Inside the CESM Factory: Model Development and Tuning

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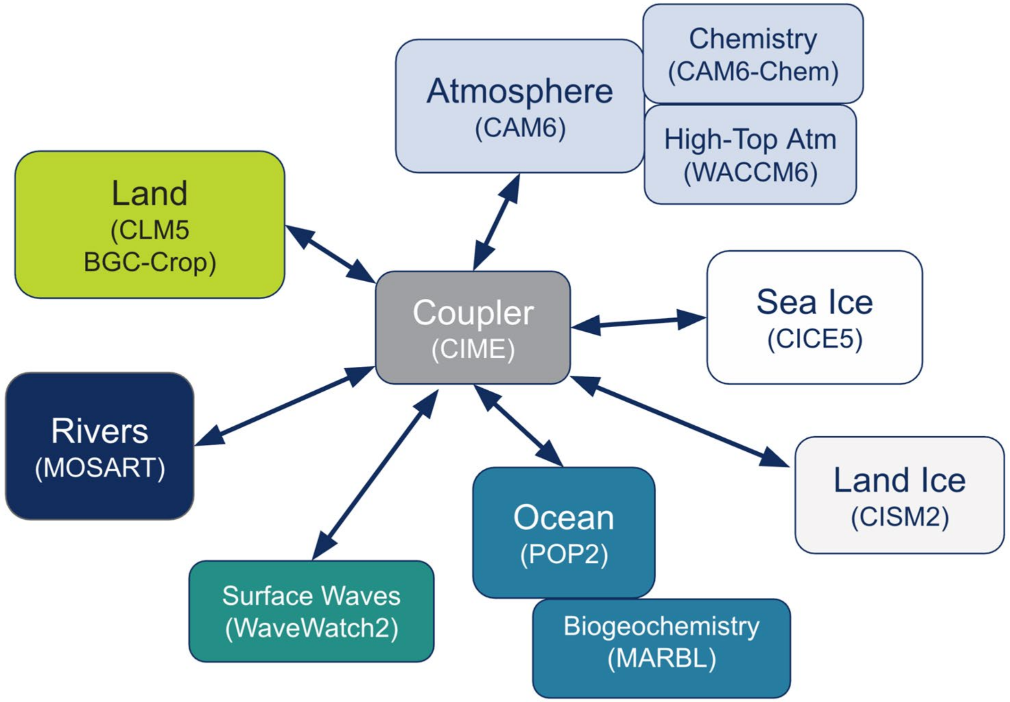
Outline

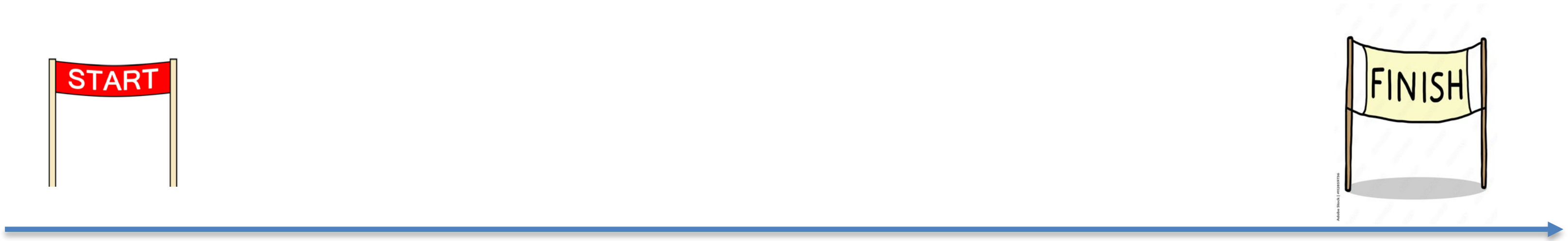
Timeline of building CESM2

The art of tuning

Model development tales



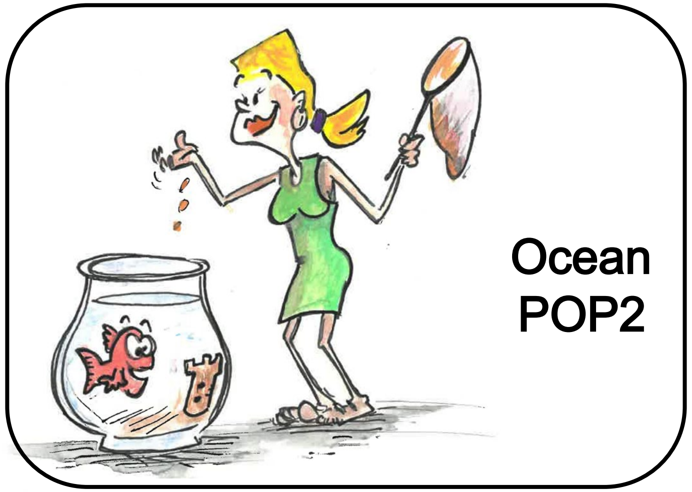
Timeline of building CESM2

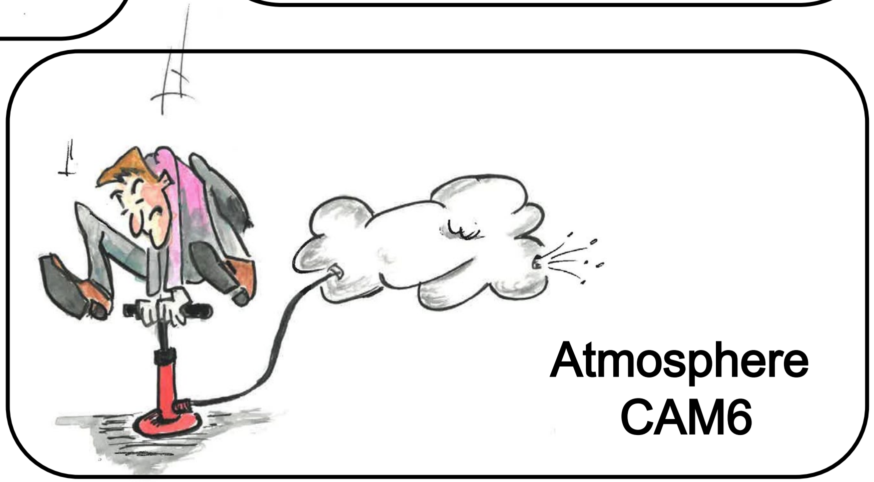


CESM2: Development of the individual components

Phase 1: “Let’s build the model components” (5 years)

- For CESM2: the effort began around 2010
- Individual components were built within each working group



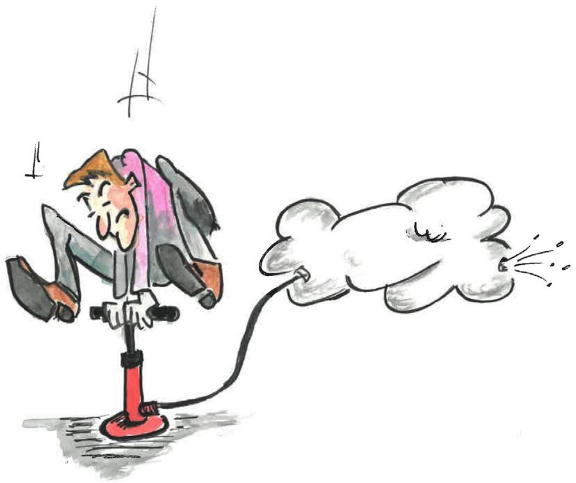


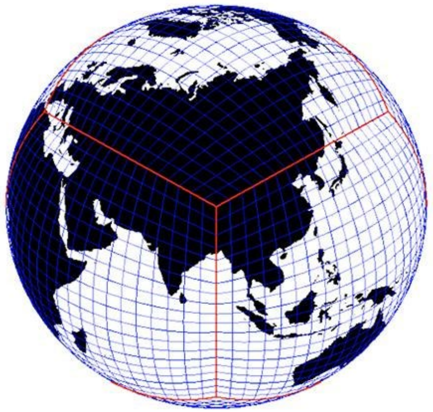
CESM2: Development of the individual components

Phase 1: "Let's build the model components" (5 years)

