Cloud Evaluation and Impacts in Large Scale Models

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Outline

Main Story: From identifying biases to process improvement using the ‘weather’ scale

- Motivation: the impact of clouds for weather & climate: focus mostly on climate examples
- Example of a cloud parameterization “suite”
- How we simulate and observe clouds
- Evaluation methods: some examples
  - The traditional way
  - Best practices
- Summary of Best Practices for Evaluation
- Challenges

Warning: Focus is on climate.

Motivation: Weather

Hypothesis: “most impacts of extreme weather occur through cloud processes.” Exceptions: windstorms, heat and cold.

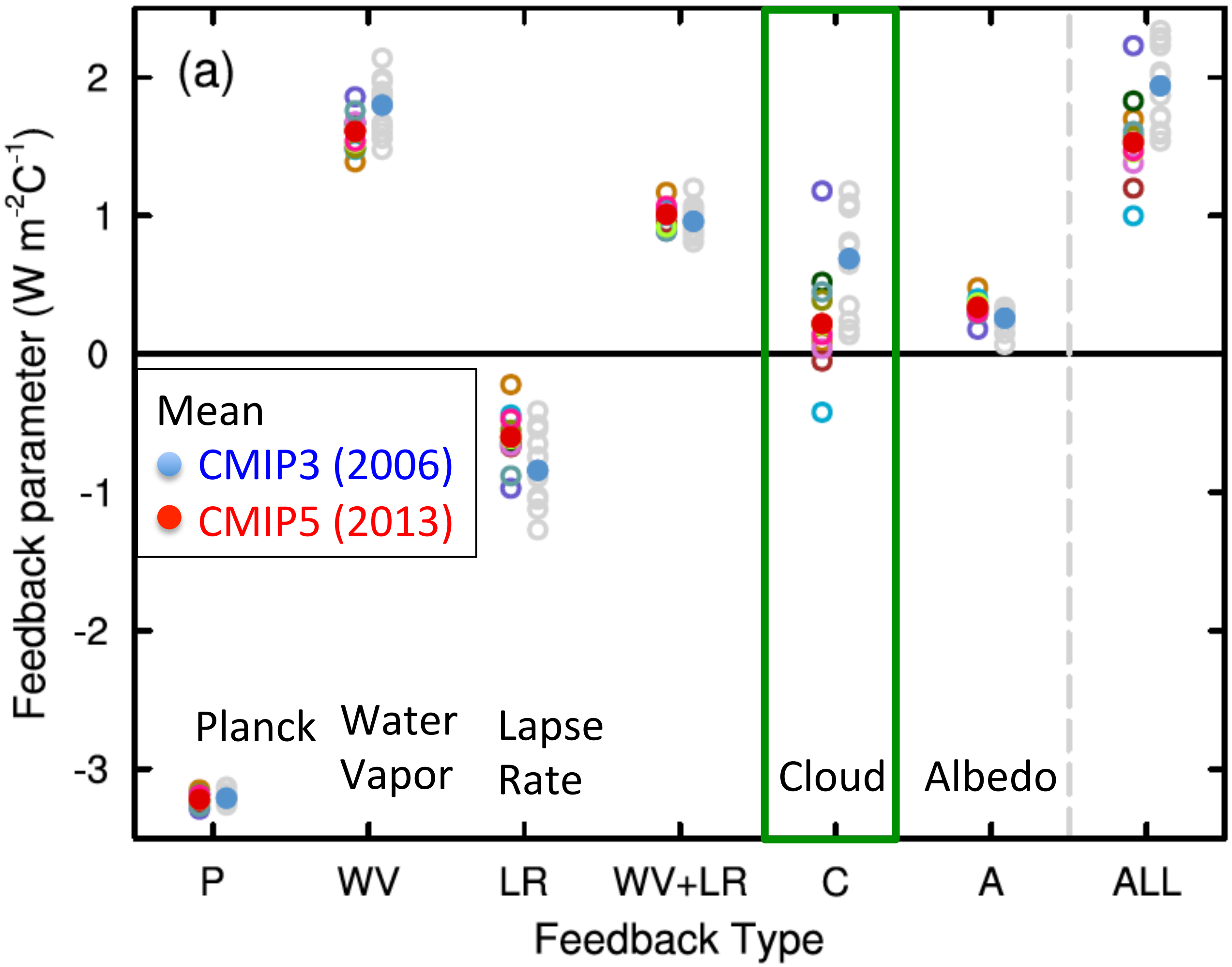
- Precipitation (or lack thereof)= flooding, drought
- Severe Thunderstorms, Hail, Tornadoes
- Tropical Cyclones
- Ice storms

Motivation: Climate

Hypothesis: "clouds are the largest uncertainty in our ability to predict future climate change."

- Cloud Radiative Effects
- Cloud Feedbacks
- In addition to understanding the frequency of extreme weather

Climate Feedbacks: Cannot be Directly Observed



Planck $\varepsilon = \sigma T^4$ (-)

Water Vapor
+T & RH=C → +H2O (+)

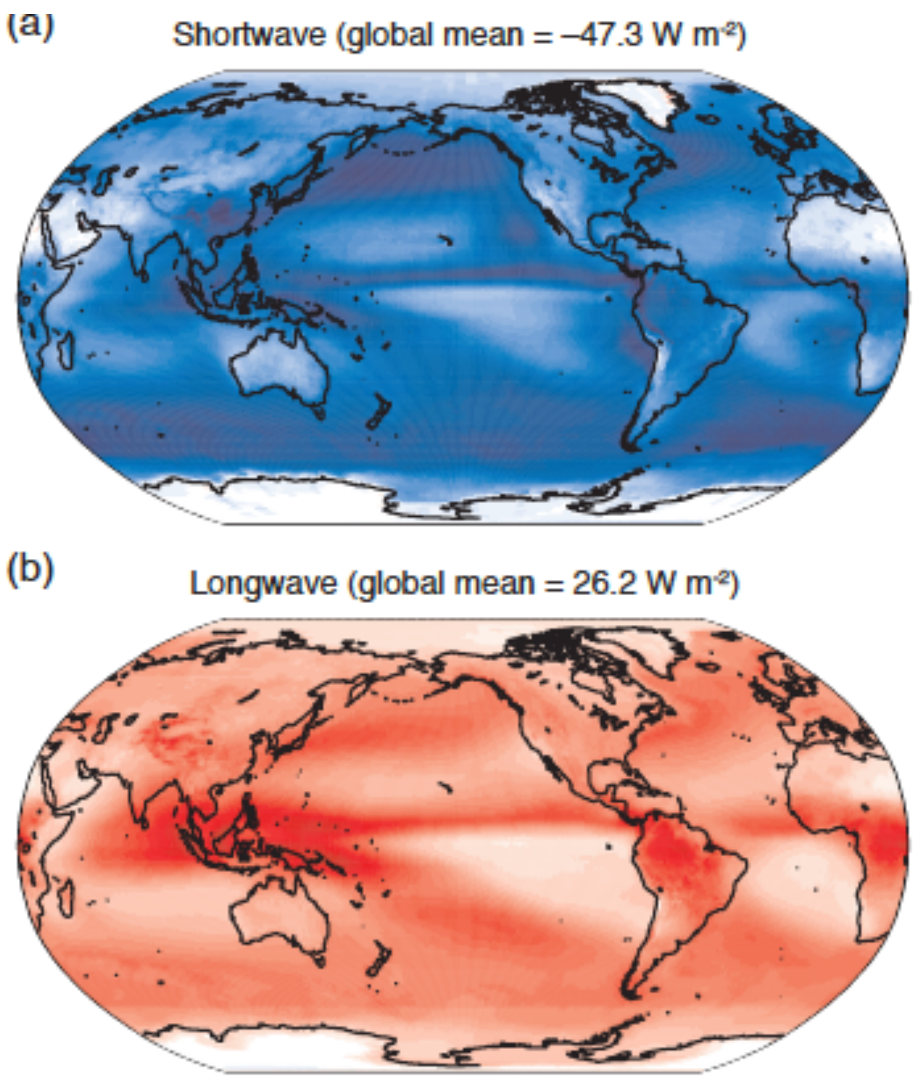
Lapse Rate (-)

Albedo (snow, ice)
+T → less snow, ice
-T → more snow, ice (+)

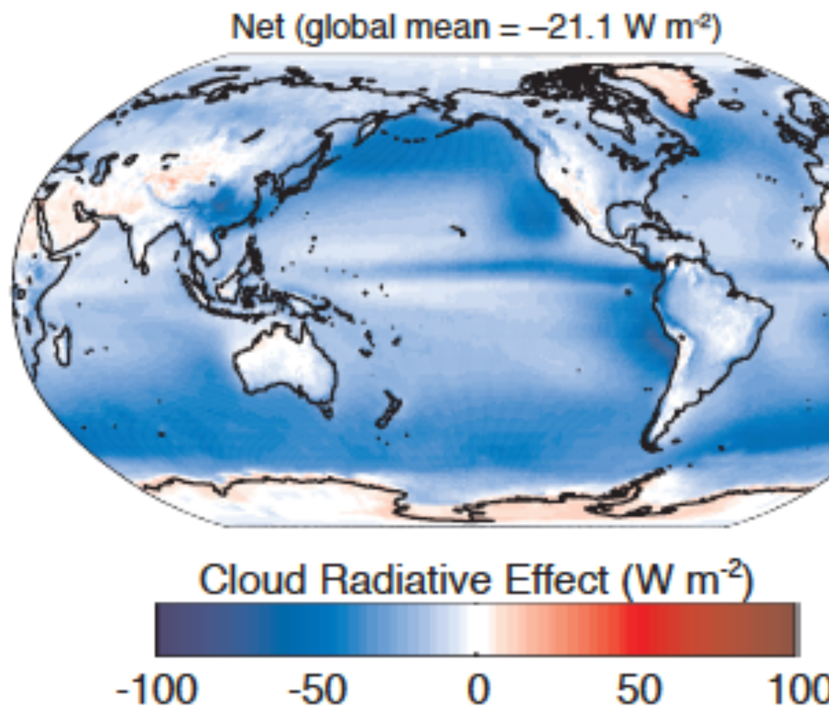
Clouds: Complicated (+)

IPCC, 2013 (Ch 9, Hartmann et al 2013) Fig 9.43

Cloud Radiative Effects



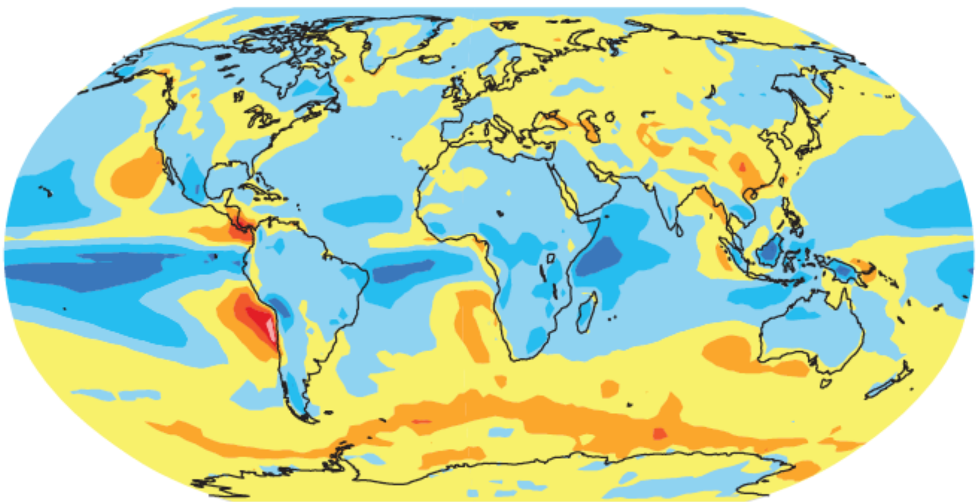
$R_{cloudy} - R_{clear}$



IPCC 2013 (Boucher et al 2013) Fig 7.7

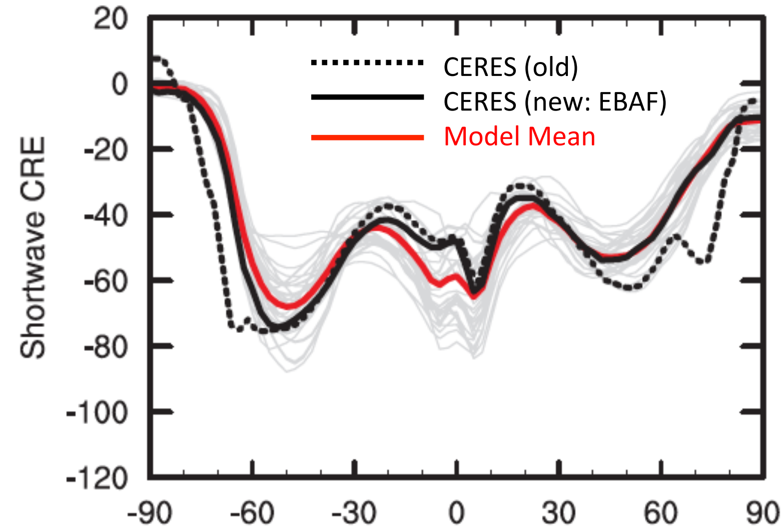
S. Ocean Cloud Biases: CMIP5

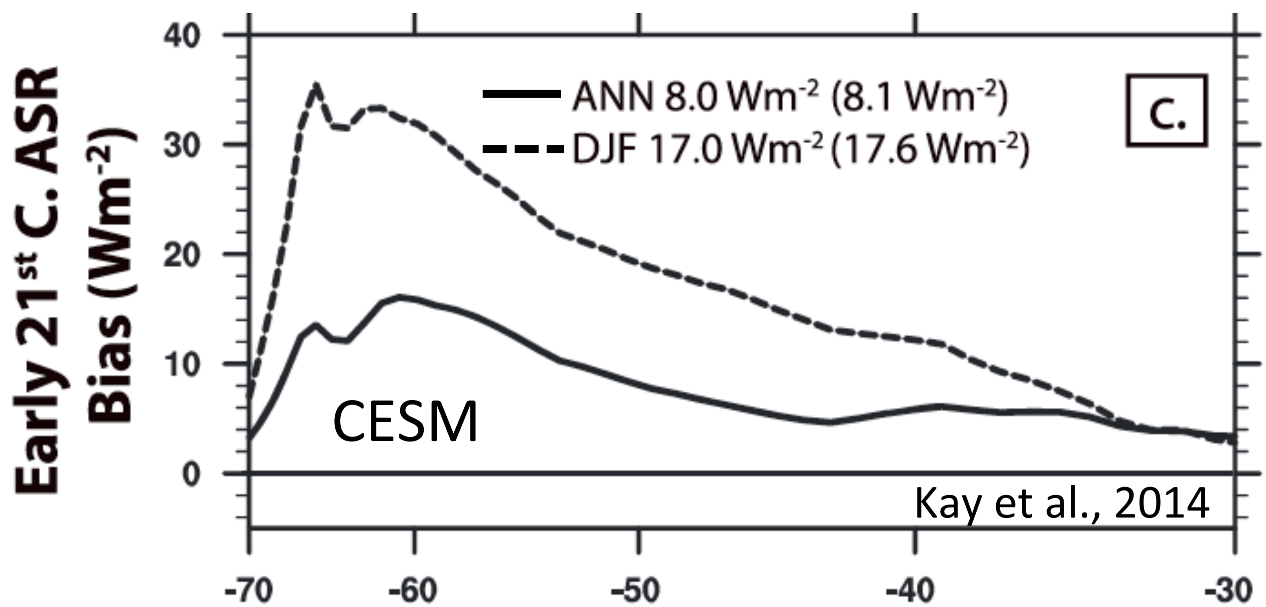
(a) Shortwave cloud radiative effect - MOD-OBS



IPCC AR5, 2013: Fig 9.5

(d) zonal average of shortwave CRE





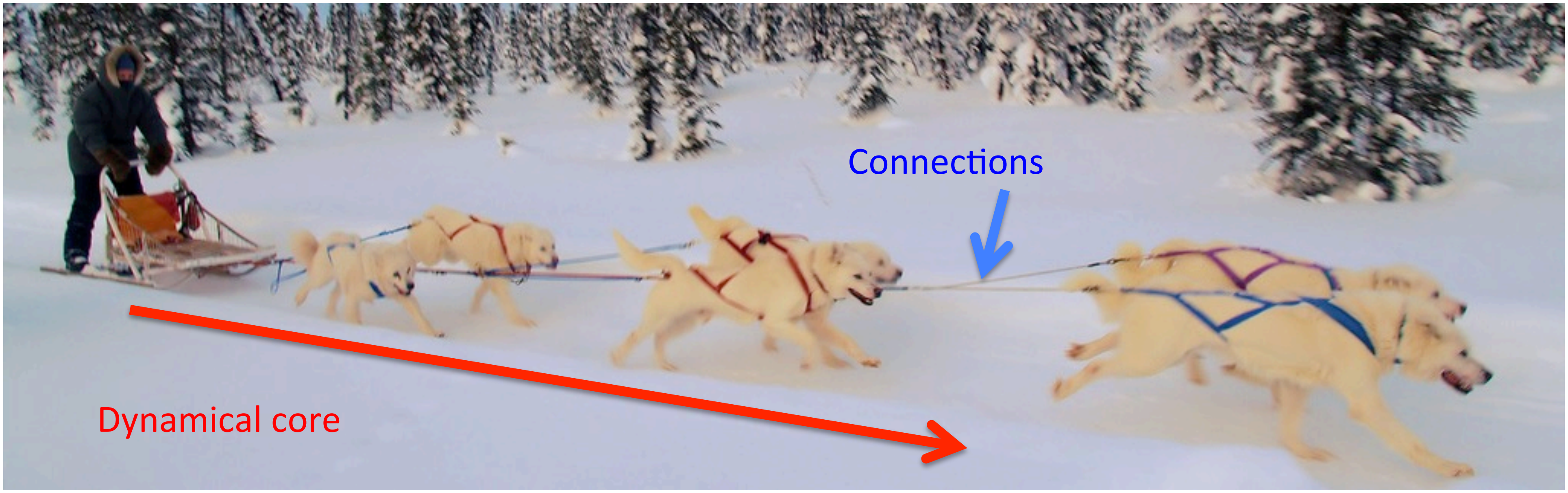
How do we represent clouds in models?

- Turbulence parameterizations [Yesterday]
  - Deep, Shallow convection
  - Boundary layer turbulence (moist)
- Condensation, Large scale closure [Richard]
- Microphysics (precipitation) [Jason]

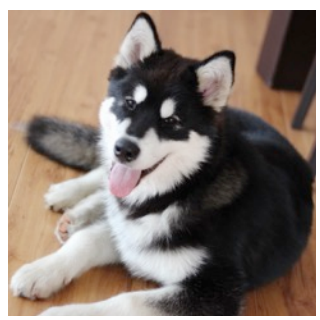
+ Lots of Plumbing

Current state of cloud Schemes

Model developer just hanging on!



