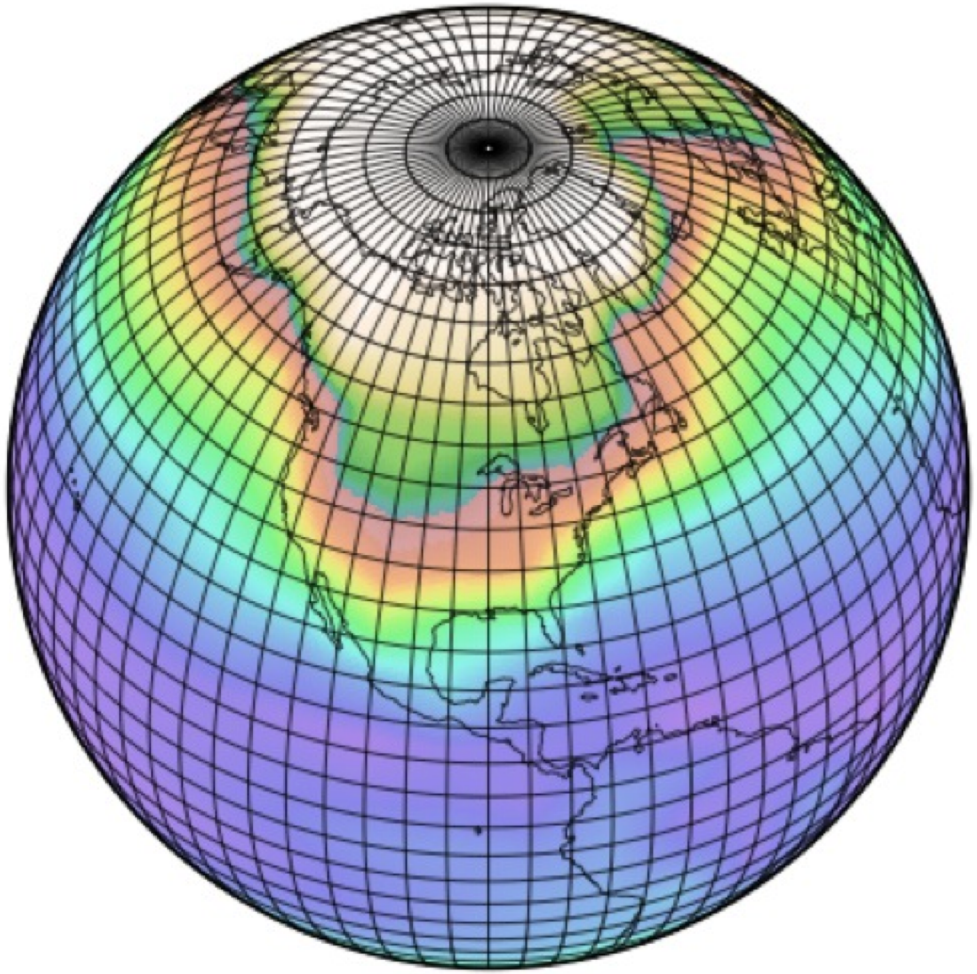
Model Hierarchies

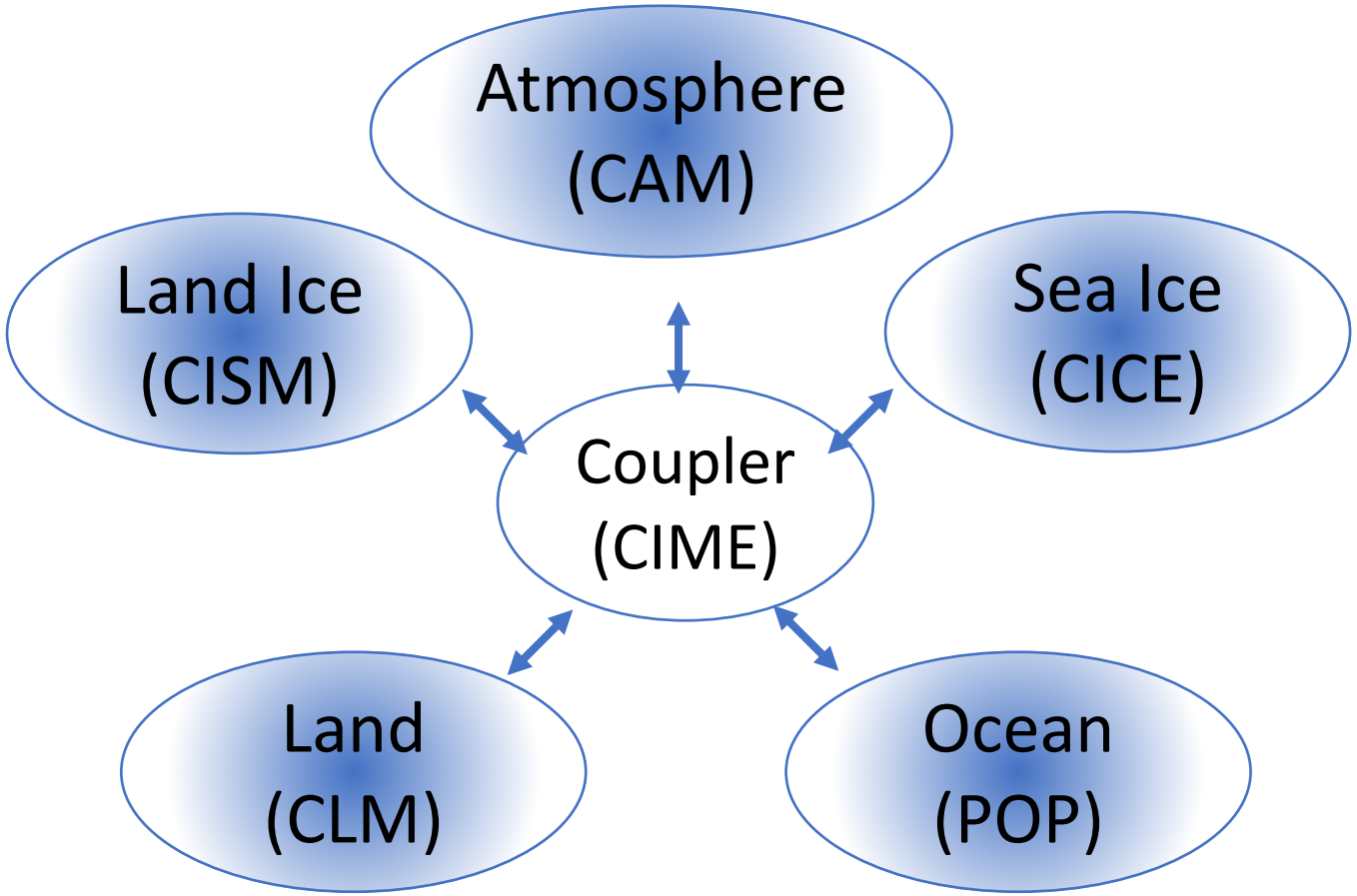
Alice DuVivier and Hansi Singh

2019 CESM Polar Modeling Workshop, NCAR

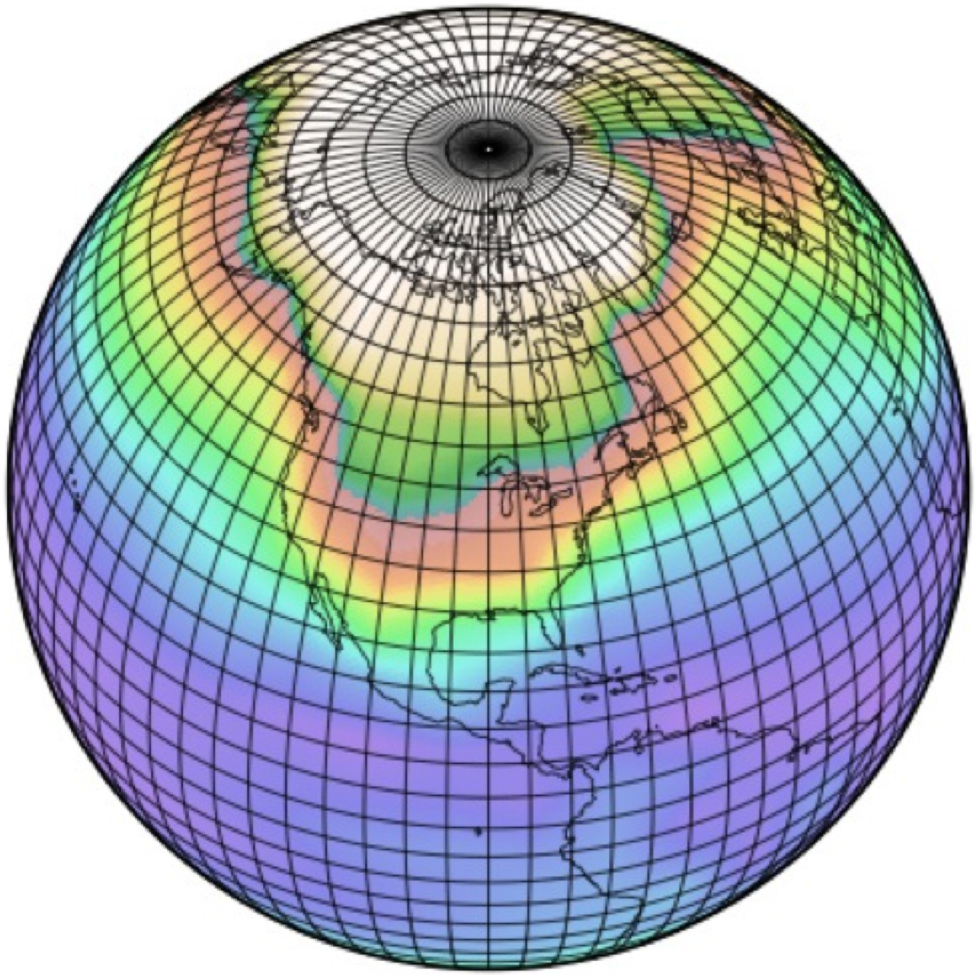
Image: Brian Medeiros

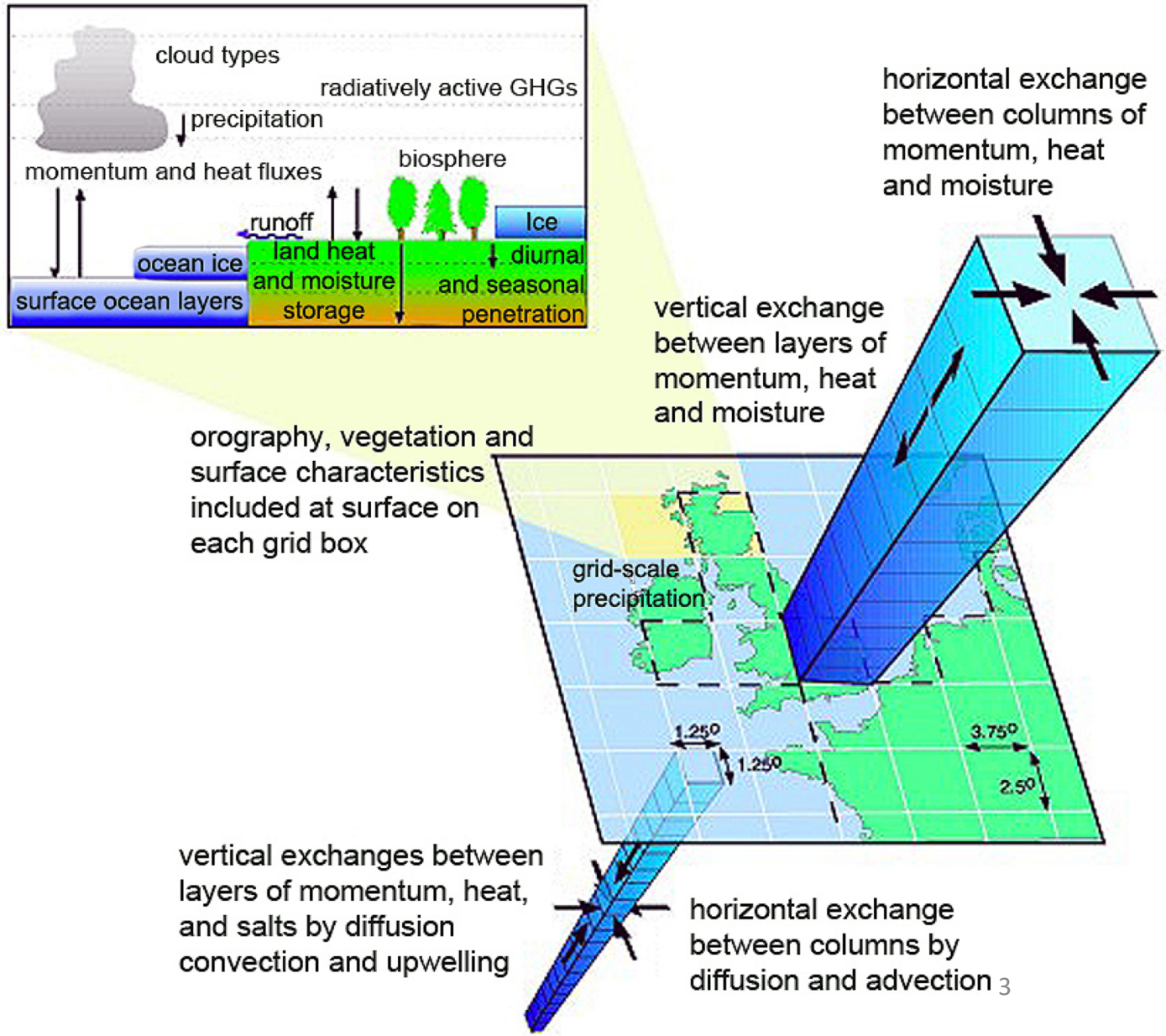
CESM components





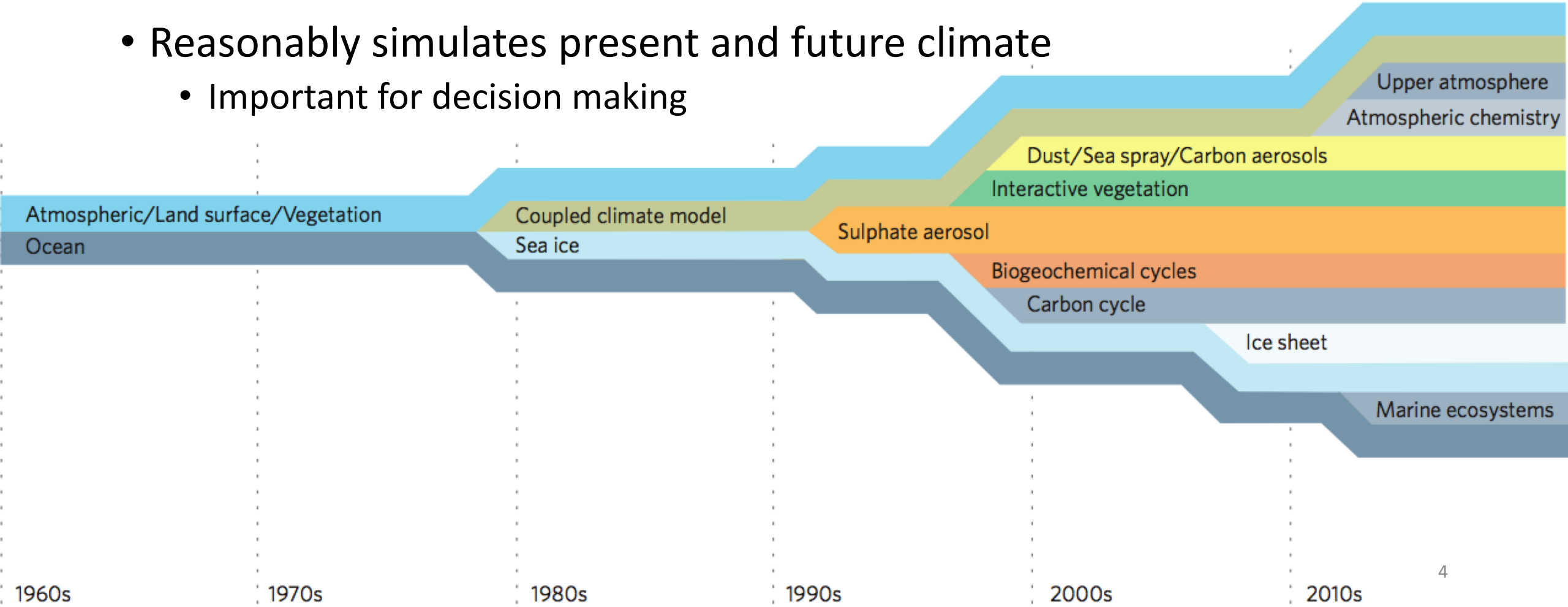
CESM represents many processes





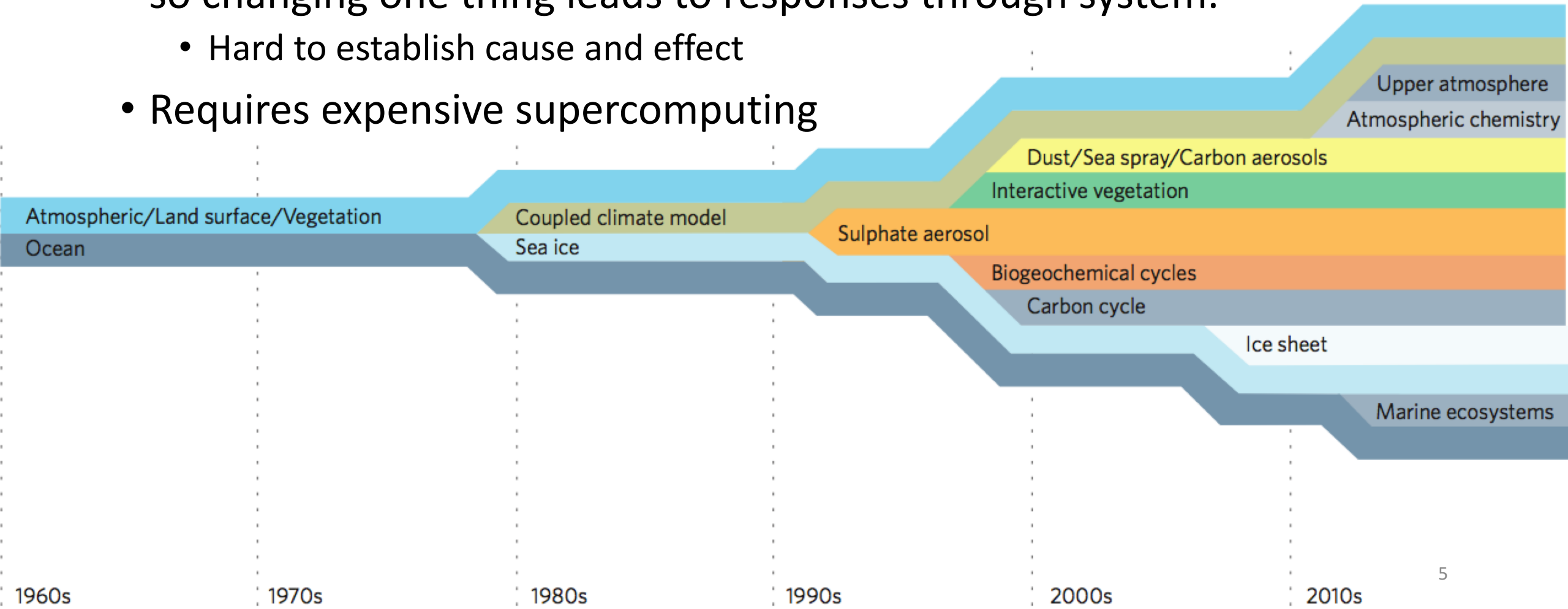
Advantages of coupled ESMs:

- CESM credibly simulates many important processes in the components of Earth system
  - High and low resolution possibilities
- Reasonably simulates present and future climate
  - Important for decision making



Disadvantages of coupled ESMs:

- CESM is complicated
- To conserve energy/momentum/moisture system is strongly coupled so changing one thing leads to responses through system.
  - Hard to establish cause and effect
- Requires expensive supercomputing



"We try to ***simulate*** by capturing as much of the dynamics as we can in comprehensive numerical models … we try to ***understand*** by simplifying and capturing the essence of a phenomenon in idealized models."

Isaac Held, BAMS 2005

“All models are wrong, but some are useful.”
- George Box

- When does studying the earth system blur into just studying the model? Does understanding one model translate to other models?
- Possible model simplification along multiple axes

→ strip out physics, change resolution, global vs. regional, coupled, boundary conditions, etc.

