Assessing and tuning model parameterizations

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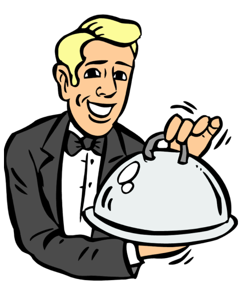
Recipe to include a new parameterization

Developing the parameterization

Assessing the parameterization => Part 1

Tuning the model => Part 2



Bon appétit

Part 1: Assessing the parameterization

The straightforward road

- Climate runs

Alternate ways

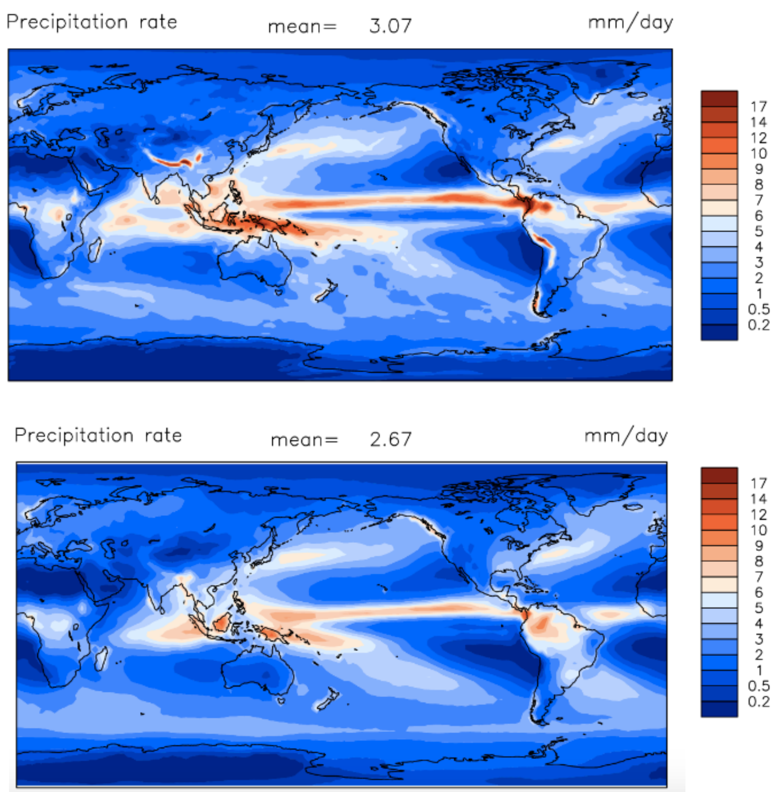
- Forecasts runs
- Single Column Model

Climate runs

Precipitation (ANN, 10-year)

CAM

GPCP



Strategy

- Make multiple-year run
- Compare the climatology with observations
- Probabilistic approach

Advantages

- Tests the parameterization as it is intended to be used

Limitations

- Very expensive
- Results are complicated and depend on all aspects of the model (physics, dynamics, feedback)

How many years do we need ?

- 1-year can be enough to have a quick look at global means
- 5-year is needed to look at the tropics
- 10-year is needed to capture variability in the Arctic

Typical climate runs to assess parameterization

CAM standalone (no active ocean)

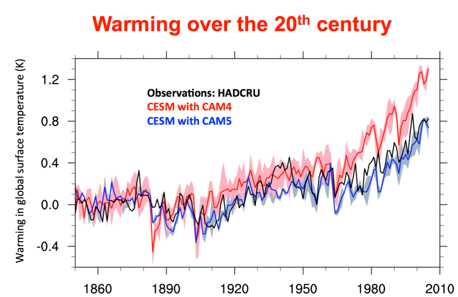
- **AMIP runs**
  Standard protocol for testing GCMs
  GCM is constrained by realistic sea surface temperature and sea ice from 1979-2005

- **Climo SSTs**
  Variant of AMIP
  Use 12-month climatologies for boundary datasets
  Repeat year 2000 to produce present day climate

Fully coupled model (atm+lnd+ocn+ice)

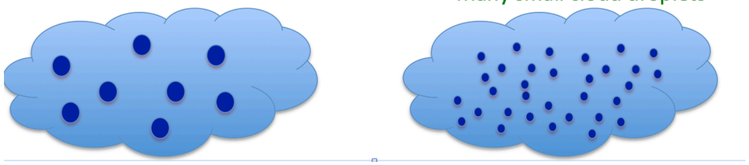
- **1850 control**
  Control simulation for pre-industrial time
  Repeat year 1850 to produce pre-industrial climate

- **20th century**
  Simulation of the 20th century



Typical climate runs to assess parameterization

Aerosol effect



- Amplitude of cooling (direct and indirect effect)

Two climo SSTs runs with every kept the same except aerosols (pre-industrial versus present day)

Climate sensitivity

- Equilibrium change in surface temperature due to a doubling of CO2

Slab Ocean Model runs with $1xCO_2$ and $2xCO_2$

A quick way to look at a climate run
The AMWG diagnostics package

AMWG diags tool

Compute climos

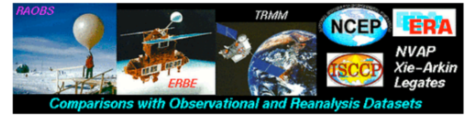
Create a webpage with 100s of tables and plots
- global means
- zonal means
- lat/lon plots
- annual cycle
- cloud simulator
- Taylor diagrams
- and many more…

Comparison
Model to observations
Model to model

Coming soon

Write and submit the paper

AMWG Diagnostics Package
gpci_cam5.1_cosp_1d_001

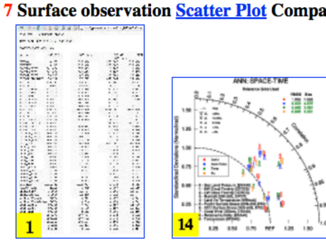


Plots Created
Tue Aug 5 12:01:48 MDT 2014

Set Description
1 Tables of ANN, DJF, JJA, global and regional means and RMSE.
2 Line plots of annual implied northward transports.
3 Line plots of DJF, JJA and ANN zonal means
4 Vertical contour plots of DJF, JJA and ANN zonal means
4a Vertical (XZ) contour plots of DJF, JJA and ANN meridional means
5 Horizontal contour plots of DJF, JJA and ANN means
6 Horizontal vector plots of DJF, JJA and ANN means
7 Polar contour and vector plots of DJF, JJA and ANN means
8 Annual cycle contour plots of zonal means
9 Horizontal contour plots of DJF-JJA differences
10 Annual cycle line plots of global means
11 Pacific annual cycle, Scatter plot plots
12 Vertical profile plots from 17 selected stations
13 Cloud simulators plots
14 Taylor Diagram plots
15 Annual Cycle at Select Stations plots
16 Budget Terms at Select Stations plots

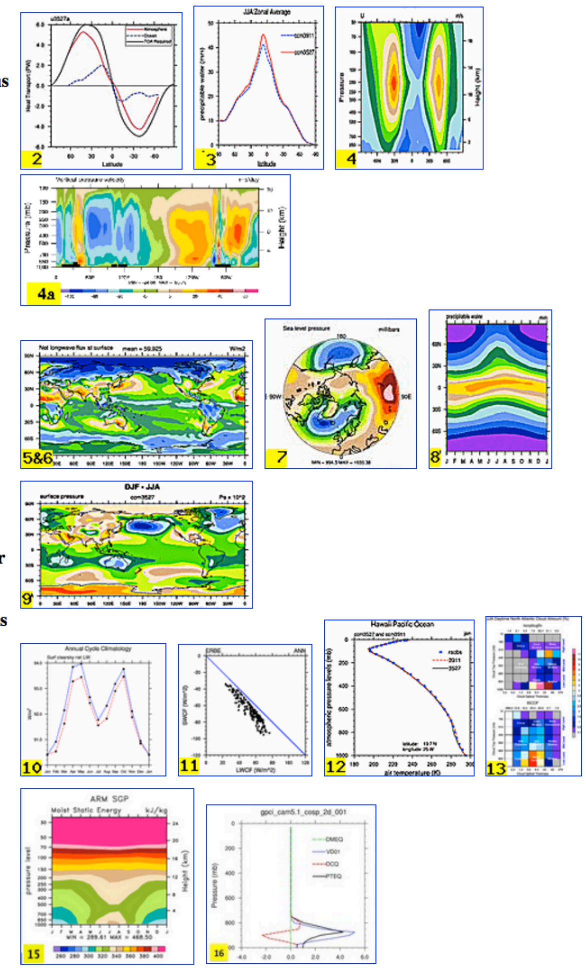
WACCM Set Description
1 Vertical contour plots of DJF, MAM, JJA, SON and ANN zonal means (vertical log scale)

Chemistry Set Description
1 Tables / Chemistry of ANN global budgets
2 Vertical Contour Plots contour plots of DJF, MAM, JJA, SON and ANN zonal means
3 Ozone Climatology Comparisons Profiles, Seasonal Cycle and Taylor Diagram
4 Column O3 and CO lon/lat Comparisons to satellite data
5 Vertical Profile Profiles Comparisons to NOAA Aircraft observations
6 Vertical Profile Profiles Comparisons to Emmons Aircraft climatology
7 Surface observation Scatter Plot Comparisons to IMROVE



