Assessing and tuning model parameterizations

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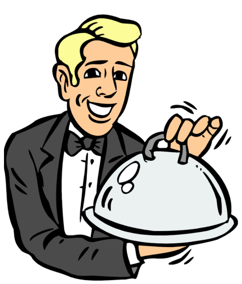
Recipe to include a new parameterization

Developing the parameterization

Assessing the parameterization **=> Part 1**

Tuning the model **=> Part 2**



Bon appétit

Outline

Part 1: Assessing the parameterization

- The straightforward road
  - Climate runs
- Alternate ways
  - Forecasts runs
  - Single Column Model

Part 2: Tuning the model

- Tuning basics
  - Whatsdat ?
  - Tuning at a glance
- Examples of tuning
  - Tuning of a recent CAM6 run
  - Tuning challenge: Finite volume versus spectral element

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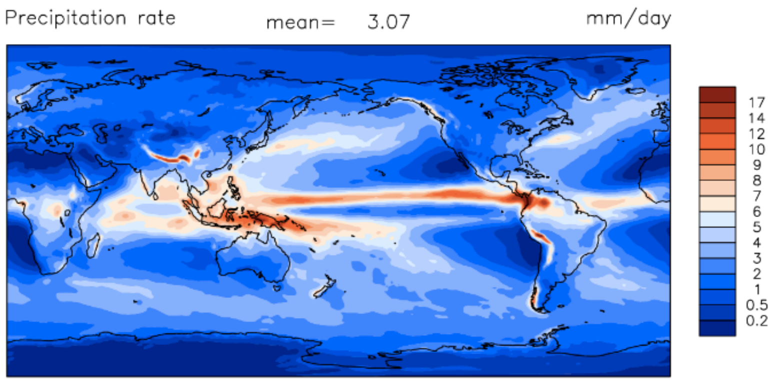
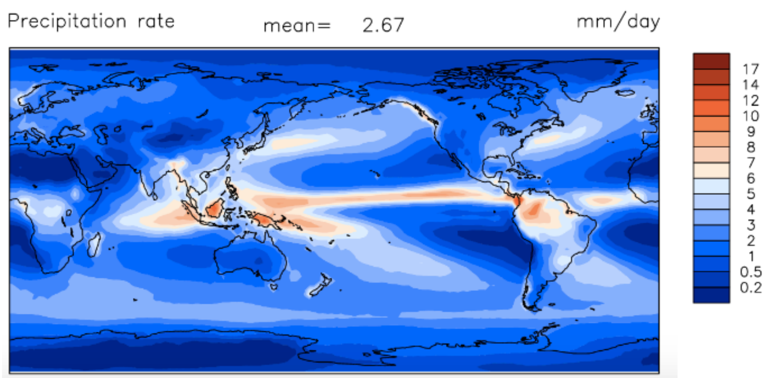
Climate runs

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 runs (atm+lnd) F case
- Fully coupled model runs (atm+lnd+ocn+ice) B case
- Runs to assess aerosol effect F case
- Climate sensitivity runs E case

Typical climate runs to assess parameterization

CAM standalone (no active ocean)

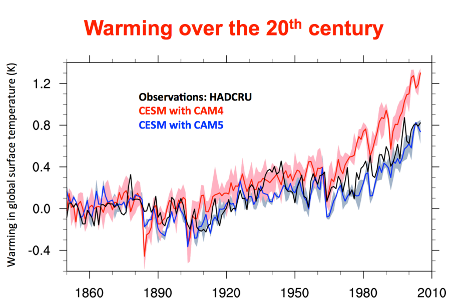
- **AMIP runs**
  Standard protocol for testing GCMs
  GCM is constrained by realistic sea surface temperature and sea ice from 1979-2005

- **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 20^{th} century

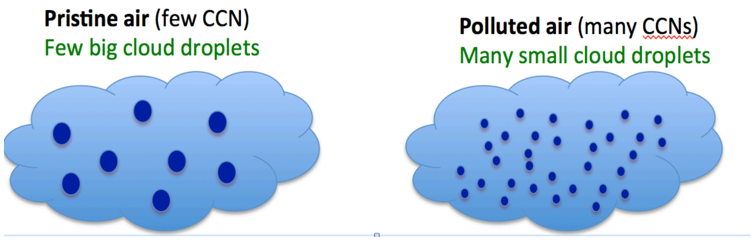


Typical climate runs to assess parameterization

Runs to assess aerosol effect

- **Direct effect**
  Aerosols scatter and absorb radiation => Cooling effect

- **Indirect effect**
  Cloud with smaller droplet has higher albedo
  => Cooling effect



- **To estimate amplitude of cooling**
  Two climo SSTs runs with every kept the same except aerosols (pre-industrial versus present day aerosols)

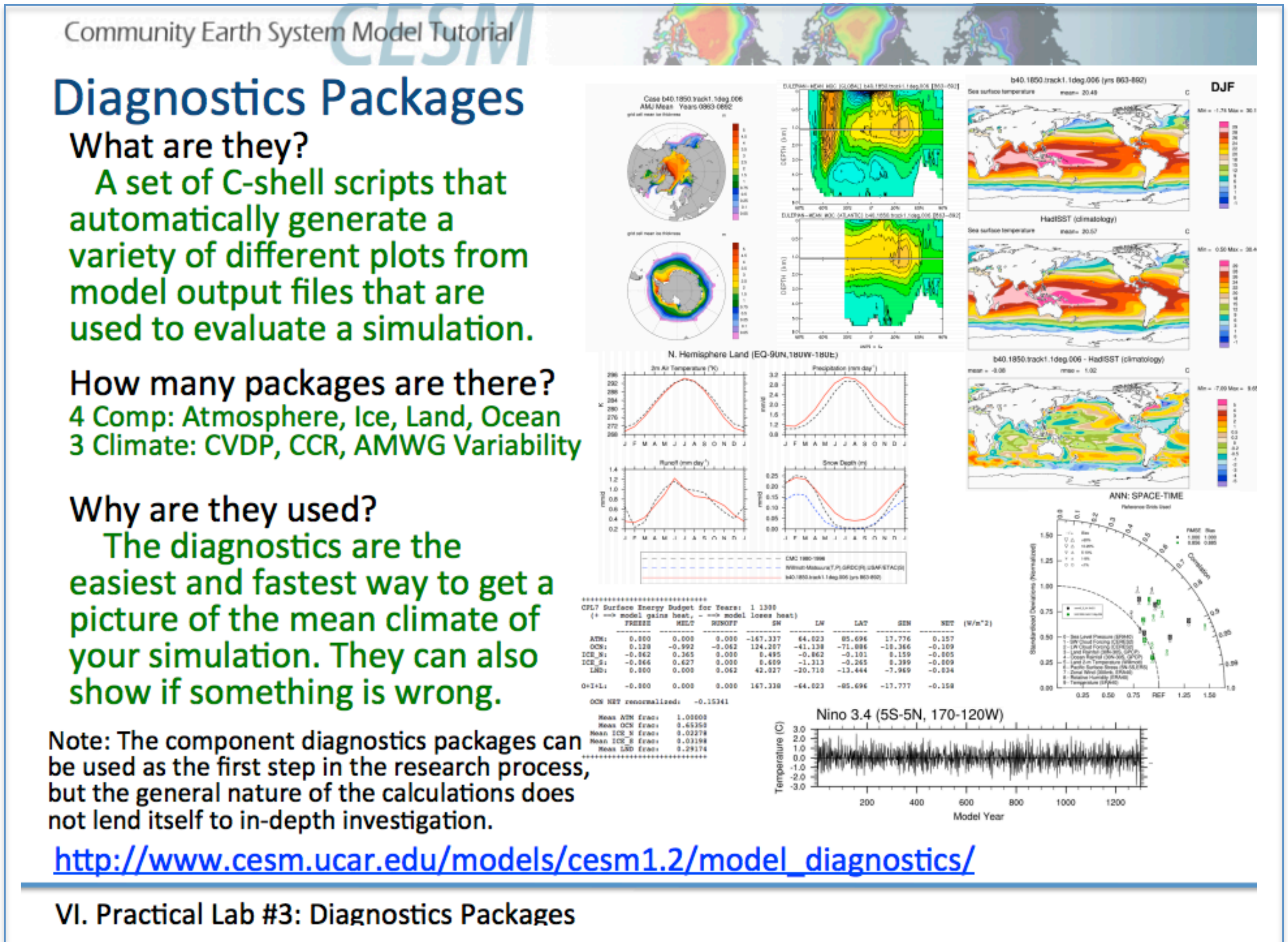
Climate sensitivity runs

- **Equilibrium change in surface temperature due to a doubling of CO2**
  Slab Ocean Model runs with 1xCO_2 and 2xCO_2

How do we analyze all these runs ?

We have a quick way to look at climate runs: The diagnostics packages

For reference: look at Adam's talk (Wednesday)



