Assessing and tuning model parameterizations

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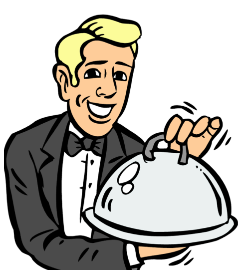
Recipe to include a new parameterization

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
  - Tuning at a glance
  - Issues when coupling
- Examples of tuning
  - Tuning of a recent CESM2 run

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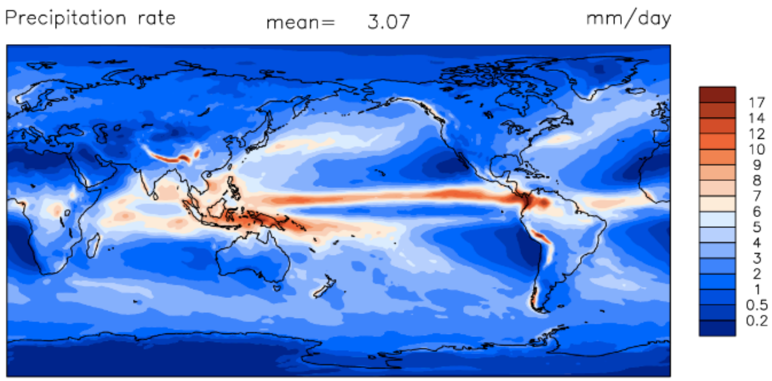
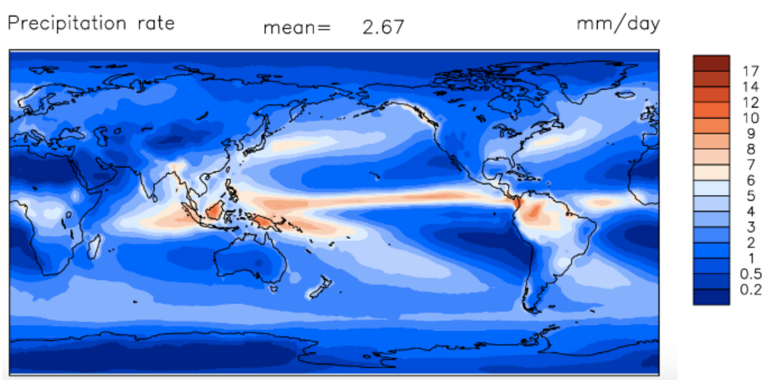
Climate runs

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)

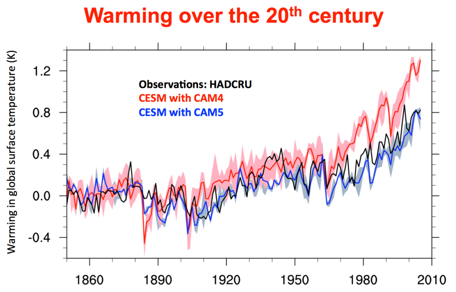
- **AMIP runs** — Standard protocol for testing GCMs
  GCM is constrained by realistic sea surface temperature and sea ice from 1979-2005

- **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 20th century

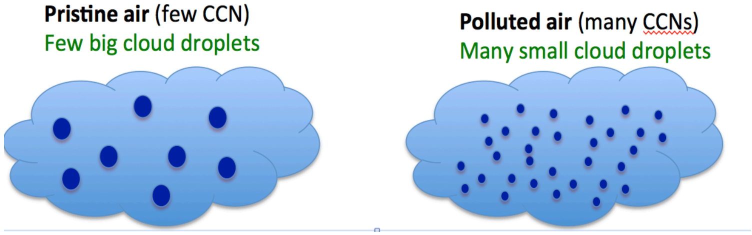


Typical climate runs to assess parameterization

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)

