

Climate change from 1850 to 2005

WACCM vs CCSM4

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WACCM

Whole Atmosphere
Community Climate Model



Outline

- Differences between WACCM & CCSM4 used for CMIP5
- Describe CCSM4-WSET (CCSM4 with WACCM settings)
- ENSO variability
- Stratospheric sudden warmings and northern annular modes
- SH stratospheric temperature trends
- Comparison of regional climate change in N.Atlantic / Europe



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Community Climate Model



Important differences from CCSM4 used for CMIP5

- Model top at ~140 km (66 levels) vs. ~40 km (26 levels)
- Horizontal (lat x lon) resolution: $1.9^\circ \times 2.5^\circ$ vs. $0.94^\circ \times 1.25^\circ$
- Fully-interactive chemistry
- Nudged Quasi-Biennial Oscillation (QBO)
- Forced with daily varying spectral irradiance rather than annual mean TSI
- Thermospheric processes - aurora, ion chemistry, molecular diffusion
- Additional parameterization for gravity waves from convection and fronts (same orographic parameterization)
- “Turbulent mountain stress” (TMS) turned on



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WACCM

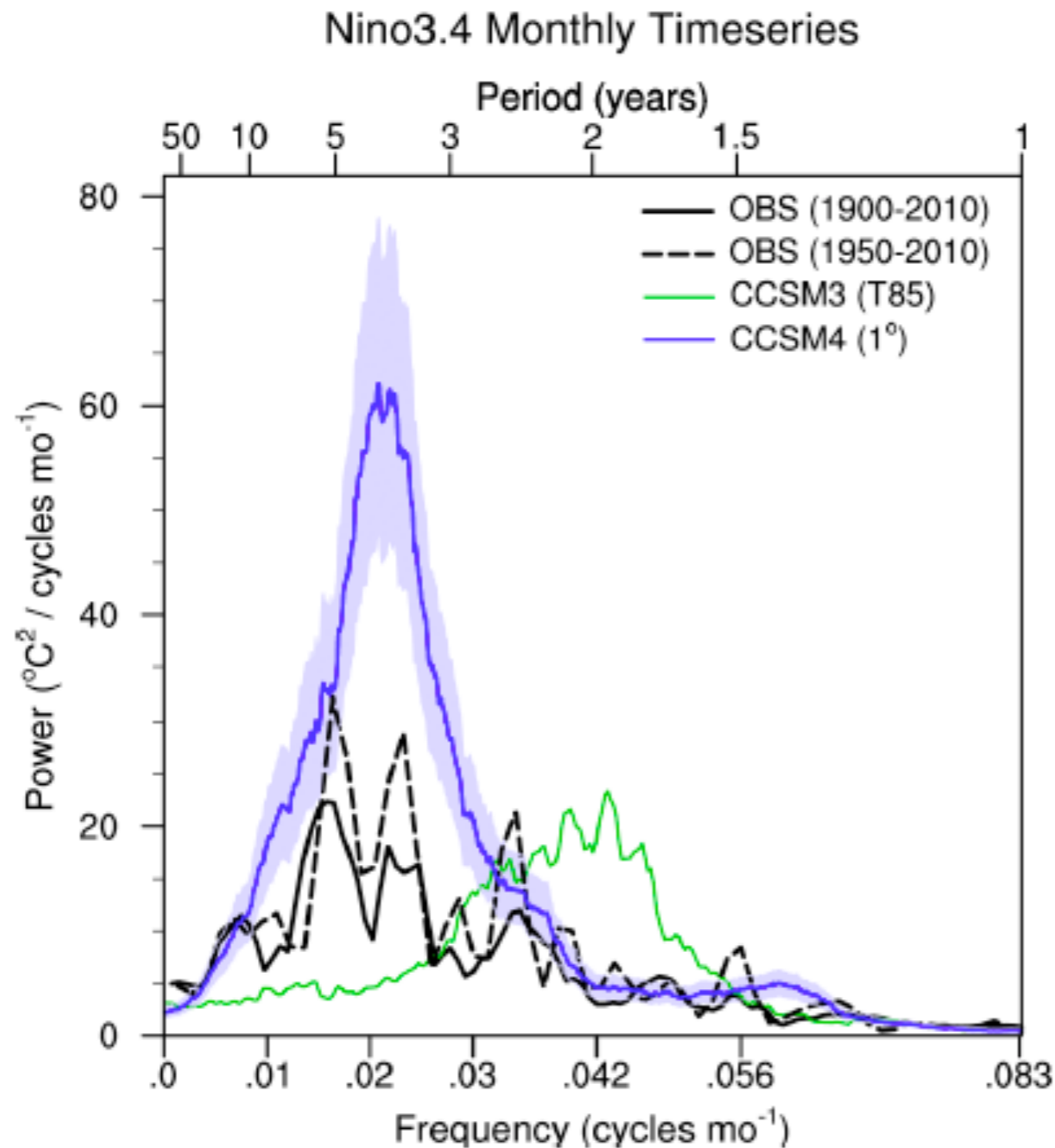
Whole Atmosphere
Community Climate Model



How then to investigate the influence of a ‘high-top’?

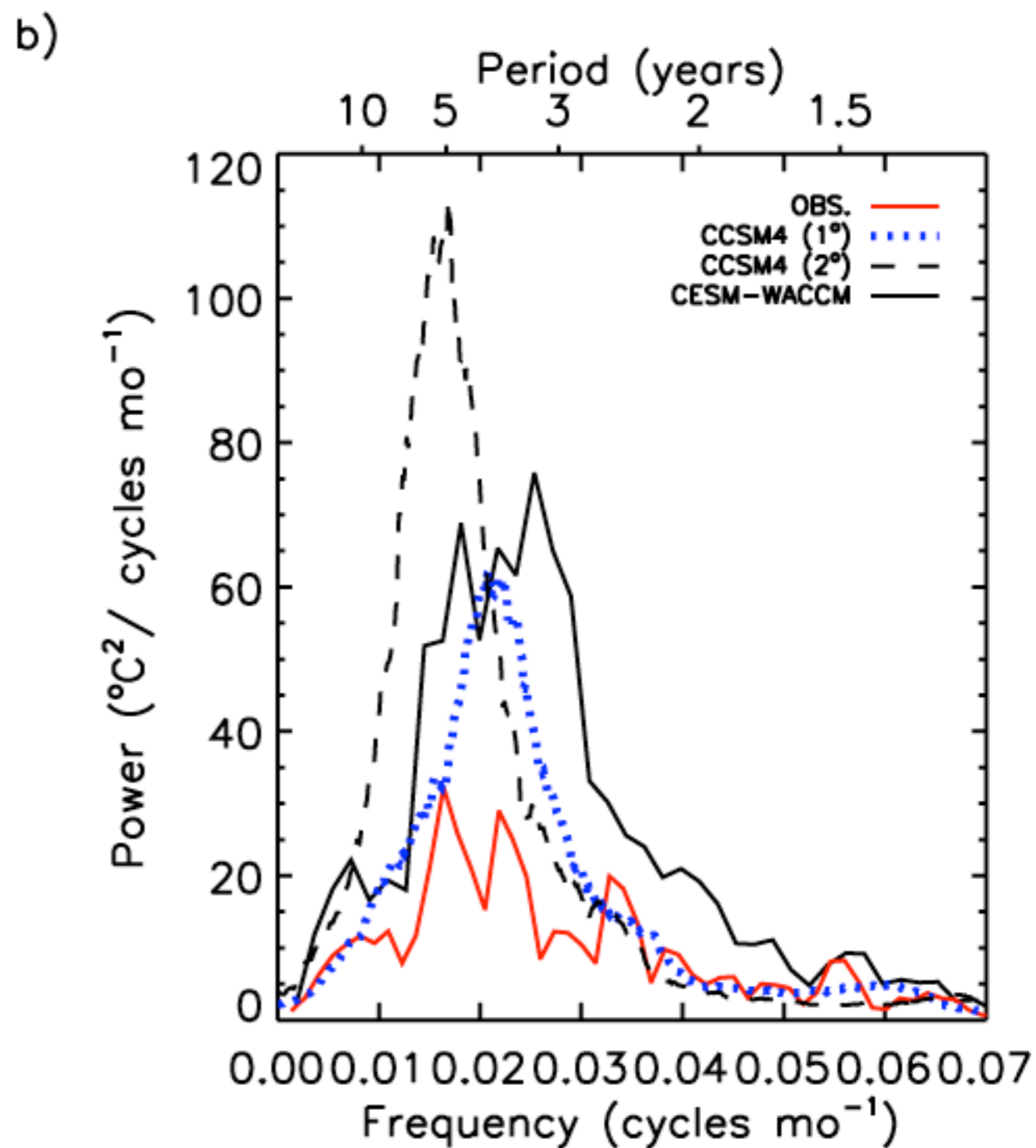
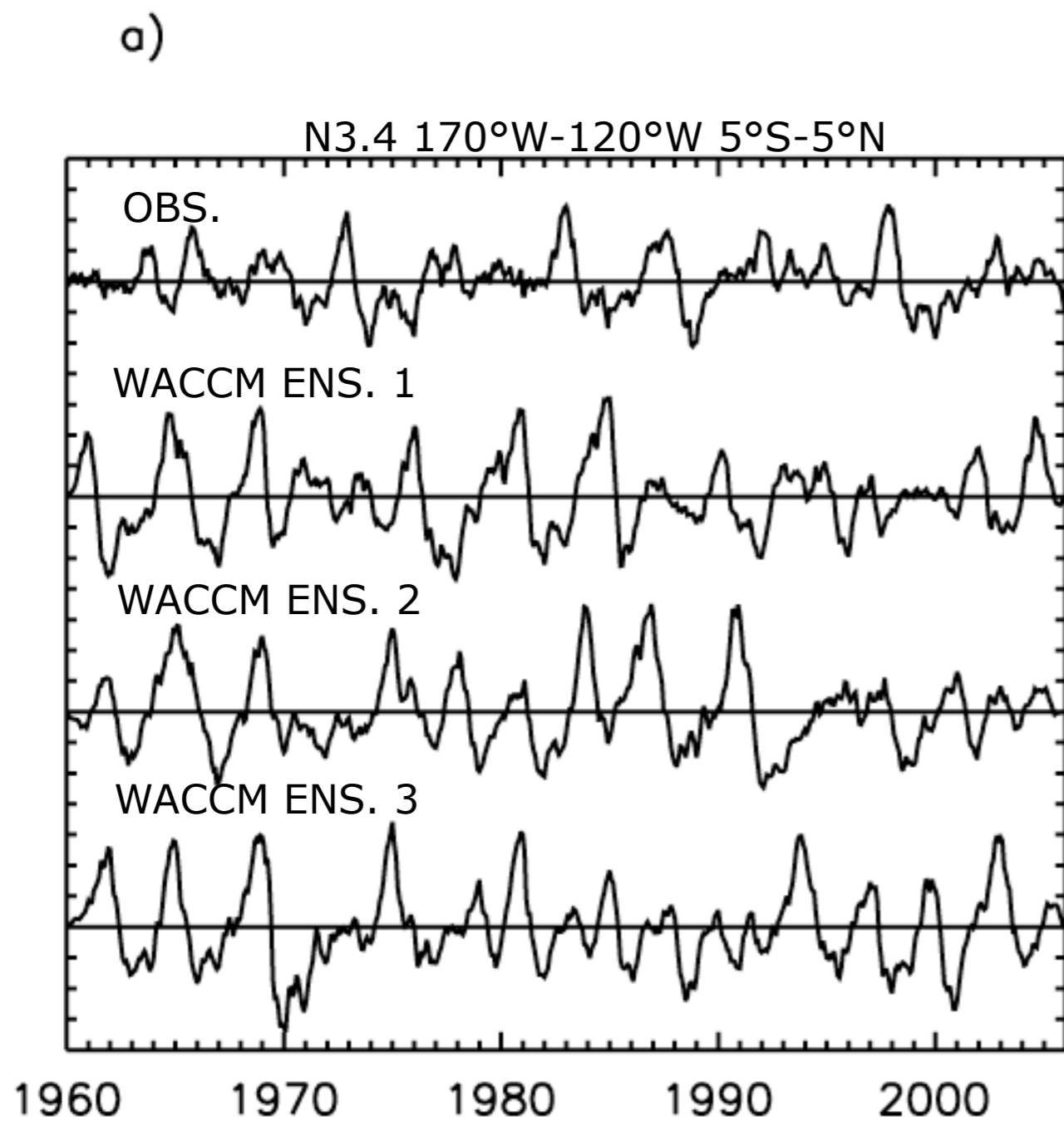
- Parallel simulations of CCSM4 configured in a similar manner to WACCM
 - Horizontal (lat x lon) resolution: $1.9^\circ \times 2.5^\circ$
 - Daily TSI
 - TMS turned on
- We term this model CCSM4-WSET
- Note: all simulations (WACCM, CCSM4 1° , and CCSM4-WSET) run with the same POP2 active ocean at 1°

El Niño/Southern Oscillation (ENSO) in CCSM4



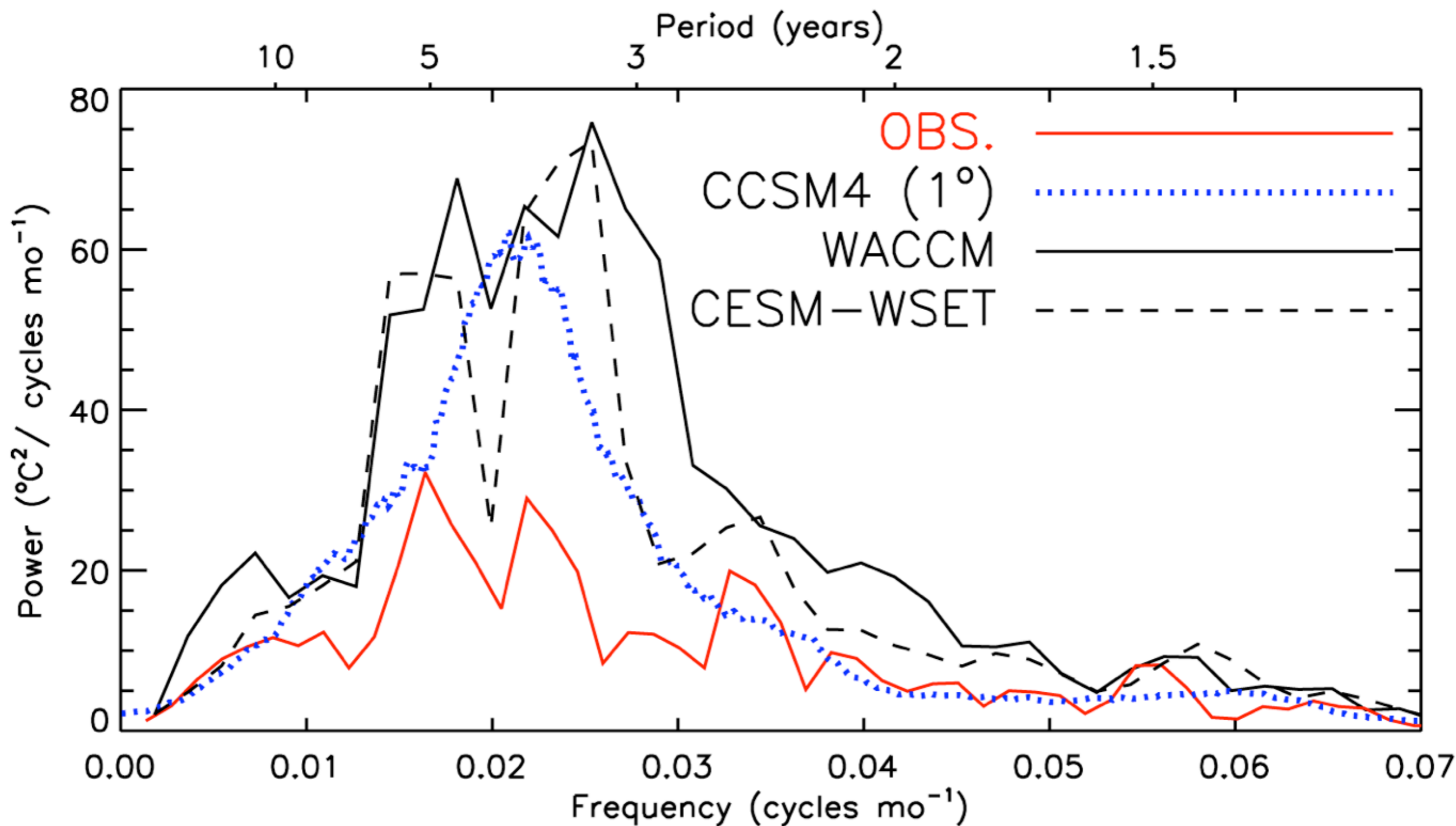
“ENSO and Pacific Decadal Variability in Community Climate System Model Version 4”, Deser et al., J. Clim., 2011

ENSO SST anomalies (Niño-3.4) 1960-2005



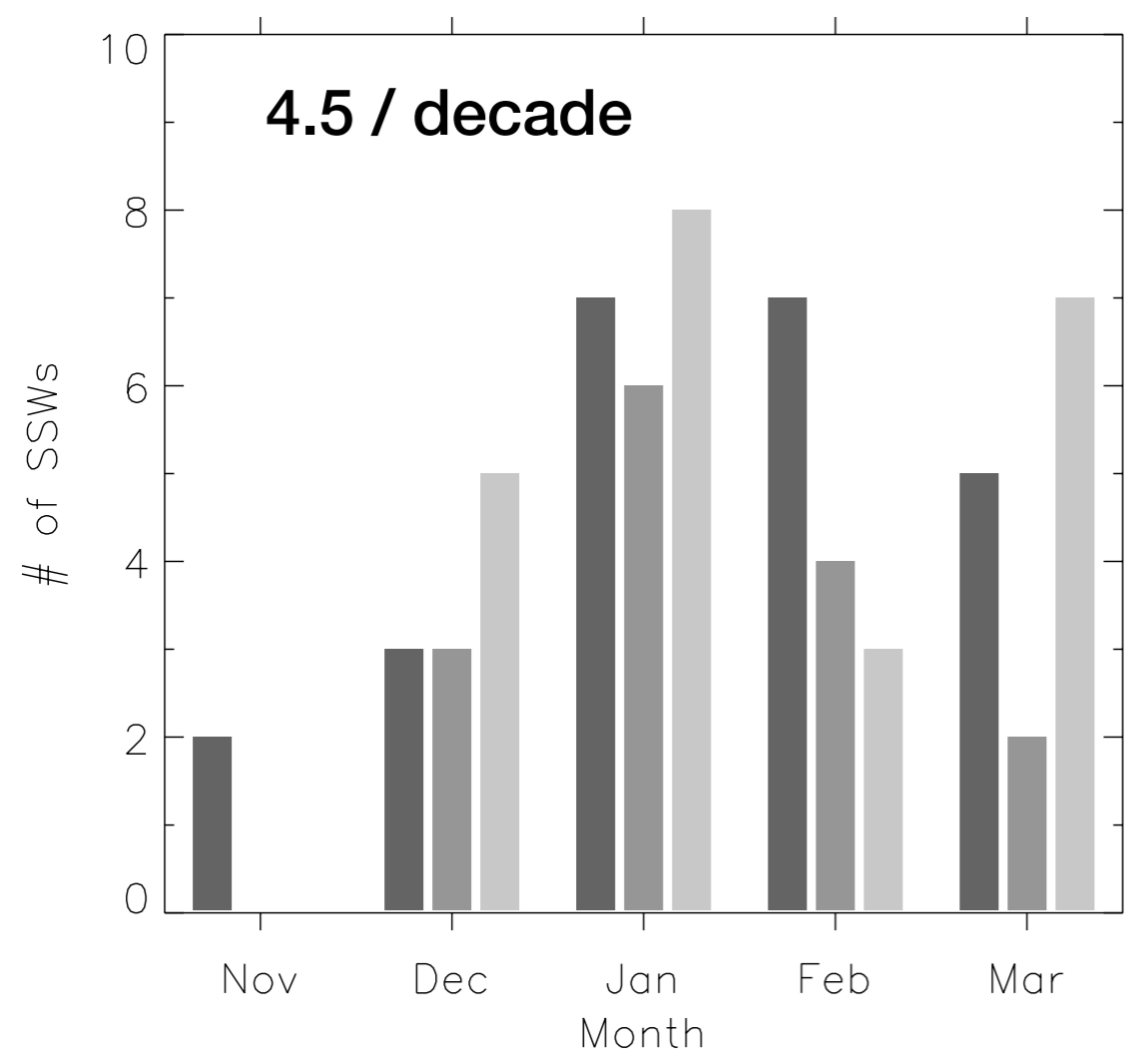
Note change in vertical scale.

ENSO SST anomalies (Niño-3.4) 1960-2005

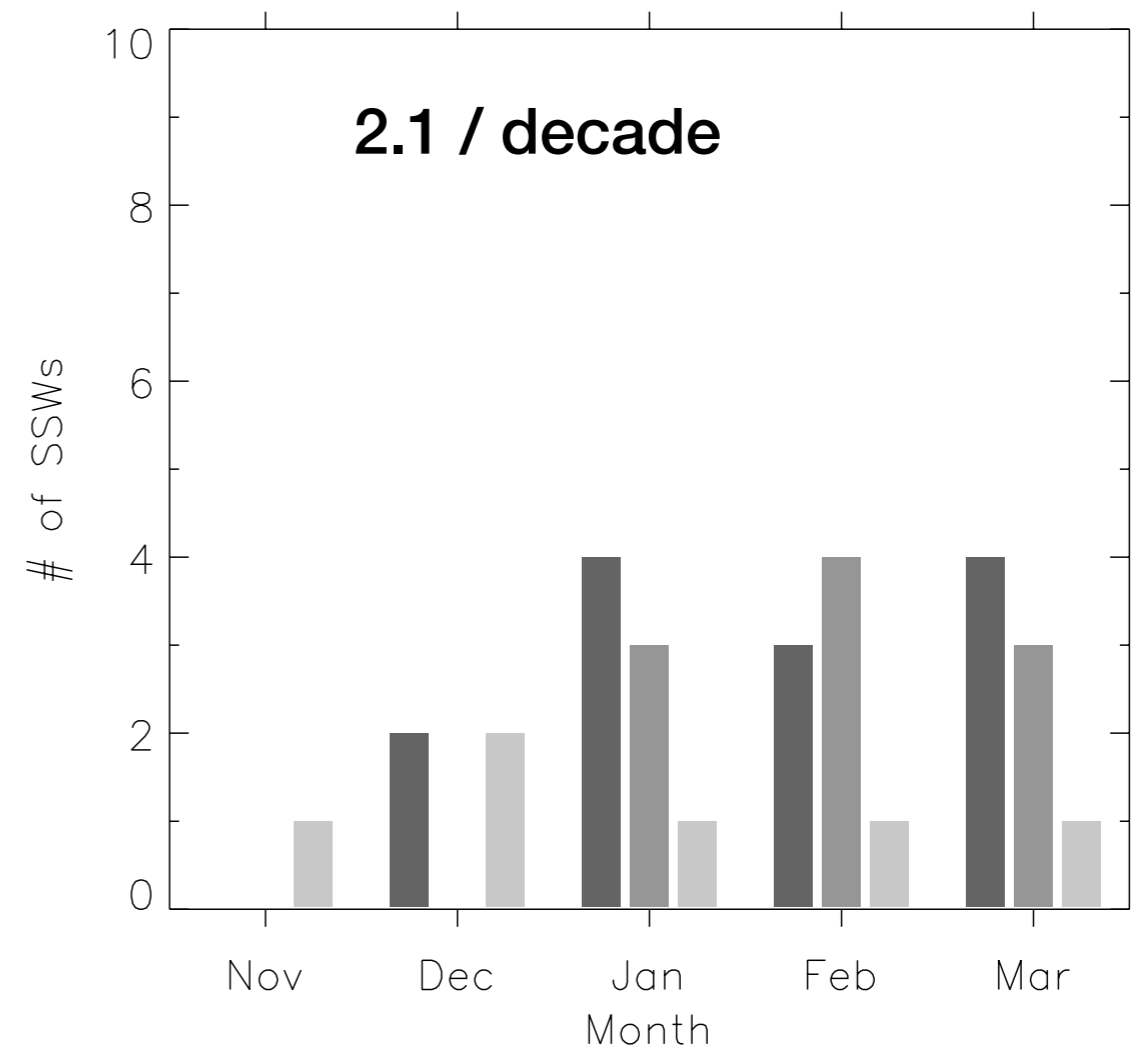


Stratospheric Sudden Warmings (1960-2005)

