The Impact of Polar Stratospheric Ozone Loss on Southern Hemisphere Stratospheric Circulation and Surface Climate

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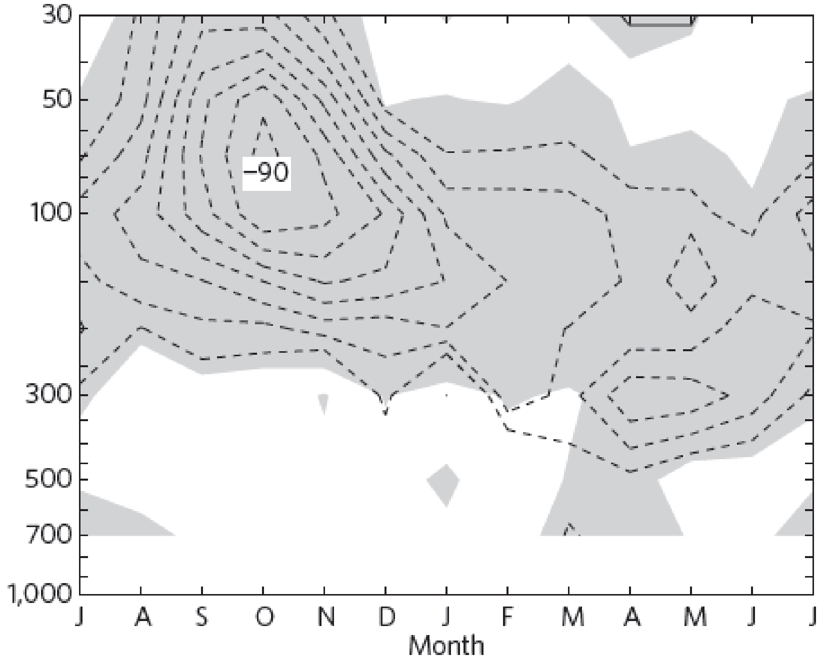
Outline

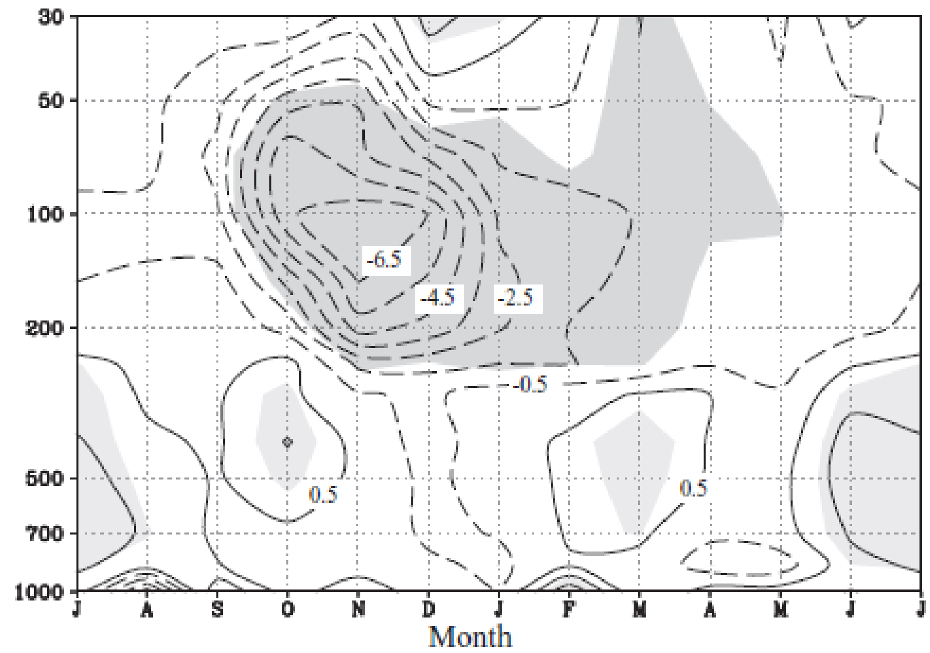
- Introduction:
  - Recent **trends** in polar stratospheric ozone and temperature
  - Overview of Stratosphere-Troposphere coupling and the importance of the ozone hole on SH climate
- Understanding the **trends**: Modelling the impacts of Stratospheric Ozone Depletion using UMUKCA
- Results:
  - Ozone changes
  - Temperature changes and their attribution
  - Tropopause height, heat fluxes and circulation changes
  - Tropospheric response
- Summary and outlook

Observed differences between pre ozone-hole and present day conditions

Ozone Change [%]



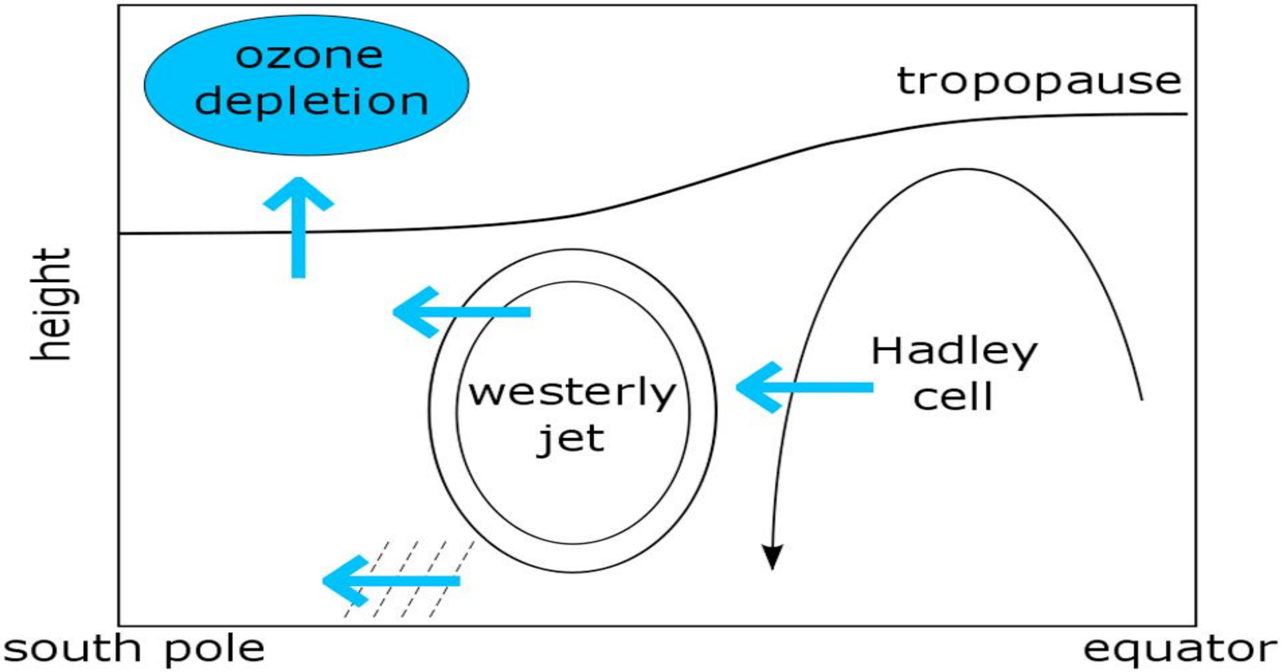
Temperature Trend [K per 30 yr]