Courtesy:
Adam Philipps

The AMWG diagnostics package

Capabilities of AMWG diag

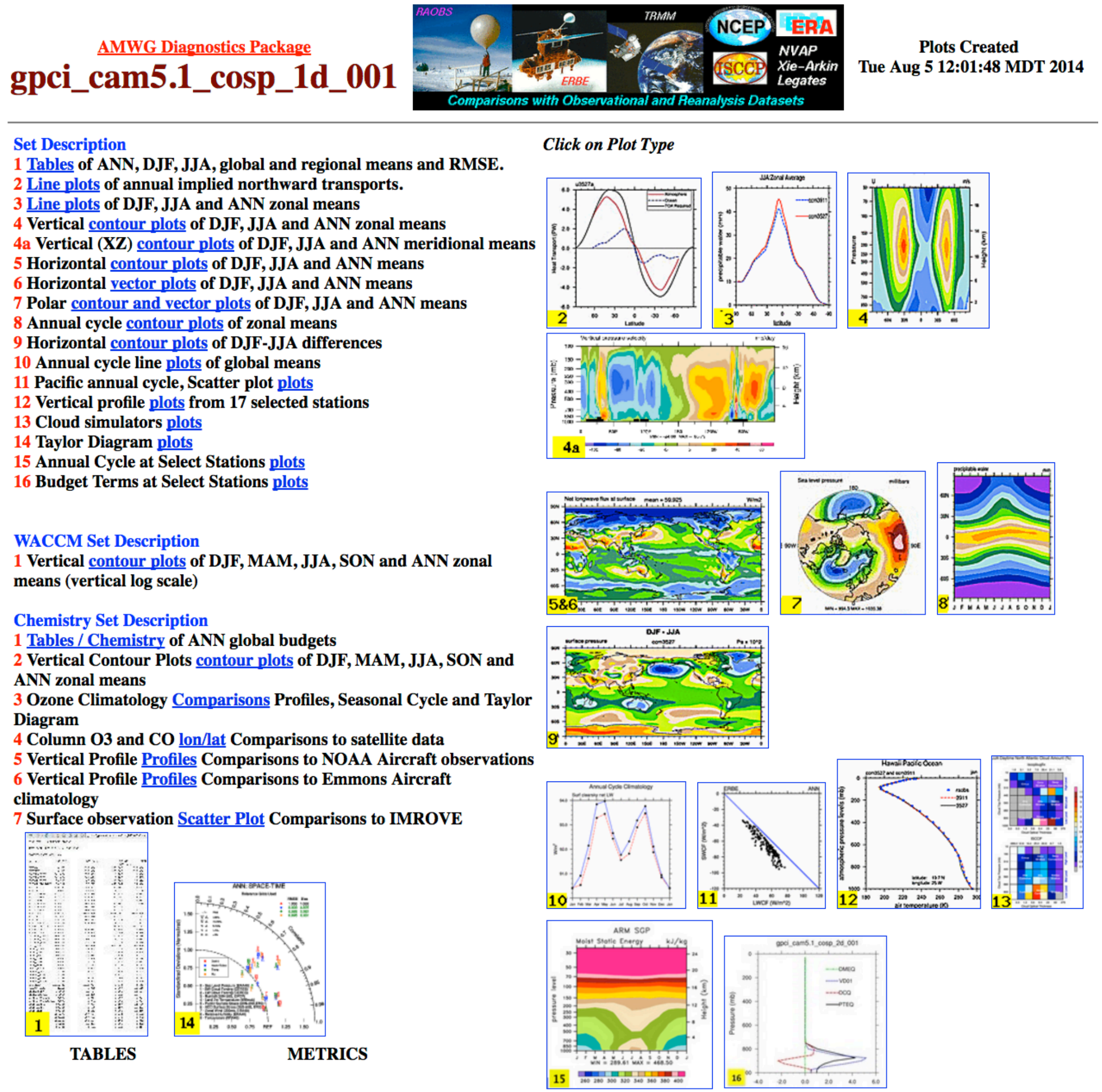
Compute climos

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…

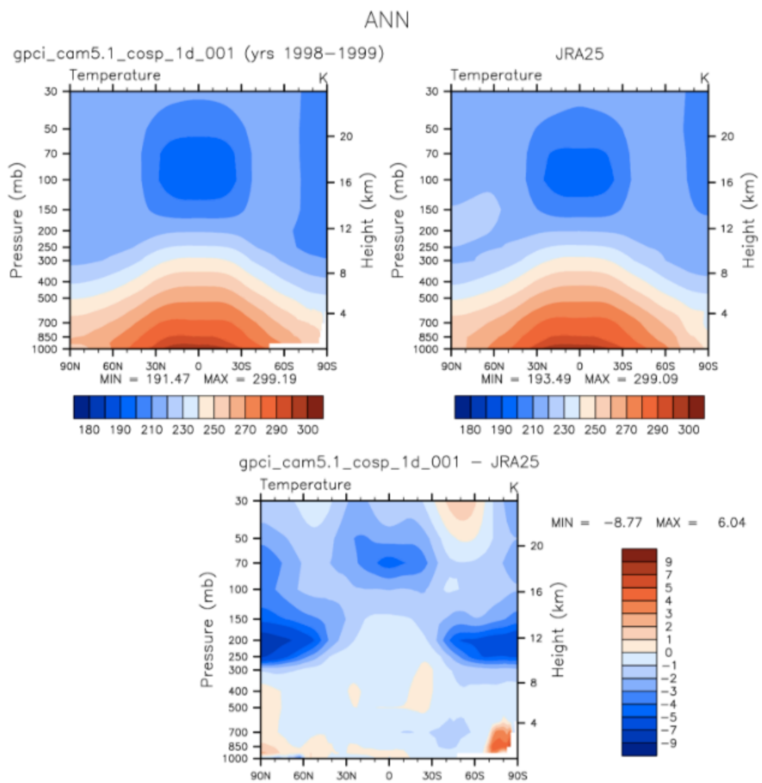
Comparison
Model to observations
Model to model

Coming soon
Write and submit the paper

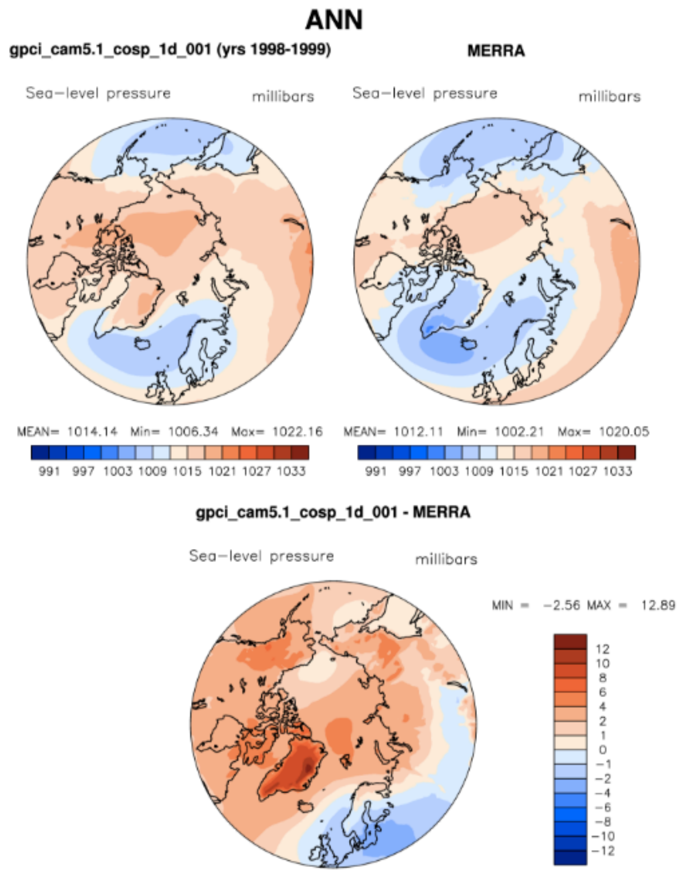


The AMWG diagnostics package: Examples

Zonal mean: Temperature



Polar plots: Sea level pressure

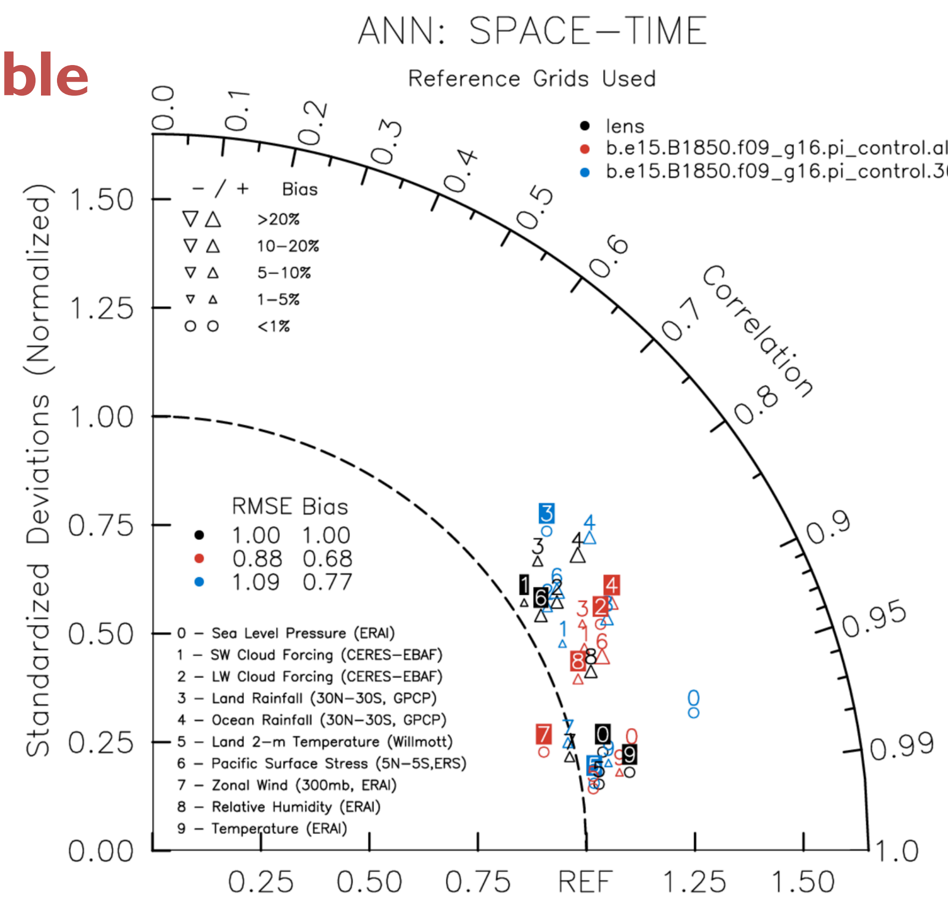


Taylor diagrams

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

An example of using climate runs to assess parameterizations: The CAM5.5 assessment

