LLNL Triennial Climate Scientific Focus Area Review

PCMDI Accomplishments and Future

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PCMDI
Program for Climate Model Diagnosis and Intercomparison

CAPT
Cloud-Associated Parameterizations Testbed

ESGF
Earth System Grid Federation

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PCMDI's dual mission is unique and appropriate for a national lab

- Advance climate science through individual and team research contributions,
  - Perform cutting-edge, high profile research to understand the climate system and reduce uncertainty in climate model projections.
  - Establish ourselves as scientific leaders in chosen specialty areas.

- Provide international leadership and infrastructure for activities that promote and facilitate research by others.
  - Plan and manage coordinated climate modeling activities and provide access to multi-model output.
  - Promote development of performance metrics for summarizing model merits and limitations.

Scientific questions drive our research:

- Why do models differ and how reliable are their projections? Are there systematic errors in models that deserve more attention?
  - We lead model intercomparison and related activities. (Taylor)
- Can we detect significant climate change in the observed record and attribute it to specific “forcings”?
  - We are recognized leaders in detection and attribution research. (Santer)
- Can we improve understanding of targeted aspects of climate model behavior?
  - Drawing on special areas of expertise, we conduct in-depth studies to evaluate model fidelity. (Sperber)
- What are the relative merits and limitations of individual models, and are models improving?
  - We establish metrics and invent innovative graphical techniques to summarize model skill in compact form. (Gleckler)

Who is funded?

- 6 Climate scientists devote at least 75% their time to this SFA research:
  - Curt Covey
  - Paul Durack (post-doc)
  - Peter Gleckler
  - Ben Santer
  - Ken Sperber
  - Karl Taylor
- 5 other climate scientists also partially supported: Celine Bonfils, Detelina Ivanova, Kate Marvel (post-doc), Tom Phillips, Yuying Zhang.
- 4 Computational/software scientists partially supported: Charles Doutriaux, Bob Drach, Renata McCoy, Jeff Painter.
- 11 + 4 = 15 contributors partially supported by 8 FTE's
  (5.5 climate + 1 postdoc + 1.5 comp. sci. + some admin.)

Outline

- Leadership and community support activities
- Detection and attribution
- Model diagnosis
- Model performance metrics
- Integrating theme and concluding remarks

Leadership and community support activities

- Establish ongoing model intercomparison activities (CMIP, AMIP, CFMIP, PMIP, GeoMIP, etc.) –Taylor poster
- Facilitate use of observational datasets in support of model evaluation ("obs4MIPs")
- Engage with outside experts to develop standardized performance metrics – Gleckler poster
- Establish and provide governance and leadership for data standards
  - CF netCDF conventions
  - CMOR software to facilitate compliance
- Lead efforts to develop software infrastructure to make data available to users from a distributed archive (Dean Williams)
- Serve as IPCC authors and on a number of WCRP panels

The climate research community relies on PCMDI to provide leadership and key contributions to CMIP5

Planning, consensus building, groundwork, and software infrastructure (CLIVAR Exchanges Newsletter, Vol. 15, No. 1, 40-42, 2011.)

