The Impact of Stratospheric Ozone on Southern Hemisphere Climate Change

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Abstract

The decline in stratospheric ozone observed over the last several decades is on the verge of reversing. The models participating in the SPARC chemistry climate model validation (CCMVal) project predict that the ozone hole will close in the first half of the 21st century (Fig. 1). Analyses of both CCMVal and IPCC/AR4 model output show that this ozone recovery will have a profound effect on the Southern Hemisphere summer climate. Specifically, the expected closing of the ozone hole will likely weaken or even reverse the present trend in the Southern Annular Mode, resulting in a wind deceleration in the southern high latitudes. Accompanying this change in the westerly jet, the recent expansion of the Southern Hemisphere Hadley cell is expected to slow down. Furthermore, ozone recovery is likely to accelerate warming over the Antarctic and reduce precipitation in the southern high latitudes.

Antarctic Ozone

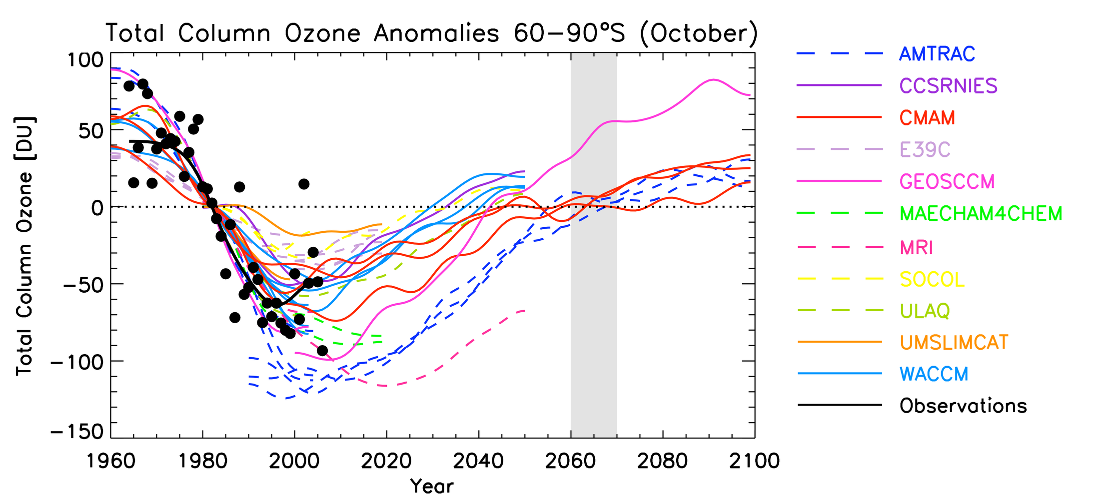

Figure 1. October Antarctic (90°S to 60°S) total column ozone anomalies from CCMVal models (colored lines) and the mean from four observational data sets (thick black line for smoothed curve and black dots for individual years). Time series have been smoothed by applying 1-2-1 filter iteratively 30 times, and anomalies have been calculated by subtracting the 1980-1984 mean from the smoothed time series. Light gray shading between 2060 and 2070 shows the period when stratospheric concentration of halogens in the polar lower stratosphere are expected to return to their 1980 values. From Eyring et al. (2007 JGR).

Data

- IPCC/AR4: all 20C3M and A1B integrations (see Fig. 3 legend).
- SPARC CCMVal: 7 long-term scenario integrations (see Fig.3 legend).
- GEOS-CCM: 4 sensitivity integrations.