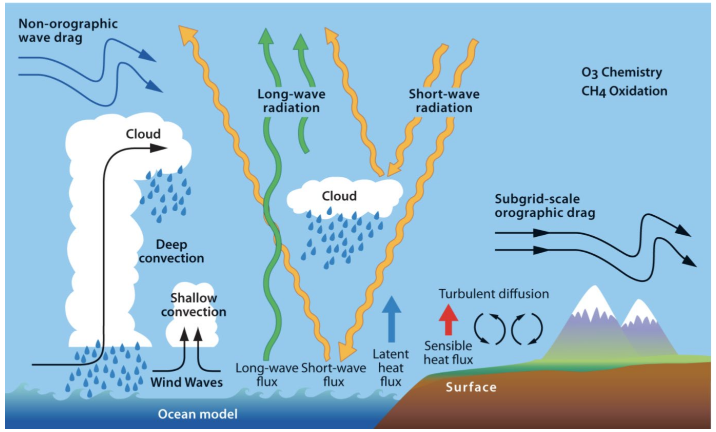
During the building phase, working groups focus on aspects of their model they want to improve

Atmosphere
CAM



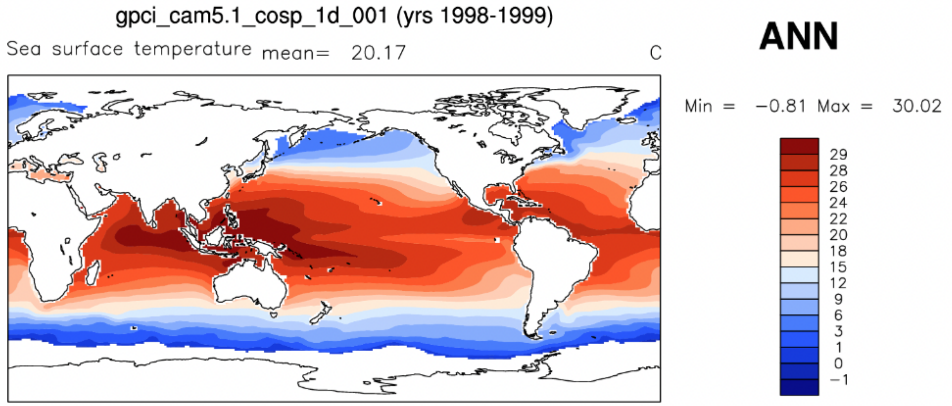


Dynamical core, resolution



Physical parameterizations

Many uncoupled simulations + analysis



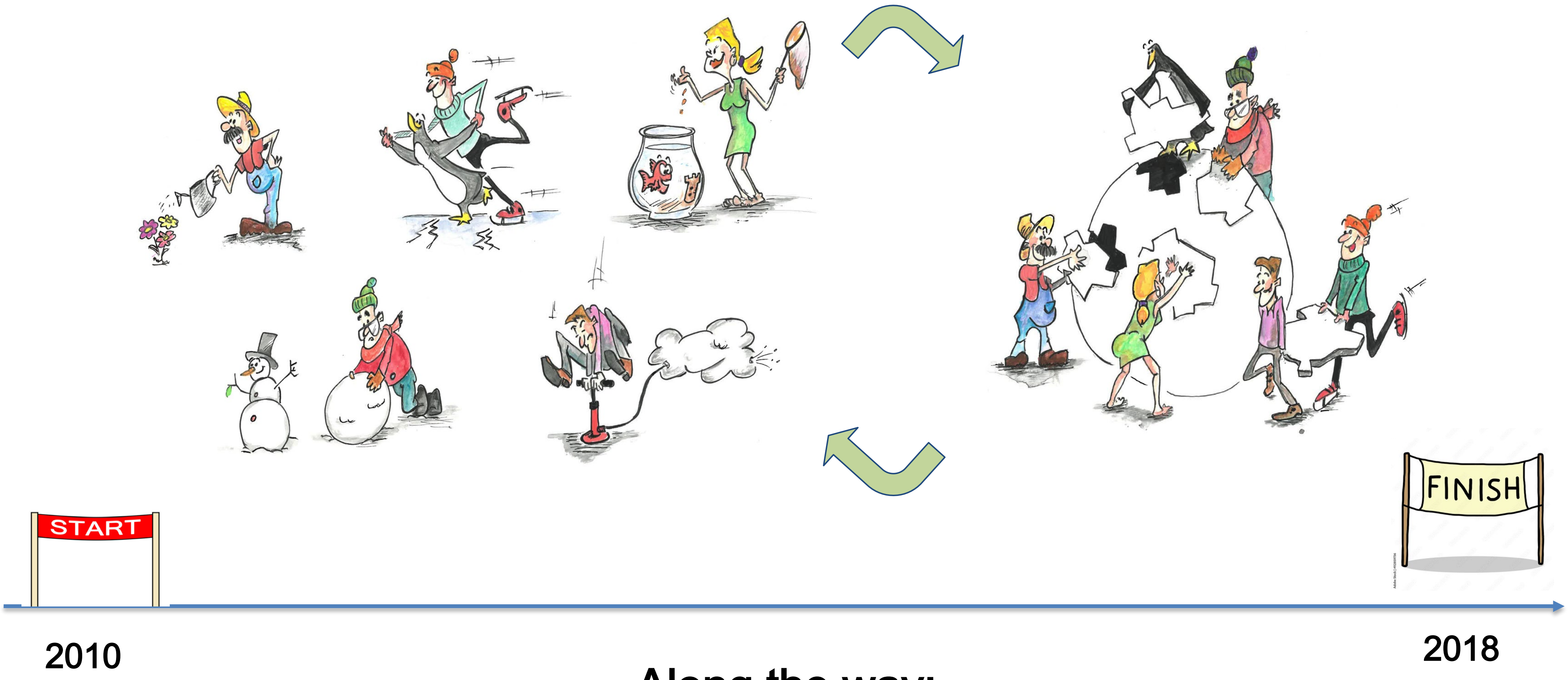
CESM2: Coupling of the individual components

Phase 2: "Let's put it together" (3 years)

- Collaborative effort started in Nov 2015
- Many meetings with "everybody"
  (all working group co -chair/liaisions)
- 300 configurations
- Thousands of simulated years
  and diagnostics

CESM2 Release: June 2018

Building CESM2 Timeline



Along the way:
Model Tuning

The Art of Tuning

Model tuning

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

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Cirrus clouds

- cloud made up of ice crystals (cloud ice)
- altitudes higher 5 km

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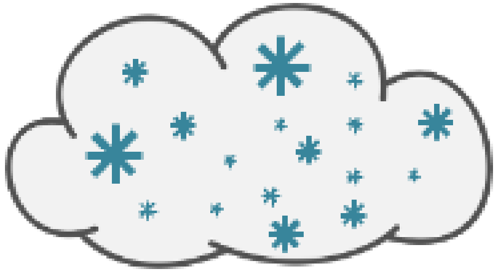

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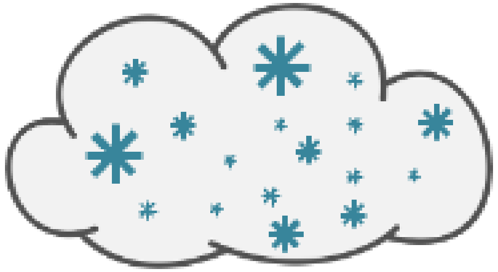
big ice crystals fall out of the cloud
=> cloud ice "converts" to snow



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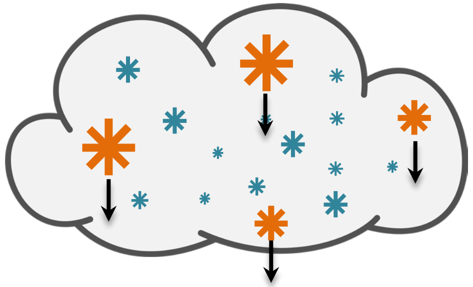
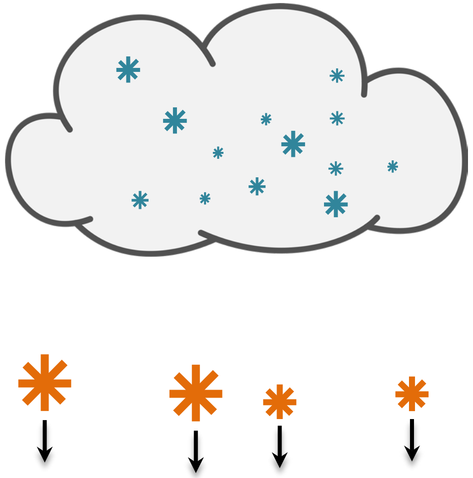


Model tuning

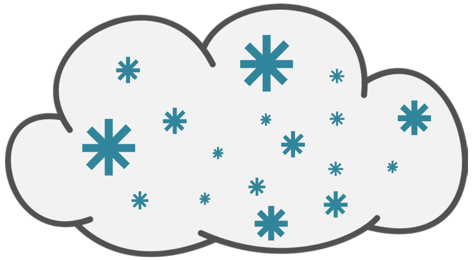
Dcs = Threshold diameter to convert cloud ice particles to snow

Smaller Dcs

Less cloud ice



Larger Dcs



More cloud ice

What is the impact on climate ?