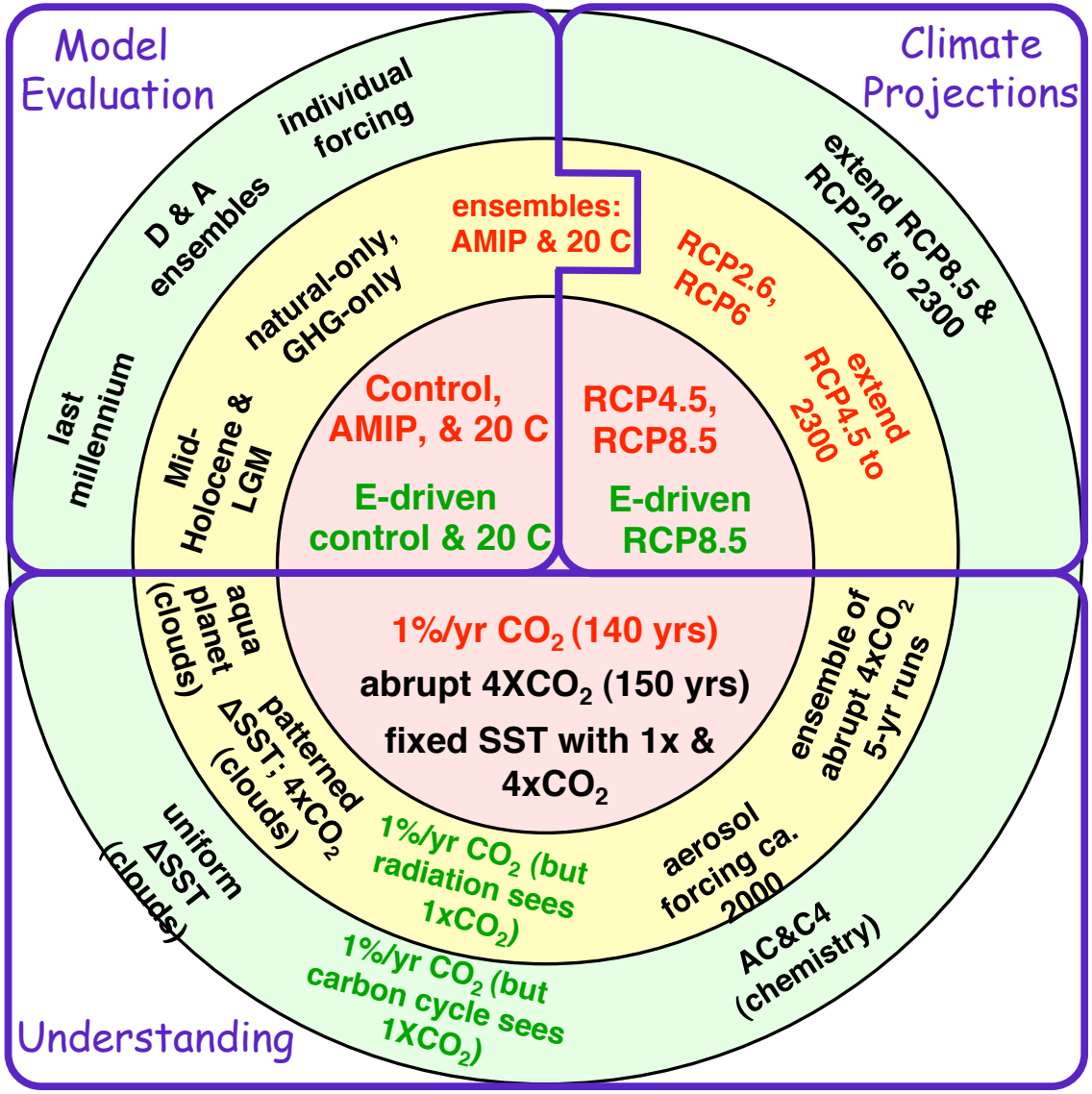
- International "buy-in" and endorsement by modeling groups
- *Experiment design built on community consensus (Taylor *et al*., *BAMS*, 2011) see also http://cmip-pcmdi.llnl.gov/cmip5/experiment_design.html
- *Agreed to standard model output based on community input (e.g. WGOMD, IDAG, TGICA) http://cmip-pcmdi.llnl.gov/cmip5/output_req.html
- *Development and community acceptance of data standards (e.g., CF-conventions, "standard names") http://cf-pcmdi.llnl.gov/
- *Specification of model output requirements http://cmip-pcmdi.llnl.gov/cmip5/output_req.html
- Agreed upon "terms of use" http://cmip-pcmdi.llnl.gov/cmip5/citation.html
- Common forcing datasets used by all groups (including concentrations/ emissions, ozone, land-use) http://cmip-pcmdi.llnl.gov/cmip5/forcing.html
- *Website and errata page http://cmip-pcmdi.llnl.gov/cmip5/index.html
- *CMIP5 archive-related software development and ongoing support (ESGF) (Dean Williams)

PCMDI provides additional support to CMIP5 and related projects

- Standards for documenting models and their simulations (key partners: METAFOR, CURATOR, ES-DOC)
- QC checks on model output (key partners: DKRZ, BADC)
- Assignment of “doi’s” to model output datasets, as step toward ensuring traceability of research results and (key partner: DKRZ)
- Help desk (key partners: BADC, DKRZ)
- Coordination, guidance and application of CMIP5 infrastructure to sister MIP’s (e.g., PMIP, CORDEX, GeoMIP, TAMIP, CFMIP)

See Taylor poster

Ambitious experiment design: Model evaluation, projections, and understanding



Red subset matches the entire CMIP3 experimental suite

Green subset is for coupled carbon-cycle climate models only

Taylor et al., "CMIP5 Experiment Design"
http://cmip-pcmdi.llnl.gov/cmip5/experiment_design.html

Taylor, Stouffer & Meehl
BAMS, 2012

Call for more comprehensive model output (substantially exceeding CMIP3 requirements)

- Domains (number of monthly variables*):
  - Atmosphere (60)
  - Aerosols (77)
  - Ocean (69)
  - Ocean biogechemistry (74)
  - Land surface & carbon cycle (58)
  - Sea ice (38)
  - Land ice (14)
  - Clouds (~100)
- Temporal sampling (number of variables*)
  - Climatology (22)
  - Annual (57)
  - Monthly (390)
  - Daily (53)
  - 6-hourly (6)
  - 3-hourly (23)