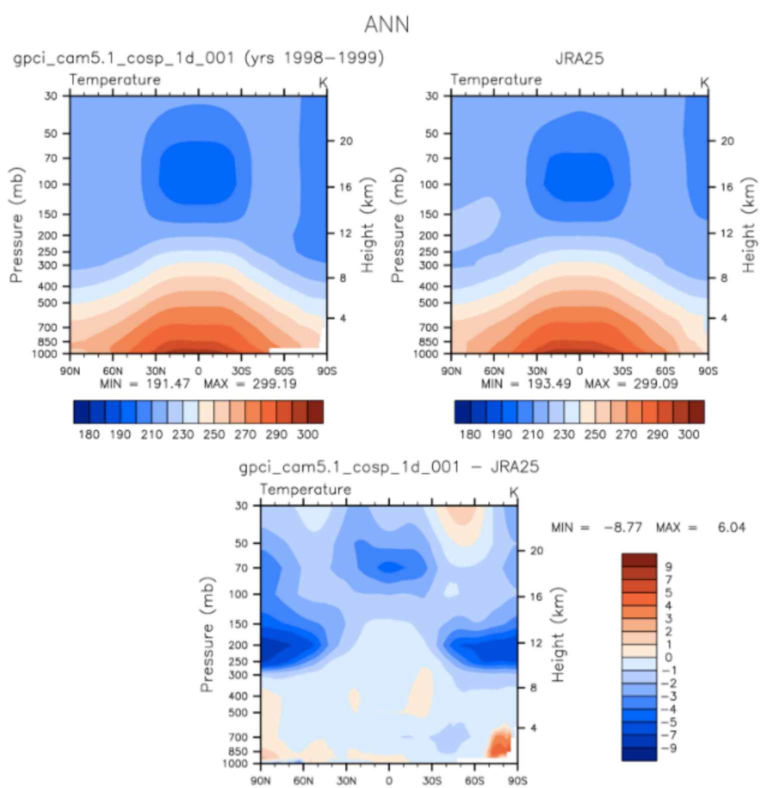
TABLES METRICS

Click on Plot Type

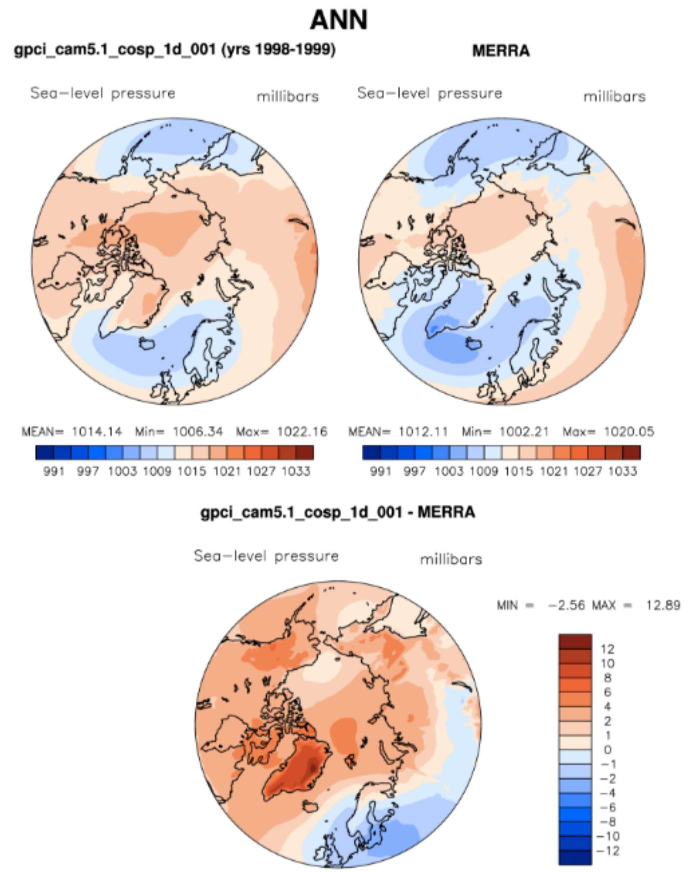


The AMWG diagnostics package: Examples

Zonal mean: Temperature



Polar plots: Sea level pressure

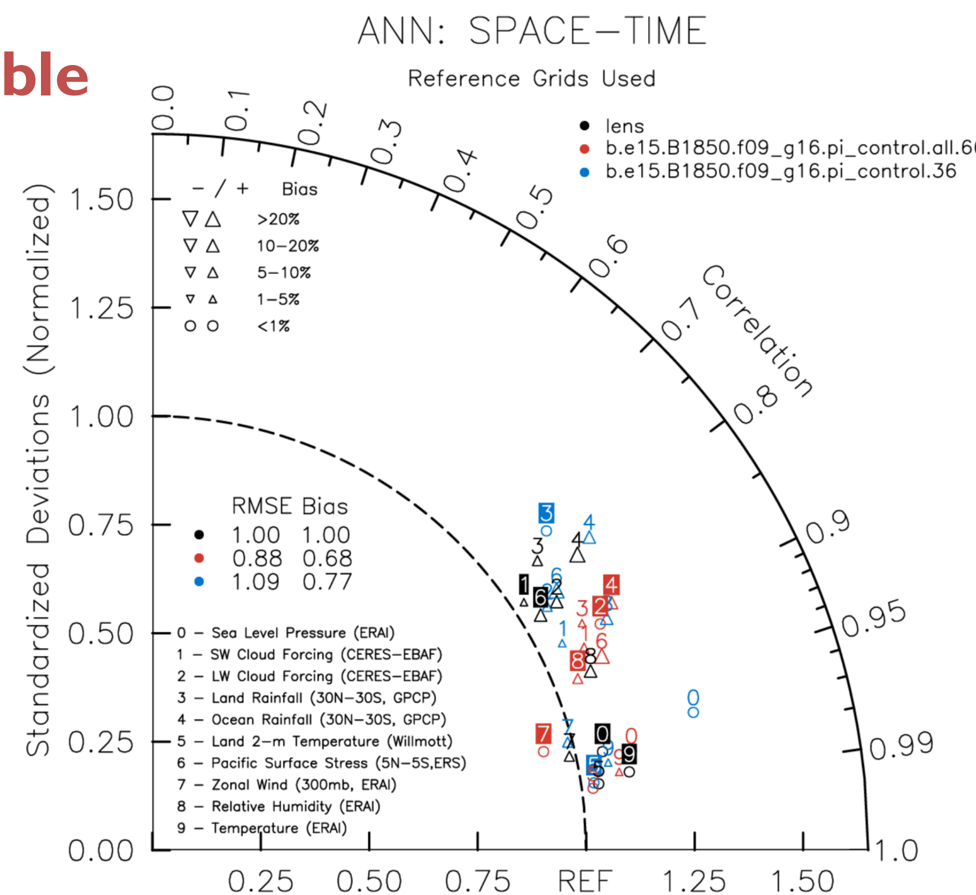


Taylor diagrams

Metrics: condense information about variance and RMSE of 10 variables we consider important, when compared with observations

Reference = Large-ensemble (LENS)

	RMSE	Bias
LENS	**1.00**	**1.00**
CESM2	**0.88**	**0.68**
CESM1.5	**1.09**	**0.77**



Everything you need to know about the AMWG diags

https://www2.cesm.ucar.edu/working-groups/amwg/amwg-diagnostics-package

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AMWG DIAGNOSTICS PACKAGE

ABOUT THE AMWG DIAGNOSTICS PACKAGE

The AMWG diagnostics package produces over 600 plots and tables from CCSM (CAM) monthly netcdf files.

The diagnostics package computes climatological means of the simulations and produced plots and tables of the mean climate in a variety of formats. The diagnostics package can be used to compare two CCSM (CAM) model simulations or for comparing a model simulation to the observational and reanalysis data. (Information about the AMWG datasets can be found in the Climate Data Guide.)

EXAMPLES OF THE WEBPAGES CREATED BY THE DIAGNOSTICS PACKAGE

Included in the package are HTML files which provide the infrastructure for a basic website for the display of all your plots and tables. The c-shell script has a switch for creating webpages automatically. When this is used the end result of running the script is a tar file of all the plots in gif, jpg or png format and the needed html files organized in the proper subdirectories. The user can then untar this file in a directory of their choosing and create a link to it.

- Model fields compared with observational data plots
- Comparison of two different models plots
- CAM-chem diagnostics plots

AMWG DIAGNOSTICS PACKAGE

- Package Overview
- What's new?
- Where to find the code?
- AMWG Dataset Information
- Documentation
- Support?
- Mailing List
- Known Bugs/Problems
- Copyright & Terms of Use

Example of using climate runs to assess parameterization: CAM5.5 assessment process

Candidate parameterizations for CAM5.5
- **Unified Convection scheme (UNICON)**
- **Cloud-Layers Unified By Binormals (CLUBB)**

Developers produced full suite of climate simulations (AMIP and 1850 control, indirect effect)

Simulations reviewed by panel of experts

Panel gave a recommendation about CAM5.5

To know more, visit:
http://www.cesm.ucar.edu/working_groups/Atmosphere/development/cam5.5-process/

See also Rich's talk

Part 1: Assessing the parameterization

The straightforward road

- **Climate runs**

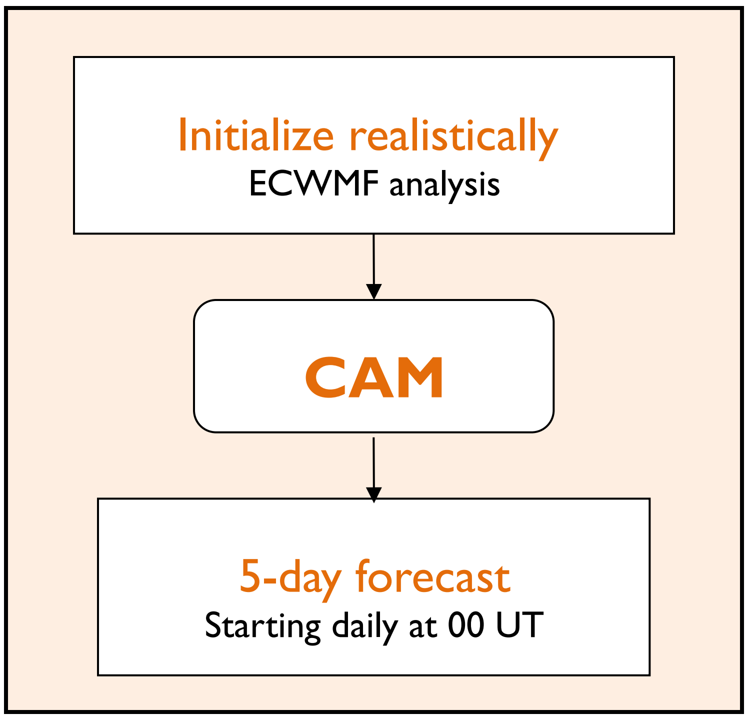
Alternate ways

- **Forecasts runs**

- **Single Column Model**

Methodology for the forecasts

Forecast



Evaluation

AIRS, ISCCP, TRMM, GPCP, SSMI, CloudSat, Flash-Flux, ECWMF analyzes

Strategy

If the atmosphere is initialized realistically, the error comes from the parameterizations deficiencies.

Advantages

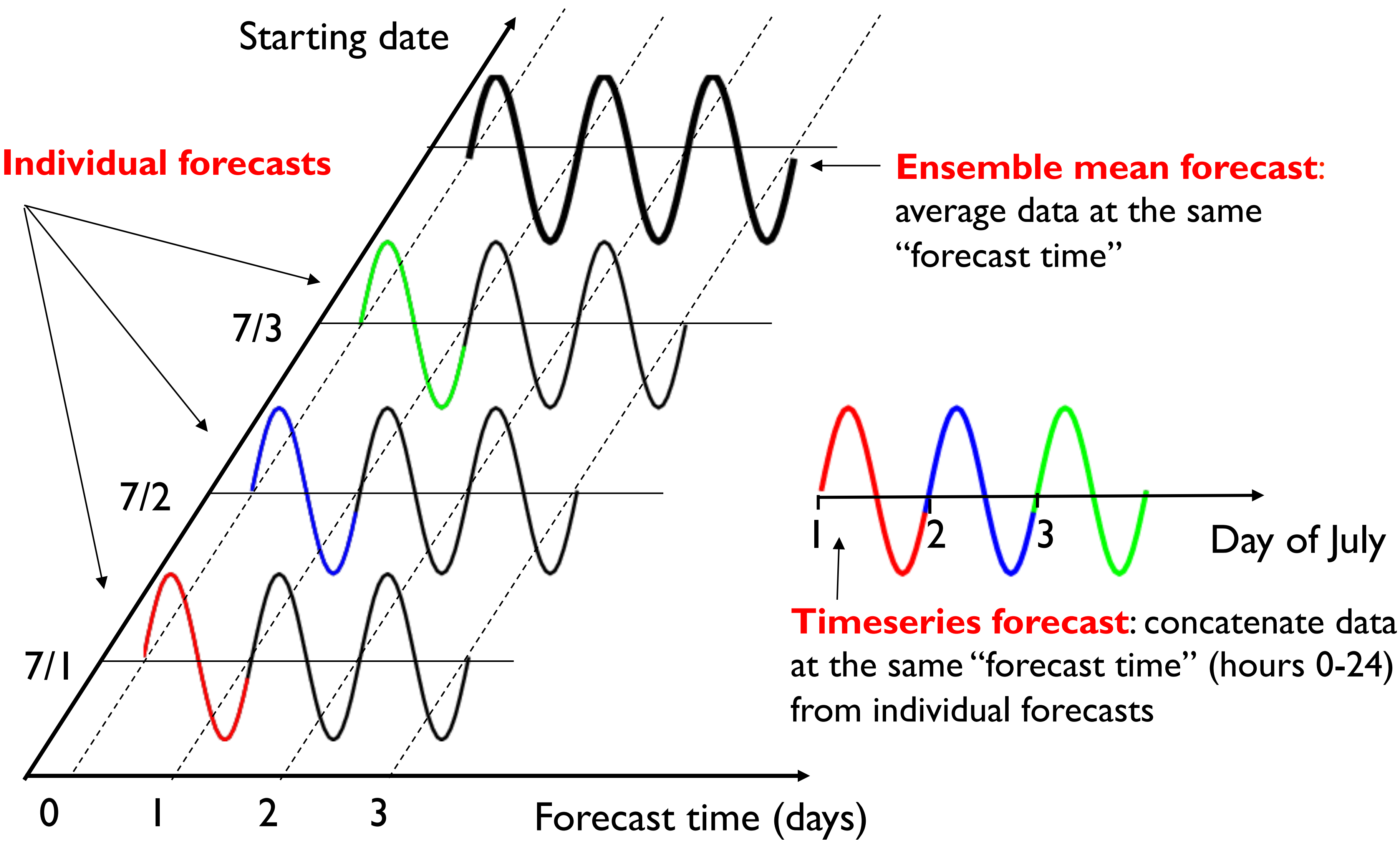
- Evaluate the forecast against observations on a particular day and location

- Evaluate the nature of moist processes parameterization errors before longer-time scale feedbacks develop.

