Climate signals from anthropogenic and natural external forcings

Julie Arblaster

Jerry Meehl, Katja Matthes, Fabrizio Sassi, David Karoly

[1]National Center for Atmospheric Research
[2]Australian Bureau of Meteorology
[3]University of Melbourne

Anthropogenic (GHG) and natural (solar) forcings

- Anthropogenic

  Increasing GHGs drive robust poleward shifts in the SH storm tracks

  These will be modified in some seasons by ozone recovery

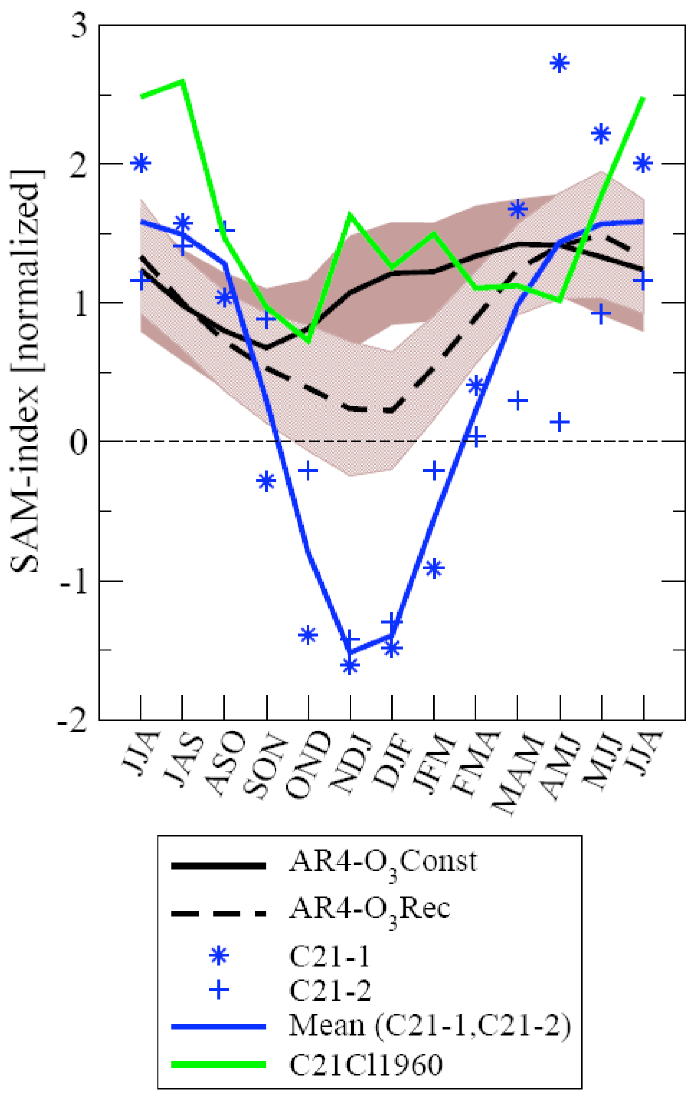
- Solar

  Two proposed mechanisms for the impact of the 11 year solar cycle on the surface:

  Top-down: enhanced stratospheric ozone leads to changes in circulation

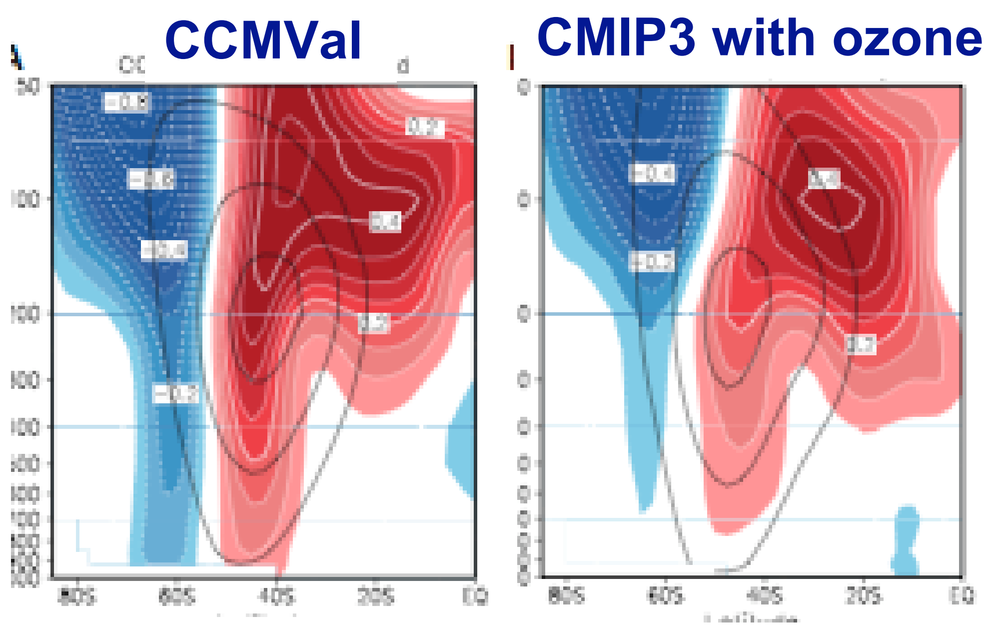
  Bottom-up: coupled air-sea processes due to enhanced solar in cloud-free regions

SAM index from CMIP3 & CCMVal models



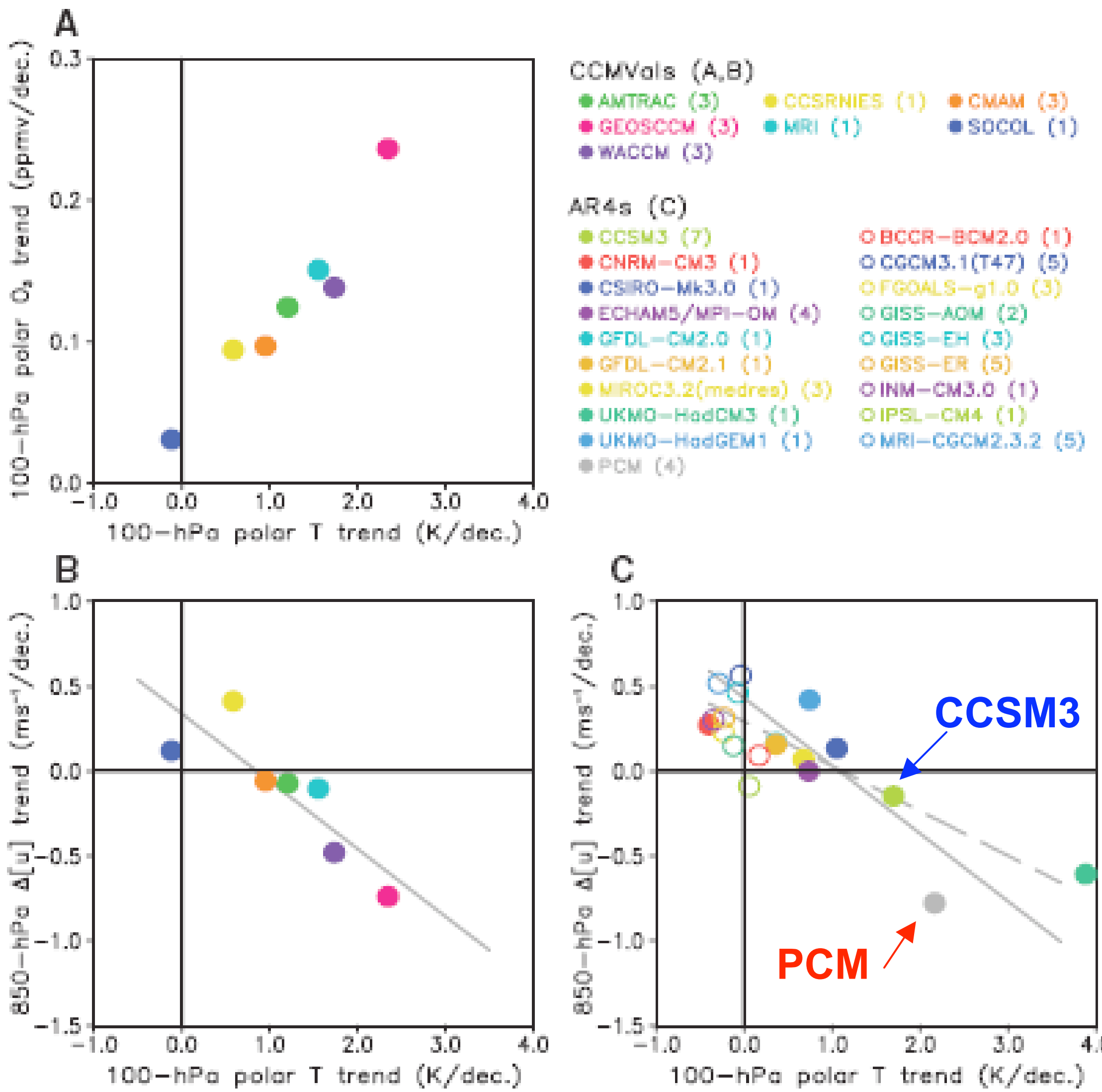
Perlwitz et al (2008), GRL and Son et al (2008), Science

Chemistry-climate models suggest negative DJF trend in SAM over 21stC, opposite to IPCC AR4 multi-model mean



SAM index from CMIP3 & CCMVal models

CCMval models show a strong relationship between 100 hPa polar cap winds and changes in SAM.
AR4 models with ozone recovery show a similar, while weaker relationship.



