CESM1-WACCM: Comparison with CCSM4/ CESM CMIP5 simulations

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WAWG meeting, Boulder, February 2011

NESL

NCAR is sponsored by the National Science Foundation

NSF

Notable improvements over WACCM3.1

- Chemistry module updated to JPL-2006 - validated in CCMVal2
- Quasi-biennial oscillation may be imposed by relaxing the winds to observations in the tropics
- Heating from stratospheric volcanic aerosols is now computed explicitly
- Effects of solar proton events are now be included
- Gravity waves due to convective and fronts are parameterized based upon the occurrence of convection and the diagnosis of regions of frontogenesis in the model

TMS & SSW frequency

- Unresolved orography is parameterized as a surface stress (turbulent mountain stress - TMS). Leads to improved frequency of SSWs.

Toward a Physically Based Gravity Wave Source Parameterization in a General Circulation Model

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TABLE 1. Frequency of occurrence of stratospheric sudden warmings: number of events per year.

Warming type	ERA-40	WACCM3	WACCM3.5	WACCM3.5ntms
Major midwinter (NDJF)	0.5	0.1	0.4	0.1
Major midwinter (NDJFM)	0.6	0.1	0.6	0.25
Minor (NDJF)	0.9	0.7	1.0	0.4
Minor (NDJFM)	1.4	1.4	1.4	0.65

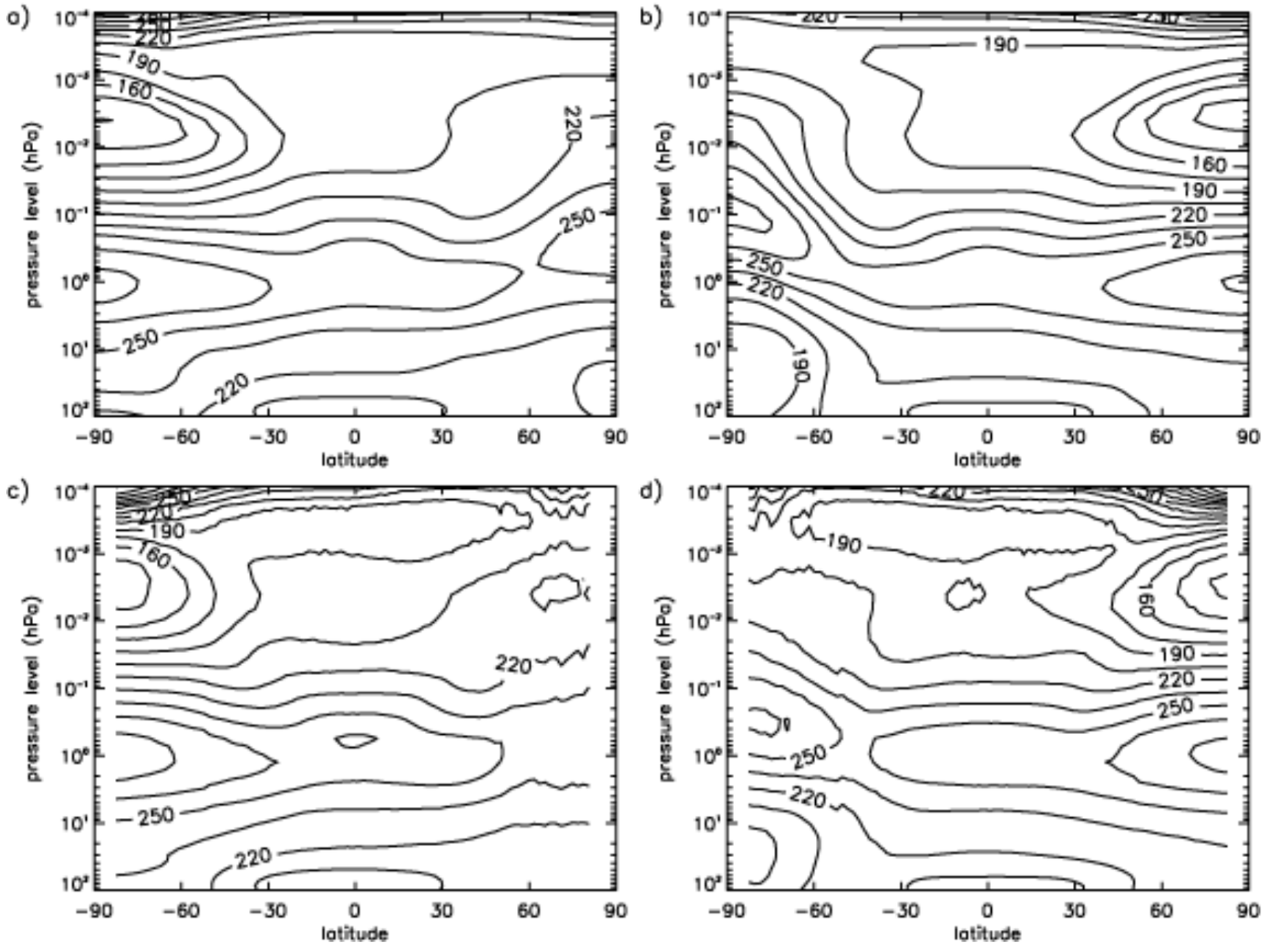
CESM1-WACCM

- Standard configuration:
  - Atmosphere: 1.9° x 2.5° x 66 lev (0 to ~135 km)
    - CAM4 physics - no aerosol indirect effect
    - Fully interactive chemistry with 57 species + AOA tracers
    - Observed spectral irradiance
    - TMS turned on
    - Fall velocity of ice reduced by 50% to improve stratospheric water vapor
  - Ocean: 1° x 60 lev
  - Land: 1.9° x 2.5° with CN

Zonal mean temperatures 2002-2005 vs SABER

January **July**

WACCM 2°

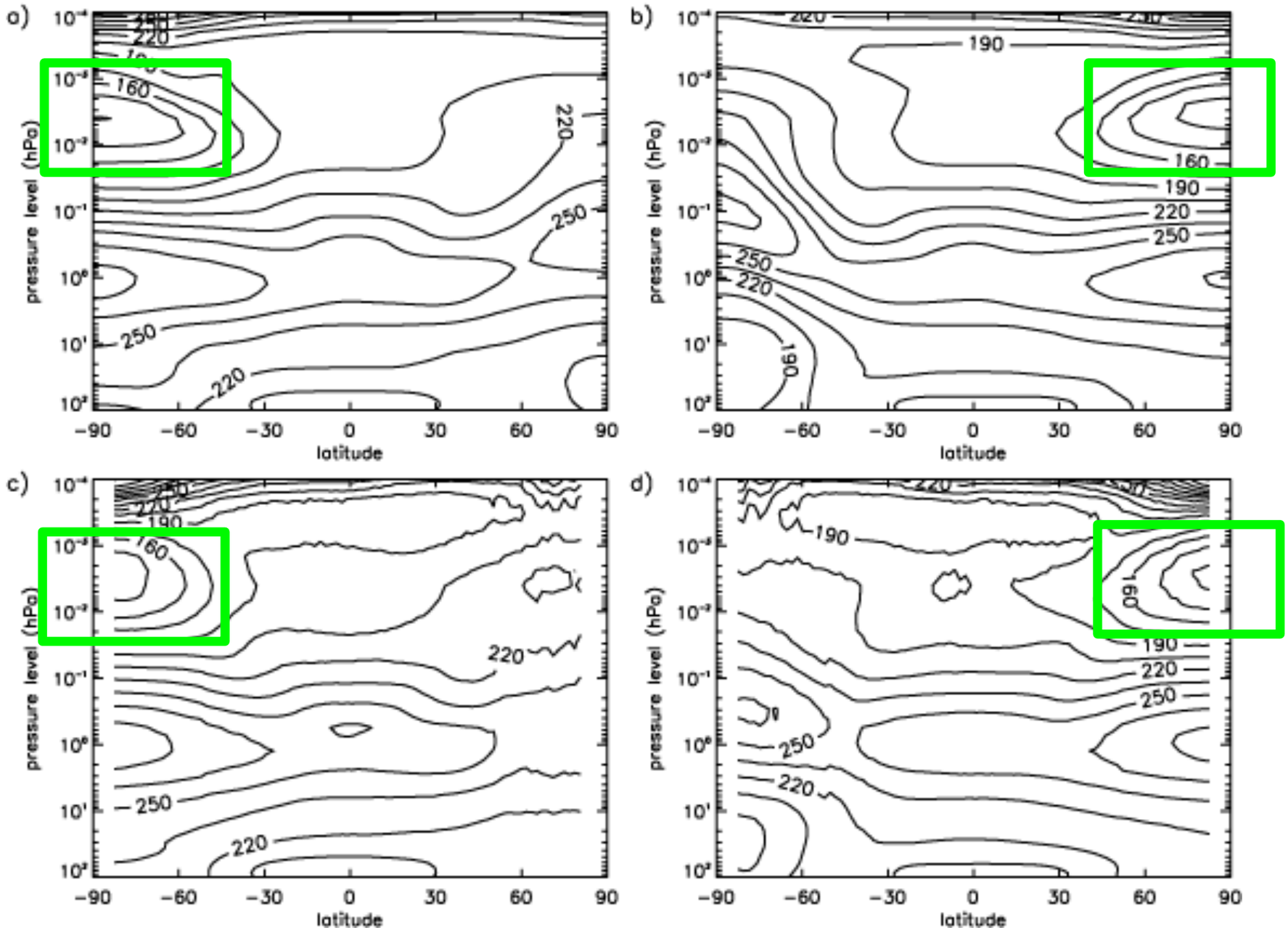


SABER

Zonal mean temperatures 2002-2005 vs SABER

January **July**

WACCM 2°



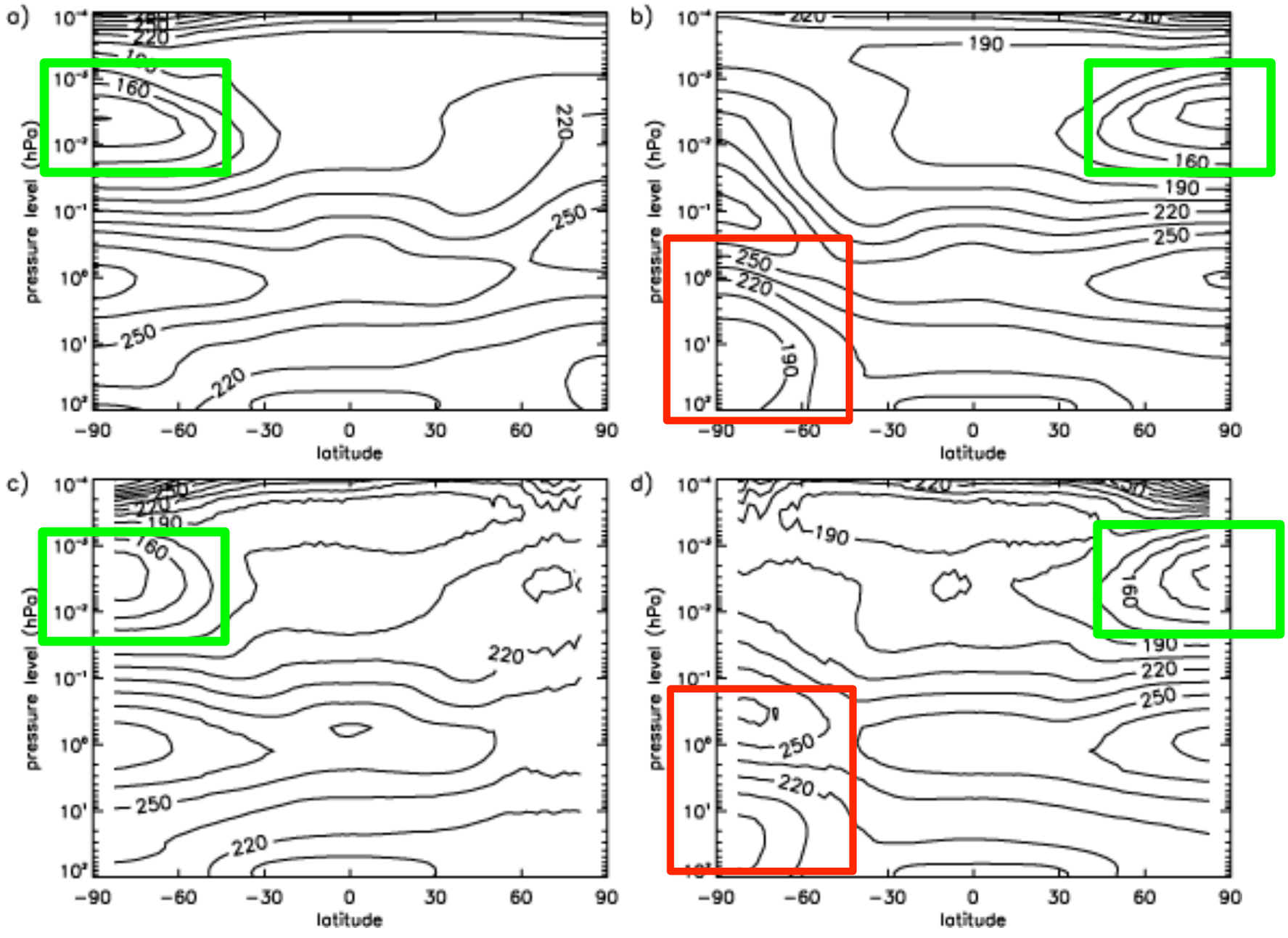
SABER

Zonal mean temperatures 2002-2005 vs SABER

January **July**

WACCM 2°

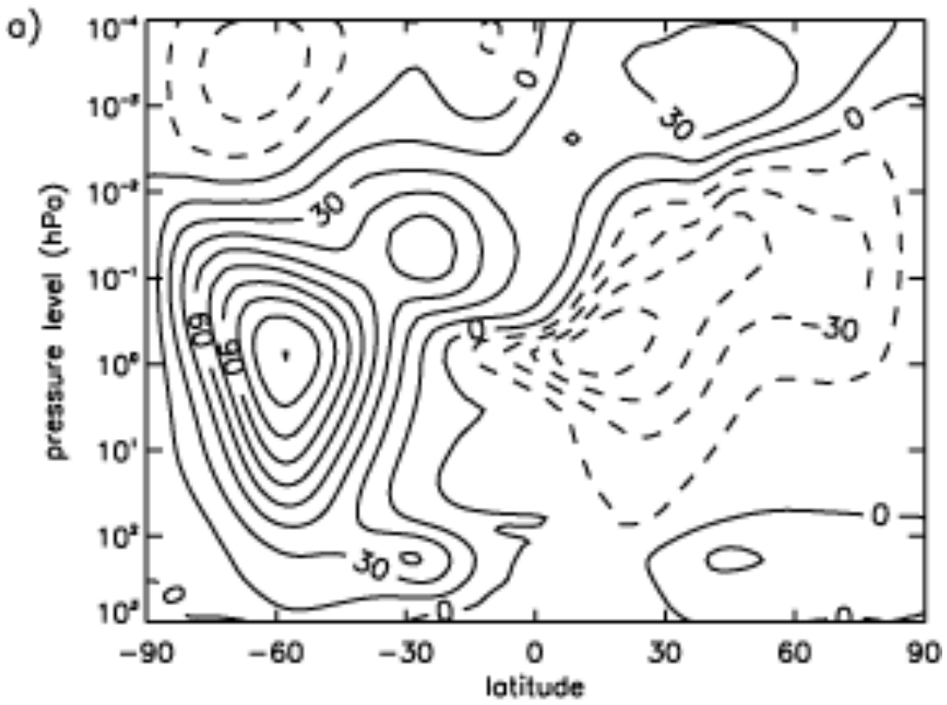
SABER



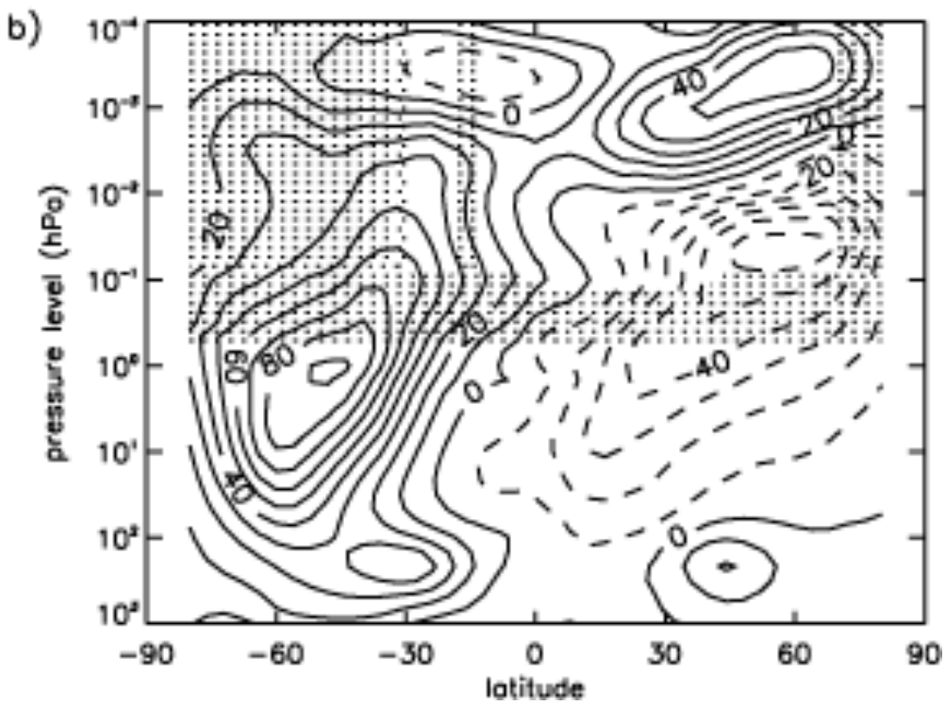
Zonal winds vs. URAP

July

WACCM 2°



URAP



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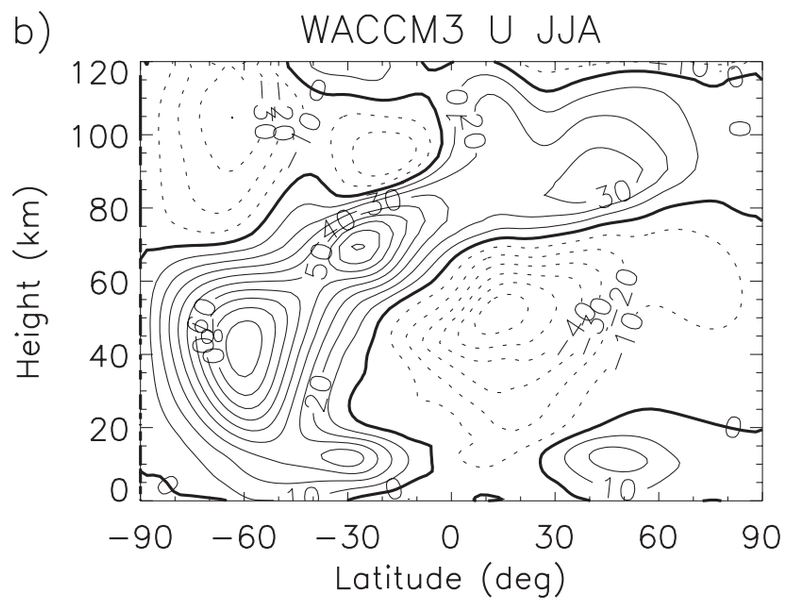
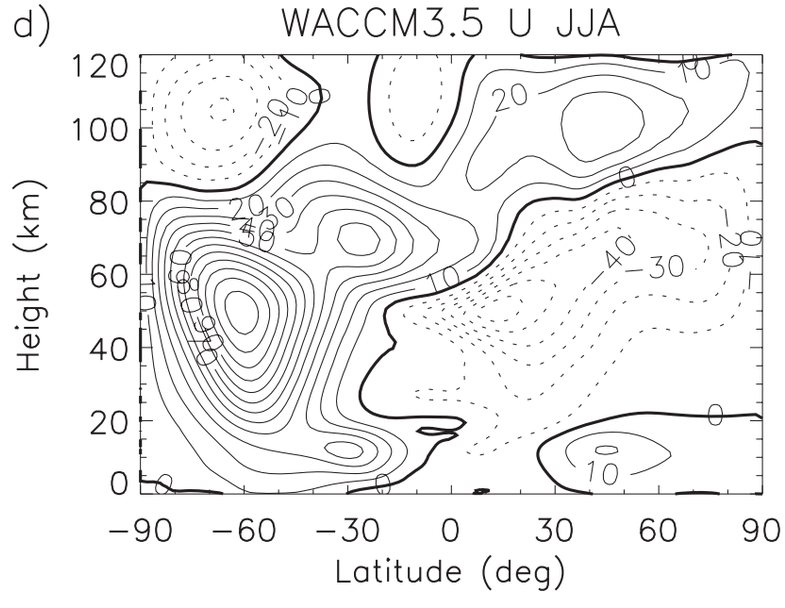




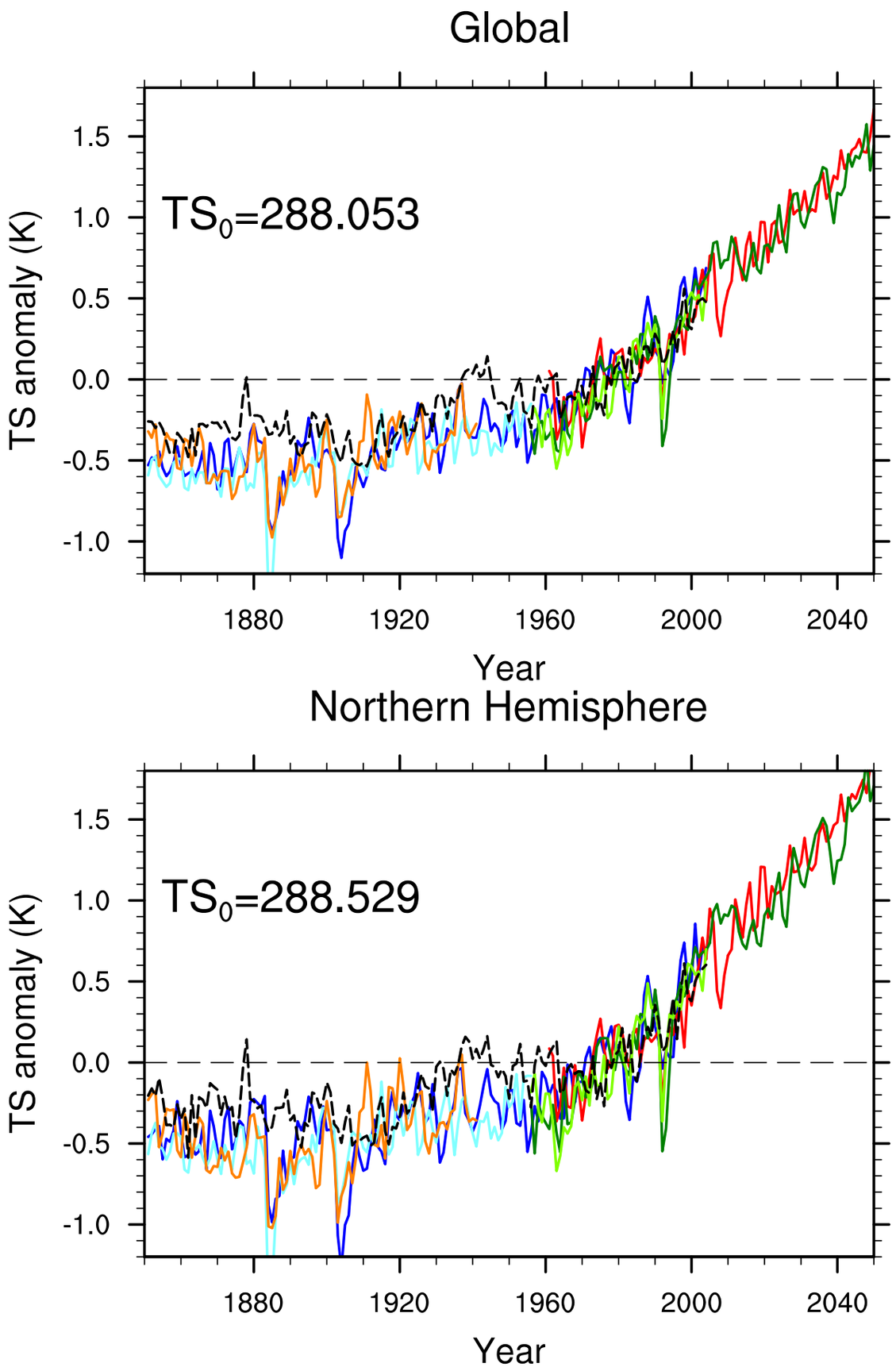
Sudden Stratospheric Warming Climatology