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/

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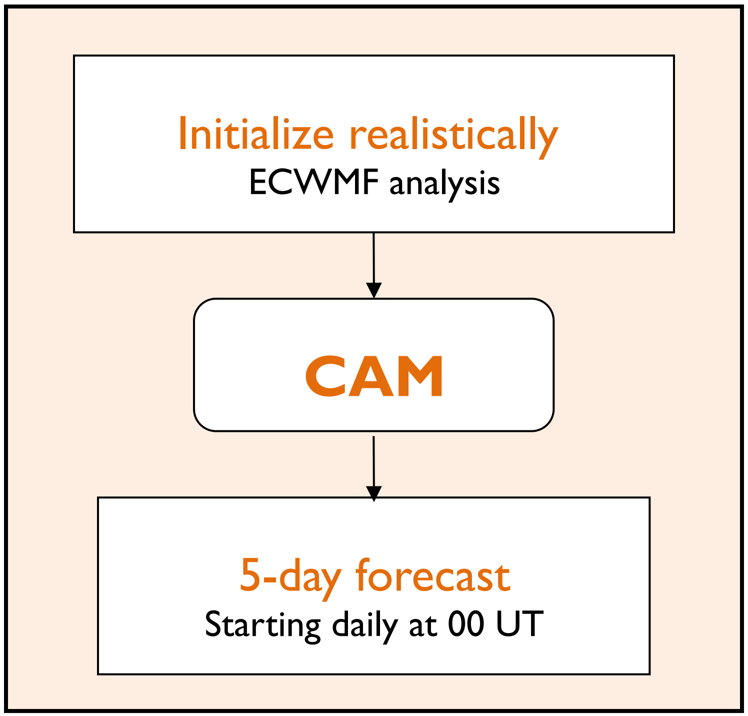
Methodology for the forecasts

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

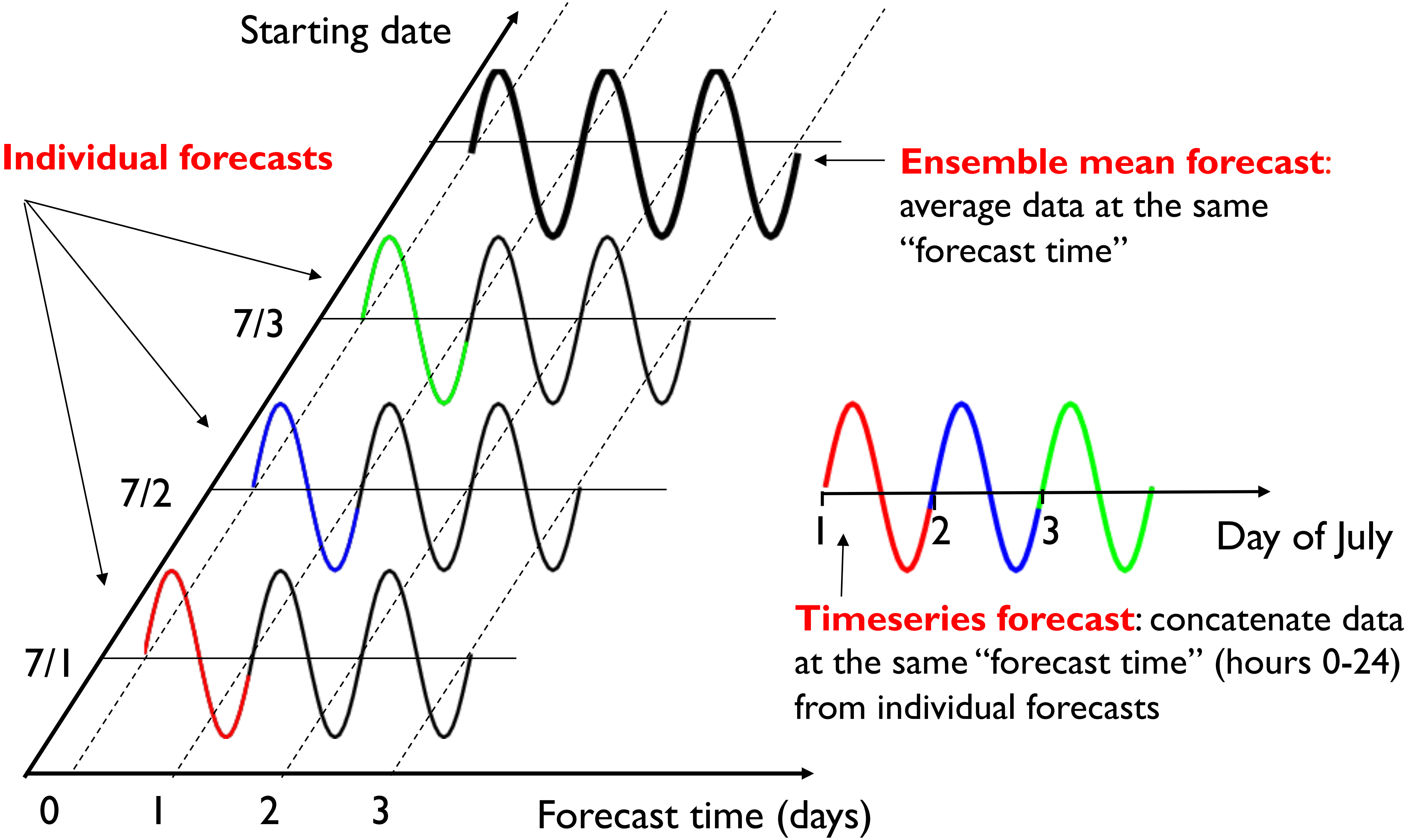
- Evaluate the forecast against observations on a particular day and location

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

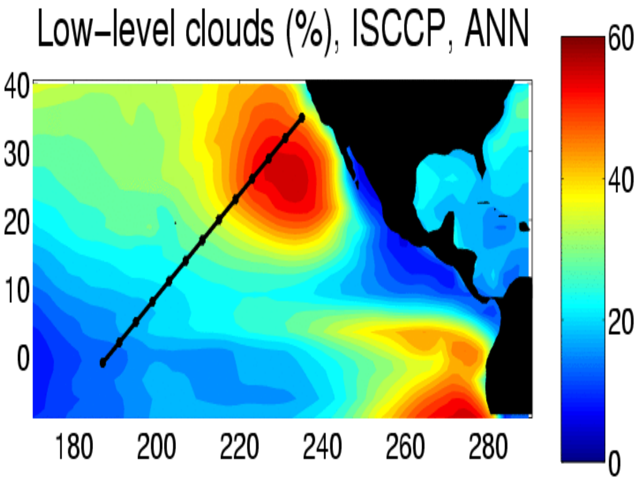
Limitations

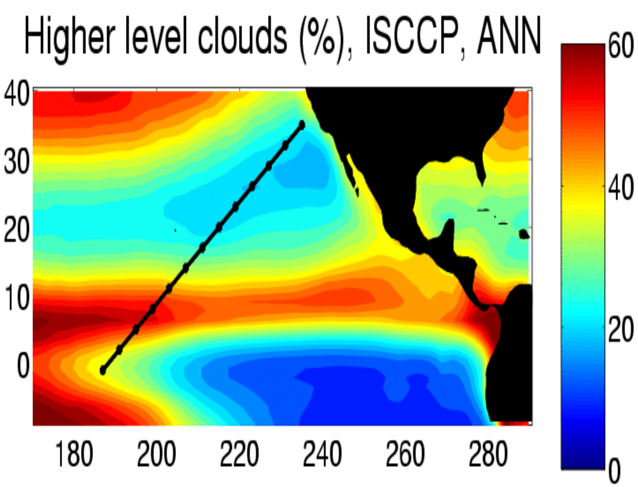
Accuracy of the atmospheric state ?

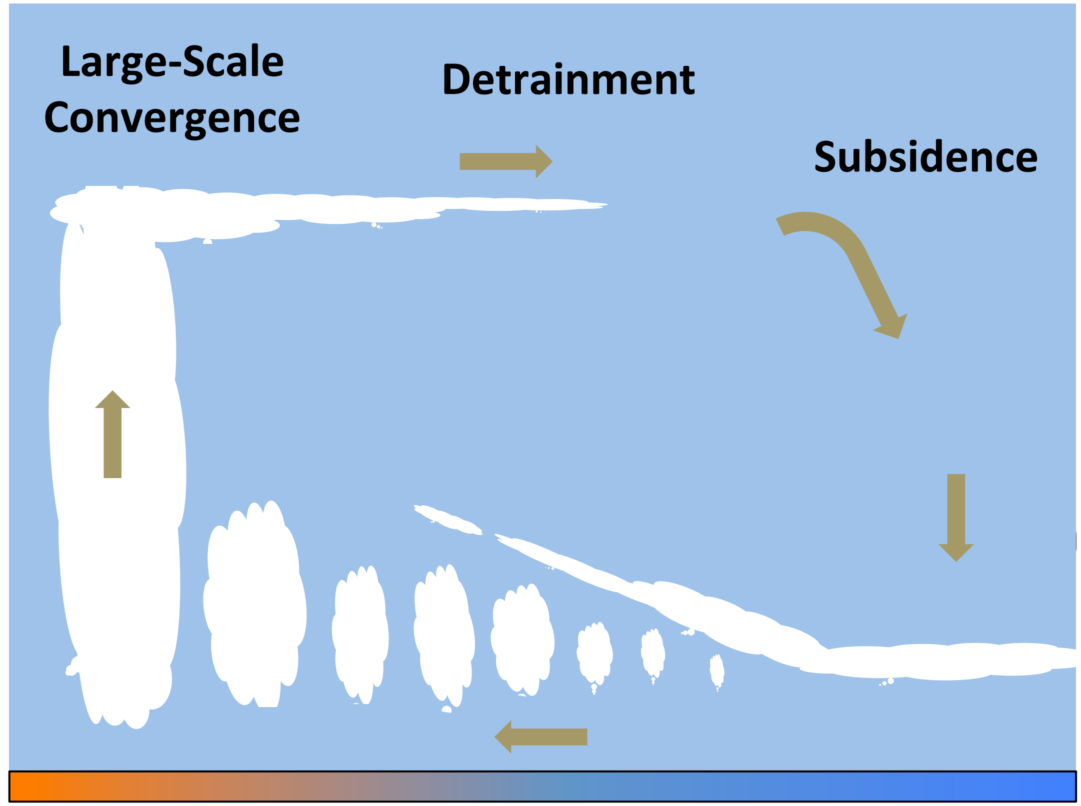
Ensemble mean forecast and timeseries forecast



