Behind the scenes of building a climate model

The Art of Tuning and Coupling

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Outline

Timeline of building CESM2

The art of tuning

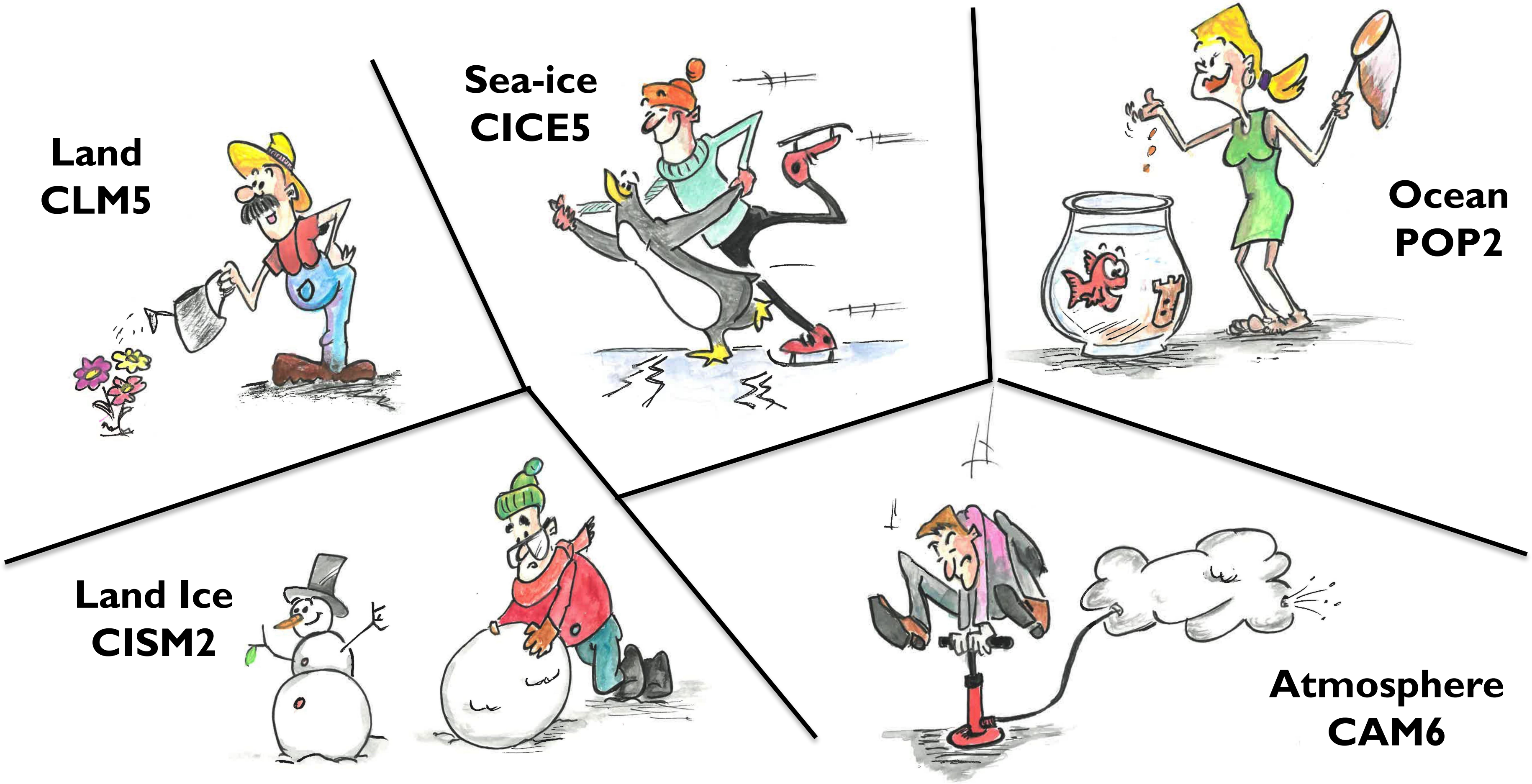
Tales of coupling

Timeline of building CESM2

CESM2: Development of the individual components

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

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

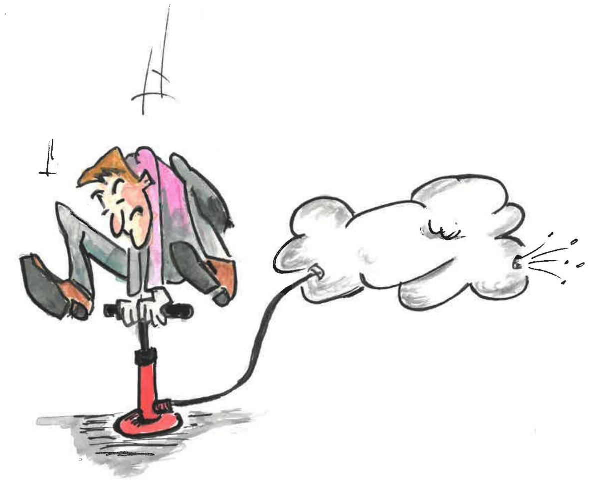


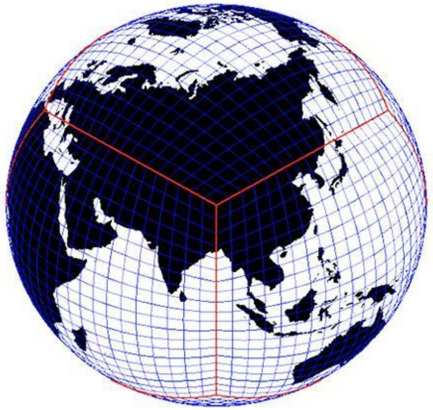
CESM2: Development of the individual components