***Not all variables are saved for all experiments and time-periods**

http://cmip-pcmdi.llnl.gov/cmip5/output_req.html

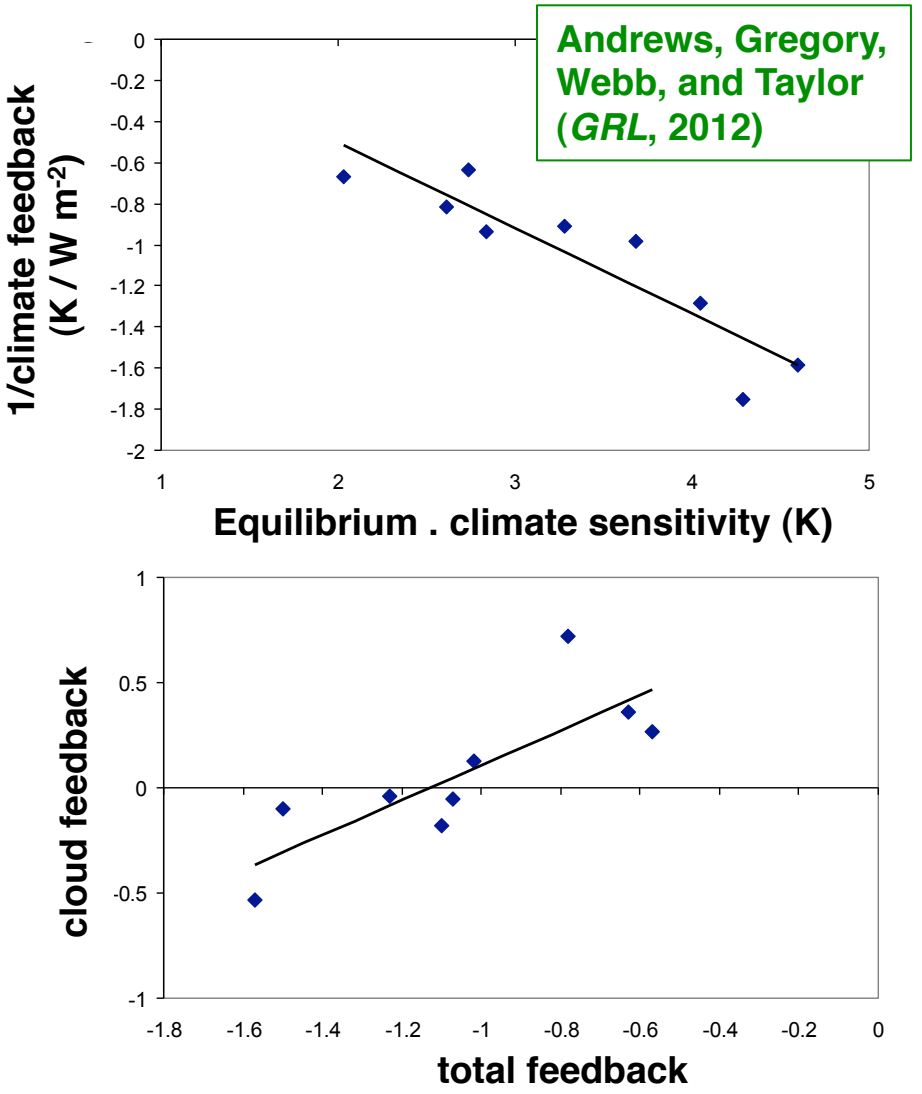
CMIP5 timeline:

- 2006: Planning began
- December 2009: Experiment design in place
- March 2011: Output requirements and list of requested output finalized
- June 2011: Distributed data archive software readied
- July 2011: first model output available for analysis
- August 2011: RCP forcing datasets finalized
- March 2012: A petabyte of data stored in 2,000,000 files available from about 40 models from 20 modeling centers
- March 2012: Impressive collection of CMIP5 multi-model results presented at a WCRP workshop (~200 participants)
- July 2012: More than 200 publications based on CMIP5 output already submitted or published
- Now: 60 models available from 24 modeling centers
- CMIP5 research just beginning

1 year

Sample (from 200+ journal articles) of what we are learning from CMIP5

- In CMIP5 we see no reduction in range of model estimates of climate sensitivity.
- Differences in feedbacks, not forcing, are primarily responsible for the range of equil. climate sensitivities.
- Differences in cloud feedback remain responsible for a large fraction of the range of feedback strengths.



PCMDI leadership goals are evolving:

- Promote core CMIP experiments as benchmarks expected to be performed during model development, with output contributed for community scrutiny.
- Capitalize on our leadership position in the WCRP's "metrics panel" to establish sets of performance metrics that can serve multiple purposes. (more on this later)
- Continue to work with partners to improve services connected to data archive (citation, notification, documentation, etc.).
- Continue to encourage and support the community-wide effort (known as "obs4MIPs") to make observational datasets available in formats and structures similar to model output.

