Effects of Climate Change on the Atmospheric Hydrologic Cycle

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- IPCC Fourth Assessment Report (Chapters 8 and 10, particularly)
- Phil Mote, Eric Salathe, Lara Whitely Binder (Climate Impacts Group)
- Roger Marchand (JISAO)
- NASA, DOE ARM

It’s the WATER!

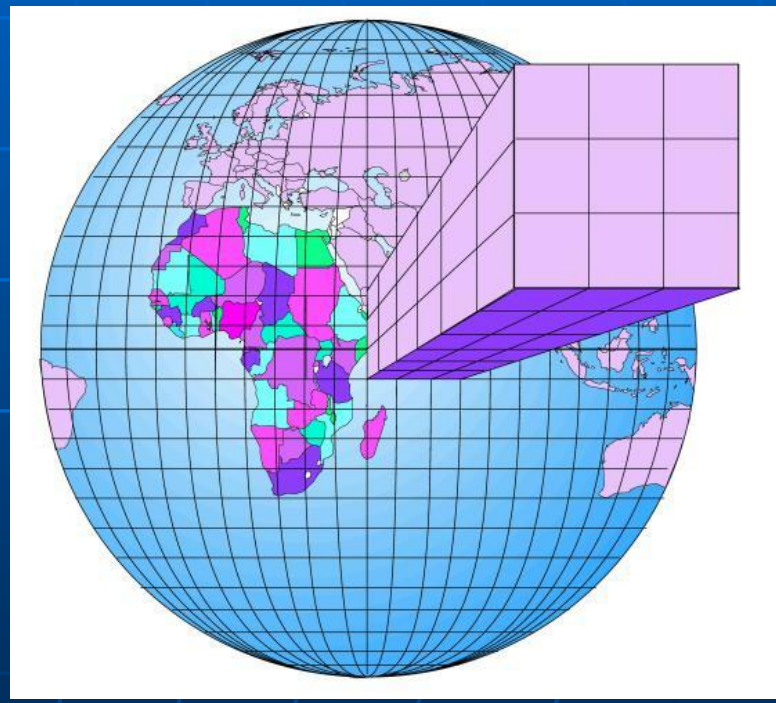
- Climate change literature tends to focus on surface temperature change, but WATER is the key to understanding climate change impacts

Two key pieces of the water cycle

- Clouds
  - Global thermostat – reflect solar radiation and enhance greenhouse effect
  - On average, clouds cool the planet
  - How will the amount of cooling change as climate changes
- Precipitation
  - Regional fresh water => living needs, agriculture, hydropower, fish, etc.
  - Timing => monsoons, seasonal cycle
  - Enhanced extremes => drought, intense events

Atmospheric Global Climate Model

- Climate model sensitivity = change in average surface temperature for a fixed change in some climate forcing
- Determined by
  - Direct response
  - Feedbacks
- Feedback = additional radiative forcing produced by a change in temperature



IPCC Fourth Assessment Report

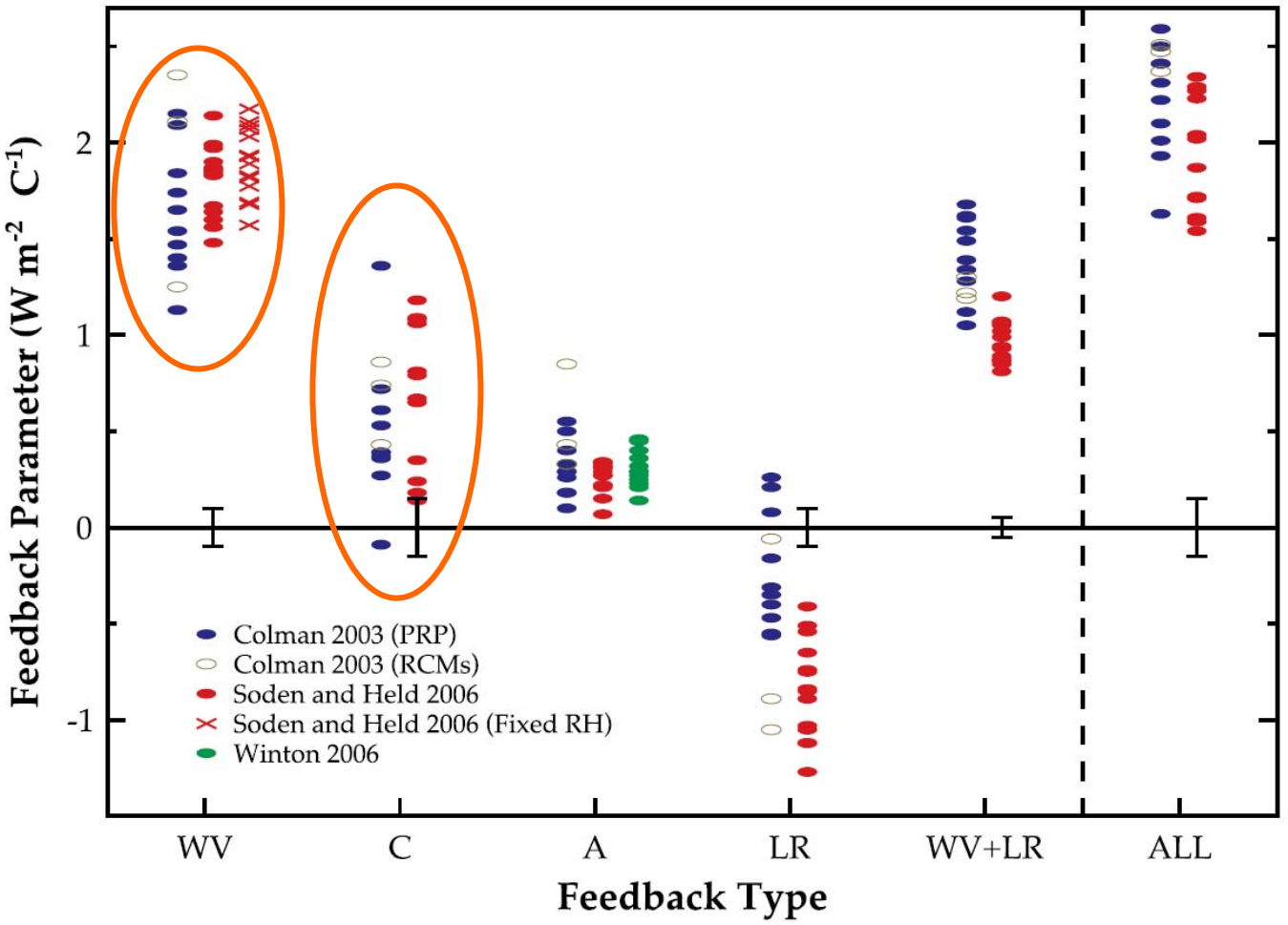
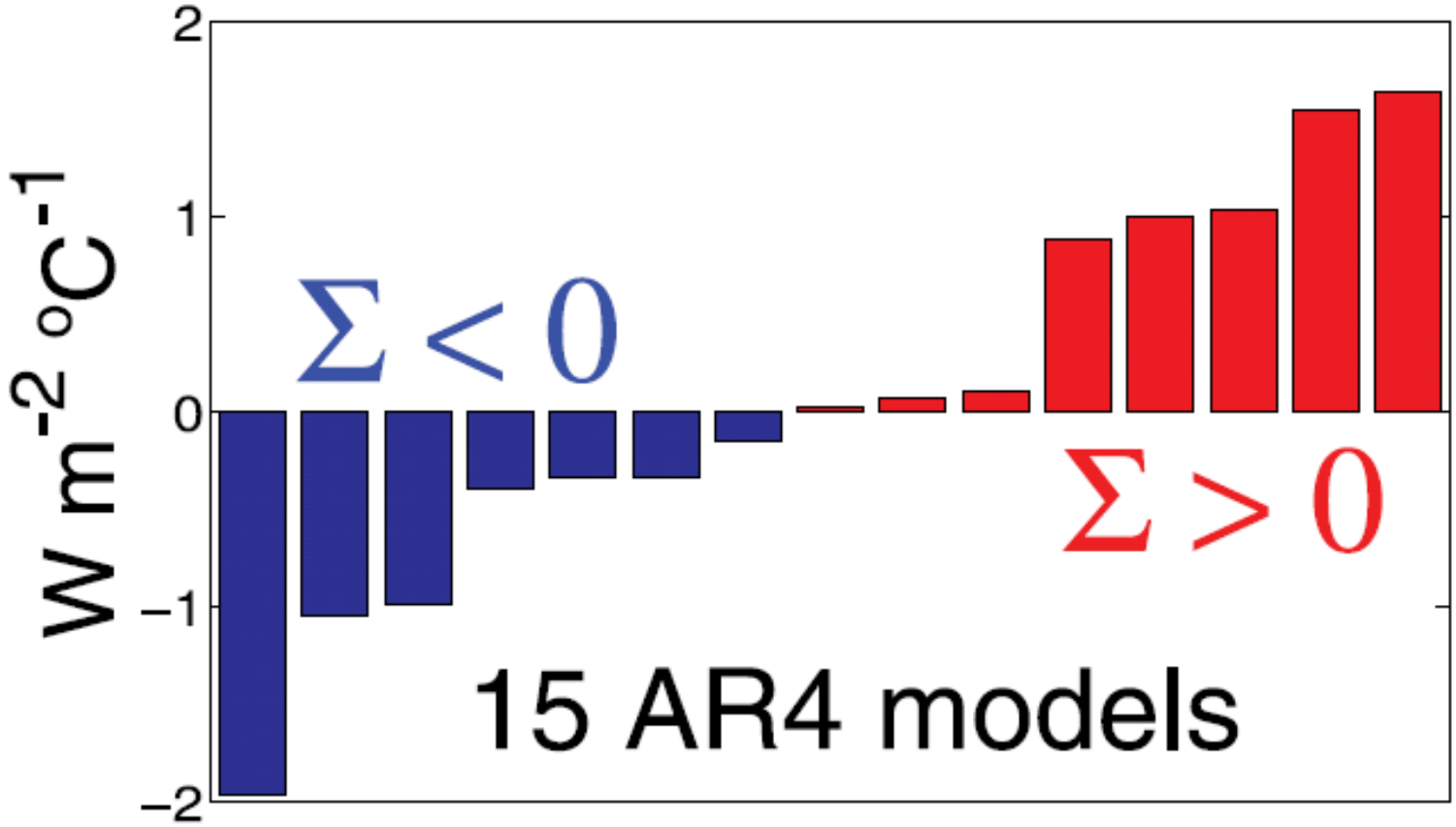


