Example Biases and Development Needs for CESM

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(On behalf of the CESM Project)

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CESM Status

- CESM2 currently being assembled
  - CAM5.5, POP2+, CLM5, CICE5

- CESM has benefitted from previous CPTs

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CESM Status

- CESM2 currently being assembled
  - CAM5.5, POP2+, CLM5, CICE5
- CESM has benefitted from previous CPTs
- Numerous biases remain within CESM
- We highlight examples of some important biases across different model components and the need for new model capabilities
- The examples given are areas where process understanding could lead to model improvements

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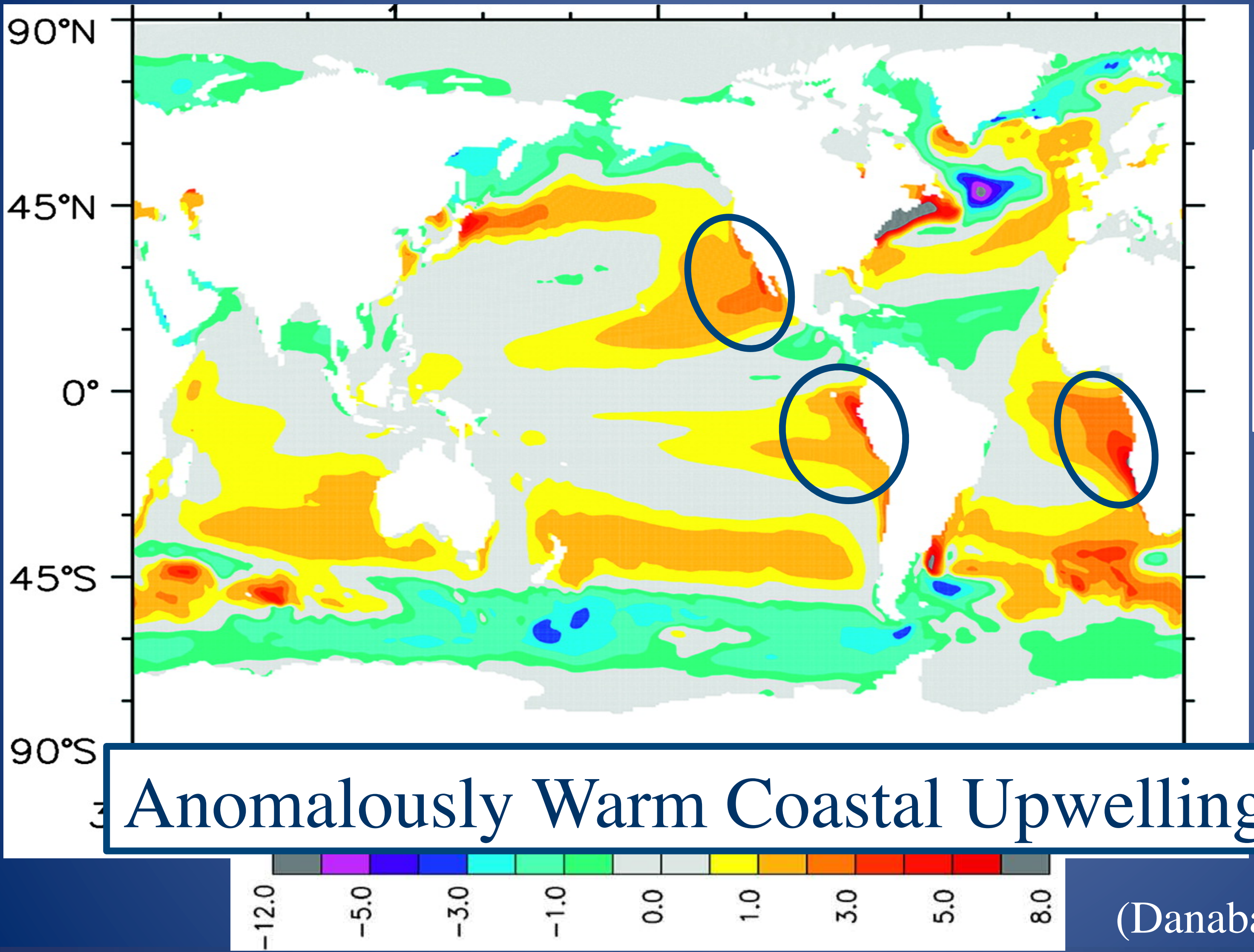
Example: SST Bias



Anomalously Warm Coastal Upwelling Regions

Late 20th Century Relative to HadISST

(Danabasoglu et al. 2012)

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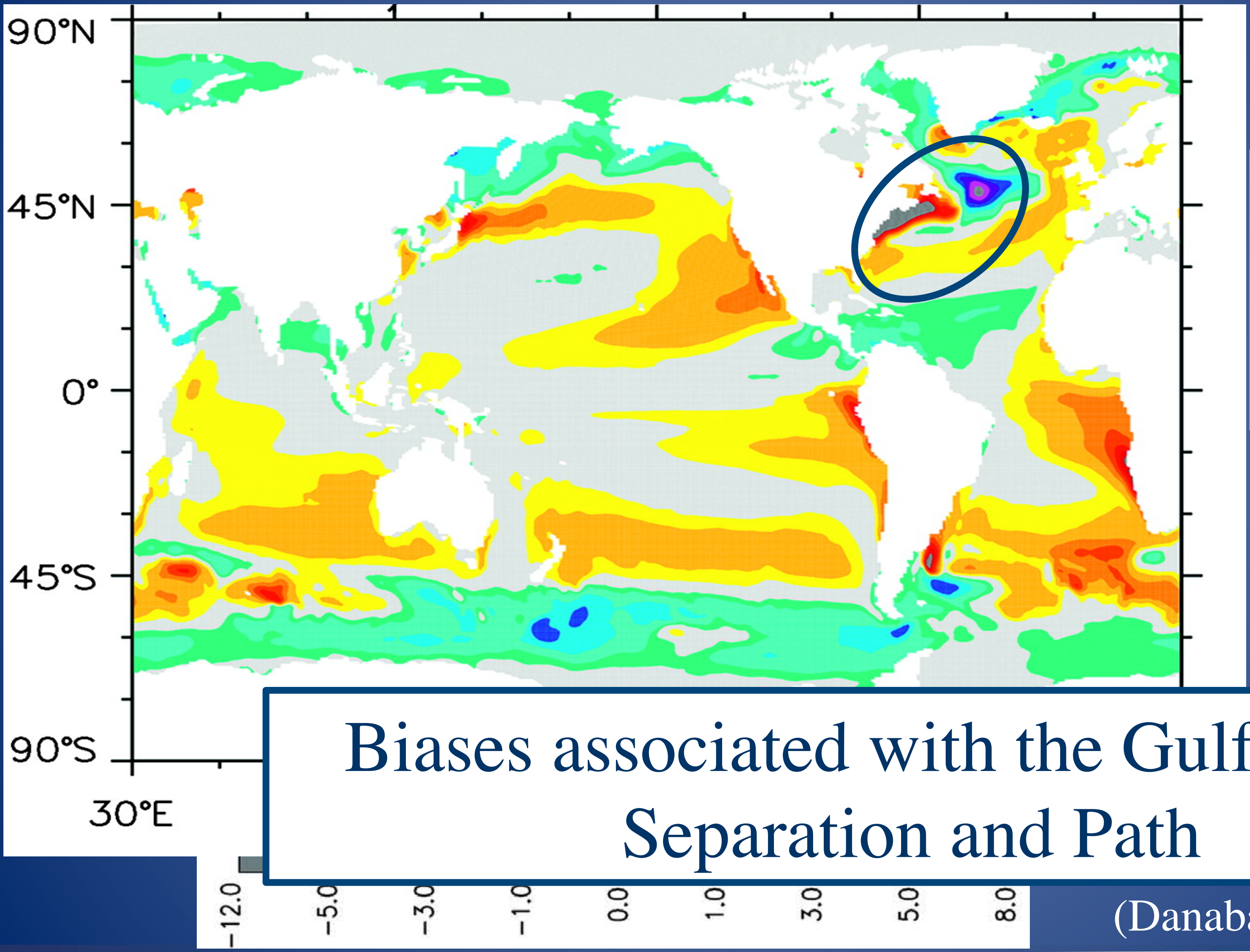
Example: SST Bias



Late 20th Century Relative to HadISST

Biases associated with the Gulf Stream Separation and Path

(Danabasoglu et al. 2012)

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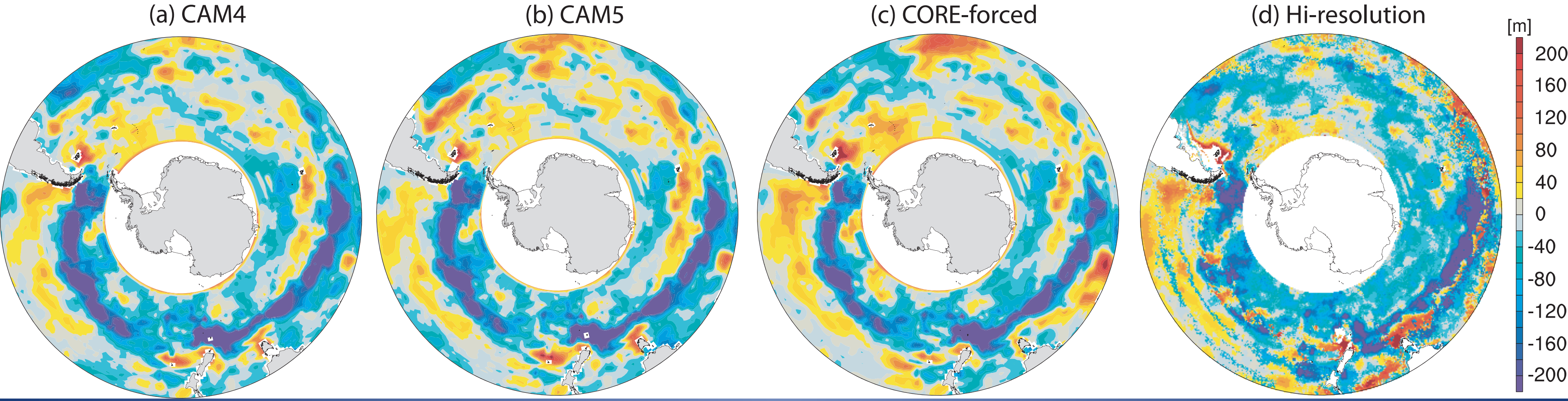
Bias Example: Southern Ocean

Shallow Mixed Layer Depths



- CESM simulations have shallow mixed layer depths in the Southern Ocean
- This bias is not strongly dependent on the atmosphere or model resolution
- It is affected by vertical and lateral ocean mixing processes