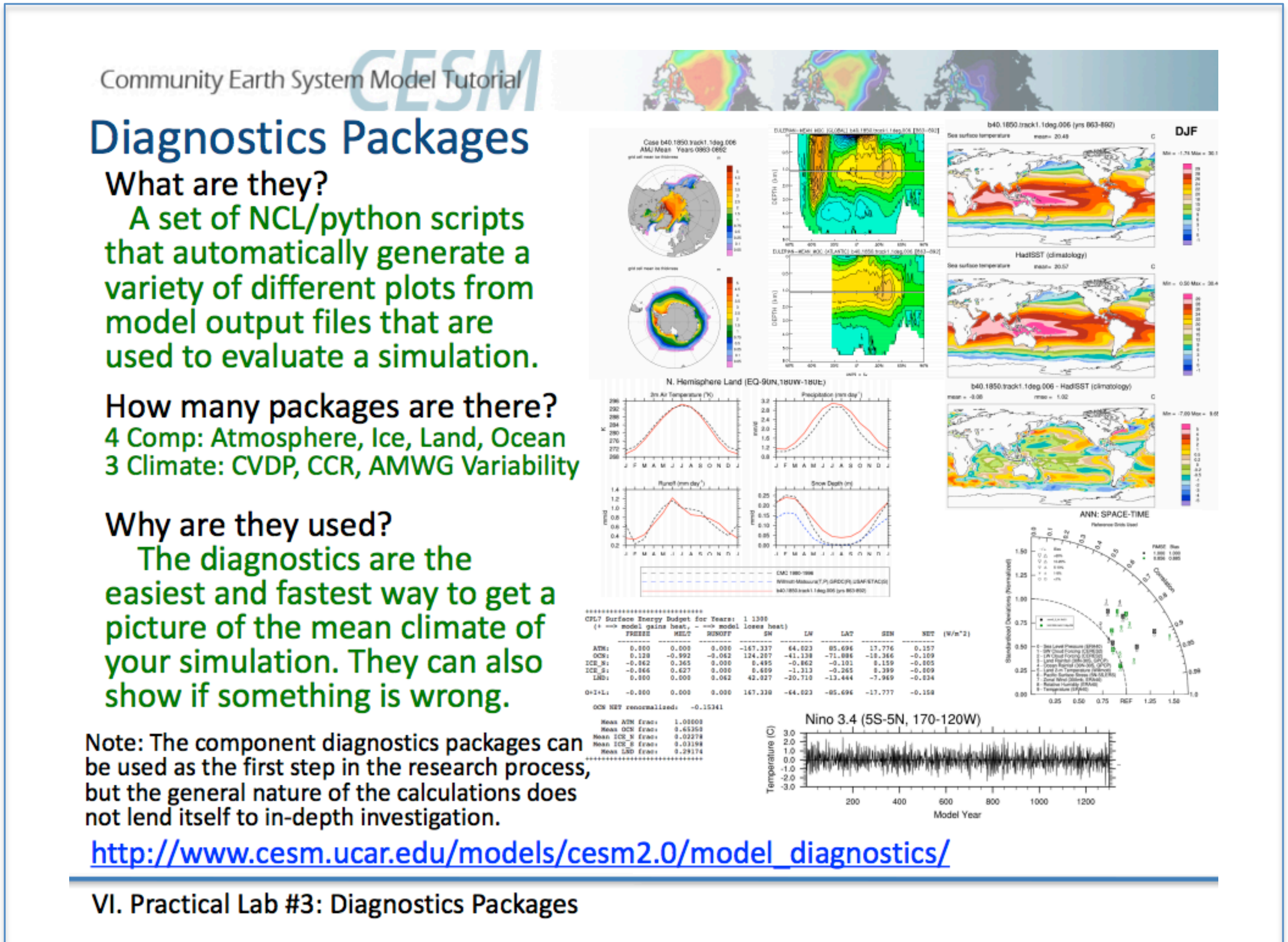
Climate sensitivity runs

- **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 Phillips

The AMWG diagnostics package

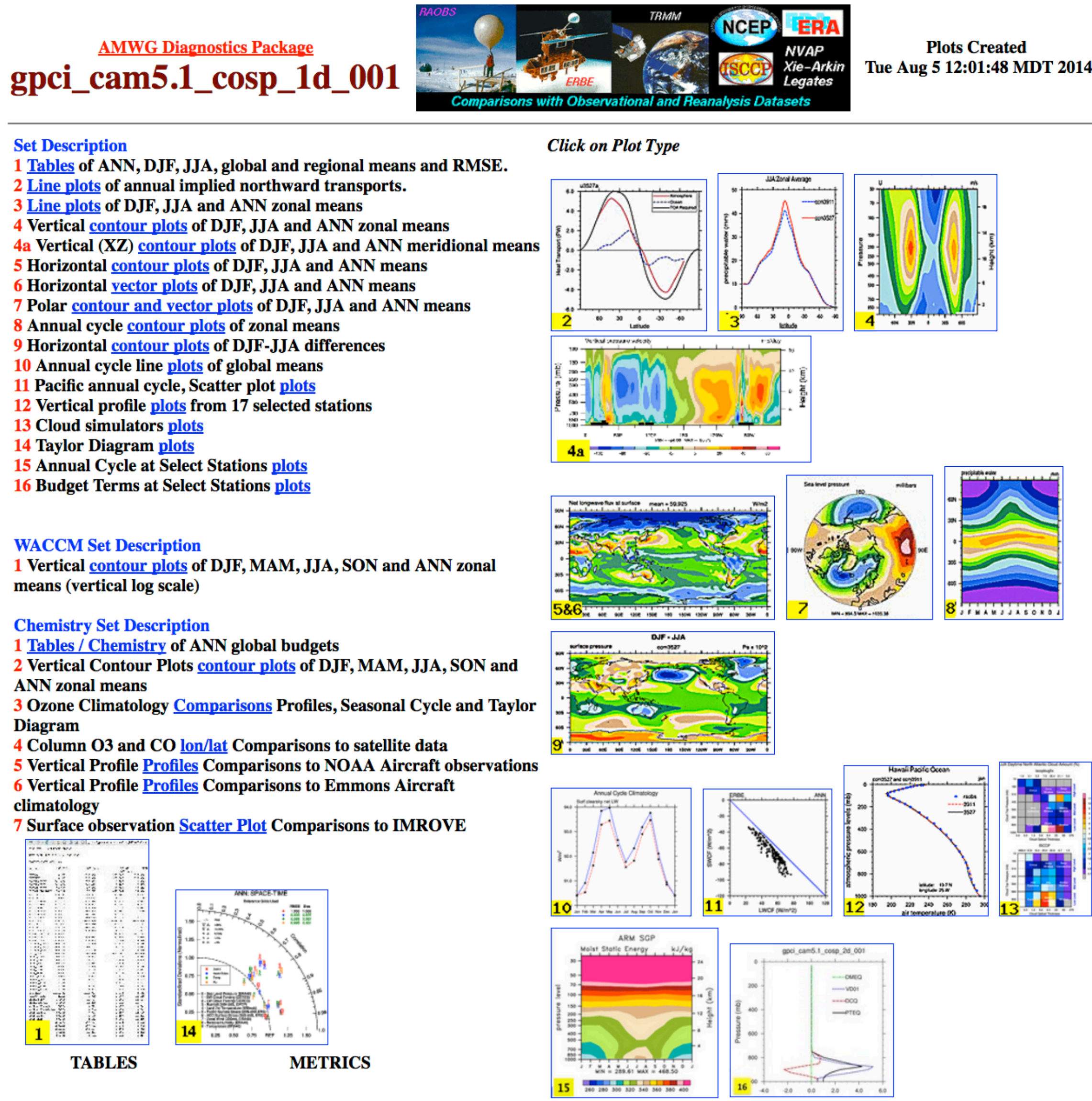
Capabilities of AMWG diag

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



AMWG Diagnostics Package
gpci_cam5.1_cosp_1d_001

RAOBS TRMM NCEP ERA NVAP Xie-Arkin Legates ISCCP ERBE
Comparisons with Observational and Reanalysis Datasets

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)

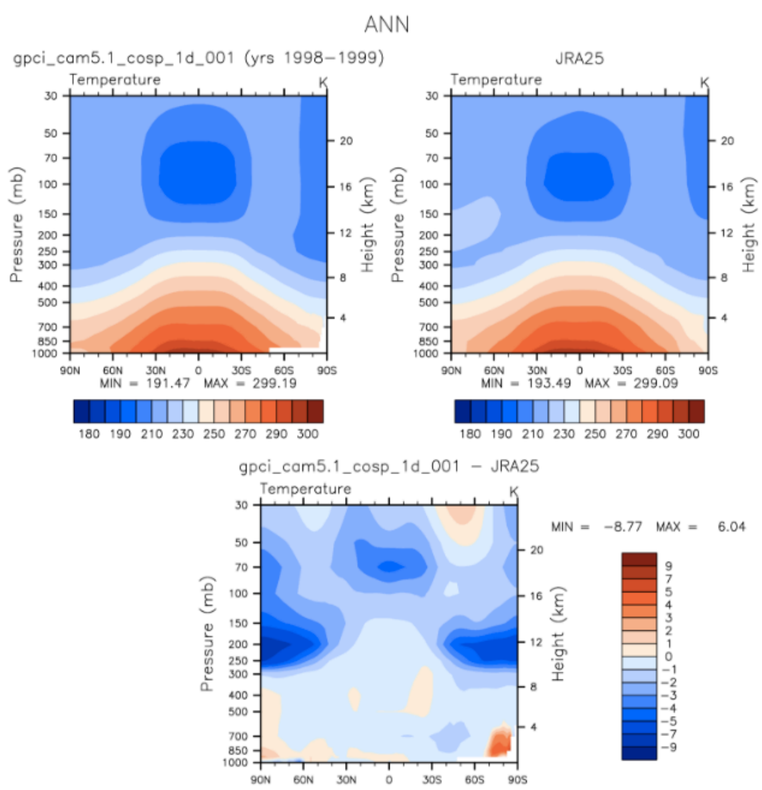
Chemistry Set Description
1 Tables / Chemistry of ANN global budgets
2 Vertical Contour Plots contour plots of DJF, MAM, JJA, SON and ANN zonal means
3 Ozone Climatology Comparisons Profiles, Seasonal Cycle and Taylor Diagram
4 Column O3 and CO lon/lat Comparisons to satellite data
5 Vertical Profile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