Thompson and Solomon, 2002

Stratosphere-Troposphere Interaction

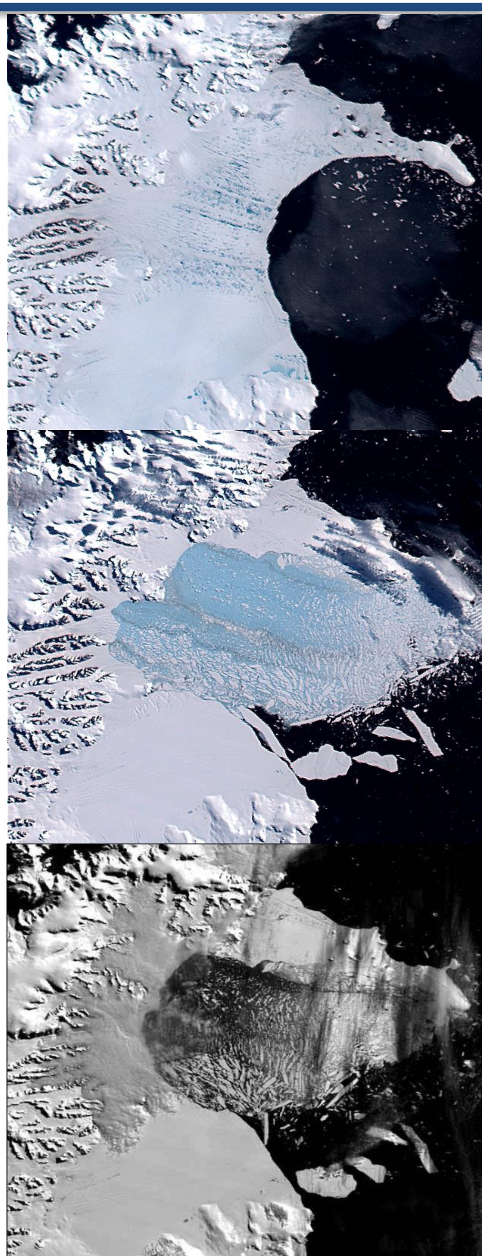
Antarctic ozone depletion cools the polar lower stratosphere
Jet and circulation cells change position and/or extent
Possible link to collapse of Larsen B ice shelf



Son, S.-W., et al. (2010)

Atmospheric circulation changes may change CO_2 uptake by the Southern Ocean, as discussed by Le Quéré et al., 2007.

January 2002
March 2002
March 2005



Modelling the impacts of Stratospheric Ozone Depletion using UMUKCA

Model:

- Met Office's Unified Model (UM) with United Kingdom Chemistry and Aerosols (UKCA) module
- Chemistry configuration focuses on the stratosphere
- 3.75° (longitude) x 2.5° (latitude)
- 60 vertical levels and a model top at ~85km

Previously:

- Investigations have predominantly used two methods: prescribed ozone climatologies or different stratospheric loadings

Here:

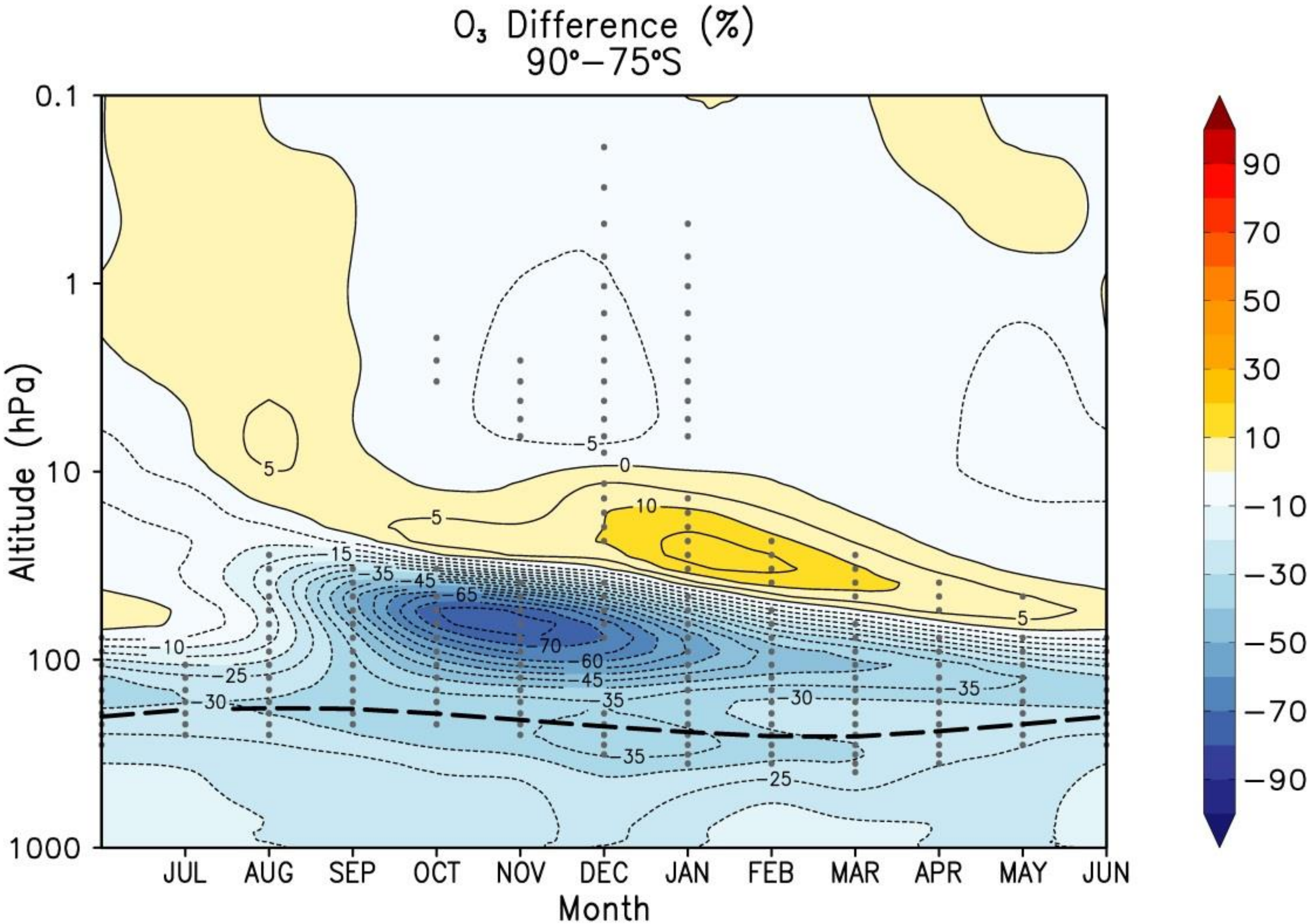
- Two simulations: a reference integration with perpetual year 2000 conditions, and an identical simulation in which halogen activation on PSCs is suppressed

Aside:

- Manzini et al. (2003) estimate a threshold value to be ~2.2 ppbv Cl_y is necessary for heterogeneous processes to be effective