Son et al 2008

NCAR CMIP3 models

Two NCAR coupled models that contributed to CMIP3:

PCM

⇒ CCM3
⇒ T42 horizontal resolution (~2.8 degrees)
⇒ 18 vertical levels, very few in stratosphere

CCSM3

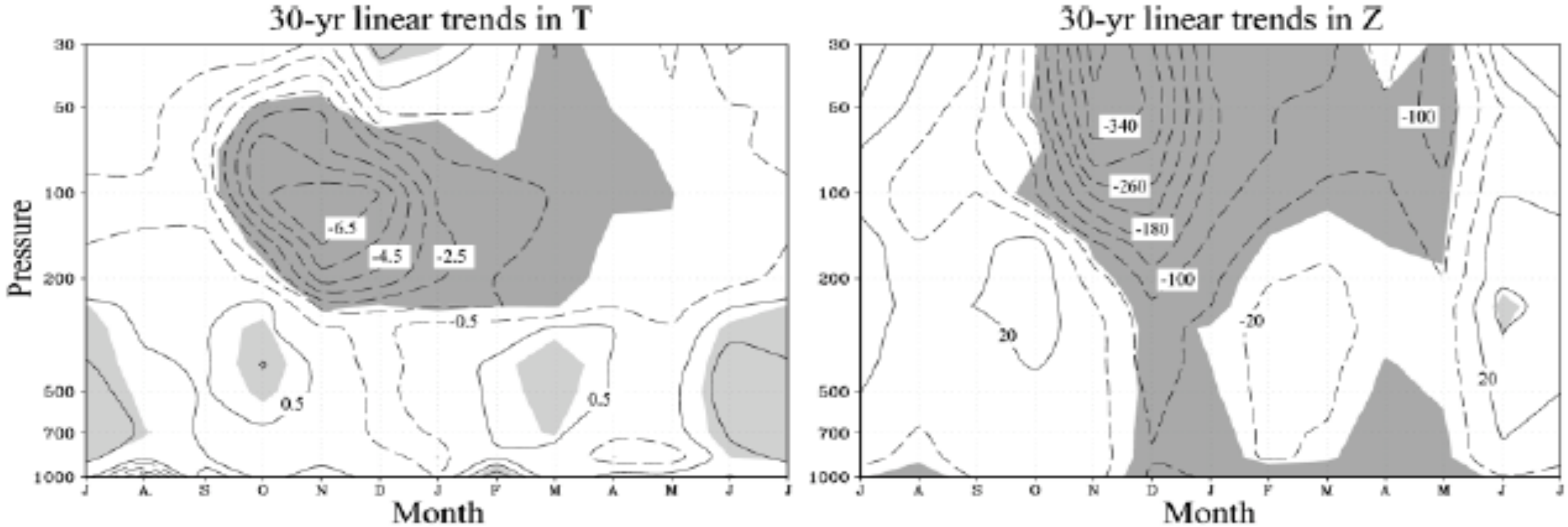
⇒ CAM3
⇒ T85 horizontal resolution (~1.8 degrees)
⇒ 26 vertical levels, very few in stratosphere

Similar ocean, land and sea-ice components

No interactive chemistry, prescribed ozone

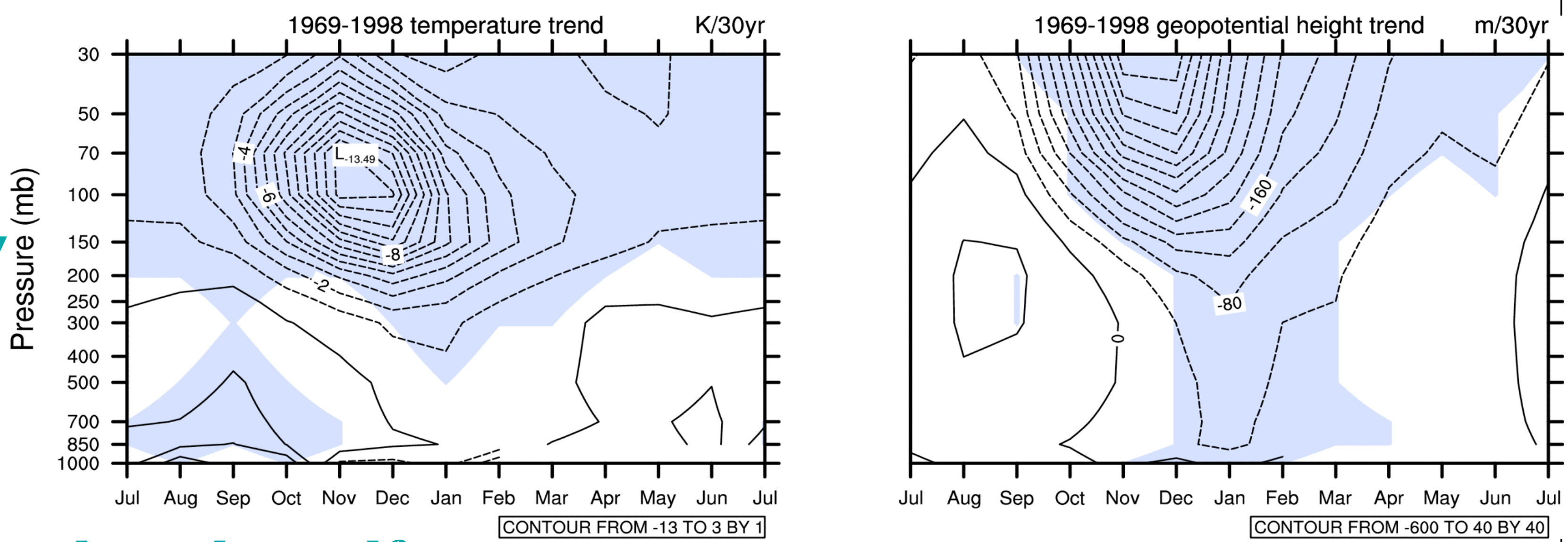
Trends over Antarctic cap in NCAR PCM

Obs



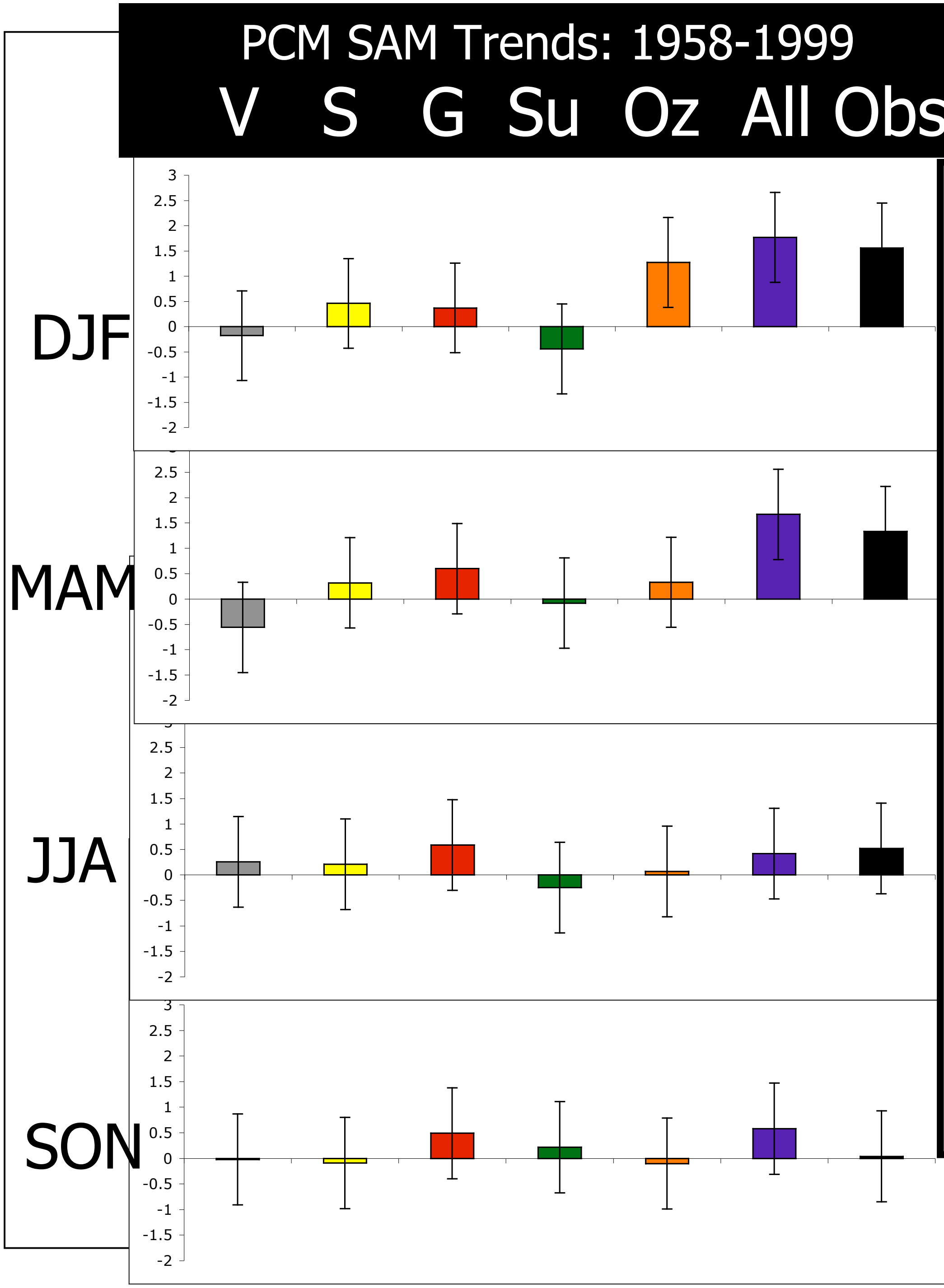
[Thompson & Solomon, *Science*, May 2002]