Parameterizations
(Tendency Generators)



Deep Convection

Microphysics

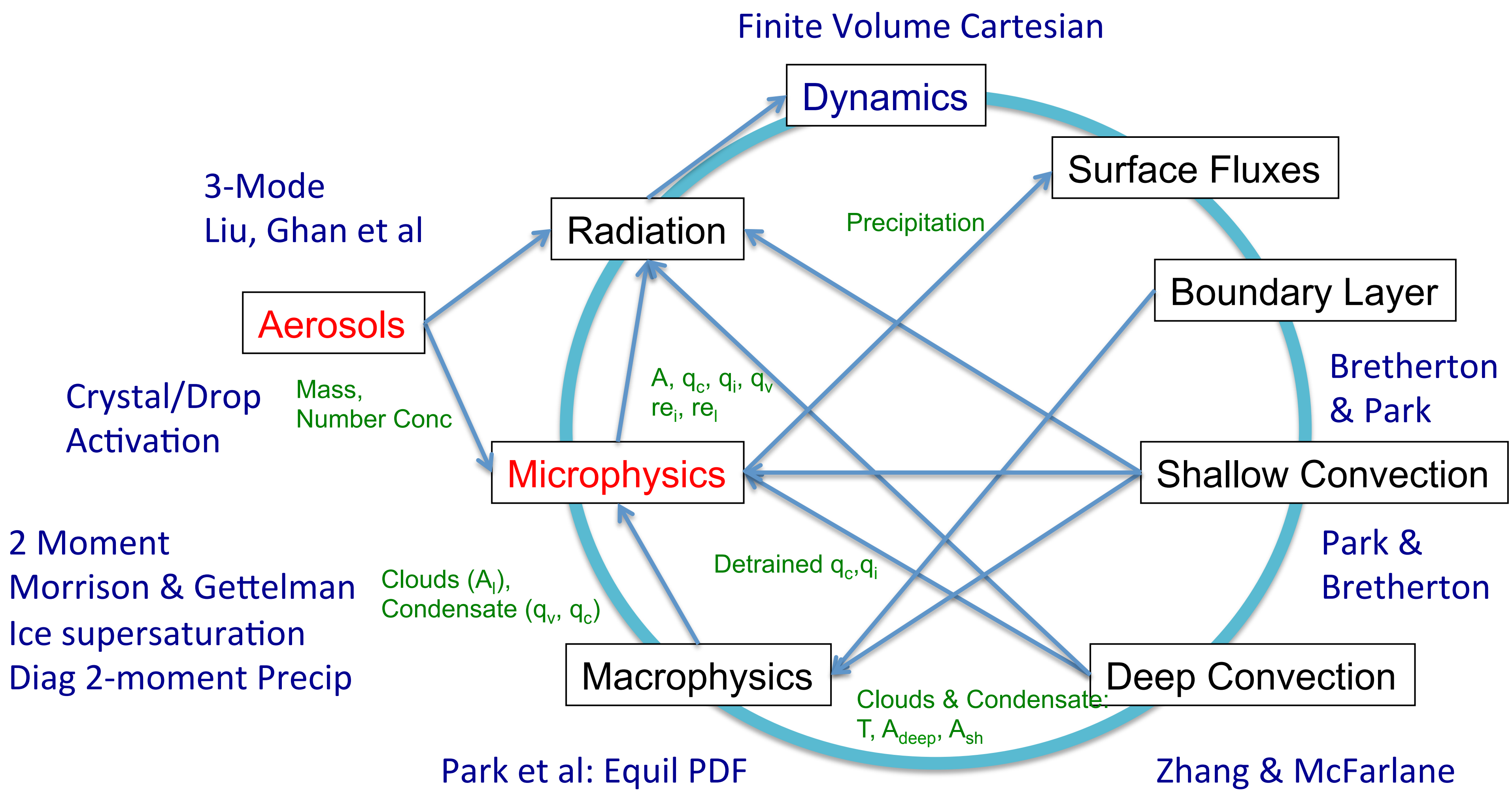
Condensation
/Fraction

Building a unified cloud scheme

- Can we do better with clouds?
- Connections (plumbing) are often a problem
- Goal: more unified and scale-insensitive codes
  - Not “scale aware”: want to do the same thing at all scales
- How? Unified Schemes.

Community Atmosphere Model (CAM5)

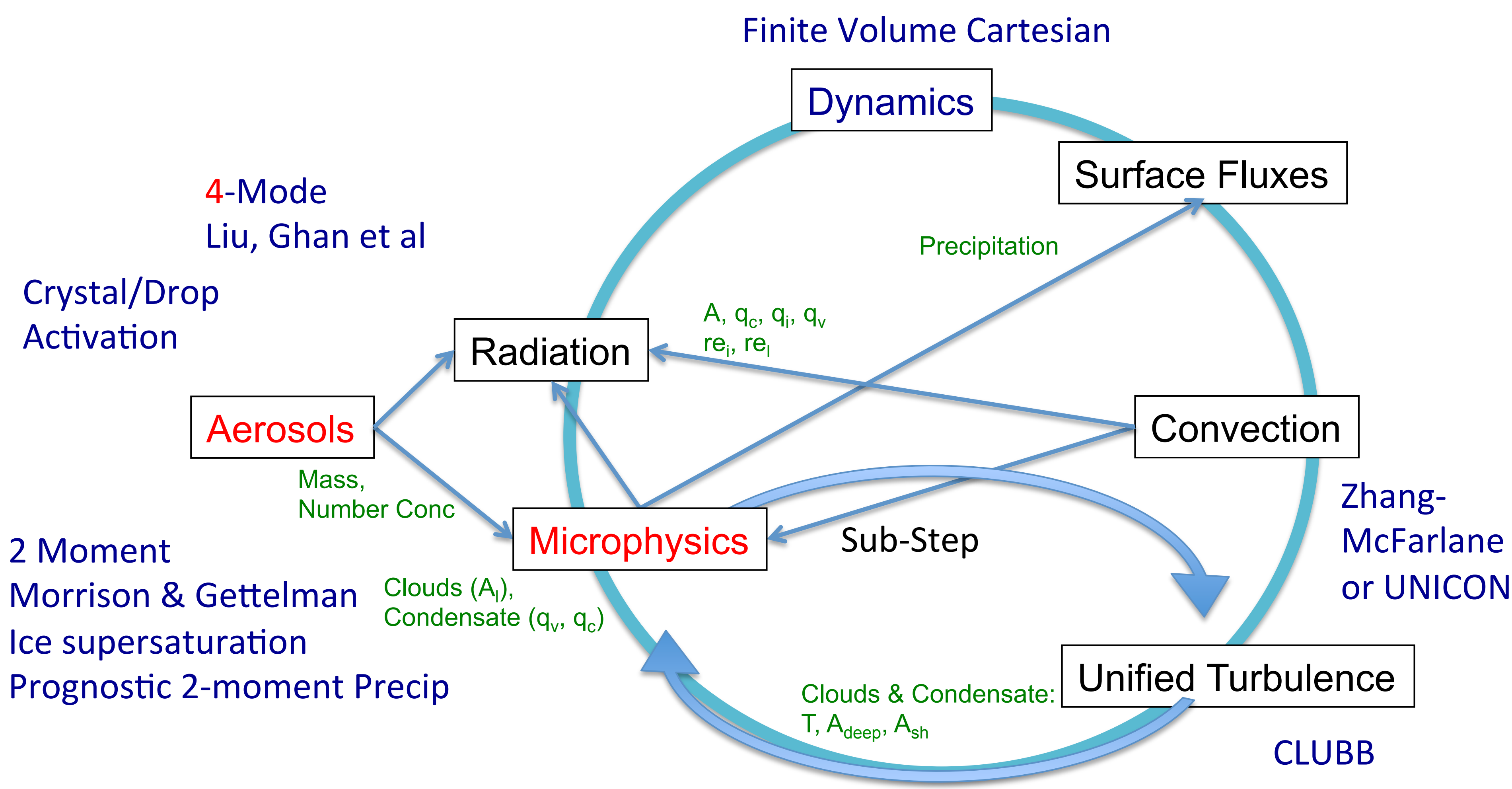
CAM5.1-5.3: IPCC AR5 version (Neale et al 2010)



A = cloud fraction, q=H_2O, re=effective radius (size), T=temperature
(i)ce, (l)iquid, (v)apor

Community Atmosphere Model (CAM5.5)

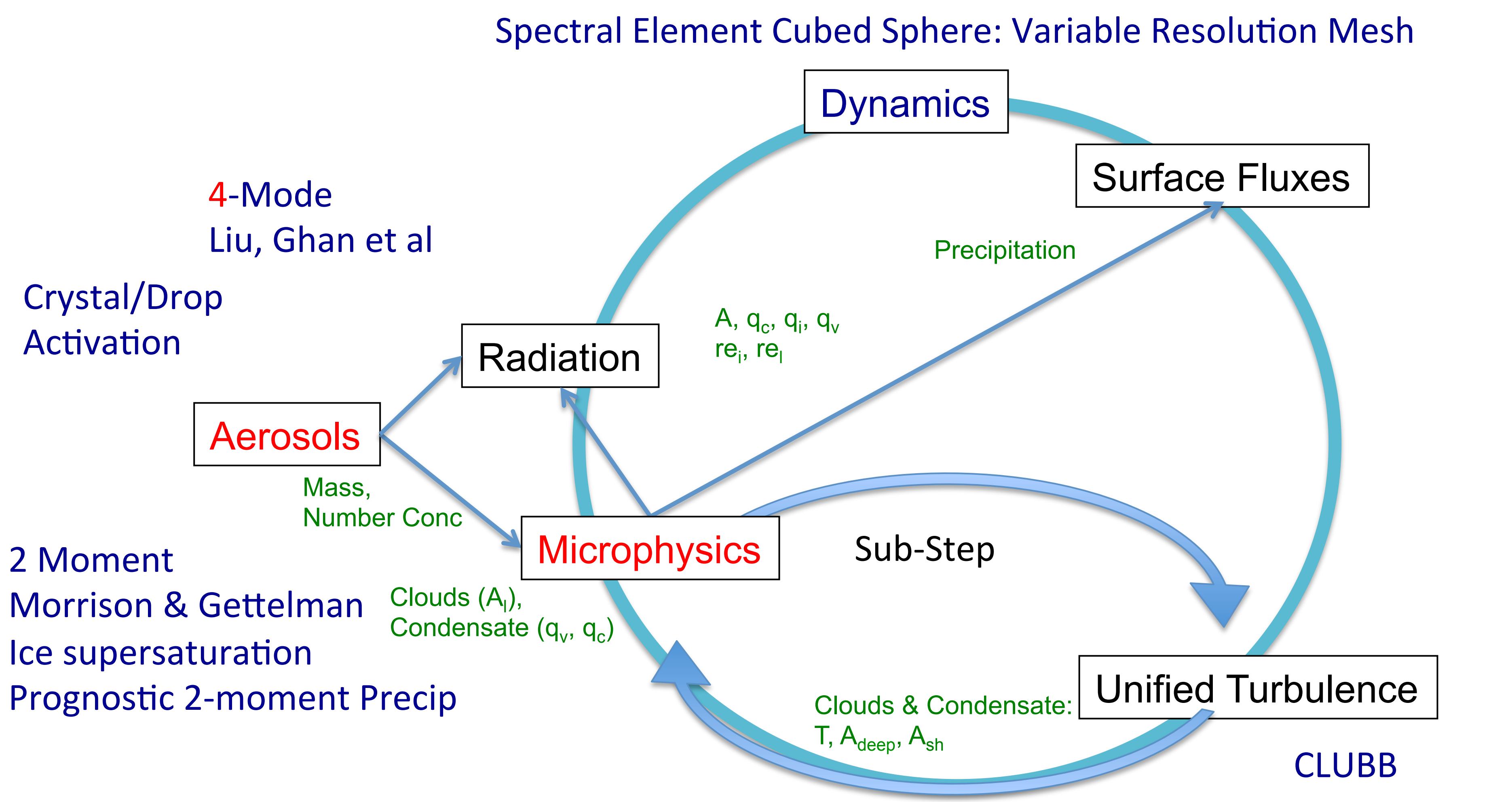
Baseline for CMIP6 model (CAM6)



A = cloud fraction, q=H_2O, re=effective radius (size), T=temperature
(i)ce, (l)iquid, (v)apor

Community Atmosphere Model (0.25°)

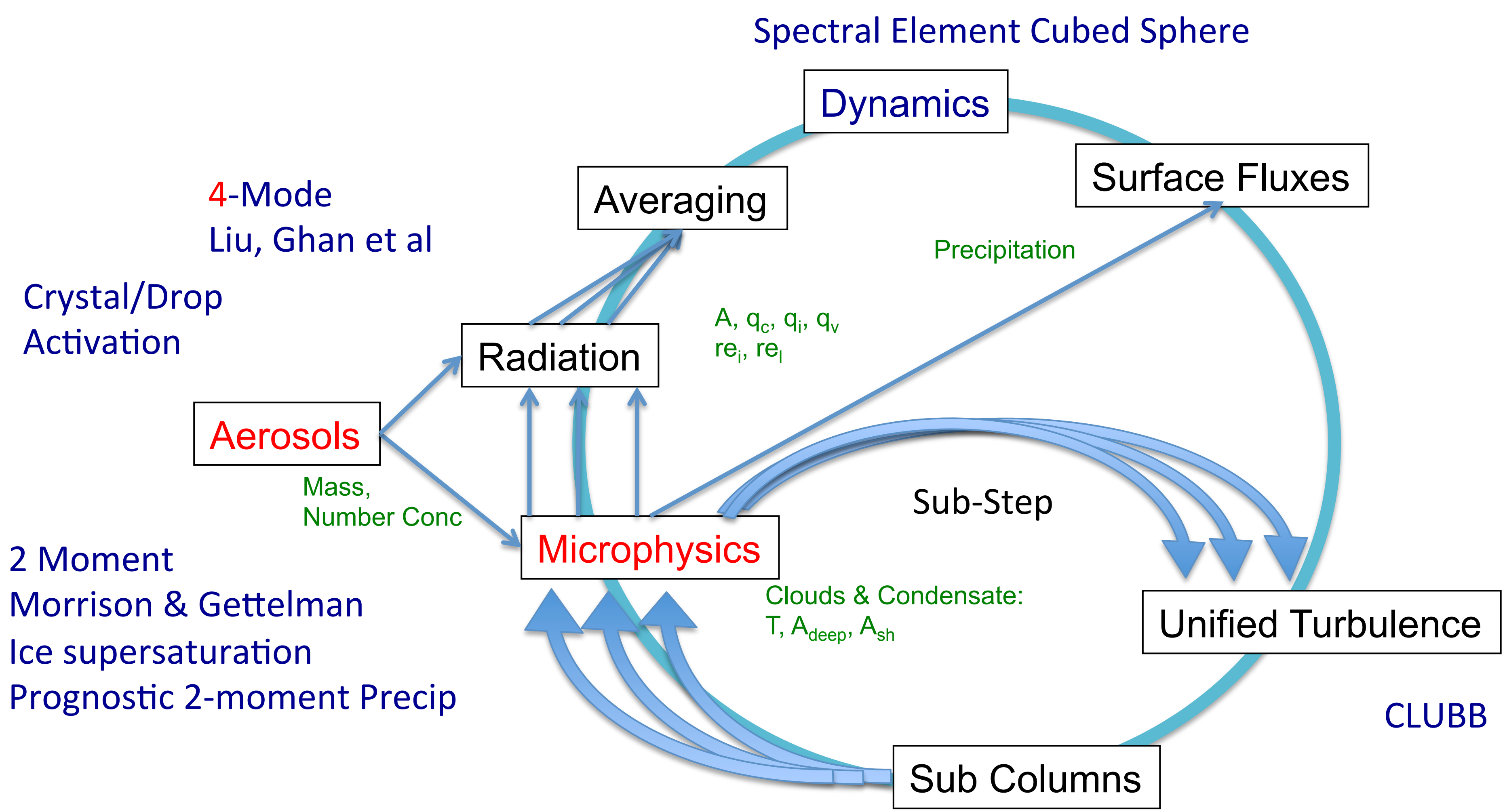
Working on this as an option



A = cloud fraction, q=H_2O, re=effective radius (size), T=temperature
(i)ce, (l)iquid, (v)apor

Community Atmosphere Model (CAM5.X++)

Now in development: Sub-columns



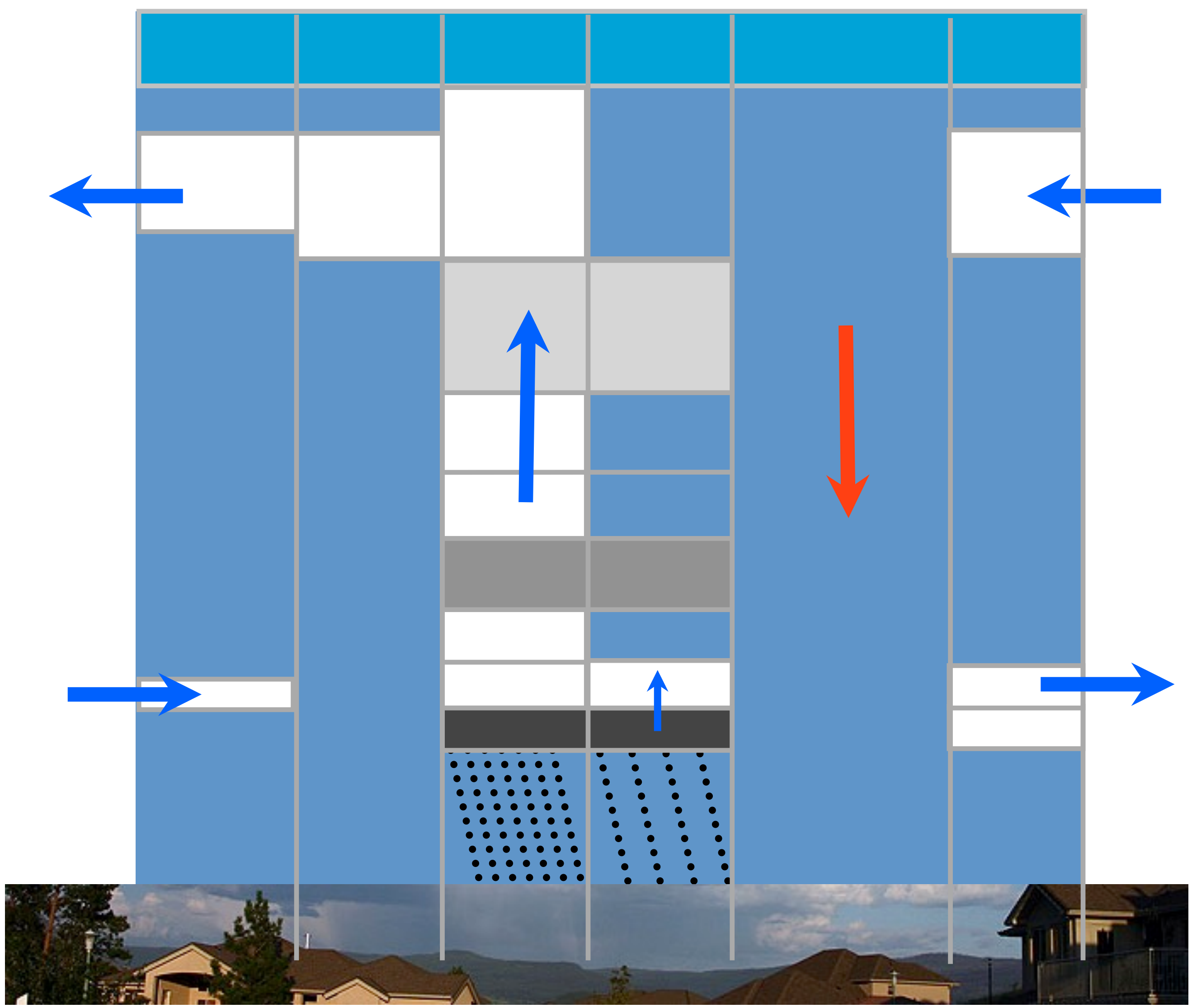
A = cloud fraction, q=H_2O, re=effective radius (size), T=temperature
(i)ce, (l)iquid, (v)apor