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

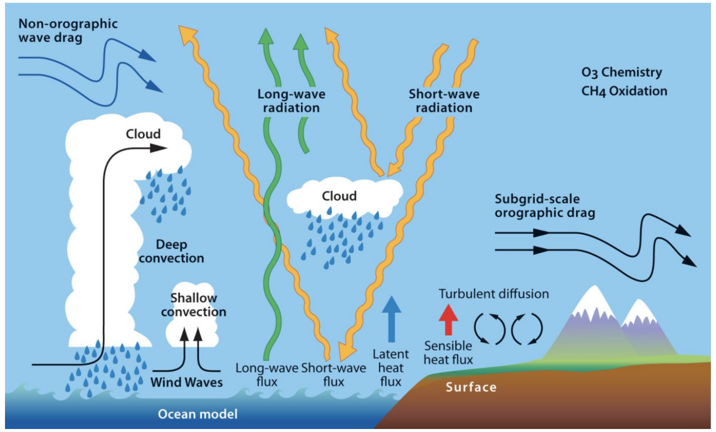
During the building phase, working groups focus on aspects of their model they want to improve

Atmosphere CAM



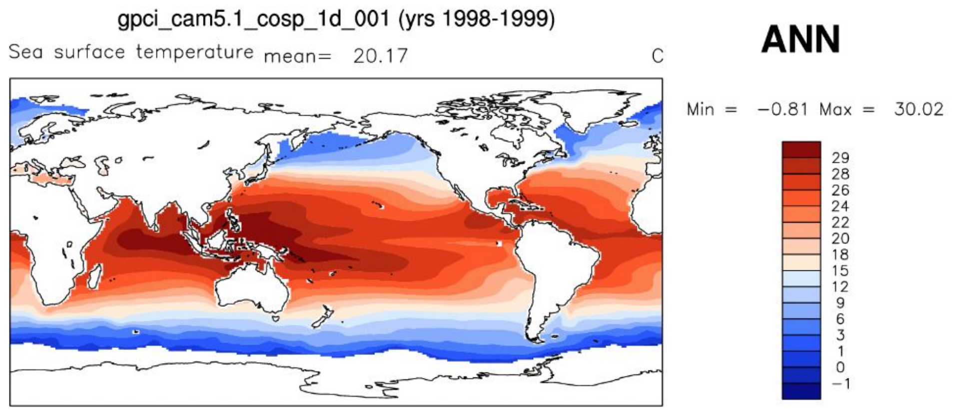


Dynamical core, resolution



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

2010

2018

Along the way:
Tuning and Coupling

The Art of Tuning

Model tuning

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

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- altitudes higher 5 km

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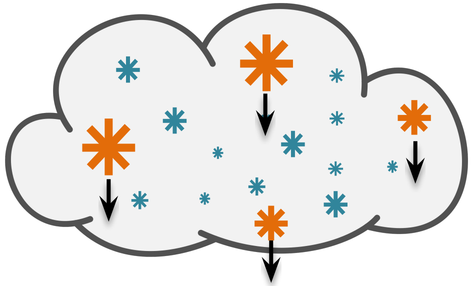
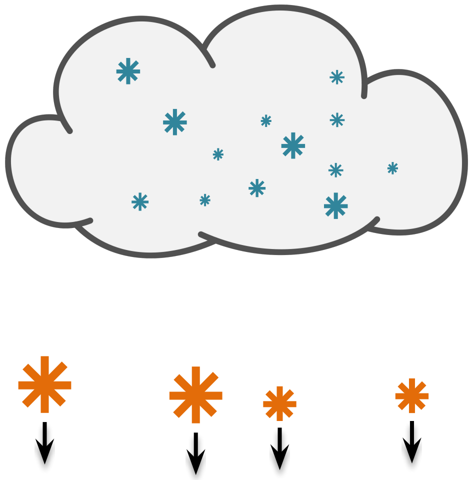


Model tuning

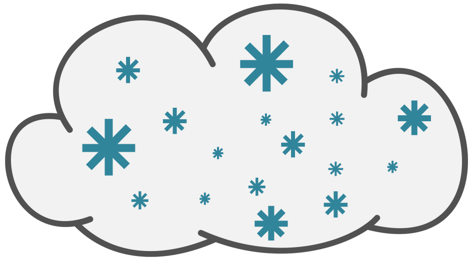
Dcs = Threshold diameter to convert cloud ice particles to snow