Pcm "All"



volc+solar+ghg+sulfate+ozone

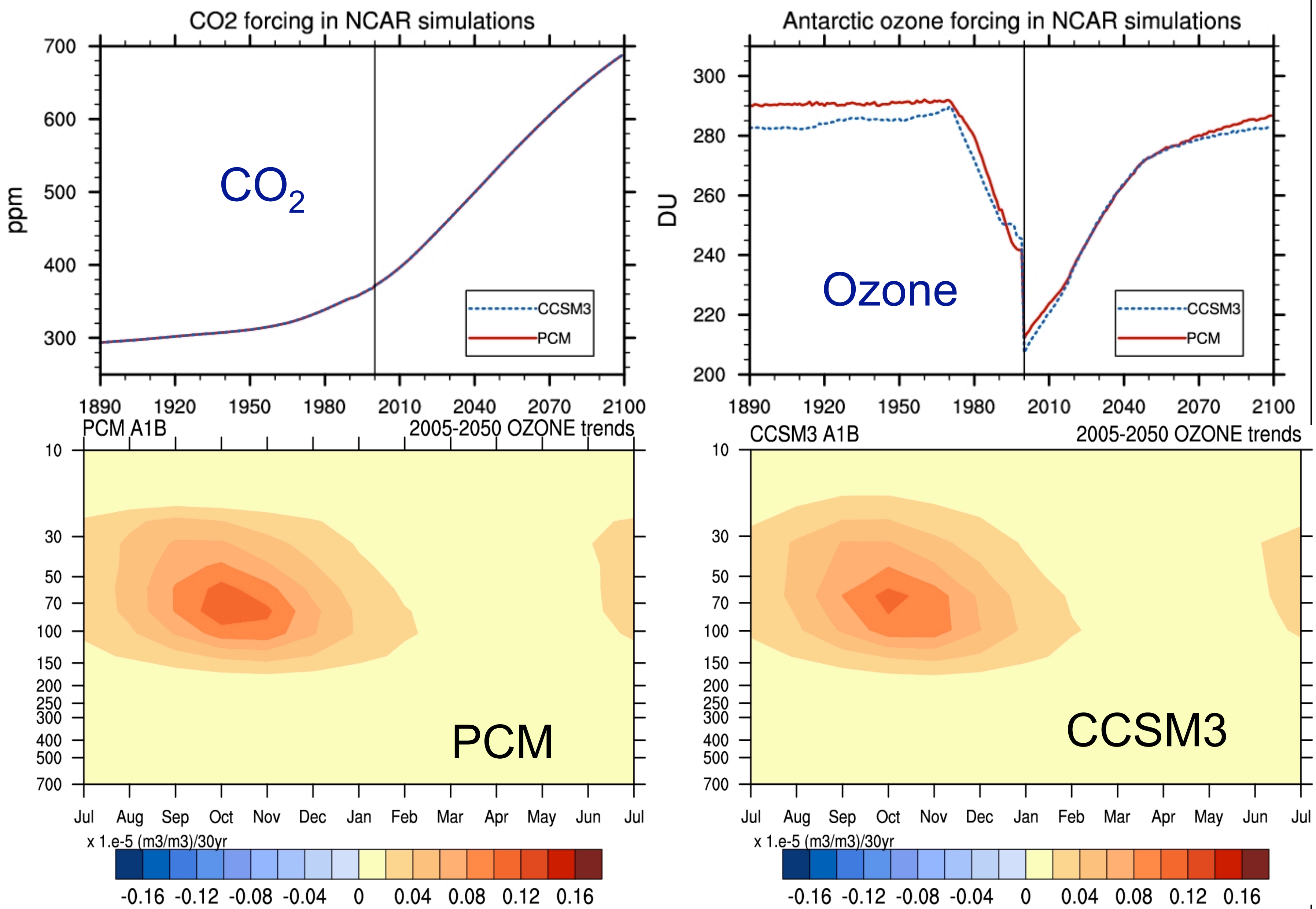
Arblaster & Meehl, 2006



Trends from 1958-1999 of the SAM index (normalized units/30yr). The SAM index is defined as the difference in normalized zonally averaged sea level pressure between 40°S and 65°S. The error bars indicate the 95% confidence intervals obtained from the PCM 1000 year control run