$$\underset{\text{Fluid}}{\begin{pmatrix}\text{compressible}\\ \text{hydrostatic}\\ \text{QG}\\ \text{static}\end{pmatrix}} \times \underset{\text{Rotation}}{\begin{pmatrix}\text{Coriolis}\\ \beta-\text{plane}\\ f-\text{plane}\\ \text{none}\end{pmatrix}} \times \underset{\text{Ocean}}{\begin{pmatrix}\text{dynamical}\\ \text{column}\\ \text{slab}\\ \text{non-uniform } T_s\\ \text{uniform } T_s\end{pmatrix}} \times \underset{\text{Surface}}{\begin{pmatrix}\text{land}+\text{ice}\\ \text{real land}\\ \text{ideal land}\\ \text{aqua}\end{pmatrix}} \times \underset{\text{Convection}}{\begin{pmatrix}\text{explicit moist}\\ \text{super}-\text{param.}\\ \text{parameterized}\\ \text{large}-\text{scale}\\ \text{dry}\end{pmatrix}} \times \underset{\text{Radiation}}{\begin{pmatrix}\text{spectral}\\ \text{gray}\\ \text{Newtonian}\\ \text{fixed}\end{pmatrix}}. \quad (1)$$

Jeevanjee et al. 2017

Model Hierarchies

- Use combination of complex and simpler versions of CESM to answer science questions and better understand the Earth System.

Pros	Cons

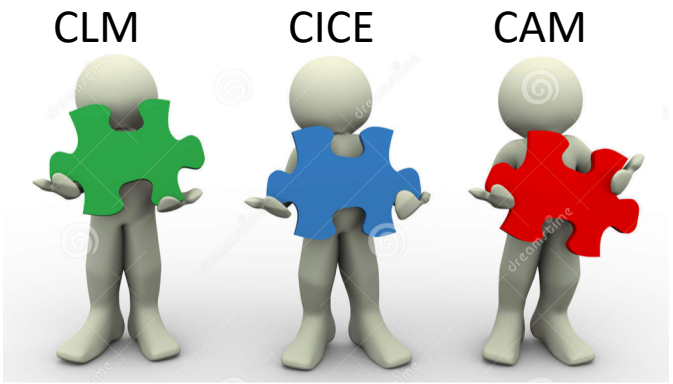
Model Hierarchies

- Use combination of complex and simpler versions of CESM to answer science questions and better understand the Earth System.

Pros

- Easy to perturb
- Idealized experiments can identify causal pathways
- Easier parameter sensitivity testing
- Important model development tool
- Cheaper

Cons



Model Hierarchies

- Use combination of complex and simpler versions of CESM to answer science questions and better understand the Earth System.

Pros

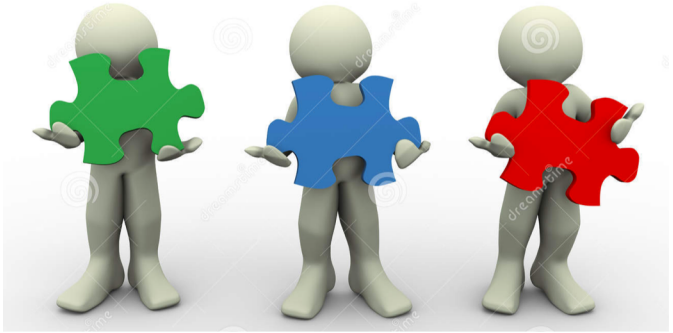
- Easy to perturb
- Idealized experiments can identify causal pathways
- Easier parameter sensitivity testing
- Important model development tool
- Cheaper