Courtesy of Matt Long

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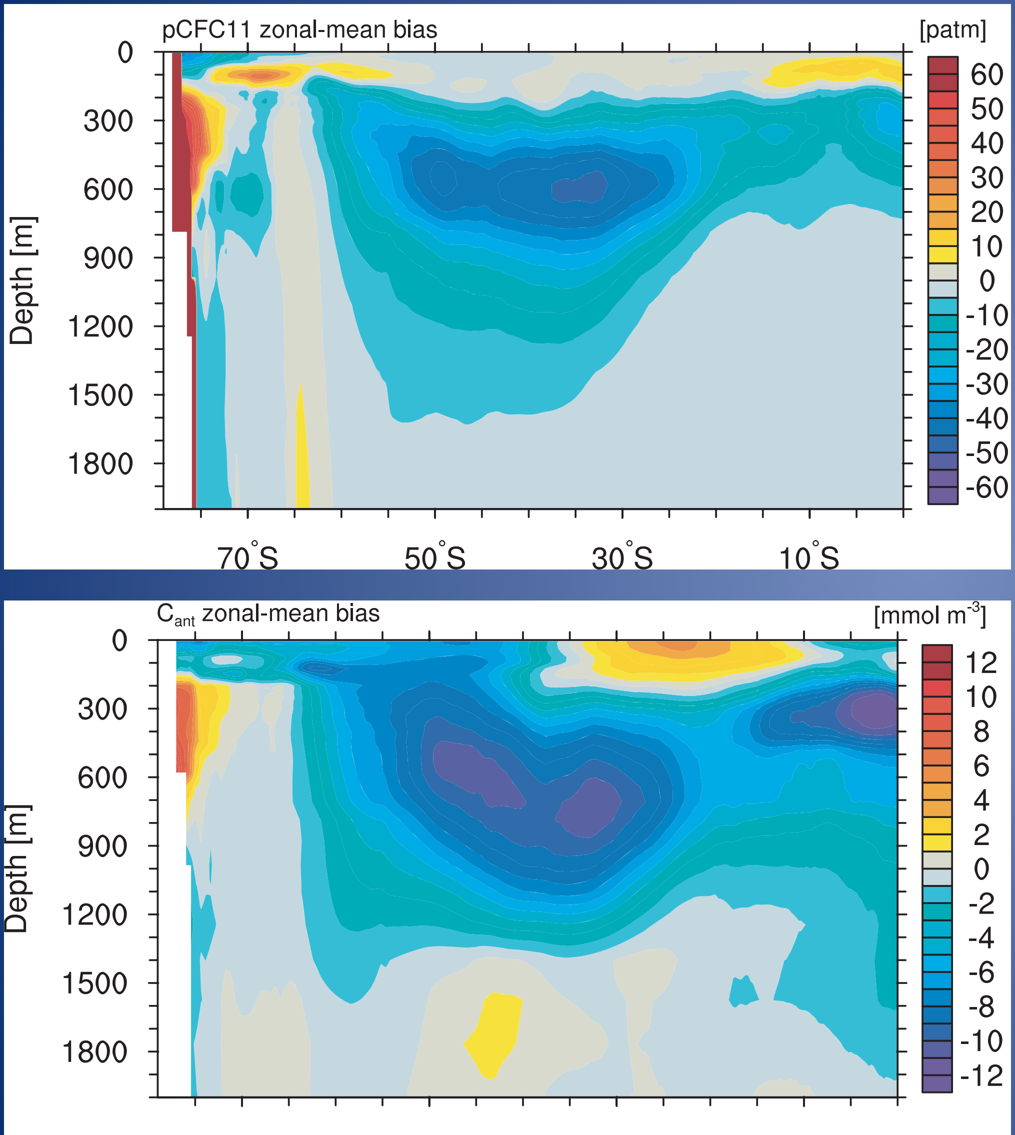
Bias Example: Southern Ocean



Comparisons of simulated and observed ocean CFCs

Indicate too little Southern Ocean uptake

Anthropogenic Carbon uptake bias

20th century runs simulate too little carbon uptake

Courtesy of Matt Long

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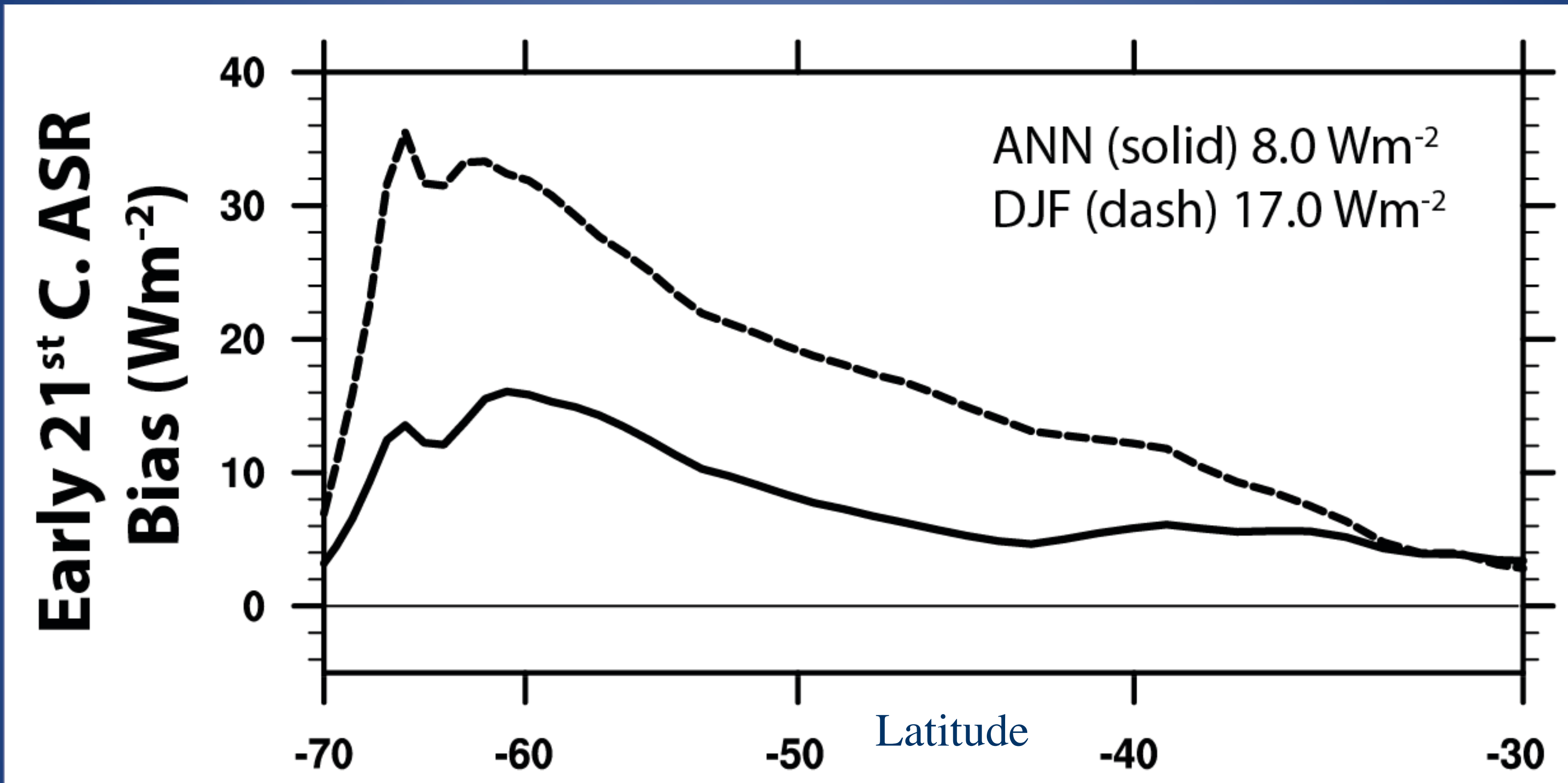
Bias Example: Excessive Southern Ocean Absorbed Shortwave Radiation



CESM-CAM5 simulates excessive TOA Absorbed Shortwave Radiation

(Kay et al., 2014)

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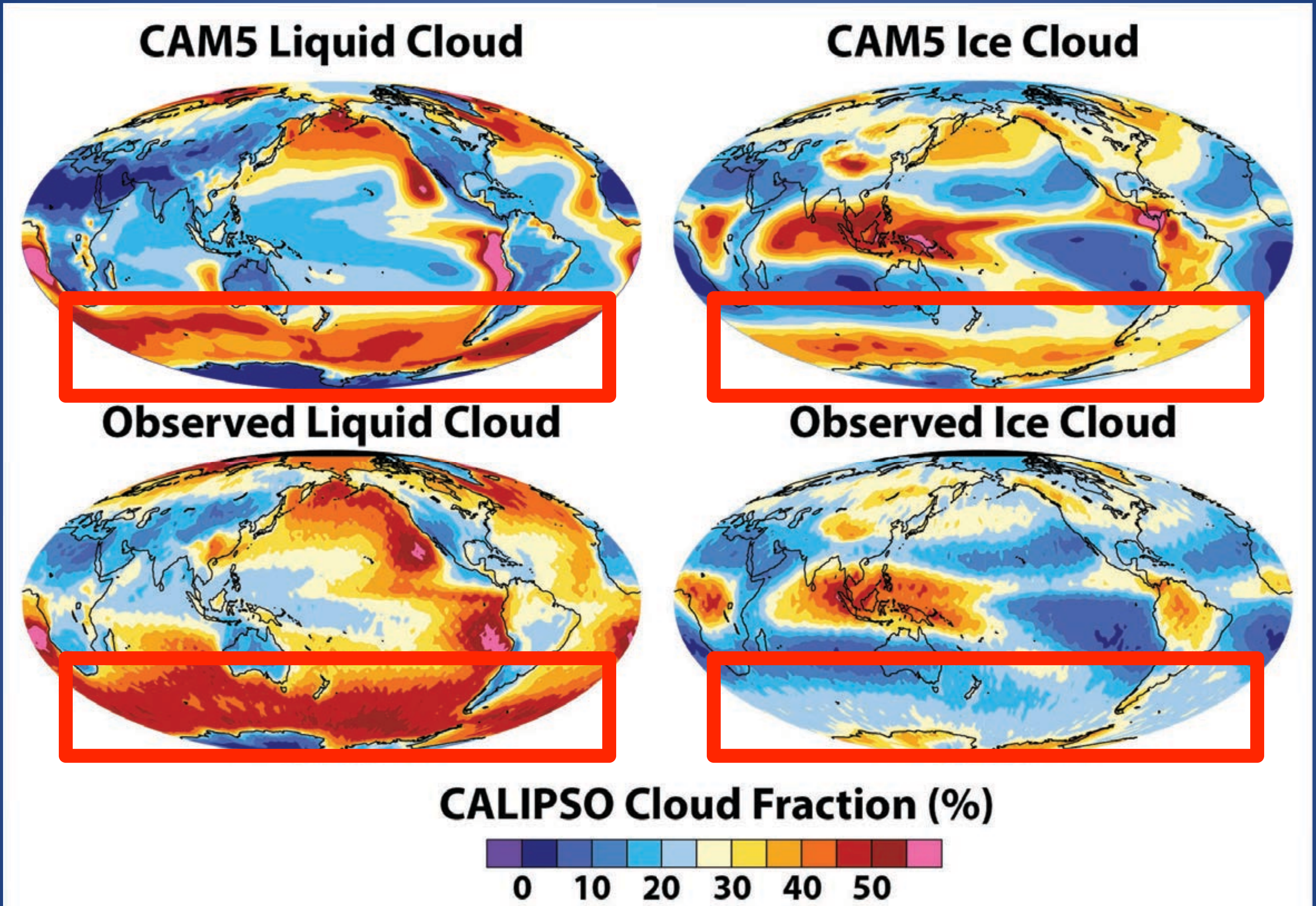
Cloud phase biases in atmosphere-only CAM5 runs