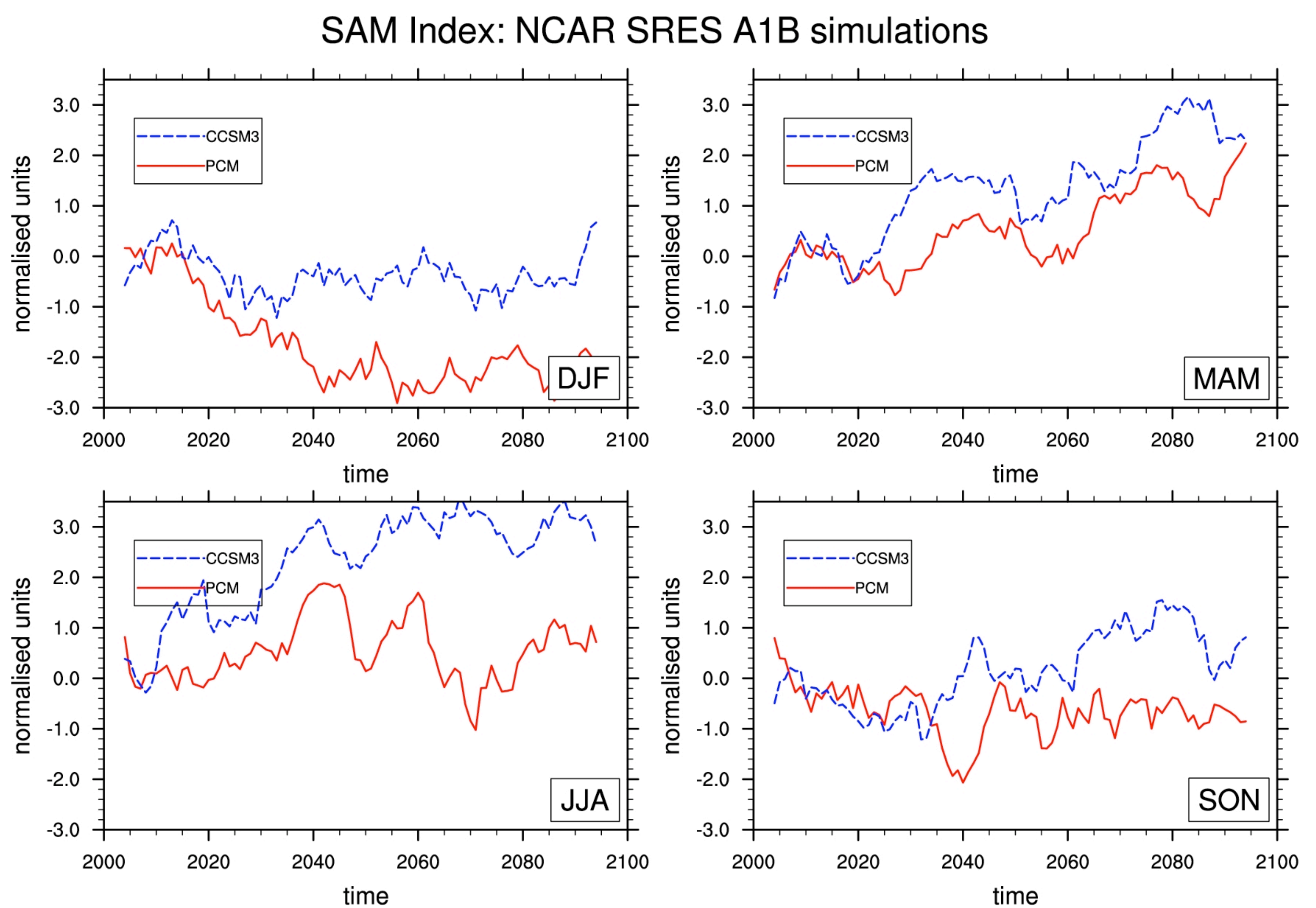
Arblaster & Meehl, 2006

21stC forcing used in NCAR AR4 models



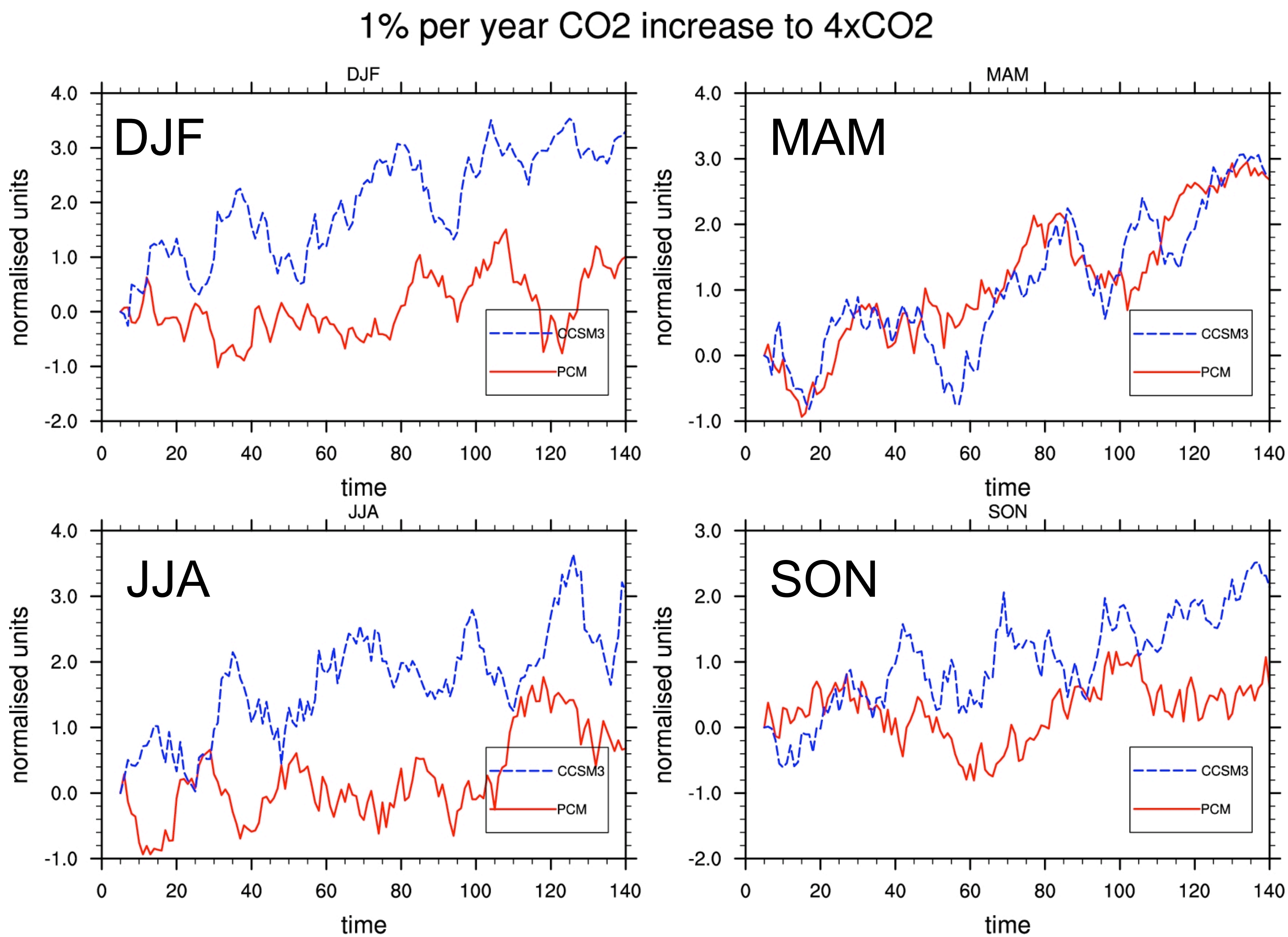
Arblaster et al 2010

SAM index from NCAR A1B runs



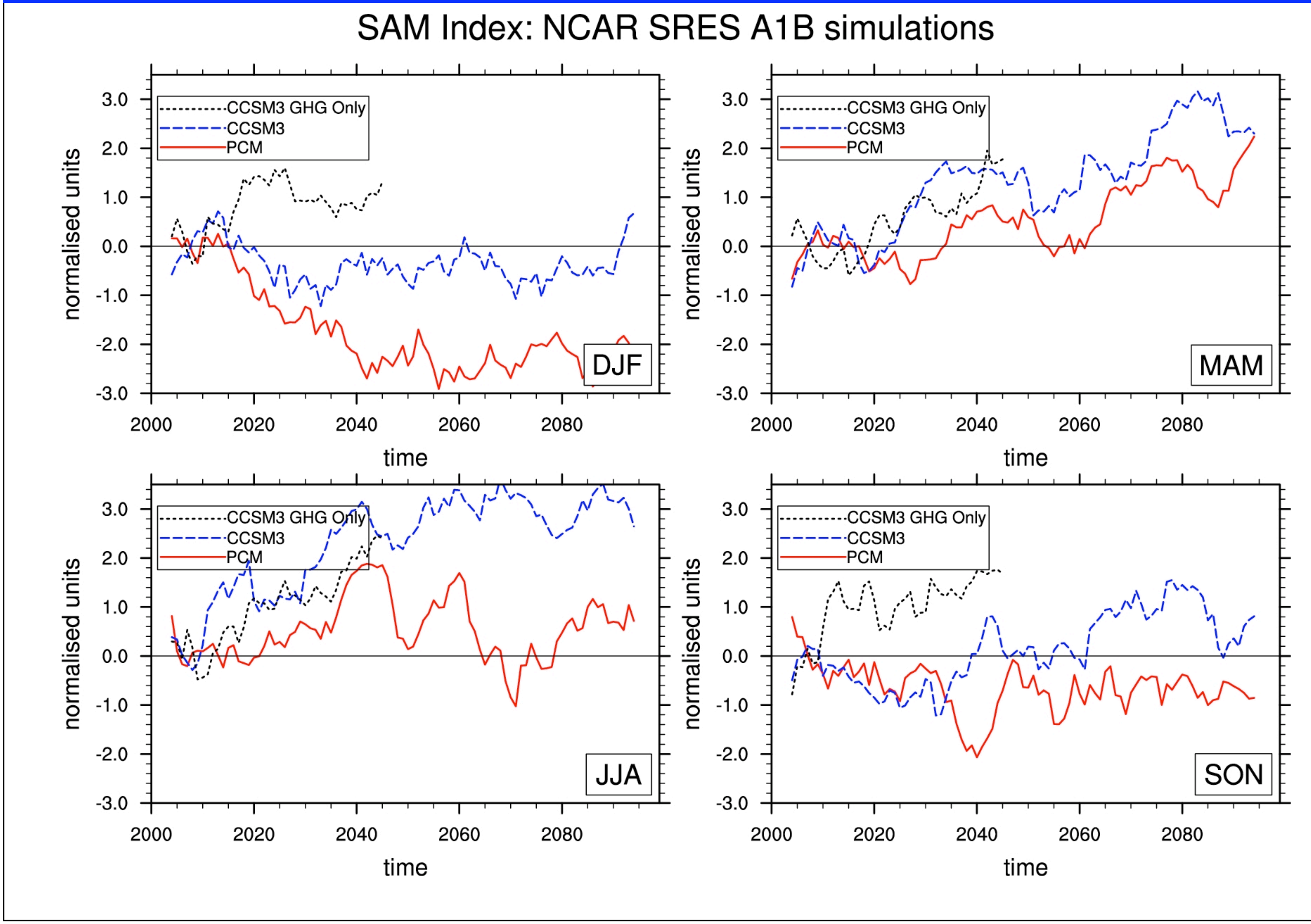
Arblaster et al 2010

SAM index from NCAR 1%/yr CO_2 incr runs



Arblaster et al 2010

SAM index from NCAR A1B runs



Arblaster et al 2010

SAM DJF trends from NCAR runs

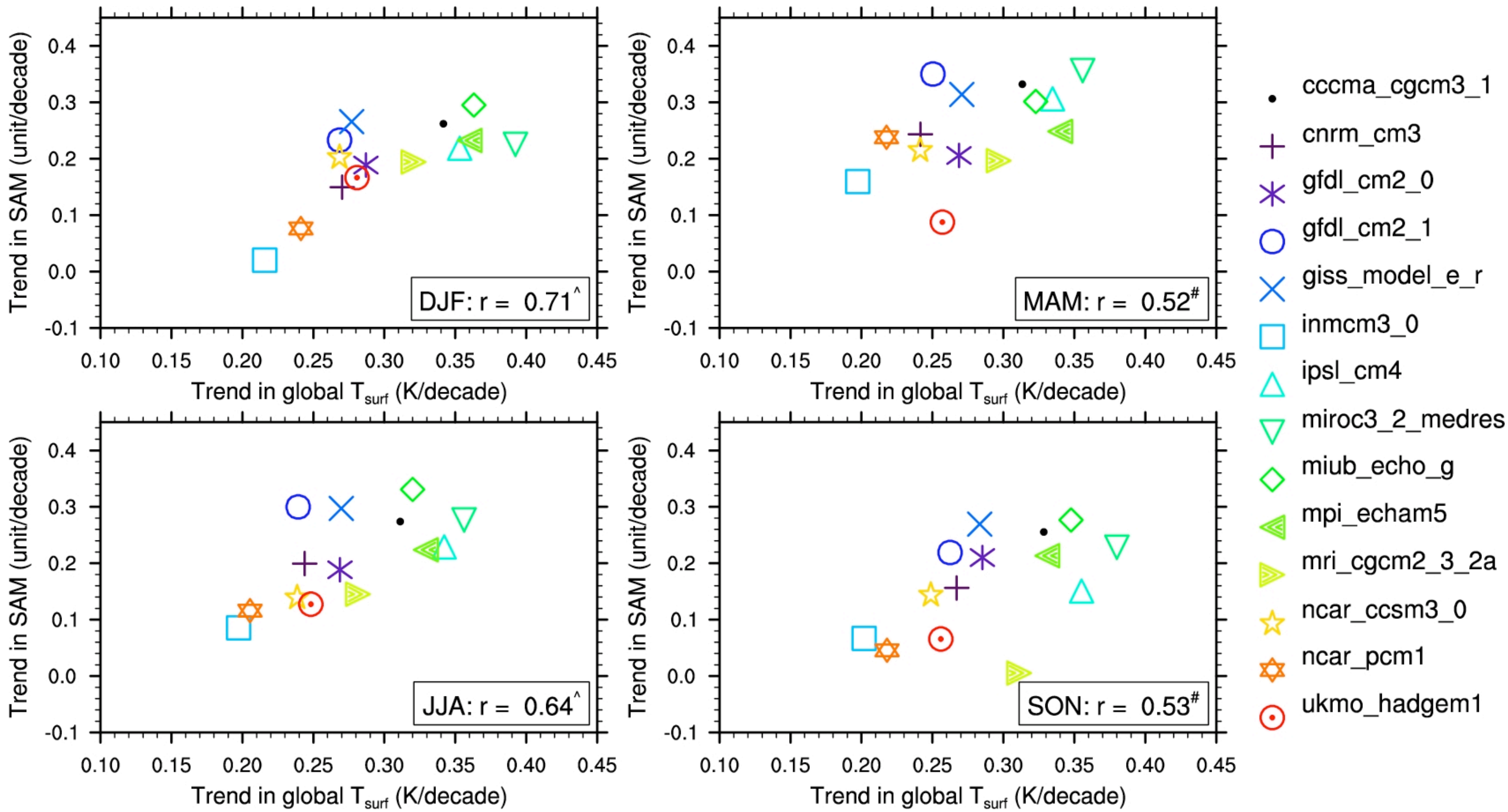
DJF SAM trends (unit/decade)	SRES A1B	1%/year CO_2	SRES A1B (GHG)	SRES A1B $(\text{Ozone})^{\text{estimated}}$
