Cloud and precipitation physics most limiting ESM skill (IMHO)

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MPAS-A DYAMOND Simulations

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Two Threads

1. Stubborn large scale questions (E3SMv3, CESM2)

    -Base state of clouds

    - Cloud Feedbacks

    - Aerosol Forcing (Indirect)

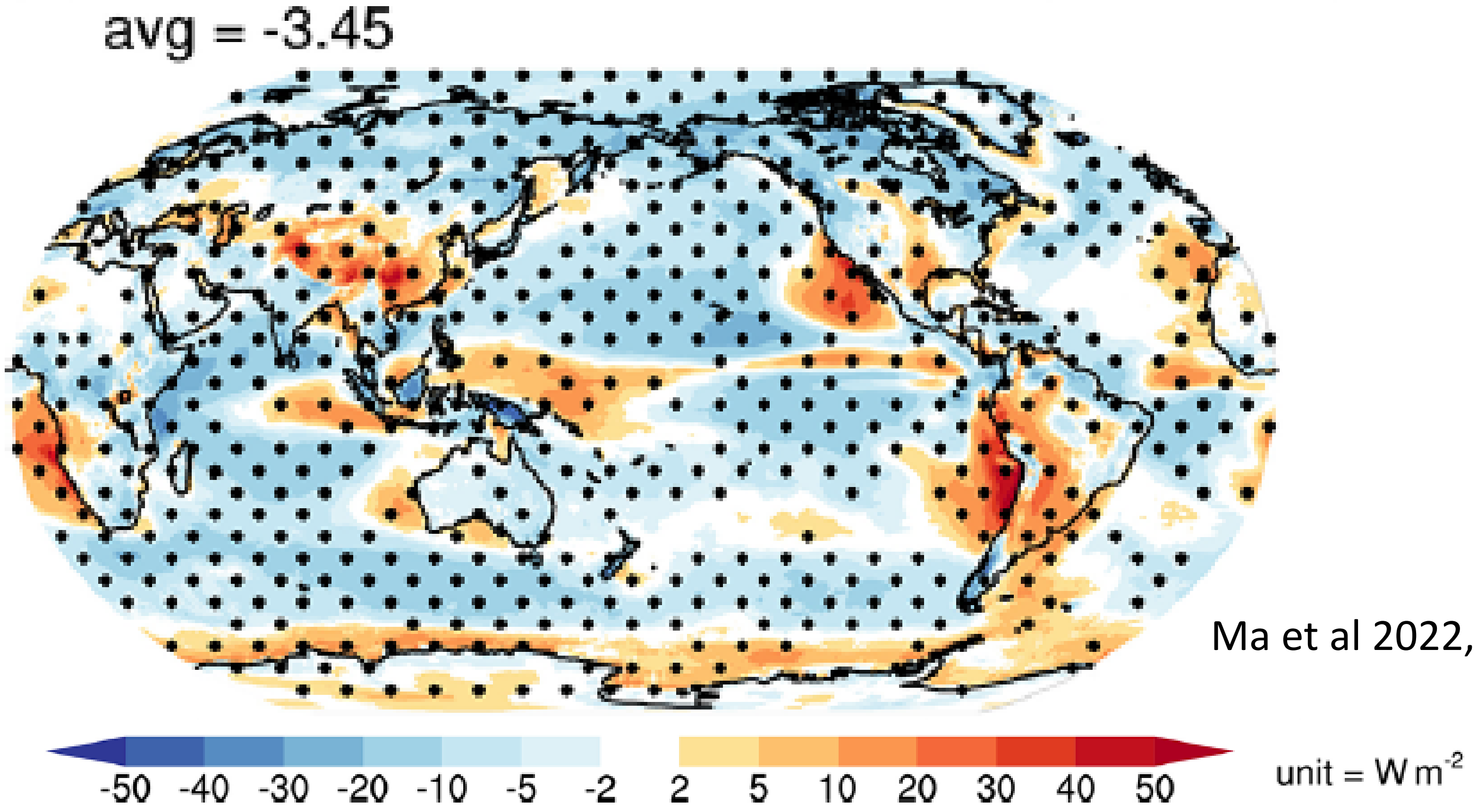
2. Extreme Weather (SCREAM, EarthWorks)

    - Precipitation Extremes, MCSs, Tropical Cyclones, Ice phase
    - We need to learn and collaborate better to finer scales

Spoiler alert: the issues are related!

We still have lots of biases in clouds

Example: E3SMv1 Biases in TOA SW CRE (v. CERES)



