NCAR CMIP5 experience with CCSM4 and CESM1/CAM5

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At the end of CMIP3 and the IPCC AR4 process in 2007, climate science underwent a fundamental shift:

--first generation Earth System Models (with at least a coupled carbon cycle)

--high-top coupled models

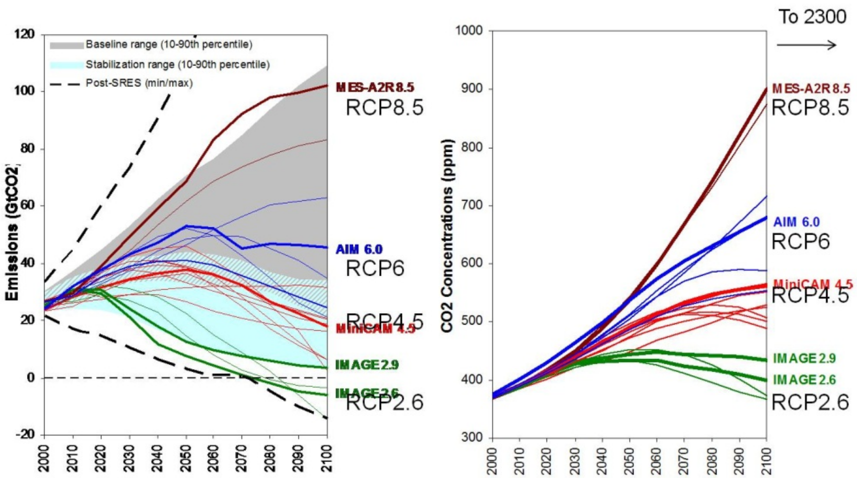
--high resolution time-slice experiments

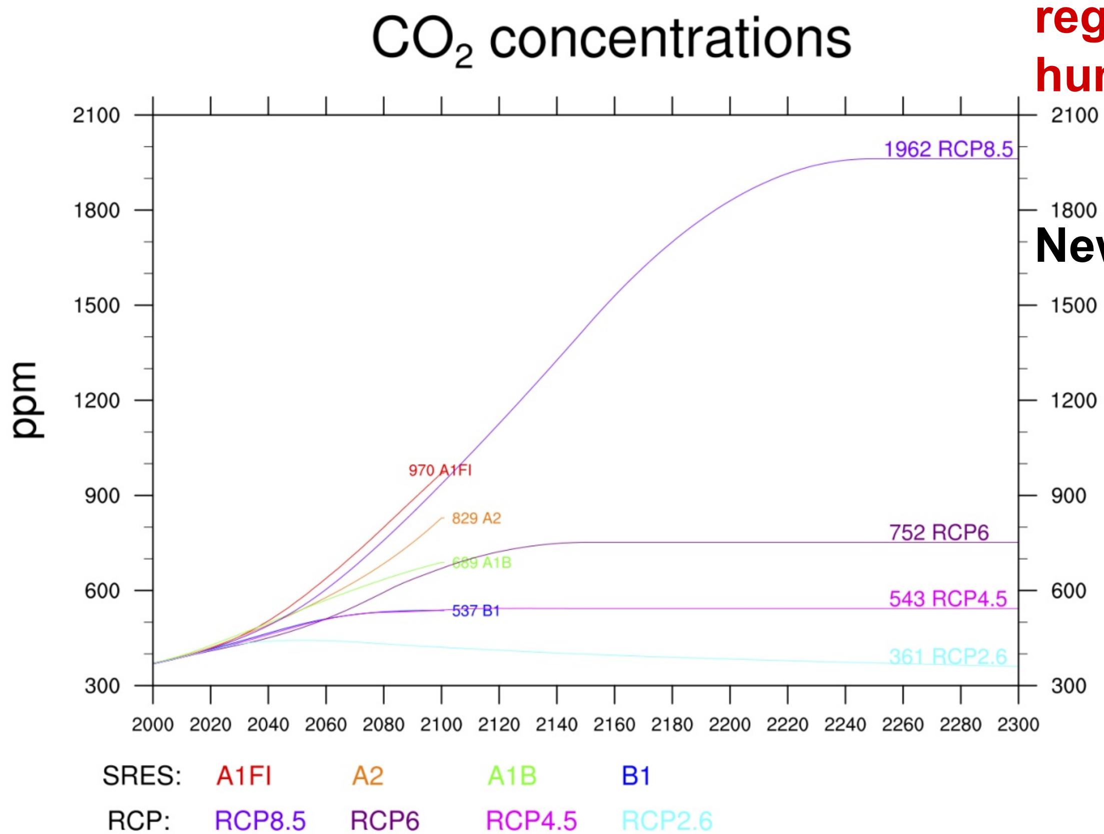
--mitigation scenarios and a re-framing of the climate change problem

--decadal climate prediction

CMIP5 was formulated to provide a coordinated multi-model experiment framework to address new science questions and new scenarios (it was organized by the WCRP Working Group on Coupled Models—WGCM—and not dictated by IPCC)

Representative Concentration Pathways (RCPs)





CMIP5: a new way of framing the climate change problem

CMIP3: "what if?"

CMIP5: "what mitigation actions are necessary to achieve certain climate change targets?"

With different mitigation choices, what is the remaining time-evolving regional climate change to which human societies will have to adapt?

New mitigation scenarios: the RCPs

what's new in CMIP5?

(new experimental design formulated at an Aspen Global Change Institute workshop in summer, 2006)

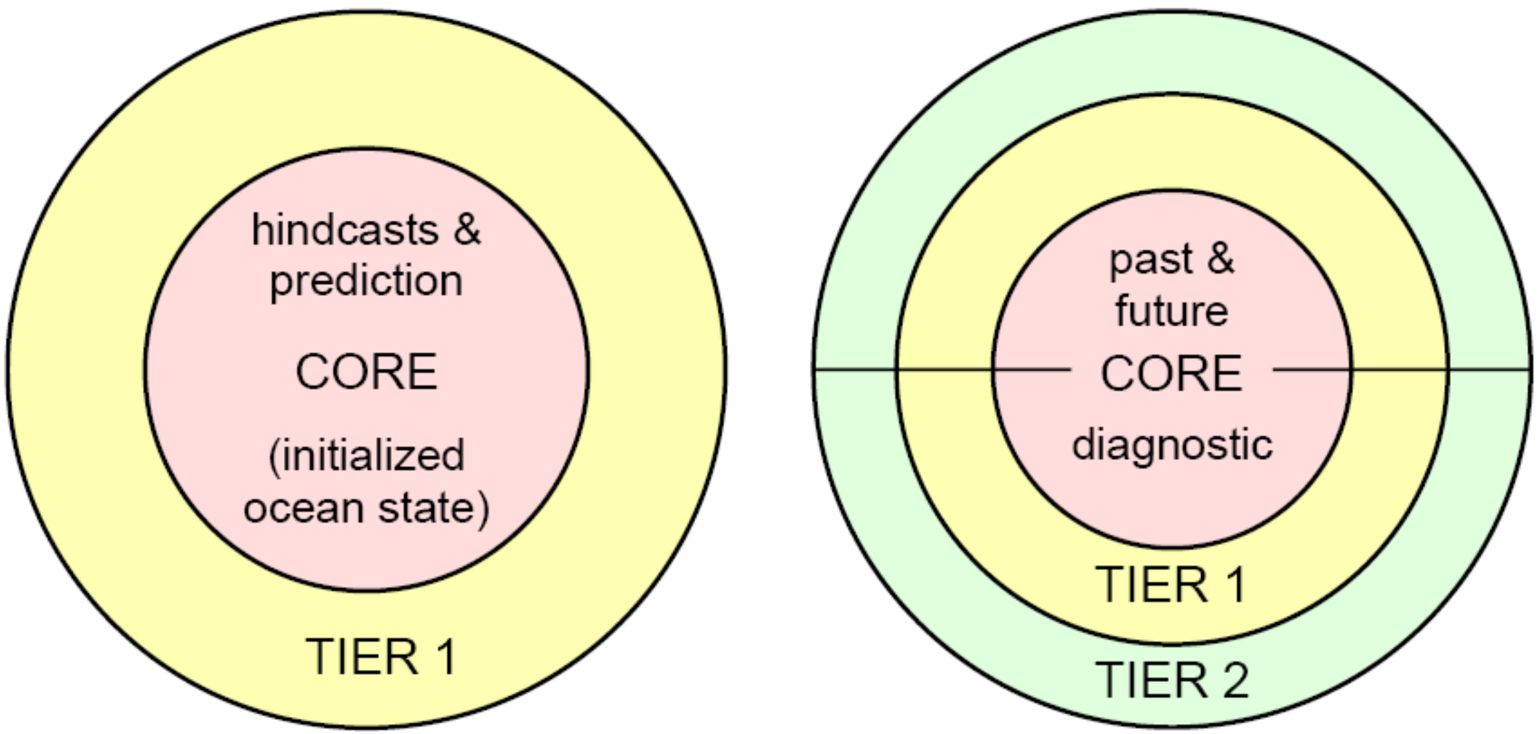
The new concept was for two classes of models for two timescales and two sets of science problems

All totally new experiments

"Near-Term"
(decadal)

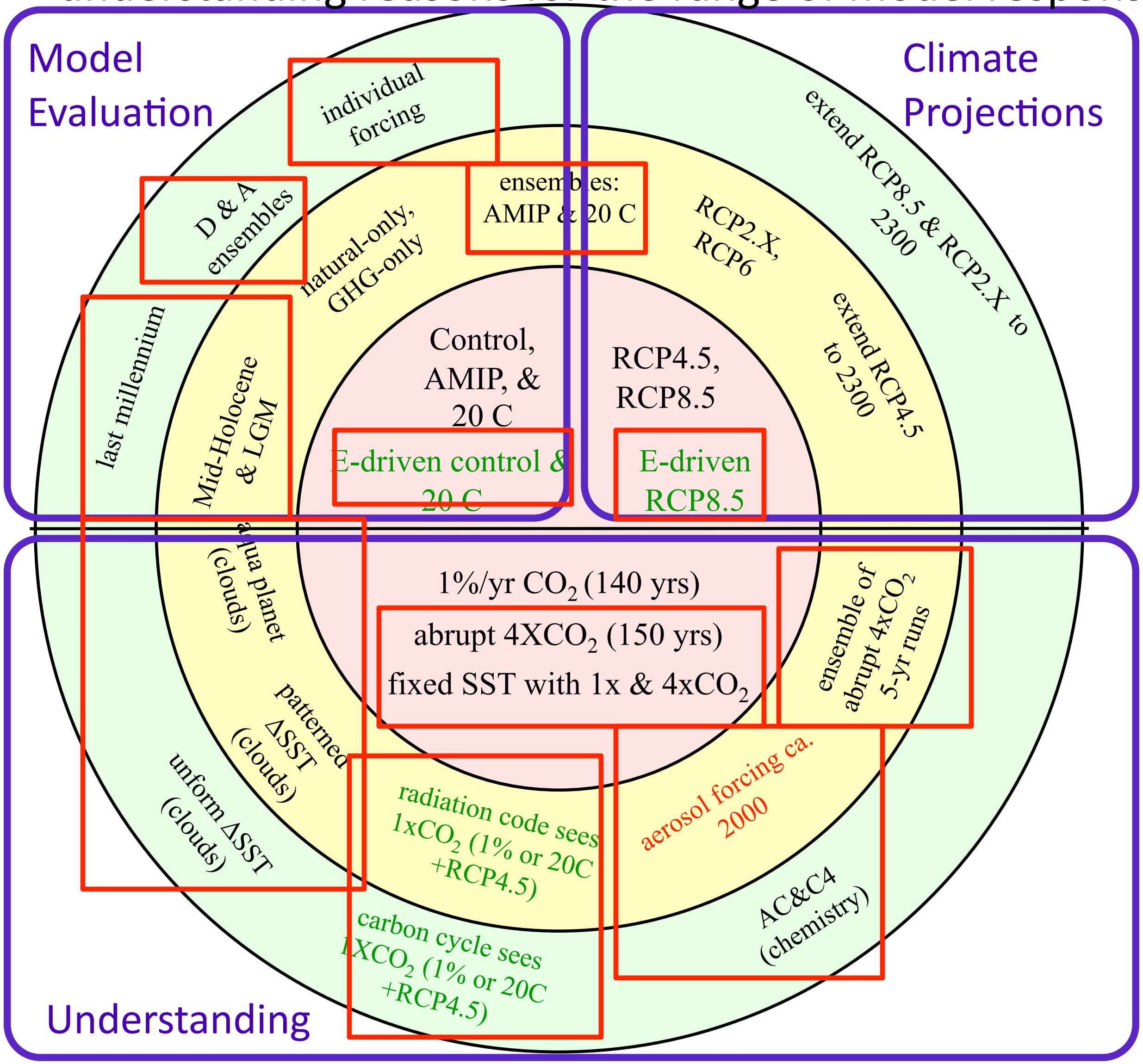
Many new experiments

"Long-Term"
(century & longer)