Limitations

Accuracy of the atmospheric state ?

Ensemble mean forecast and timeseries forecast



Clouds: Multiple Categories

Stratiform (large-scale) clouds

• Responds to large-scale relative humidity

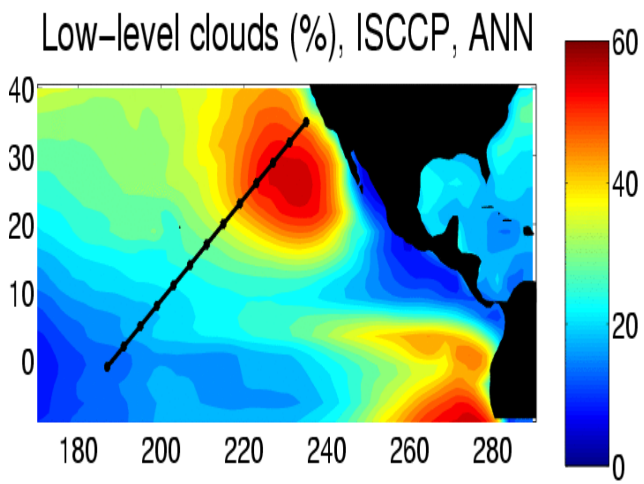
Shallow convection clouds

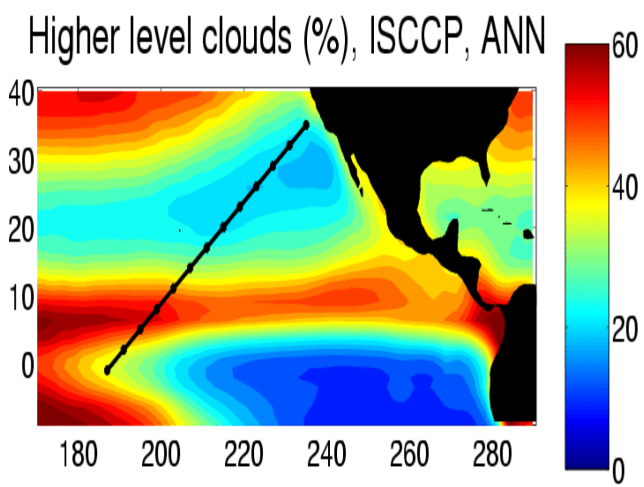
• 10 - 100 meters
• Non precipitating (mostly)
• Responds to surface forcing

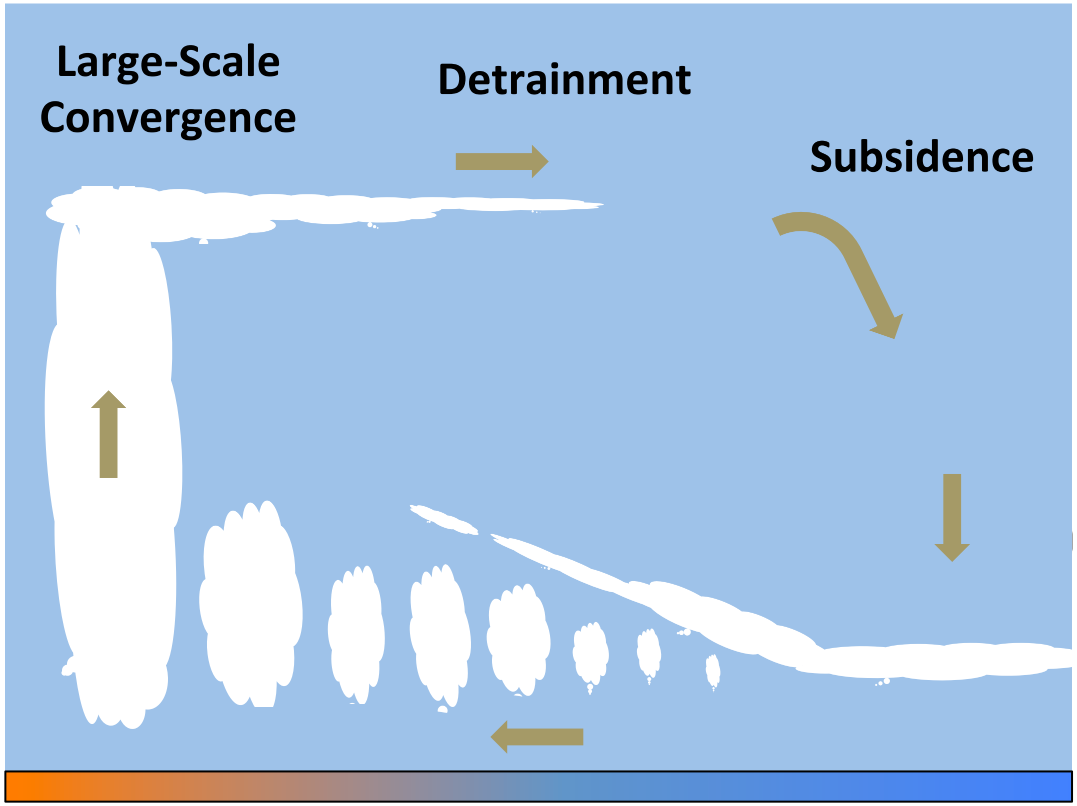
Deep convection clouds

• 100m – 10km
• Penetrating convection (surface -> tropopause)
• Precipitating
• Responds to surface forcing and conditional instability

Cloud regimes along Pacific Cross-section





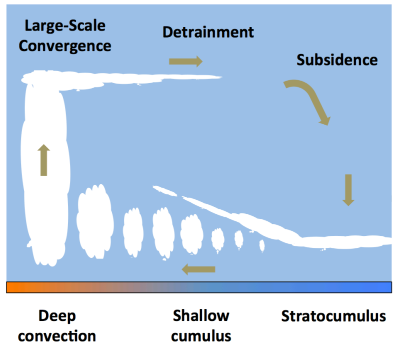


Deep convection

Shallow cumulus

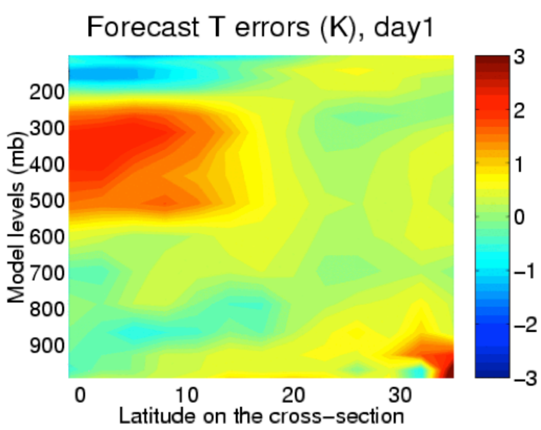
Stratocumulus

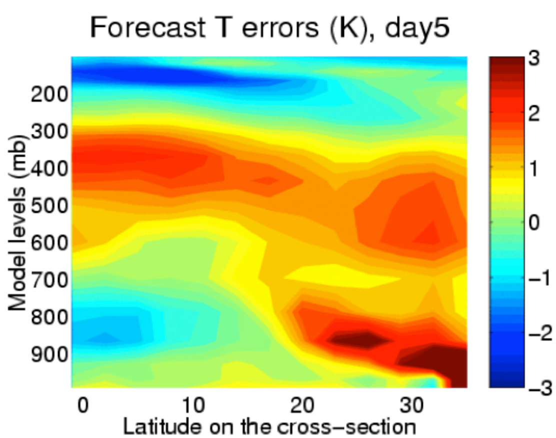
Forecast and climate errors (JJA 1998)

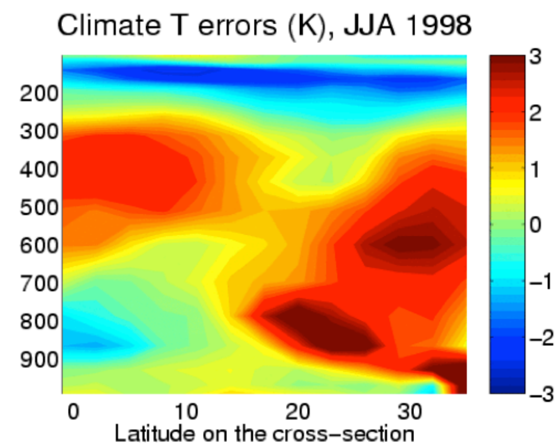


Climate bias appears very quickly

- **where deep convection is active, error is set within 1 day**
- **5-day errors are comparable to the mean climate errors**







Let's compare forecasts from 3 model versions

CAM3	**Release 2004**
CAM4	**Release April 2010** **New physics:** **- Deep convection (Neale and Richter, 2008)**
CAM5	**Release June 2010** **New Physics:** **- Cloud microphysics (Morrison, Gettelman)** **- Radiative Transfer (Iacono, Collins, Conley)** **- PBL and Shallow convection (Bretherton and Park)** **- Macrophysics (Park, Bretherton, Rasch)** **- Aerosol formulation (Ghan, Liu, Easter)** **- Ice clouds (Gettelman, Liu, Park, Mitchell)**

