NCAR CMIP5 experience with CCSM4 and CESM1/CAM5

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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)
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

To achieve reasonable output performance, all fields at each time sampling interval are put into a single netCDF file. This file may contain more than one time sample (for example, for daily and subdaily time frequencies), but the basic structure of the model output has remained the same for many years.

However, this format is exactly the opposite of what the CMIP5 requirements specify - all time samples for each field in a single (or small set) of netCDF files.

The consequence of the difference in the two formats is that even if only one field from a given netCDF output stream is needed for the CMIP5 request, all the model output must be transferred from archive to disk, and then parsed to access the one field needed. It is because of the inefficiency of the history file format that it was decided to postprocess the history output into single-field format files, and use those to create the CMIP5-compliant data.

Only about 16% of the total relevant history output data was needed for the CMIP5 submission. The original history data still needed to be postprocessed in its entirety just to extract out the prescribed data.

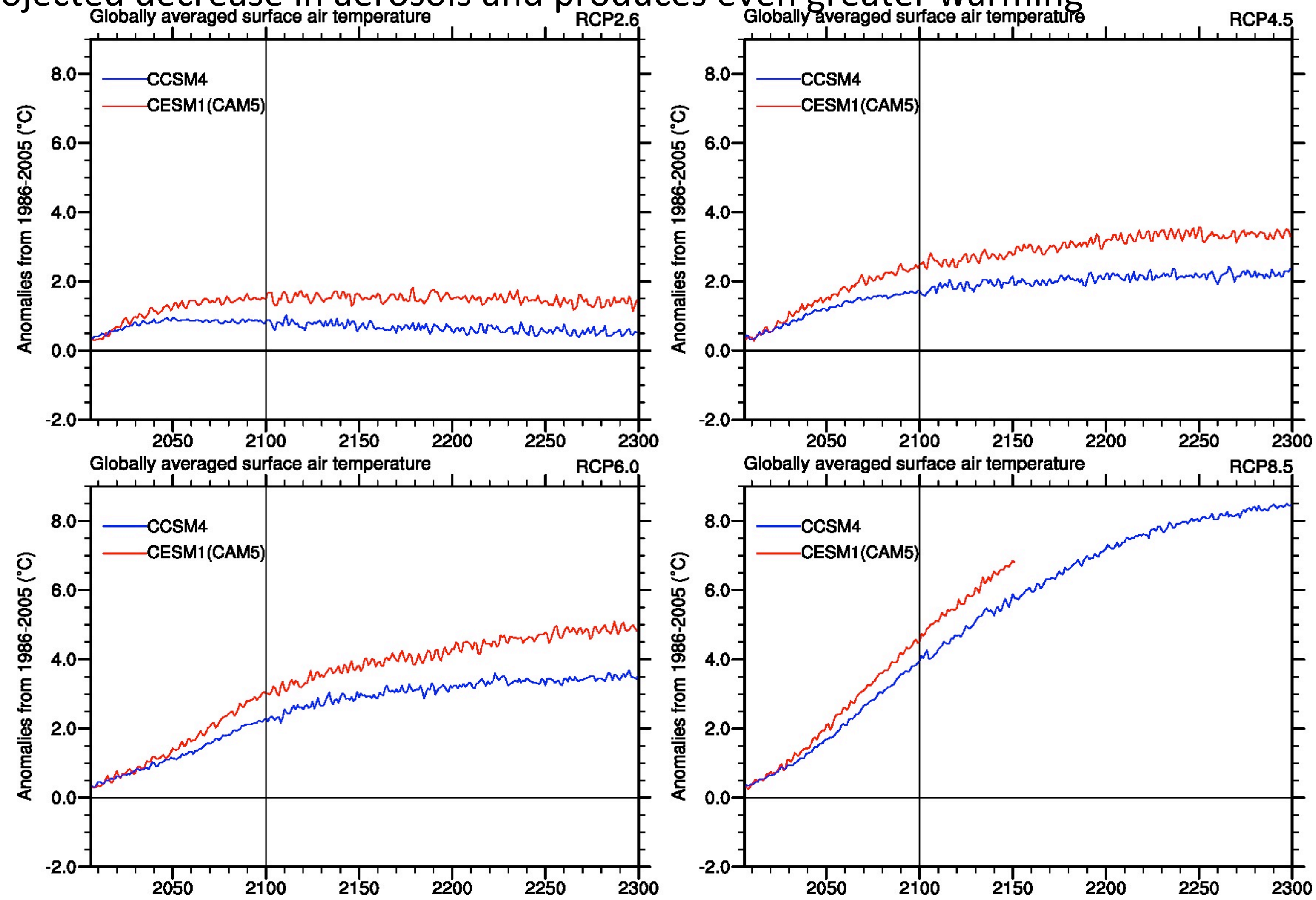
The process:

1.Read all the history tapes and transpose the file format data to single-field format (break out each time-dependent field in the history file into a separate netCDF file, then concatenate the individual files for each field into a single file that contains all the time samples for that specific field) using a set of shell scripts that employ the netCDF operators (NCO) package. The resulting files are then archived to tape.