Experiment	Length	Halogens	GHG	SST/Ice
C20Cl1960	1951-2005	Fixed cl to 1960' value	Observed	Had1SST
C20	1951-2005	Observed	Observed	Had1SST
C21Cl1960	2001-2099	Fixed cl to 1960' value	A1B scenario	NCAR-CCSM3.0
C21	2000-2099	Ab scenario	A1B scenario	NCAR-CCSM3.0

Future Jet (19 IPCC/AR4 & 7 CCMVal)

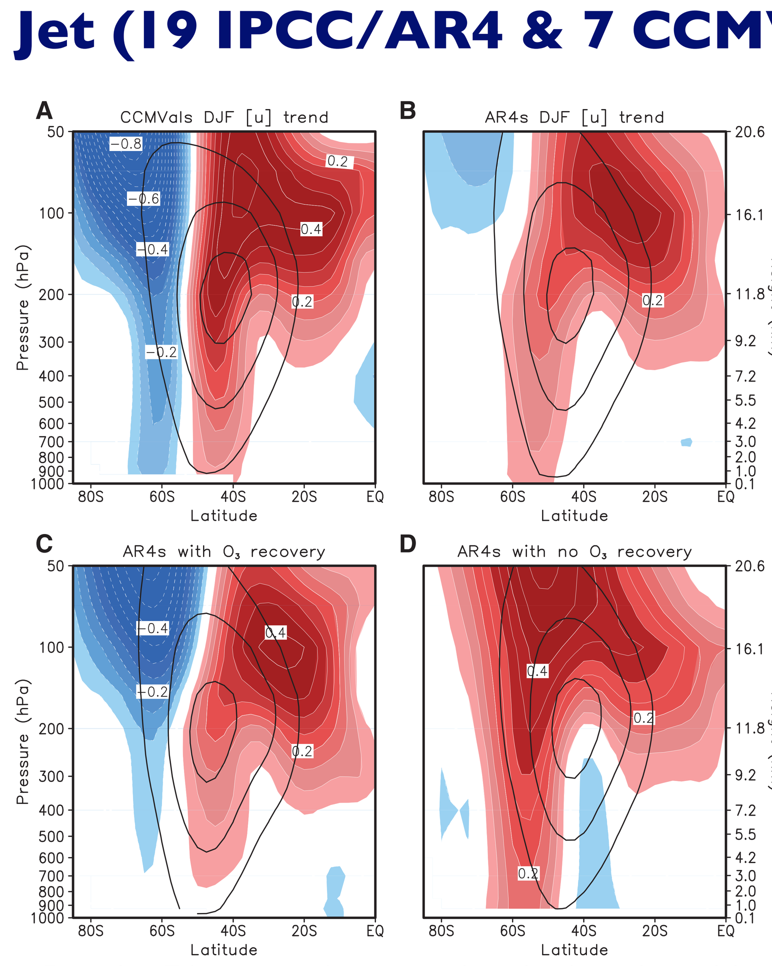

Figure 2. Trends in December-February zonal-mean zonal wind. The multi-model mean trends between 2001 and 2050 are shown **A**, for the CCMVal models; **B**, for the AR4 models; **C**, for the AR4 models with prescribed ozone recovery; and **D**, for the AR4 models with no ozone recovery. Shading and contour intervals are 0.05 ms^{-1}/decade. Deceleration (acceleration) is indicated with blue (red) colors, and trends weaker than 0.05 ms^{-1}/decade are omitted. Superimposed black solid lines are December-February zonal-mean zonal wind averaged from 2001 to 2010, with a contour interval of 10 ms^{-1} starting at 10 ms^{-1}. From Son et al. (2008 Science).

