Processes Controlling 21st Century Southern Ocean Climate-Cloud Feedbacks

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Thanks to Lorenzo Polvani and Cecilia Bitz

Why study Southern Ocean clouds?

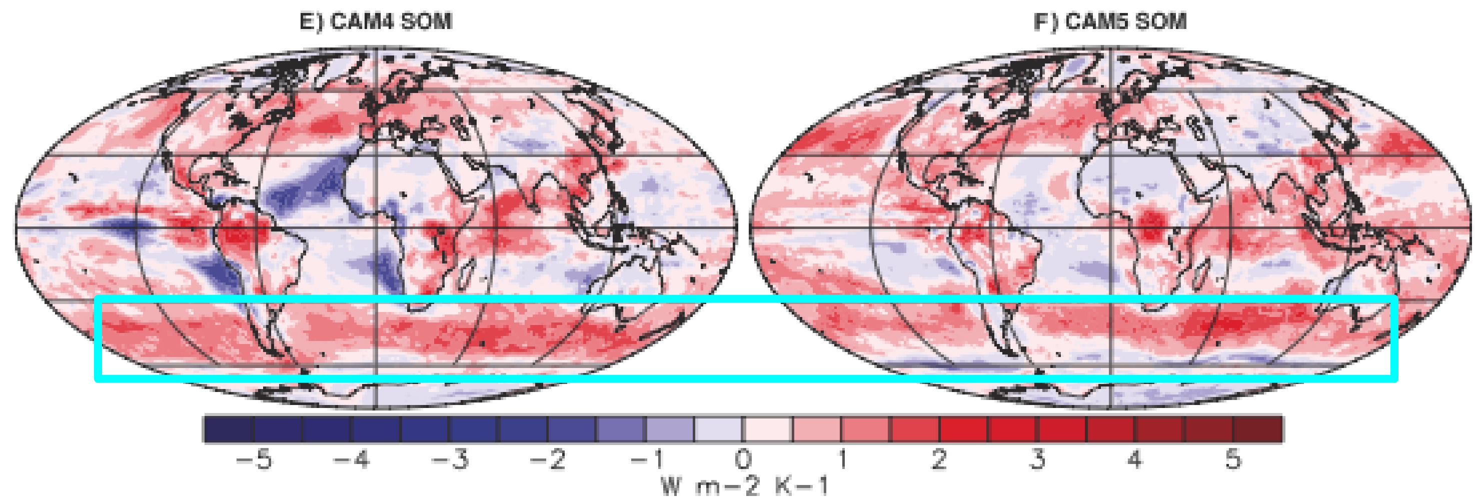


FIG. 6. Adjusted cloud feedback (W m^{-2} K^{-1}) for ASCF in (a) CAM4-SOM and (b) CAM5-SOM, for ALCF in (c) CAM4-SOM and (d) CAM5-SOM, and For net ACF in (e) CAM4-SOM and (f) CAM5-SOM.

Gettelman, Kay, and Shell (2012)

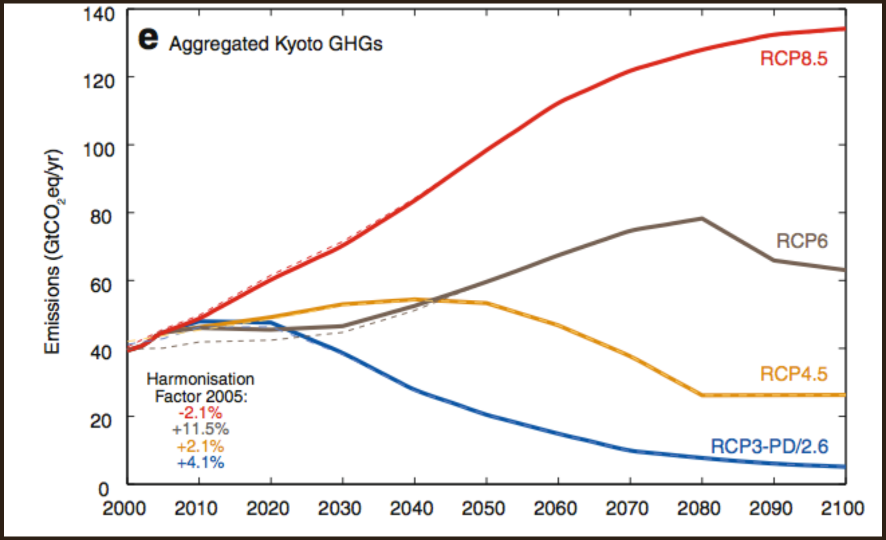
Southern ocean research questions …

1) Which processes control climate-cloud feedbacks over the Southern Ocean (30-70° S)?

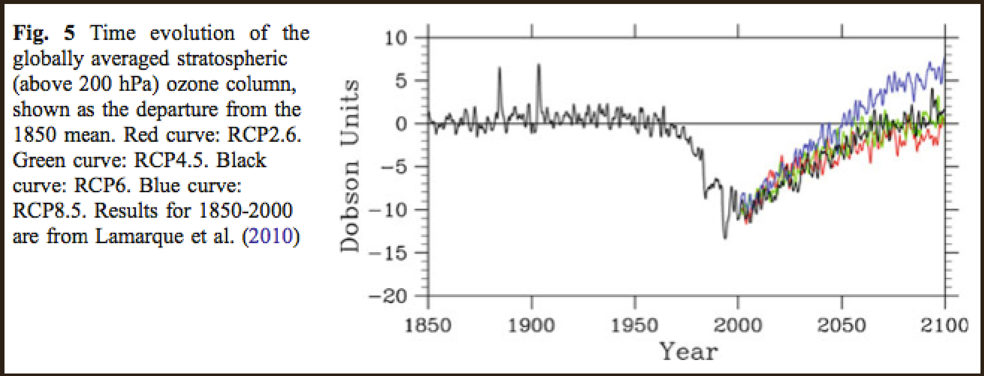
2) Are the model processes controlling these feedbacks realistic? Are there observational constraints?