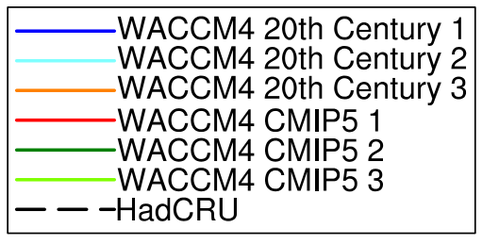
	1960-1970		1971-1981		1982-1992		1993-2003	
	minor	major	minor	major	minor	major	minor	major
ens1	17	5	14	7	19	6	19	4
ens2	17	4	17	3	19	9	16	2
ens3	14	9	15	9	18	4	23	3
mean/decade	14.5	5.5	13.9	5.8	17.0	5.8	17.6	2.7

ERA40 5-6 major warmings / decade

Completed CMIP-5 simulations

- Control
  - 1850 control (245 yrs)
- Historical
  - 3 realizations of “20th Century” run: 1850-2005 branched from control at yr 96
  - 3 simulations from 1960 - 2005 branched from 20C at year 1955
- RCPs
  - RCP4.5
    - 2x 2005 - 2050
    - 1x 2005 - 2100
  - RCP8.5: 1x 2005-2100


Global
TS anomaly (K)
TS$_0$=288.053
1.5
1.0
0.5
0.0
-0.5
-1.0
1880
1920
1960
2000
2040
Year


WACCM4 20th Century 1
WACCM4 20th Century 2
WACCM4 20th Century 3
WACCM4 CMIP5 1
WACCM4 CMIP5 2
WACCM4 CMIP5 3
HadCRU

Northern Hemisphere
TS anomaly (K)
TS$_0$=288.529
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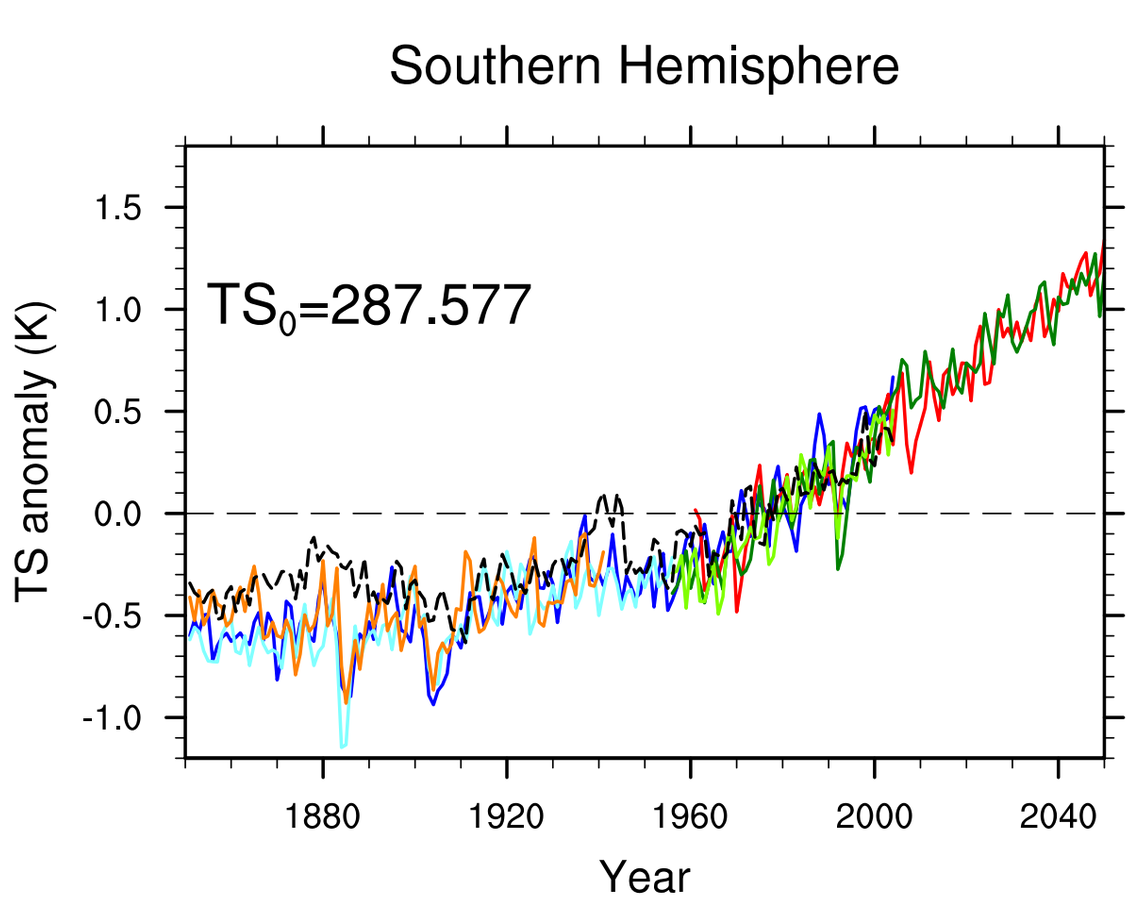
1.0
0.5
0.0
-0.5
-1.0
1880
1920
1960
2000
2040
Year


Southern Hemisphere
TS anomaly (K)
TS$_0$=287.577
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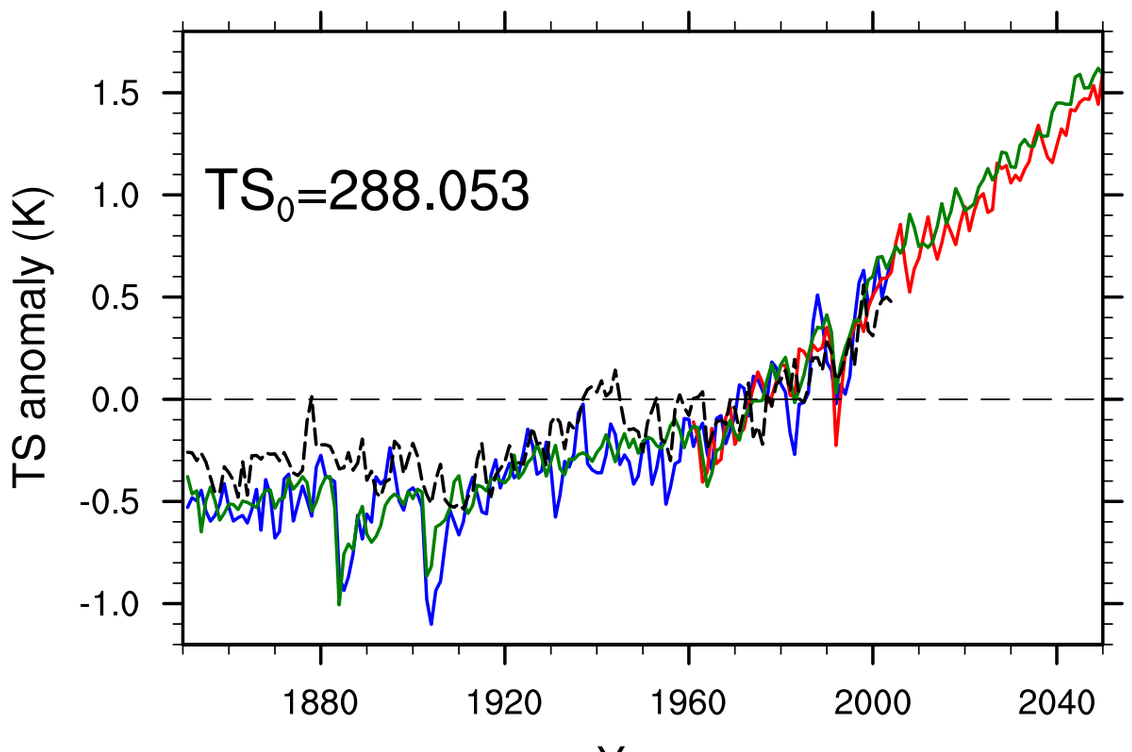
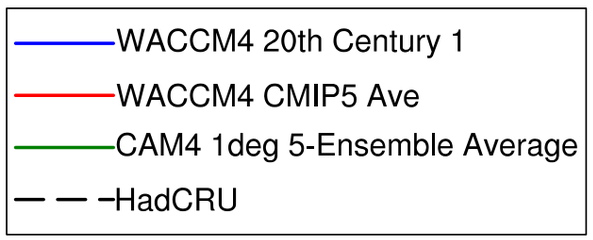
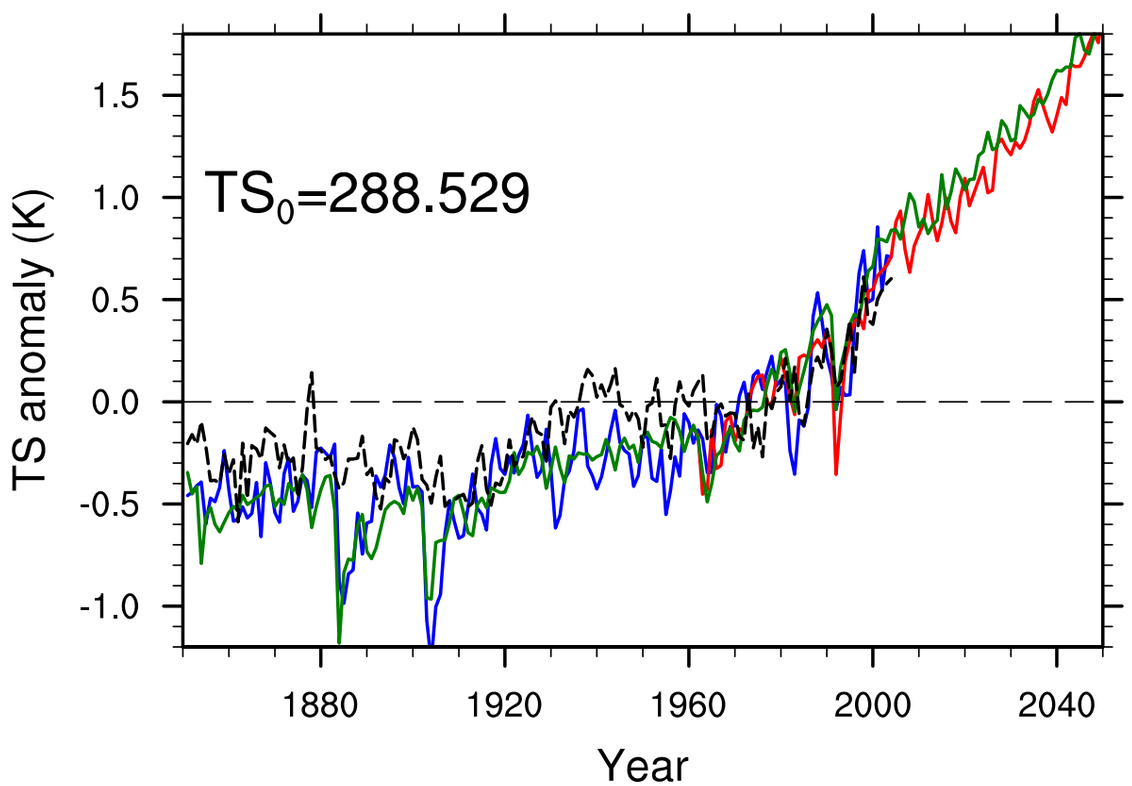
1.0
0.5
0.0
-0.5
-1.0
1880
1920
1960
2000
2040
Year

Global

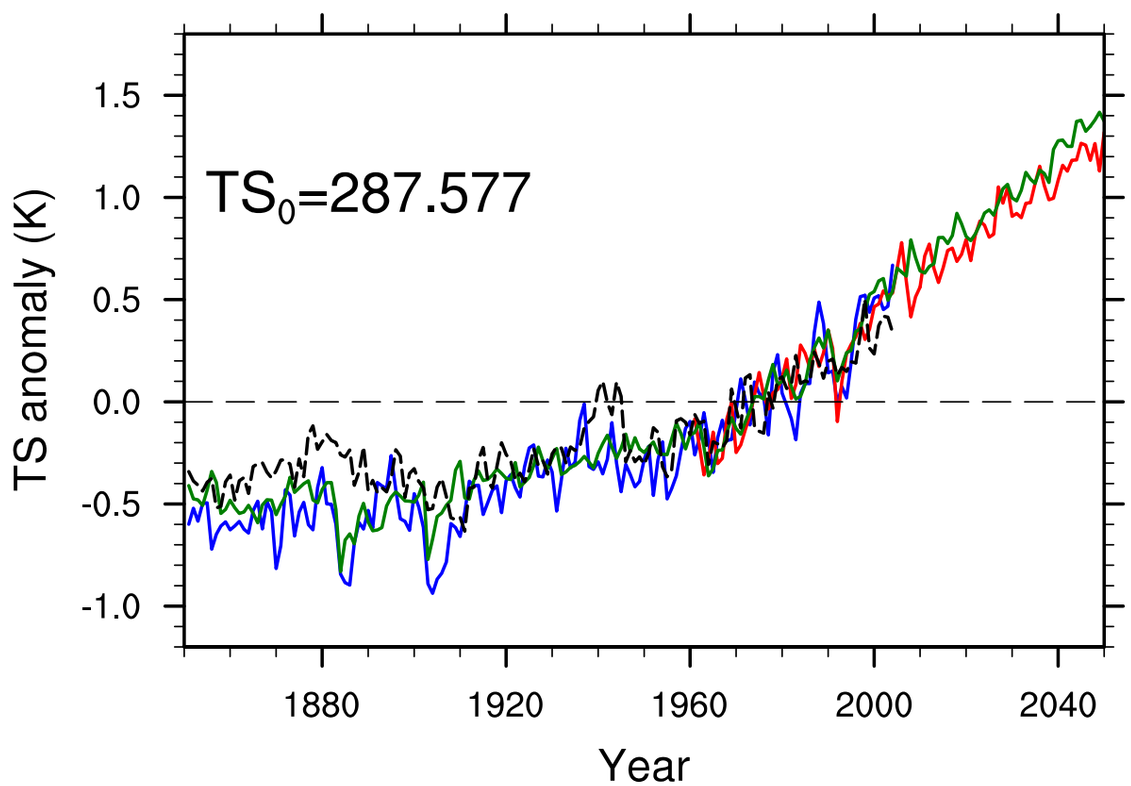




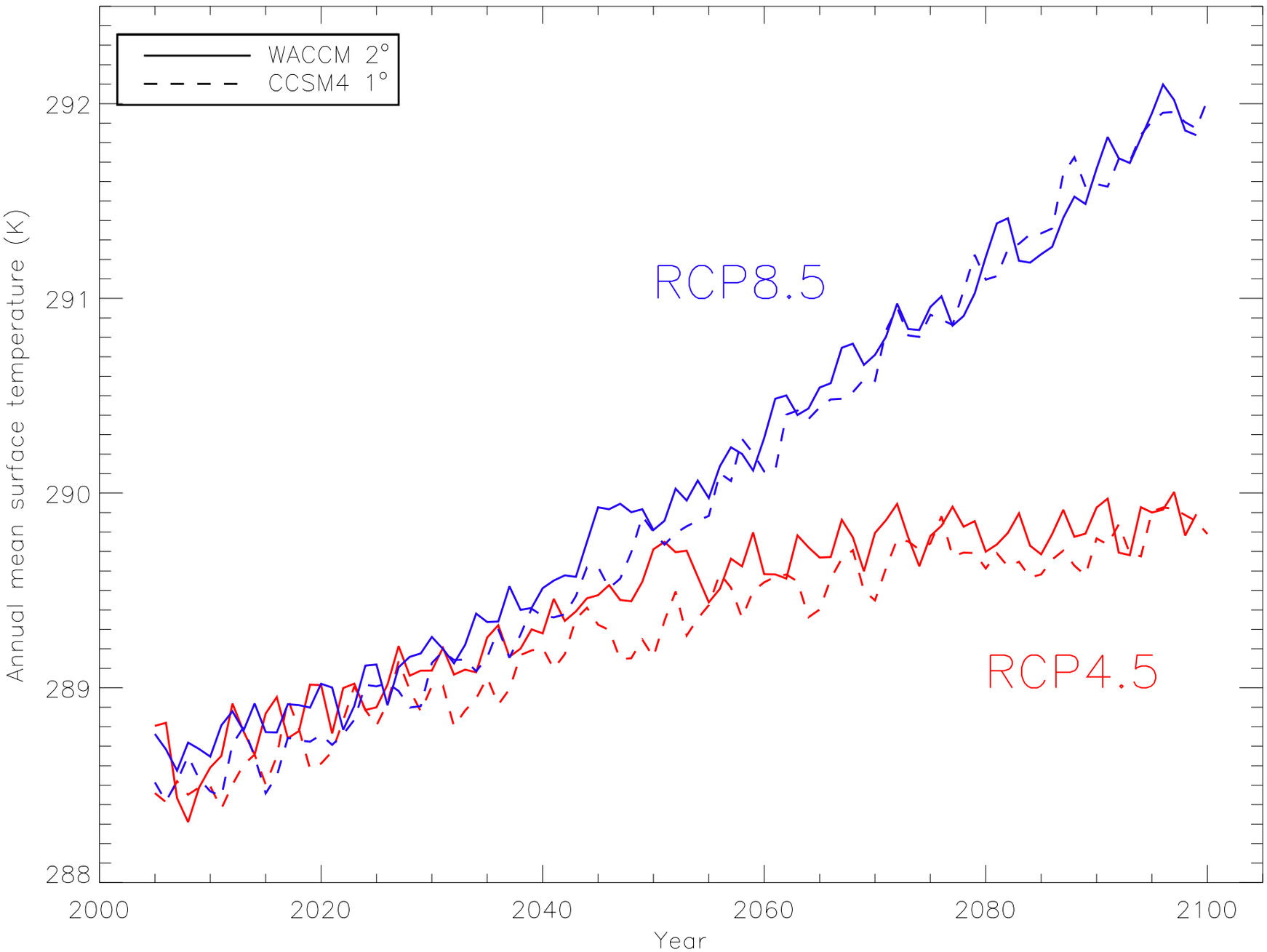
Northern Hemisphere



Southern Hemisphere



Annual mean surface temperature RCP4.5 & 8.5



RCP4.5 2080-2098

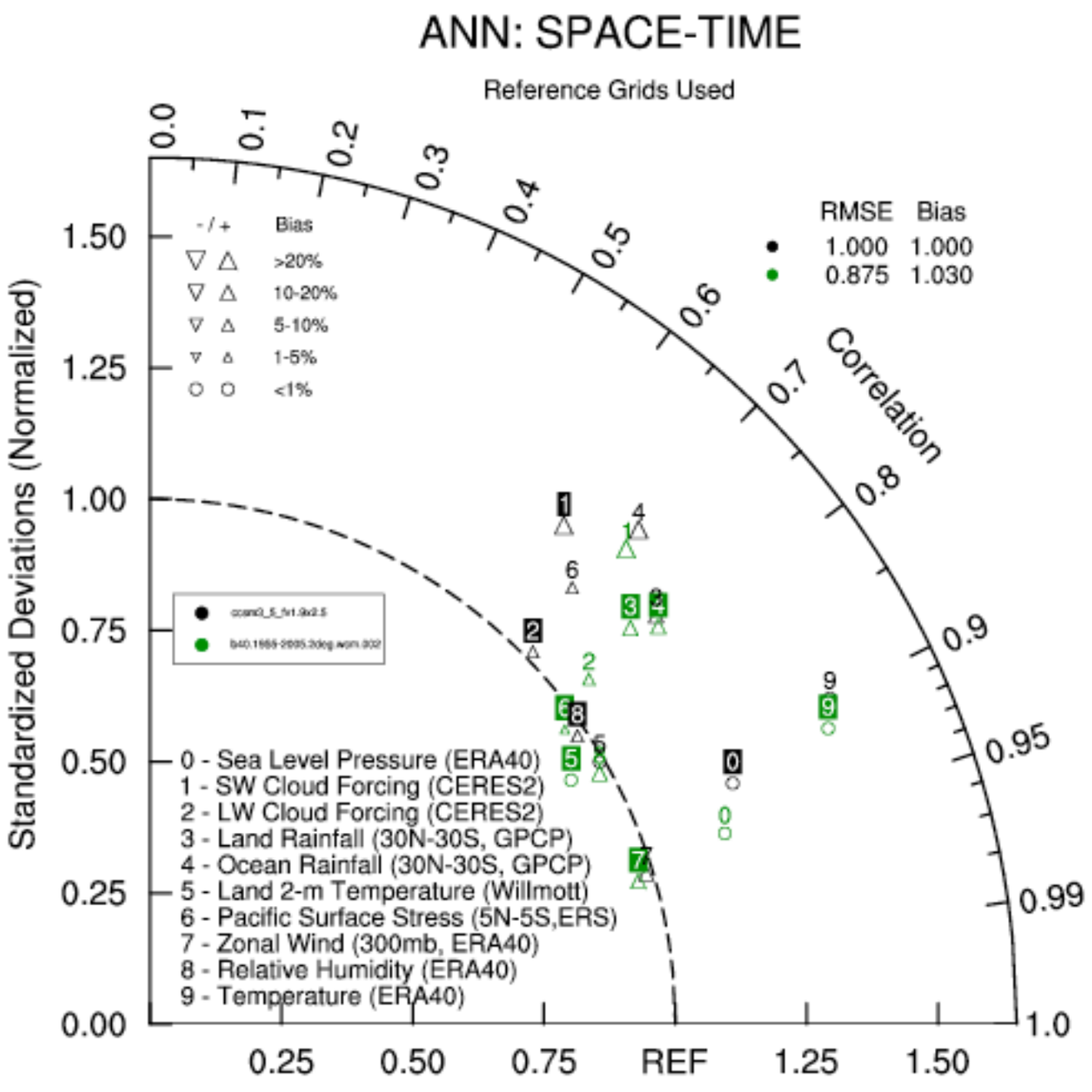
TOA imbalance:

WACCM: 0.904 W/m2
CCSM4: 0.915 W/m2

Global TS:

WACCM: 289.83 K
CCSM4: 289.76 K

1986-2005: Taylor diagram



CAM3.5 - 2°
Bias = 1.0
RMSE = 1.0

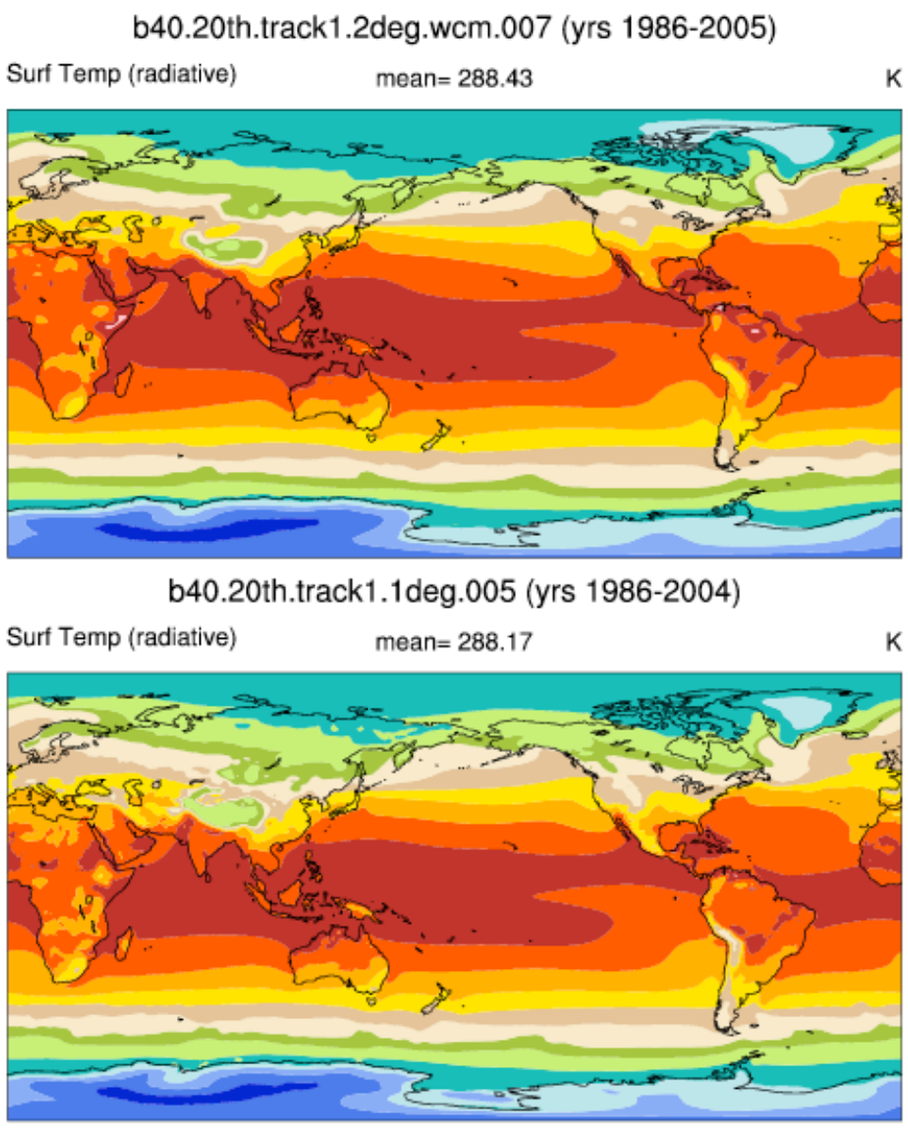
CCSM4 - 1°
Bias = 0.88
RMSE = 0.88

WACCM - 2°
Bias = 1.03
RMSE = 0.88

CAM5 - 2°
Bias = 1.09
RMSE = 0.86

CAM5.1 - 1°
Bias = 1.14
RMSE = 0.77

Late 20th Century: surface temperature vs. CCSM4



WACCM - 2°

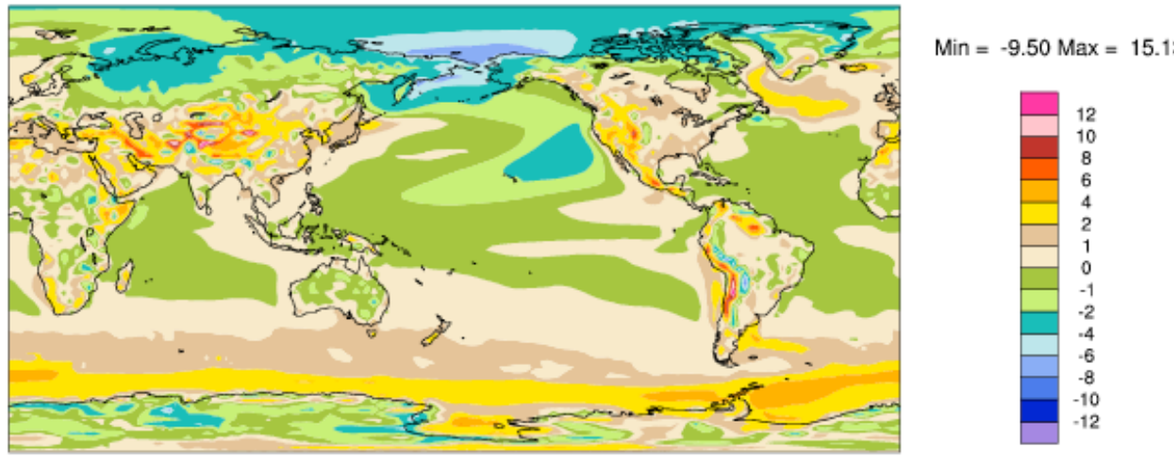
mean = 288.43

CCSM4 - 1°

mean = 288.17

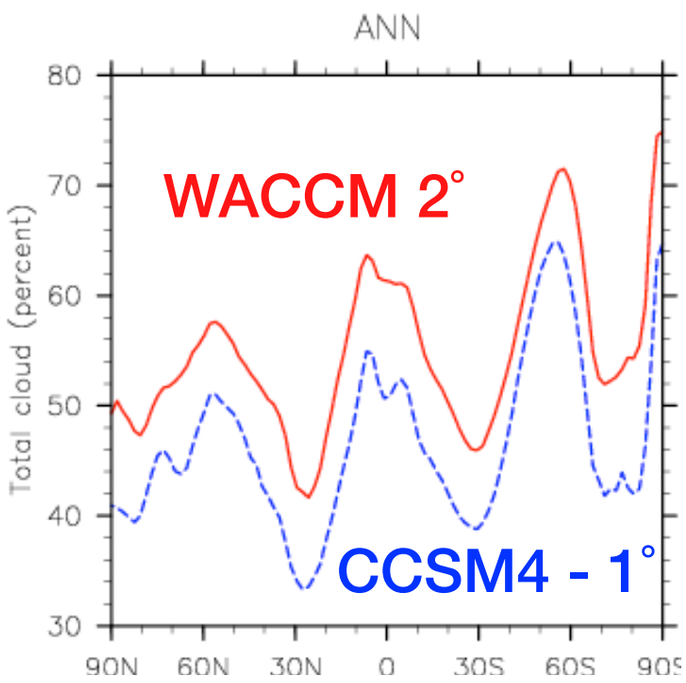
Diff. = 0.26

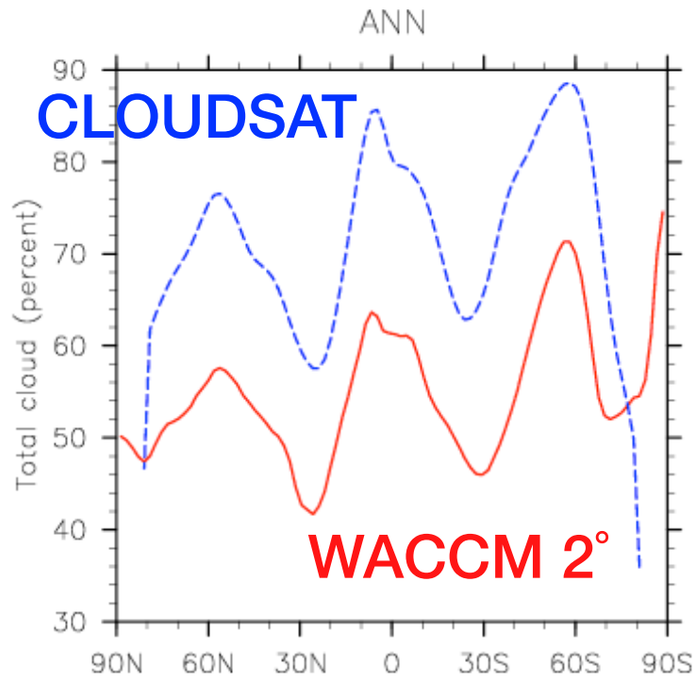
RMSE = 1.68

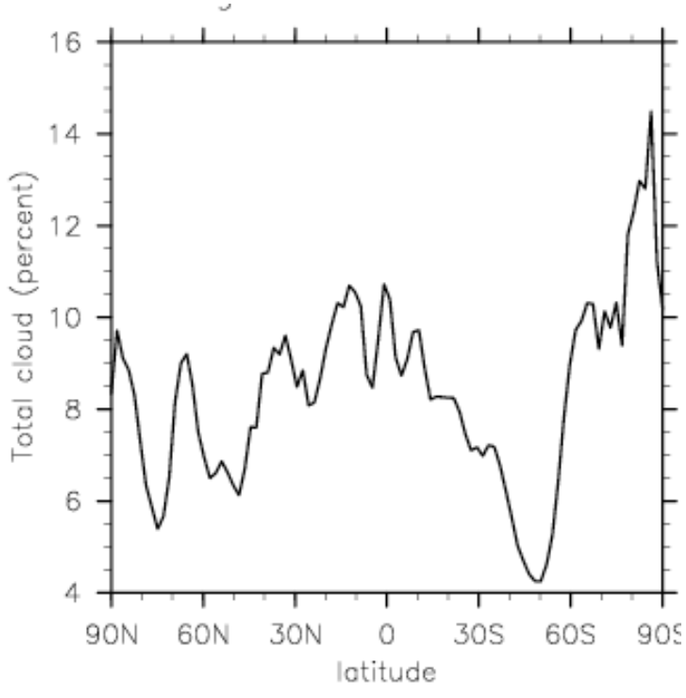


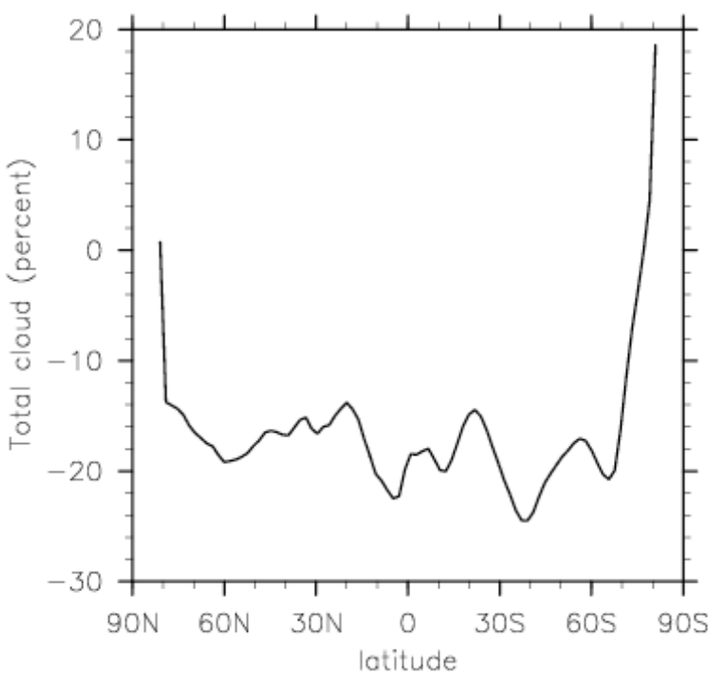
1850 Control: total cloud

Modifying ice fall velocity to get stratospheric water vapor close to that observed leads to an increase in total cloud relative to CCSM4.





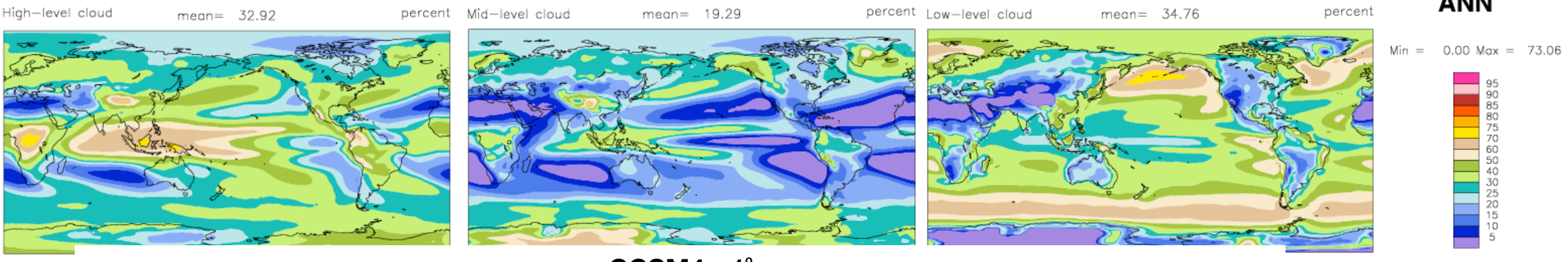




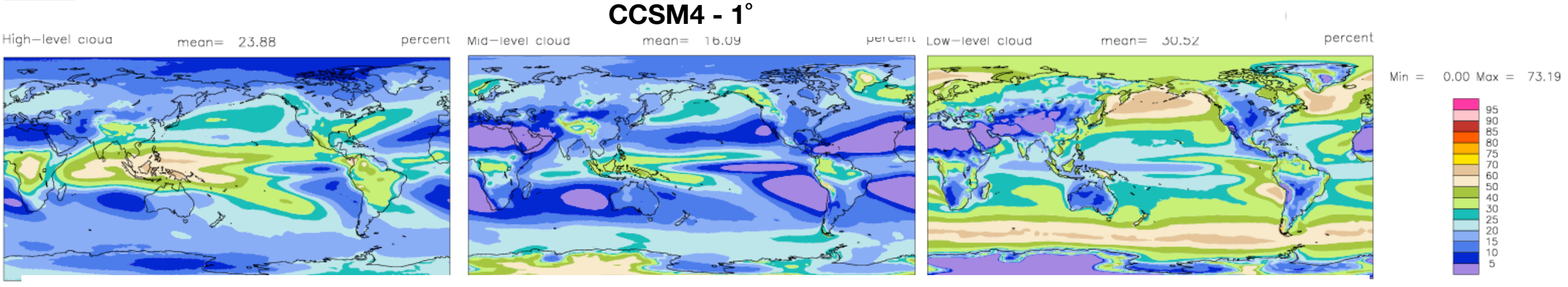
1850 Control: Cloud fraction

CLDHGH	32.9	23.9	+9%
CLDMED	19.3	16.1	+4%
CLDLOW	34.8	30.5	+3%

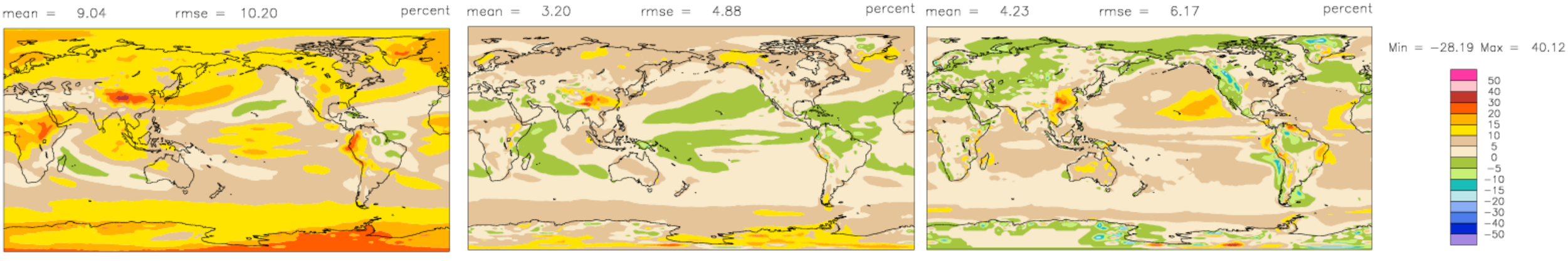
WACCM - 2°



CCSM4 - 1°

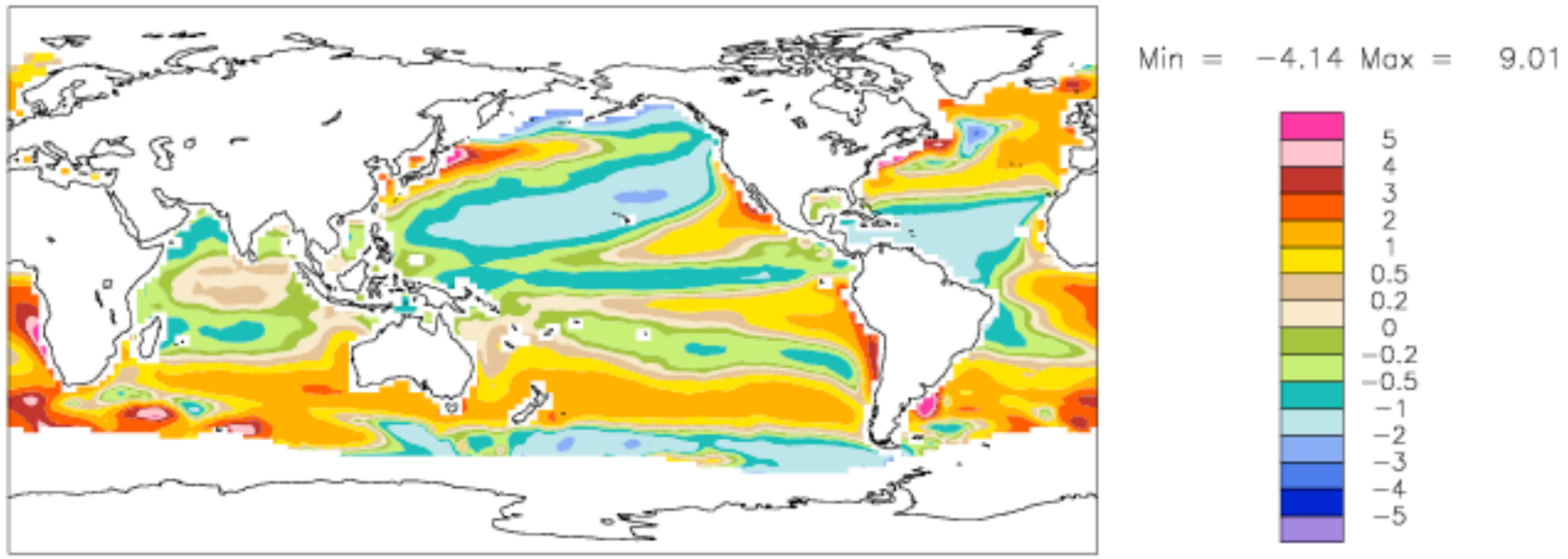


WACCM - CAM4

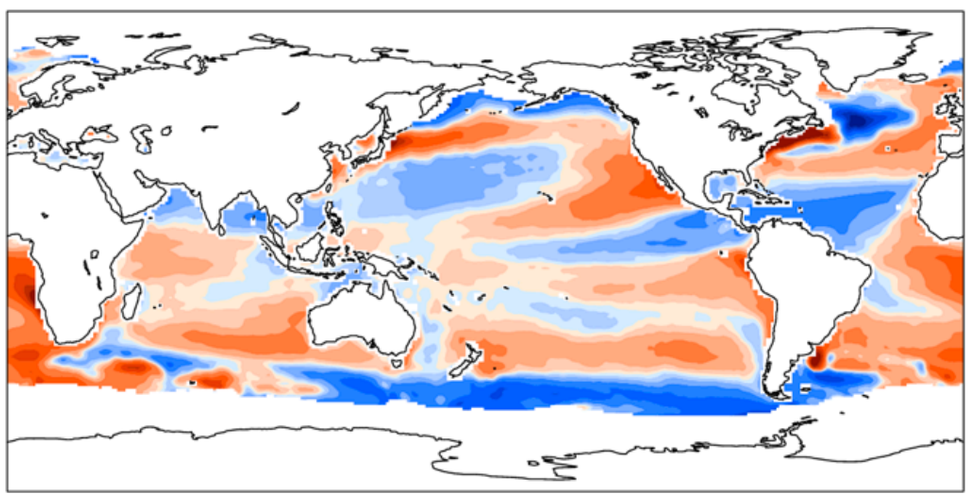


1850 control: SSTs vs. 1870-1900 obs.

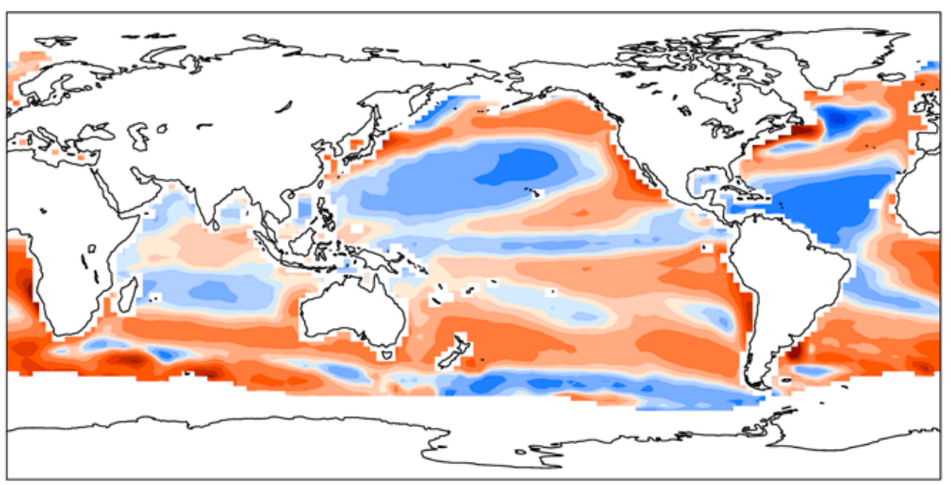
CESM-WACCM - 2° **Mean = 0.25 RMSE = 1.23**



CCSM4 - 1° **Mean = 0.18 RMSE = 1.07**



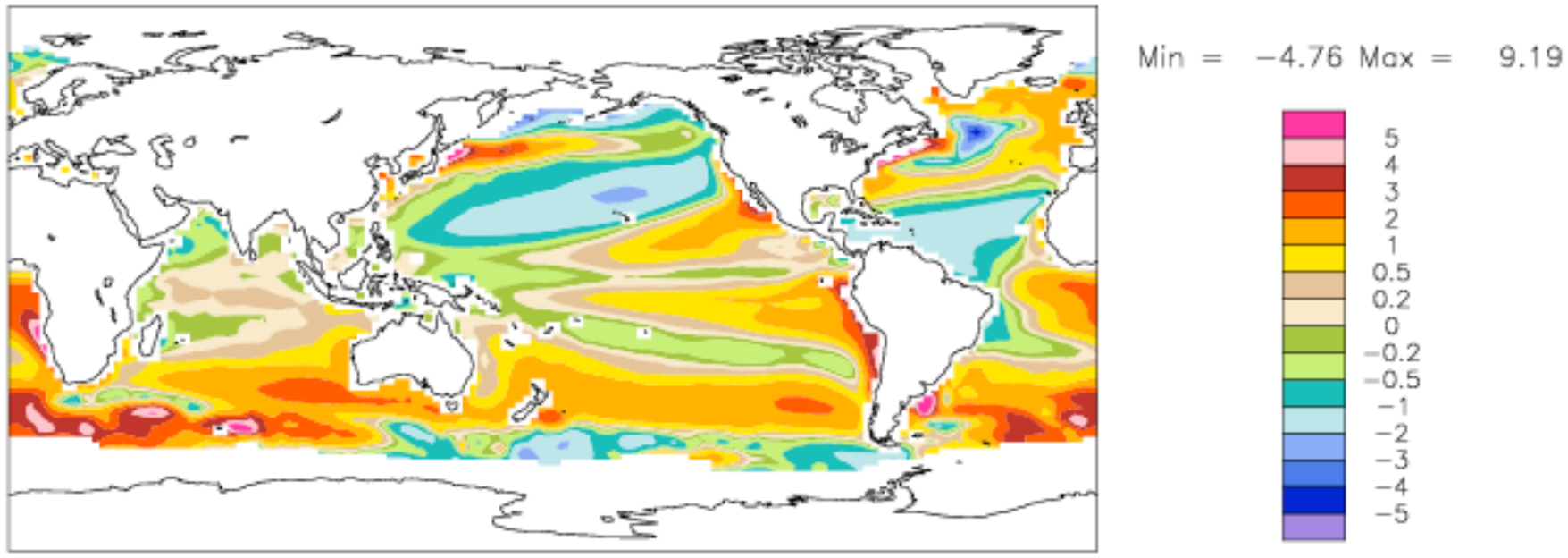
CAM5 - 2° **Mean = 0.43 RMSE = 1.17**



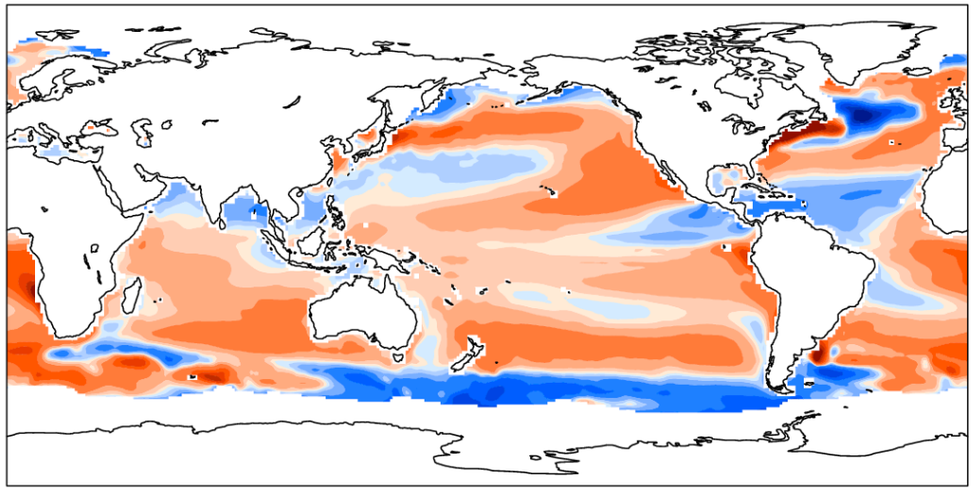
CAM courtesy Cécile Hannay

Late 20th Century: SSTs vs. present day obs.