Obs4MIPs: Applying MIP capabilities to observations

- Data written in same structure and format as CMIP5 model output.
- Data obtainable through ESGF.
- First products from NASA and from ARM now available.
- ESA and NOAA have interest.
- Wiki describing Obs4MIPs now at: http://obs4mips.llnl.gov:8080/wiki
- A parallel effort is underway to make reanalyis products available (currently NASA MERRA).
- We are promoting Obs4MIPs in partnership with NASA JPL and with encouragement from the WCRP Data Council.

See Gleckler poster

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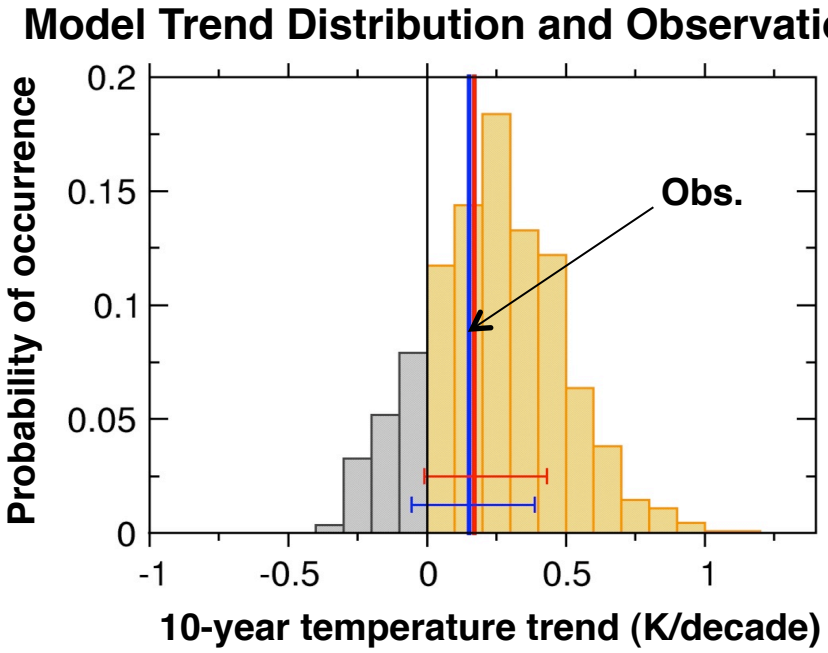
PCMDI remains a leader in climate-change detection and attribution research (led by Ben Santer)

- Published dozens of highly-cited journal articles.
- Made major contributions to high-impact reports:
  - IPCC's 2nd, 3rd and 4th assessments
  - Two USGCRP reports
  - A National Academy report
- Invited, on occasion, to provide congressional testimony.

Advances in D&A research include:

- A multi-model study which determined that positive detection of global water vapor changes was insensitive to model skill (Santer et al., *PNAS*, 2009).
- Climate "noise" can only easily explain observed temperature changes on time scales of a decade or less. Also model simulated "noise" does not appear to be underestimated. (Santer et al., *JGR*, 2011).