WACCM



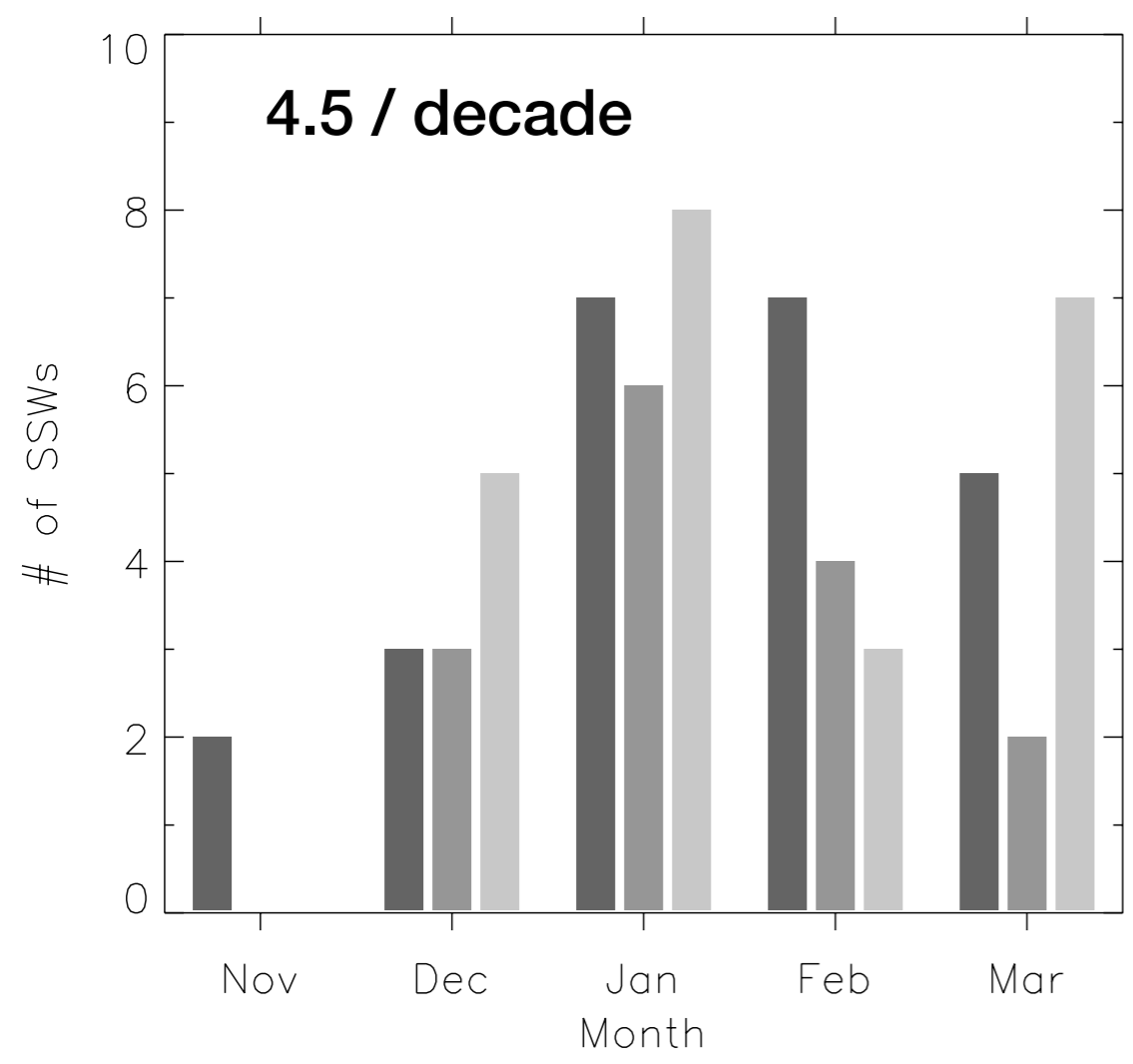
CCSM4-WSET



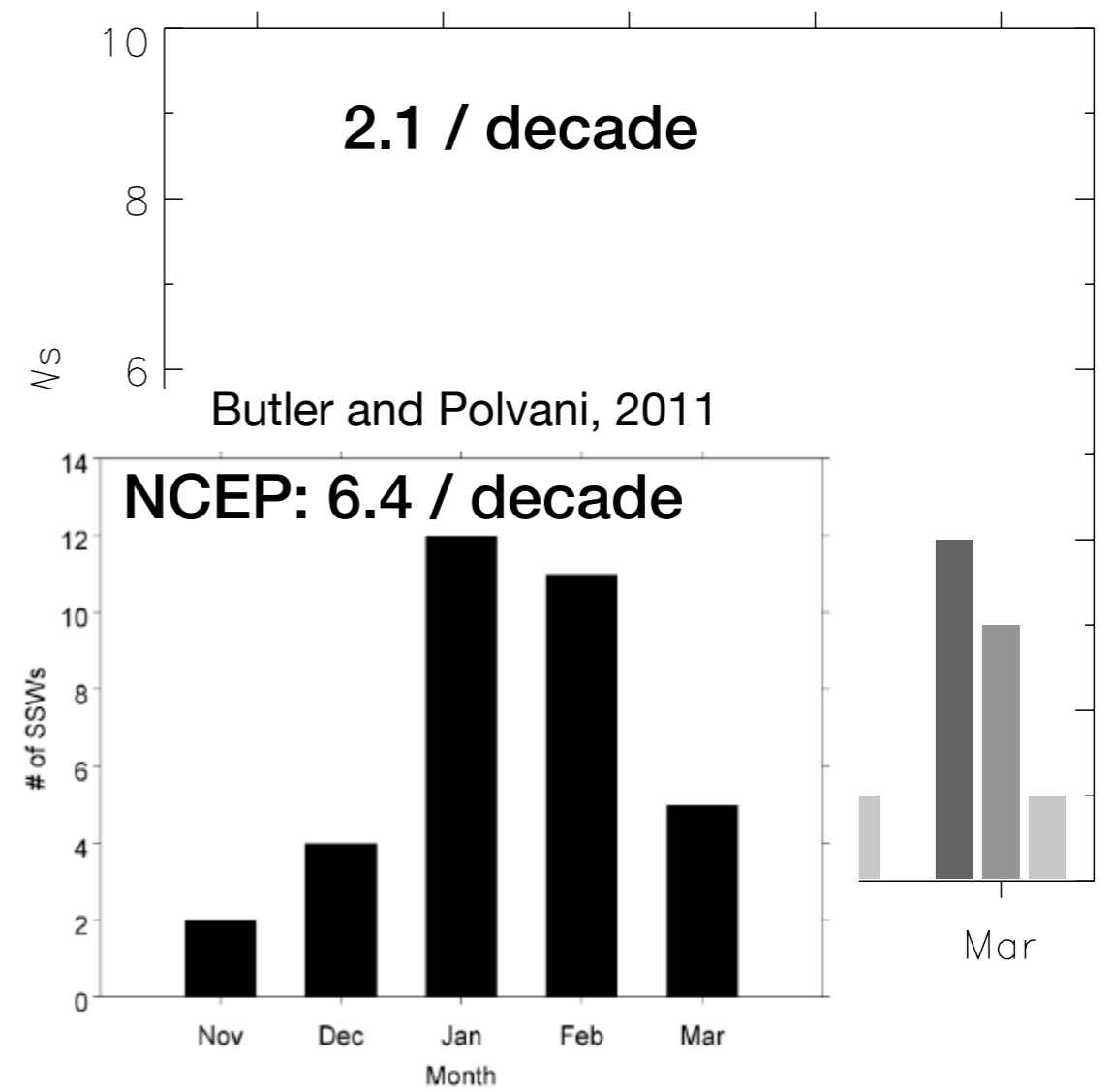
SSWs: “a major midwinter warming occurs when the zonal mean zonal winds at 60N and 10 hPa become easterly during winter, defined here as November-March (NDJFM)” - Charlton and Polvani, J. Clim. 2007

Stratospheric Sudden Warmings (1960-2005)

WACCM



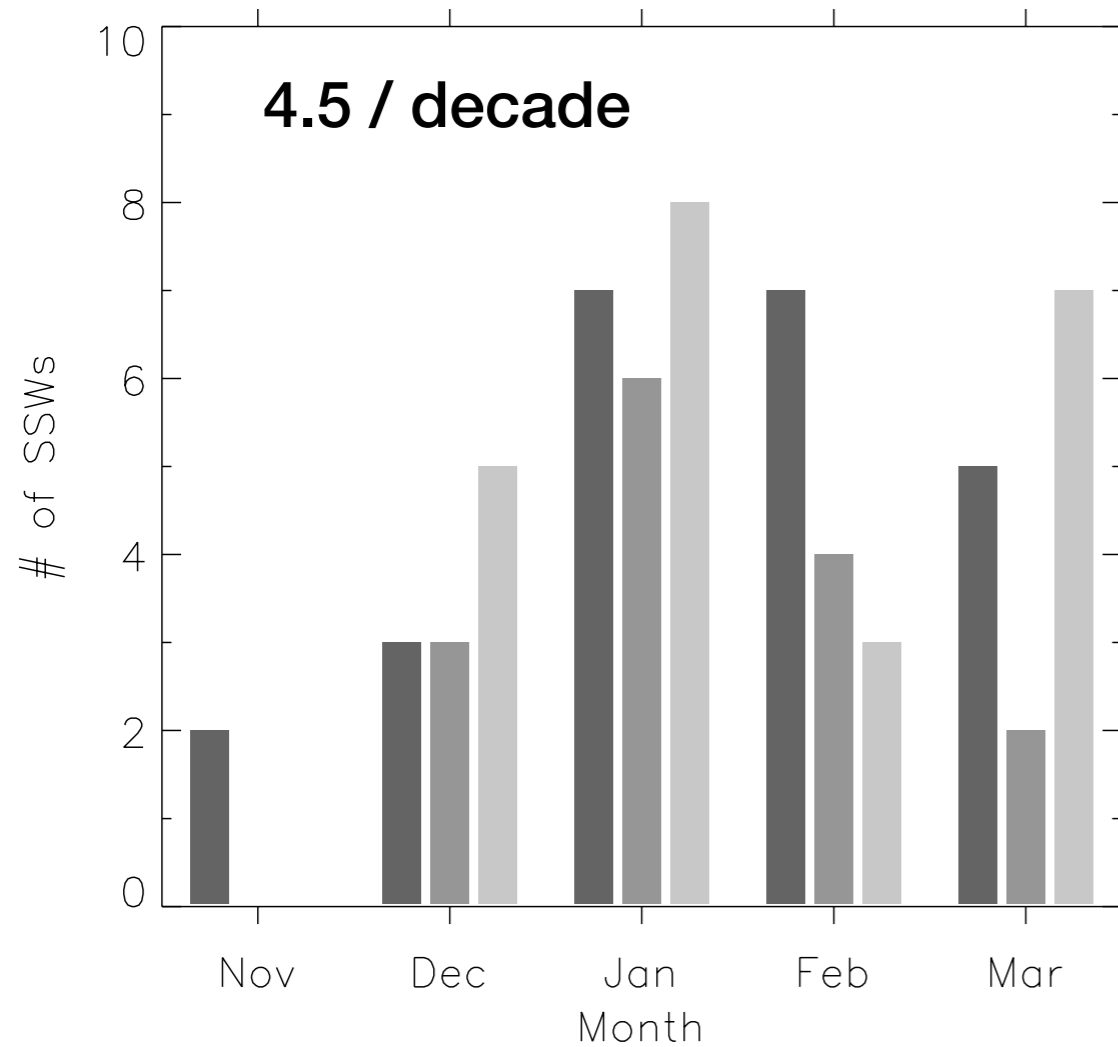
CCSM4-WSET



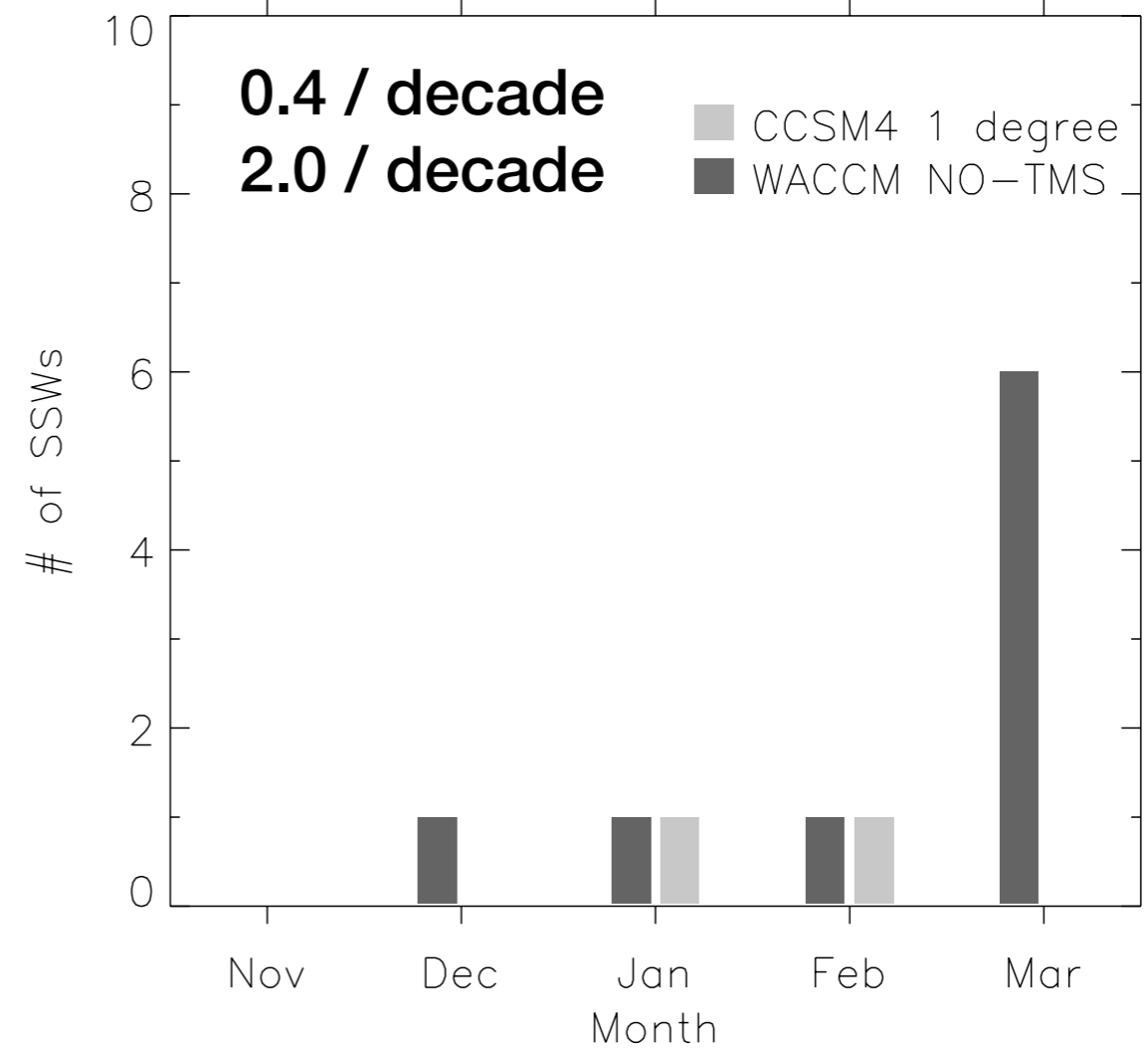
SSWs: “a major midwinter warming occurs when the zonal mean zonal winds at 60N and 10 hPa become easterly during winter, defined here as November-March (NDJFM)” - Charlton and Polvani, J. Clim. 2007

Stratospheric Sudden Warmings (1960-2005)

WACCM



CCSM4-1° & WACCM w/out TMS





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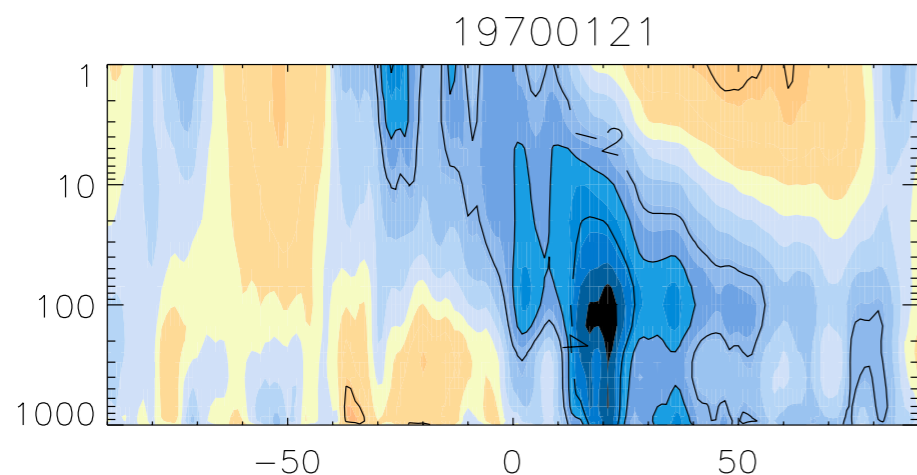
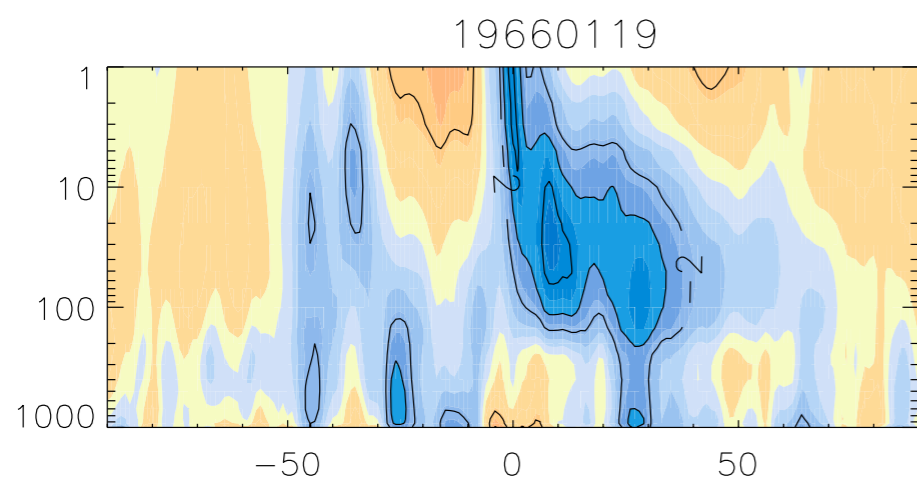
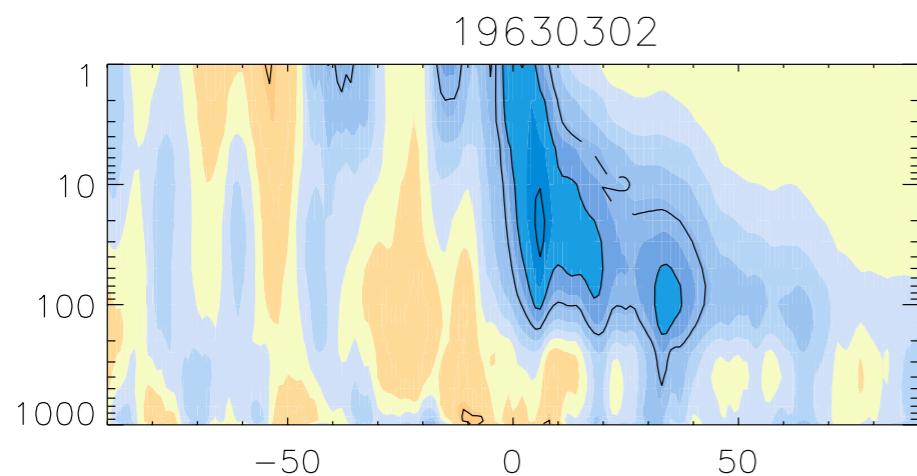


WACCM

Whole Atmosphere
Community Climate Model

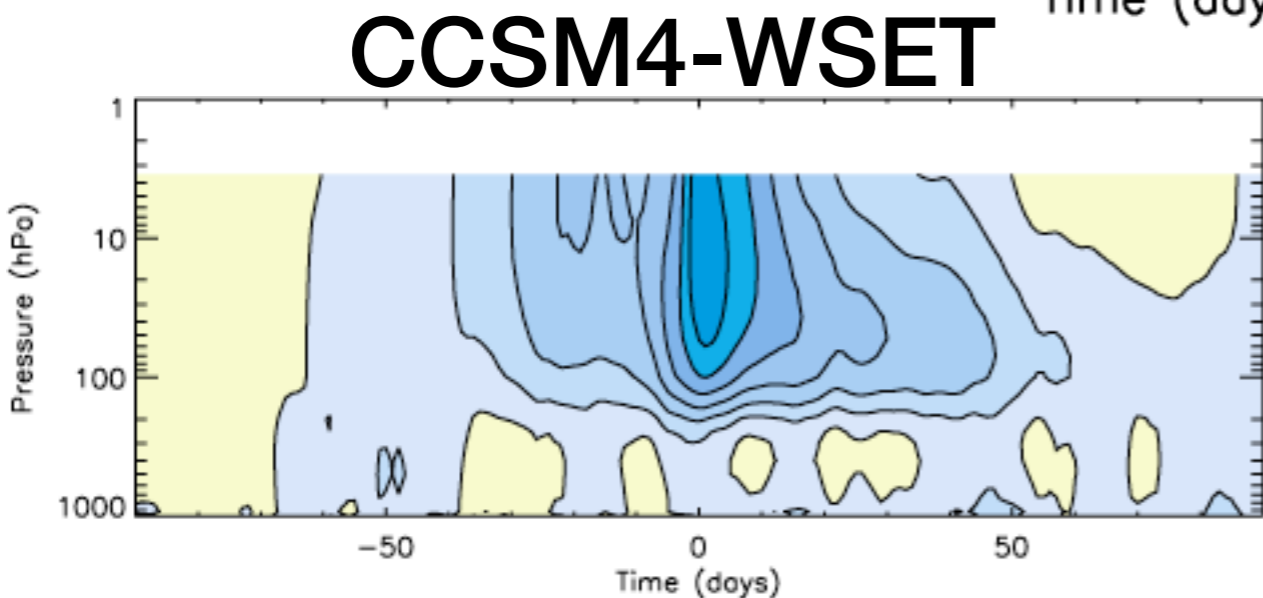
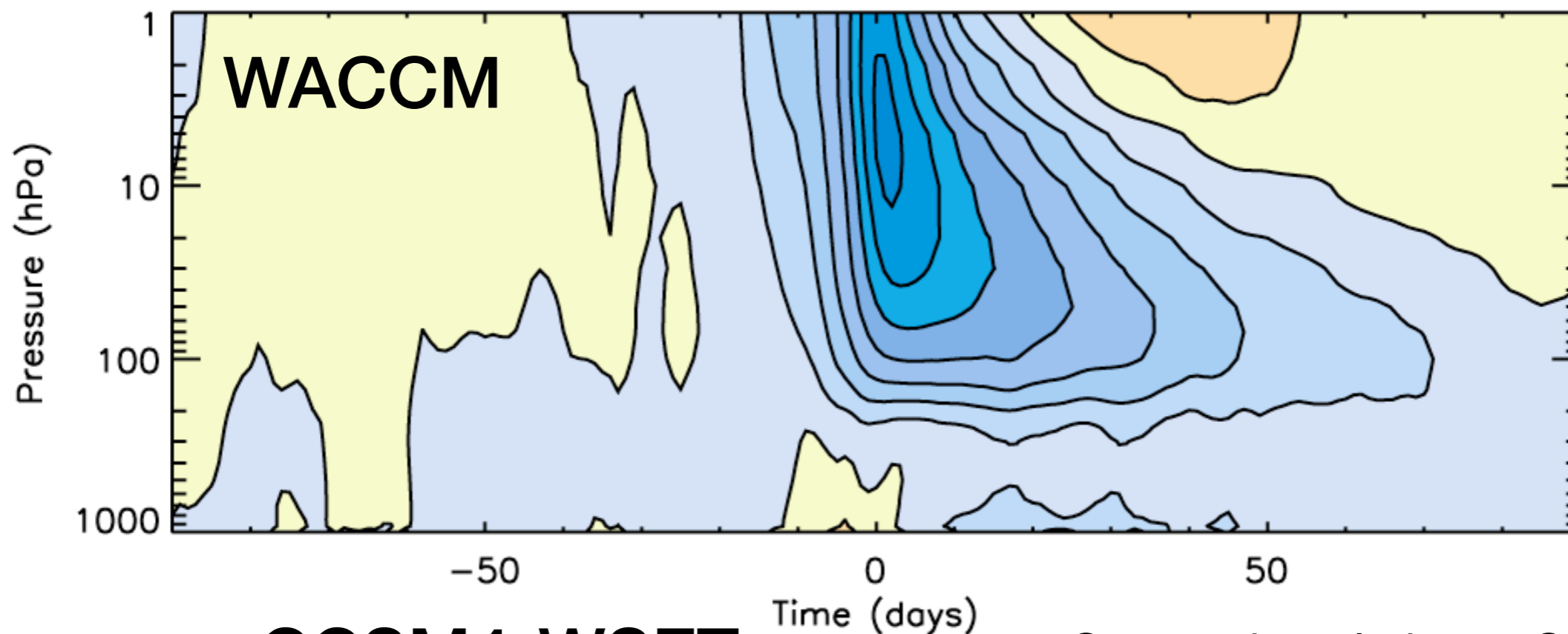