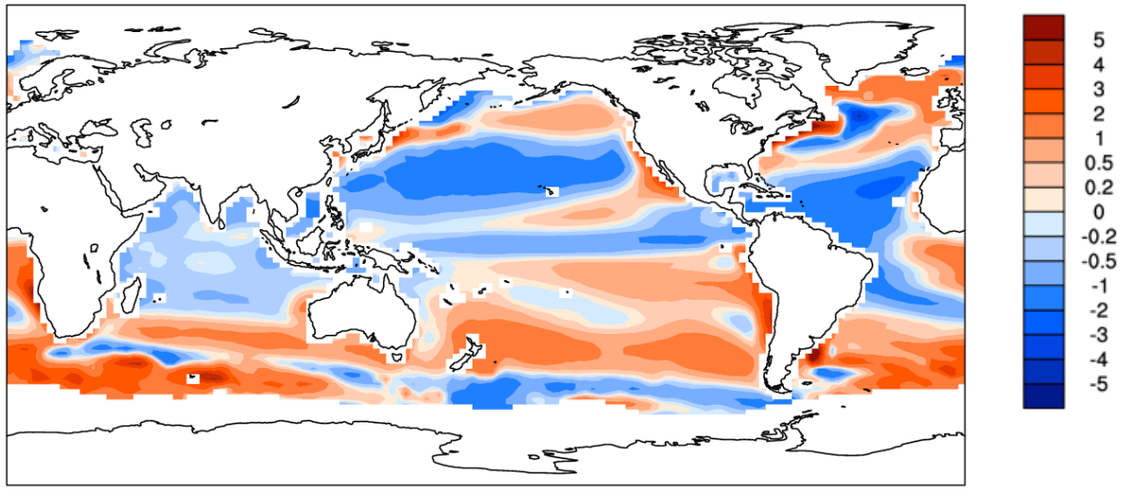
CESM-WACCM - 2° **Mean = 0.45 RMSE = 1.30**



CCSM4 - 1° **Mean = 0.18 RMSE = 1.07**



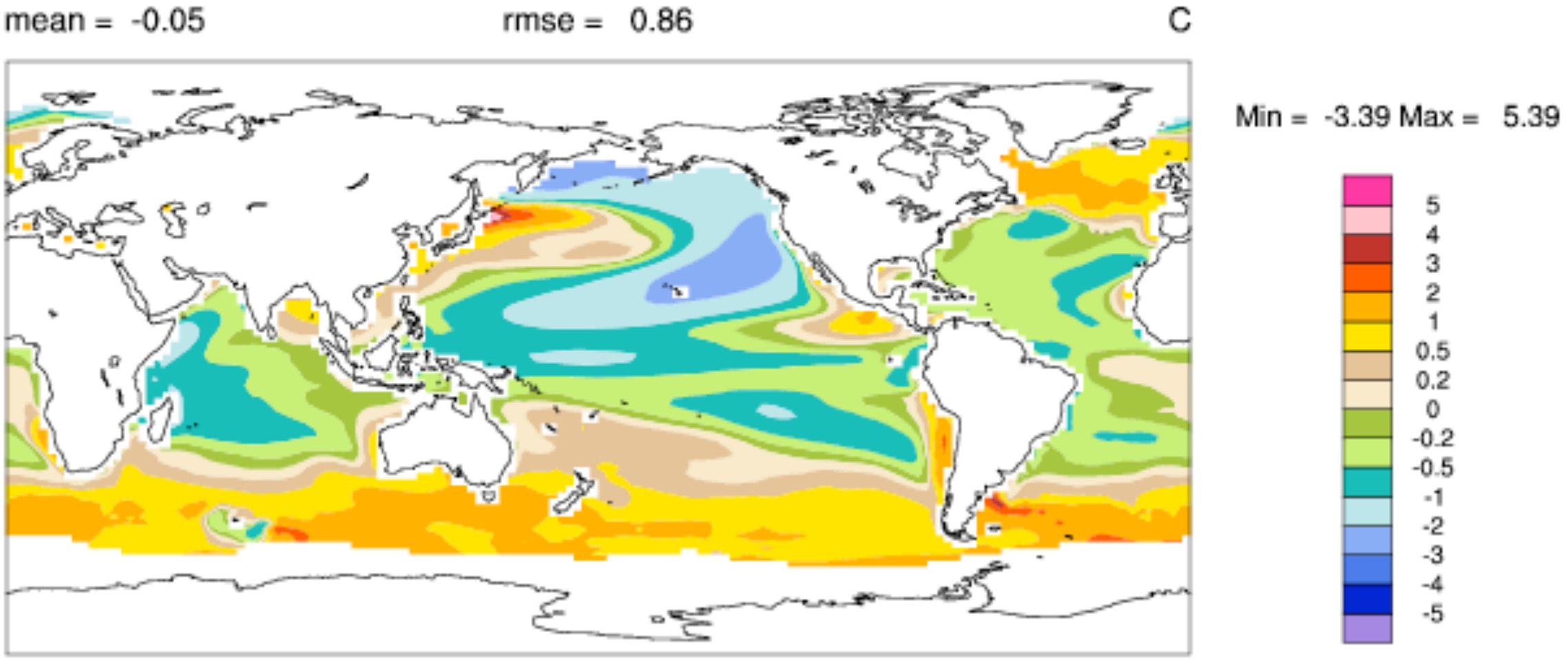
CAM5 - 2° **Mean = 0.42 RMSE = 1.17**



CAM courtesy Cécile Hannay

SST differences RCP4.5 yrs 2080-2098

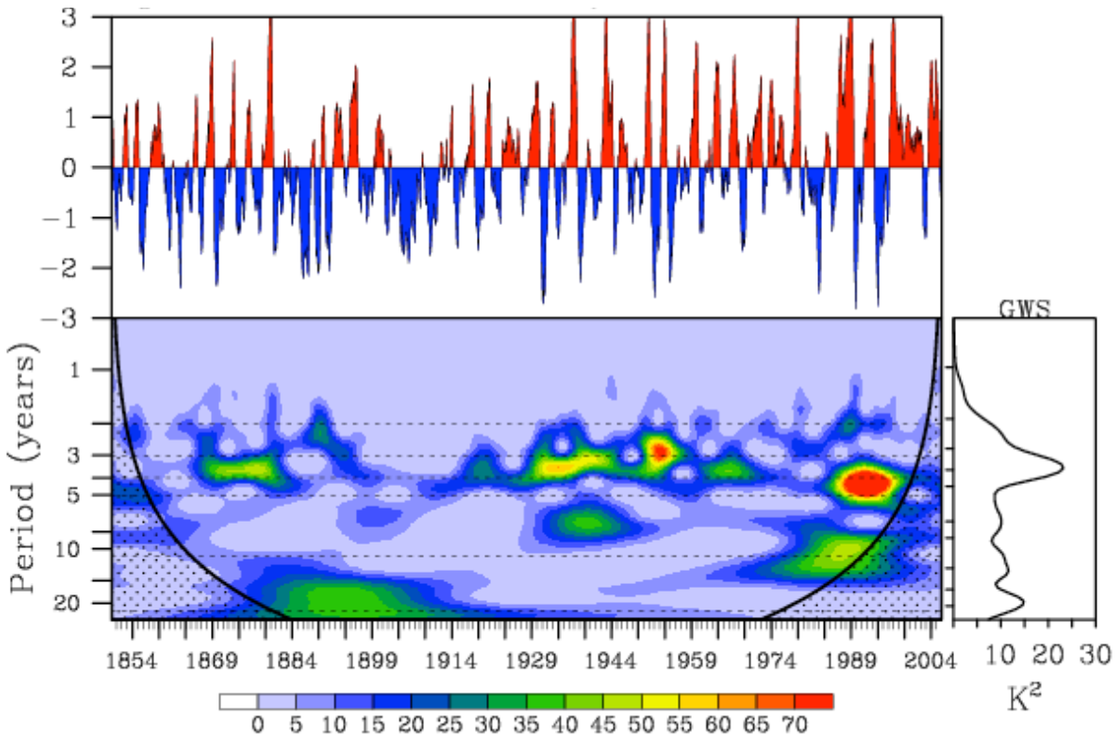
WACCM4 2° - CCSM4 - 1°

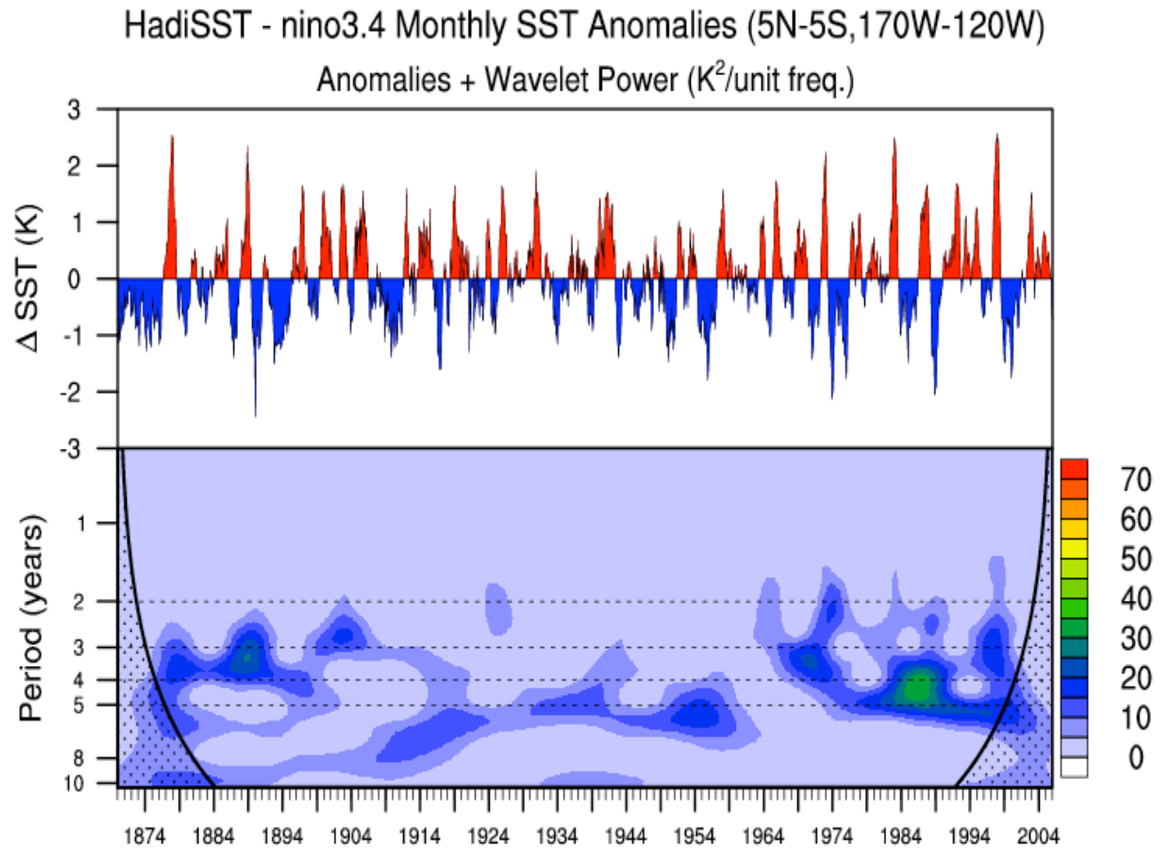


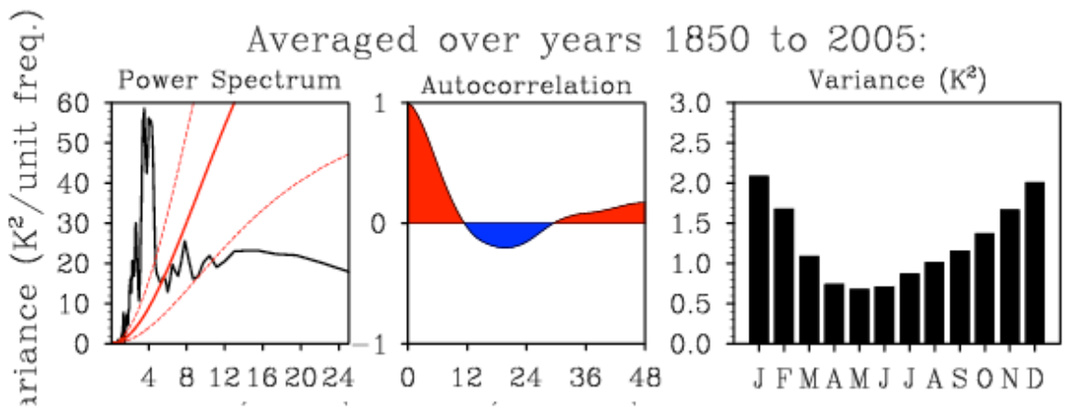
Less of an SST trend in WACCM?