based on years	*2005-2050*	*1-140*	*2005-2050*	*2005-2050*
PCM	$-0.56^{\wedge}$ (± 0.40)	$0.07^{\wedge}$ (± 0.07)		-0.66
CCSM3	-0.24 (± 0.42)	$0.22^{\wedge}$ (± 0.07)	$0.34^{\#}$ (± 0.39)	-0.57

^ indicates trends are significant at 95% level, # at 90% level

*Ozone trends can be estimated from A1B - 1.5 * 1%/yr CO_2*

Arblaster et al 2010

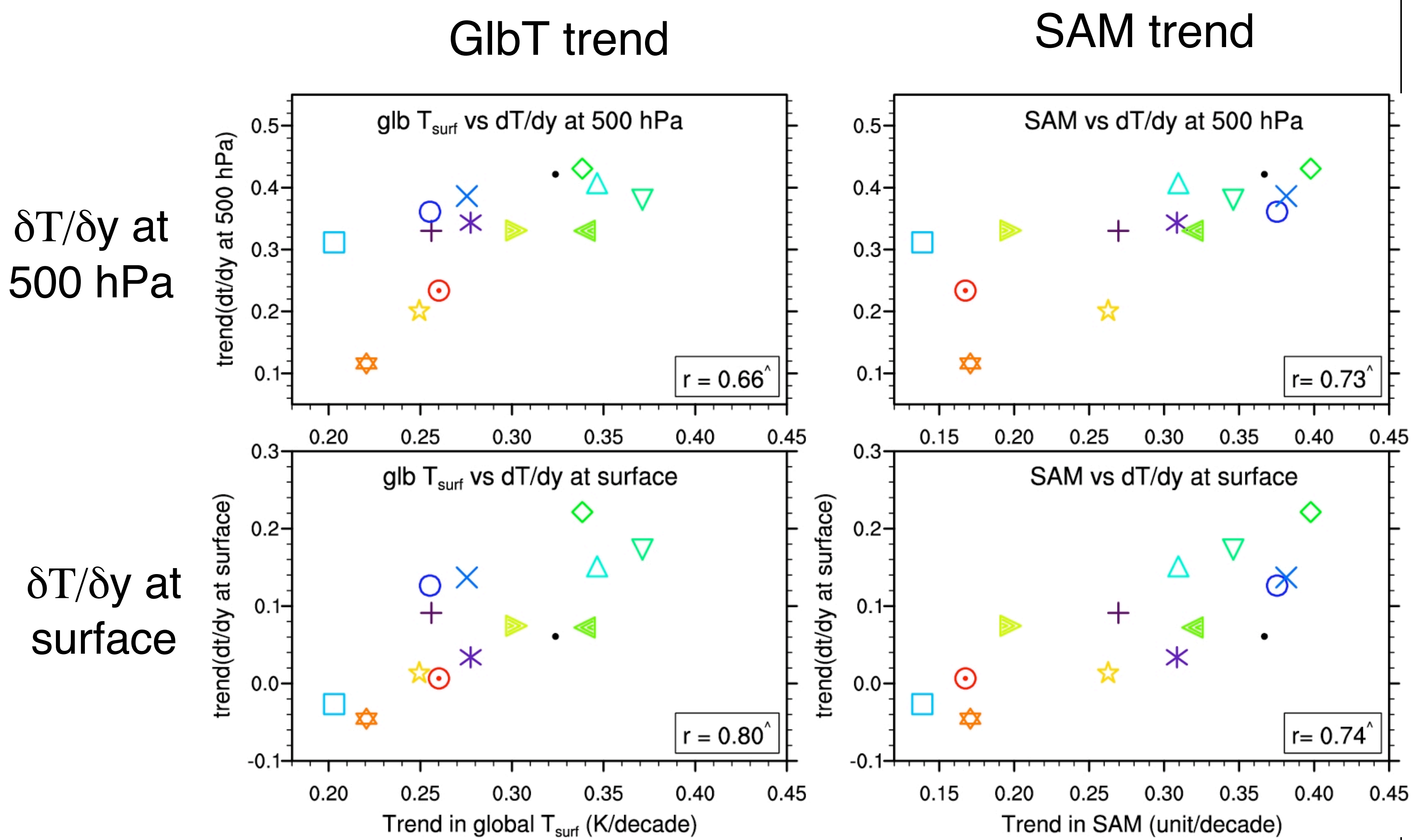
Global temperature trends vs SAM in 1%/yr runs



1%/yr incr CO2 runs

Arblaster et al 2010

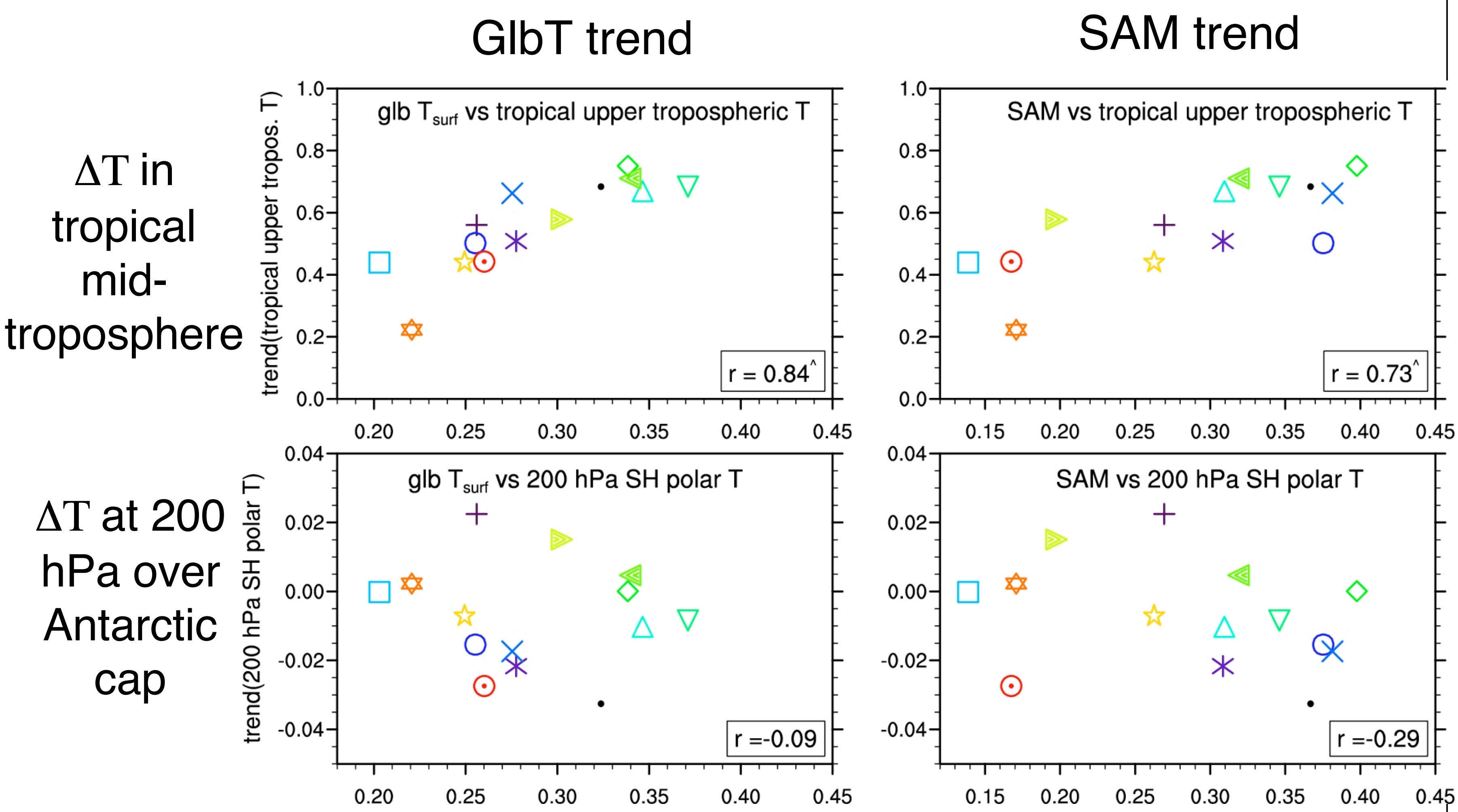
CMIP3 relationships with temperature regions in strat/trop