Cons

- Less realistic/missing feedbacks
- Results can differ in coupled system

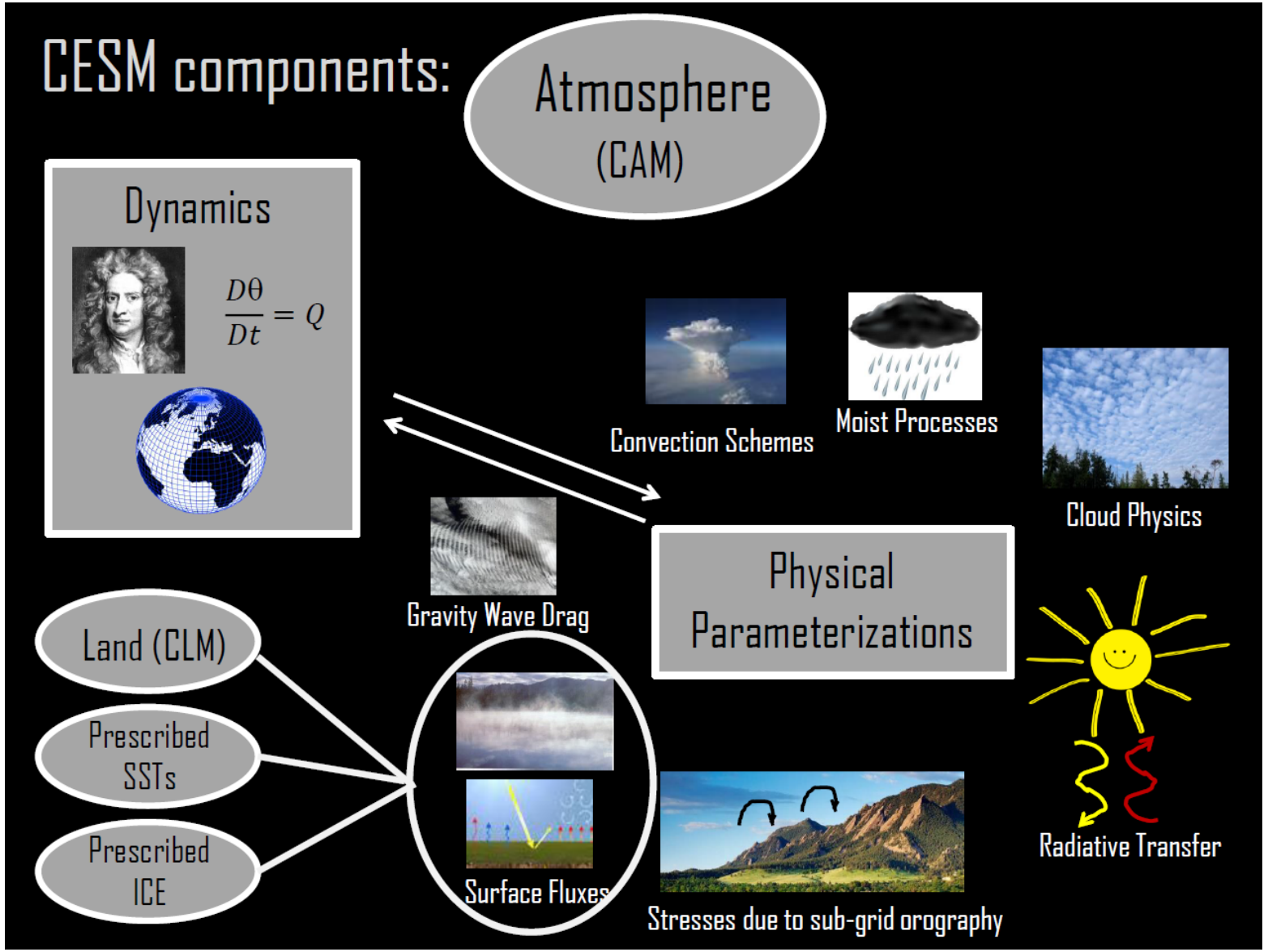
→ keep eye on the "real" world

→ Know the model's limitations



Simplified CAM versions

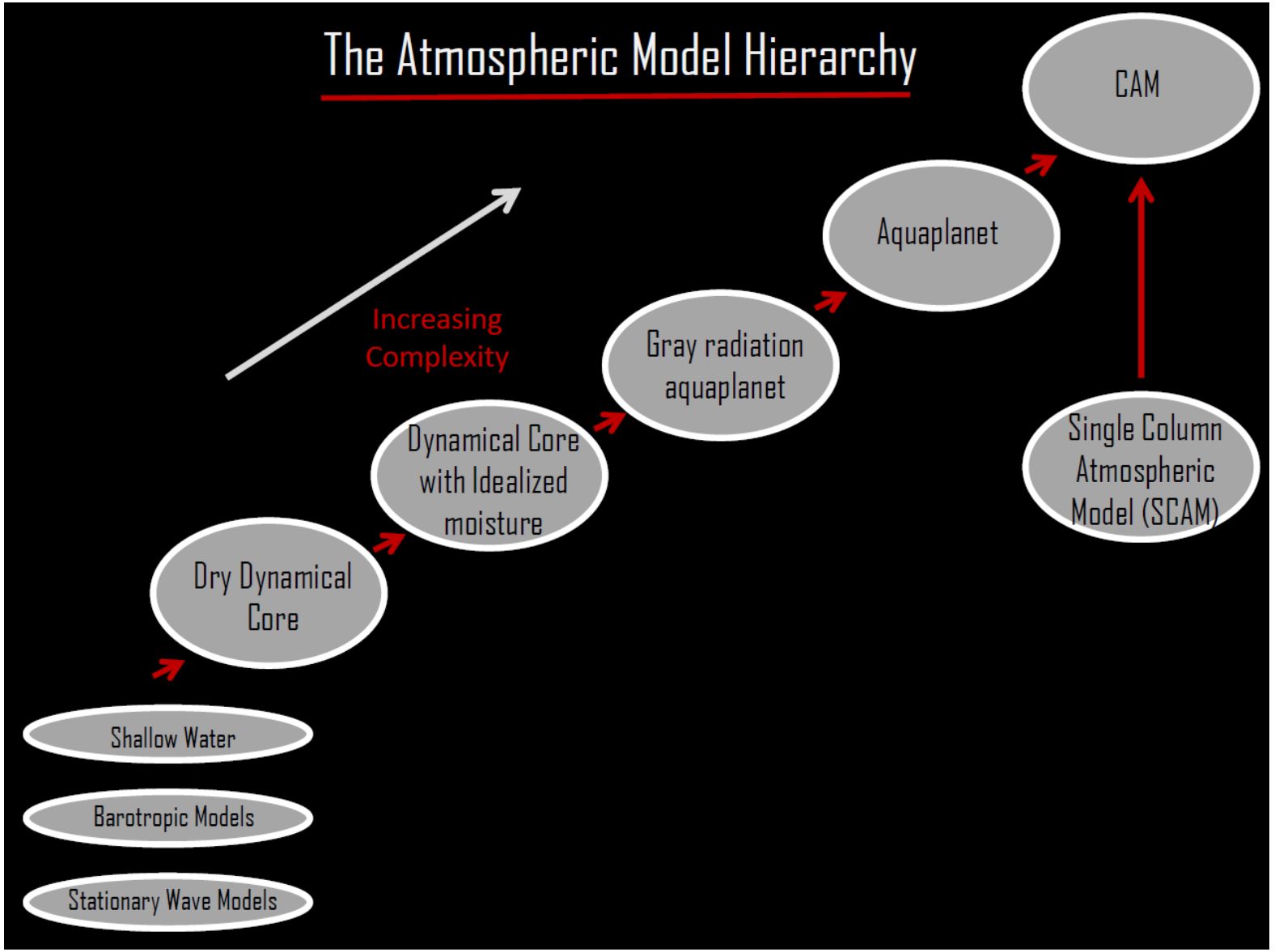
- Can we simplify the ways CAM runs and learn more about the earth system?



http://www.cesm.ucar.edu/models/simpler-models/

Simplified CAM versions

- Supported CAM simpler models part of CESM2 release
  - Dry Dynamical Core (Held and Suarez 1994)
  - Aquaplanet
  - Single column CAM still in development



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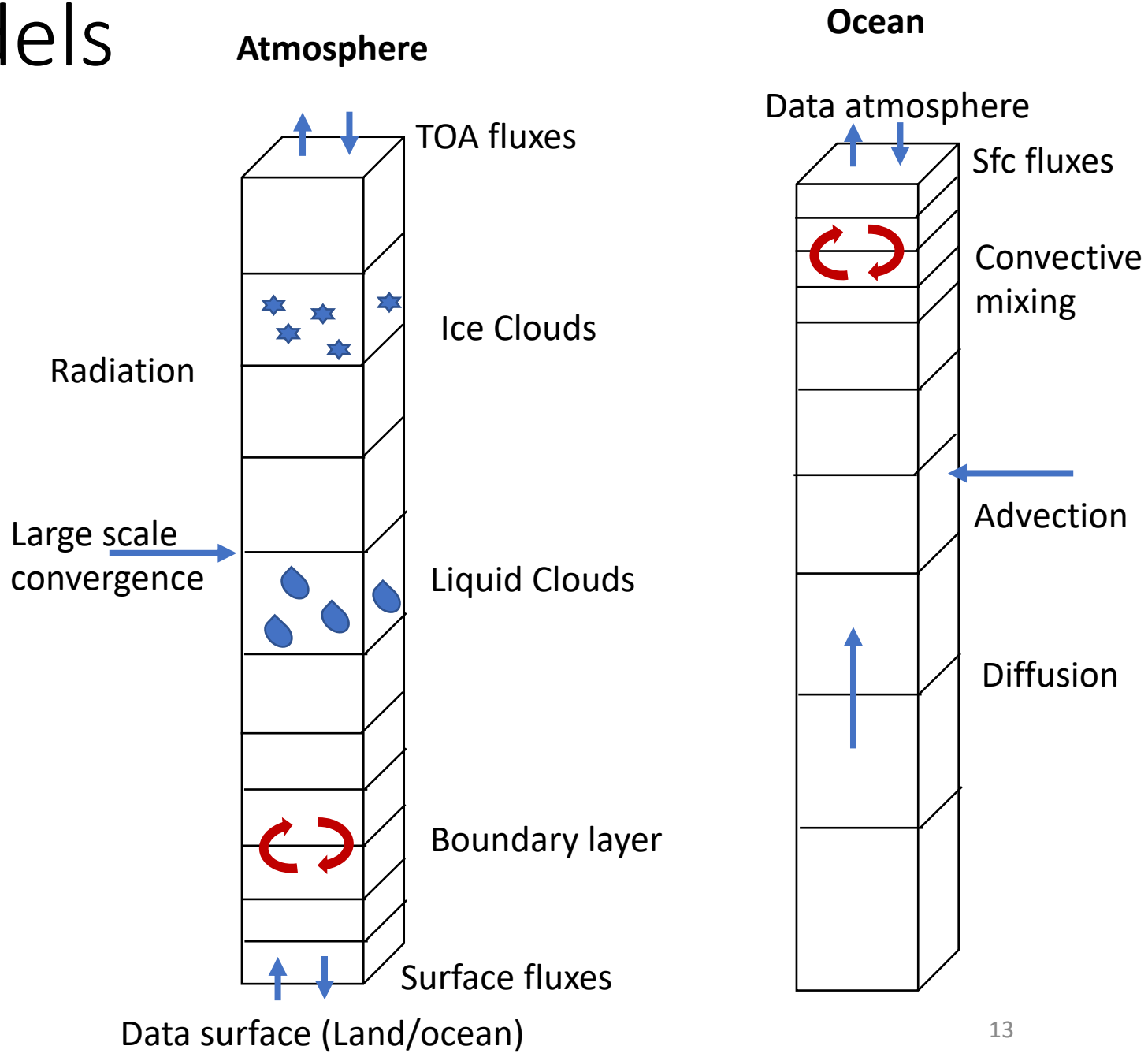
Single column models

- Examine behavior of physical parameterizations in single column in absence of dynamical feedbacks
- Generally done by component



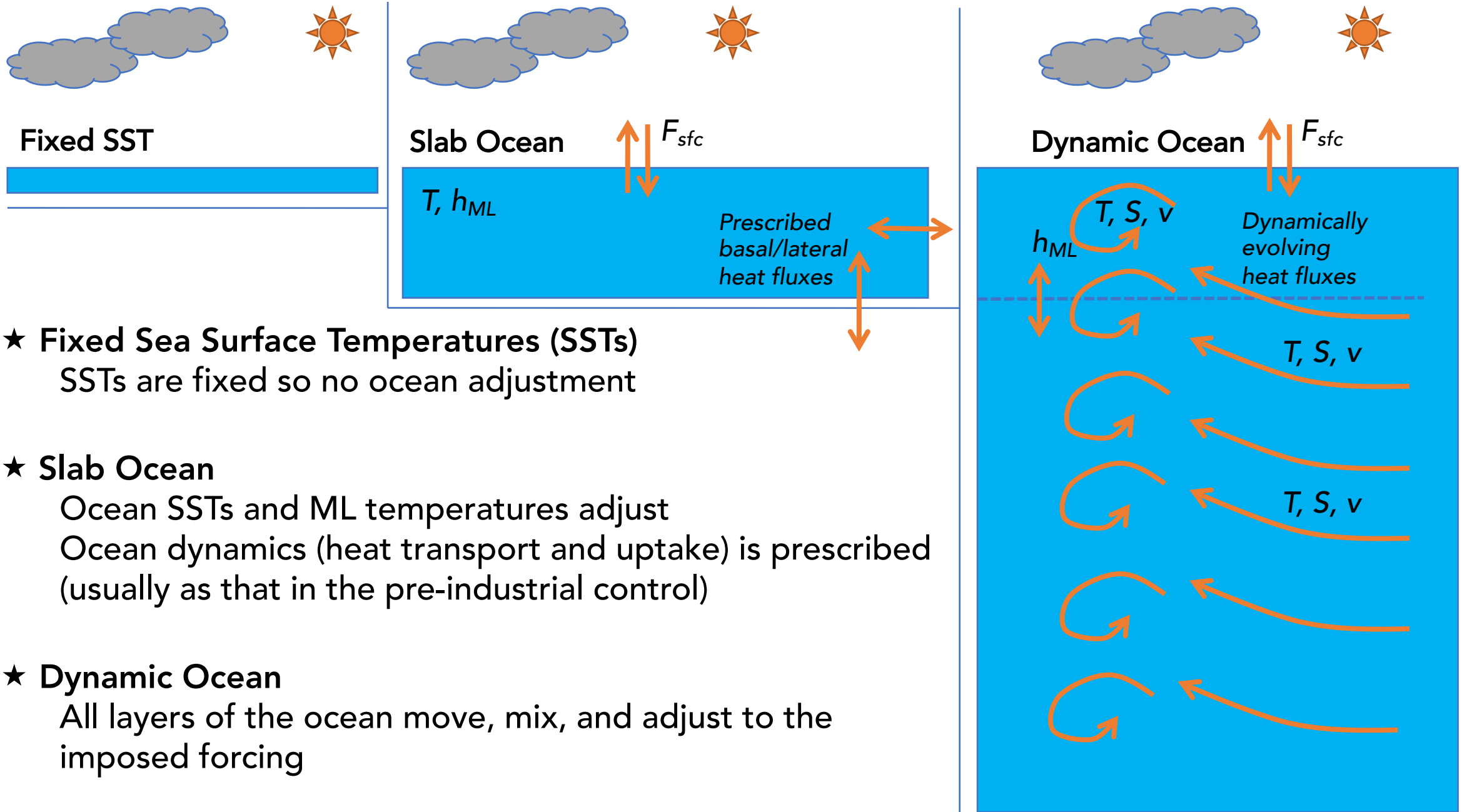
CESM single column

- Atmosphere → SCAM
  - Andrew Gettleman, Isla Simpson
  - https://ncar.github.io/CAM/doc/build/html/users_guide/atmospheric-configurations.html#cam-single-column-fscam-compset
- Land → CLM option
  - Sean Swenson
  - https://escomp.github.io/ctsm-docs/doc/build/html/users_guide/running-single-points/index.html
- Sea Ice → Icepack
  - Dave Bailey, Alice DuVivier
  - https://github.com/CICE-Consortium/Icepack/
- Ocean → POP “Pencil” Model (not supported), MOM6 options
  - Gokhan Danabasoglu, Gustavo Marques

CESM compsets

- CESM supports a number of compsets to run the model coupled or in “standalone” model mode as well as various combinations.
  - **B**: fully coupled, all components active
  - **E**: slab ocean, all other components active
  - **F**: specified SST/sea ice boundary condition, active atmosphere

Fixed SSTs, Slab Oceans, and Dynamic Oceans



★ **Fixed Sea Surface Temperatures (SSTs)**
SSTs are fixed so no ocean adjustment

★ **Slab Ocean**
Ocean SSTs and ML temperatures adjust
Ocean dynamics (heat transport and uptake) is prescribed (usually as that in the pre-industrial control)

★ **Dynamic Ocean**
All layers of the ocean move, mix, and adjust to the imposed forcing

CESM compsets

- CESM supports a number of compsets to run the model coupled or in "standalone" model mode as well as various combinations.
  - **B**: fully coupled, all components active
  - **E**: slab ocean, all other components active
  - **F**: specified SST/sea ice boundary condition, active atmosphere
  - **G**: specified atmosphere boundary condition, active sea ice/ocean
  - **D:** specified atmosphere, active sea ice, slab ocean
  - **I**: specified atmosphere boundary condition, active land
  - **J**: specified atmosphere boundary condition, all other components active
  - **T**: specified land boundary condition, active glacier

Useful links:

http://www.cesm.ucar.edu/models/cesm2/cesm/compsets.html

Note: SATM = stub atmosphere, DATM = data atmosphere

https://escomp.github.io/cesm/release-cesm2/cesm_configurations.html#cesm2-component-sets

http://www.cesm.ucar.edu/models/simpler-models/slab-ocean-model.html

3 examples of using model hierarchies to answer polar science questions

- What are the climate impacts of flattening Antarctica?