(using simulator-enabled comparisons with CALIPSO)



Over the Southern Ocean: Not enough Liquid, Too much Ice

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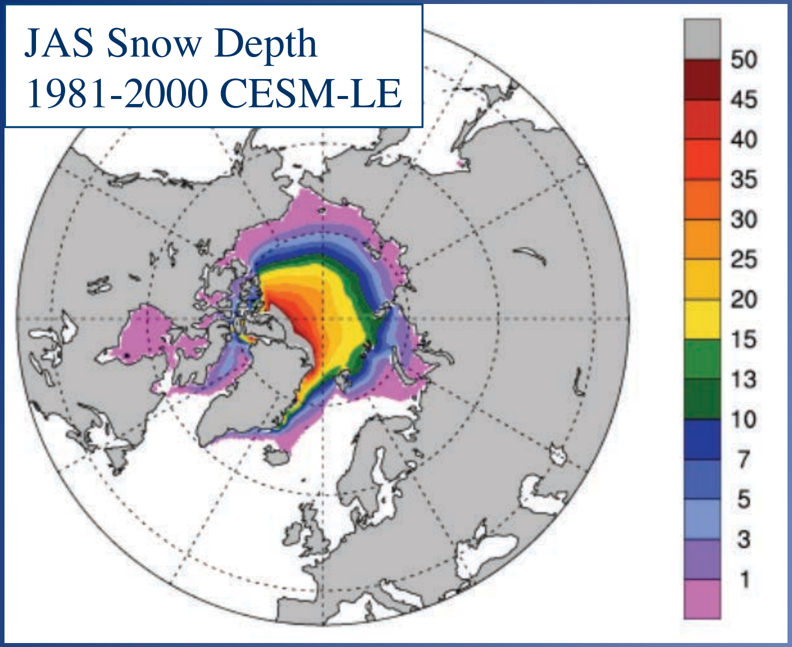
Bias Example: Snow on Sea Ice



CESM retains excessive snow cover on sea ice during summer

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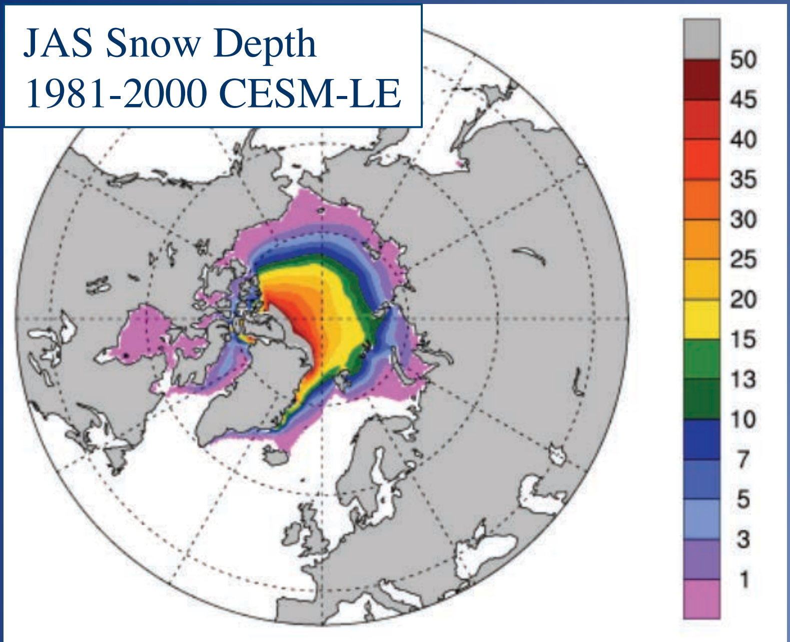
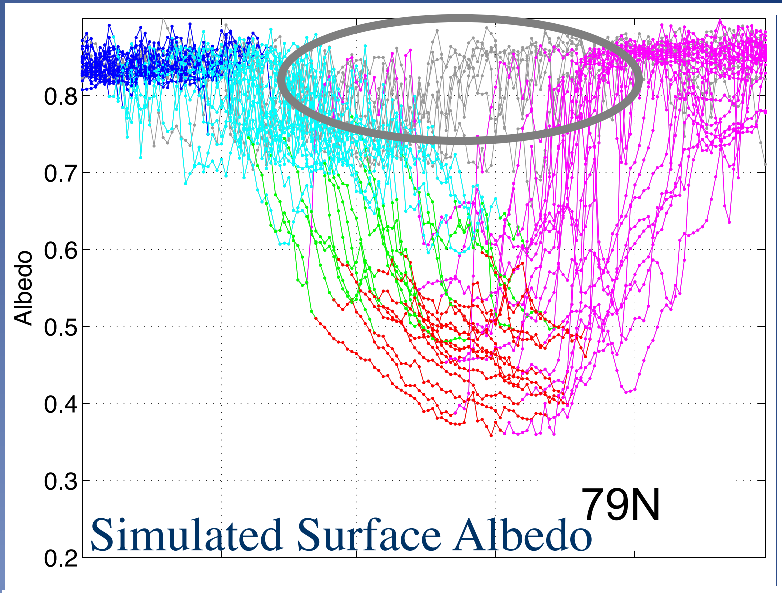
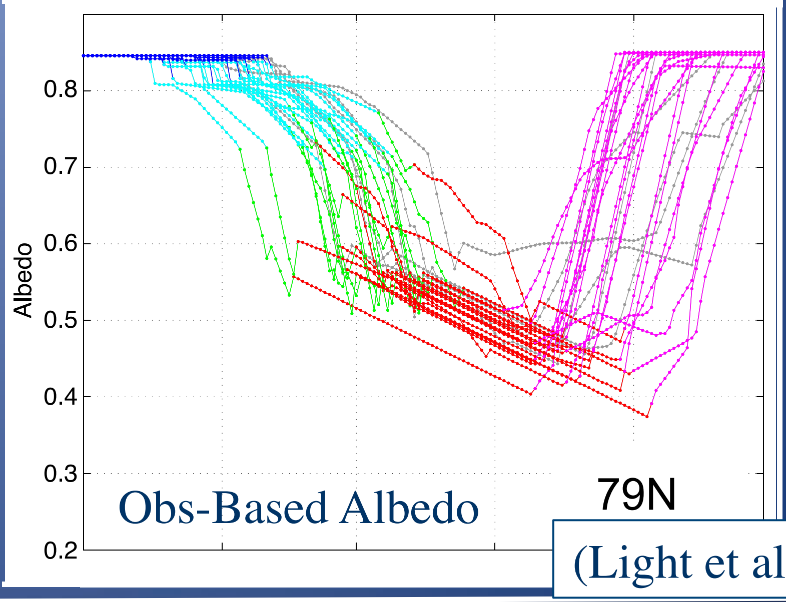
Bias Example: Snow on Sea Ice







(Light et al., 2015)

- High snow cover leads to high albedo
- Modifies surface albedo response and feedbacks
- This is an intermittent phenomena associated with ephemeral summer snowfall events

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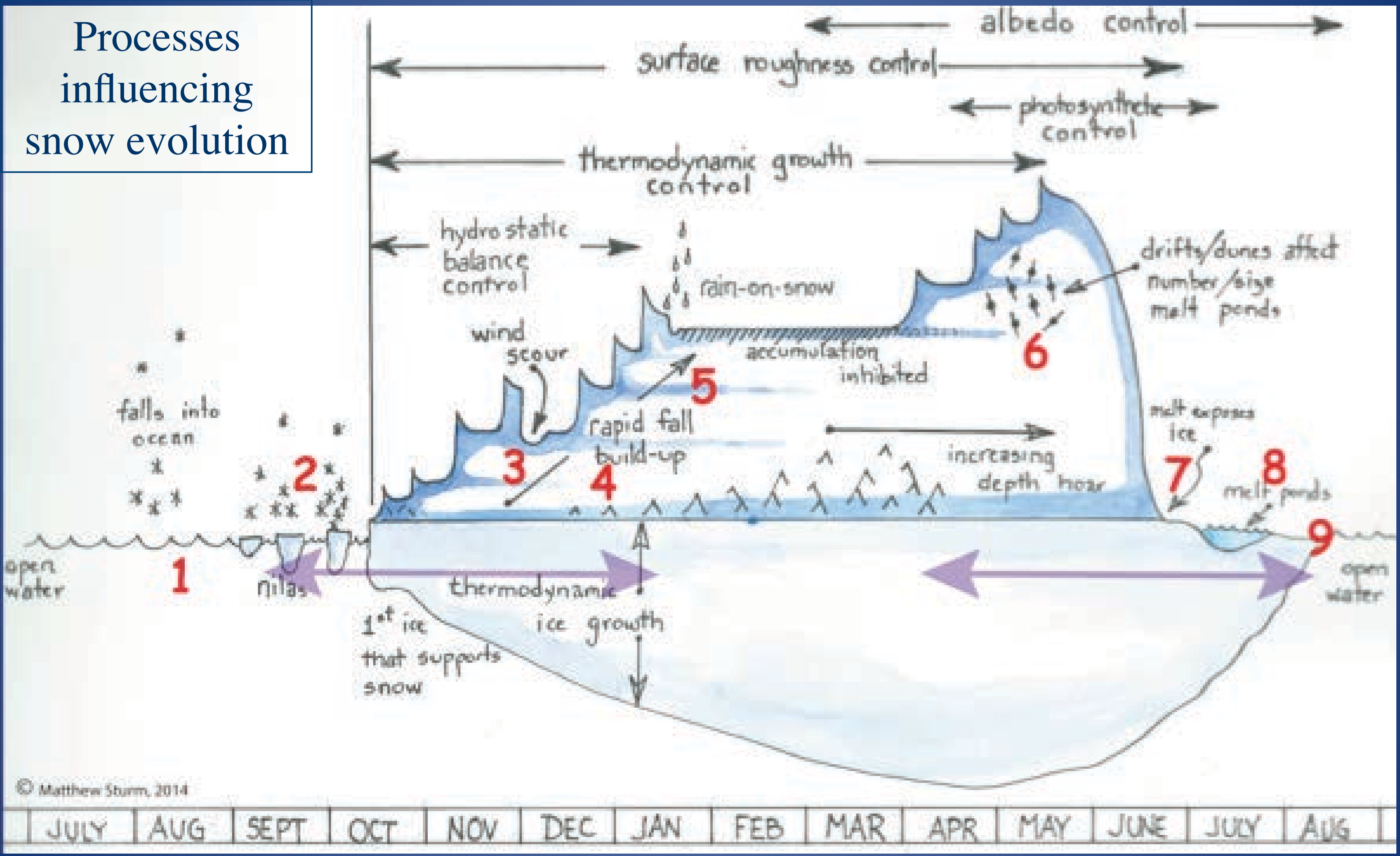
Many known snow processes are not incorporated into CESM