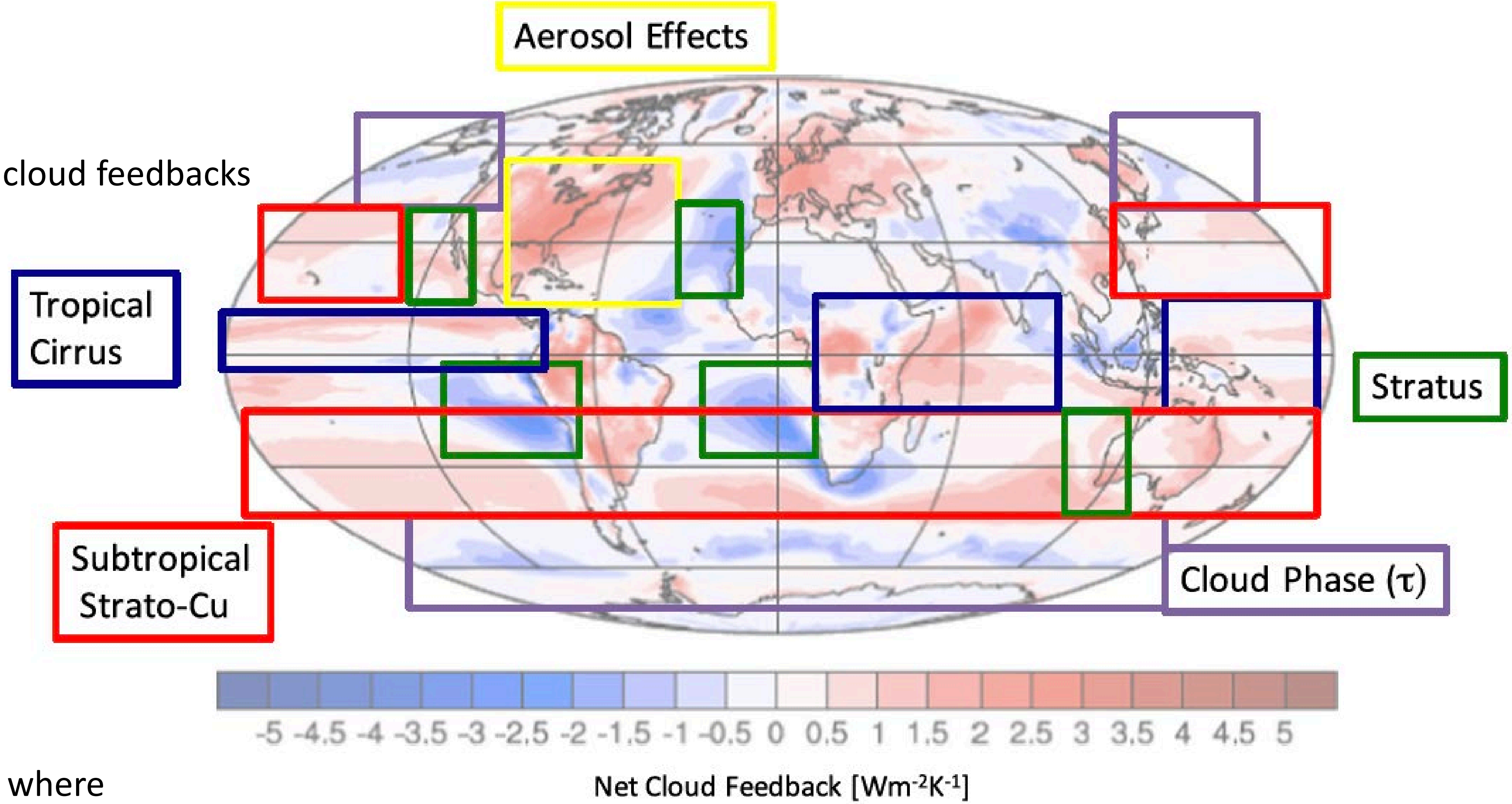
Ma et al 2022, Fig 4a

Issues with shallow stratus and strato cu clouds, also tropical high clouds
What does that say about our ability to simulate cloud responses/adjustments?
Nothing good!

Cloud Feedbacks

Where are the biggest impacts?

- Stratus Decks
- Tropical Cirrus
- Subtropics: Cloud Phase
- Note 'aerosol mediated' cloud feedbacks

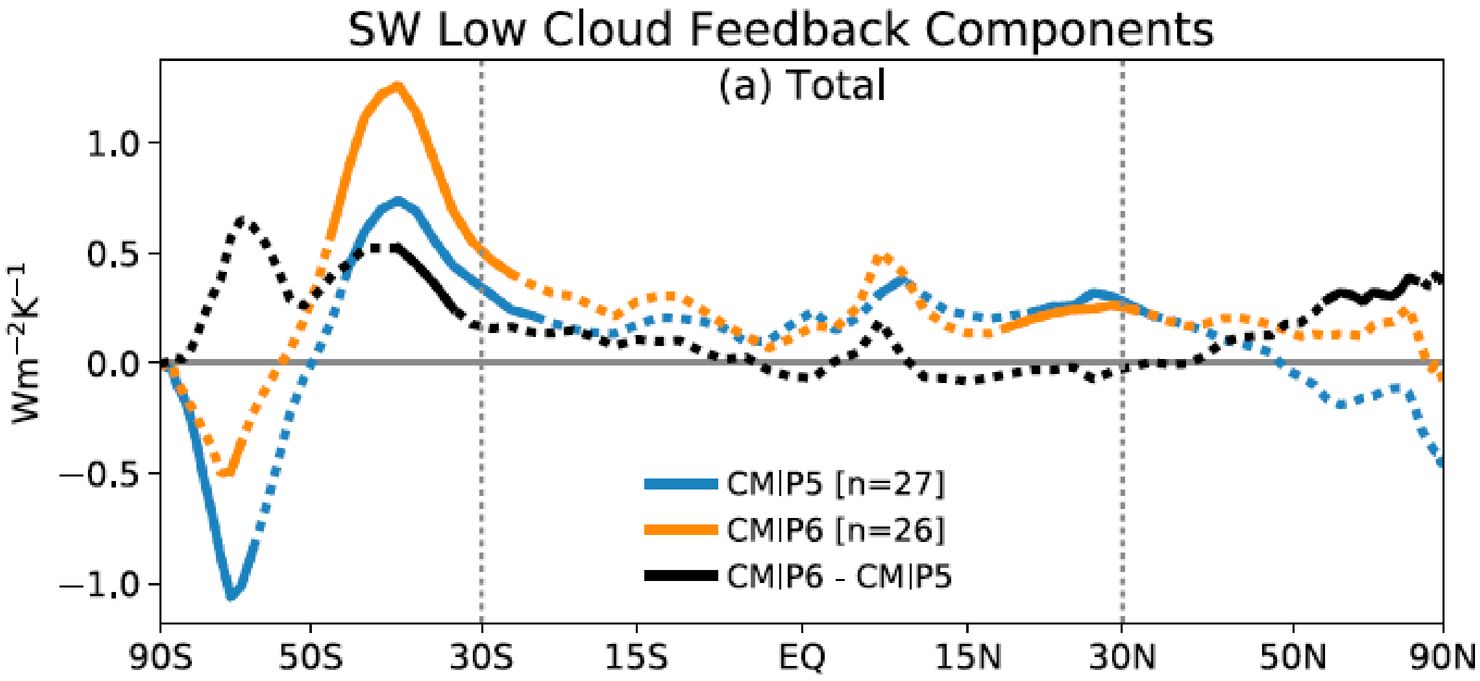


These are similar regions to where there remain large biases in clouds

Gettelman & Sherwood 2016, Curr. Climate Change Rpts

Cloud Feedbacks

High Sensitivity Models?



Zelinka et al 2020

S. Ocean, Cloud Amount & Scattering Feedback

30-70˚S: less negative in CMIP6 than CMIP5

What processes cause changes?