1%/yr incr CO2 runs

Arblaster et al 2010

CMIP3 relationships with temperature regions in strat/trop

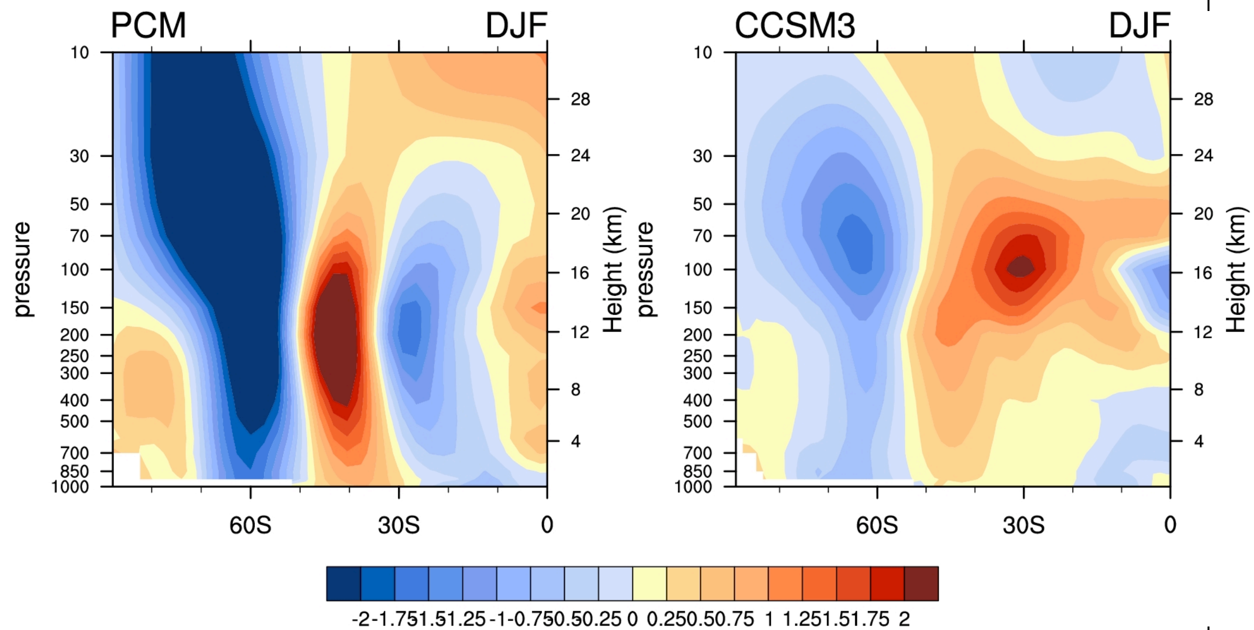


1%/yr incr CO2 runs

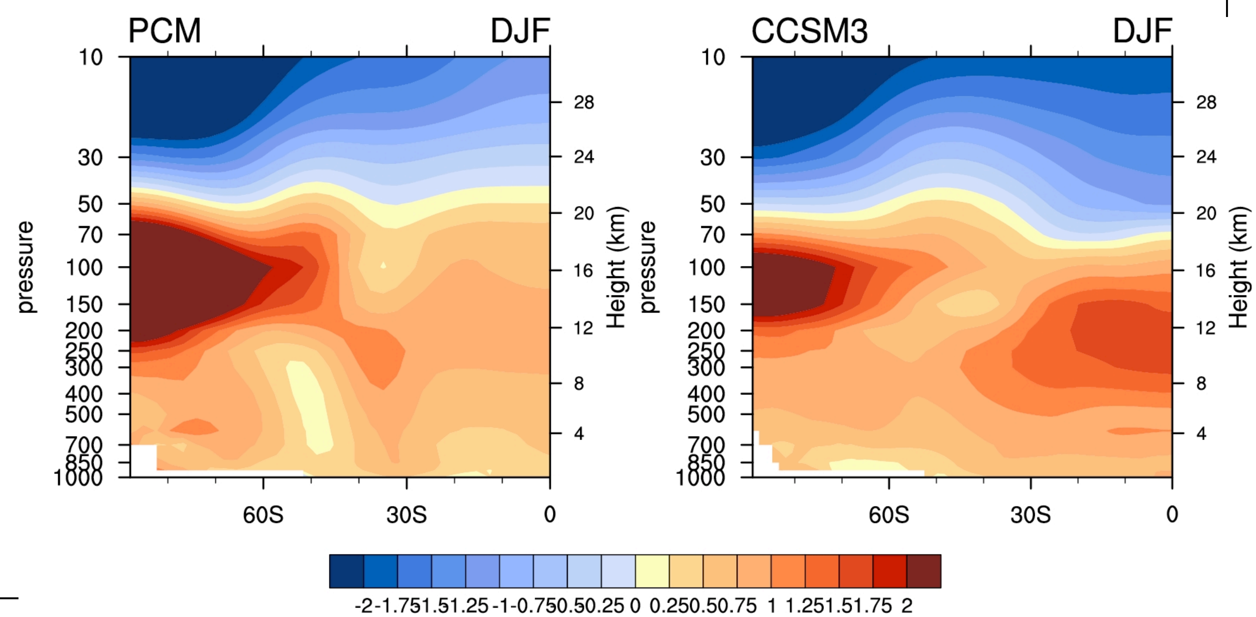
Arblaster et al 2010

Zonal trends in NCAR A1B simulations: 2000-2050

Zonal wind trends



Zonal temperature trends

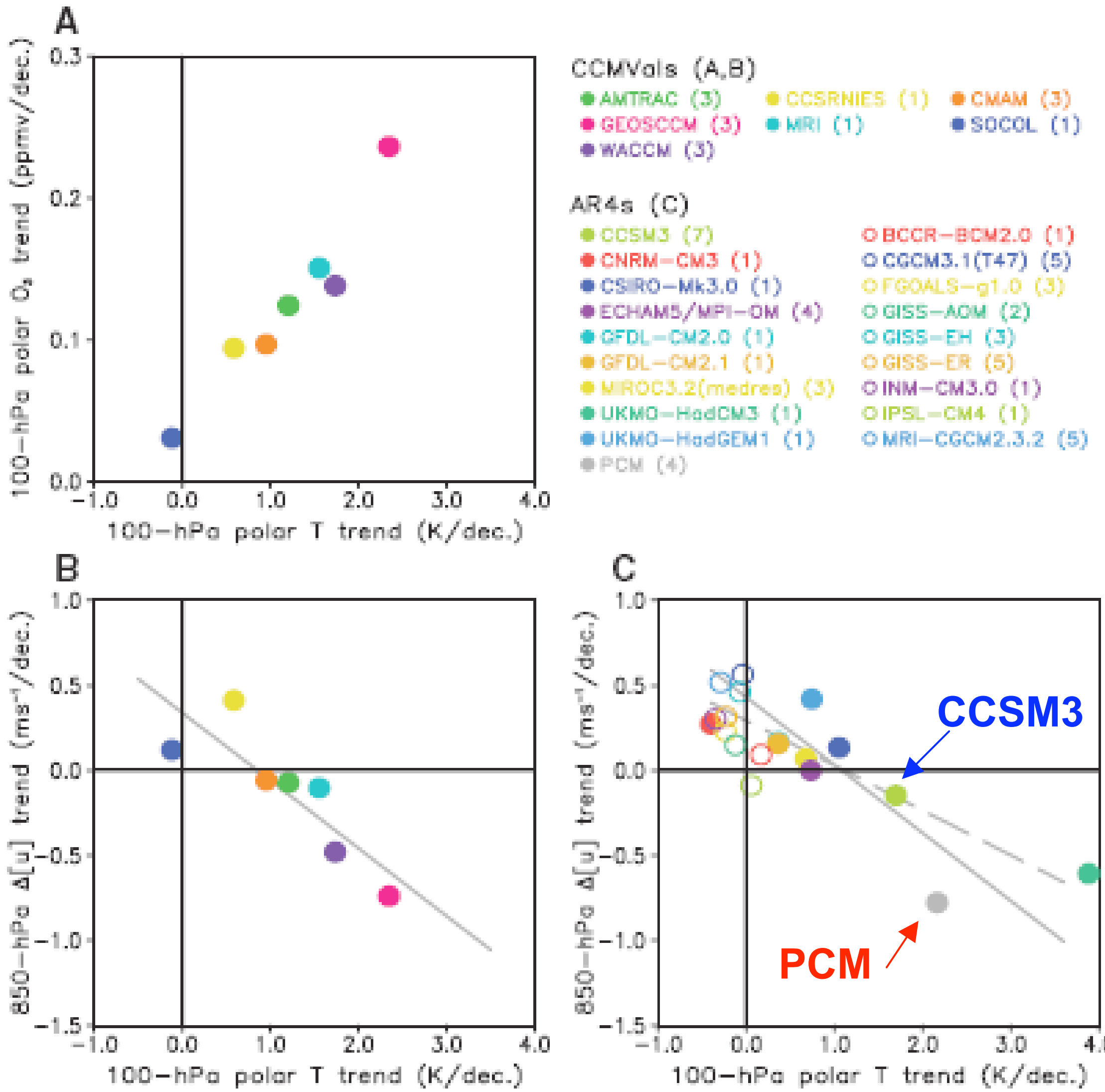


SAM index from CMIP3 & CCMVals models

The difference between CCSM3 & PCM is due mostly to climate sensitivity

How does this impact comparison between CCMVals and CMIP3 models?