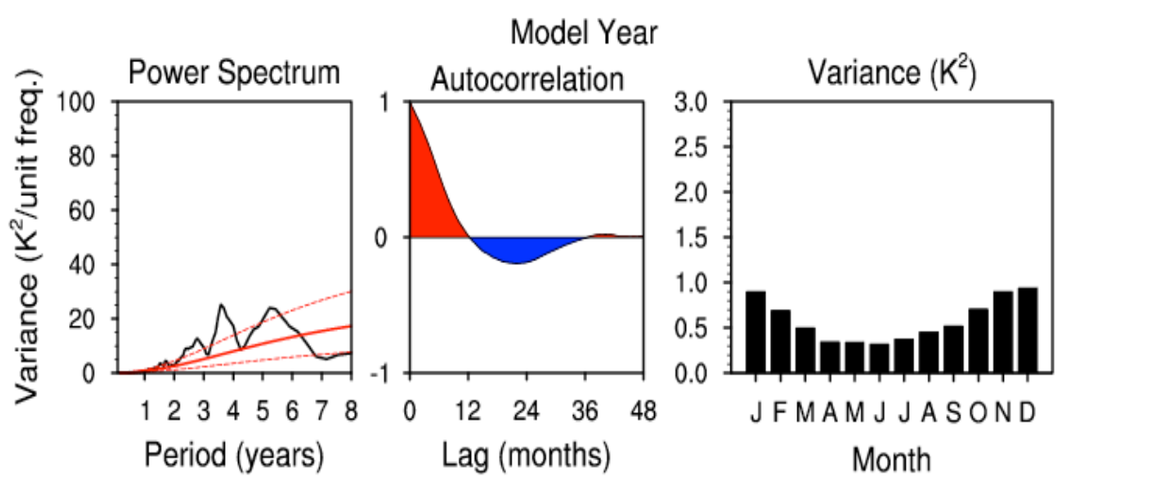
ENSO: WACCM4 n3.4 timeseries

WACCM 1850-2005



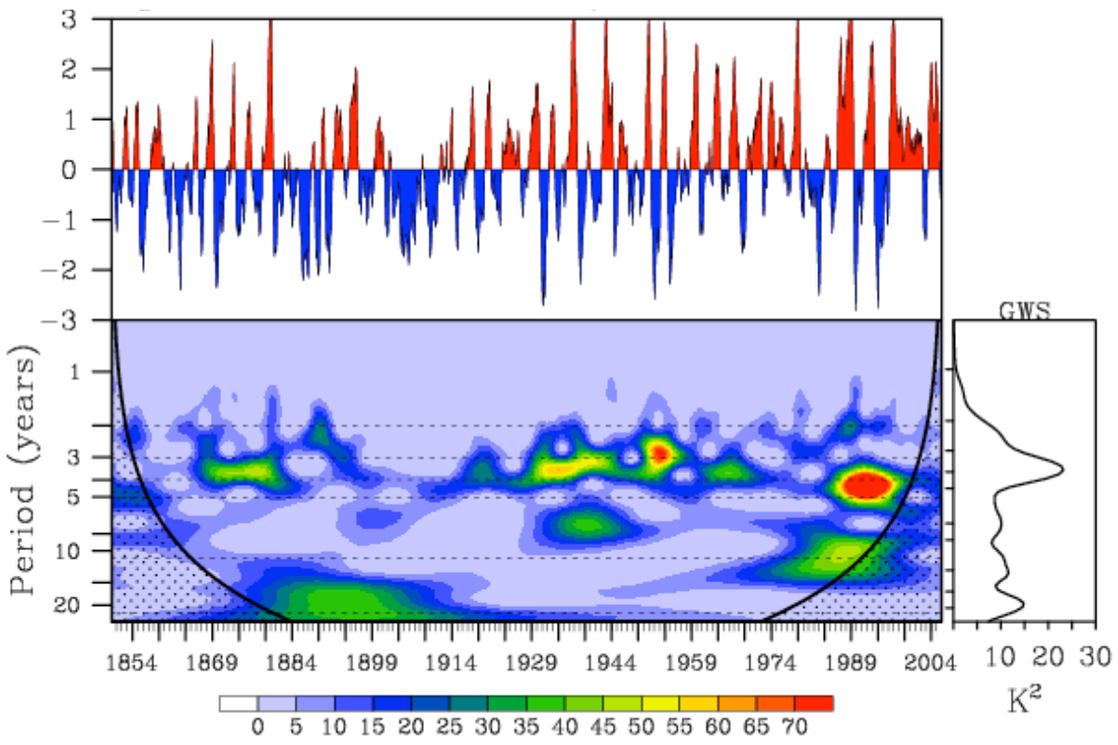




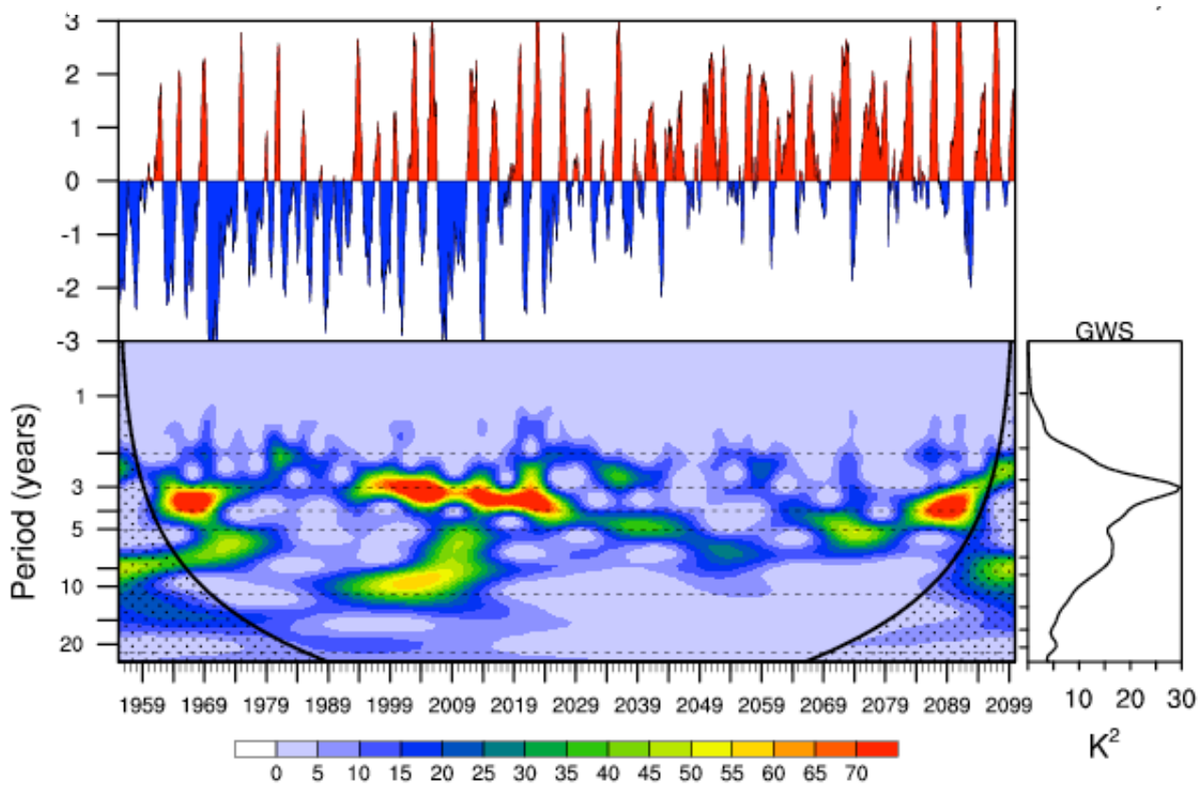


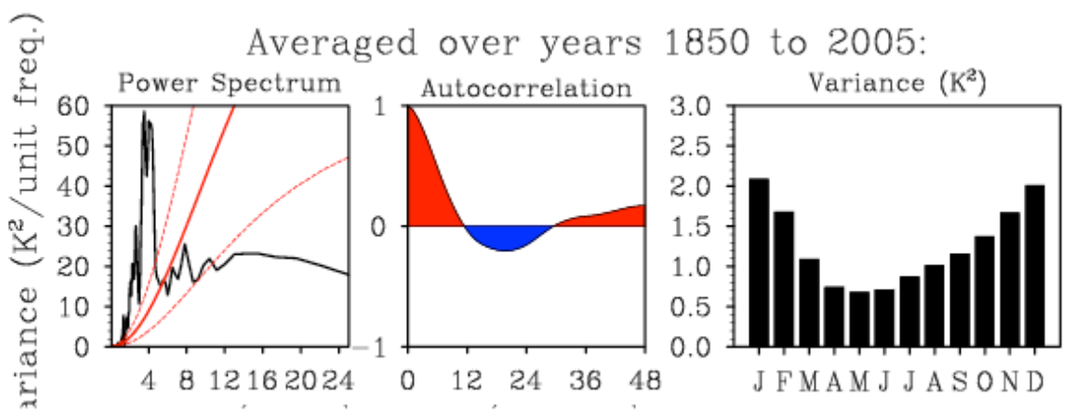
ENSO: WACCM4 n3.4 timeseries

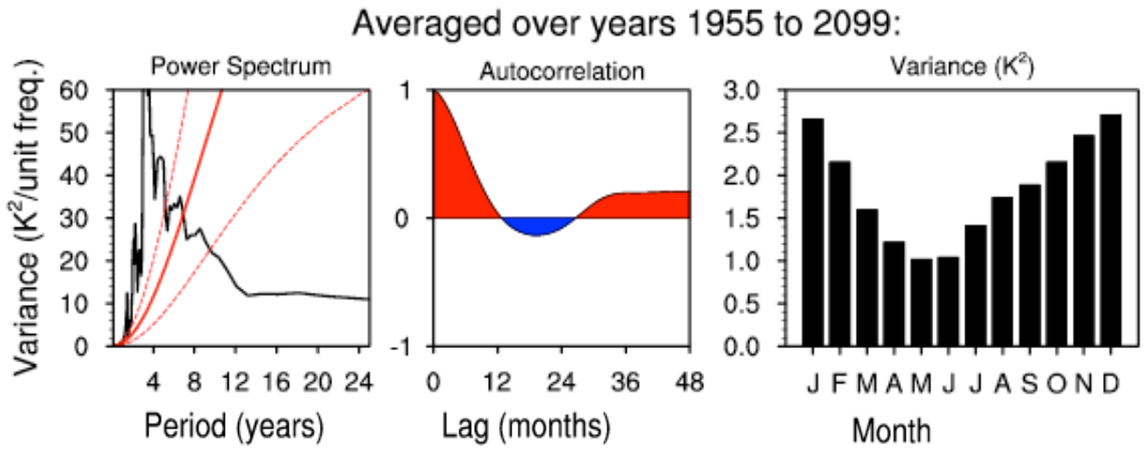
WACCM 1850-2005



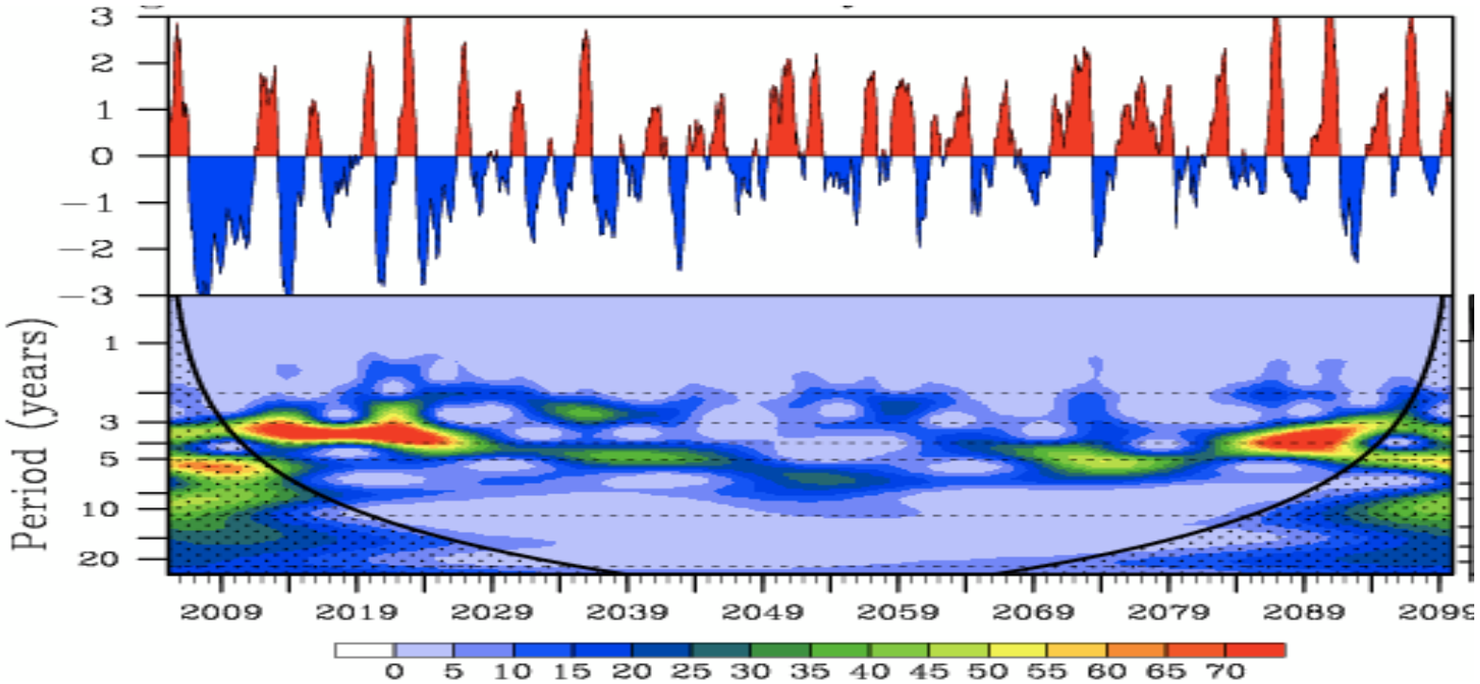
1955-2099

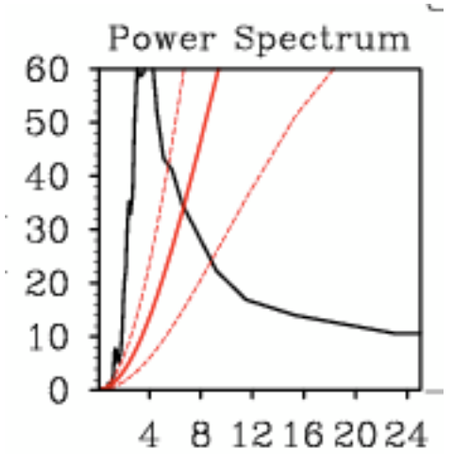


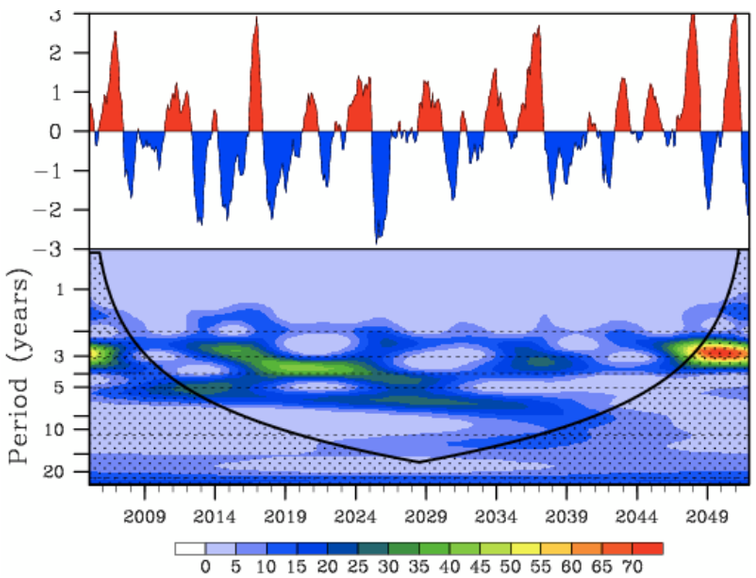


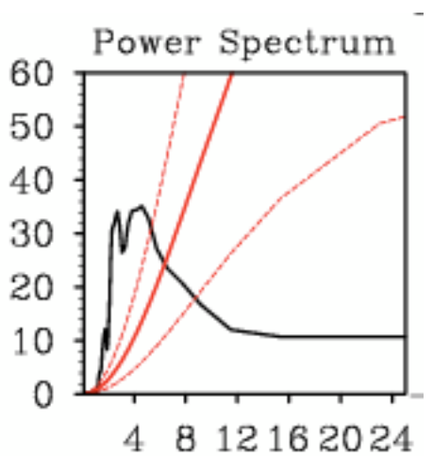


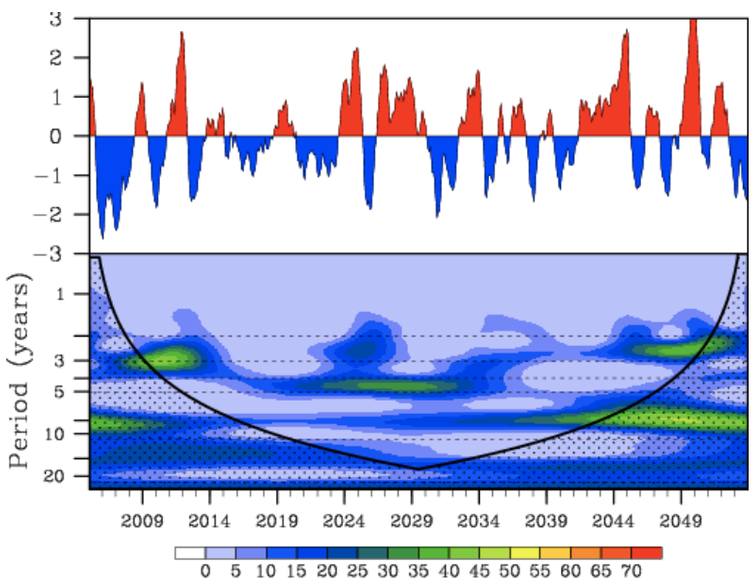
ENSO: n3.4 WACCM RCP4.5

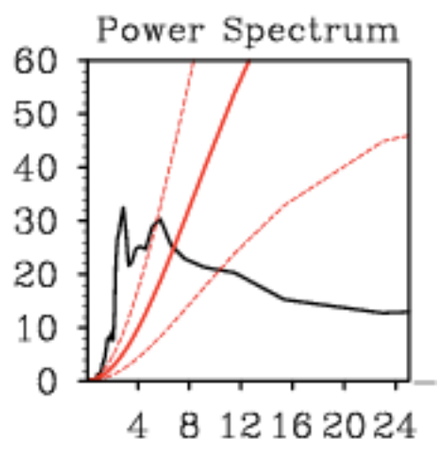




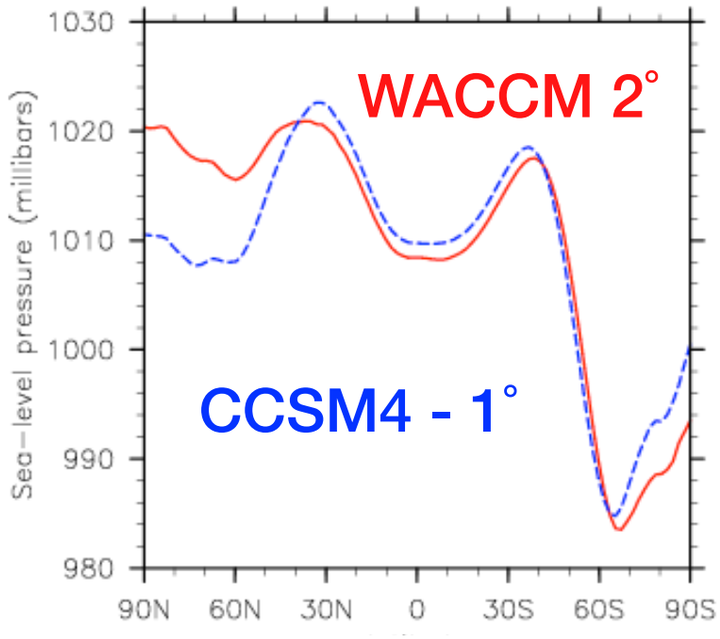


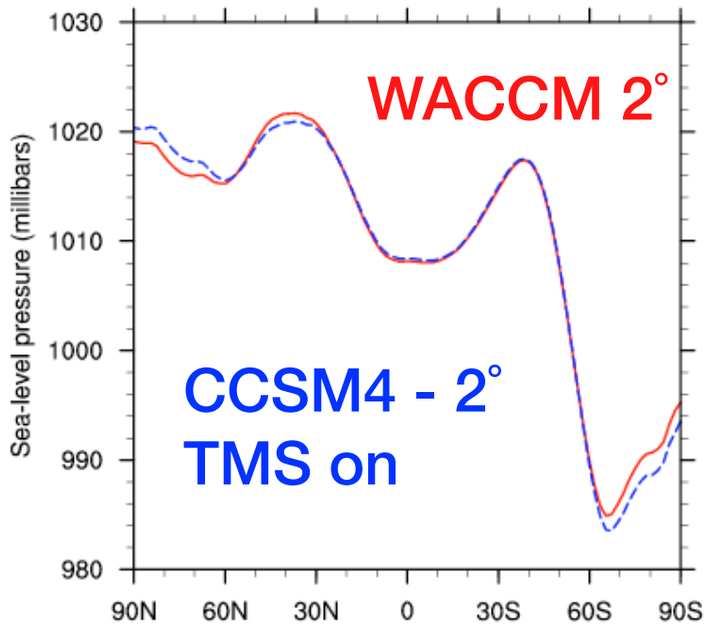


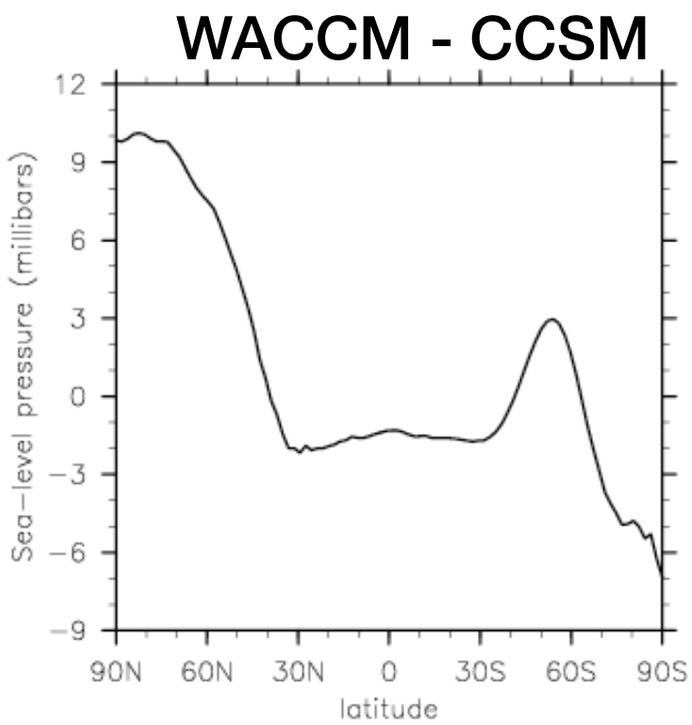


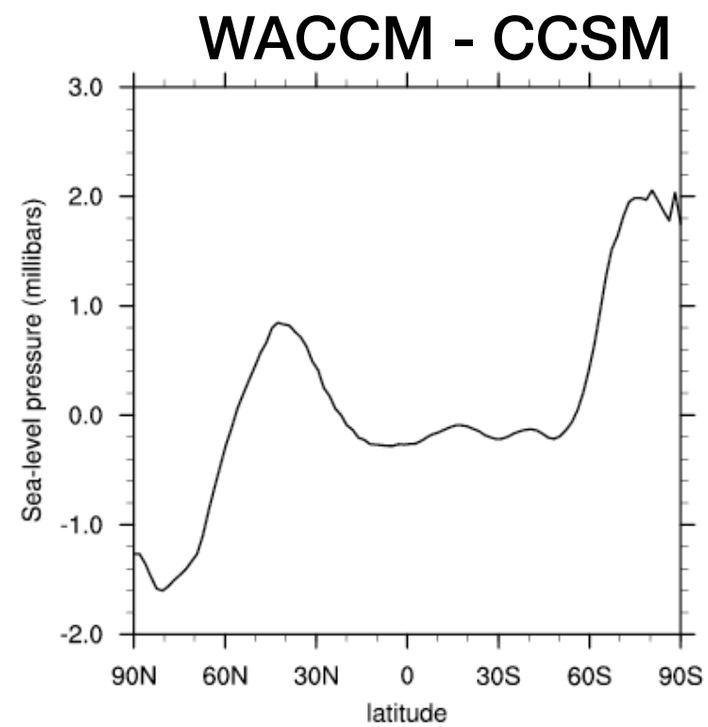


1850 Control DJF SLP - the downside of TMS



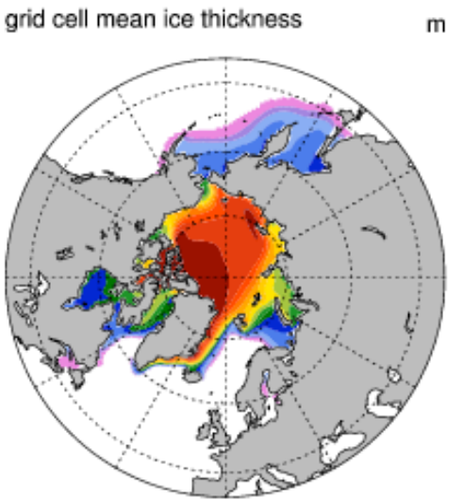




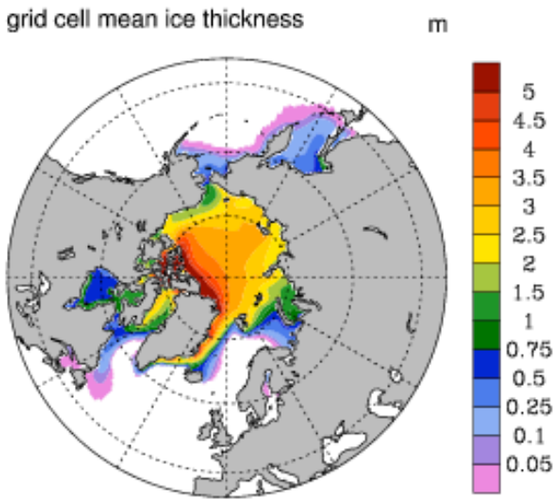


1850 control: Annual mean sea ice thickness

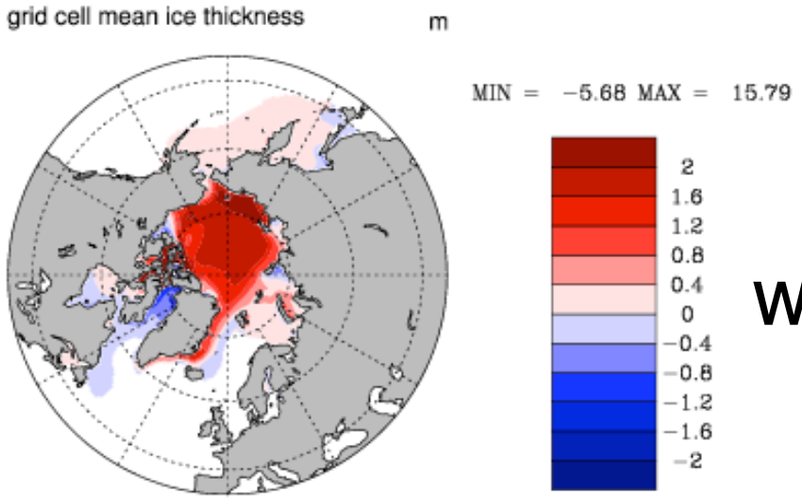
WACCM



CCSM4 1°

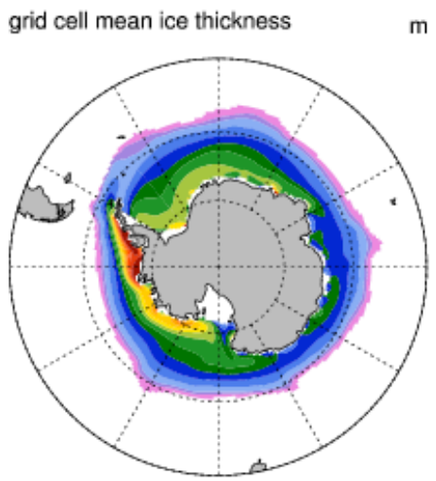


b40.1850.track1.2deg.wcm.007 - b40.1850.track1.1deg.006

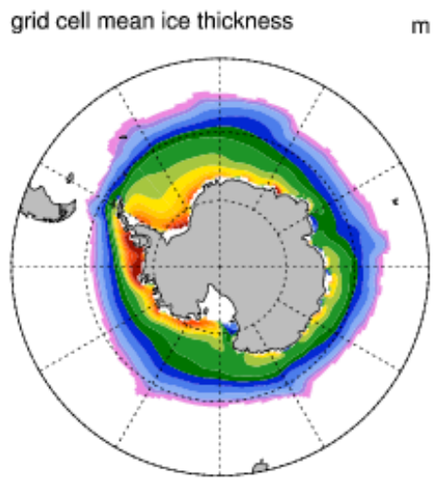


WACCM - CCSM

WACCM



CCSM4 1°



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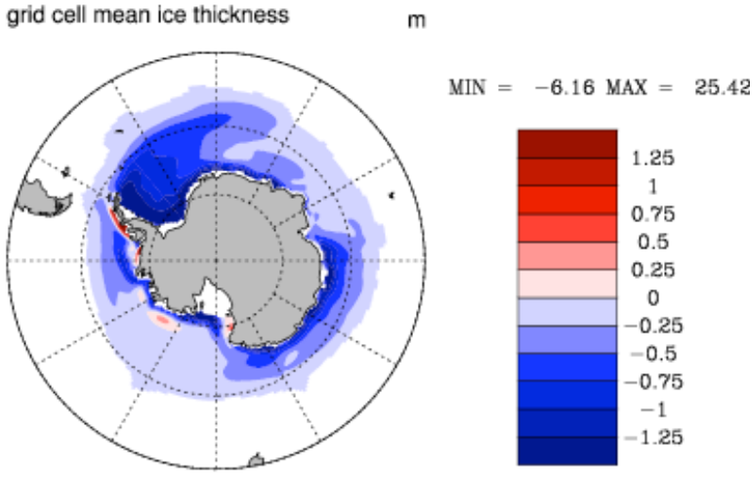
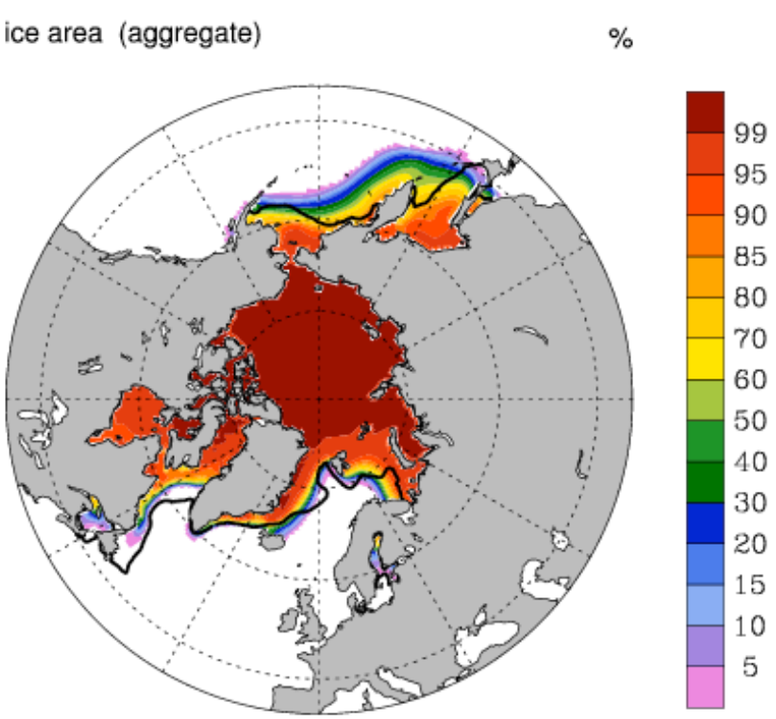
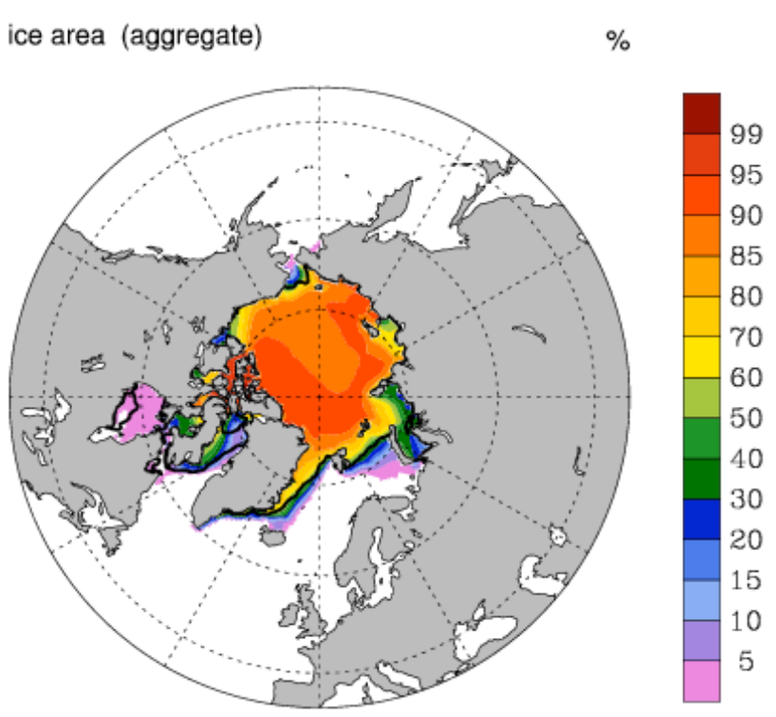