Simulating and Observing Clouds

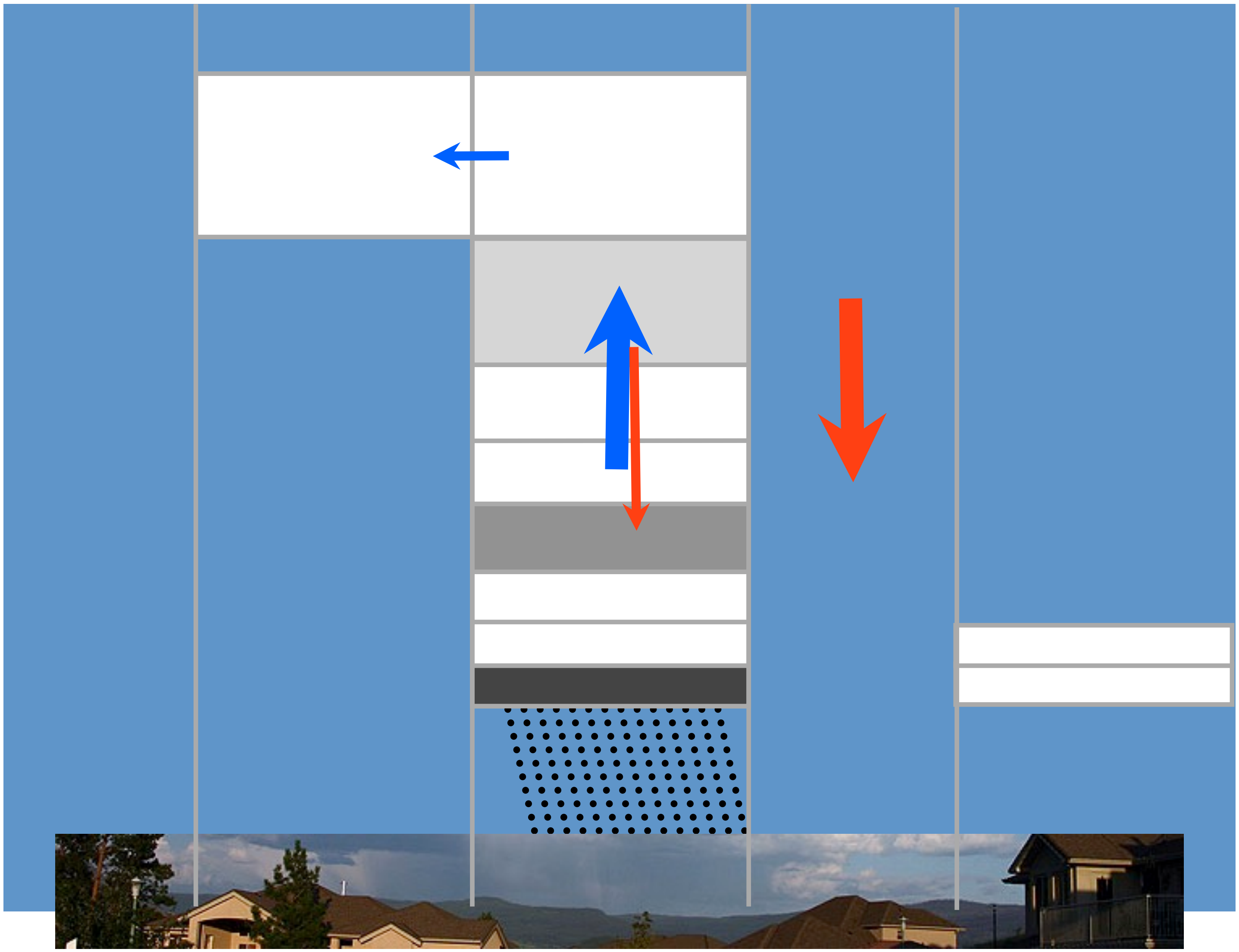

Ceci n'est pas un nuage

How does a model see clouds?

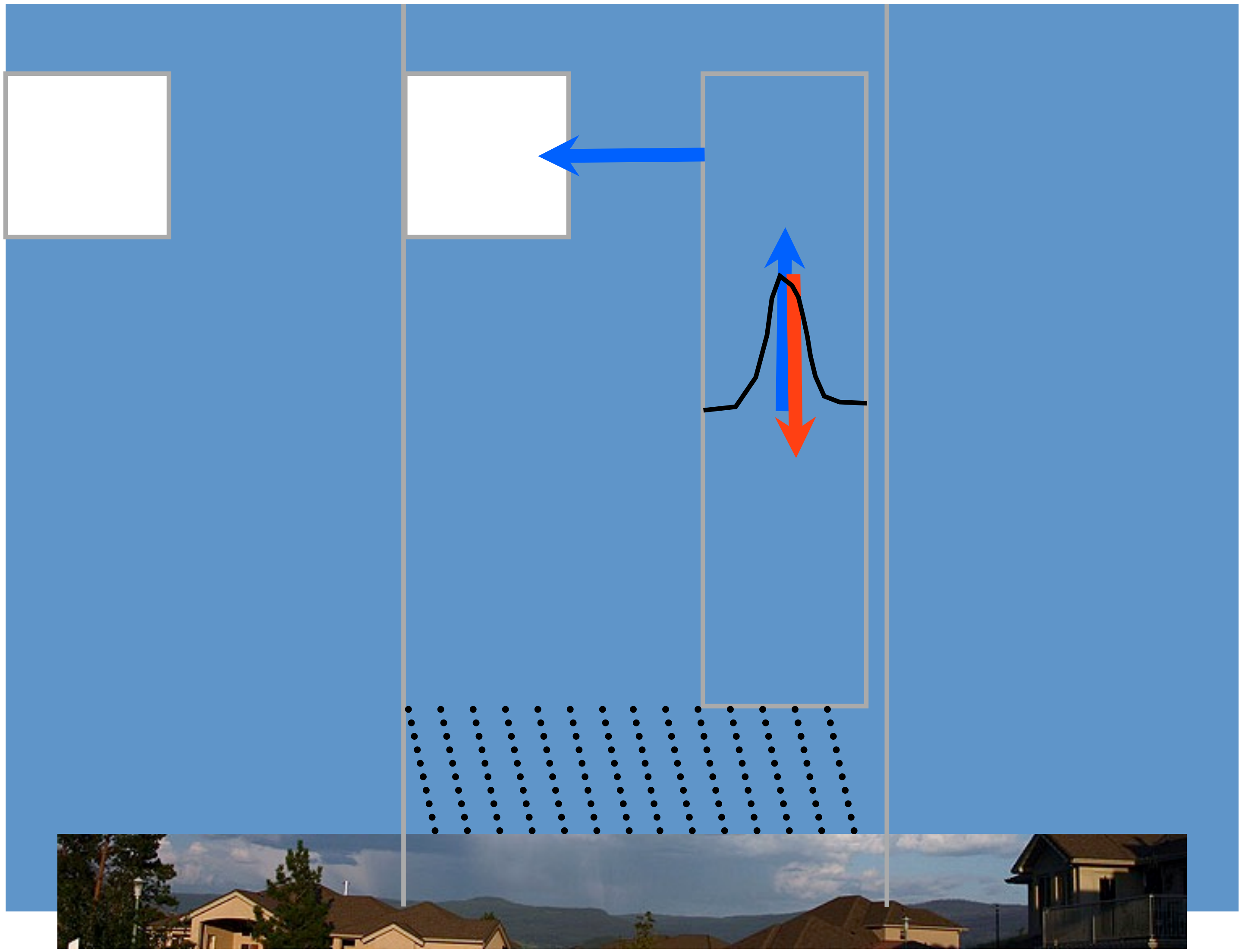
CRM/LES Convective Cloud



Mesoscale Convective Cloud



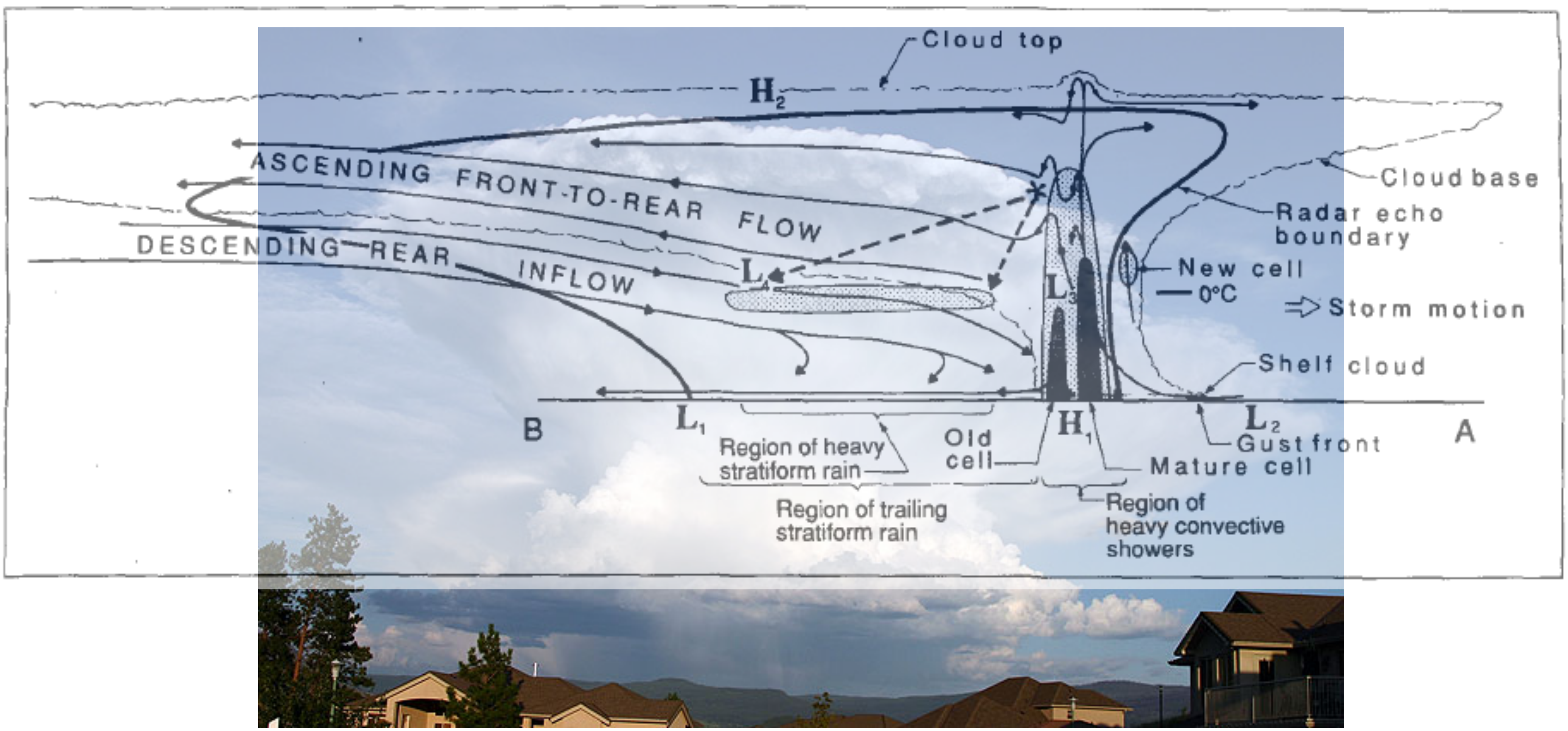
GCM Convective Cloud



This is a (picture of a) Cloud

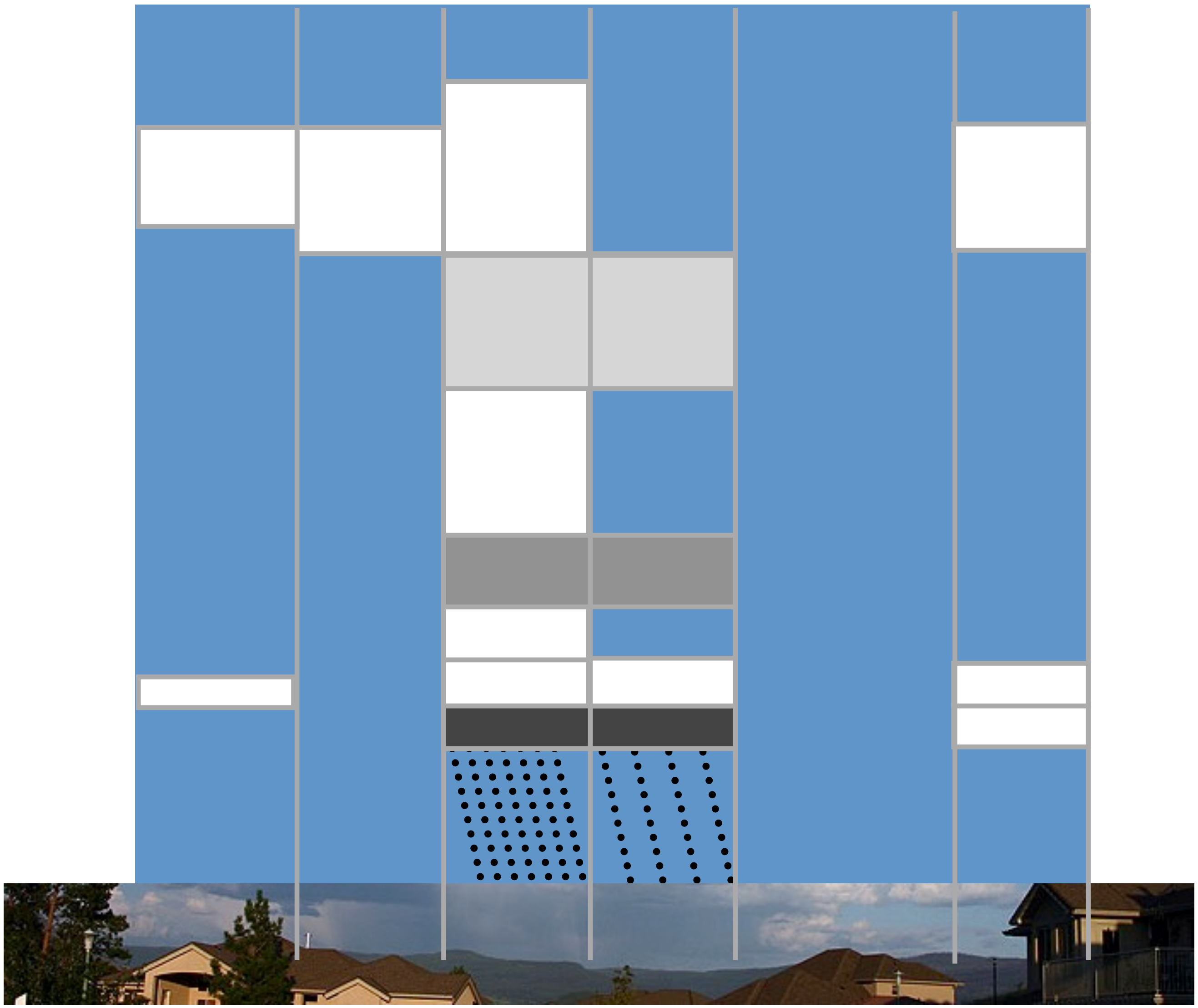
How do we observe it?