Mixed phase clouds: removal of a cloud phase feedback

More and brighter sub-tropical clouds

Some high cloud issues exist too

Base state of ice microphysics may be important for high cloud feedback

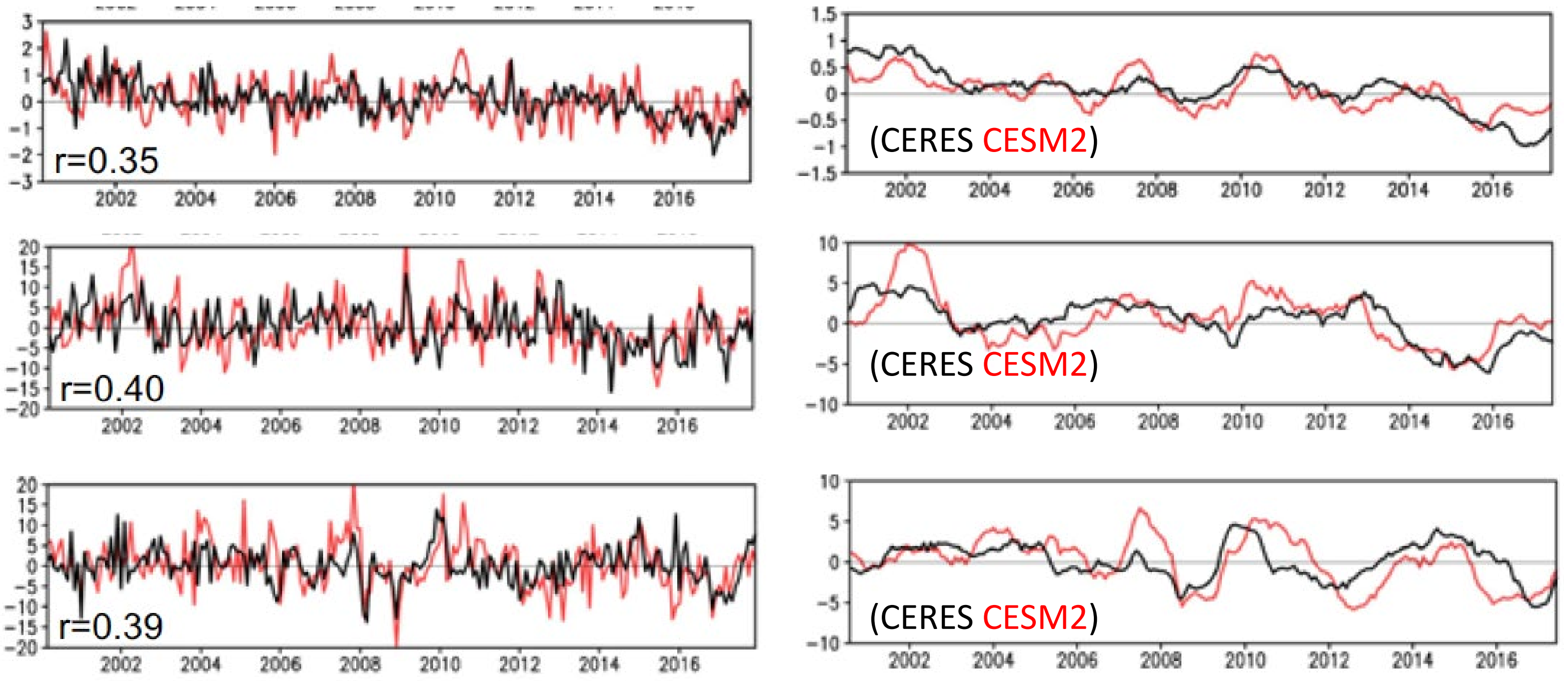
What really scares me: cloud response

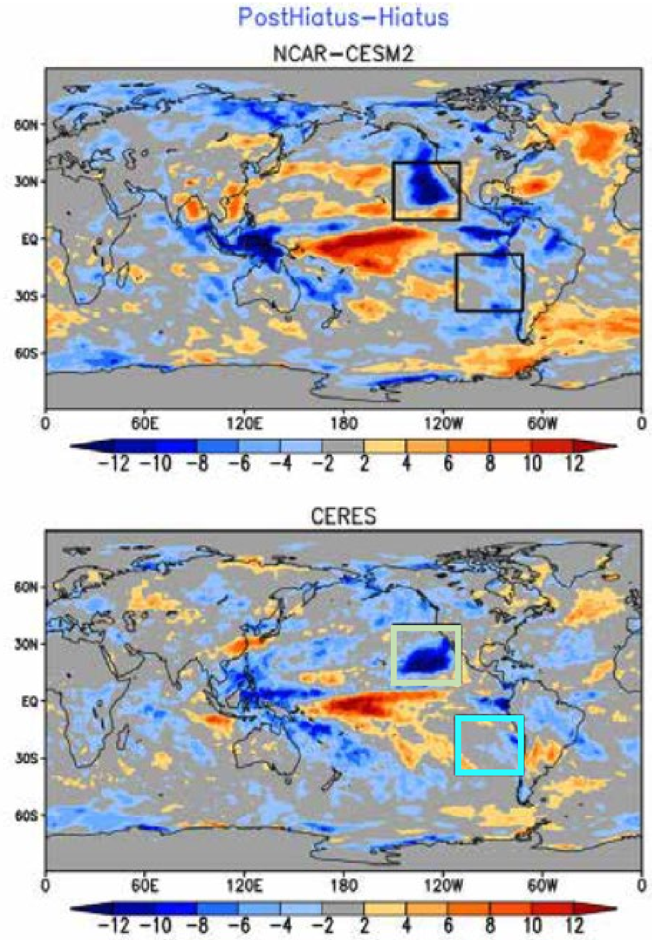
Variability in TOA SW flux compared to CERES EBAF 4.1 from 2000-2017
CESM2 does a really good job, and clouds ARE decreasing
(though some is ENSO). Actually even MORE than in models….
We cannot falsify all high sensitivity models!