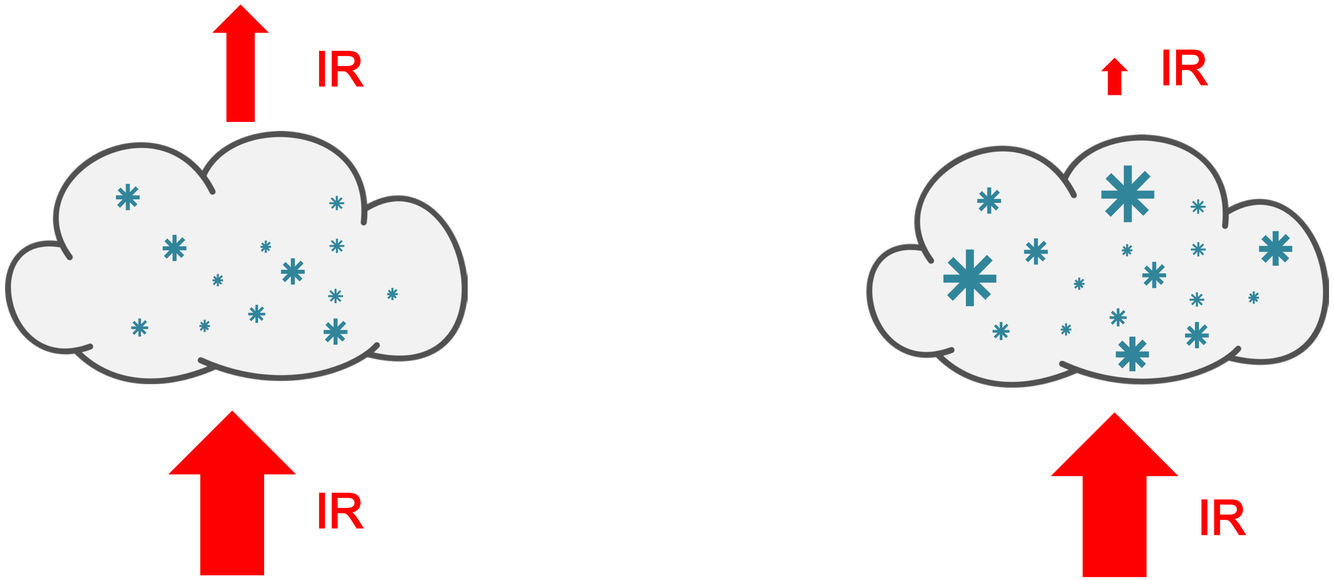
Model tuning

Dcs = Threshold diameter to convert cloud ice particles to snow

Smaller Dcs

Larger Dcs

Less cloud ice



More cloud ice

More cloud ice => less infrared radiation (IR) go to space

Model tuning

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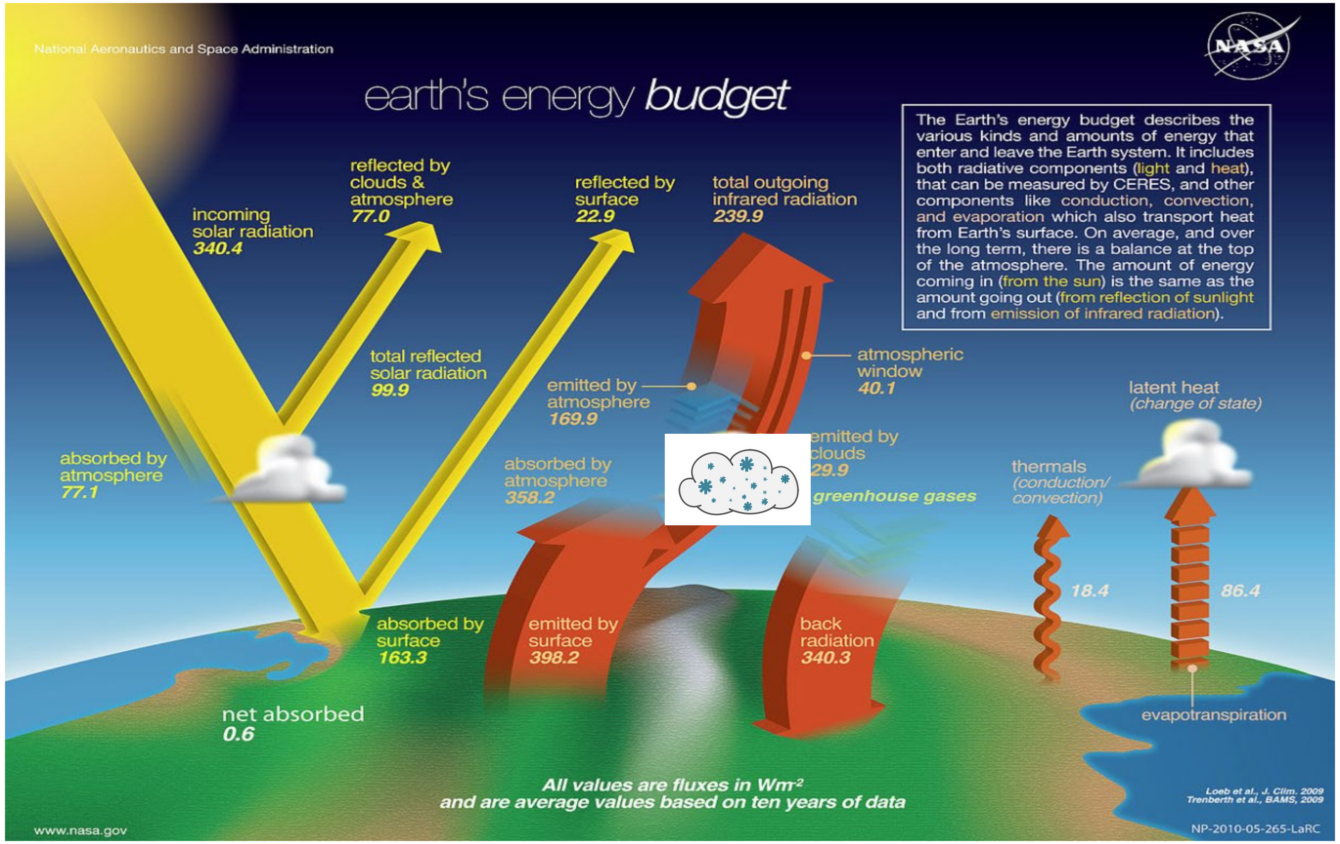
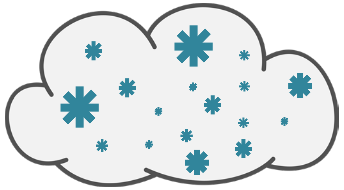