Processes influencing snow evolution



Courtesy of Matthew Sturm

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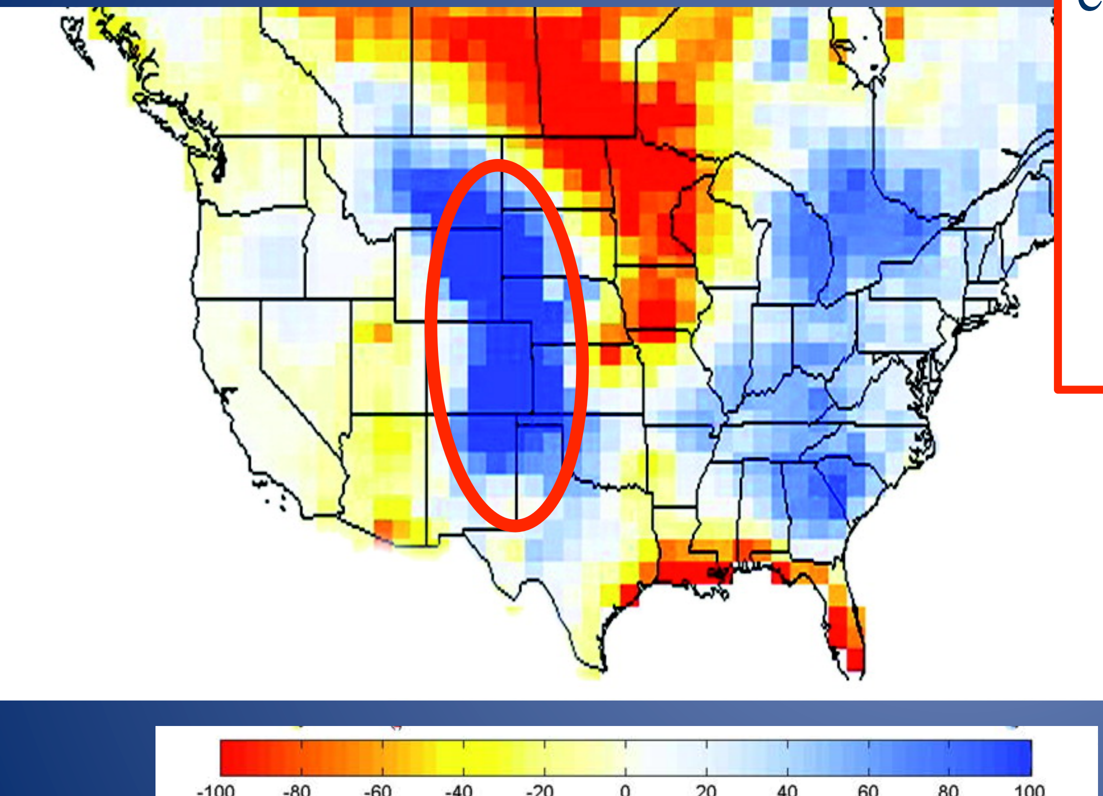
Model Bias – Rainfall Spatial Distribution



Poor representation of orographic effects

- Resolution of complex topography
- Boundary layer processes over orography
- Cloud microphysics

Summer precipitation bias in percent CCSM4 minus observations

Peacock, 2012

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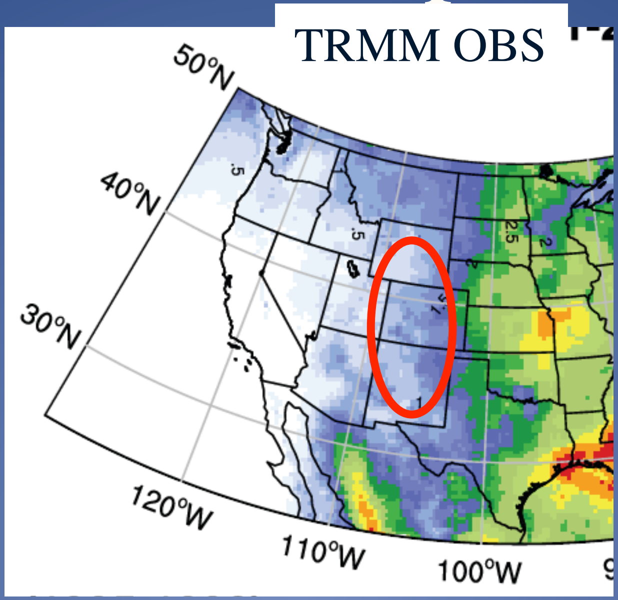
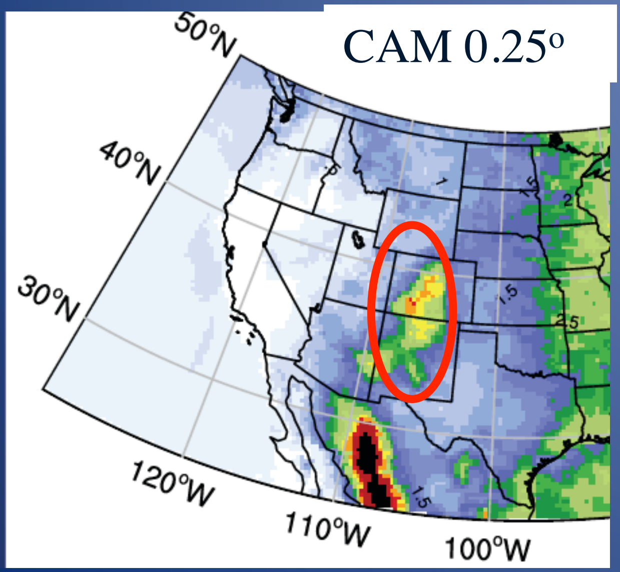
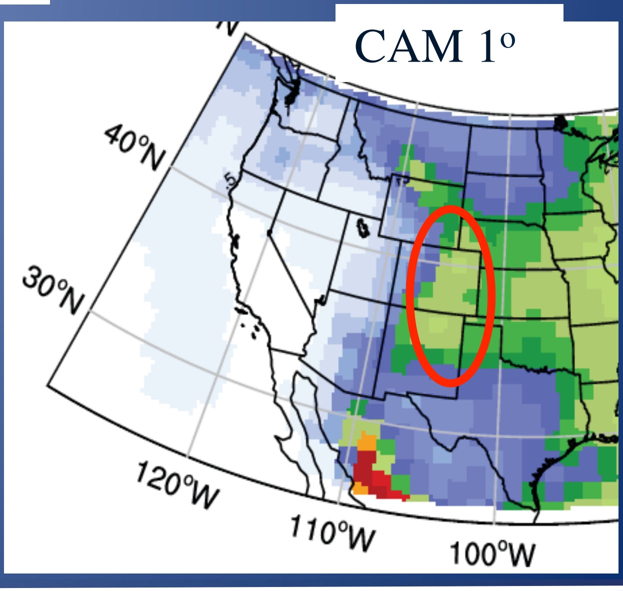
Model Bias – Rainfall Spatial Distribution

Summer Rainfall



Courtesy of Rich Neale





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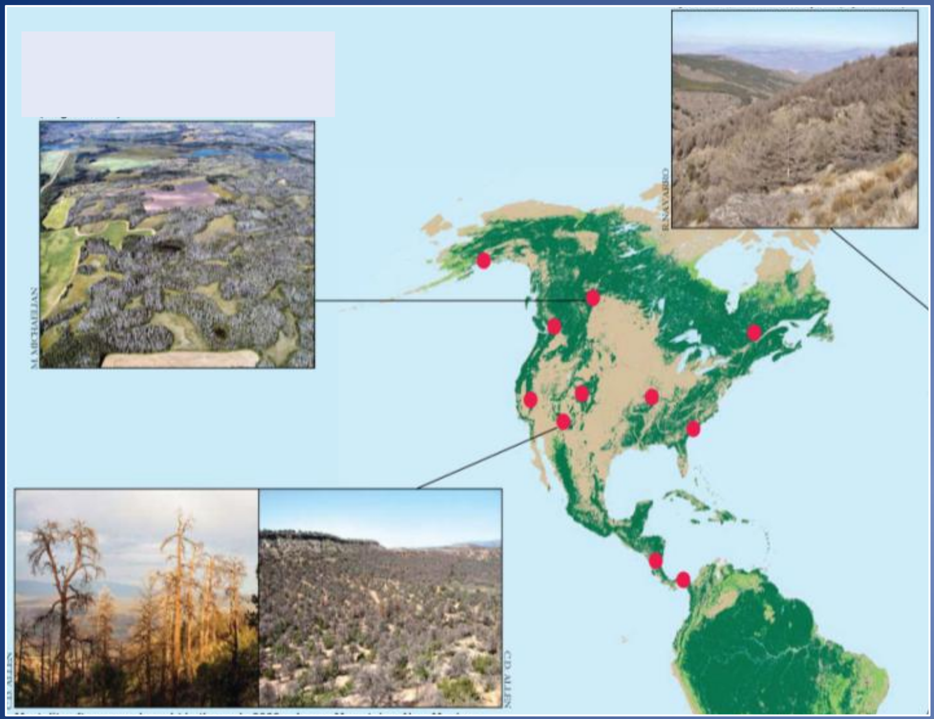
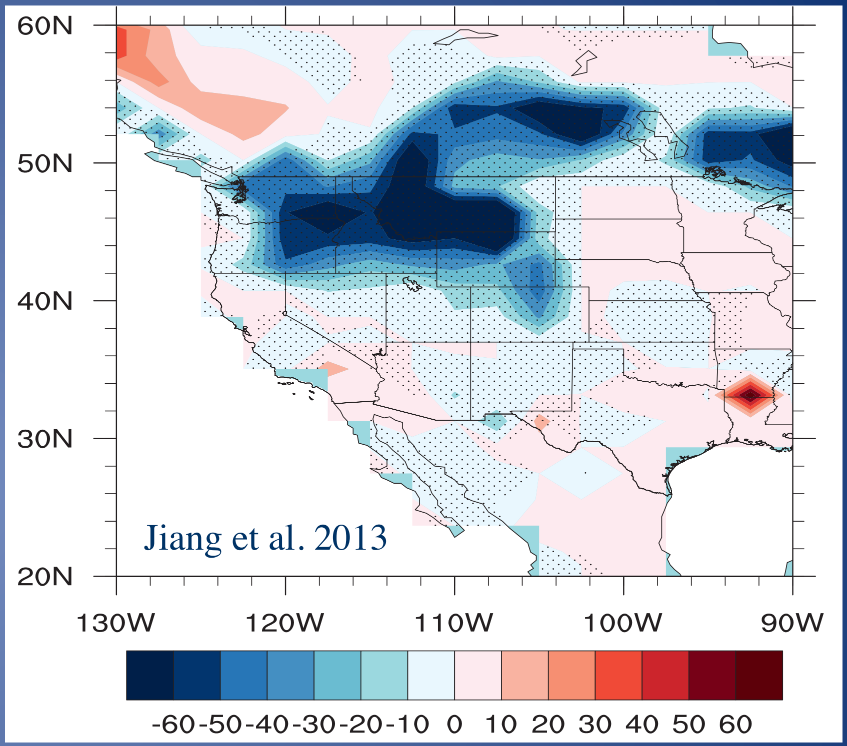
A need for new model capabilities
Example: Forest Vulnerability