Ozone Changes

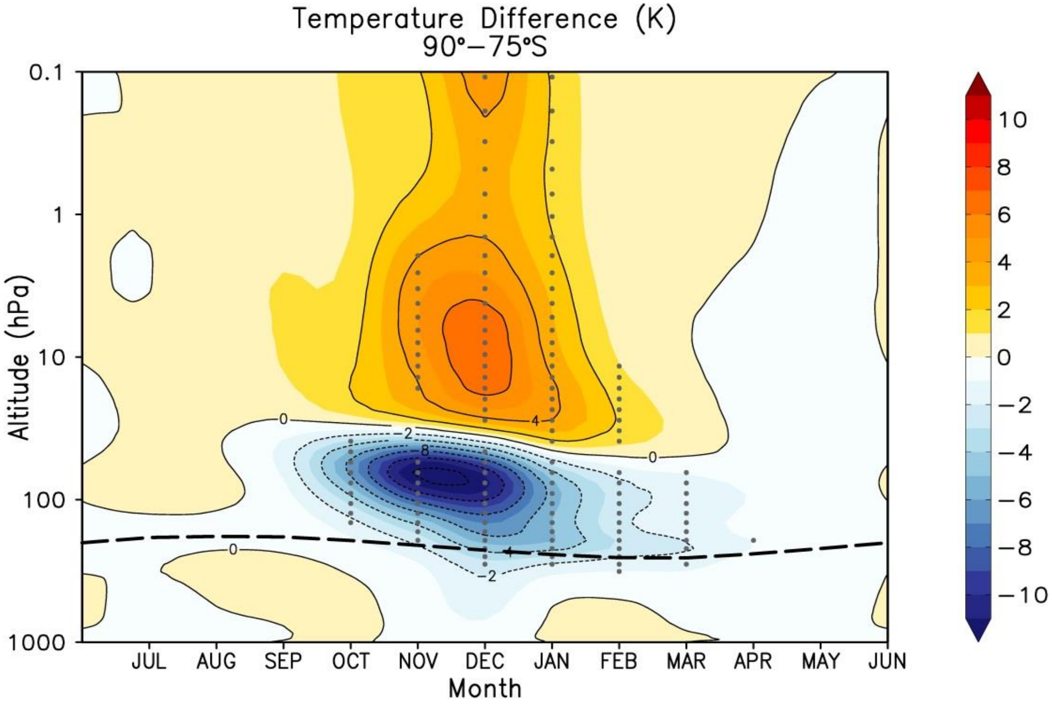
Large spring time ozone losses in the polar lower stratosphere (expected)
Statistically significant increases at higher altitudes in DJFM

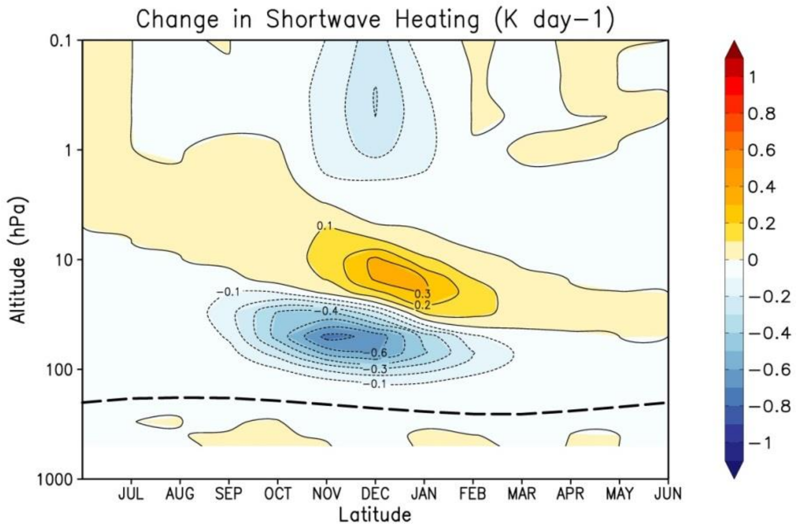


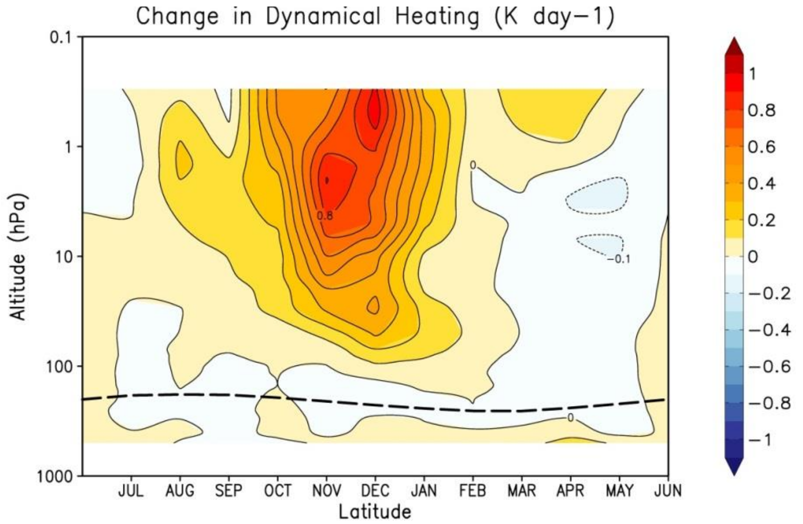
Results shown as differences: **with halogen activation - without**

Temperature Difference (K)

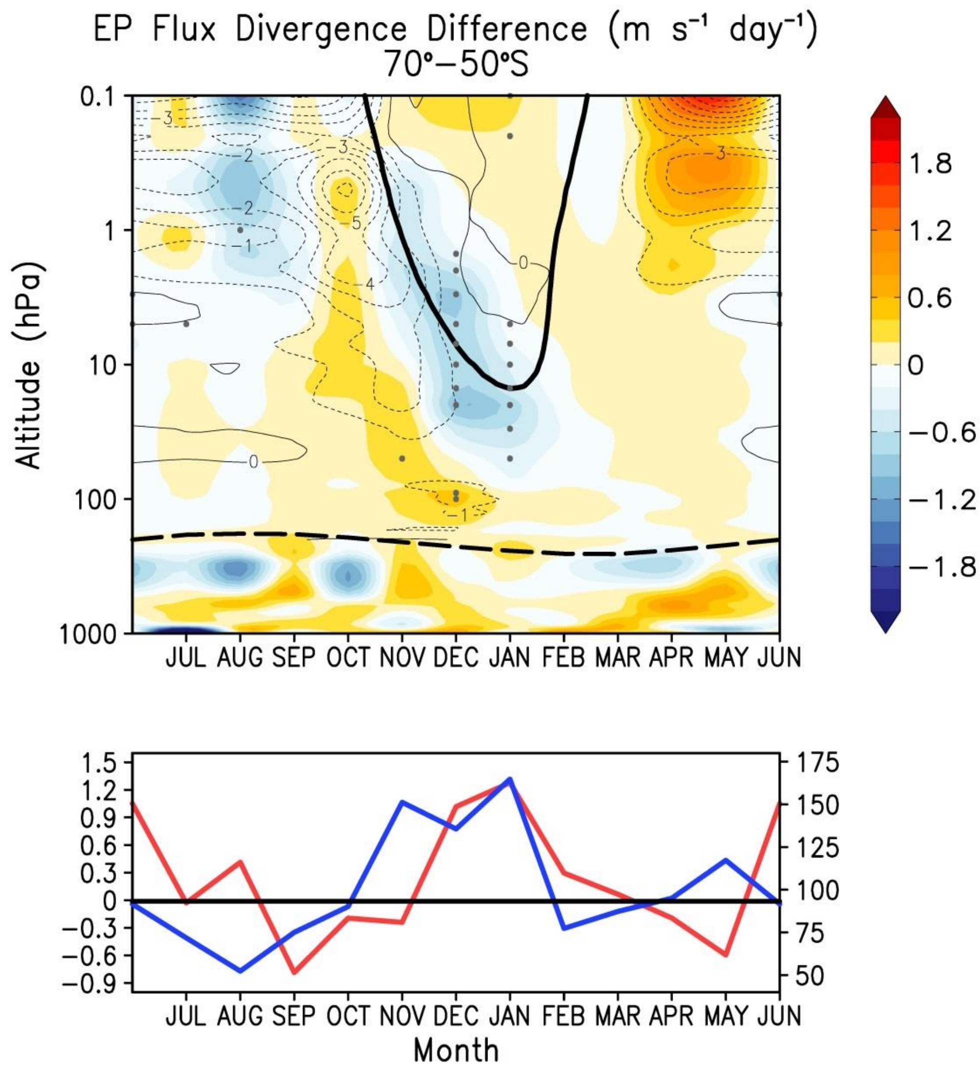
Temperature difference between the two runs (below), and the contributions from short wave and dynamic heating rates (right).