New decadal climate prediction experiments, and CMIP5 Long-Term Experiments

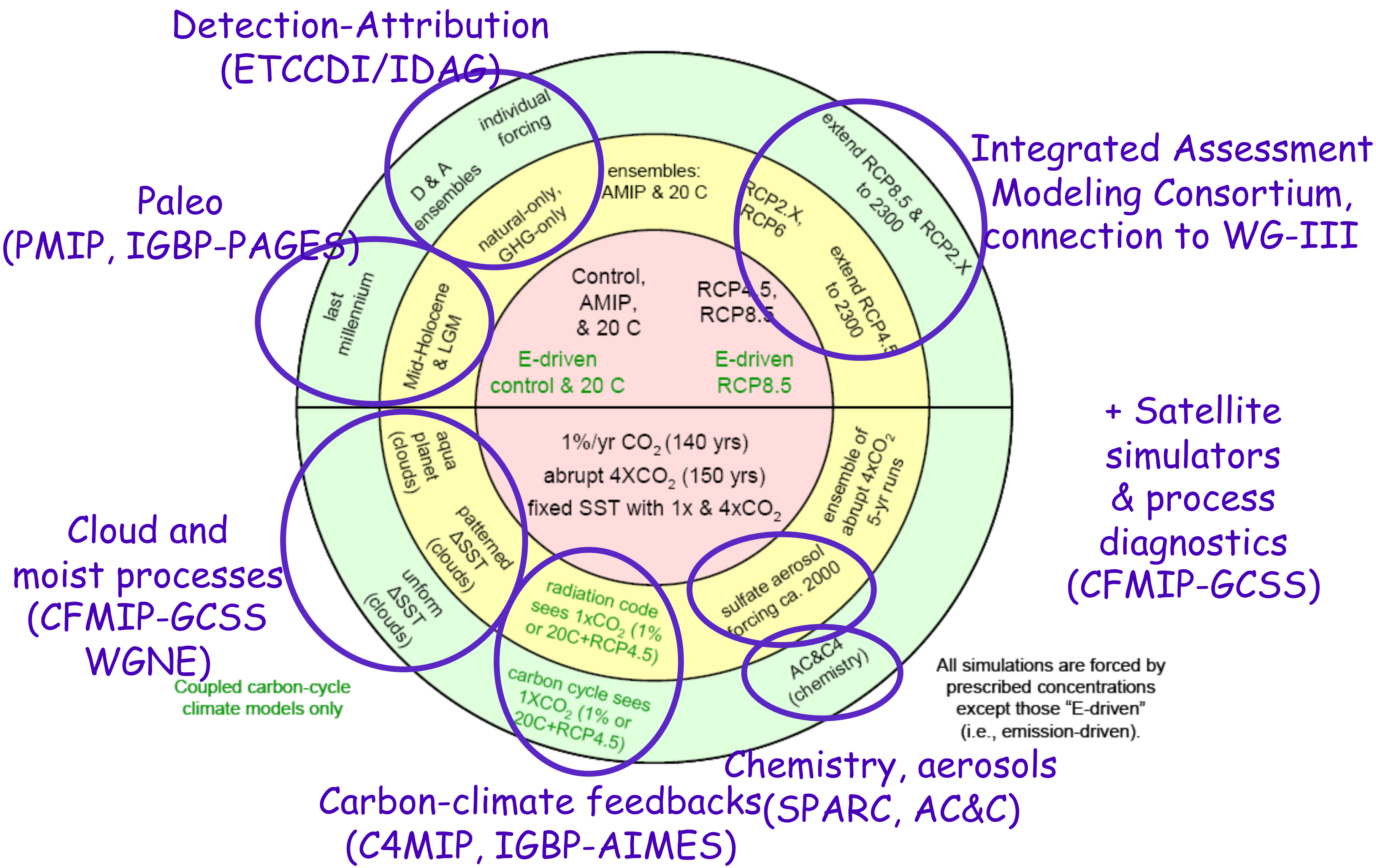
An important new focus on model evaluation in comparison to observations and understanding reasons for the range of model responses



Experiments new to CMIP5 outlined in red

CMIP5 Long-Term Experiments

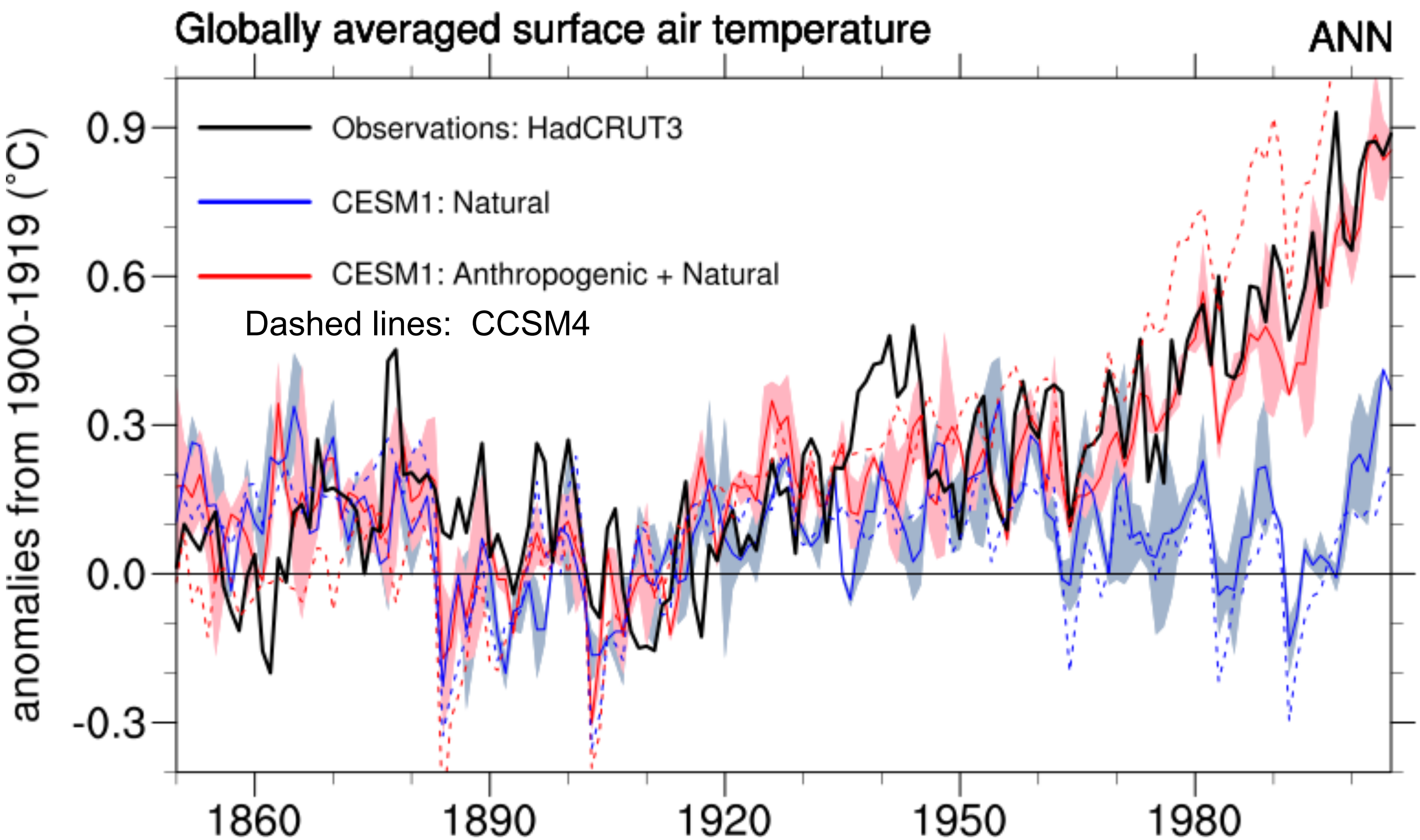
new direct participation and collaboration with many communities



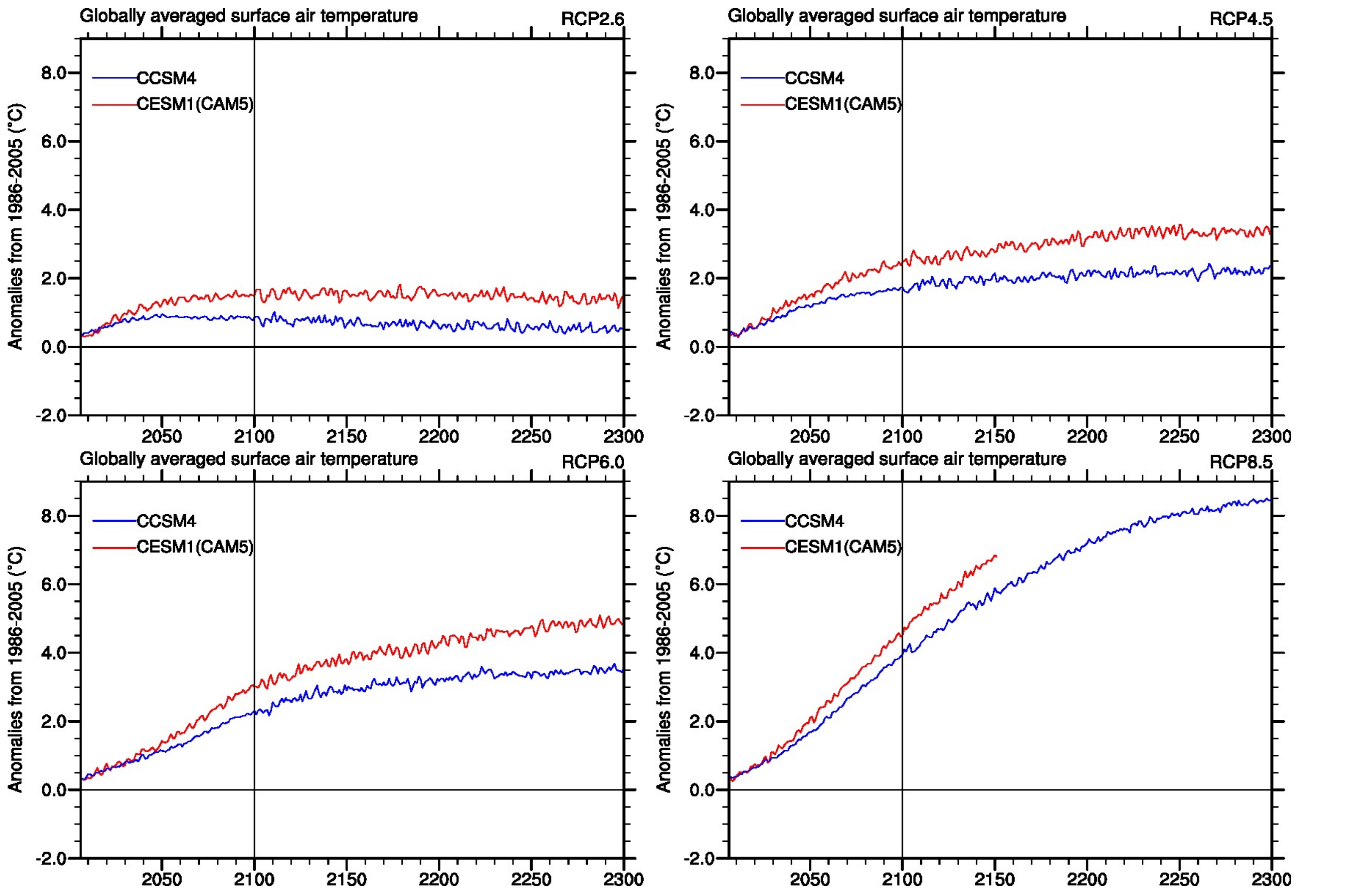
The NCAR experience: 15 times more data volume submitted for CMIP5 than for CMIP3
--ratio of original model output generated was about 10 times greater.