Click on Plot Type

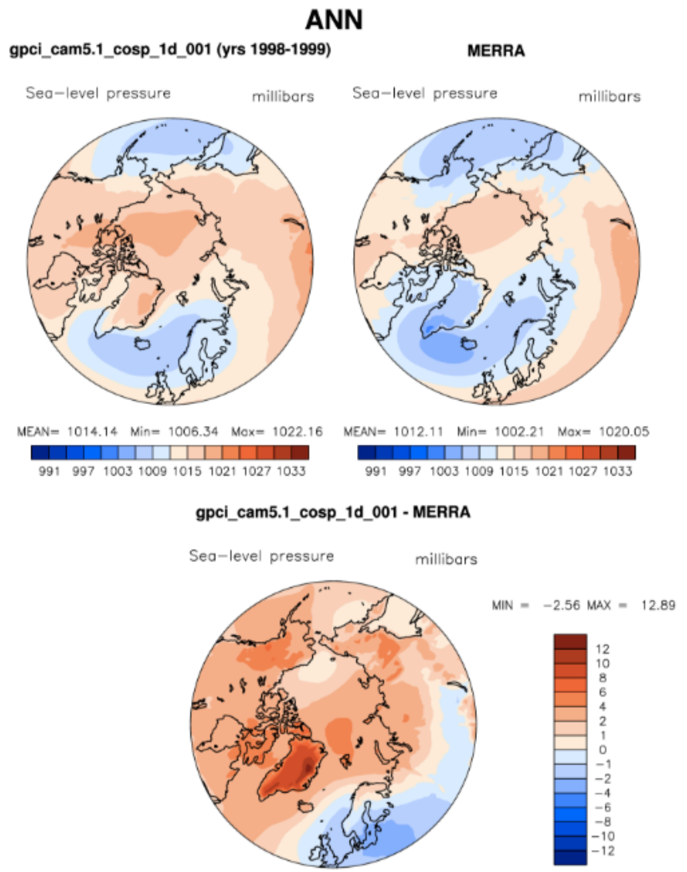
TABLES
METRICS

The AMWG diagnostics package: Examples

Zonal mean: Temperature



Polar plots: Sea level pressure

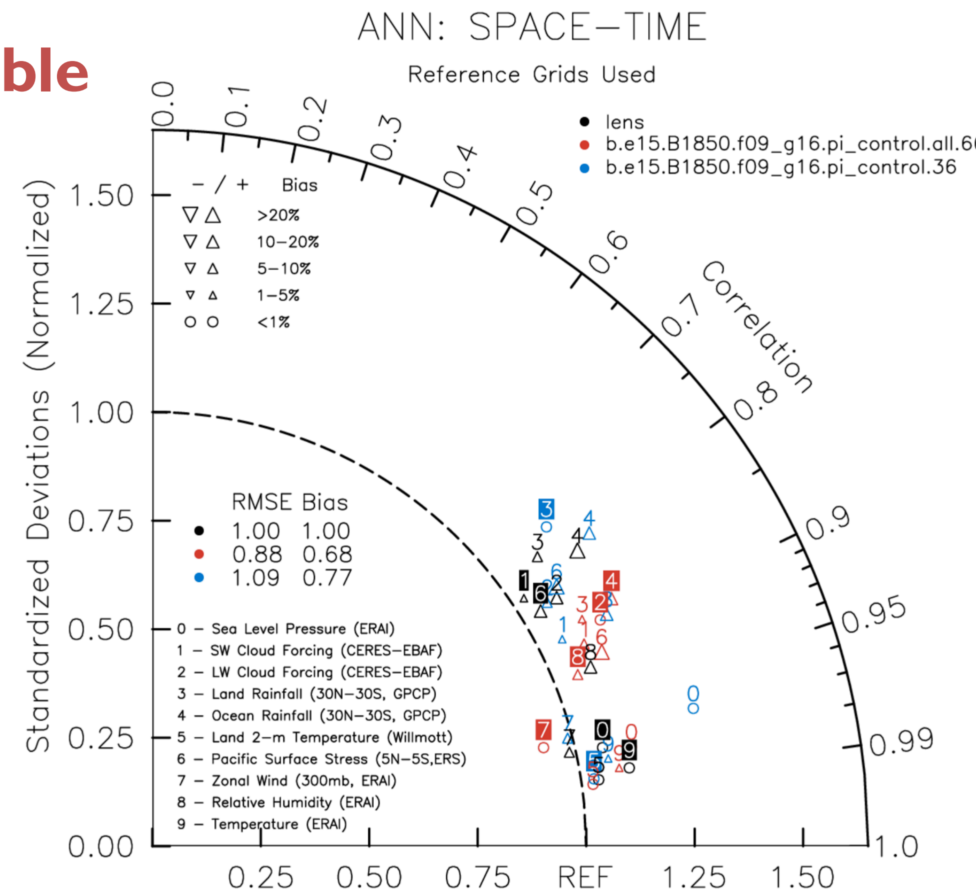


Taylor diagrams

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



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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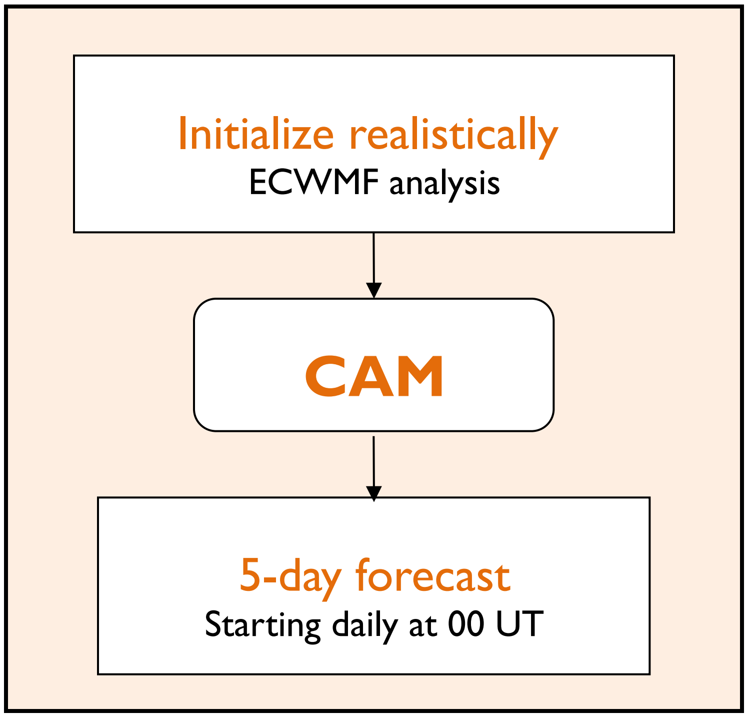
Methodology for the forecasts

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.

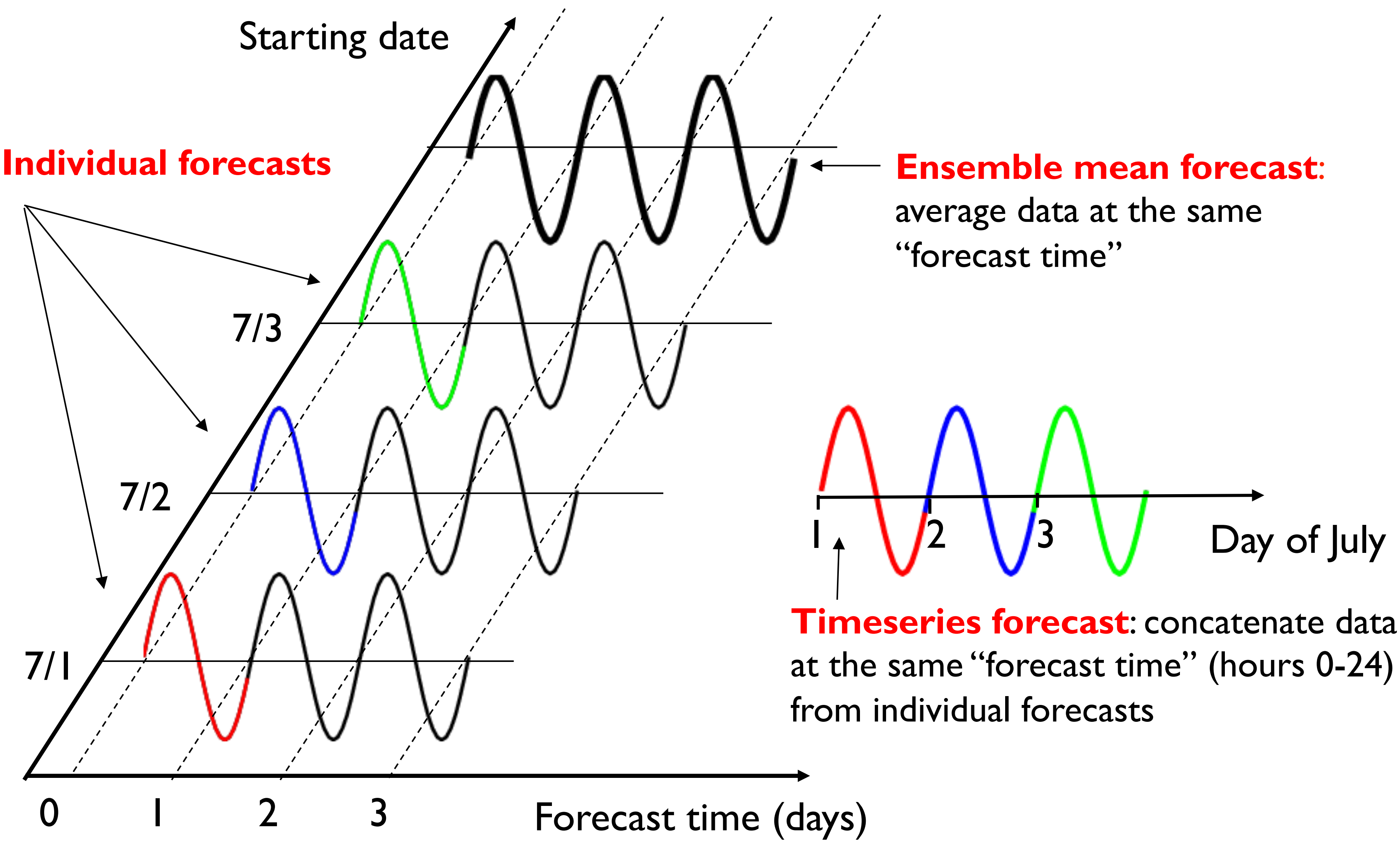
Advantages

- **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.**

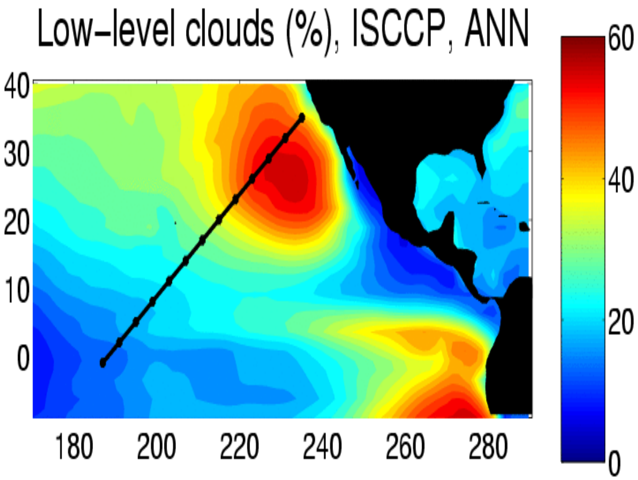
Limitations

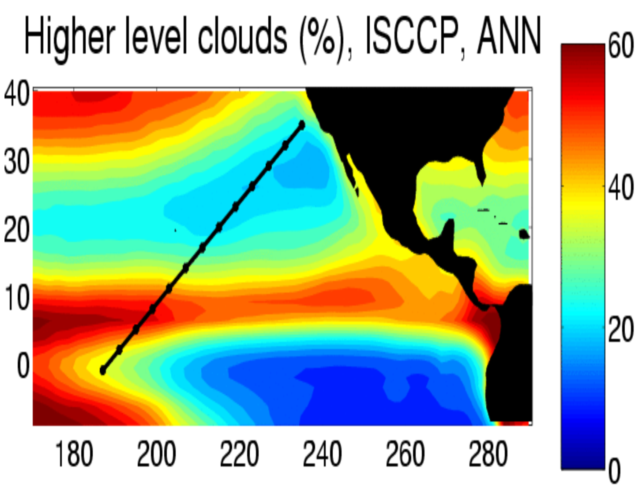
Accuracy of the atmospheric state ?