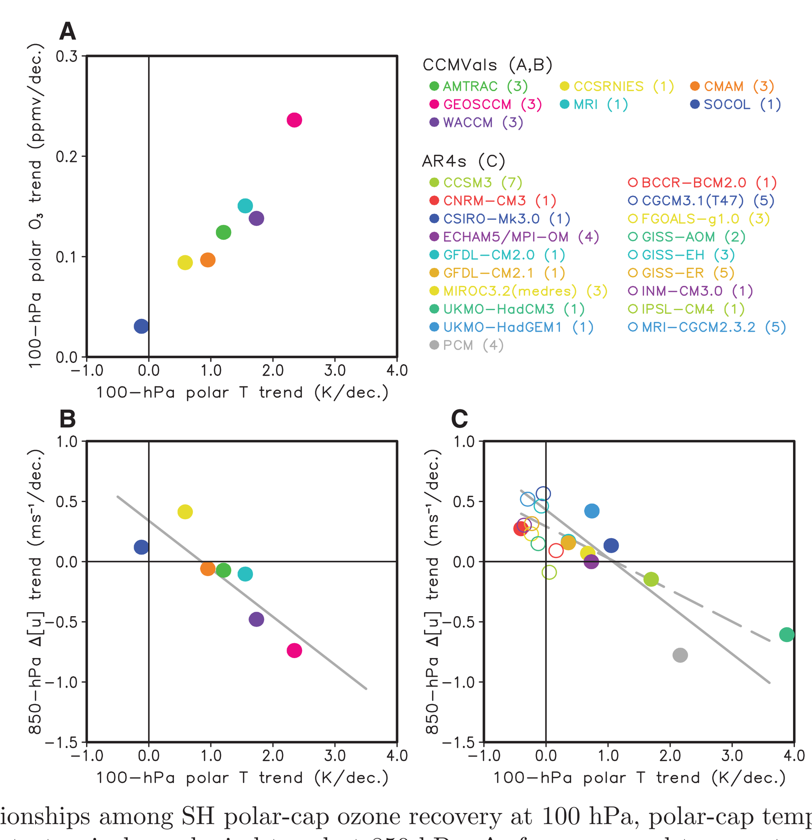

Figure 3. Relationships among SH polar-cap ozone recovery at 100 hPa, polar-cap temperature trend at 100 hPa, and extratropical zonal wind trend at 850 hPa; **A**, for ozone and temperature trends as simulated by CCMVal models; **B**, for zonal wind and temperature trends as simulated by CCMVal models; and **C**, for zonal wind and temperature trends as simulated by AR4 models. Here, ozone and temperature trends are calculated for September-December and November-January mean quantities, respectively. The averaging months are chosen to reflect the largest trends at 100 hPa, as seen in Fig. 1. The zonal wind trends at 850 hPa are quantified by $\Delta[u]$, the difference in December-February averaged zonal wind at $\pm 10°$ from the latitude of maximum wind. Negative values denote the deceleration (acceleration) of westerlies on the poleward (equatorward) side of the maximum wind. The filled and open circles in (C) correspond to the AR4 models with and without prescribed ozone recovery. Solid and dashed gray lines in (B) and (C) respectively indicate linear fit for CCMVal models and AR4 models with prescribed ozone recovery. Parenthesized numbers in the legend denote the number of ensemble members used for each model. From Son et al. (2008 Science).

RESULTS I

1. *Reversal of westerly jet trend (Fig. 2)* : SH westerly is predicted, by both CCMVal and IPCC/AR4 models with ozone recovery, to decelerate on the poleward side of the climatological jet.
2. *Linear relationship between stratospheric ozone and tropospheric jet changes (Fig. 3)* : Stratospheric ozone recovery → Antarctic polar-cap warming → Equatorward acceleration of the near-surface westerlies.

Hadley Cell (15 IPCC/AR4 & GEOS-CCM)

- Both past (1960-1999) and future trends (2000-2049) are examined.
- 15 IPCC/AR4 models: 6 models use climatological ozone, whereas 9 models use time-varying ozone. Only models with resolution higher than T42 are used.

