Cross-Working Group Session:

Coupled Model Initialization and Tuning

Cécile Hannay and Charles Jackson

Gokhan Danabasoglu, Jean-Francois Lamarque, Dave Lawrence, Keith Lindsay, Rich Neale, Phil Rasch and Joe Tribbia

Thanks to gazillions of people including: Mariana Vertenstein, Julio Bacmeister, Patrick Callaghan, Andy Mai, Dave Williamson, Matt Long, and many others…

CESM Workshop, 16 –19 June 2014, Breckenridge, Colorado

Motivation

- Traditionally, initialization and tuning handled individually for each model component by the corresponding working group.

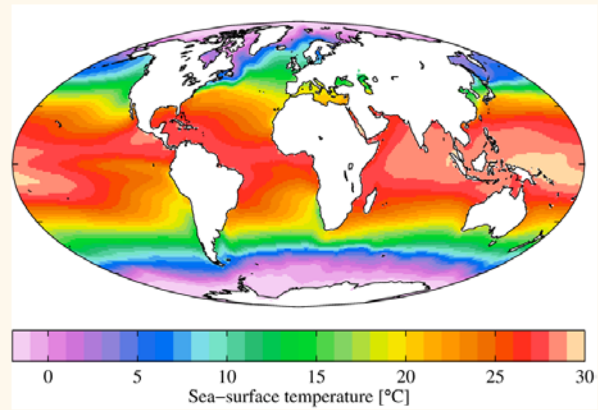
- Each working group had its own strategy.

- Now, there is a general agreement that we want to move to a more common strategy in the grand scheme of CESM.

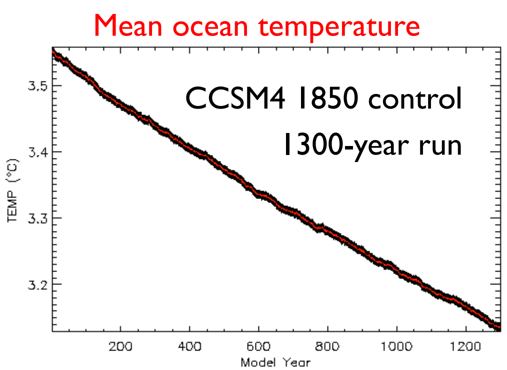
Today:
Overview of the initialization and tuning
Discussion of current issues

CESM Initialization

Ways to initialize the ocean in CESM

Levitus	Start from Levitus climatology based on observations	
Long spunup ocean	Start from a long previous run (or succession of runs) “spunup ocean” CCSM4 – 1300 yrs CESM1.1 – Several 100s yrs CESM1.2 – Several 100s yrs	

Pros and Cons of each initialization

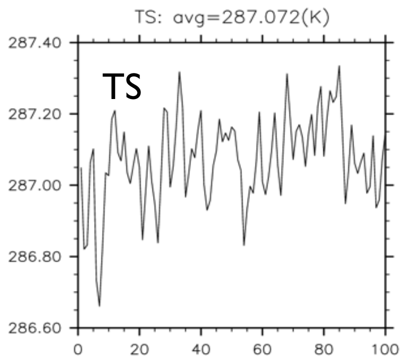
	Pros	Cons
Levitus	"Clean" way to initialize	Each run requires long spin-up. - At each experiment we will repeat this long spunup - More challenging to tune (*). Levitus is present day ocean. Is it best to initialize 1850 ?
Long spunup ocean	Fast to adjust Easier to tune	The model has drifted far away from reality.  Difficult to reproduce.

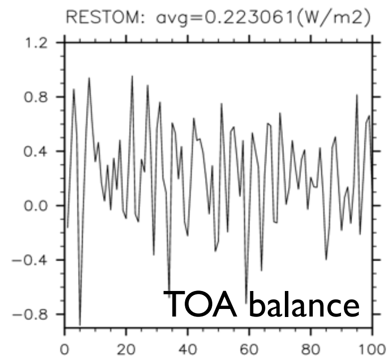
* tune = adjust parameters ("tuning parameters") to achieve TOA radiative balance ~ 0 W/m^2

What happens in the first 100 years of the run?

CESM1.1: Finite volume (FV)

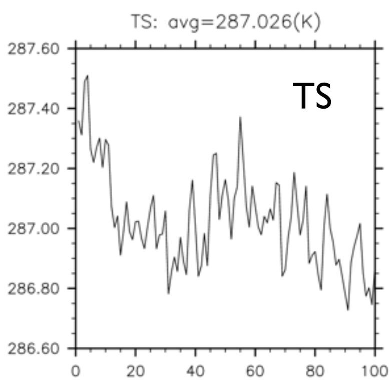
Spunup ocean

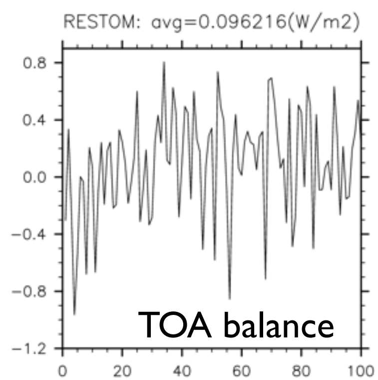




When starting from spunup ocean, model quickly adjusts (20 years)

Levitus

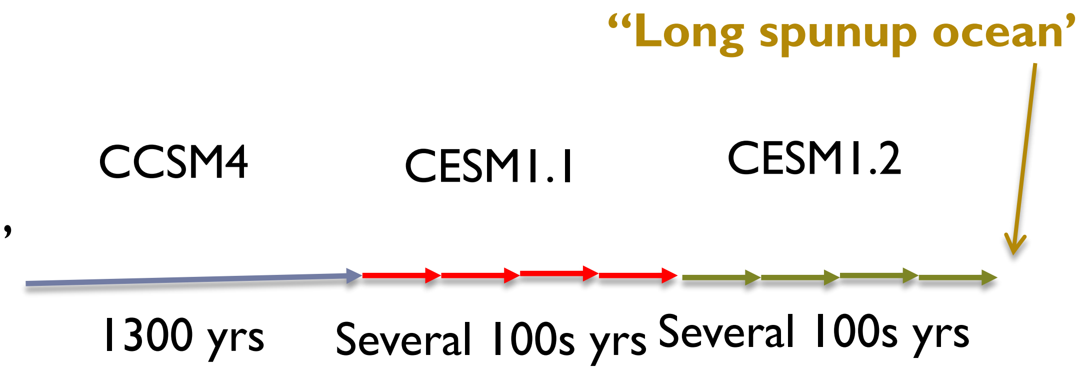




When starting from Levitus, model spinups longer (100 years).

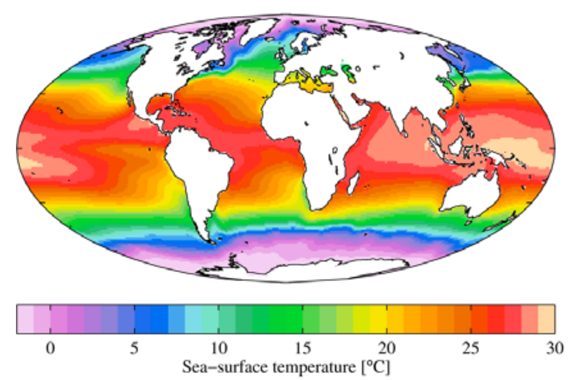
Proposed strategy to tune the model

Use best of both worlds !



(1) Use “long spunup” initialization,
to obtain tuning parameters
to adjust TOA balance ~ 0 W/m2

(2) Use tuning parameters obtained in (1)
and restart the run from Levitus



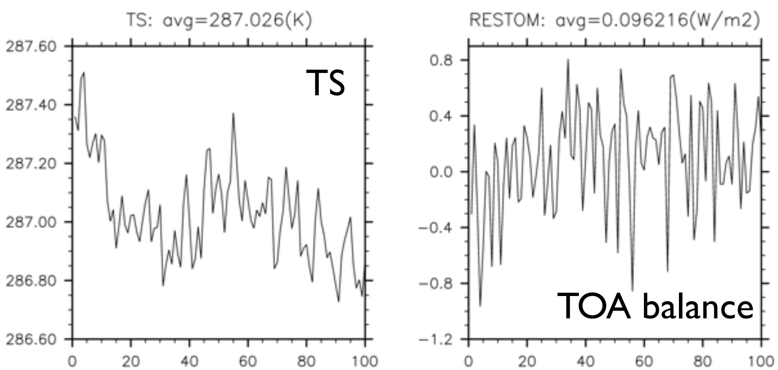
(3) Retune “along the way” if needed to maintain TOA balance ~ 0 W/m2

Let's apply the proposed strategy

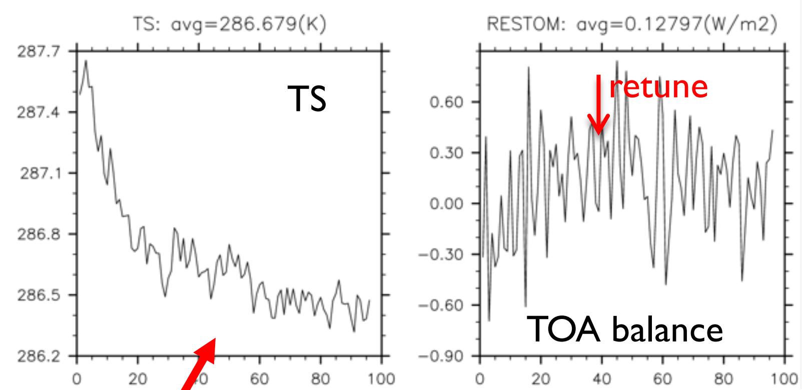
1. Obtain tuning parameters starting from spunup ocean
2. Use tuning parameters obtained in (1) and restart the run from Levitus
3. Retune "along the way" if needed

Restart from Levitus

CESM1.1: Finite volume (FV)



CESM1.2: Spectral element (SE)



Strategy was quite successful in CESM1.1

Used for "large-ensemble"