Smaller Dcs

Less cloud ice



Larger Dcs



More cloud ice

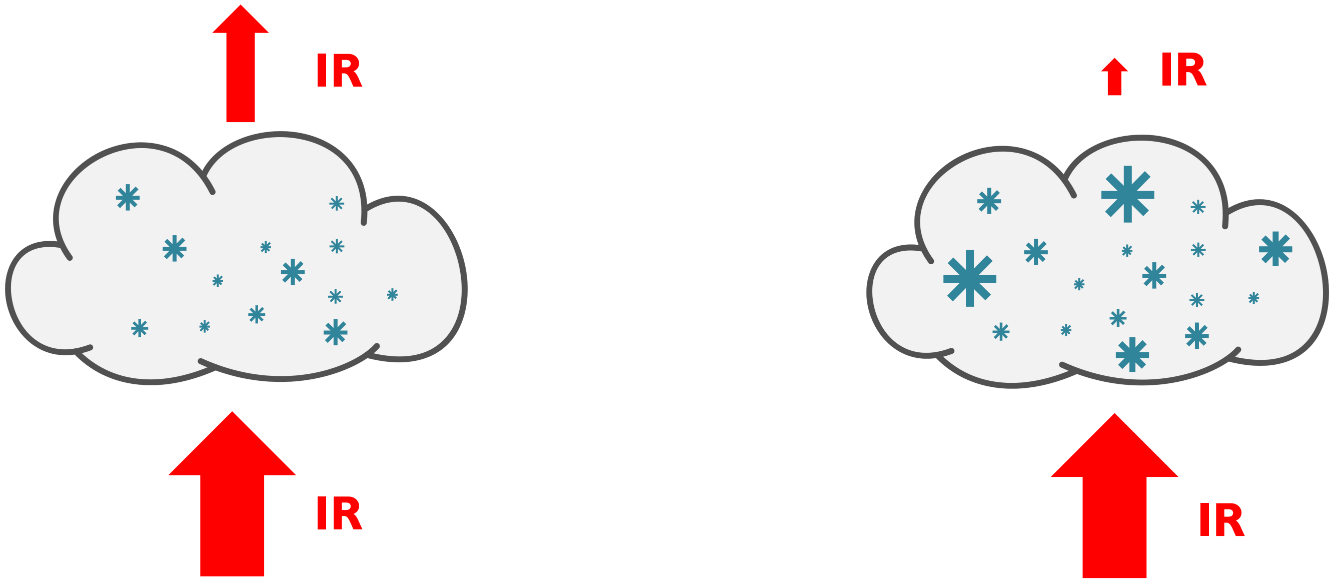
What is the impact on climate ?

Model tuning

Dcs = Threshold diameter to convert cloud ice particles to snow

Smaller Dcs | **Larger Dcs**

Less cloud ice

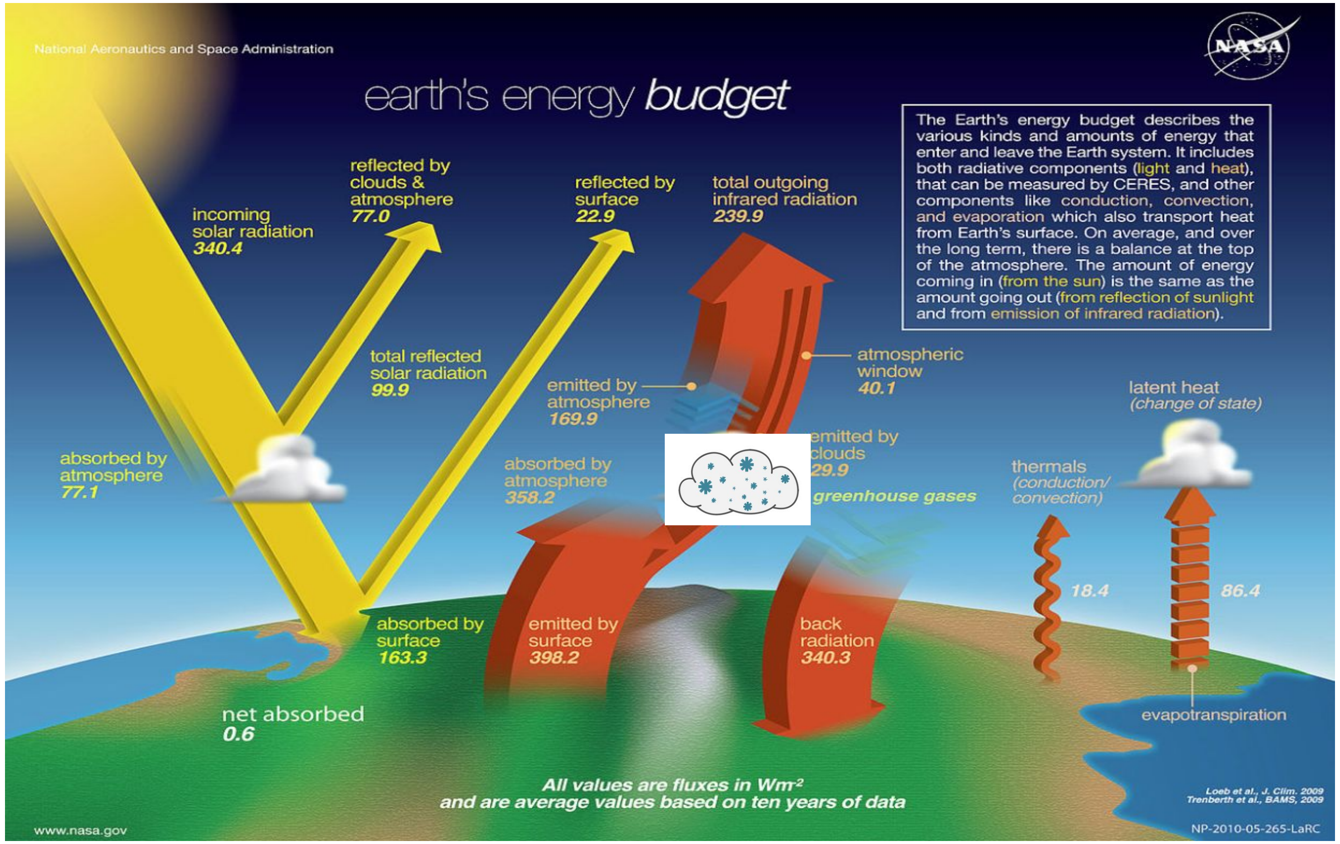


More cloud ice

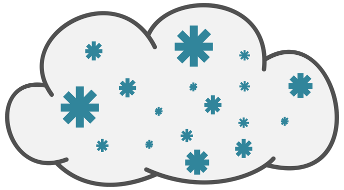
More cloud ice => less infrared radiation (IR) go to space