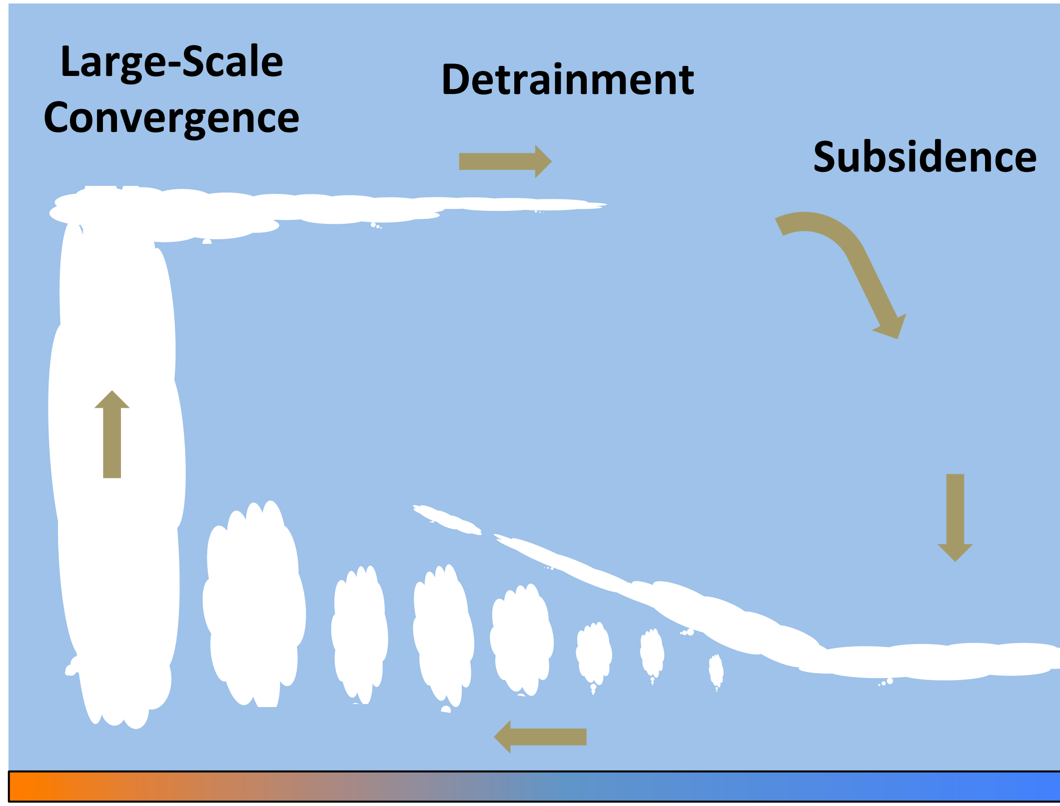
Ensemble mean forecast and timeseries forecast



Cloud regimes along Pacific Cross-section

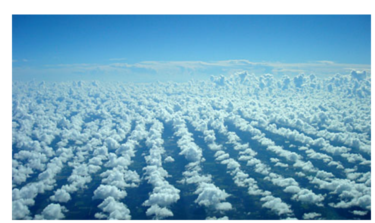




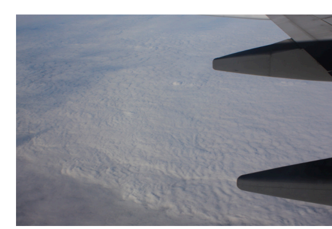


Deep convection

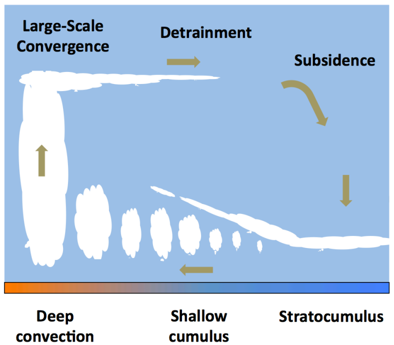
Shallow cumulus



Stratocumulus



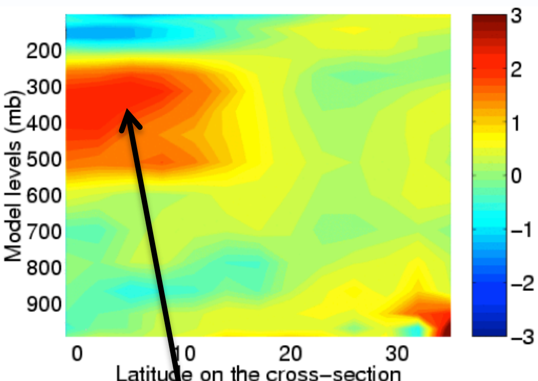
Forecast and climate errors along Pacific Cross-section (JJA 1998)



Let's run the model in forecast mode and climate mode and look at the temperature error along Pacific cross-section

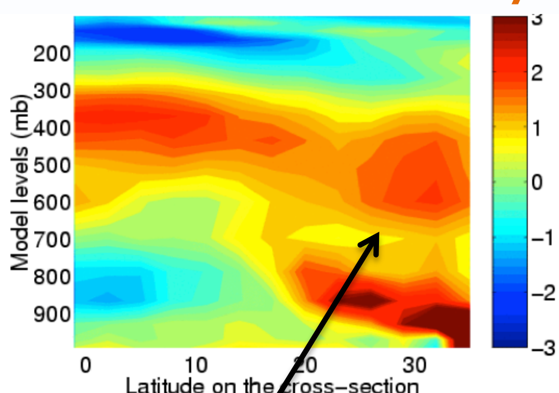
Climate bias appears very quickly
- **where deep convection is active, error is set within 1 day**
- **5-day errors are comparable to the mean climate errors**

Forecast errors after 1 day



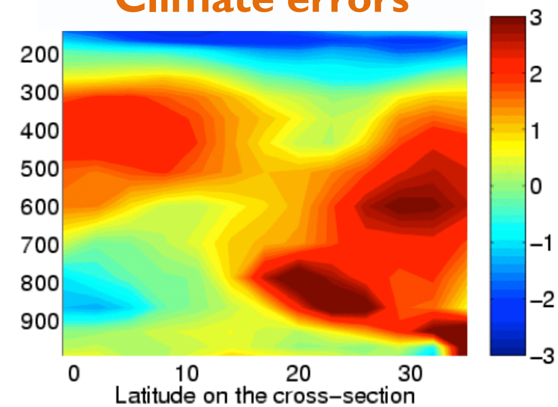
Large error where deep convection is active

Forecast errors after 5 days



Error develops in the rest of the domain

Climate errors



Error looks basically the same in climate mode

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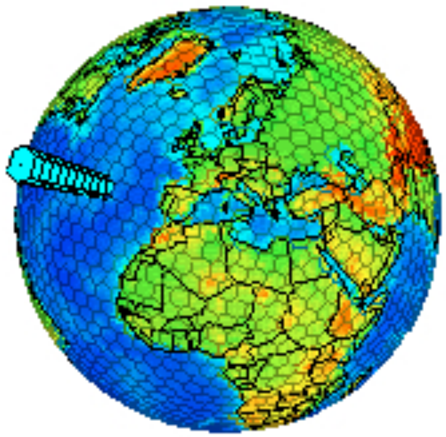
Single Column Modeling (SCM)



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

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

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

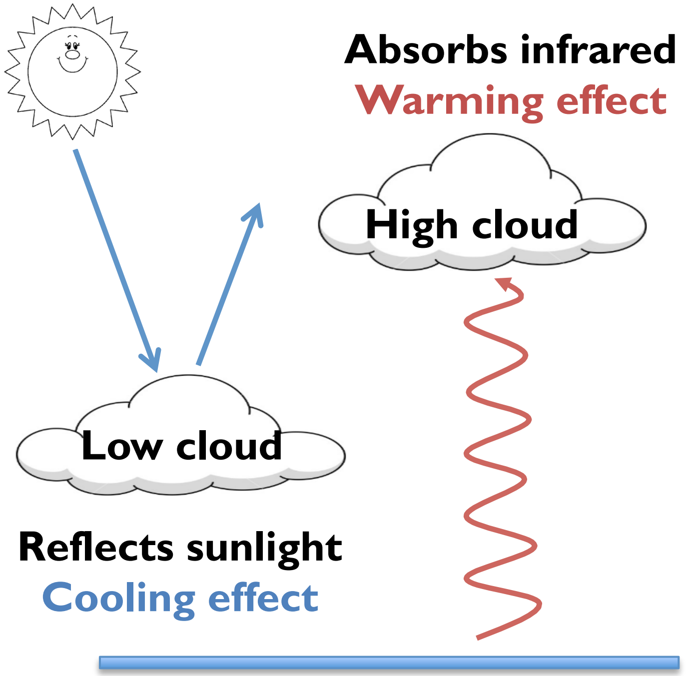
- **Data requirements (tendencies needs to be accurate to avoid growing error)**
- **Cannot detect problem in feedback**