Changes to Wavedriving



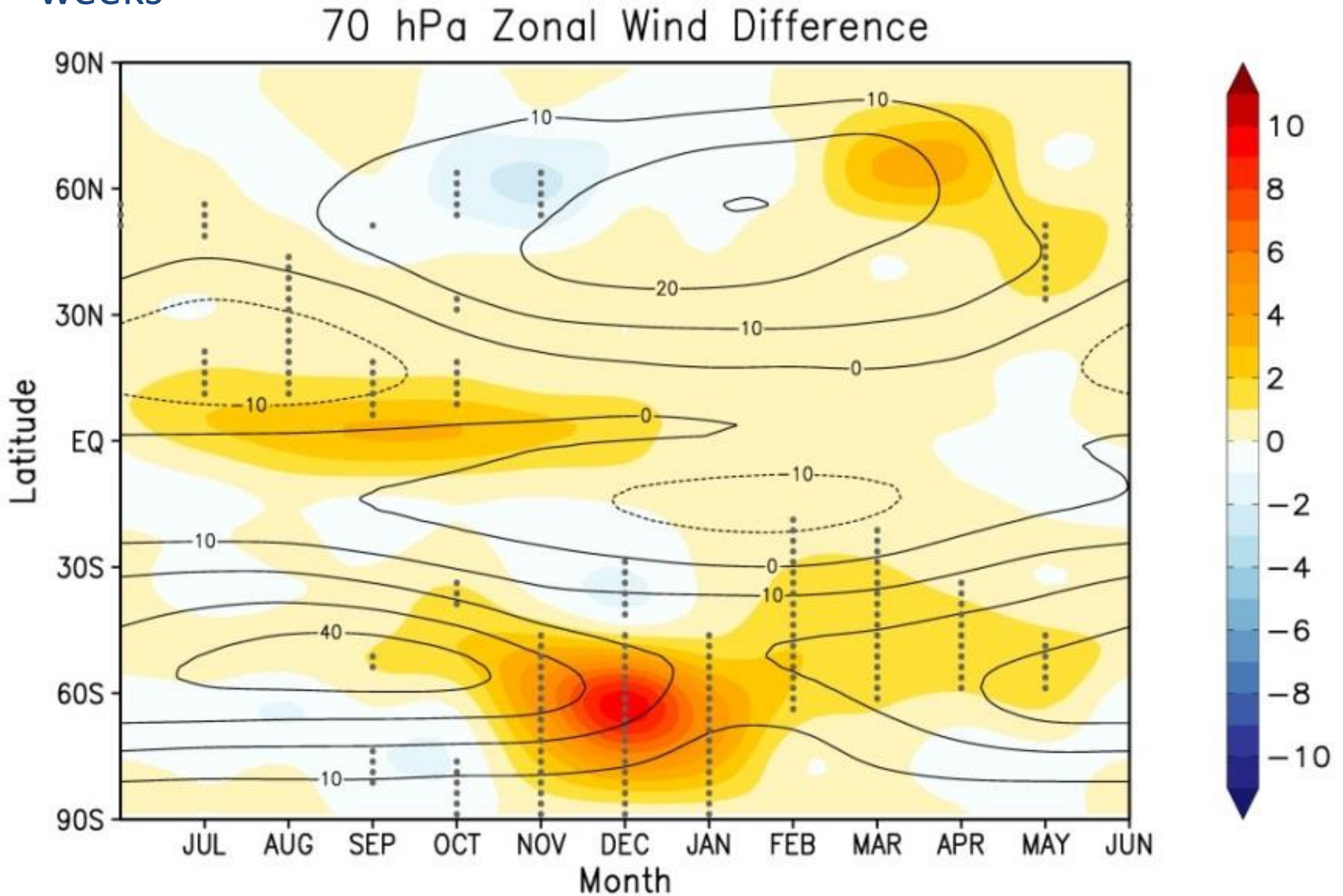
EP Flux divergence difference, indicating changes to wave breaking between the two integrations. Negative values indicate **increased** wave breaking with PSC halogen activation

Red –100 hPa F_Z difference. The vertical component of the EP Flux, which is proportional to the meridional heat flux ($\overline{v'T'}$), used as a measure of upward propagating planetary wave activity entering the stratosphere from the troposphere