Models like CESM with CLM-DGVM suggest widespread conifer die-off by 2100

- However, tree response to soil moisture deficits not well represented
- Forest loss is a complex problem that requires combined consideration of climate, hydrology, ecology, and plant physiology and diversity

(Courtesy of Dave Lawrence)

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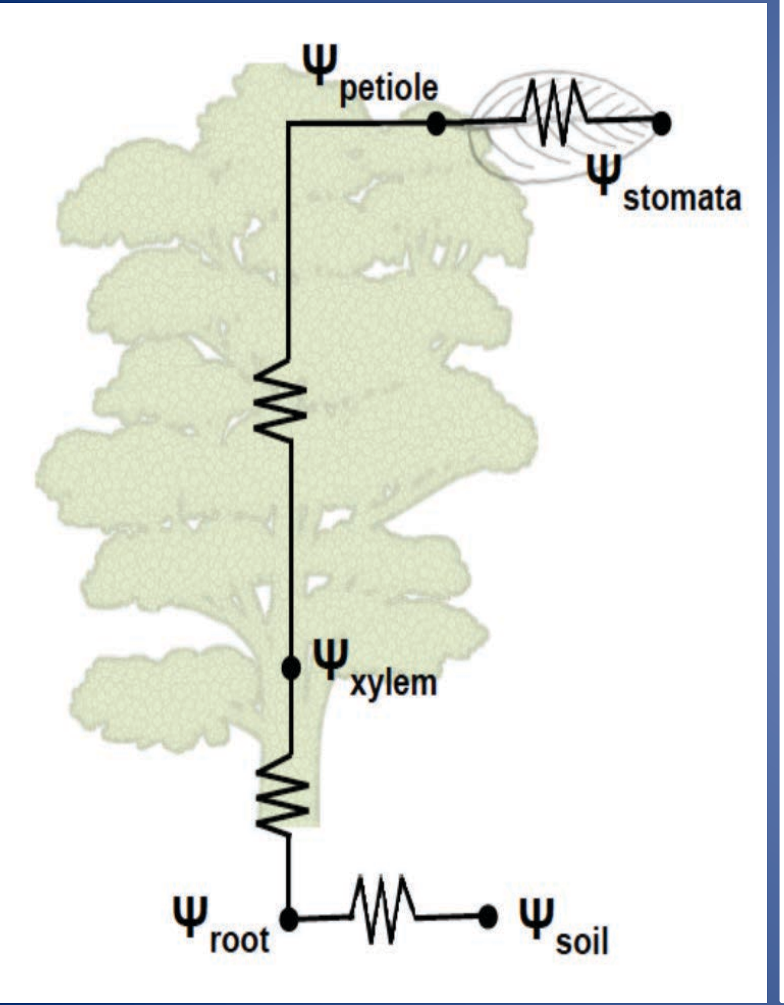
A need for new model capabilities
Plant hydrodynamics



- Current soil moisture stress parameterization has limited physical meaning.
- Measurements exist that would inform new plant hydrodynamics parameterizations
  - Sap flow
  - Physical properties of plant water use (wood density, conductance, water potential)
  - Satellite information on properties related to canopy/leaf water content.

(Courtesy of Dave Lawrence)

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Summary

- Biases exist across all components of CESM
- There is also a need for new capabilities that will enhance process representation
- Improvements in both of these areas will increase the reliability of the simulated climate system response
- In many cases, process knowledge and observational information exist that could and should inform model developments in these areas

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Questions?

Figure courtesy of Steve Ghan

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Extra Slides

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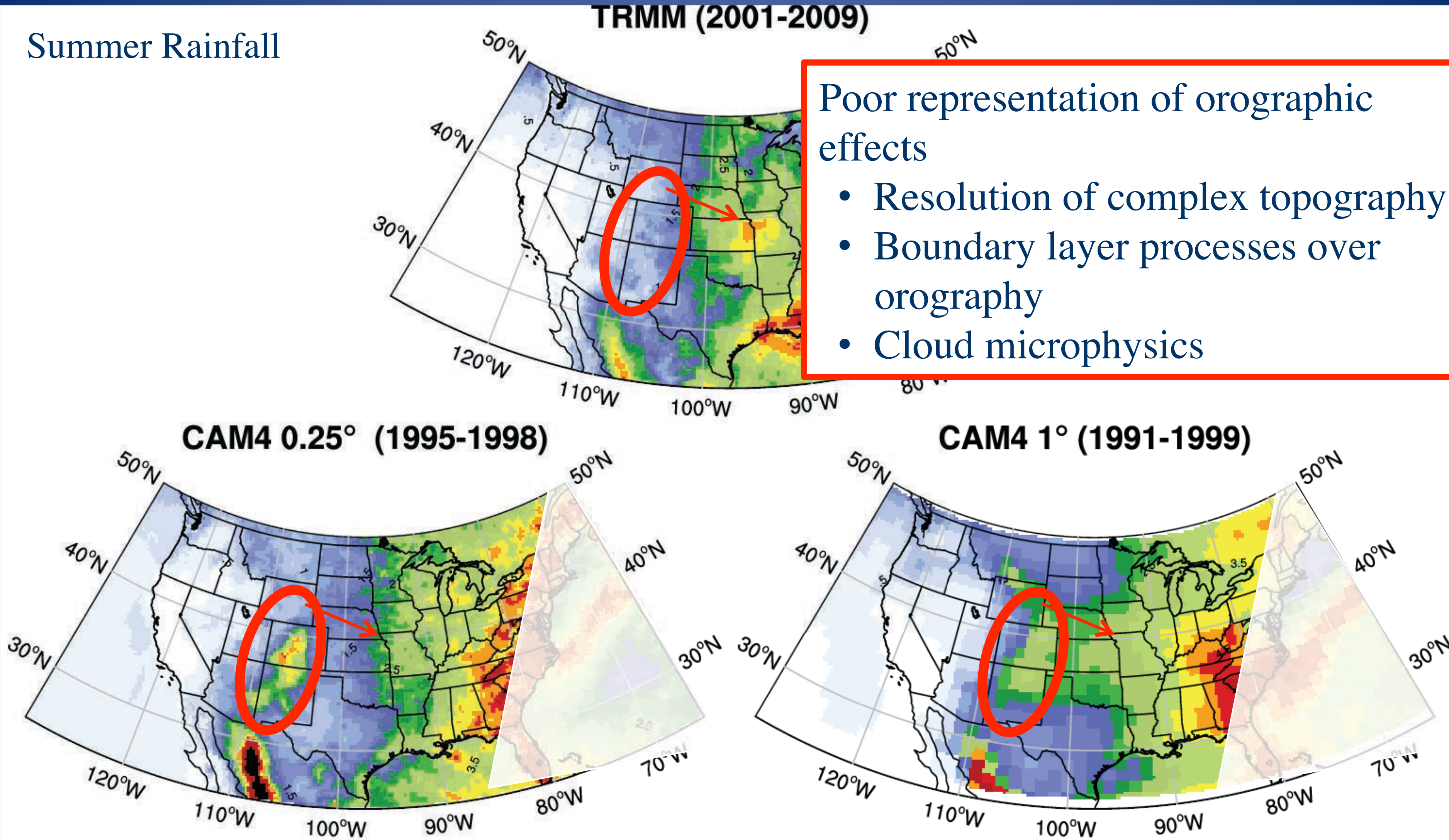
Model Bias – Rainfall Spatial Distribution

Summer Rainfall



Poor representation of orographic effects

- Resolution of complex topography
- Boundary layer processes over orography
- Cloud microphysics

Courtesy of Rich Neale

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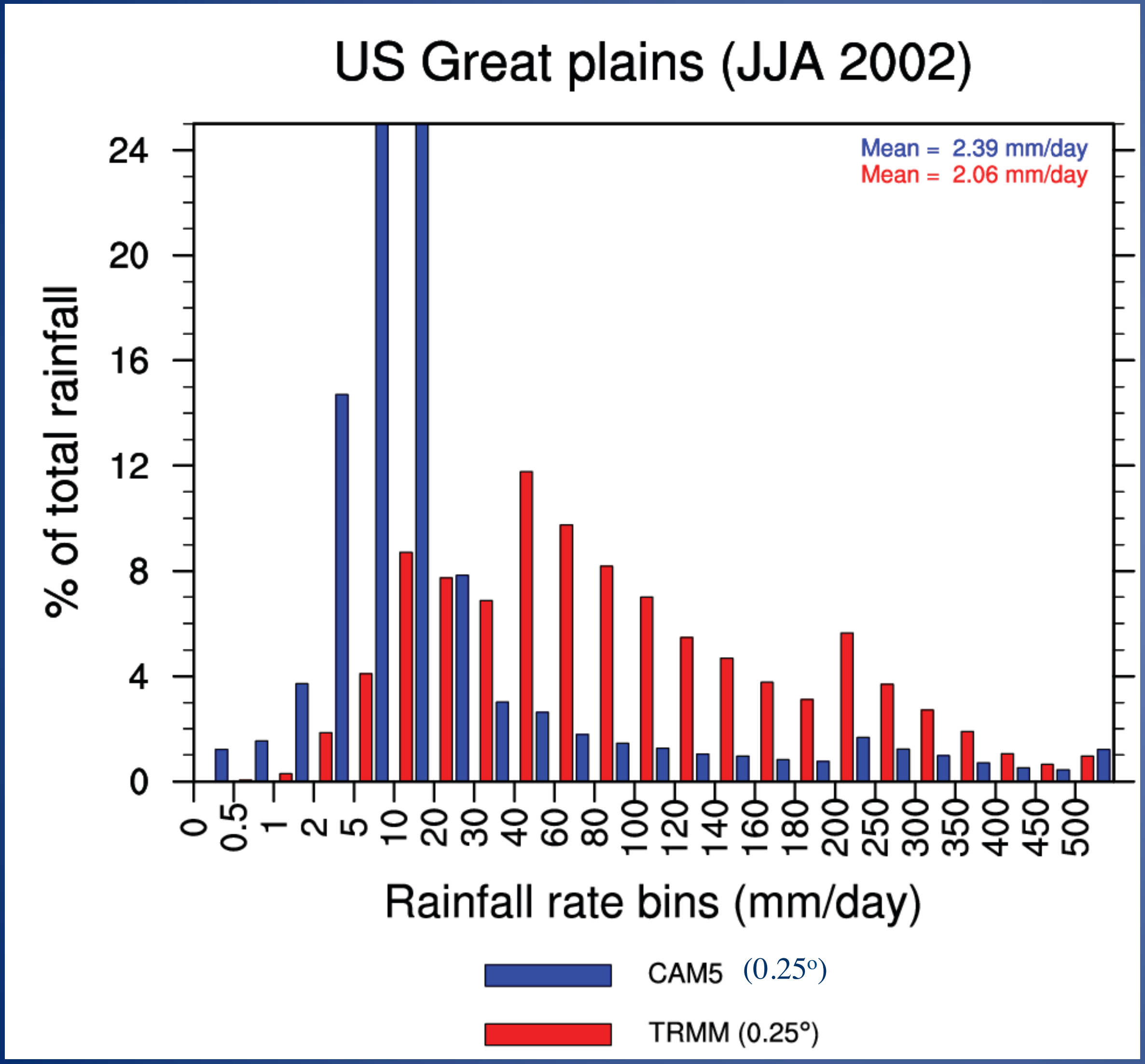
Model Bias: Rainfall frequency



