Confronting Global Models with Observations and the Promise and Pitfalls of Improved Prediction

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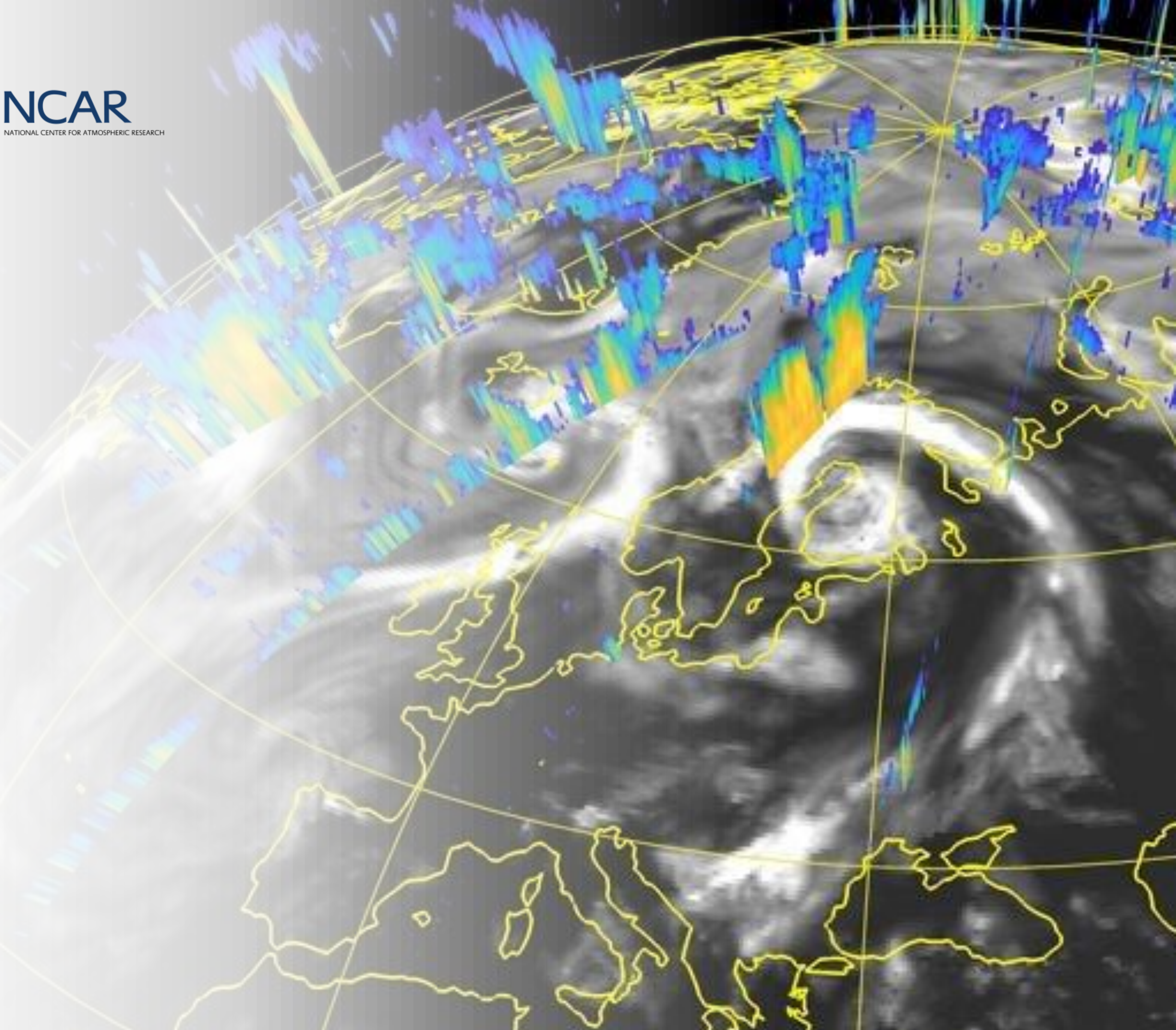


Mark Fielding, ECMWF Newsletter

Outline

- ESM Advancements (at any scale)
- Some examples of new methods: Model-Data Synergies, Machine Learning
- Larger vision: Model-Data Fusion

Improving (weather, climate) predictions requires synergistic use of observations and models

EarthCARE can help with critical cloud processes: great timing!

Where are ESMs Going?

- GSRMs (e.g. uniform high resolution)
- Traceable to lower resolution Global, Regional
  - Merging with mesoscale models (especially cloud processes)
  - Scalable complexity: chemistry, aerosols, cloud processes (e.g. rimed ice)
- New methods
  - Emulators, Machine Learning (new generation of 'empirical' parameterizations)
- Better analysis, optimization methods
  - Satellite Simulators
  - Data Assimilation for Climate (especially for clouds)

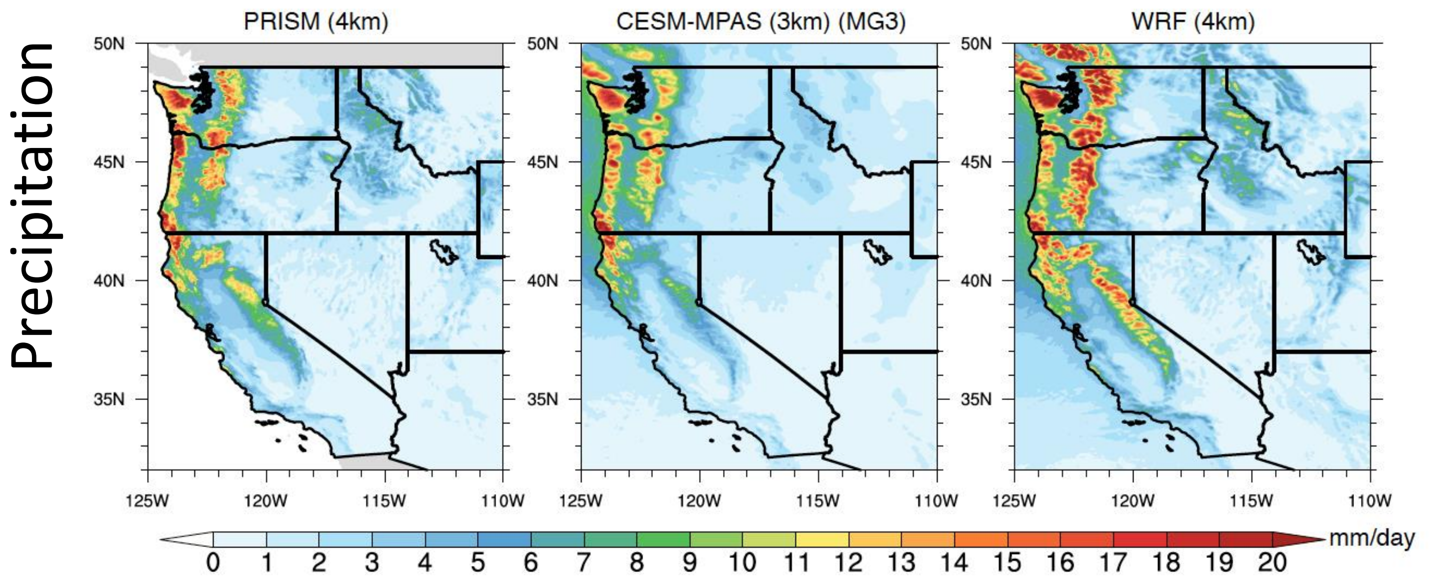
Climate Extremes: Variable-Resolution (60→3 km)