	CMIP3	CMIP5
Models used	2 (CCSM3 and PCM)	5 (CCSM4, CESM1-BGC, CESM1- WACCM, CESM1-FASTCHEM, CESM1-CAM5)
Total volume submitted	~ 9.2 TB (over 10 month period)	~136 TB (over one year period) **(factor of 4 greater than ALL of the CMIP3 multi-model data set)**
Total volume generated	~120 TB	~1380 TB
Total simulated years	~14,900	~28,500
Number of model runs	107 total 73 (CCSM3), 34 (PCM1)	555 total 91 (CCSM4 long-term) 400 (CCSM4 decadal prediction) 64 (other configurations)
Experiments requested	12	37
Output categories	6	19
Number of requested fields	137	951

CCSM4 vs. CESM1/CAM5; Equilibrium climate sensitivity: CCSM4 = 3.2°C CESM1/CAM5 = 4.1°C; **model with higher sensitivity produces cooler historical climate** in latter part of 20th century and early 21st century due in part to inclusion of the aerosol indirect effect



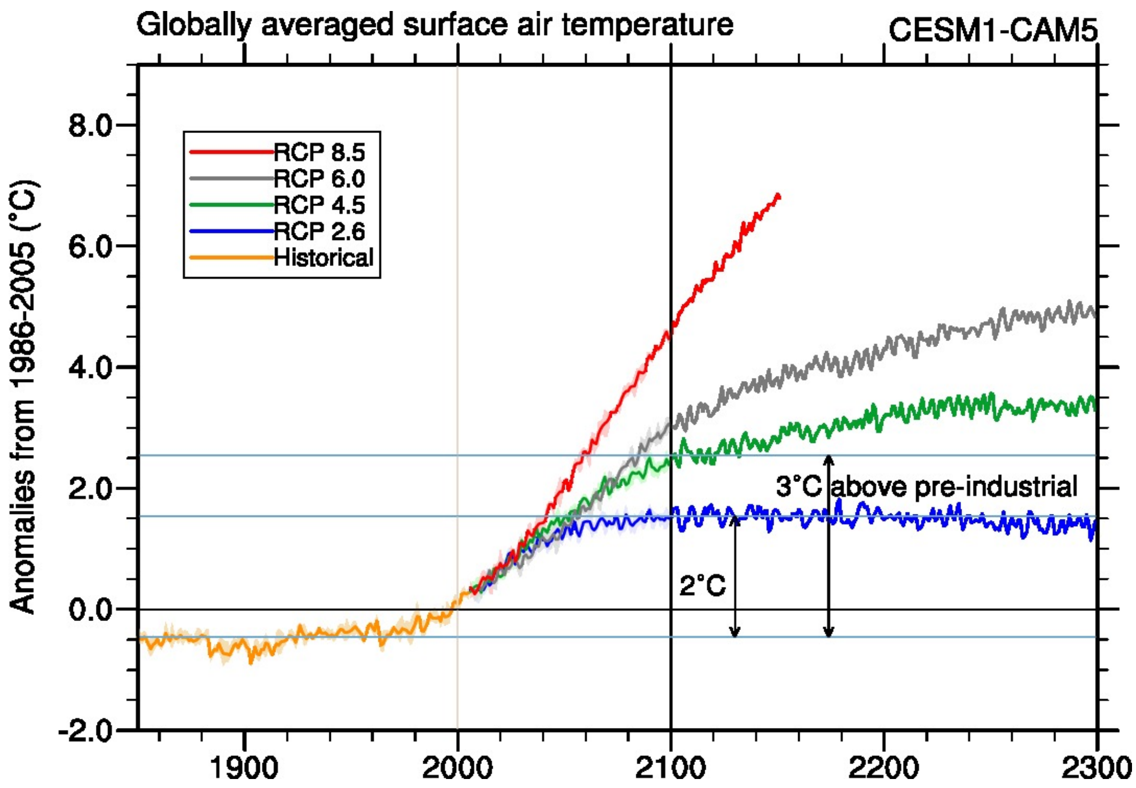
CCSM4 vs. CESM1/CAM5; Equilibrium climate sensitivity: CCSM4 = 3.2°C CESM1/CAM5 = 4.1°C; **model with higher sensitivity produces warmer future climate** due to greater amplitude response to the projected decrease in aerosols



(Meehl, G.A., W.M. Washington, J.M. Arblaster, A. Hu, H. Teng, C. Tebaldi, B. Sanderson, J.F. Lamarque, A. Conley, and W.G. Strand, 2012: Climate change projections in CESM1/CAM5. *J. Climate,* submitted).

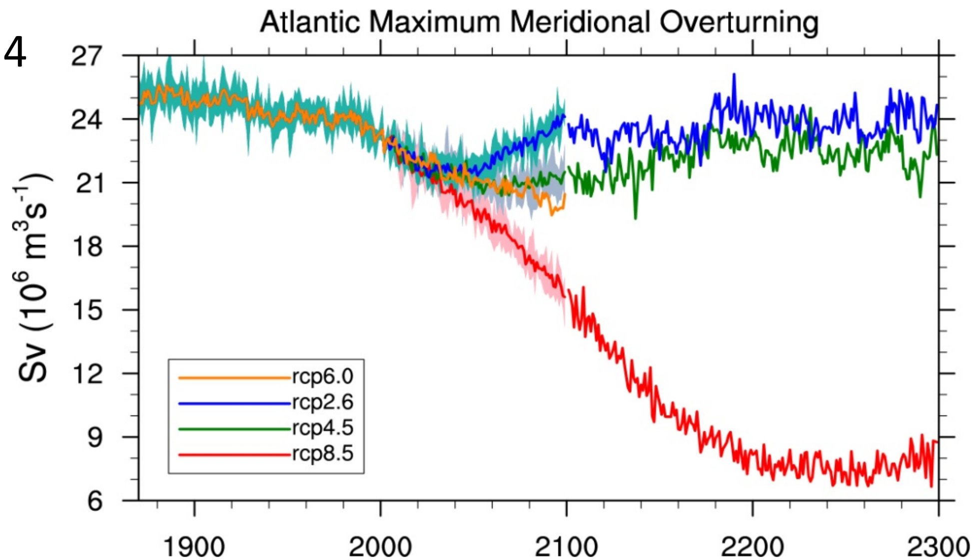
The aggressive mitigation scenario targets warming to 2°C above pre-industrial

(illustrated here with results from CESM1/CAM5)

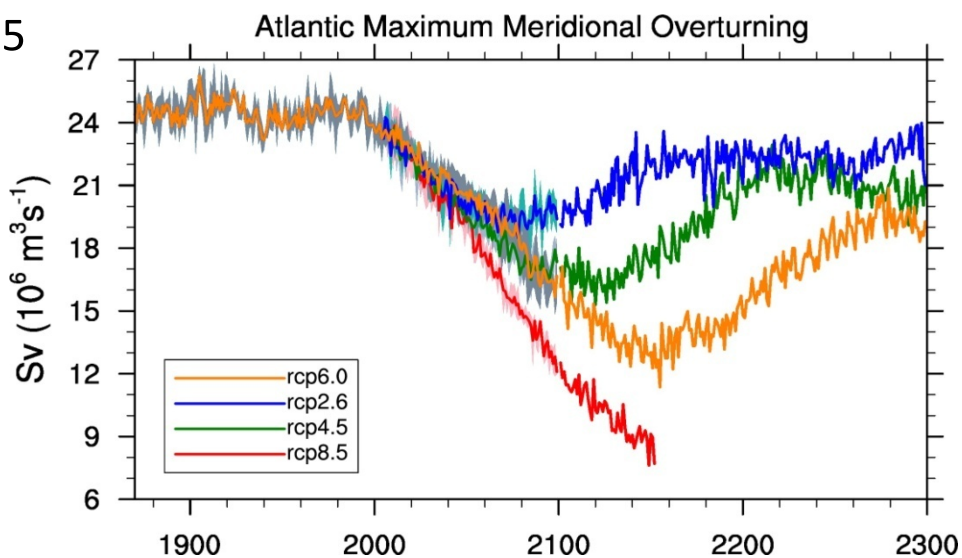


(Meehl, G.A., W.M. Washington, J.M. Arblaster, A. Hu, H. Teng, C. Tebaldi, B. Sanderson, J.F. Lamarque, A. Conley, and W.G. Strand, 2012: Climate change projections in CESM1/CAM5. *J. Climate,* submitted*)*.

CCSM4

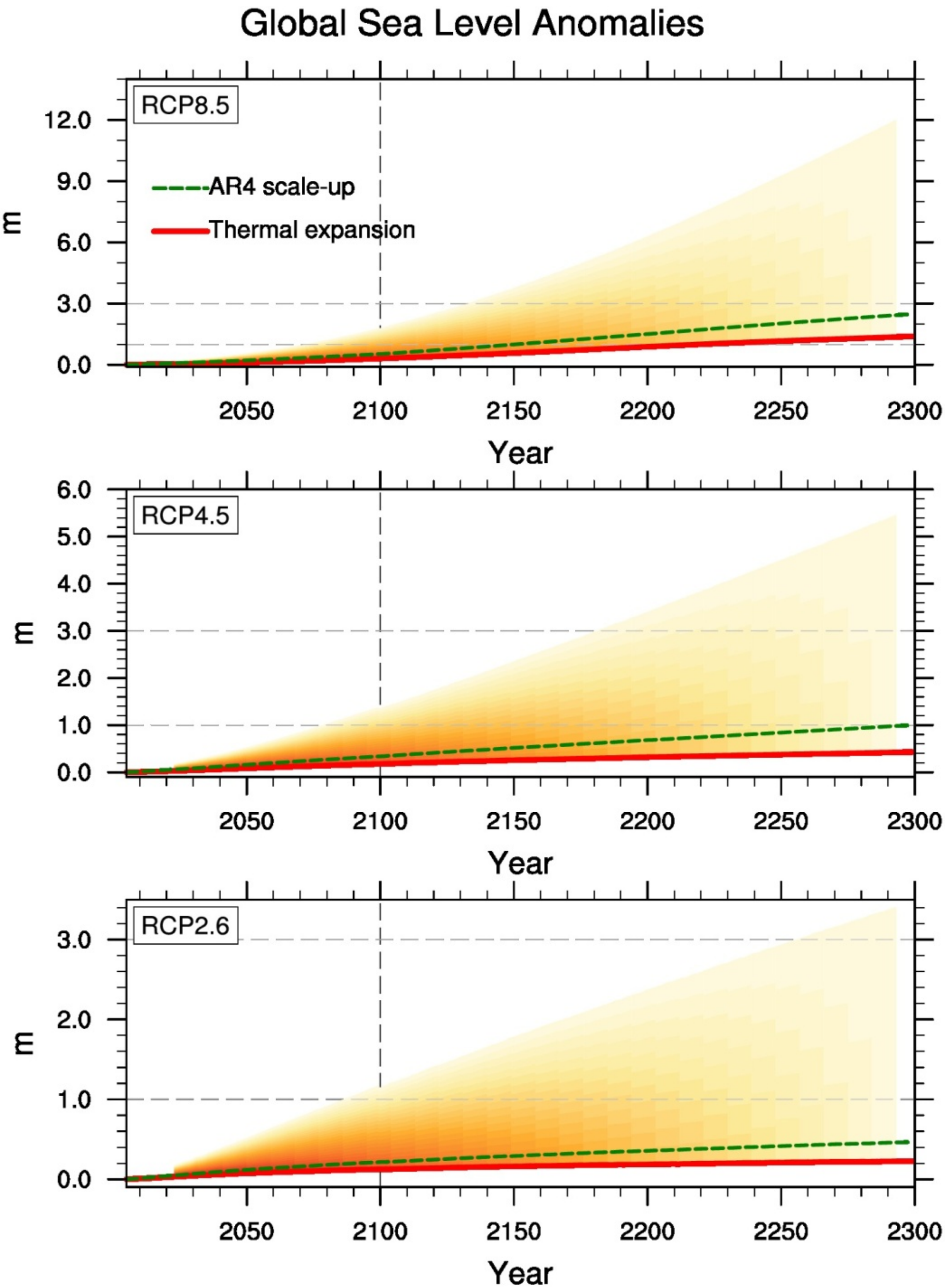


CESM1/CAM5

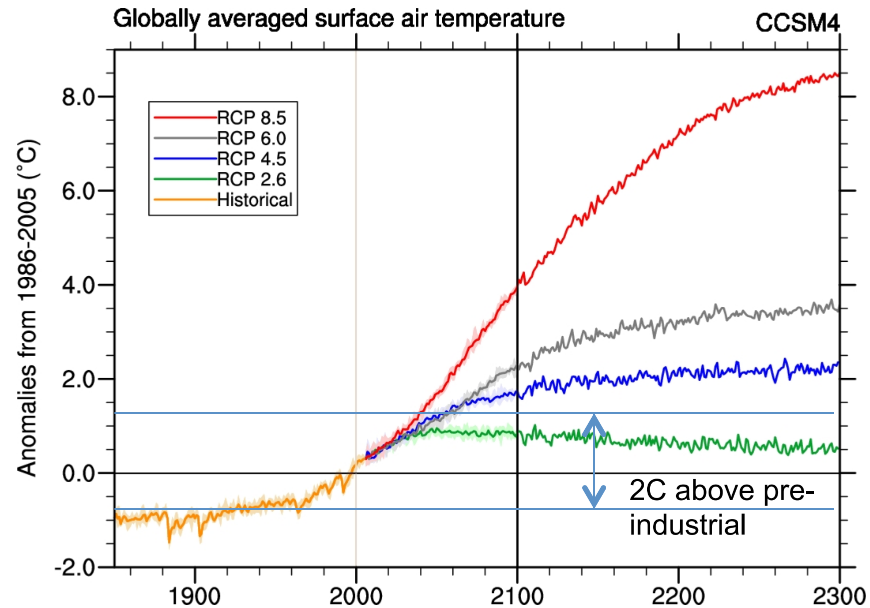


larger response and slower recovery of the AMOC in the future in the higher sensitivity CESM1/CAM5 vs. CCSM4

(Meehl, G.A., W.M. Washington, J.M. Arblaster, A. Hu, H. Teng, C. Tebaldi, B. Sanderson, J.F. Lamarque, A. Conley, and W.G. Strand, 2012: Climate change projections in CESM1/CAM5. *J. Climate,* submitted*)*.