Northern Annular Modes



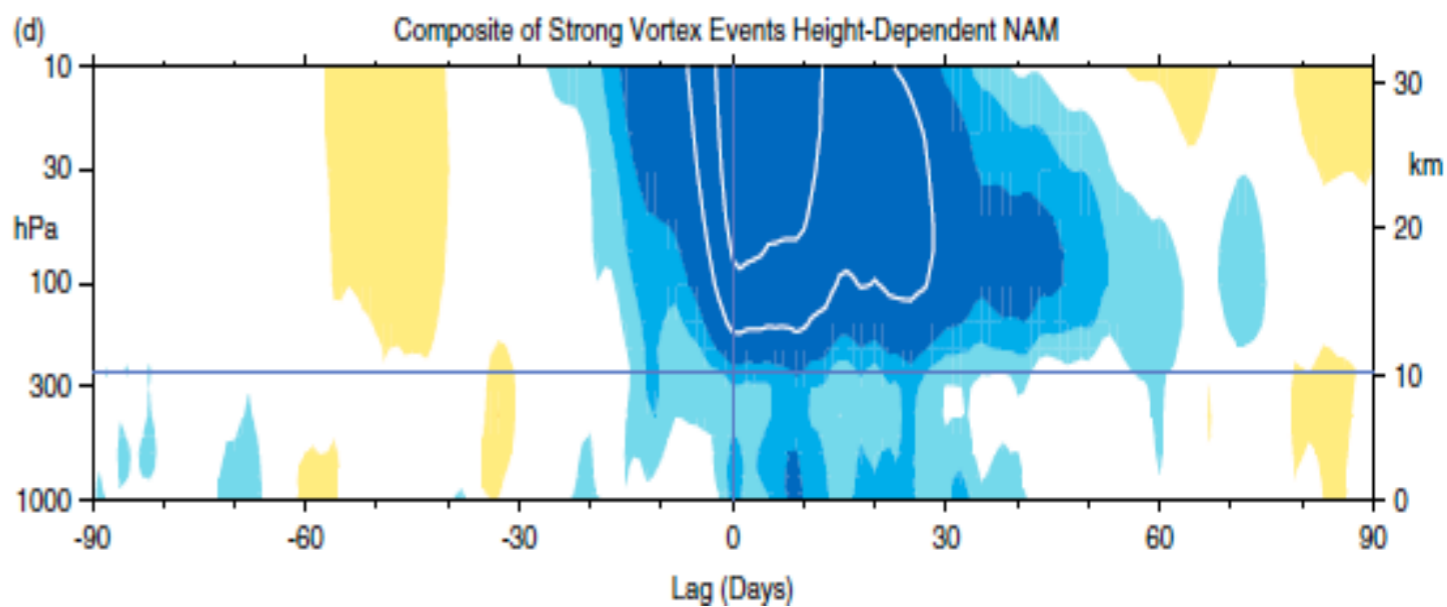
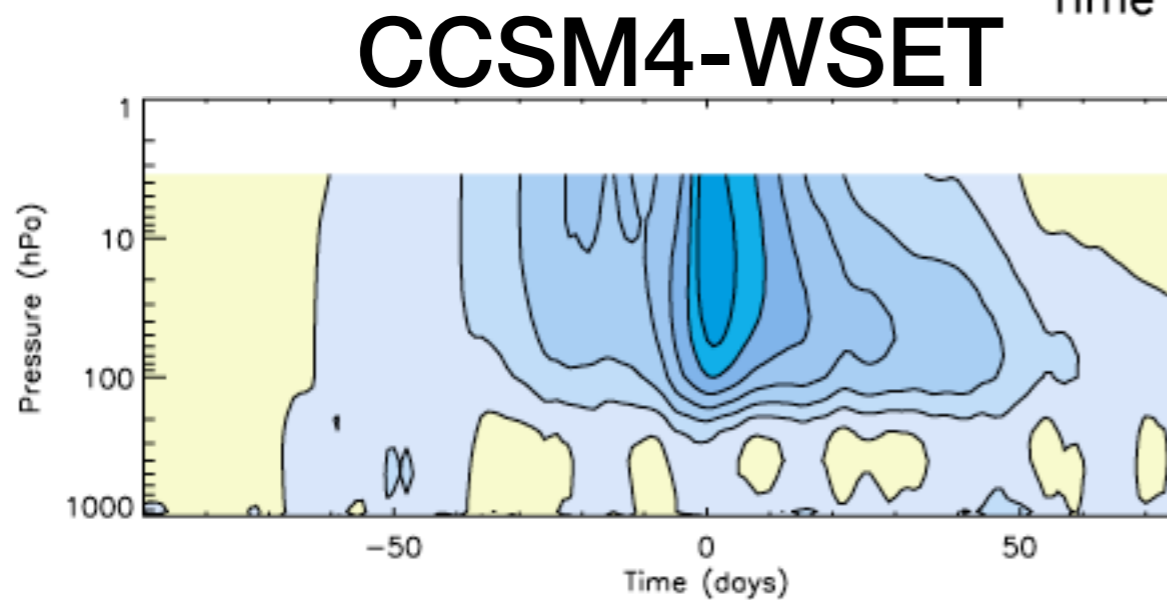
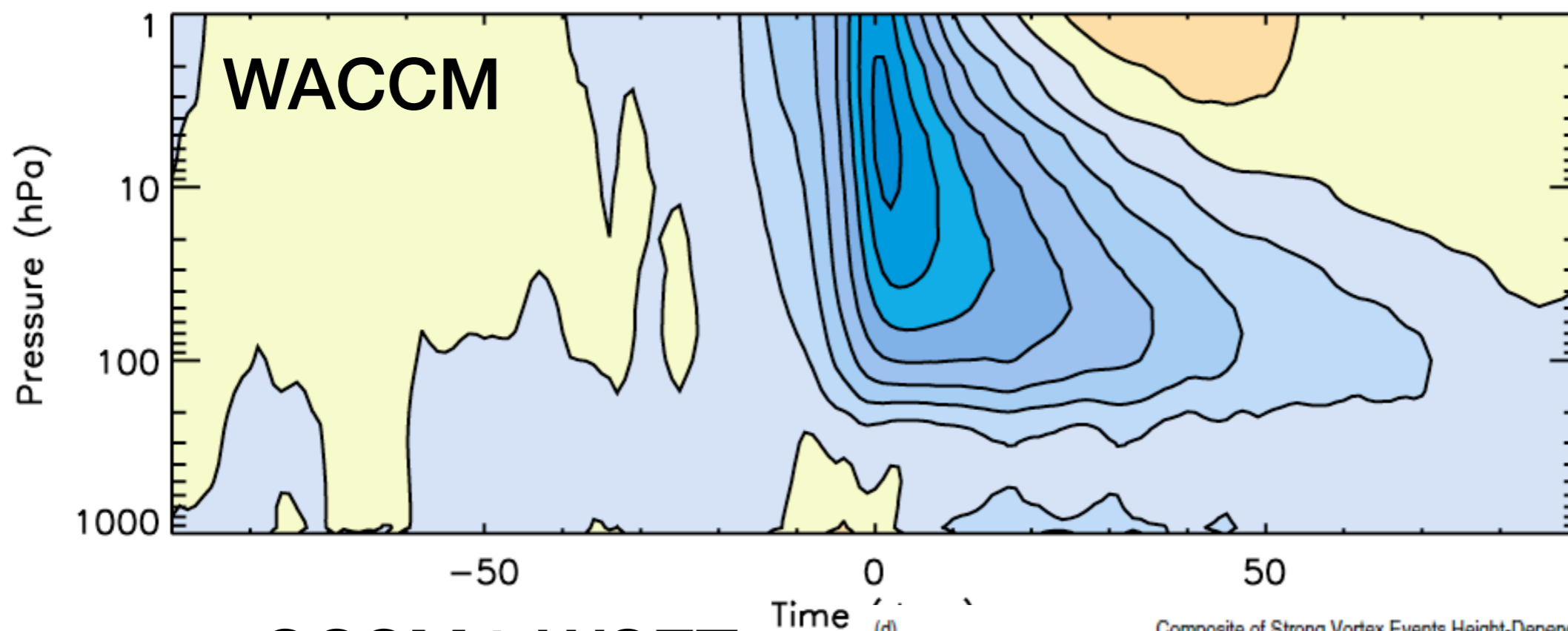
- Calculated from daily geopotential height by:
 - Remove daily global mean at each level
 - Average over polar cap ($>65^\circ\text{N}$)
 - Time mean and linear trend removed
 - Multiply by -1 and scale by standard deviation at each level
- Recipe courtesy of Lorenzo Polvani and Edwin Gerber.
- Shown relative to SSW 'central date'

NAM composite



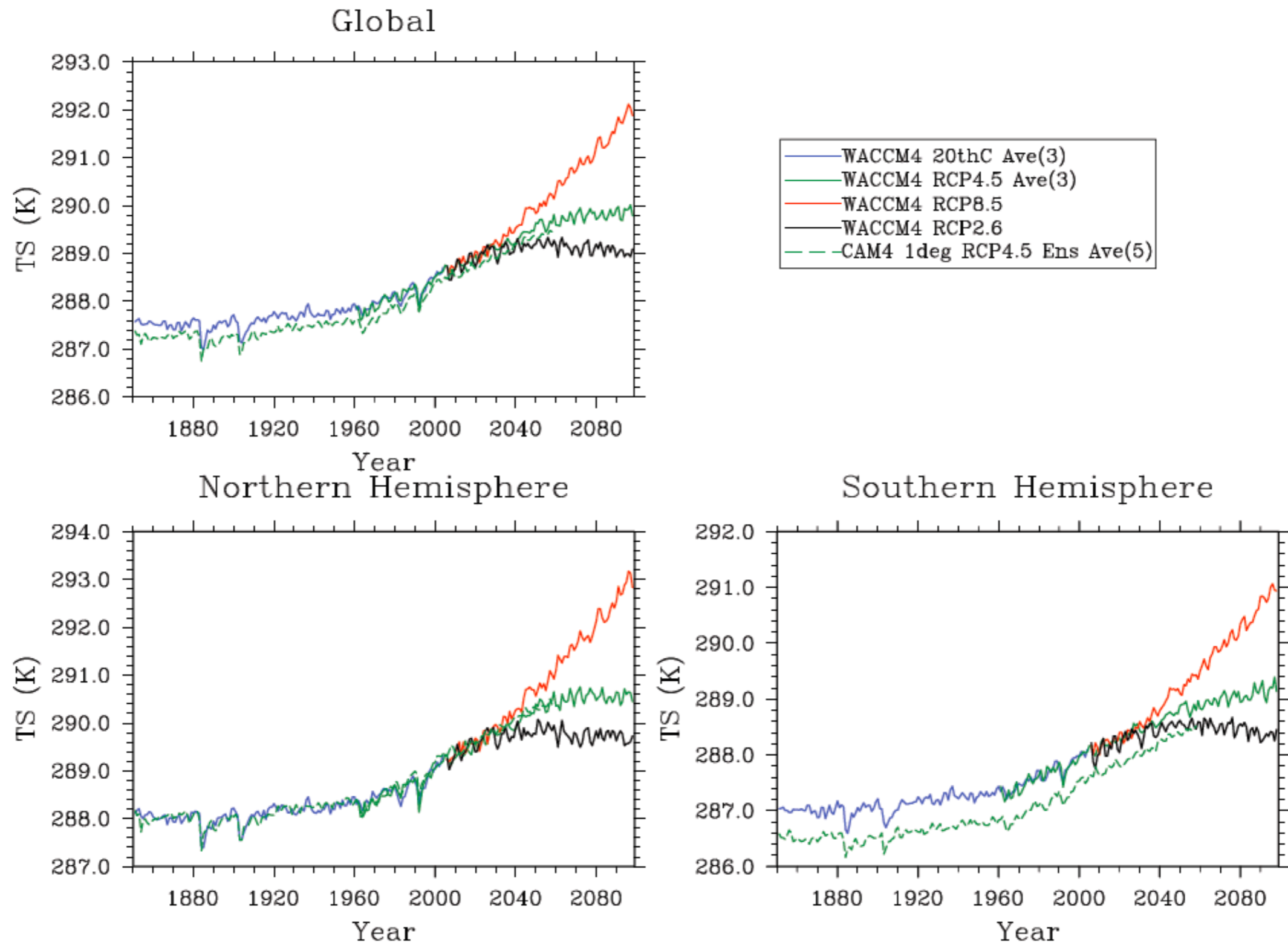
- Composite relative to SSW central date
- CCSM4-WSET is weaker, shorter-lived, and half as frequent
- Essentially this does not occur in CCSM4 for CMIP5

NAM composite



ERA-40 reanalysis Baldwin & Thompson (2009)

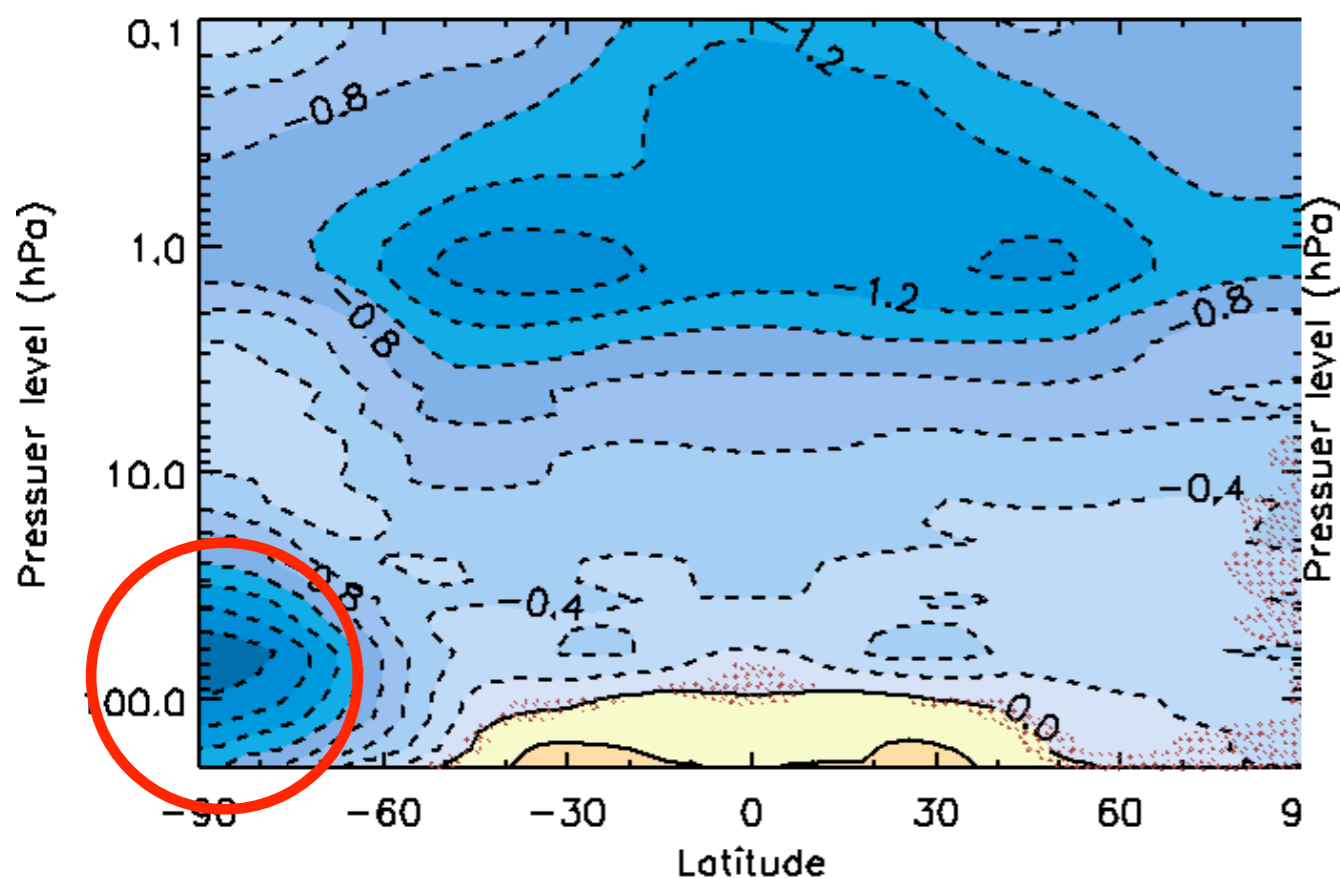
Annual mean surface temperature



Stratospheric T and Ozone trends 1960-2005

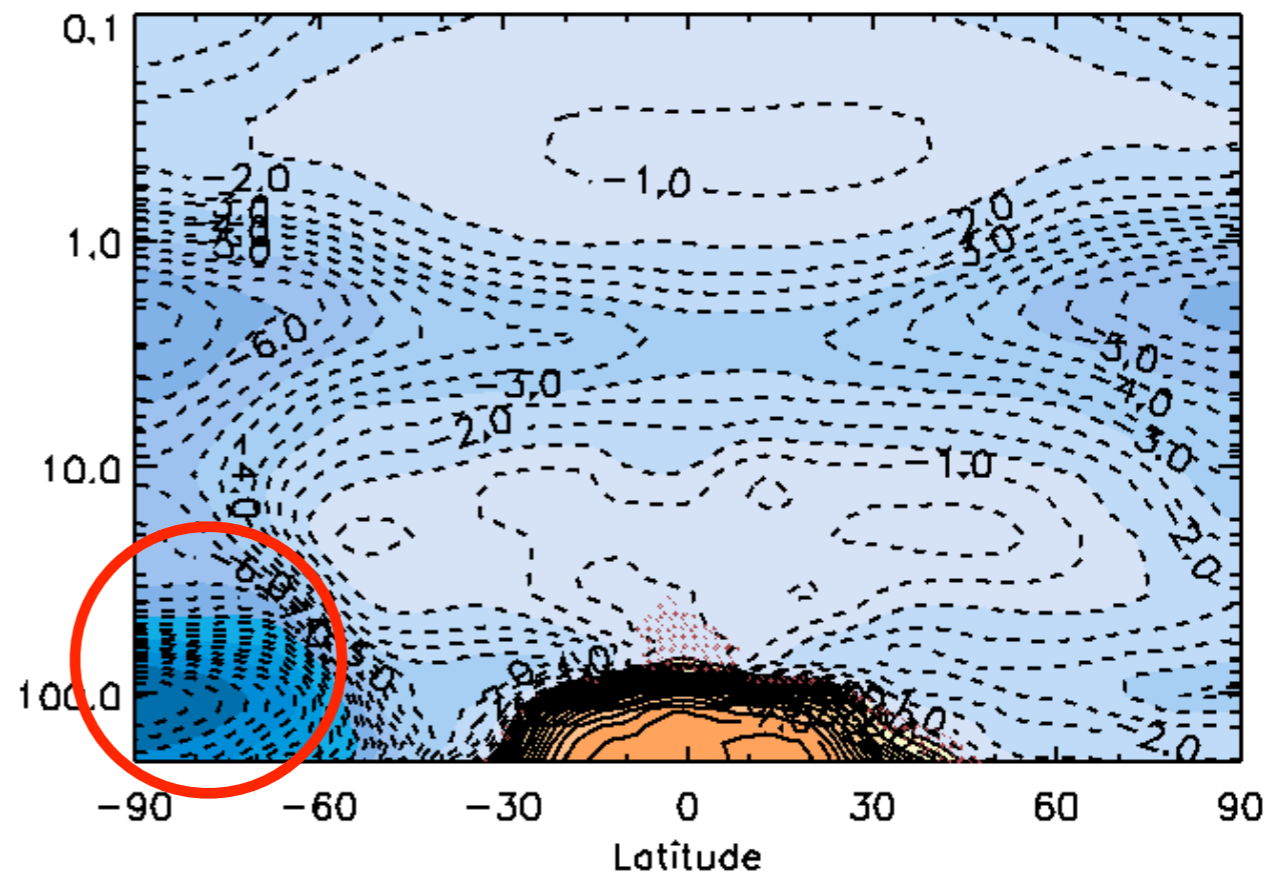
WACCM ensemble member 1

Temperature K/decade



1 to 1.4 K/decade cooling at the stratopause

Ozone %/decade



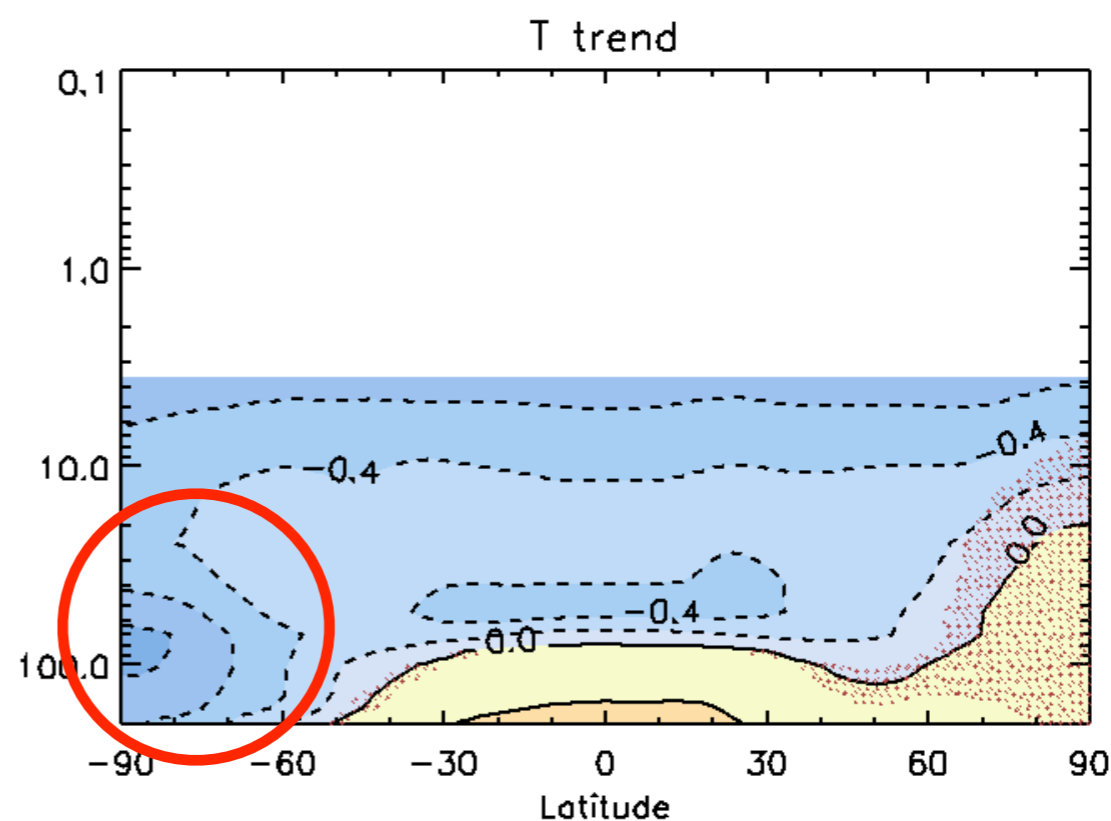
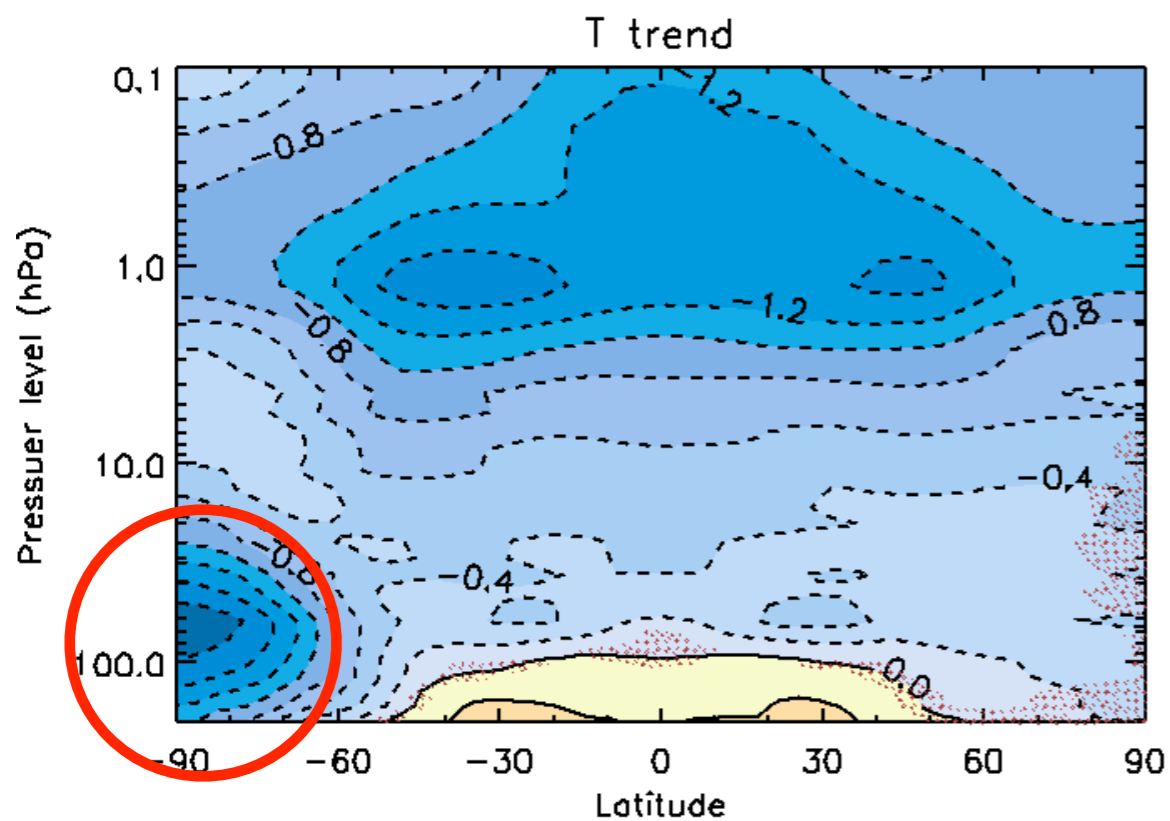
-3 to -8 %/decade decrease in the upper stratosphere

