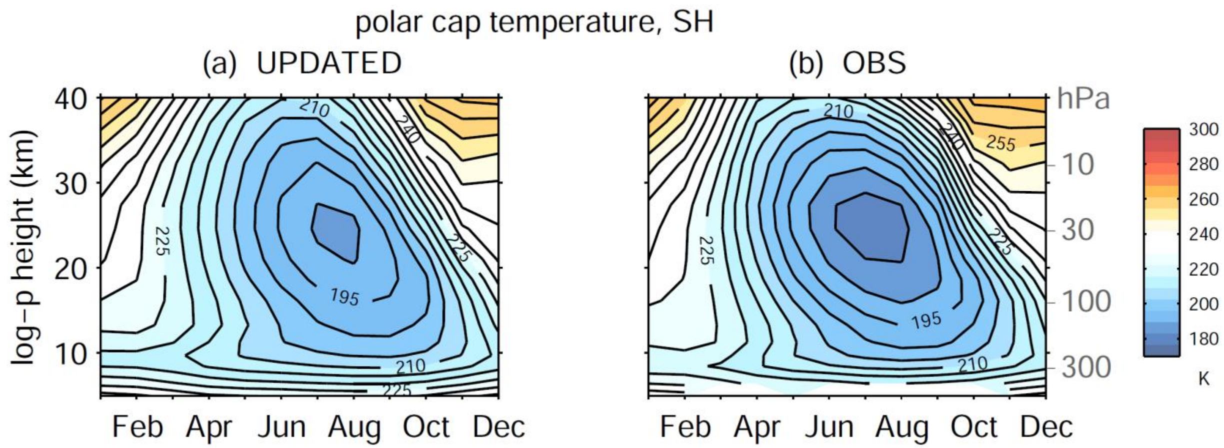
Change in Polar Cap Temperature



Cold spring pole bias in a different model version (20 model years)

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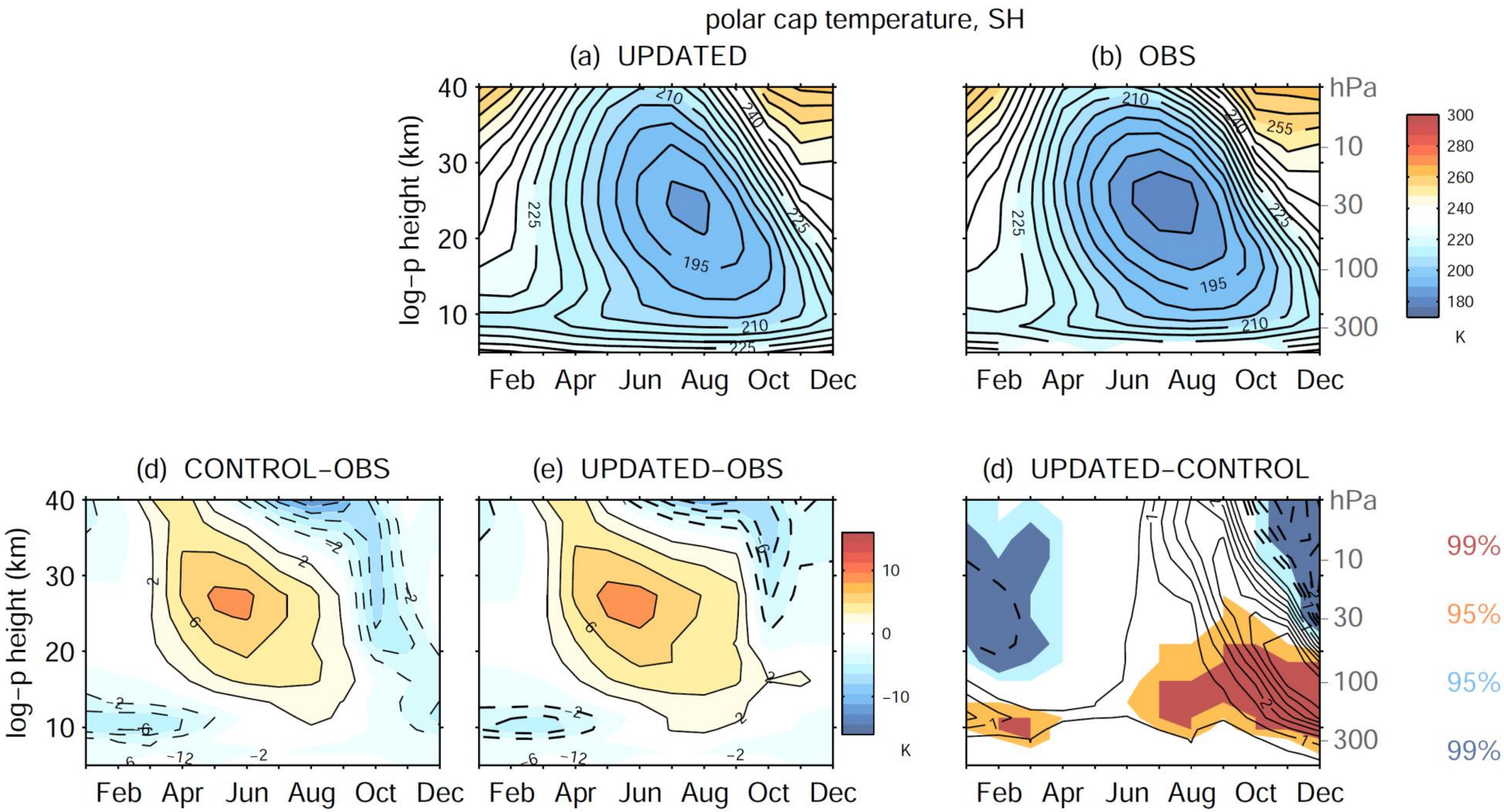
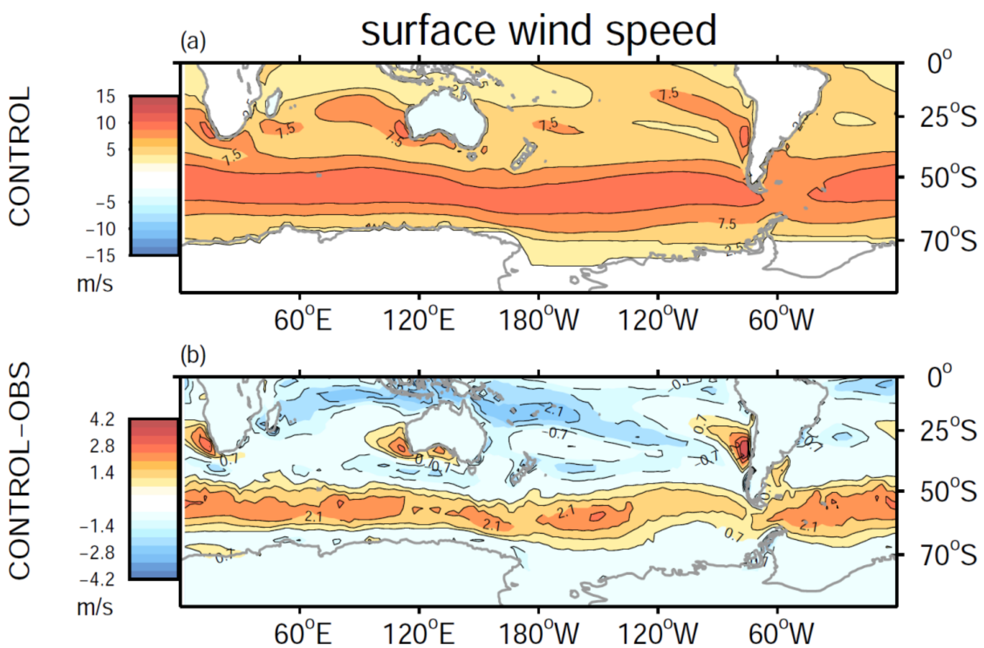
Change in Polar Cap Temperature