Model tuning

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



Adjust Dcs

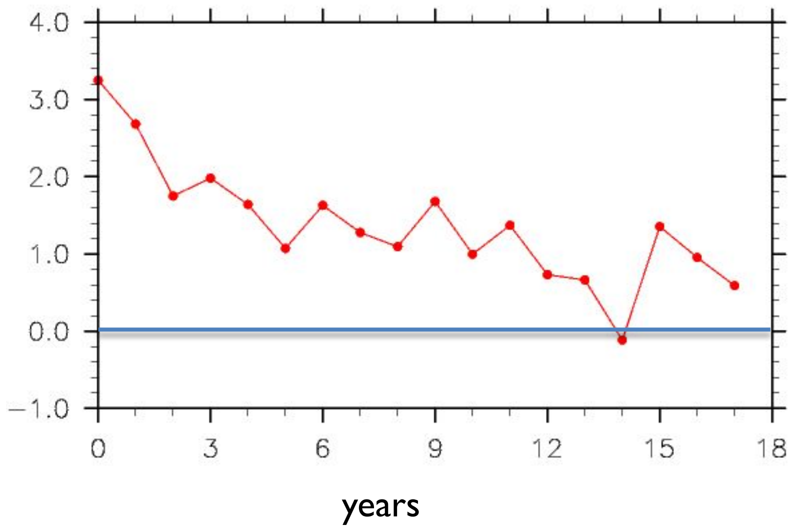


Top of atmosphere radiative balance should be near zero

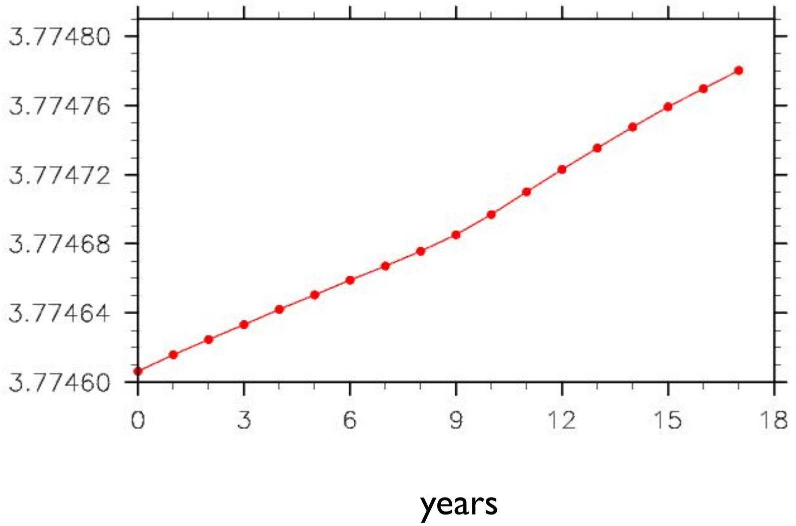
Model tuning

Why is it so important to tune atmosphere radiative balance ?

Radiative balance



T ocean



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**

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.

The Art of Coupling

Coupling = Unleashing the Beast

AMIP run

- Prescribed SSTs
- No drift

Coupled run

- Fully active ocean
- Coupled bias and feedback

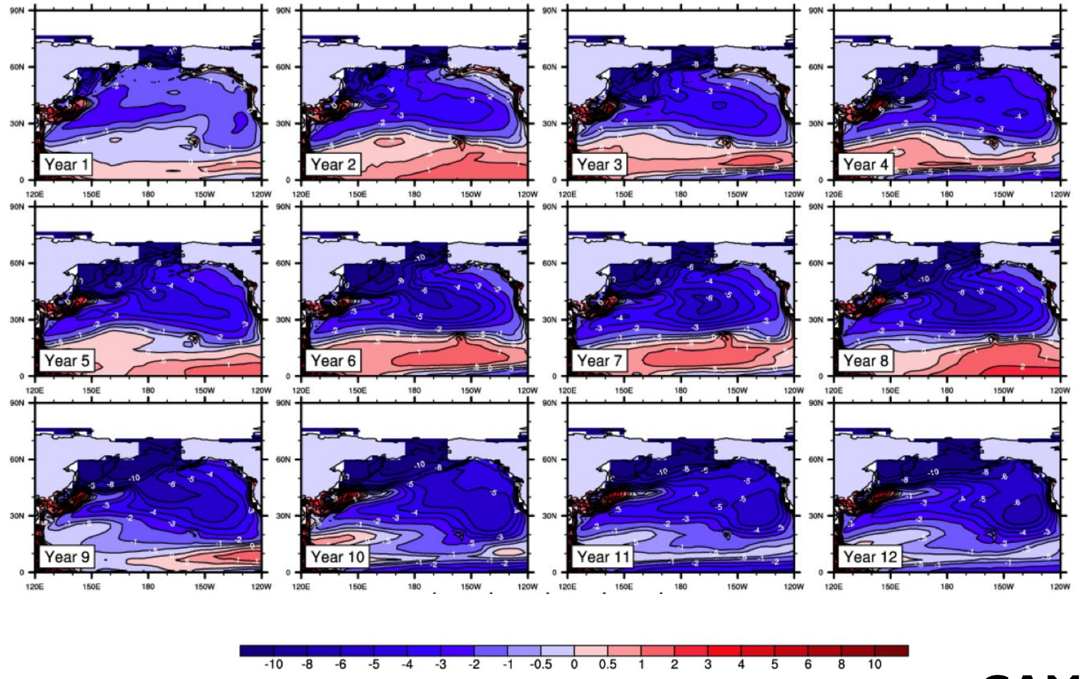
SSTs = Sea Surface Temperatures
AMIP = type of run when SSTs are prescribed