Conceptual Picture

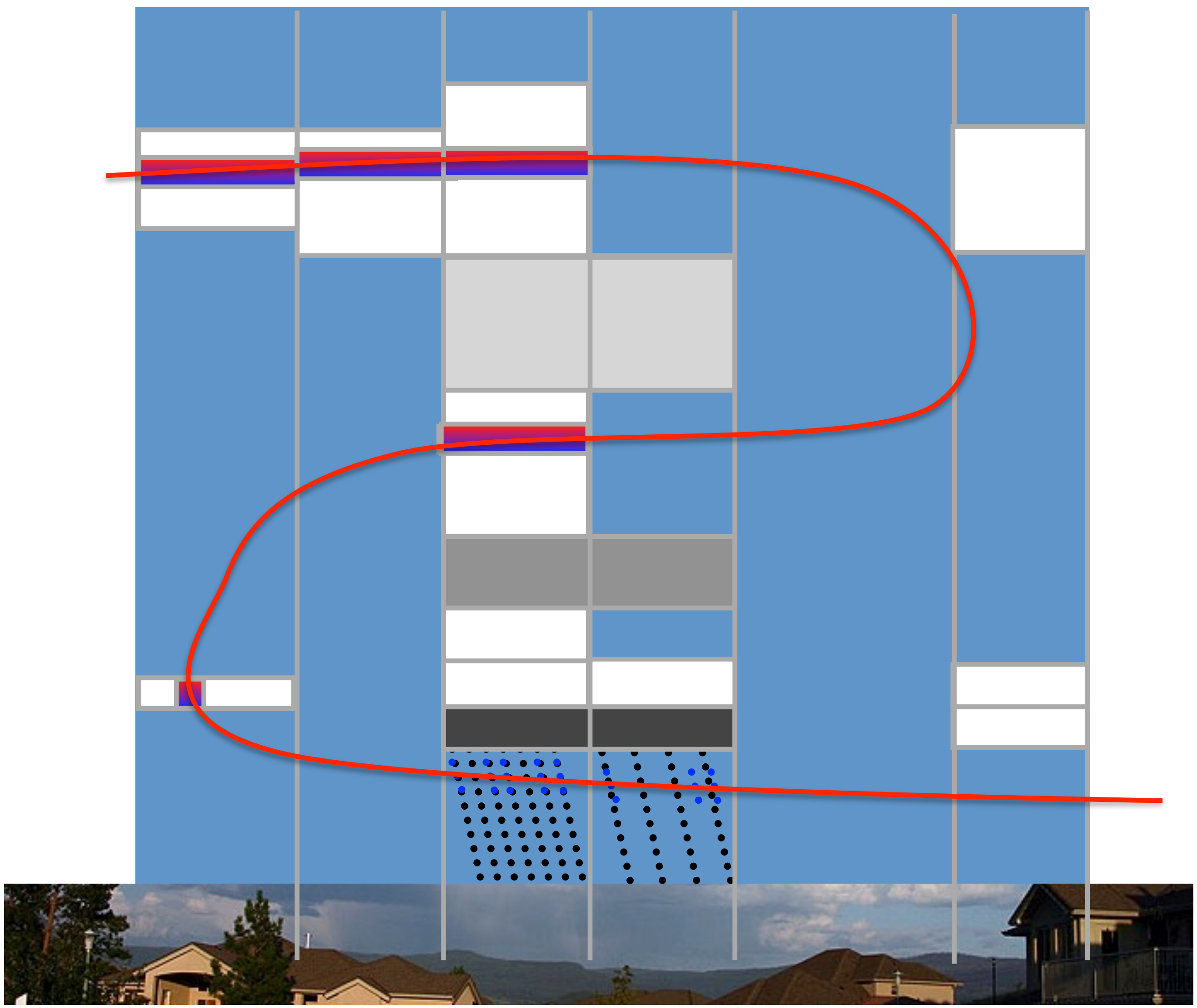


Houze et al., BAMS, 1989

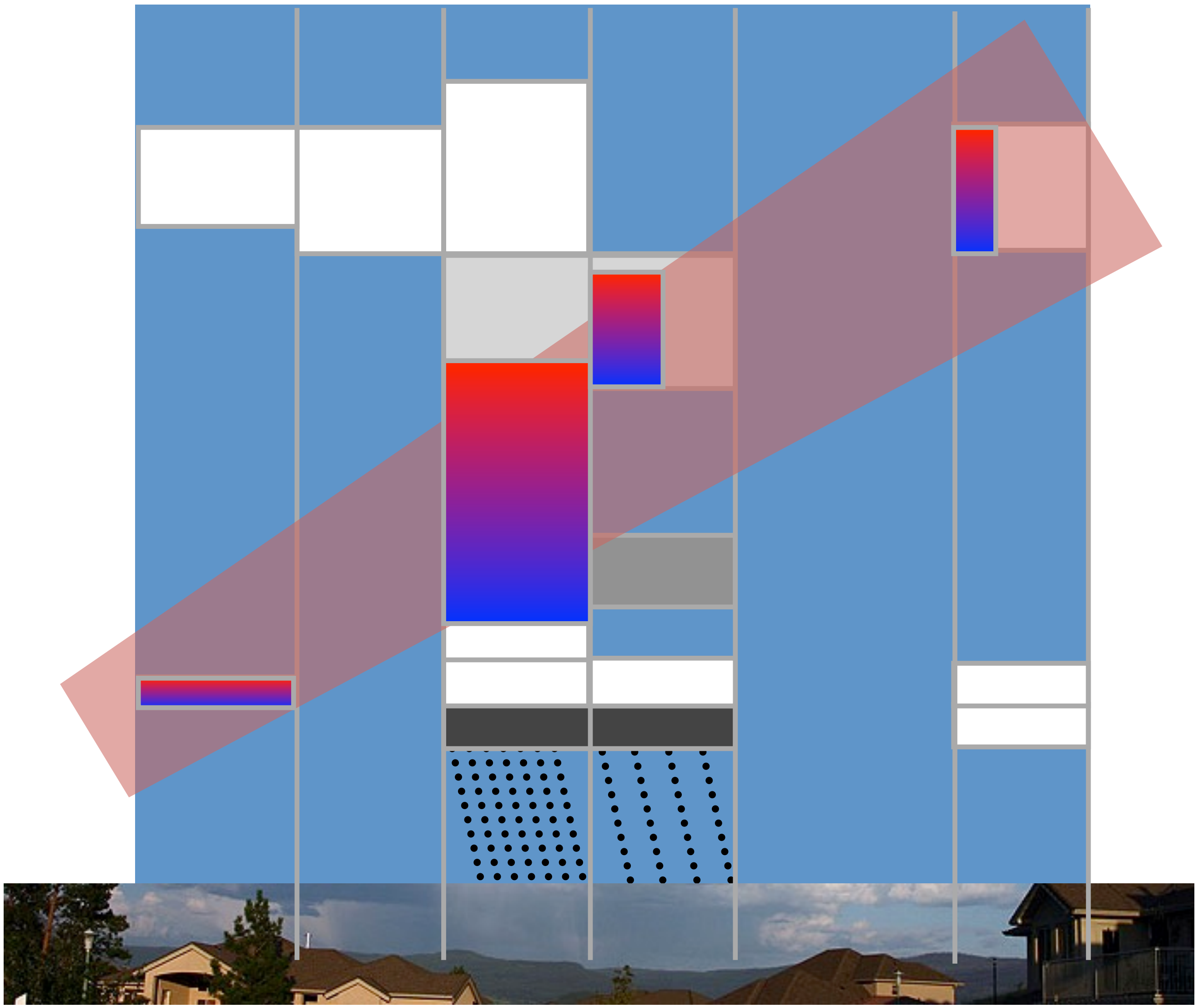
Convective Cloud



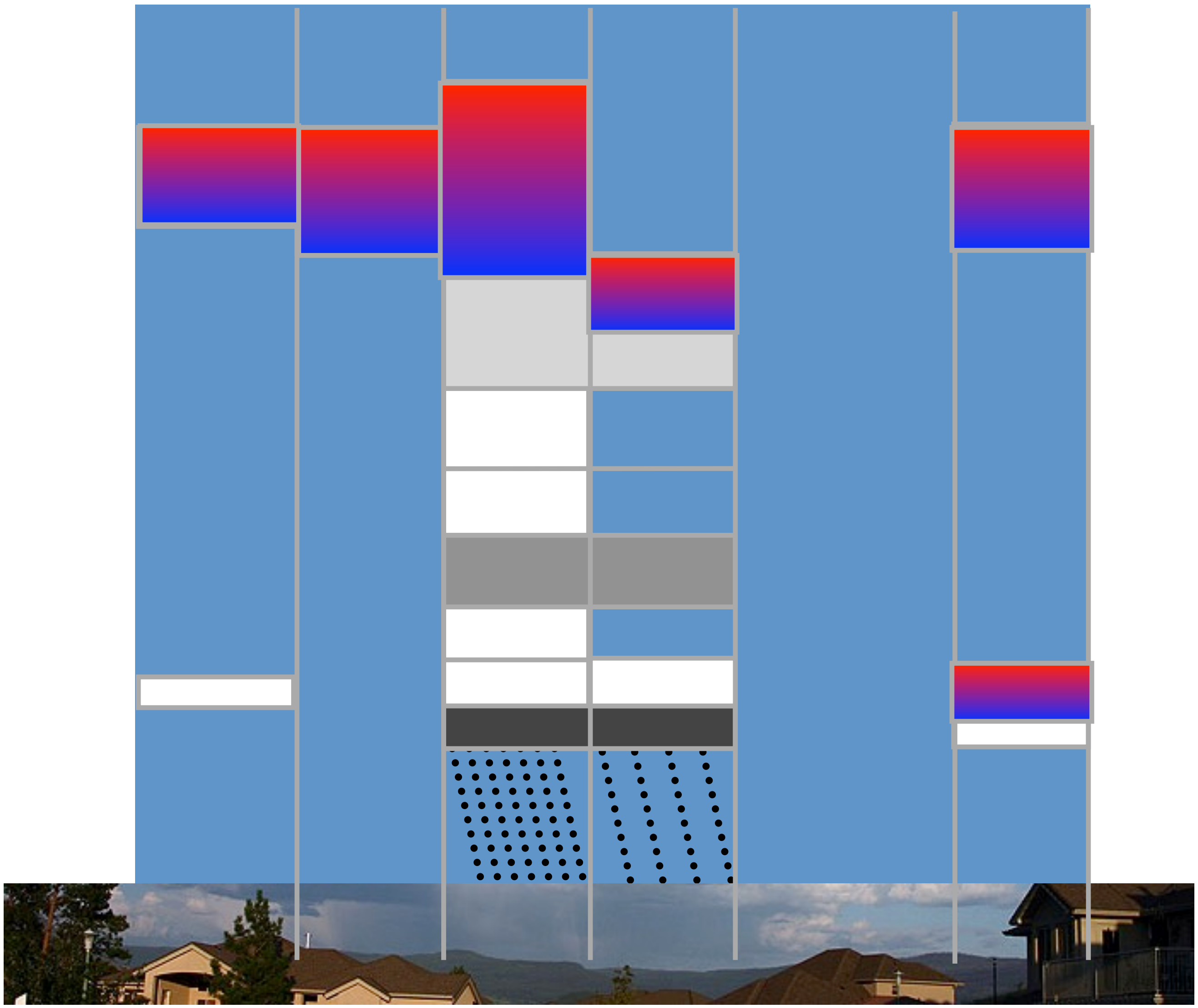
Aircraft Convective Cloud



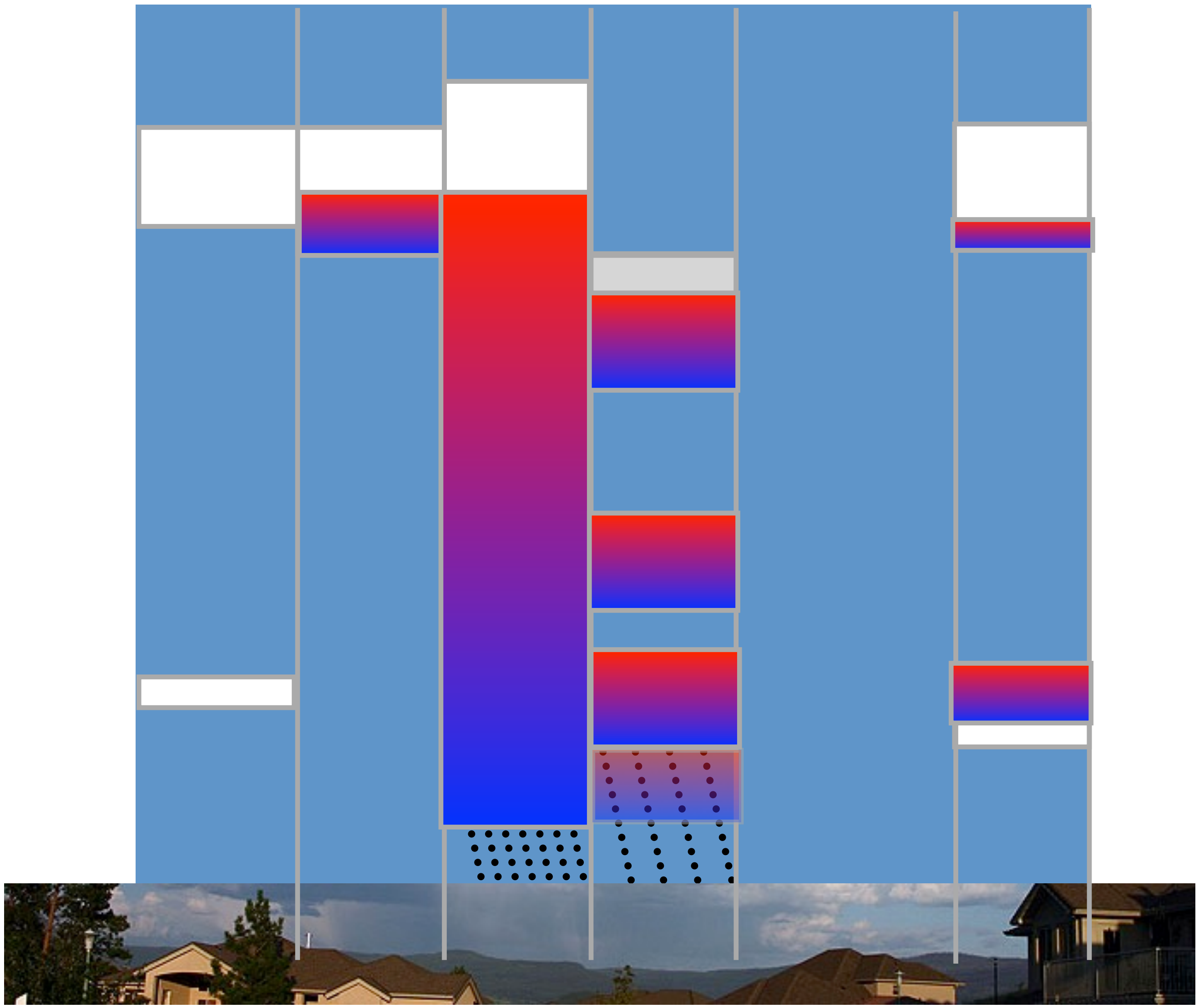
Radar Convective Cloud



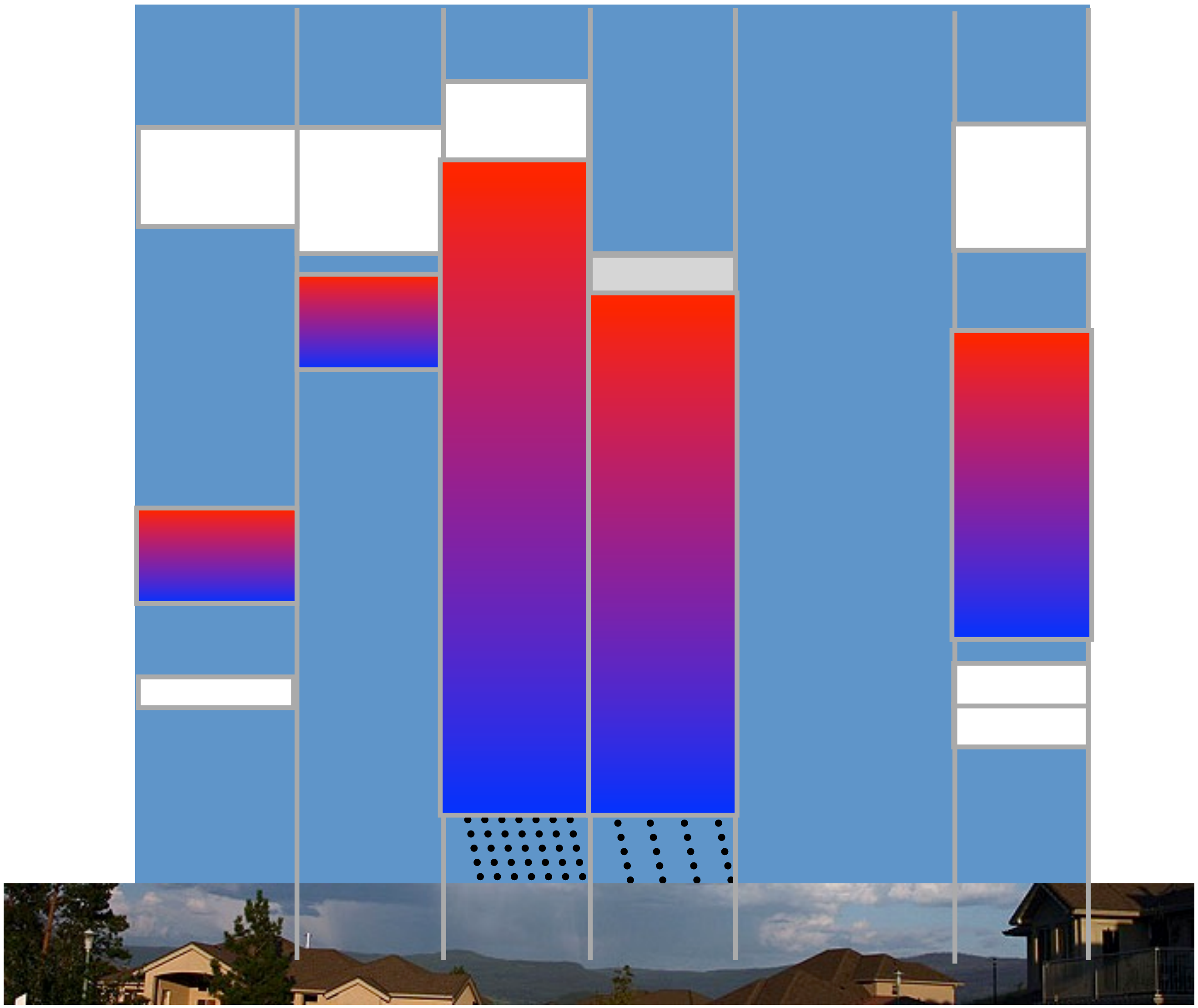
Lidar (CALIPSO) Convective Cloud



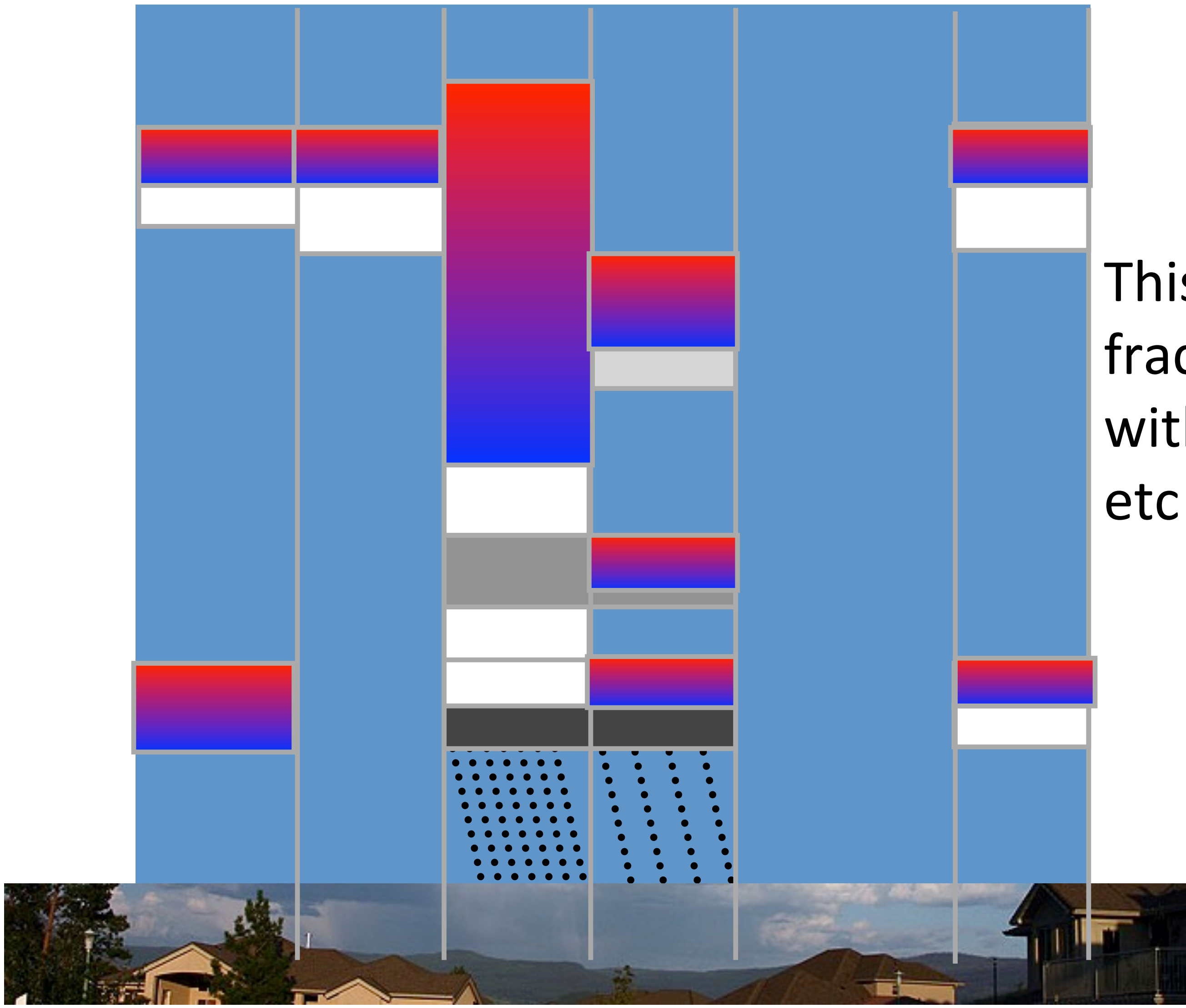
Radar (CloudSat) Convective Cloud



IR (MODIS) Convective Cloud



Vis/IR (MISR) Convective Cloud



This is just cloud fraction: try it with LWP, re, etc !