WACCM vs 'low-top' CCSM4 temperature changes

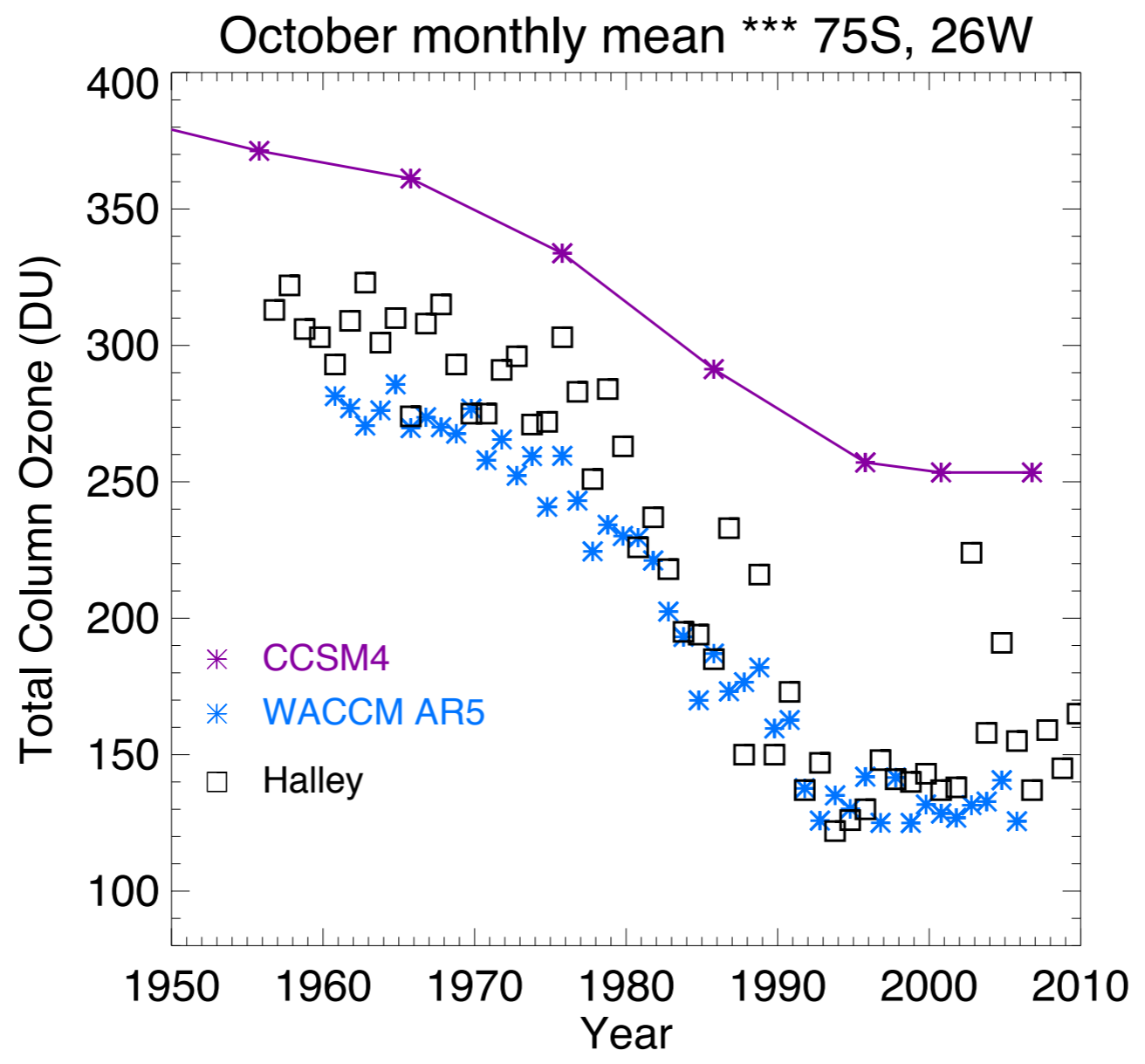
WACCM ensemble member 1

CCSM4-WSET ensemble member 1

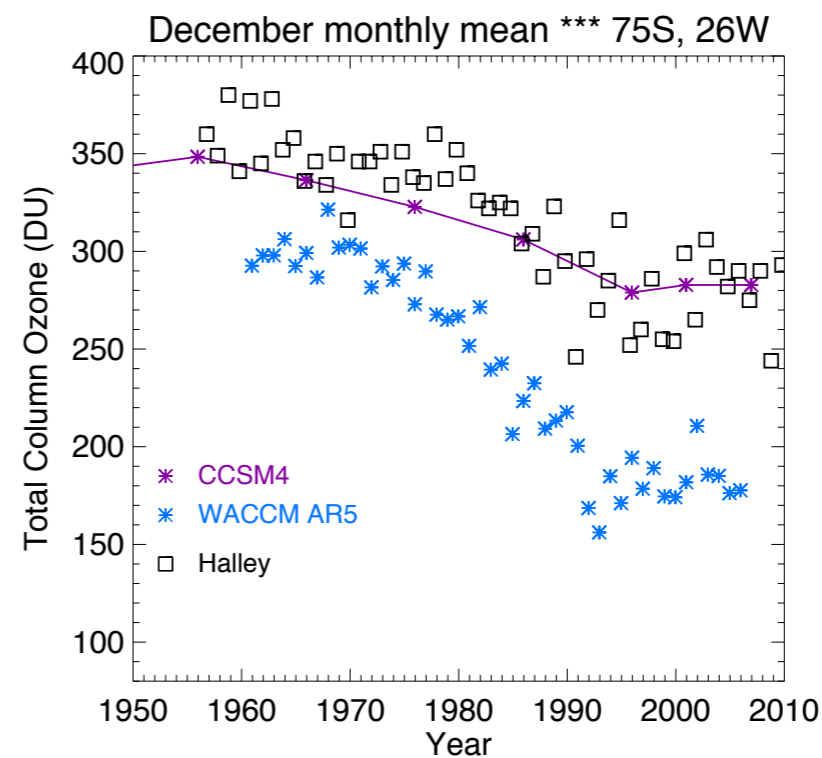
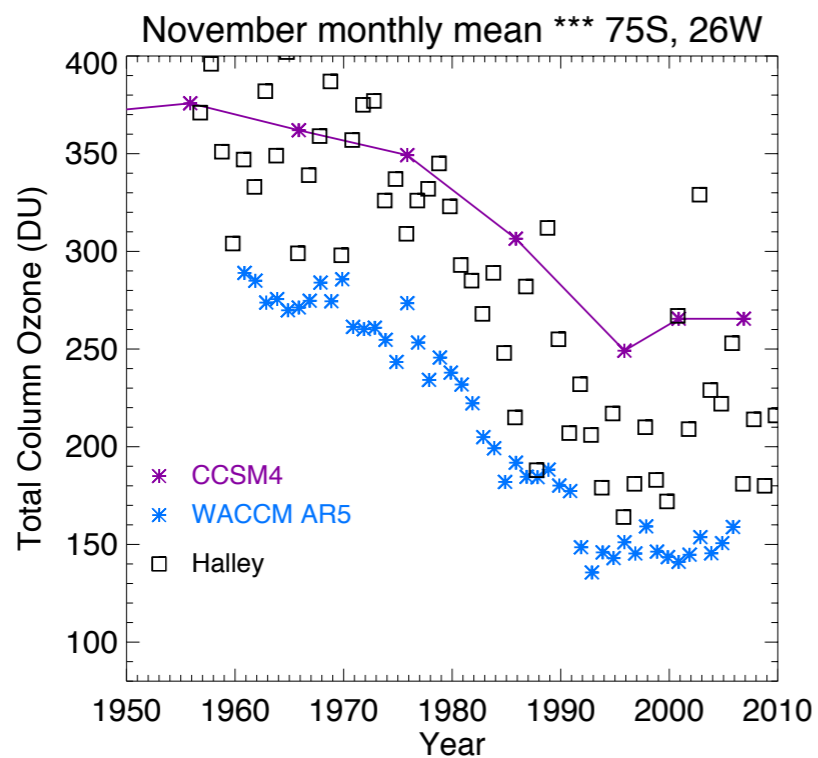
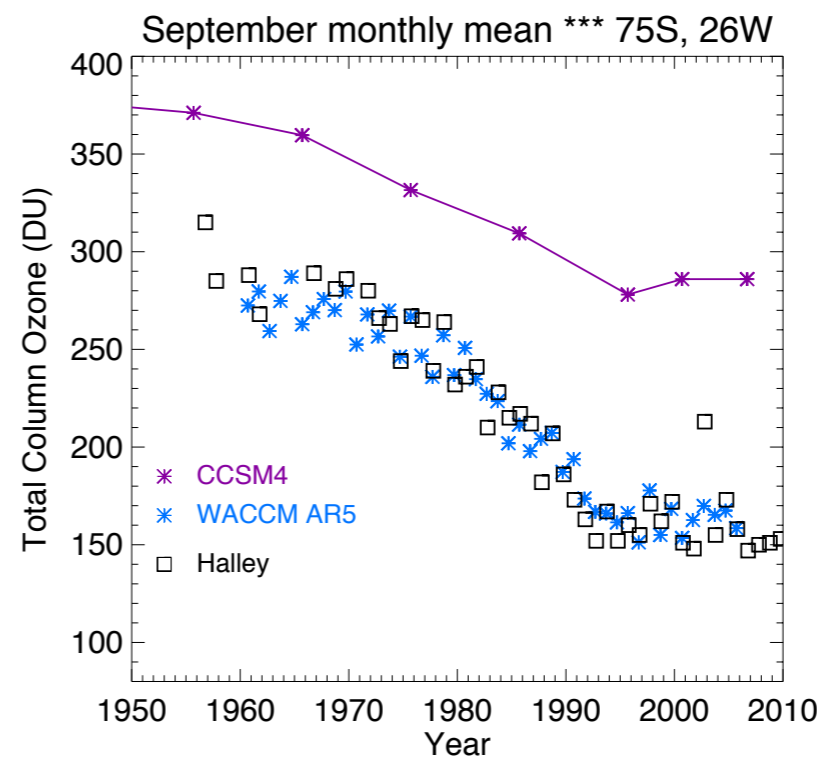
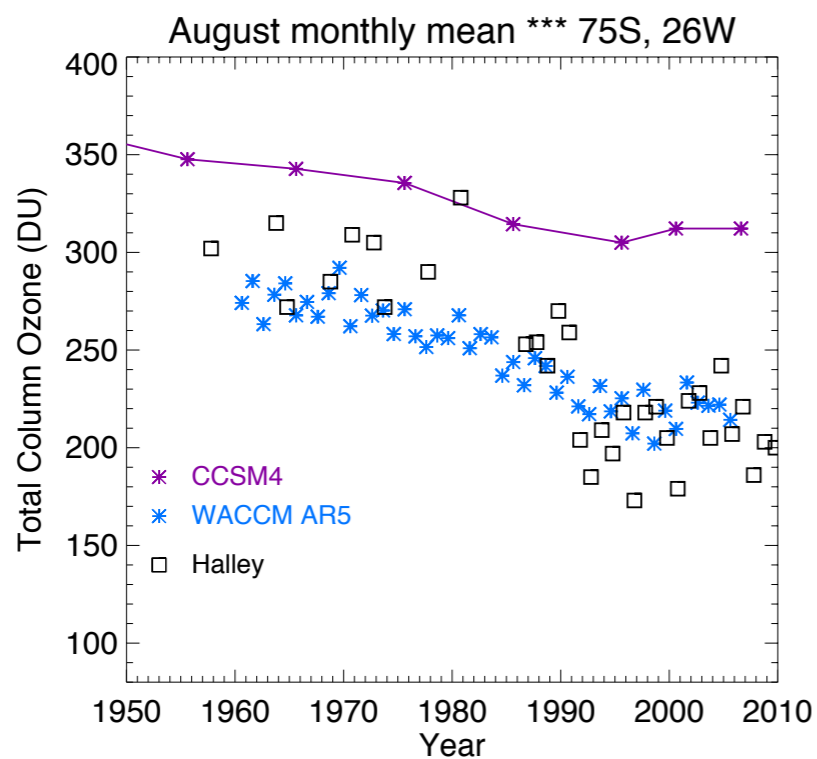
trends 1960-2005



Total Column Ozone - October, Halley Bay



Total Column Ozone - Halley Bay

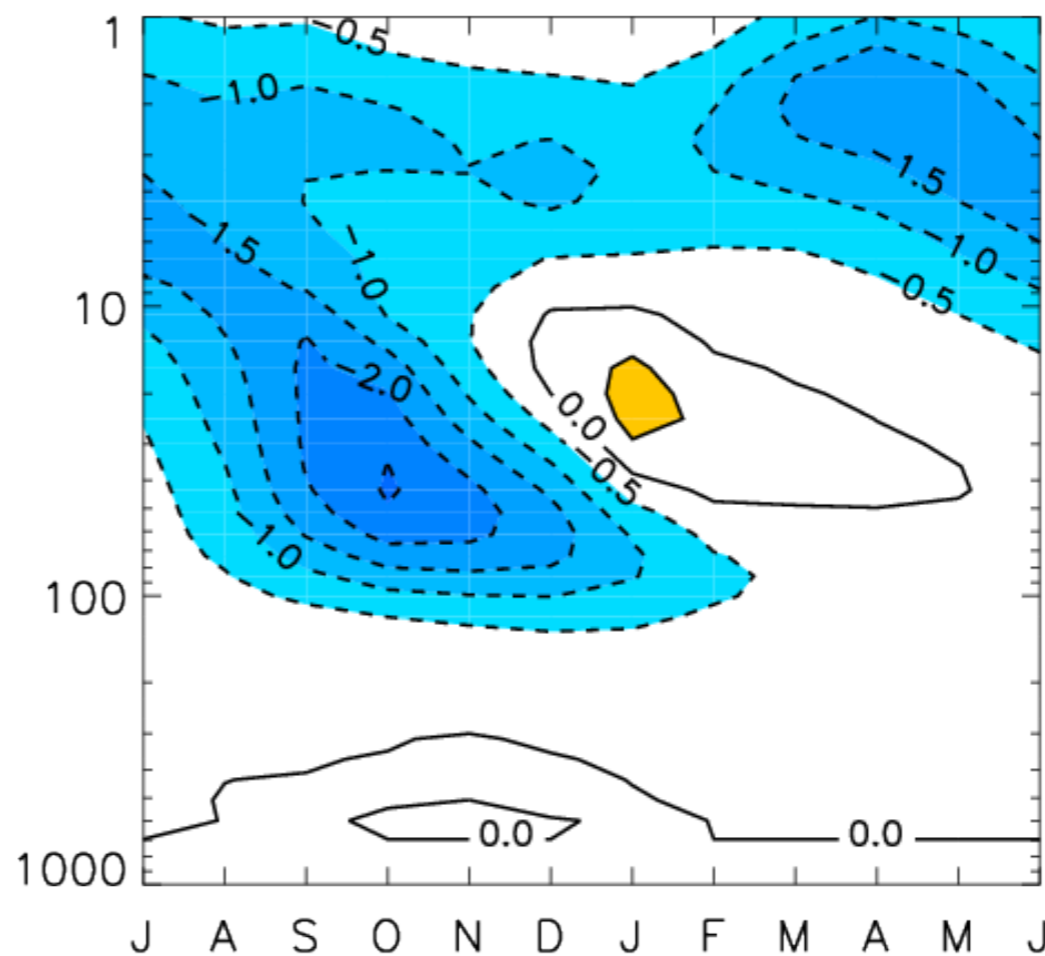
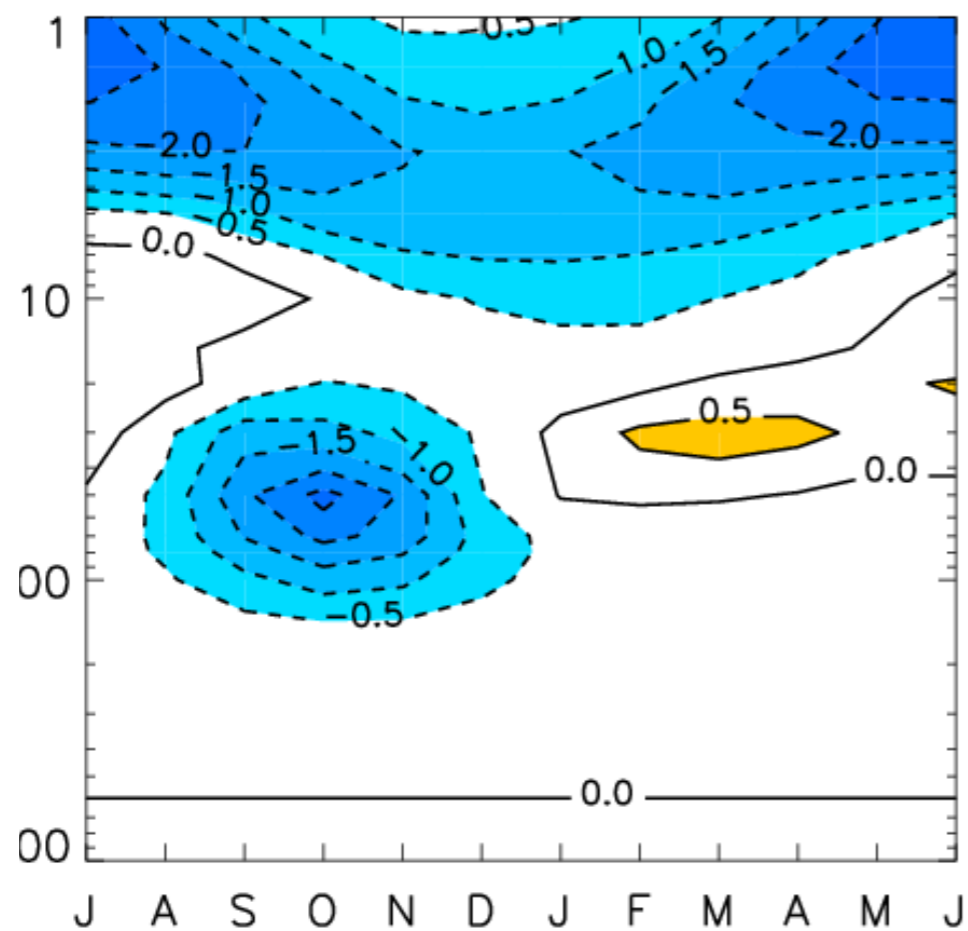


SH polar cap ozone trends

1969-1998

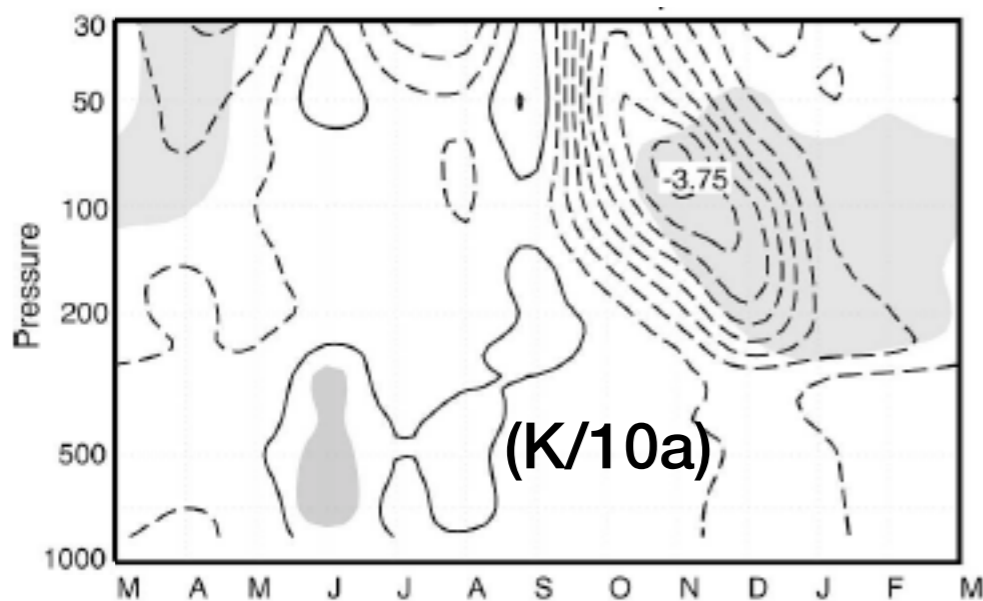
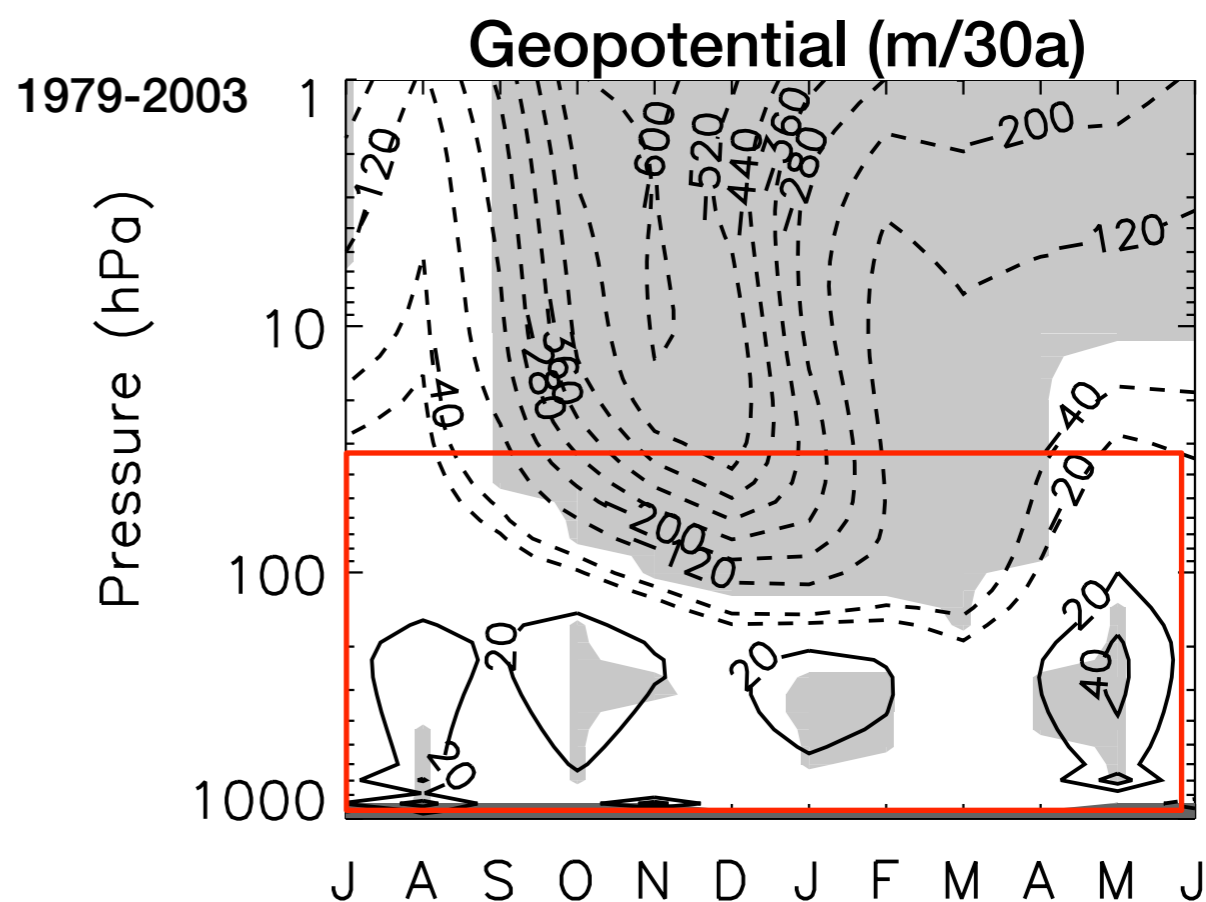
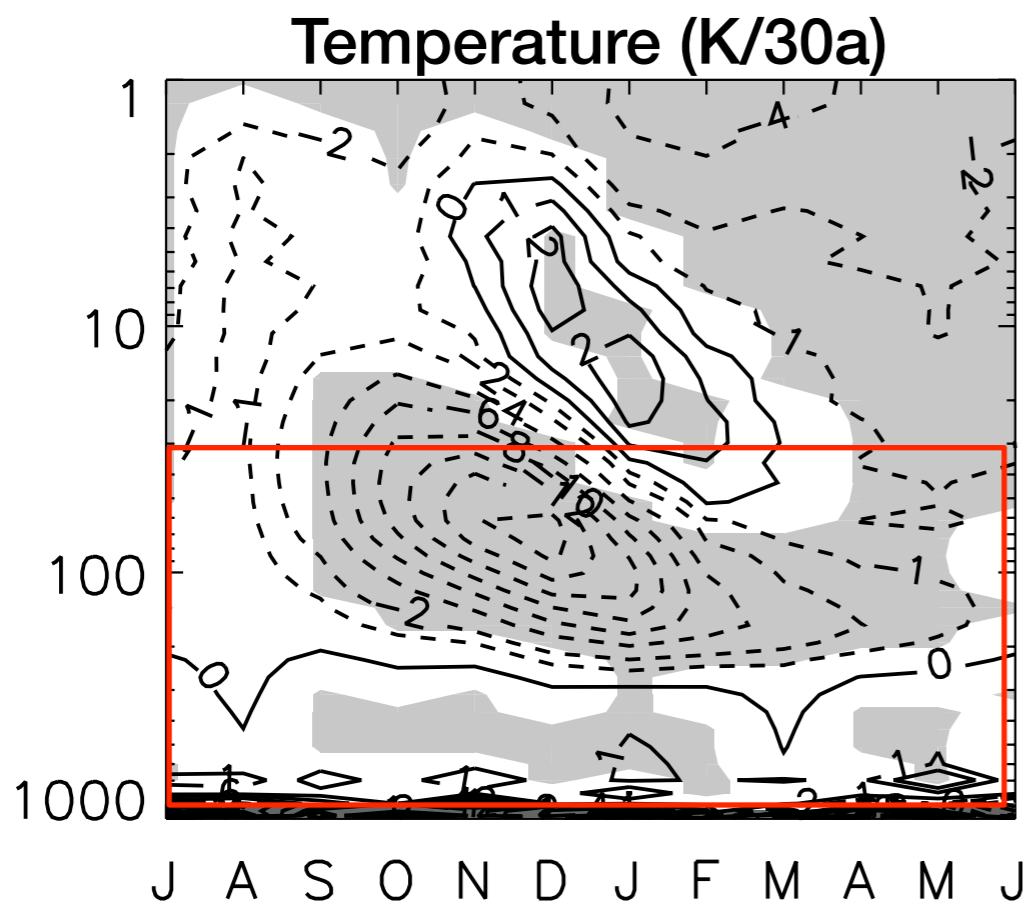
OBS. (SPARC)