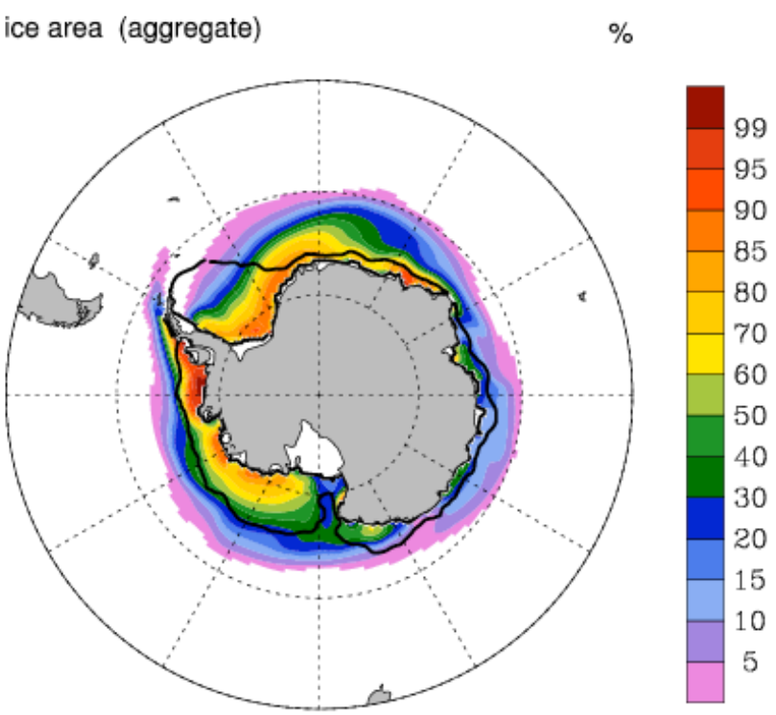
WACCM Ice Area (%) 1986-2005

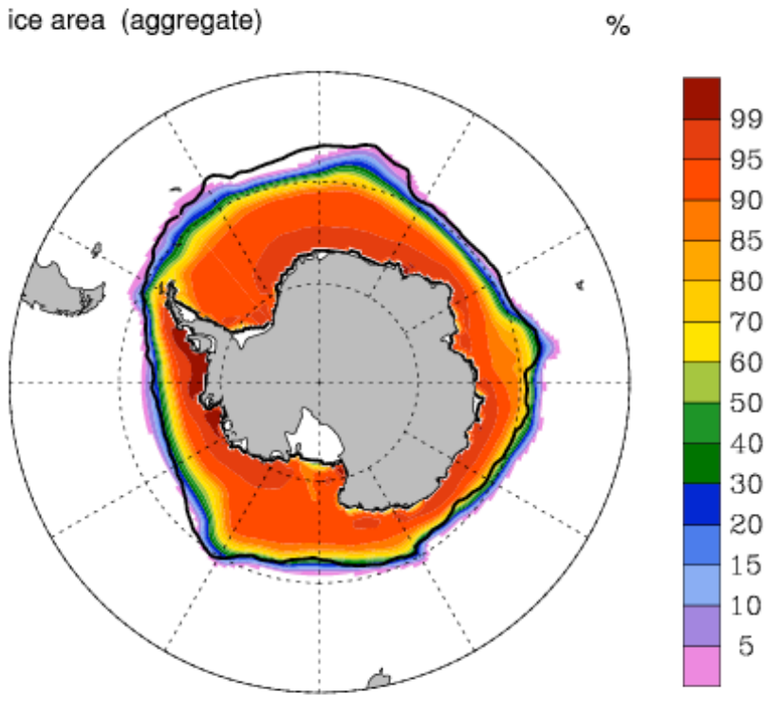
JFM



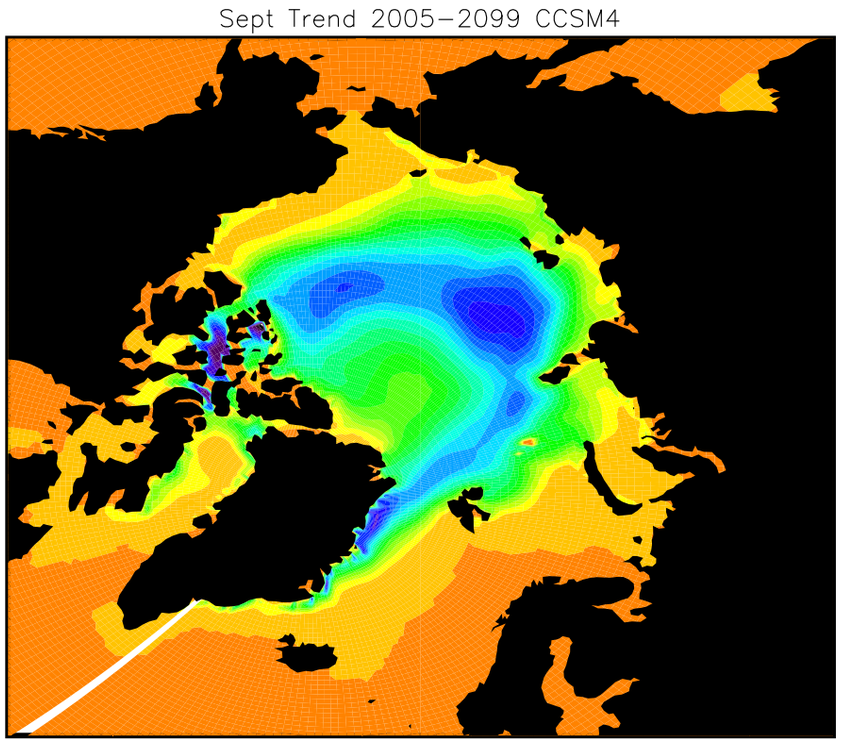
JAS

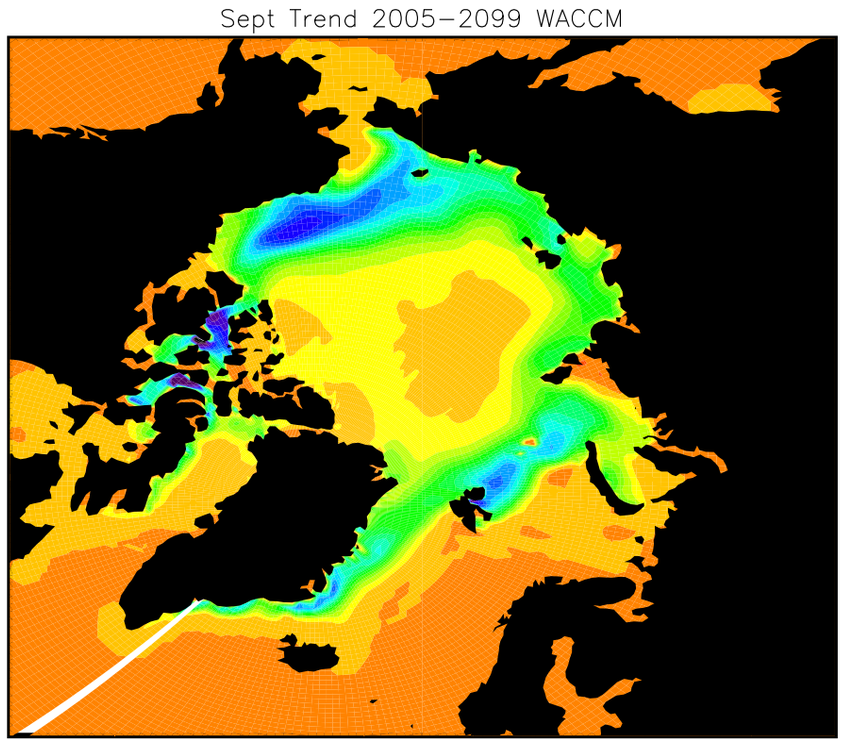


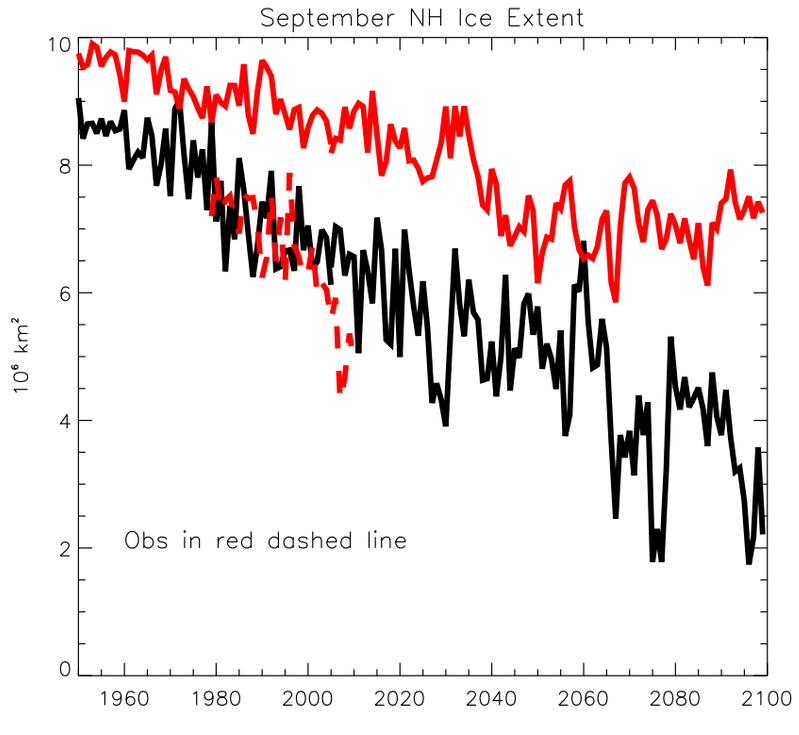


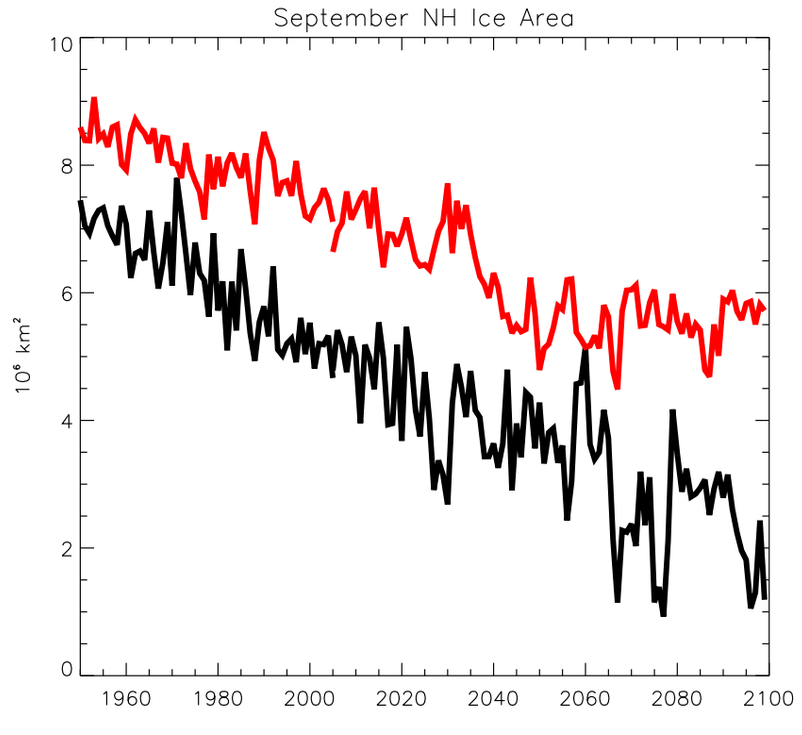


NH Ice area trends



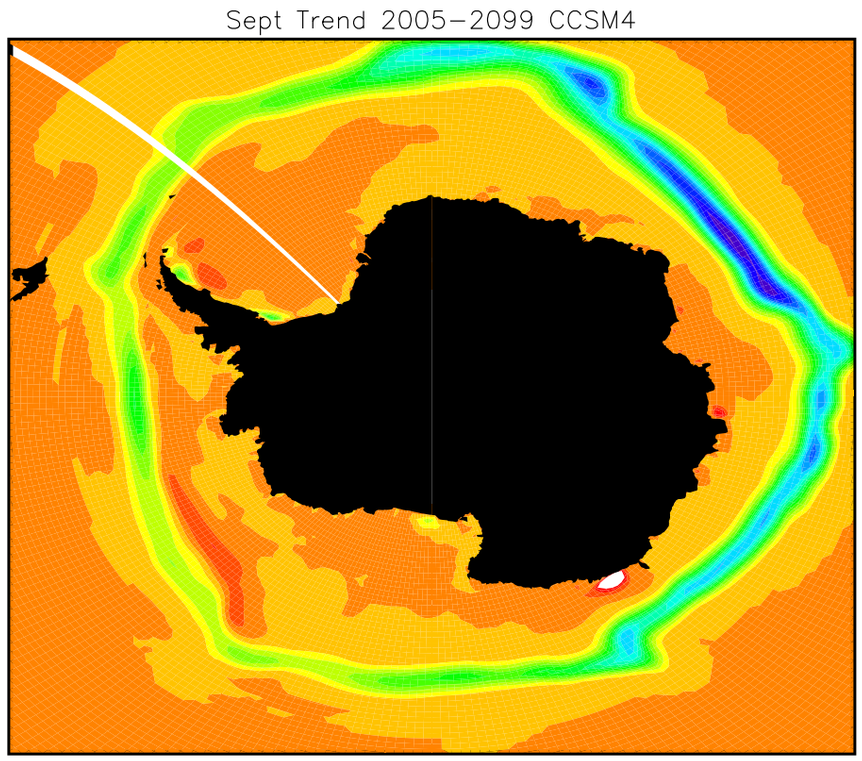


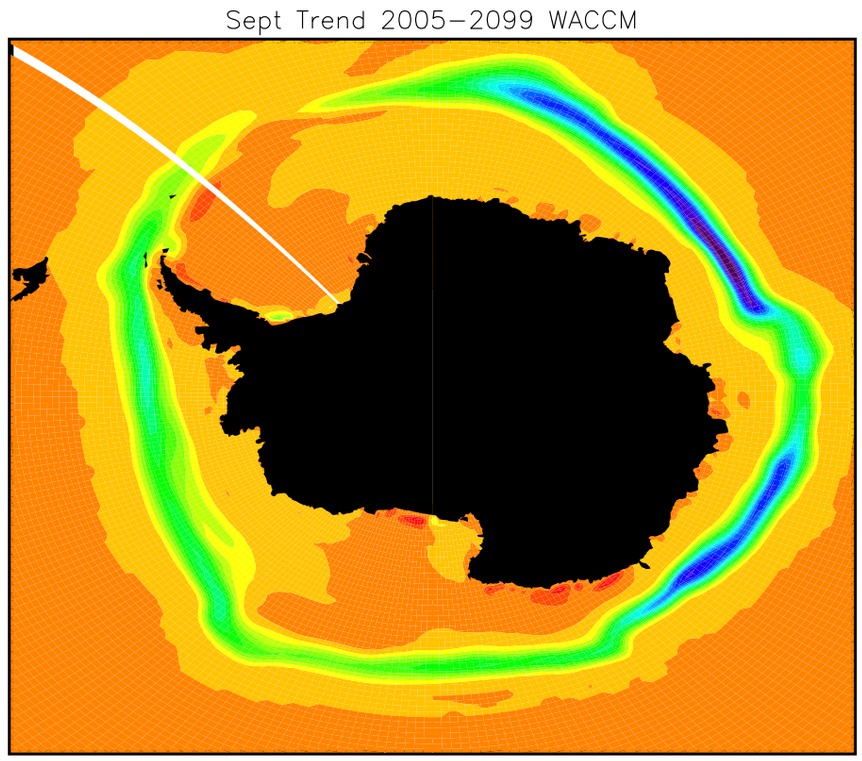


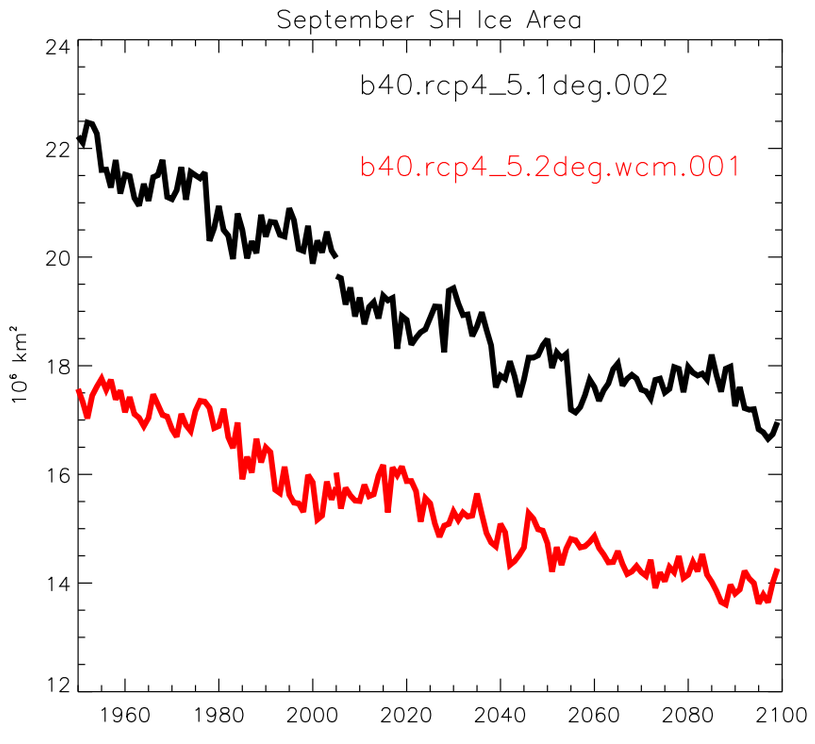


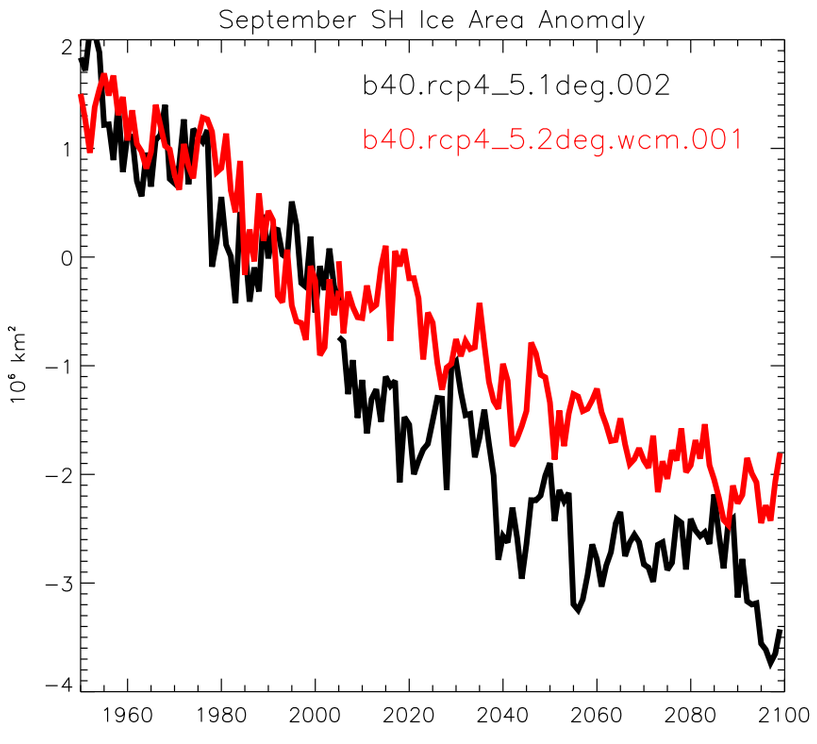
Analysis by
M. Holland

SH Ice area trends







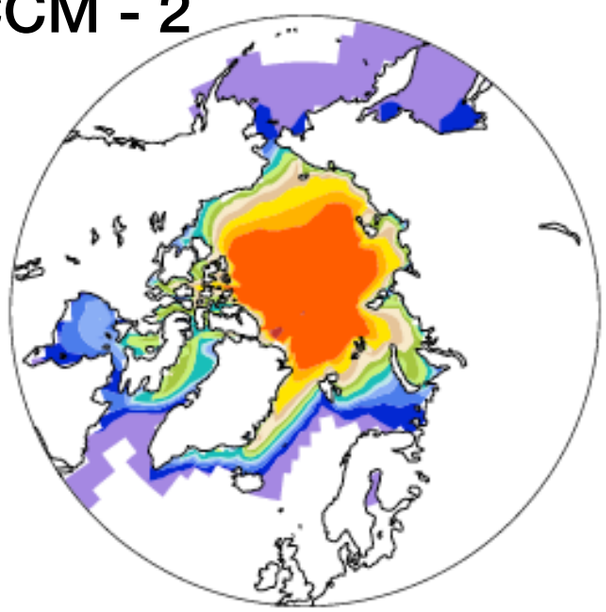


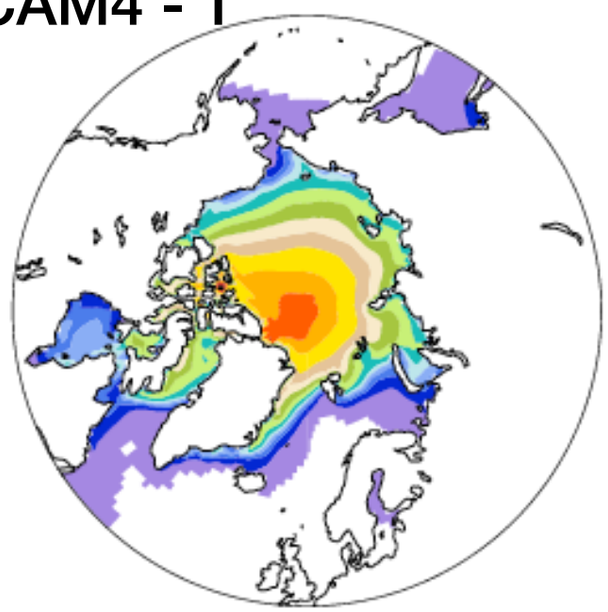
RCP4.5 yrs 2080-2098 Sea Ice Concentration (%)