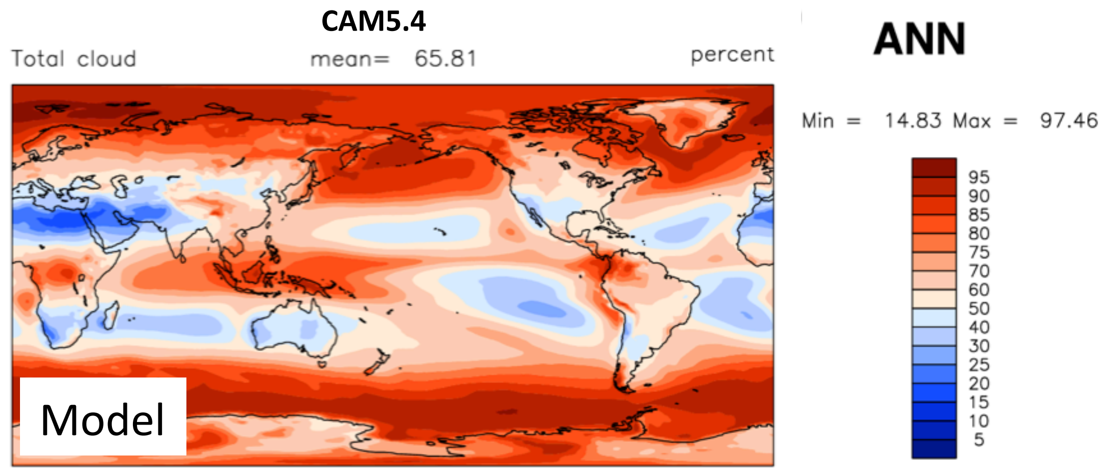
Traditional Evaluation Methods

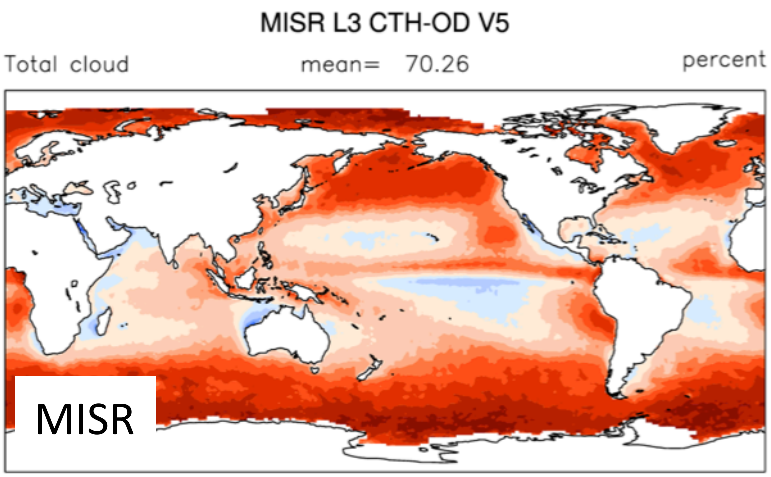
- Climate Evaluation
  - Use the easy variables: Cloud Fraction
  - Means or Climatology
- Weather Evaluation
  - Forecast: Looks okay
  - Composites
  - Forecast Skill Metrics

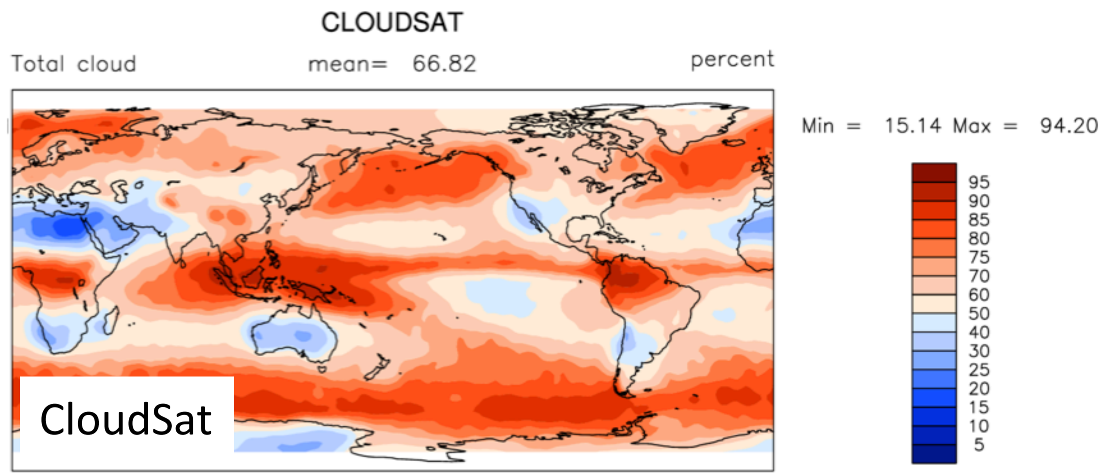
Climate Evaluation:

Cloud fraction…

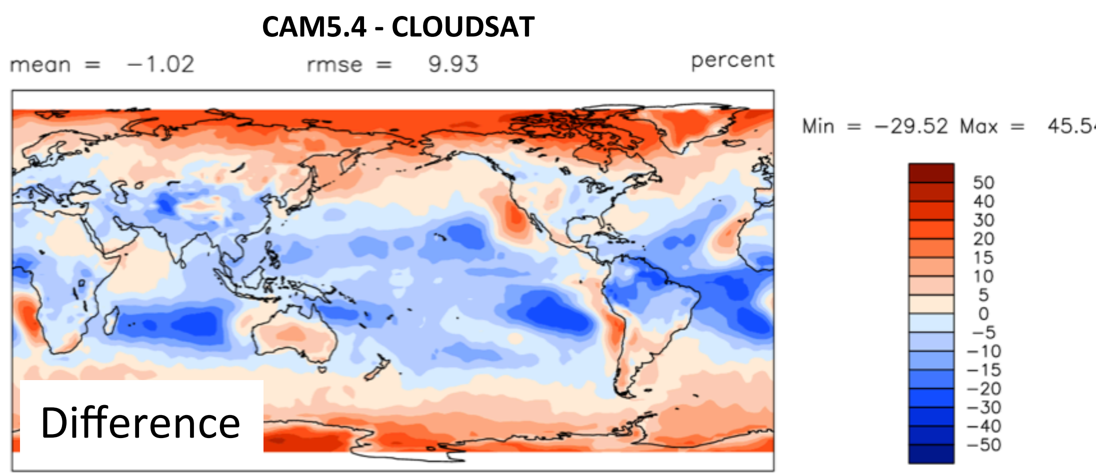
Traditional View: Model – CloudSat (Radar+ Lidar)





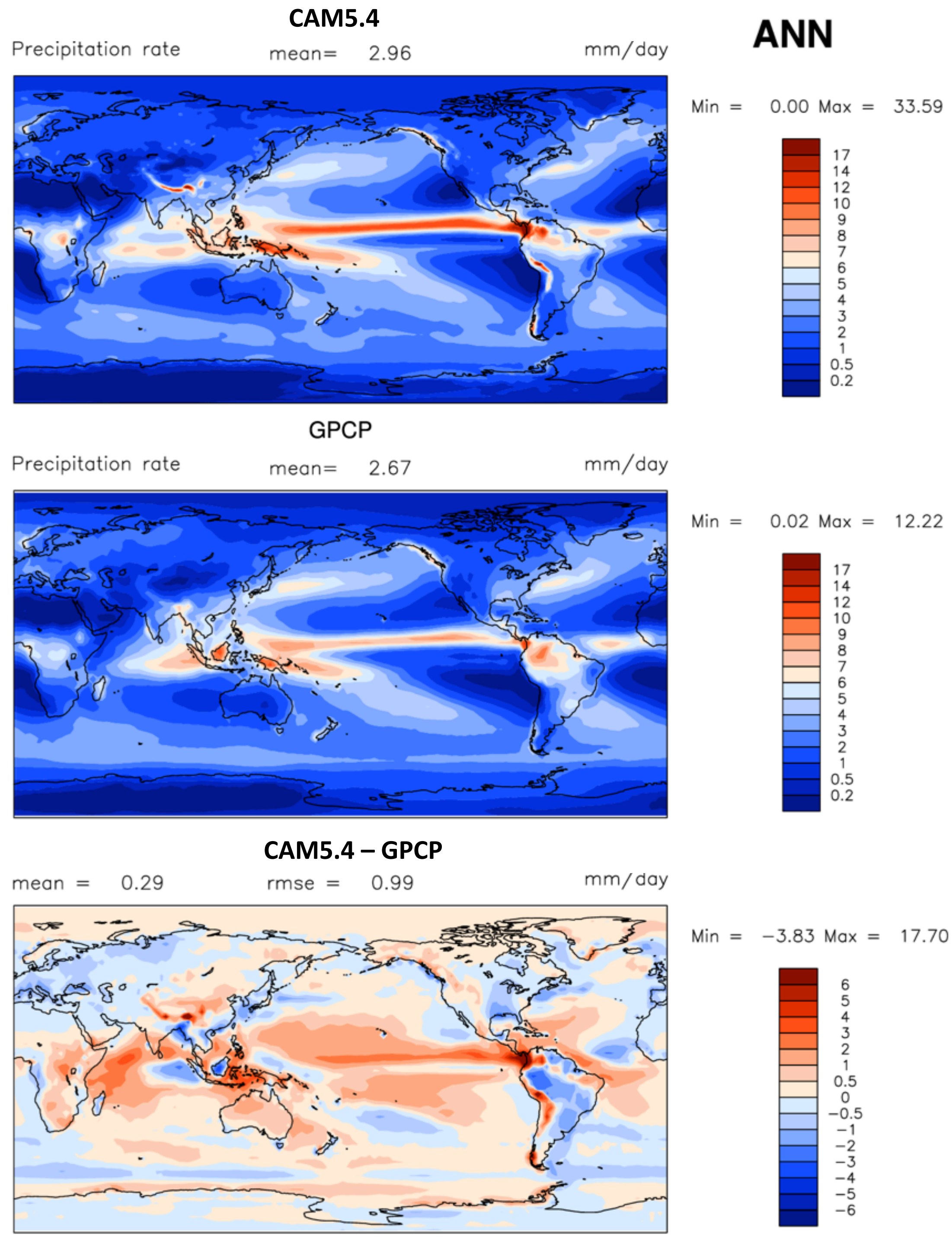


Biases change with data set.
May even change sign!



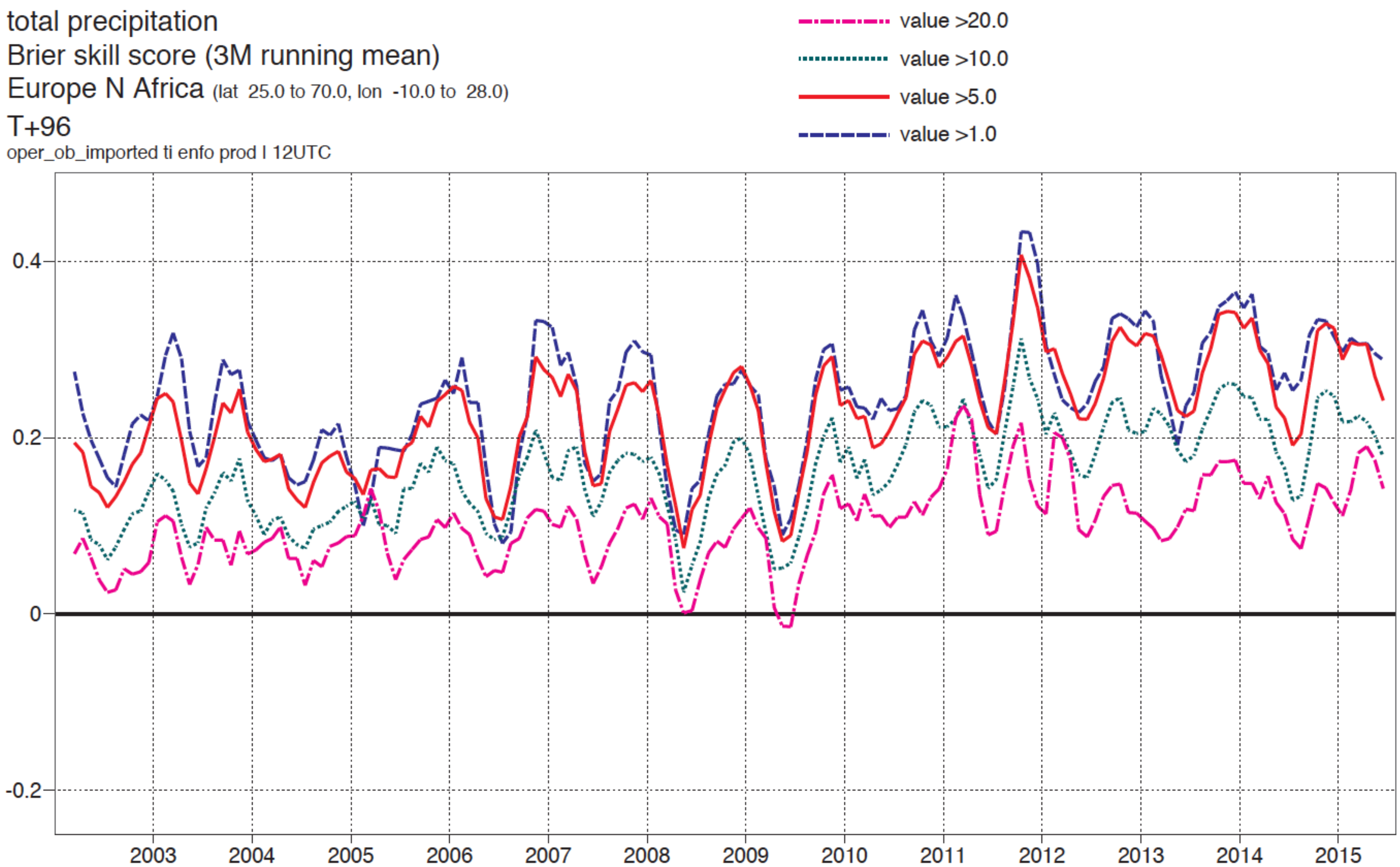
Mean Metrics

Example: Precipitation



Weather: Forecast Verification

Brier (1950) skill score, or cost function



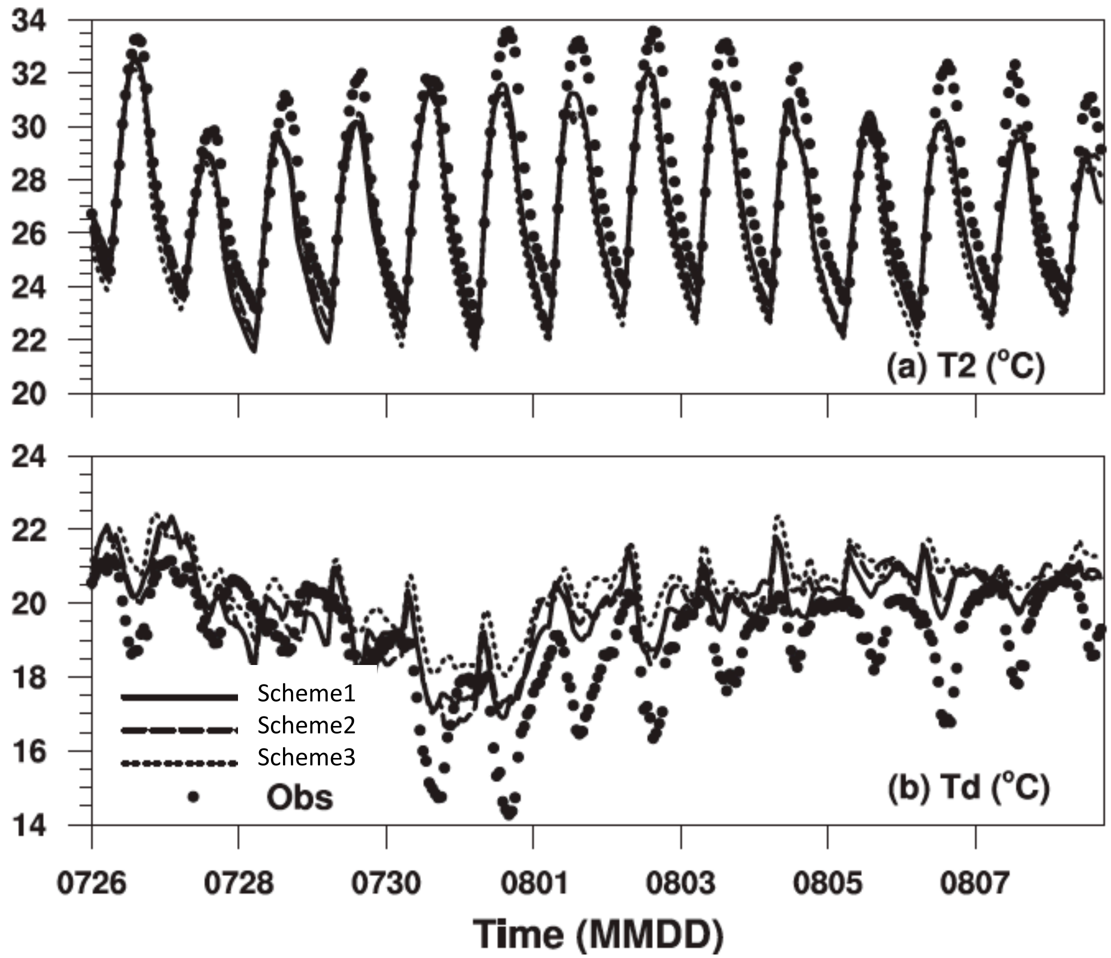
http://www.ecmwf.int/en/forecasts/charts/medium/brier-skill-score-weather-parameters

Weather Forecast Evaluation

Observed and simulated Temperature and Dewpoint
In a Mesoscale model over Texas
Votes for your favorite boundary layer scheme anyone?