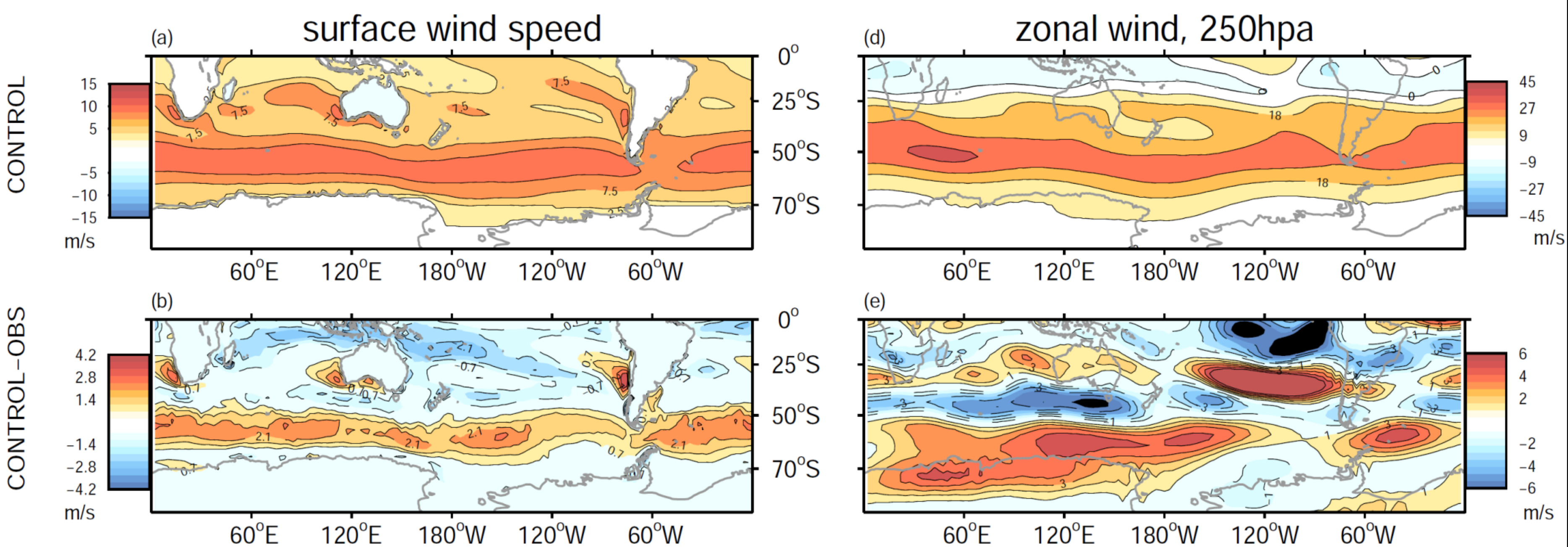
Cold spring pole bias wholly ameliorated (midwinter bias still there; 20 model years)

Bias in surface wind (January and February)



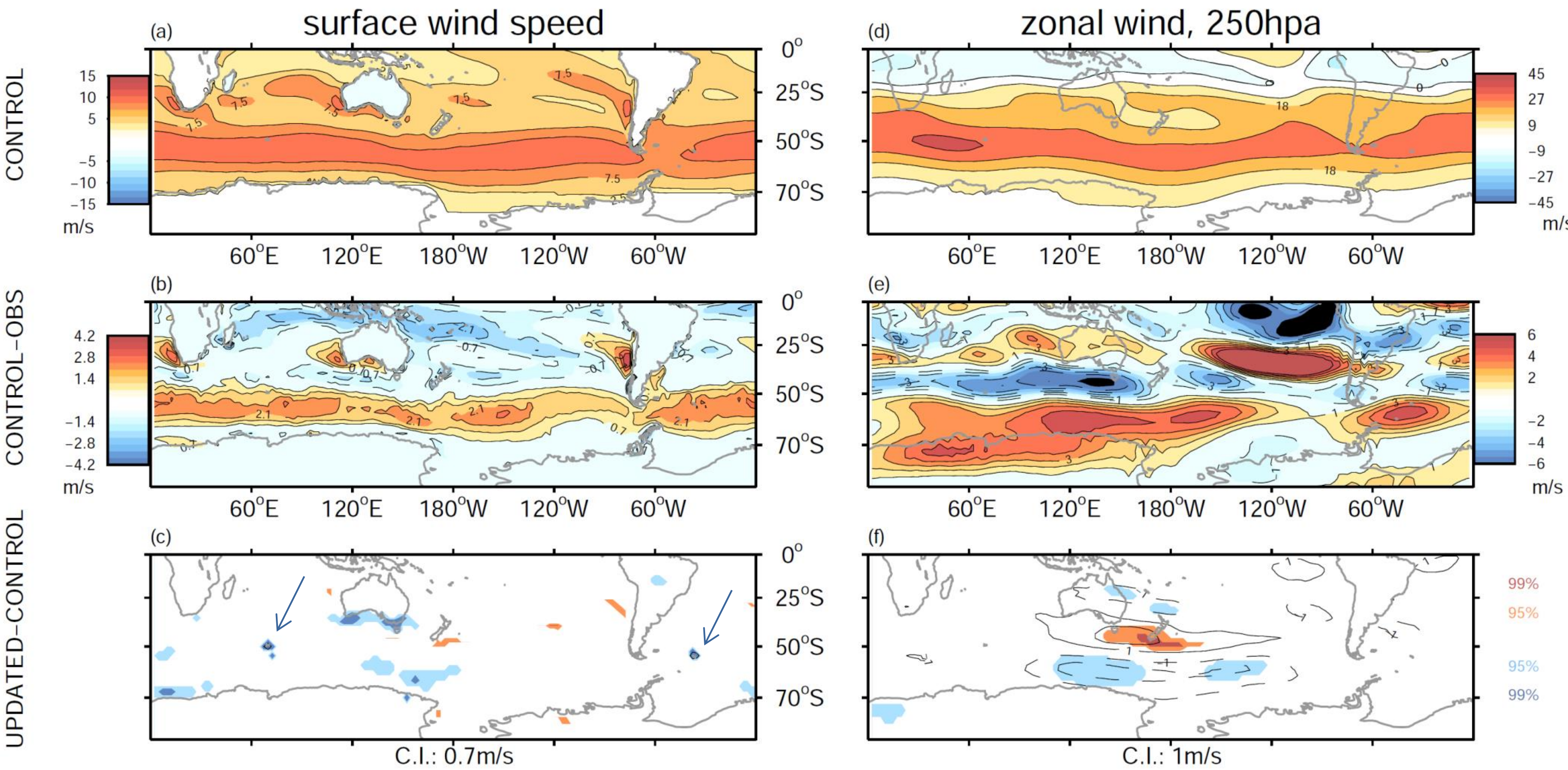
Model suffers from overly strong wind speeds

Bias in surface wind (January and February)



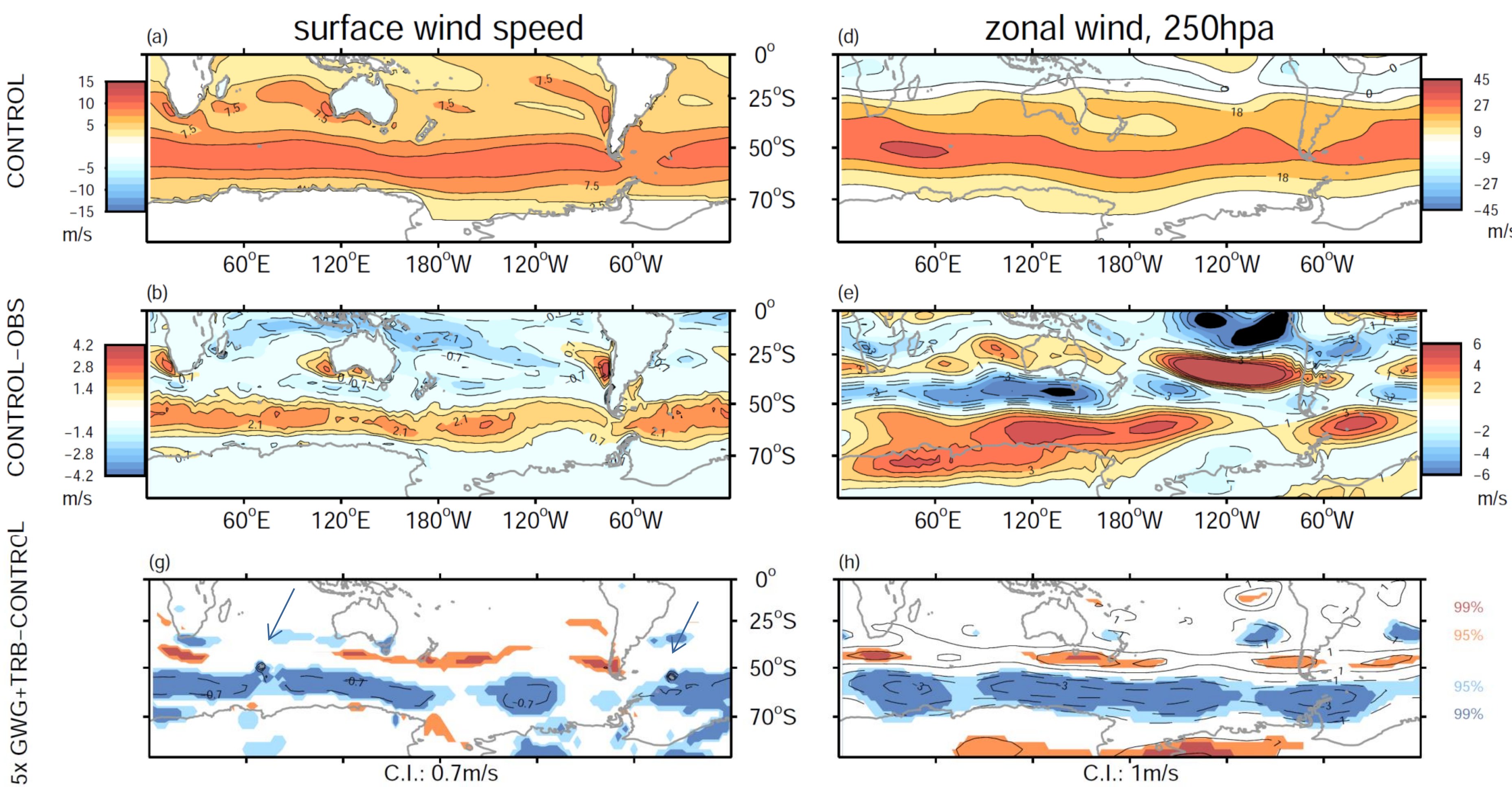
Model suffers from overly strong wind speeds