Huang et al, 2022, GMD

- 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



Wet-season (Nov-March) mean precipitation over western US (1999-2000)

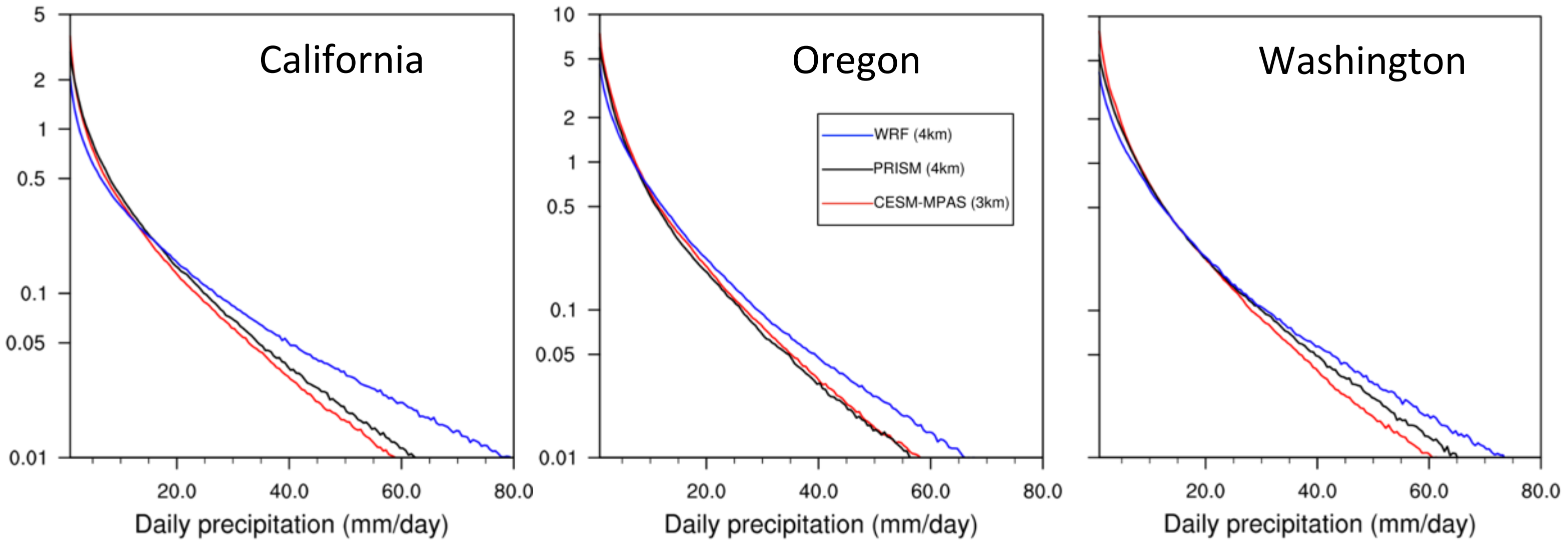
Daily precipitation Intensity PDF

4km Mesoscale Model (WRF)

3km Global Model (CESM)

4km Observations

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



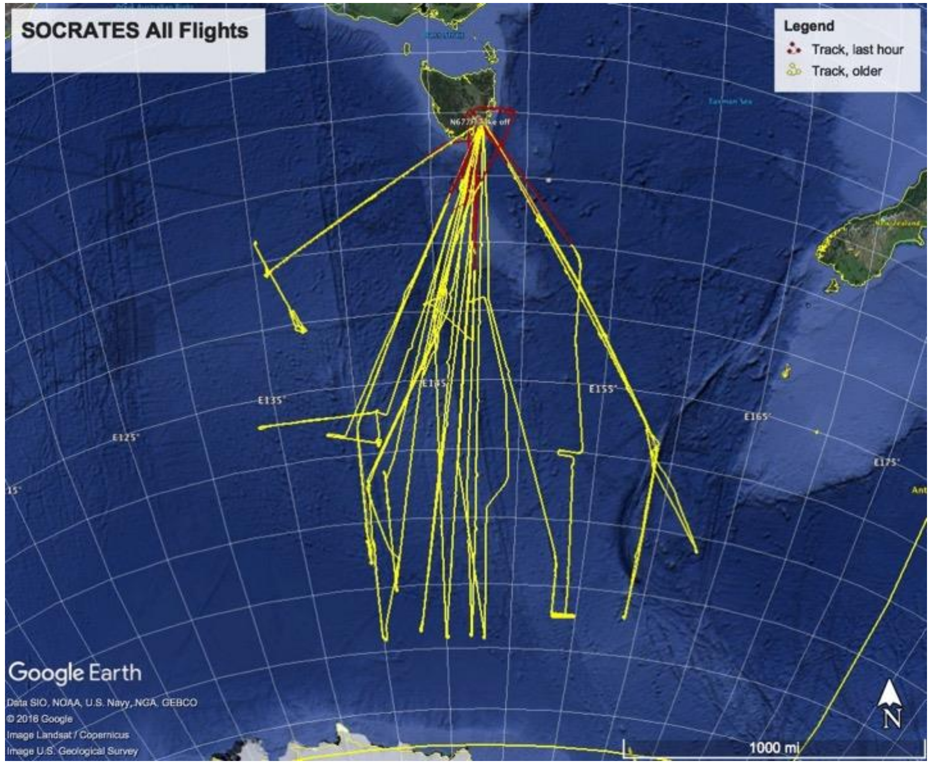
Major Issues for Clouds, Precip and Aerosols