- Common bias for many regions: Too much light rainfall, not enough heavy rainfall
- True even with 25km atmospheric model resolution
- Likely related to convection

Courtesy of Rich Neale

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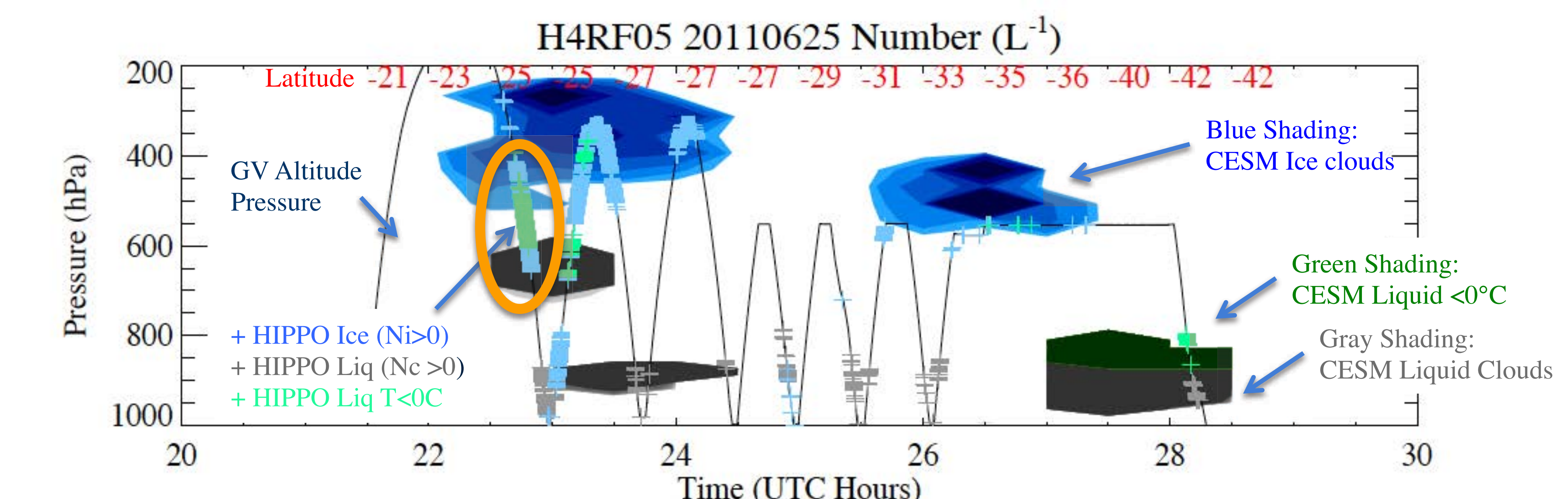
Consistent with comparisons to In-Situ Data

- Simulation of individual events with CESM using specified dynamics
- NSF G-V Aircraft flights over the Southern Ocean

Example: Research Flight: June 2011 Specified Dynamics version of CESM to simulate a particular day. Force winds and Temps. What do the clouds do?



Model Missing Supercooled Liquid

Courtesy of Andrew Gettelman

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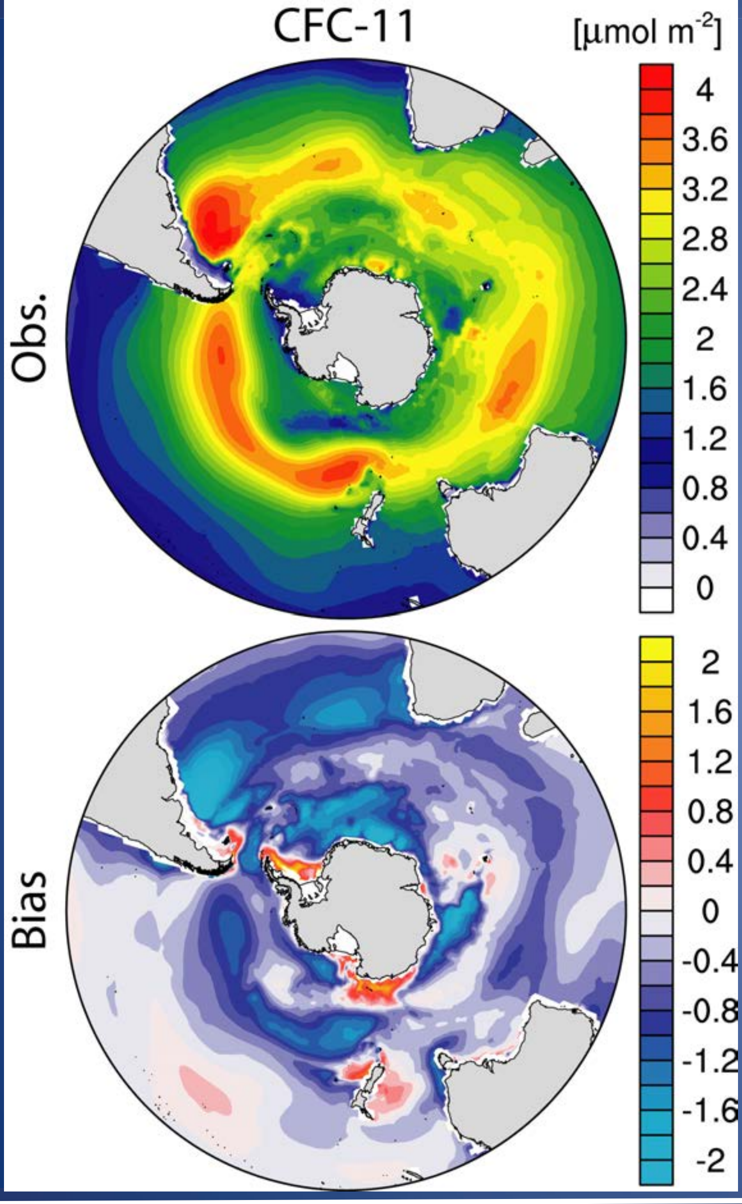
Bias Example: Southern Ocean Ventilation



CESM1-CAM5 20th Century Simulation

Comparisons of simulated and observed ocean CFCs

Indicate too little Southern Ocean uptake

Has implications for simulated ocean heat and carbon uptake

Courtesy of Matt Long

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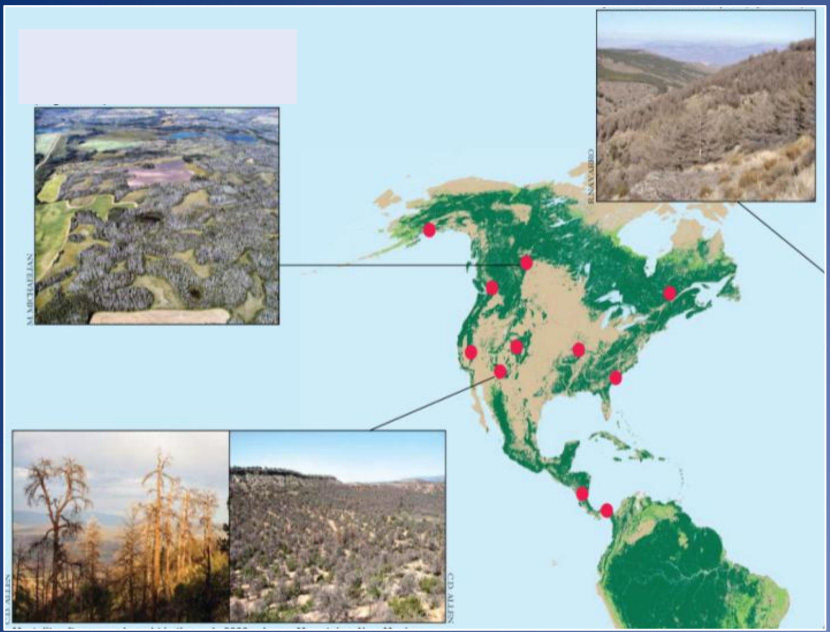
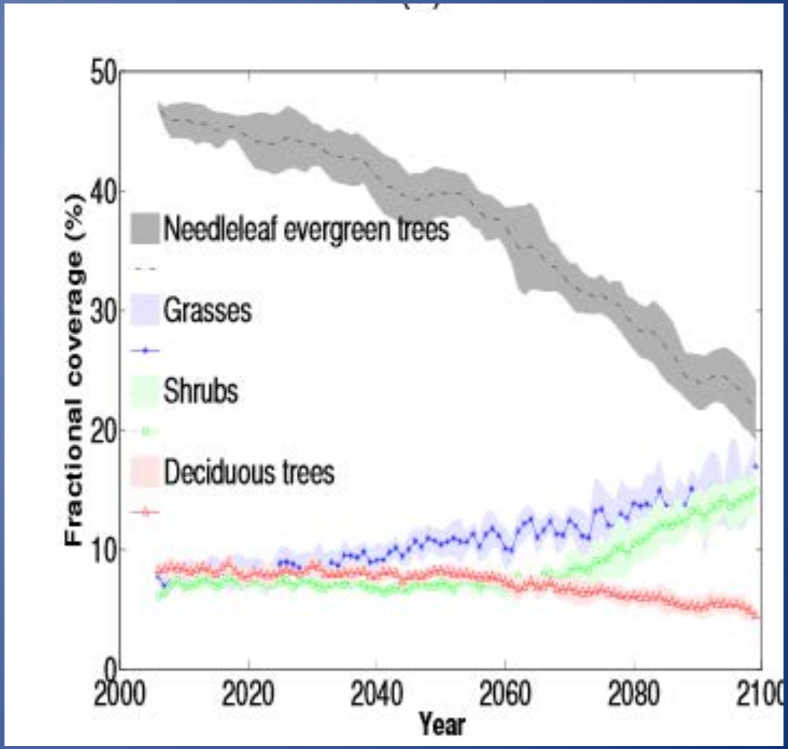
How vulnerable are Western US forests to climate change?