Change in surface wind (January and February)



Surface wind reduction by South Georgia Island, Kerguelen, and Heard Islands
Equatorward jet shift aloft (likely due to weakened vortex)

Change in surface wind (January and February)



For the 5x experiments, wind biases are reduced.

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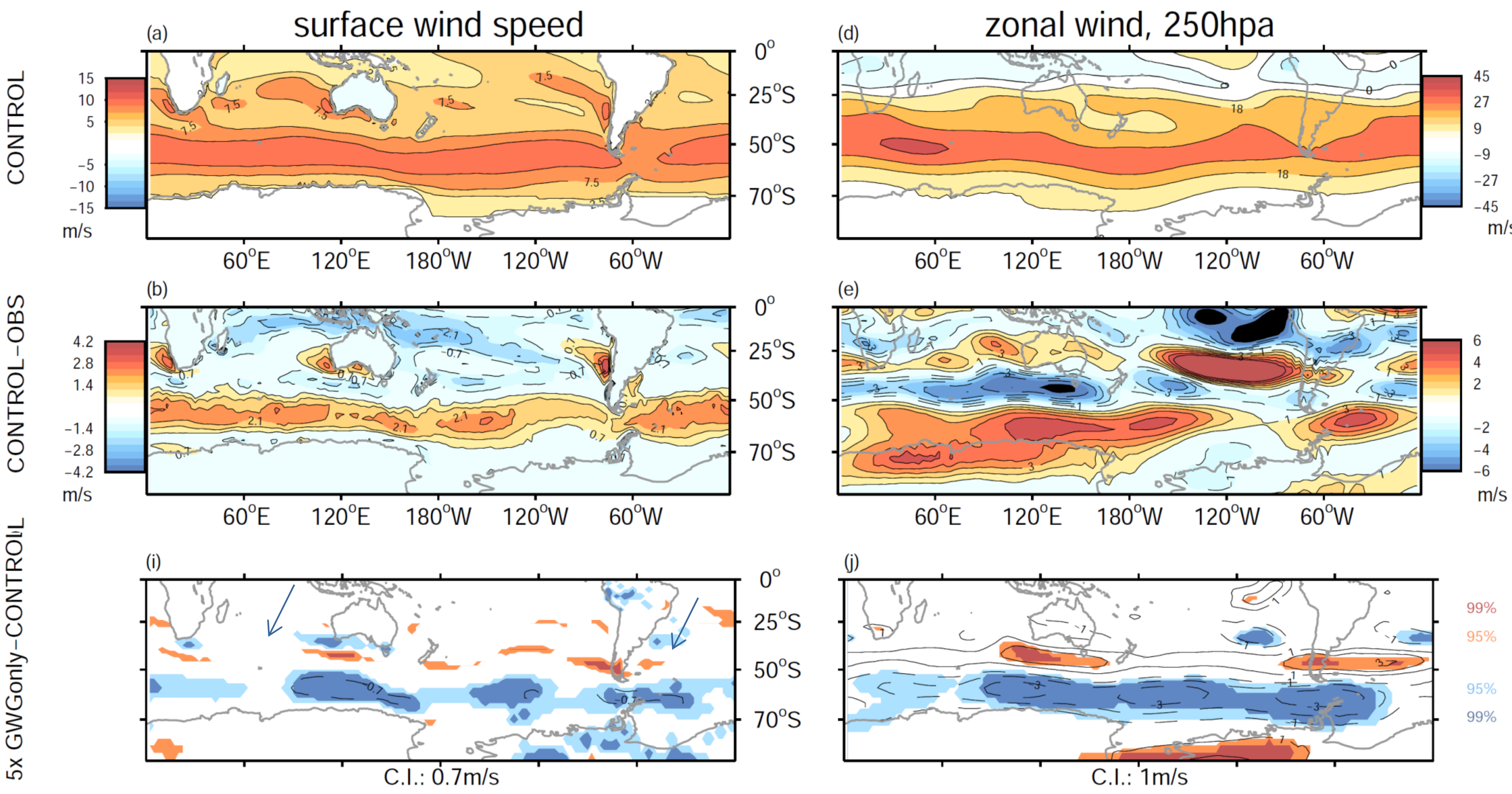
Change in surface wind (January and February)



For the 5x experiments, wind biases are reduced.

Summary of Results

1. Increasing the gravity wave drag from Southern ocean islands does lead to improved surface winds and to a more realistic stratospheric circulation.
2. However, the improvements are relatively small unless the increase in drag is unjustifiable large, and for such an increase in drag surface wind speed decreases by ~2m/s in the immediate vicinity of the islands.

Take Home Message:

Drag parameterization can affect large-scale circulation

Question : Is it justified to separately modify the variance for the turbulent PBL drag from the GW drag?