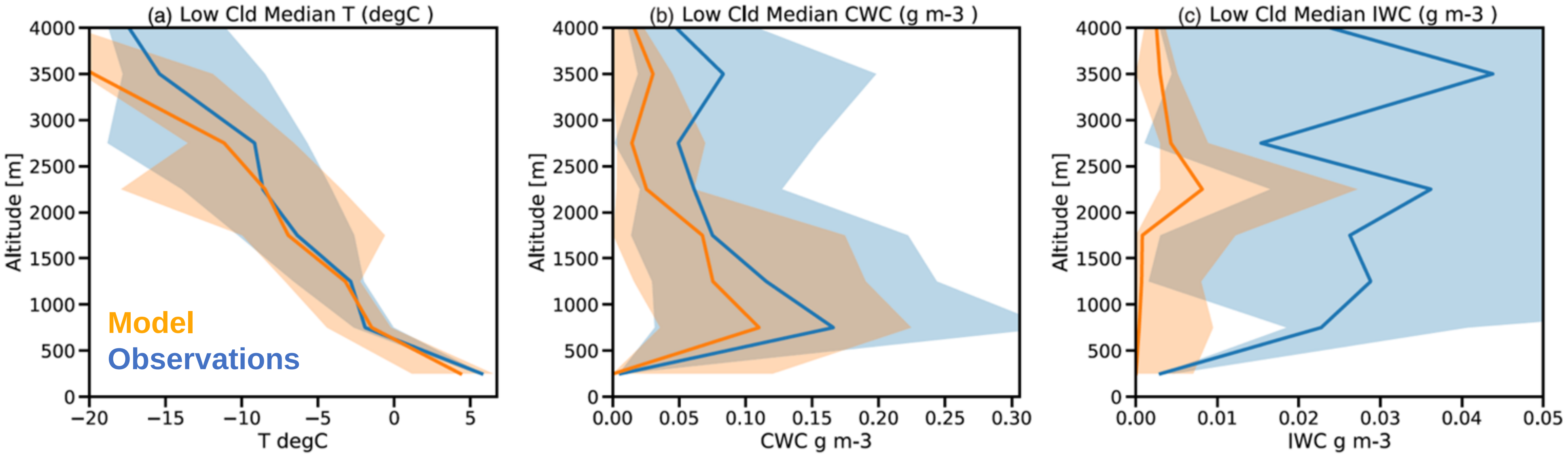
- Cold Cloud Phase:
  - Critical for high latitude radiative effects, cloud feedbacks, weather extremes
- Cloud Microphysics:
  - Size distributions govern process rates
  - Cross scale convective processes
- Dynamics-Microphysics coupling
  - Vertical structure of clouds: cloud base, freezing, entrainment at top
- Aerosol activation (cloud-aerosol interactions)
  - Vertical velocity critical
- Precipitation Formation: Frequency & Intensity
- Convective organization across scales

Cloud Phase

SOCRATES in-situ flights over the S. Ocean used to understand & improve models

CAM6: Too little ice. This contributes to high climate sensitivity.



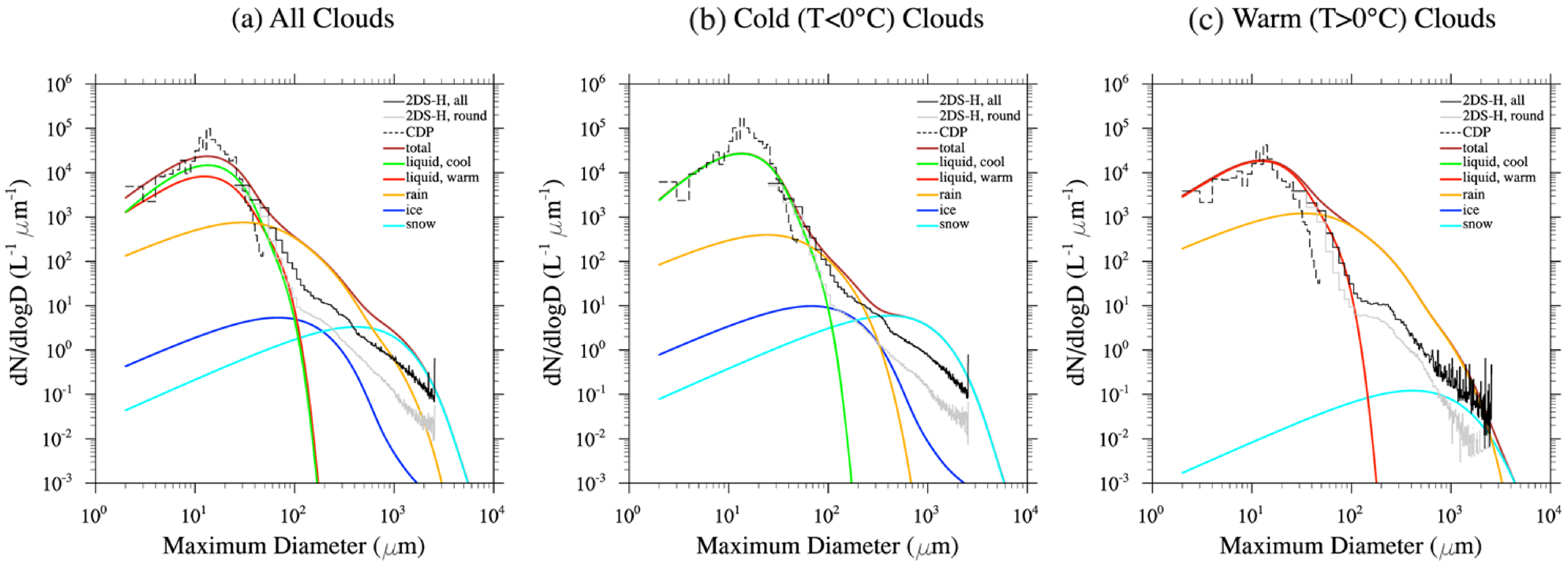


Gettelman et al 2020

Microphysics, Size distributions

Advanced GCMs/GSRMs can be compared directly to cloud microphysical size distributions (here from SOCRATES).