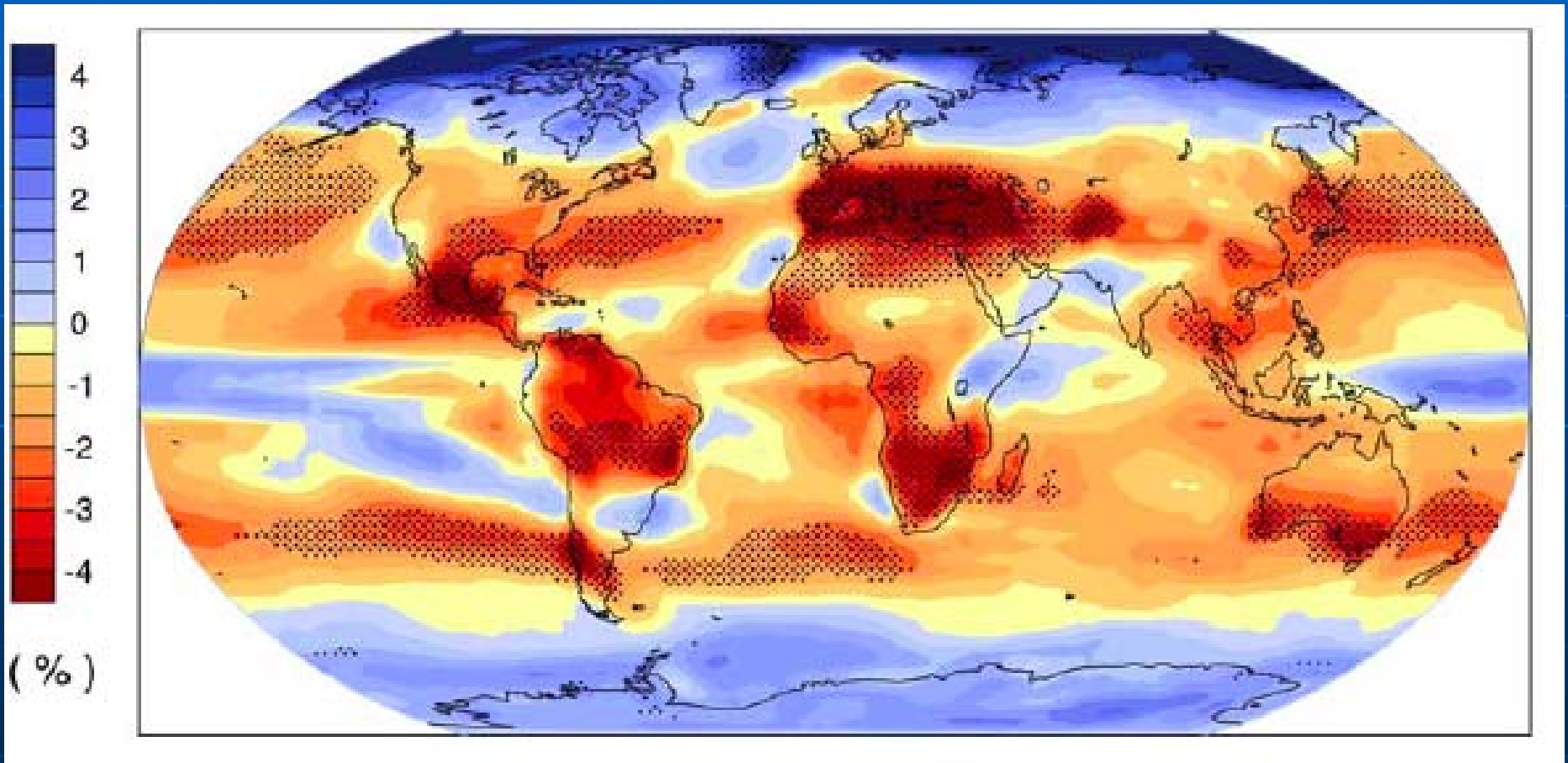
Figure 8.14. *Comparison of GCM climate feedback parameters for water vapour (WV), cloud (C), surface albedo (A), lapse rate (LR) and the combined water vapour plus lapse rate (WV + LR) in units of W m^{-2} °C^{-1}. 'ALL' represents the sum of all*