Global

NE Pacific

SE Pacific



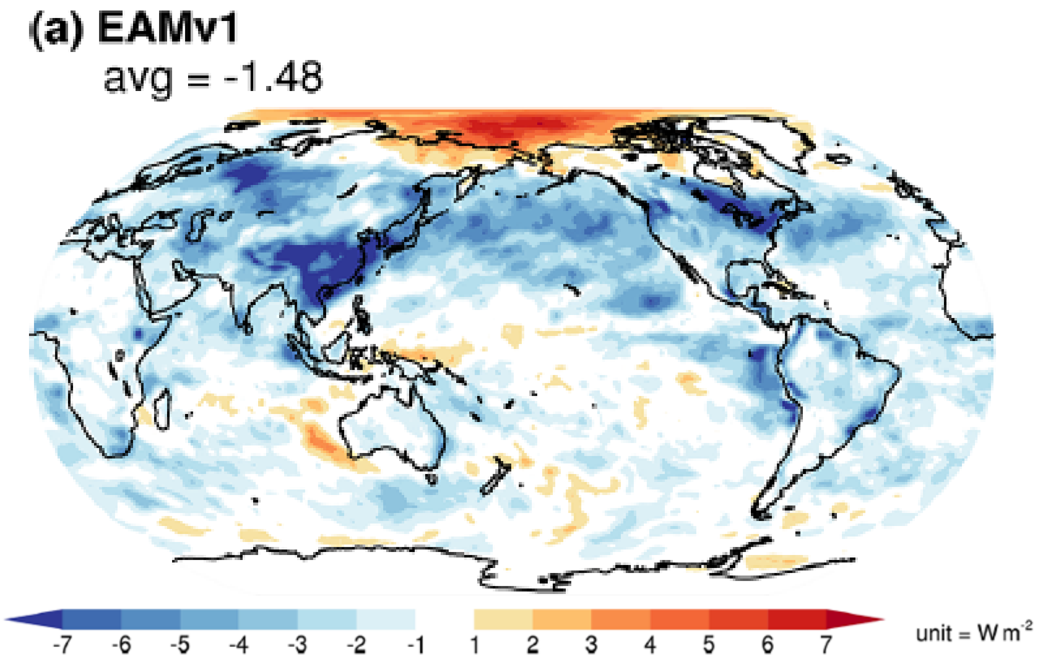


Loeb et al, 2020, GRL

Aerosol Forcing

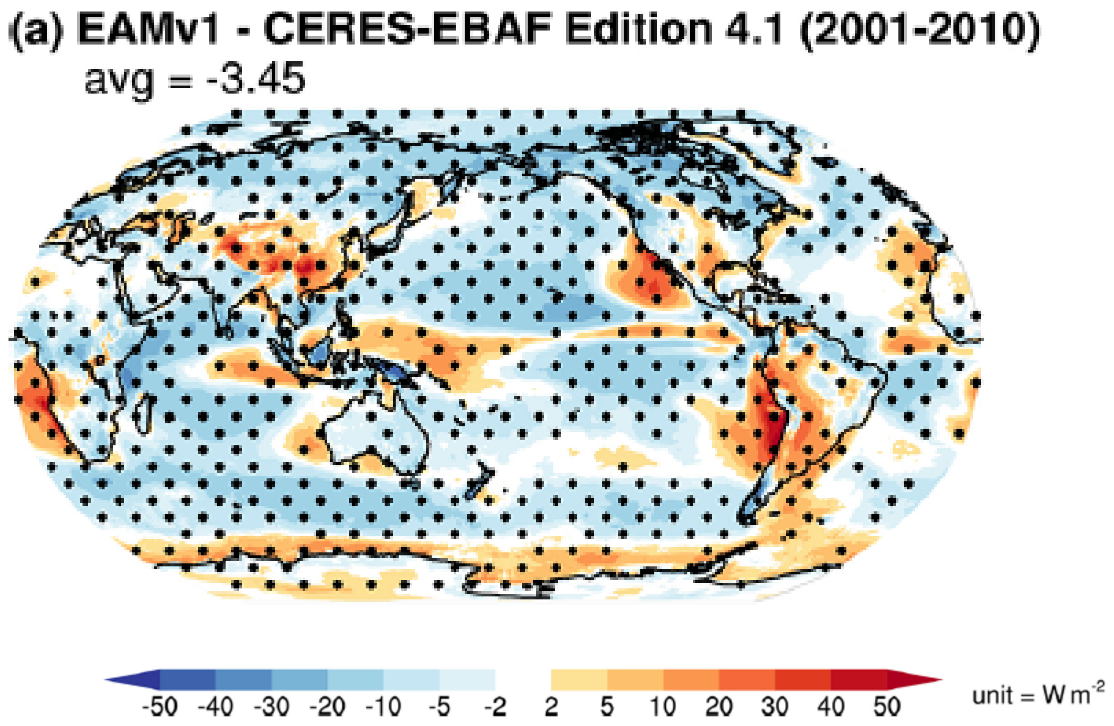
Key Regions of aerosol forcing have large biases in base state!

Aerosol Forcing (ERFaer)



Ma et al 2022 Fig 14

Base State SW CRE Biases



Ma et al 2022 Fig 4

Cloud Adjustments

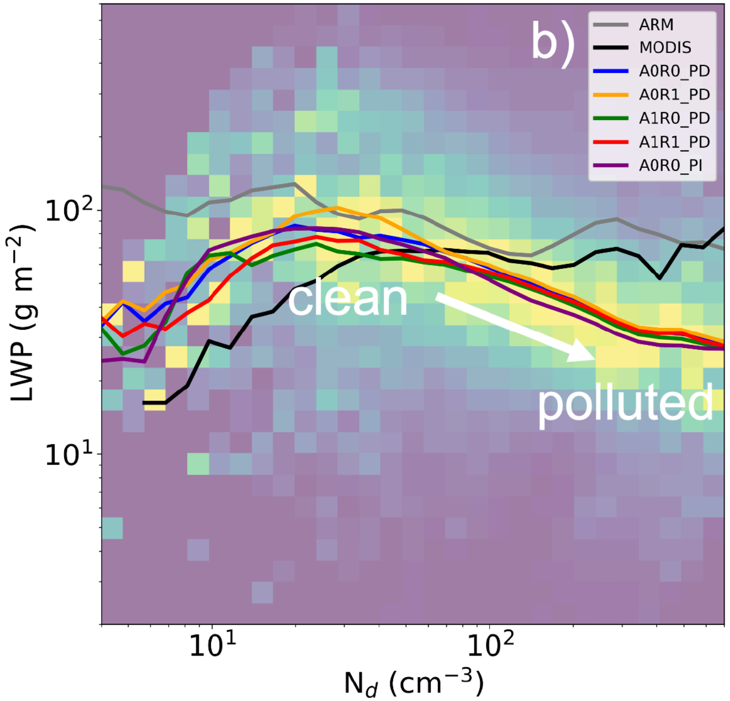
Is simulated LWP response correct?