2. Read all those save tapes and pass the data and metadata to the CMOR2 software to create CMIP5-compliant data.

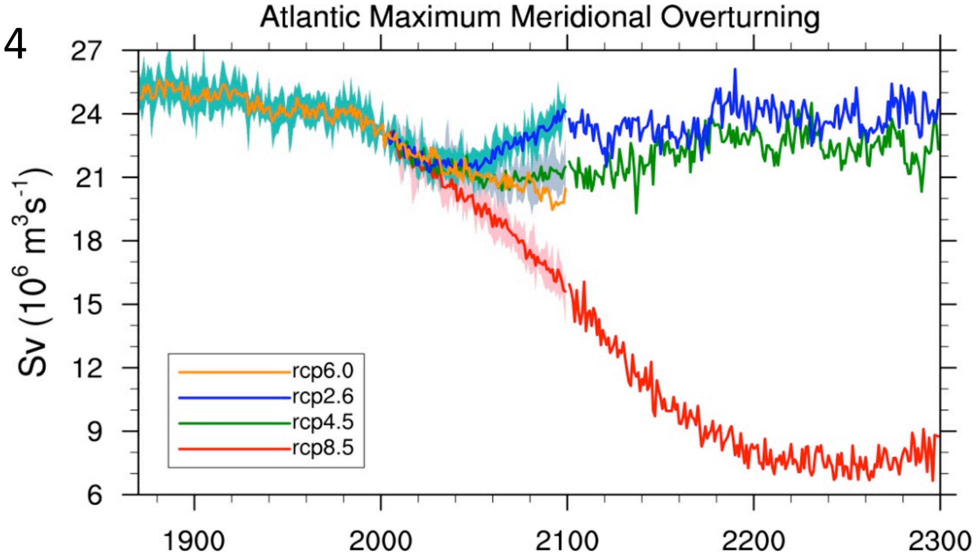
3. Publish the CMIP5-compliant data to the NCAR Earth System Grid portal.

CCSM4 vs. CESM1/CAM5; Equilibrium climate sensitivity: CCSM4 = 3.2°C CESM1/CAM5 = 4.1°C; model with higher sensitivity responds more to the projected decrease in aerosols and produces even greater warming

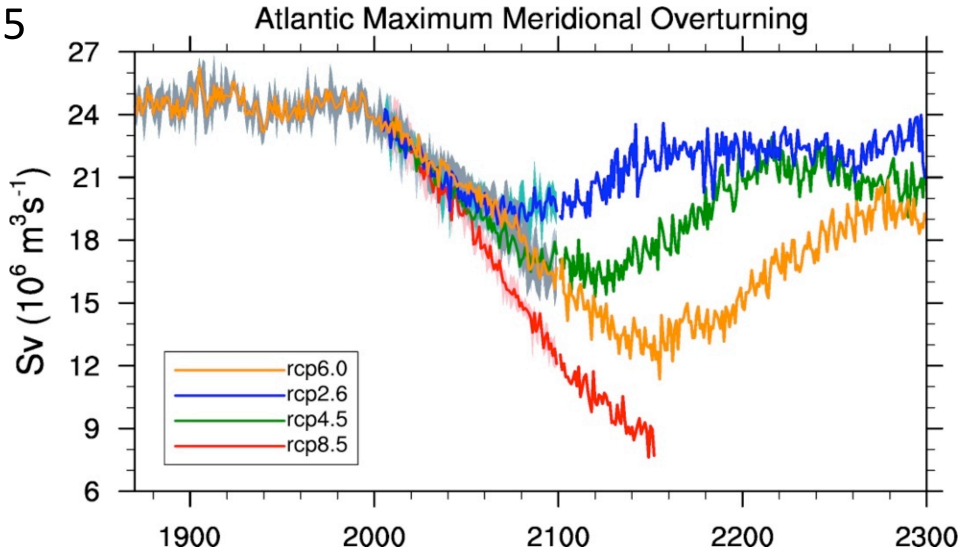


(Meehl, G.A., W.M. Washington, J.M. Arblaster, A. Hu, H. Teng, C. Tebaldi, B. Sanderson, J.F. Lamarque, A. Conley, and W.G. Strand, 2012: Climate change projections in CESM1/CAM5. *J. Climate,* submitted).