Blue – Tropopause height difference

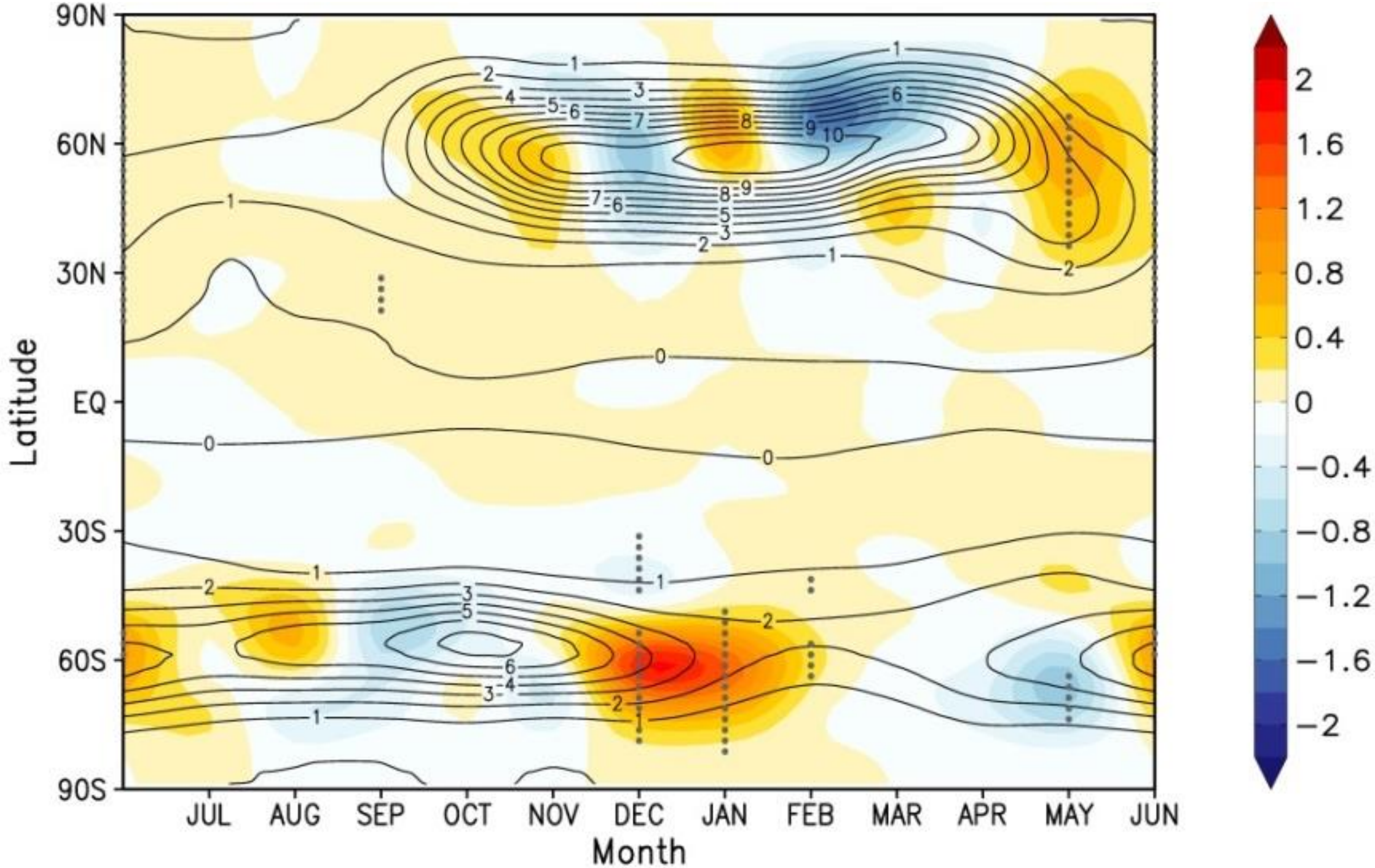
70 hPa Zonal Wind Difference

Zonal wind response a result of thermal wind balance. Polar jet strengthens and moves polewards, and the breakdown of the polar vortex is delayed by ~2 weeks



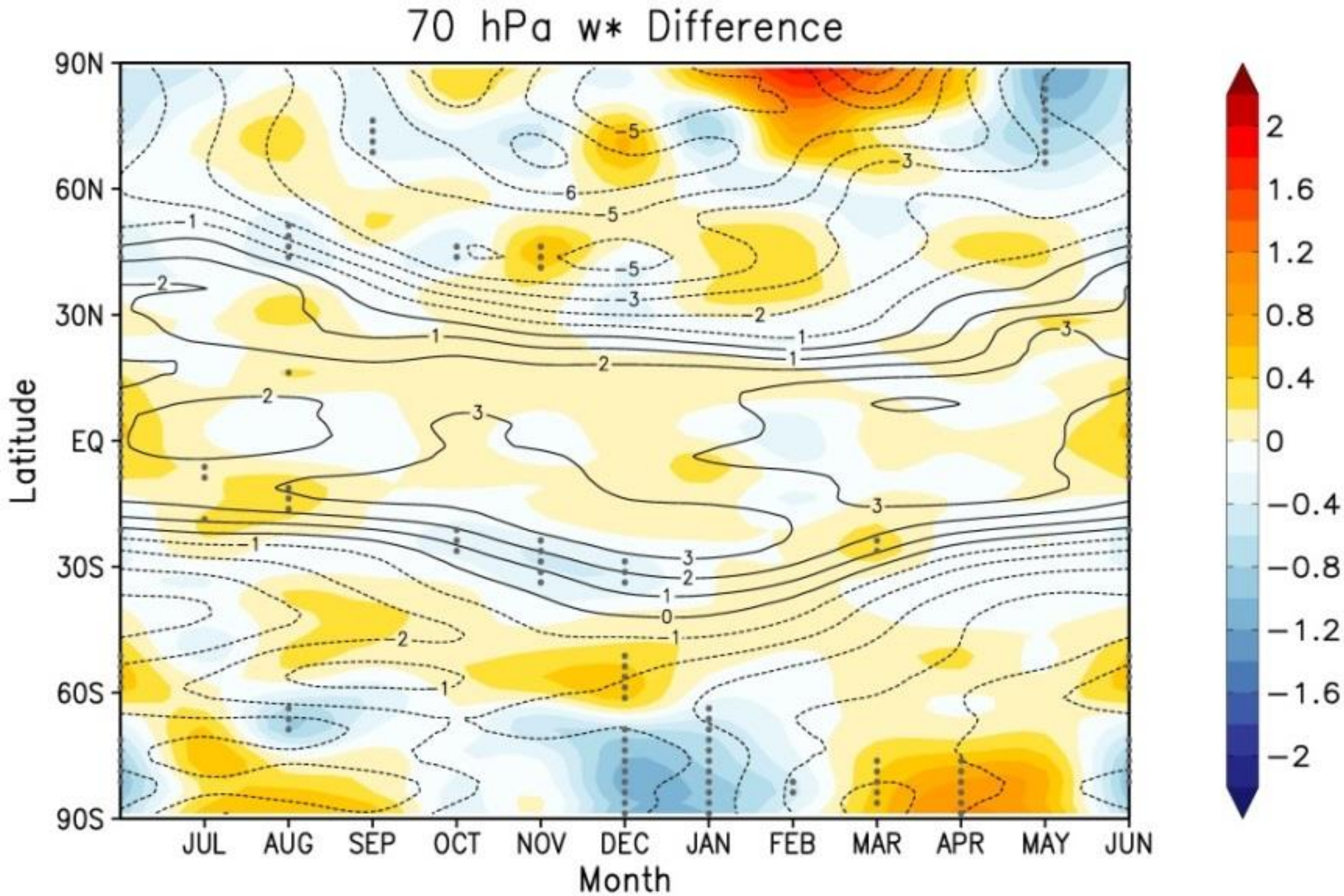
70 hPa F_Z Difference

Vertical planetary wave propagation can only occur when the zonal mean flow satisfies $0<\bar{u}<U_c$, where $U_c \equiv \beta\left(k^2 + l^2 + \frac{f^2}{4N^2H^2}\right)$