Bulk schemes average dLWP/dA monotonically positive
Probably 2/3 of forcing (previous slide)

But detailed analyses (see right) seem to indicate more appropriate non-monotonic dLWP/dA (one regime)

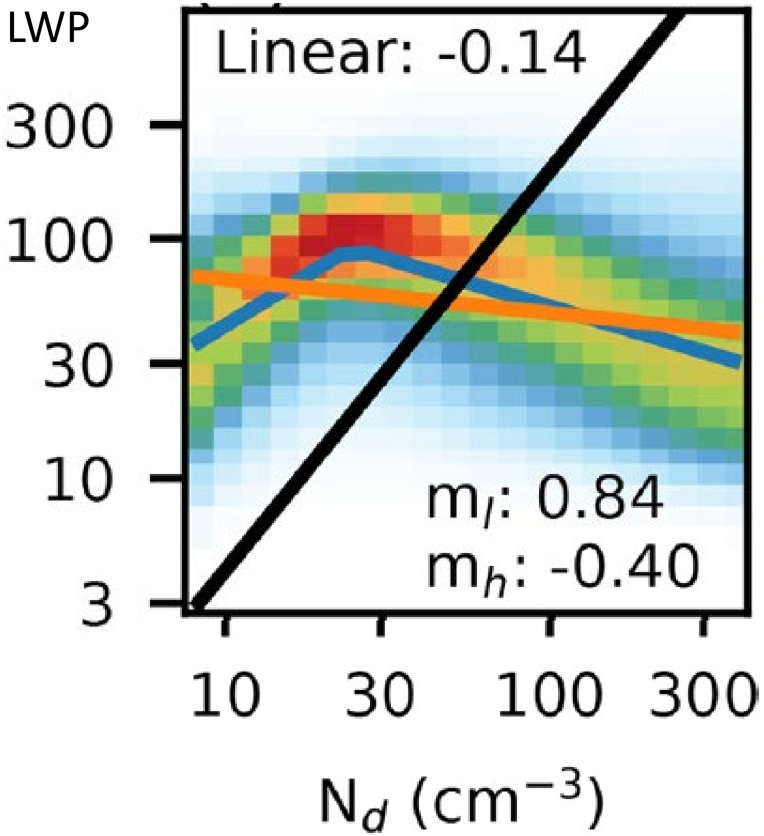
What is going on? Biases in Nd?

E3SM



Christensen et al 2022, ACPD

MODIS

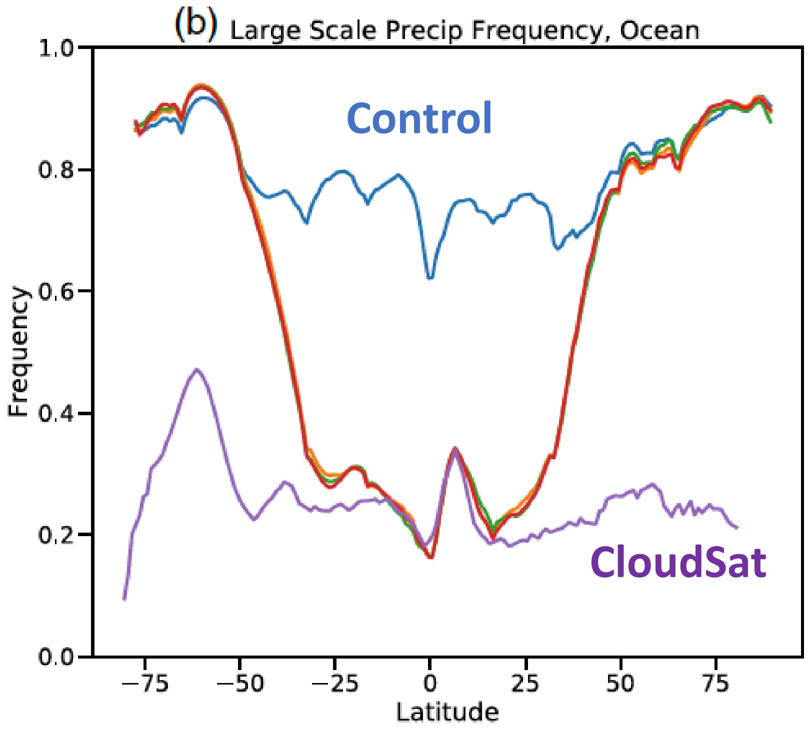


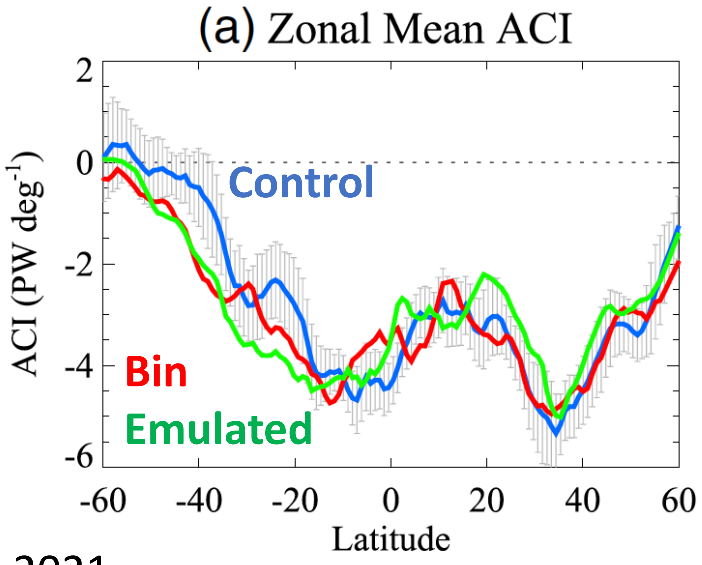
Gryspeerdt et al 2019, ACP

Precipitation

Is Autoconversion & Accretion the answer?