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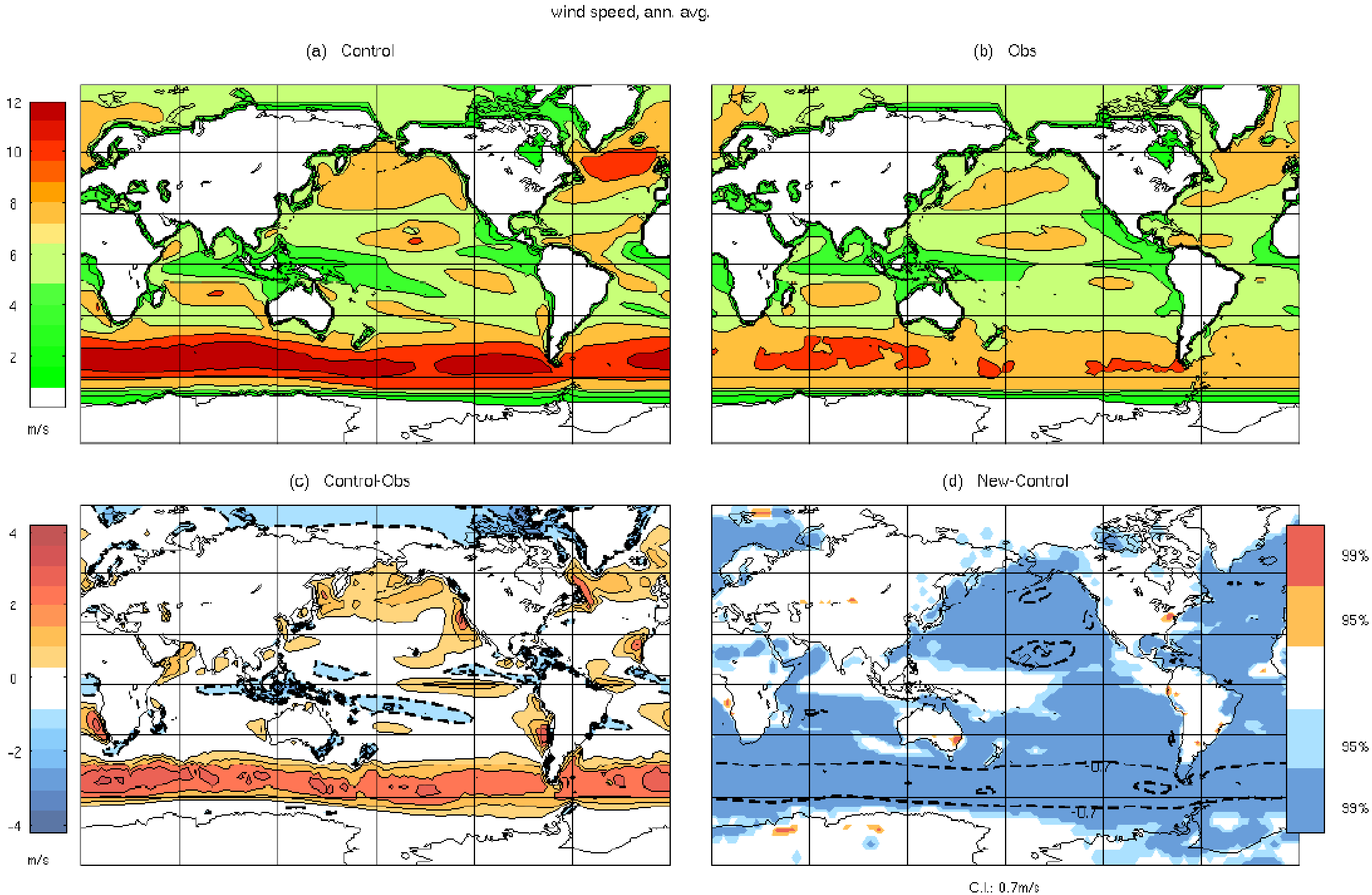
Surface Wind, GEOS-5 AGCM



Winds are too strong in the Southern Ocean.

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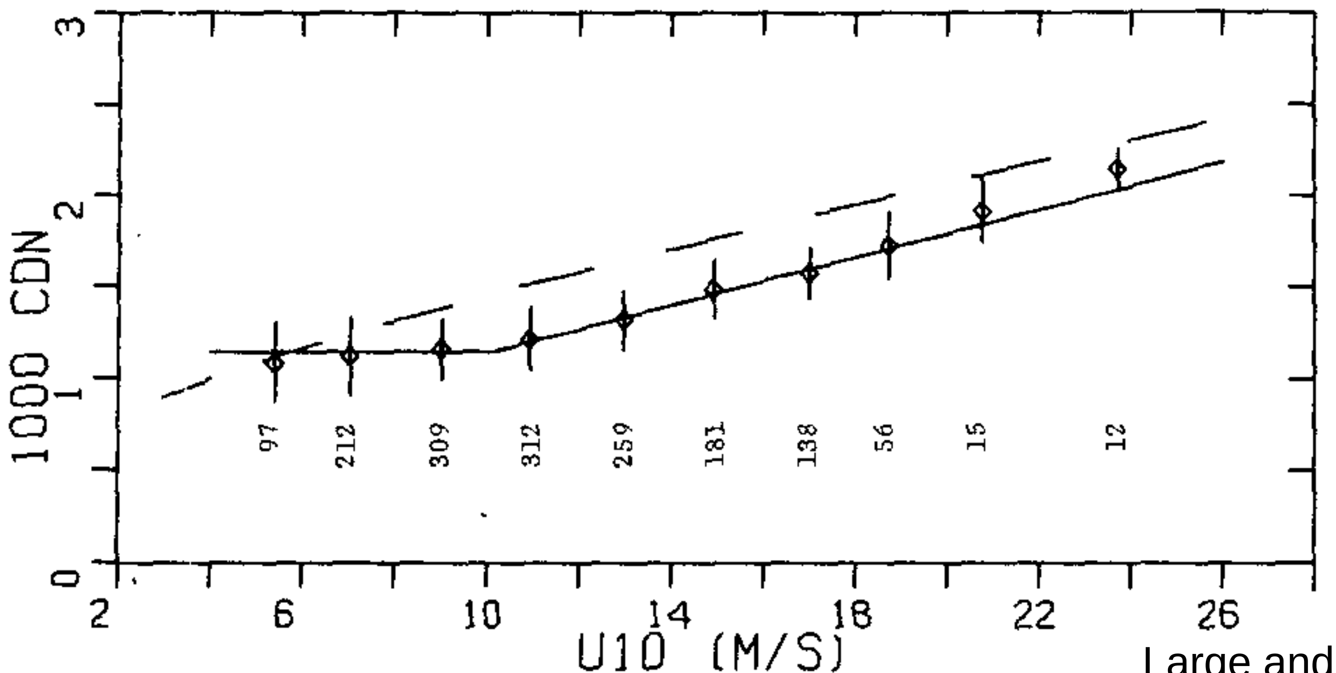
30 Year Old Observations



Large and Pond (1981)

FIG. 6. CDN averaged over wind speed bands. Vertical bars extend $\pm 1\sigma$ and the number of points in a band is shown below each average. Lines show the Charnock representation of Garratt (1977) (dashed) and Eq. (19) (solid).

Old model parameterization was based on Large and Pond (1981).

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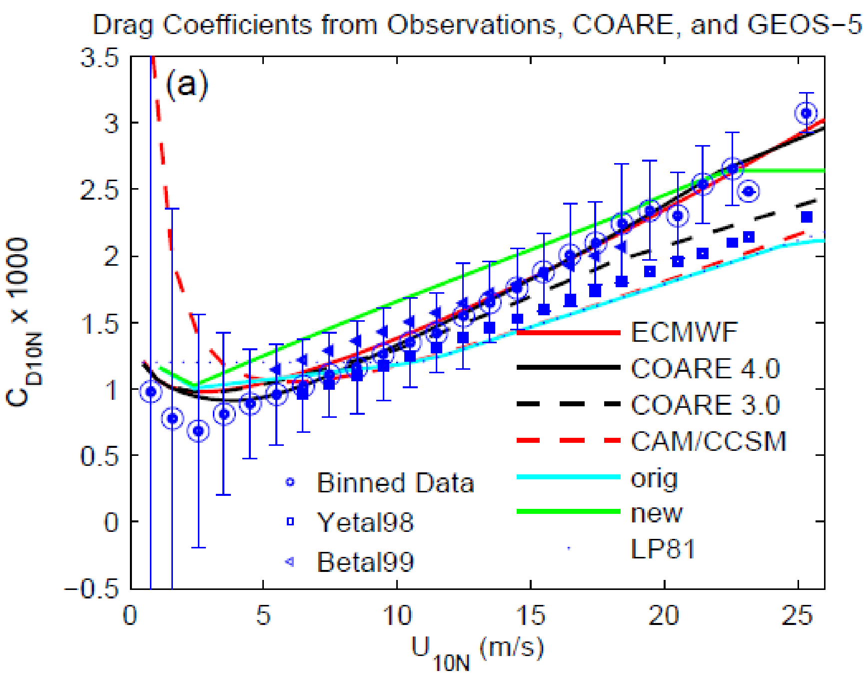
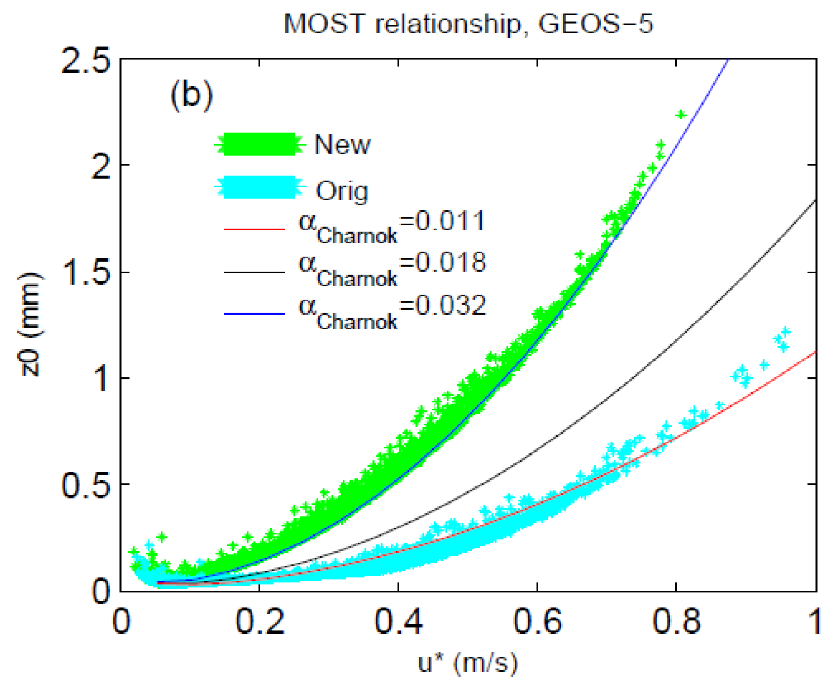
Direct Change in Model

Observations taken over the past 30 years suggest that parameterizing the model as in Large and Pond might result in too little drag. (Edson et al 2008)





The surface layer parameterization has been updated, and a 60 year long "new" experiment and a 60 year long "orig" or "control" experiment have been performed. These experiments differ only in the air-sea roughness parameterization.