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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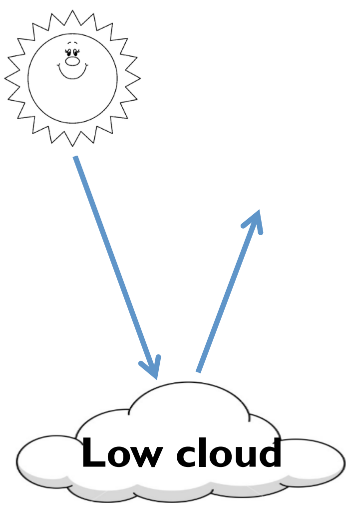
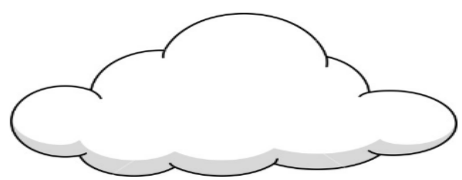


Reflects sunlight
Cooling effect

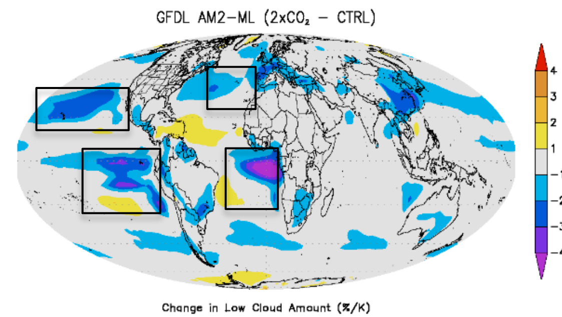
In a warmer climate

Less low cloud
Warming effect
Positive feedback

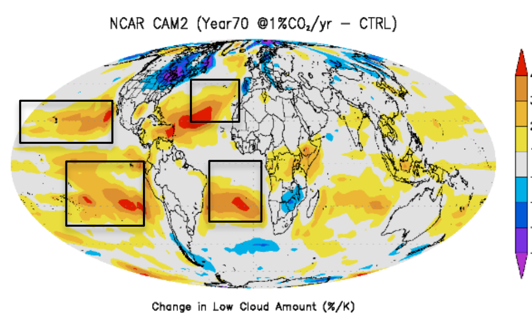


More low cloud
Cooling effect
Negative feedback

Low cloud feedback in 2 US models



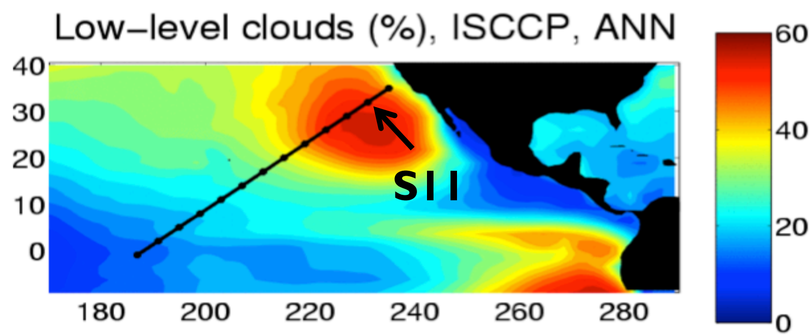
GDFL: Positive feedback



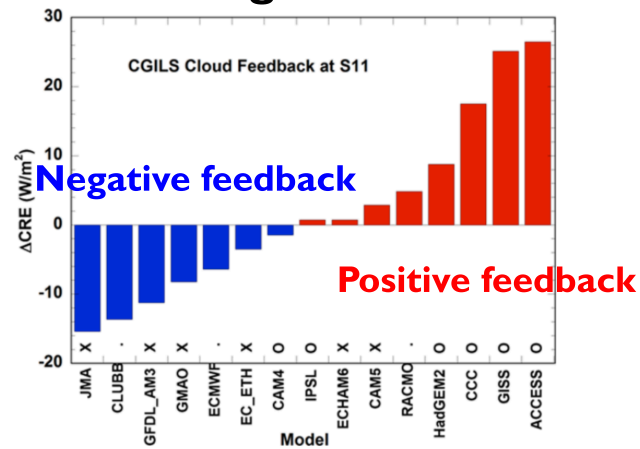
NCAR: Negative feedback

Example: CGILS study (Zhang et al, 2013)

Goal: Understanding mechanisms of low cloud feedback in SCM



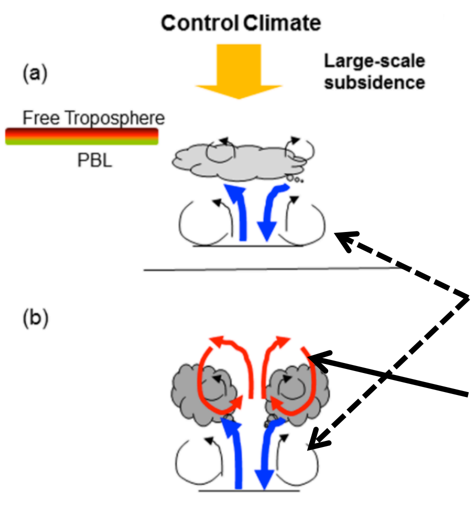
SCM experiments to determine low cloud feedback sign at S11 in 15 models



Models with no active shallow convection

Models with active shallow convection

Proposed mechanism

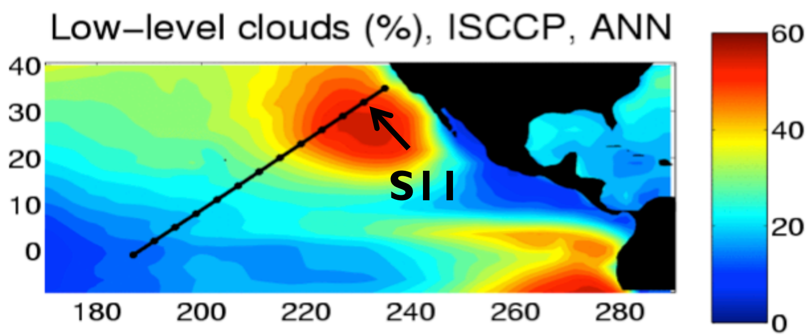


PBL scheme is moistening the cloud (blue arrow)

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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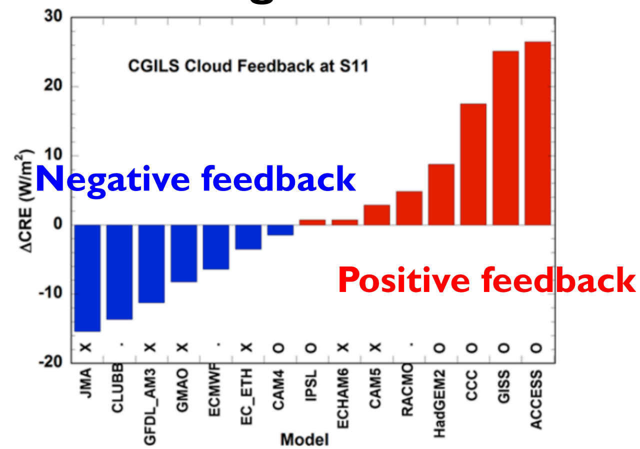

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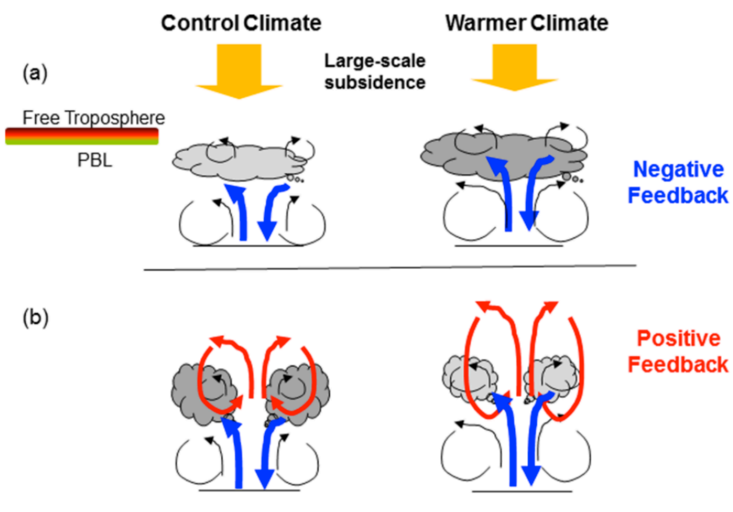