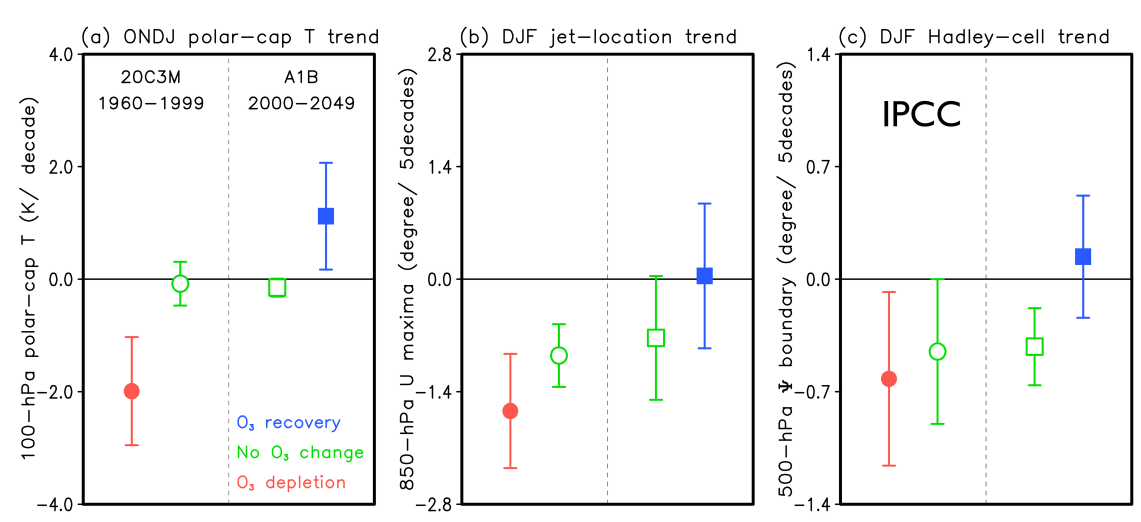

Figure 4. Sensitivity of the SH circulation trends to Antarctic ozone as simulated by the IPCC/AR4 models: (a) polar-cap temperature, integrated south of 70°S, at 100 hPa for October-January, (b) location of westerly jet maximum at 850 hPa for December-February, and (c) location of the poleward boundary of the Hadley cell for December-February. The long-term trends are computed with a least square fit, for the time period of 1960-1999 in the 20C3M integrations (circles) and for the time period of 2000-2049 in the A1B scenario integrations (squares). The multi-model ensemble mean and one standard deviation are shown. Negative trends in (b,c) denote poleward shift in westerly jet or poleward expansion of the Hadley cell. From Son et al. (2008, manuscript in preparation).