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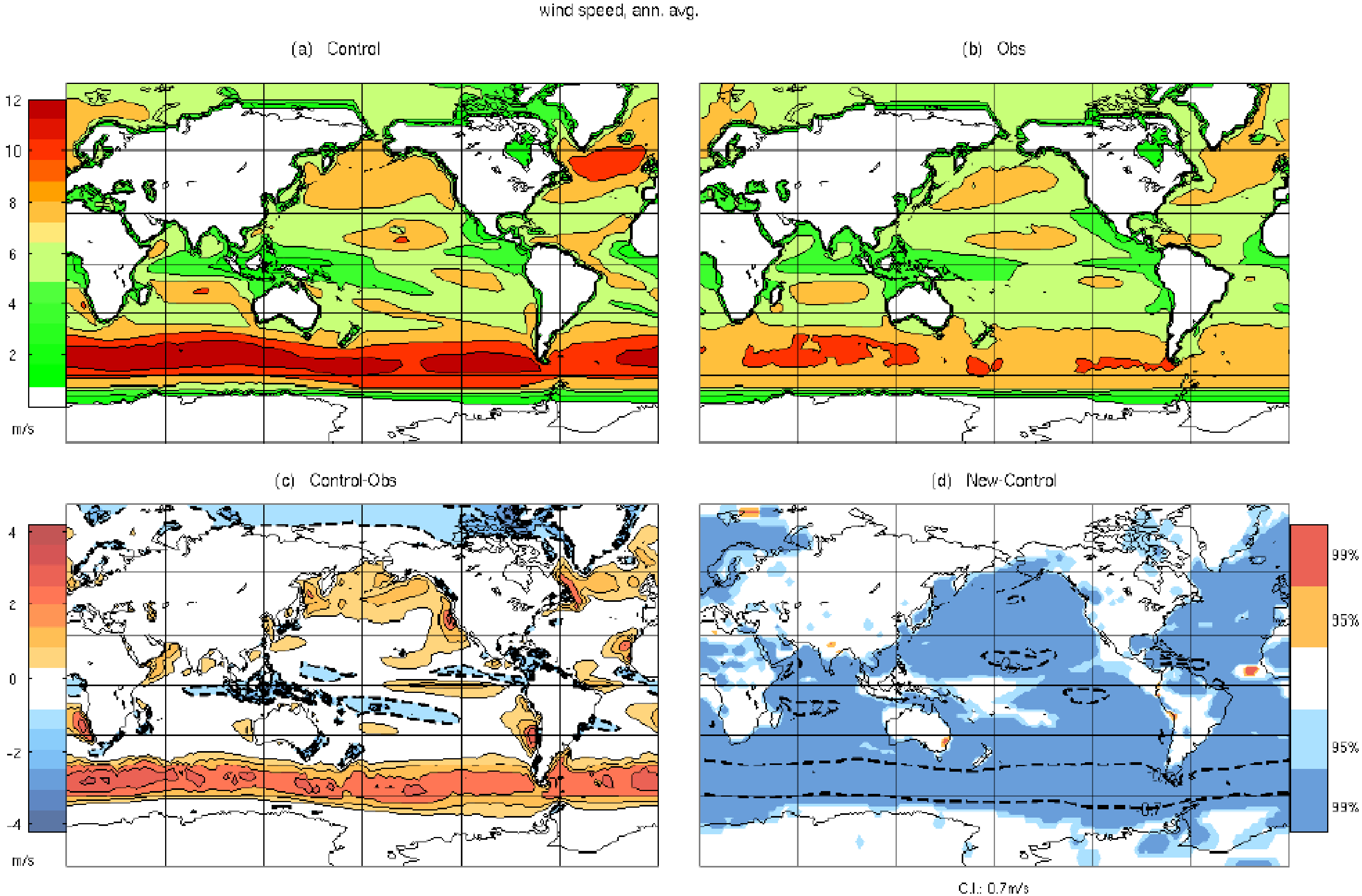
Surface Wind, Annual Average



Improvement in Southern Ocean and over most ocean regions. Peak improvement is nearly 1.5m/s, which is roughly half of the original bias.