CCSM4

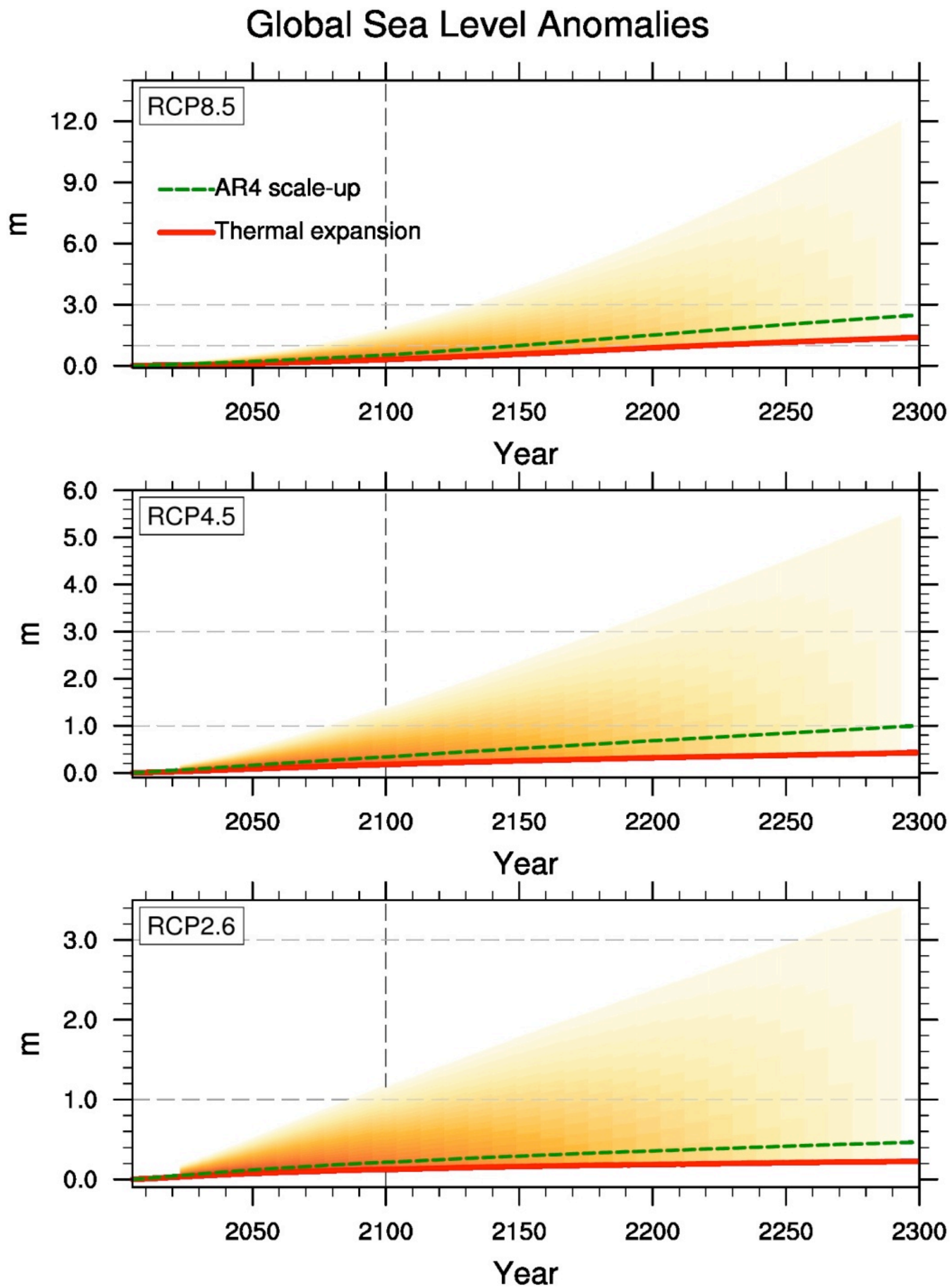


CESM1/CAM5

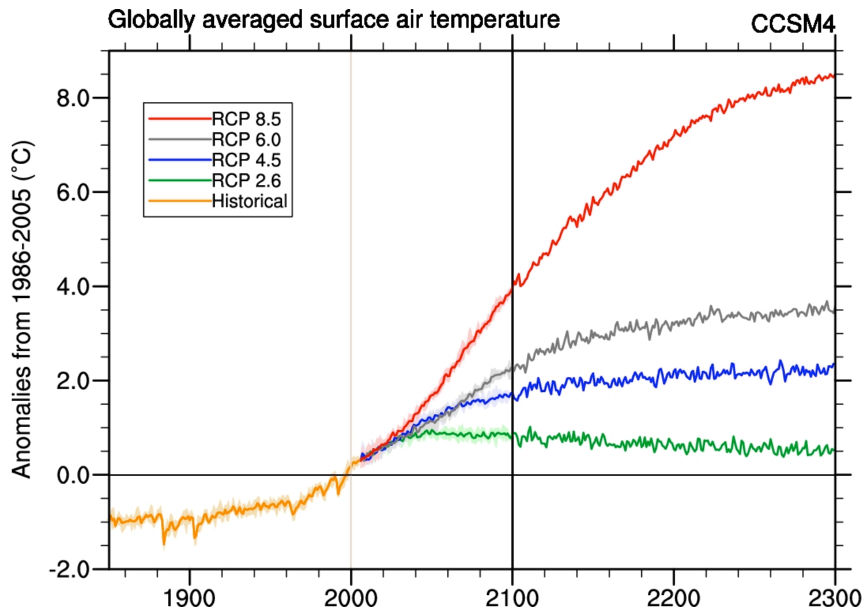


larger response and slower recovery of the AMOC in CESM1 vs. CCSM4

(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)*.