Comparison is GCM cloud microphysics along aircraft flight tracks with in-situ data

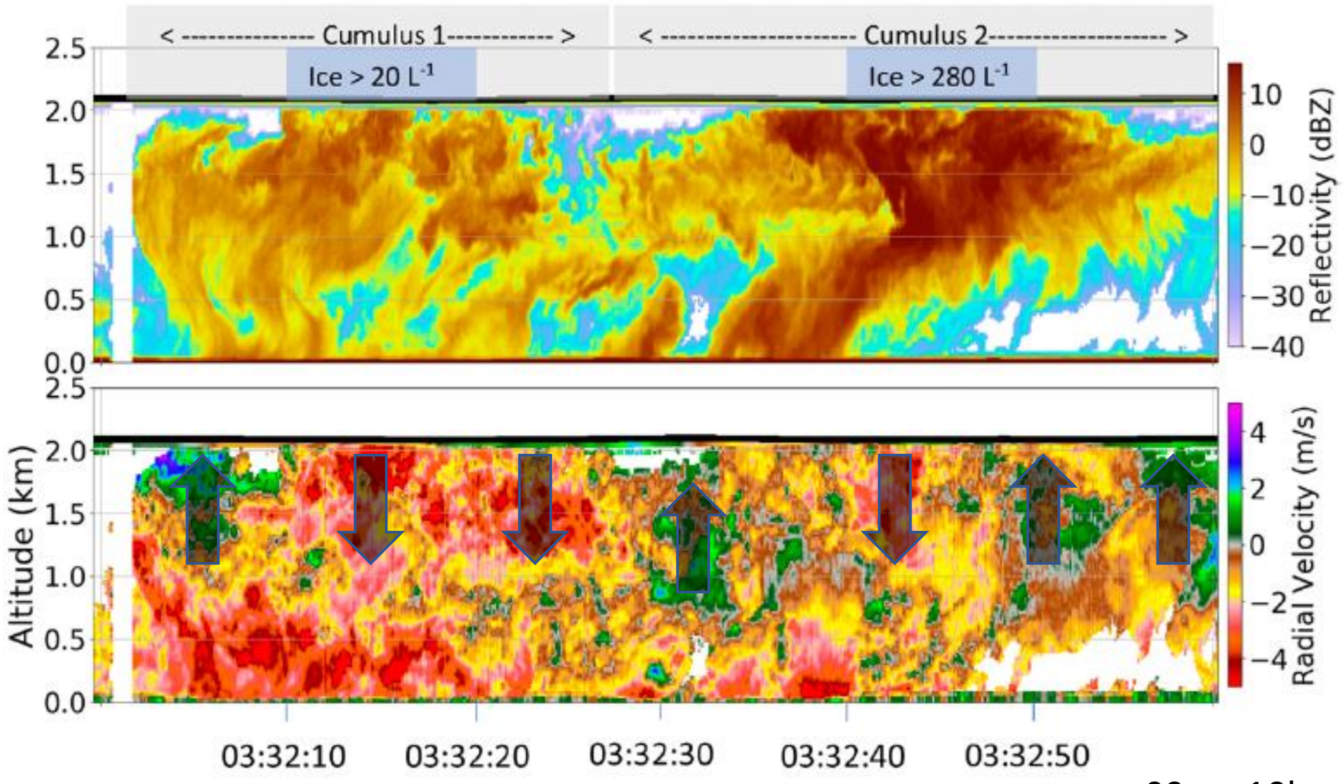


Note potential issue with too large rain sizes

Gettelman et al 2020

Cloud Dynamics & Microphysics

- Cloud dynamics (velocity) influences/controls cloud microphysics & aerosol activation
- Leads to different cloud drop/crystal number, precipitation & radiative effects
- S. Ocean SOCRATES example
- Note: GSRMs are still not 'resolving' these interactions