What is the role of the ocean in the climate response if the Antarctic Ice Sheet was flattened?

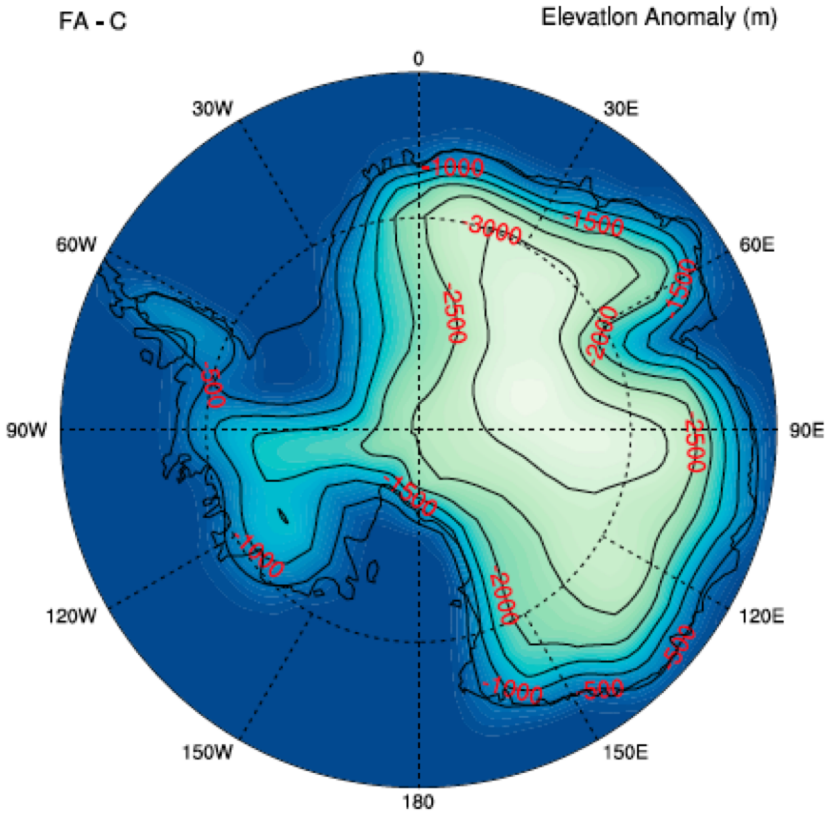
Singh et al. 2016. J. Clim. The Global Climate Response to Lowering Surface Orography of Antarctica and the Importance of Atmosphere-Ocean Coupling. doi: 10.1175/JCLI-D-15-0442.1

What role does atmosphere-ocean coupling play in the climate system response to flattening of the Antarctic Ice Sheet?

4 experiments* using CCSM4 (2^o atm/land; 1^o ocn/ice)

- **B** compset → fully coupled, full depth ocean with dynamics + thermodynamics
- **E** compset → fully coupled, slab ocean with thermodynamic mixed layer only

**All have full atmosphere components*

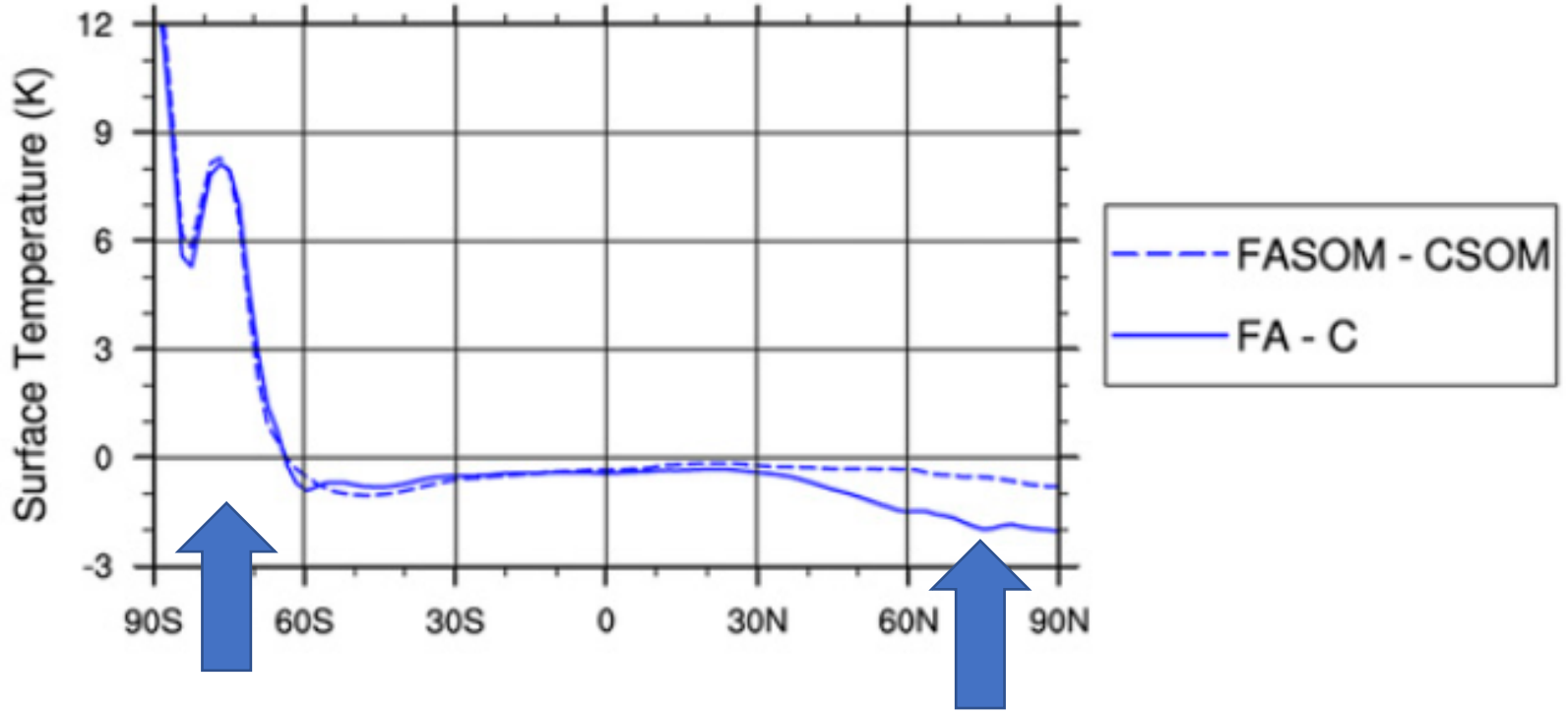


Control: unaltered orography

Experiments: Antarctica orography decreased 90%

The (remote) Global Temperature Response to Antarctic Flattening Depends on Ocean Dynamics

Note:
FA = B case, Flat Antarctica
FASOM = E case, Flat Antarctica
C = B case, control
CSOM = E case, control



Similar responses here
Probably (mostly) atmospheric

Different responses here
Requires the ocean

The (remote) Global Temperature Response to Antarctic Flattening Depends on Ocean Dynamics

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FA = B case, Flat Antarctica
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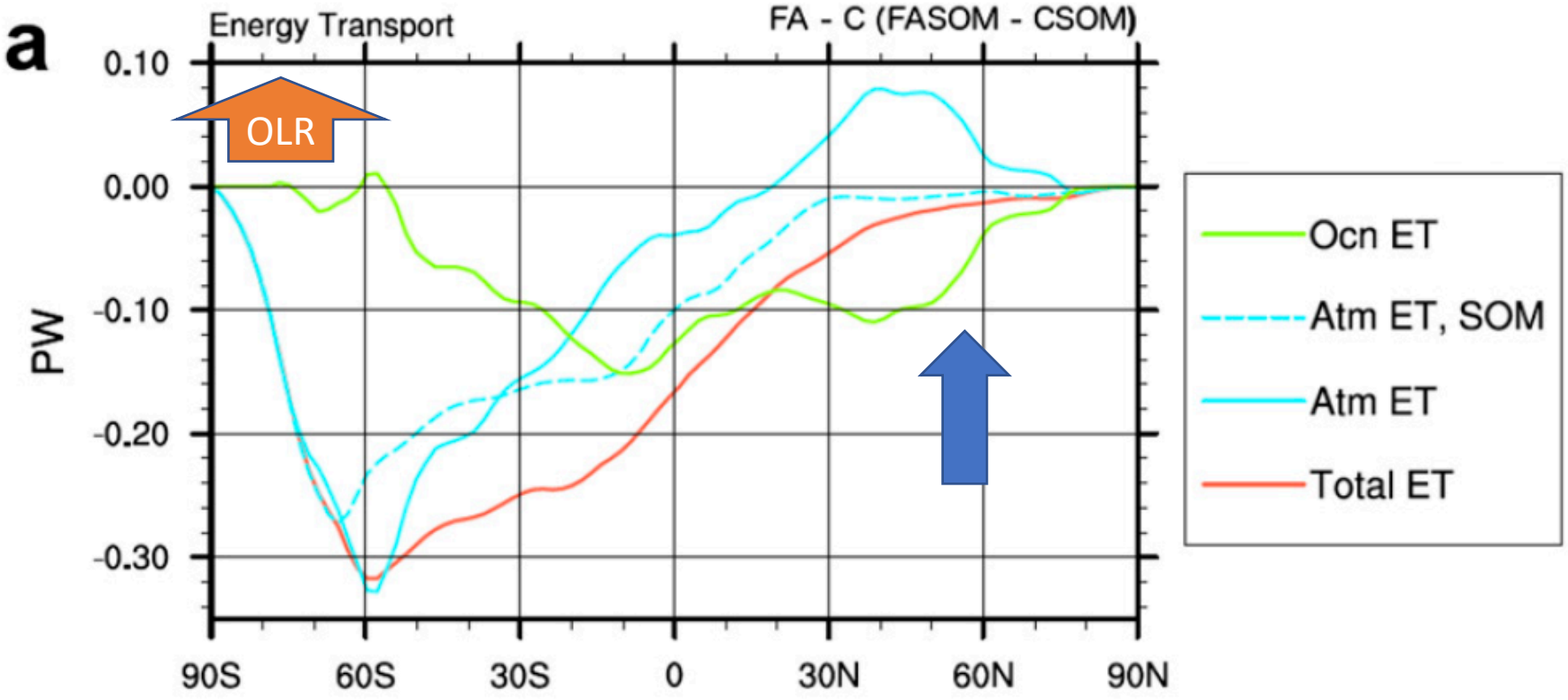
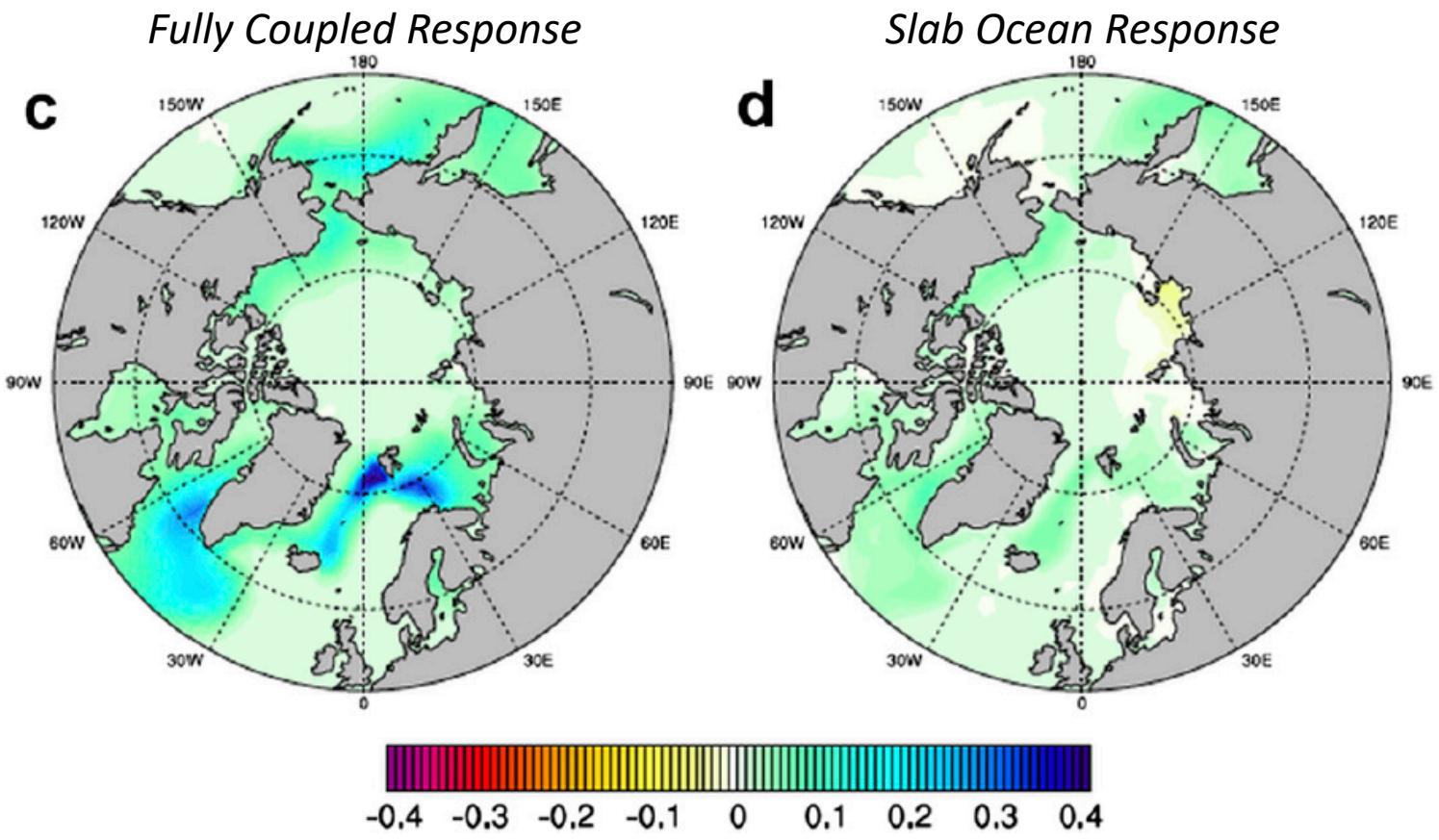


<u>Fully-Coupled Response</u>: OHT into the Arctic decreases and the Arctic cools

<u>Slab Ocean Response</u>: OHT cannot change (by design of the slab ocean) and the Arctic does not cool

When the atmosphere and ocean are fully-coupled, sea ice in the *Arctic* expands when Antarctica is flattened.