WACCM



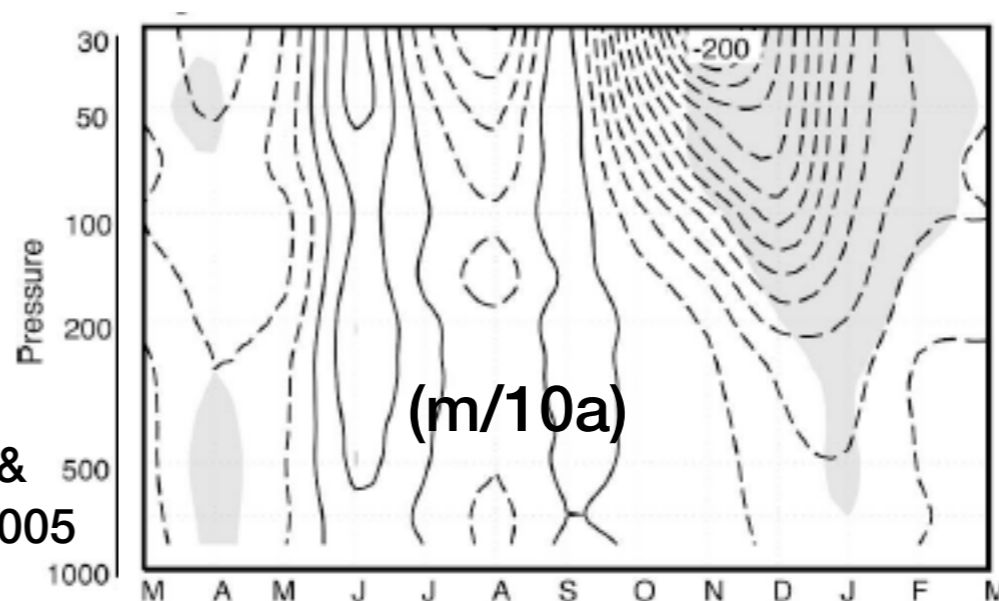
Contours: 0.2 ppbv/30yrs

Temperature & geopotential height trends 1979-2003



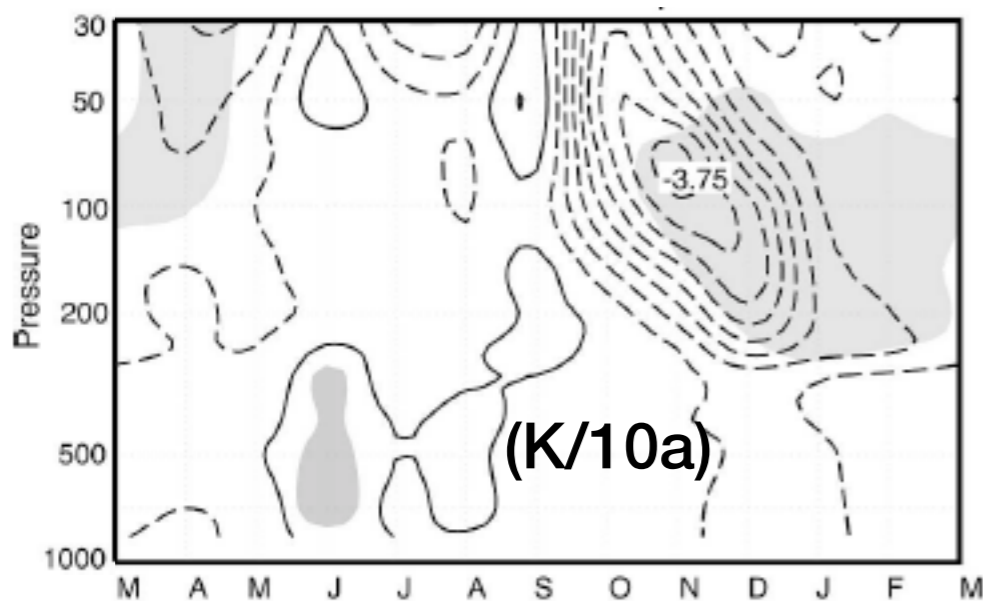
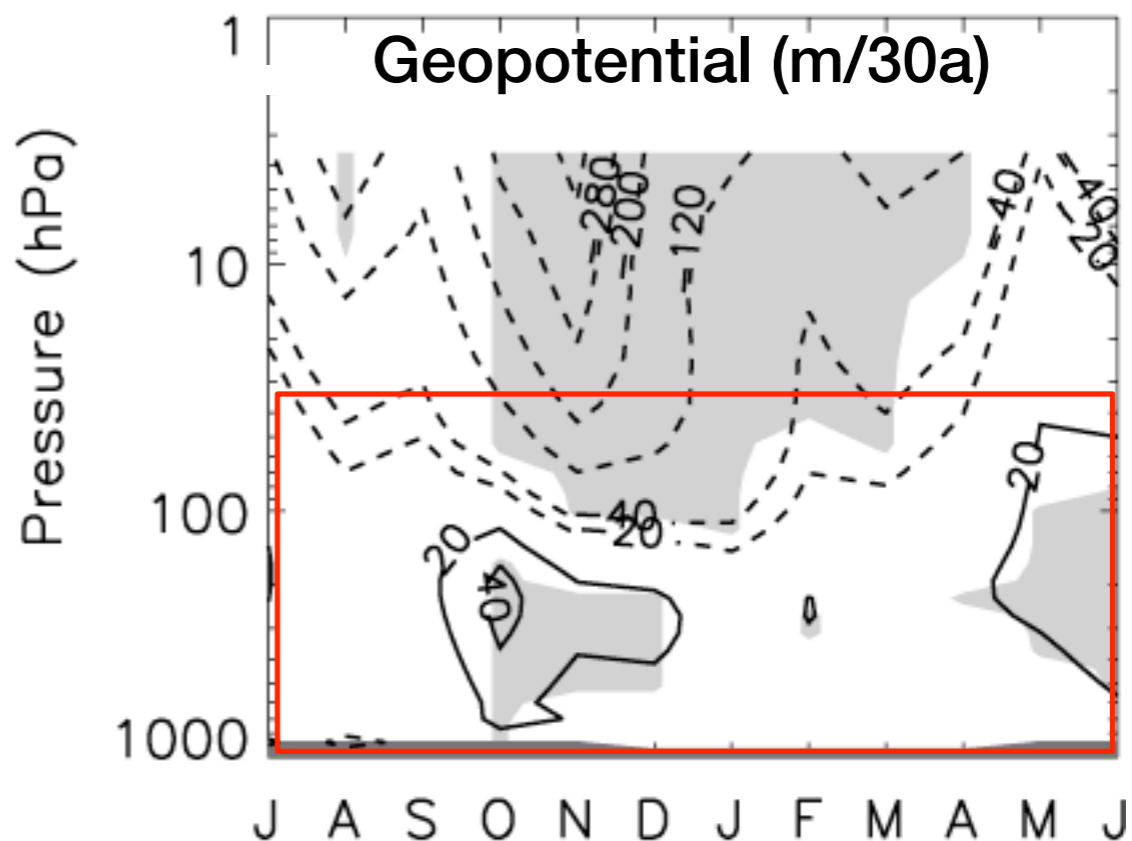
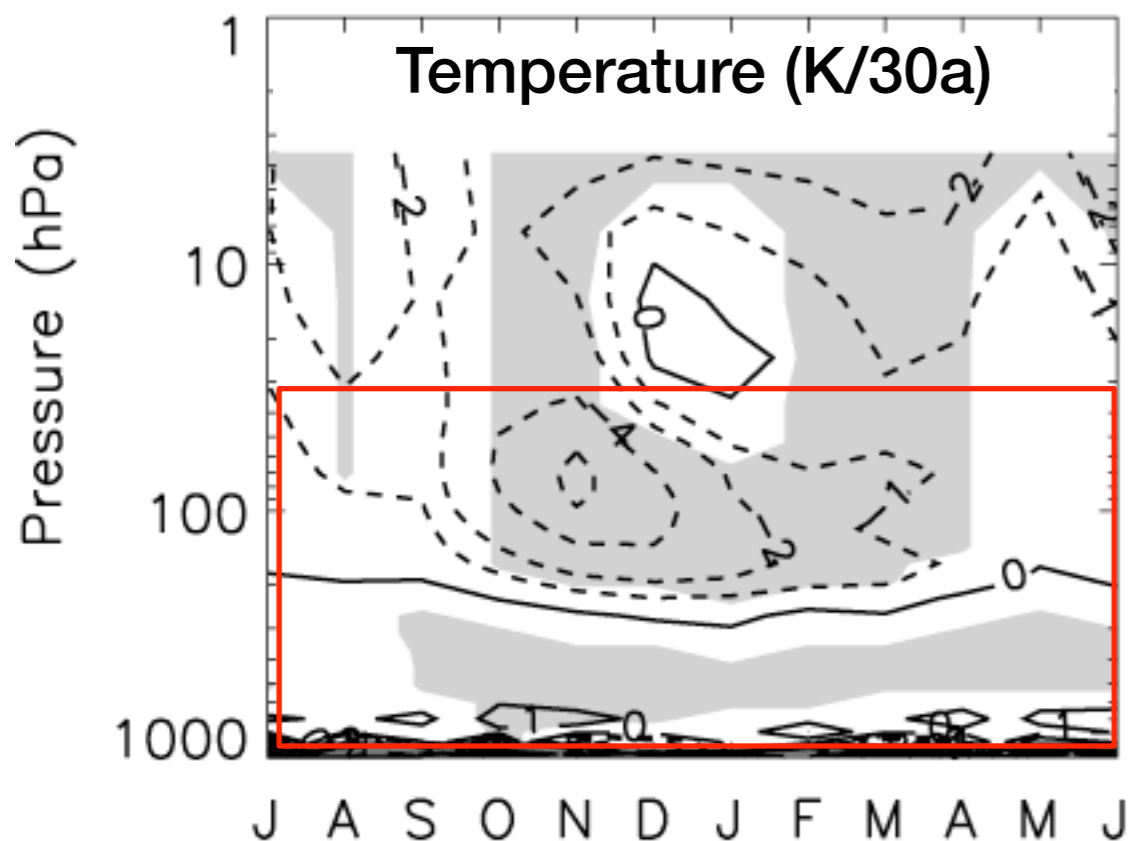
1979-2003

Thompson & Solomon, 2005



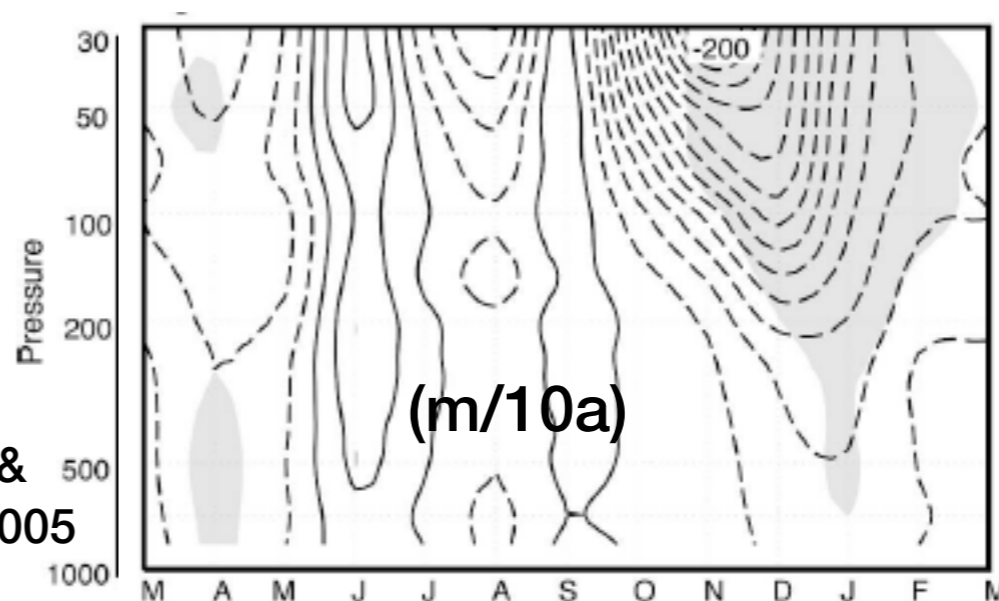
Temperature & geopotential height trends 1979-2003

Trends weaker in CCSM4-WSET

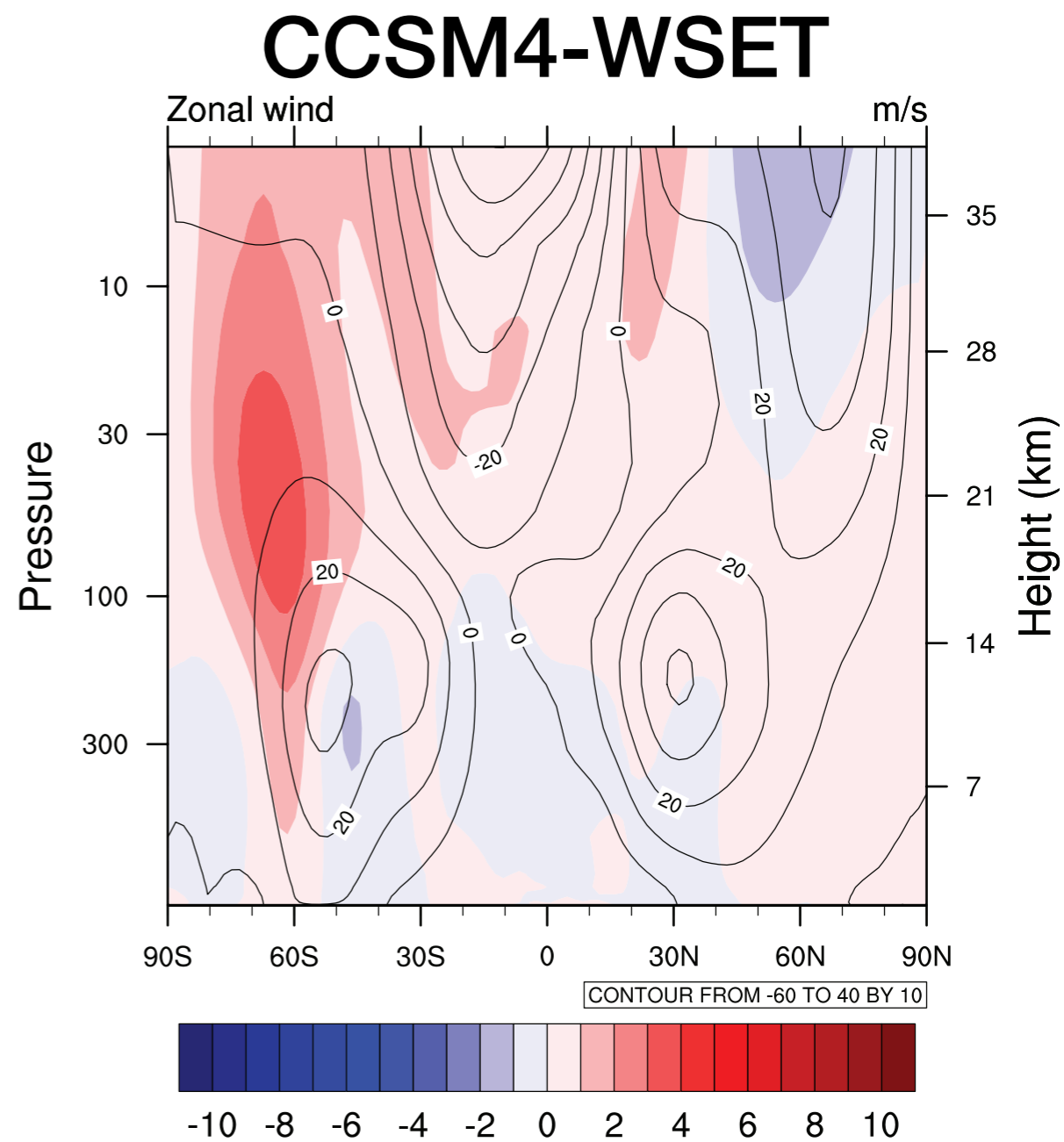
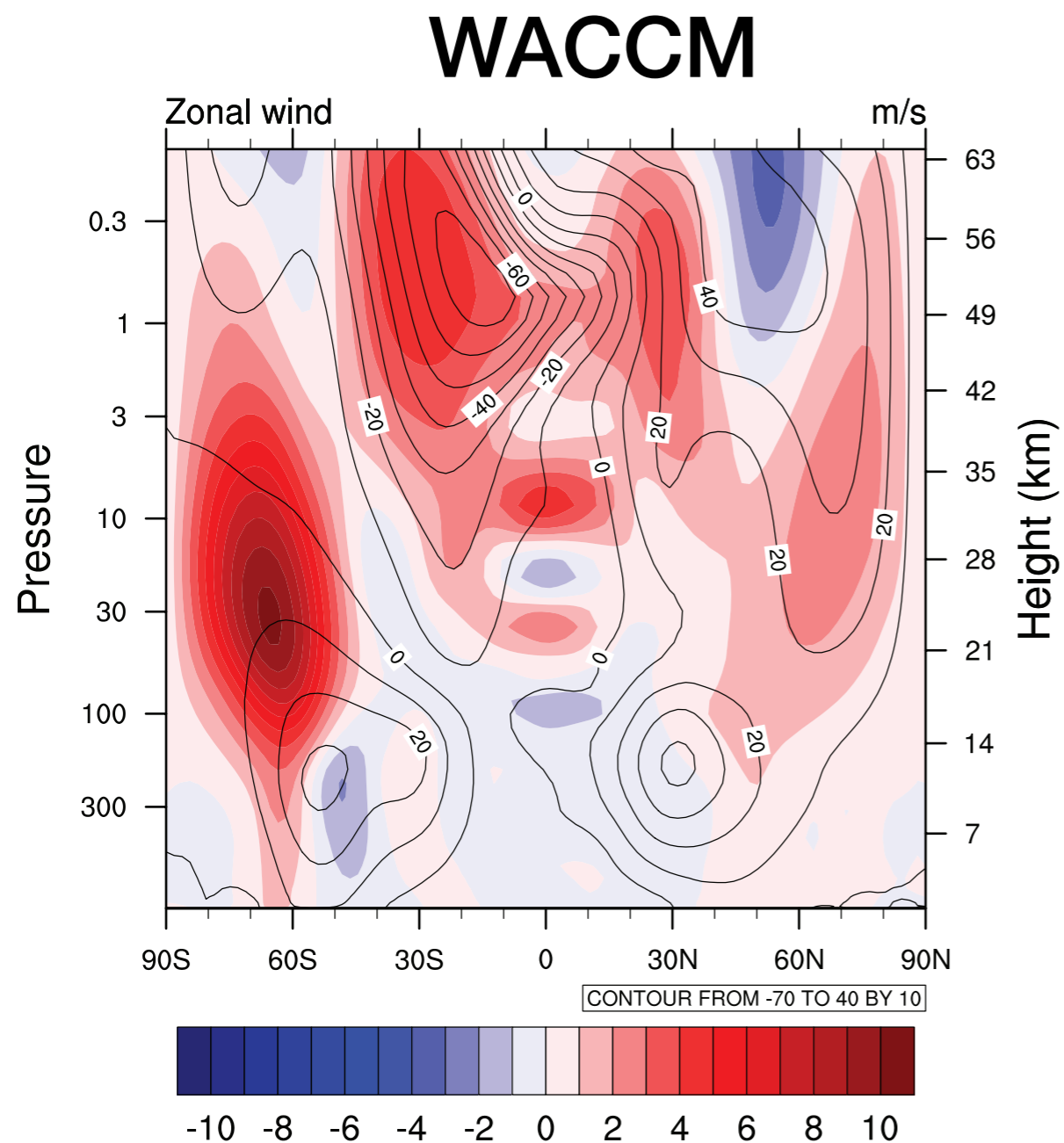


1979-2003

Thompson & Solomon, 2005



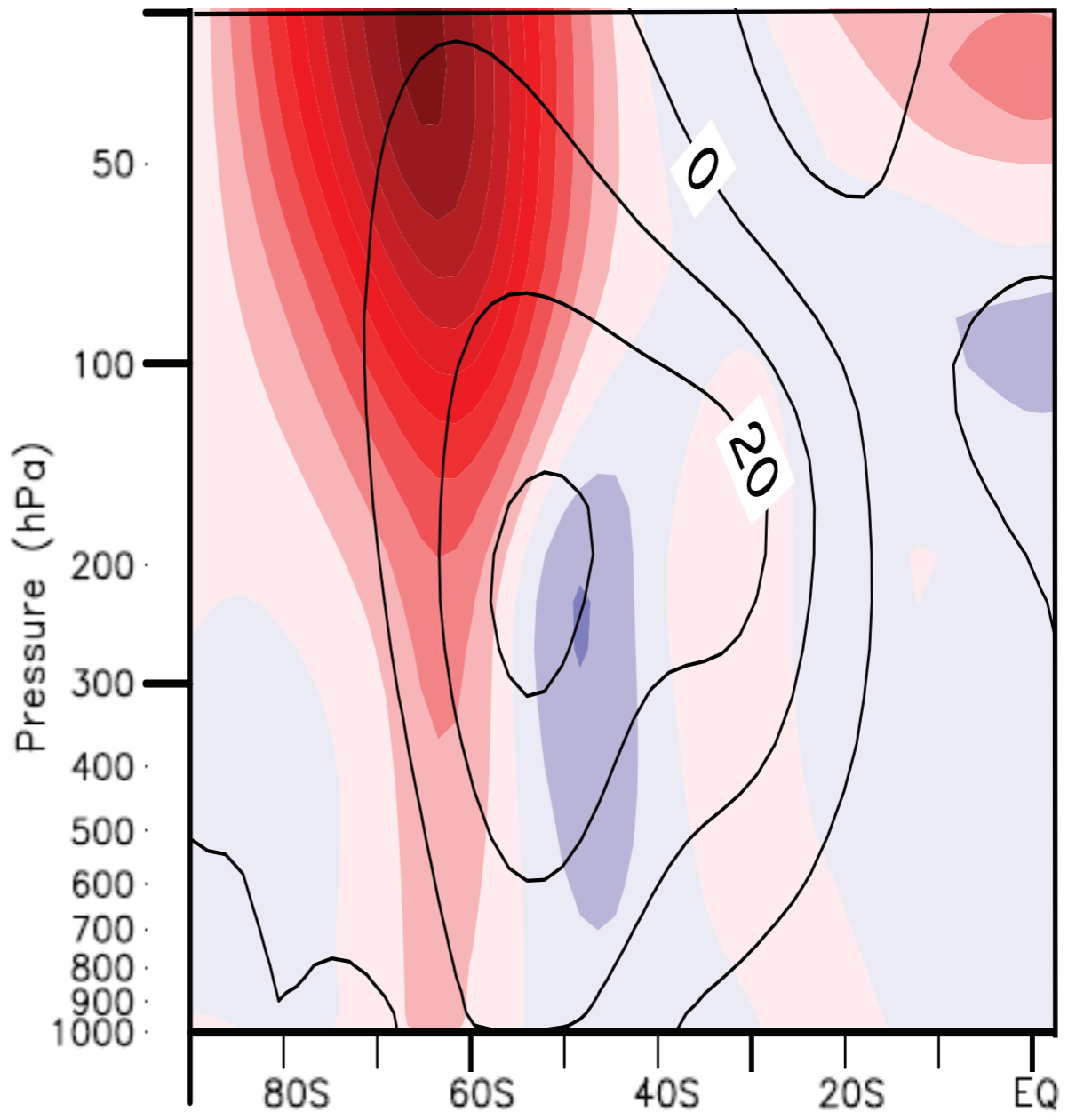
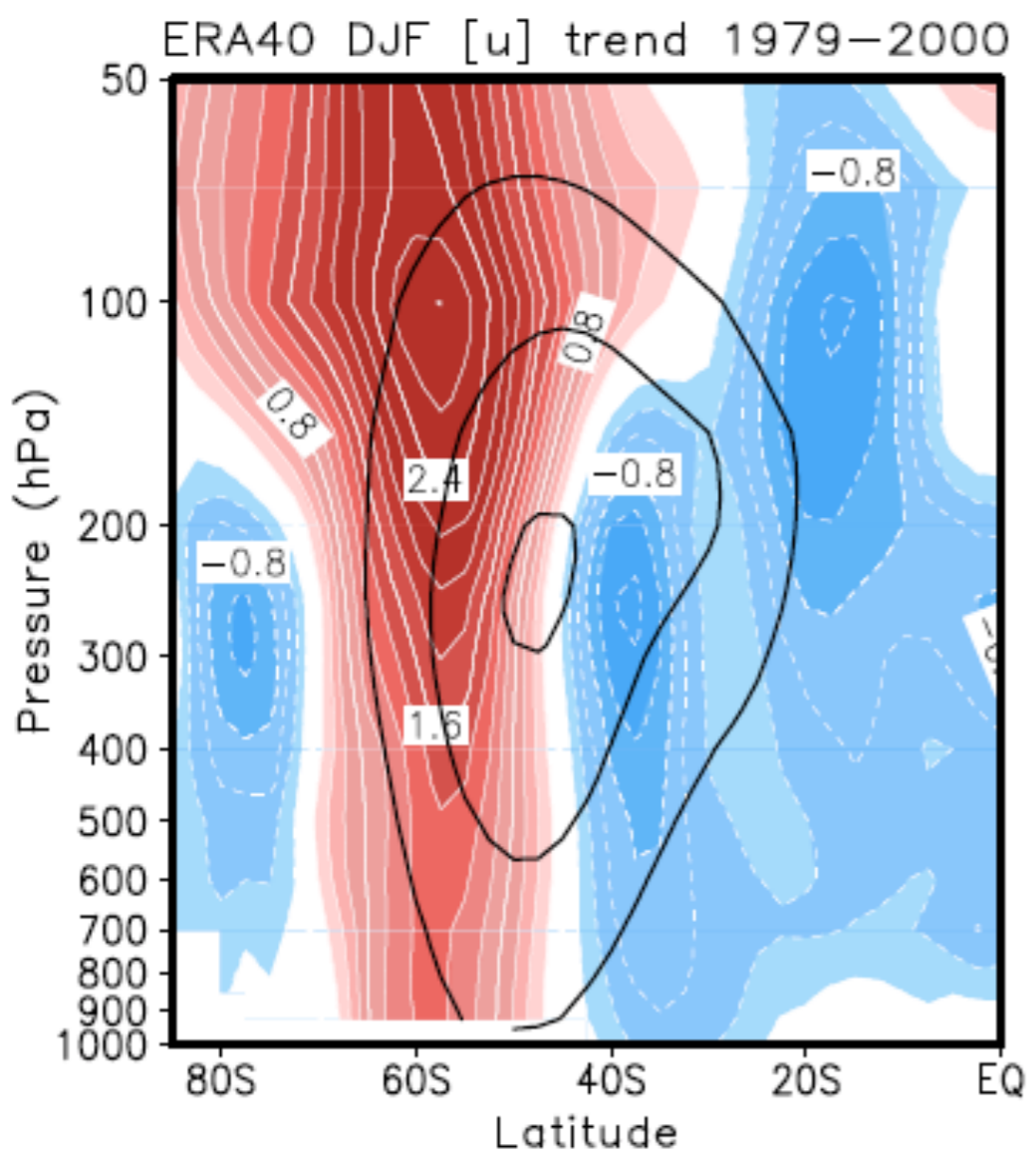
DJF zonal wind (m/s)



Colors: 1986-2005 average minus 1960-79 average.
Lines: 1960-79 average.