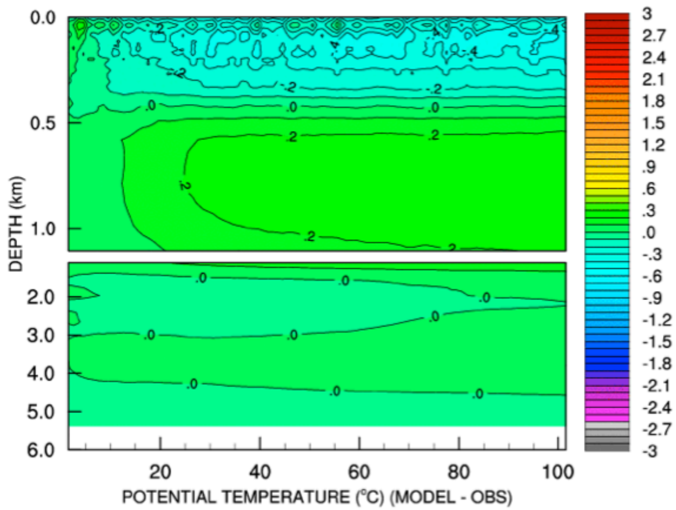
"Houston, we have problem"

This problem is present ONLY when starting from LEVITUS

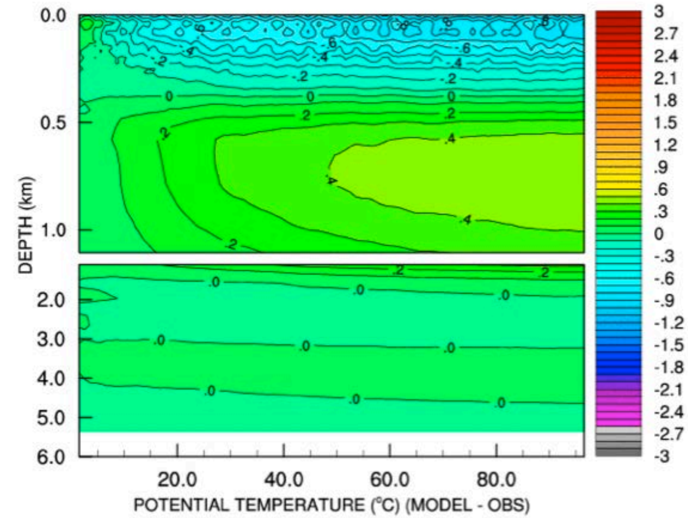
Ocean temperature bias

T bias = Tocn - Levitus

Finite Volume



Spectral Element



When starting from Levitus:

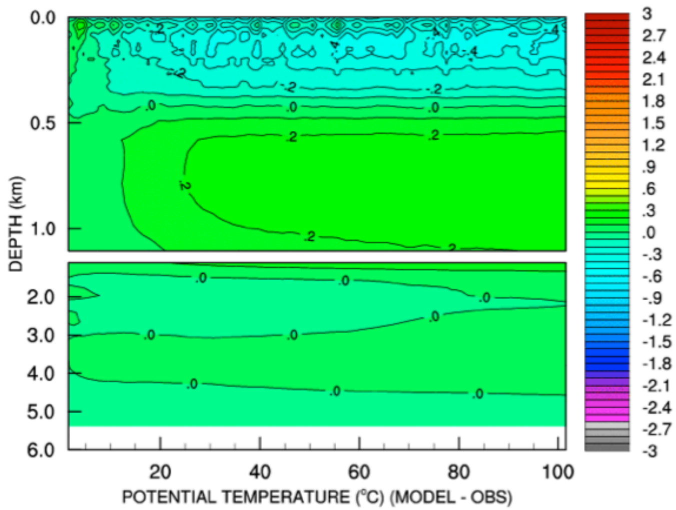
- cools near the surface
- warms around 750 meter

Exacerbated in Spectral Element

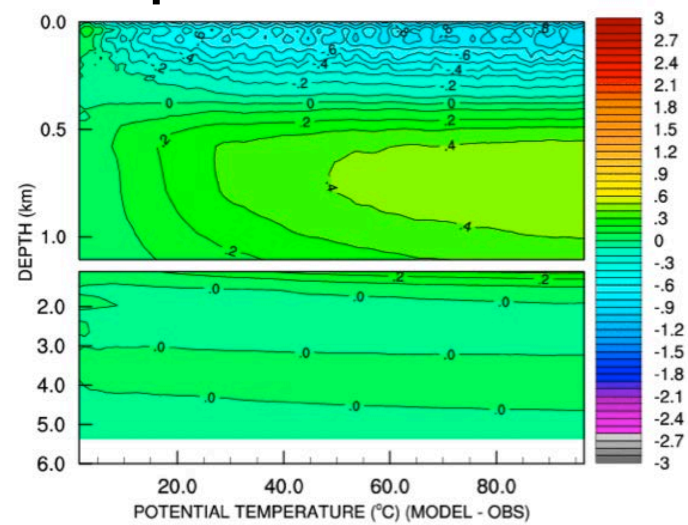
Ocean temperature bias

T bias = Tocn - Levitus

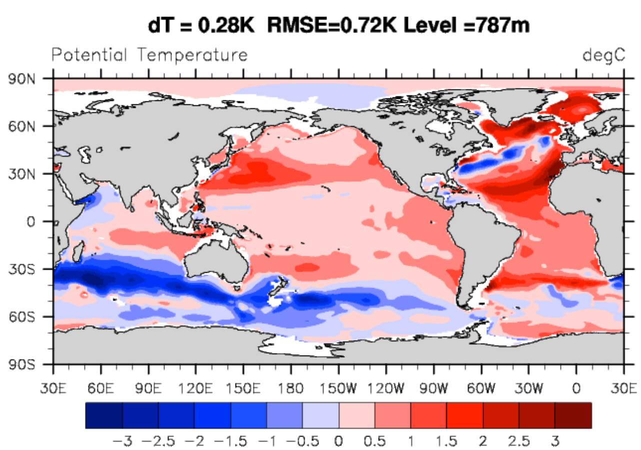
Finite Volume



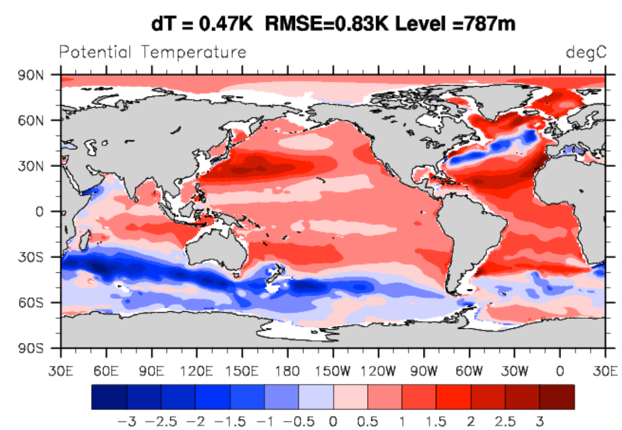
Spectral Element



Bias at 750m = T 750-m – Levitus



yrs 70-89

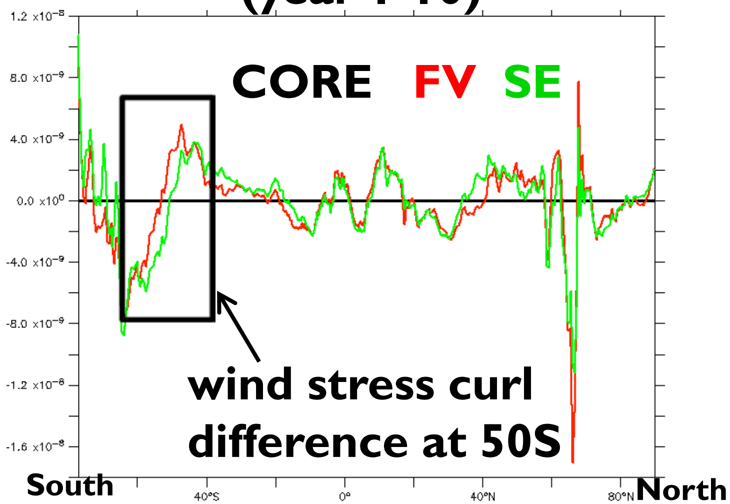


Warming is not uniform: areas of warming and cooling

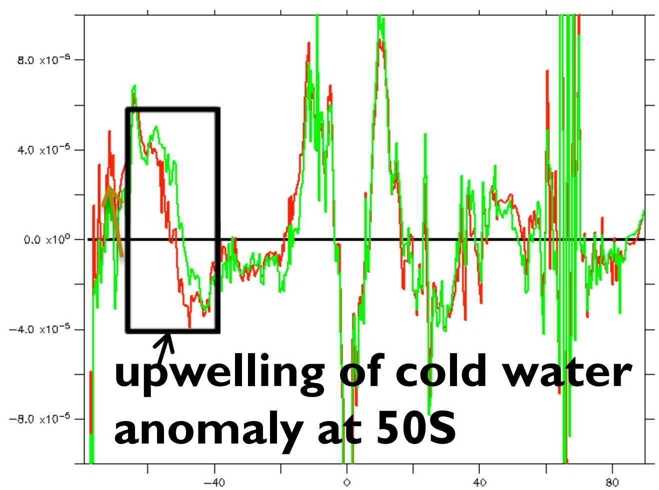
Warming also exists in Finite Volume but cooling compensates warming globally.