The remote climate response to a regional forcing may depend on dynamic atmosphere-ocean coupling.



3 examples of using model hierarchies to answer polar science questions

- What are the climate impacts of flattening Antarctica?
- What are the climate impacts of Arctic Sea Ice loss?

Does ocean coupling matter for the extratropical atmospheric response to Arctic sea ice loss?

Deser et al. 2015. J. Clim. The Role of Ocean-Atmosphere Coupling in the Zonal Mean Atmospheric Response to Arctic Sea Ice Loss. doi: 10.1175/JCLI-D-14-00325.1

Deser et al. 2016. GRL. Does ocean coupling matter for the northern extratropical response to projected Arctic sea ice loss? doi: 10.1002/2016GL067792

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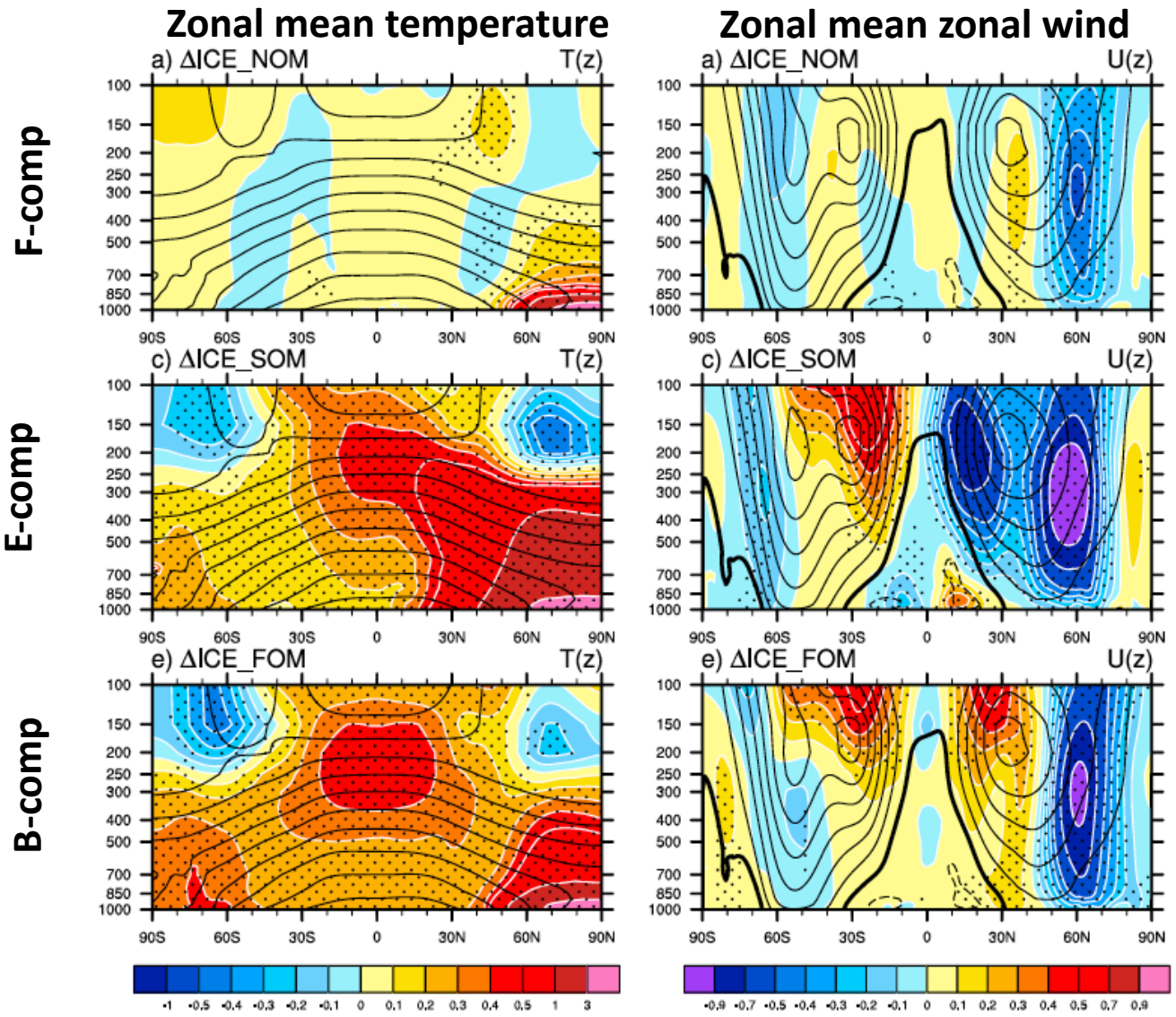
3 experiments* using 1° CCSM4

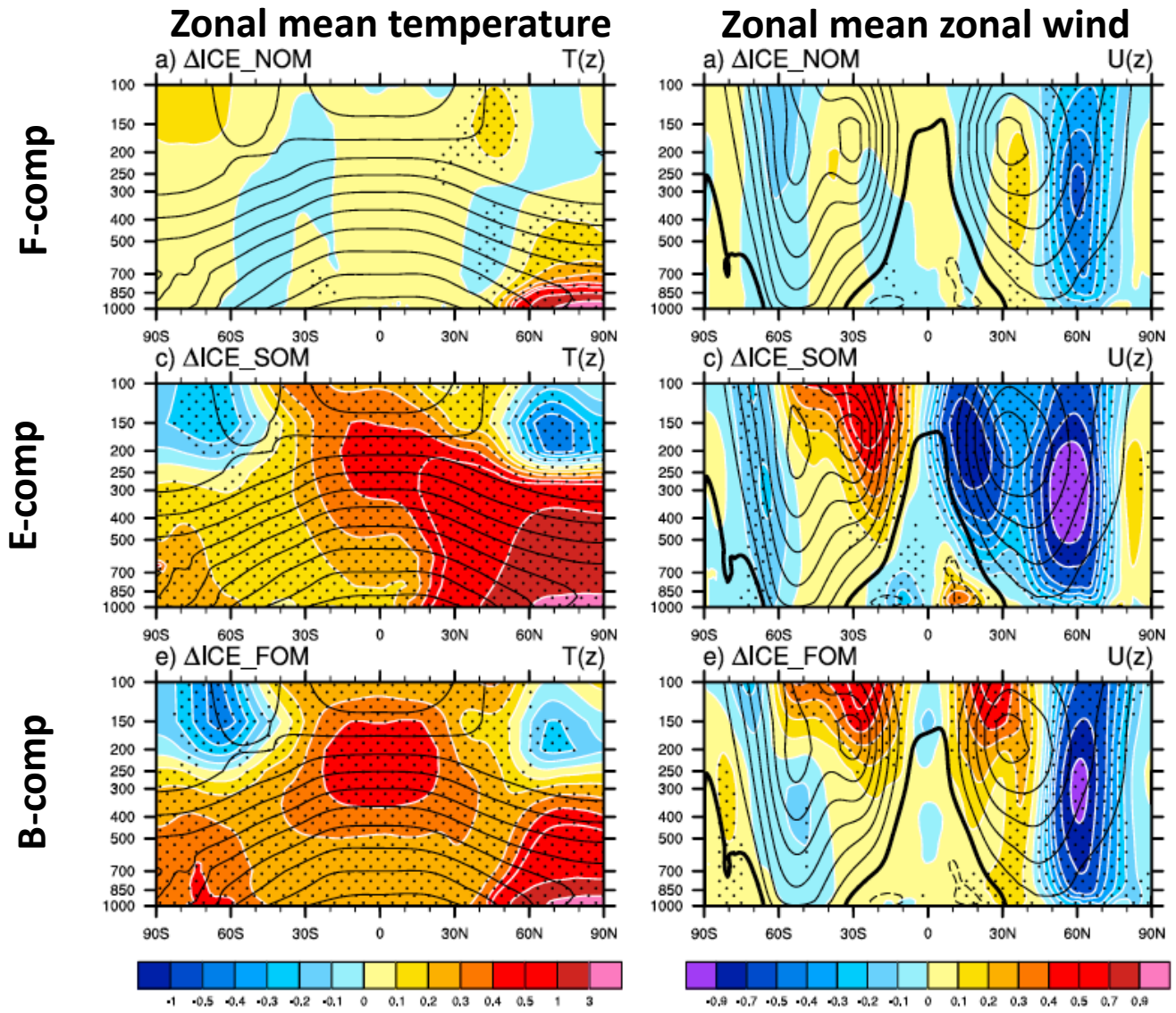
- **B** compset → fully coupled, full depth ocean with dynamics + thermodynamics
- **E** compset → fully coupled, slab ocean with prescribed ocean heat transport and thermodynamic mixed layer only
- **F** compset → specified SST and sea ice

* All use active atmosphere

What differences do you see?



What differences do you see?



Just a few:

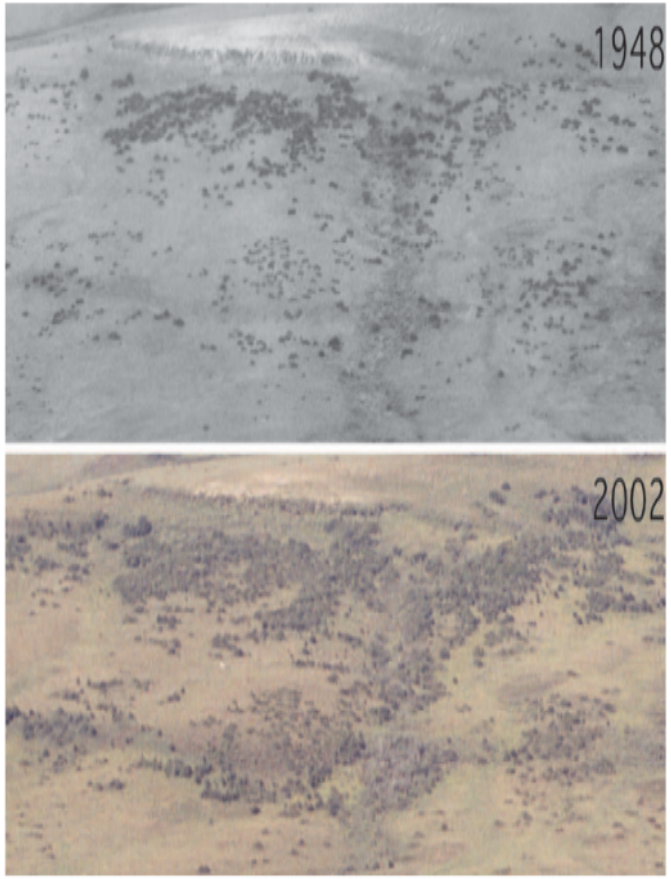
- Meridional extent of Arctic amplification
- Upper atmosphere tropical heating
- Magnitude of NH polar jet stream
- Southern hemisphere tropical jets
- Magnitude of precipitation in the Arctic over land and Sea.

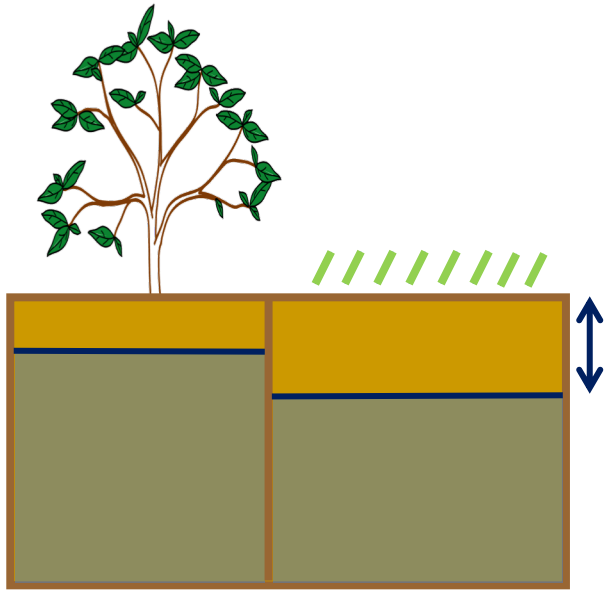
3 examples of using model hierarchies to answer polar science questions

- What are the climate impacts of flattening Antarctica?
- What are the climate impacts of Arctic Sea Ice loss?
- How does Arctic shrub expansion impact permafrost thaw?