tropical CRF sensitivity to SST



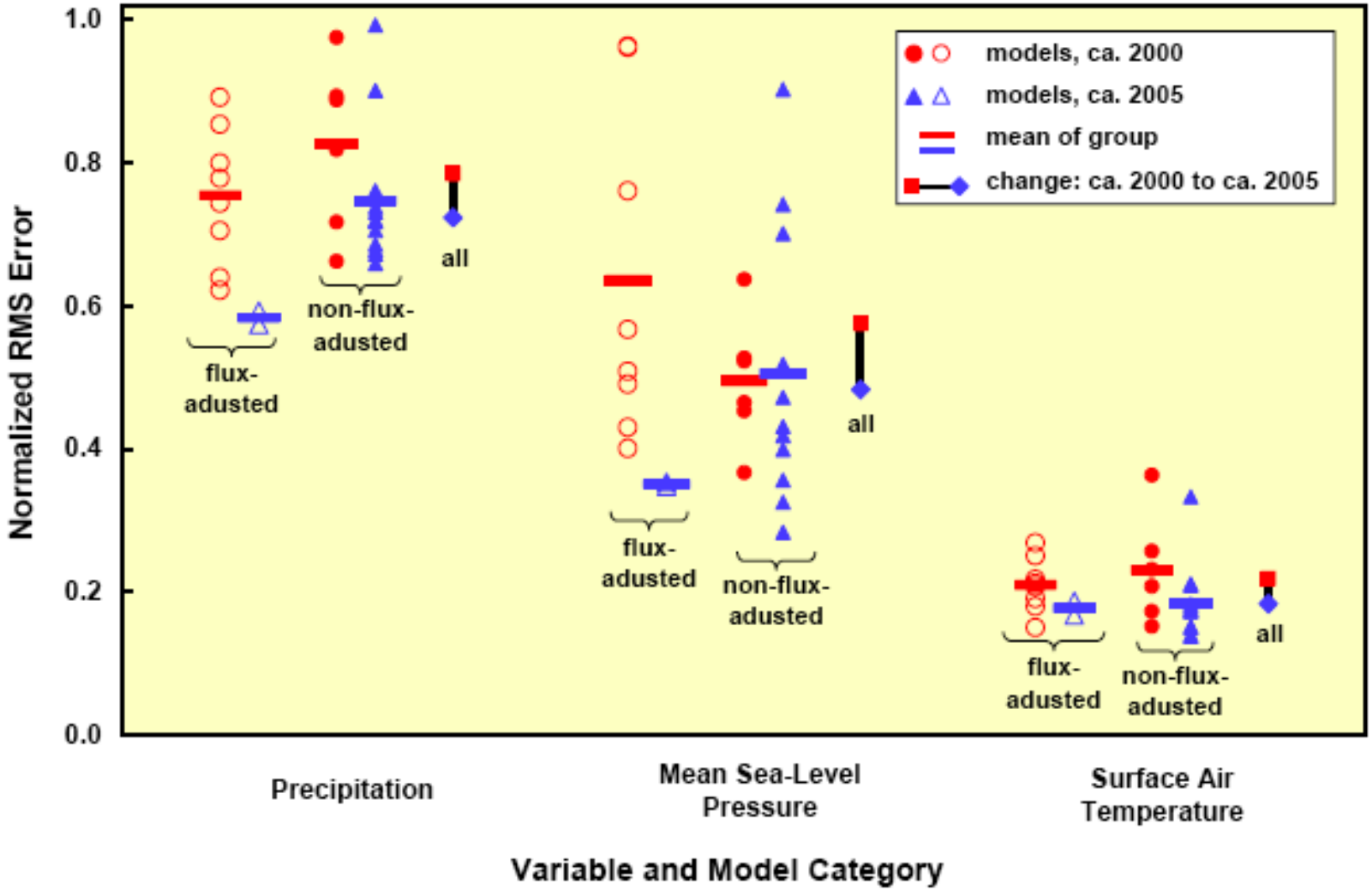
Limited confidence in cloud change

Change in cloud amount in 21st century:
A1B Scenario



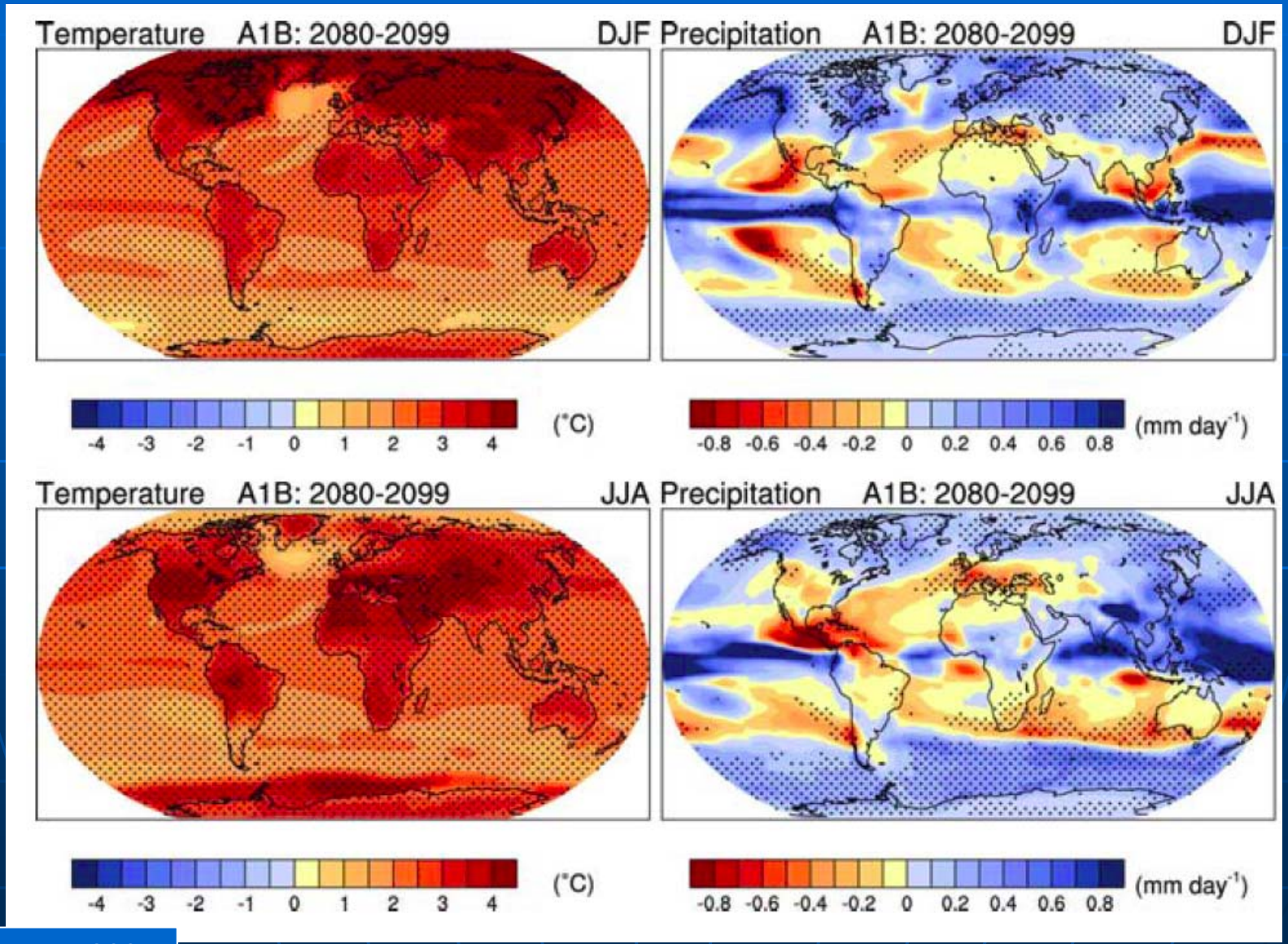
IPCC AR4, 2007

Fidelity of meteorological fields



IPCC AR4, 2007

Limited confidence in predicted rainfall



IPCC AR4, 2007

The problem is multiple scales.

Cloud-scale processses
Well understood

Meso-scale statistics
Poorly understood

Global scale

This is where parameterization comes in.

Borrowed from Dave Randall, CSU

Parameterization

- Blends theory with empiricism
- Requires
  - Knowledge of how small scale properties (clouds) depend functionally on large scale predicted fields
  - Data (at cloud and large scale) to constrain functional fits and deduce relationships
- Inherently statistical
- Dang hard work!

So, what we need is a global model running at cloud-scale resolution!