In warmer climate

- **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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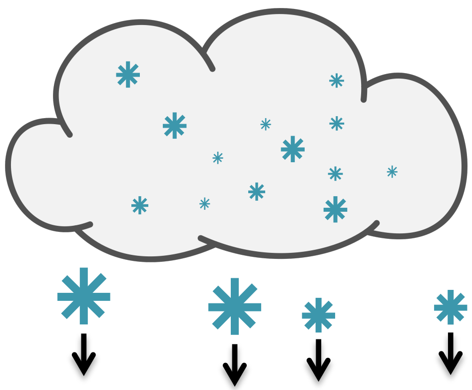
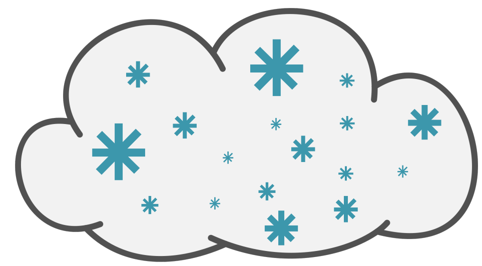
Model tuning

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

Tuning knobs = parameters weakly constrained by observations

Dcs = Threshold diameter to convert cloud ice particles to snow





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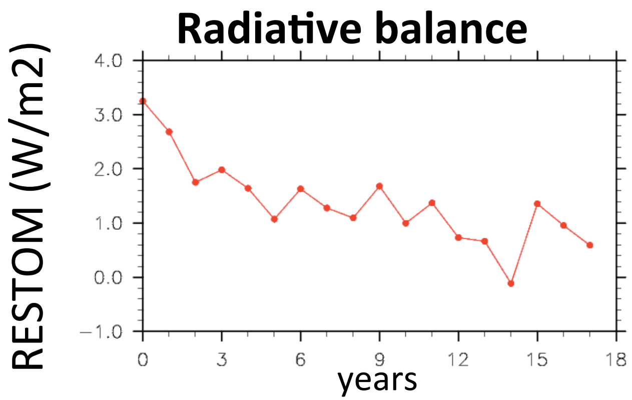
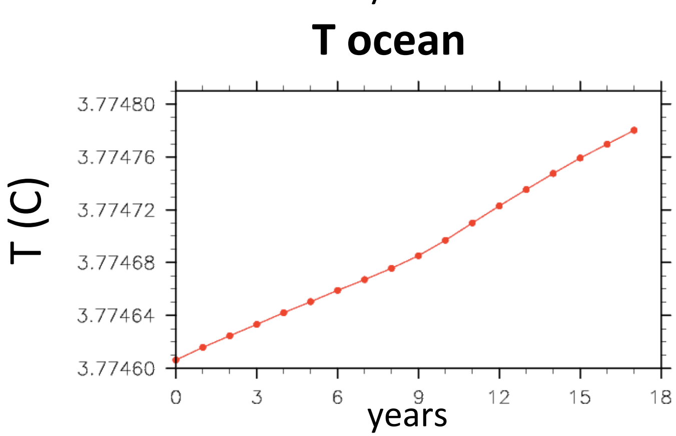
Top of atmosphere radiative balance should be near zero





Other targets when tuning

- **Cloud forcing**
- **Precipitation**
- **ENSO amplitude**
- **AMOC**
- **Sea-ice thickness/extent**

Dilemmas while tuning

- **Subjectivity of tuning targets**

  Tuning involves choices and compromises
  Overall, tuning has limited effect on model skills

- **Tuning for pre-industrial ⇔ Tuning for present day**

  Pre-industrial: Radiative equilibrium
  Present day: Available observations

- **Tuning individual components ⇔ Tuning coupled model**

  Tuning individual components is fast
  But no guarantee that results transfer to coupled model

- **Tuning exercise is very educative**

  We learn a lot about the model during the tuning phase.

Dilemmas while tuning

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Coupling = Unleashing the Beast

AMIP run

- Prescribed SSTs
- No drift

Coupled run

- Fully active ocean
- Coupled bias and feedback

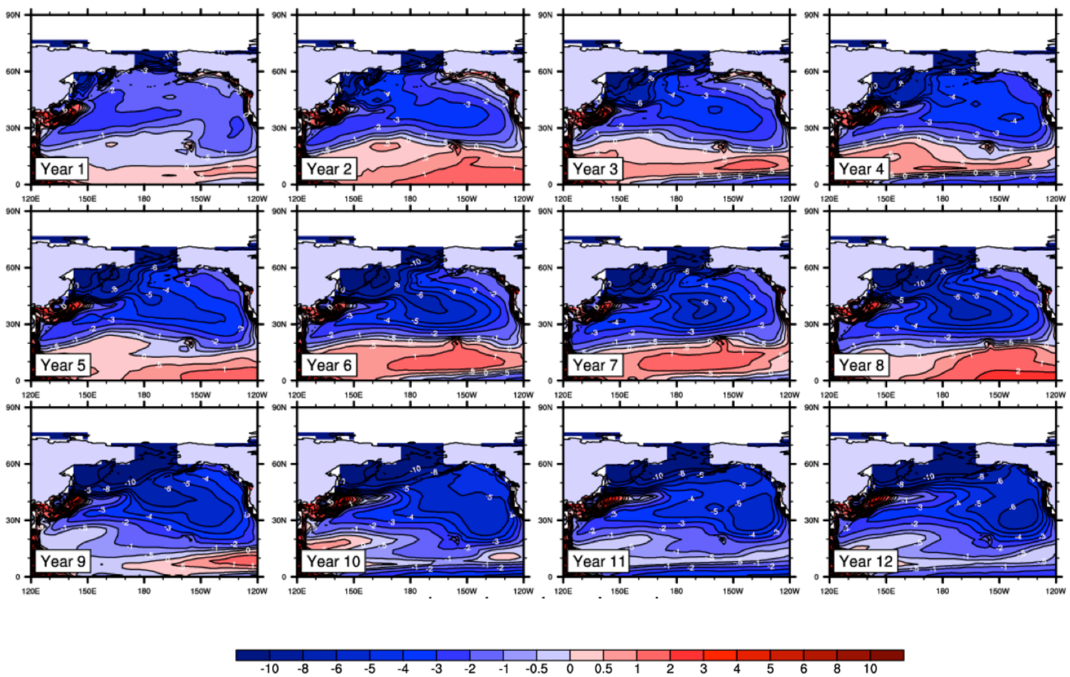
Simulation that can look acceptable in standalone can produce runaway coupled simulation

Example of unleashing the beast (1)

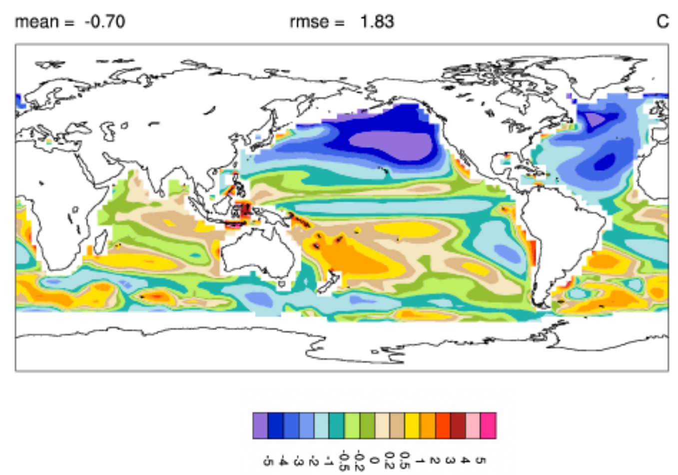
Tuning CAM5 (CESM1 development, 2009)

- Tuning was done in CAM: looks like "perfect" simulation
- In coupled mode: strong cooling of the North Pacific (bias > 5K)

Evolution of the SST errors (K)



Mean SST errors (K)