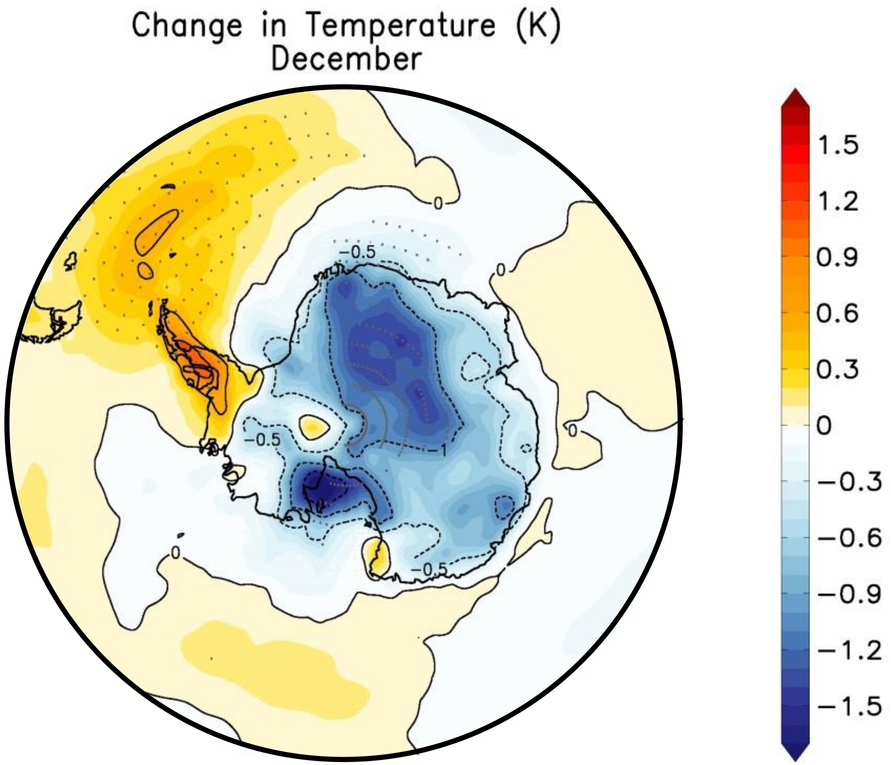


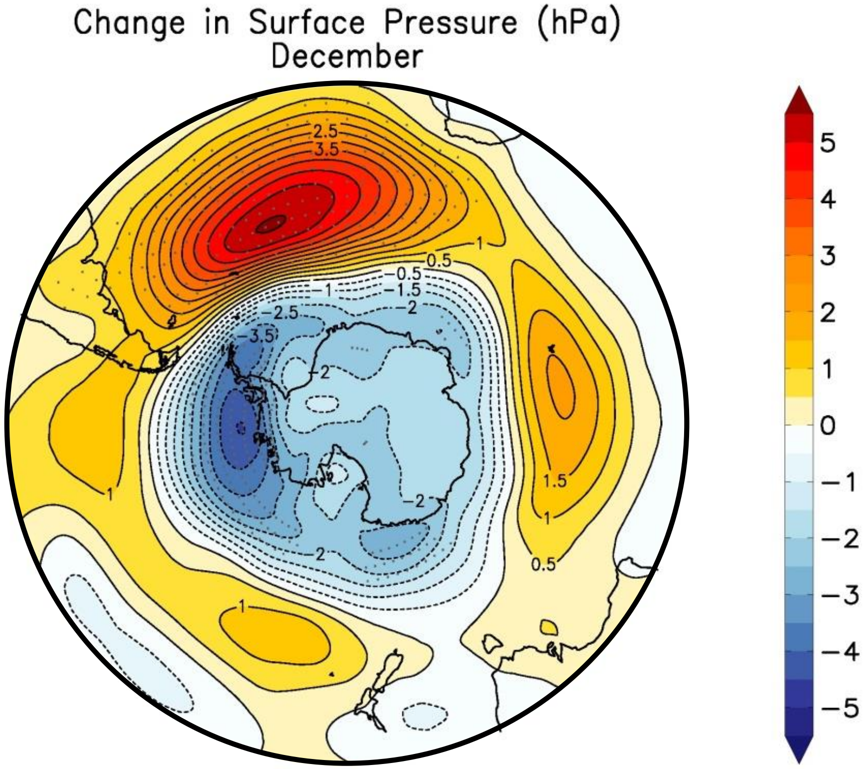
70 hPa Residual Mean Vertical Velocity Difference

Changes to wavebreaking drive changes to downwelling, assessed using TEM diagnostics



Surface Impacts





Statistically significant surface response in December for a number of variables

Surface response extends well beyond the Antarctic continent

Summary and Outlook

- Ozone and temperature response consistent with observations and earlier modelling studies using prescribed ozone
- Using a fully coupled chemistry climate model it is possible to fully asses the impacts of polar stratospheric ozone loss on stratospheric circulation and surface climate:
  - Ozone loss leads to a pronounced cooling of the lower stratosphere
  - Through thermal wind balance, this leads to a strengthening and poleward shift of the polar night jet
  - Changes to the zonal wind alter the propagation of planetary waves into the stratosphere, which drives enhanced downwelling in Dec-Jan
  - This leads to dynamical heating of the middle and upper stratosphere
- Stratospheric changes lead to a tropospheric response consistent with observations – although the mechanism driving the tropospheric response not clear

Thank you for listening

Acknowledgements: Luke Abraham, Paul Telford, Scott Hoskin and Andrew Orr

Corinne Le Quéré *et al*. (2007), **Saturation of the Southern Ocean CO2 Sink Due to Recent Climate Change,** *Science* 316, 1735