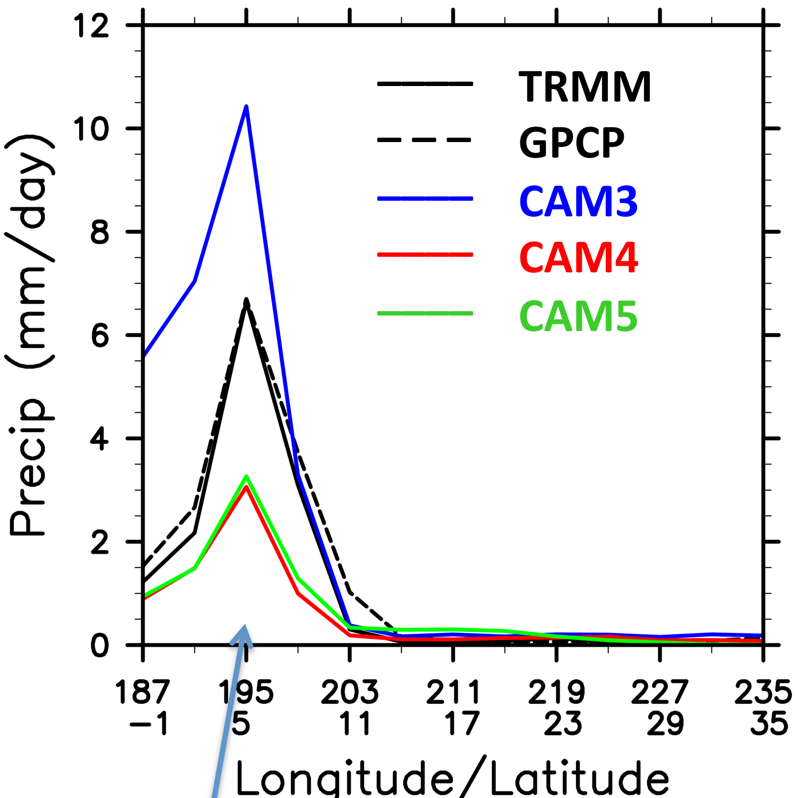
Known issues in CAM3

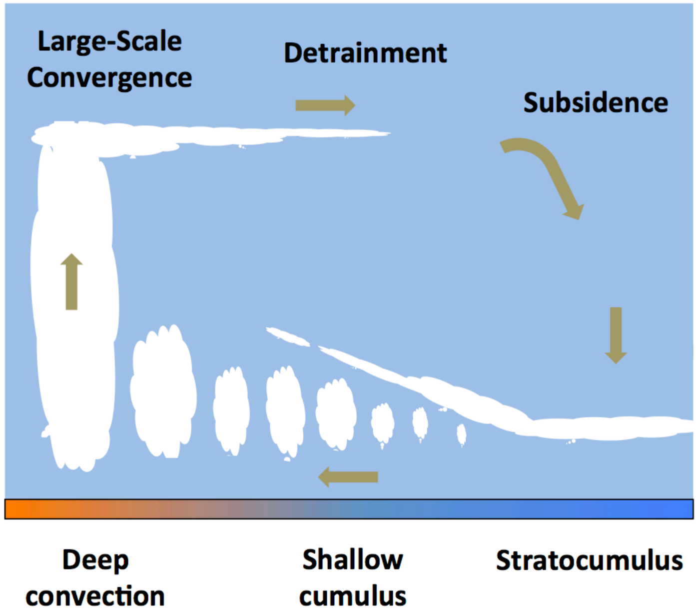
- **Deep convection: Too much precipitation**
- **Stratocumulus: PBL too shallow**

What can we learn from forecasts along cross-section ?

Precipitation: Monthly means, June 2008

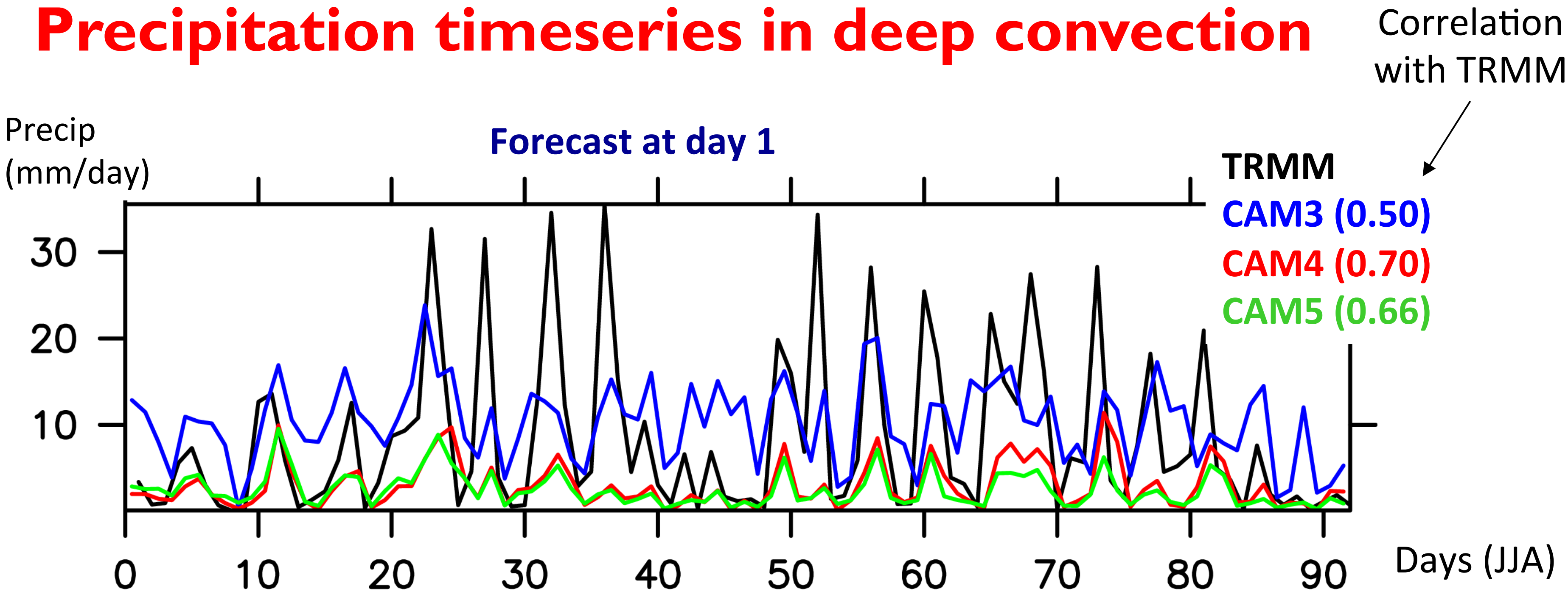
Forecast at day 1





- **CAM3:** overestimates **the precipitation in the deep convection**
- **CAM4/5:** reduction **in the ITCZ precipitation**

Precipitation timeseries in deep convection



In the deep convection zone:

Mixing parcel⇔ env

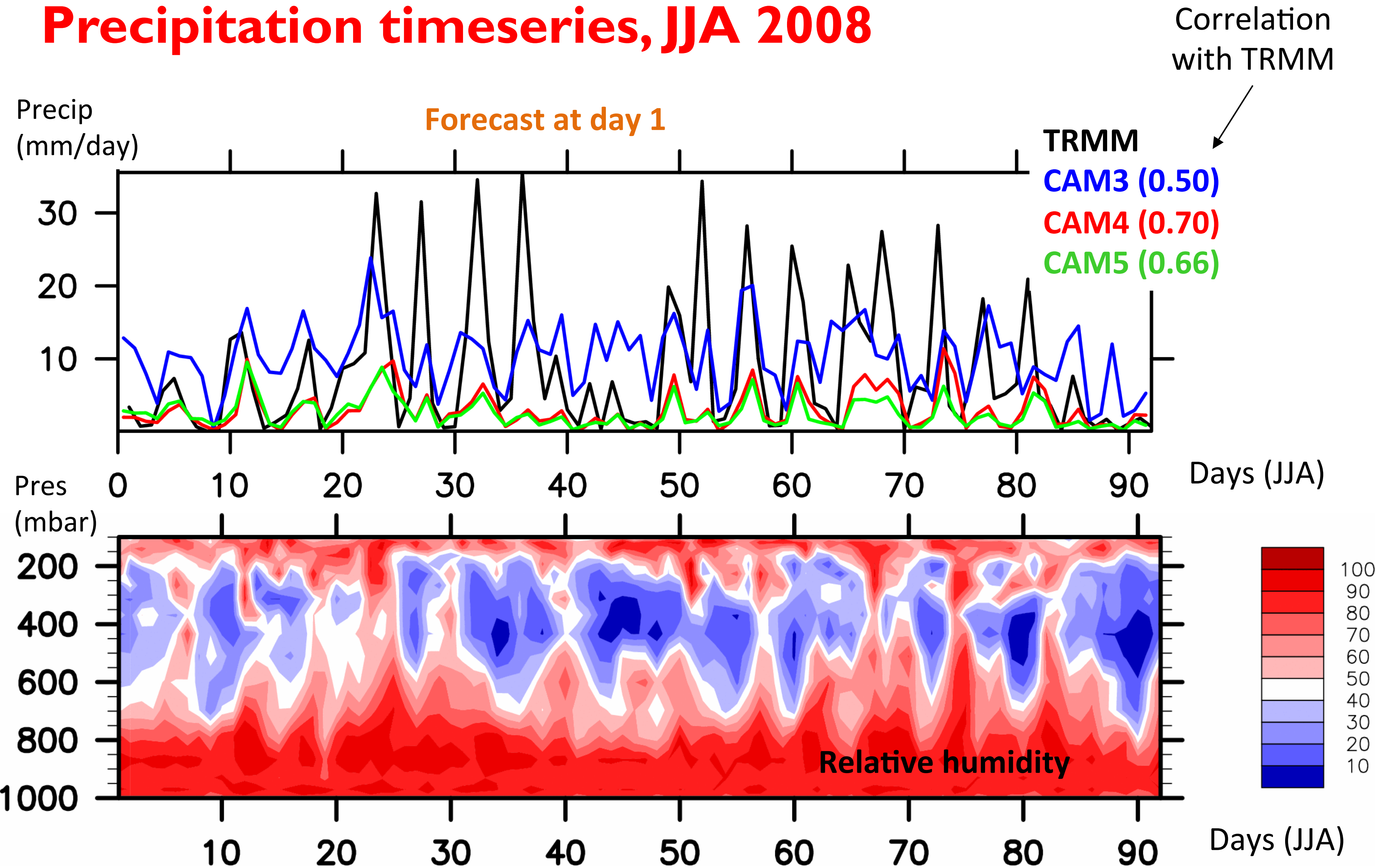
- **CAM3:** **overestimates the precipitation**
  rains all the time

No mixing

- **CAM4/5:** **reduction in the precipitation**
  better correlation with observed precipitation
  underestimates strong events