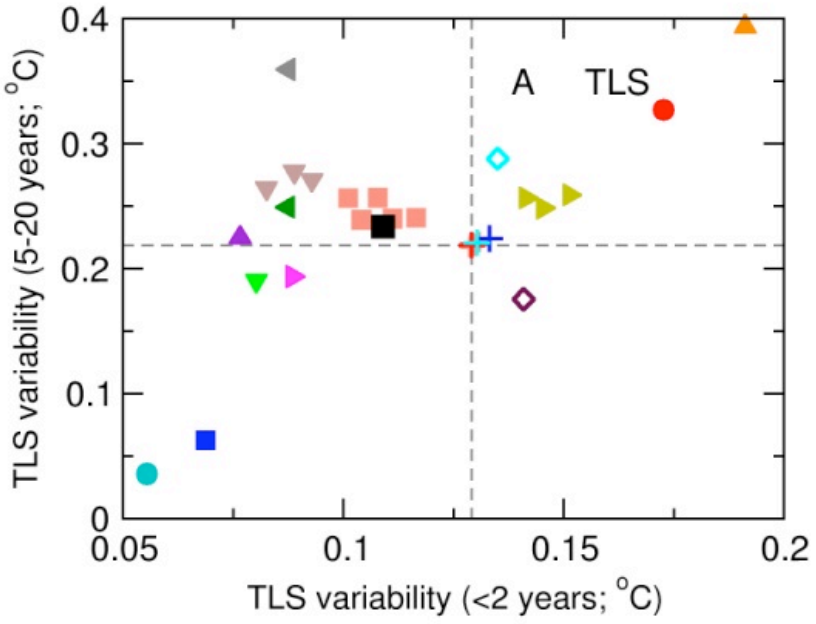


Santer talk

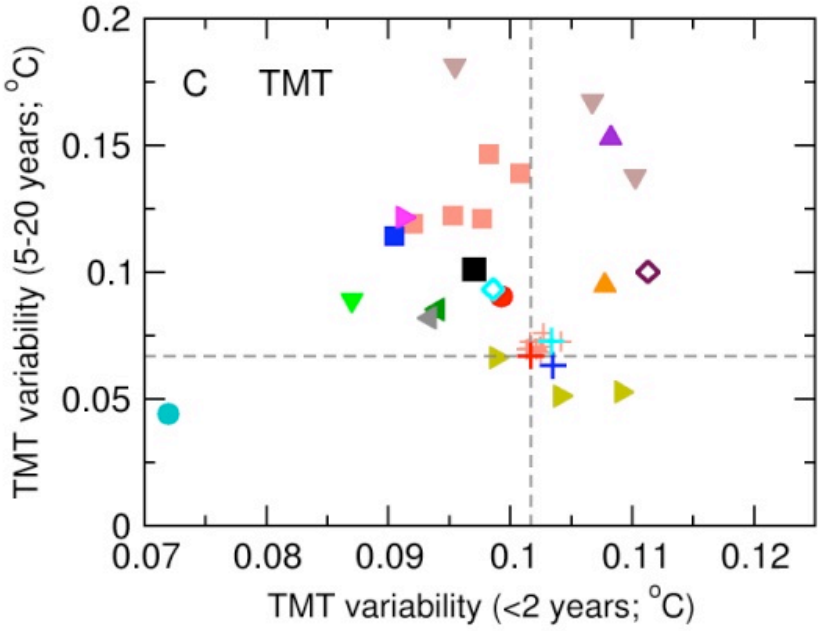
Detection and attribution research: Evaluation of variability in models

5-20 year timescales vs. < 2 year timescales

lower stratosphere temperature



mid-troposphere temperature



+ + **Obs.**

■ **Multi-model mean**

Santer *et al.*, *PNAS*, in review

Detection and attribution research: Future directions

- Make increasing use of multi-model ensembles (e.g. CMIP5).
- Build on recent collaborative efforts to estimate uncertainty in observed trend estimates (Mears et al., 2011).
- Provide community access to “value added” model output products (e.g, synthetic MSU datasets).
- Expand on work to develop performance metrics to identify models that provide the most credible estimates of unforced variability.
- Partner with cloud experts at PCMDI to examine trends in clouds and perform formal D&A analysis.

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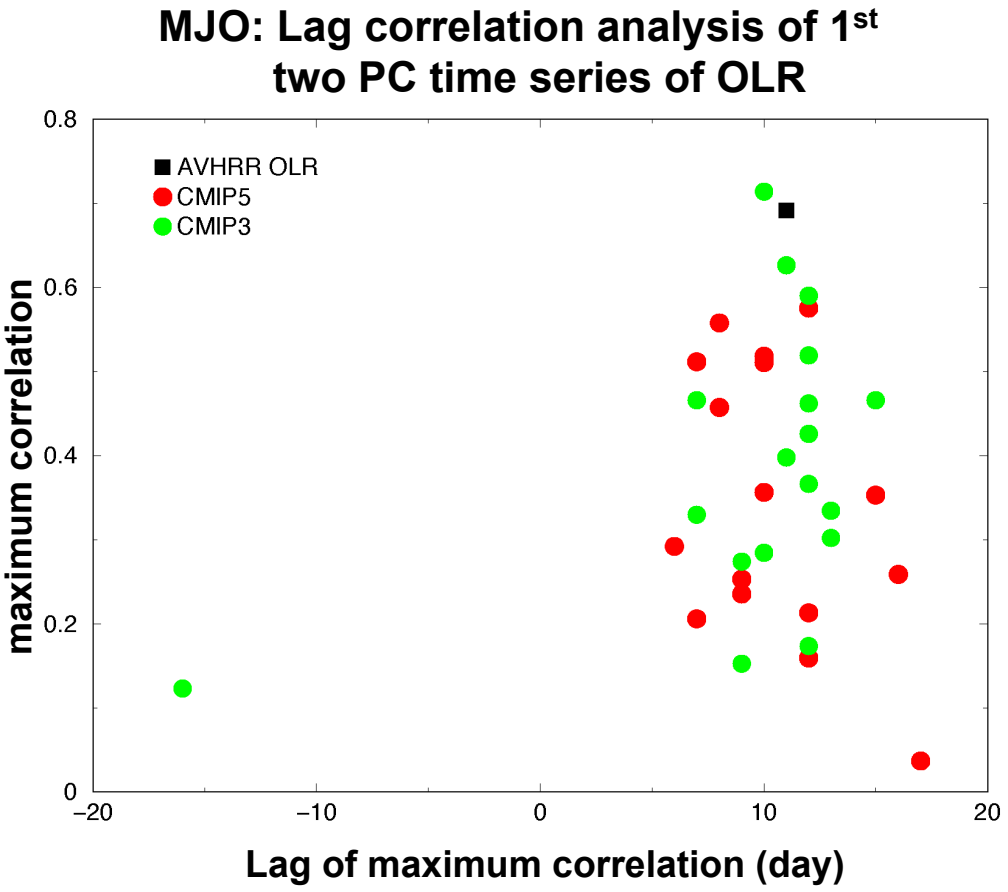
PCMDI research covers a variety of phenomena: 1) Modes of variability

- MJO evaluation and metrics (Sperber poster)
- Monsoons (Sperber talk)
- Aliasing between PDO trends and global warming was eliminated through improved definition of the PDO index (Bonfils and Santer, *Clim. Dyn.*, 2011).
- As a member of international working groups and panels, Sperber is developing metrics of model performance on intraseasonal time-scales.