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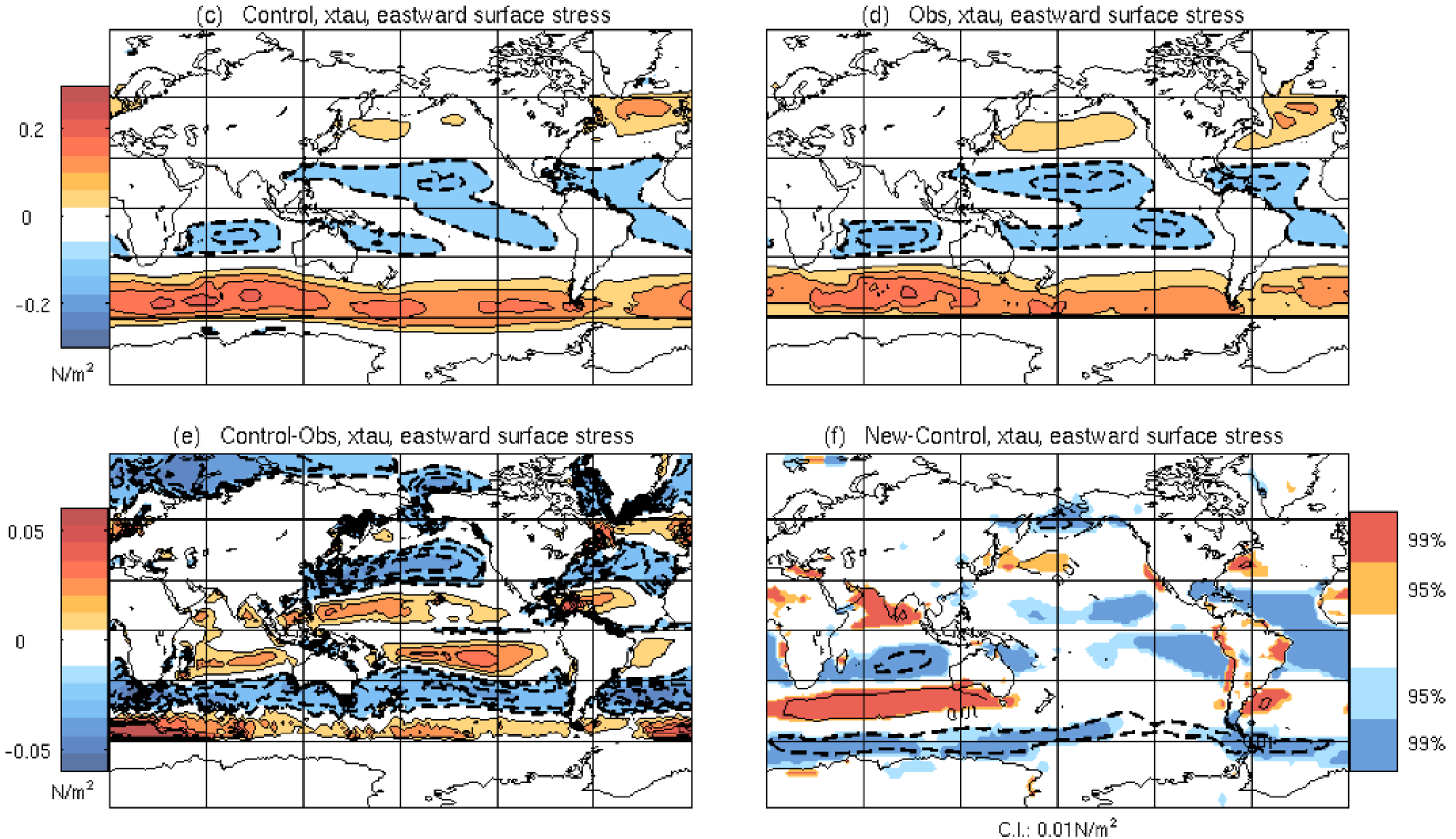
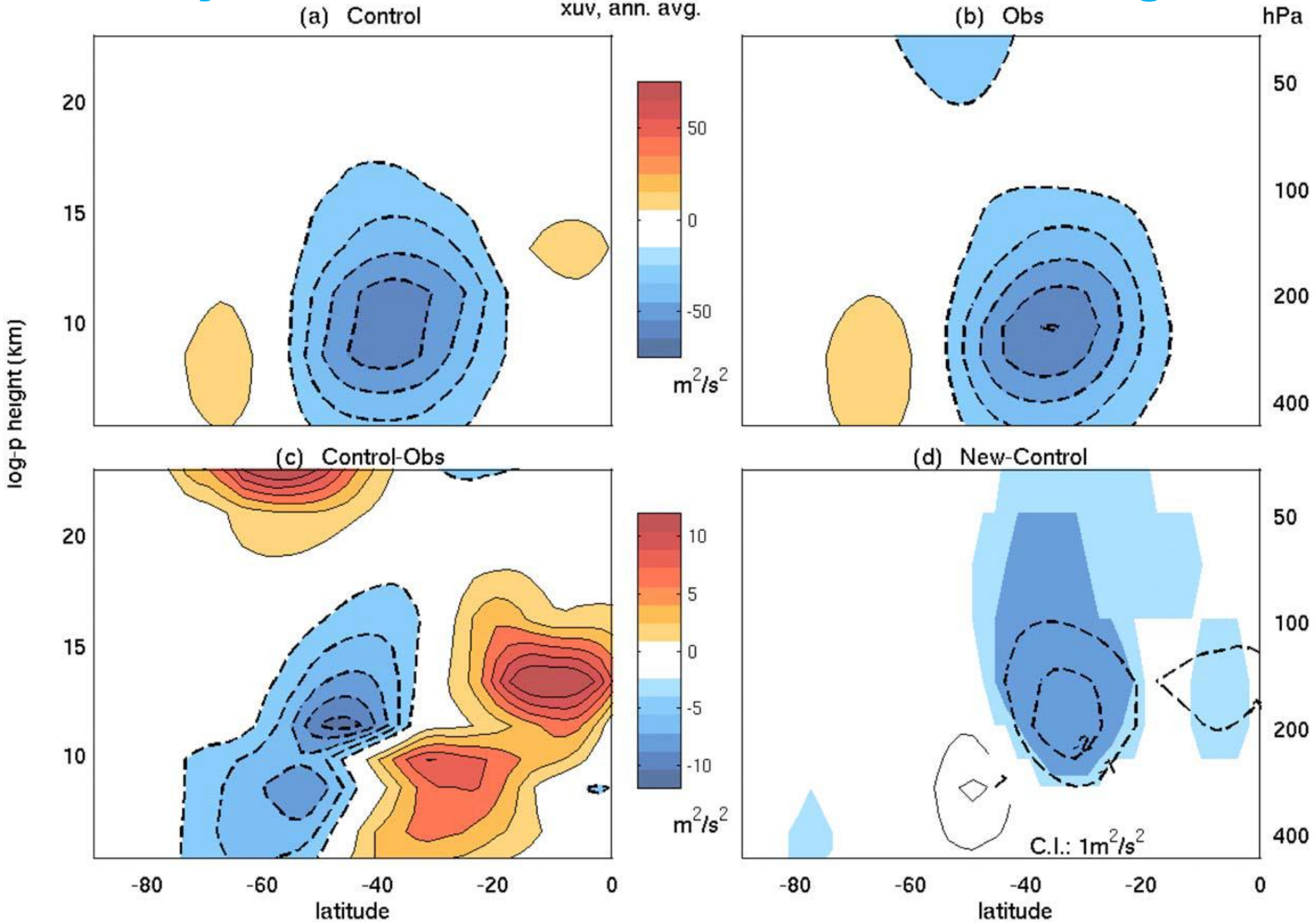
Eastward Surface Stress, Annual Average



Surface stress is also improved. Biggest change is in Indian Ocean sector.

Eddy momentum flux, Annual average



Enhanced friction leads to improvements in upper tropospheric eddy momentum flux as well- eddy momentum fluxes are more efficient (Barnes and Garfinkel, 2012 JAS)

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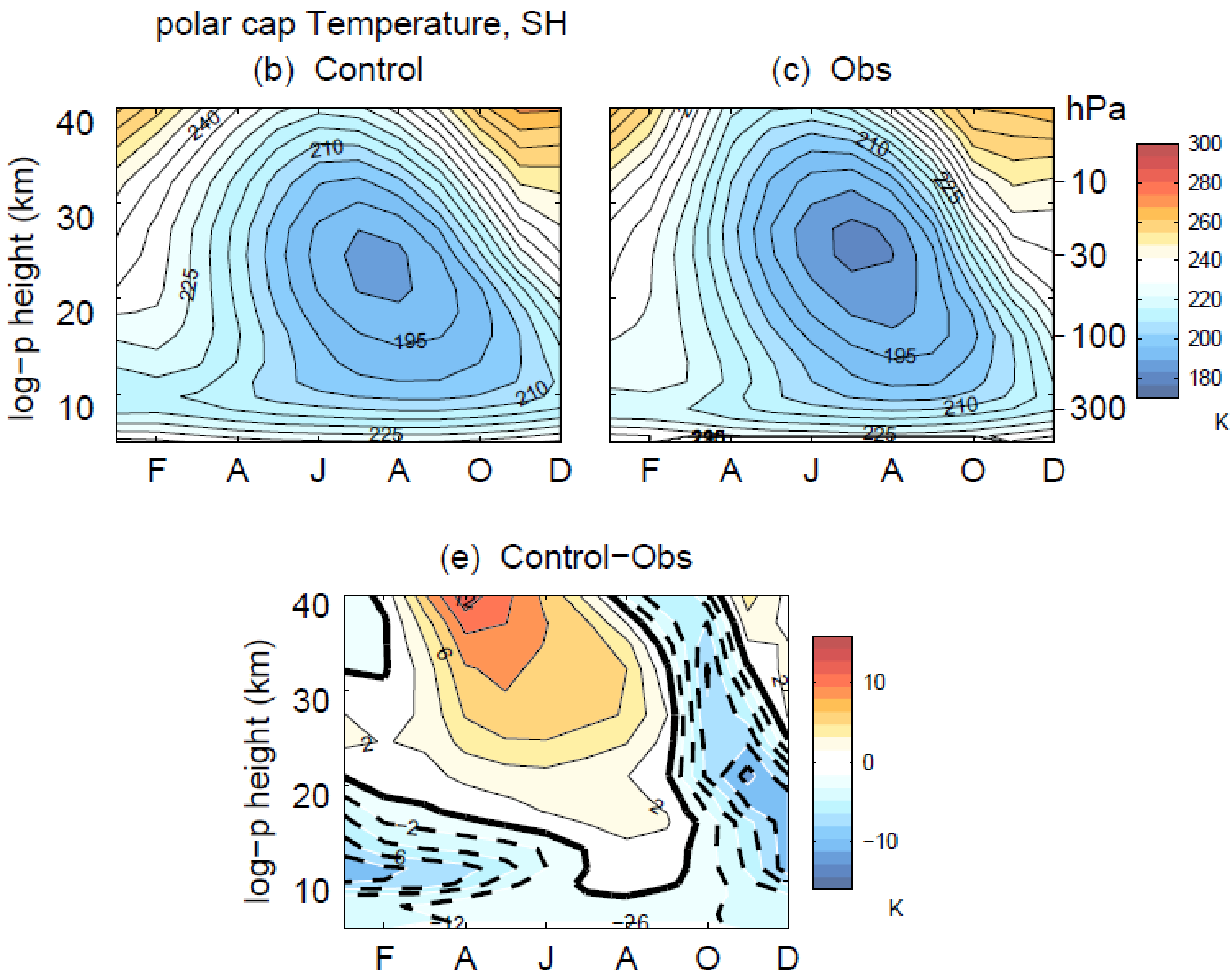
SH Polar Cap Temperature (70S and poleward)



Stratospheric polar vortex is too cold in spring yet too warm in midwinter (Hurwitz et al 2010). This pair of biases is common to many models, and is very difficult to “fix”.