Mechanism responsible of SST cooling in SE

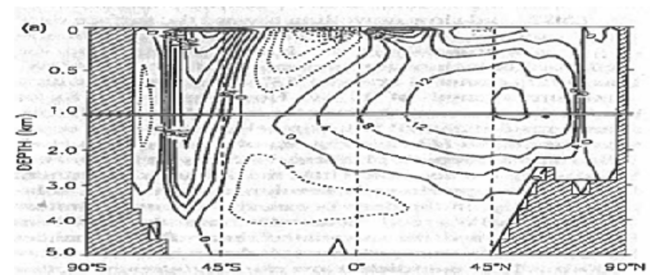
Wind stress curl anomaly (year 1-10)



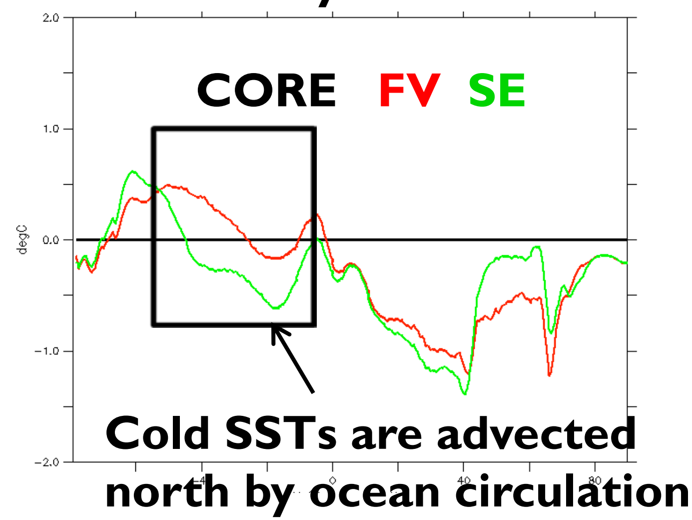
100-m vertical velocity anomaly



Ocean circulation



SST anomaly from CORE

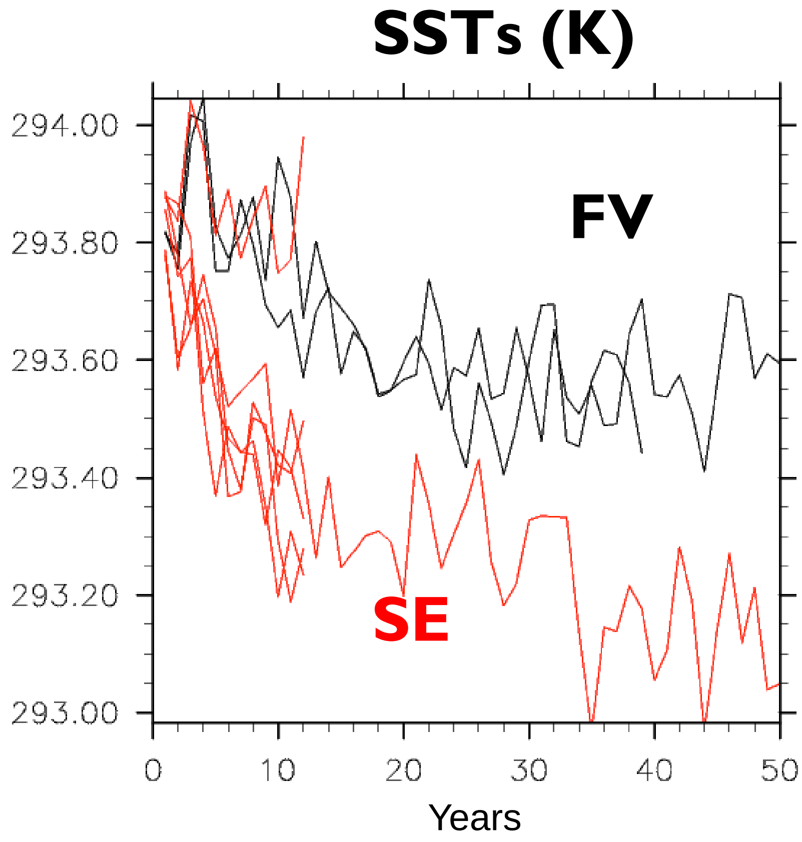


Changes in location of upwelling zones associated with ocean circulation is responsible of the SST cooling

What controls SST cooling in SE ?

Inventory of differences (SE ⇔ FV)

- Tuning parameters
  - Use FV tuning for dust, rhminl, rpen
- Topography
  - Use smoother topography
- Remapping (ocn ⇔ atm)
  - Use bilinear for state variables
- Grid differences at high latitude
  - Use refined poles grid
- Surface stresses
  - Turn off turbulent mountain stress
  - Increase turbulent mountain stress
  - Change gravity wave
  - Nudging to Finite Volume winds

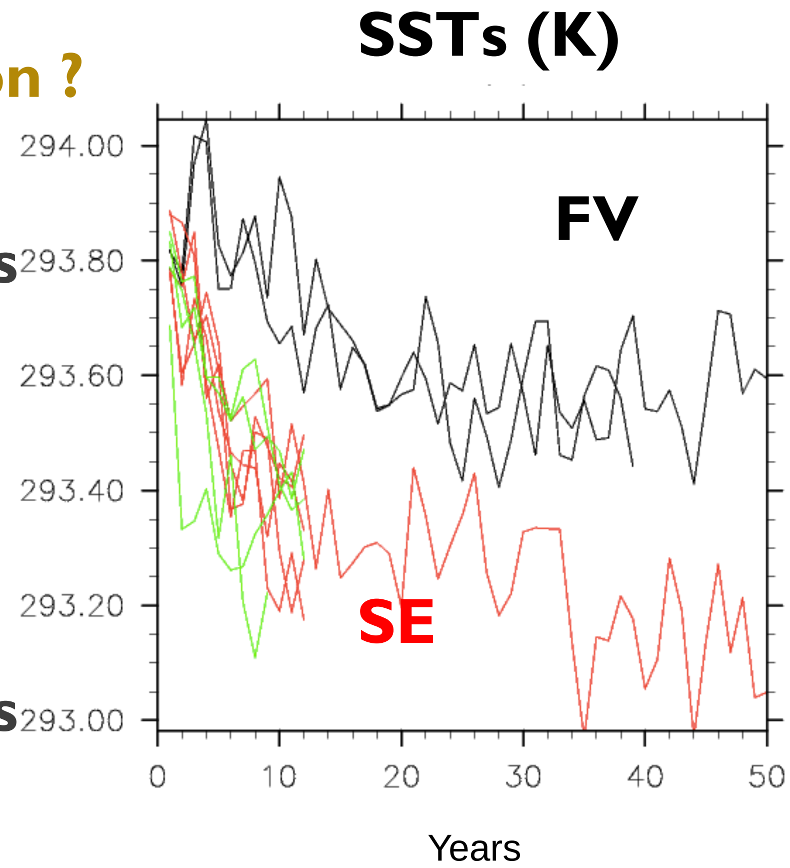


FV tuning parameter restore the SSTs but with 1 W/m2 TOA imbalance

What controls SST cooling in SE ?

Can we impact the ocean circulation ?

- min(kappa_{iso,thic}) = 600 m^2/s
- min(kappa_thic) = 600 m^2/s, min(kappa_iso) = 1200 m^2/s
- min(kappa_{iso,thic}) = 600 m^2/s and KPP modification (stability-dependent surface layer depth)
- GM kappa reduced by 25%



Summary

Ideally, we would like to start coupled runs from Levitus

Spinup issue with the Spectral Element dycore

When starting from Levitus

- **SSTs are cooling too much**
- **Formation of 750m warm layer**

How do we move forward ?

- **Did we get lucky with finite volume dycore**
- **Can we live with starting from spunup ocean ?**
- **How can we reduce the cost of the spinup?**
  - **Accelerated ocean spinup (Kiehl and Shields) ?**

CESM Tuning

Tuning of a climate model

During model development, desired properties are adjusted or "tuned" to achieve the best agreement with observations.

This is done by adjusting uncertain parameters ("tuning knobs") related to processes not represented at grid resolution.

Examples

- **Desired property**

  TOA radiative balance: Net SW - Net LW ~ 0

- **Tuning knobs**

  rhminl = relative humidity threshold for low clouds (~ 0.9)

rhminl ↓ => cloud fraction ↑ => Net SW at TOA ↓

CAM Tuning at a glance

- **5-10 year standalone CAM simulations**

- **Focus on our favorite variables:**

  TOA radiative balance
  SW cloud forcing (= Net $SW_{all\ sky}$ - Net $SW_{clear\ sky}$)
  LW cloud forcing (= Net $LW_{all\ sky}$ - Net $LW_{clear\ sky}$)
  Precipitable water
  Precipitation

- **For each diagnostics, we have our favorite observation/reanalysis dataset**

- **Evaluation of favorite variables versus favorite datasets**

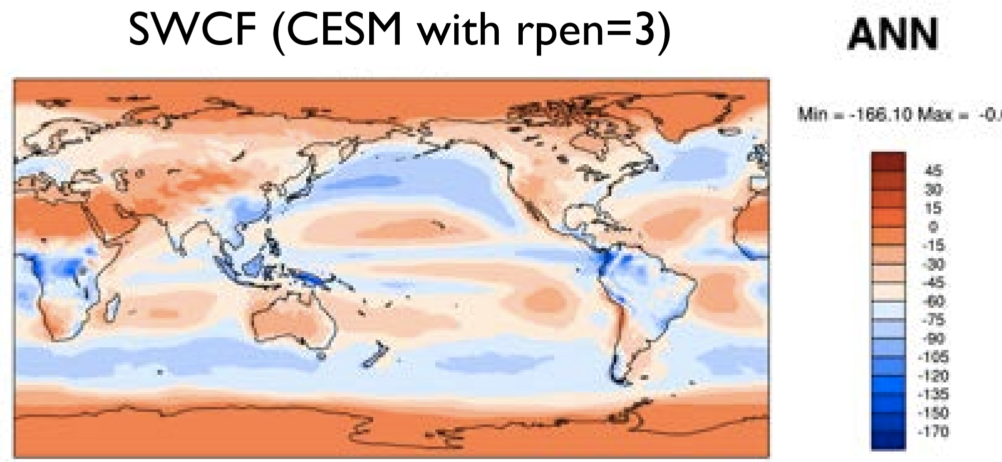
  global averages
  zonal means
  lat-lon plots
  Taylor diagrams
  Timeseries of TS and RESTOM

- **Expert team**

CAM5: needs to be tuned in coupled mode

During CAM5.2 development
rpen=3 produced excellent standalone simulation

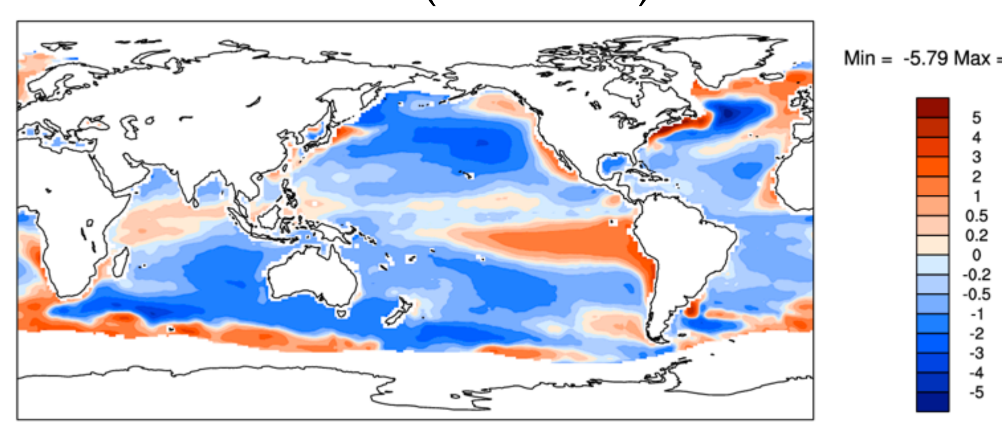
SWCF (CESM with rpen=3)



When running coupled, rpen=3 produced a runaway climate

b.