Models with simple representation of plant water use and mortality, like CLM-DGVM, suggest widespread conifer die-off by 2100

But … these results are likely unreliable; tree response to soil moisture deficits is represented in ad hoc way in land models. Forest loss is complex problem that requires combined consideration of climate, hydrology, ecology, and plant physiology and diversity



Jiang et al. 2013

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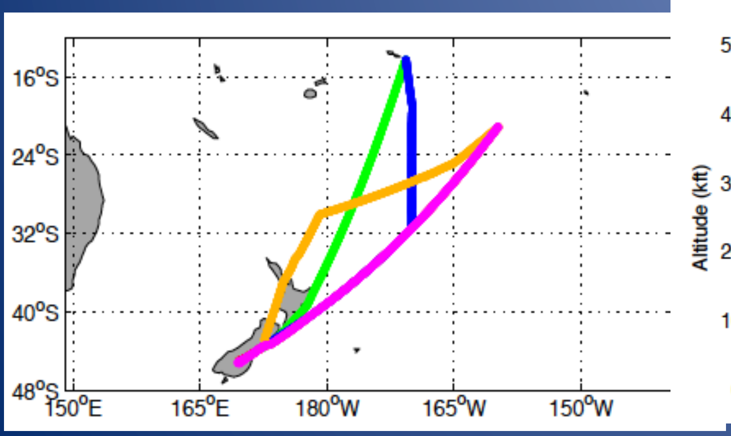
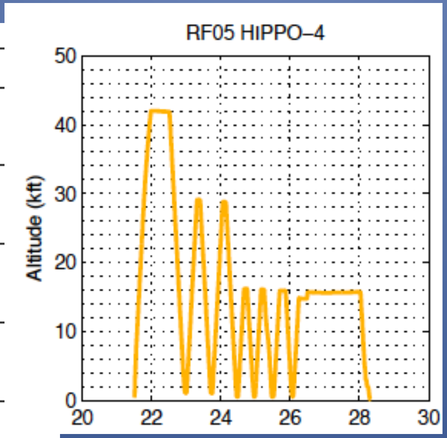
Process-Evaluations: In-Situ Data

- Can simulate individual events with CESM
- Example: NSF G-V Aircraft flights over the Southern Ocean looking at Cloud Microphysics





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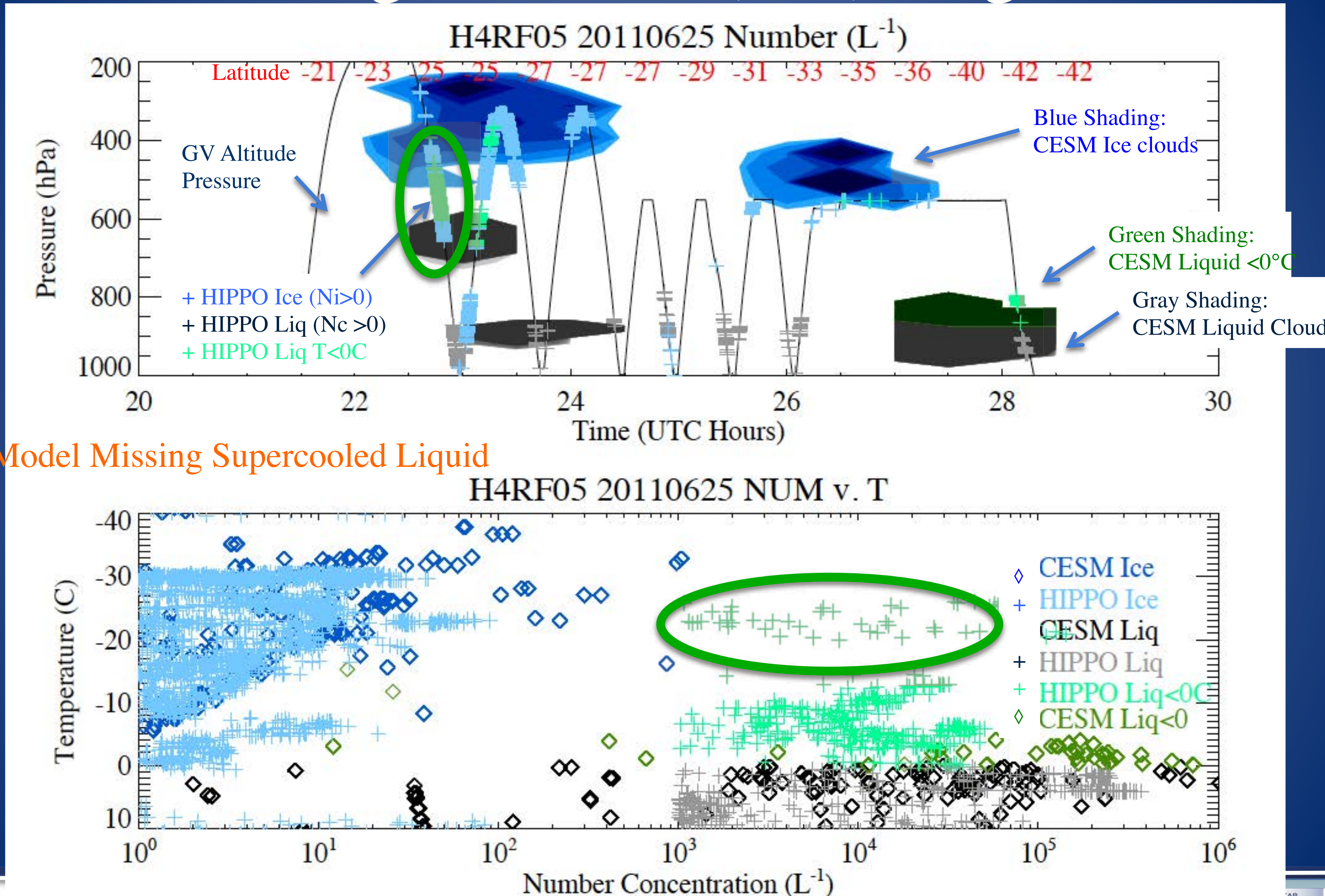
Section along H4RF05 (Jun) Flight Track



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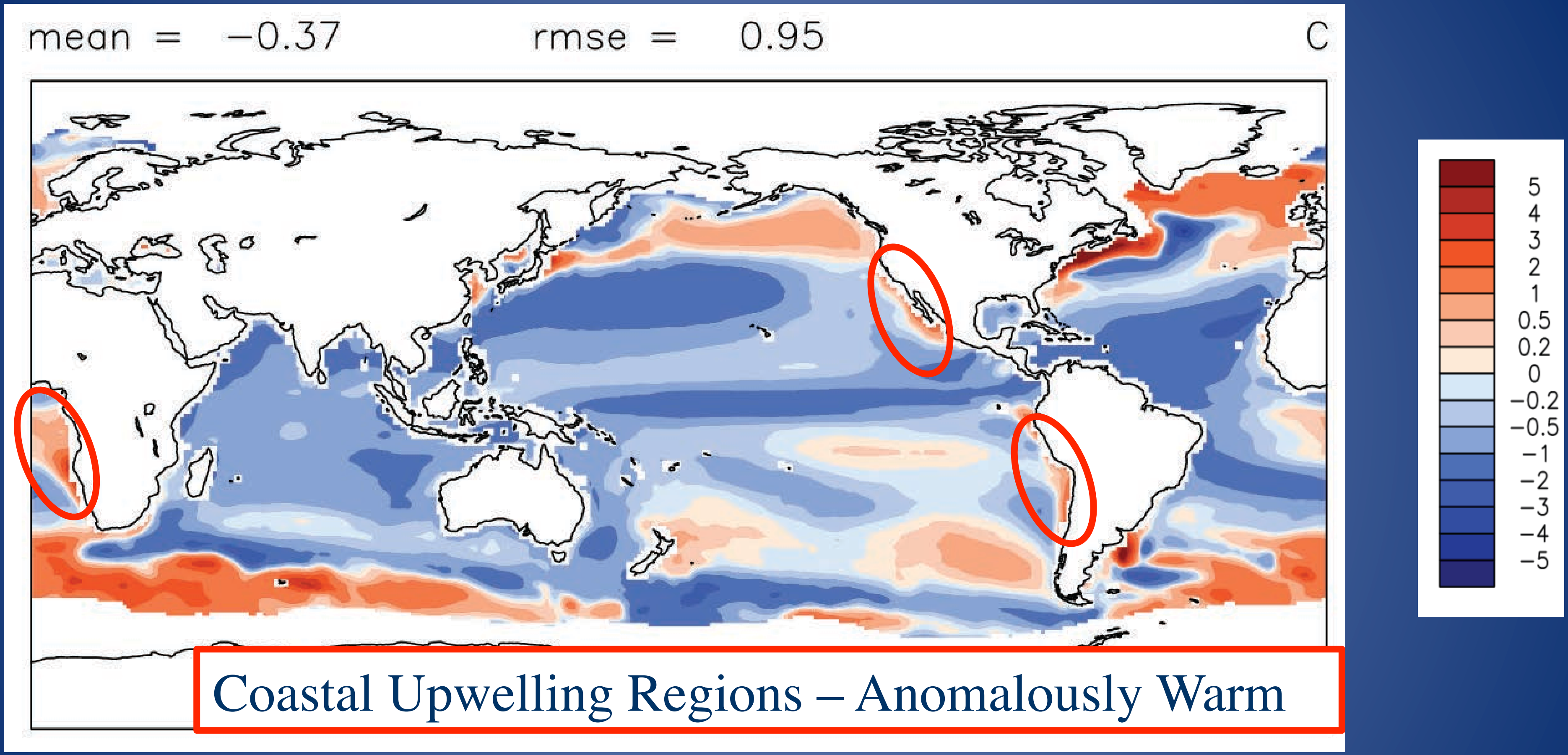
Example: SST Bias



CESM-CAM5 Late 20th Century Relative to HadISST

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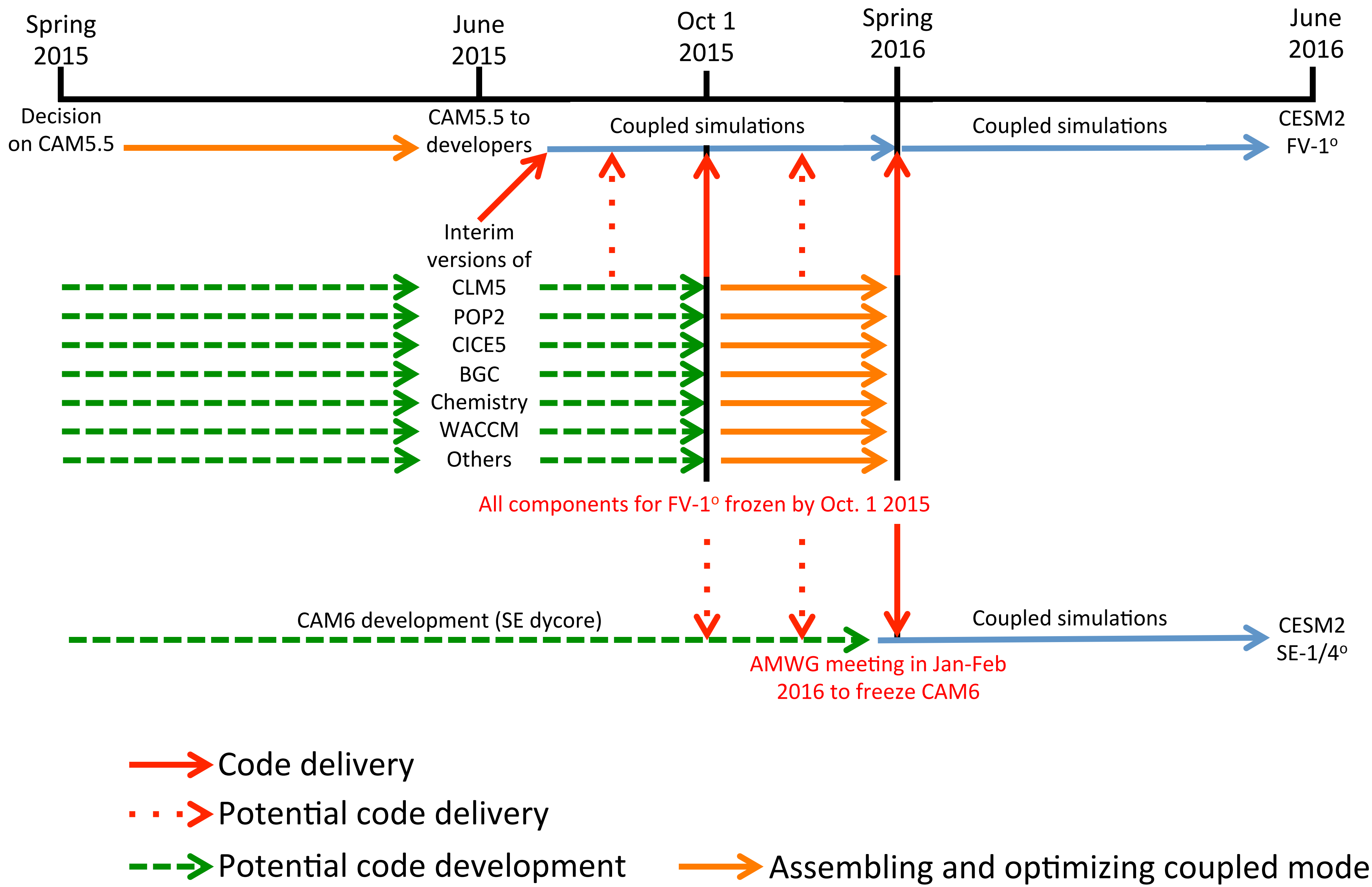
Timeline for CESM2