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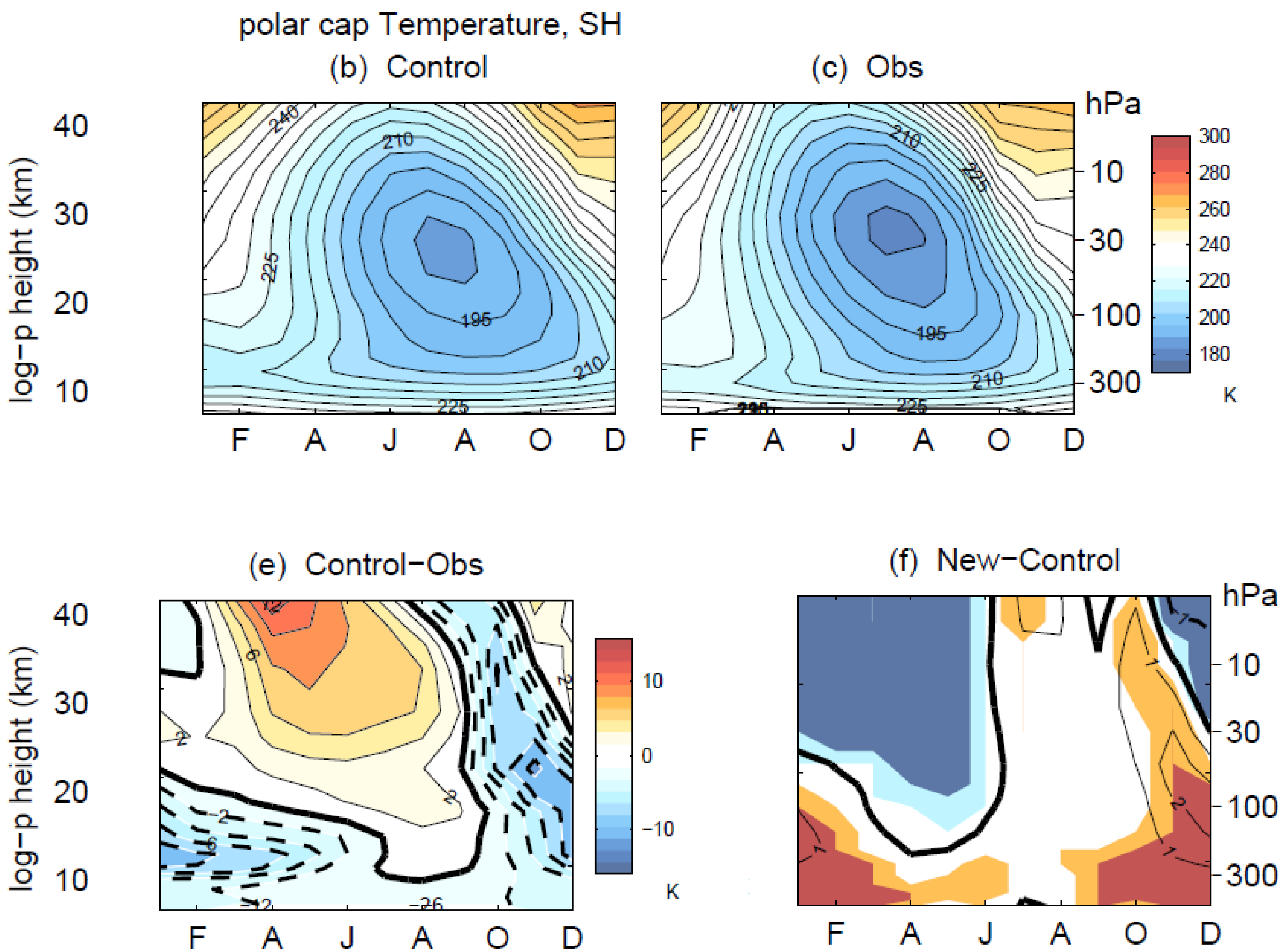
Improved SH Spring Stratospheric Evolution



Updated parameterization leads to warming of polar cap by nearly 3K in November and December. Spring breakup of vortex occurs earlier.

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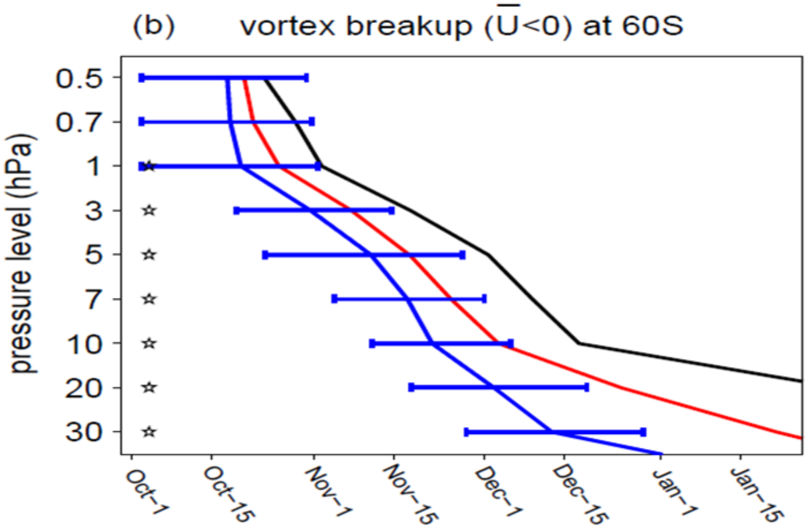
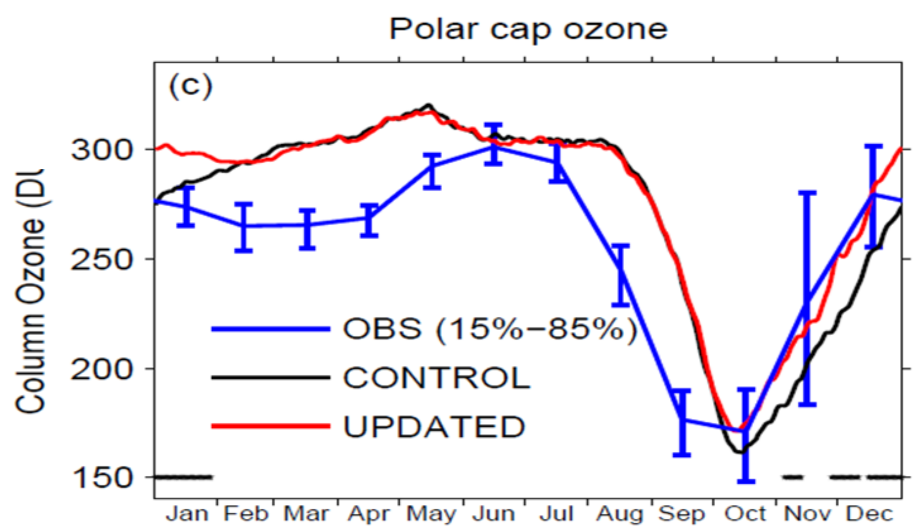
Stratospheric Evolution in Super-tuned Experiment





- A sensitivity experiment has been performed in which the surface drag is increased beyond that physically justified.
- In this experiment, the improvements are even more dramatic.

Summary of Results

1. Old Surface Layer Scheme is based on 30-year old observational data. Newer data suggests seas are rougher.
2. Updating the model leads to
   (i) Improved Surface Winds.
   (ii) Improved eddy momentum fluxes and surface stress
   (iii) Improved Springtime Breakup of the SH Polar Vortex.
3. Other models have a similar surface layer scheme.