Example of unleashing the beast (1)

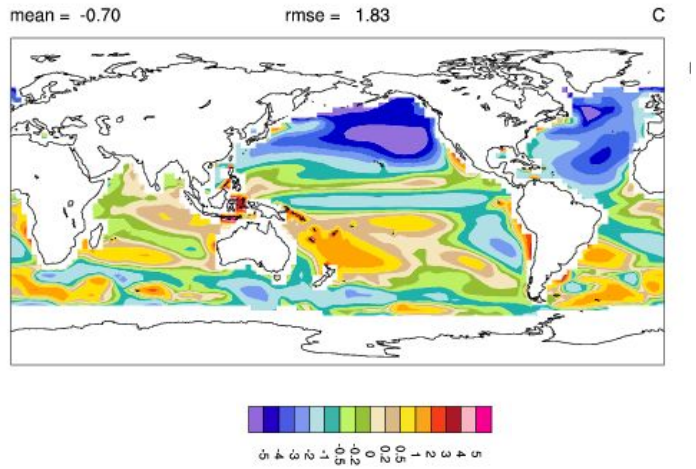
Tuning CAM5 (CESM1 development, 2009)

- **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

Example of unleashing the beast (I)

Tuning CAM5 (CESM1 development, 2009)

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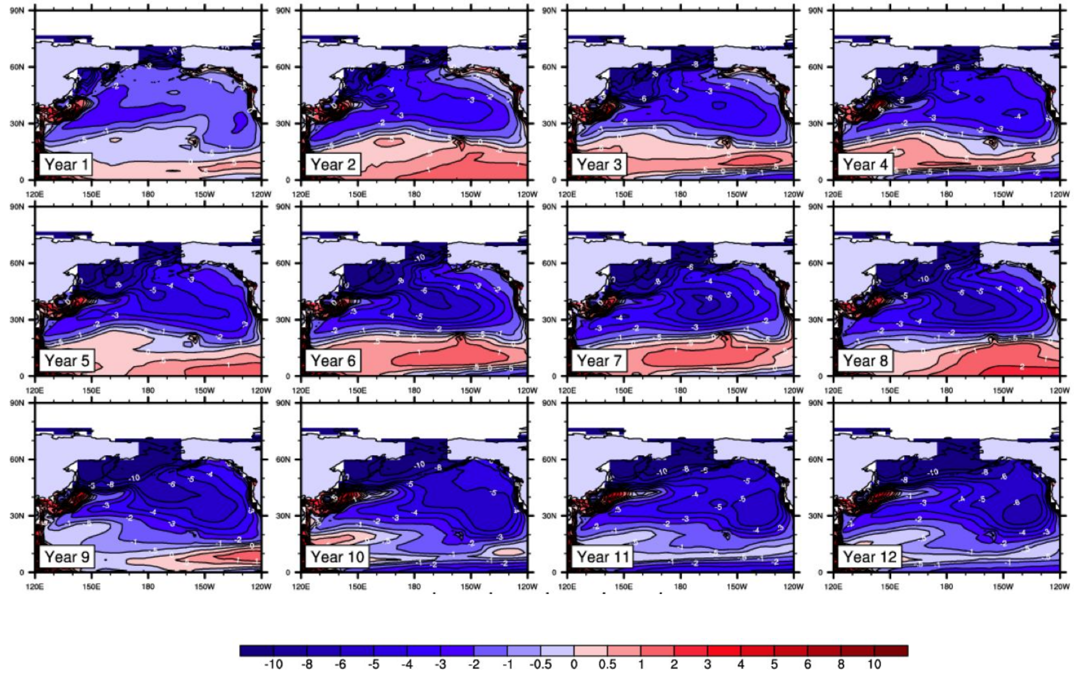
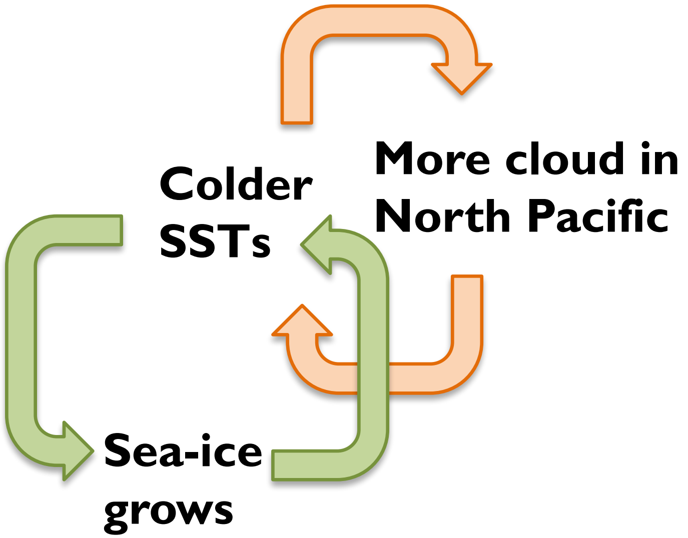
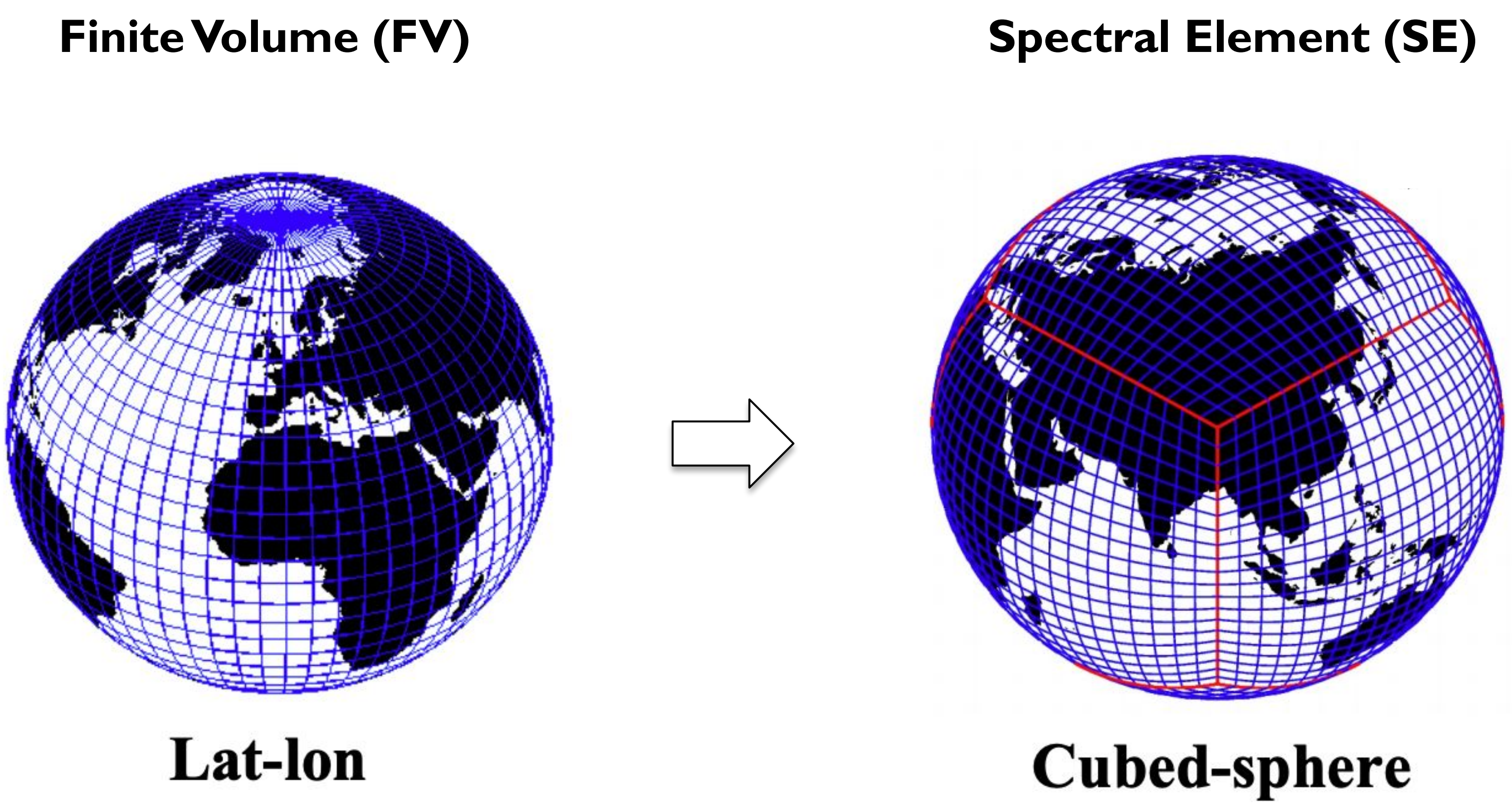




Courtesy Rich Neale

Example of unleashing the beast (2)

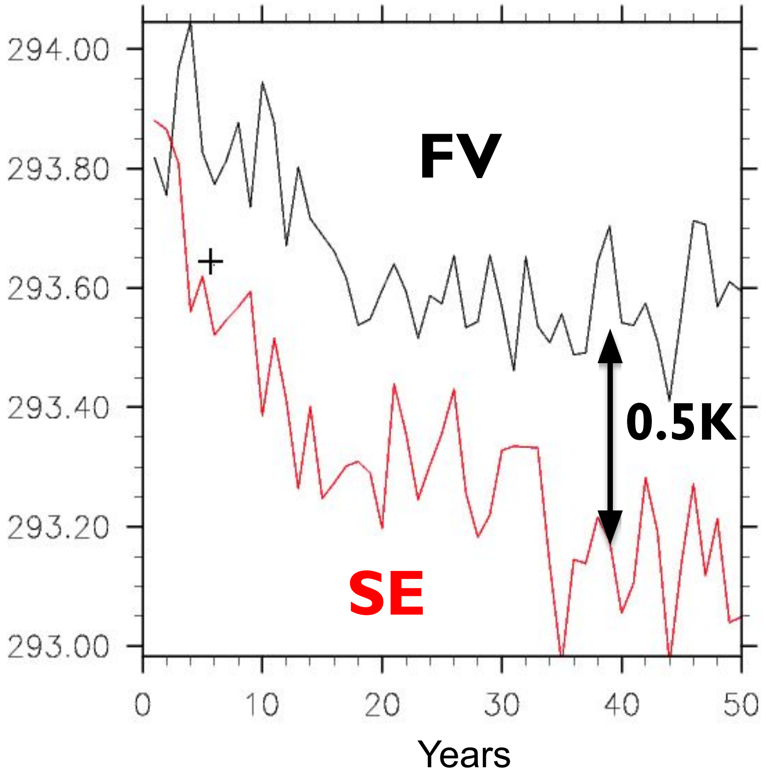
Spectral Element dycore development (CESM1.2, 2013)