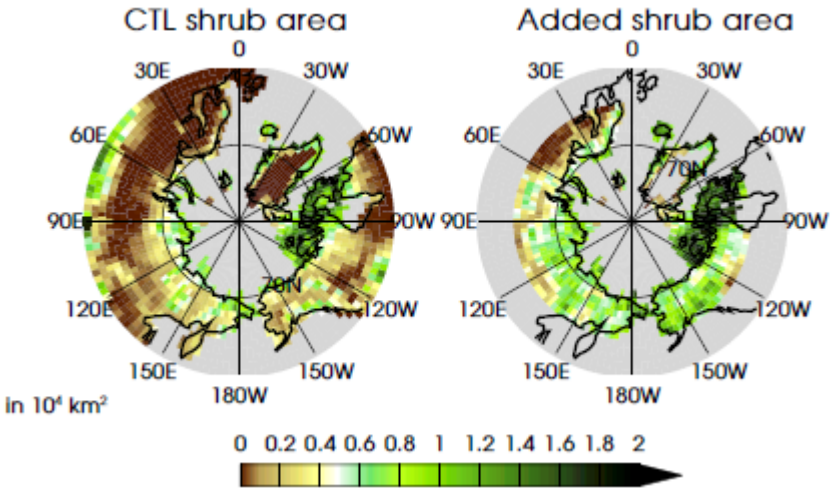


Update of Sperber & Kim (Atmos. Sci. Letts., 2012)

PCMDI research covers a variety of phenomena: 2) Atmospheric tides; 3) Climate change mechanisms

- Covey et al. (*JAS*, 2011): Can models accurately simulate atmospheric tides?
  - CMIP3 simulations of tides are largely consistent with observations.
  - Surprising since ozone layer not well resolved in many models.
  - Possible cancellation of errors between weak ozone response and unrealistically reflective model “lid”.
- Bonfils et al. (*Env. Res. Letts.*, 2012): What might be implications of global warming induced changes in boreal shrub area and density.
  - Found positive feedback.