Adjust Dcs

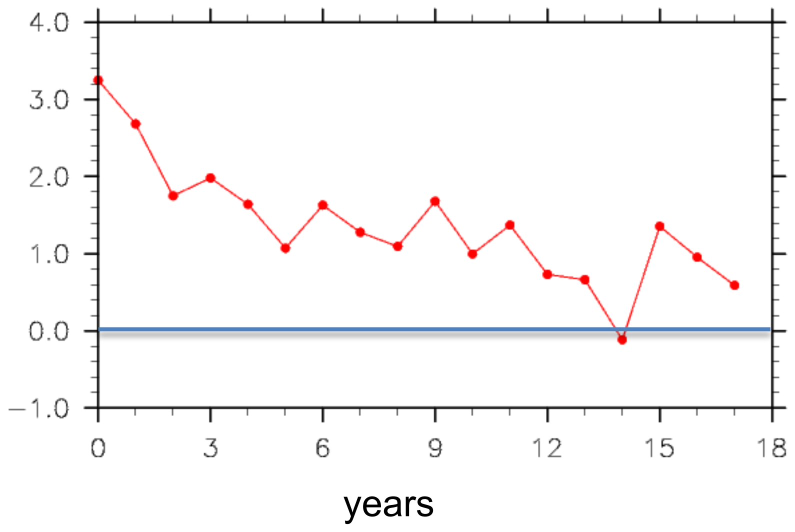


Top of atmosphere radiative balance should be near zero

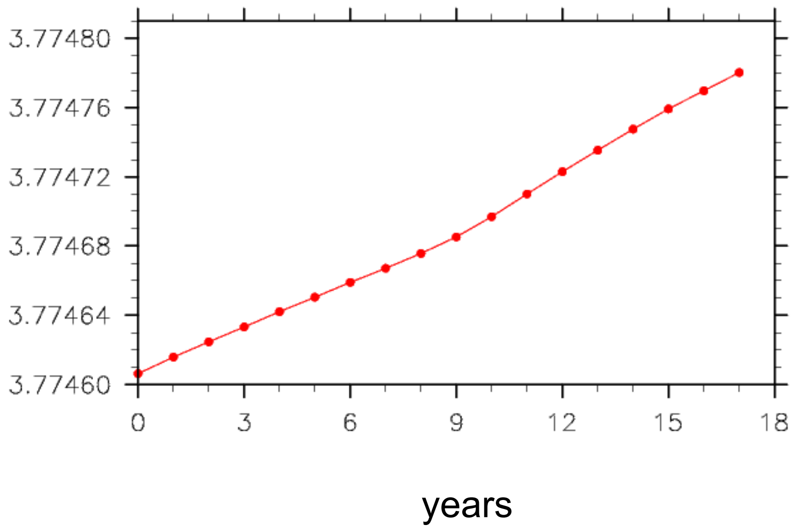
Model tuning

Why is it so important to tune atmosphere radiative balance ?

Radiative balance (W/m2)



T ocean (°C)



If the atmosphere radiative balance is positive, the ocean is warming

Model tuning

Top of atmosphere radiative balance should be near zero

Other targets when tuning

- Cloud forcing
- Precipitation
- ENSO amplitude
- Atlantic Meridional Ocean Circulation (AMOC)
- Sea-ice thickness/extent
- …

Tuning involves choice and compromise
We learn a lot about the model while tuning

What could go wrong during model development?

Model development tales

Coupling = Unleashing the Beast

AMIP run

- Prescribed SSTs
- No drift

Coupled run

- Fully active ocean
- Coupled bias and feedback

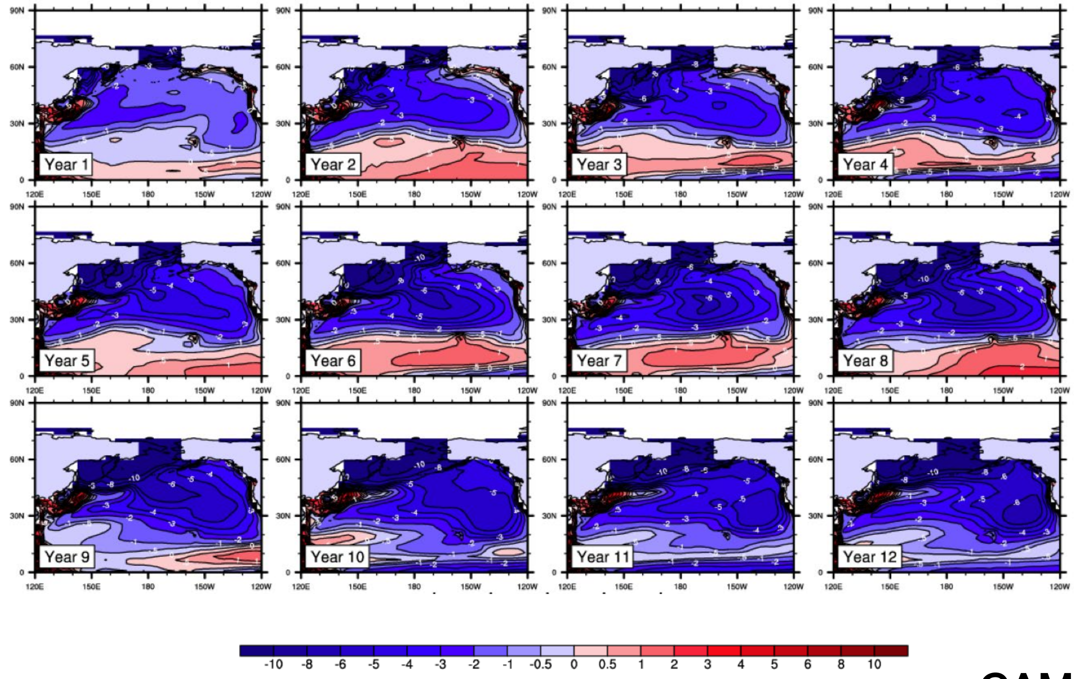
SSTs = Sea Surface Temperatures
AMIP = type of run when SSTs are prescribed

Example of unleashing the beast (1)

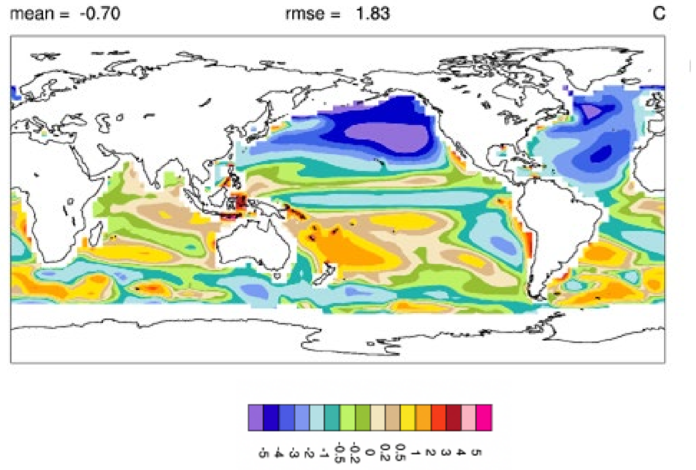
Tuning CAM5 (CESM1 development, 2009)

- Tuning was done in AMIP mode: 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)



Courtesy Rich Neale

CAM = Community Atmospheric Model
SST = Sea Surface Temperature
AMIP = type of run when SST are prescribed