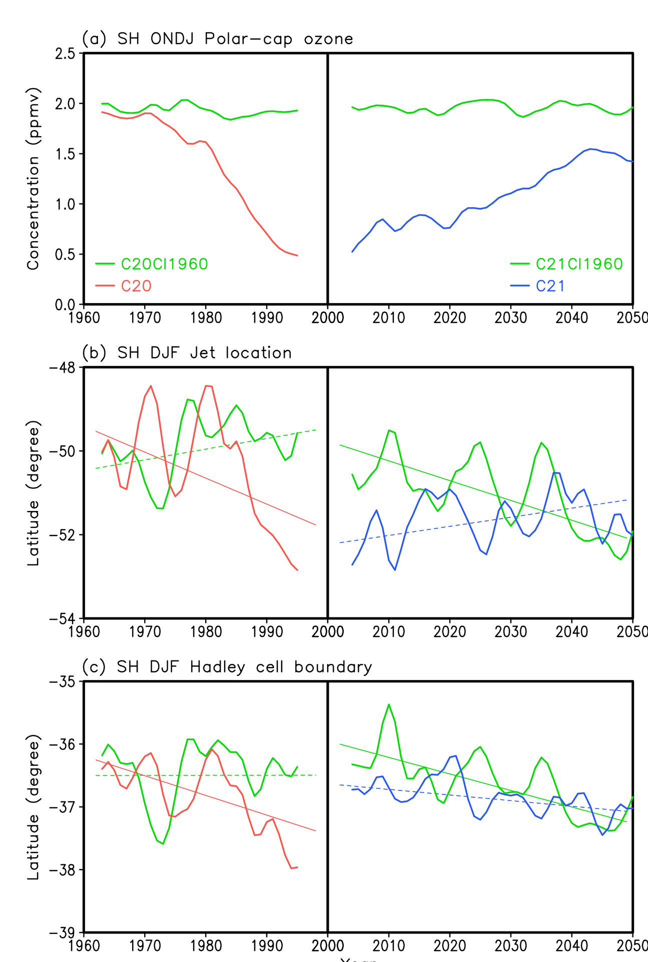

Figure 5. Results of the GEOS-CCM integrations as a function of time: (a) polar-cap ozone, integrated south of 70°S, at 100 hPa during October-January, (b) location of westerly jet maximum at 850 hPa during December-February, and (c) location of poleward boundary of the Hadley cell during December-February. All time series are smoothed by applying 1-2-1 filter three times, roughly equivalent to half amplitude at 6.7 years. Thin straight lines show the least square fits for the unfiltered data. The fits which are significantly different from the zero at the 95% confidence level are denoted with solid lines, and dashed lines otherwise. From Son et al. (2008, manuscript in preparation).

GEOS-CCM

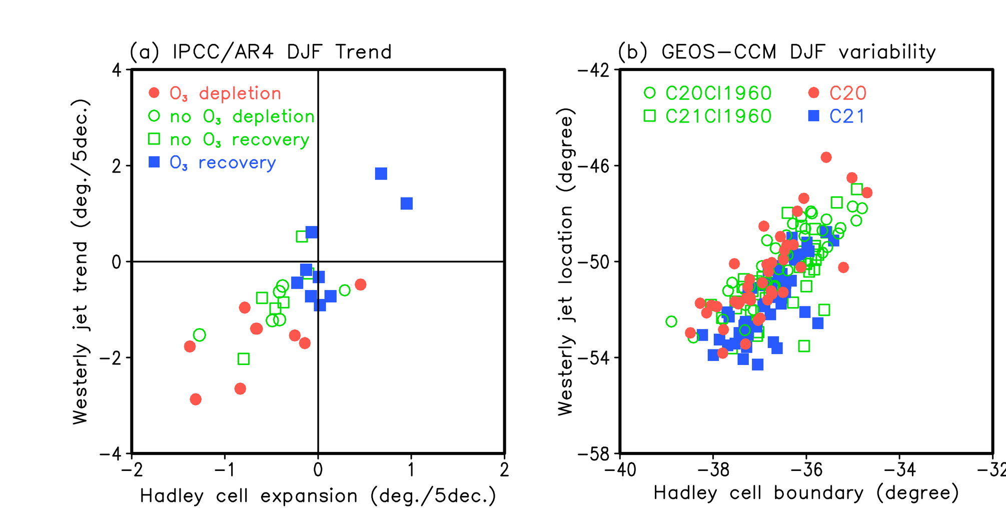

Figure 6. Relationship between the location of westerly jet maxima and the poleward boundary of the Hadley cell during December-February: (a) trends as simulated by all IPCC/AR4 models, and (b) interannual variability as simulated by all GEOS-CCM integrations. From Son et al. (2008, manuscript in preparation).