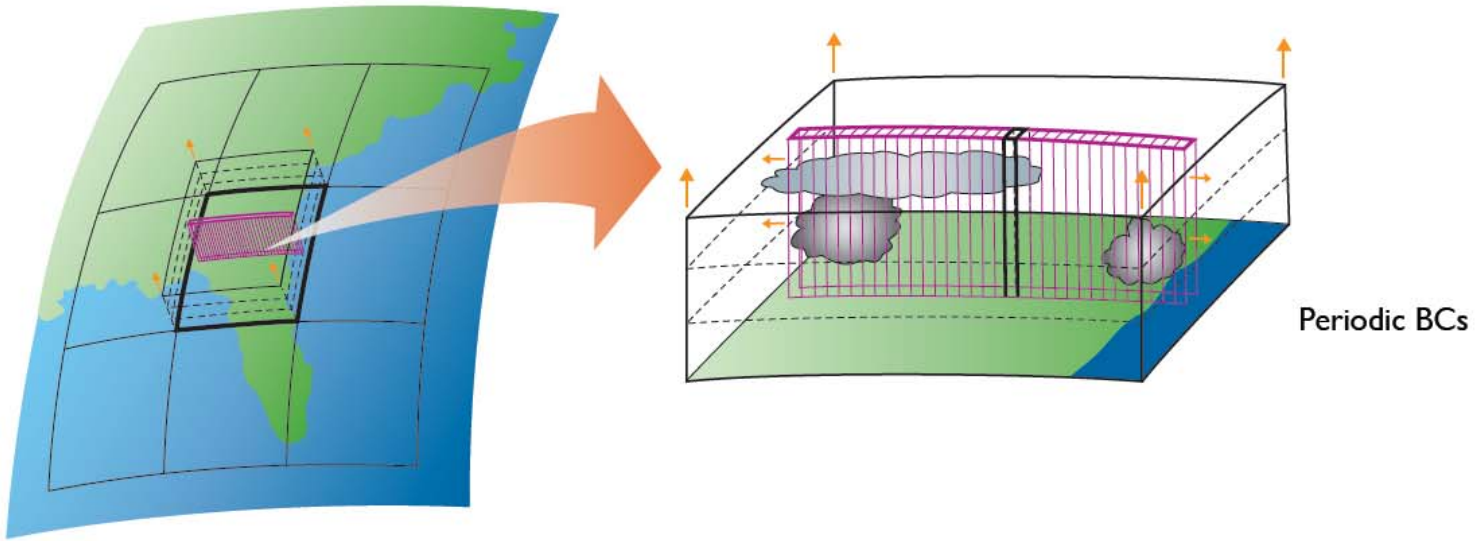
- Issues
  - Computer time
  - Computer storage
  - Analysis tools
  - People

Other options

- Multi-scale modeling framework
- Nested models

Super-Parameterization

(a.k.a. the Multiscale Modeling Framework, or MMF)



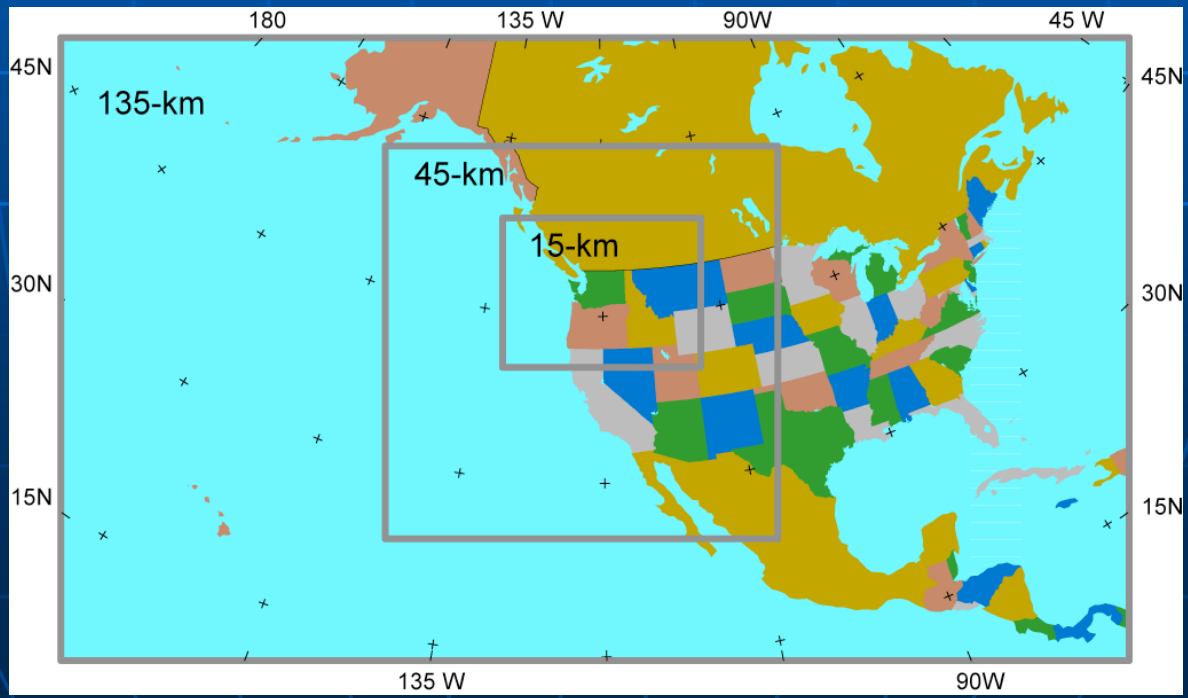
A super-parameterized climate model is about 250 times slower than a conventional GCM with climate resolution.

It is more flexible and less expensive, but also more complicated, than a global cloud-resolving model.

Borrowed from Dave Randall, CSU

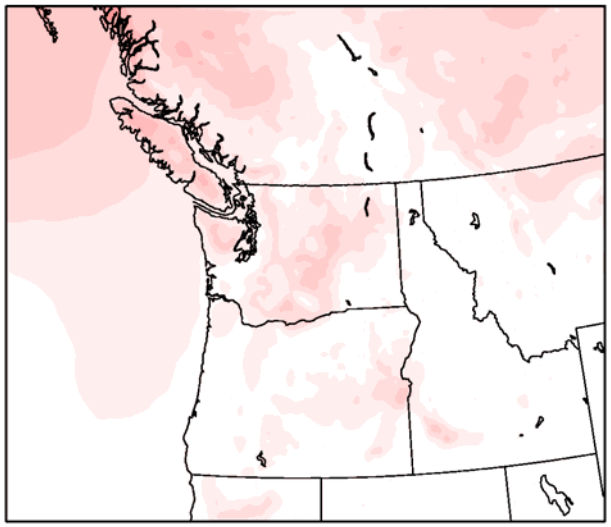
Mesoscale Climate Model

- Based on **MM5 Weather Model**
- Nested grids 135-45-**15** km
- **Nudging** on outermost grid by forcing **global model**
- Advanced land-surface model (NOAH) with interactive deep soil temperature