DJF zonal wind (m/s)

WACCM



Son et al., 2008



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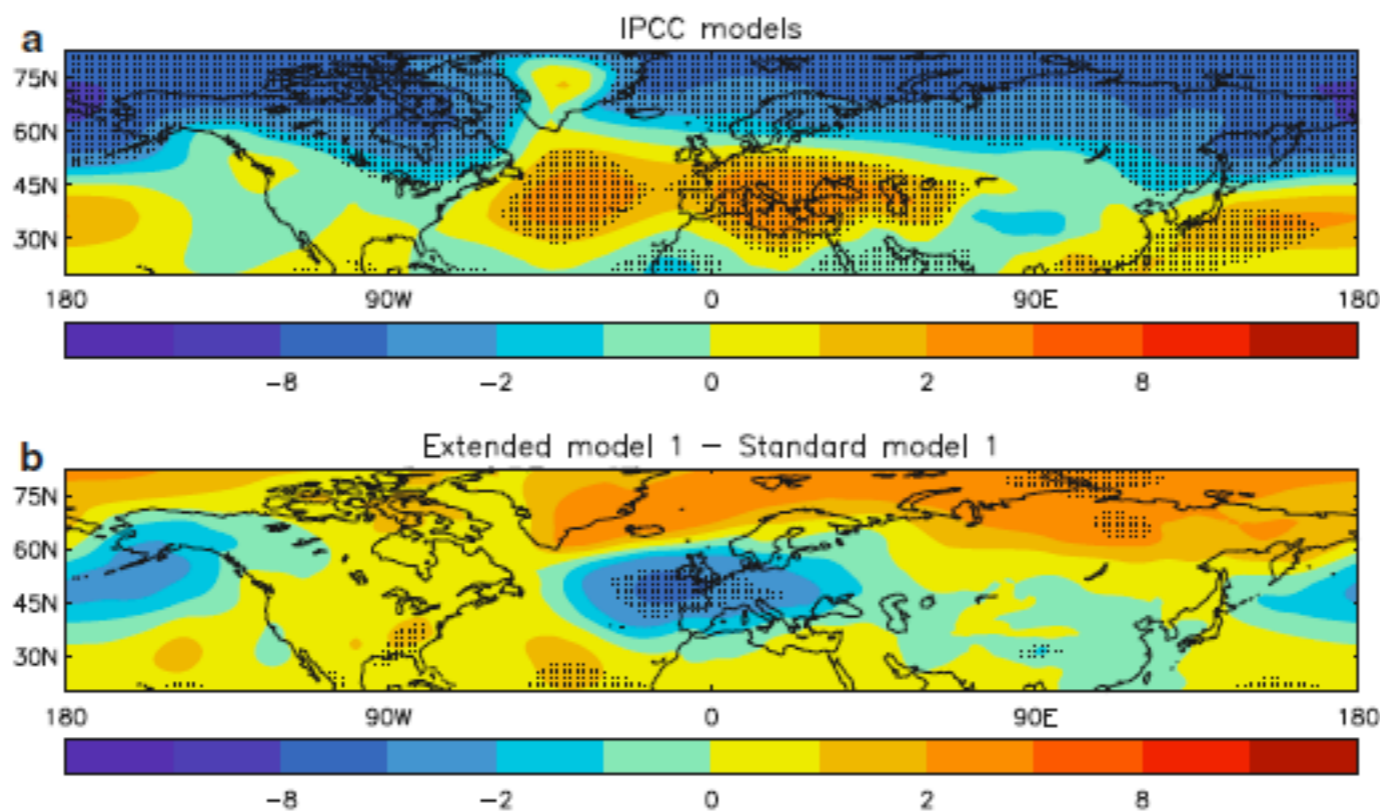
NH surface response

Clim Dyn

DOI 10.1007/s00382-011-1080-7

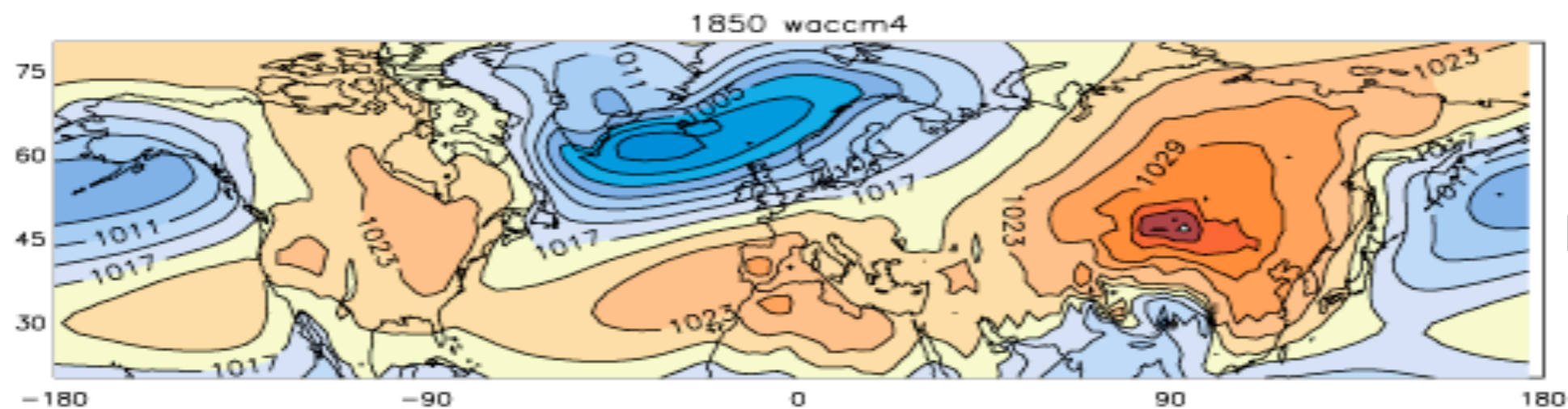
Climate change projections and stratosphere–troposphere interaction

Adam A. Scaife · Thomas Spanghel · David R. Fereday · Ulrich Cubasch · Ulrike Langematz · Hideharu Akiyoshi · Slimane Bekki · Peter Braesicke · Neal Butchart · Martyn P. Chipperfield · Andrew Gettelman · Steven C. Hardiman · Martine Michou · Eugene Rozanov · Theodore G. Shepherd

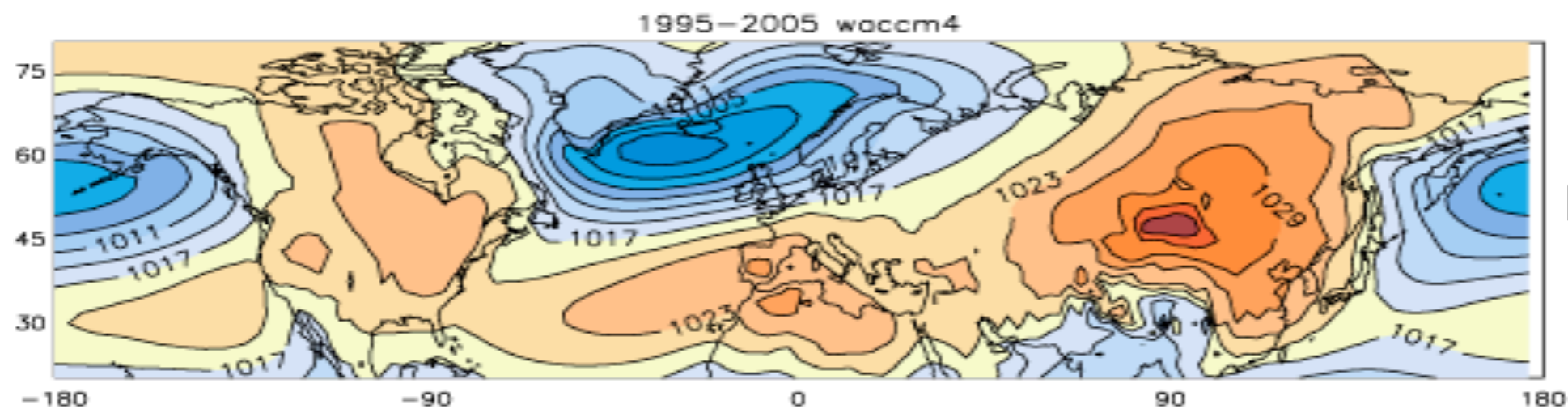


DJF SLP
(4 x CO₂)-(1 x CO₂)

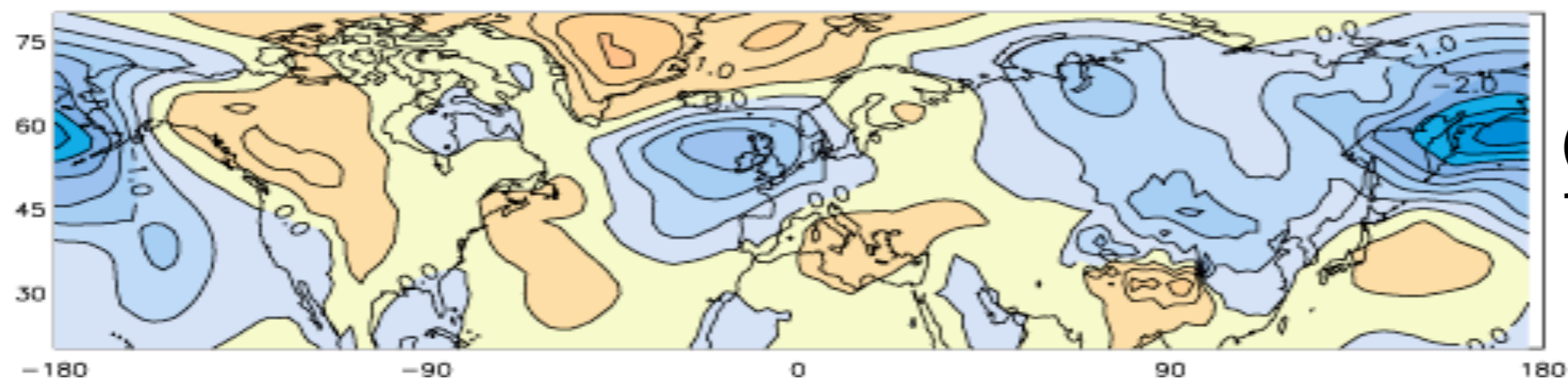
DJF SLP WACCM



1850 Control

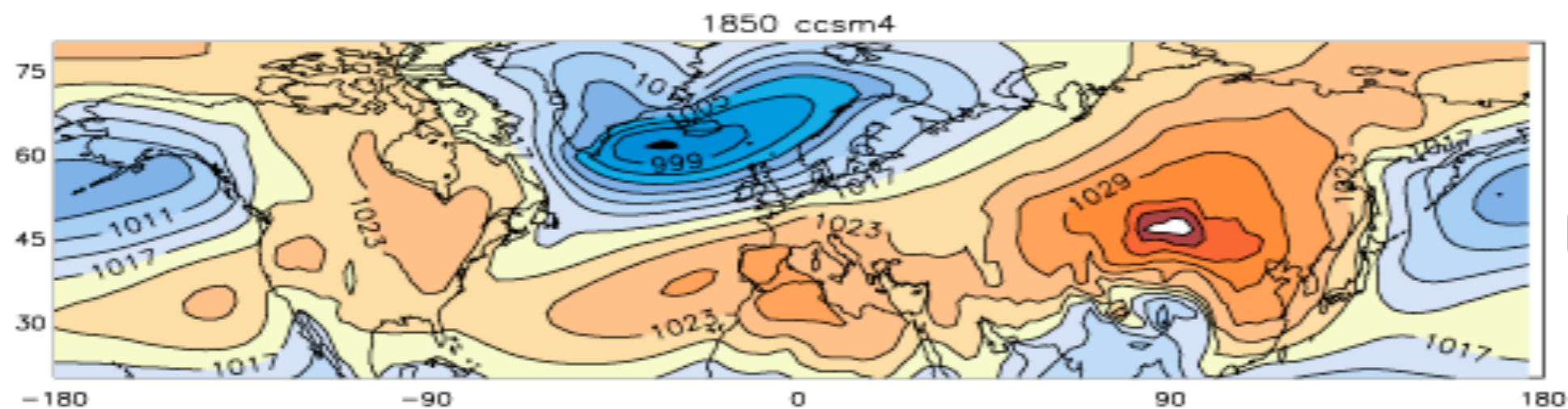


1995 to 2005

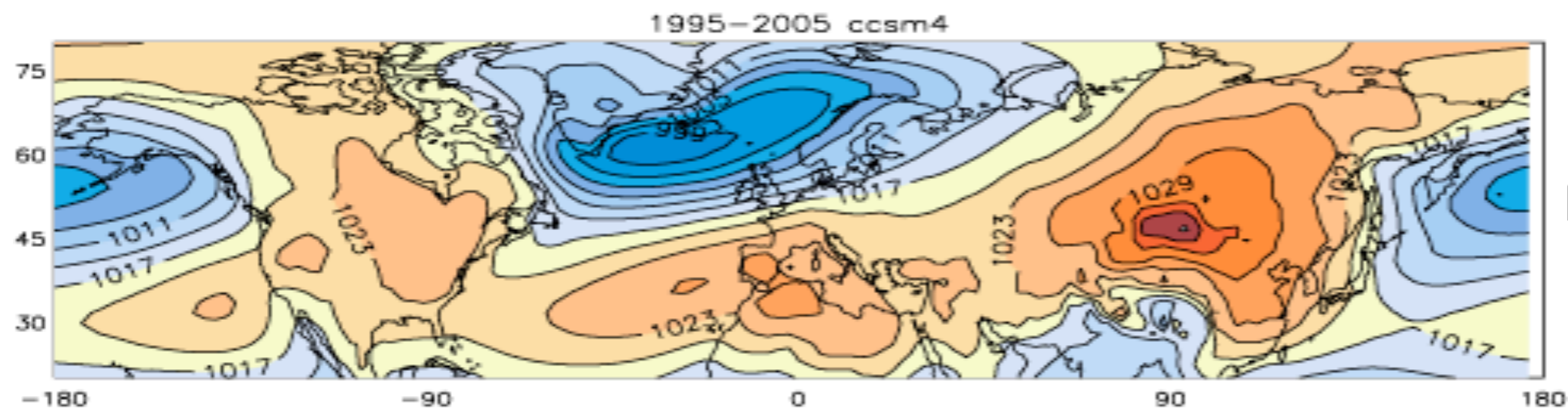


(1995 to 2005) -
1850 control

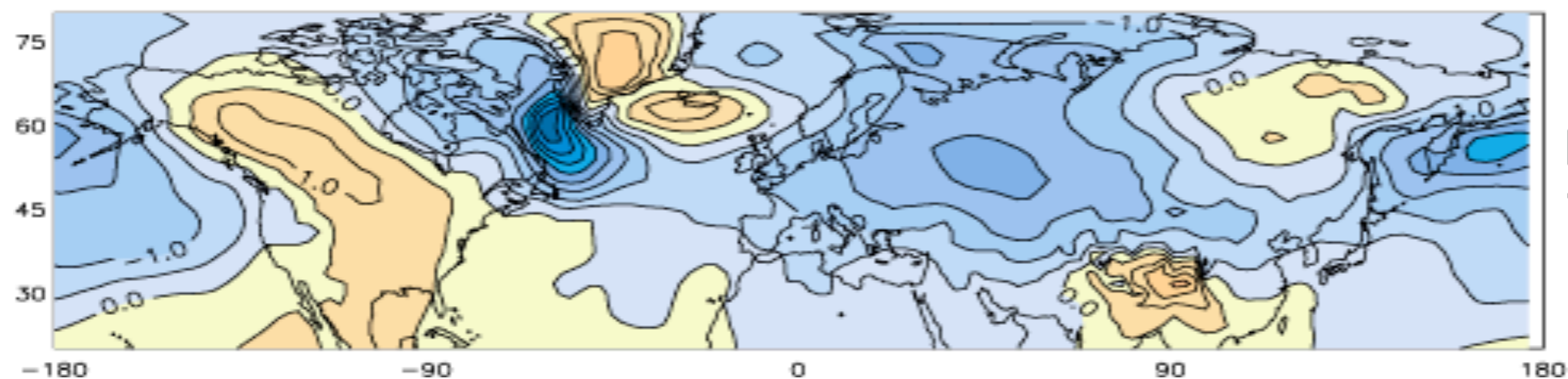
DJF SLP CCSM4-WSET



1850 Control

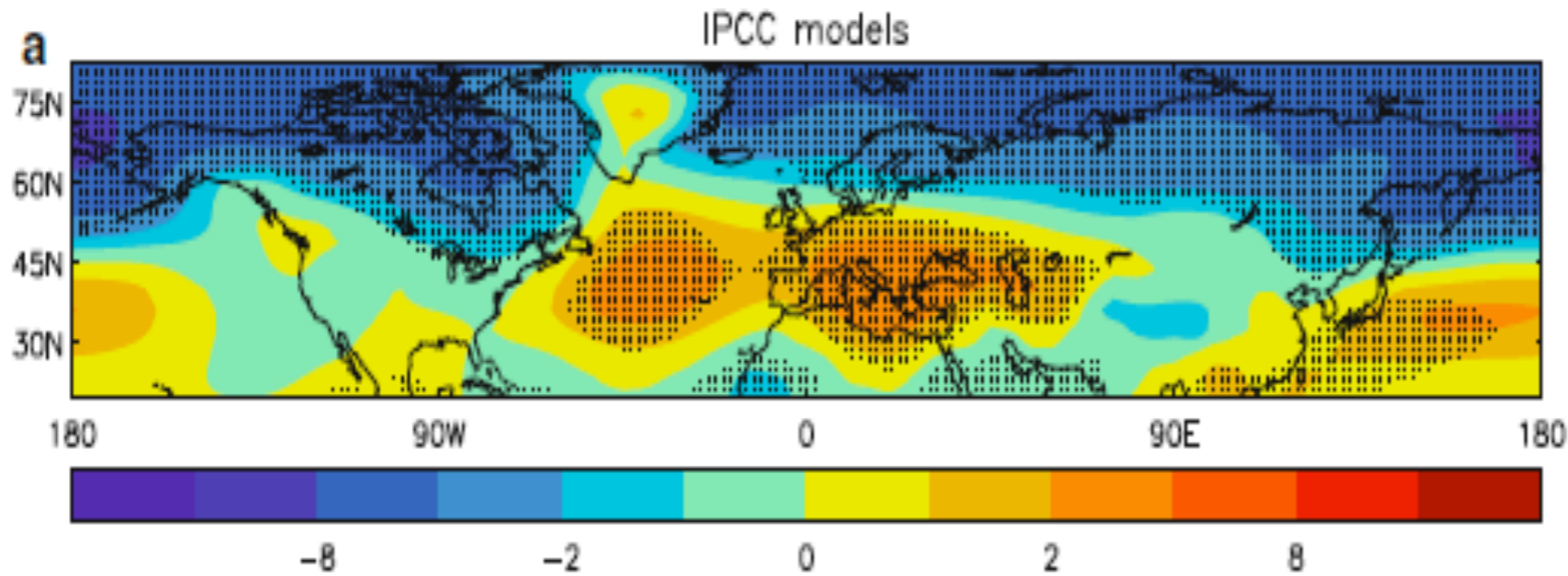


1995 to 2005

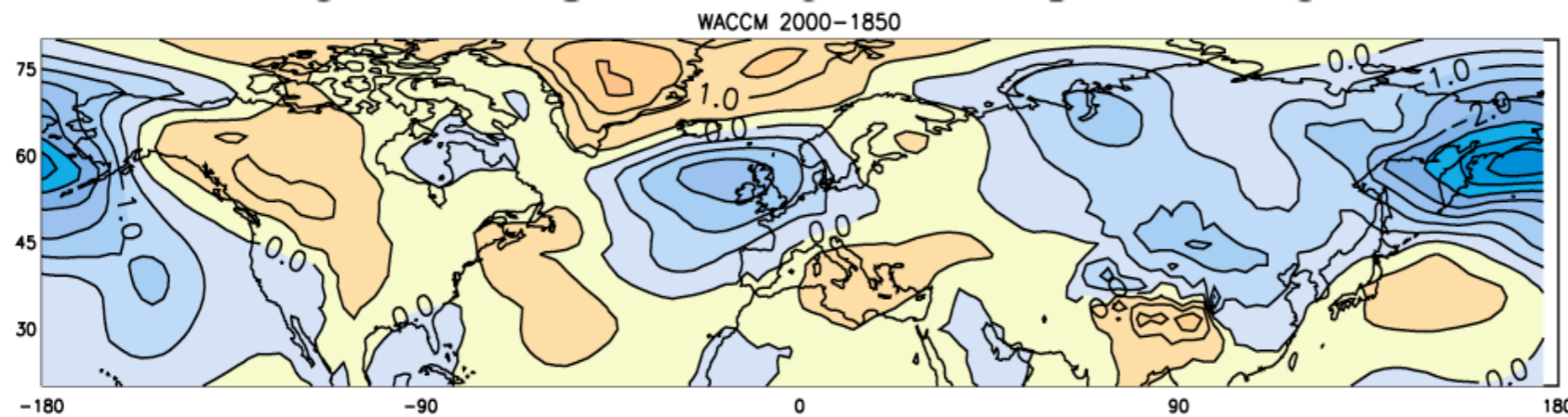


(1995 to 2005) -
1850 control

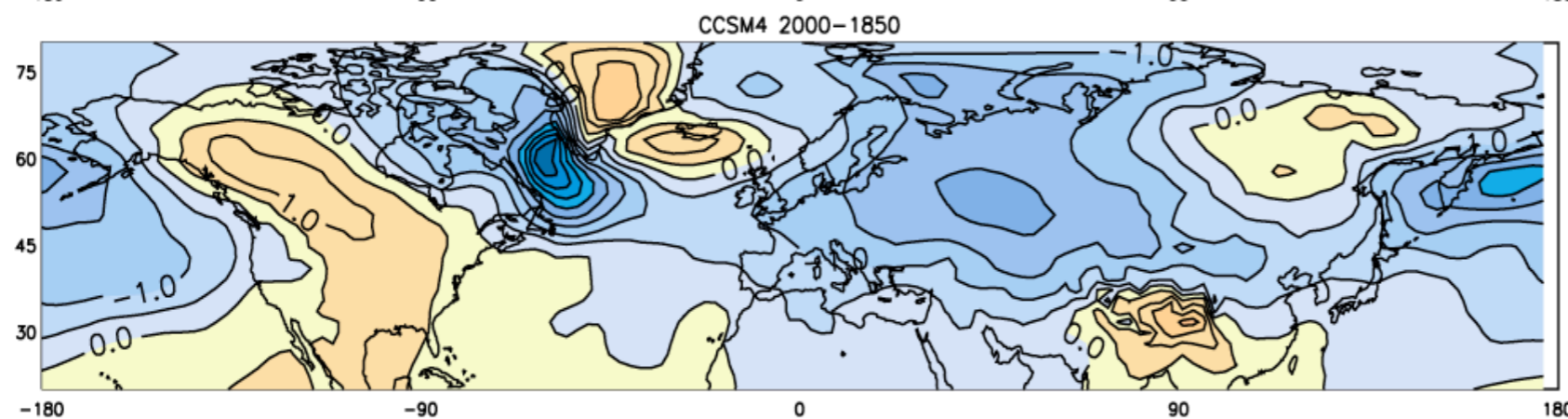
Sea Level Pressure for 4 x CO₂



AR4 - coupled low-top models
Scaife et al.(2011)