SST bias (CESM-obs)



Offline vs Coupled Model Tuning of CLM

- **CLM5 will include several features that are non-linearly dependent on the climate simulation (especially precip)**
  - Fire, CH_4 emissions, river flooding, dust emissions

	CLM4.5	CAM5-CLM4.5
Fire area:	~370 Mha/yr	~700 Mha yr^{-1}
River discharge:	~28,000 km^3/yr	~44,000 km^3/yr

- **In past, we have tuned CLM offline only and used these parameters in all coupled simulations**
- **For CESM2, the LWMG tentatively propose that there could/should be a separate set of parameters for offline and coupled simulations**

Summary

- **Currently, tuning:**
  - requires multiples decades simulations
  - typically: independently performed in model components
  - issues when using set tuning parameters in coupled mode (CAM5, CLM4.5)

In order to systematize we need a strategy that accounts for the dependencies among our choices.

We need a system to account for dependencies among choices in model development. Bayesian expression of this goal:

$$PPD(\mathbf{m} \mid \mathbf{d}_{obs}, g(\mathbf{m})) \propto \exp\left[-\frac{1}{2}\left(g(\mathbf{m}) - \mathbf{d}_{obs}\right)^T \mathbf{C}_{noise}^{-1}\left(g(\mathbf{m}) - \mathbf{d}_{obs}\right)\right] \cdot prior(\mathbf{m})$$

Performance metrics expressed as a test statistic

- Need efficient strategies for evaluating maximum probability solution.
- Need metrics that identify scientifically valid model configurations.

Discussion: how do we move forward ?

Ideas for:

- Model initialization of spectral element.
  - Short-term solution
  - Long-term strategy

- Develop a strategy to get a successful coupled model state
  - Design experiments for determining metrics and parameters important to the coupled state
  - Strategy to anticipate the dependencies between components
  - Automatize the strategy

- Speed up the testing process (important for high resolution)

- Need of dedicated resources for this process.

Model initialization of spectral element.
- Short-term solution
- Long-term strategy

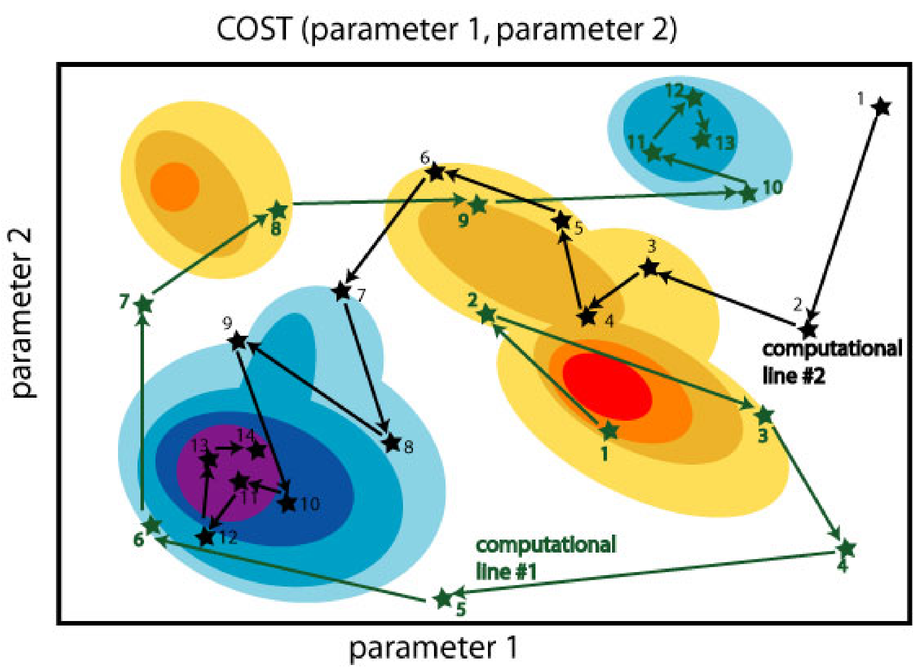
- Check: Levitus has issue in the Southern ocean. Is it the best way to initialize?
- Gokhan: Even when we start from FV spunup, we have the same problem. So it is not a Levitus problem.
- Joe: there is a single climate and we expect that if we run long enough we will reach the same climate.
- Long-term spin-up of Hadley circulation

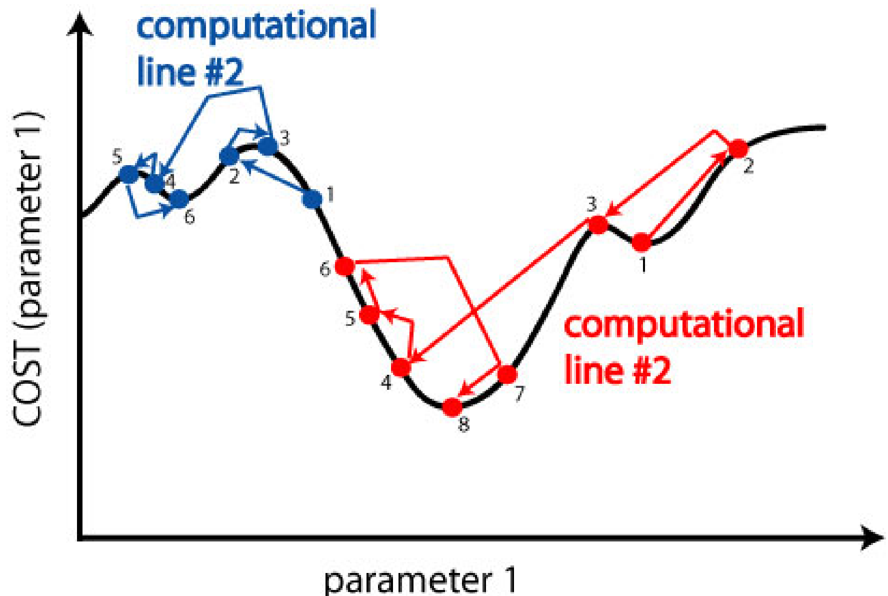
Develop a strategy to get a successful coupled model state
- Design experiments for determining metrics and parameters important to the coupled state
- Strategy to anticipate the dependencies between components
- Automatize the strategy

- Model Ensemble Control System (MECS)
- Give the set of optimum tuning parameters to the community
  => prove it is useful and people can look at it (Phil Rasch)
- Tuning is an interactive process
- Don Lucas CAM5-se? ensembles. Any solutions to southern ocean winds.
- Ben Sanderson's ensemble for cam5-se (wish he had)

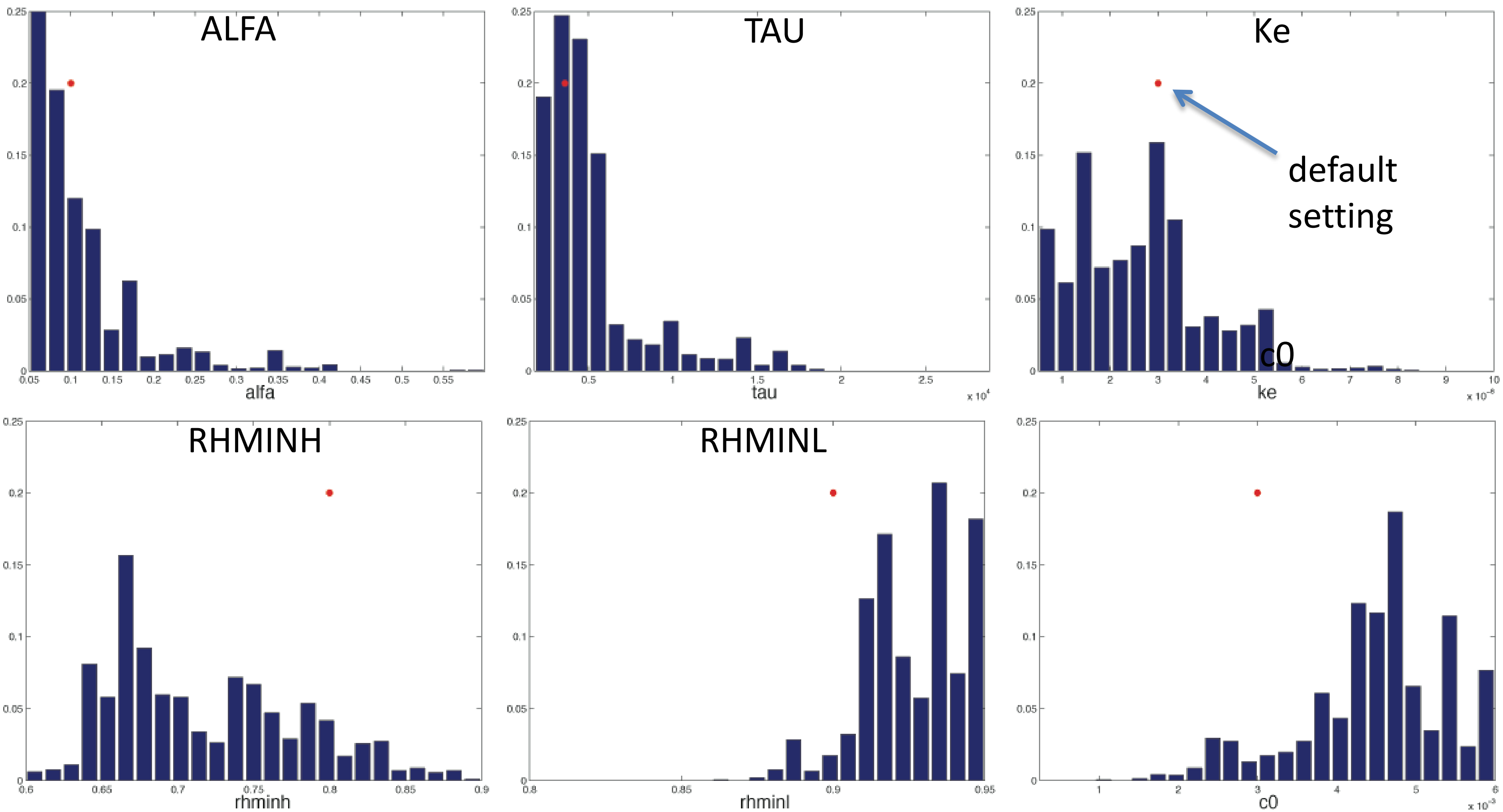
Model Ensemble Control System

- Use adaptive Markov Chain sampling to efficiently sample posterior distribution of solutions.
- MECS automates the workflow. Has restart capabilities.