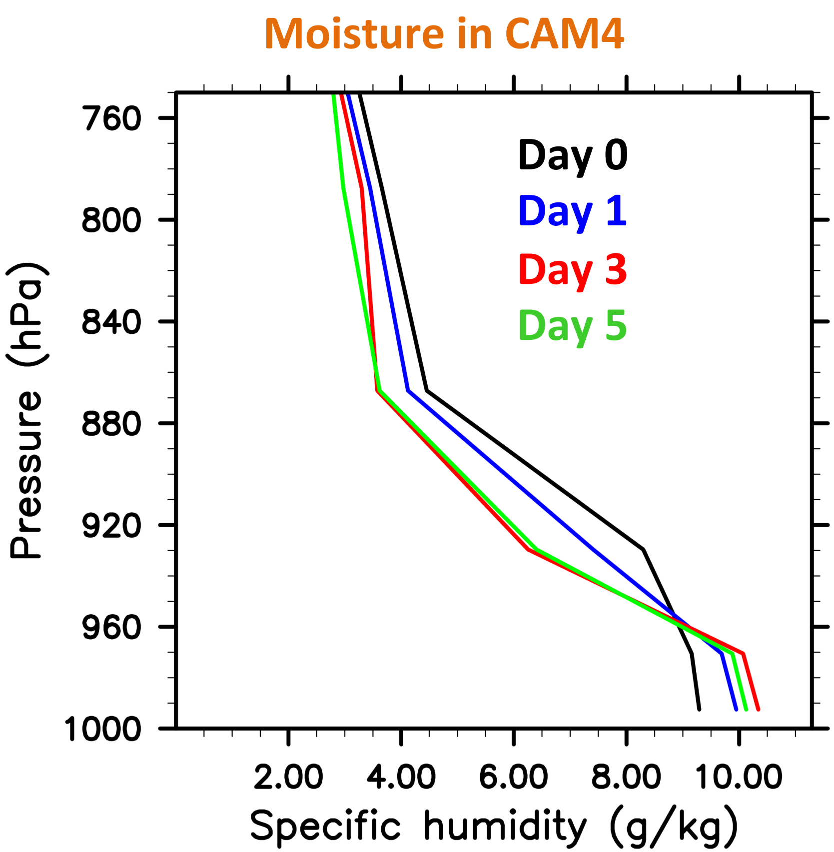
Allows mixing

Precipitation timeseries, JJA 2008



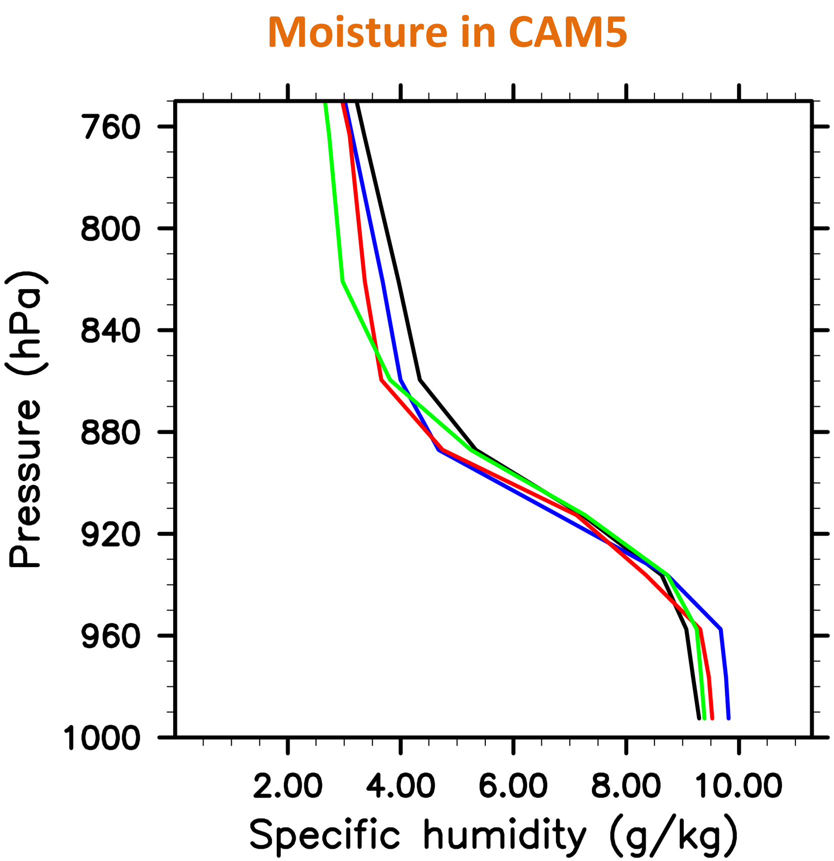
CAM4/5: precipitation better connected to mid-troposphere

Moisture profile in the stratocumulus regime



CAM4: PBL collapses

Dry and surface-driven
PBL scheme



CAM5: PBL height is maintained

scheme based on prognostic TKE
with explicit entrainment at top of PBL

What did we learn from forecasts along cross-section ?

CAM forecasts allows for diagnosing parameterization errors in different cloud regimes

CAM3

- too much precipitation in deep convection (deep convection scheme: no mixing between the parcel and its environment)
- PBL too shallow in stratocumulus (dry and surface-driven PBL scheme)

CAM4

- dramatic improvement of precipitation in the early forecast with the new convection scheme (entrainment of environment)

CAM5

- new PBL scheme produces deeper and better mixed PBLs (PBL scheme: prognostic TKE with explicit entrainment at top of PBL)

Part 1: Assessing the parameterization

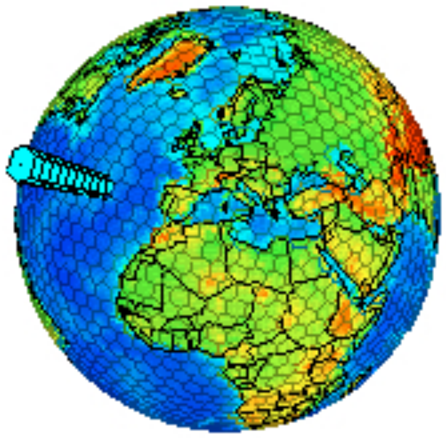
The straightforward road

- Climate runs

Alternate ways

- Forecasts
- Single Column Model

Single Column Modeling (SCM)



$$\frac{\partial\theta}{\partial t} = \left(\frac{\partial\theta}{\partial t}\right)_{phys} - \left(\vec{V}.\nabla\theta\right)_{obs} - \left(\omega_{obs}\frac{\partial\theta}{\partial p}\right)$$

$$\frac{\partial q}{\partial t} = \left(\frac{\partial q}{\partial t}\right)_{phys} - \left(\vec{V}.\nabla q\right)_{obs} - \left(\omega_{obs}\frac{\partial q}{\partial p}\right)$$

Observations for:

- **horizontal advective tendencies**
- **vertical velocity**
- **surface boundary conditions)**

Strategy

- **Take a column in insolation from the rest of the model**
- **Use observations to define what is happening in neighboring columns**

Advantages

- **Inexpensive (1 column instead of 1000s)**
- **Remove complications from feedback between physics and dynamics**

Limitations

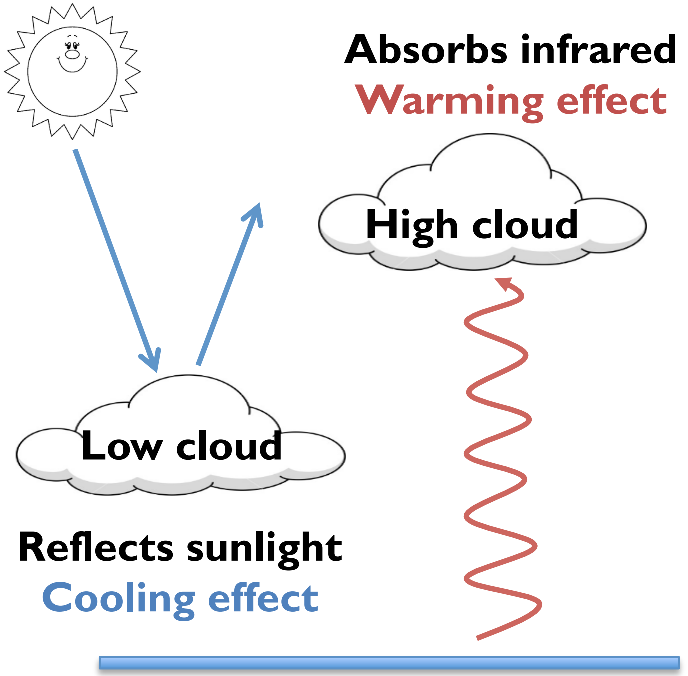
- **Data requirements (tendencies needs to be accurate to avoid growing error)**
- **Cannot detect problem in feedback**

Example: CGILS study

Goal: Understanding mechanisms of low cloud feedback in SCM

What is low cloud feedback ?

Cloud effect on climate



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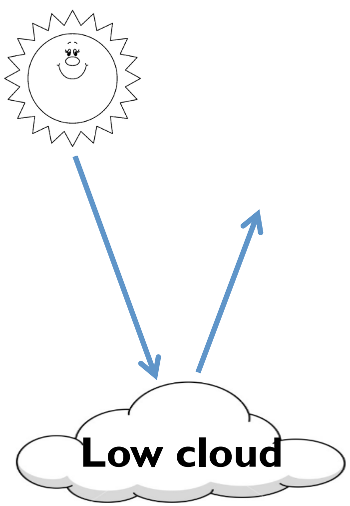
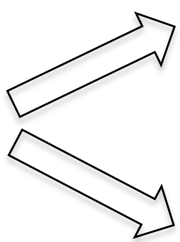
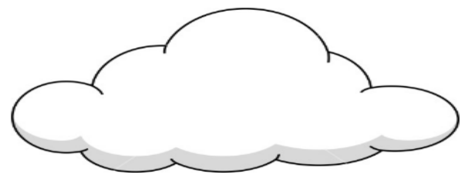


Reflects sunlight
Cooling effect

In a warmer climate

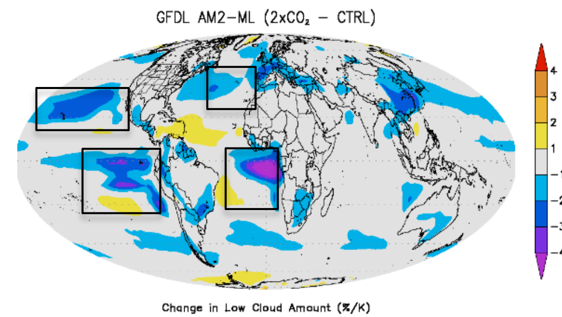




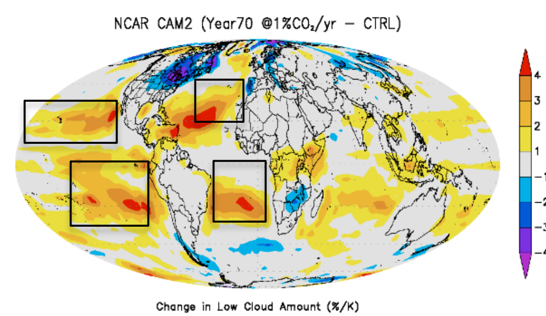
More low cloud
Cooling effect
Negative feedback

Less low cloud
Warming effect
Positive feedback

Low cloud feedback in 2 US models



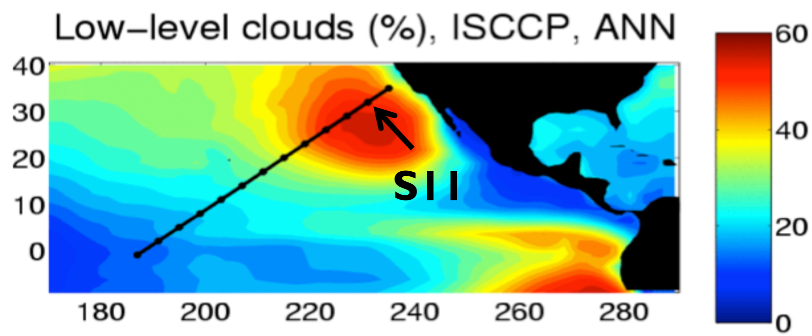
GDFL: Negative feedback



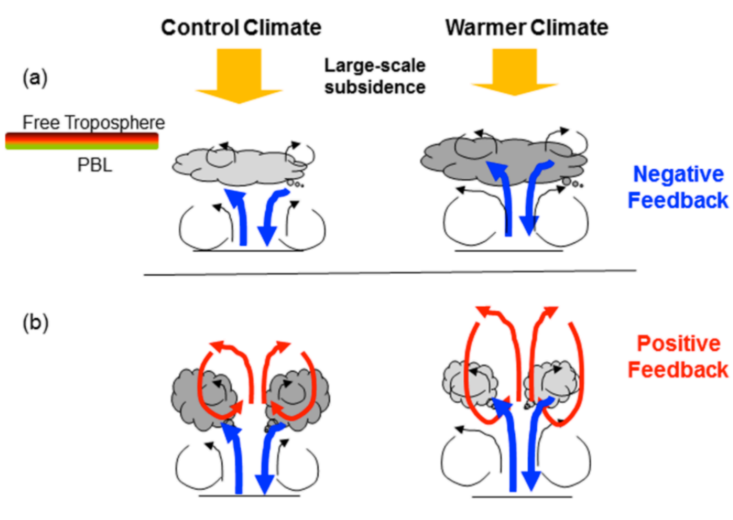
NCAR: Positive feedback

Example: CGILS study

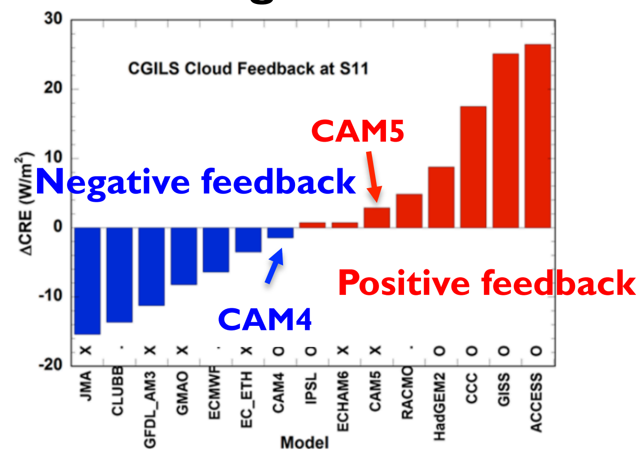
Goal: Understanding mechanisms of low cloud feedback in SCM



Proposed mechanism



SCM experiments to determine low cloud feedback sign at S11 in 15 models



Models with no active shallow convection

Models with active shallow convection

In warmer climate

- **Enhanced moistening of PBL (blue arrow)**
- **If no active shallow convection => more low cloud**
- **If active shallow => this is balanced by enhanced shallow convection (red arrow) which dries the cloud.**

Part 2: Tuning the model

Tuning basics

- Whatsdat ?
- Tuning at a glance

Example of tuning

- Tuning of a recent CAM6 run

Example of tuning challenge

- Finite volume versus spectral element coupled run

Tuning of the model

- **Tuning** = adjusting parameters ("tuning knobs") to achieve agreement with observations.