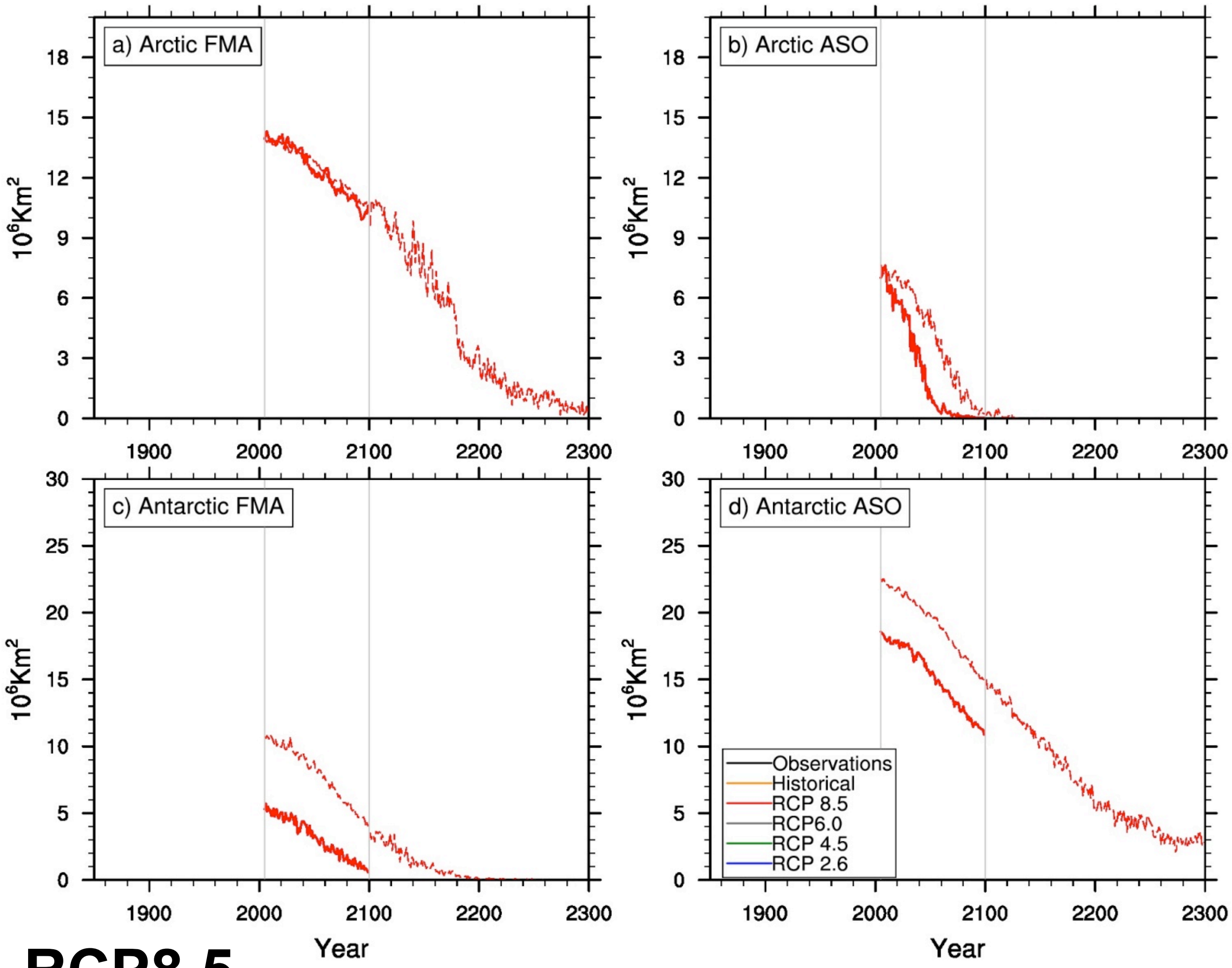


(Meehl et al., 2012, Nature Climate Change)



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)



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

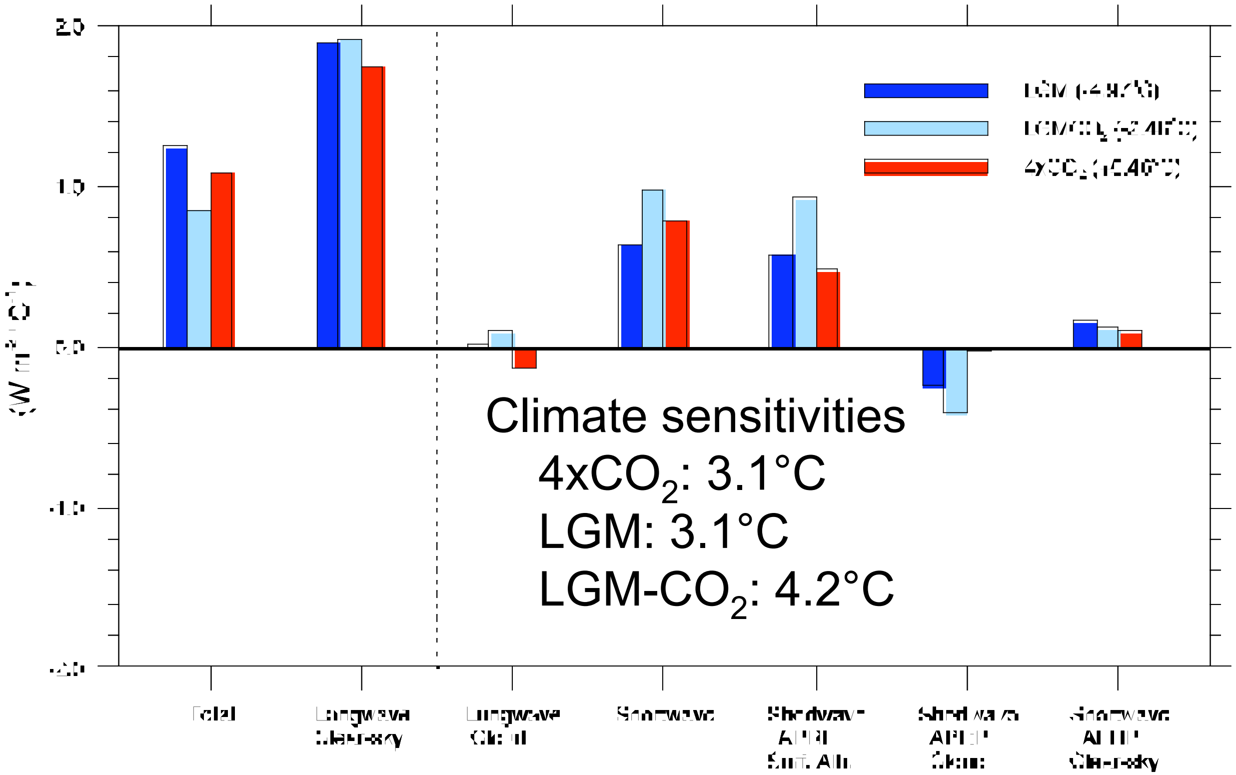
Similar present-day sea ice extent in Arctic

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)