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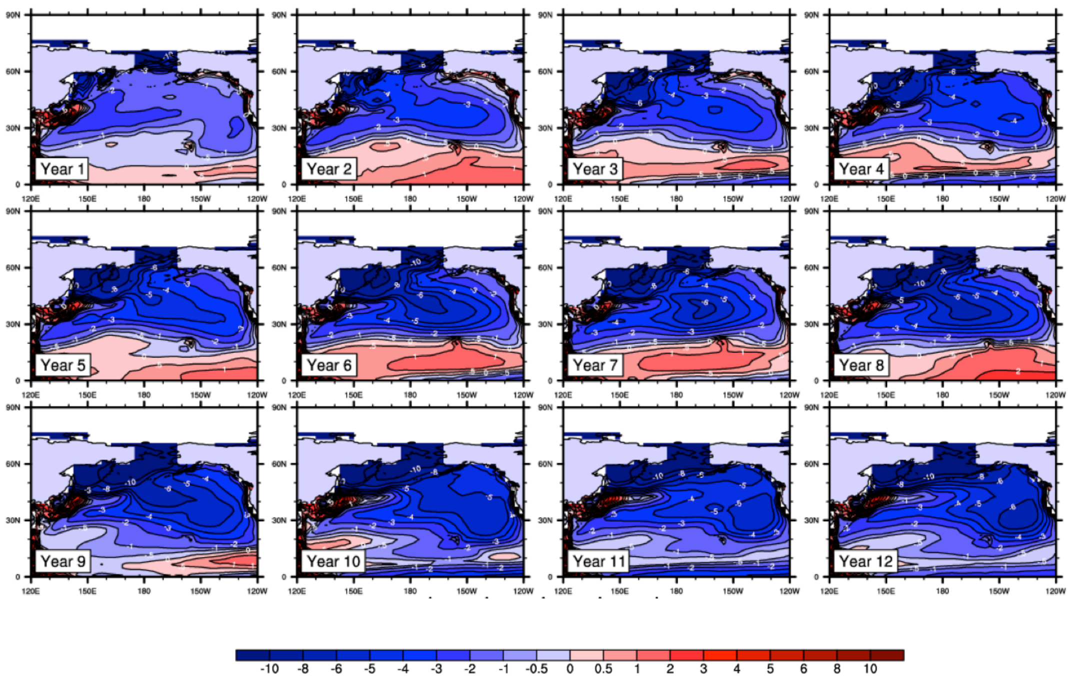
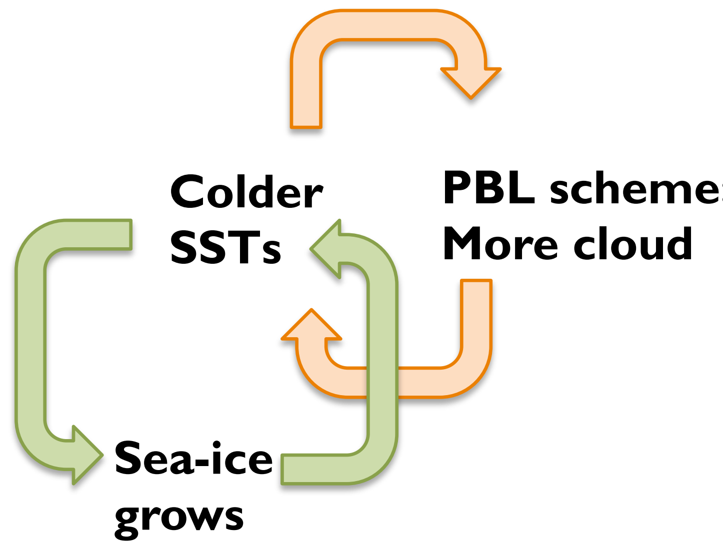


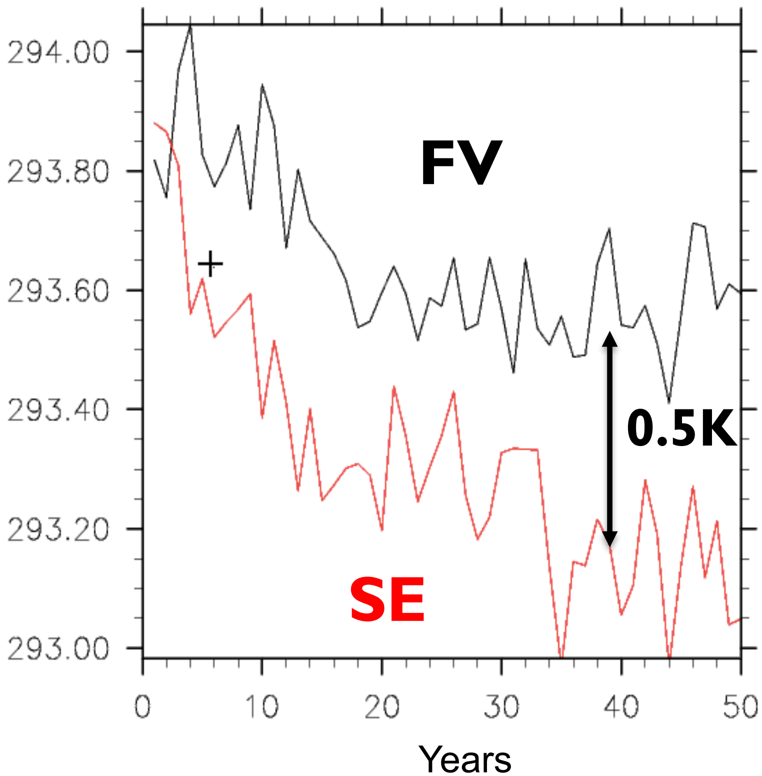


Example of unleashing the beast (2)

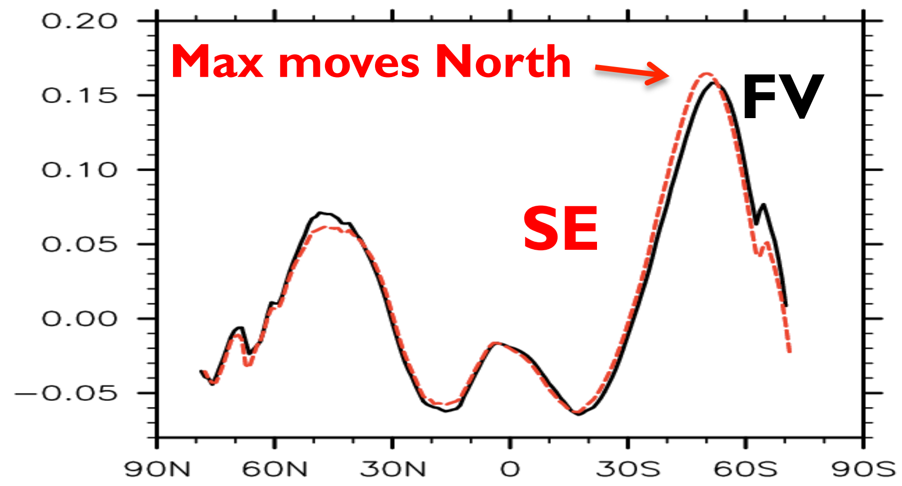
Spectral Element dycore development (CESM1.2, 2013)

- **In CAM standalone: Finite Volume (FV) and Spectral Element (SE) dycores produces very similar simulations.**
- **In coupled mode: SSTs stabilize 0.5K colder with SE dycore**

SSTs (K)



Zonal Surface Stress (N/m2)



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

Outline

Part 1: Assessing the parameterization

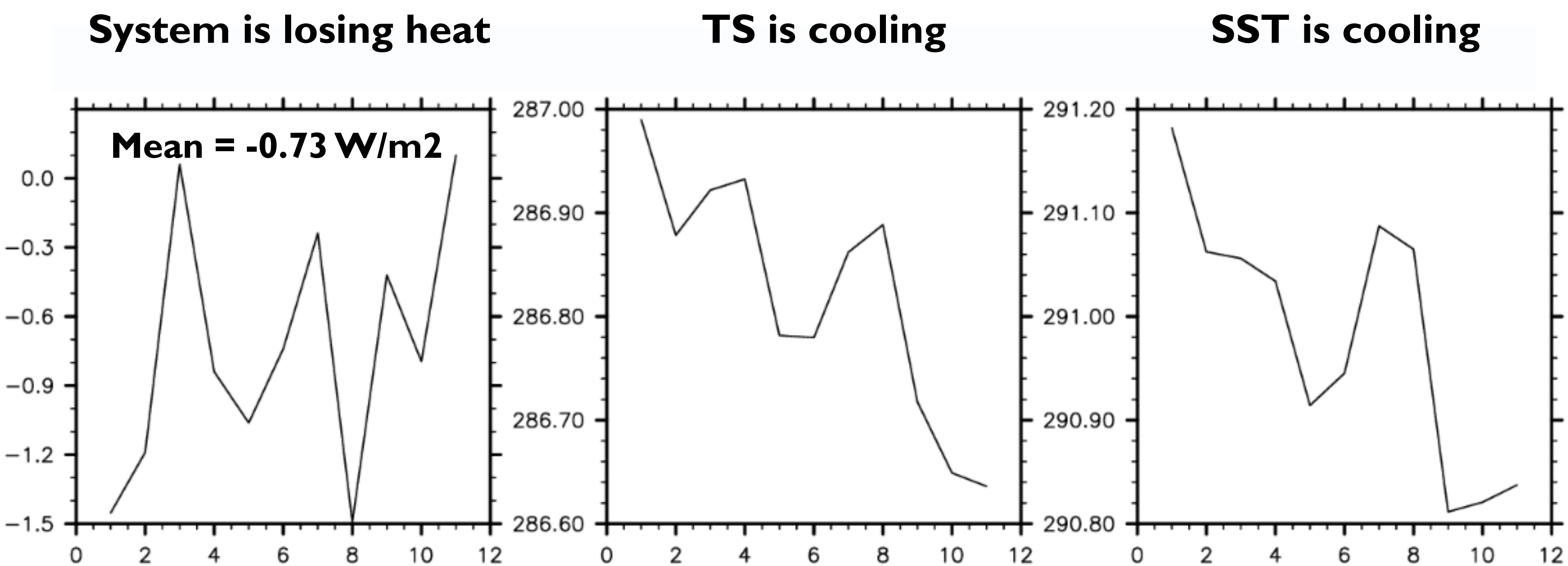
- The straightforward road
  - Climate runs
- Alternate ways
  - Forecasts runs
  - Single Column Model