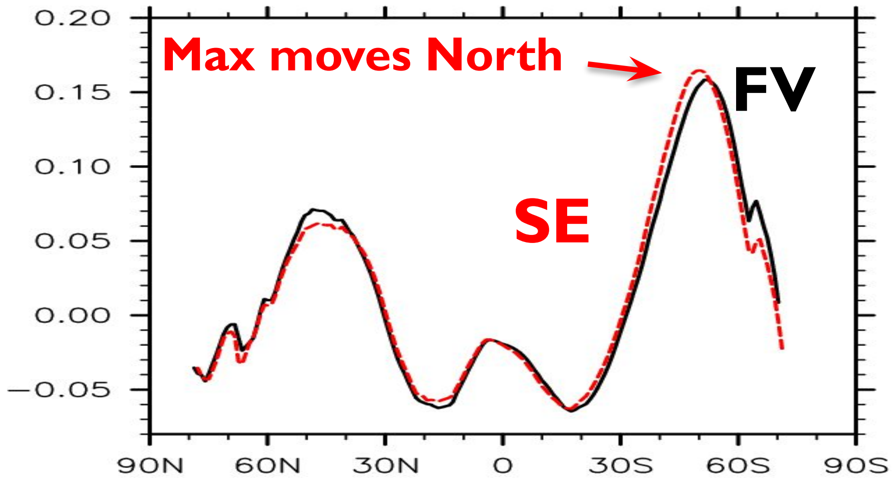
Example of unleashing the beast (2)
Spectral Element dycore development (CESM1.2, 2013)

- **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)



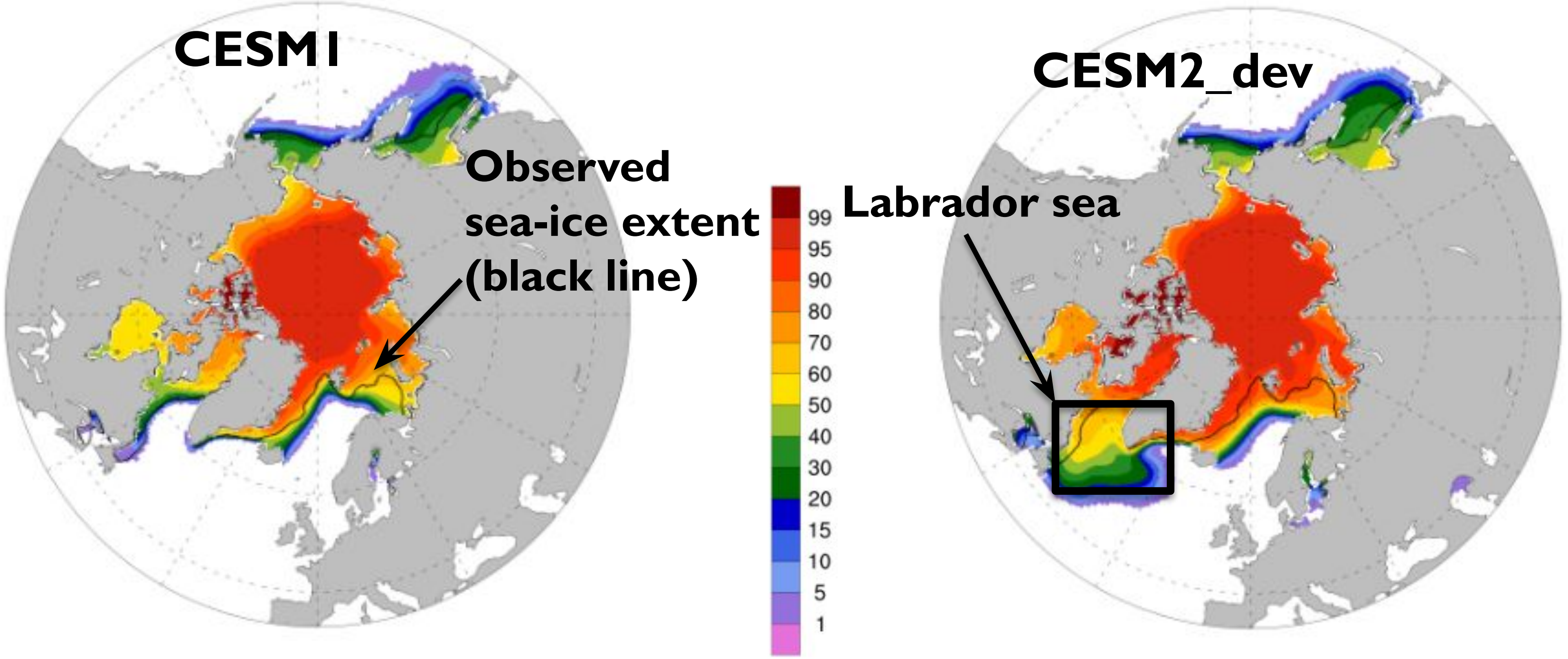
Changes in location of upwelling zones associated with ocean circulation is responsible of the SST cooling