  TOA radiative balance: Net SW - Net LW ~ 0

- **Tuning knobs** = parameters weakly constrained by obs

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

    rhminl ↘ => cloud fraction ↗ => Net SW at TOA ↘

Some tuning parameters in CAM5

Par	Description	Diag
rhminl	relative humidity threshold for low clouds	diag
a2l	Evaporative enhancement factor for stratocumulus-top entrainment rate	diag
rpen	Penetrative entrainment efficiency at the top of shallow convective plume	diag
co_lnd co_ocn	Auto-conversion efficiency of cumulus condensate into precipitation over land and ocean	diag
Dcs	Critical diameter for ice to snow auto-conversion	diag
dp1	parameter for deep convection cloud fraction.	diag

In CAM5: 20^+ tuning knobs

Tuning process at a glance

- Focus on our favorite variables:

  TOA radiative balance
  SWCF: SW cloud forcing (= Net $SW_{all\ sky}$ - Net $SW_{clear\ sky}$)
  LWCF: LW cloud forcing (= Net $LW_{all\ sky}$ - Net $LW_{clear\ sky}$)
  PREH2O: precipitable water
  Precipitation

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

- Goal: our favorite variables ⇔ our favorite datasets

Tuning process at a glance

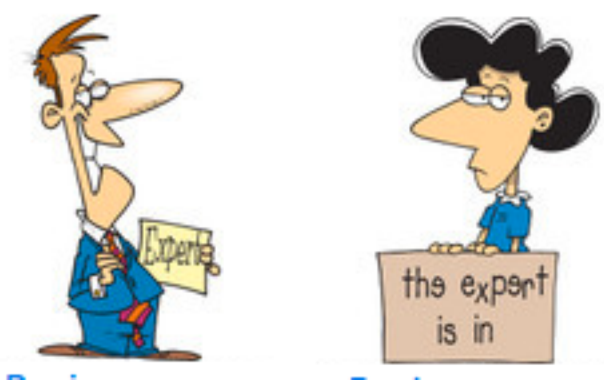
- Suite of runs

  5-10 year standalone CAM simulations (guidance)
  10^{+} yr coupled runs (tuning)

- Evaluation of favorite variables versus favorite datasets using AMWG diagnostic package

  global averages
  zonal means
  lat-lon plots
  Taylor diagrams
  Timeseries of radiative balance and surface temperature

- Expert team



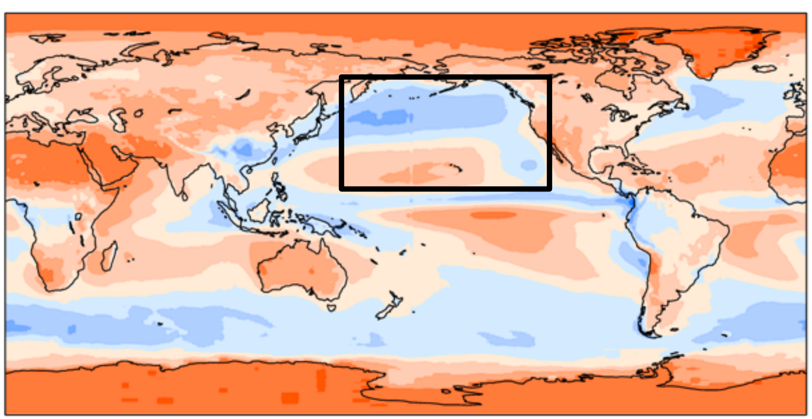
Why tuning in coupled mode ?

- **CAM standalone misses the feedback atm ⬄ ocn**
- **Simulation that can look acceptable in standalone can produce runaway coupled simulation**

SWCF

Obs

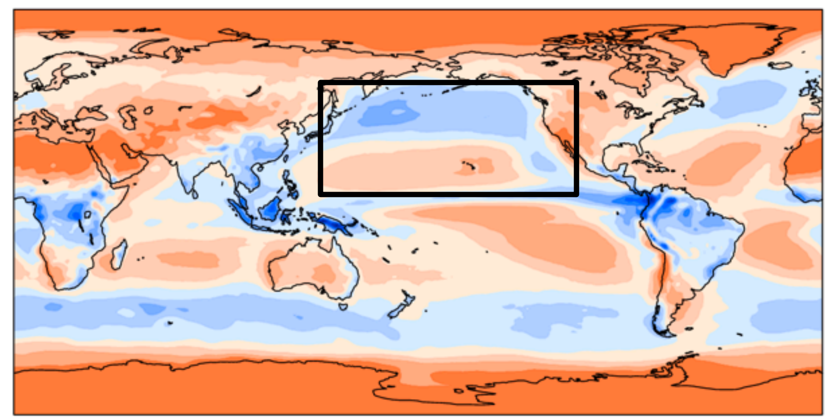
TOA SW cloud CERES-EBAF W/m^2



f.e11.FC5.ne30_ne30.tuning.018 (yrs 2-5)

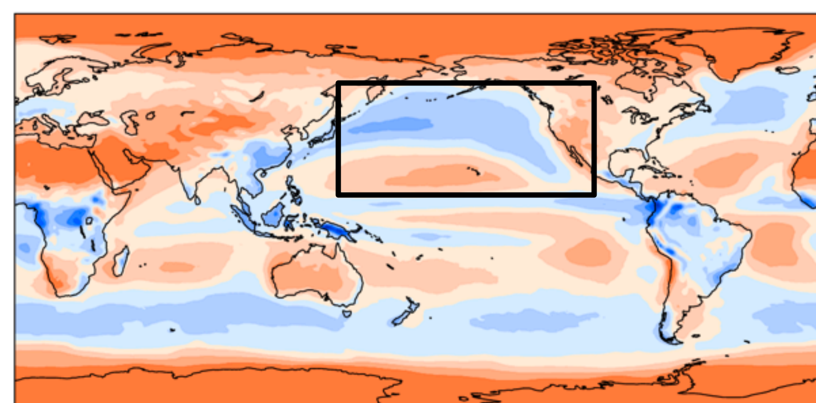
CAM - standalone

TOA SW cloud forcing mean= -49.88 W/m^2



CESM-Coupled

TOA SW cloud forcing mean= -49.29 W/m^2



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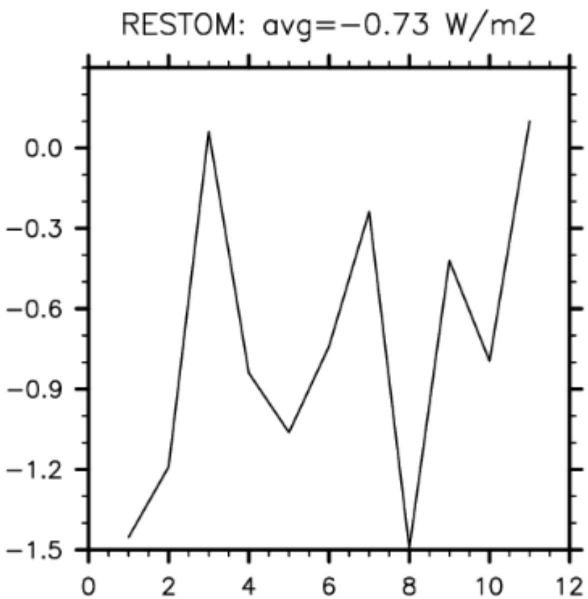
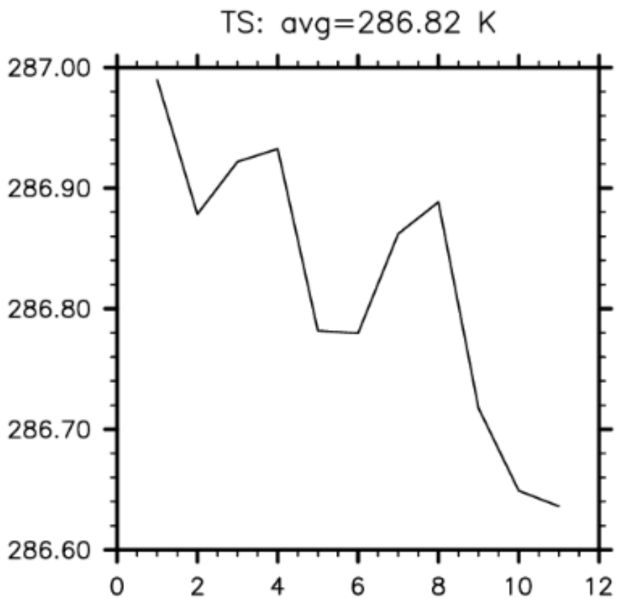
Example: Tuning of a recent CAM6 run