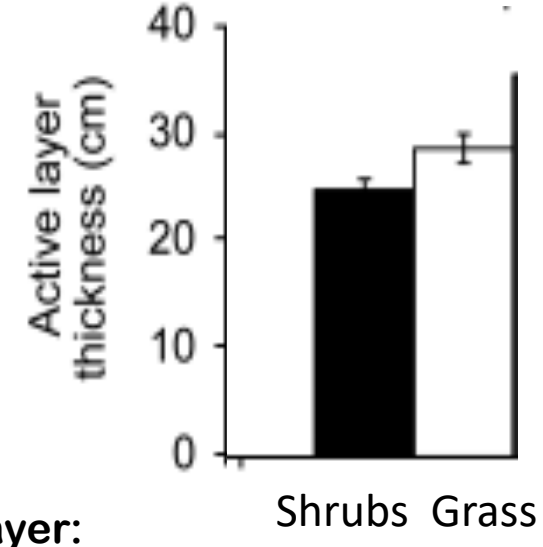
Field studies suggest expanding shrub cover may reduce permafrost thaw.

Arctic is greening: +7% increase in shrubs in Alaska, 1950 to 2005





Active layer: layer that freezes and thaws each year



Blok et al. 2010. Global Change Biology. Shrub expansion may reduce summer permafrost thaw in Siberian tundra. doi: 10.1111/j.1365-2486.2009.02110.x

Slides adapted from D. Lawrence; adapted from McGuire et al., 2006

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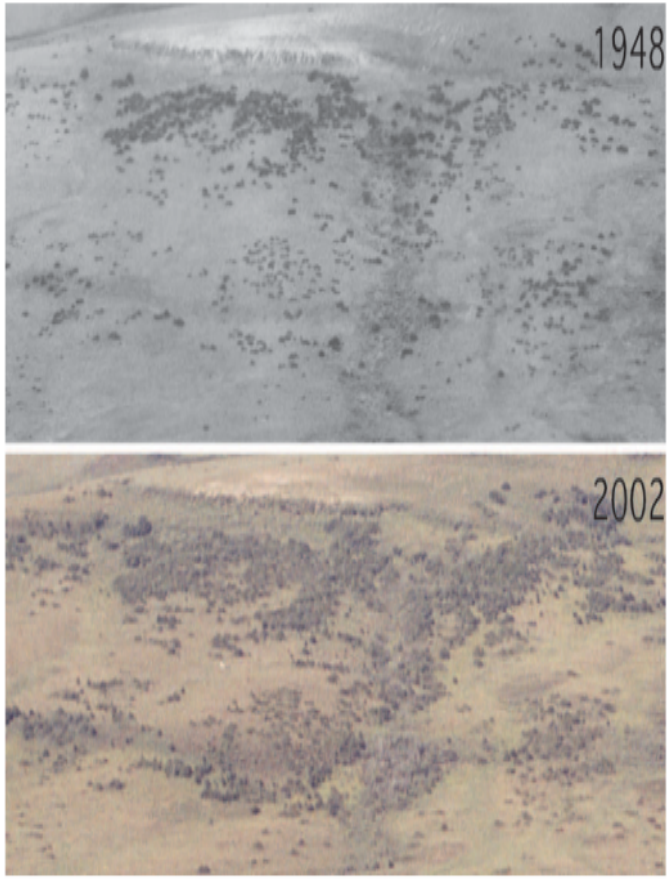

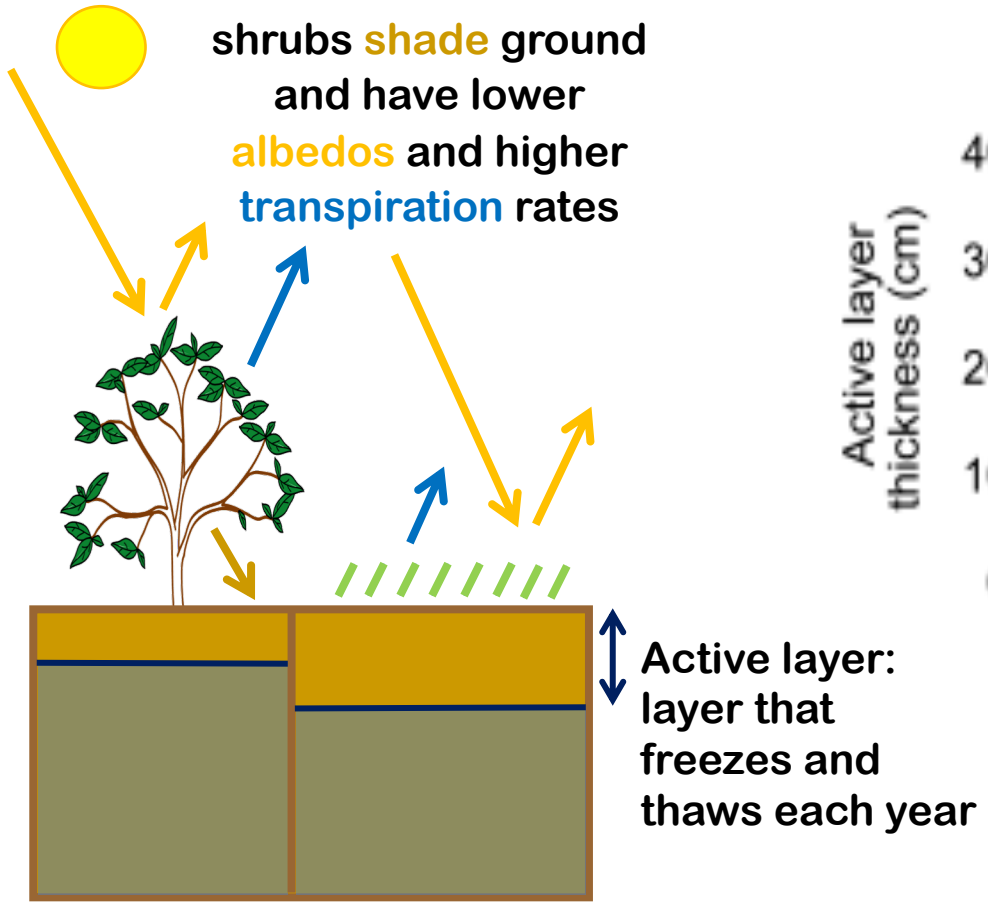

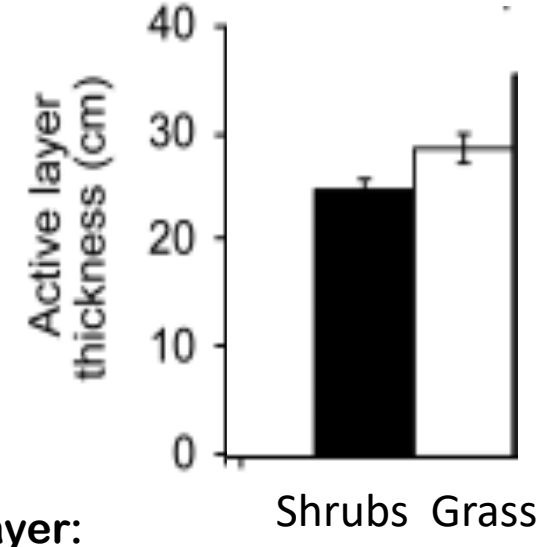

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Does expansion of shrubs in Arctic affect summer permafrost thaw?

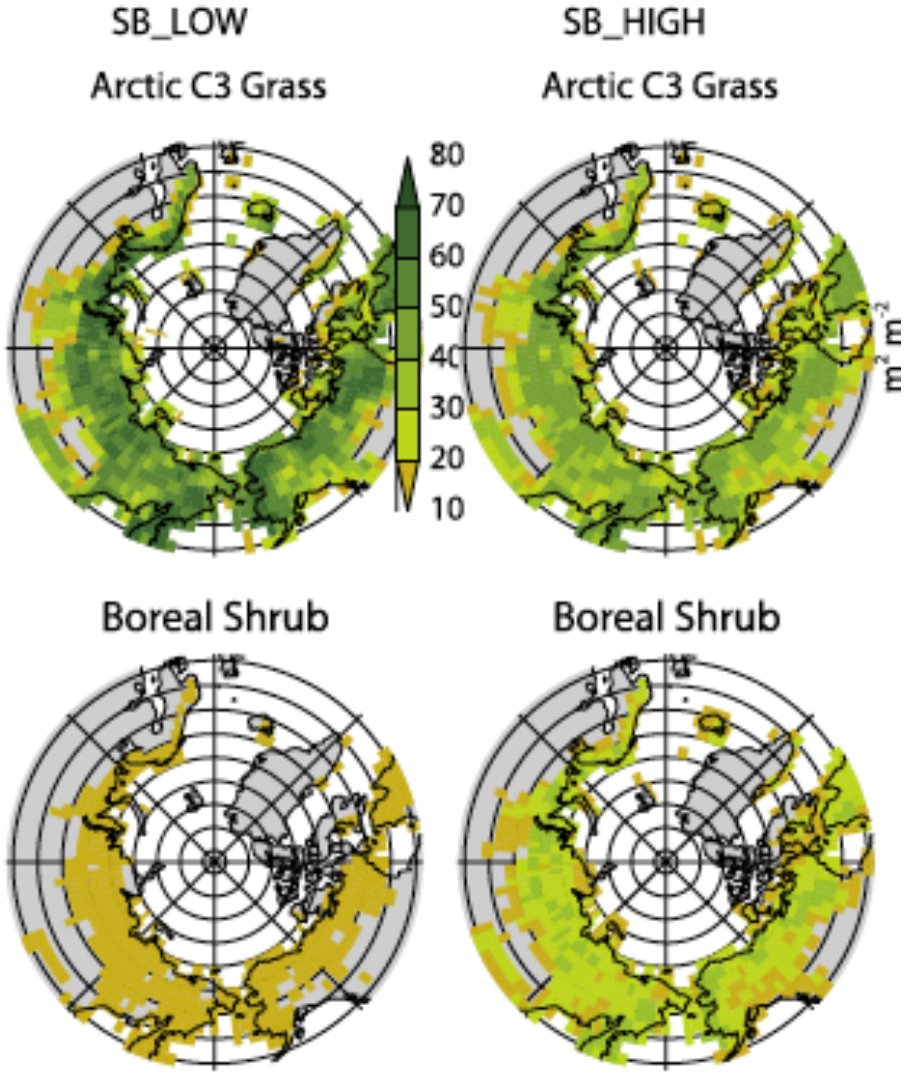
Lawrence and Swenson. 2011. ERL. Permafrost response to increasing Arctic shrub abundance depends on relative influence of shrubs on local soil cooling vs. large-scale climate warming. doi: 10.1088/1748-9326/6/4/045504

Does expansion of shrubs in Arctic affect summer permafrost thaw?

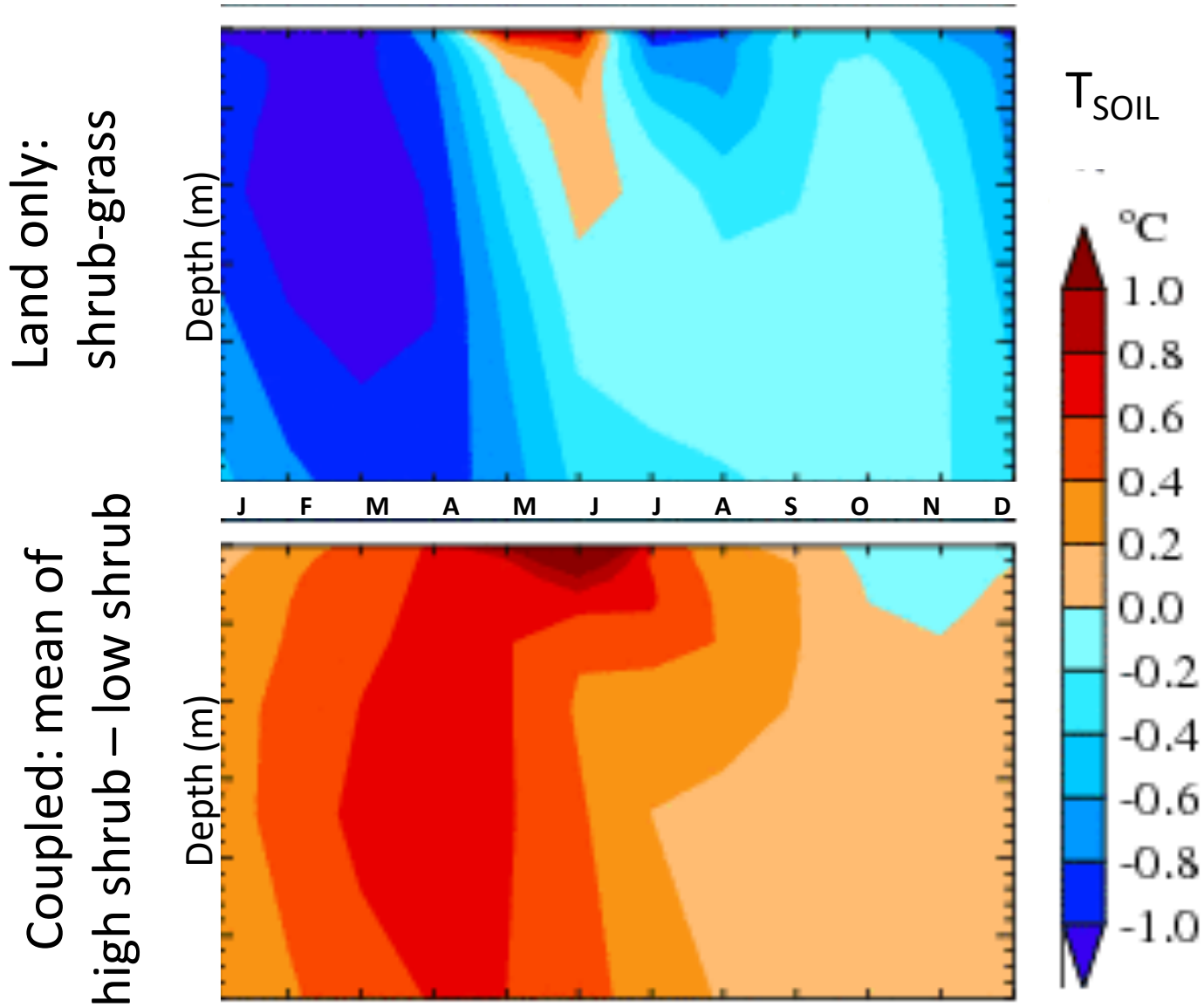
4 experiments* using 1° CCSM4

- **B** compset → everything coupled
- **I** compset → active land, data atmosphere
- Both use experiments with high shrub fraction vs. low

- Control: unaltered (low) shrub fraction
- Experiments: High shrub fraction



What differences do you see?