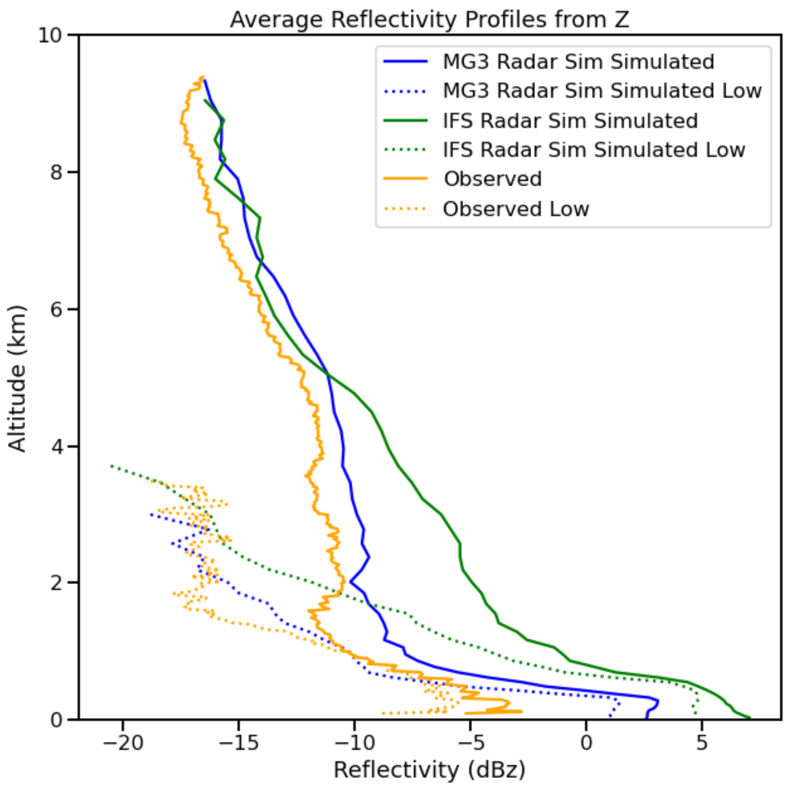


60s ~ 10km

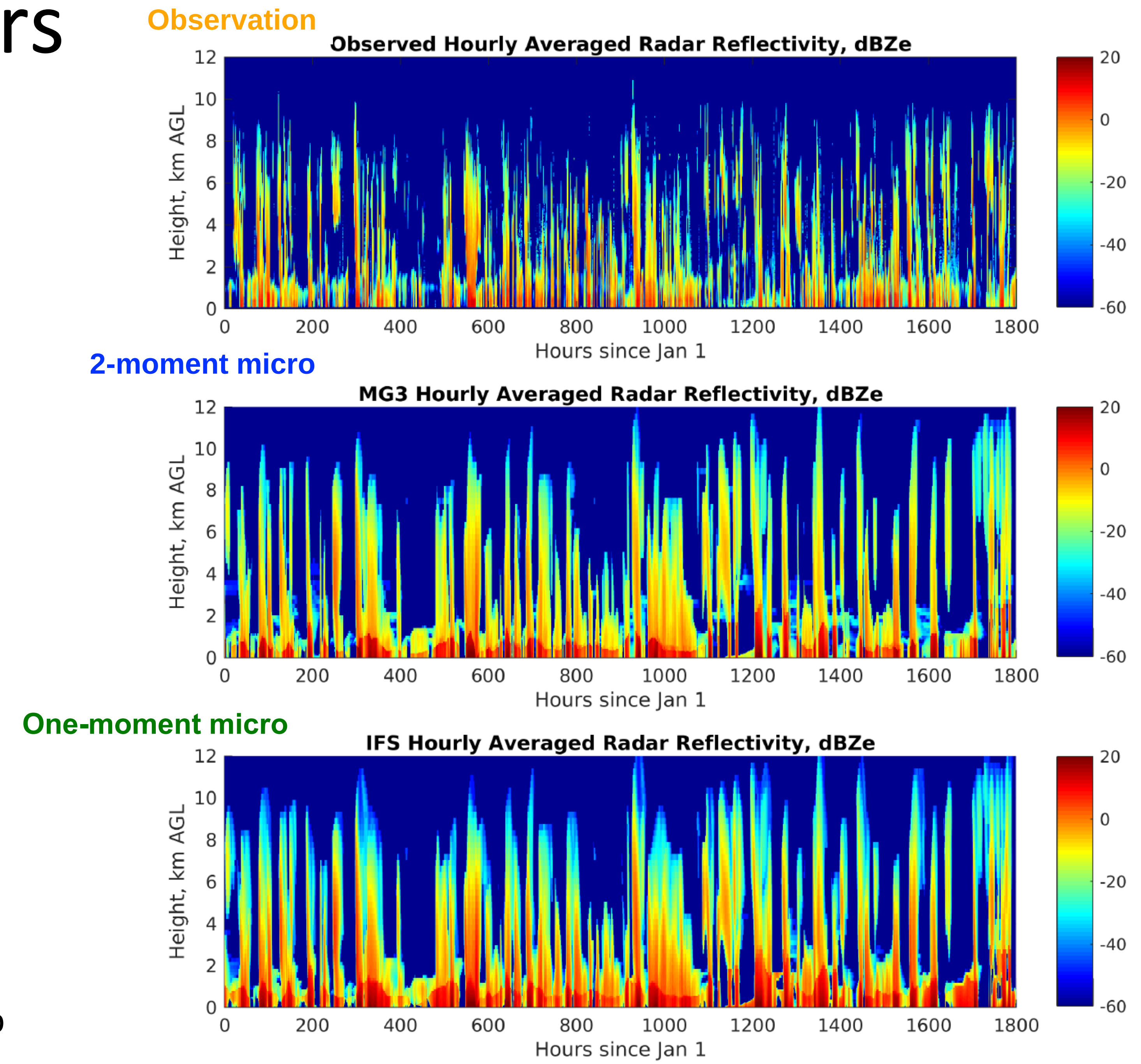
McFarquhar et al 2020

Observation Simulators
(Reflectivity)

Comparisons over Macquarie Island in S. Ocean between a **precipitation radar** and single column simulations with **one-moment** and **2-moment** microphysics in the ECMWF-IFS SCM.



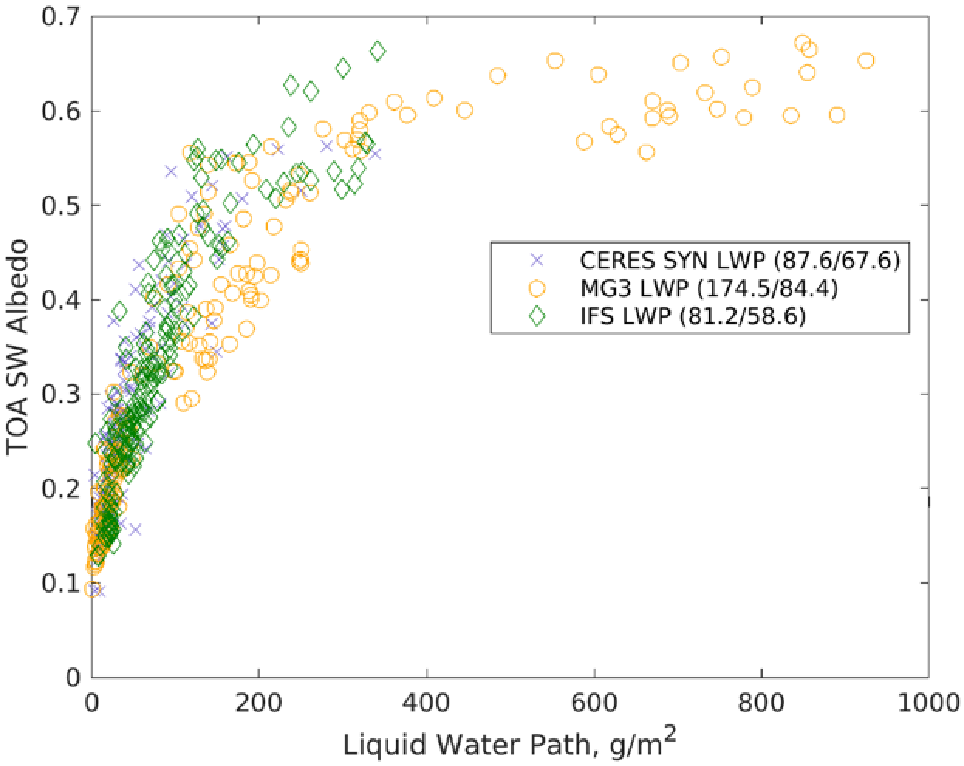
Gettelman, Forbes, Marchand, Fielding, in Prep