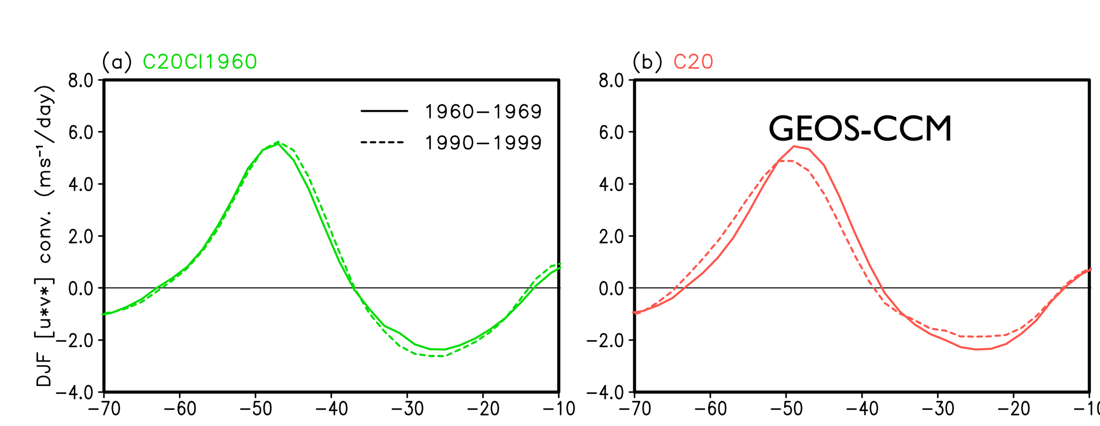

Figure 7. DJF-mean eddy momentum flux convergence at 200 hPa as simulated by the GEOS-CCM integrations: (a) C20Cl1960 [with fixed ozone], and (b) C20 integrations [with ozone depletion]. Solid and dashed lines denote the first and last 10-year averages, respectively. From Son et al. (2008, manuscript in preparation).

RESULTS II

3. *Weakening of Hadley cell expansion (Figs. 4,5)* : Both IPCC/AR4 and GEOS-CCM predict weaker Hadley cell expansion due to stratospheric ozone recovery.
4. *Linear relationship between jet location and Hadley cell boundary (Figs. 6)* : Both quantities change coherently during austral summer. This suggests that both the jet location and the Hadley cell boundary are modulated by the same physical process.
5. *Importance of midlatitude eddies (Fig.7)* : Systematic changes are caused by midlatitude eddies, which are affected by stratospheric ozone.

Surface Climate (21 IPCC/AR4)

- Both past (1960-1999) and future trends (2000-2049) are examined.
- 21 IPCC/AR4 models: 11 models use climatological ozone, whereas 10 models use time-varying ozone.