Joint probability distributions for 15 CAM parameters important to convection, clouds, and radiation. All CAM configurations are in radiative balance and have reduced biases relative to default configuration.

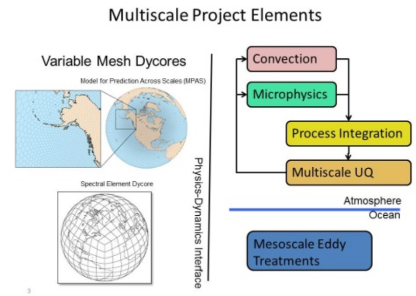


Speeding up the testing process

- Efficient Characterization of Model Sensitivity using ensembles of shorter simulations (PNNL)
- CAPT (NCAR/PCMDI)
- Single column model to anticipate global response, including land biases. (Ben Sanderson)

Efficient Characterization of Model Sensitivity

Hui Wan, Phil Rasch, Kai Zhang, Yun Qian, Huiping Yan, and Chun Zhao (PNNL)



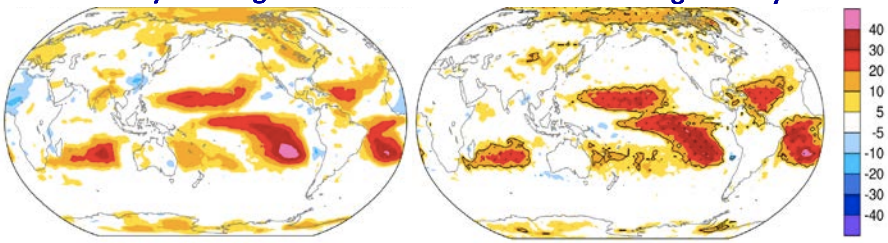
- Multiple simulation years are often required in sensitivity studies to overcome natural variability - inconveniently expensive at high resolutions
- We explored an alternative strategy using ensembles of shorter simulations, exploiting the important role of fast processes in determining model characteristics
- New method can correctly reproduce the main signals of model sensitivities revealed by long-term climate simulations, but at a fraction of total computation time and turnaround time.
- A powerful tool to efficiently use flagship computing facilities (e.g. Titan at Oak Ridge) and to speed up model development

Reference:

Wan et al. (2014), Geosci. Model Dev. Discuss., 7, 2173-2216, doi:10.5194/gmdd-7-2173-2014

Example I: Sensitivity of Total Cloud Cover to Model Time Step

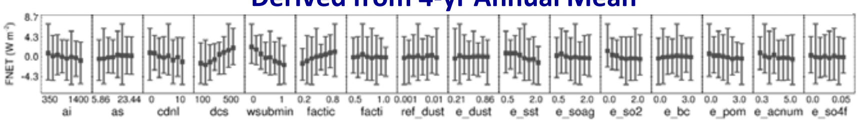
5-yr Average **50-member Average at Day 3**



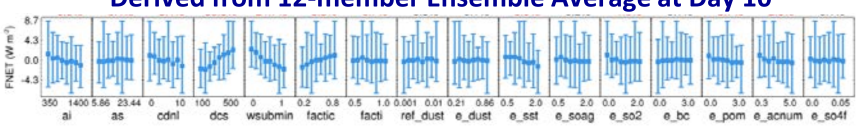
Factor of 15 reduction in CPU time;
Factor of 300 reduction in turnaround time.

Example II: Sensitivity of Global Mean TOA Net Radiation Flux to Cloud and Aerosol Related Model Parameters (UQ)

Derived from 4-yr Annual Mean

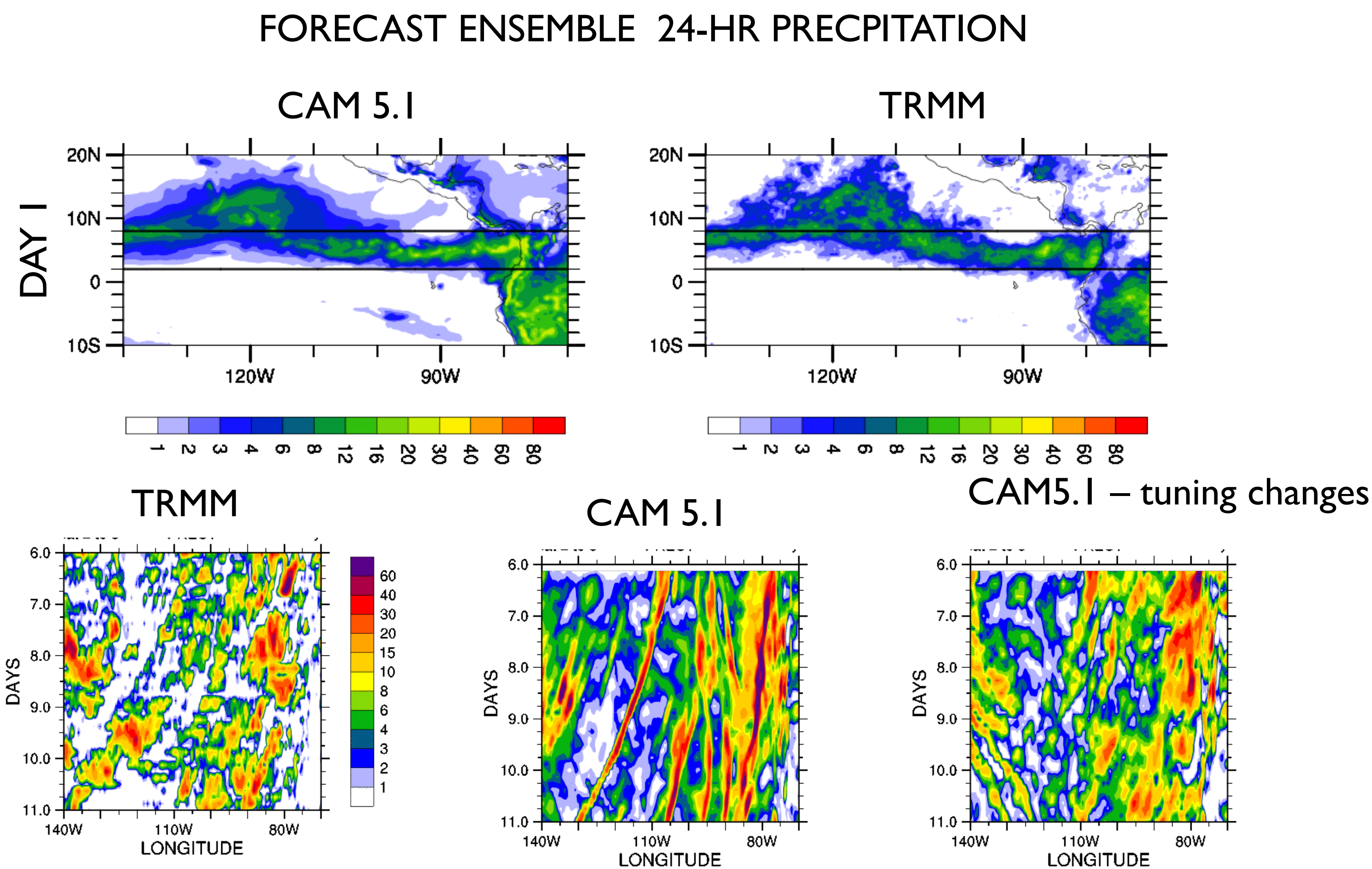


Derived from 12-member Ensemble Average at Day 10



Factor of 15 reduction in CPU time; 12x256 simulations finished in a few hours on Yellowstone at NCAR/CISL.

CAPT hindcasts for tuning



- **CAPT allows to look at the process level (not statistics).**

David L. Williamson (2012) High resolution CAM5 – CAPT hindcasts. CESM workshop, Breckenridge.

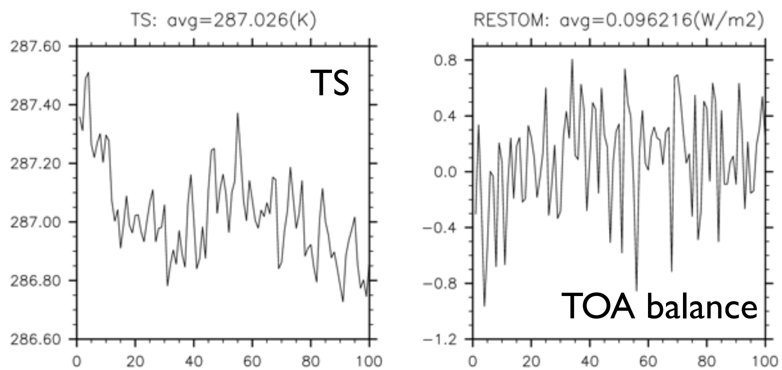
Extra slides

Let's apply the proposed strategy

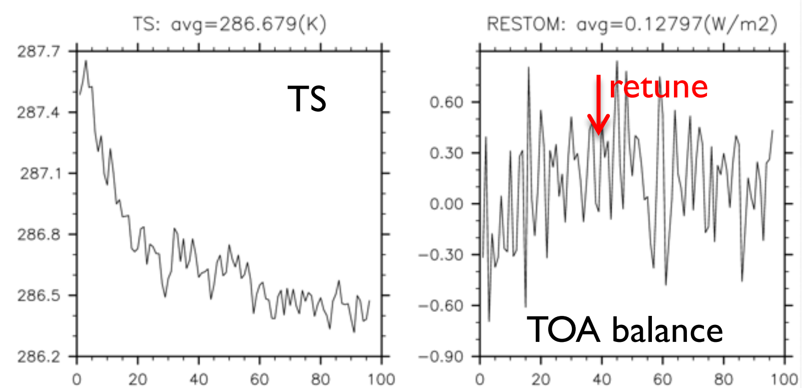
1. Starting from spunup ocean, to obtain tuning parameters
2. Use tuning parameters obtained in (1) and restart the run from Levitus
3. Retune "along the way" if needed to maintain TOA balance ~ 0 W/m2