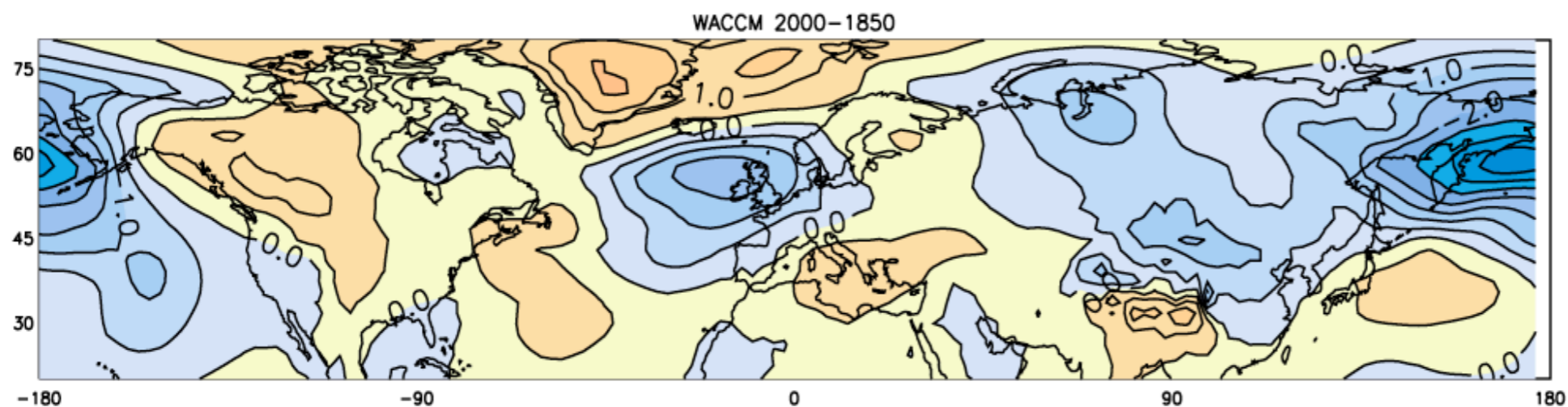


WACCM

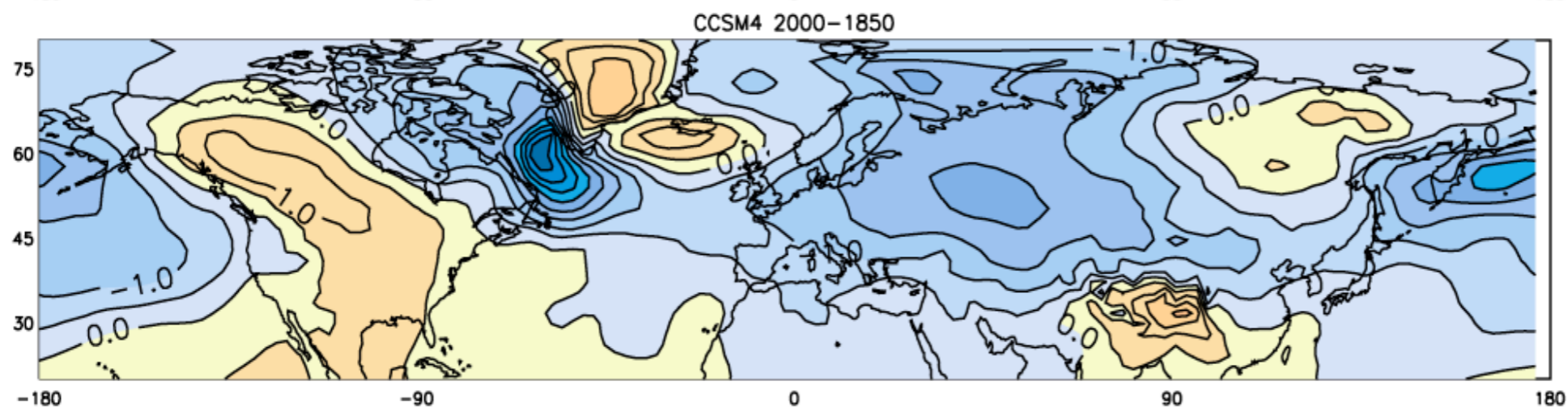


CCSM4-WSET

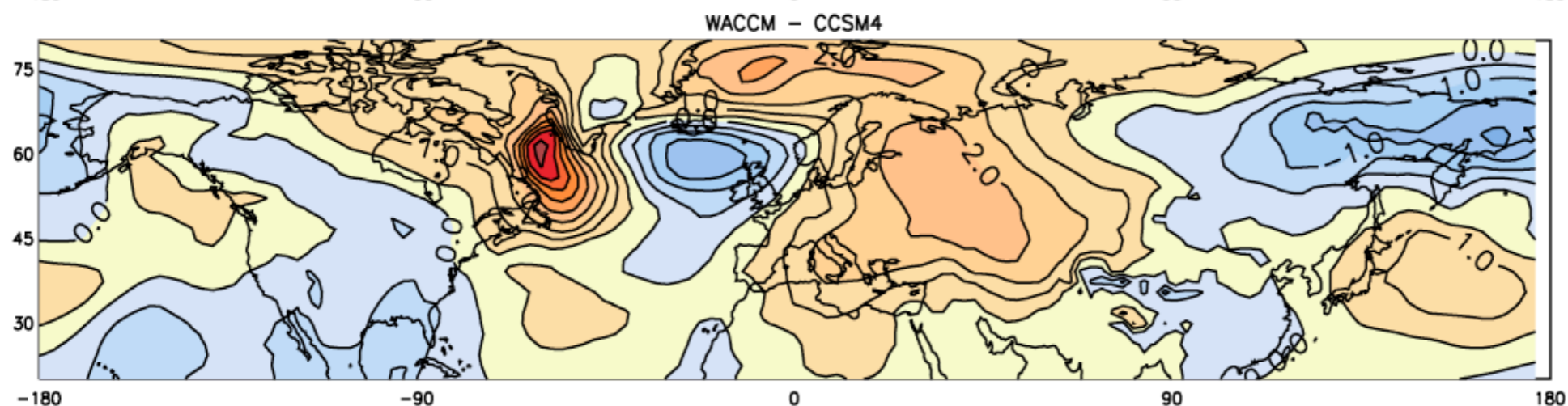
DJF SLP change WACCM - CCSM4-WSET



WACCM change



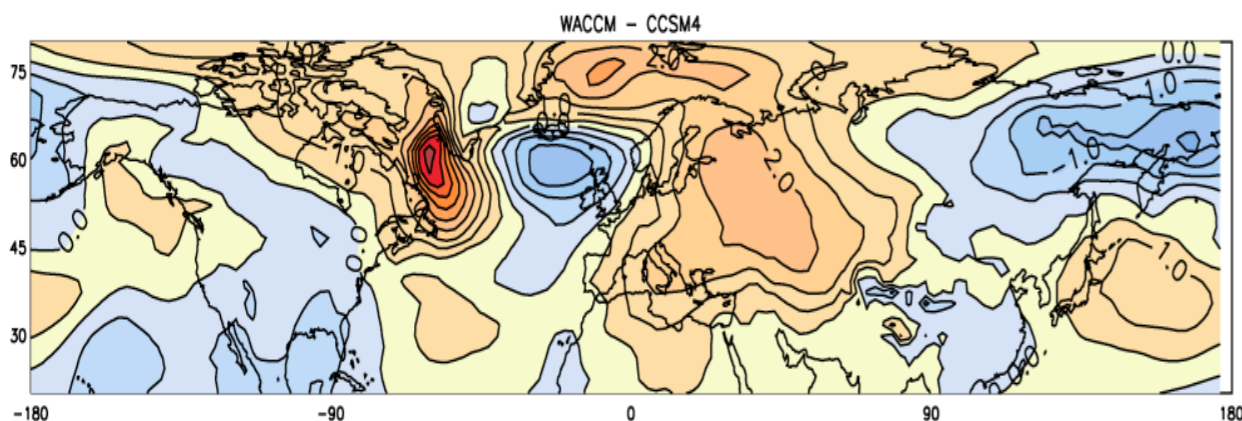
CCSM4-WSET change



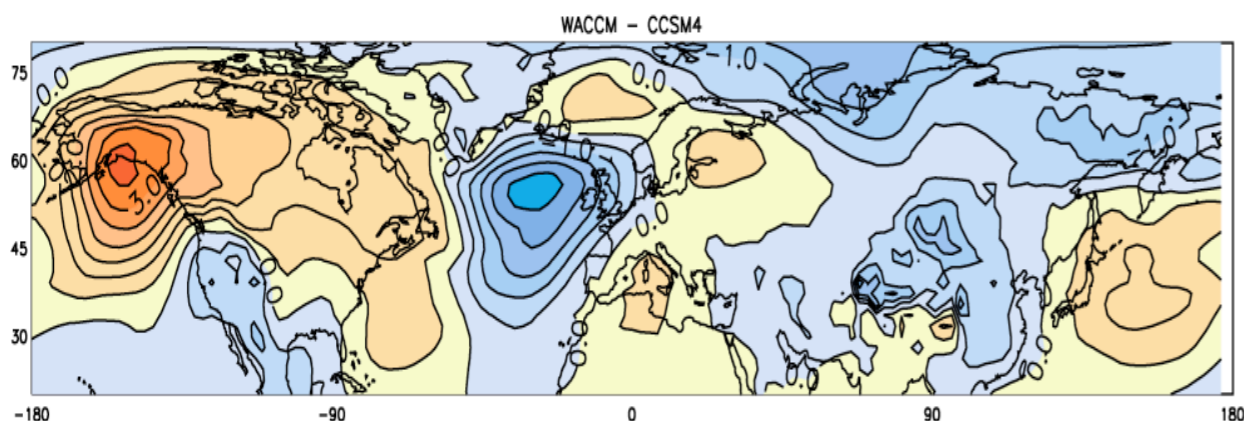
WACCM change -
CCSM4-WSET
change

high - low top differences in SLP differences

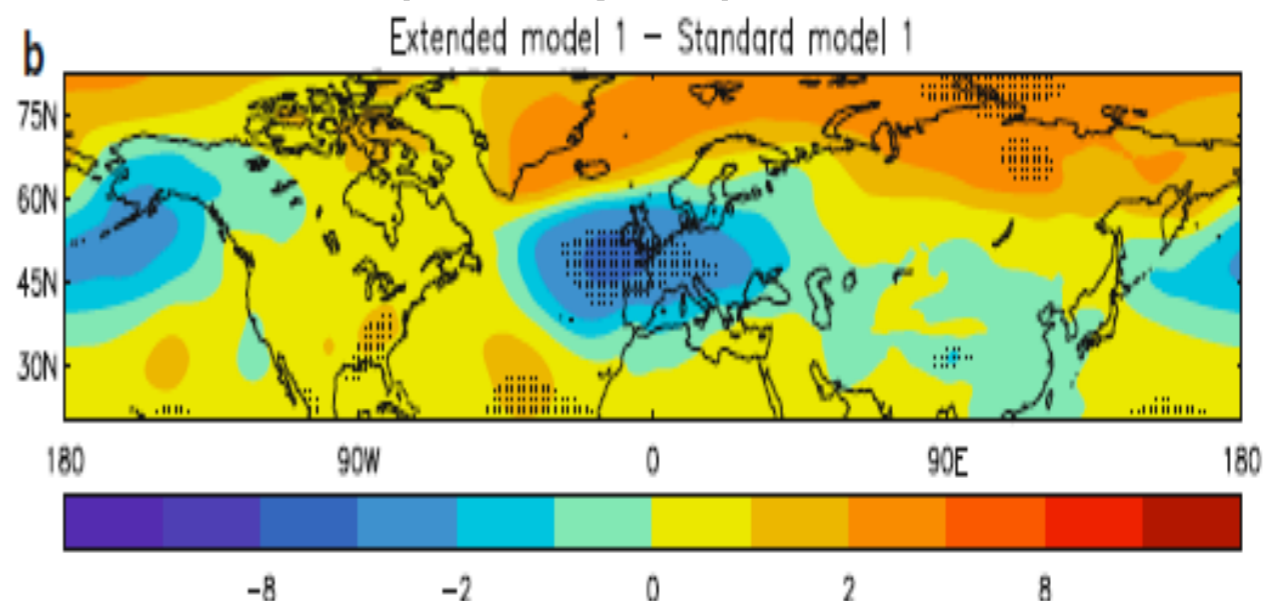
WACCM change - CCSM4-WSET change



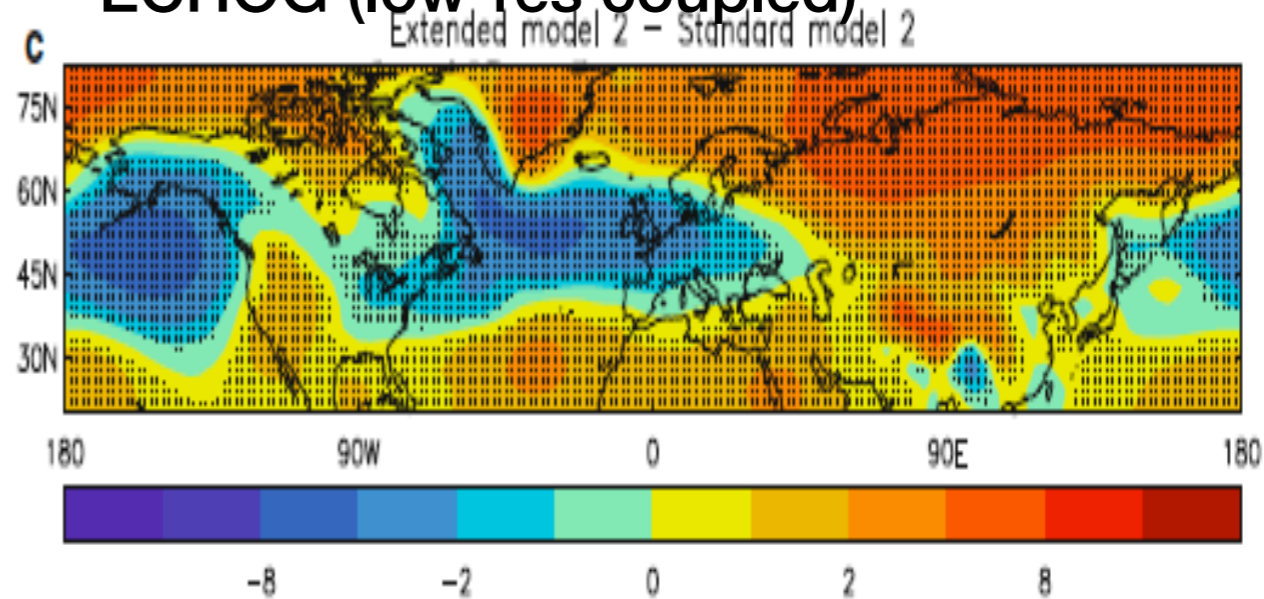
WACCM change - CCSM4 change



high top - low top models for 4xCO₂
HadGEM (uncoupled)



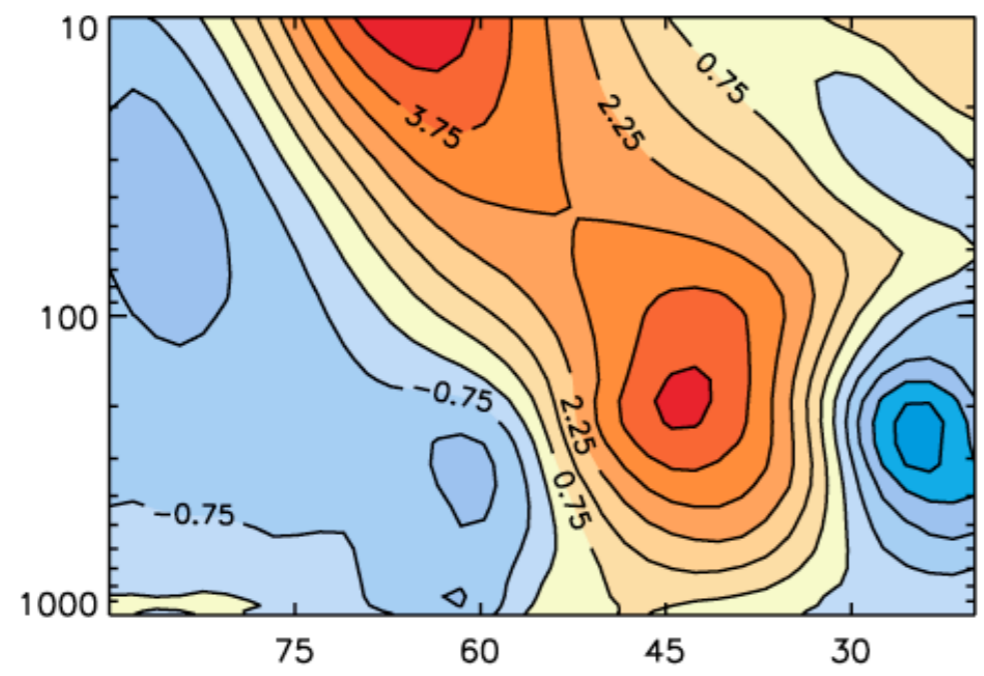
ECHOG (low-res coupled)



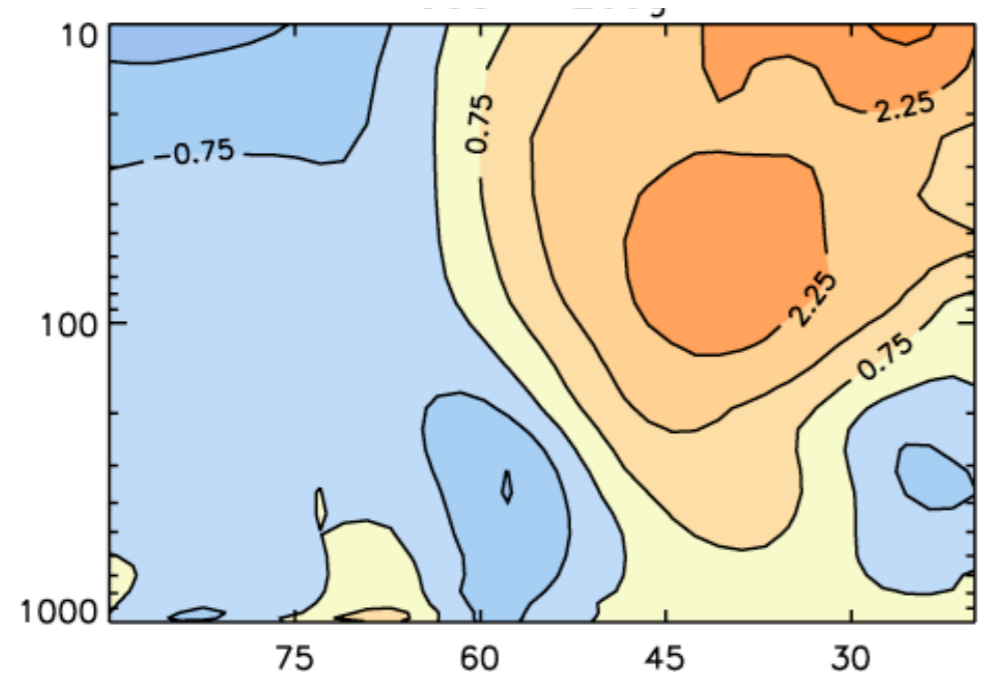
Scaife et al.(2011)

Zonal wind change 10 °W

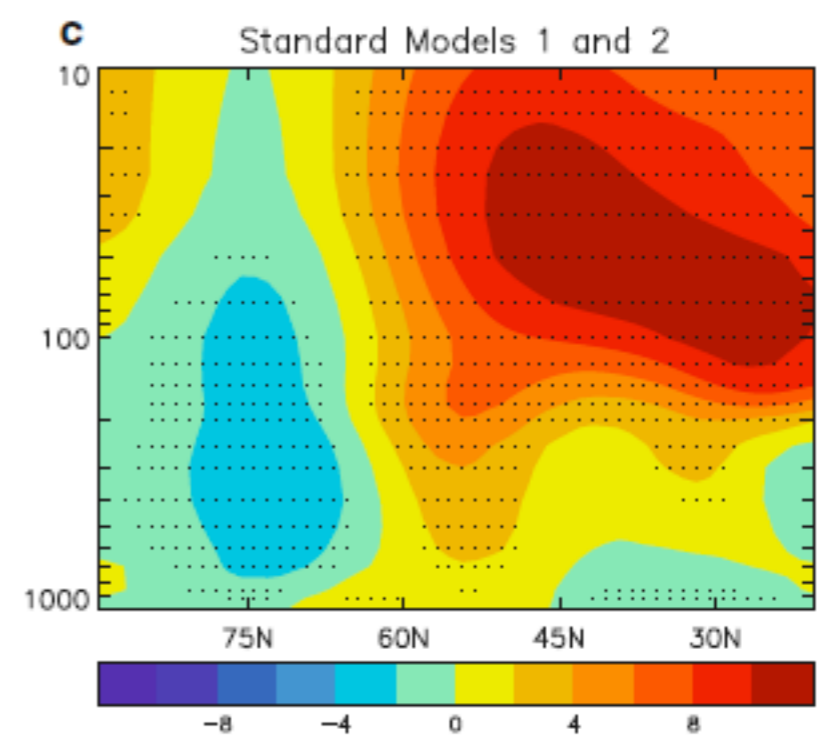
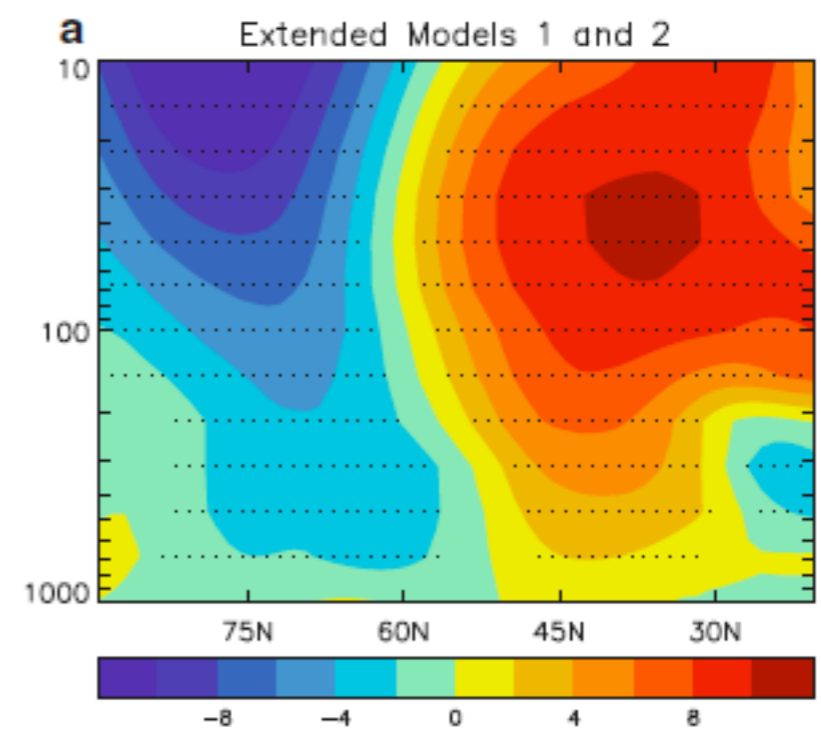
WACCM change