2m-Temp

Dewpoint



[redacted] Reference Redacted (see me later)

How do we do this better?

Issue: these evaluations are loosely related to specific processes.

- Evaluation of Variability, Climate Modes
- Process based evaluation (weather, climate)
- Hindcast experiments for Weather, Climate Models
  - Multiple forecasts and forecast increments
  - Case studies in particular regions
- Satellite simulators

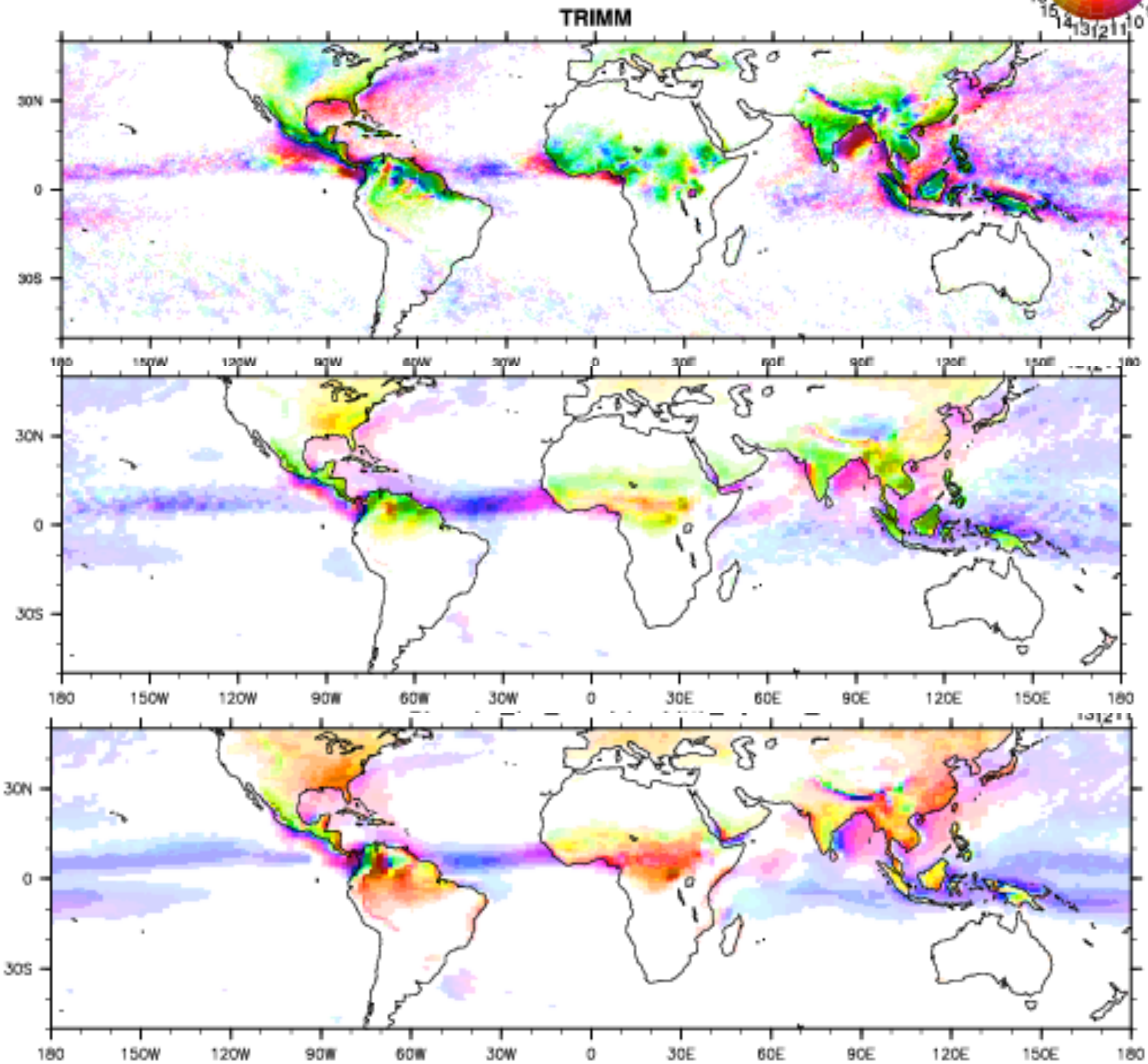
Variability: Diurnal Cycle of Precip

JJA Precipitation Rate

TRMM: OBS

CAM5.5 (new)

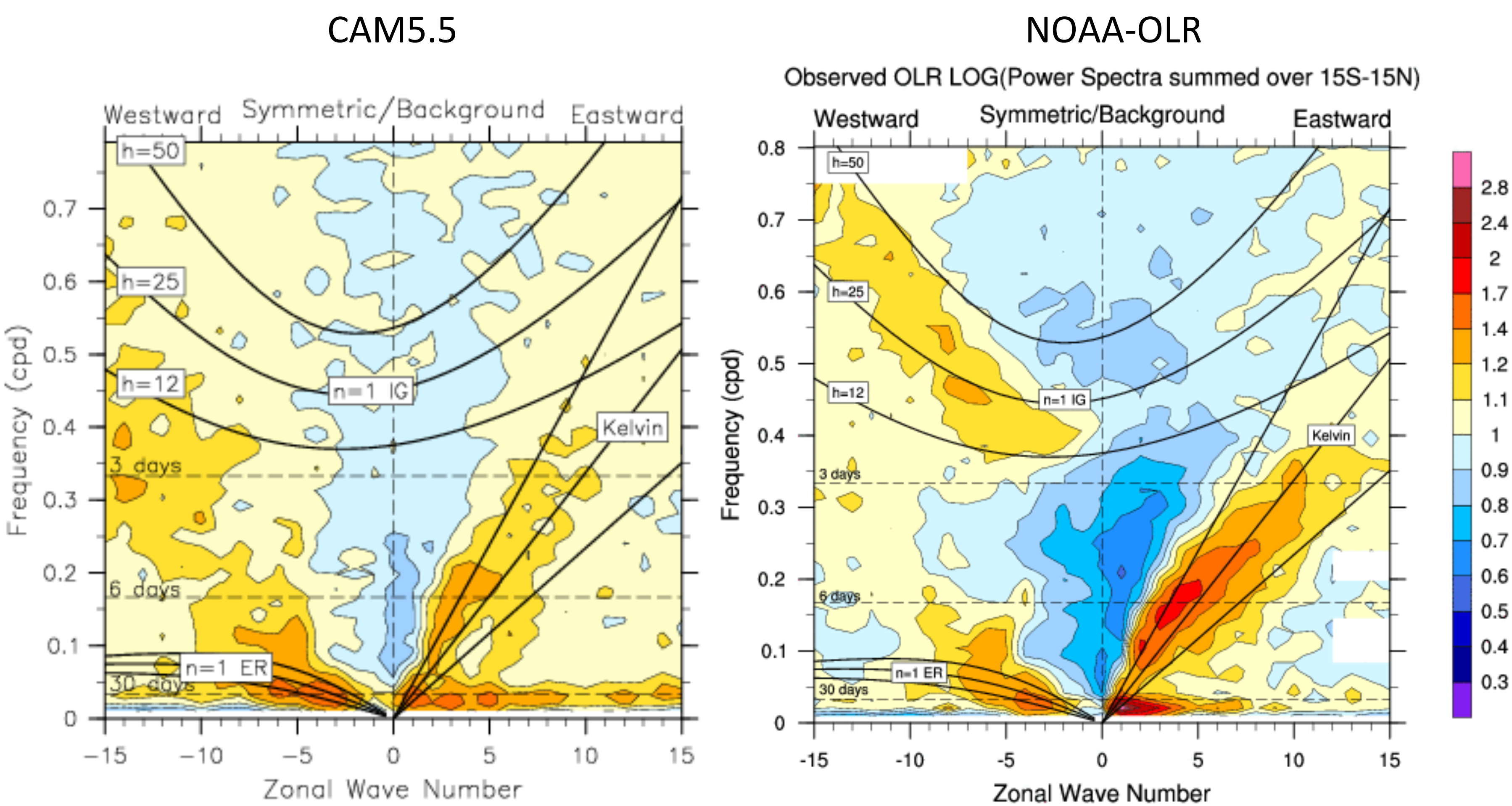
CAM5.3 (Old)



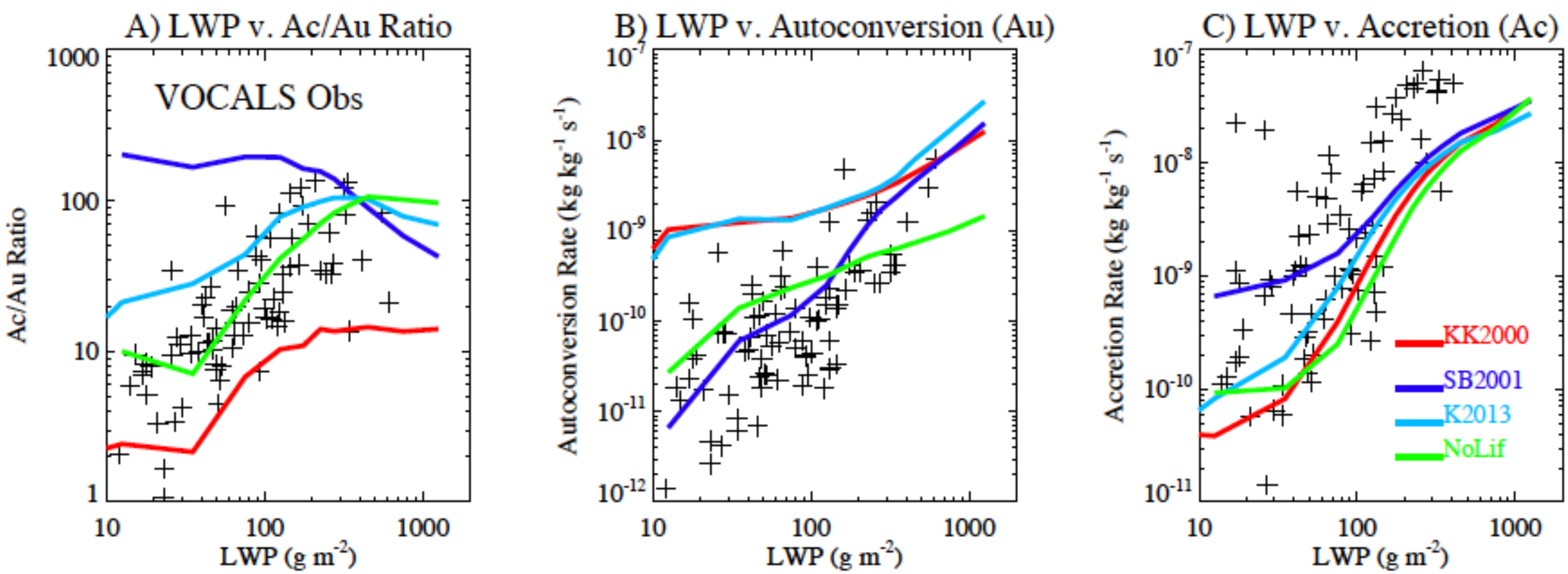
Thanks to R. Neale, C-C. Chen

Variability: Tropical Waves

Symmetric OLR Spectrum (Wheeler & Kiladis, 1999)



Process Rate Based Evaluation: Autoconversion



Gettelman, 2015, submitted to ACP

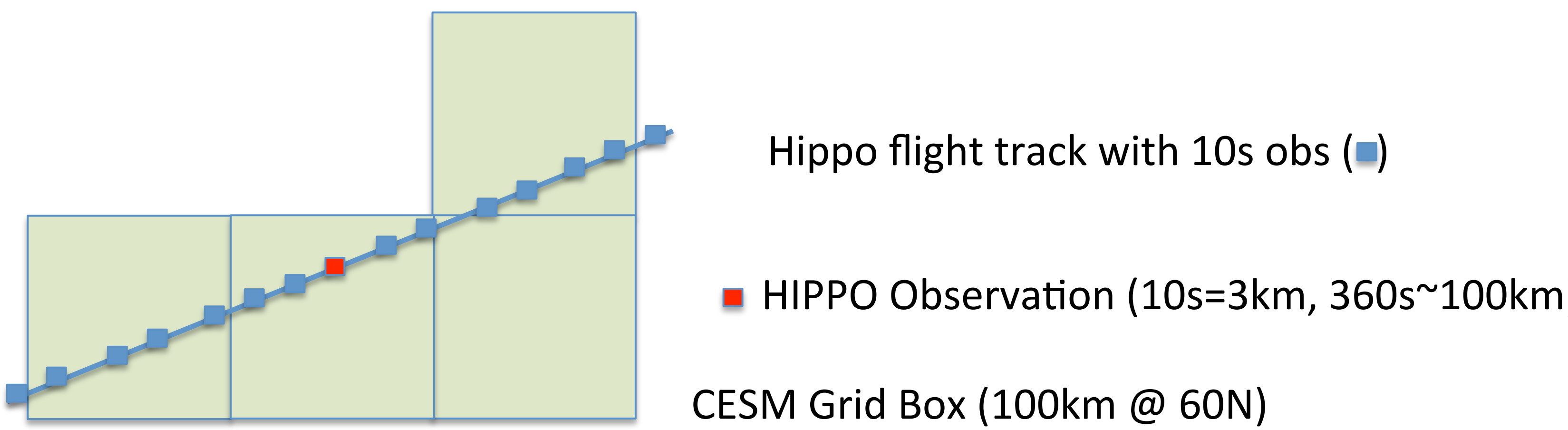
Observations = Calculations with detailed model and observed size distributions from S. E. Pacific (Terai and Wood, 2013)

Current Autoconversion, Alternative Schemes, Fixed Drop Number

Global Model Forecasts

Use a climate model like a weather model. Simulate individual cases.

- Specified Dynamics simulation: 2008-2011
- CESM1.2 (CAM5.3): GEOS-5 Meteorology, 200km resolution (equator)
  - Winds and Temps forced
  - Water species (q, clouds, aerosols) model calculated
  - Climate is reasonably in balance (-1.6 Wm^{-2} TOA)
- Output columns along (and around) HIPPO flight tracks
- Sample CESM box containing point & adjacent grid boxes
- Do every 10s. Model timestep is 1800s (oversample model)

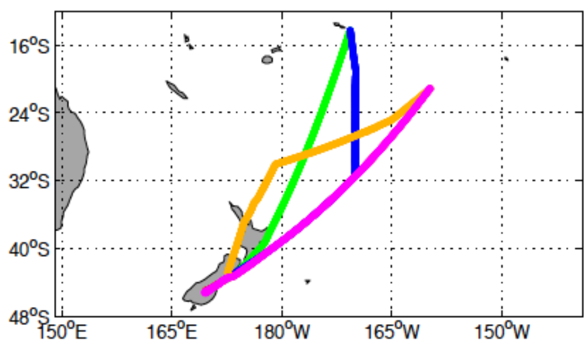


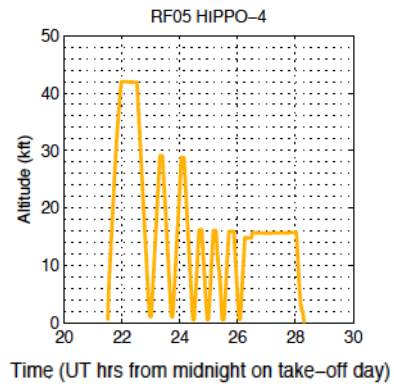
NSF G-V HIPPO Experiment

'HIAPER Pole to Pole Observations': multiple deployments (different seasons)

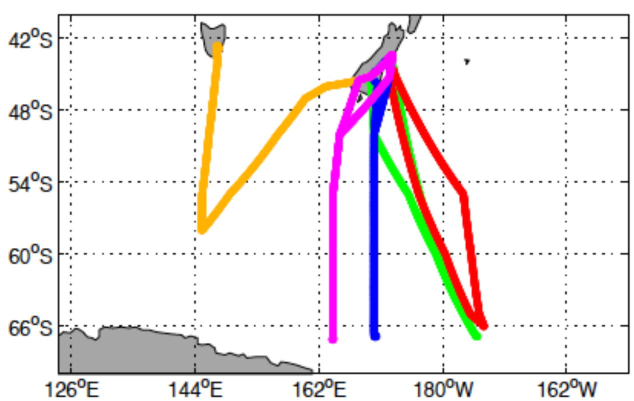
- Measured mass of liquid & ice and particle number concentrations
- Selected 2 flights with microphysics data in S. Ocean or S. Pacific