Restart from Levitus

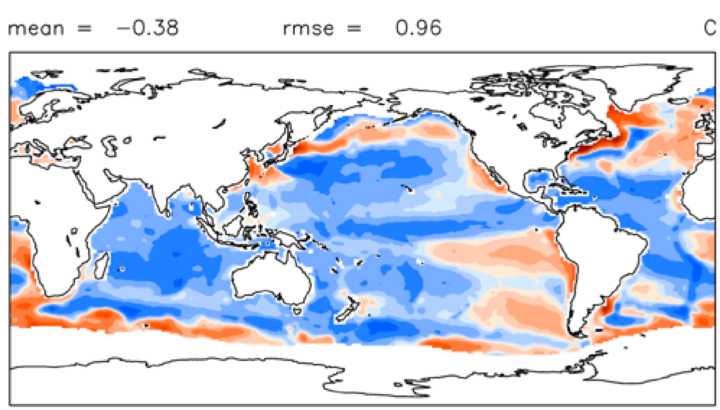
CESM1.1: Finite volume (FV)



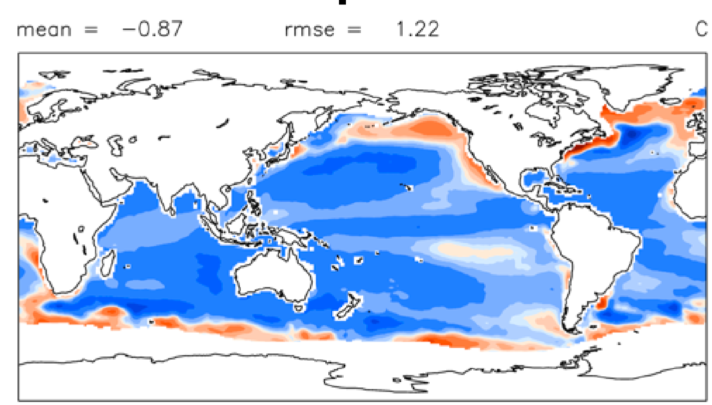
CESM1.2: Spectral element (SE)



SSTs bias in Finite Volume



SSTs bias in Spectral Element



SSTs stabilize but too cold compared to obs

SST: 0.5K colder than FV

Alternative methods are being explored

- **Model Ensemble Control System (MECS)**
  Charles Jackson, University of Texas

- **Efficient Characterization of Model Sensitivity using ensemble of shorter simulations**
  Hui Wan, Phil Rasch et al. (PNNL)

- **CAPT allows to look at the process level (not statistics).**
  Dave Williamson, Jerry Olson et al. (NCAR)
  Steve Klein, Shaocheng Xie et al. (PCMDI)

What is different (Finite Volume⇔Spectral Element) ?

Tuning parameters

	FV	SE
rhminl	0.8925	0.884
rpen	10	5
dust_emis	0.35	0.55

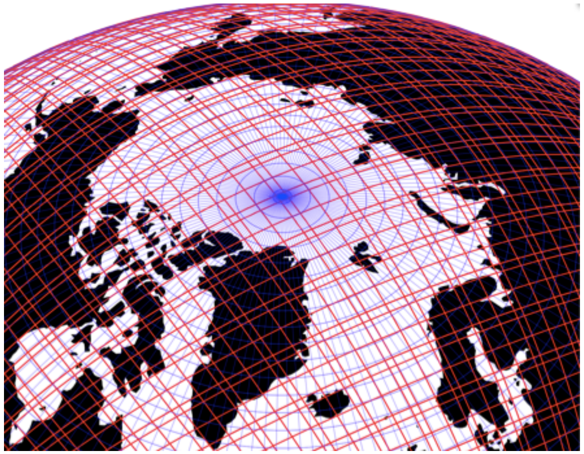
Topography

New software to generate topography (accommodate unstructured grids and enforce more physical consistency)

Climate

SST colder in SE than FV
Atmosphere is drier in SE that FV
Surface stress in Southern Oceans

Grid differences at high latitudes

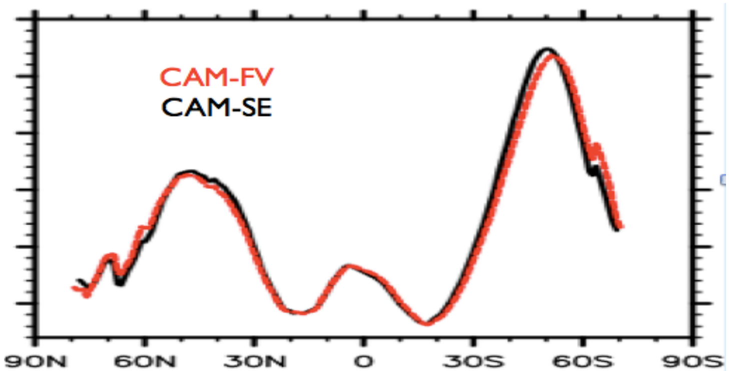


Red: CAM-SE grid
Blue: CAM-FV grid
(at about 2 degree)

Courtesy:
Peter Lauritzen

Remapping differences (ocn ⇔ atm)

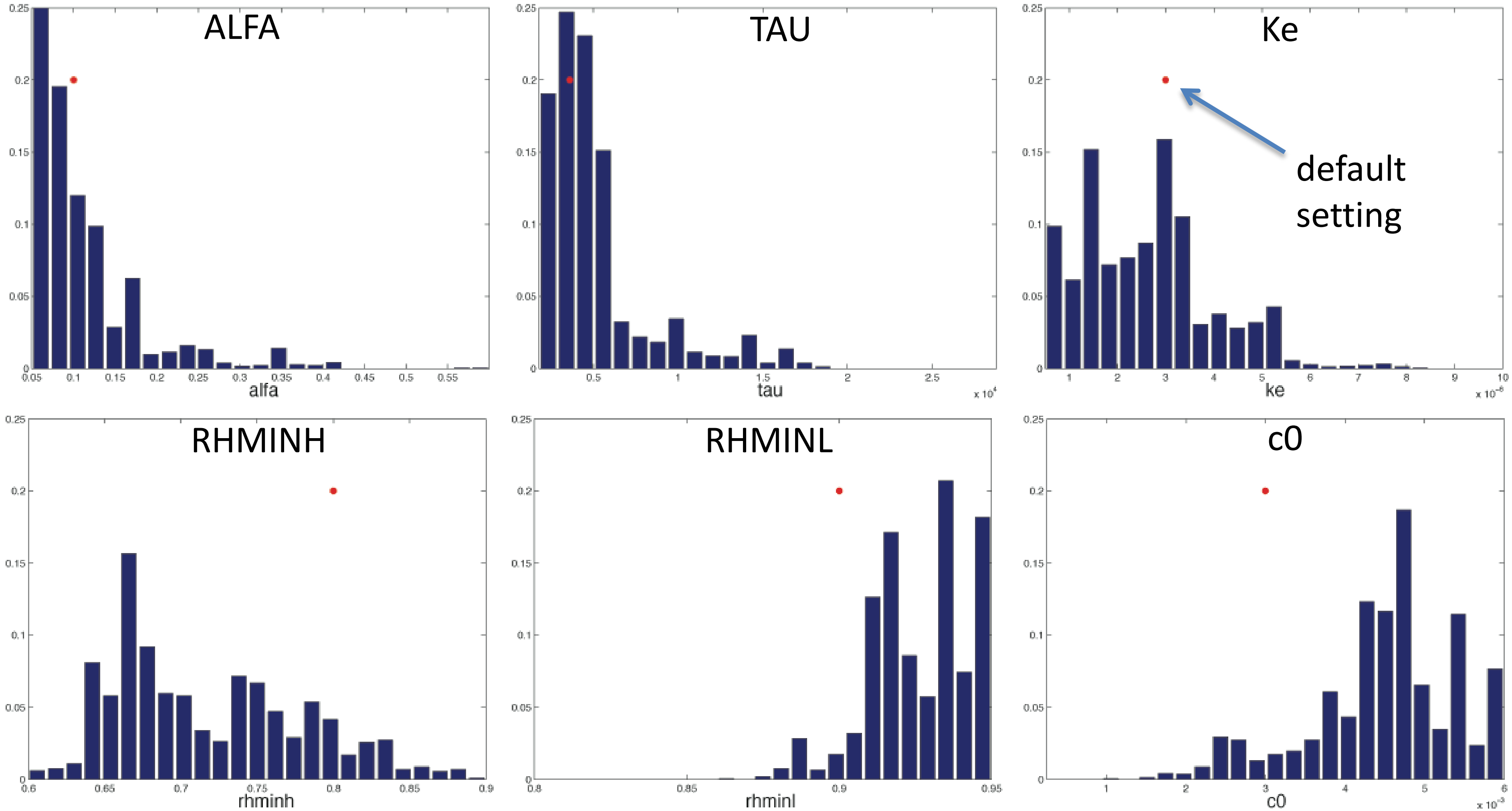
State variables: FV uses "bilinear" and SE "native"