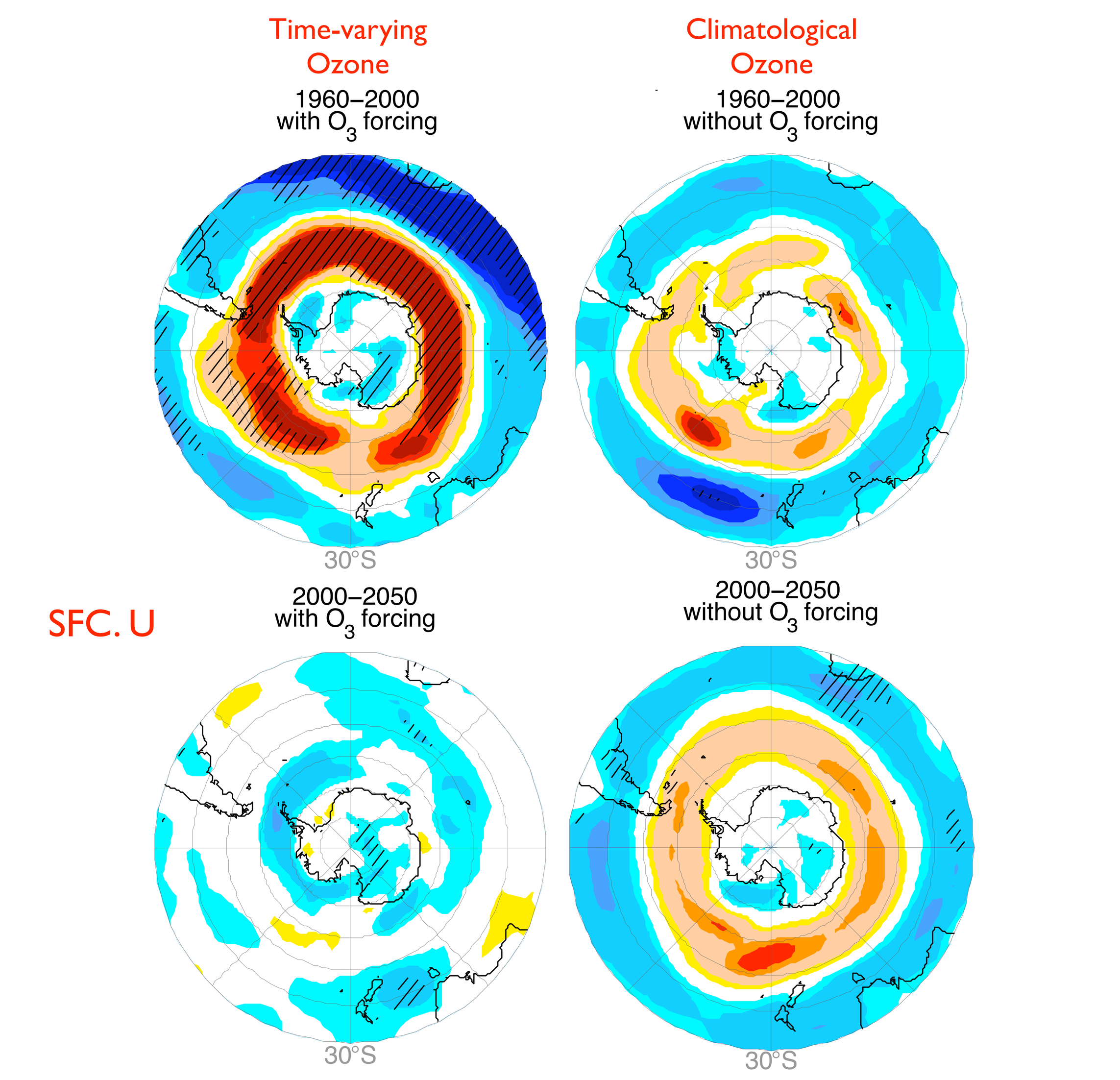

Figure 8. Long-term trends in DJF-mean surface zonal wind as simulated by IPCC/AR4 models: Top row for 20C3M integrations with and without ozone depletion, and bottom row for corresponding A1B scenario integrations. Negative and postive trends are shown in blue and red, respectively. Shading interval is indentical in all panels. From Tandon et al. (2008, manuscript in preparation).