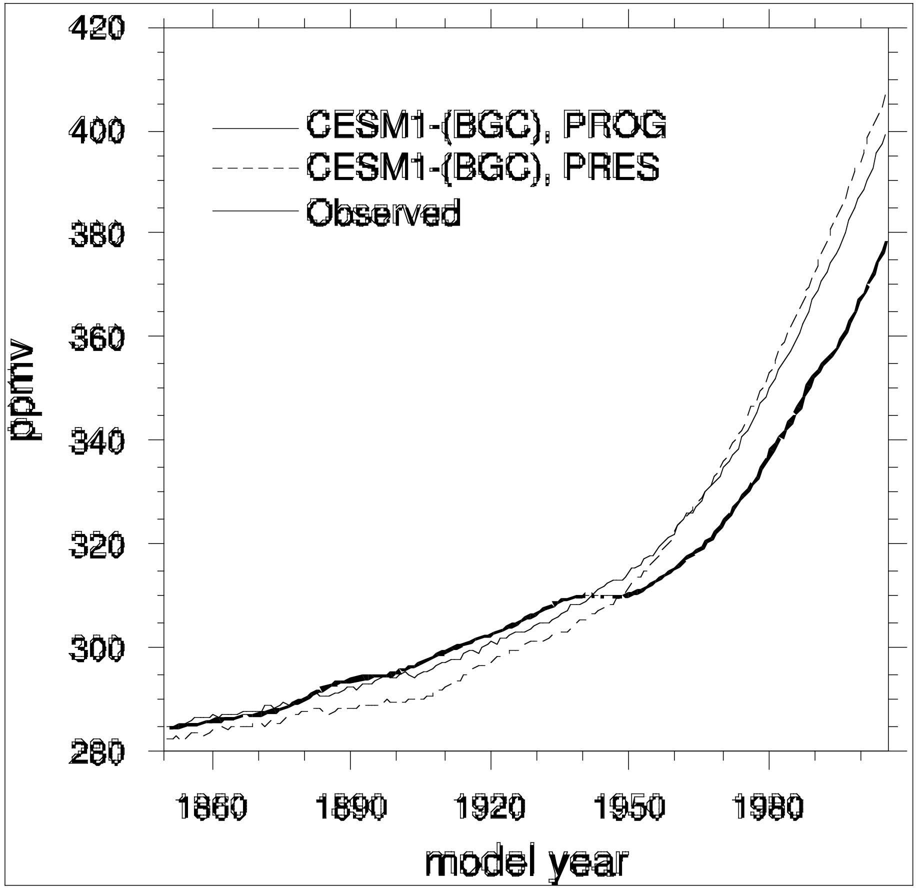
A nearly ice-free summer Antarctic by 2100 in CESM1 (vs. about 2090 in CCSM4)

CMIP5 Simulations with CCSM4
Climate Feedbacks: Past and Future



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

CO_2 in 20th Century Experiments



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 J Clim

Summary

The new atmospheric model in CESM1/CAM5 took longer to finalize that anticipated, thus delaying the simulations with the newer model version (CMIP5 simulations with that model are still running; some have been posted for CMIP5), though the full suite of CMIP5 experiments was run with CCSM4; the volume of model data from all these simulations so far already exceeds the ENTIRE volume of data from all models in CMIP3

Post-processing of model data was a real problem—having to read back through all the history tapes to do the translation to CMIP5 format took way too much time, and required scripts to be developed for the different model versions with different fields; next time conversion scripts will be designed to run with the model so that CMIP-compliant output is saved as the model runs

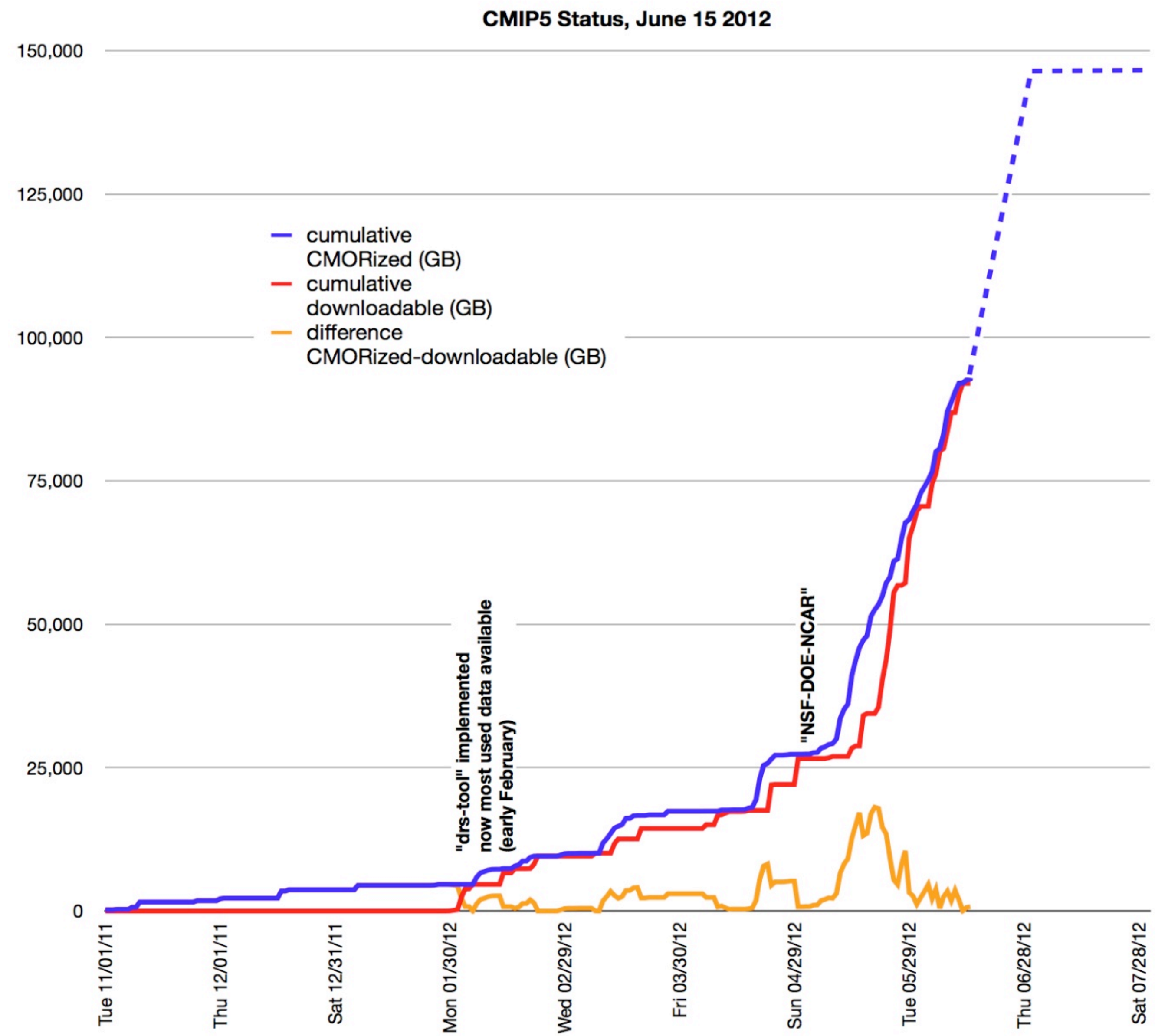
The potential for emission-driven ESM runs wasn't exploited, particularly to look at land use change feedbacks on the carbon cycle