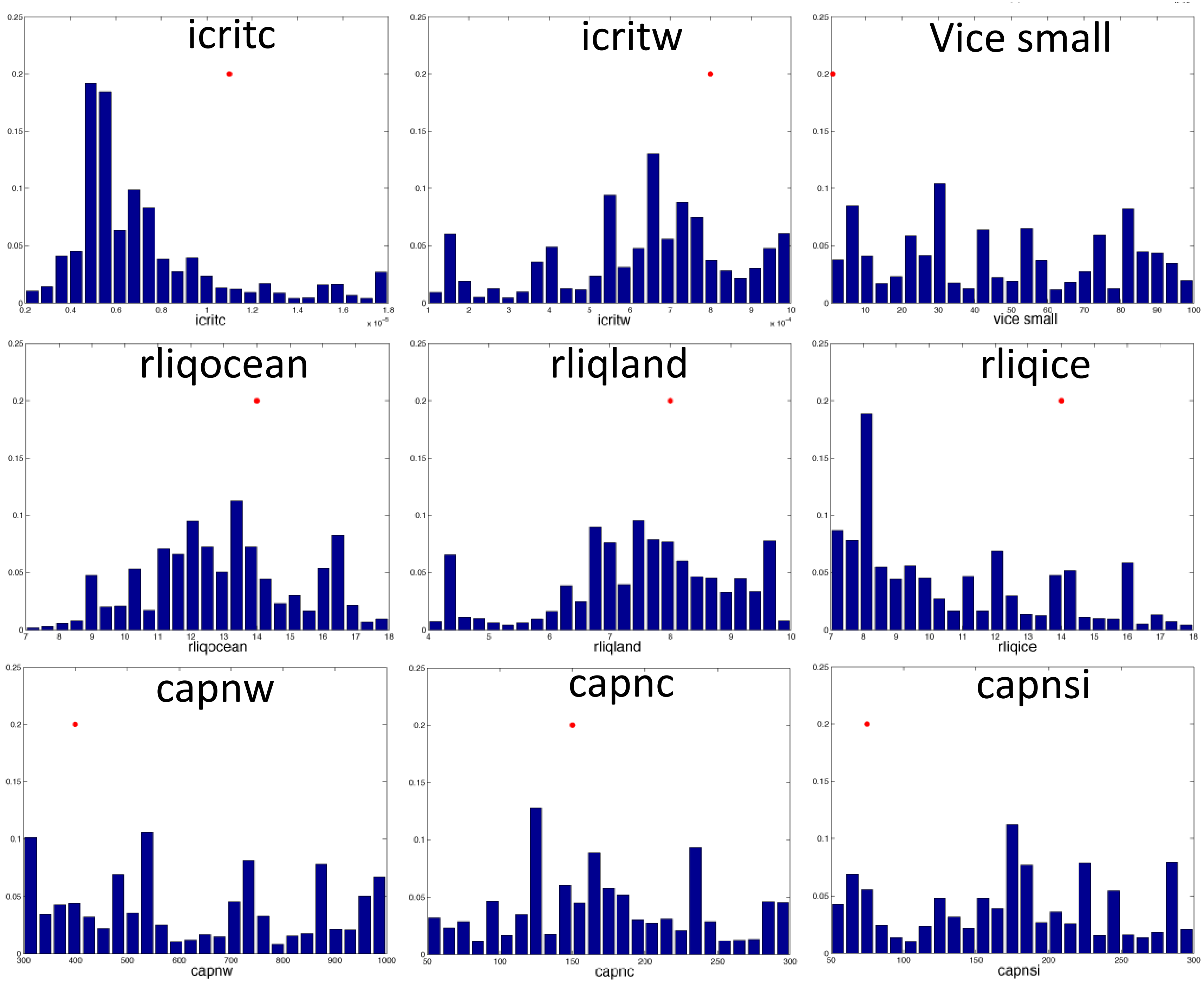


TAUX in CAM-SE:

- Location: maximum moves north
- Amplitude increases

Marginals of a joint probability distribution for 15 cam3 parameters important to convection, clouds, and radiation.




icritc
icritw
Vice small
rliqocean
rliqland
rliqice
capnw
capnc
capnsi
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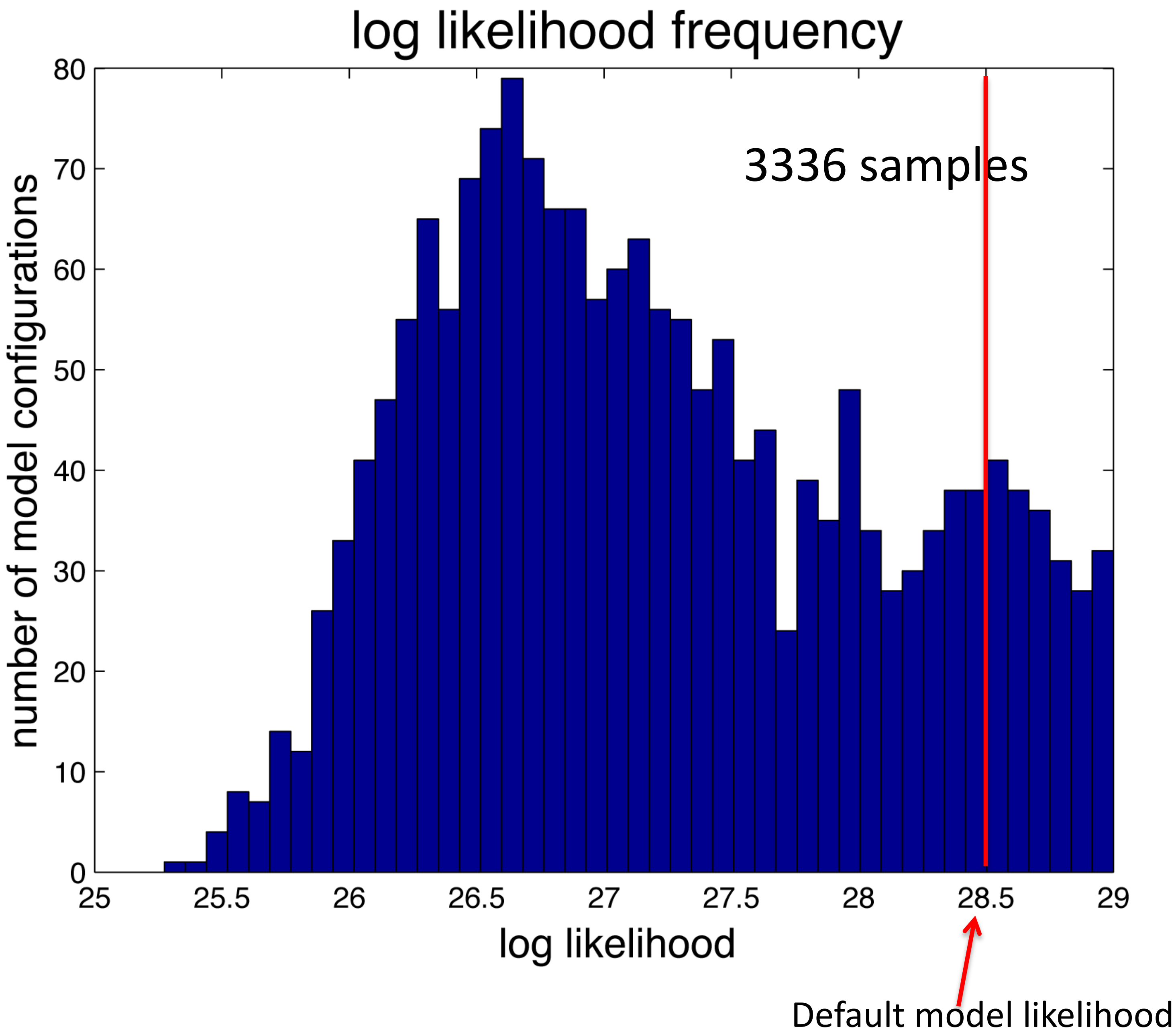
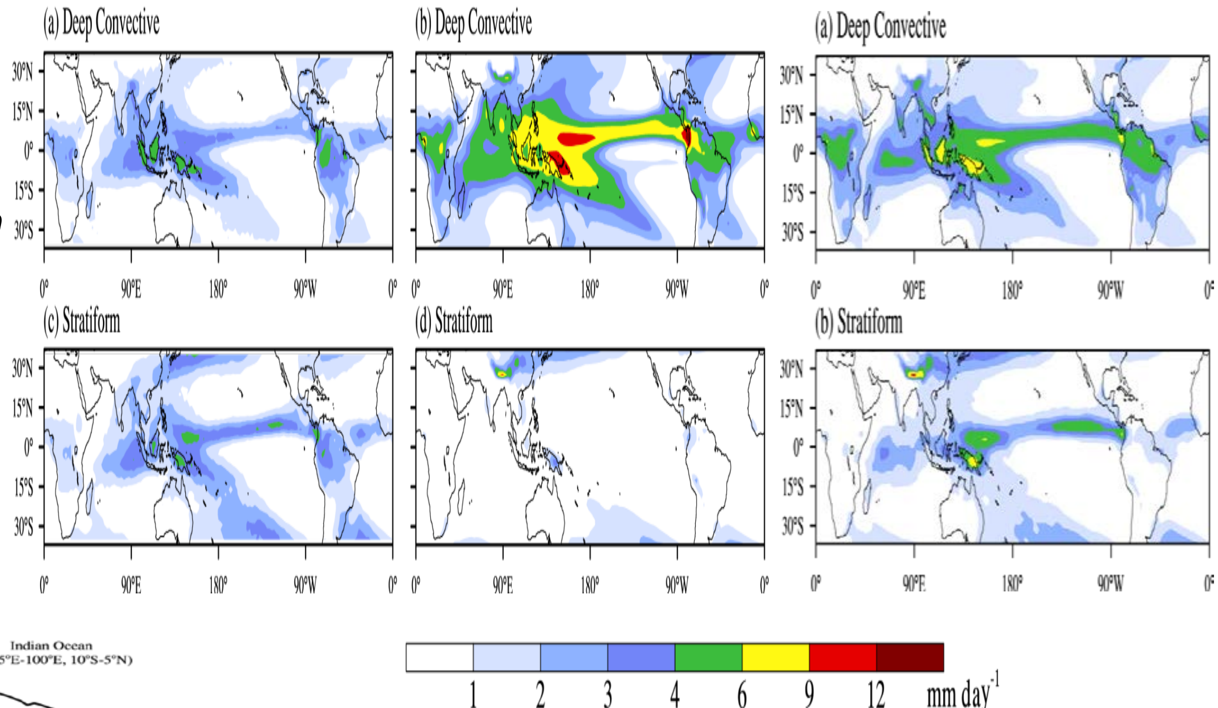

log likelihood frequency
3336 samples
number of model configurations
log likelihood
0
10
20
30
40
50
60
70
80
25
25.5
26
26.5
27
27.5
28
28.5
29
Default model likelihood