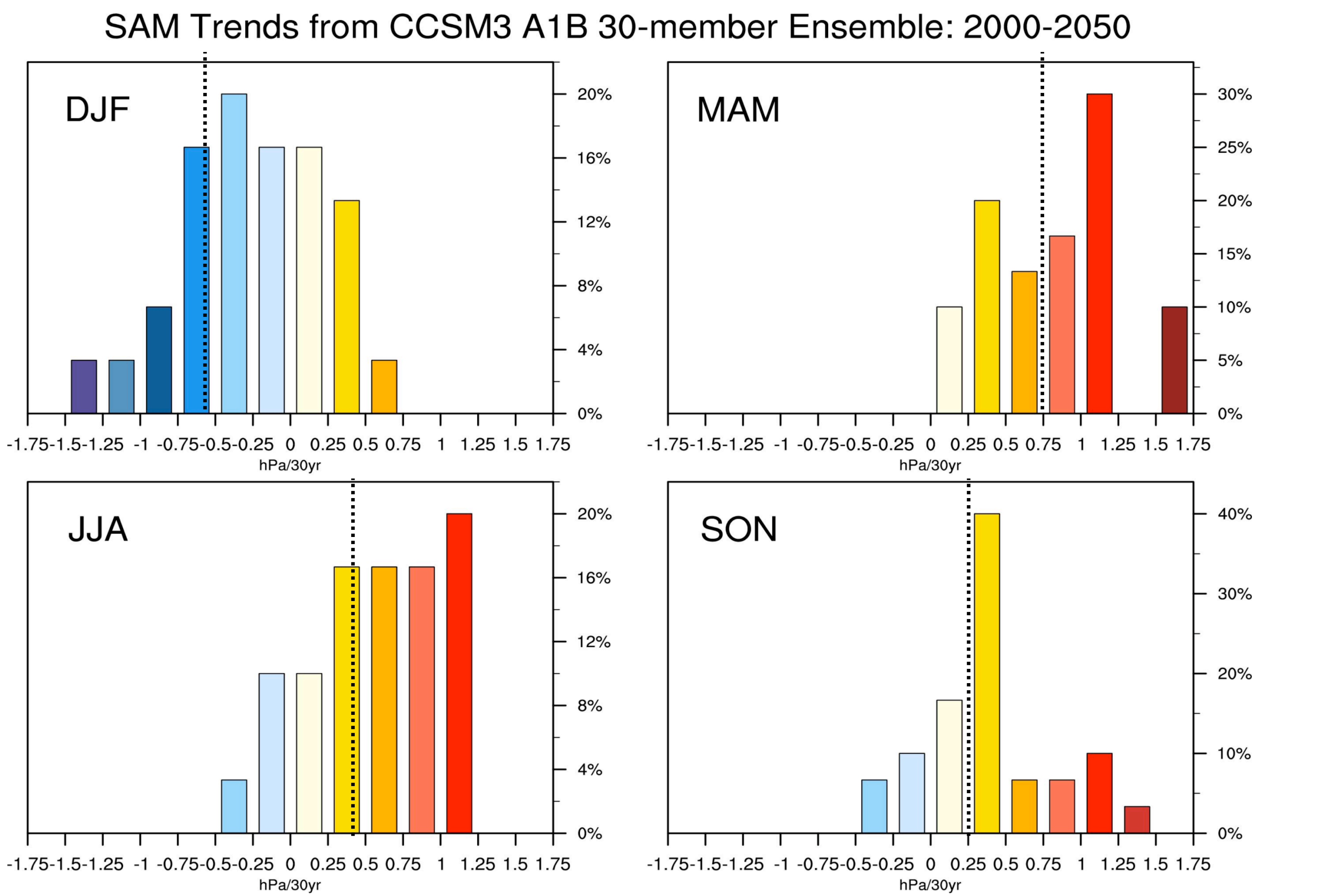
Son et al 2008



Arblaster et al 2010

Southern Annular Mode (SAM) projections

histograms of 2000-2050 trends



Conclusions (SAM)

⇒Investigated SAM trends in NCAR climate models where competing effects of ozone and greenhouse gases can be quantified. Climate sensitivity appears to play a strong role in the variation between the two models

⇒ SAM trends strongly correlated with climate sensitivity in CMIP3 models

⇒Tropical upper tropospheric warming is more relevant than polar stratospheric cooling to SAM trends in CO2 only simulations

⇒ Need to control for climate sensitivity when comparing SAM trends between sets of models

Conclusions (SAM)

⇒ Implications

Complementary to studies by:

Kidston & Gerber (2010): storm track is too far equatorward in CMIP3 models, correlated with strength of SAM response

Trenberth & Fasullo (2010): biases in SH energy budget are strongly correlated with climate sensitivity

Suggests improvements in Southern Ocean biases could lead to much improved projections

⇒ Next Steps

CCMVal2 shows closer agreement with CMIP3 for SAM trends

CMIP5 will include coupled runs with high-tops and archive ozone fields

⇒ Needs

Single forcing runs for future scenarios

11-year solar cycle

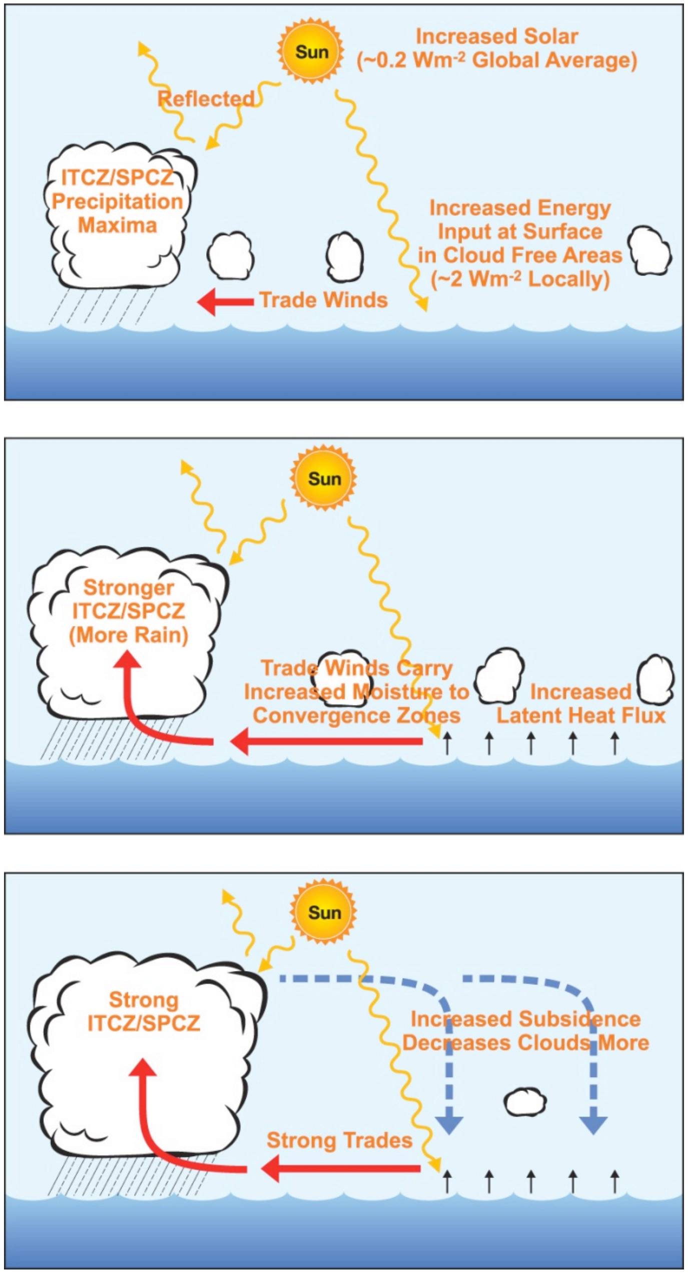
The amplitude of the solar cycle is small (total solar irradiance change of 0.2 Wm^{-2}) and the observed global SST response of 0.1ºC would require 0.5 Wm^{-2}

Two proposed mechanisms for amplification of the solar signal

The top-down stratospheric ozone mechanism

Increased solar ⇒ increased ozone heating/increased ozone amount ⇒ modified temperature and zonal wind ⇒ altered wave propagation ⇒ changed equator to pole energy transport and circulation ⇒ enhanced tropical precipitation