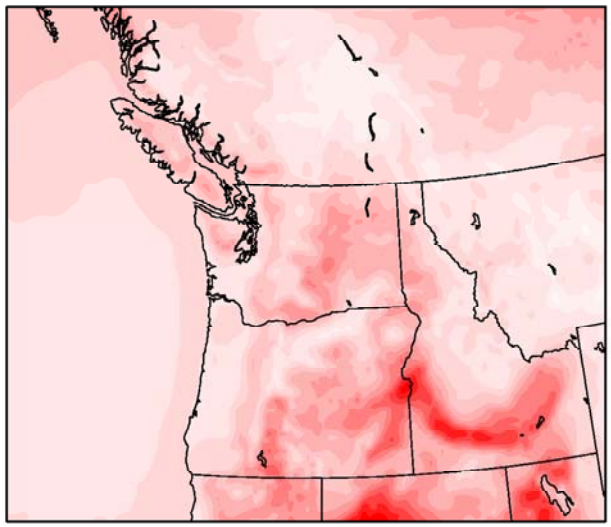


Temperature trends

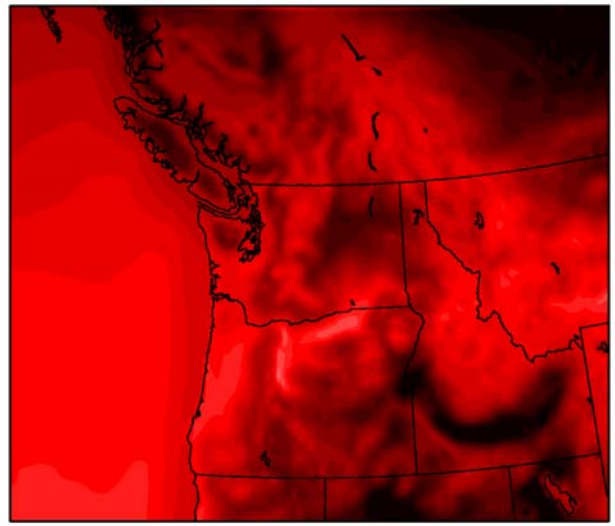
2020s



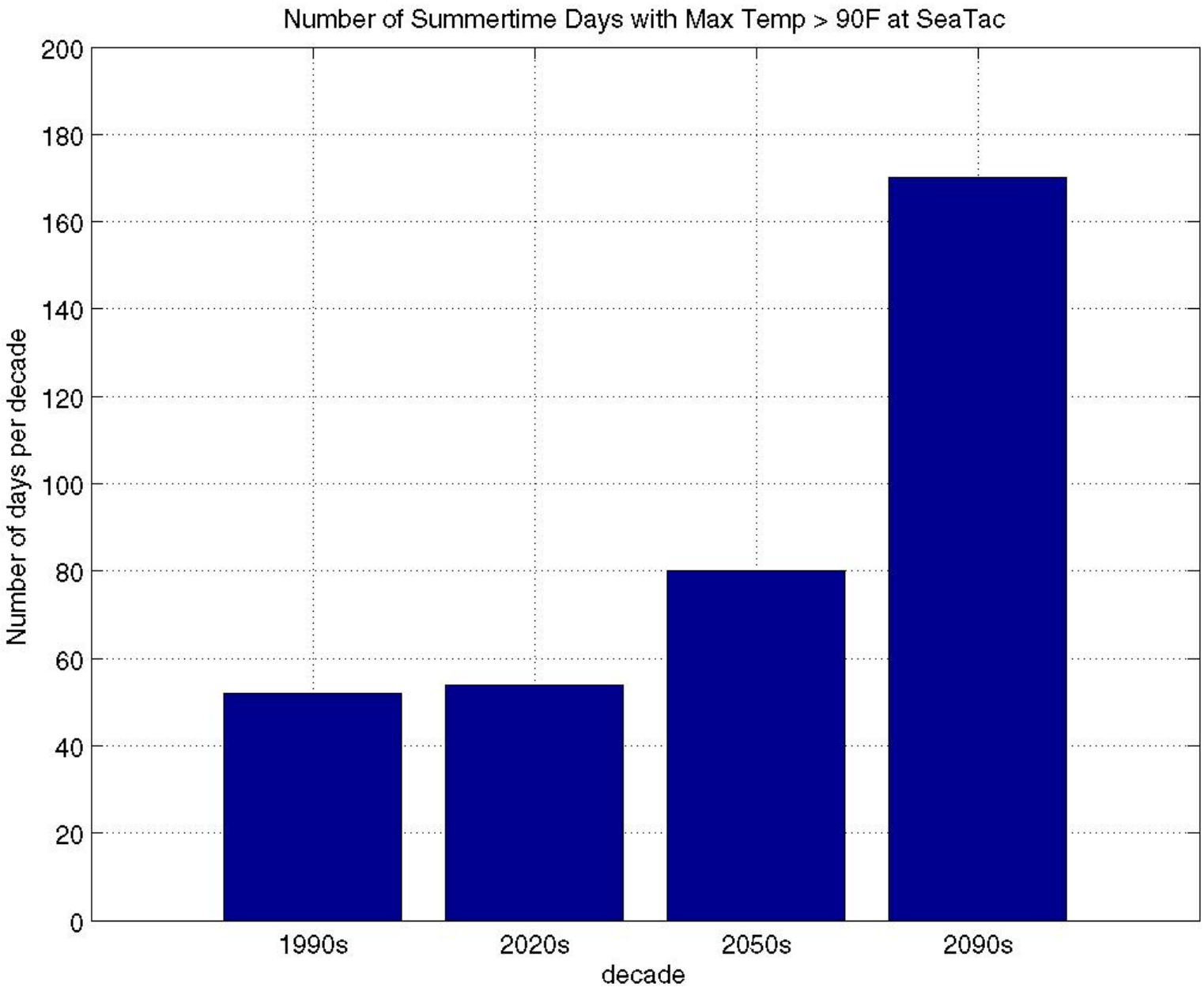
2050s



2090s

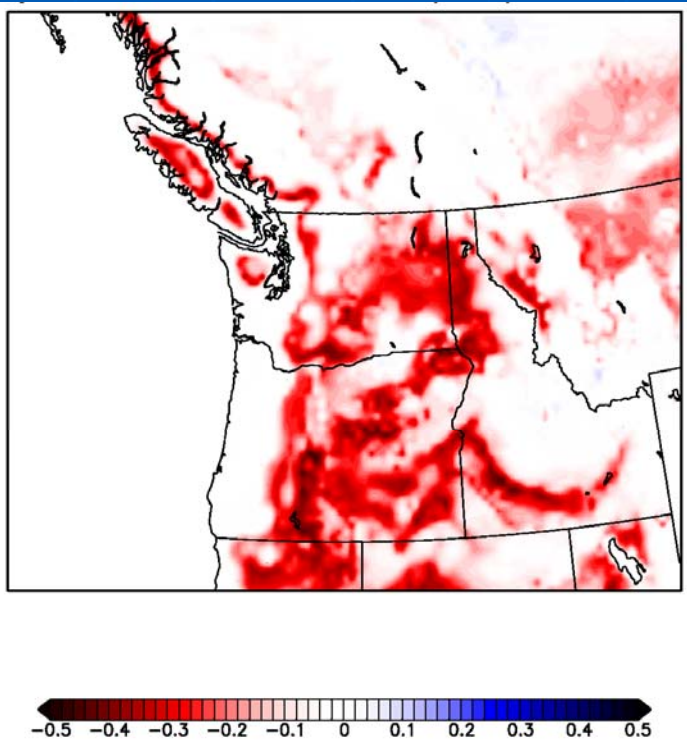


Change in Winter Temperature (degrees C)


Number of Summertime Days with Max Temp > 90F at SeaTac
Number of days per decade
200
180
160
140
120
100
80
60
40
20
0
1990s
2020s
2050s
2090s
decade