Parameterization Sensitivity to “Uncertain Parameters”: UQ on Convection

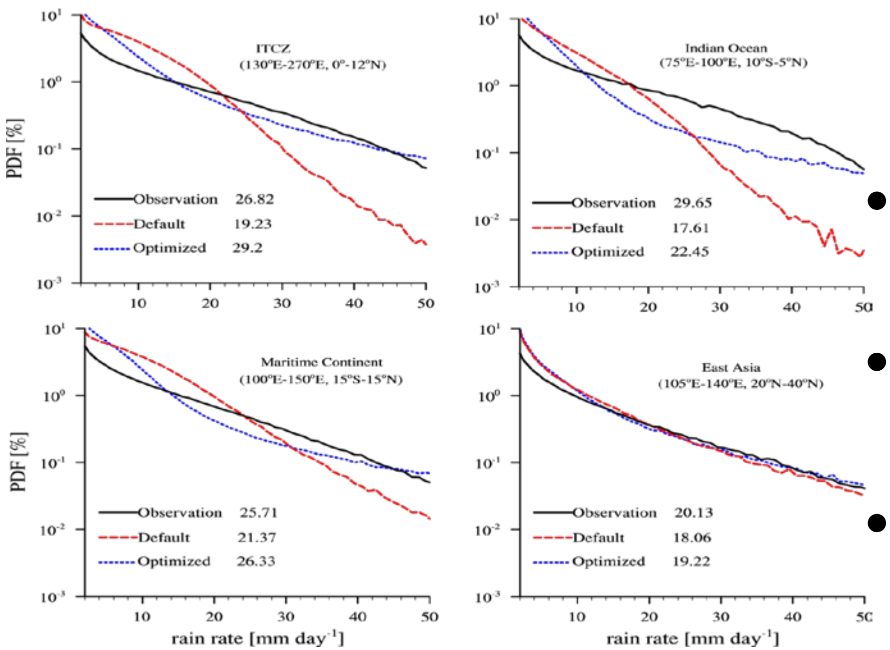
Optimization via a Multiple Very Fast Annealing Algorithm

(Yang et al., 2012b)

Observation | Simulation (default) | Simulation (optimized)



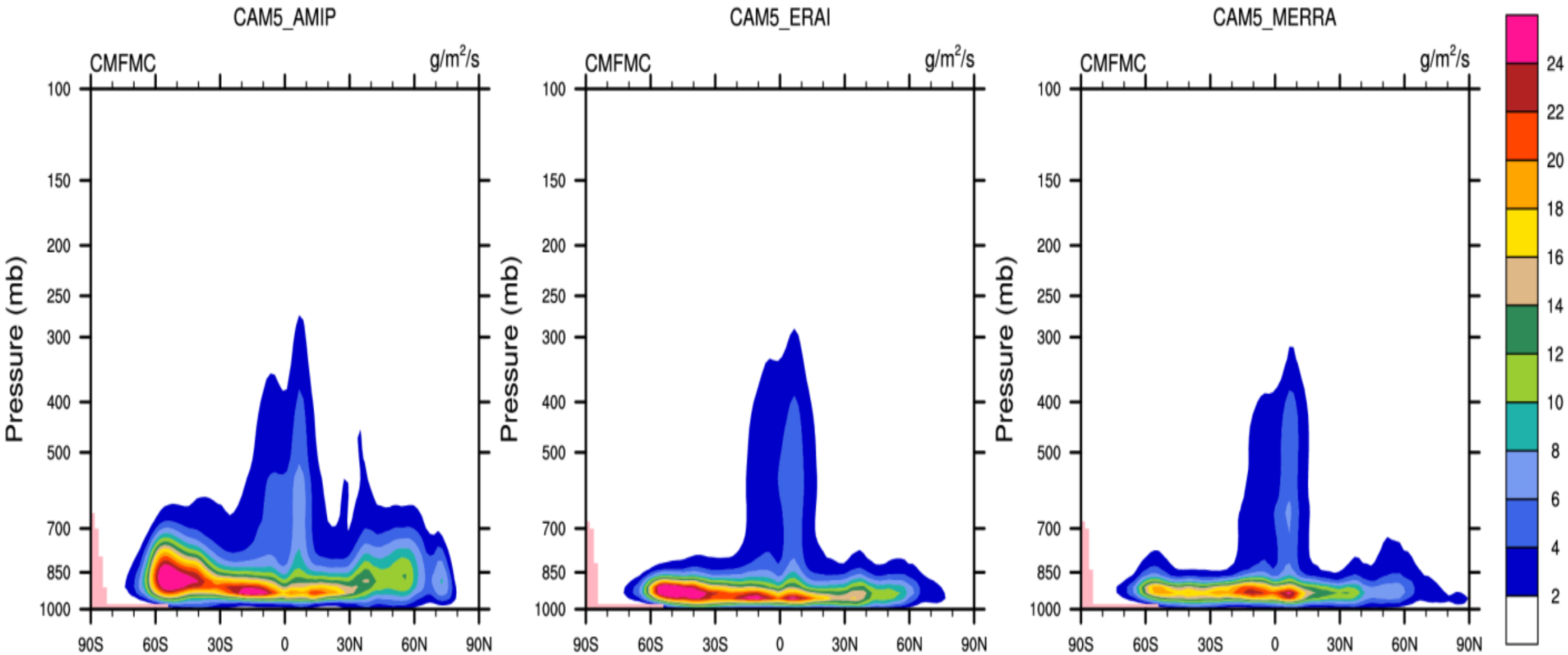
Histogram of precip intensity



- Most sensitive to CAPE consumption timescale, parcel fractional mass entrainment rate, and downdraft mass fraction.
- partial mitigation of double ITCZ, improved East Asian monsoon precipitation, and annual cycles of the cross-equatorial jets.
- Substantial improvement to frequency of occurrence of extremes in precipitation

Balance of Processes are Different with a Free-Running Model

Annual and zonal mean convective mass flux from the shallow convection parameterization from three, 3-year simulations



Free-running CAM5 (AMIP SST)

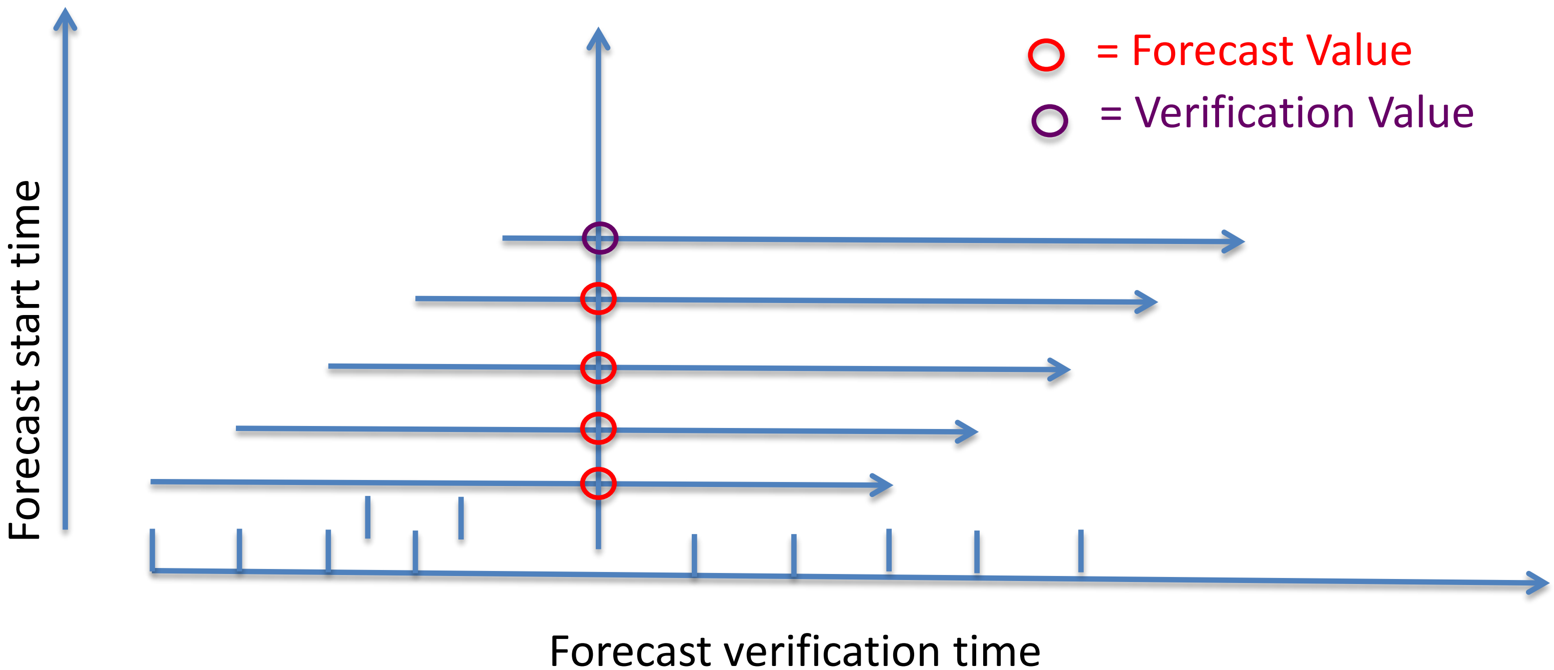
Offline CAM5 driven by ERA-Interim

Offline cam5 driven by MERRA

The balance of processes are distinctly different in free running models, and models with states very very close to observations

Optimizing for "Process" and "State" Agreement through Very Short Forecasts

- Initialize from re-analysis or analysis (as in Transpose AMIP, CAPT)
- Minimize differences in state (e.g. temperature)
  and process properties (e.g. turbulence strength, depth of shallow convection)
  during the first 24 hours!
- Optimize in regions & seasons where we have confidence in analysis
- Computational burden much reduced compared to usual optimization methodologies



Ideas about tuning/initialization

- Each component can learn what they need to get right to yield a successful coupled model state.
- One can either include new metrics to search for models with particular properties (i.e. ones that result in reduced model drift) or test from among the ensemble of tuned models.
- Model testing may benefit from additional interactivity. Perhaps we should be tuning CAM5 coupled to a slab ocean to account for ocean thermal response to changes in CAM5 parameters.

Ideas about tuning/initialization

- This type of problems needs a fresh look with more exploration to systematize and to create a framework for model initialization and tuning
- A lot to lean along the road
- Needs focus effort if it is a high priority
- Incorporated in question about Uncertainty Quantification.

Ideas about tuning/initialization

- Would answer how good a model is.
- Charles Jackson: collaboration with AMWG to find a combination of parameters
- To make computation burden smaller:
  DART
  PNNL
- How to use these tools to come up with a satisfactory design of a coupled state
- Strategy to search out for the best coupled model: needs collaboration between modelers and “experiments designers’.
- Metrics sensitive to processes to make sure we get the right solution for the right reasons (see; CAPT)