Slides adapted from D. Lawrence; Lawrence and Swenson, ERL, 2011

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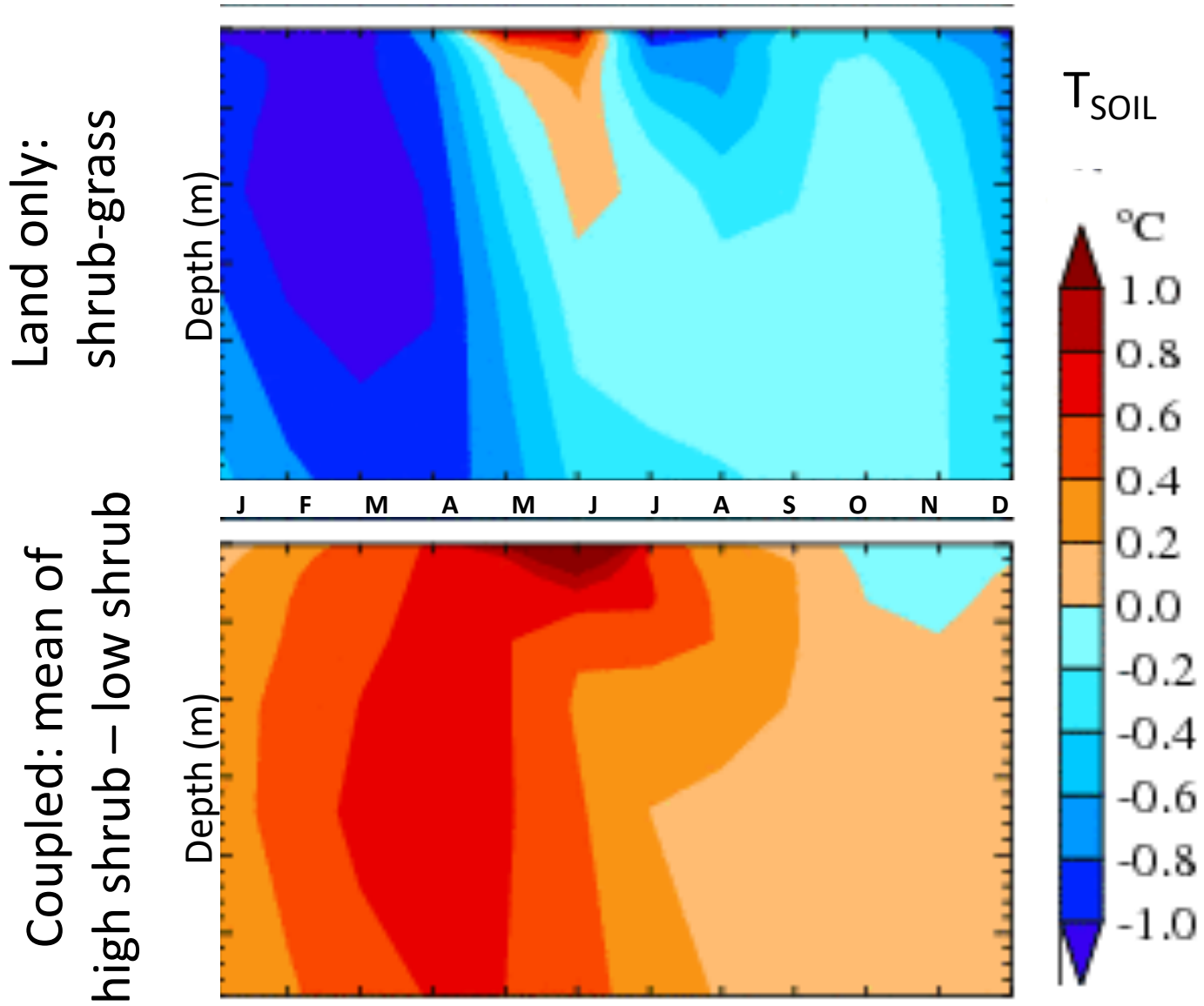


- Land only experiment consistent with field obs – shrub columns colder than grass, thinner active layer
- Coupled shows high shrub has warmer soil and active layer is thicker.
  - Impact of direct local cooling effects vs. indirect climate warming with coupled system

Slides adapted from D. Lawrence; Lawrence and Swenson, ERL, 2011

Now it's your turn to explore!

We will use a hierarchy of models to explore the role of active ocean-atmosphere coupling in the following:

1. *the climate system response to CO_2-doubling*
2. *Interannual, decadal, and interdecadal variability*

- Groups will go through <u>two</u> pre-prepared jupyter notebooks

- Instructions for the practical labs can be found here:

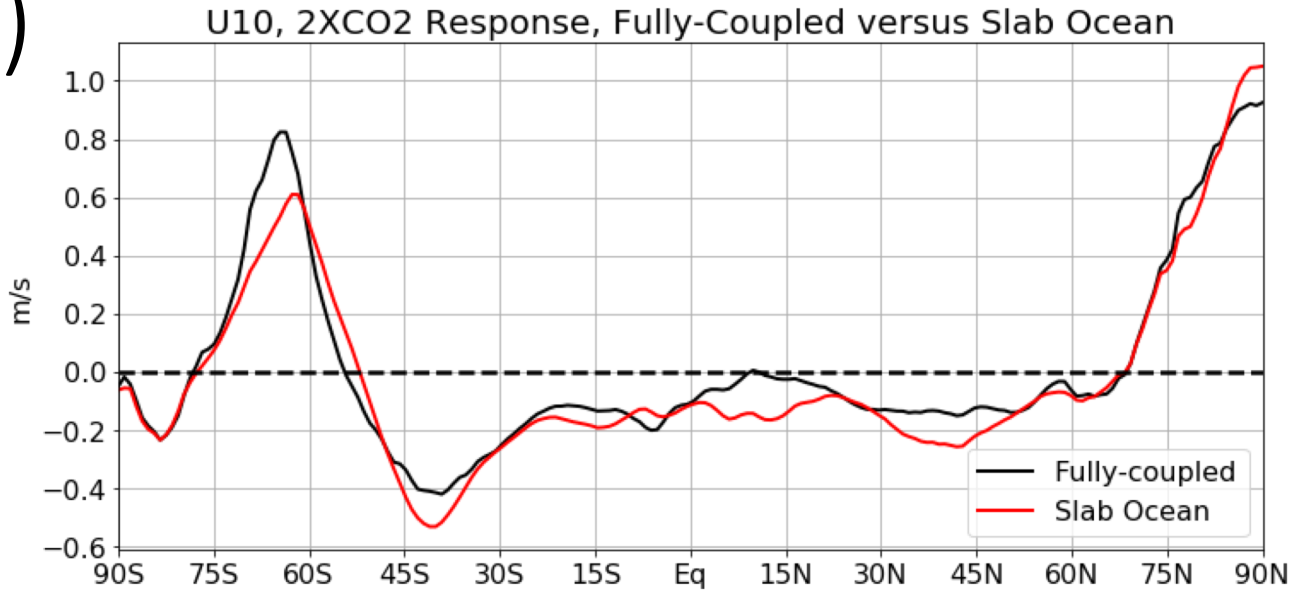
  /glade/p/cesm/pcwg/PWS2019/day2/jupyter_instructions_casper.txt

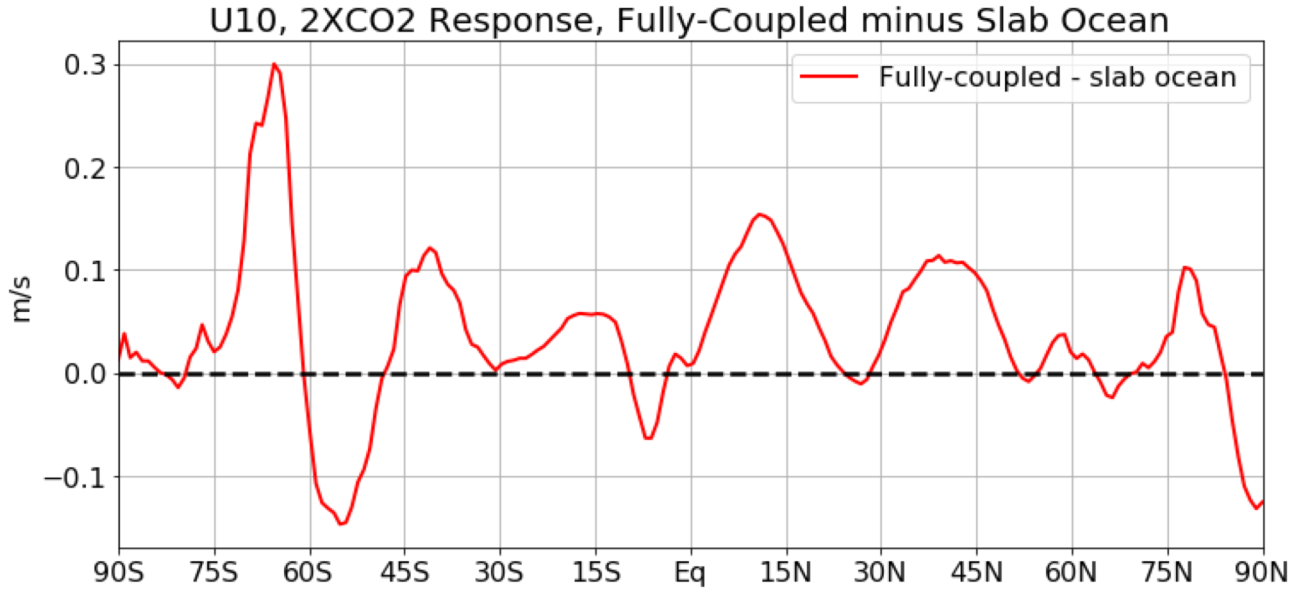
- To log in to casper directly:

  ssh -Y USERNAME@casper.ucar.edu

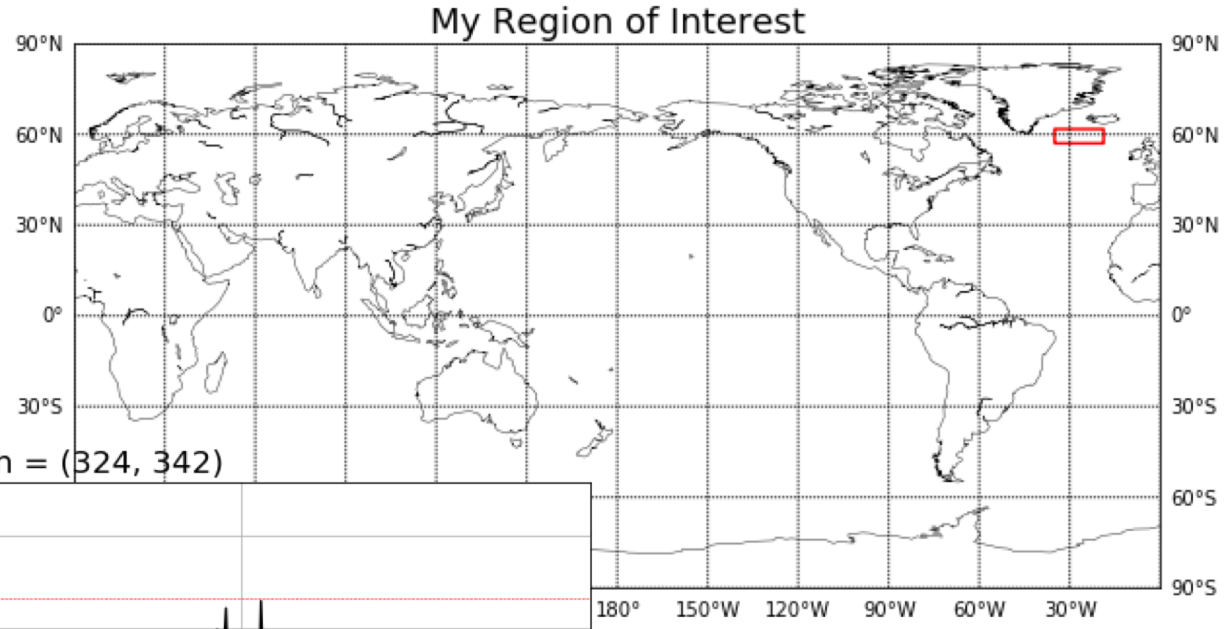
- We'll reconvene **<u>at 11:30</u>** to discuss – each group should send Alice (duvivier@ucar.edu) your favorite figure from the activities for the discussion.