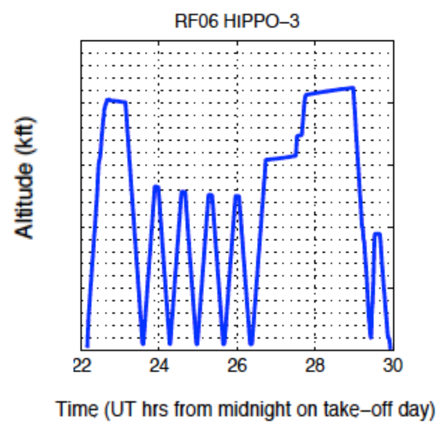
Subtropical Winter



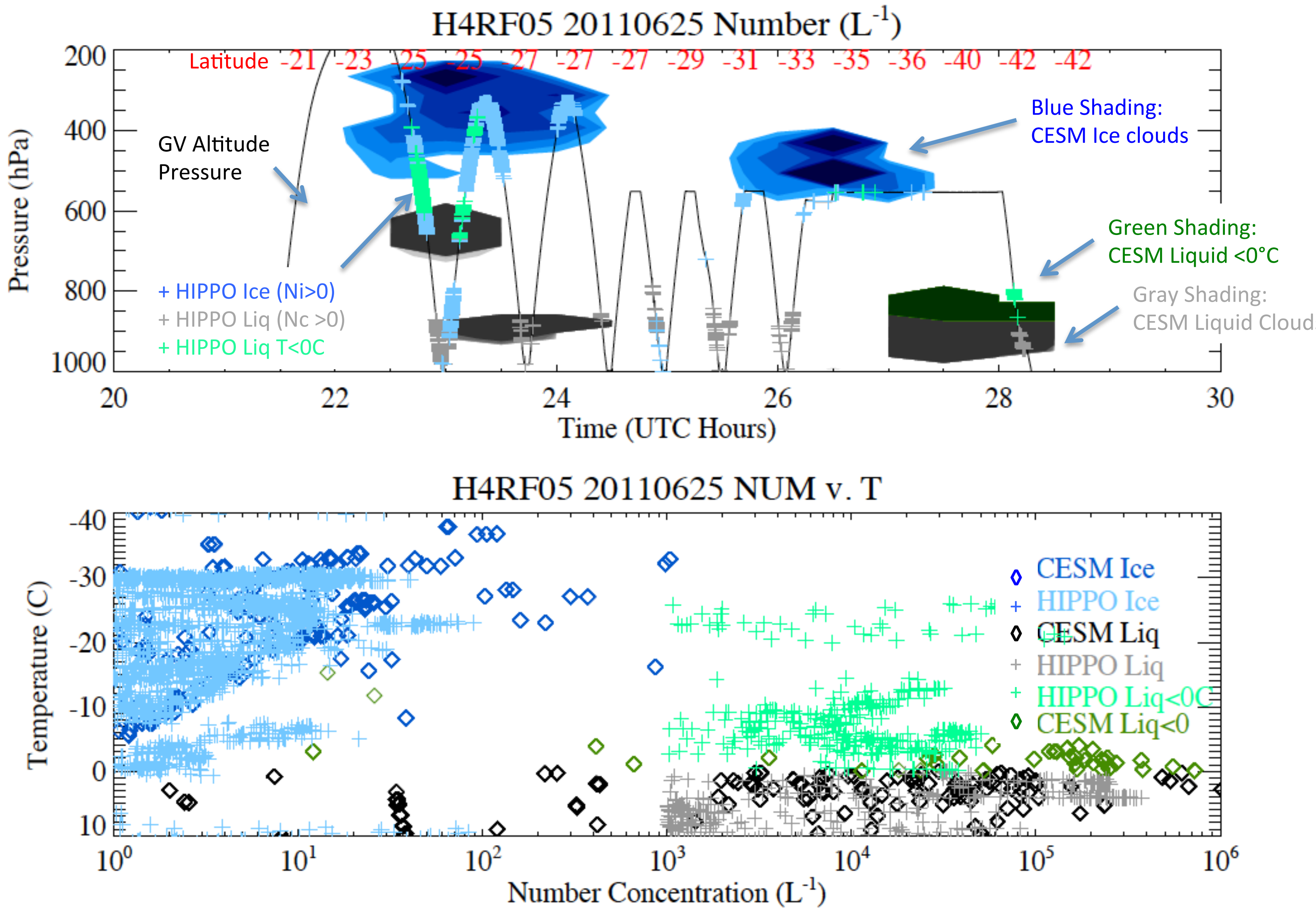


S. Ocean in Fall



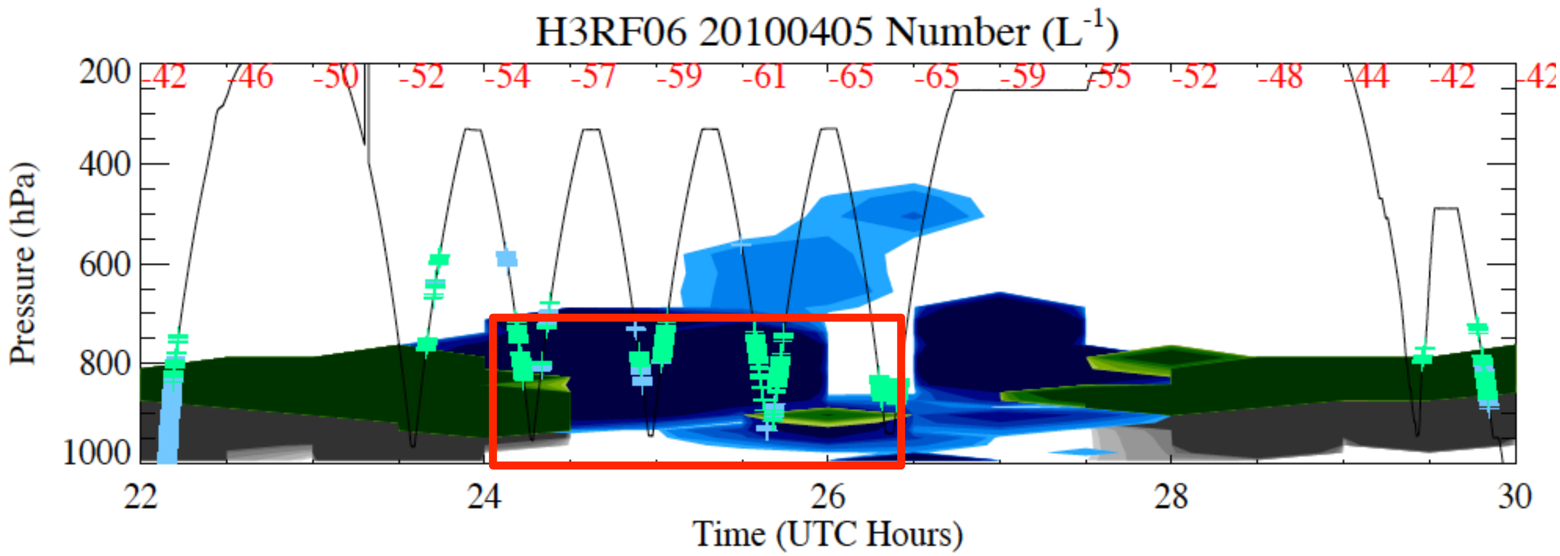


Section along H4RF05 (Jun) Flight Track

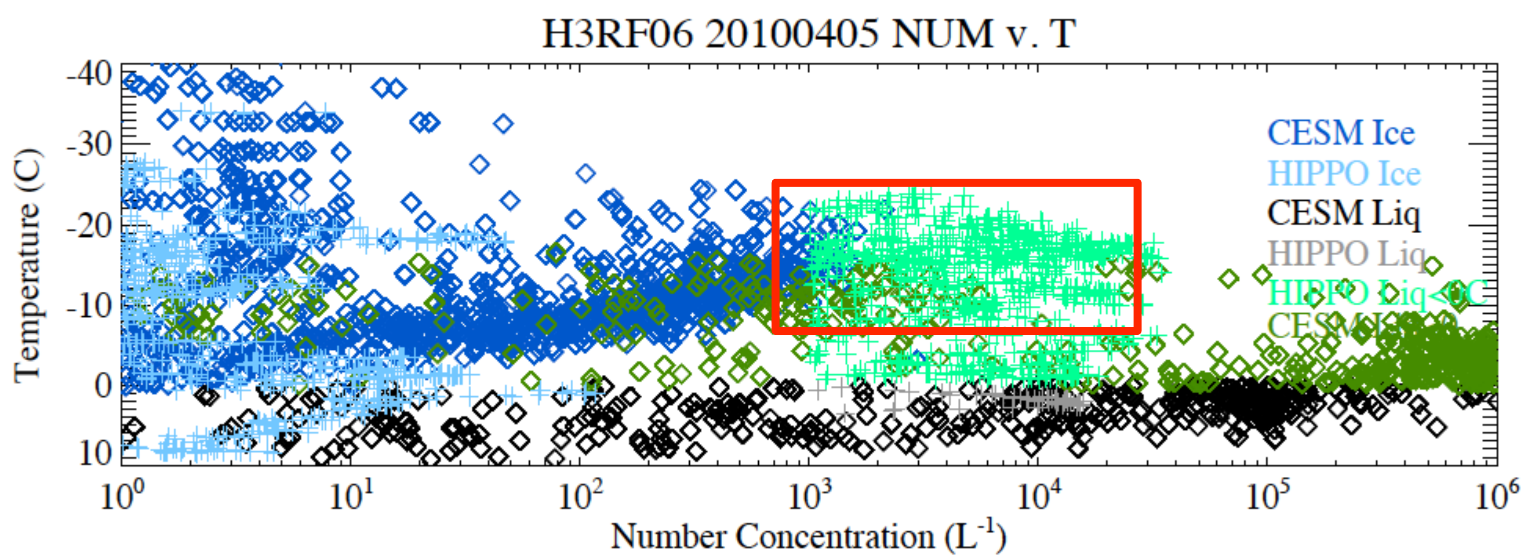


CAM5.3

Across S. Ocean (H3RF06) April

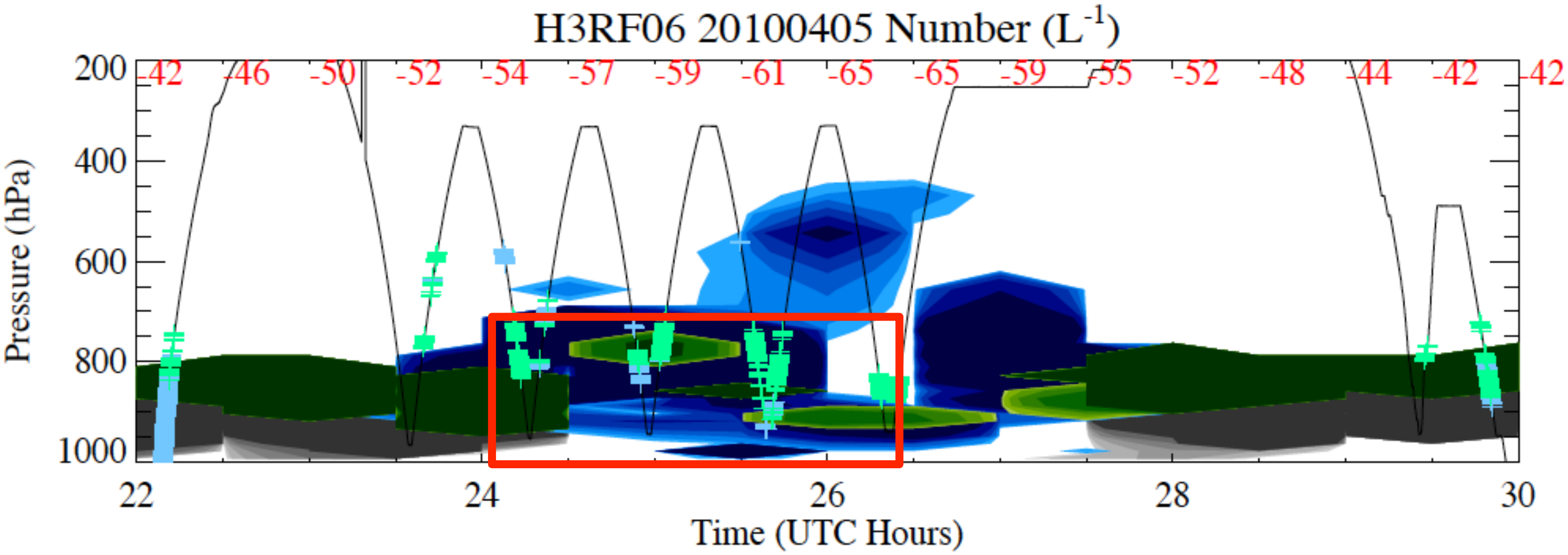


Obs=Liquid
Model = Ice

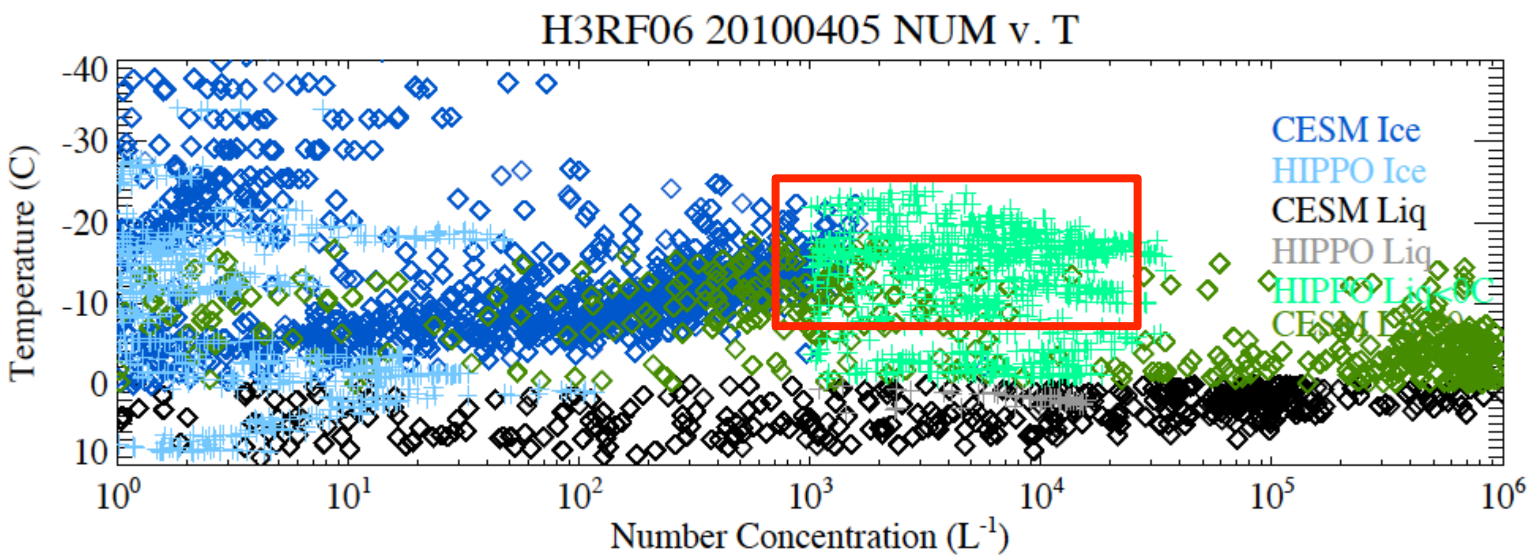


CAM5.4 (+ New Mixed Phase Ice Nucleation [Hoose et al. 2010])