- Replace bulk Autoconversion and Accretion (**control**) with **bin scheme** Stochastic collection (also **emulated**)
- Improves lots of aspects of precipitation (e.g. frequency)
- ACI unchanged
- Is Autoconversion/Accretion the problem?
- If it's not rain, it's turbulence, entrainment? (We have tried that too)





Gettelman et al 2021

Summary/Thoughts: Large Scale

Cloud feedback:

- Analysis is usually not process based. Not just emergent constraints.
- How would you use ARM assets to explore cloud feedback? What clouds do we need most need to constrain?
  - (A) High latitude cloud phase
  - (B) Shallow clouds and transition to shallow cu in subtropics (existing biases)
  - (C) Tropical high clouds and LW feedbacks

Aerosol Forcing:

- How does precipitation interact with drop number? Bulk schemes don't precipitate right (NB: we can fix this, it did not seem to alter ACI).
- How does turbulence interact with drop/crystal number?
- Options: mining ARM data (SGP, ENA). Want gradients in aerosol not correlated with meteorology. Think about easy first target for new AAF

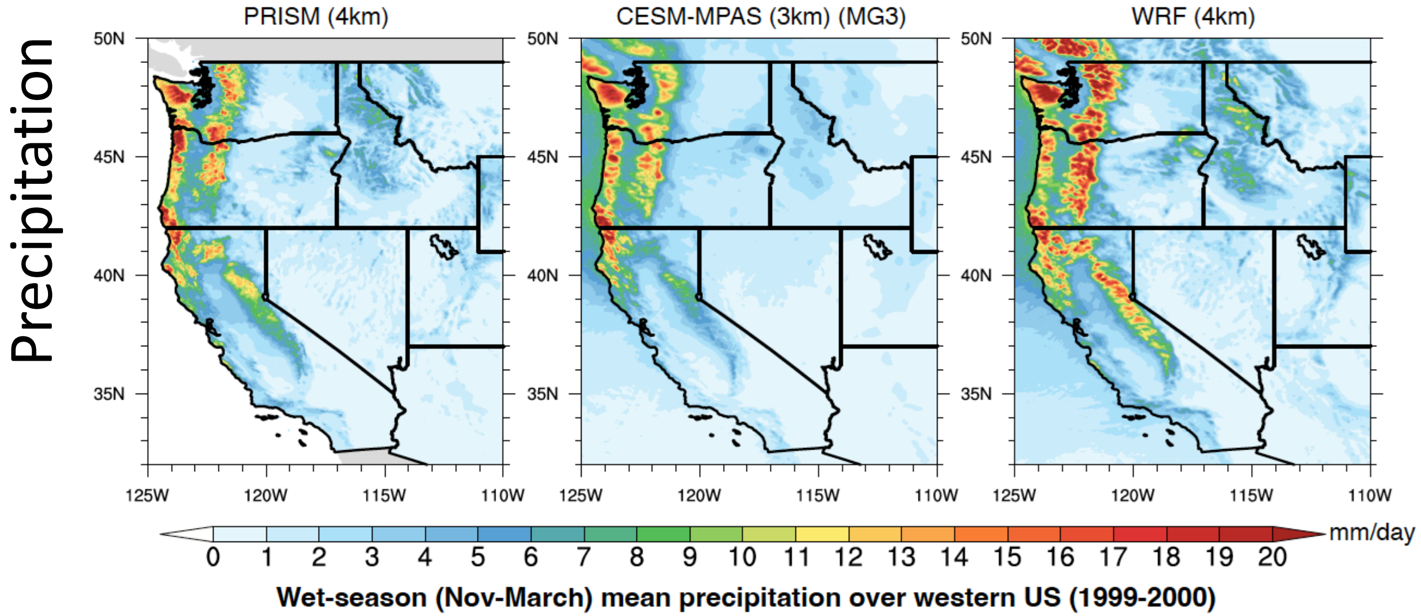
Both: Reduce biases in base state (for the right reasons!). Not just CRE.

Small Scale: Climate Extremes & Precip

- Global Model: CESM-MPAS: 3km regional, non-hydrostatic dynamics.
- Regional climate model: WRF (CONUS) 4km (Rasmussen et al., 2021)

W. USA Wet-season (Nov-Mar) precip (5yrs)

- CESM-MPAS results compare well to obs
- Smaller biases than WRF mesoscale model