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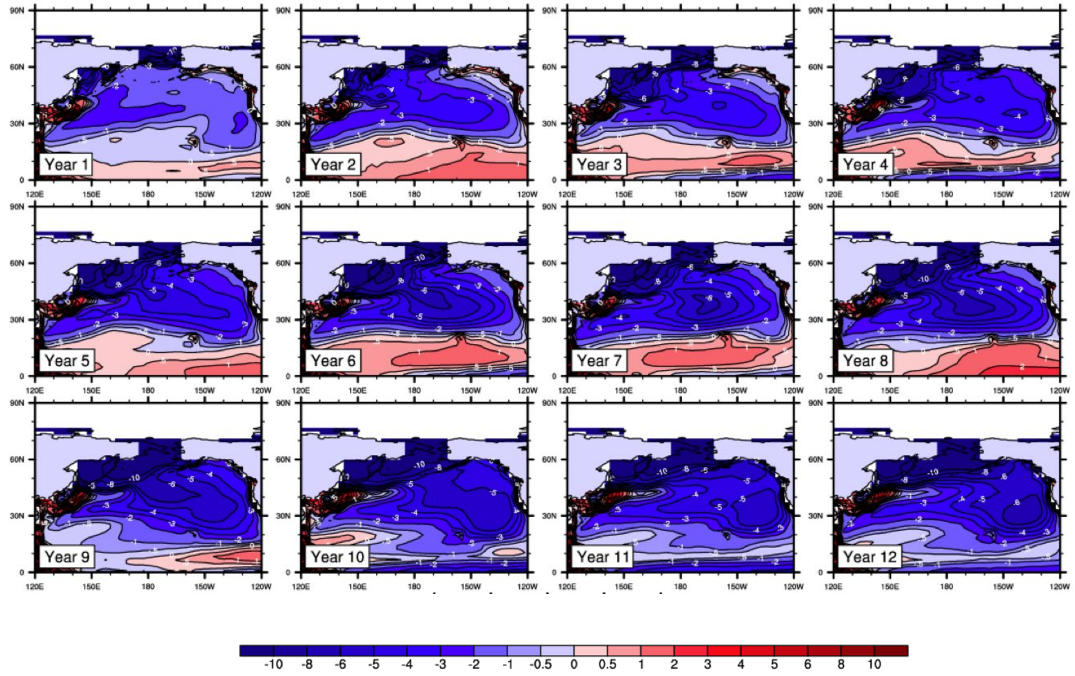
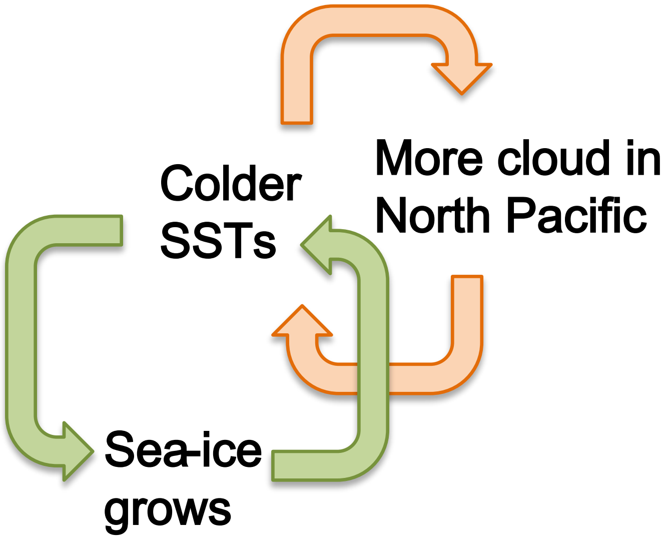




Courtesy Rich Neale

Example of unleashing the beast (2)

Spectral Element dycore development (CESM1.2, 2013)

Finite Volume (FV)

Lat-lon

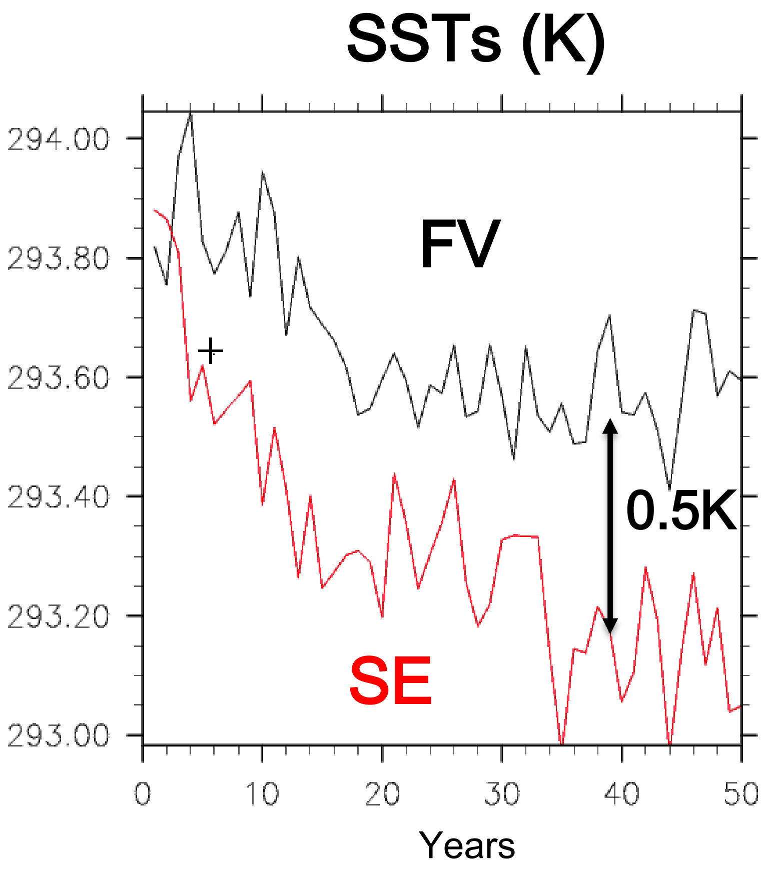
Spectral Element (SE)

Cubed-sphere

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



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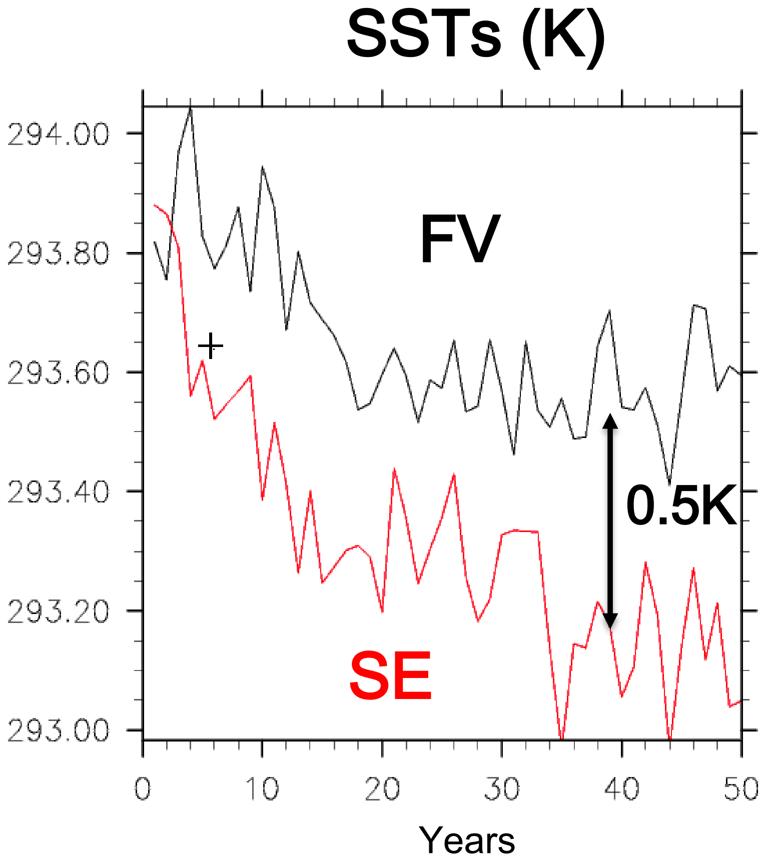
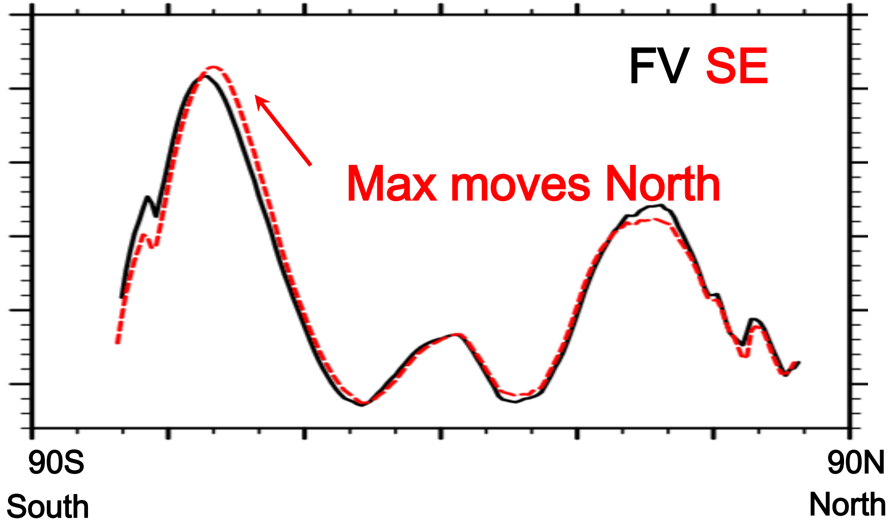
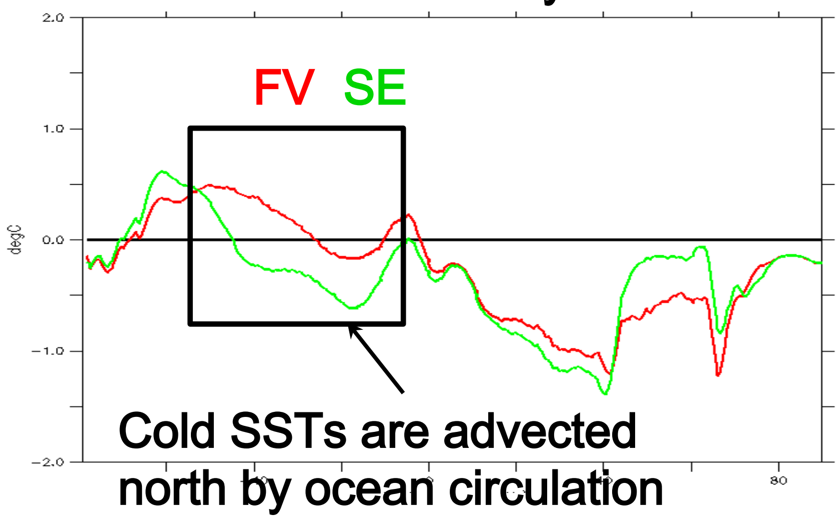
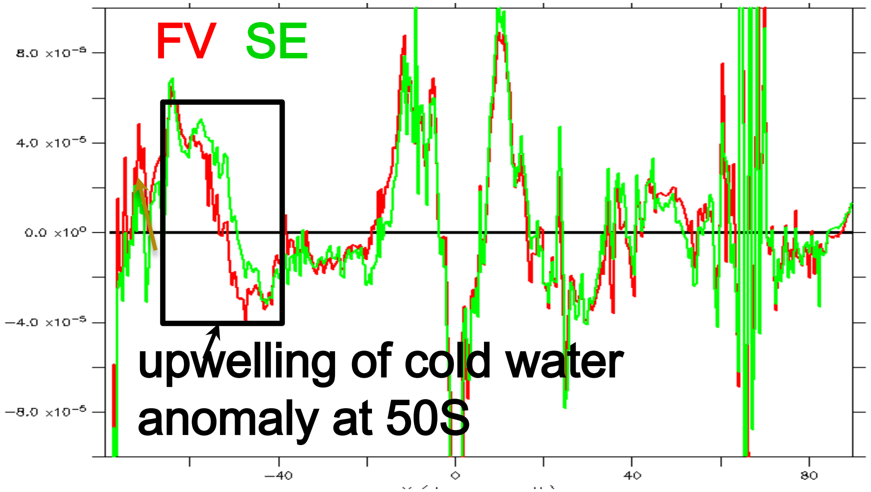