Cloud regimes along Pacific Cross-section

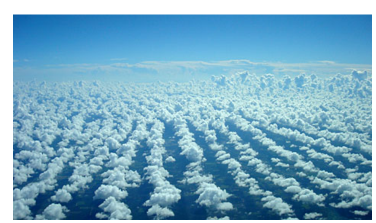




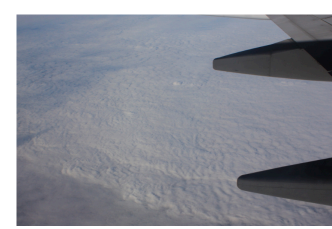


Deep convection

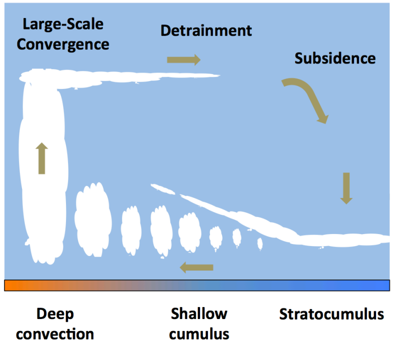
Shallow cumulus



Stratocumulus

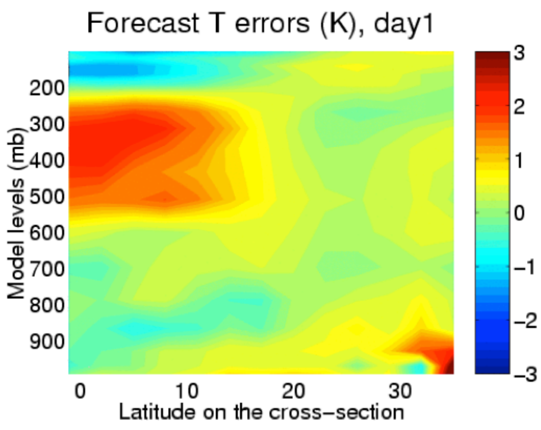


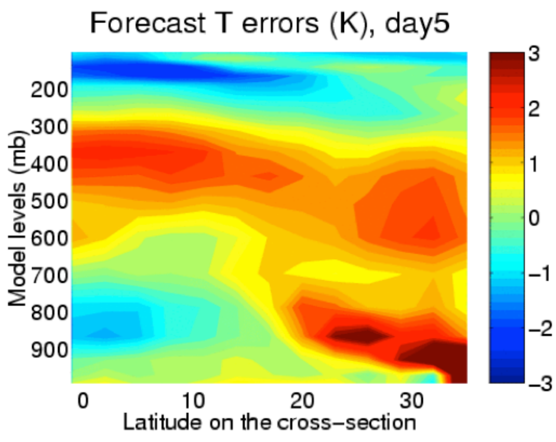
Forecast and climate errors along Pacific Cross-section (JJA 1998)

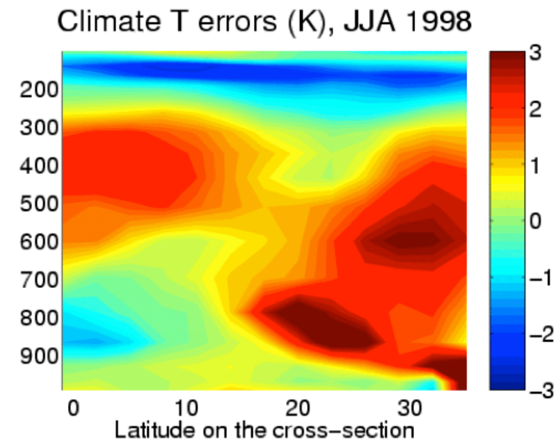


Climate bias appears very quickly

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







Using forecasts to assess a parameterization

CAM3

- Release in 2004
- Deep convection: Zhang-McFarlane (1995)

  Too much precipitation in deep convection area

CAM4

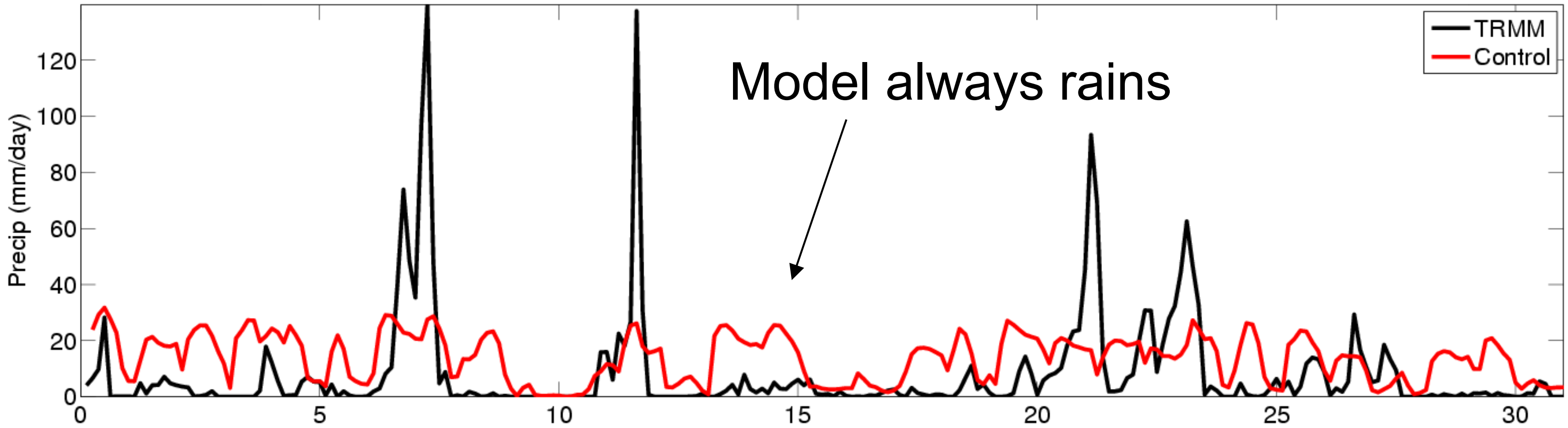
- Release in 2010
- Deep convection: Neale and Richter (2008)

What can we learn from forecasts with CAM3 vs CAM4?