3) How do Southern Ocean climate-cloud feedbacks affect the global climate system?

CESM-CAM5 21st century runs with RCP8.5 forcing



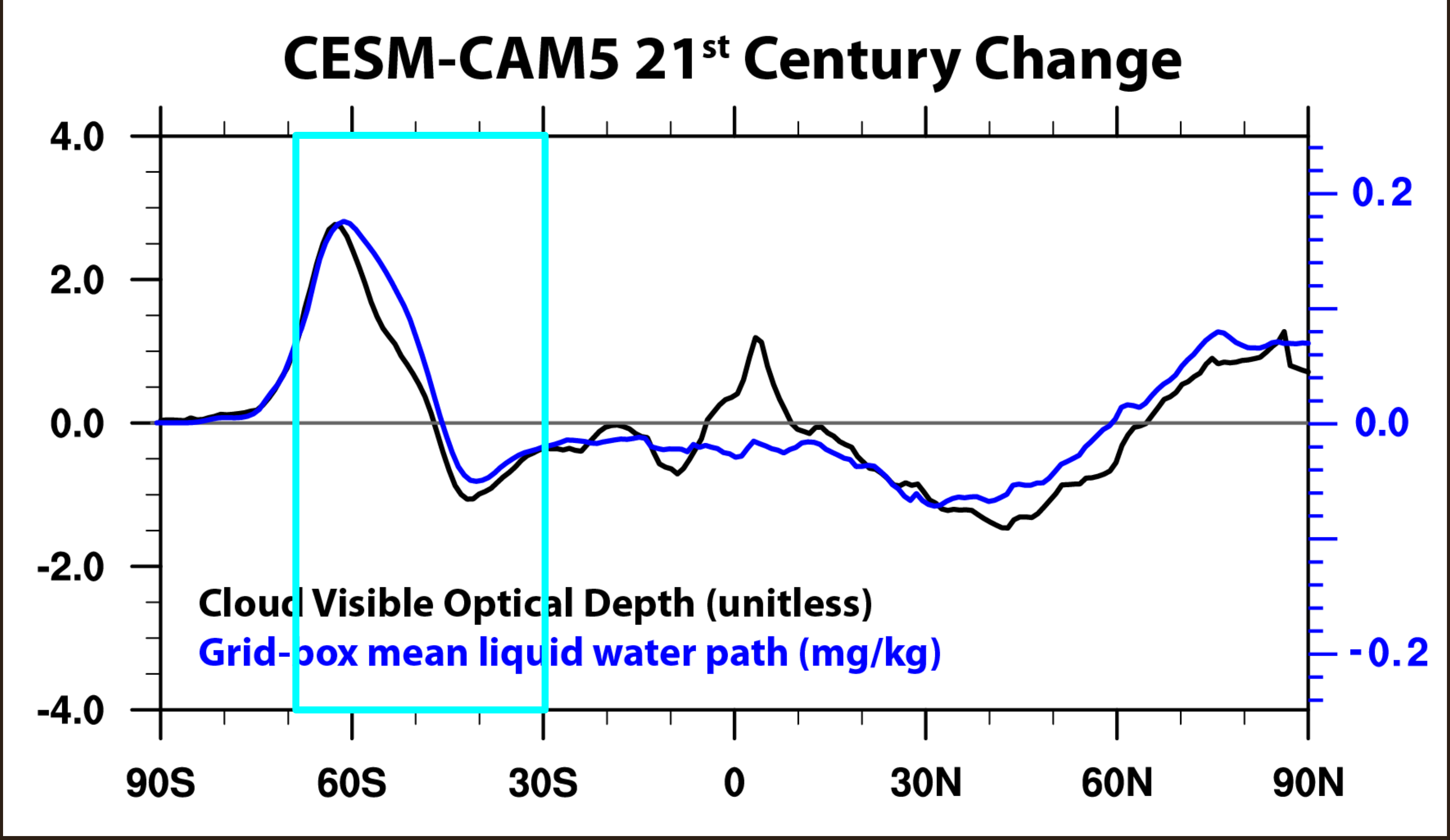
Meinshausen et al. 2011



Lamarque et al. 2011

RCP8.5 forcing	avg(2006-2025)	avg(2080-2099)
CO_2 equivalence	465 ppm	1162 ppm (2.5x)
Stratospheric O_3 (anomaly from 1850)	-9 Dobson Units	+5 Dobson Units