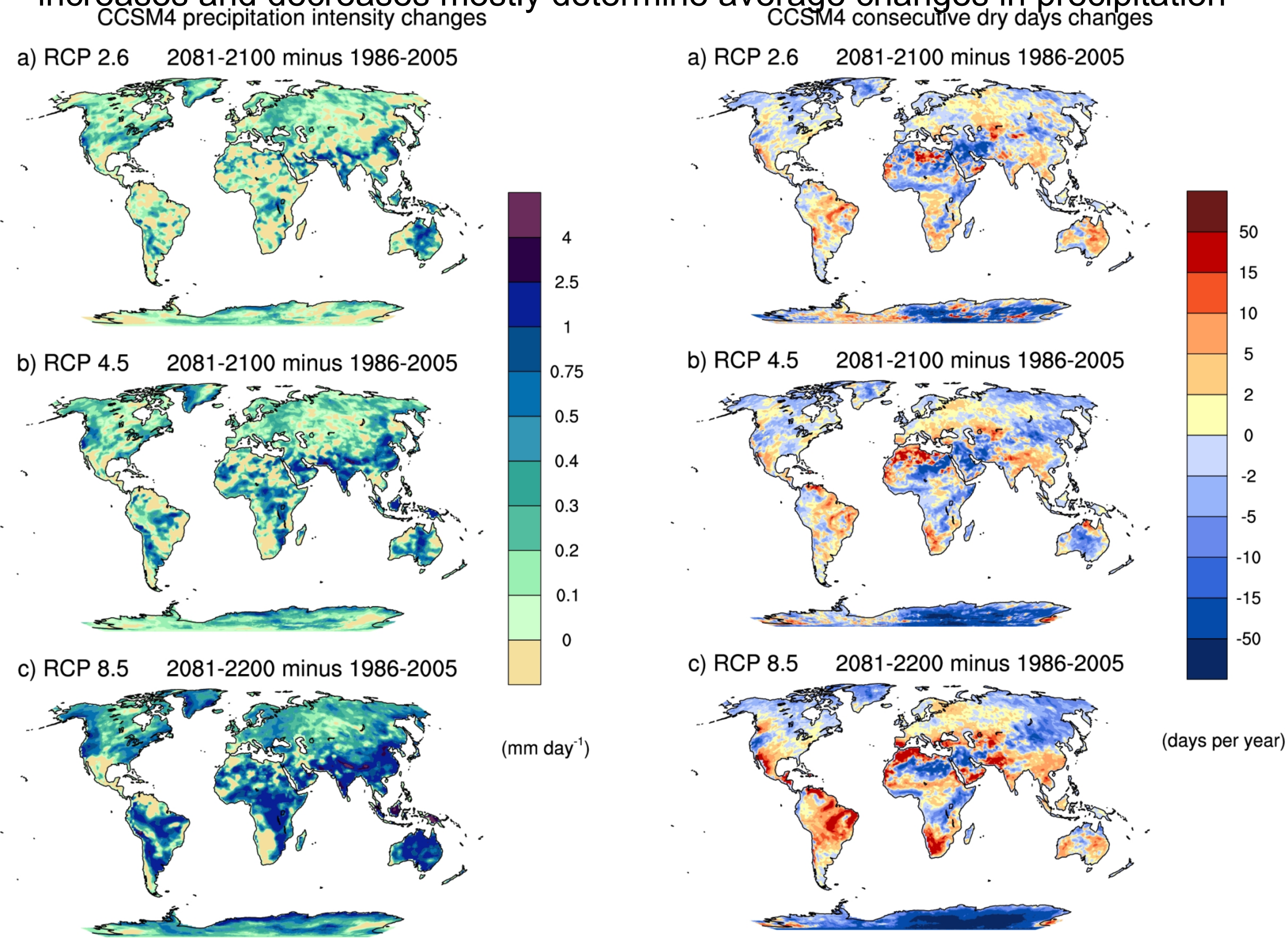
(Meehl et al., 2012, Nature Climate Change)



In the RCP scenarios, we can mitigate temperature but not sea level rise

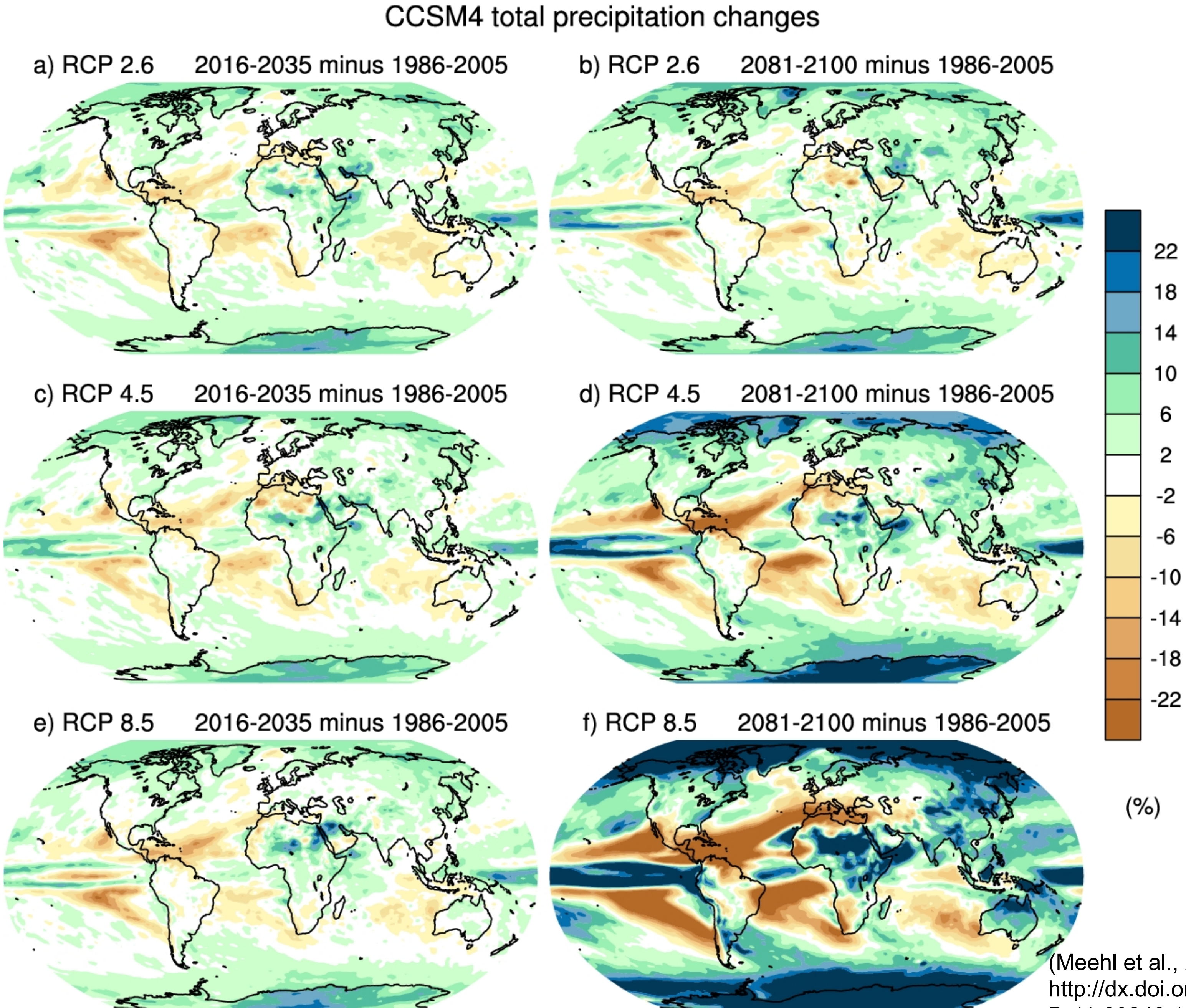
(note: There are various ways to attempt to estimate what the magnitude and timing of global sea level rise will be, with the best known contribution from thermal expansion, another using the "example" in the AR4 taking into account some contribution from accelerated ice sheet discharge, and semi-empirical methods)

Precipitation extremes: increased intensity everywhere, but dry days with a mix of increases and decreases mostly determine average changes in precipitation



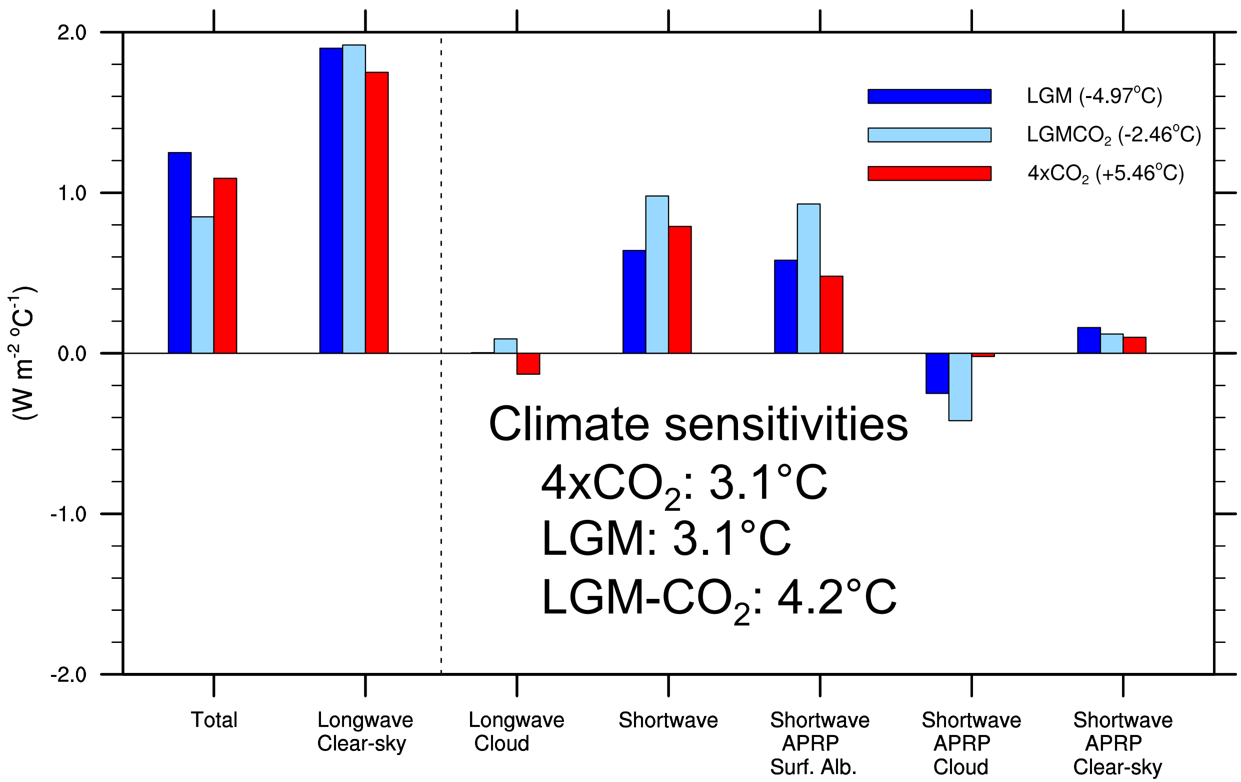
(Meehl et al., 2012, J. Climate, doi: http://dx.doi.org/10.1175/JCLI-D-11-00240.1)

Average precipitation changes: dry areas get drier, wet areas get wetter (mostly)



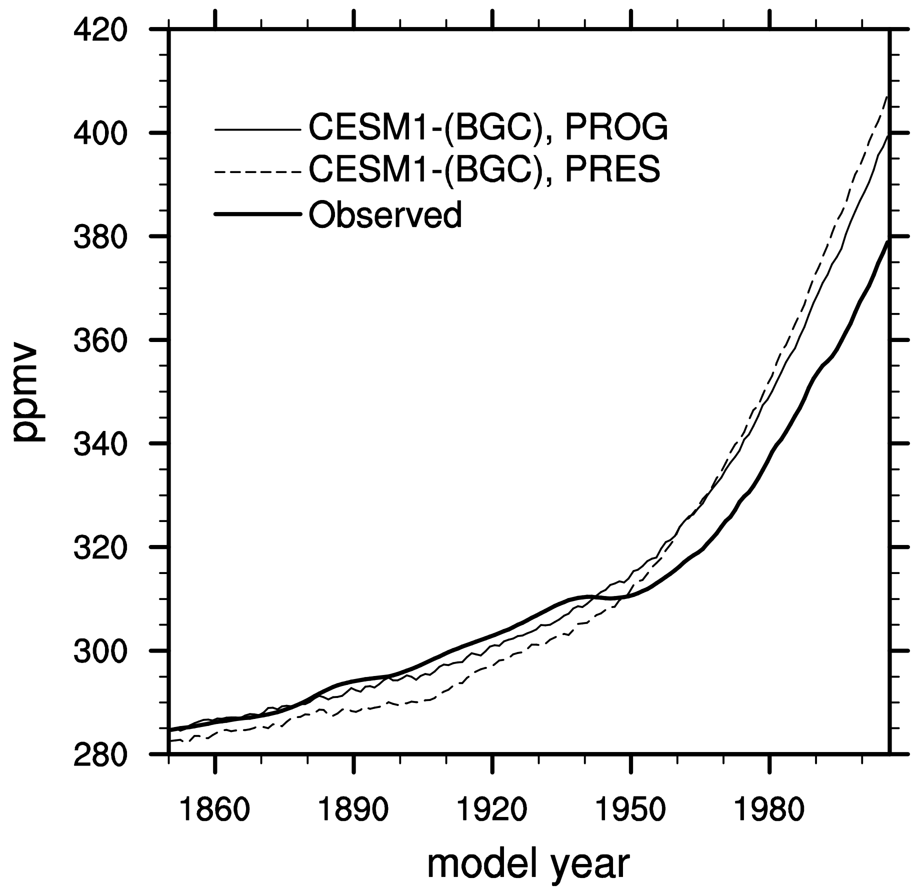
(Meehl et al., 2012, J. Climate, doi: http://dx.doi.org/10.1175/JCLI-D-11-00240.1)