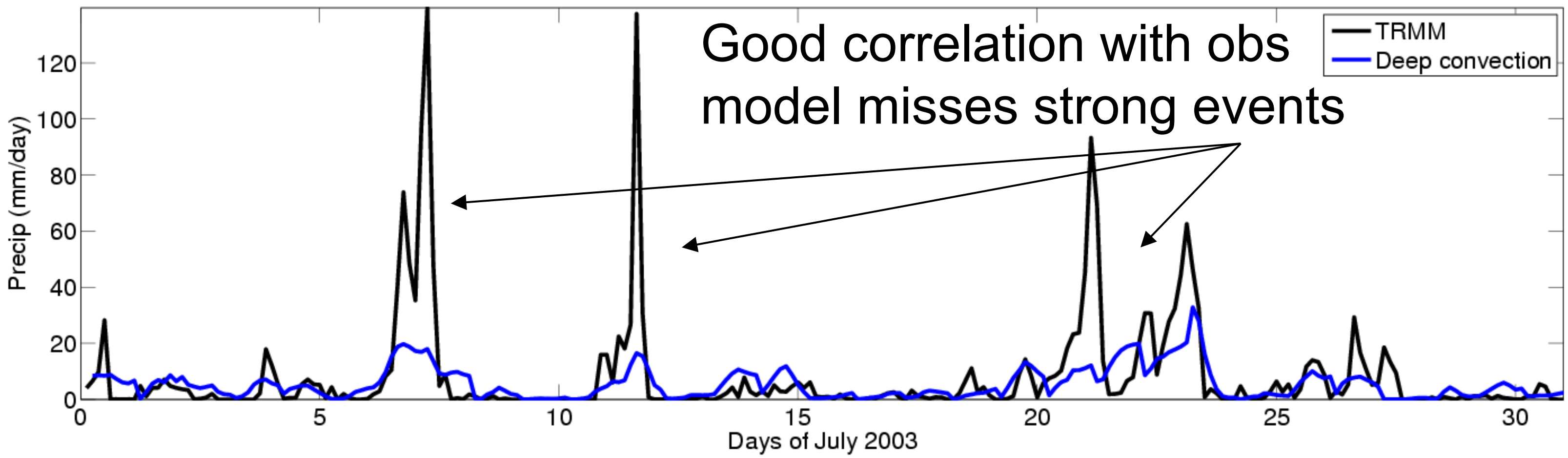
Hindcast Performance

CAPT – 1-day forecasts in the tropical East Pacific

CAM3



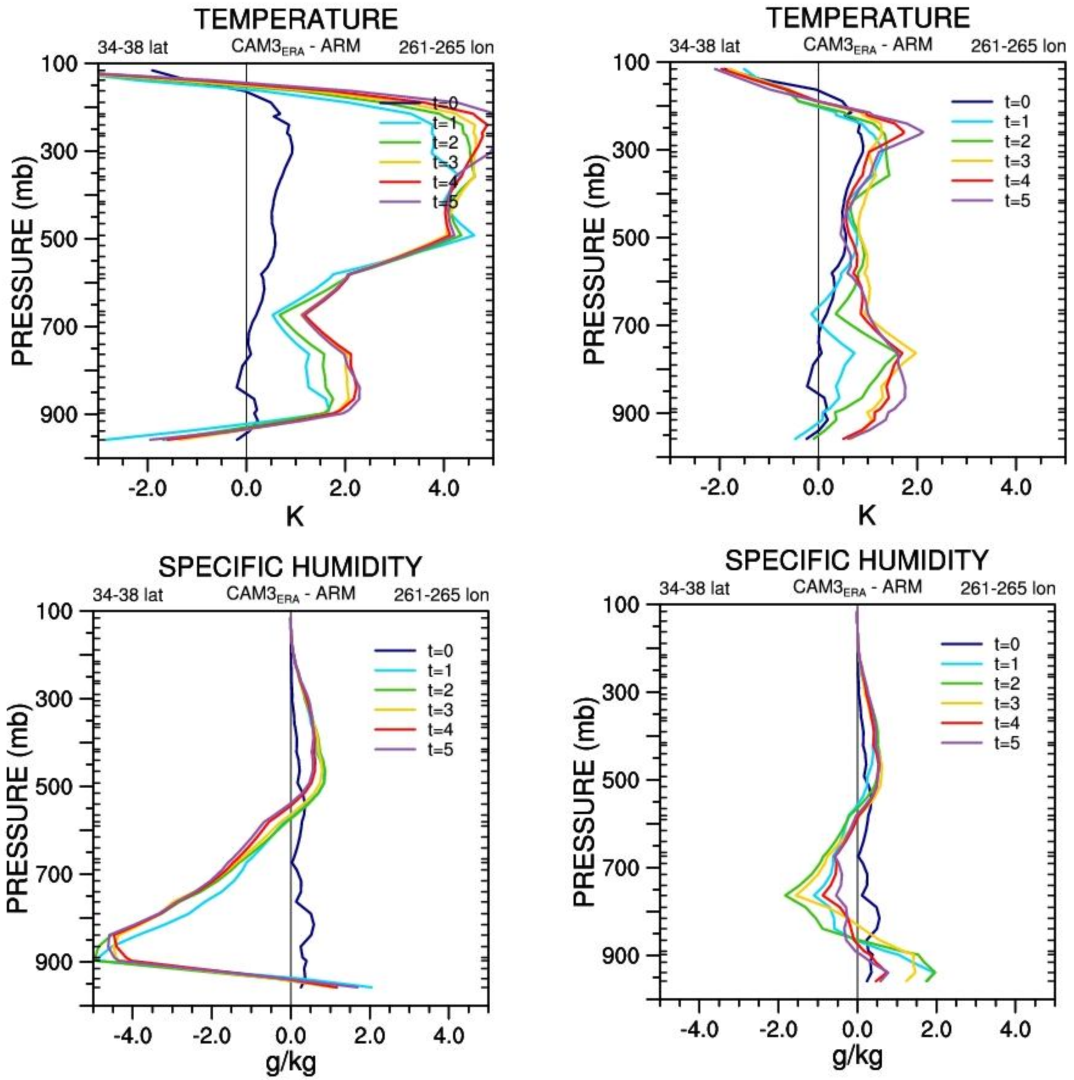
CAM4



Courtesy: Rich Neale

Hindcast Performance

CAM3 **CAM4**



- CAPT simulations
- Southern Great Plains
- Deep convection is the fastest process
- Errors in model state (T,q) response to convection will show first

Courtesy: Rich Neale

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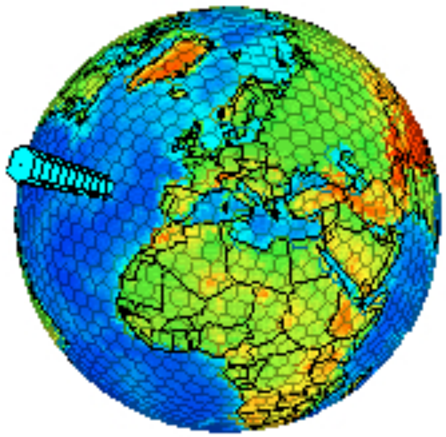
Single Column Modeling (SCM)



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

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

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

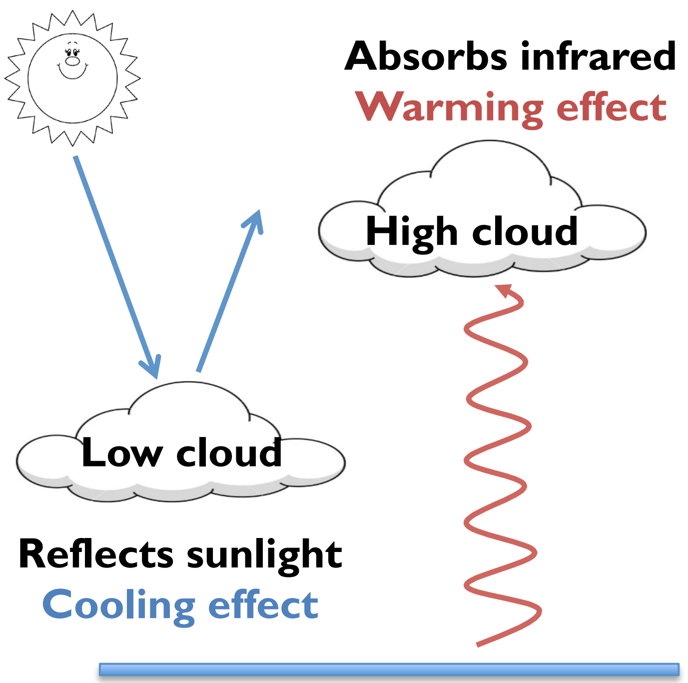
- **Data requirements (tendencies needs to be accurate to avoid growing error)**
- **Cannot detect problem in feedback**

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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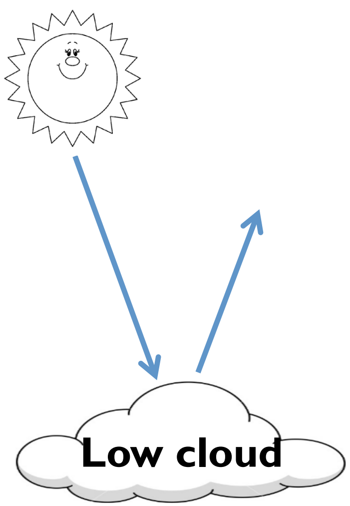
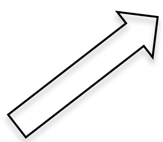
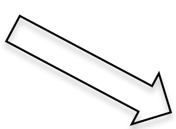


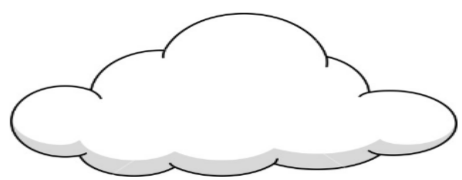
Reflects sunlight
Cooling effect

In a warmer climate



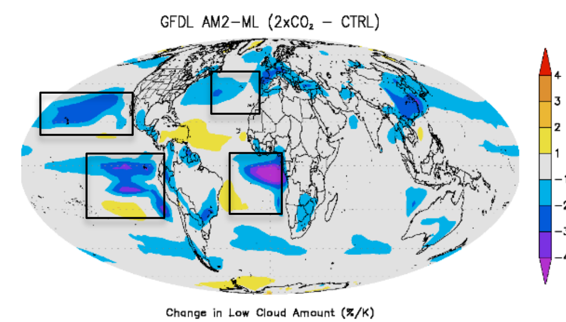
Less low cloud
Warming effect
Positive feedback



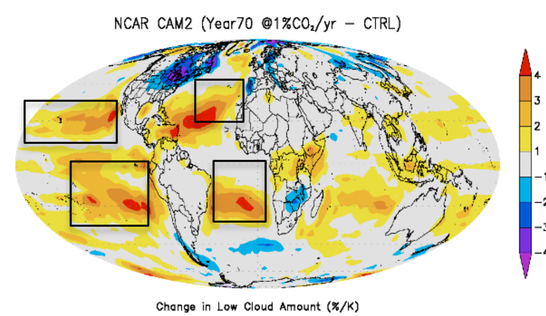


More low cloud
Cooling effect
Negative feedback

Low cloud feedback in 2 US models



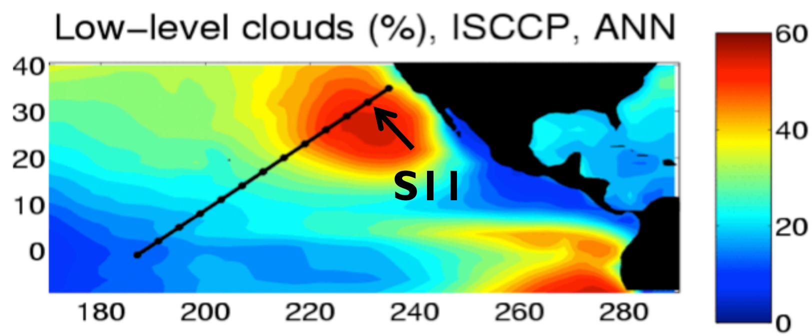
GDFL: Positive feedback



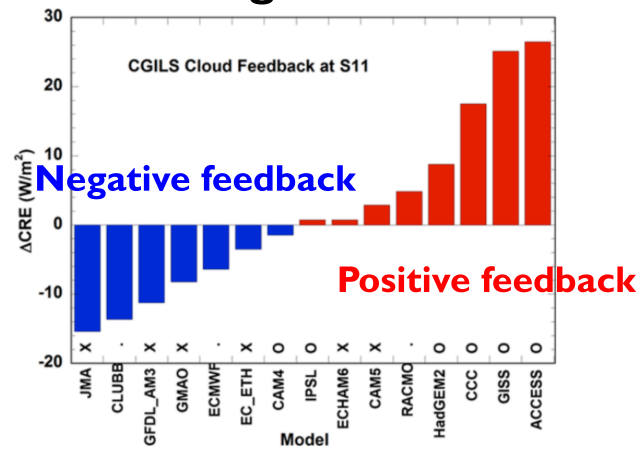
NCAR: Negative feedback

Example: CGILS study (Zhang et al, 2013)

Goal: Understanding mechanisms of low cloud feedback in SCM



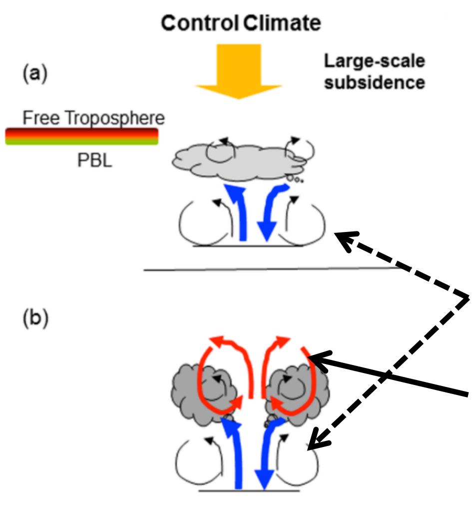
SCM experiments to determine low cloud feedback sign at S11 in 15 models



Models with no active shallow convection

Models with active shallow convection

Proposed mechanism

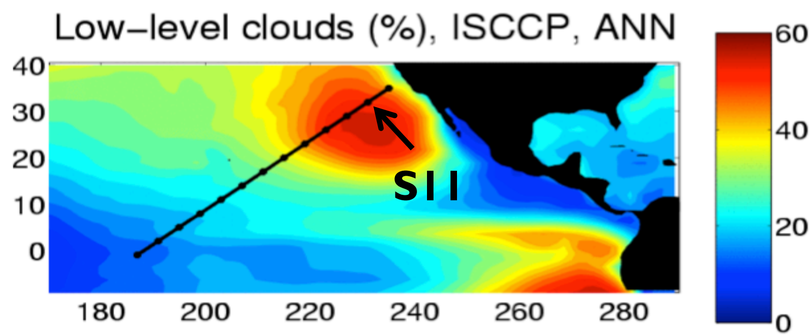


PBL scheme is moistening the cloud (blue arrow)