RCP8.5 Cloud Changes



Large changes and large gradients

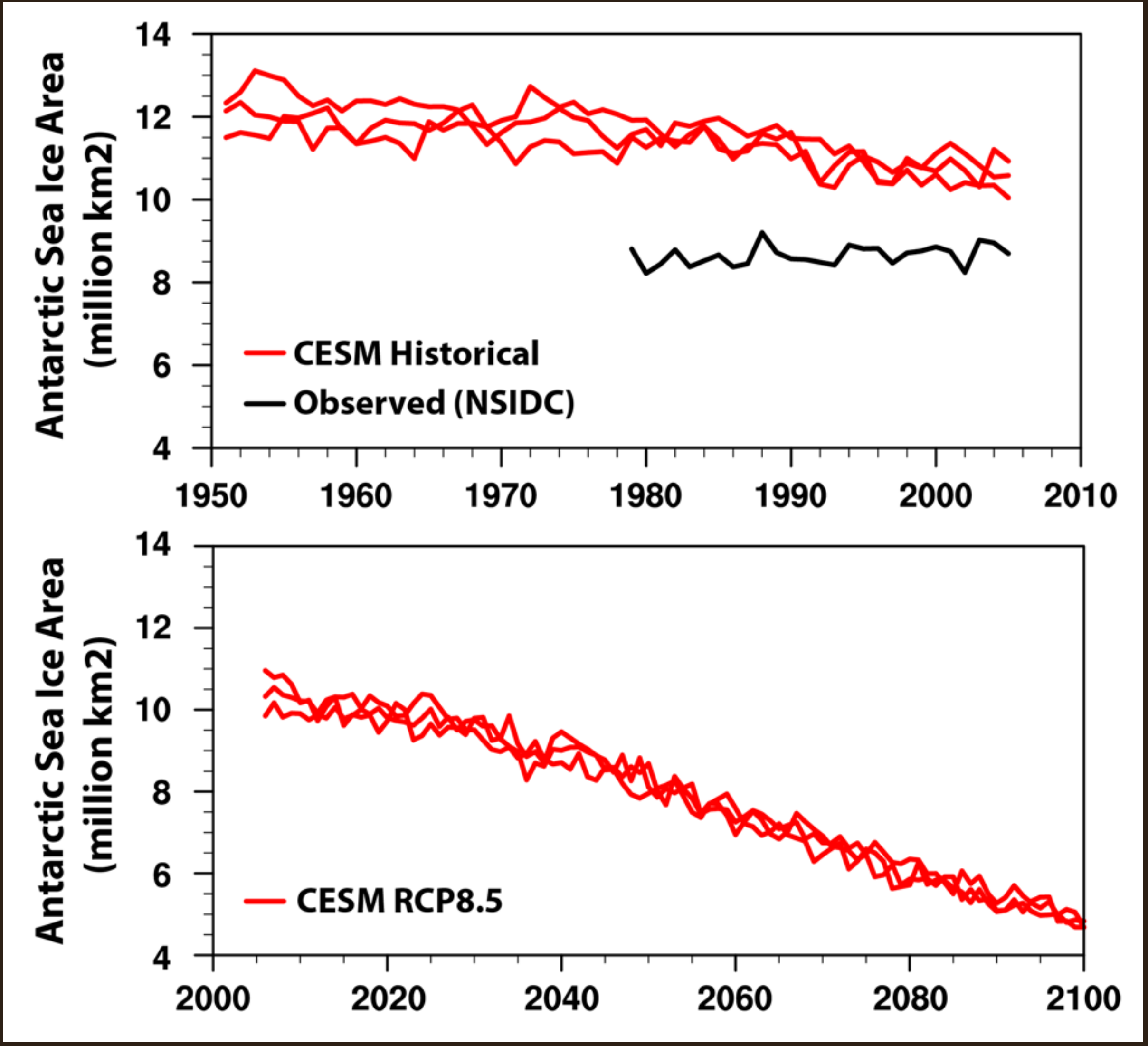
21st century cloud changes resemble $2xCO_2$ cloud feedbacks

OUTLINE:

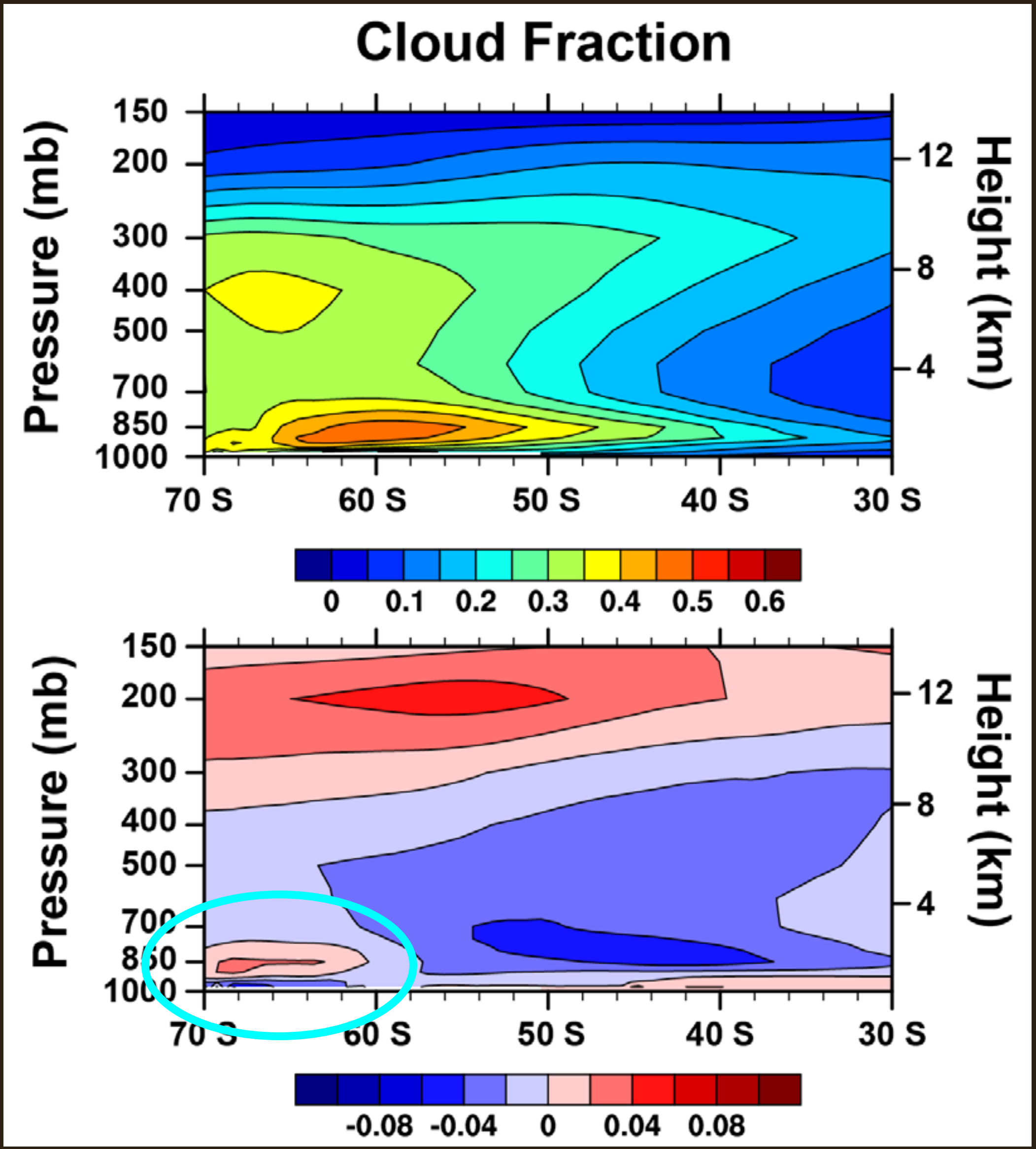
I. Processes affecting 21st C Southern Ocean cloud-climate changes
   1) Antarctic sea ice loss
   2) Large-scale atmospheric circulation shifts (“dynamics”)
   3) Warming (“thermodynamics”)