WACCM - 2°

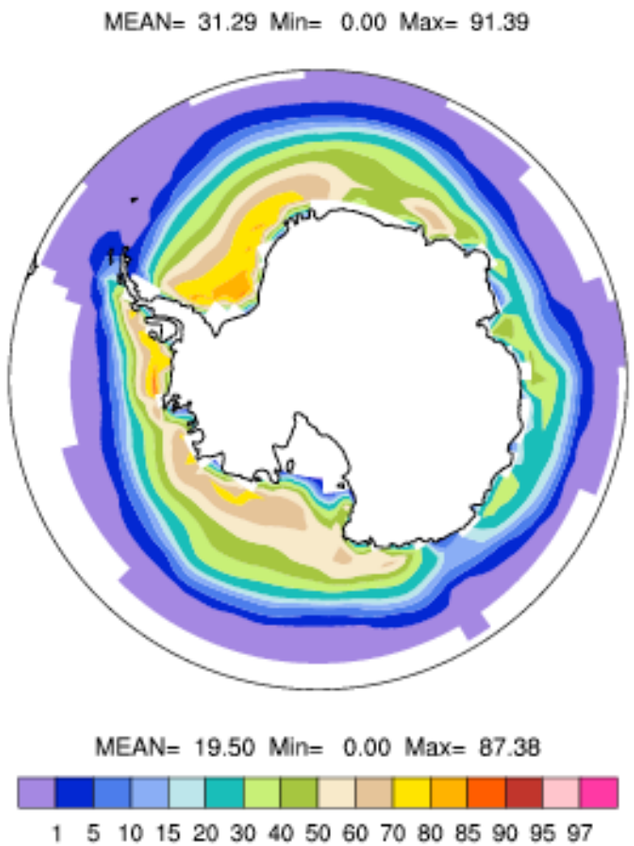
CAM4 - 1°

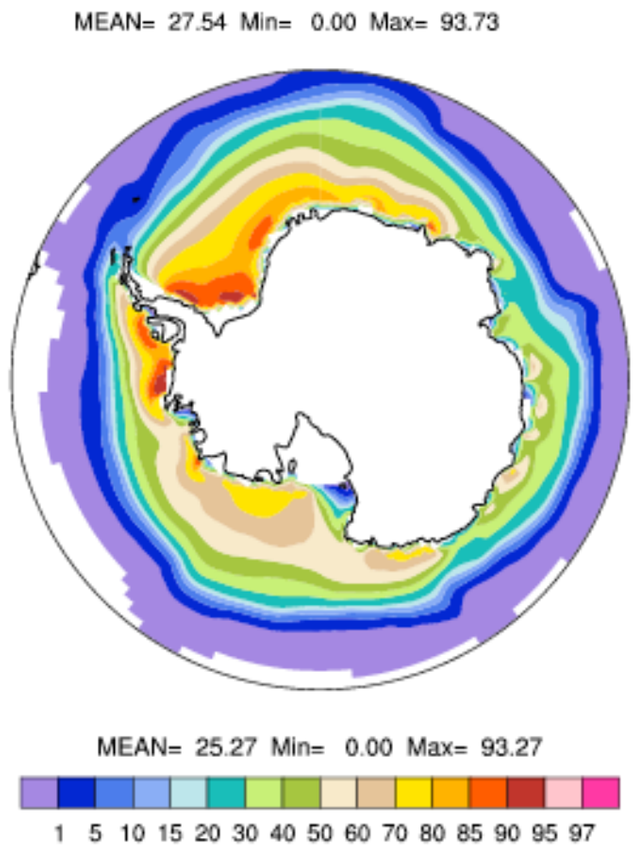
JJA NH





DJF SH

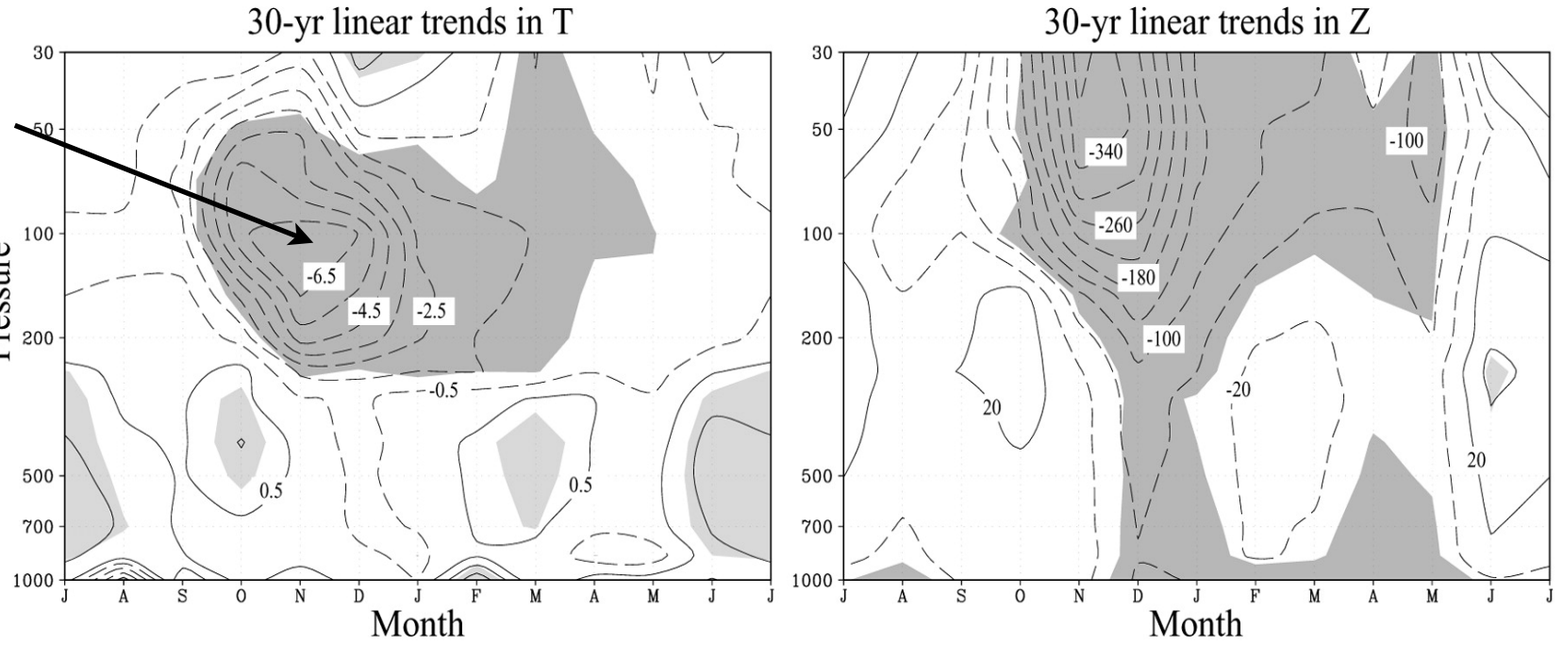


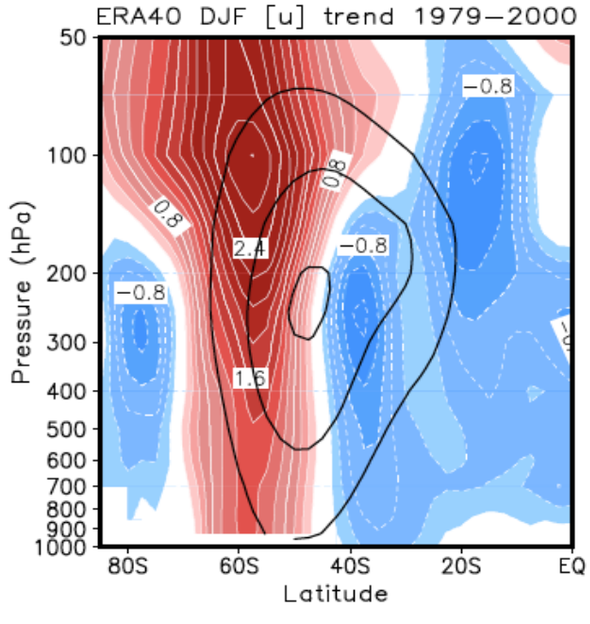


SH UTLS trends

Observed trend 1969-1998 (Thompson and Solomon, 2002)

-6.5 K/30yr

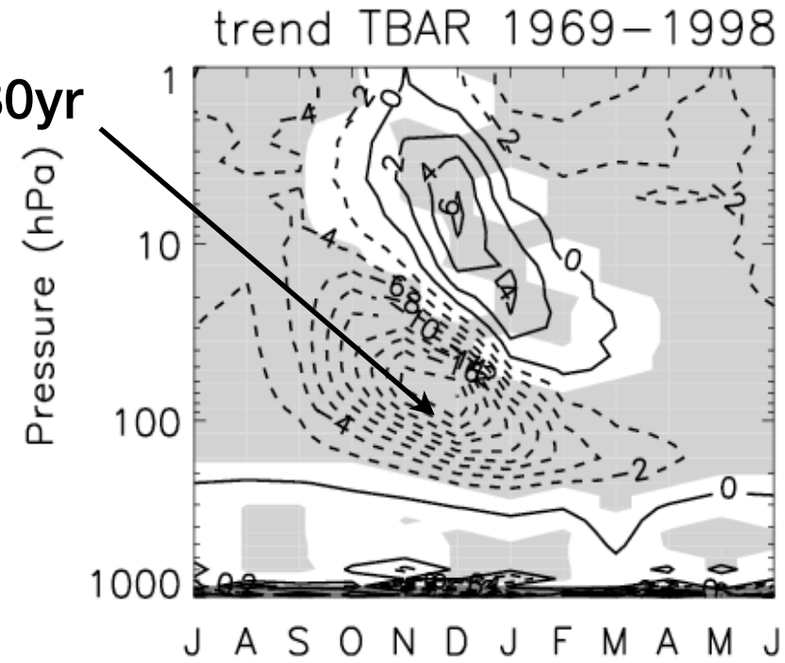




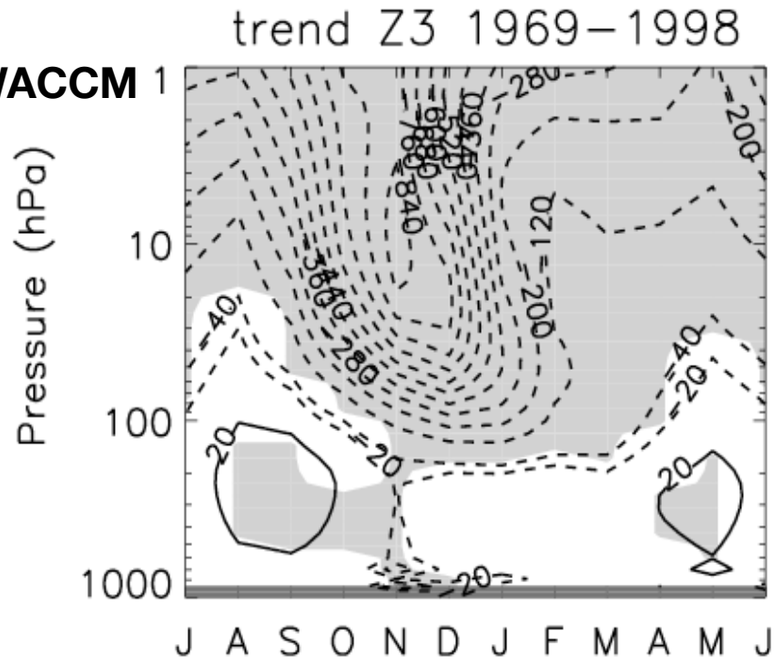
ERA40 Zonal wind trend
1979-2000 (Son et al., 2002)

CMIP5 WACCM and CCSM4 2° trends

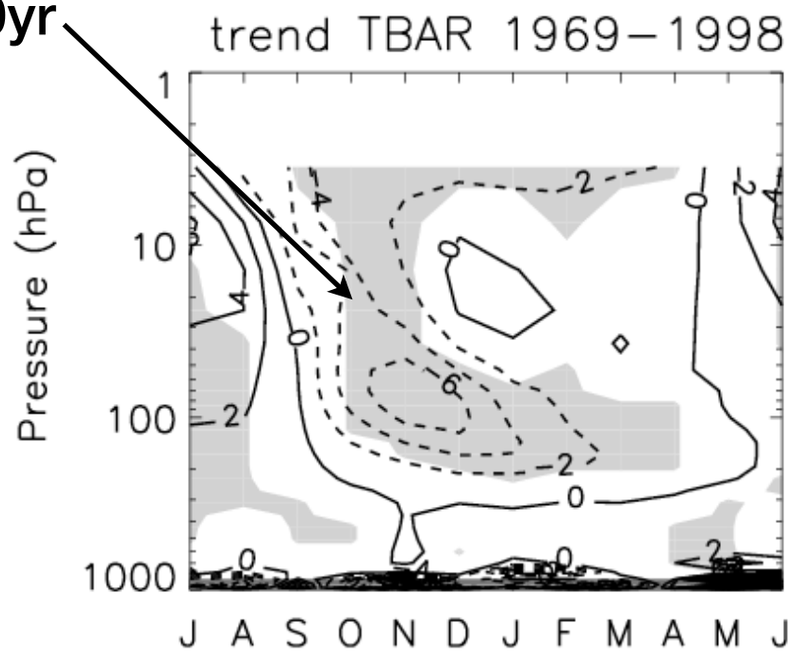
-18 K/30yr



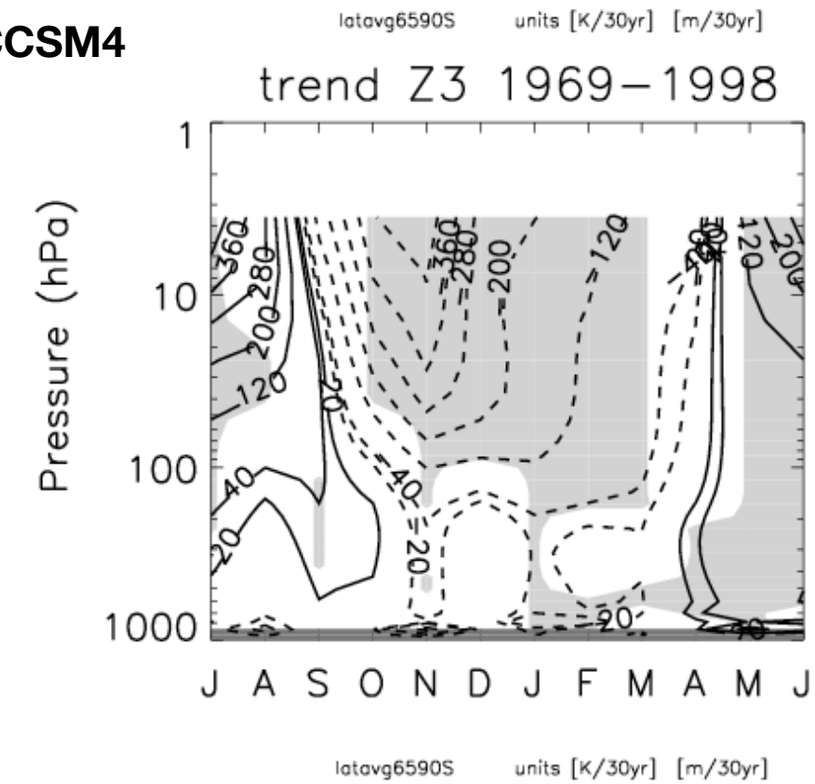
WACCM



-6 K/30yr



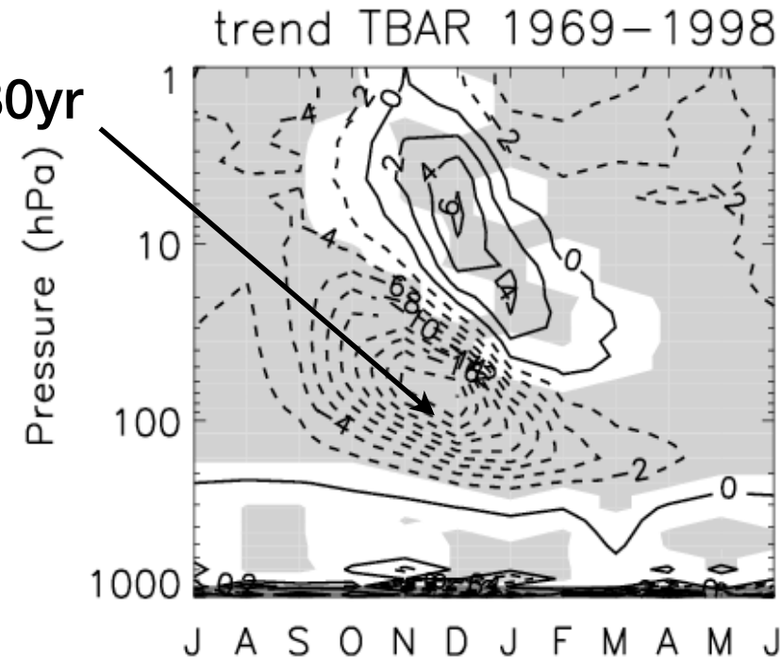
CCSM4



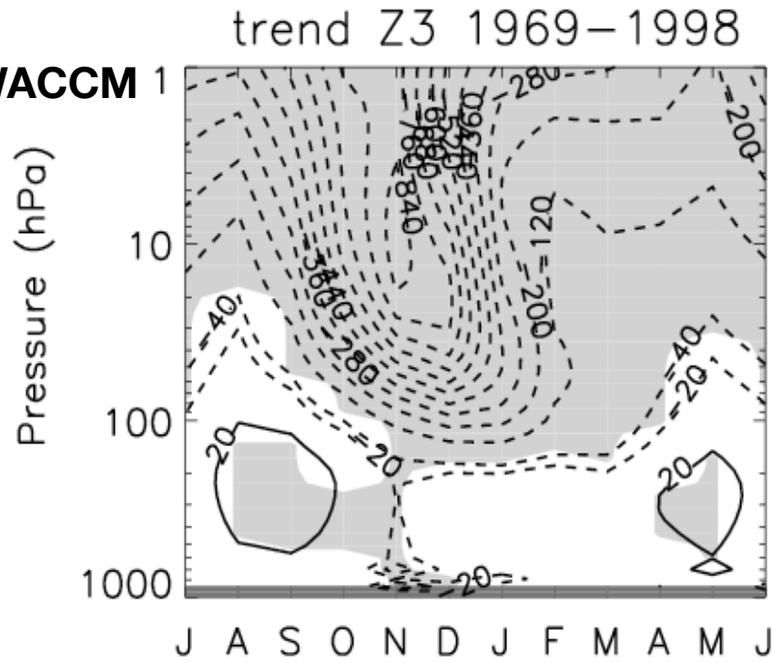
Analysis by
N. Calvo

CMIP5 WACCM and CCSM4 2° trends

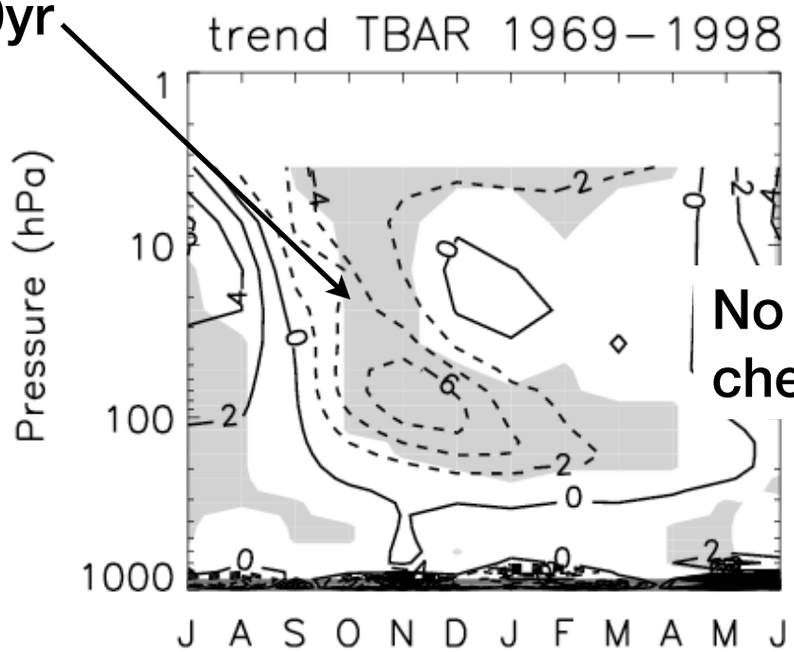
-18 K/30yr



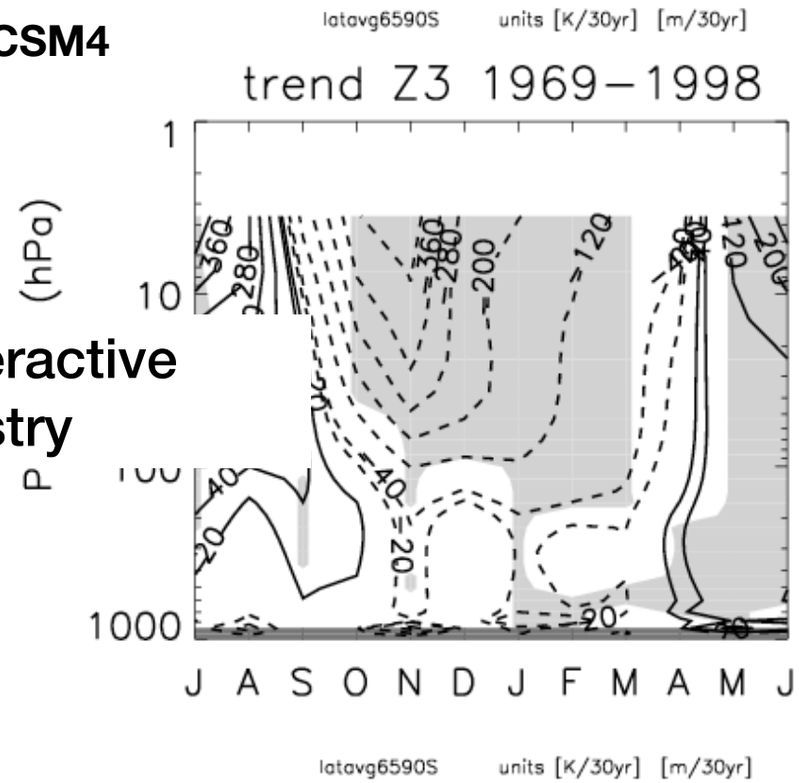
WACCM



-6 K/30yr



CCSM4

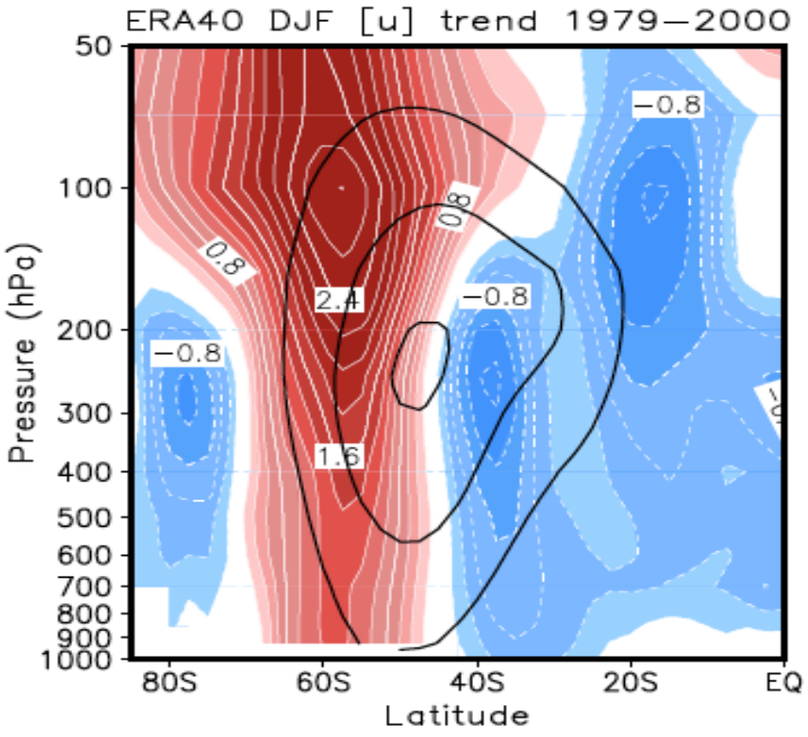


No interactive chemistry

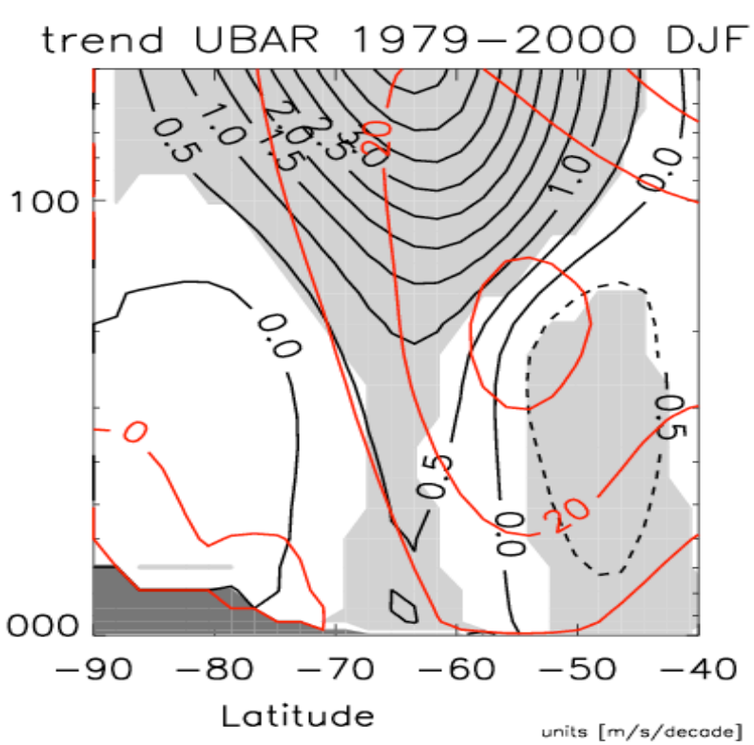
Analysis by N. Calvo

Zonal mean wind trends (m/s/decade)