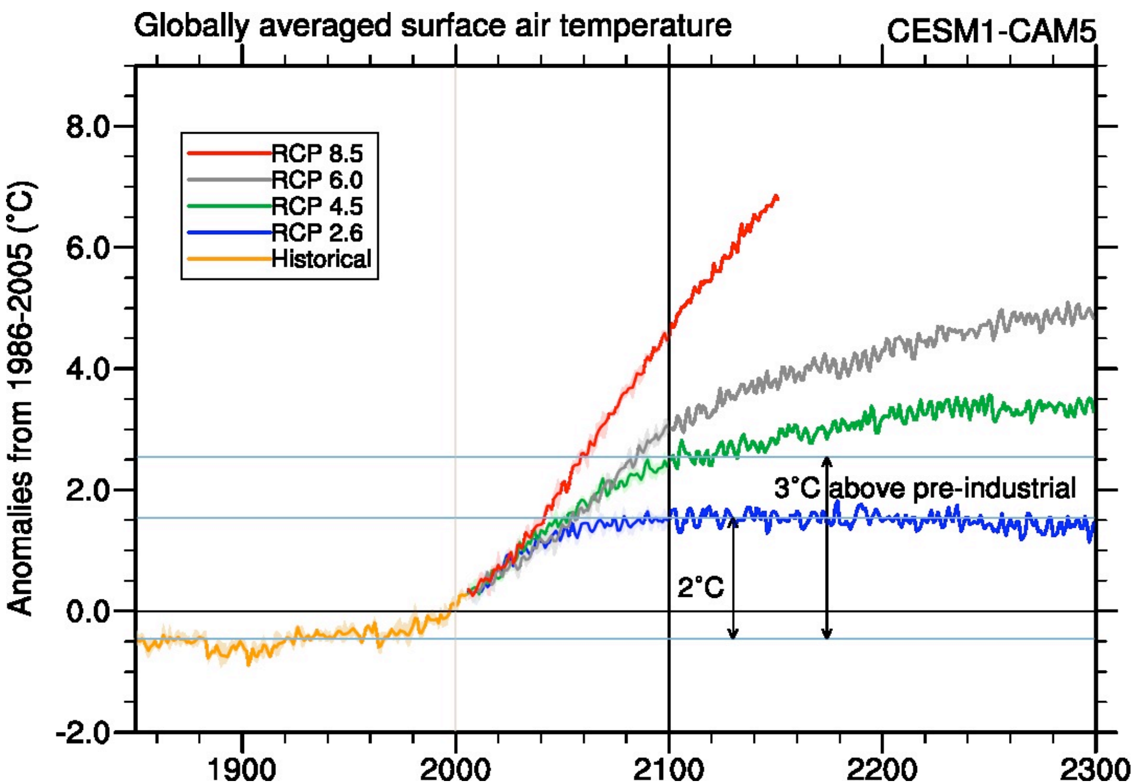
There were delays in preparing the 50km coupled version of CCSM4, and RCP8.5 is just now finishing—there is a lot of potential for more experiments at that resolution

high resolution time slice experiments had the lowest priority, those experiments still need to be run and analyzed, and there is a lot that can be done there with 25 km and 12.5 km resolutions