II. Summary and ongoing work

PROCESS #1: Antarctic sea ice loss



CESM Vertical cloud structure



Early 21st century

Change over 21st century

Cloud response to Antarctic sea ice loss

PROCESS #2: Large-scale atmospheric circulation shifts

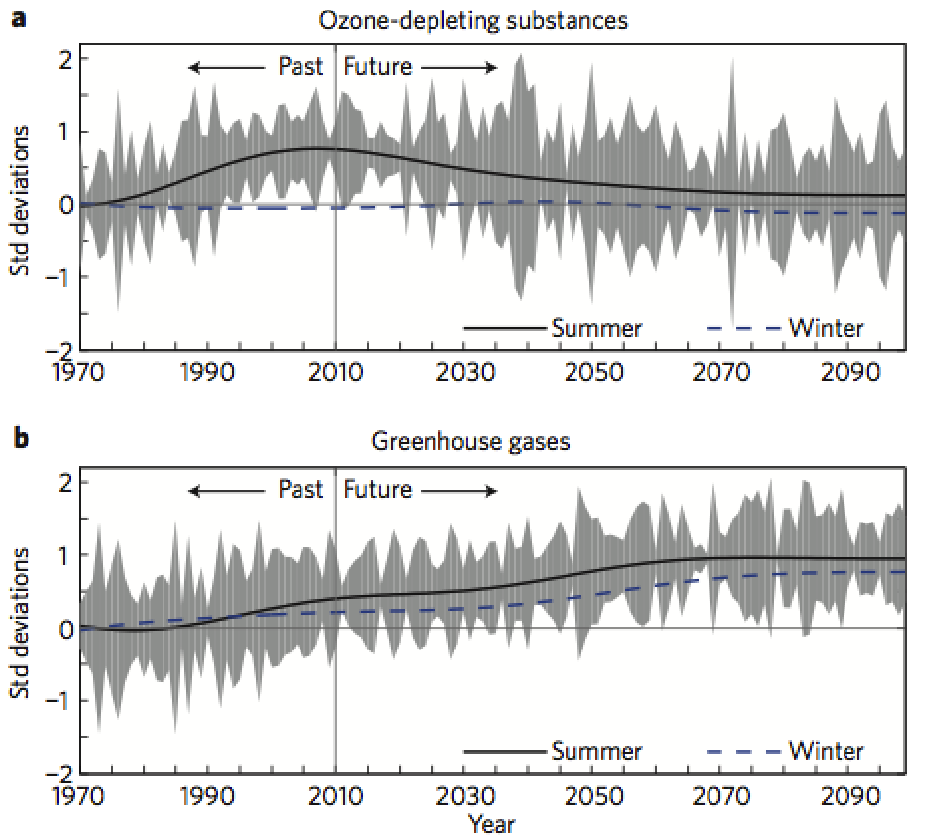


Figure 3 | Time series of the southern annular mode from transient experiments forced with time-varying ozone-depleting substances and greenhouse gases. Results are from experiments published in ref. 28.