Mechanism responsible of SST cooling in Spectral Element (SE)







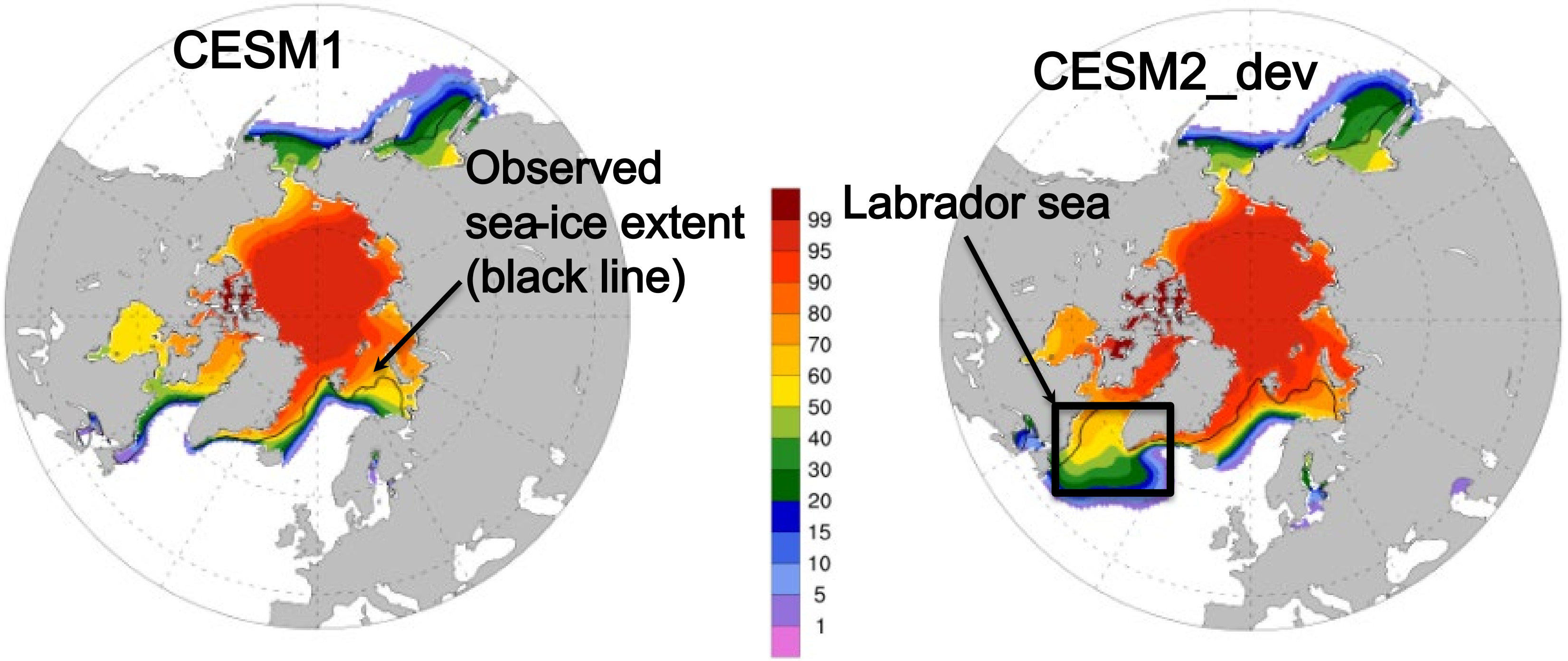
Changes in zonal surface stress in location of upwelling zones associated with ocean circulation is responsible of the SST cooling

Example of unleashing the beast (3)

The Labrador Sea issue (CESM2 development, 2016)

- The Labrador Sea was freezing in CESM2_dev.