Radiation Comparisons

MICRE Low Cloud Cases

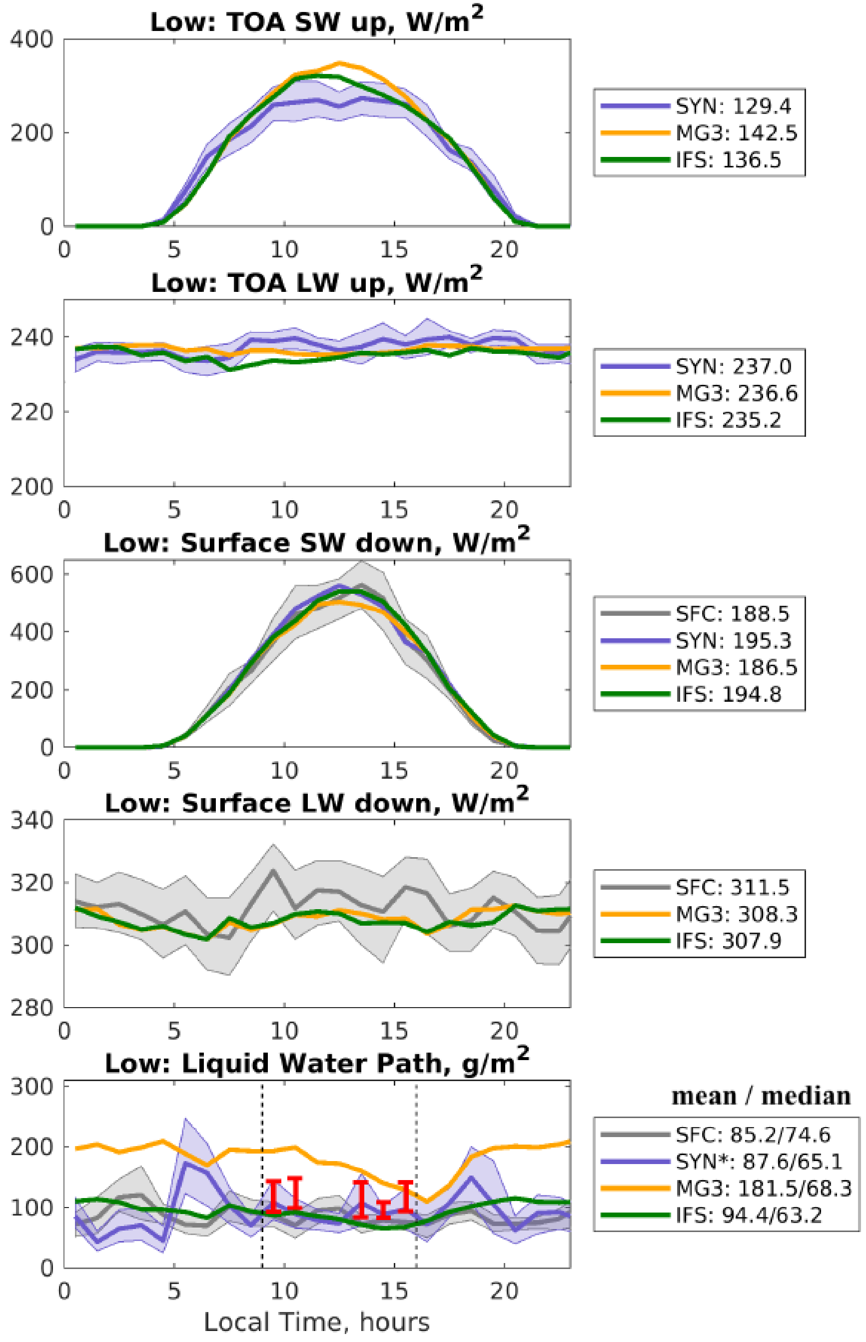
- 2-Moment Microphysics does a good job of reproducing the radiative fluxes
- Low clouds too bright at TOA, okay at surface?
- But large LWP bias!
- LWP v. Albedo saturates



Observation

2-moment micro

One-moment micro



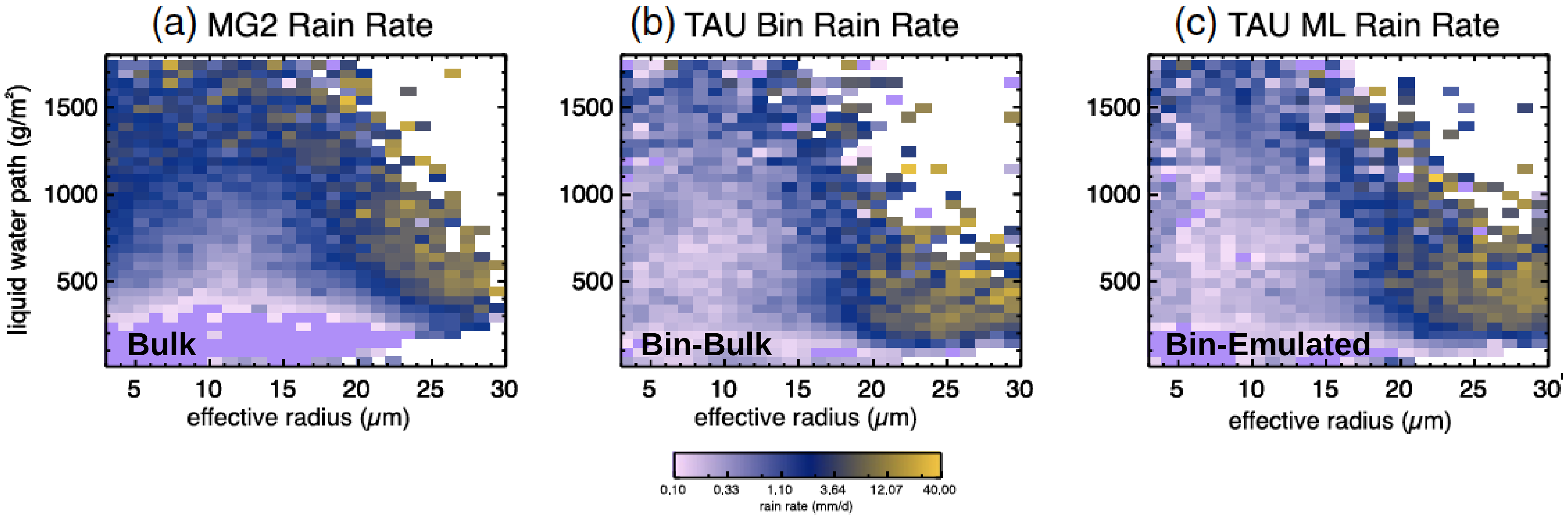
Gettelman, Forbes, Marchand, Fielding, in Prep