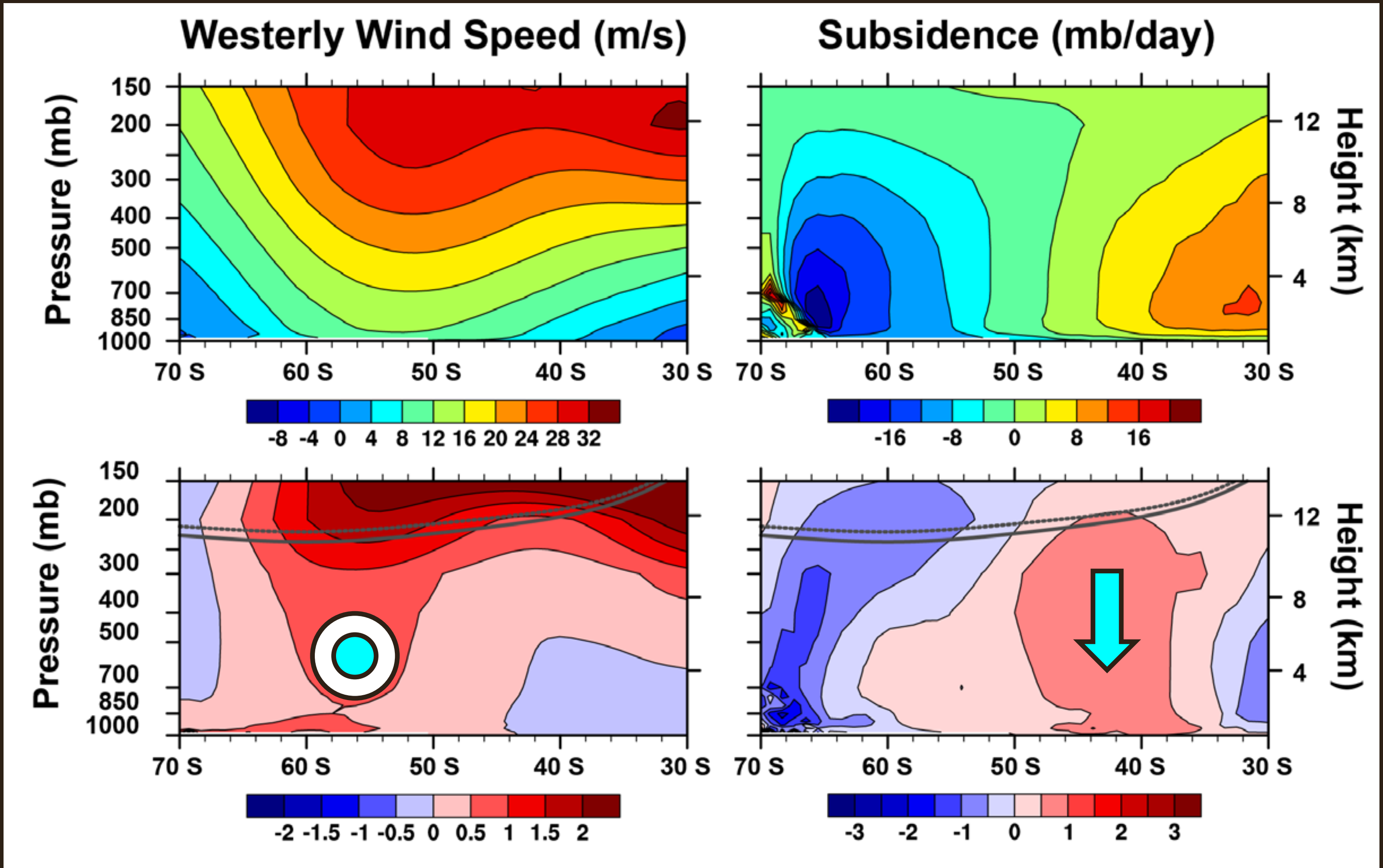
Thompson et al. 2011

20th C = poleward SH stormtrack shift
O_3 ↓ (GHG ↑)

21st C = poleward SH stormtrack shift
GHG ↑ (despite O_3 ↑)