CLM Development Timelines: *The path towards CLM5/CESM2*

Biogeochem

Ecosystem Demography (CLM-ED) development

CLM5(ED) ready for coupled sims 1/2017?

C, N refactor and param updates

Extension of crops to global, fertilization

Biogeohys

Soil hydrology and snow refactor and updates
(reactive transport modeling, water isotopes)

Urban updates

CLM5 BGC eval/tune (fire, CH_4, flood, dust)

RTM

MOSART river model

Flood/wetland full implement

Fully coupled BGC eval/tune of CLM5 and/or CAM5.5

Coupled model / capabilities

Dynamic landunits

Land model processes benchmark system

CAM5-CLM4.5BGC eval/tuning
Fully coupled CESM1.2 BGC simulations

CLM5 control sims (BGC-crop, SP, ED?)

CLM5 in CESM2 (CAM5.5, CAM6)

1/2014 | 6/2014 | 1/2015 CAM5.5 | 6/2015 CESM1.3 | 1/2016 | 6/2016 CESM2

Development goals for CLM5

- **Ecosystem Demography model – future biogeochemical core of CLM**

  Goal: Globally functional CLM5(ED)for CESM2; CESM2 coupled runs within CMIP6 timeframe; will not be CESM2 default configuration

- **Land cover and land use change**

  Goal: Global / transient crop simulation with irrigation, fertilization, and cultivation of crops (land management) as default for historical runs

  More realistic land cover change impact on water and energy fluxes

- **Carbon cycle**

  Goal: Improved 20th century land carbon storage trend, response to N-additions

  Thoroughly revised Nitrogen cycle processes, improved wood harvest

- **Hydrology**

  Goal: Hydrology model that is closer to state-of-art understanding in hydrology

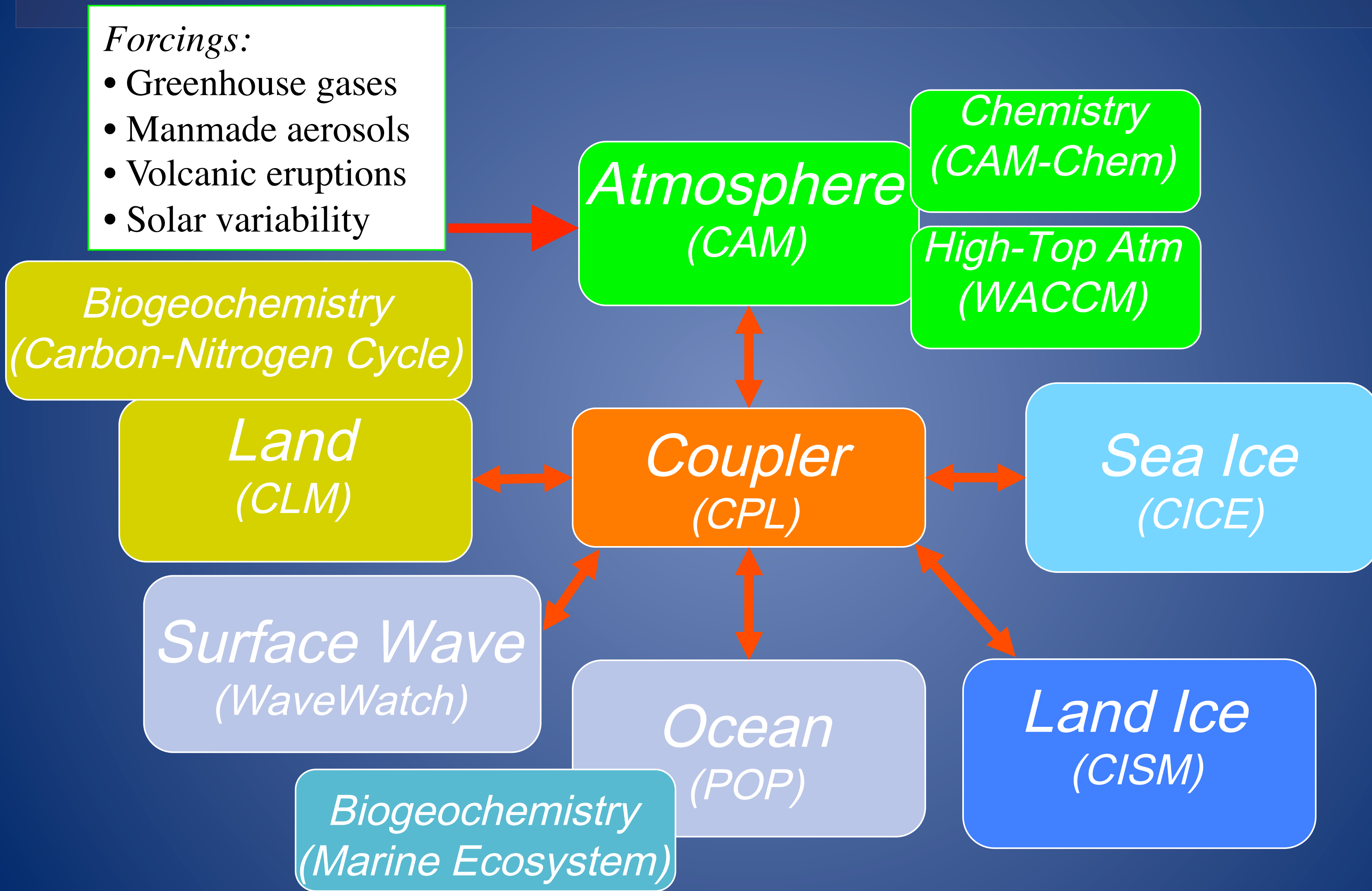
  New river model, updated groundwater, snow,

- **Land-atmosphere chemistry coupling**

  Goal: enhanced interactions, fire emissions, ozone damage to plants

- **Water and carbon isotopes**

Community Earth System Model



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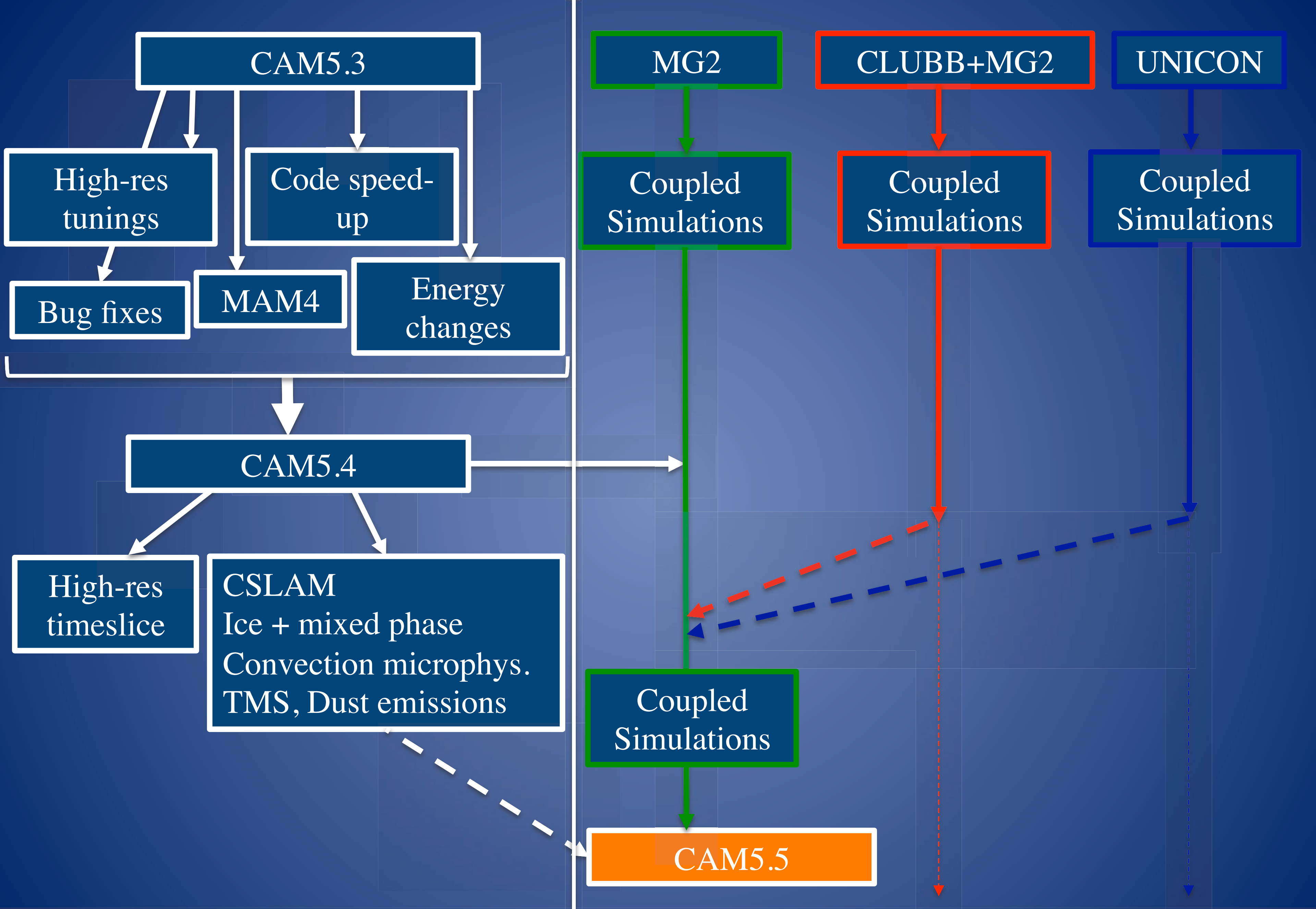

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