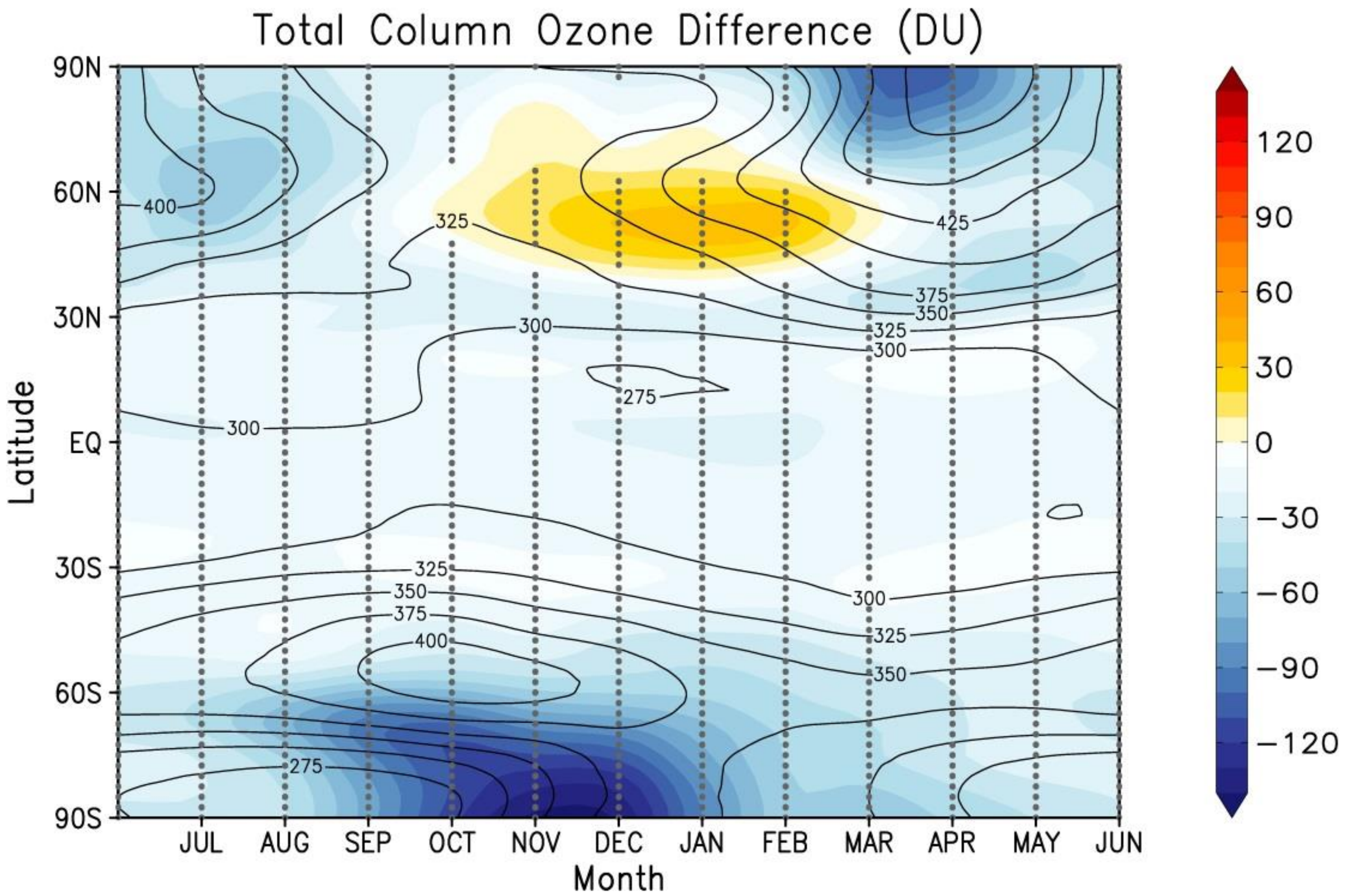
Son, S.-W., et al. (2010), **Impact of stratospheric ozone on Southern Hemisphere circulation change: A multimodel assessment**, J. Geophys. Res., 115

Thompson, D.W.J., and S. Solomon (2002), **Interpretation of recent Southern Hemisphere climate change**, Science, 296, 895-899

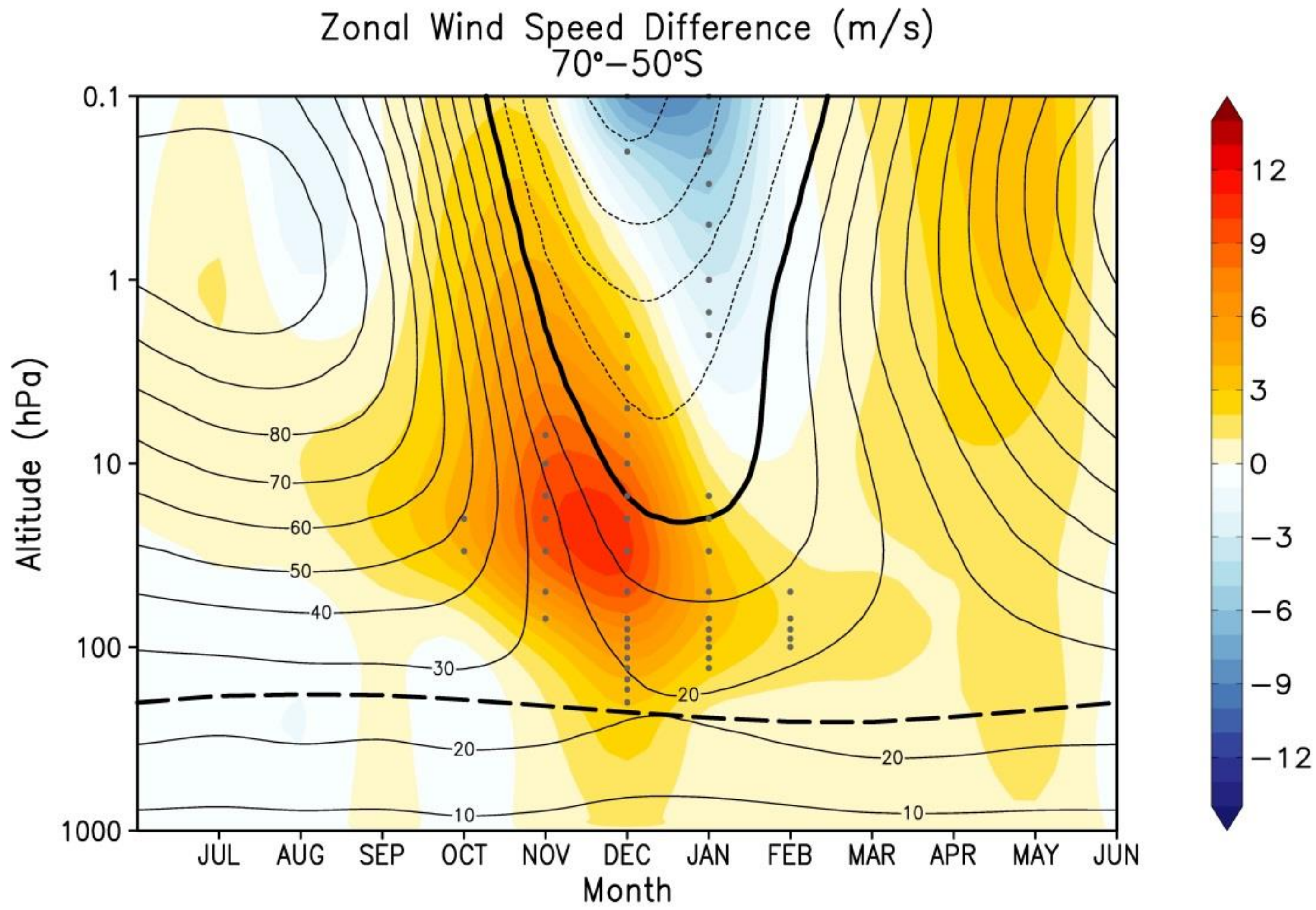
Manzini, E, et al. (2003), **A new interactive chemistry-climate model: 2. Sensitivity of the middle atmosphere to ozone depletion and increase in greenhouse gases and implications for recent stratospheric cooling**, J. Geophys. Res., 108, 4429