Zonal mean SH CESM Circulation

top=early 21st C, bottom=21st C change



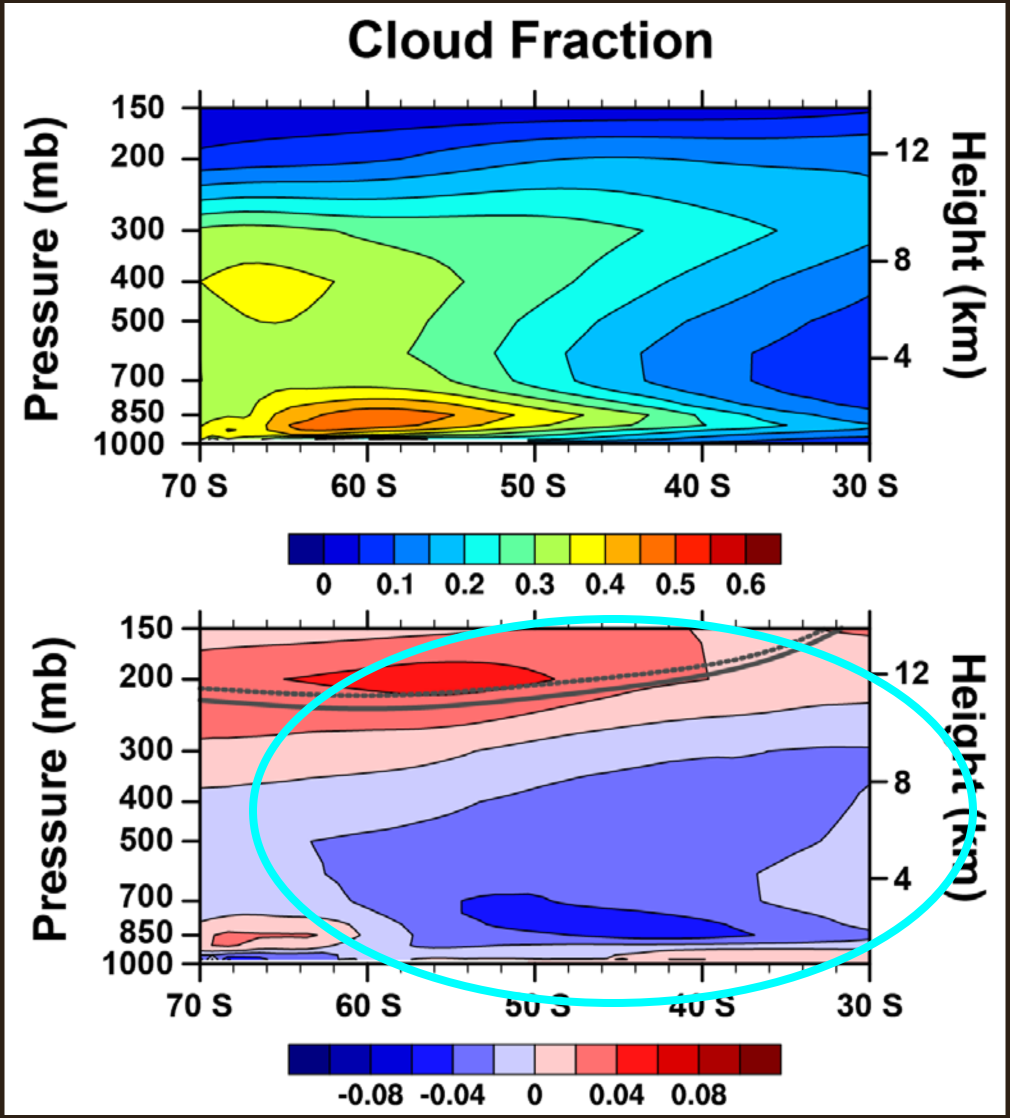
Early 21st century

Change over 21st century

Stronger Westerlies

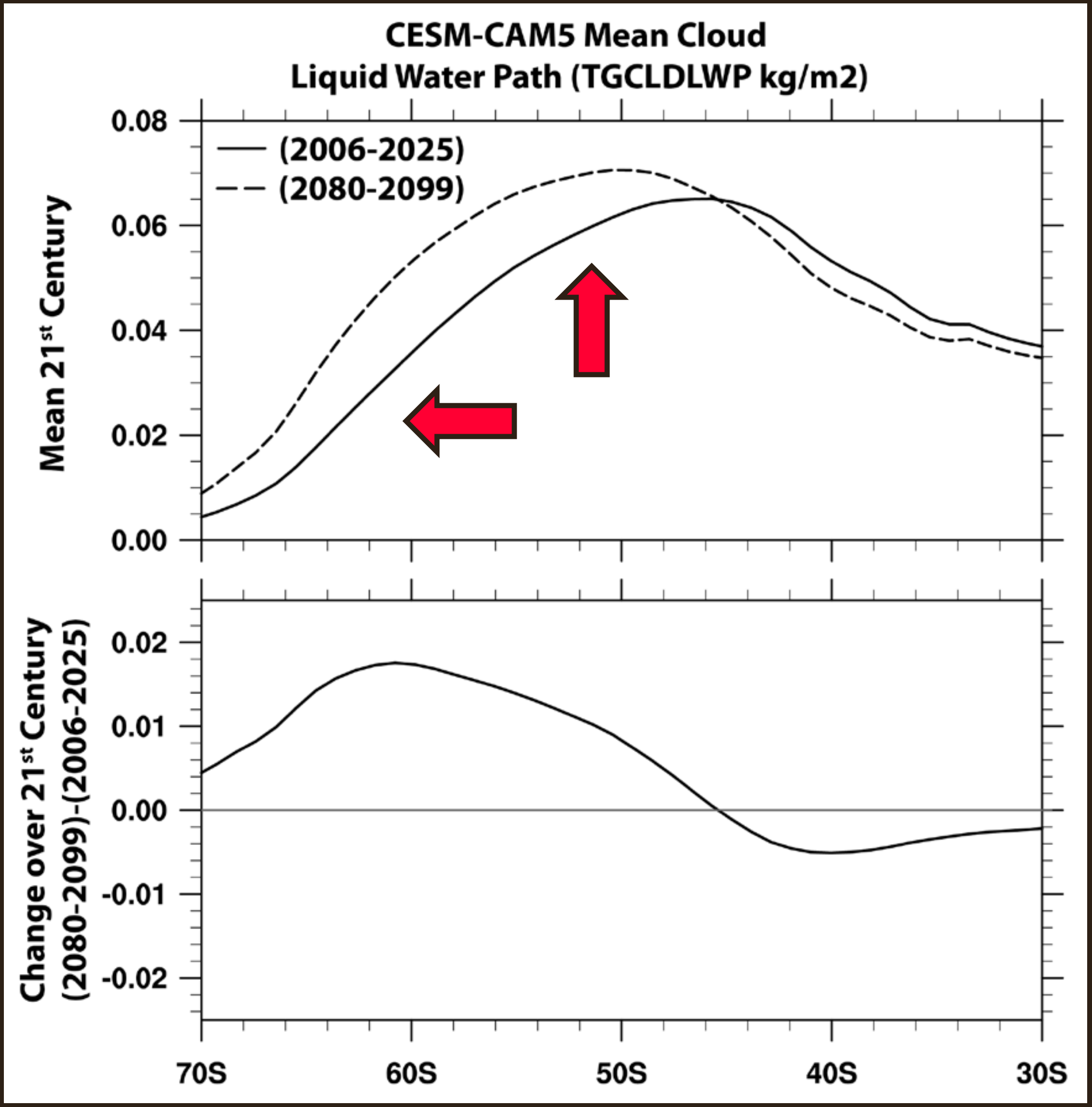
Increased subsidence

CESM clouds respond to increased subsidence over the 21st Century



Cloud fraction decreases except near the surface

PROCESS #3: Thermodynamics

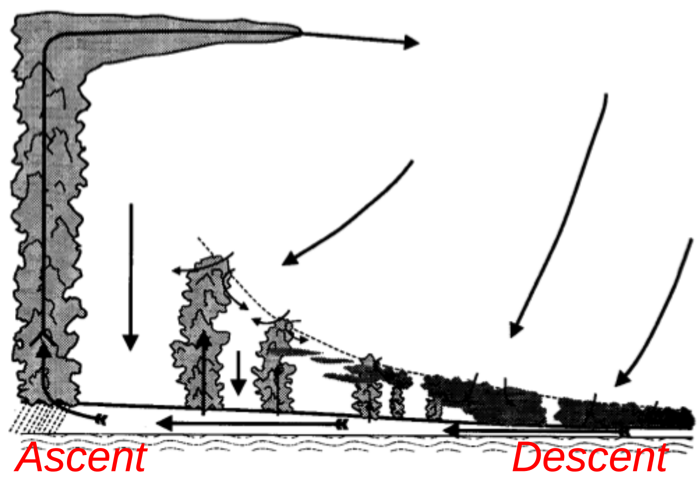


Zonal mean change shows both a poleward shift and larger maximum cloud liquid water path.

How do we separate the influence of “dynamics” and “thermodynamics” on these cloud changes?

"Bonygrams" can separate the dynamic and thermodynamic components of tropical cloud changes

Fig. 1 Structure of the tropical atmosphere, showing the various regimes, approximately as a function of sea surface temperature (decreasing from *left* to *right*) or large-scale vertical velocity in the mid-troposphere (from mean ascending motions on the *left* to large-scale sinking motions on the *right*). (*From* Emanuel 1994)