Shallow convection scheme is drying dries the cloud (red arrow)

Example: CGILS study (Zhang et al, 2013)

Goal: Understanding mechanisms of low cloud feedback in SCM



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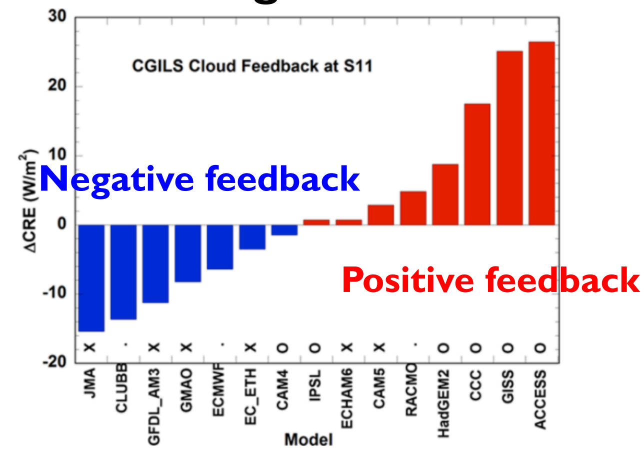
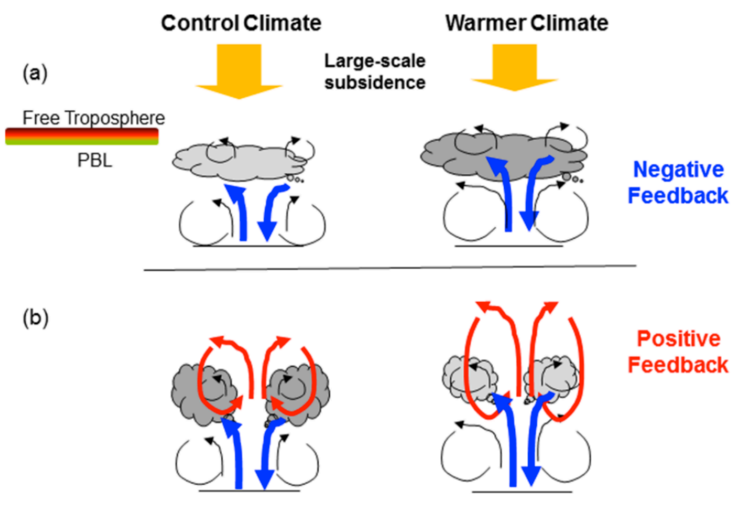


Proposed mechanism



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 1: Assessing the parameterization

In Summary

	Climate runs	Forecasts runs	Single Column Model
Info	Make multiple-year run starting from random initial condition Compare the climatology with observations	Initialize model globally with observations and run short runs (“forecasts”) Compare a particular day/ location with observations	Take a column and use observations to define what is happening in neighboring columns. Compare a particular day/ location with observations
Pros	Tests the parameterization as it is intended to be used	Evaluate the parameterization errors (before the error in the atmospheric state develop)	Inexpensive (1 column⇔1000s) Remove complications from feedback physics ⇔ dynamics
Cons	Very expensive Results are complicated and depend on all aspects of the model (physics, dynamics, feedback)	Expensive Data requirements (accuracy of the atmospheric state) Results are complicated to disentangle	Cannot detect problem in feedback Data requirements (need accurate tendencies)

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Tuning of the model

- Tuning = adjusting parameters ("tuning knobs") to achieve better 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

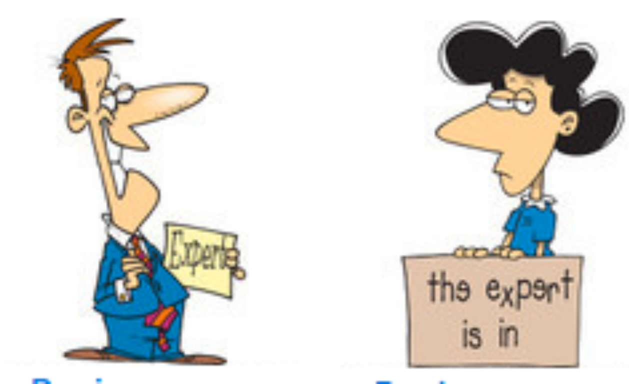
- Suite of runs

  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 ?

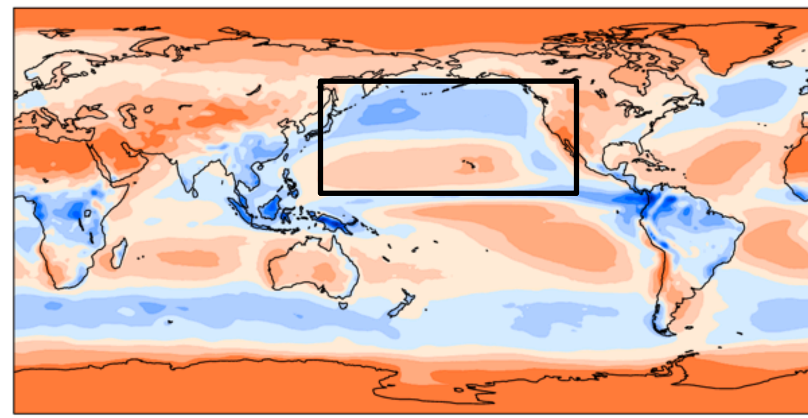
- **CAM standalone misses the feedback atm ⇔ ocn**
- **Simulation that can look acceptable in standalone can produce runaway coupled simulation**

SWCF

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

CAM - standalone

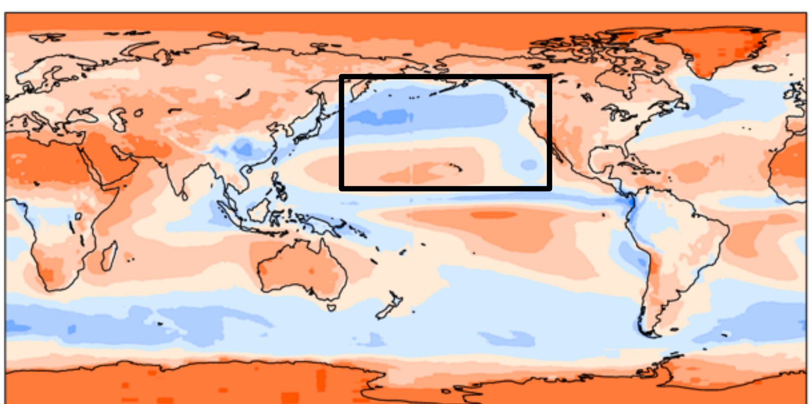
TOA SW cloud forcing mean= -49.88 W/m^2



Obs

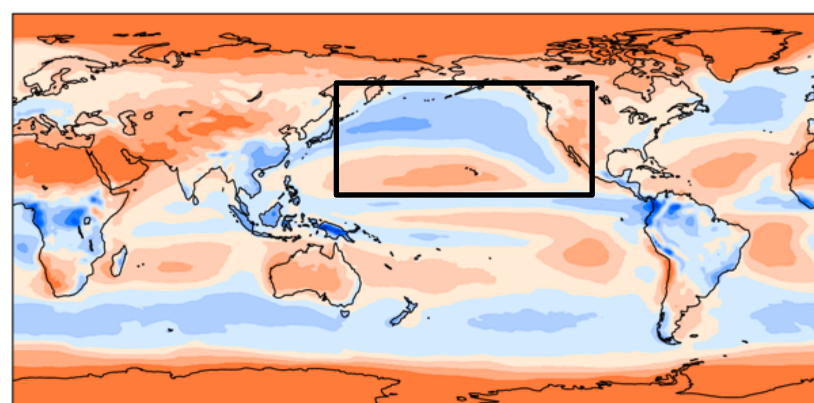
CERES-EBAF

TOA SW cloud W/m^2



CESM-Coupled

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



Outline

Part 1: Assessing the parameterization

- The straightforward road
  - Climate runs
- Alternate ways
  - Forecasts runs
  - Single Column Model

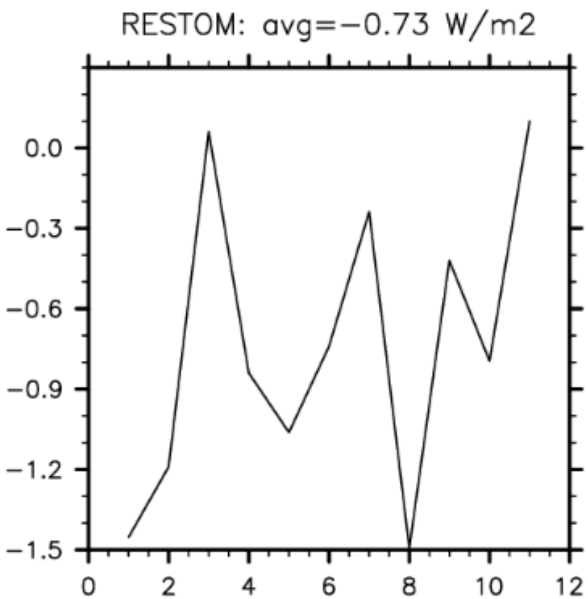
Part 2: Tuning the model

- Tuning basics
  - Whatsdat ?
  - Tuning at a glance
- **Examples of tuning**
  - **Tuning of a recent CAM6 run**
  - Tuning challenge: Finite volume versus spectral element