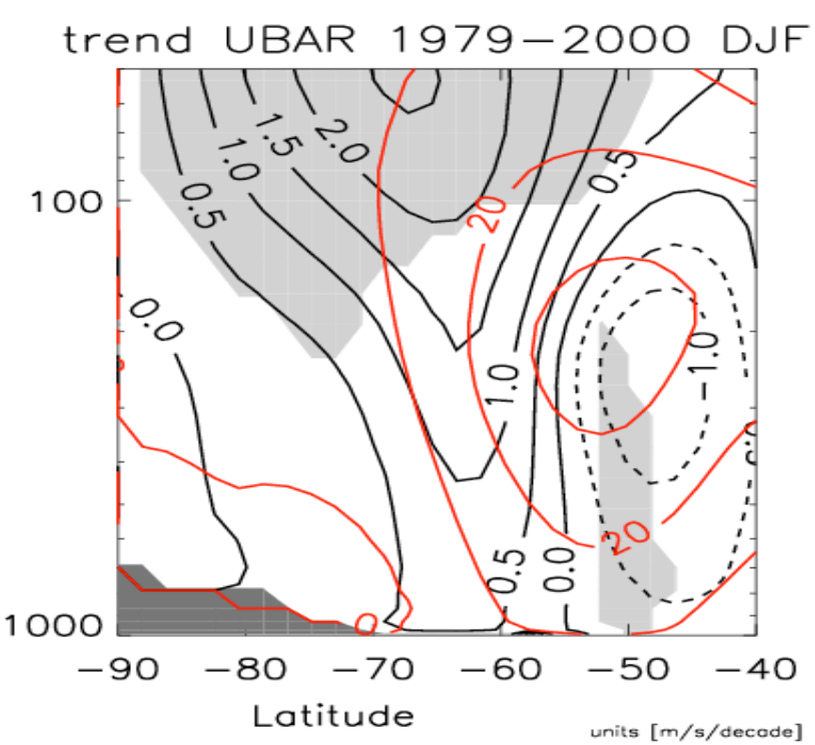
ERA-40



WACCM

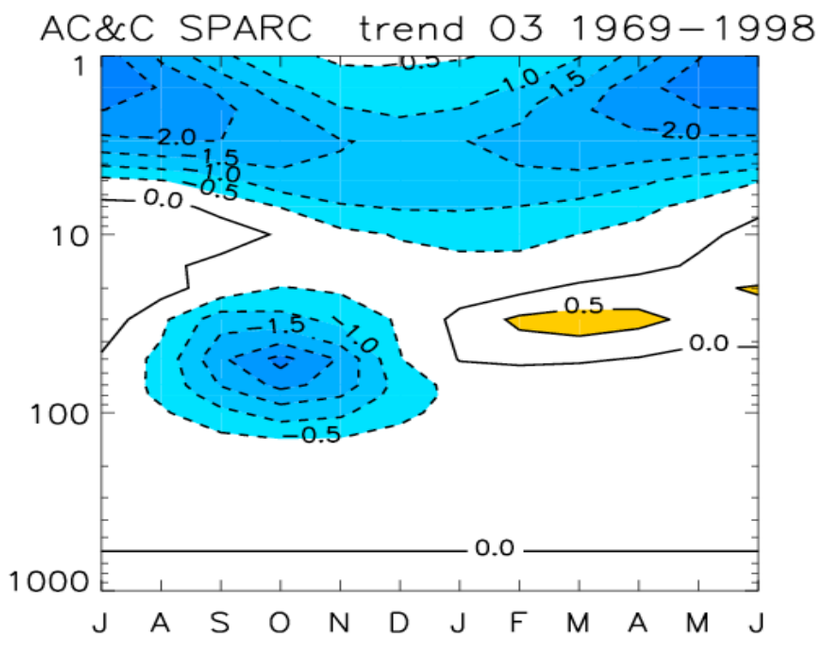


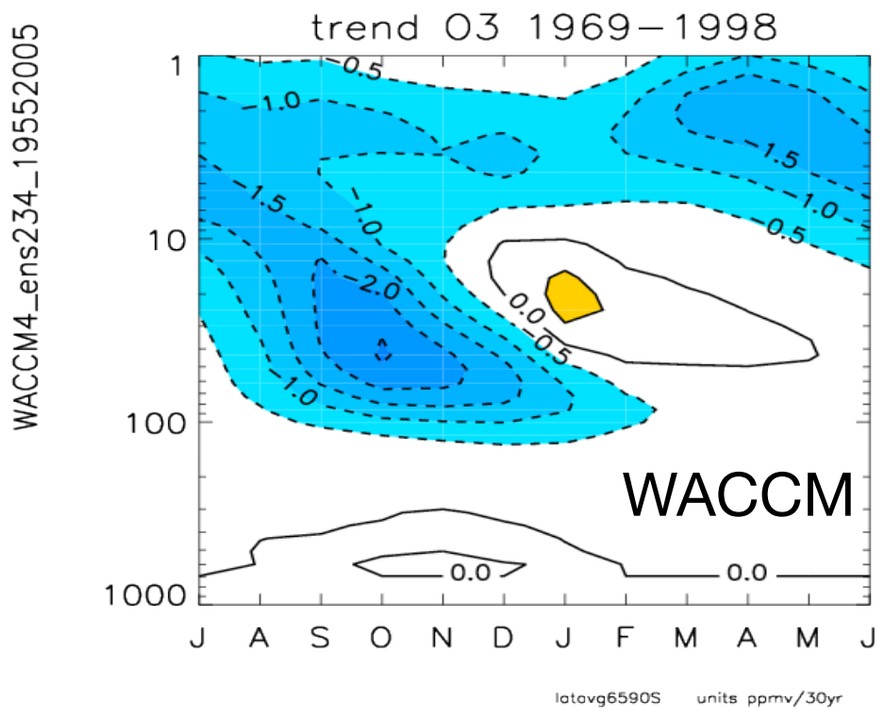
CCSM4



CCSM4 produces temperature and wind trends closer to observations

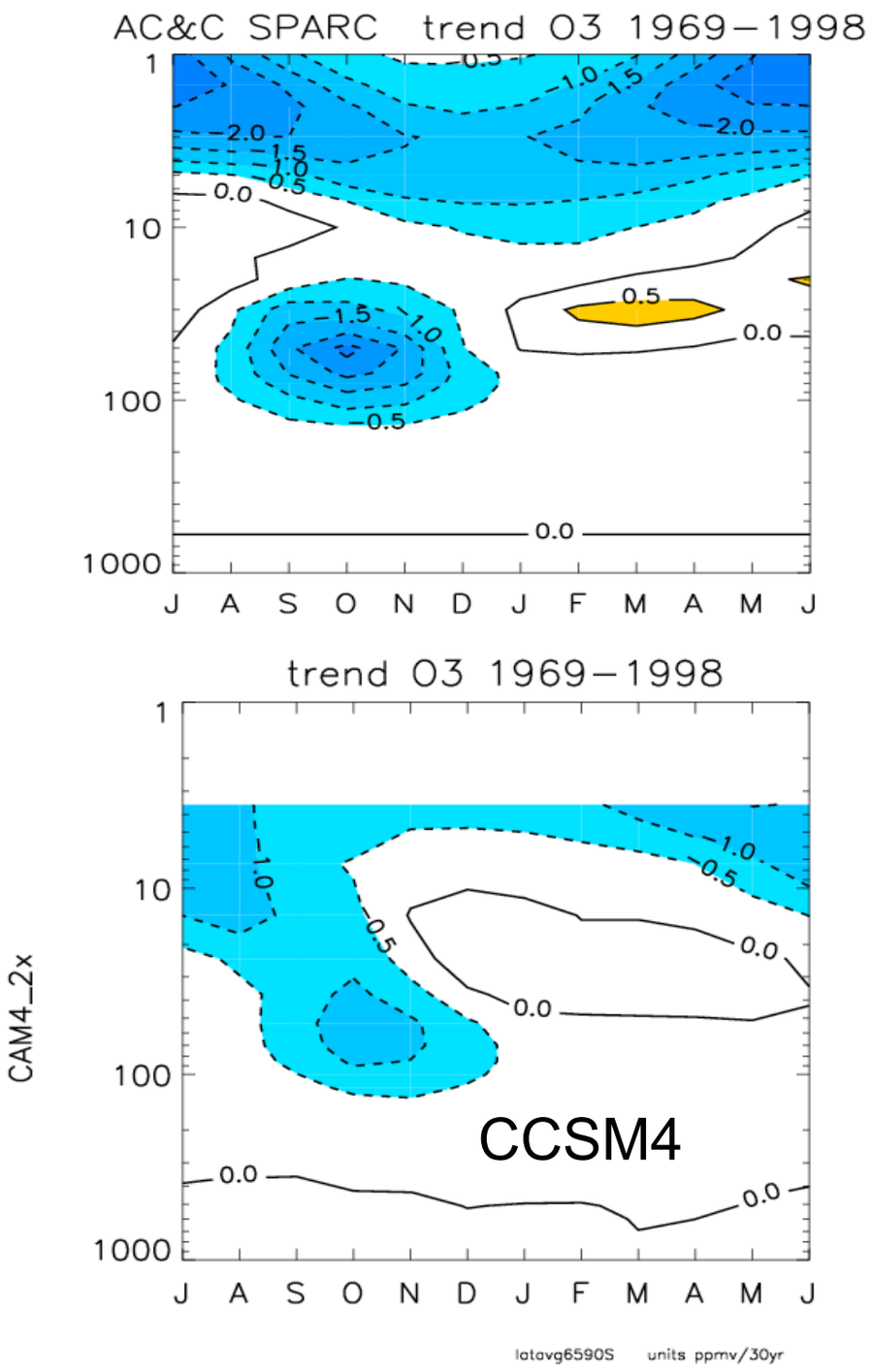
Ozone trends vs. month 1969-1998

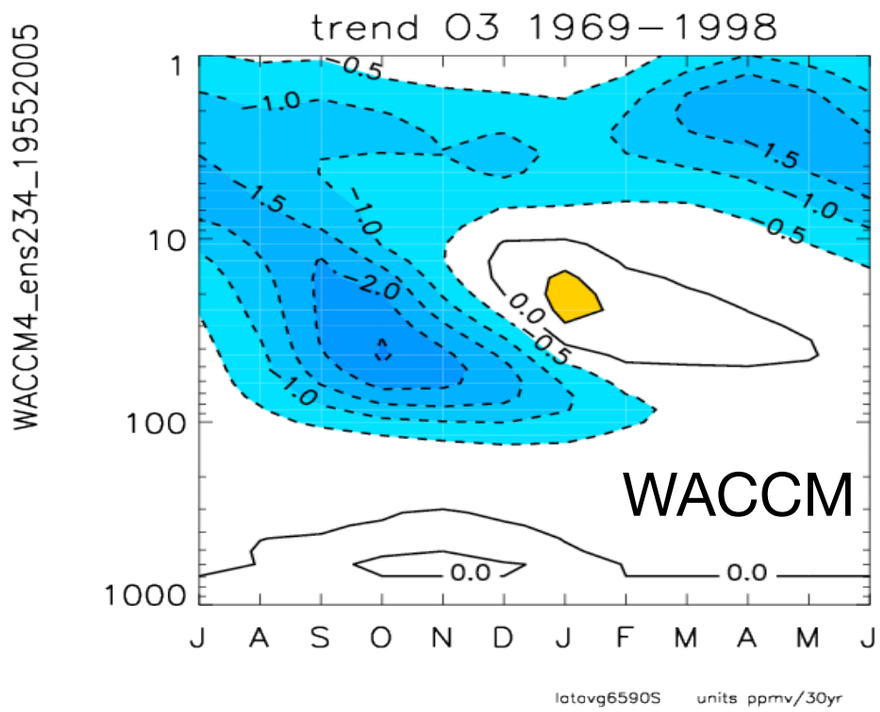




- WACCM ozone trends similar to observed
- Ozone dataset used to drive CCSM4 weaker by factor of 3

Ozone trends vs. month 1969-1998

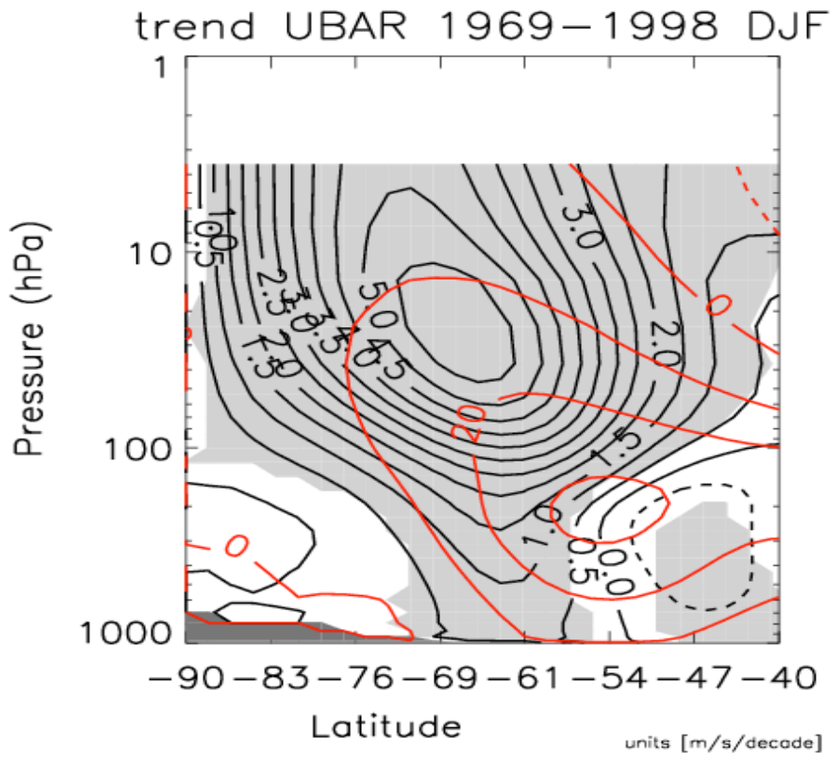




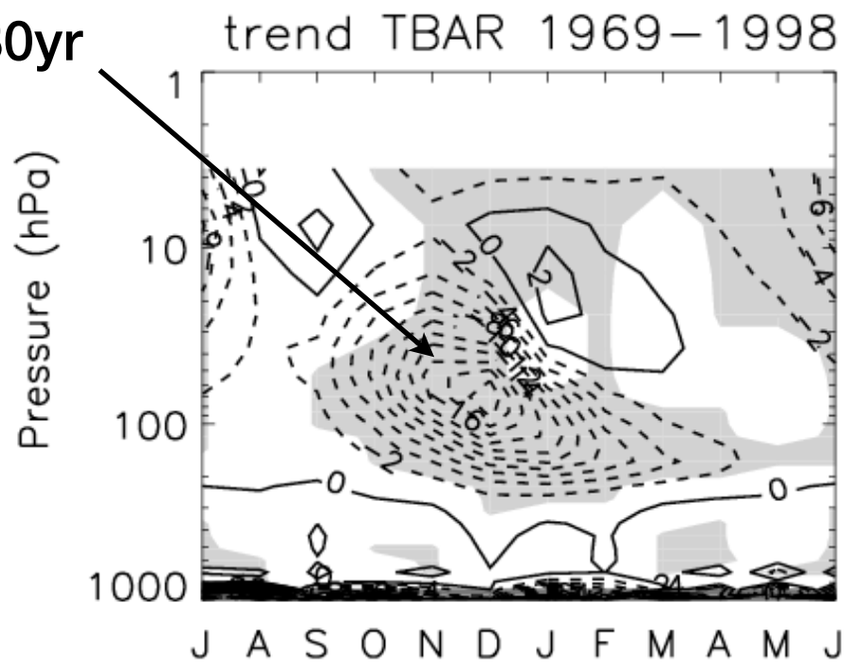
- WACCM ozone trends similar to observed
- Ozone dataset used to drive CCSM4 weaker by factor of 3

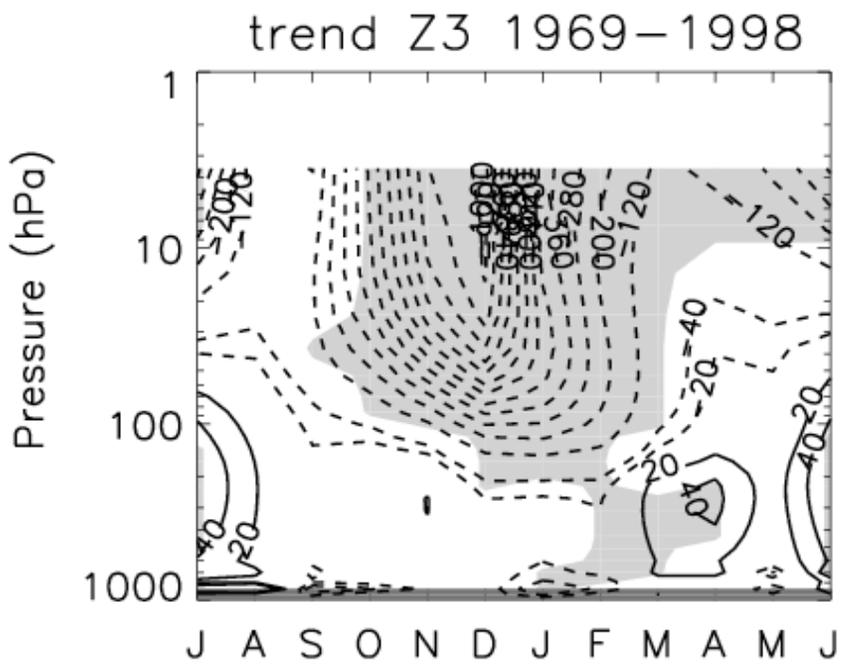
CCSM4 driven with WACCM ozone

- CCSM4 produces trends comparable to WACCM4

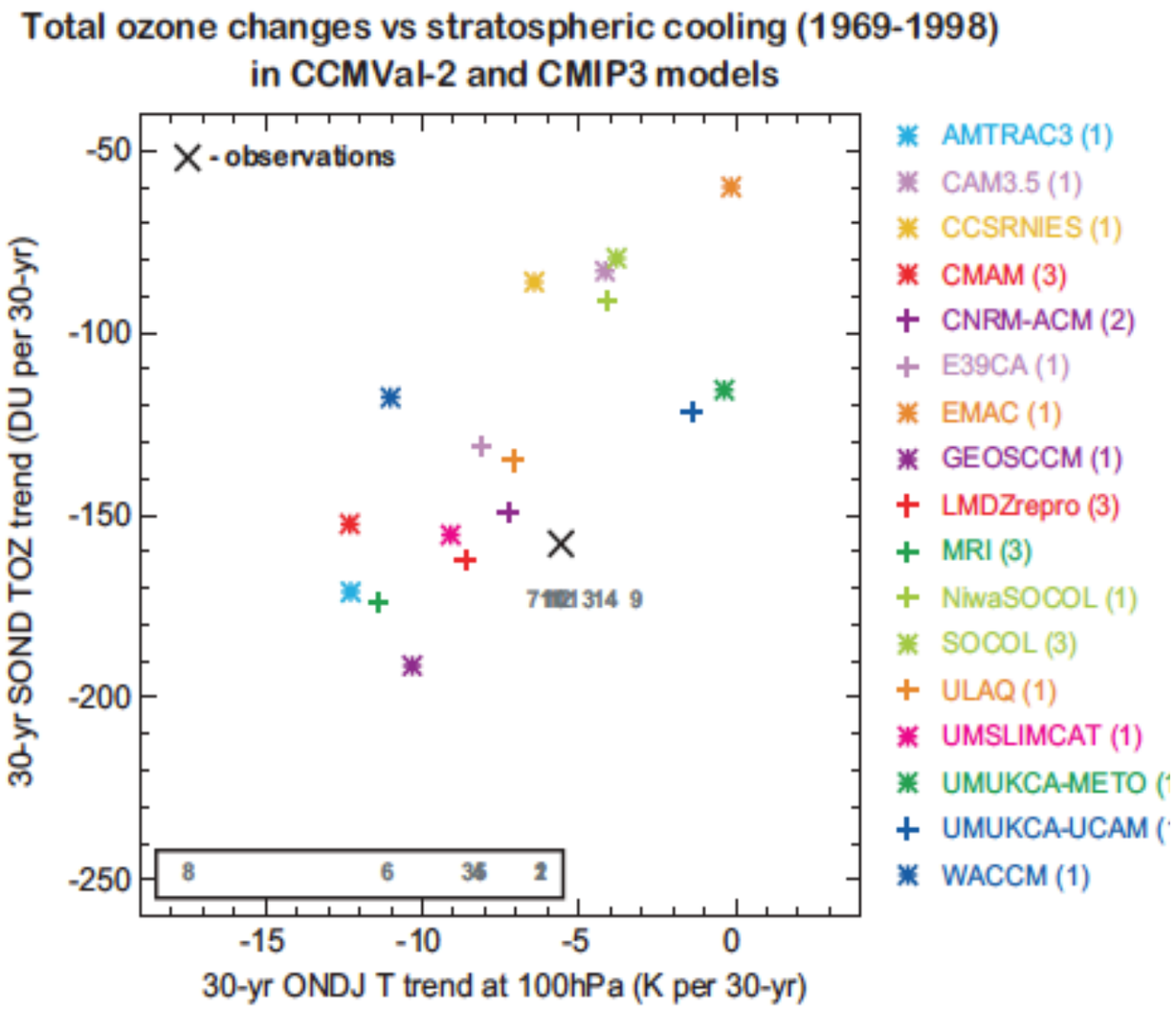


-16 K/30yr



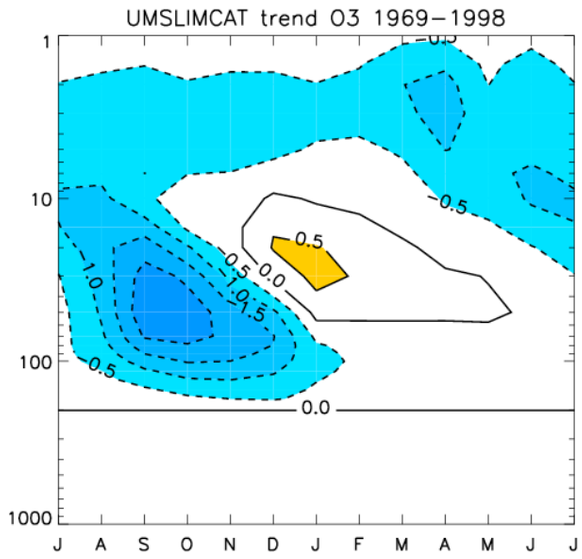


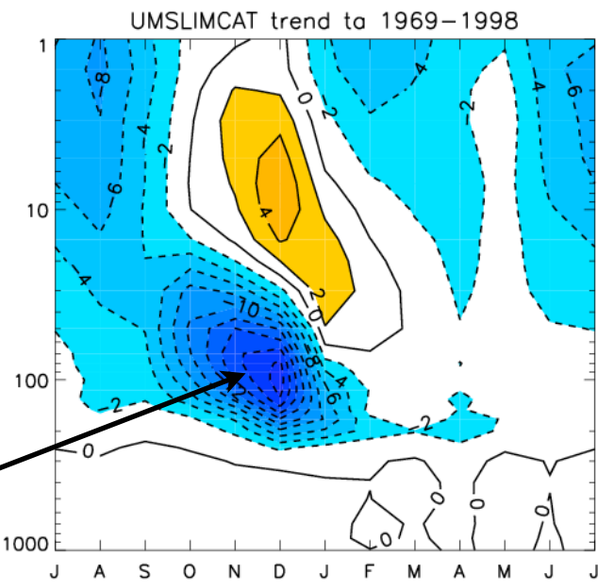
Problem not limited to WACCM



CCMVal-2 report

SLIMCAT





-18 K/30yr

Why does CCSM4 get the right answer for the wrong reason?

- In the lower stratosphere the trends in shortwave heating due to changes in ozone are balanced by trends in longwave cooling. i.e. it is in radiative balance. A smaller ozone trend yields a smaller temperature trend.

- A possible cause is that the models do not produce significant trends in downwelling over the pole in the lower stratosphere that could reduce the cooling through adiabatic heating.

- Future work will look at wave dissipation in WACCM/CCSM4 to explore reasons for this discrepancy. Does it also show up in HOMME simulations?

Summary

- CESM-WACCM with a active ocean produces stratosphere/mesosphere very similar to WACCM3.5. Tempertures, ozone, SSWs and water vapor vertually identical.

- Surface temperature trends, SSTs & ENSO very similar to CCSM4

- TMS and ice physics changes lead to significant differences in SLP, cloud fraction, sea ice thickness/trends.

- Biases seen in AMIP runs persist in the coupled model (SH “cold pole” problem & excessive temperature trends in UTLS)

Thank you

NCAR is sponsored by the National Science Foundation