CMIP5 Paleo Simulations
Climate Feedbacks: Past and Future (CCSM4)



(Brady, E.C., B.L. Otto-Bliesner, J.E. Kay, and N. Rosenbloom, 2012: Sensitivity of CCSM4 to glacial forcing. *Journal of Climate.)*

CMIP5 Earth System Model experiments: CO_2 in 20[th] Century Experiments with coupled carbon/ nitrogen cycle



Modeled increase of CO_2 over 1850-2005 too large:

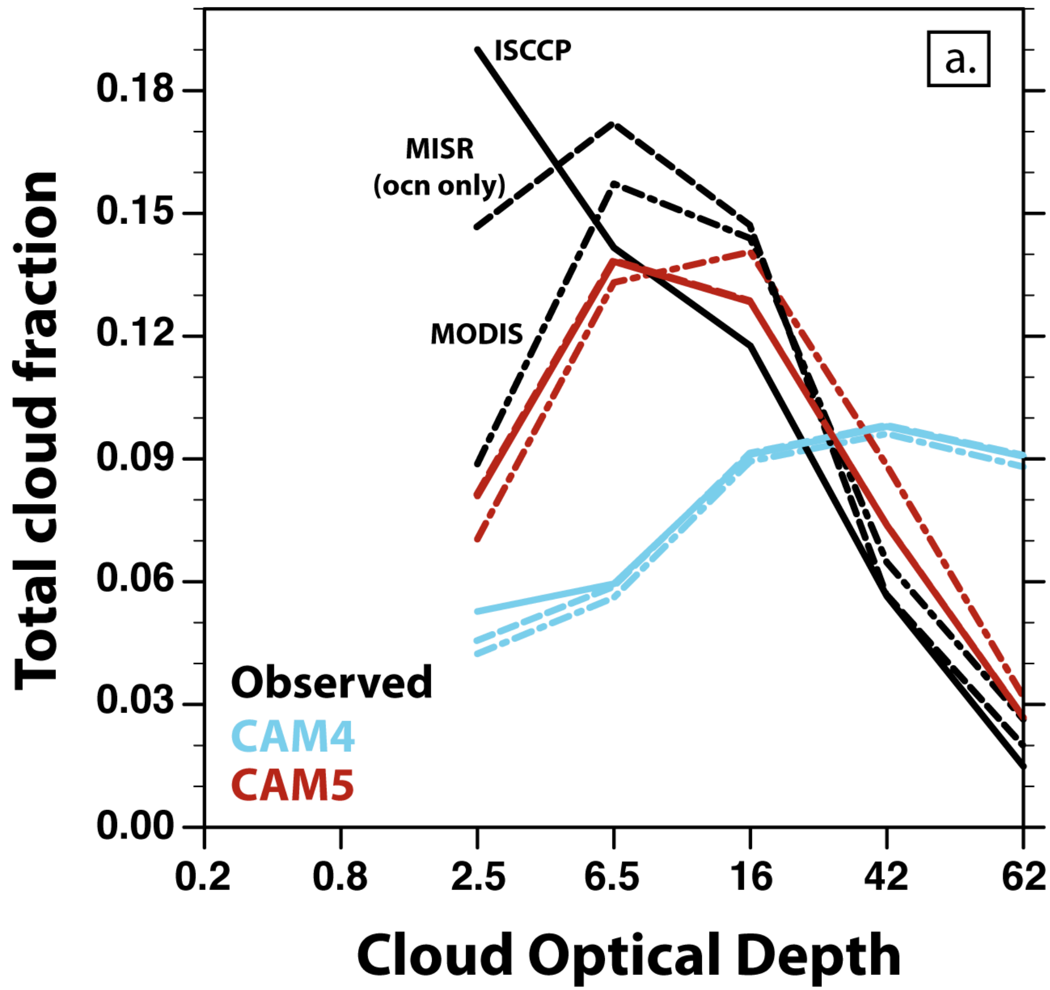
Observed: 94 ppmv

Diagnostic CO_2 tracer: 125 ppmv

Prognostic CO_2 tracer: 114 ppmv

(Lindsay et al., submitted to J Climate)

CMIP5 cloud feedback experiments: COSP-enabled comparisons robustly show that the CAM5 physics has reduced long-standing climate model cloud biases (too many optically thick clouds, too few clouds) evident in CAM4 and many other climate models (e.g. Zhang et al. 2005).



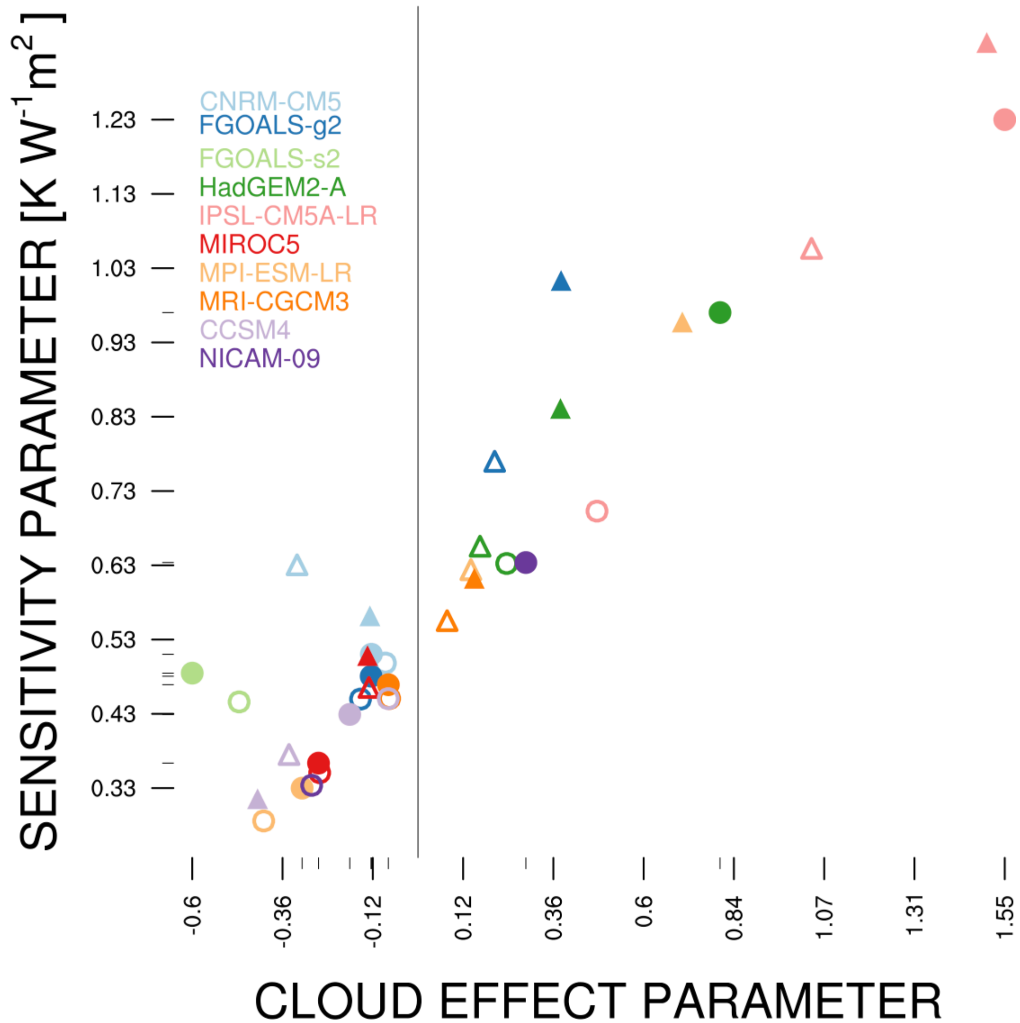
(Kay et al. 2012, *J. Climate*)

CMIP5 cloud feedback experiments: aquaplanet and AMIP

Spread in the simulated climate sensitivity parameter is tied to the response of the cloud radiative effect in the SST+4K experiments in both AMIP and aquaplanet configurations.

In about half of the models, the AMIP and aquaplanets show similar sensitivity and cloud response, but the other half have AMIP sensitivity and cloud response that is larger than the aquaplanets.

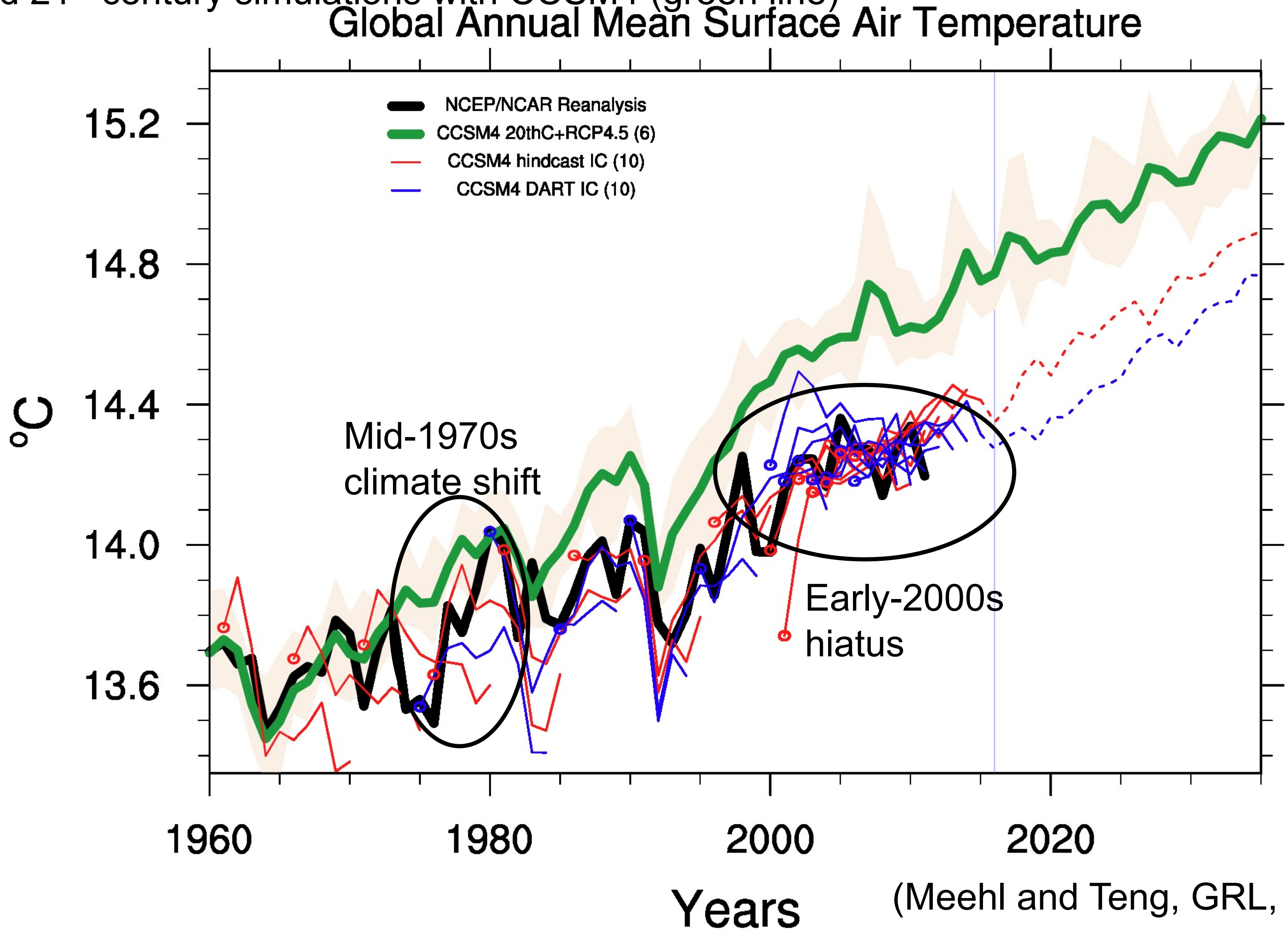
SST+4K experiments. Triangles show the AMIP experiments, circles show the aquaplanet results. Filled markers are tropical averages (-35 - 35) and unfilled markers are the global averages. Ticks mark the aquaplanet tropical values.