Timeseries of radiative imbalance and surface temperature

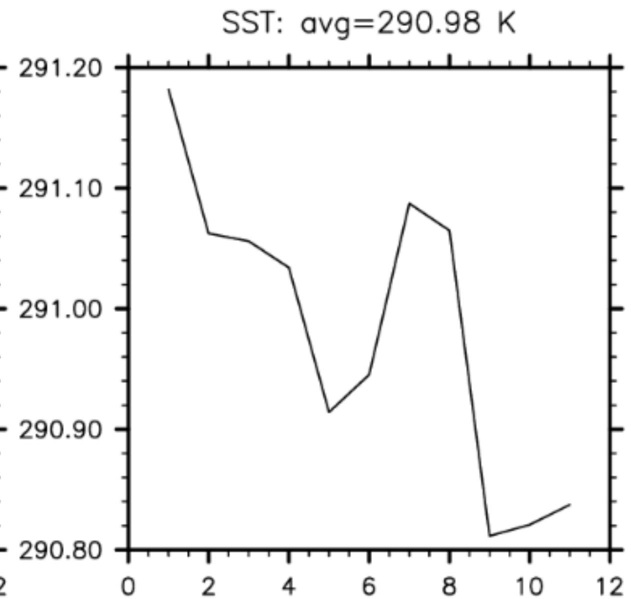
RESTOM = -0.73 W/m2



TS is cooling



SST is cooling

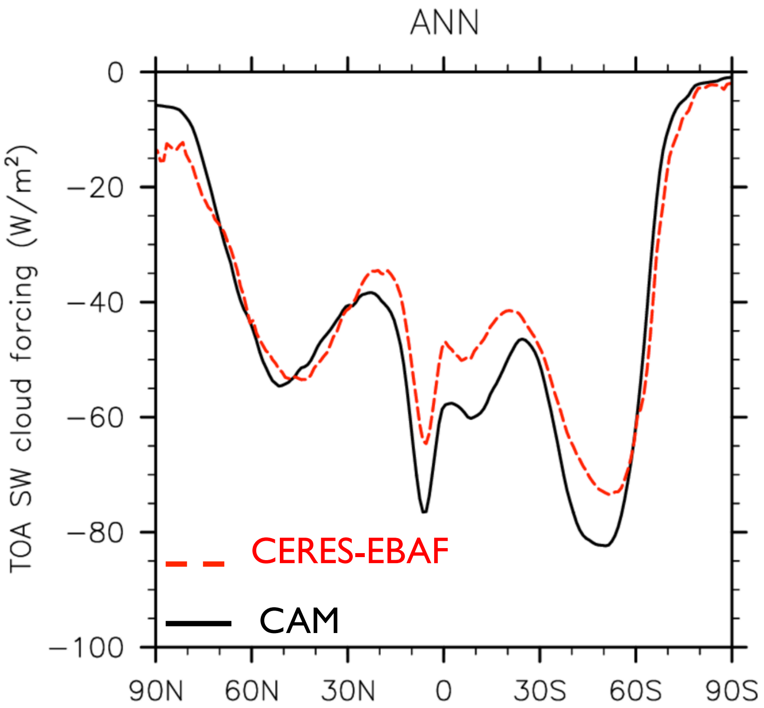


Negative radiative imbalance and surface temperature cooling

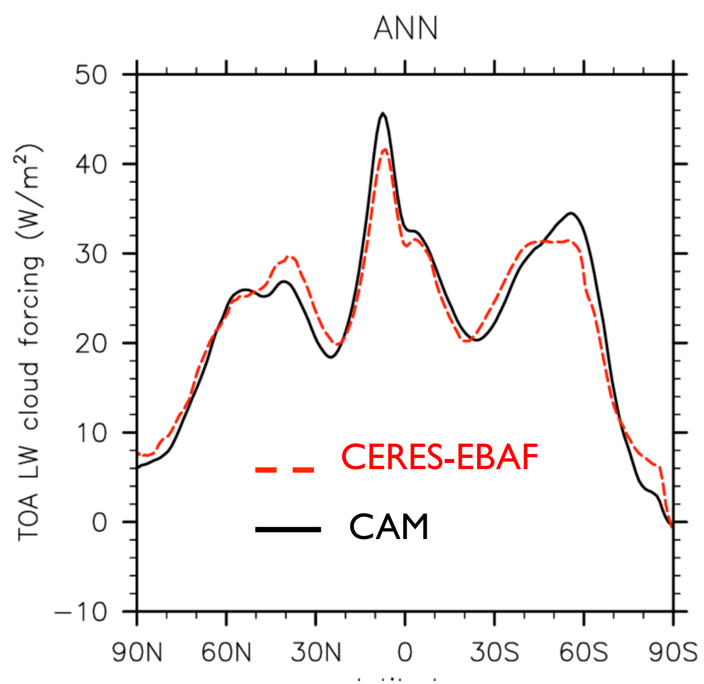
Example: Tuning of a recent CAM6 run

Zonal SW and LW cloud forcing

SWCF too strong



LWCF



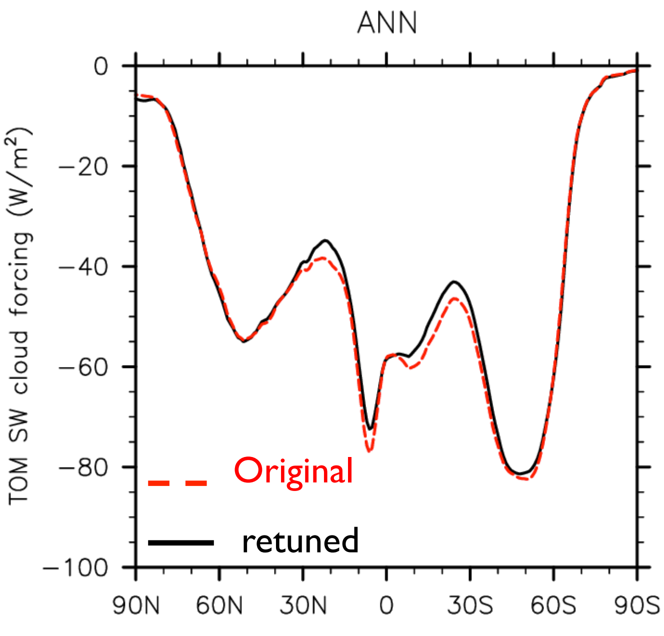
SWCF: global error of 5 W/m2
LWCF: global error of 0.2 W/m2

=> This could explain the cooling

Example: Tuning of a recent CAM6 run

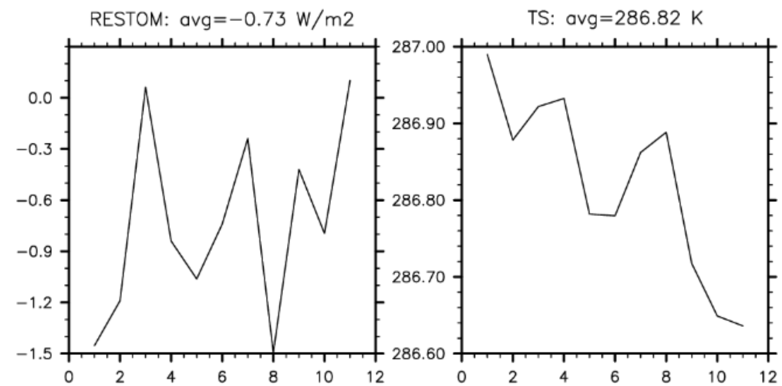
Adjust parameters to decrease SCWF => Better radiative balance

SCWF

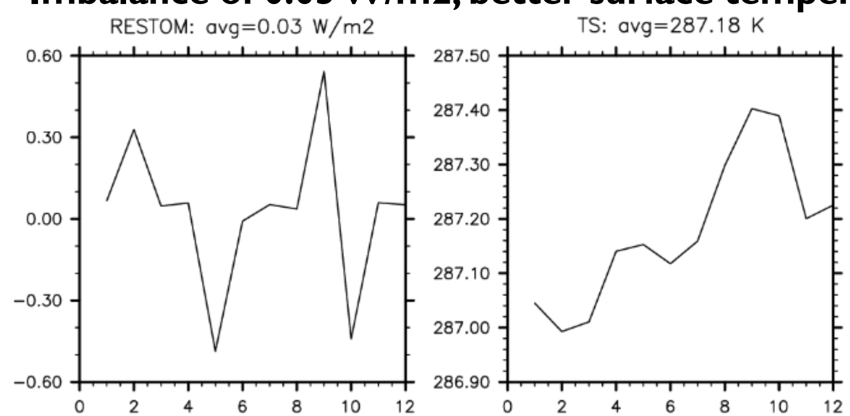


Globally SCWF bias is reduced by 1.7 W/m2

Original:
Imbalance of -0.73 W/m2; surface temperature cooling



Retuned:
Imbalance of 0.03 W/m2; better surface temperature



Part 2: Tuning the model

Tuning basics

- Whatsdat ?
- Tuning at a glance

Example of tuning

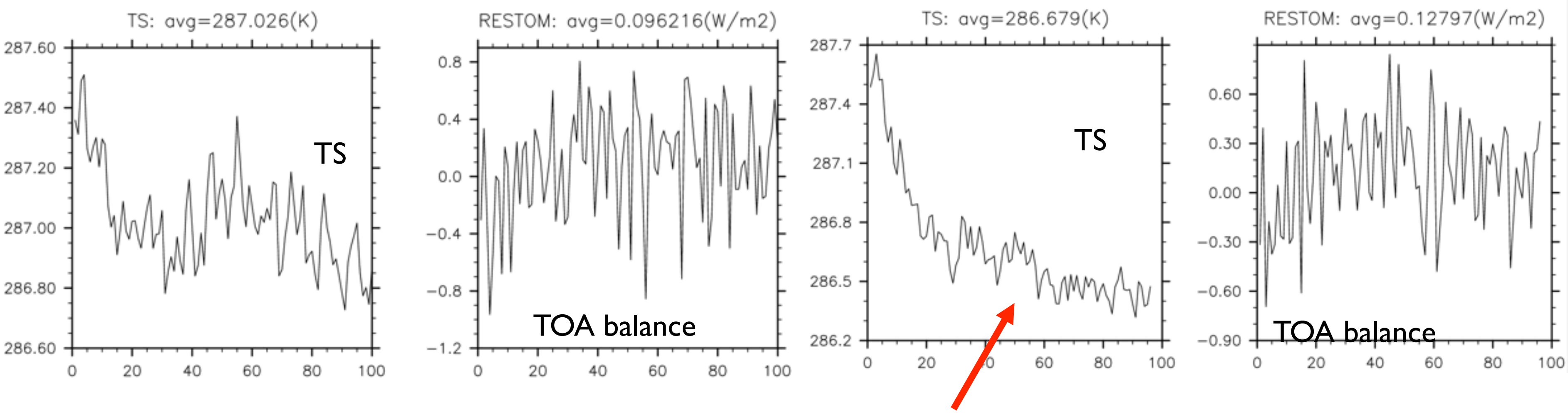
- Tuning of a recent CAM6 run

Example of tuning challenge

- Finite volume versus spectral element coupled runa

Example of tuning challenge

CESM1.1: Finite volume (FV) **CESM1.2: Spectral element (SE)**

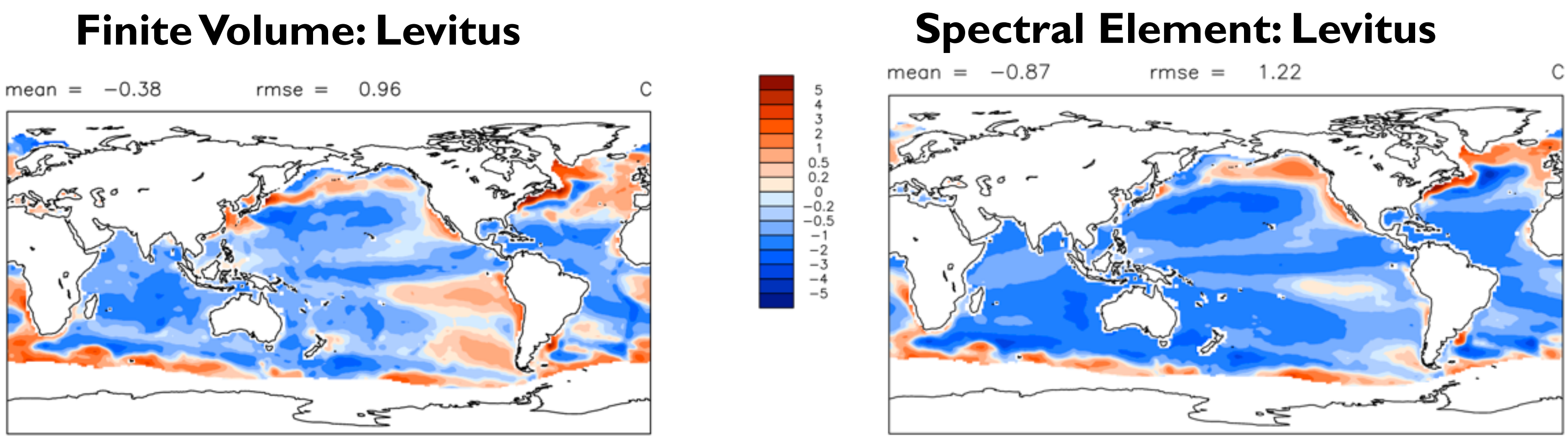


"Houston, we have problem"