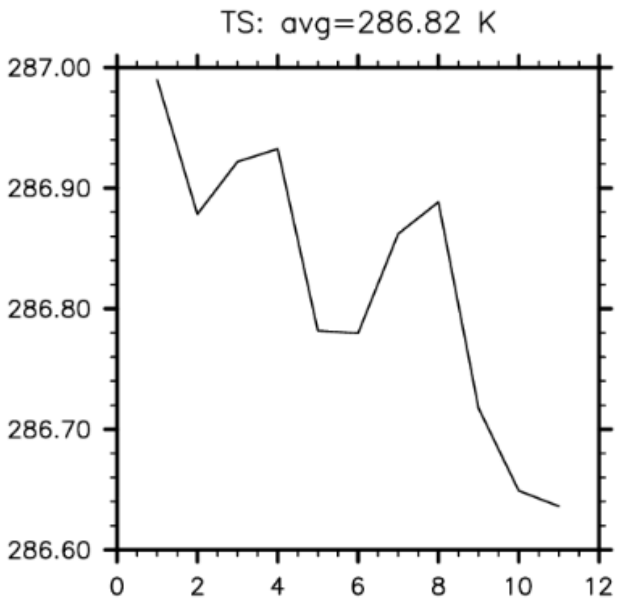
Example: Tuning of a recent CAM6 run

Timeseries of radiative imbalance and surface temperature

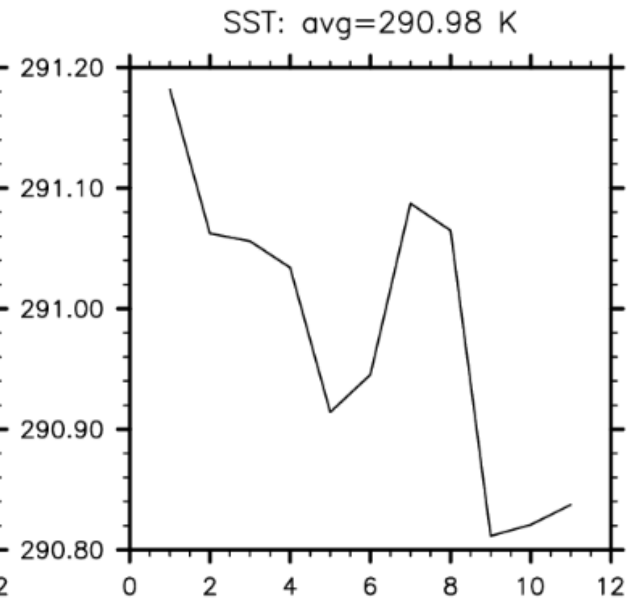
RESTOM = -0.73 W/m2



TS is cooling



SST is cooling

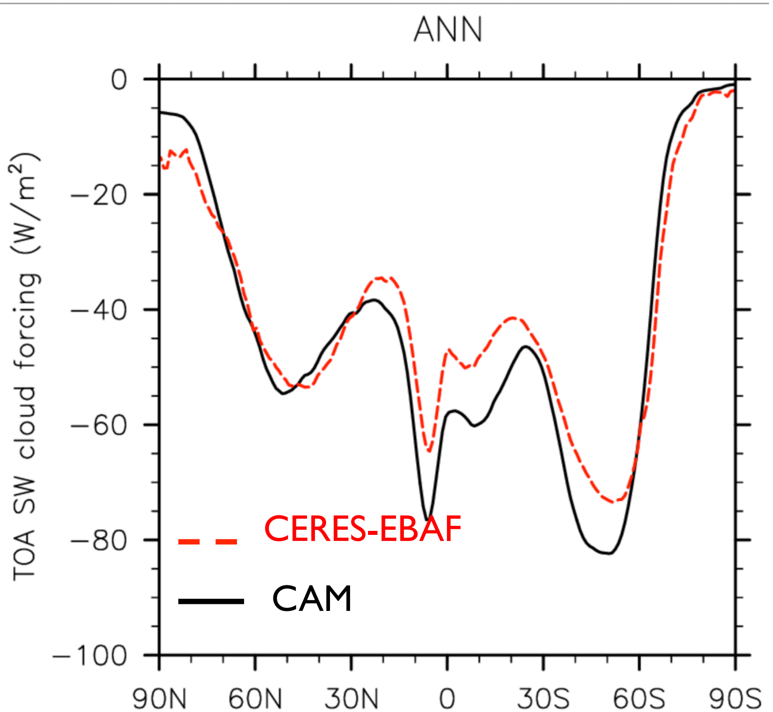


Negative radiative imbalance and surface temperature cooling

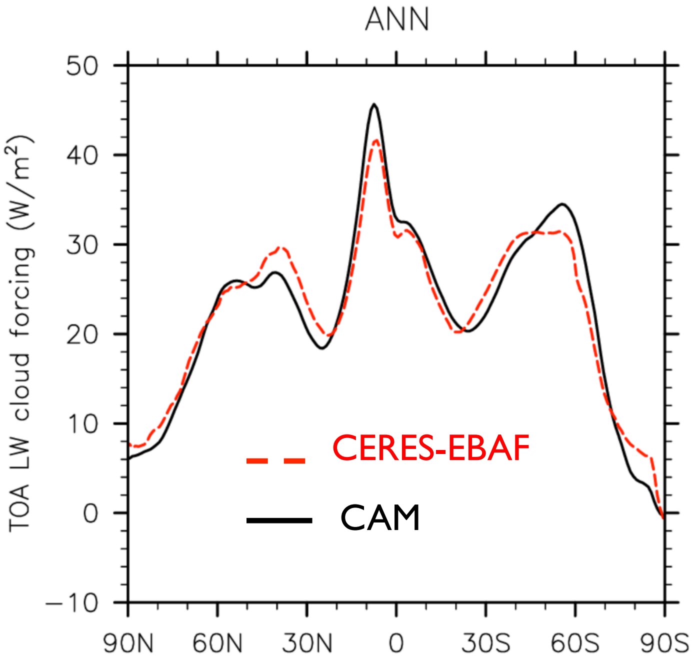
Example: Tuning of a recent CAM6 run

Zonal SW and LW cloud forcing

SWCF too strong



LWCF



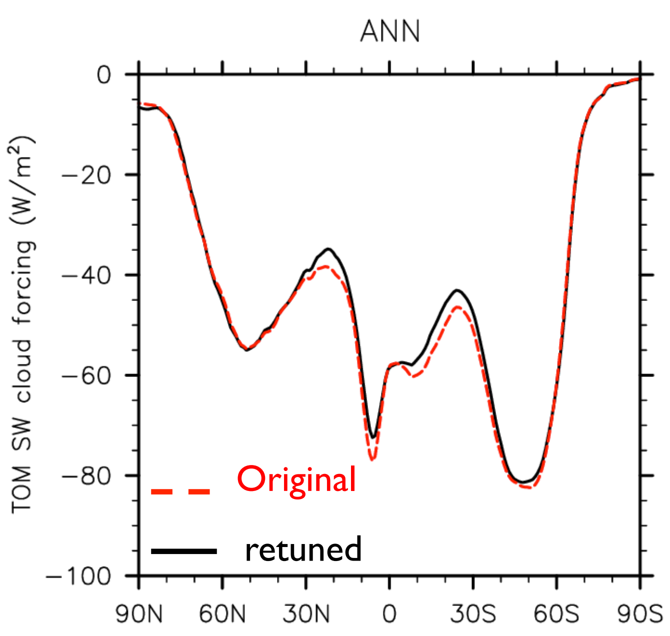
SWCF: global error of 5 W/m2
LWCF: global error of 0.2 W/m2

=> This could explain the cooling

Example: Tuning of a recent CAM6 run

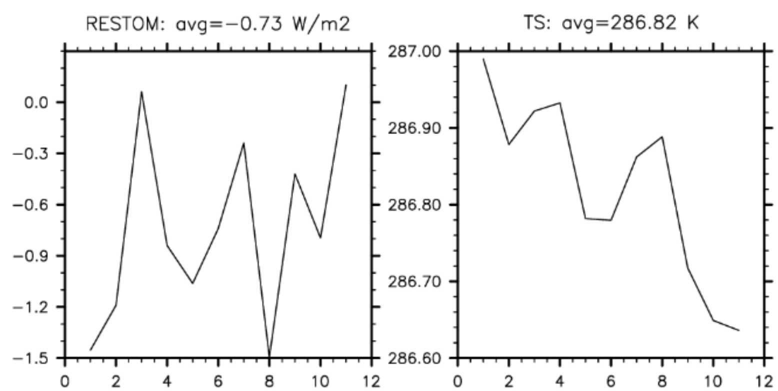
Adjust parameters to decrease SCWF => Better radiative balance

SCWF

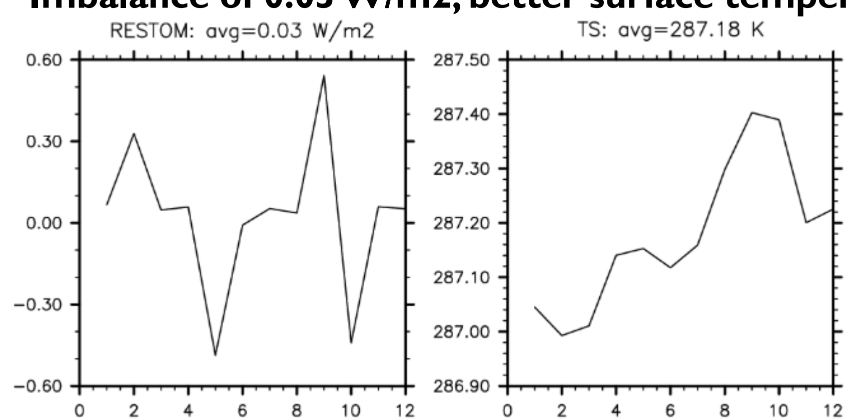


Globally SCWF bias is reduced by 1.7 W/m2

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

In Summary

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

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

- For instance, **TOA radiative balance** needs to be tuned or the model would quickly drifted away from observations

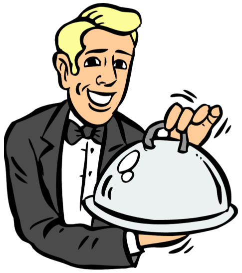
=> We provided an example of tuning the radiative banlance by improving shortwave cloud forcing (SWCF)

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 ?