(Medeiros et al. 2012, in prep)

CMIP5 decadal prediction experiments

two initialization methods with one model (CCSM4), bias adjusted ten member ensemble averages (red and blue lines) compared to observations (black line) and free-running 20th and 21st century simulations with CCSM4 (green line)

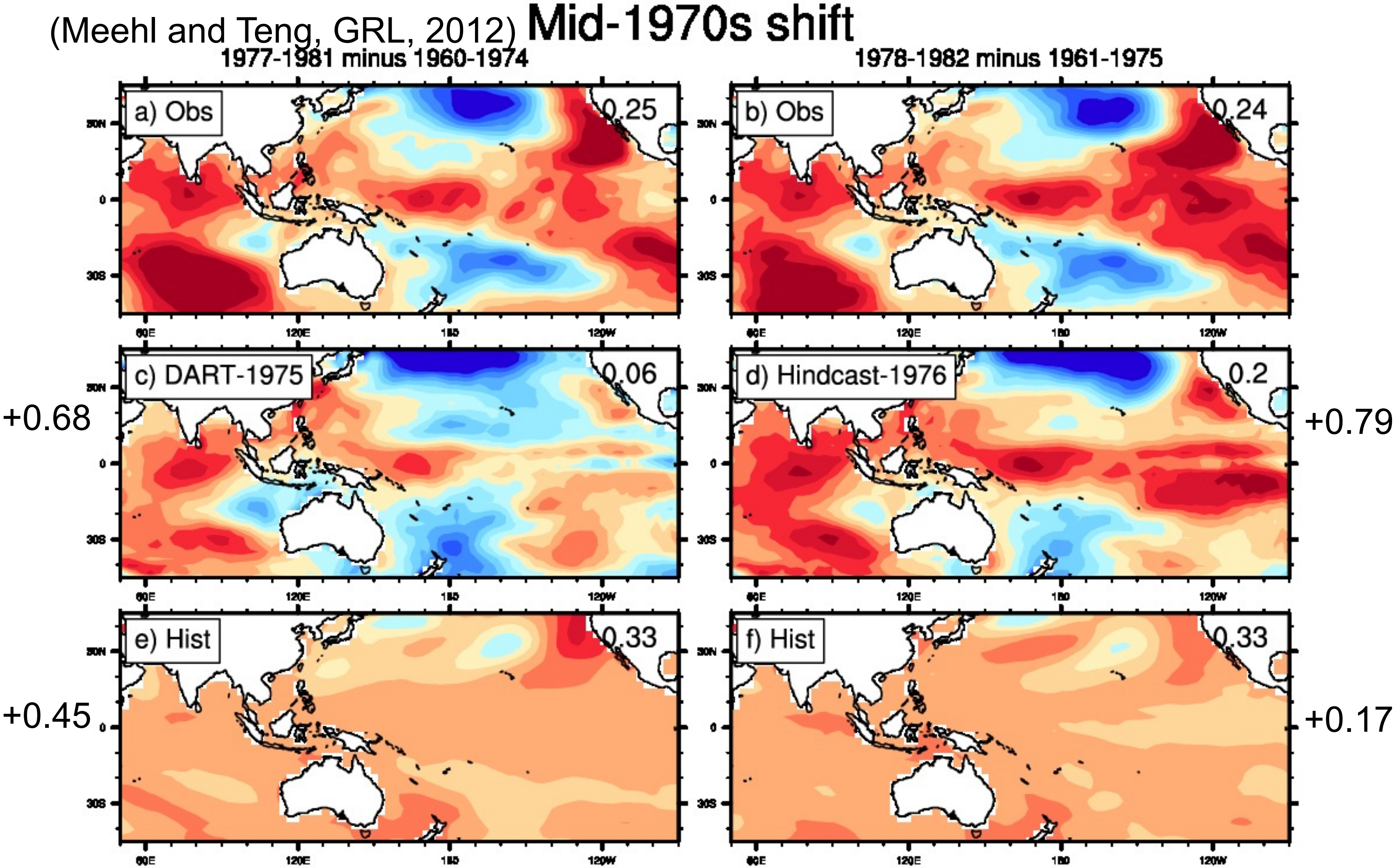


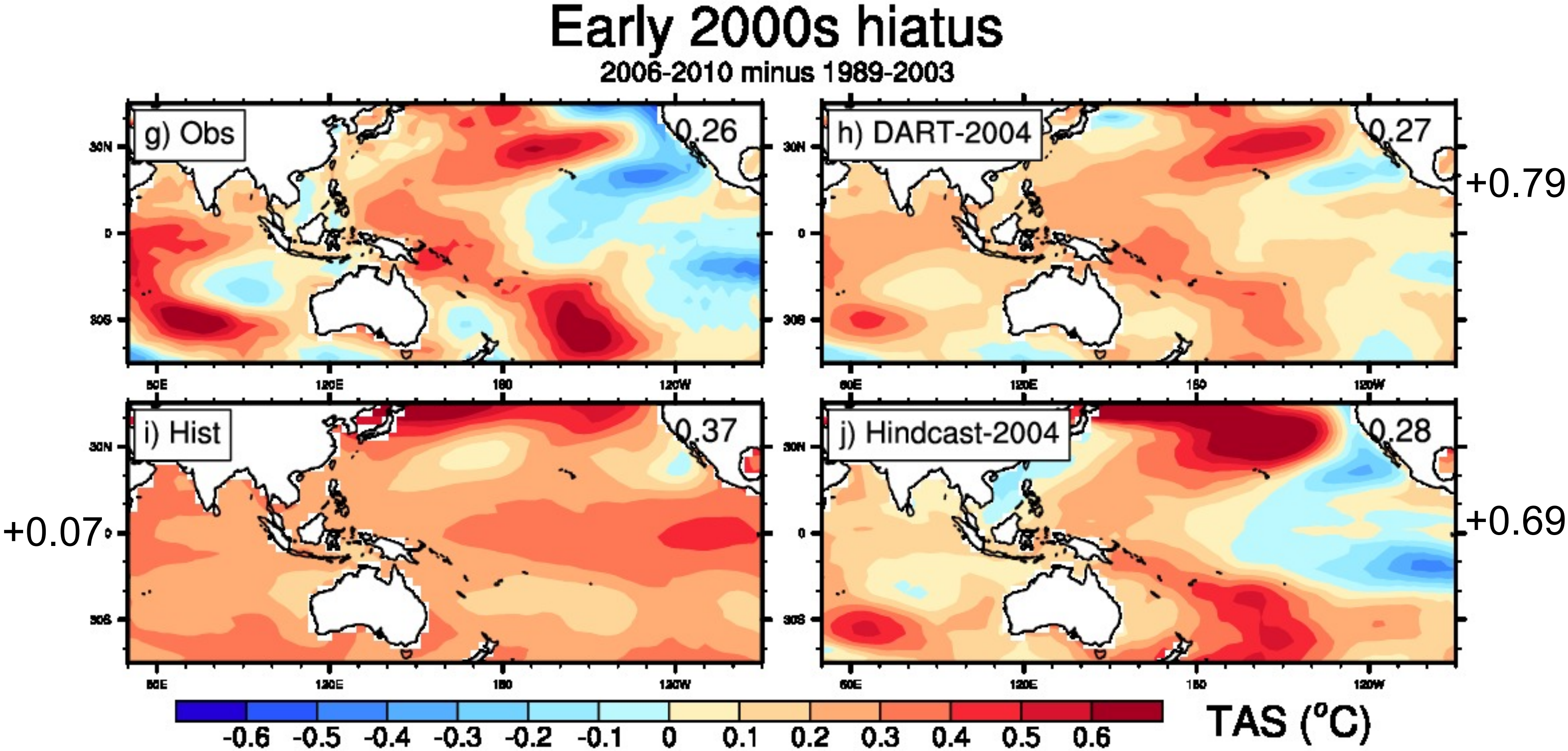
(Meehl and Teng, GRL, 2012)

Case study with CMIP5 decadal prediction experiments

Mid-1970s climate shift (prediction for 5 year average, years 3-7)

(Meehl and Teng, GRL, 2012)





Case study with CMIP5 decadal prediction experiments

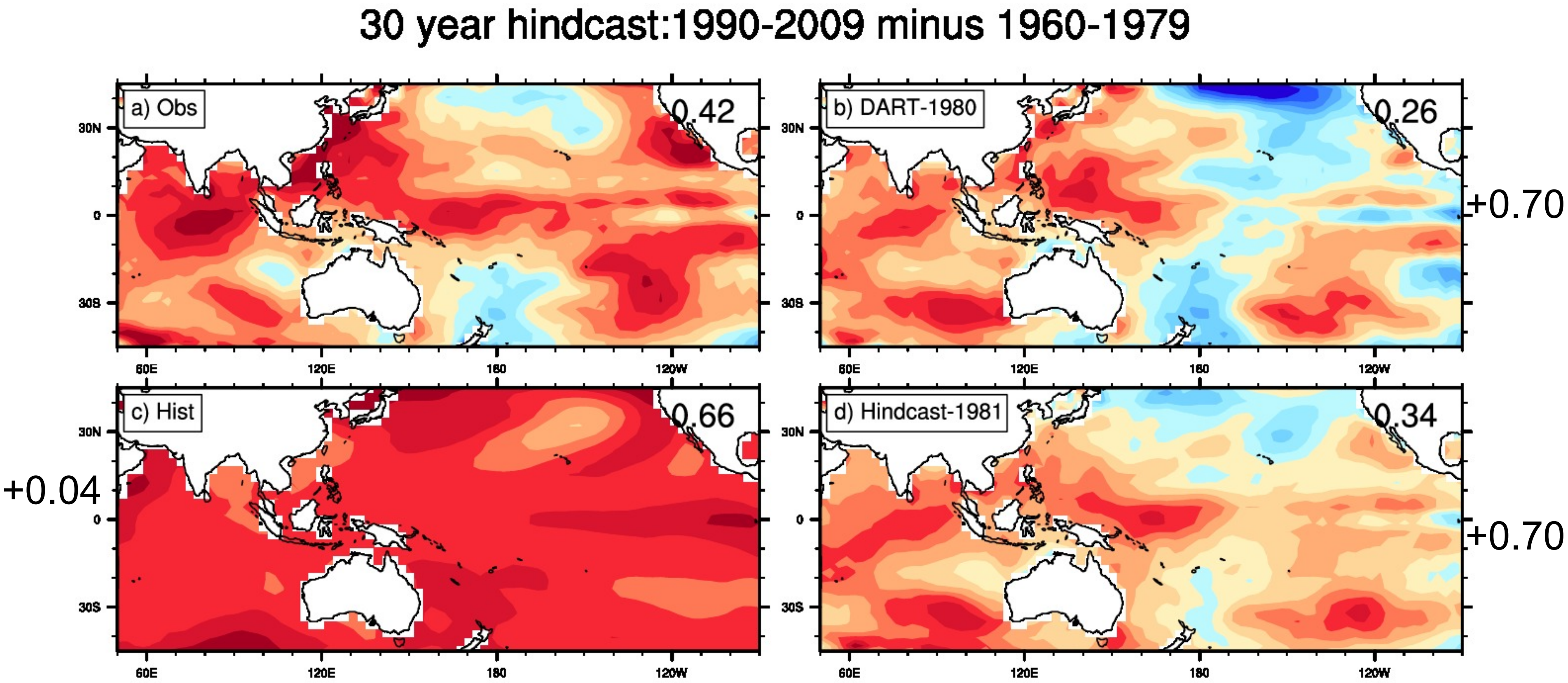
Early 2000s hiatus (prediction for 5 year average, years 3-7)

(Meehl and Teng, GRL, 2012)

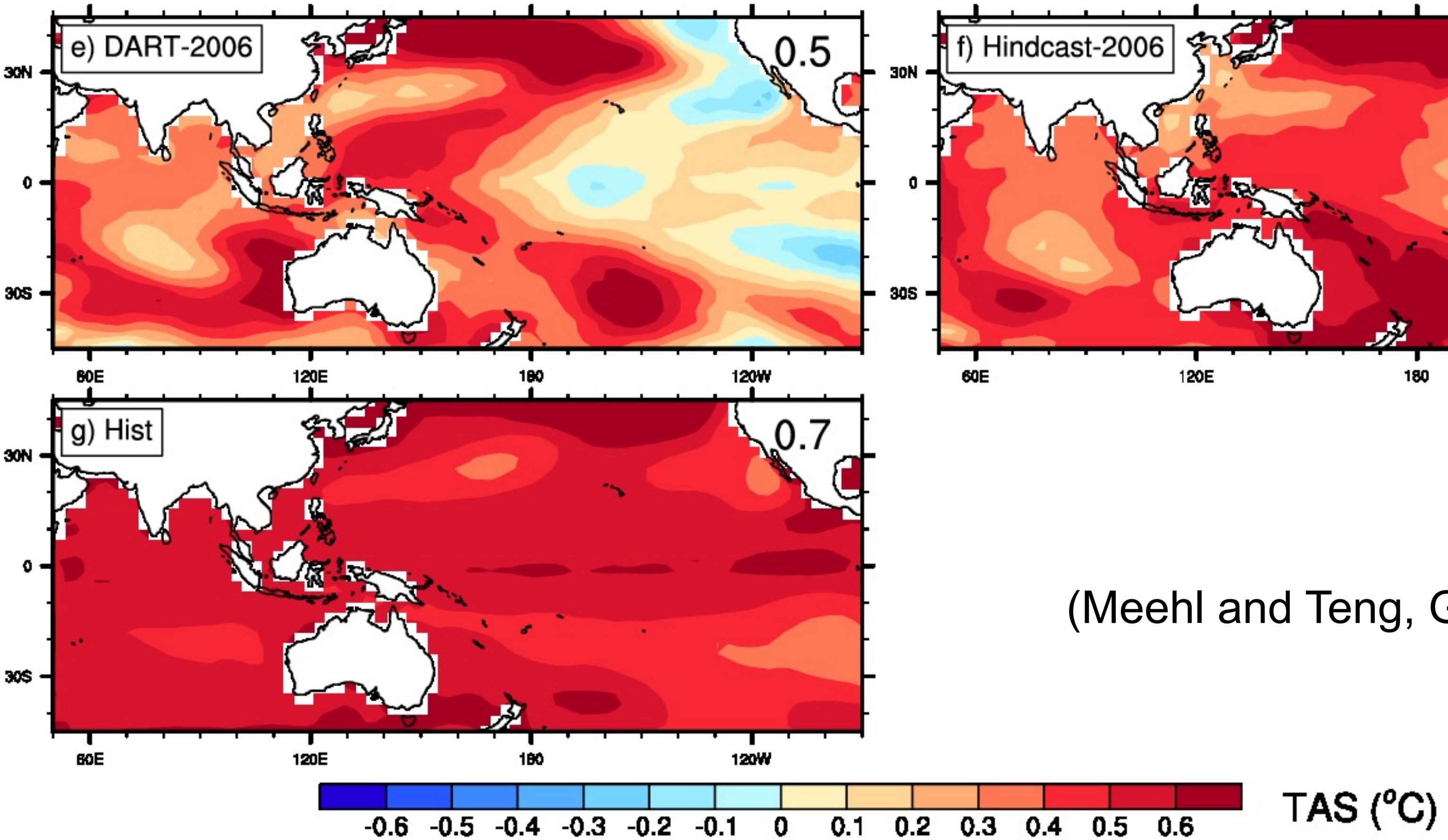
CMIP5 30 year hindcast with CCSM4

(Prediction for 20 year average, years 11-30)