Both simulations are started from Levitus and are reasonably balanced.
Finite volume produces a decent surface temperature
Spectral element produces too cold surface temperature

Sea-Surface Temperature (SST) biases

SSTs compared to HadISST/OI.v2 (pre-industrial)



SSTs stabilize but too cold compared to obs

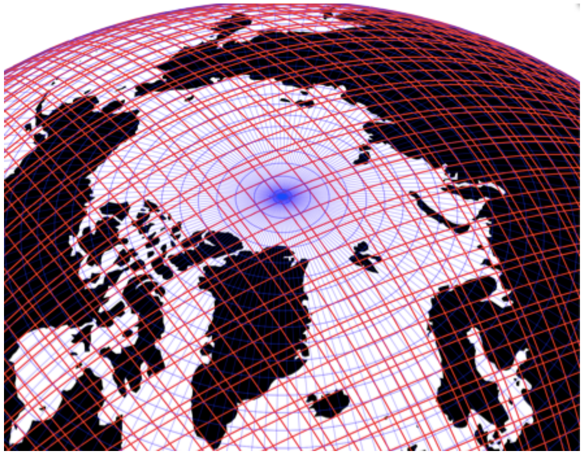
SST: 0.5K colder than FV

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

Grid differences at high latitudes



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

Courtesy:
Peter Lauritzen

Topography

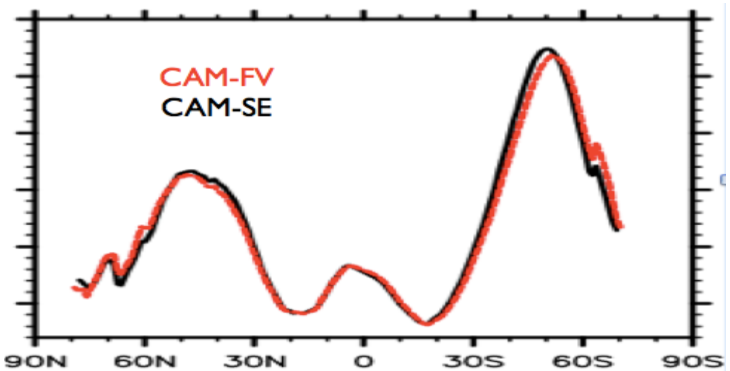
New software to generate topography (accommodate unstructured grids and enforce more physical consistency)

Remapping differences (ocn ⇔ atm)

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

Climate

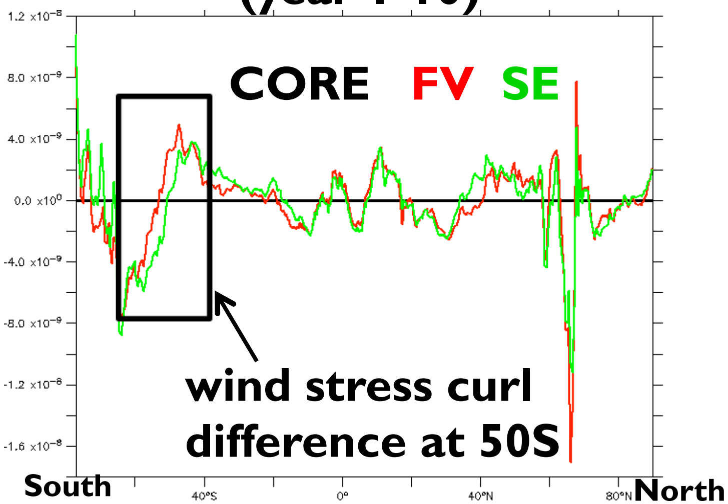
SST colder in SE than FV
Atmosphere is drier in SE that FV
Surface stress in Southern Oceans



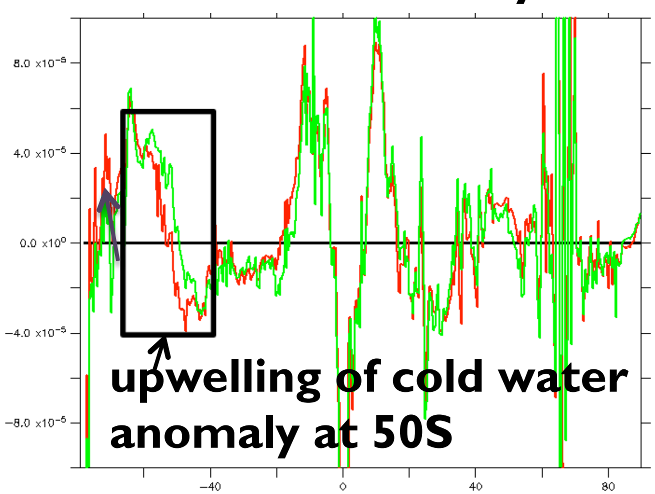
TAUX in CAM-SE:
- Location: maximum moves north
- Amplitude increases

Mechanism responsible of SST cooling in SE

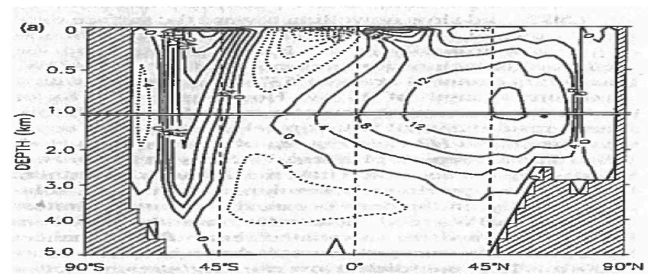
Wind stress curl anomaly (year 1-10)



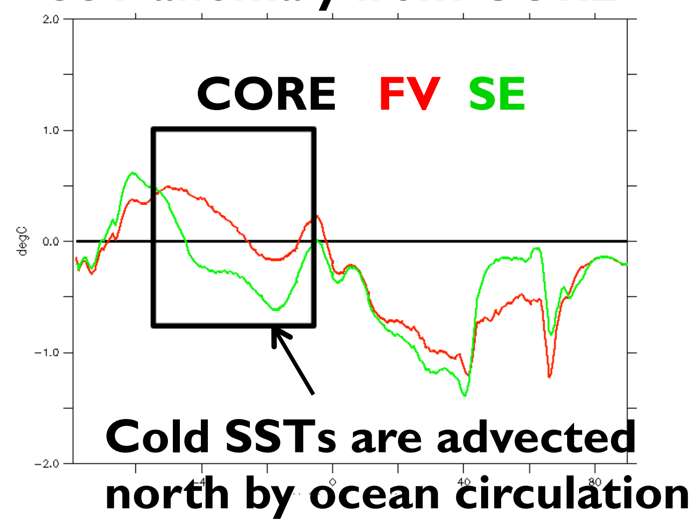
100-m vertical velocity anomaly



Ocean circulation

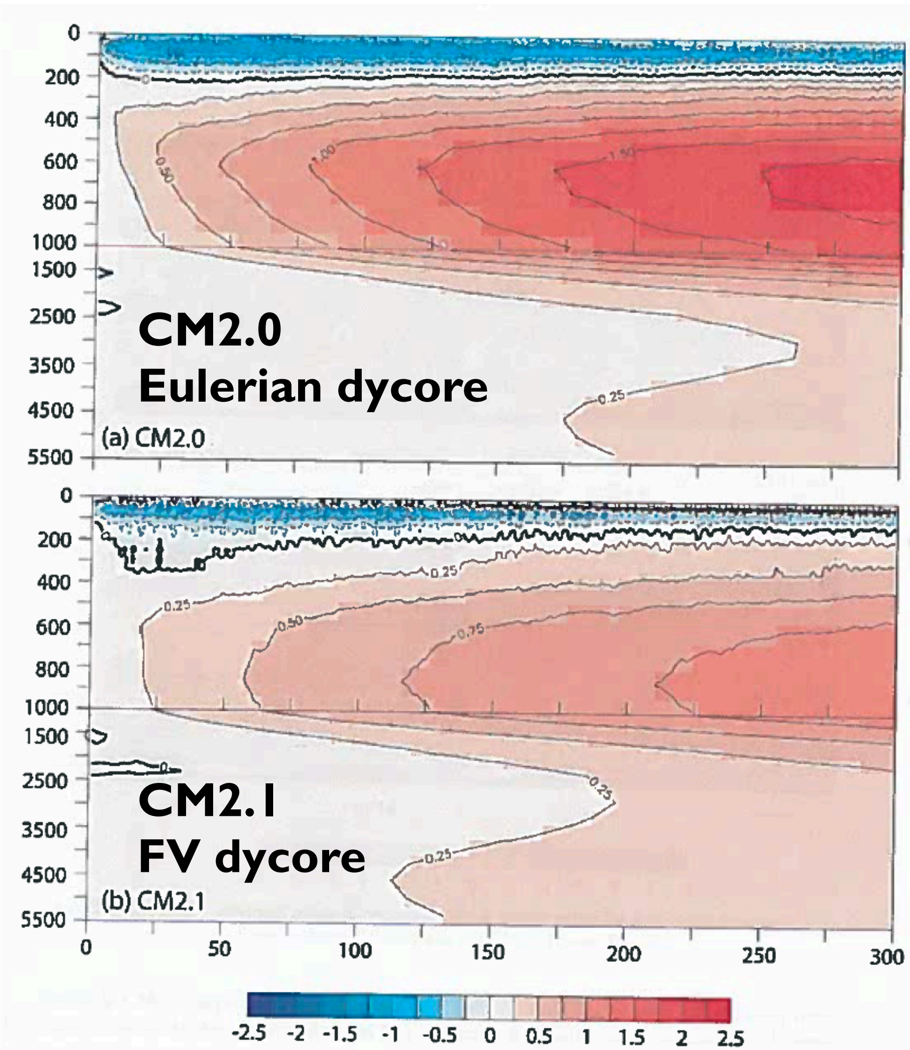


SST anomaly from CORE



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

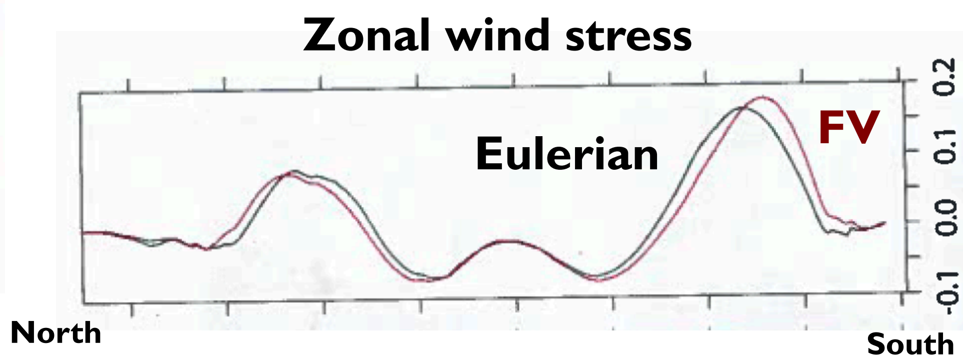
Similar behavior in GFDL model



SST cooling

warm layer at 750m

Reduced biases in FV

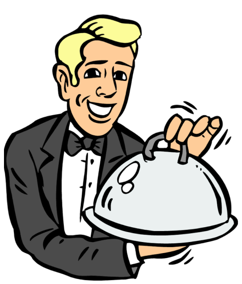


We completed the recipe to include a new parameterization

Developing the parameterization

Assessing the parameterization

Tuning the model



Bon appétit

We are ready for a new model

Questions ?