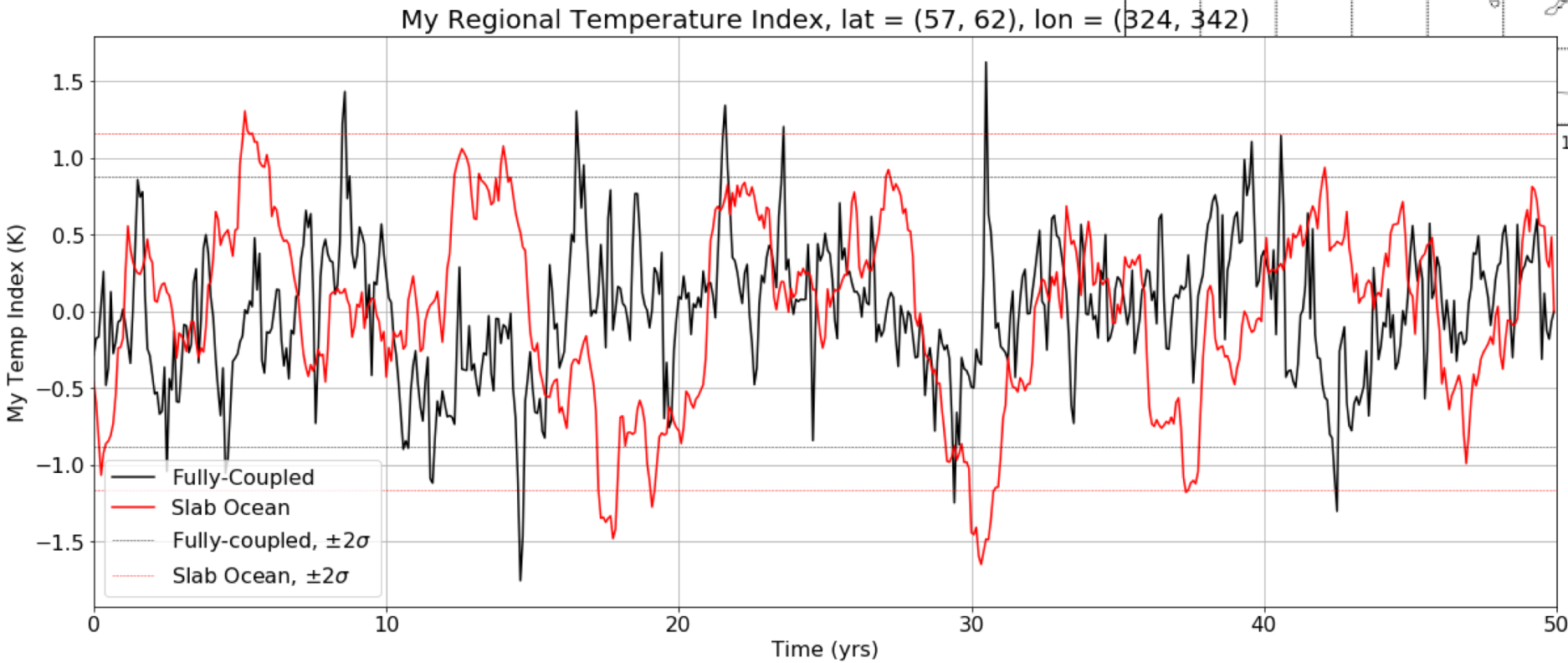
Morning debrief/discussion – Floe survivors (red/pink)



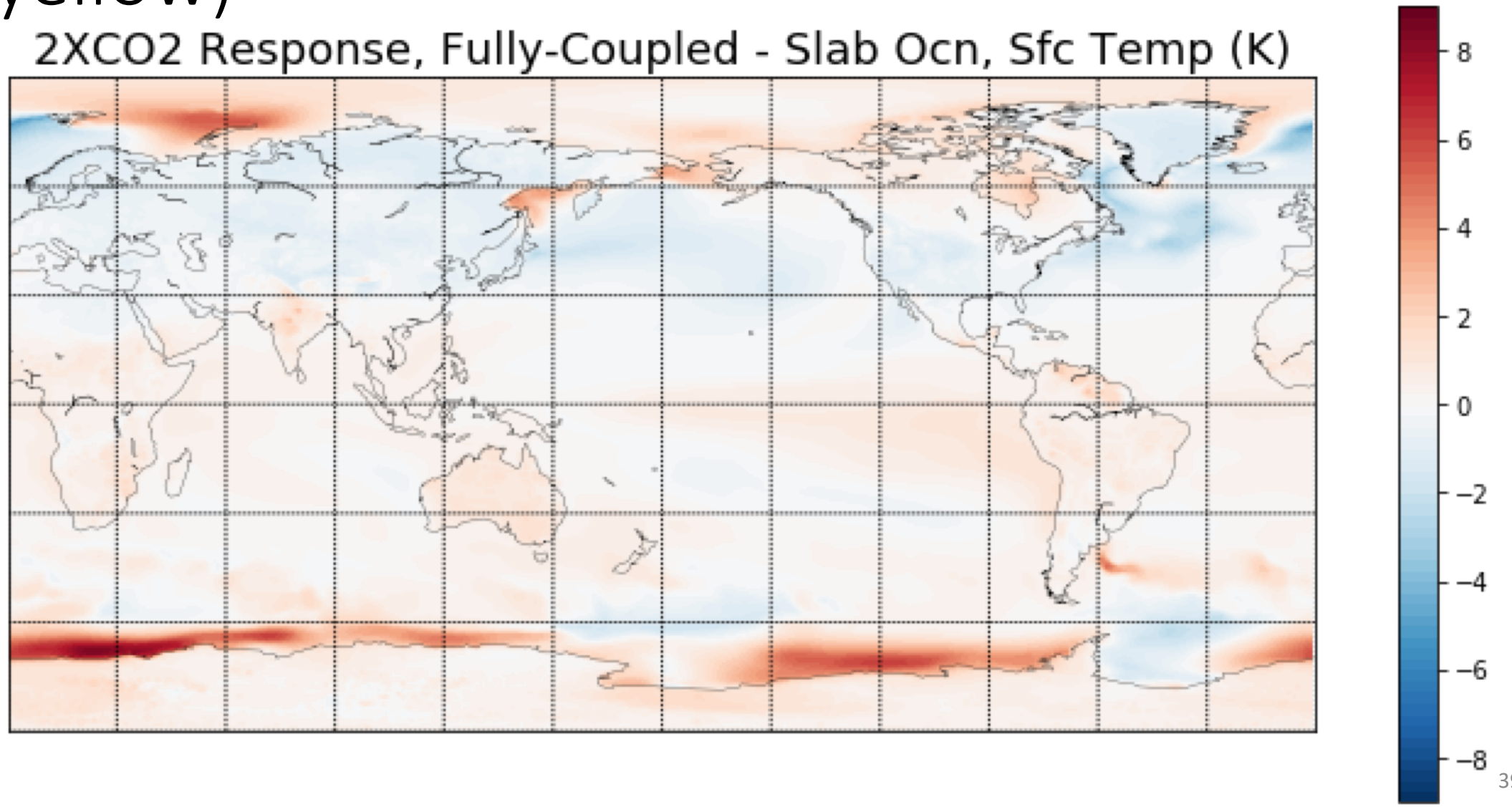


Morning debrief/discussion – Glorious Modeling Revolution (orange)

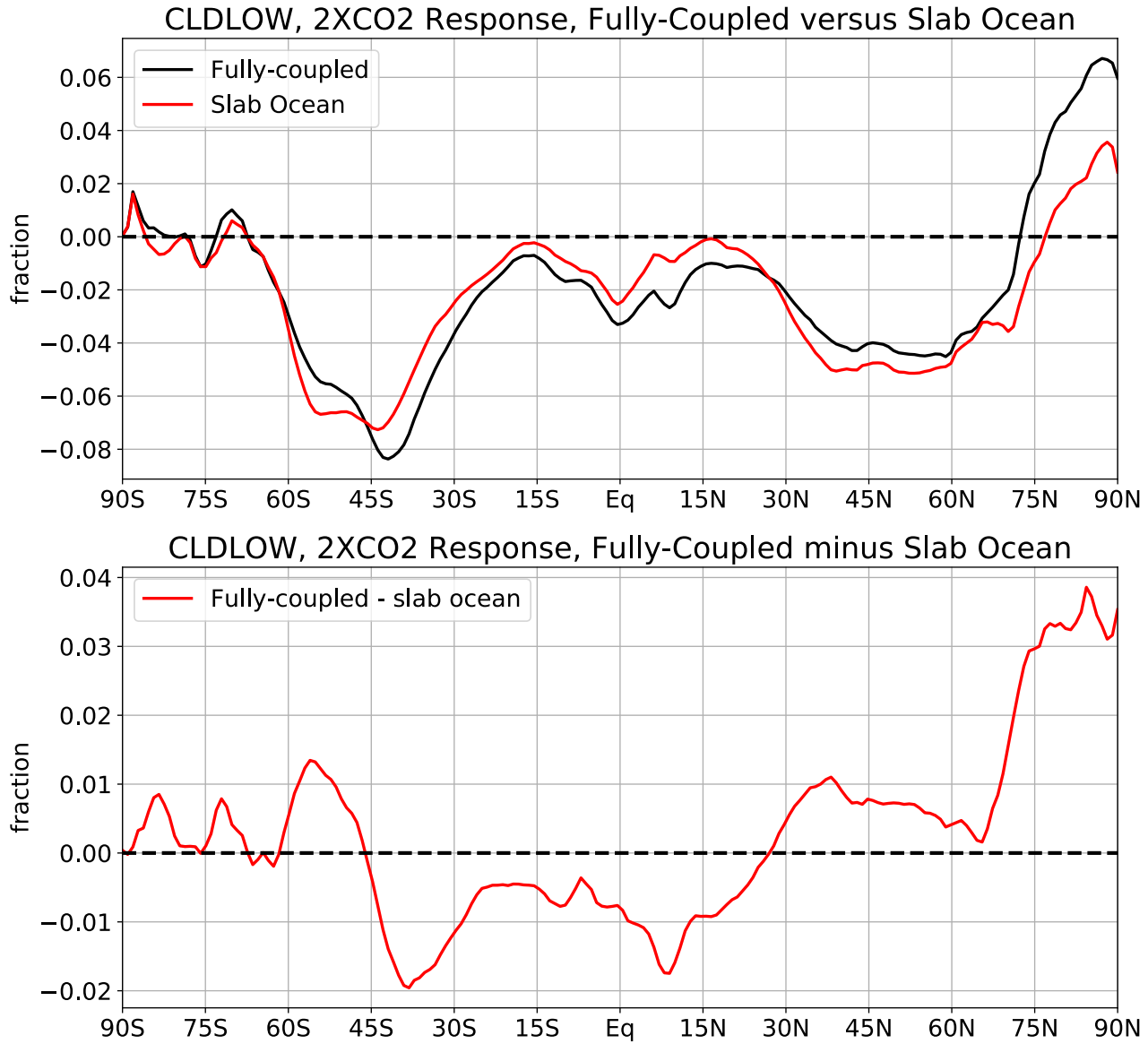




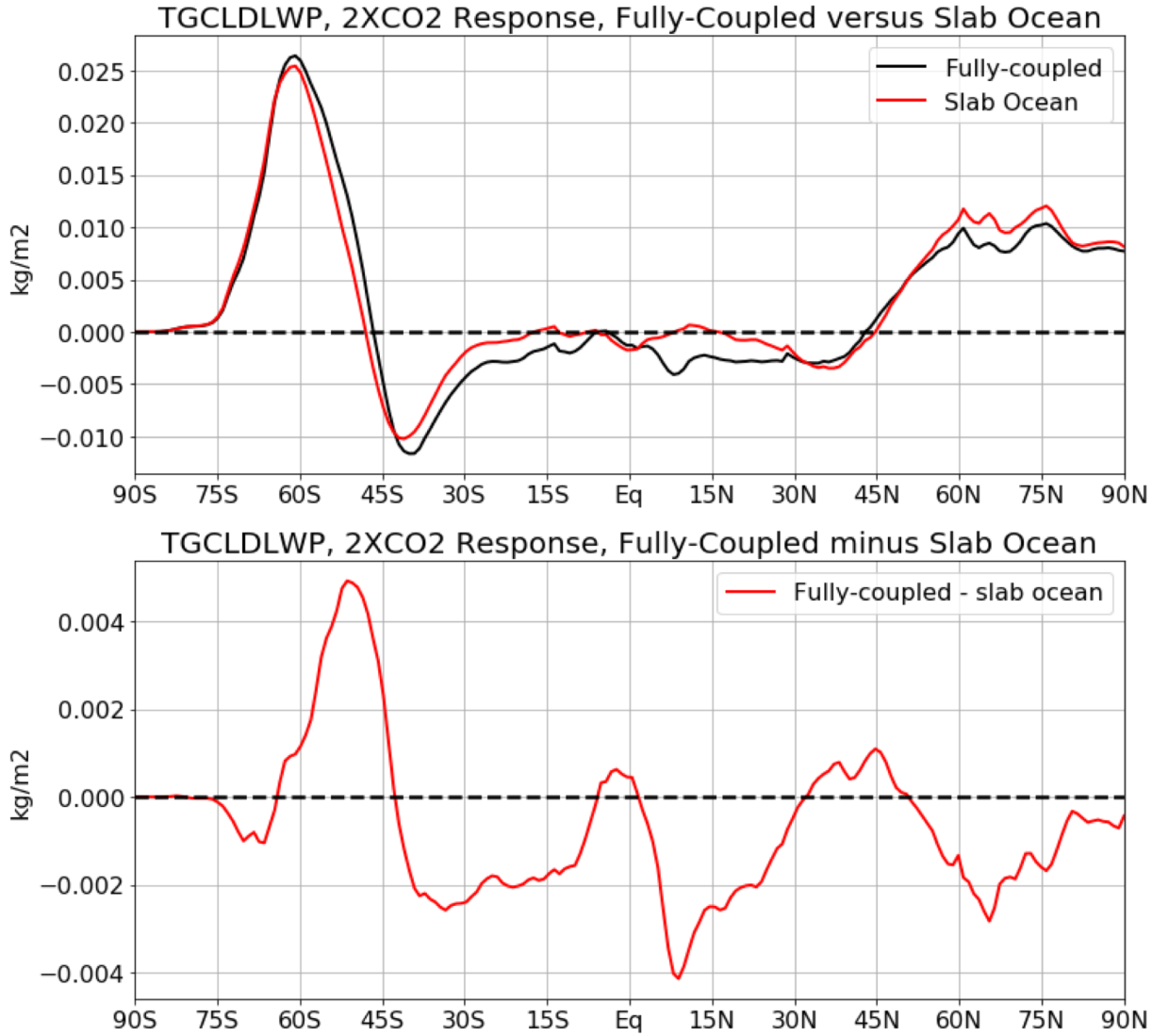
Morning debrief/discussion – Sundogs (yellow)



Morning debrief/discussion – Brine Pockets (green)



Morning debrief/discussion – Blue Mosquitoes (blue)



Morning debrief/discussion – Adelie penguins (purple)