~140 Terabytes submitted to CMIP5

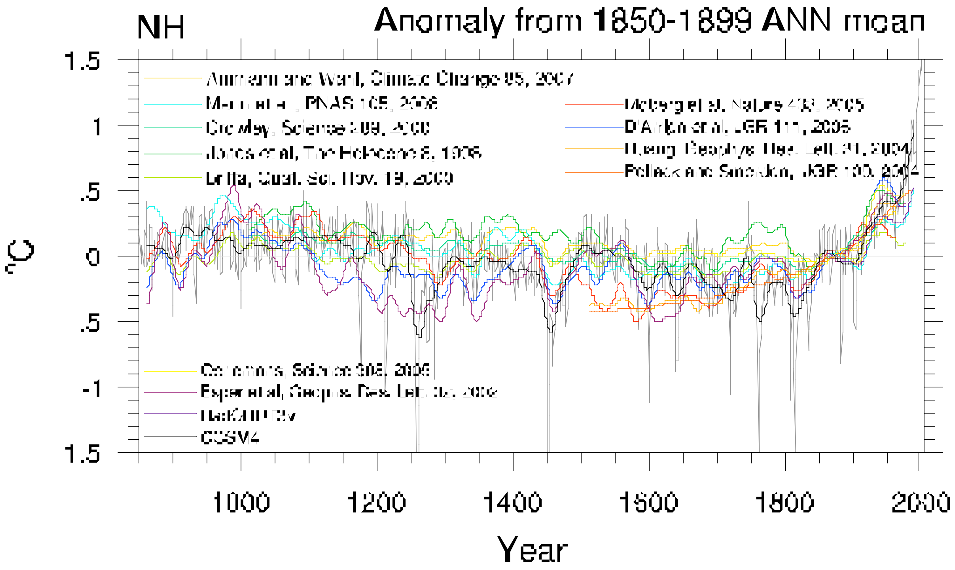
(the entire CMIP3 multi-model dataset was 31 Terabytes, CCSM's was 12 Terabytes)

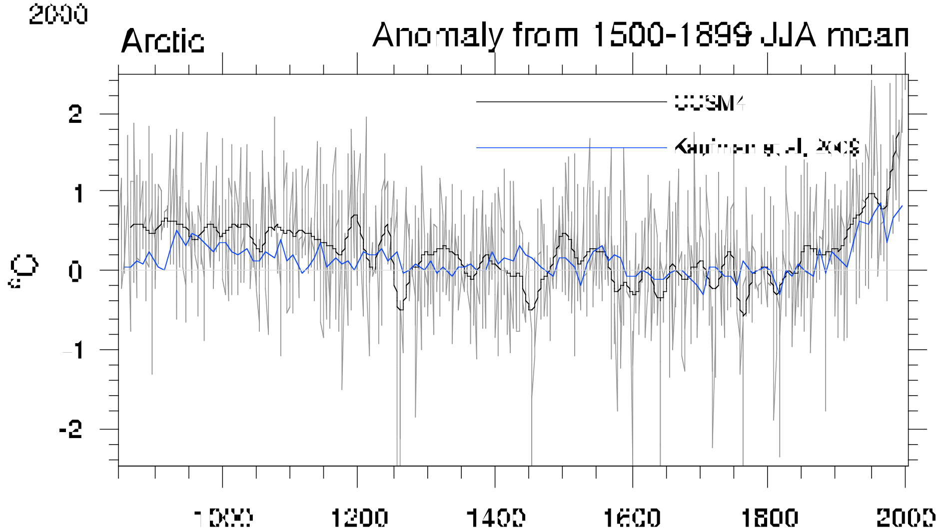




(Meehl, G.A., W.M. Washington, J.M. Arblaster, A. Hu, H. Teng, C. Tebaldi, B. Sanderson, J.F. Lamarque, A. Conley, and W.G. Strand, 2012: Climate change projections in CESM1/CAM5. *J. Climate)*.

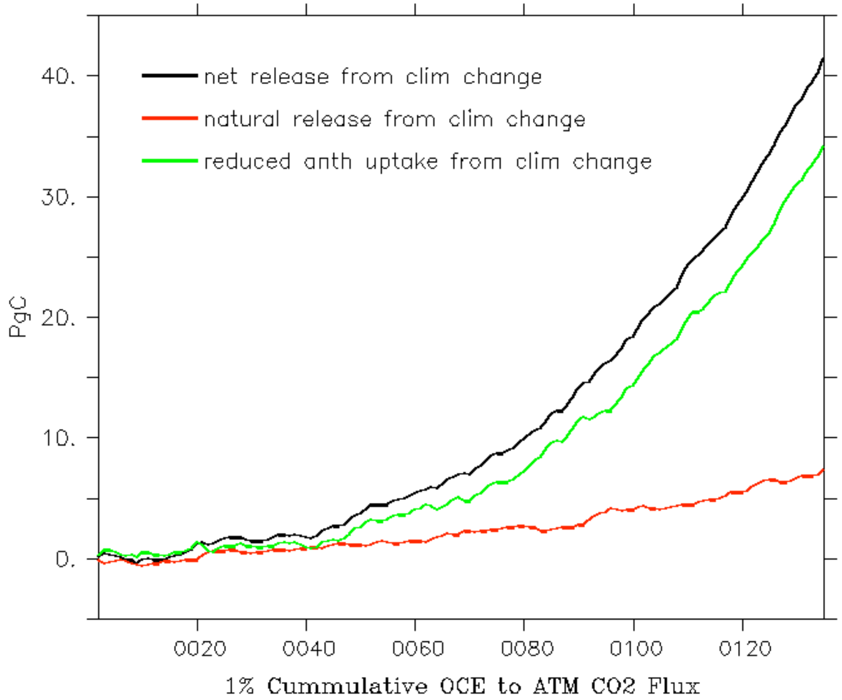
CMIP5 Simulations with CCSM4
Last Millennium