(e.g. Haigh, 1996; Shindell et al., 1999; Balachandran et al., 1999; Kodera and Kuroda, 2002)



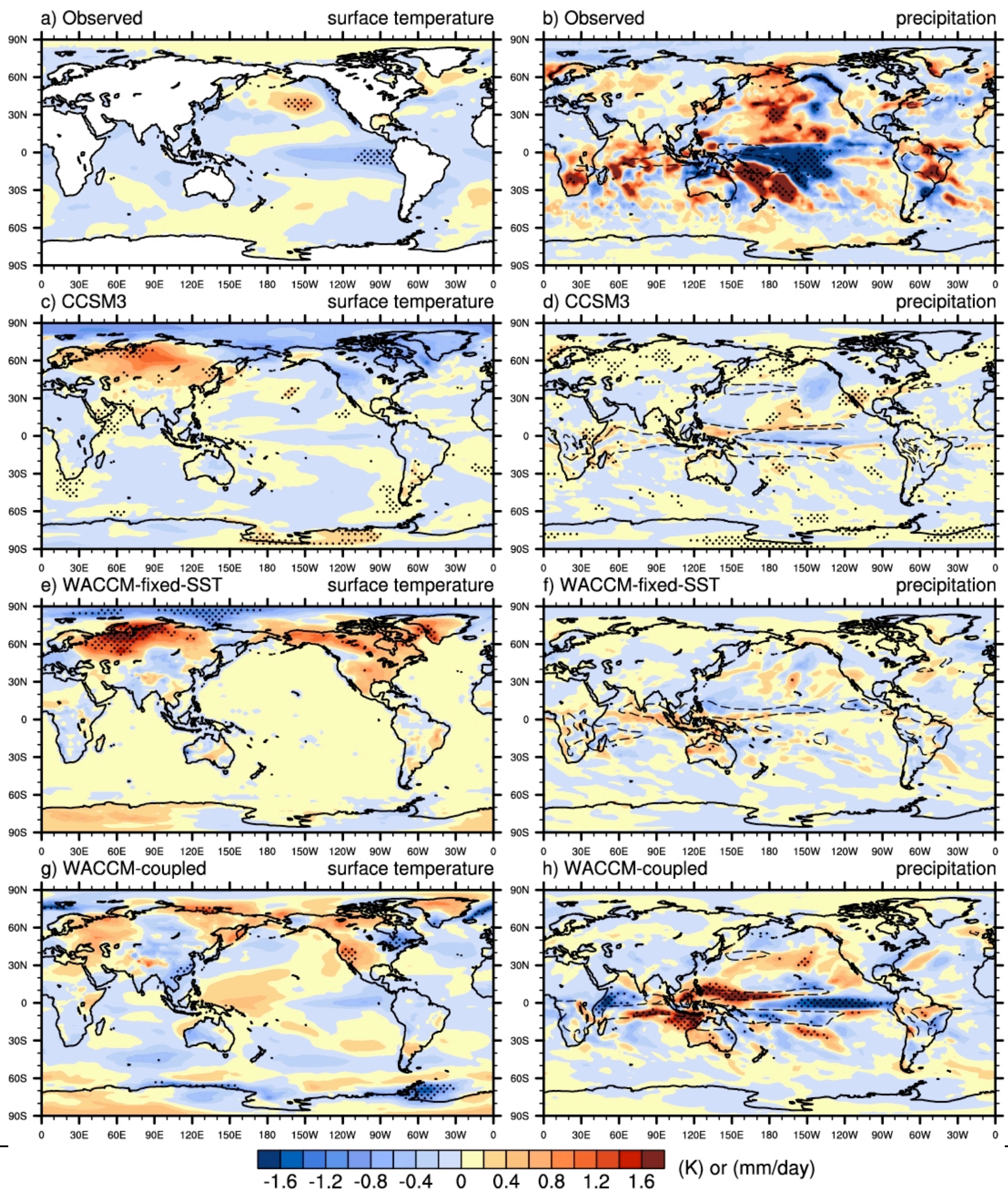
The bottom-up coupled air-sea mechanism: **increased solar over cloud-free regions of the subtropics translates into greater evaporation, and moisture convergence and precipitation in the ITCZ and SPCZ (and south Asian monsoon), stronger trades, and cooler SSTs in eastern equatorial Pacific**

Meehl, G.A., W.M. Washington, T.M.L. Wigley, J.M. Arblaster, and A. Dai, 2003, *J. Climate*

Van Loon, Meehl and Arblaster, 2004, *JASTP*

Meehl, G.A., J.M. Arblaster, G. Branstator, and H. Van Loon, 2008, *J. Climate*

Solar maximum composites



Observed

Bottom-up only

Top-down only

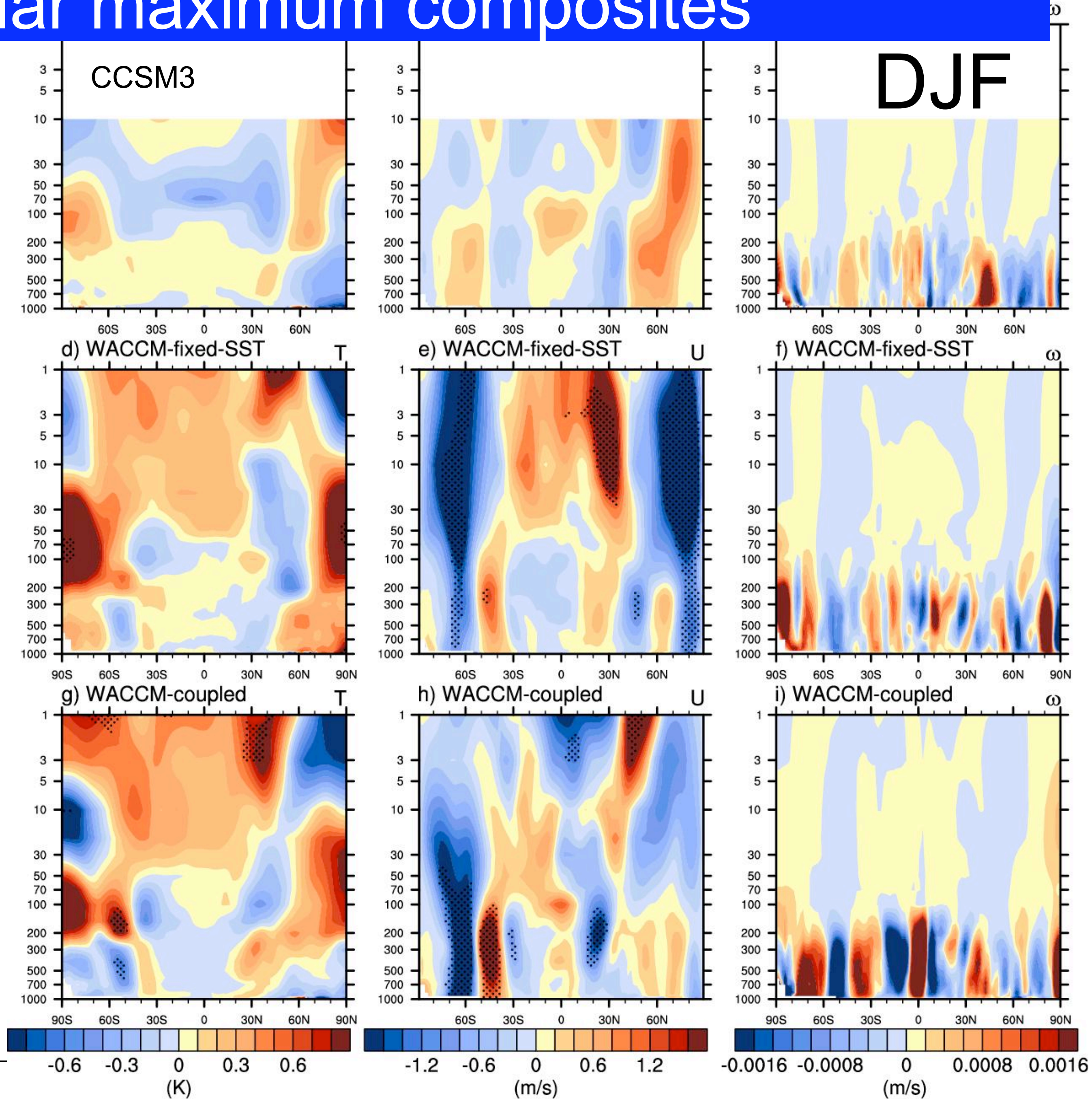
Both bottom-up and top-down

Meehl et al, Science, 2009

Solar maximum composites

Solar maximum composites of zonal temperature and winds in 20thC simulations of CCSM3 (low-top) and WACCM (high-top) get opposite signs in SAM trend

However latest version of low-top model produces solar-induced positive SAM



Conclusions (solar)

⇒ Peaks of the 11 year solar cycle forcing produce SST and precipitation anomalies with a cold event-like pattern in the Pacific

⇒ Bottom-up coupled air-sea mechanism and top-down stratospheric ozone mechanism add to strengthen tropical convection more than either one alone, and leads to amplifying cloud feedbacks

⇒Next steps
Studies with additional coupled models to test mechanisms

⇒Needs
Longer solar records: recent studies suggest solar minimum was accompanied by larger than expected decreases in UV and *increases* in visible and infrared

Internal variability of SAM trends in NCAR models