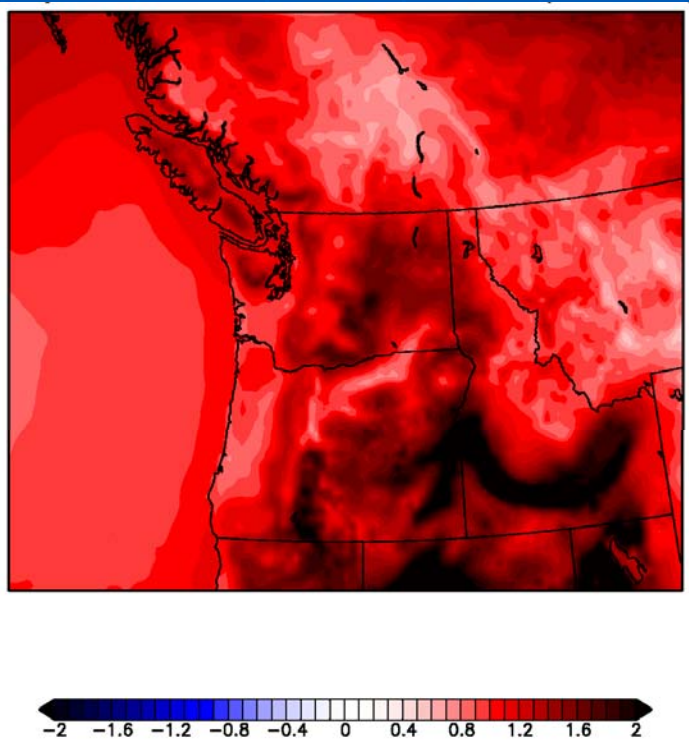
Loss of Snow cover

Snow Cover Change



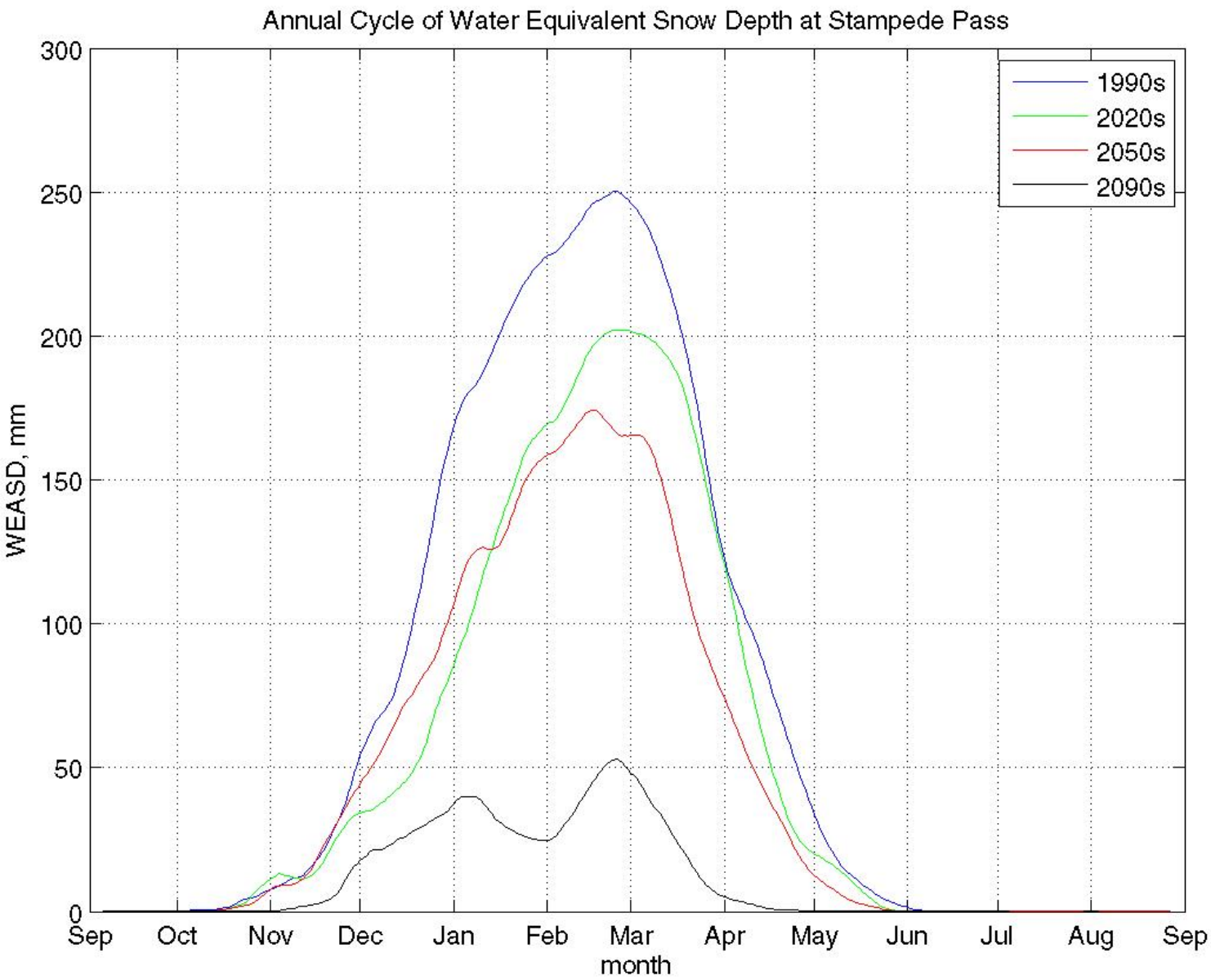
Change in fraction of days with snow cover

Temperature Change



Change in Winter Temperature (degrees C)

Snowpack Drop in the Mountains



Streamflow Impacts

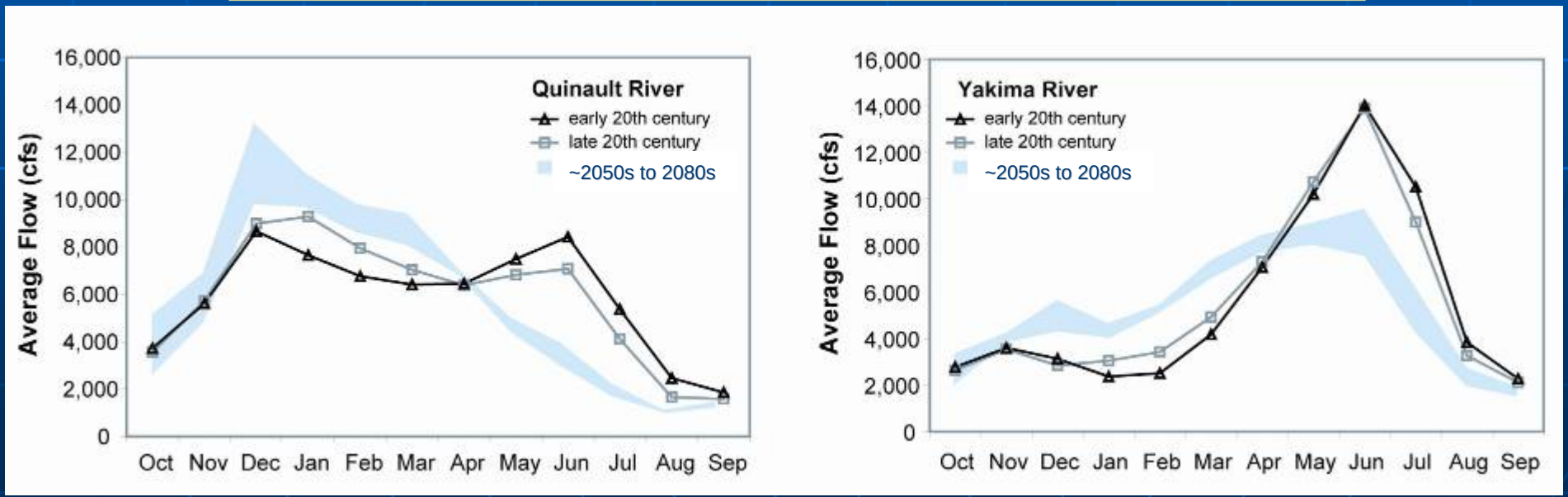
Higher winter streamflows

Earlier and lower peak runoff *(mid/high basins)*

Lower late spring streamflow

Lower, warmer summer streamflow

Projected streamflow changes in the Quinalt and Yakima Rivers



+3.6 (~2050s) to +5.4°F (~2080s)

How do we identify model improvement?

- Use of high-resolution data
  - Local surface data
    - ARM, weather radar, etc.
  - CloudSat
- Statistical comparisons
  - Joint probability distributions
  - Classification by atmospheric state