Sea-ice extent



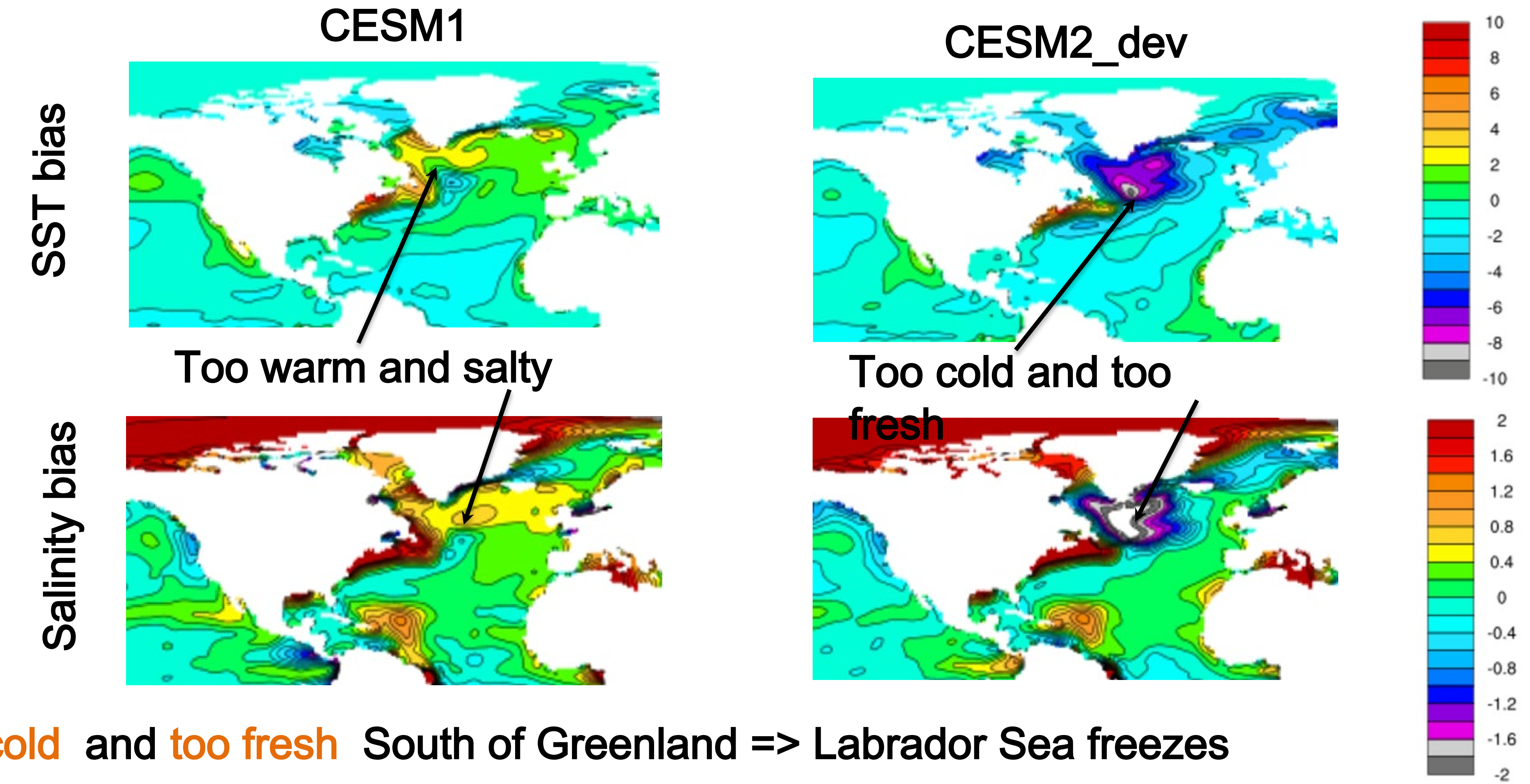
Sea-ice extent is close to obs.
Labrador sea is ice free

Labrador sea is ice -covered.

Example of unleashing the beast (3)

The Labrador Sea issue (CESM2 development, 2016)

- Why was Labrador Sea freezing ?



Too cold and too fresh South of Greenland => Labrador Sea freezes

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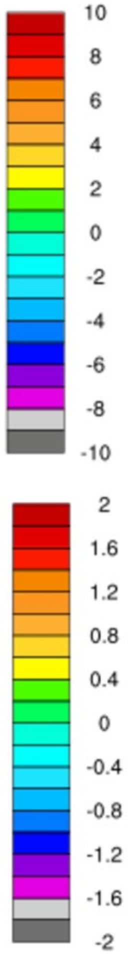

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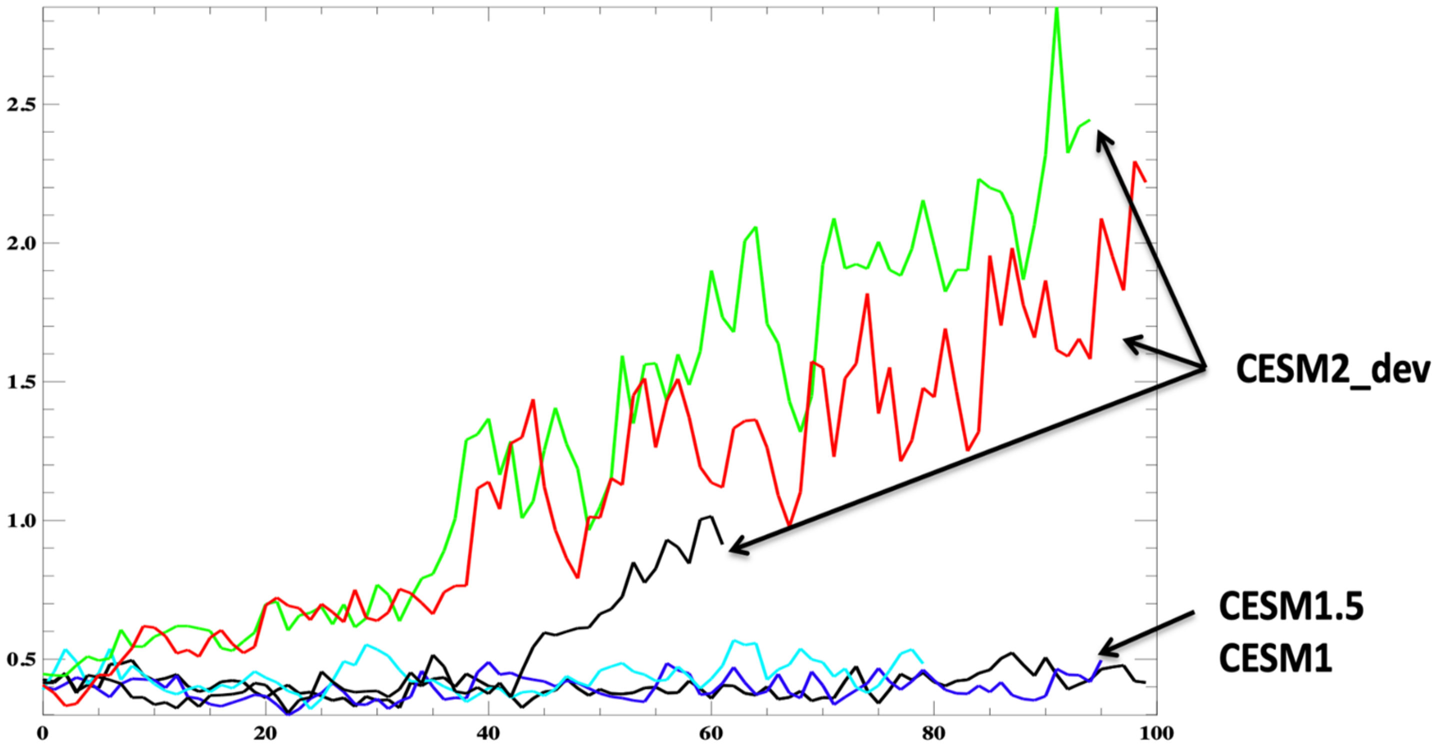
Trouble in the Labrador Sea

Timeseries of sea ice thickness in Labrador sea



Sea ice is building up in Labrador sea
This can happen after 1 yr, 40 yr, 100 + yr