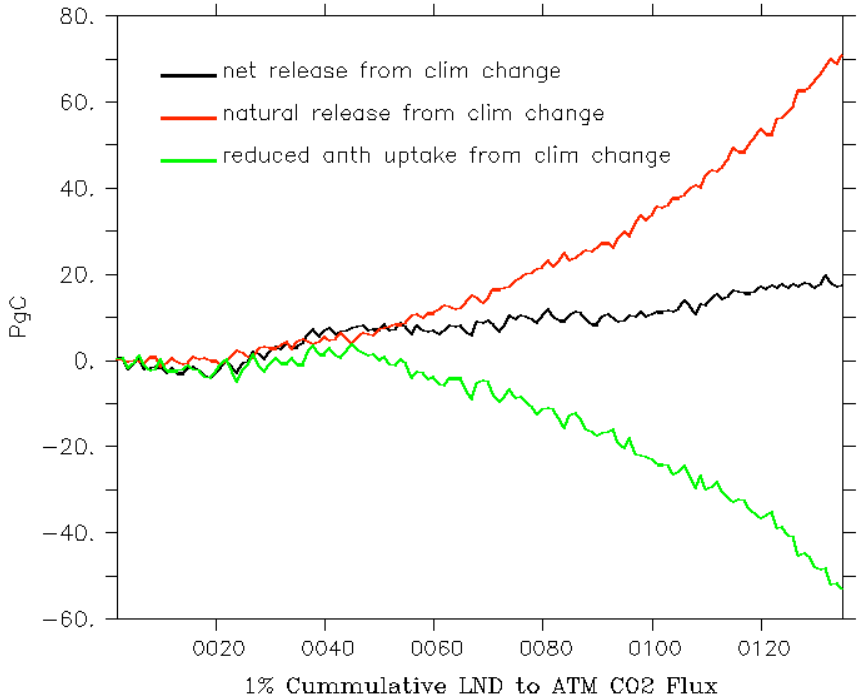




Landrum, L., B.L. Otto-Bliesner, E.R. Wahl, A. Conley, P.J. Lawrence, N. Rosenbloom, and H. Teng, 2012: Last Millennium climate and its variability in CCSM4. *Journal of Climate.*

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





Lindsay et al., in prep

Barrier 1: Less decadal predictive skill over the Pacific compared to the Atlantic

There are a number of indicators that show, for the CMIP5 hindcasts, less predictive skill over the Pacific Ocean than the Atlantic (and particularly the North Atlantic).

Defining question: What are the mechanisms and processes that lead to increased decadal prediction skill over the North Atlantic compared to the Pacific, and does this relative skill difference relate to external forcing from aerosols over the Atlantic playing more of a role than purely internally generated variability over the Pacific?

Barrier 2: Less decadal predictive skill for precipitation than temperature

Due to a variety of factors, temperature is more predictable than precipitation, with precipitation over land being particularly problematic

Defining question: What is required to improve decadal predictive skill of precipitation over land?

Barrier 3: It is still unclear what the best initialization strategy yields the best predictions

Modeling groups have tried various initialization methods, with some results showing predictions from hindcast-type initializations schemes sometimes outperforming predictions from full coupled initializations. This may be that the simpler initialization methods produce initial states closer to their systematic error state with consequent smaller bias adjustments, thus reducing possible negative effects from larger bias adjustments required by initial states closer to observations

Defining question: What is the best initialization strategy that would produce the most skillful decadal predictions

Barrier 4: Bias adjustment remains a major factor in decadal predictions, and all groups do it somewhat differently

Bias adjustments are required due to systematic errors in the models that produce rapid drifts from the initialized state to the model systematic error state. These bias adjustments are sometimes larger than the predicted signals, but will be required until model systematic errors can be reduced. Trend adjustment is often not performed as part of bias adjustment.

Defining question: What is the most effective bias adjustment strategy that would produce the most skillful decadal climate predictions?

Barrier 5: The concept of "near term" climate prediction typically extends to roughly 30 years, but the focus of most decadal climate prediction studies until now has been on the next decade.

There is the need for near term climate information that extends beyond one decade to extend out to several decades.

Defining question: Is there any skill in 30 year initialized predictions over and above uninitialized free-running climate model simulations?

Barrier 6: Need for model development

Both systematic error and drift are a major limiting factor for the realization of predictability estimates with current forecast systems. Climate prediction should join forces with other aspects of climate research to properly fund improvements in ESMs, making the most of the current observations and increased computing power.

Defining question: What are the priorities for climate prediction to make progress in model improvement?

Barrier 7: Need for large samples to obtain robust forecast quality estimates

Although the analysis of an increasing number of case studies is shedding light into some relevant aspects of climate prediction, robust forecast quality estimates can only be obtained with sufficiently large samples. This means that both larger ensembles (beyond the current 5-to-10 typical ensemble size) and frequent start dates over long periods that properly sample the observed variability are necessary. When taking into account that decadal prediction deals with long (at least 10 years) simulations, the computing power required is substantially larger than for any other climate research problem. Appropriate computing resources should be made available, especially as the tendency for increased model resolution continues.

Defining question: How to best interact with HPC managers and providers to explain the decadal prediction needs?

Barrier 8: Relevance of decadal prediction for climate services

In the wake of the current development of climate services in the framework of the GFCS, the utility of decadal predictions should be illustrated. A large amount of work is required in this front to overcome the lack of experience in downscaling, calibrating (as mentioned in Barrier 4), and combining decadal predictions to provide useful climate information for the relevant time scales. Users will have to be trained on the relevance and limitations of this sort of forecasts. The use of empirical predictions and user-oriented verification might be especially important for this topic.

Defining question: What strategy to follow to best interact with potential users of decadal predictions?

Barrier 9: Limited skill over land regions

Barrier 10: Very limited skill for extratropical atmospheric circulation