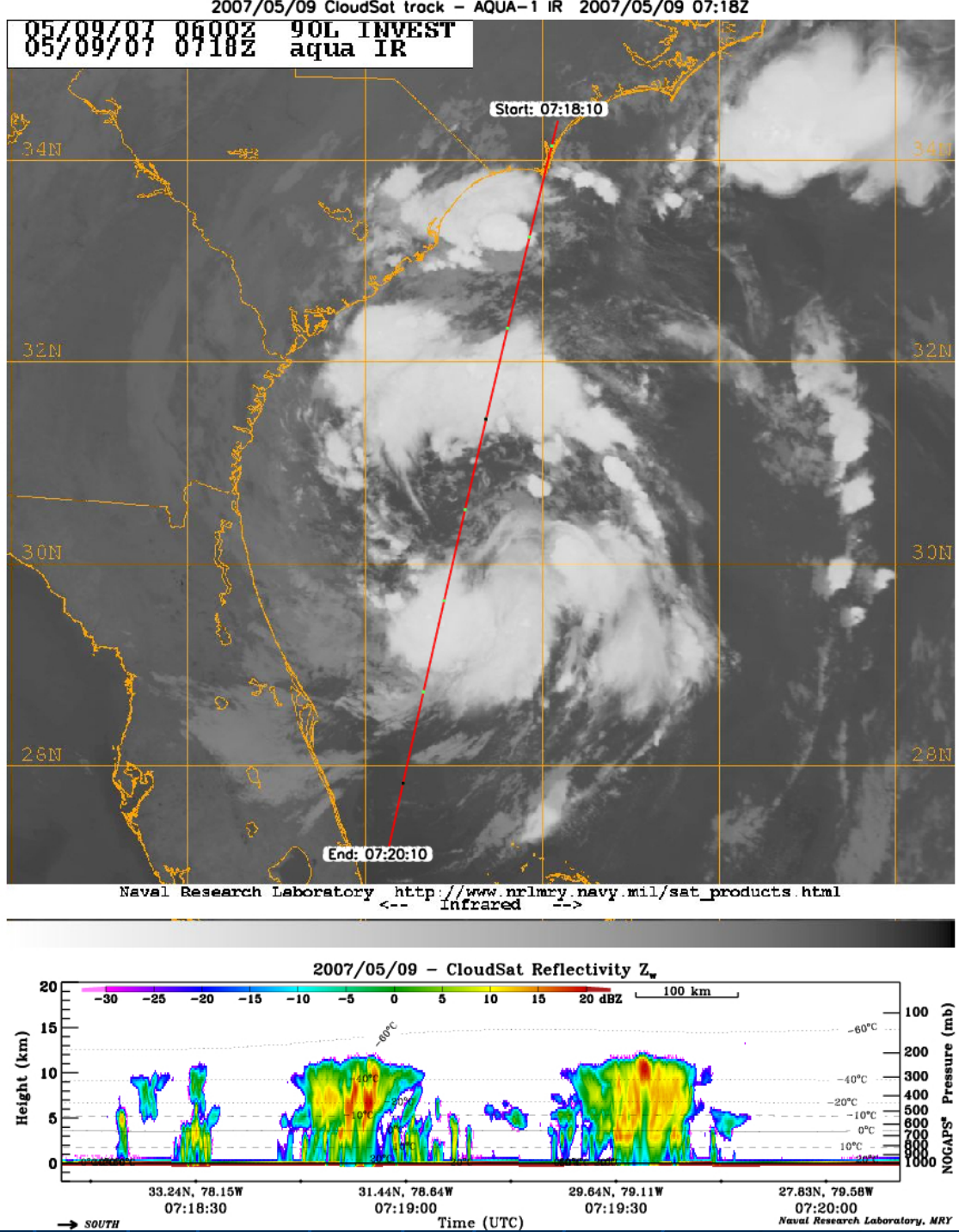
CloudSat

3 mm-wavelength radar deployed as part of the NASA A-train

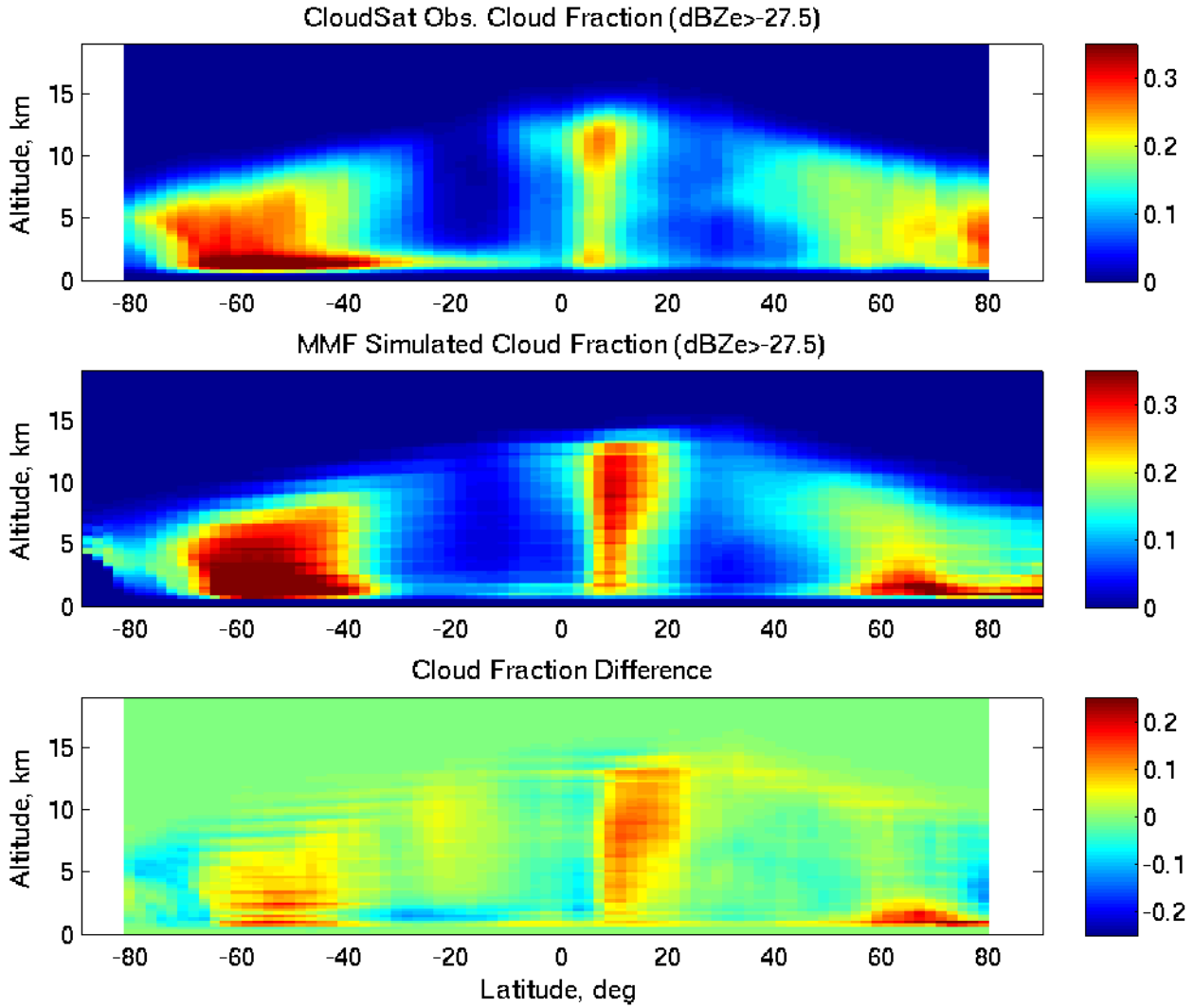
Provides a 2D “curtain” of cloud properties along the satellite path