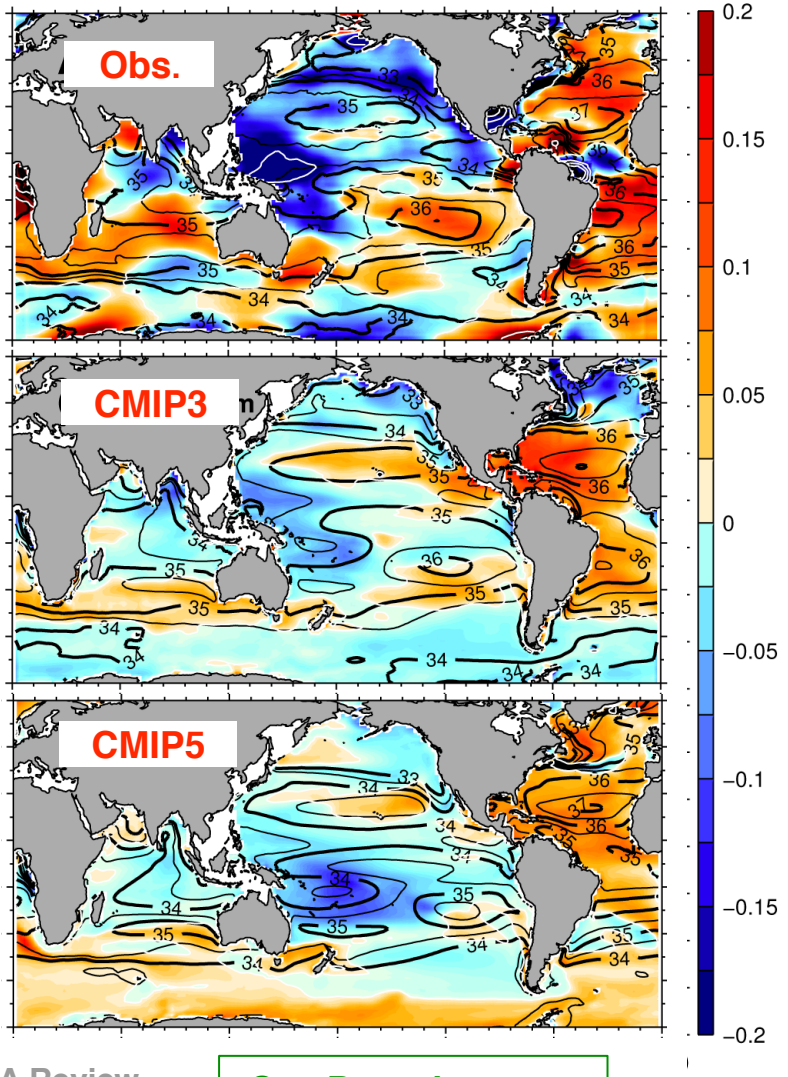
Bonfils poster



PCMDI research covers a variety of phenomena:
4) Ocean research

- Durack et al. (*Science*, 2012): What can we learn from ocean salinity trends?
  - Consistency between basin-scale observed and modeled ocean salinity trends
  - Found independent evidence of intensification of the hydrological cycle
- Ivanova et al. (*JGR*, 2012): What is responsible for the important connection between the NAO and sea-ice variability?
  - Found that NAO variability is caused both by surface flux changes and heat exchange below the ice

Surface Salinity Trends



See Durack poster

Strategy for ongoing model diagnosis and evaluation research:

- Address scientific questions or address model behavior of importance to understanding the climate system.
- Focus on research areas where PCMDI scientists have special expertise.
- Rely on multi-model ensembles like CMIP5.
- Develop summarizing performance metrics of the phenomena studied.
- Engage in collaborations across the SFA and with outside partners.

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Motivating question: How reliable are climate model projections?

- Observational record not long enough to quantify skill based on hindcasts (only 1 hindcast available).
- Attempt to determine whether models accurately represent the physics (and dynamics) of the climate system:
  - Ability to simulate important climate phenomena
  - Ability to represent individual processes
  - Ability to forecast weather and climate (on decadal and shorter time-scales)
  - Ability to simulate paleoclimates
- We seek to establish a suite of standard metrics that together
  - Can evolve into an increasingly *comprehensive* synthesis of model skill and summary of model performance
  - Provide ongoing quantification of the state of climate model problems and improvements
  - Guard against simplistic, unjustifiable conclusions concerning the relative value of different models.

Objectives and research questions

Immediate objectives:

- What do models simulate robustly, and what not?
- In which respects is my model exceptionally “good” or “bad”?
- Are some models more realistic than others?
- Are models improving?

Ultimate research questions:

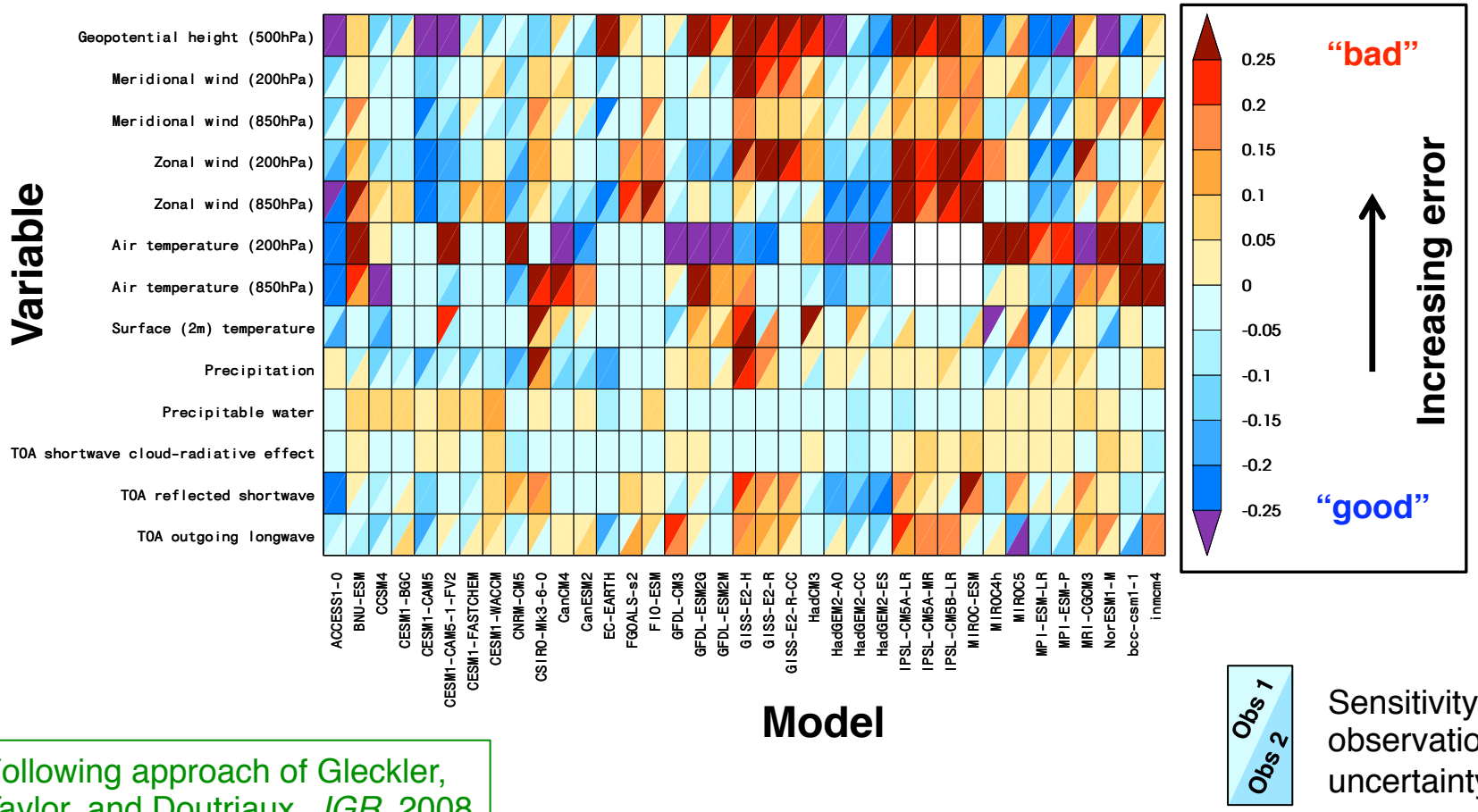
- How does skill in simulating observed climate relate to projection credibility?
- Can we justify weighting model projections based on metrics of skill?