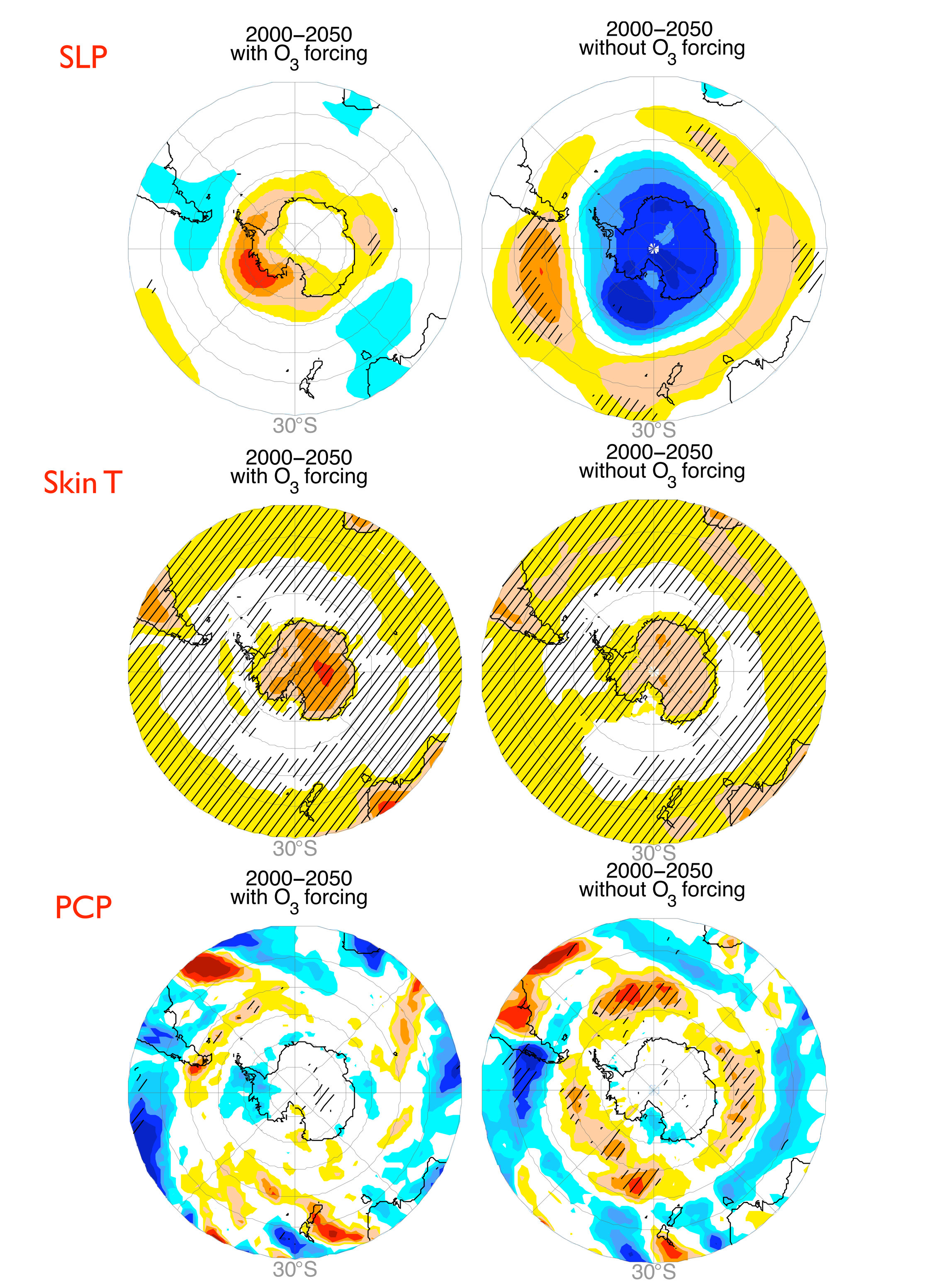

Figure 9. Long-term trends between 2000-2050 in (top) DJF-mean sea level pressure, (middle) skin temperature, and (bottom) precipitation as simulated by IPCC/AR4 scenario integrations: Left column with ozone recovery, right column without. Negative and postive trends are shown in blue and red, respectively. Shading interval is same for each pair of integrations, with and without ozone recovery. From Tandon et al. (2008, manuscript in preparation).

RESULTS III

6. *Weakening of surface westerly trend (Fig. 8)* : Stratospheric ozone recovery weakens the poleward intensification of the surface westerlies.
7. *Negative trend in Southern Annular Mode, weaker trend in precipitation, and acceleration of Antarctic warming (Fig. 9)* : These are consistent with surface wind changes.

References

- Eyring and coauthors, 2007: Multimodel projections of stratospheric ozone in the 21st century. *Journal of Geophysical Research,* D16303.
- Son, Polvani, Waugh, and CCMVal coauthors, 2008: The impact of stratospheric ozone recovery on the Southern Hemisphere westerly jet. *Science, 1486-1489.*
- Son, Polvani, Waugh, and CCMVal coauthors, 2008: The impact of stratospheric ozone recovery on tropopause height trends. *Journal of Climate,* in press.
- Son, Polvani, Waugh, Perlwitz, and Pawson, 2008: The impact of stratospheric ozone on the Southern Hemisphere Hadley cell. to be submitted to *Climate Dynamics*.
- Tandon, Son, and Polvani, 2008: The impact of stratospheric ozone on Antarctic surface climate. to be submitted to *Journal of Geophysical Research*.