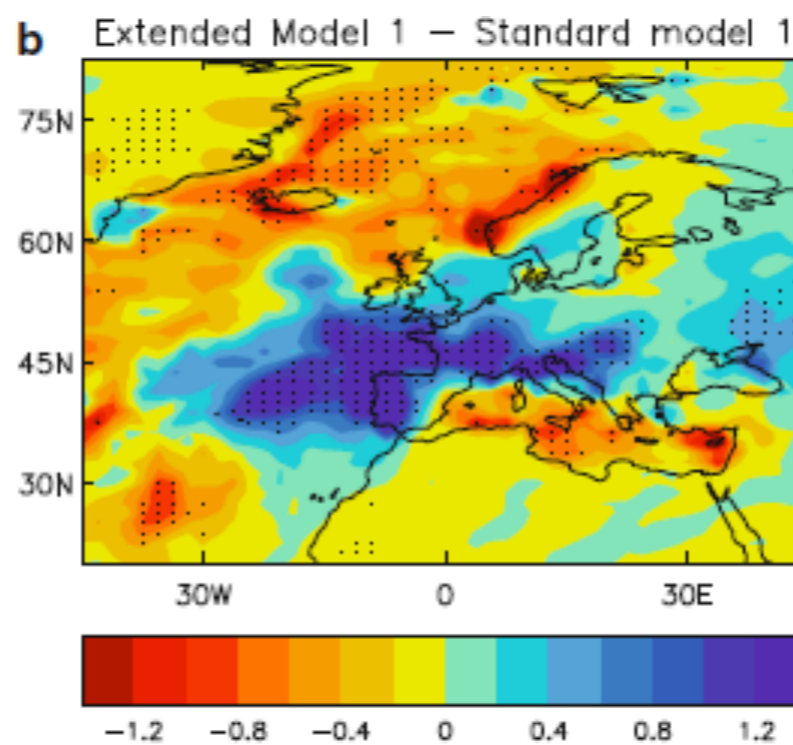
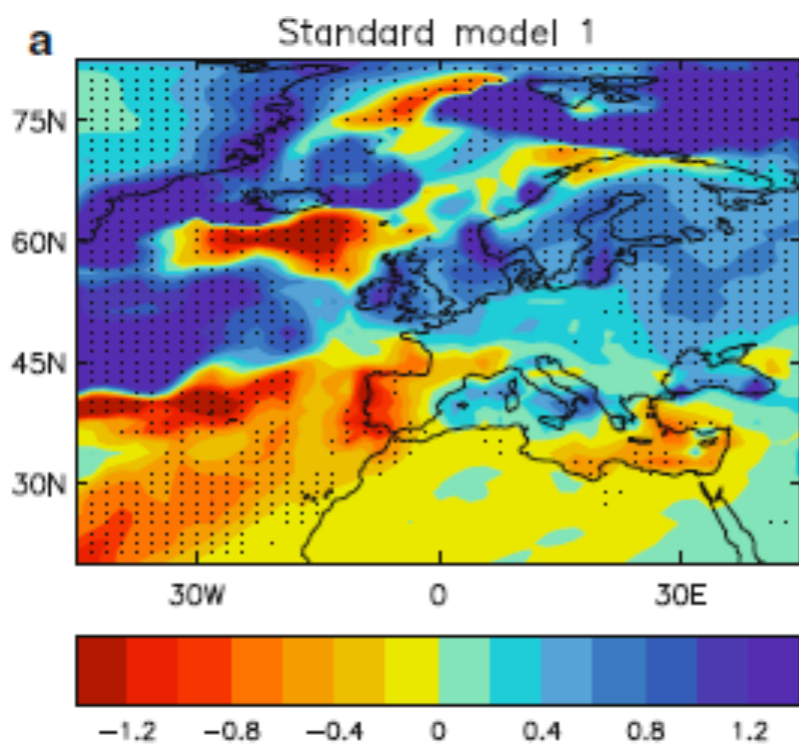
CCSM4-WSET change



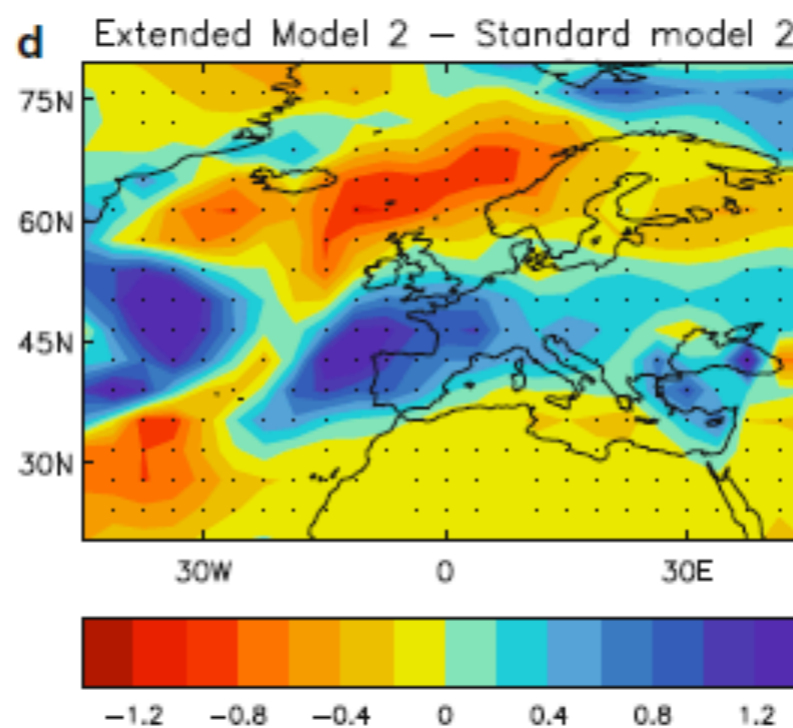
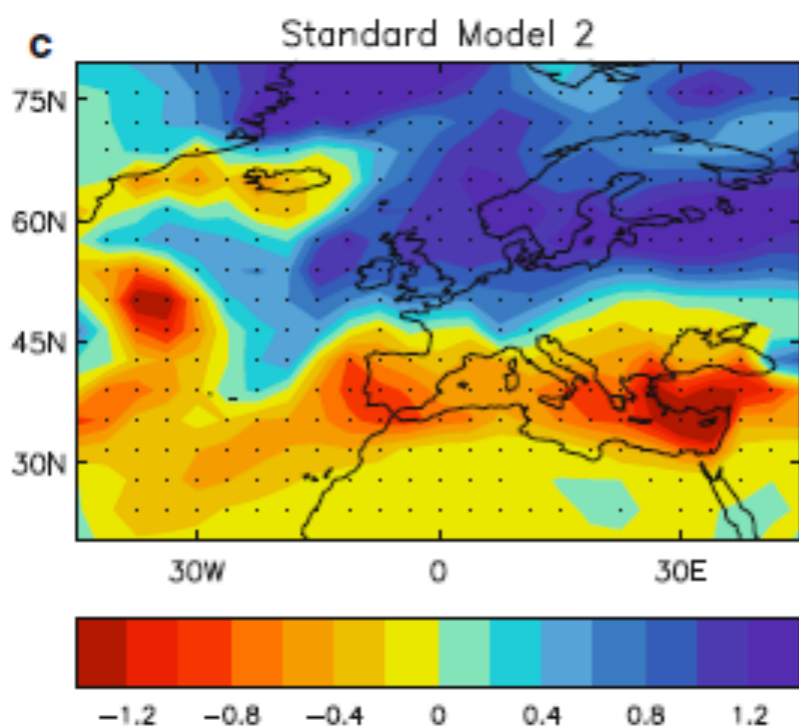
Uncoupled Scaife et al. (2011)



Change in winter mean rainfall (mm/day)



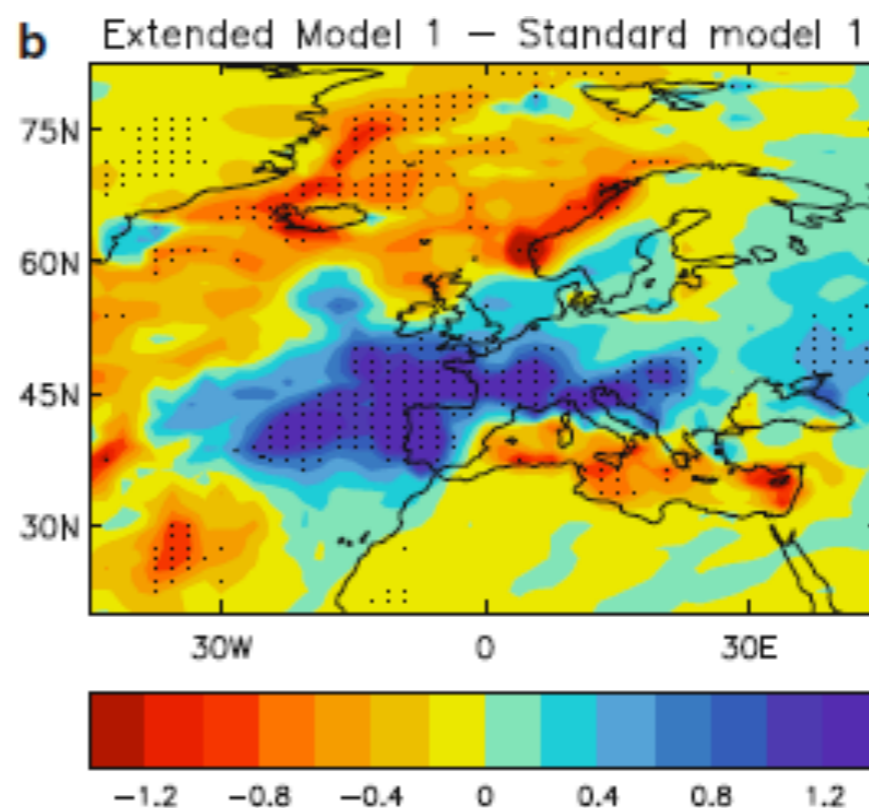
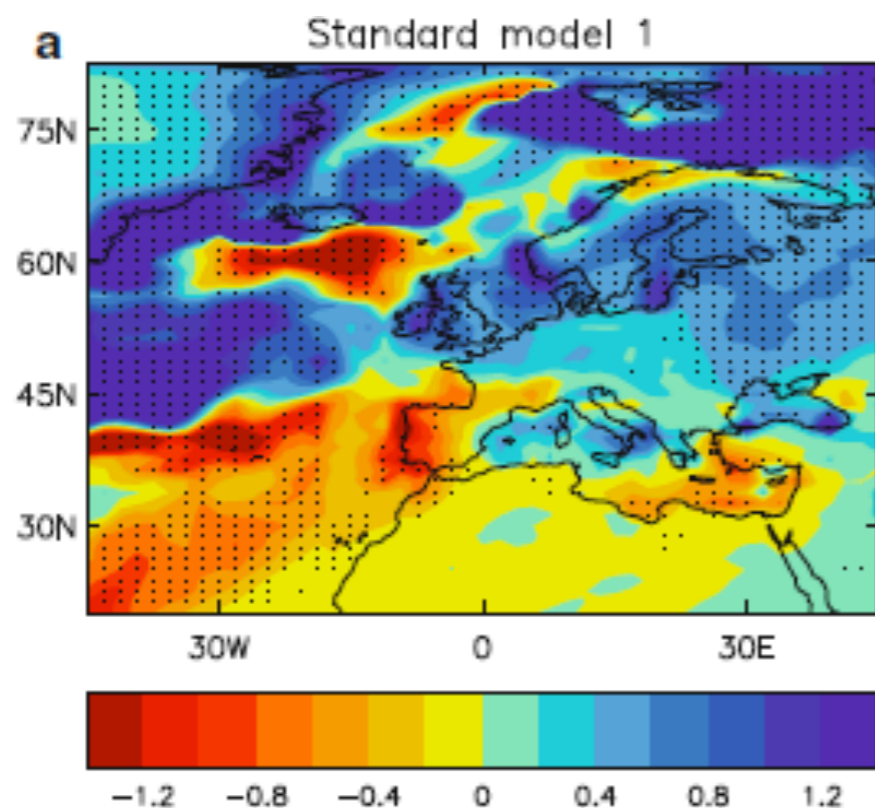
HadGEM (uncoupled)



ECHOG (low-res coupled)

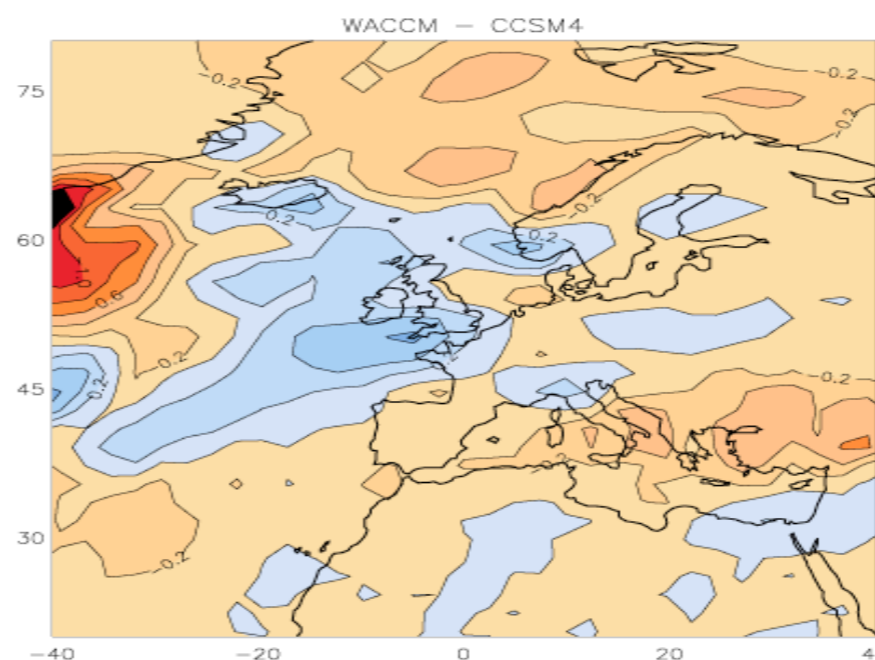
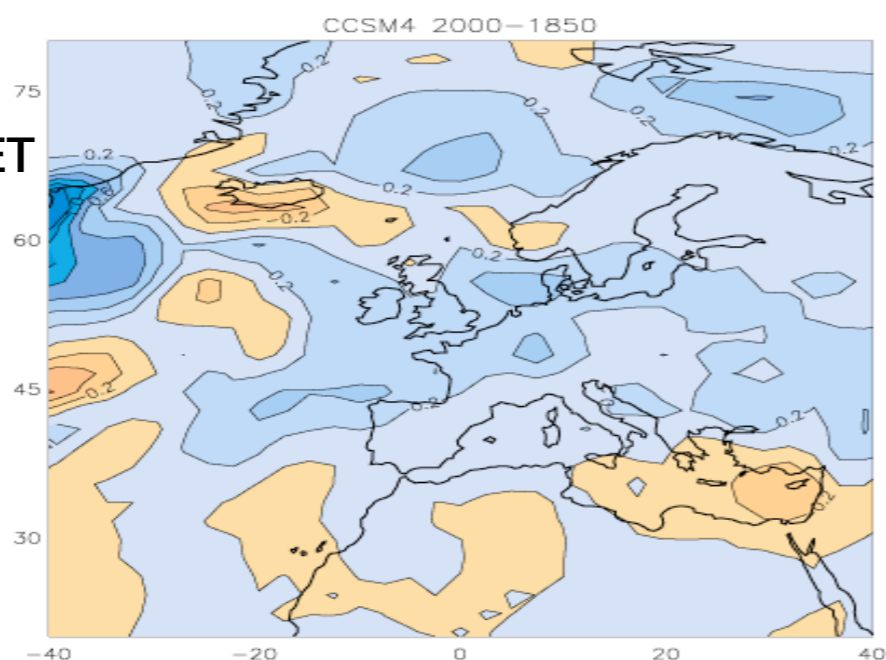
Scaife et al. (2011)

Change in winter mean rainfall (mm/day)



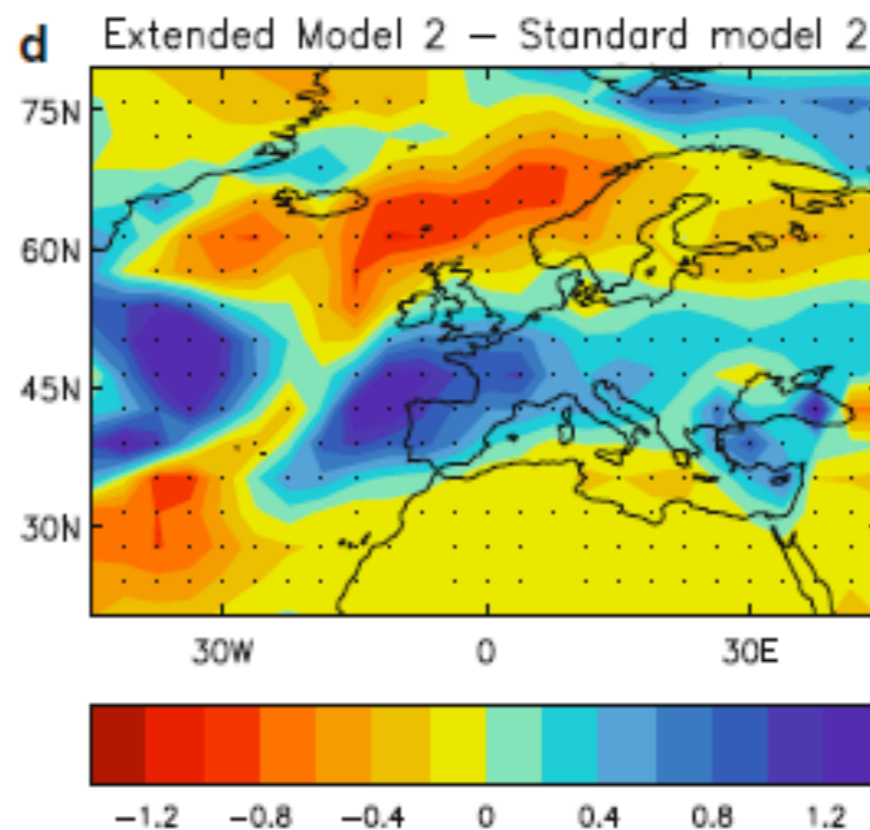
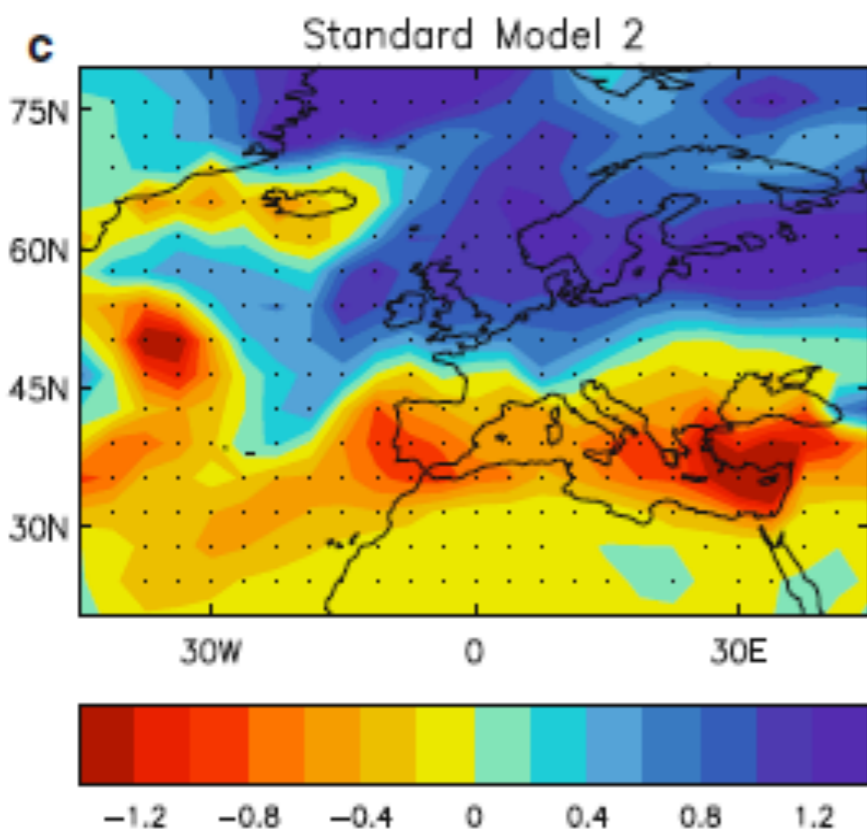
Scaife et al. (2011)

CCSM4-WSET
change

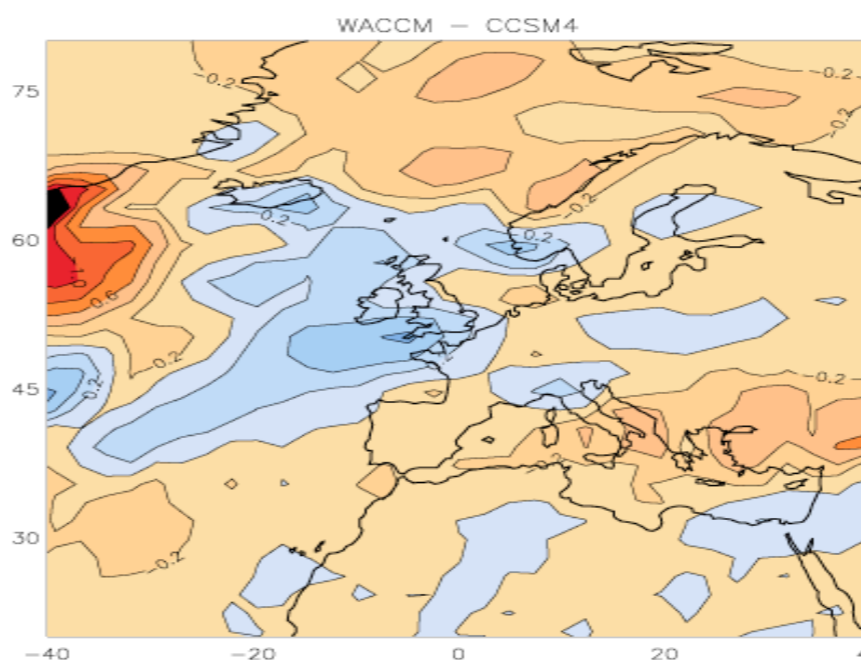
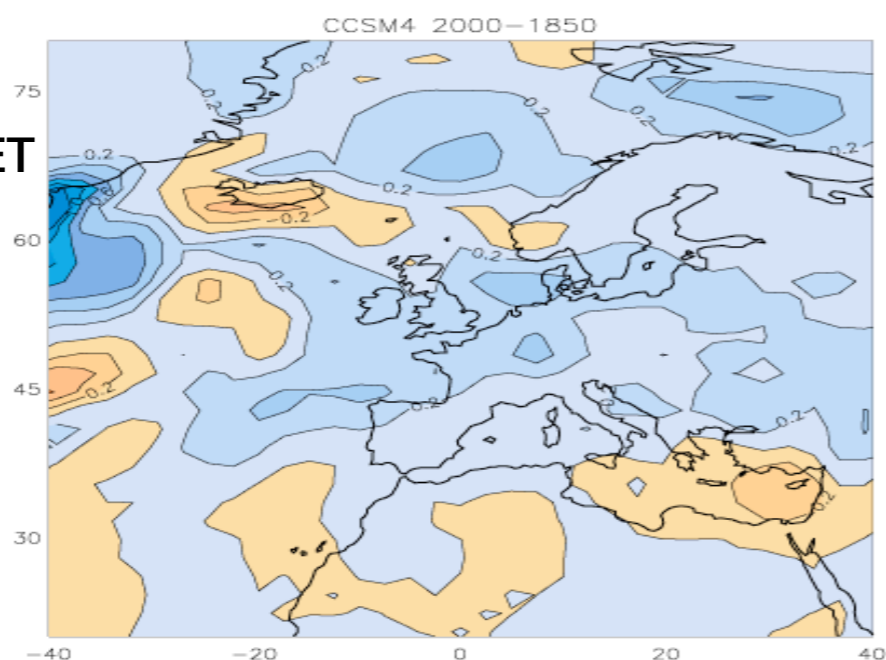


WACCM - CCSM4-WSET

Change in winter mean rainfall (mm/day)



Scaife et al. (2011)



CCSM4-WSET
change

WACCM - CCSM4-WSET

Summary I

- N3.4 period and amplitude of WACCM & CCSM4-WSET 2° comparable to CCSM4 1° and half the amplitude of CCSM4 2° (role of TMS?)
- Almost all NH winter stratospheric variability and its propagation into the troposphere are absent in CCSM4 CMIP5 integrations
 - Switching on TMS in CCSM4 increases SSW counts to ~50% of WACCM
 - NAM signal is weaker and similarly less frequent

Summary II

- New CMIP-5 CCSM4 and WACCM simulations allow investigation of the role of the stratosphere-troposphere coupling in climate change
 - Signals related to the development of the ozone hole propagate into the troposphere and appear to be more realistic in WACCM.
 - Mid-latitude NH SLP/precipitation changes in wintertime strongly dependent on whether there is a resolved stratosphere - systematic error not captured in ensemble variance
 - Representation of stratosphere-troposphere coupling could be a major source of uncertainty in regional climate change projections.



NCAR



WACCM

Whole Atmosphere
Community Climate Model



Acknowledgements

- @NCAR - Mike Mills, Natalia Calvo, Doug Kinnison, Francis Vitt, Rolando Garcia, Jean-Francois Lamarque, Andrew Conley, CESM Working group co-chairs and liaisons ...
- External collaborators - Lorenzo Polvani, Marilyn Raphael, Fabrizio Sassi
- CSEG, particularly Mariana Vertenstein and Chris Fischer
- Substantial computing resources were provided by the Climate Simulation Laboratory at NCAR's Computational and Information Systems Laboratory
- CESM project is supported by the National Science Foundation and the Office of Science (Bio. & Env. Res.) of the U.S. Department of Energy.

Thank you



NCAR is sponsored by the National Science Foundation