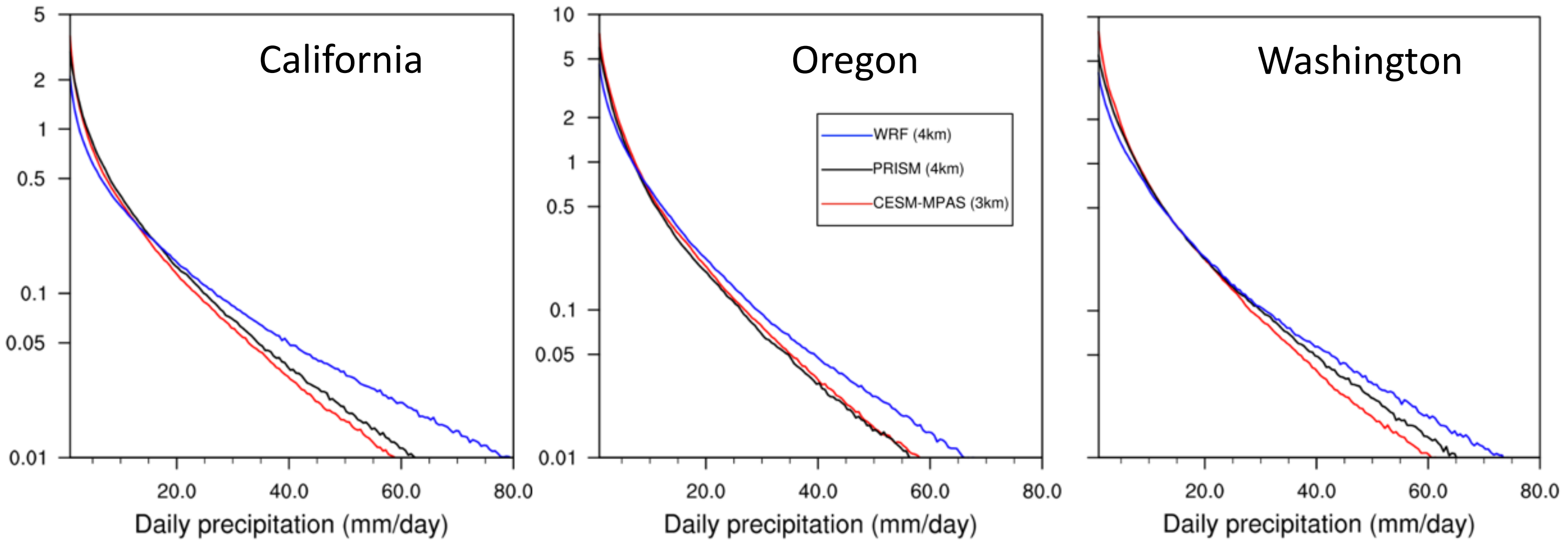
Daily precipitation Intensity PDF

4km Mesoscale Model (WRF)

3km Global Model (CESM)

4km Observations

CESM captures **observed PDF** better than **WRF**, especially for extreme precipitation



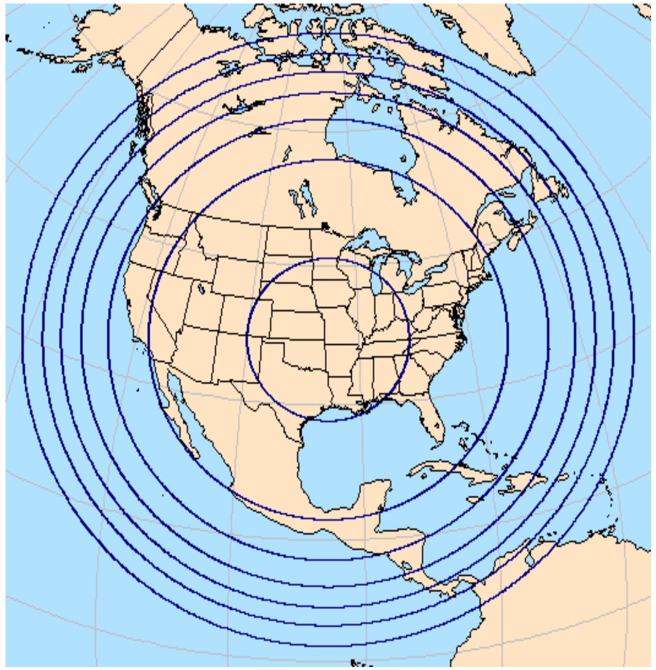
Huang et al 2022 (GMD, Accepted)

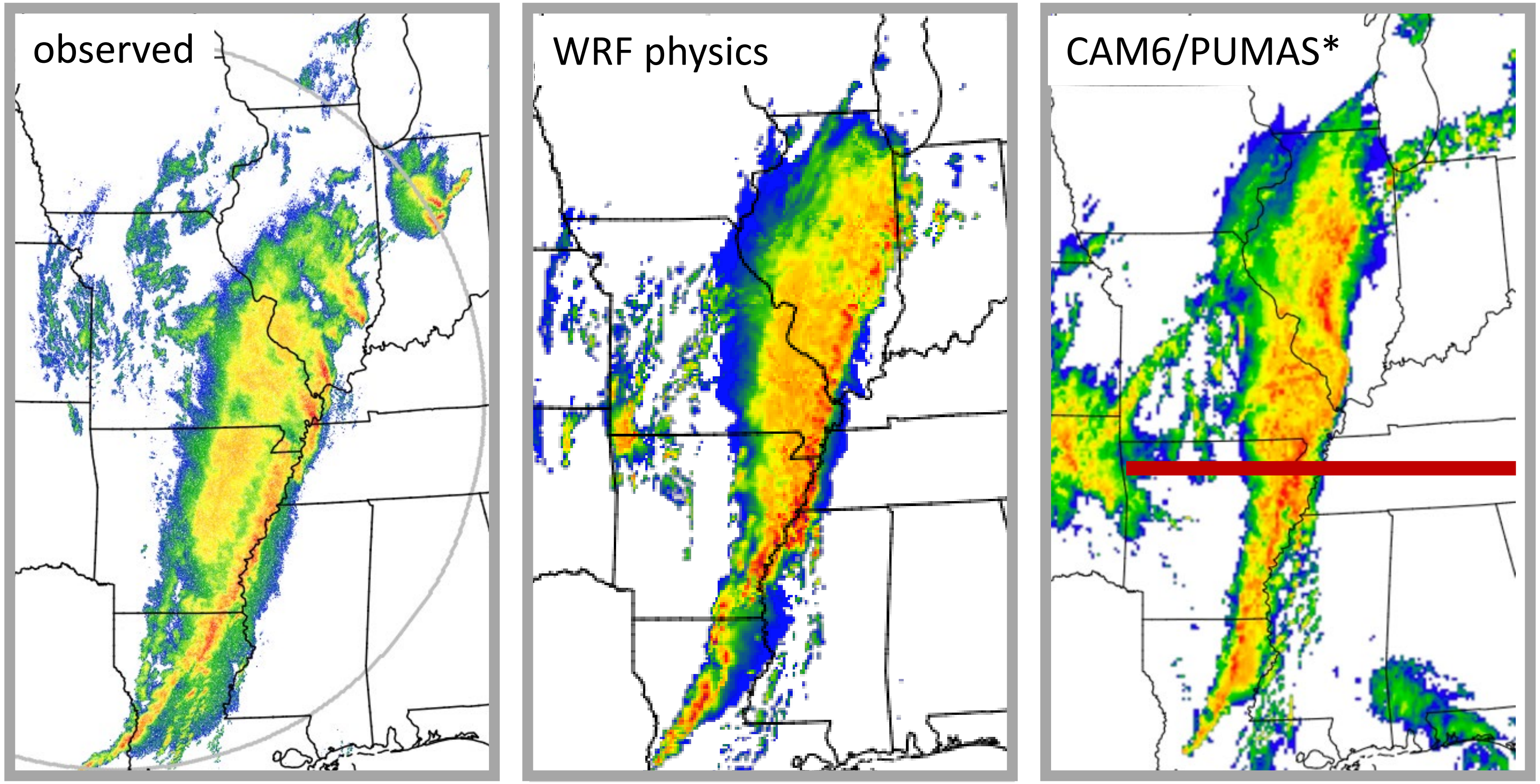
Harder Problem: Squall Lines

- Central US Summertime squall line. 24 hour forecast valid 0 UTC 27 April 2017
- Mesoscale model (MPAS-A< WRF physics) v. Climate Model (CAM6-MPAS dynamical core)