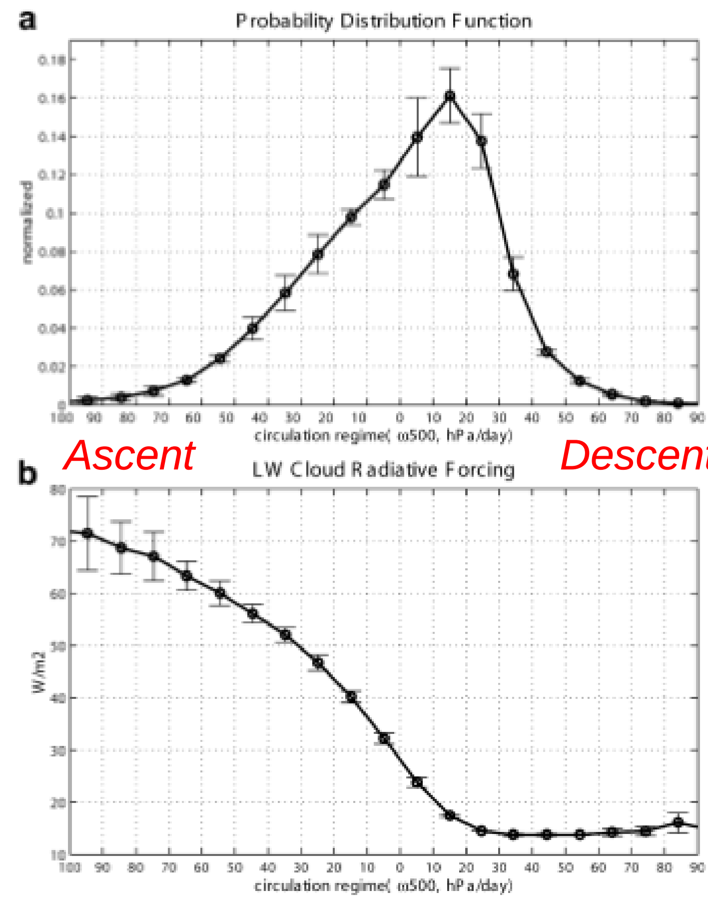
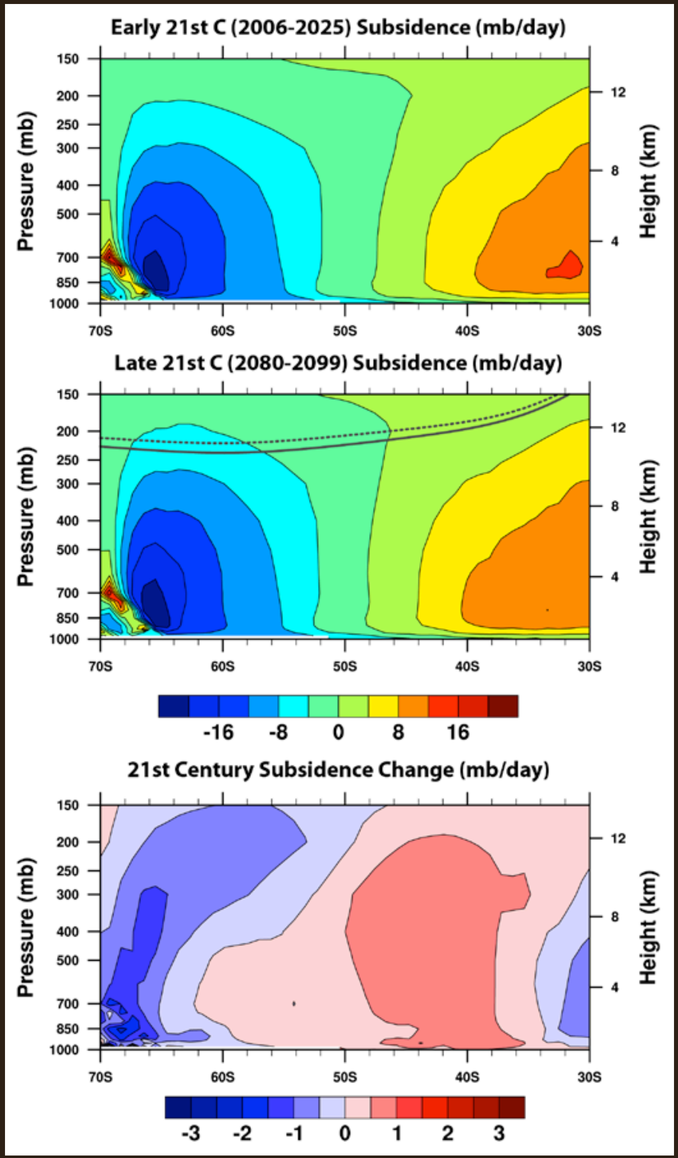
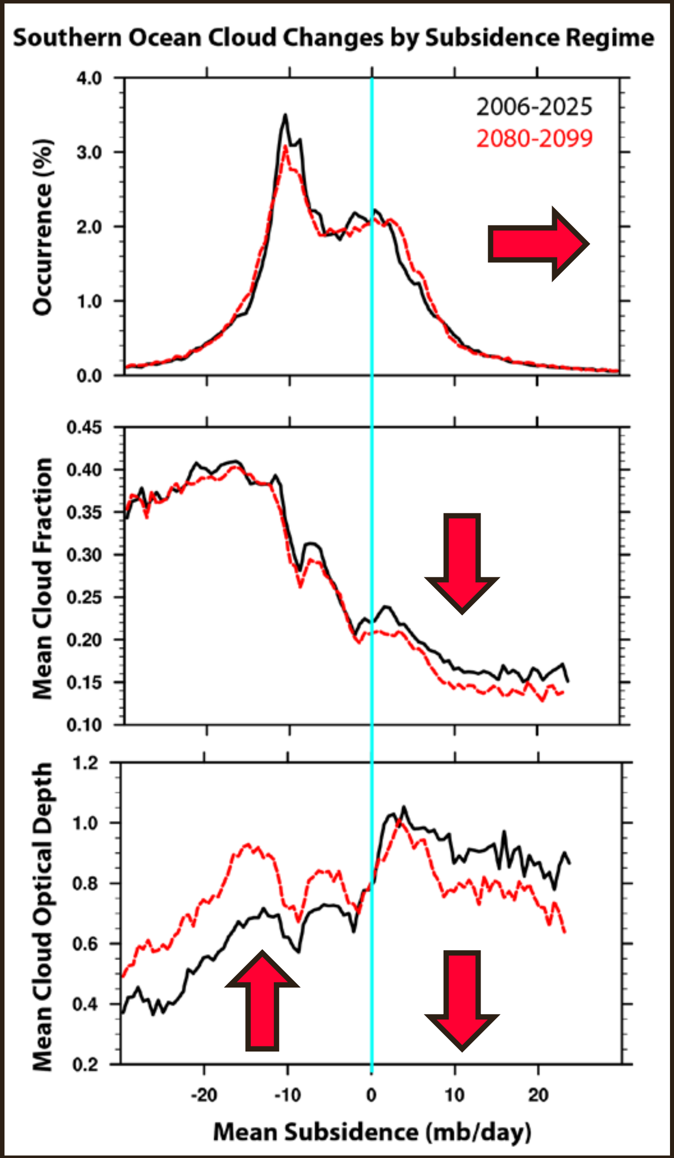