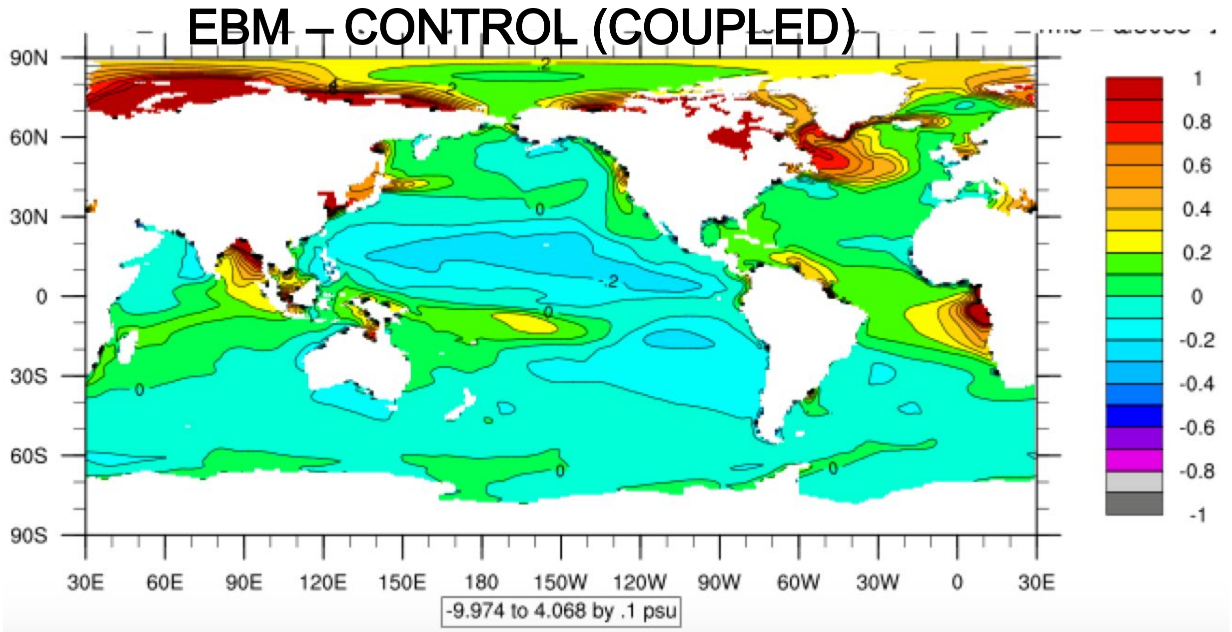
Multiple attempts to fix the issue

It is was very robust feature in CESM2_dev

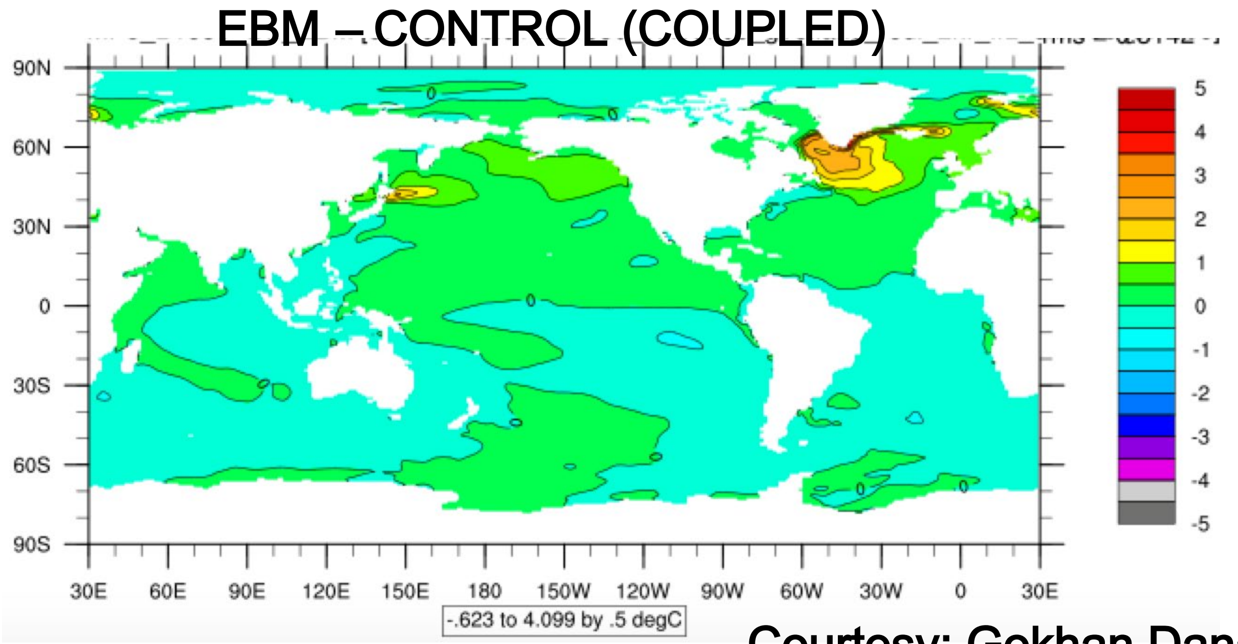
Estuary Box Model

Estuary Box Model (EBM) to the rescue!

Sea surface salinity



Sea surface temperature



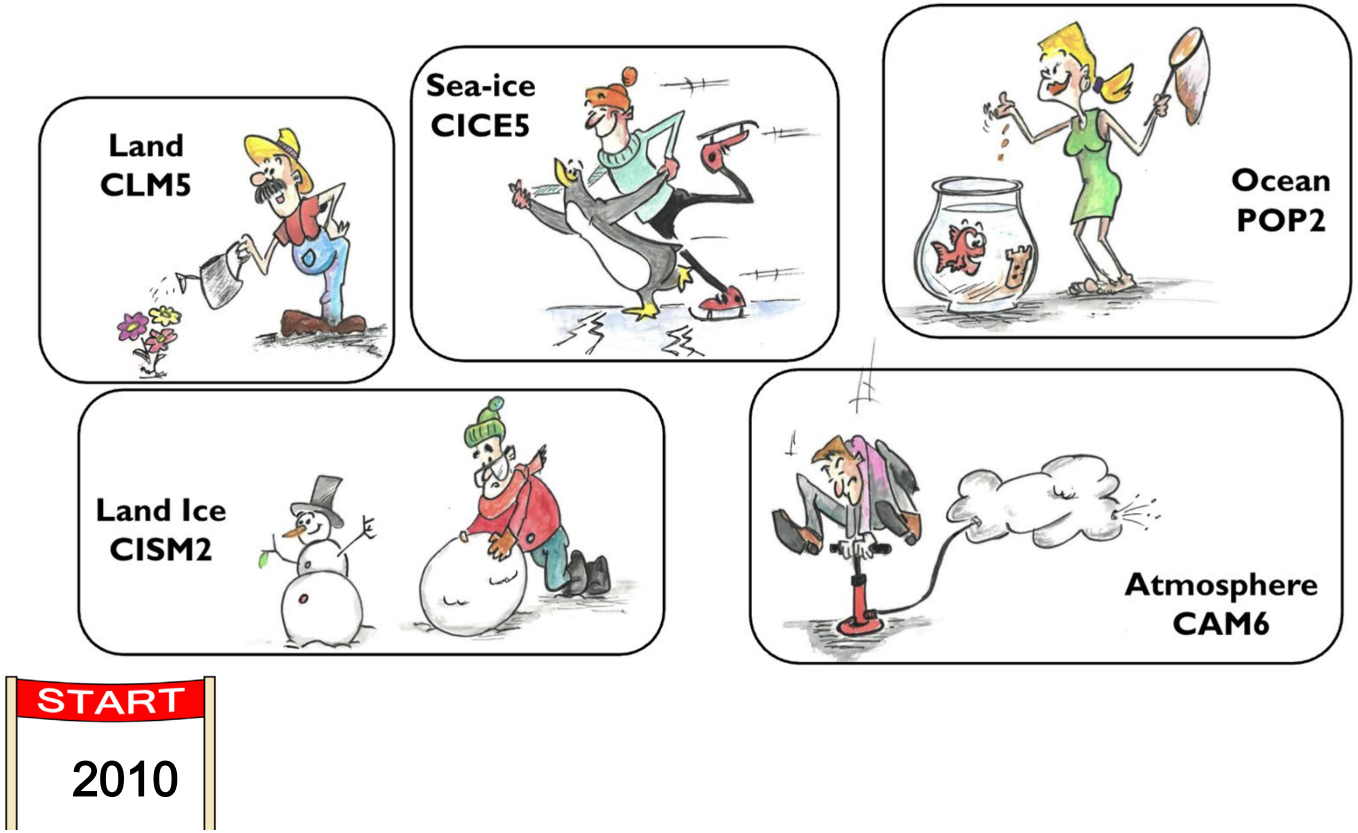
Courtesy: Gokhan Danabasoglu

Coupling = Unleashing the Beast

Summary

Building of a new version of CESM is a long process

Phase 1: Let’s build the components



Phase 2: Let’s couple the components

Summary

The Art of Tuning

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

- Tuning involves choice and compromise
- We learn a lot about the model while tuning

The Art of Coupling

Three examples of unleashing the beast:

- CESM1: cold SST bias in North Pacific with CAM5
- CESM1.2: SSTs stabilize 0.5K colder with SE dycore
- CESM2: Labrador Sea is ice -covered

Thanks !

Cartoons by non artificial intelligence:
Kolya Dols and Vincent Dols