Part 2: Tuning the model

- Tuning basics
  - Tuning at a glance
  - Issues when coupling
- **Examples of tuning**
  - **Tuning of a recent CESM2 run**

Example: Tuning of a recent CESM2 run

Timeseries of radiative imbalance and surface temperature

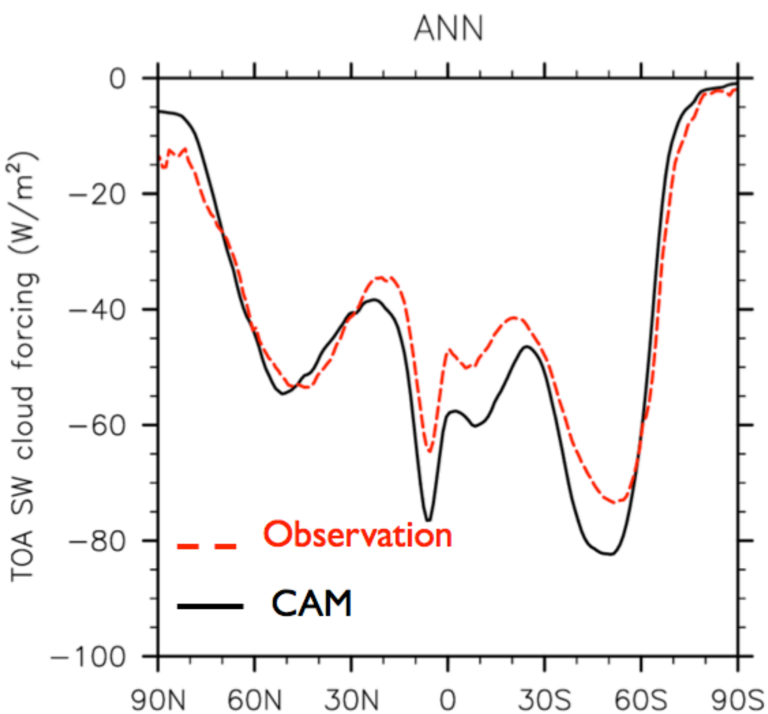


Negative radiative imbalance and surface temperature cooling

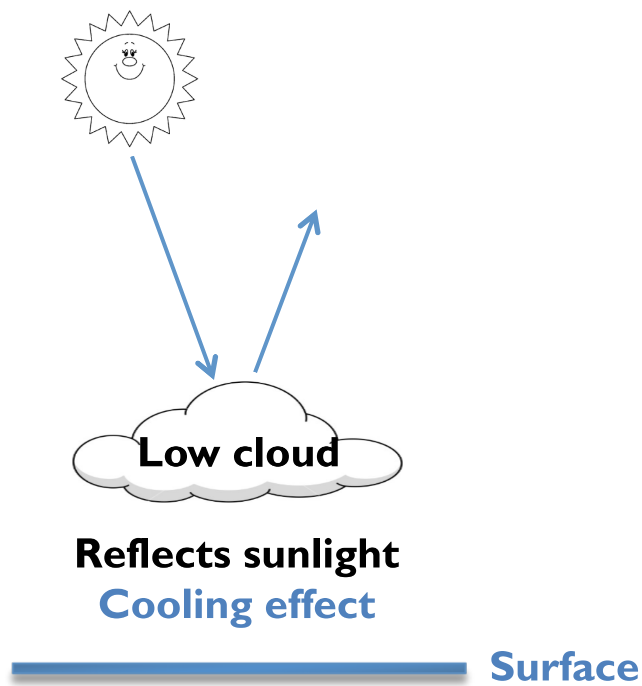
Example: Tuning of a recent CESM2 run

Zonal Shortwave Cloud Forcing (SWCF)

SWCF too strong



SW cloud effect on climate

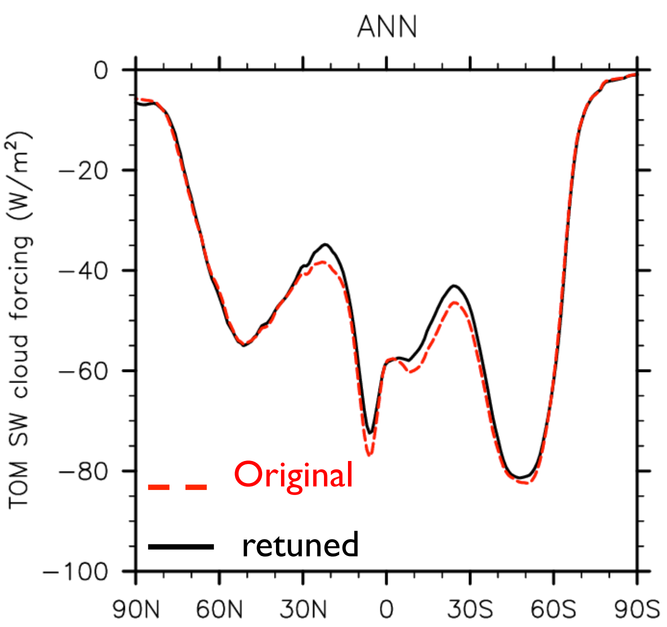


SWCF: global error of 5 W/m2 => This could explain the cooling

Example: Tuning of a recent CESM2 run

Adjust parameters to decrease SCWF => Better radiative balance

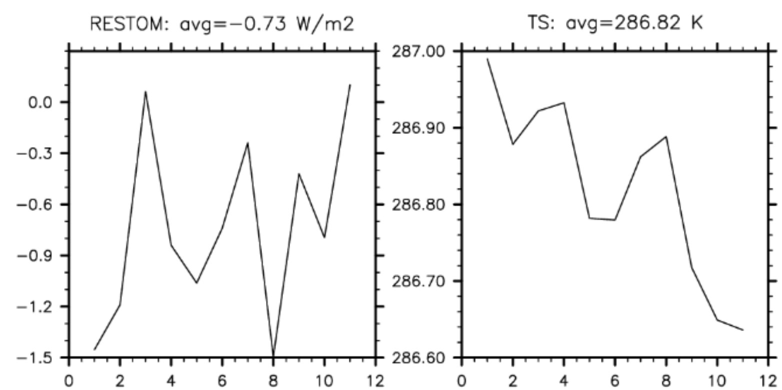
SCWF



Globally SCWF bias is reduced by 1.7 W/m2

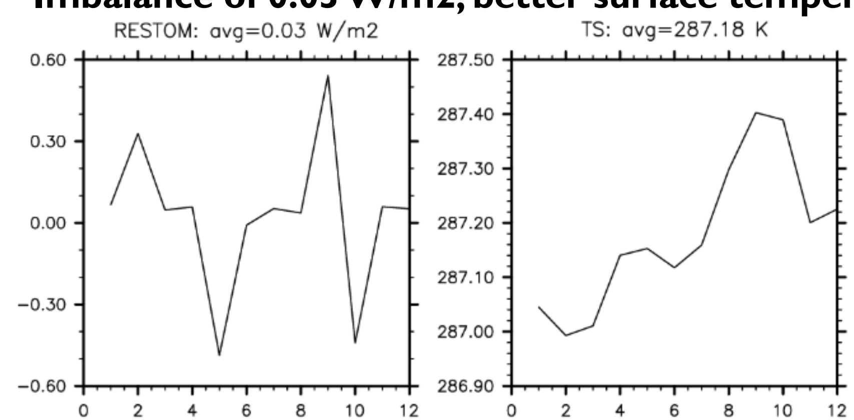
Original:

Imbalance of -0.73 W/m2; surface temperature cooling



Retuned:

Imbalance of 0.03 W/m2; better surface temperature

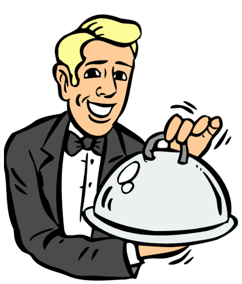


We completed the recipe to include a new parameterization

Developing the parameterization

Assessing the parameterization

Tuning the model



Bon appétit

We are ready for a new model

Questions ?