Precipitation Frequency

Improving precipitation formation with emulators of detailed models

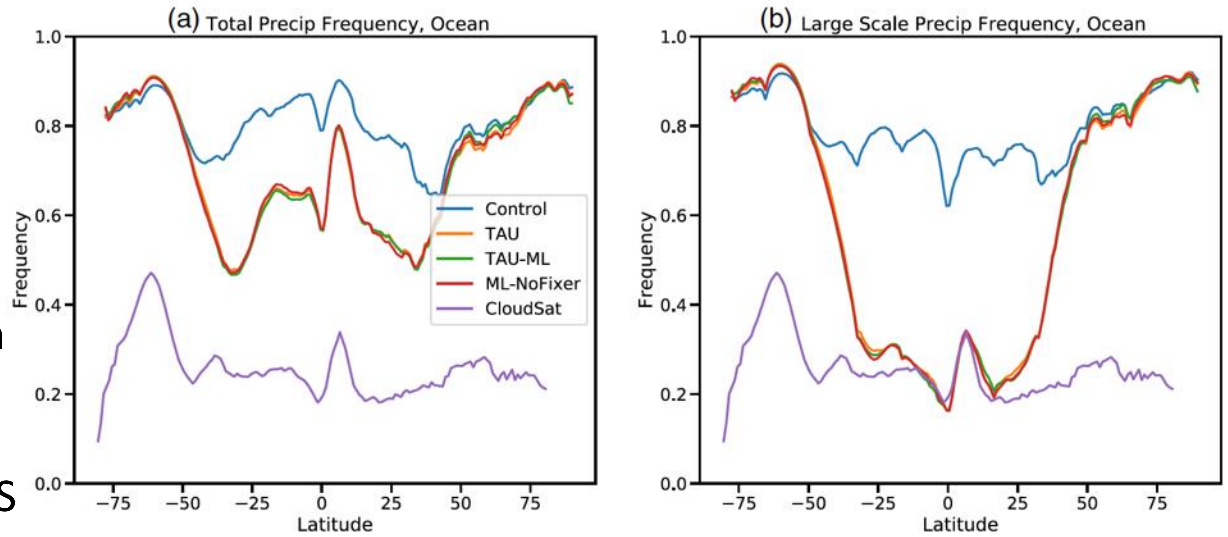
Replace autoconversion and accretion in a bulk scheme with stochastic collection with a bin scheme. Then emulate that with a neural network.

Reduces rain rate for small drop sizes but large LWP

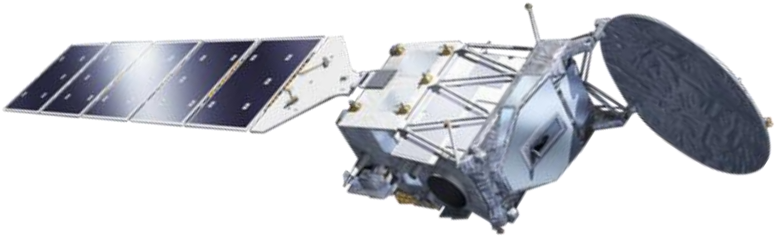


Precipitation Frequency

Control v. Observations and
Bin precipitation and ML Emulator.
Using stochastic collection from a bin scheme improves large scale precipitation frequency in shallow clouds



Gettelman et al 2021, JAMES

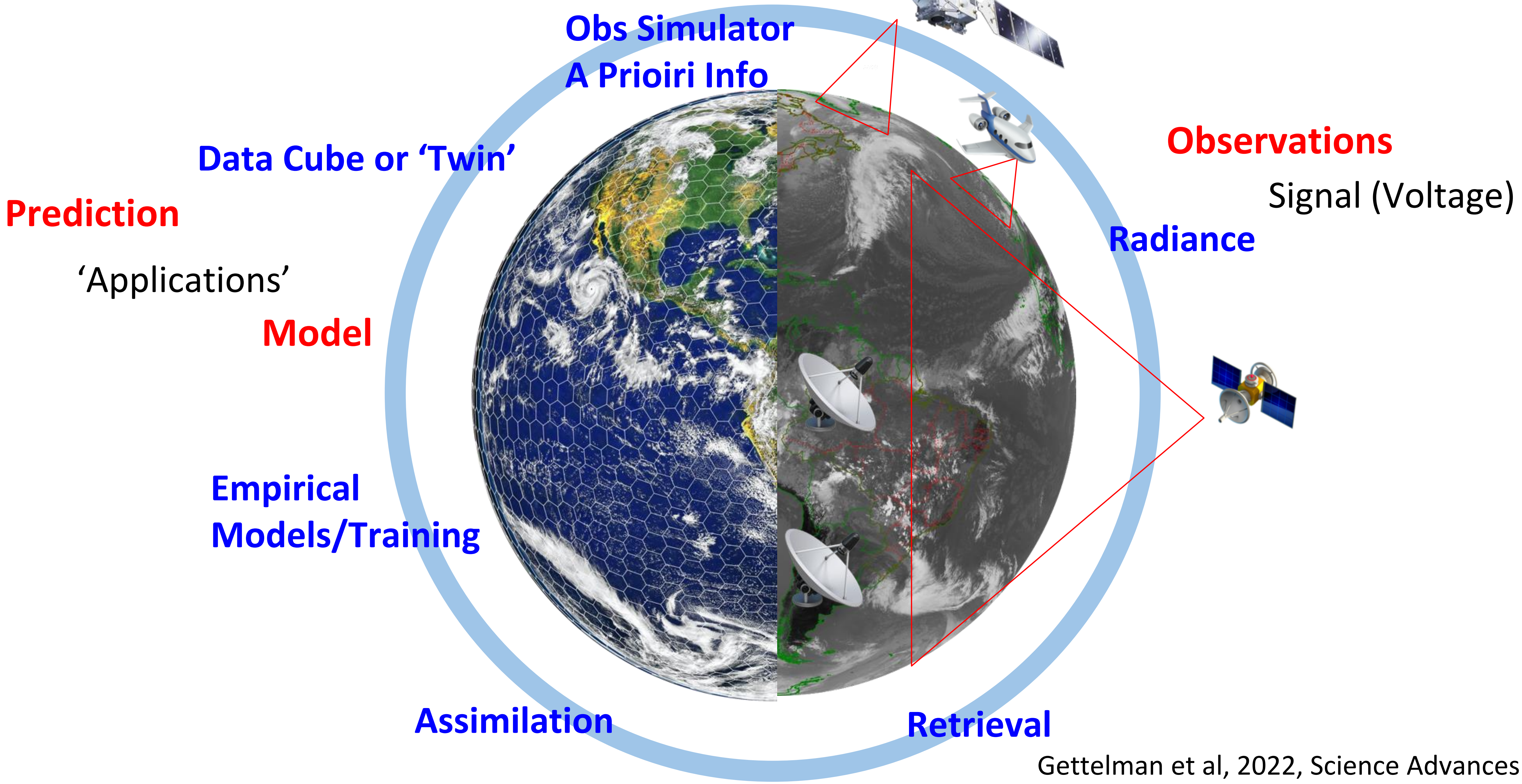
Where can  help?