Fig. 2 **a** PDF P_ω of the 500 hPa large-scale vertical velocity ω_{500} in the tropics (30°S–30°N) derived from meteorological reanalyses and **b** composite C_ω of the ERBE-derived LW CRF in different circulation regimes defined from ω_{500}. Three independent sets of reanalyses are used: the average PDF and LW CRF-ω relationship are represented by *thick lines*; *vertical bars* show the standard deviation of the PDF and of the LW CRF-ω relationship that results from differences among the reanalysis datasets. The thermodynamic and dynamic components of the CRF response to a climate perturbation arise from a change in C_ω (i.e. a change in cloud properties within each individual circulation regime) and P_ω (i.e. a change in the statistical weight of the different dynamical regimes), respectively

Bony et al. 2004, *Climate Dynamics*

“Bonygrams” for the Southern Ocean?

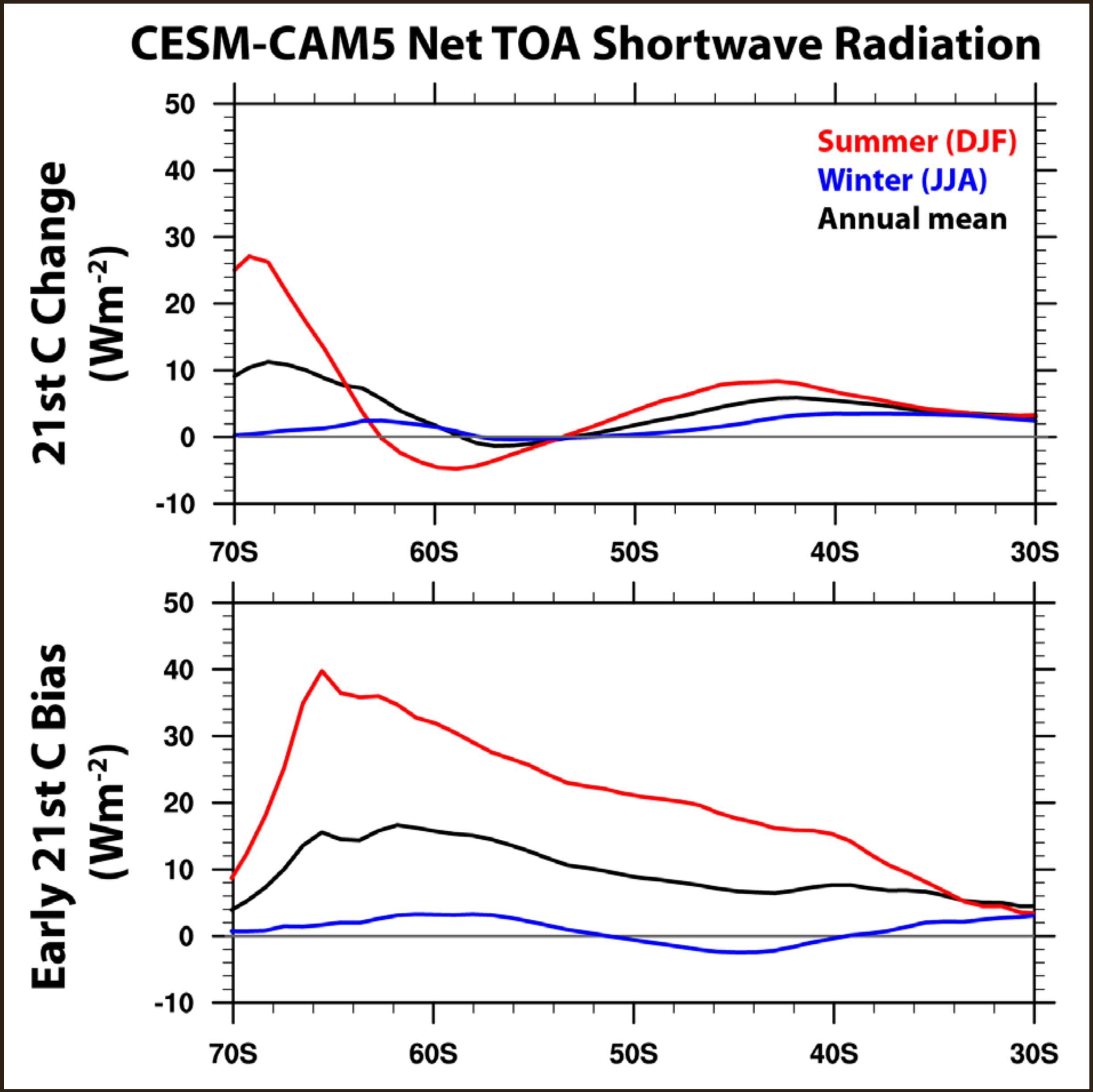




“Dynamics” = shift towards stronger subsidence…

“Thermodynamics” = reduced subtropical cloud fractions and “juicier” stormtrack clouds at a given subsidence rate

Why study Southern Ocean clouds?



Focus of this talk

Focus of the next talk

Summary

1. CESM Southern Ocean cloud-climate feedbacks vary in magnitude and sign: cooling near the Antarctic continent, warming on the equatorward flank of the mid-latitude stormtrack.
2. Over the 21st century, projected Antarctic sea ice loss, a poleward stormtrack shift, and thermodynamic changes all contribute to Southern Ocean cloud-climate feedbacks.
3. Work is ongoing. Suggestions very welcome!