Example of unleashing the beast (3)

The Labrador Sea issue (CESM2 development, 2016)

- **The Labrador Sea was freezing in CESM2_dev.**

Sea-ice extent



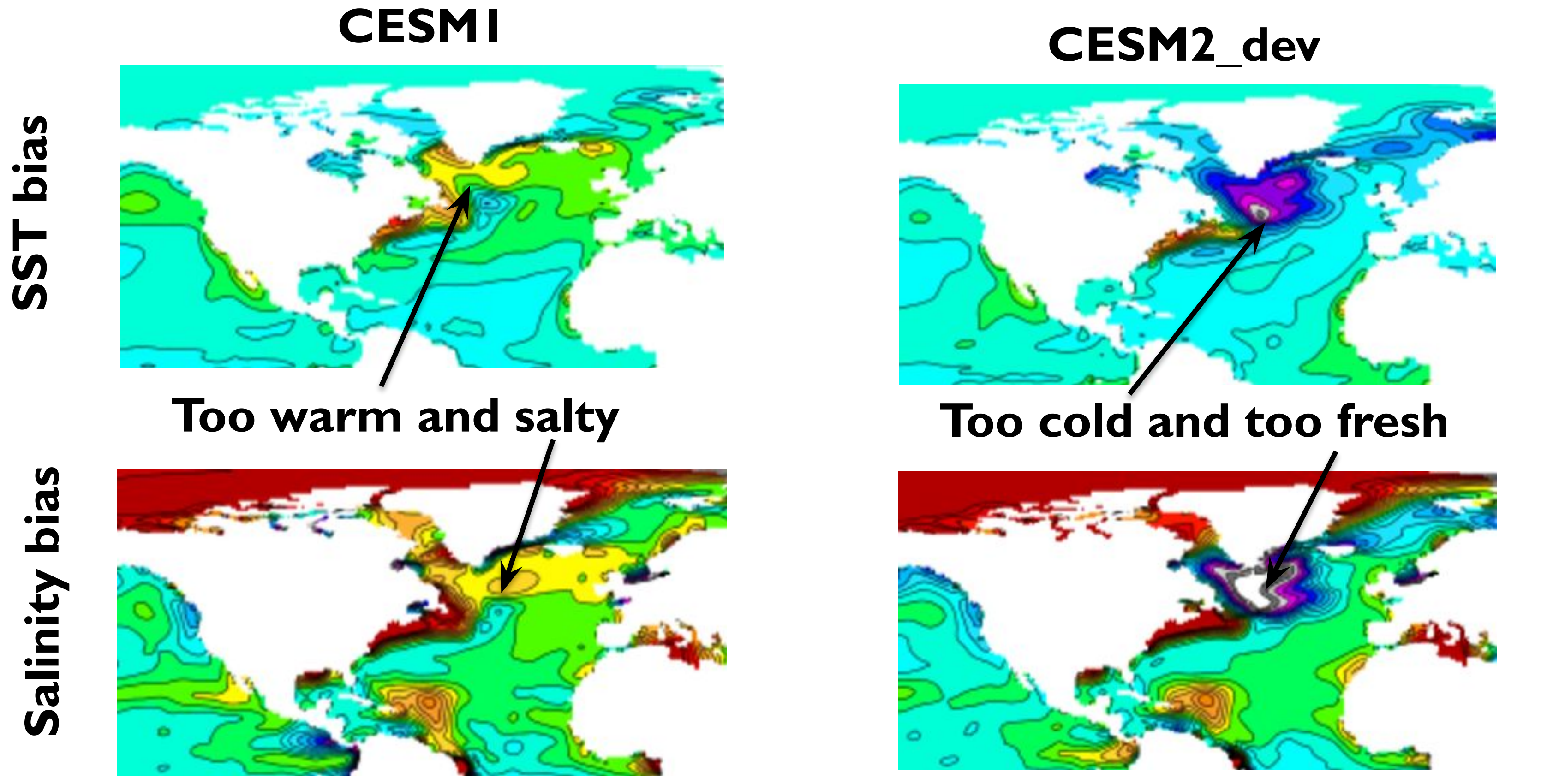
Sea-ice extent is close to obs.
Labrador sea is ice free

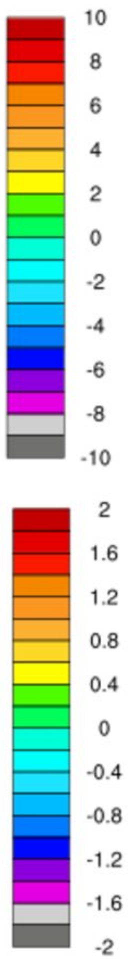
Labrador sea is ice-covered.
Can happen after 1 yr, 40 yr, 100^{+} yr

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

Coupling = Unleashing the Beast

Summary

Building of CESM happens in two phases (building and coupling components)

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 coupling challenges

- 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

Questions ?