- Doppler velocity: what are the intensity and scales of motion in shallow and deep clouds
  - Coupling to thermodynamics (e.g.: higher order closure schemes: w'q')
  - We are still parameterizing this even in GSRMs
- Reflectivity:
  - Simulate in models: if the microphysics is wrong we will know it
- Cloud phase: Synergistic use of radar & lidar
- Better simulators. Want more direct process information
  - What simulator are we going to use? J-SIM? COSP? RTTOV?
- Assimilation of cloud information for model evaluation

Goal: Improving Prediction

- Improving prediction relies on models AND observations together
- A ‘model-data fusion’
- Better models
- Better observations
- Better techniques (assimilation, evaluation of models and obs)
- Also: coupling to applications (Digital Twin Earths)

Vision: Model – Data Fusion



Gettelman et al, 2022, Science Advances

Summary

- Improving (weather, climate) predictions requires synergistic use of observations and models
  - New methods for Model-Data Fusion
  - Simulators [Let's talk more about EarthCARE simulators]
  - Assimilation
- EarthCARE can help with critical processes
- Key cloud microphysics problems:
  - Cloud Phase
  - Aerosol-Cloud Interactions (cloud dynamics-physics coupling!)
  - Precipitation
- Key places to make progress with Earth Care
  - Vertical motion, reflectivity, cloud phase

‘Digital Earth’ = Digital Twin of the Earth

An interactive information system for the past, present & future state of the earth

The Digital Earth: Understanding our planet in the 21st Century

by Al Gore

The tools we have most commonly used to interact with data, such as the "desktop metaphor" employed by the Macintosh and Windows operating systems, are not really suited to this new challenge. I believe we need a "Digital Earth". A multi-resolution, three-dimensional representation of the planet, into which we can embed vast quantities of geo-referenced data.

January 31, 1998

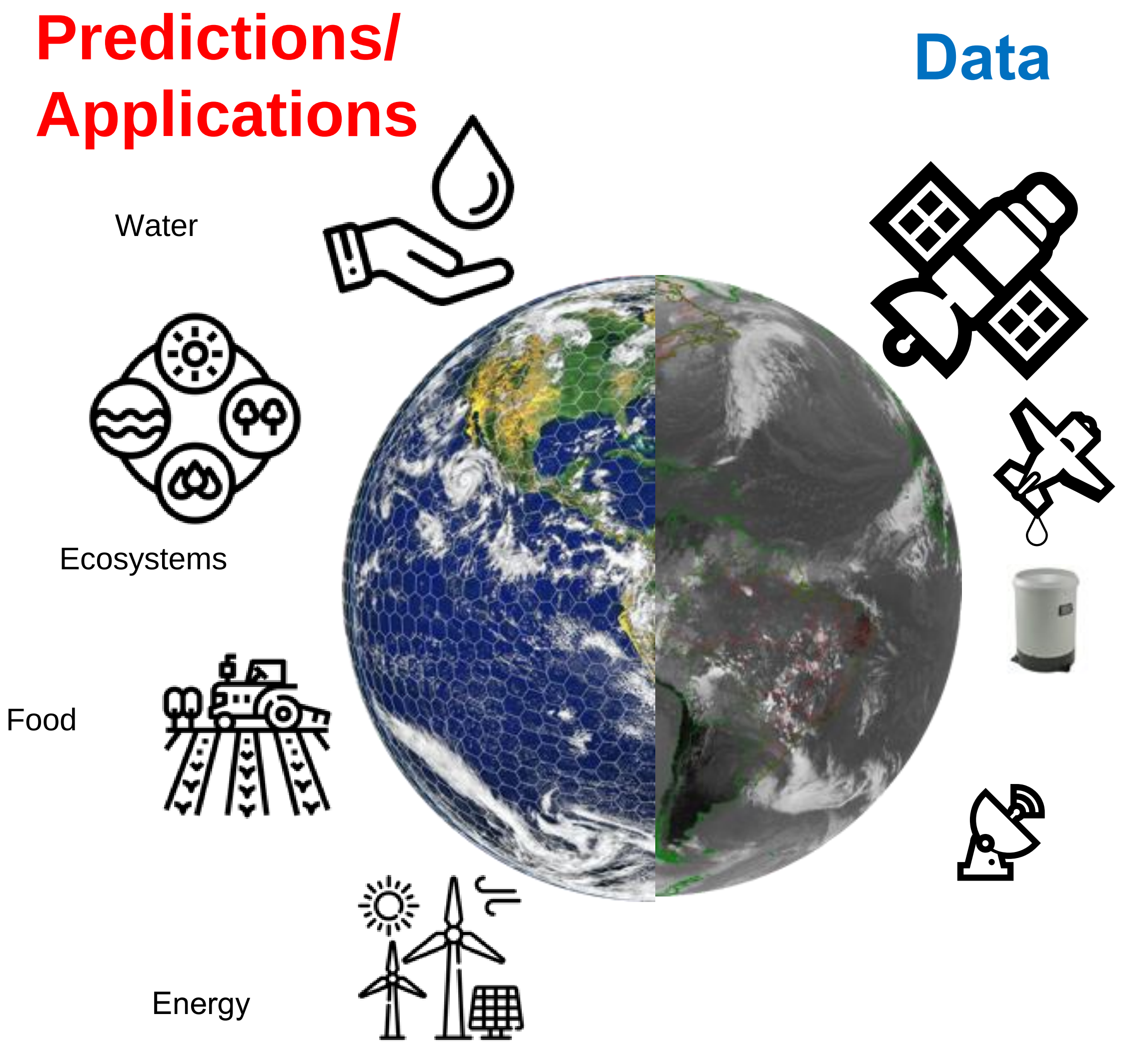
Why is a Digital Twin different than just a ‘model’?

Data *goes in. Human scale* ***predictions*** *come out*

- Key differences
  - Data: Assimilation & Data Models
  - Coupling to human systems
  - For Decision making

- Is this just Hype?

- Digital Earth may be Regional
- Hierarchy of models/configurations
- Configurable



‘Digital Earths’
WCRP Lighthouse Activity

Support the design and building of ***integrated interactive digital information systems*** *that provide global and regional information on the past, present, and future of our planet, including both natural and human systems.*

Areas of activity

– **Fully coupled km-scale regional and global models:** Need a global research network in km-scale modeling of the Earth system and individual components

– **Data assimilation for climate:** Establish an active community in data assimilation for climate, expanding on the excising numerical weather prediction and re-analysis efforts

– **Beyond the Physical Earth System:** Include human interactions on and impacts to human systems in ESMs