Summary of Results

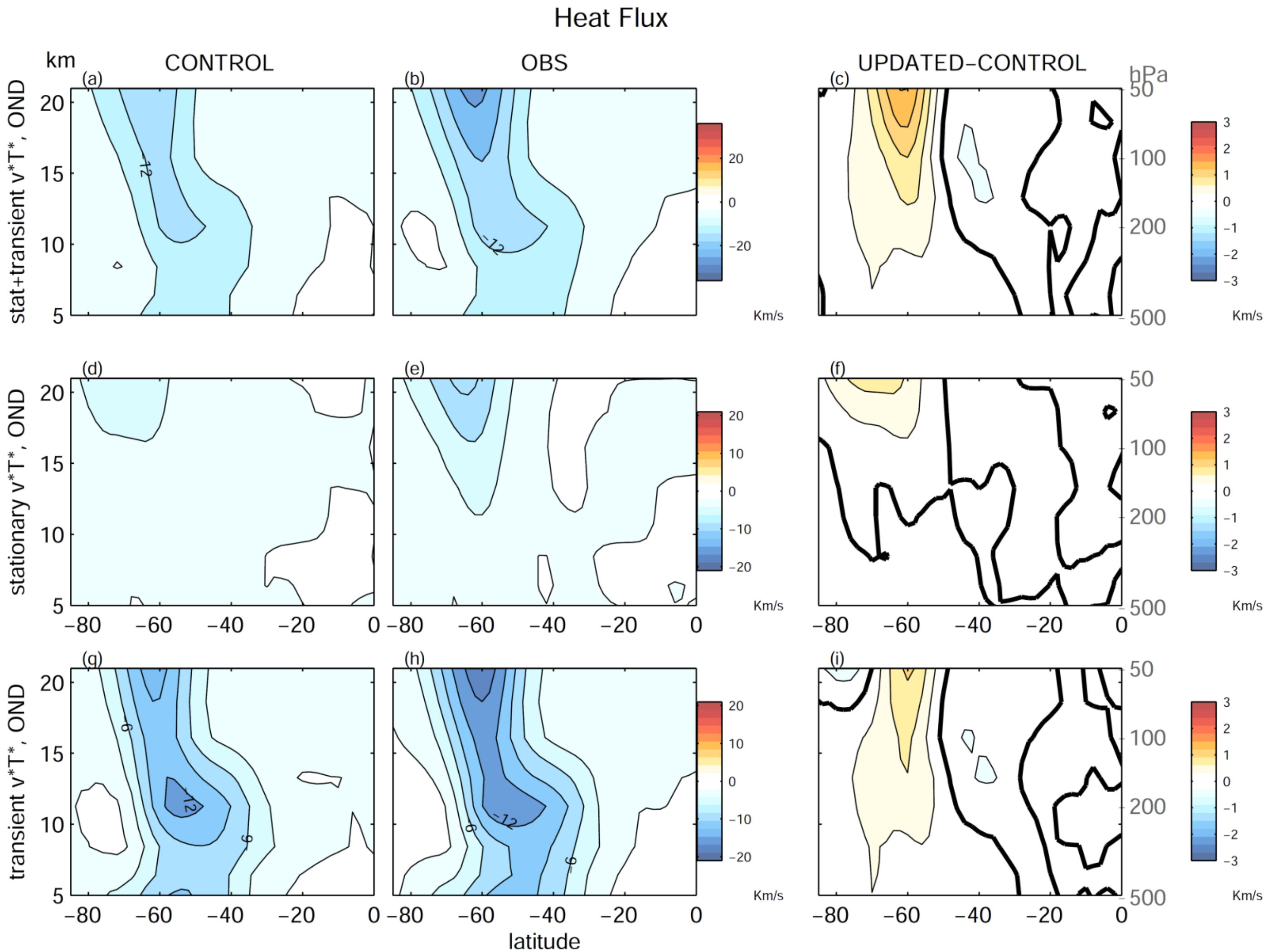
- **Take Home Message: Air-Sea roughness parameterization can influence the atmospheric circulation into the stratosphere.**

Connection between the Southern Hemisphere polar vortex spring breakup, stationary waves, and air-sea drag (2013), Garfinkel, C.I., L.D. Oman, E. A. Barnes, D. W. Waugh, M.H. Hurwitz, A. M. Molod, J. Atmos. Sci., 70, 2137--2151. doi: http://dx.doi.org/10.1175/JAS-D-12-0242.1.

Barnes, E. A. and Garfinkel, C. I.(2012), Barotropic impacts of surface friction on eddy kinetic energy and momentum fluxes: an alternative to the barotropic governor , JAS, 69, doi: 10.1175/JAS-D-11-0243.1.

Garfinkel, C.I., A. M. Molod , L.D. Oman , I-S. Song (2011), Improvement of the GEOS-5 AGCM upon updating the Air-Sea Roughness Parameterization, GRL, 38, L18702, doi:10.1029/2011GL048802

Compensation: OGWD↑ but resolved ↓



Reduced transient heat flux even within troposphere.

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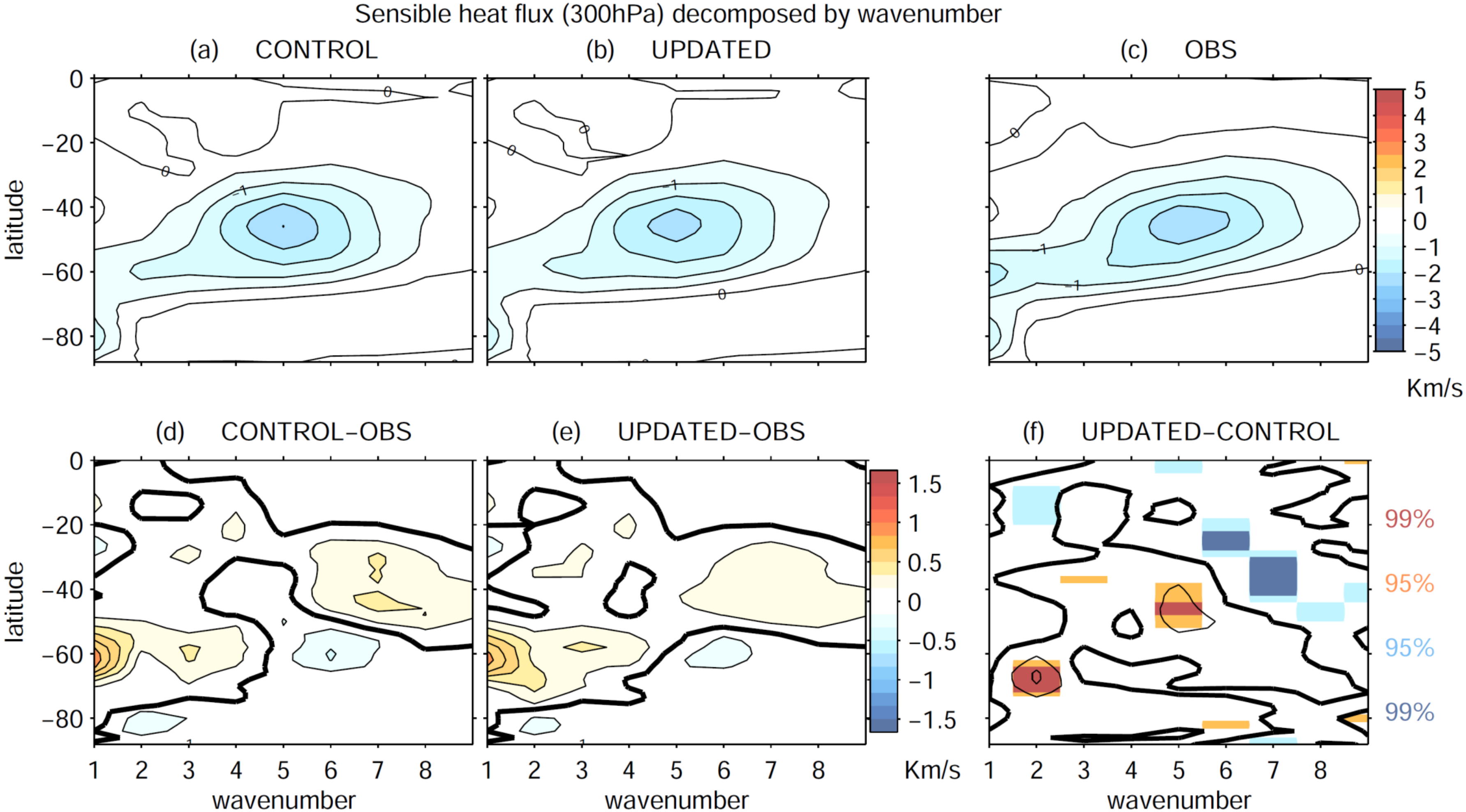
Compensation: OGWD↑ but resolved ↓



Reduced wave-2 transient heat flux.

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