Ozone Changes – Total Column

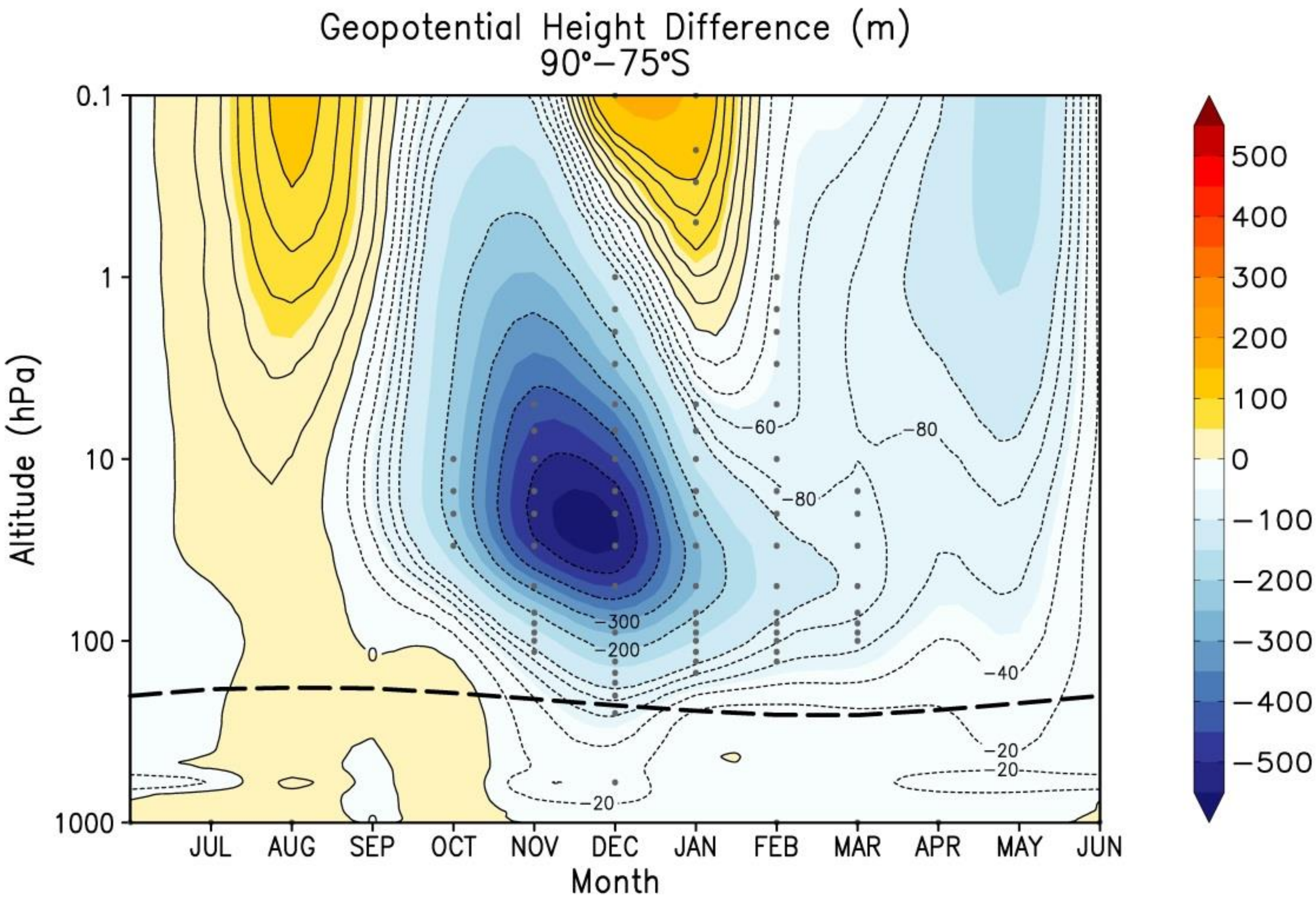
Ozone changes extend beyond the spring polar vortex.



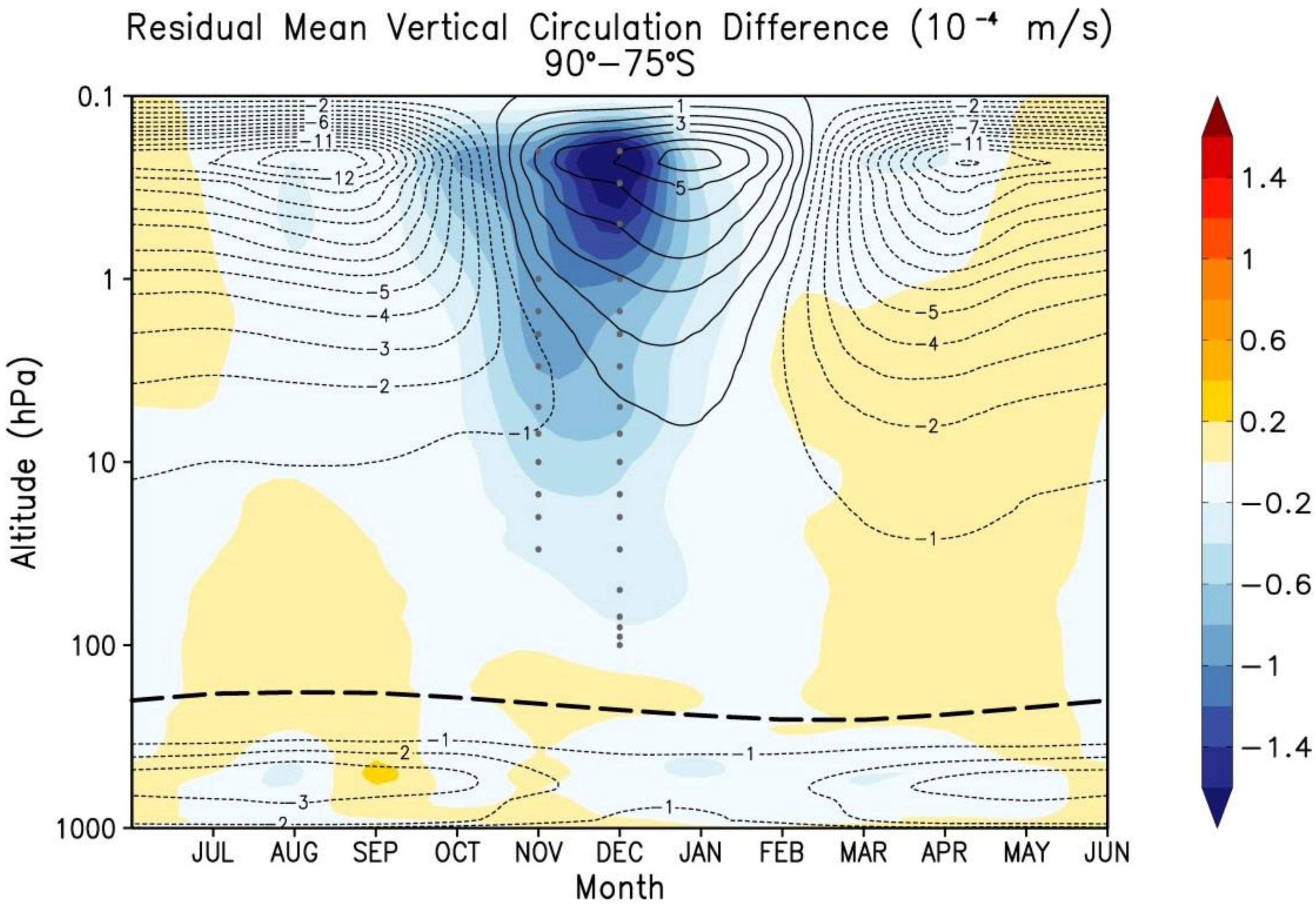
Zonal Wind Speed Difference



Geopotential Height Difference



Residual mean vertical circulation difference



Tropopause Height Difference

Tropopause height increases a direct result of cooling of the lower stratosphere changing the lapse rate