Horizontal resolution of a few km

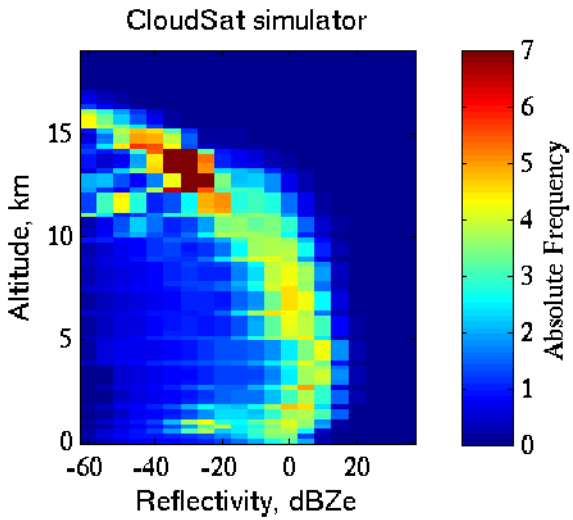
Vertical resolution of 250 m

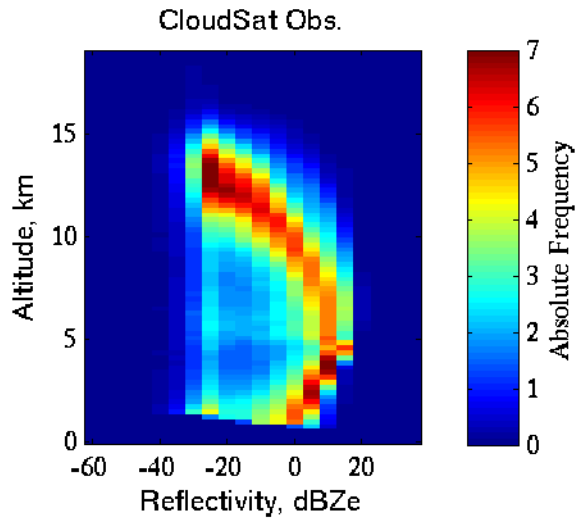


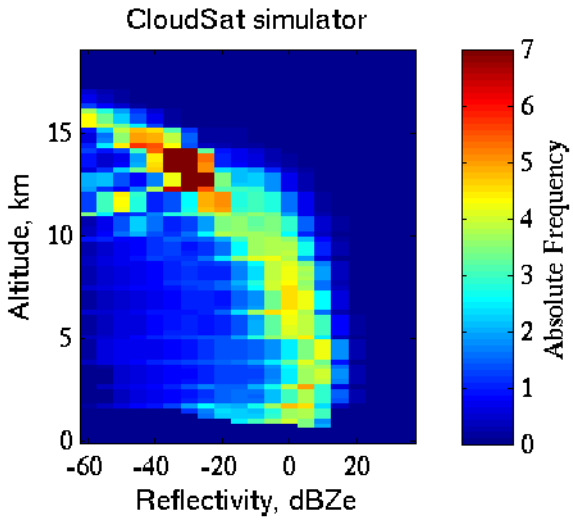
JJA (Diff = MMF – CS)

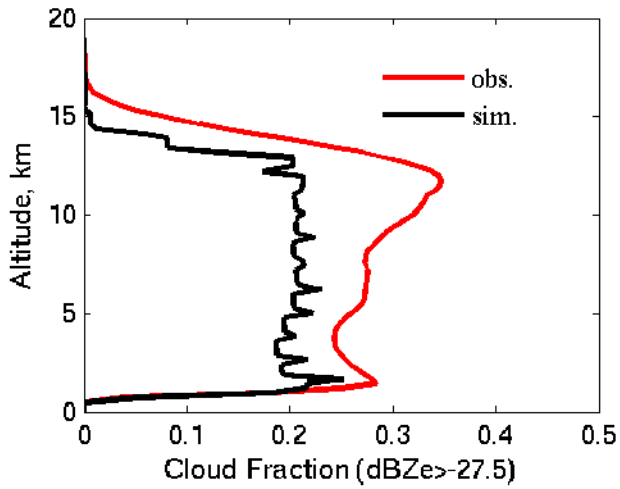


TWP - June

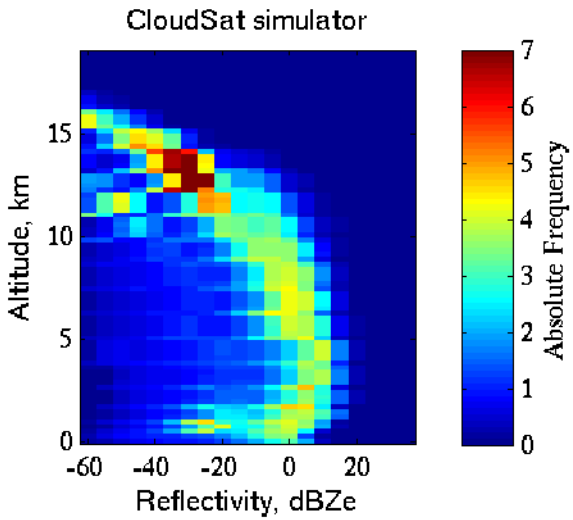

CloudSat simulator
Altitude, km
Reflectivity, dBZe
Absolute Frequency

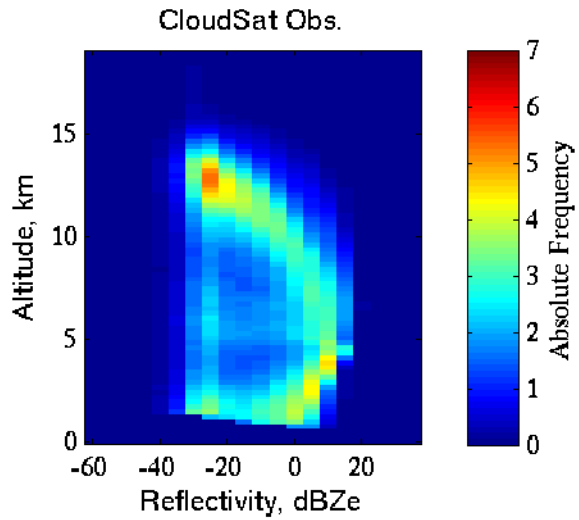

CloudSat Obs.
Altitude, km
Reflectivity, dBZe
Absolute Frequency

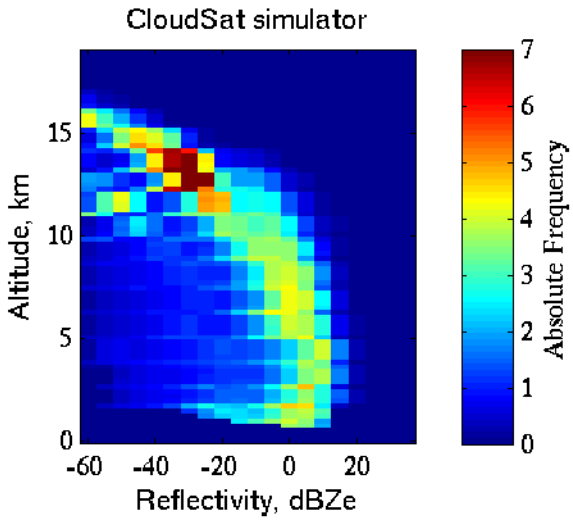

CloudSat simulator
Altitude, km
Reflectivity, dBZe
Absolute Frequency

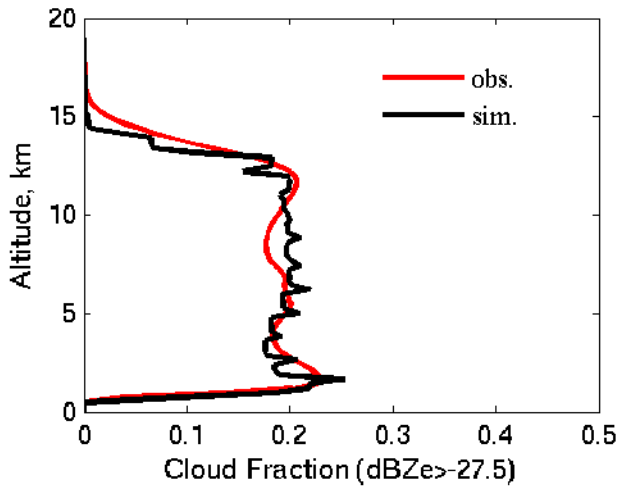

obs.
sim.
Altitude, km
Cloud Fraction (dBZe>-27.5)

TWP - July


CloudSat simulator
Altitude, km
Reflectivity, dBZe
Absolute Frequency


CloudSat Obs.
Altitude, km
Reflectivity, dBZe
Absolute Frequency


CloudSat simulator
Altitude, km
Reflectivity, dBZe
Absolute Frequency


obs.
sim.
Altitude, km
Cloud Fraction (dBZe>-27.5)

Summary

- Societal questions require better understanding of
  - Climate sensitivity => cloud feedback
  - Precipitation simulation on the regional scale
- Requires
  - Higher resolution climate models
  - Better use of high resolution data (and more data) for model evaluation and development
- We are heading down this path, but
  - No coordinated national program
  - Limited resources


Thank you for your attention!