Extra slides

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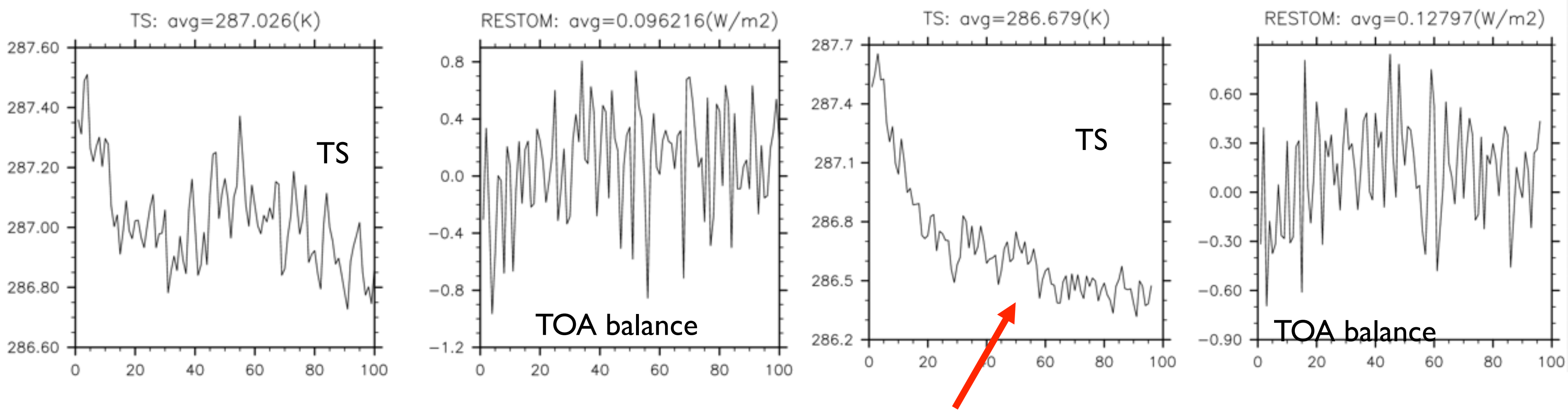
Example of tuning challenge

CESM1.1: Finite volume (FV)

CESM1.2: Spectral element (SE)

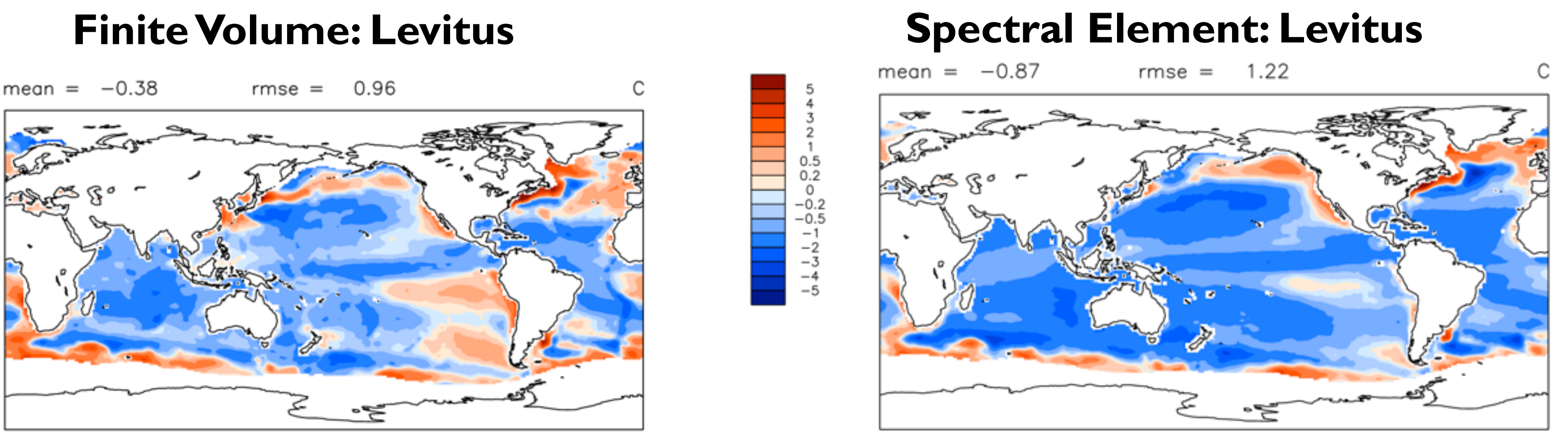


"Houston, we have problem"

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

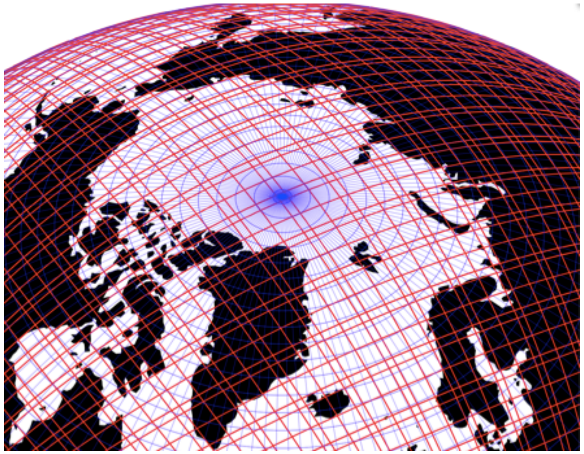
SST: 0.5K colder than FV

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

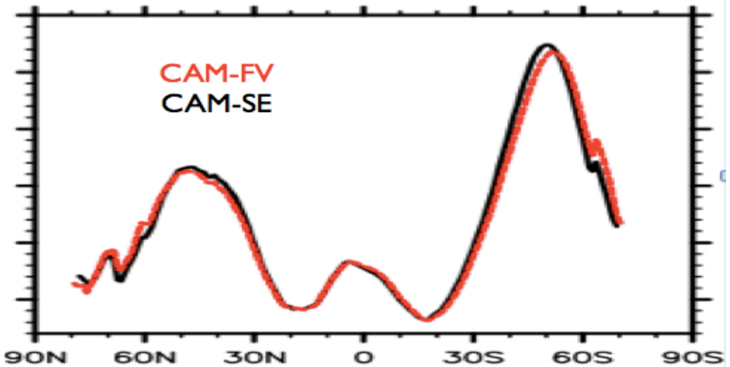
New software to generate topography (accommodate unstructured grids and enforce more physical consistency)

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

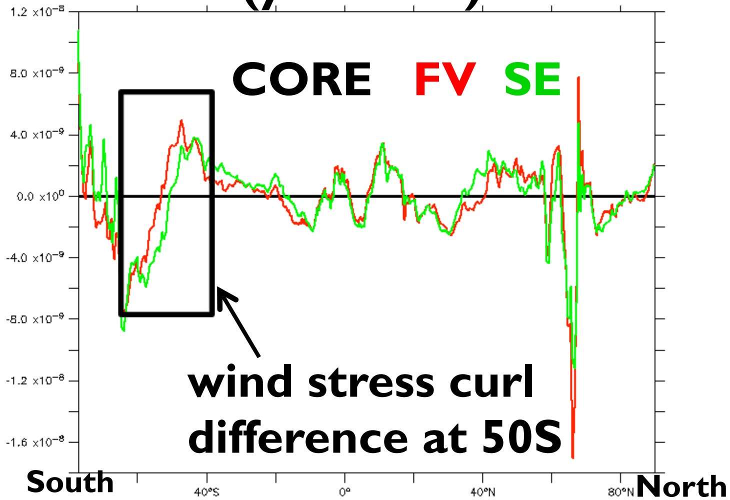


TAUX in CAM-SE:

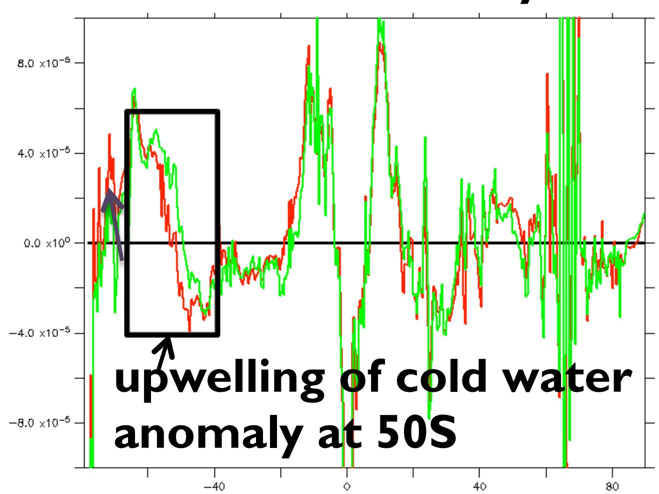
- Location: maximum moves north
- Amplitude increases

Mechanism responsible of SST cooling in SE

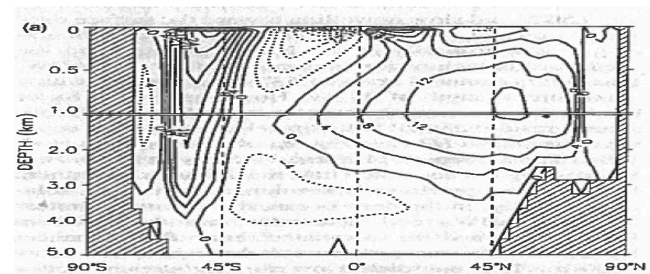
Wind stress curl anomaly (year 1-10)



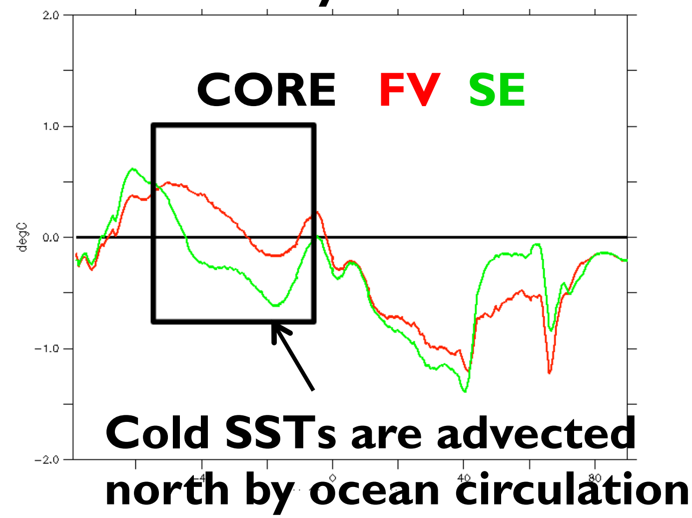
100-m vertical velocity anomaly



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