(Meehl and Teng, GRL, 2012)



30 year prediction:2016-2035 minus 1986-2005



(Meehl and Teng, GRL, 2012)

CMIP5 30 year prediction

(Prediction for 20 year average, years 11-30)

Global warming somewhat less in initialized prediction compared to free-running simulation

Issues related to a possible CMIP6

Assuming a next phase of CMIP would be in some ways comparable to CMIP5--involving several communities, with a core set of experiments with calibration idealized experiments (e.g. 1% runs, 4XCO2, etc.), historical and future prediction/projection runs, and several layers of other experiments (noting comments made related to de-couple CMIP from the IPCC assessment cycle, and recognizing the reality of having something that would be state-of-the-art for IPCC assessment, not ruling out other MIPs that would occur out of cycle due to facilitation of ESGF); **critical dependence on the ESGF and PCMDI (and DOE funding)**

Data management: Promote CMOR as standard protocol, output could be directly saved into CMOR format

"near-exabyte" scale of CMIP6—need to recognize and plan for how to handle that data volume

Evaluation: International approach to evaluation, metrics panel useful, expanded role?, semi-regular model analysis workshops

Logistics: High frequency temporal data desirable for some experiments—perhaps have a different fields list for different experiments, prioritize fields, check what fields are being used from CMIP5

make data access easier -- secure funding for ESGF, data access and retrieval need for scriptable and need better download methods

metafor needs work in concept and application

Experiment specification, requires sufficient detail far enough in advance for effective configuration, and finalize prioritized fields early

CMIP6 should have continuity with CMIP5

Try to retain continuity with scenarios, though IAM community and our community may need to adjust or add sensitivity experiments (e.g. aerosols, land use change, 2C warming bigger peak and decline in RCP2.6)

Details of land-use change that are adapted by each group needs to be addressed

Science issues:

Land use –aerosols—ESM applications—water cycle—interact with the SSPs that show quite different outcomes from RCPs

reversibility or geo-engineering

More idealized experiments, e.g. 1% runs but for other forcings, idealized aerosol, ozone, land use, like the 1% runs

Decadal prediction and extremes

systematic biases

Very high res time slice experiments for tropical cyclones, water cycle, and other aspects of storms and circulation changes

Higher res coupled simulations for tropical cyclones, extremes, and circulation changes

Coupled land ice for global and regional sea level rise

CMIP5: exploratory workshop 2006
WGCM approved experimental design 2008 (duration of CMIP5 2008-2013)
CMIP5 model analysis workshop 2012
deadline for papers: July 2012
final report published 2013

CMIP6: exploratory workshop, summer 2013
…

Summary

Fundamental shift of climate science in 2007 (e.g. mitigation scenarios and a re-framing of the climate change problem, ESMs, decadal climate prediction) **prompted formulation of CMIP5**: more model versions, more experiments including multiple communities and experiments to address new science problems and increase understanding (e.g. paleo, cloud feedbacks, carbon cycle feedbacks, decadal climate prediction) , **coordinated by WCRP Working Group on Coupled Models (WGCM)**

DOE Cooperative Agreement-funded scientists at NCAR, DOE lab scientists, NSF-funded scientists at NCAR and universities, and others contributed to running and analyzing the CMIP5 experiments

Five model versions and sets of CMIP5 experiments have been run: CCSM4, CESM1-BGC, CESM1- WACCM, CESM1-FASTCHEM, CESM1-CAM5

CCSM4 with lower climate sensitivity had a warmer 20th century climate than CESM1/CAM5 with a higher climate sensitivity, but CESM1/CAM5 had a larger 21st century warming due to the larger amplitude response to the reduction of aerosols

Aggressive mitigation in RCP2.6 produces less than 2C warming above pre-industrial and cools slightly after mid-21st century

Thus we can mitigate temperature, but not sea level rise which continues to increase in all scenarios

Summary (continued)

larger response and slower recovery of the AMOC in the future in the higher sensitivity CESM1/CAM5 vs. CCSM4

Paleo experiments with CCSM4 show similar climate sensitivity to present-day, building confidence that future projections would be consistent

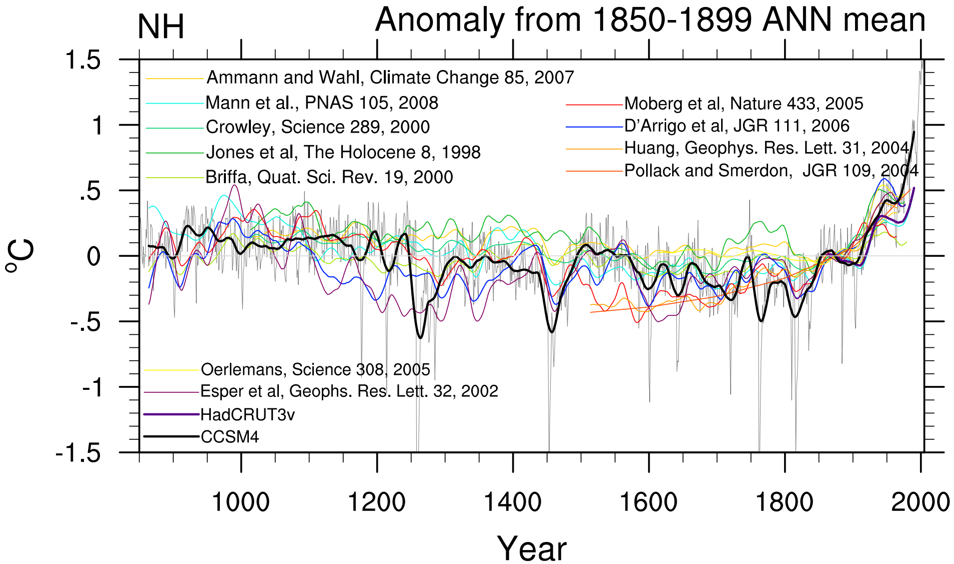
Modeled increase of CO_2 over 1850-2005 too large

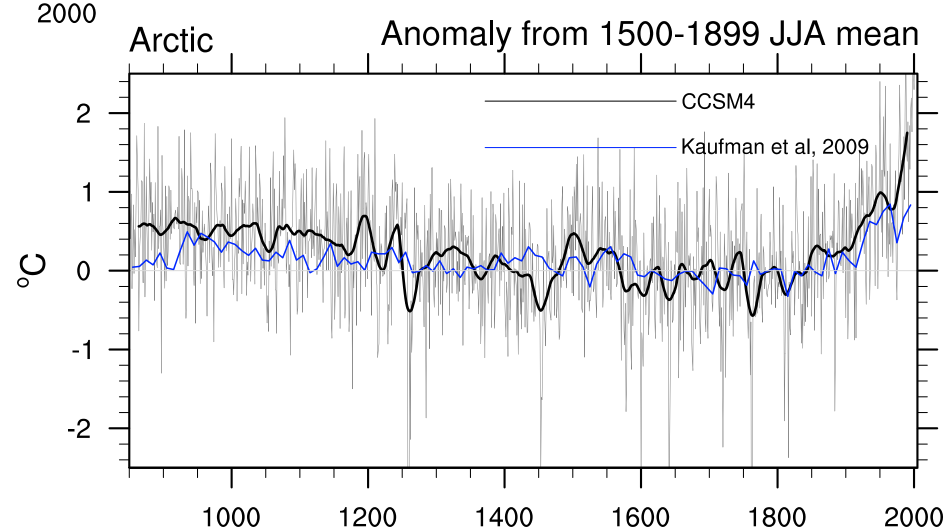
Negative cloud feedbacks in CCSM4 contribute to lower climate sensitivity

Decadal hindcasts with CCSM4 (two initialization techniques) show skill in simulating the mid-1970s climate shift and 2000s hiatus; initialized predictions show somewhat less near-term global warming than free-running non-initialized simulations

Discussions for a possible CMIP6 have started (last week at WGCM), and a small planning workshop in the summer of 2013 (an AGCI session?) will likely be the next step, involving many contributing communities

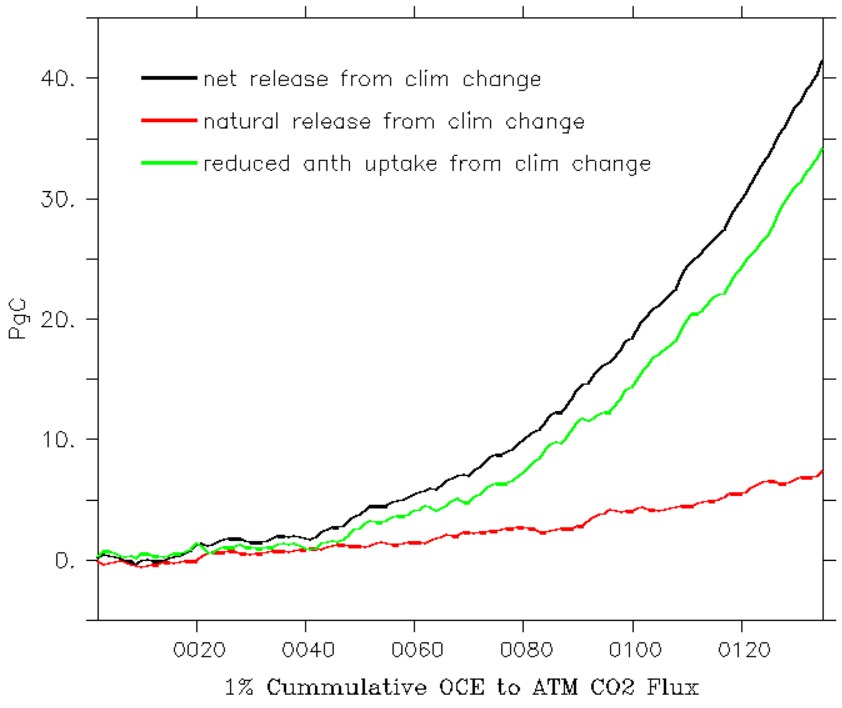
CMIP5 Simulations with CCSM4
Last Millennium