PCMDI develops model performance metrics in house and encourages community contributions.

- Across our research agenda, we construct model skill metrics as a means of characterizing various aspects of model performance:
  - Mean state and variability metrics (Santer talk)
  - Seasonal cycle climatology (Gleckler poster)
  - Ocean heat content variability (Gleckler talk)
  - MJO and monsoon skill (Sperber poster & talk)
  - Ocean salinity (Durack poster)
  - Reaches across LLNL research projects (e.g., “cloud simulator” evaluation metrics, TAMIP)
- Gleckler chairs a WCRP “Metrics Panel”:
  - Engages various WCRP/CLIVAR expert groups to contribute (e.g., MJO task force, CLIVAR ocean basin panels, CFMIP committee, monsoon panel)
  - Seeks to establish a limited set of community-based metrics that would be applied as a standard test of models and provide a first-look indication of performance.

PCMDI prepares summary performance portraits of CMIP models

CMIP5 Summary of Skill in Simulating Spatial Pattern of Seasonal Cycle



Following approach of Gleckler, Taylor, and Doutriaux, *JGR*, 2008

Climate model performance metrics plans

- Expand on recent ocean metrics work (3-d temperature, salinity, mass transports)
- Examine model performance across time and space scales.
  - Climatology
  - Trends
  - Modes of variability
- Package LLNL's climate metrics to enable a diverse summary of CMIP model performance (contributing to the WCRP metrics panel – see Gleckler poster)
- Continue effort to engage community in development of metrics covering the full climate system, which
  - Reflect general fidelity of model in simulating important aspects of mean climate and variability
  - Provide evidence that models are accurately representing key physical processes
- Explore "independence" of metrics, with objective of minimizing set

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Integrating themes result in synergistic benefits

- Model intercomparison:
  - Provides PCMDI scientists with a rich multi-model dataset that can be exploited:
    - Detection attribution studies
    - Performance metrics development
    - Systematic error identification
  - Establishes us as an essential contributor to climate science : We enable specialists from around the world to carry out multi-model research.
- Model performance metrics:
  - Rely on fundamental in-house research and CMIP results to provide an increasingly comprehensive perspective of model performance.
  - Establishes our credentials to lead an international effort with the same goals
    - Gleckler (chair) and Taylor serve on the WCRP metrics panel

Close and interactive relationship between this and the other SFA components

- We look for cross-fertilizing opportunities with cloud, chemistry and aerosol research:
  - Cloud feedbacks.
  - Detection and attribution: clouds & understanding role of stratospheric chemistry.
  - Observational data sets: satellite simulator, ARM (Obs4MIP).

Close and interactive relationship between this and the other SFA components

- We look for cross-fertilizing opportunities with cloud, chemistry and aerosol research.
- We capitalize on the symbiotic relationship between our climate scientists and computer scientists:
  - Software development focuses on the needs of climate researcher's.
    - Our climate scientists provide the research perspective needed for really useful software.
    - We test prototypes and suggest changes.
  - The software facilitates our research.
  - Working with computer scientists we develop codes and datasets that benefit the climate science community.
    - Model-derived MSU temperatures
    - Regridding of non-Cartesian model output
    - Codes for reading and interpreting CMIP files

Dean Williams talk

With ongoing support, PCMDI will continue to carry out its dual mission

- Engage in cutting-edge climate research.
- Provide leadership of modeling activities that enable research by others.