(* Computed using single-moment reflectivity diagnostic)

0 UTC 26 April 2017 initialization
60-3 km variable-resolution mesh





MG3+Collapsed PDFs in CLUBB's saturation adjustment

M. Chen, W. Skamarock, X. Huang, NCAR

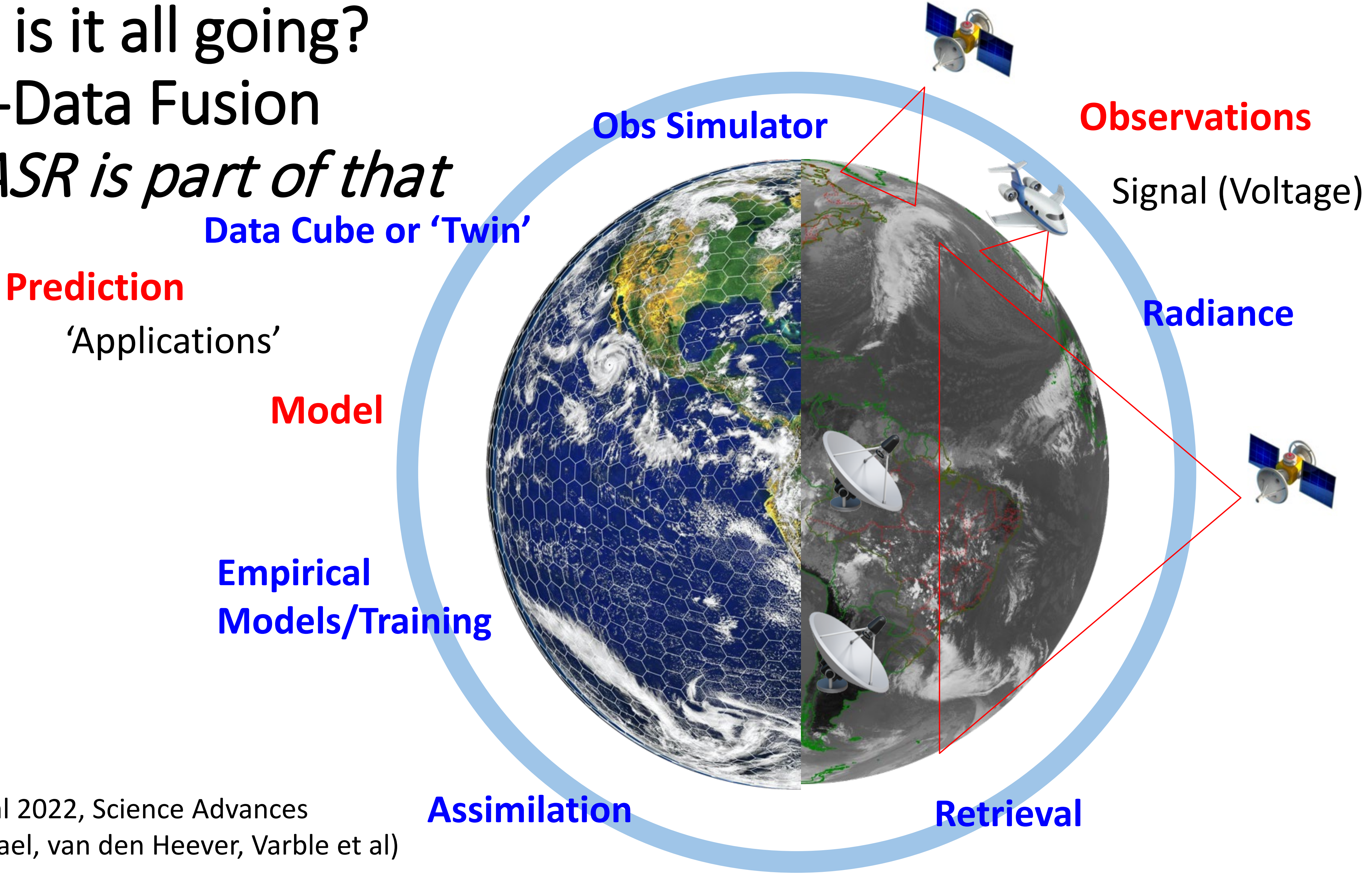
Summary: Small Scale

- Getting the mesoscale through the global scale right.
- Key weather Regimes under climate change (showed 2 examples, there are lots more)
- Precipitation formation and intensity. Interactions with dynamics
- How do we represent the convective permitting gray zone (1-5km).
  - What parameterizations do we need?
  - Does the turbulence really scale?
  - Do you want deep convection parameterized? Is higher order closure enough?
- Need to learn from the weather/LES scale
  - What ARM/ASR has been set up to do: are we fulfilling that promise?
- Global effort to coordinate ESM work at km scale: WCRP Digital Earth Lighthouse activity

Common Themes & Some ideas

- Turbulence across scales (from boundary layer and entrainment to shallow to deep). Importance for cloud adjustments, also basic maintenance of low cloud decks (correctly)
  - Can the new AAF seek this out?
  - Where do our parameterizations break down?
- Ice microphysics for high clouds: models are still crude here
  - Again, possible role for AAF
- How to bring ARM/ASR to bear?
  - Better cross scale interaction: go up and down the hierarchy. We have all the tools, not well integrated. E.g. LASSO with an ESM
  - Better use of data: Model-data fusion. Focused high resolution bring our models to observations. ARM Instrument simulator efforts are great. Integrate into ESMs

Where is it all going?
Model-Data Fusion
ARM/ASR is part of that



Gettelman et al 2022, Science Advances
(With Carmichael, van den Heever, Varble et al)