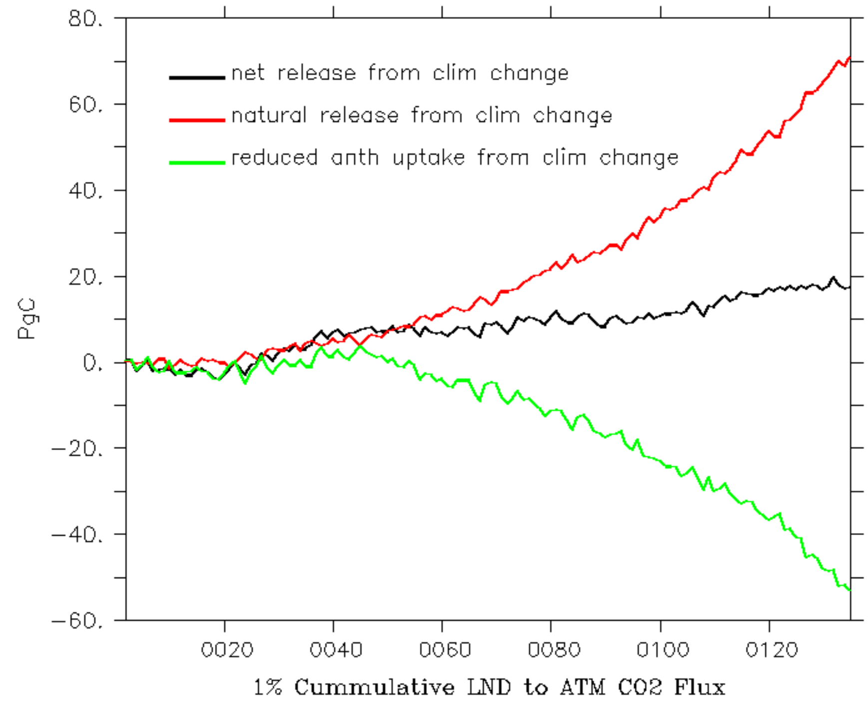




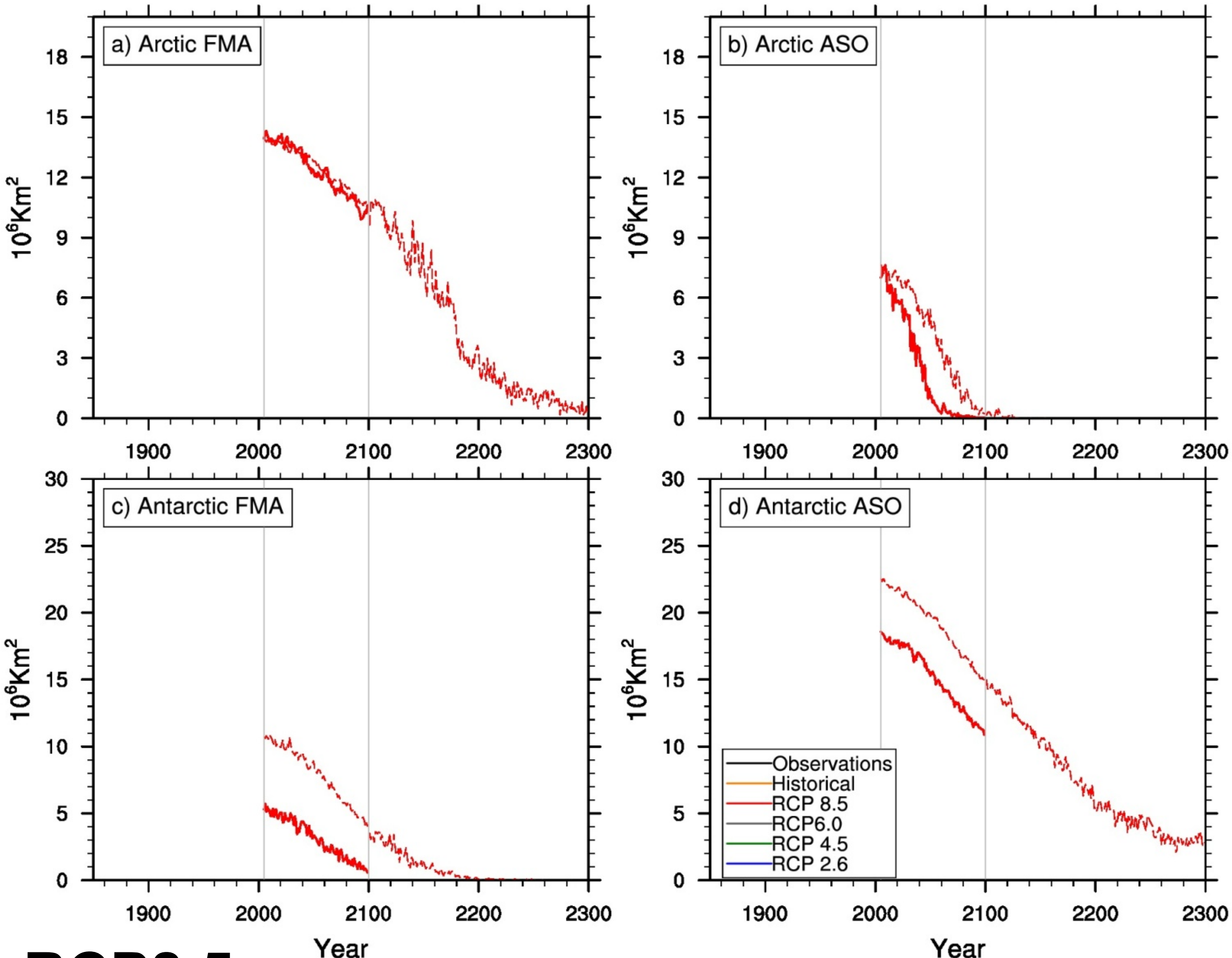
Landrum, L., B.L. Otto-Bliesner, E.R. Wahl, A. Conley, P.J. Lawrence, N. Rosenbloom, and H. Teng, 2012: Last Millennium climate and its variability in CCSM4. *Journal of Climate.*

CESM1 (BGC) 1%/yr CO_2 Experiments
Impact of Warming on Cummulative CO_2 Fluxes





Lindsay et al., in prep



RCP8.5

(Meehl, G.A., W.M. Washington, J.M. Arblaster, A. Hu, H. Teng, C. Tebaldi, B. Sanderson, J.F. Lamarque, A. Conley, and W.G. Strand, 2012: Climate change projections in CESM1/CAM5. *J. Climate,* submitted).

RCP8.5 Sea ice extent

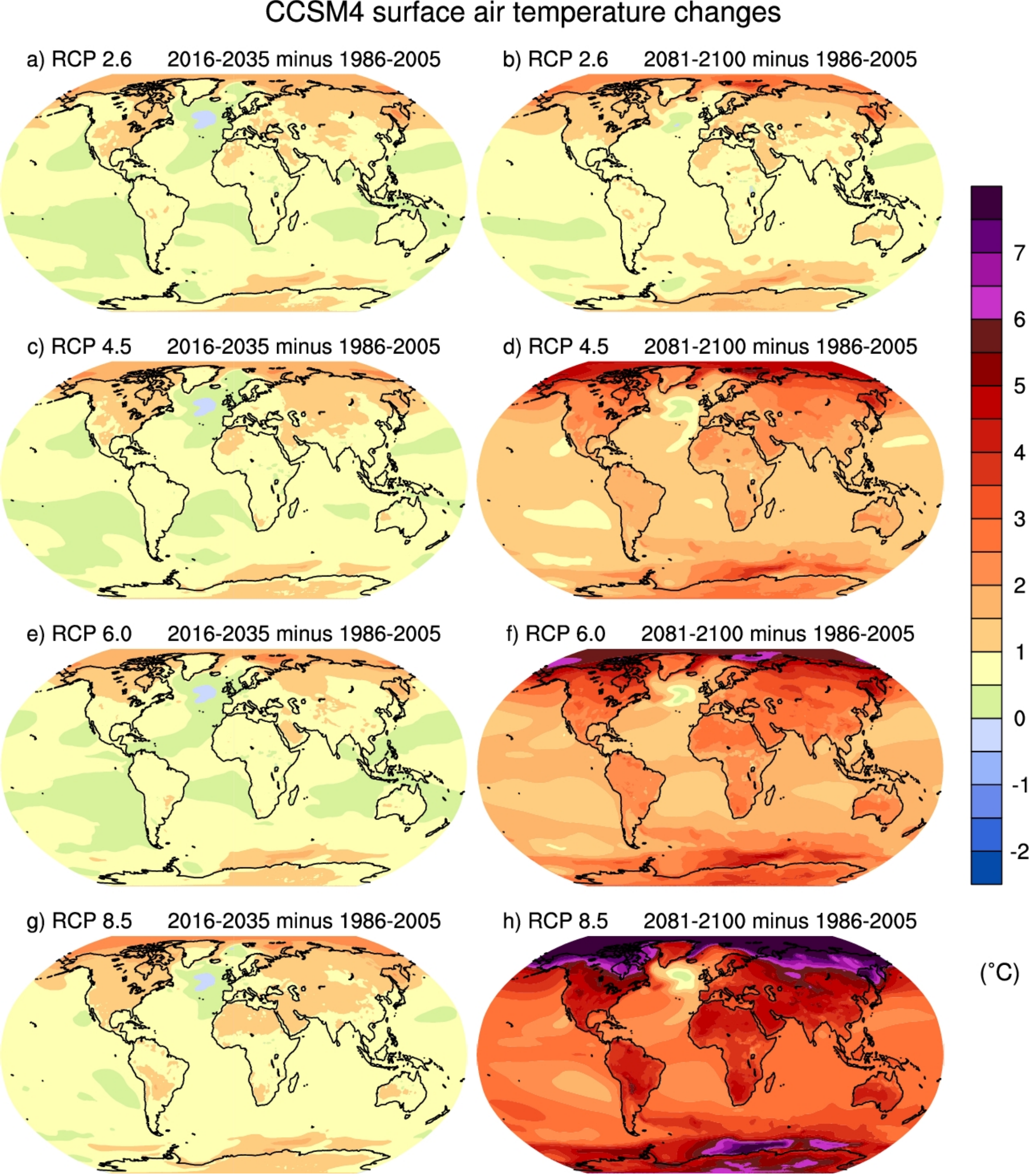
CCSM4: dashed
CESM1/CAM5: solid

Similar present-day sea ice extent in Arctic

summer nearly ice-free Arctic 20 years earlier in CESM1 (about 2080 vs. 2100 in CCSM4)

Less present-day sea ice in Antarctic in CESM1 (closer to obs)

A nearly ice-free summer Antarctic by 2100 in CESM1 (vs. about 2090 in CCSM4)



Warming in the near-term (2016-2035, left column) is similar no matter what scenario is followed—near term climate change is an adaptation problem

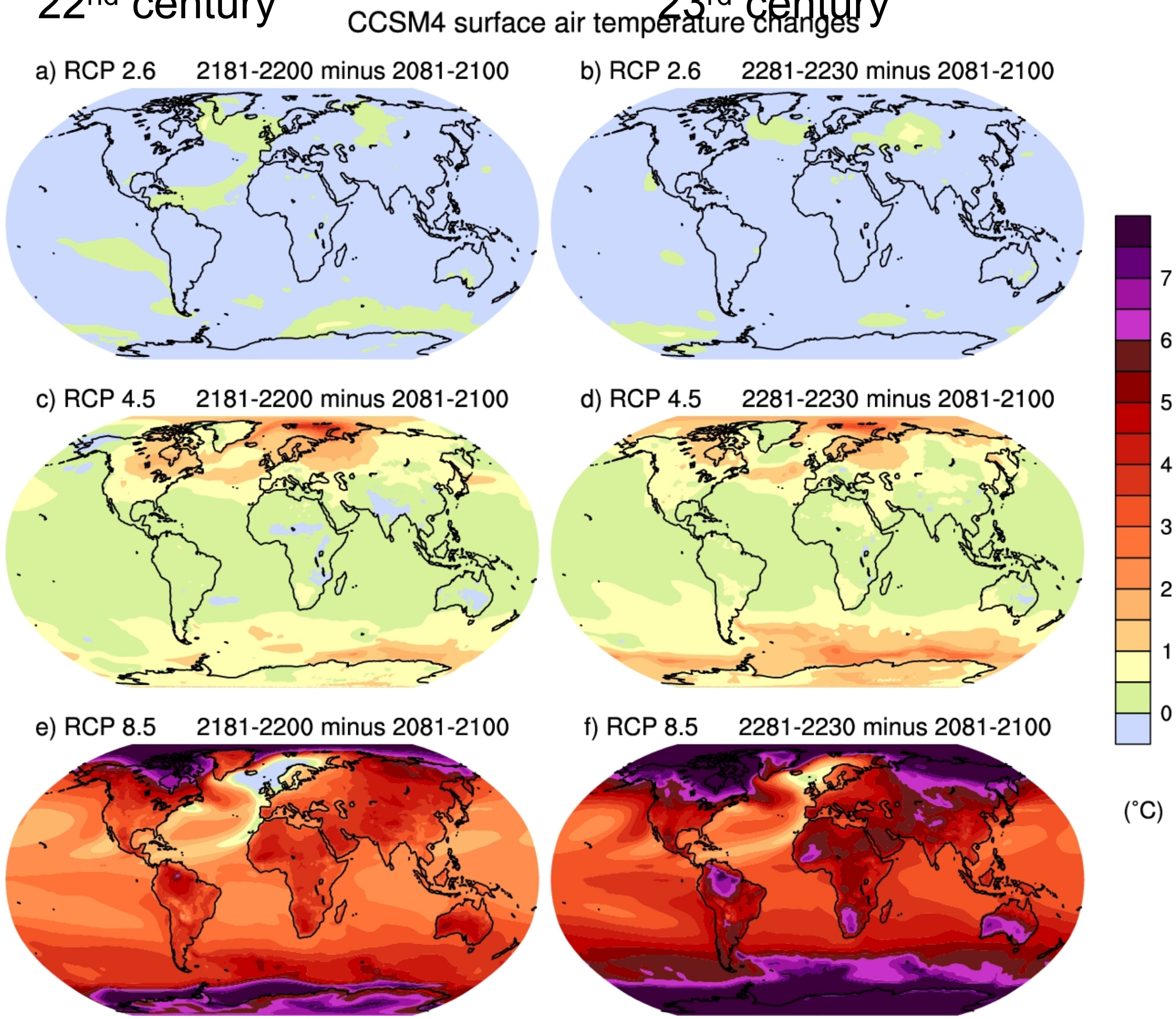
Magnitude of the warming later in the century (2081-2100, right column) depends a lot on what scenario is followed—the mitigation path we follow makes a big difference after mid-century

(Meehl et al., 2012, J. Climate, doi: http://dx.doi.org/10.1175/JCLI-D-11-00240.1)

Climate change doesn't stop at 2100

Aggressive mitigation in RCP2.6 produces cooling after 2100 (top) but little mitigation in RCP8.5 results in ongoing large warming to 2300 (bottom)

22nd century   23rd century



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