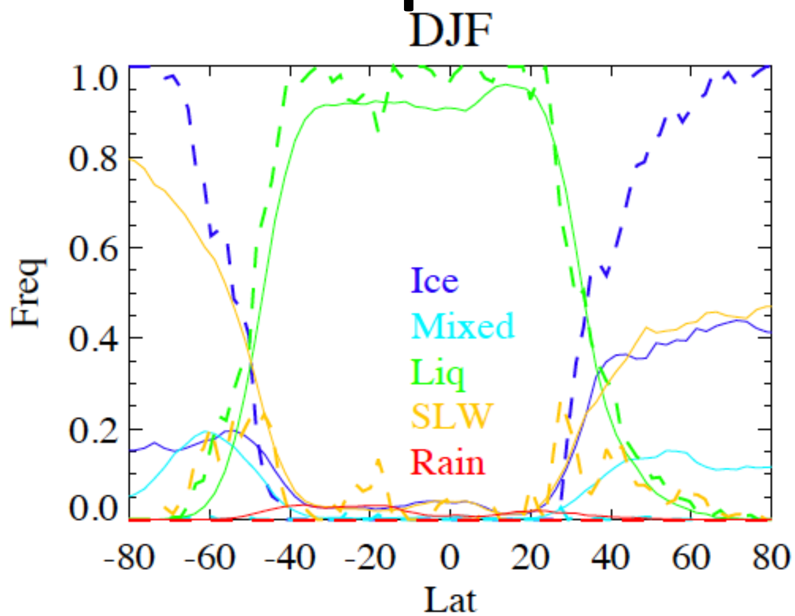
Across S. Ocean (H3RF06) April

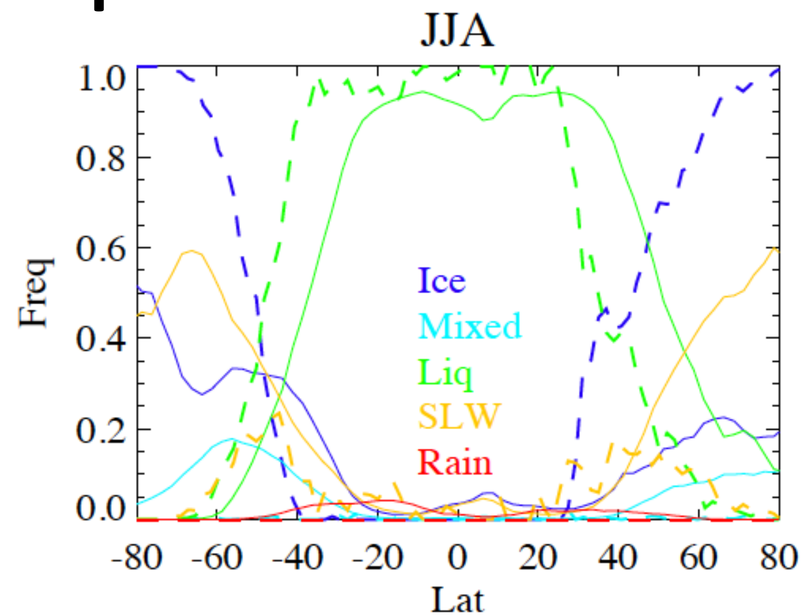


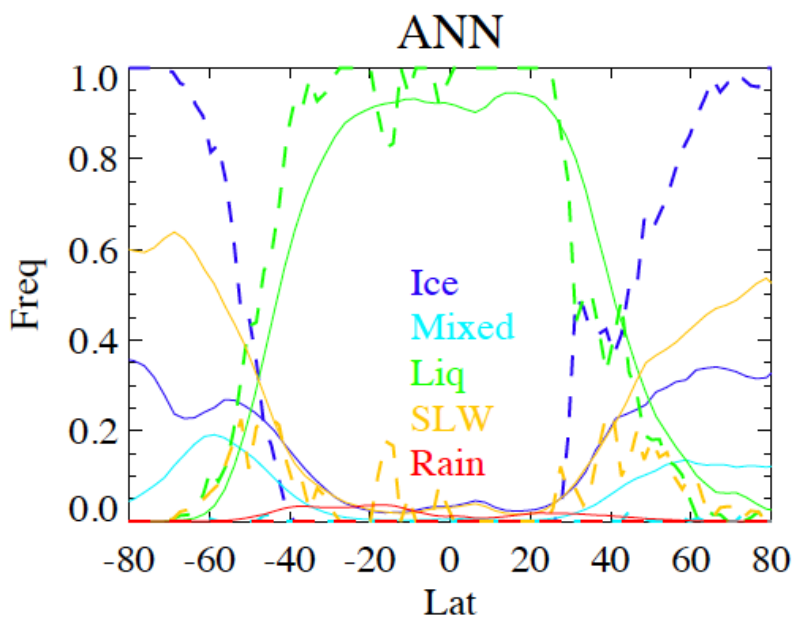
Obs=Liquid
Model = Ice



Supercooled liquid in CESM







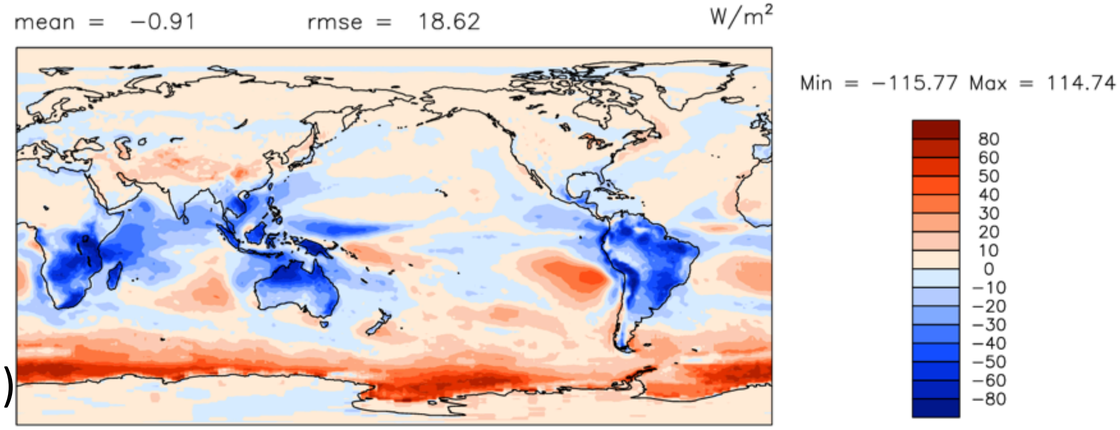
Frequency of occurrence of different hydrometeors at cloud top.
Solid = Satellite observations. (DARDAR)
Dashed = CAM5.4

Getting some super-cooled liquid water (SLW), not quite enough
Liquid looks good (too much Ice)

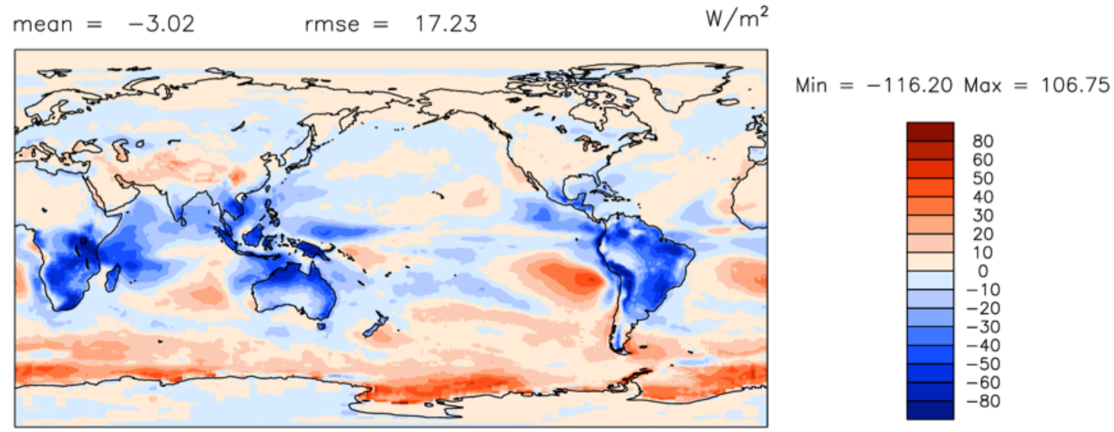
CESM2 development

DJF SW Cloud Radiative Effect
Bias v. Satellite (CERES)
Bias = too much Absorbed Solar (ASR)
Free running (Fixed SST) simulations

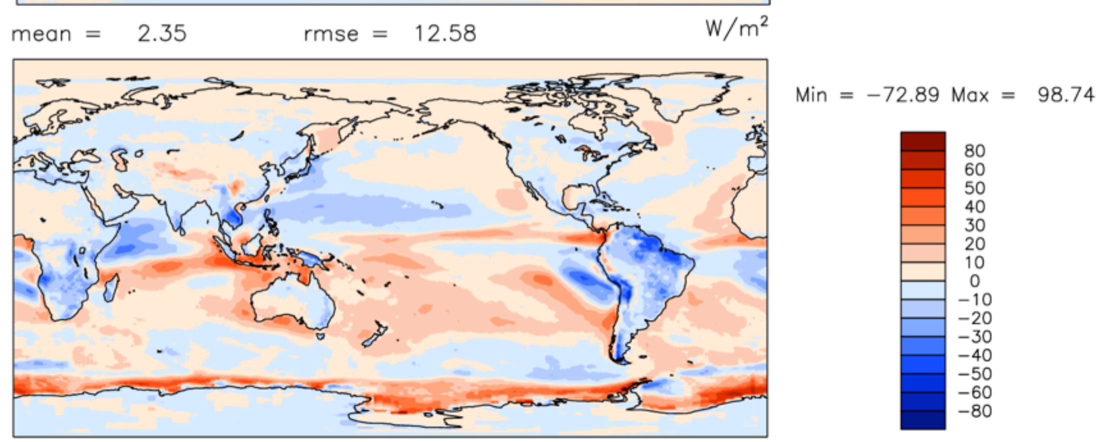
Current (CESM1.2-CAM5.3)



CAM5.4 (new ice nucleation)



CESM2α



Instrument Simulators

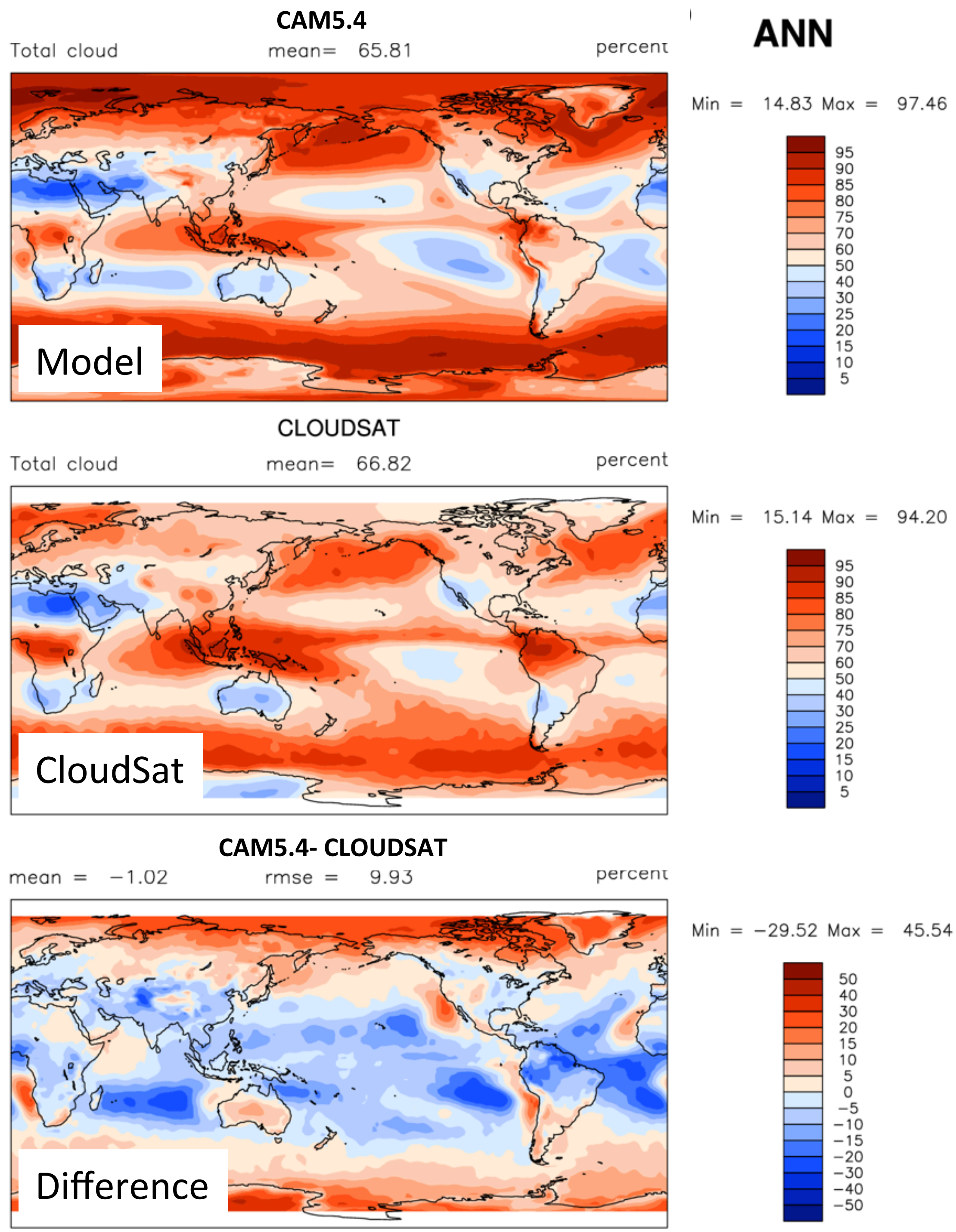
- Designed to “simulate” retrievals of a variety of satellites: includes MODIS, MISR, CloudSat, CALIPSO, ISCCP
- Why? Better comparisons between models and observations
- Mostly Cloud fraction, but also cloud microphysics from MODIS
- CFMIP Observation Simulator Package (COSP)
  - CFMIP = Cloud Feedback Model Intercomparison Project

Why?

- Different instruments have different sensitivities
- Need to sample the model correctly to compare apples to apples
- Examples:
  - Cloud Fraction
  - Liquid Water Path

Cloud fraction…

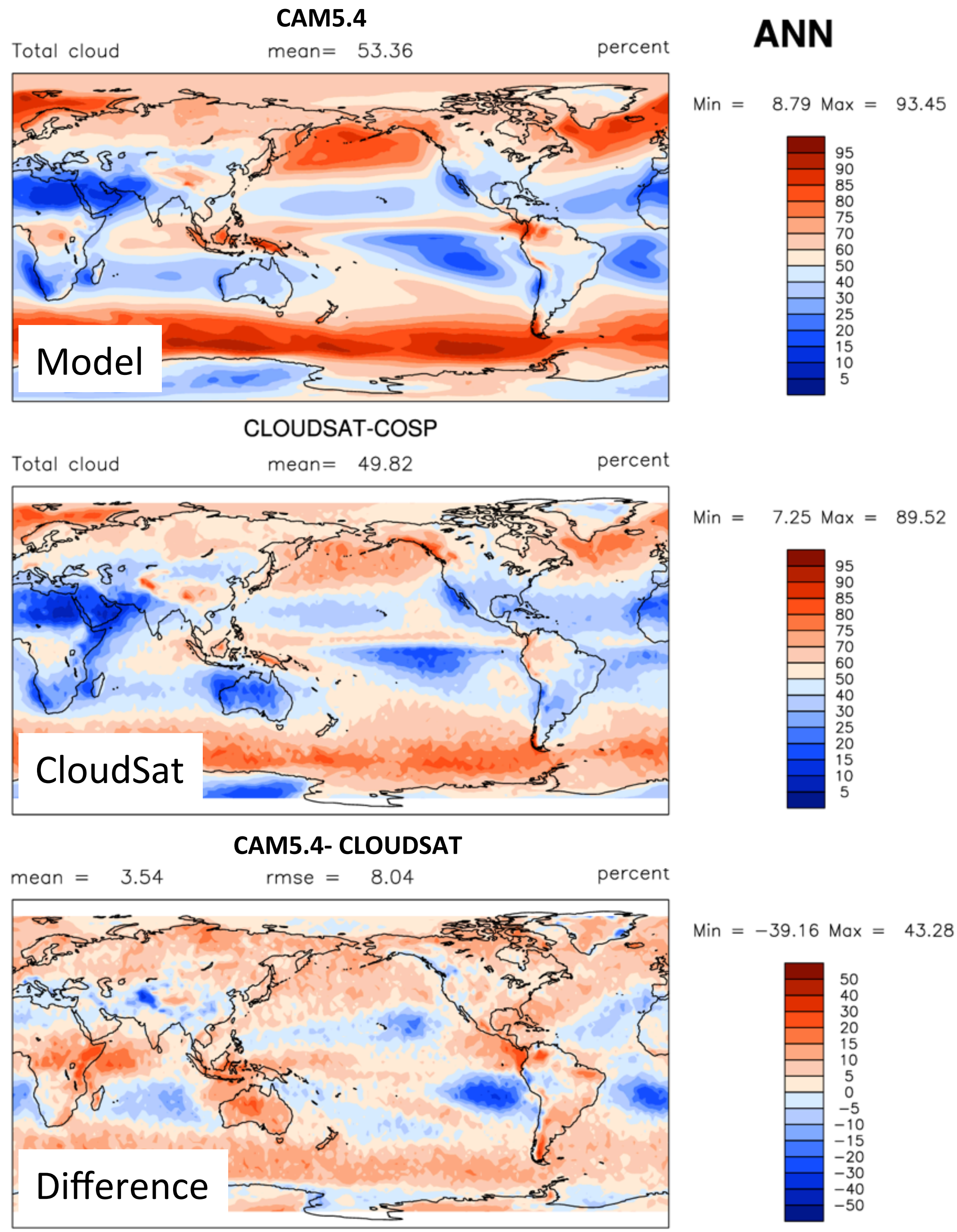
Traditional View: Model – CloudSat (Radar+ Lidar)



Cloud fraction…

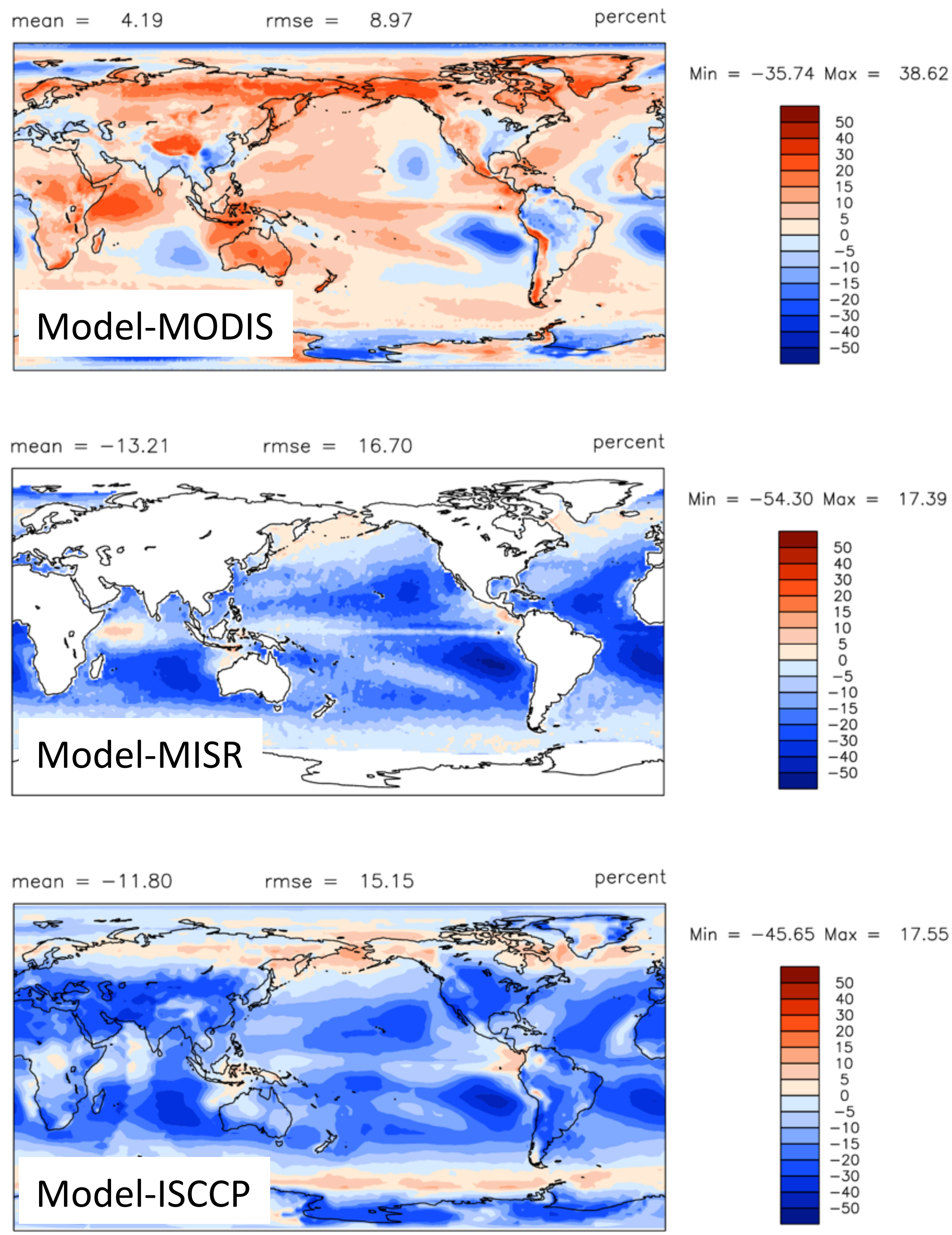
SIMULATOR VIEW Model – CloudSat

CloudSat Product only. Fewer clouds (no Lidar). Model higher in tropics.



Cloud Fraction Differences (τ>0.3)

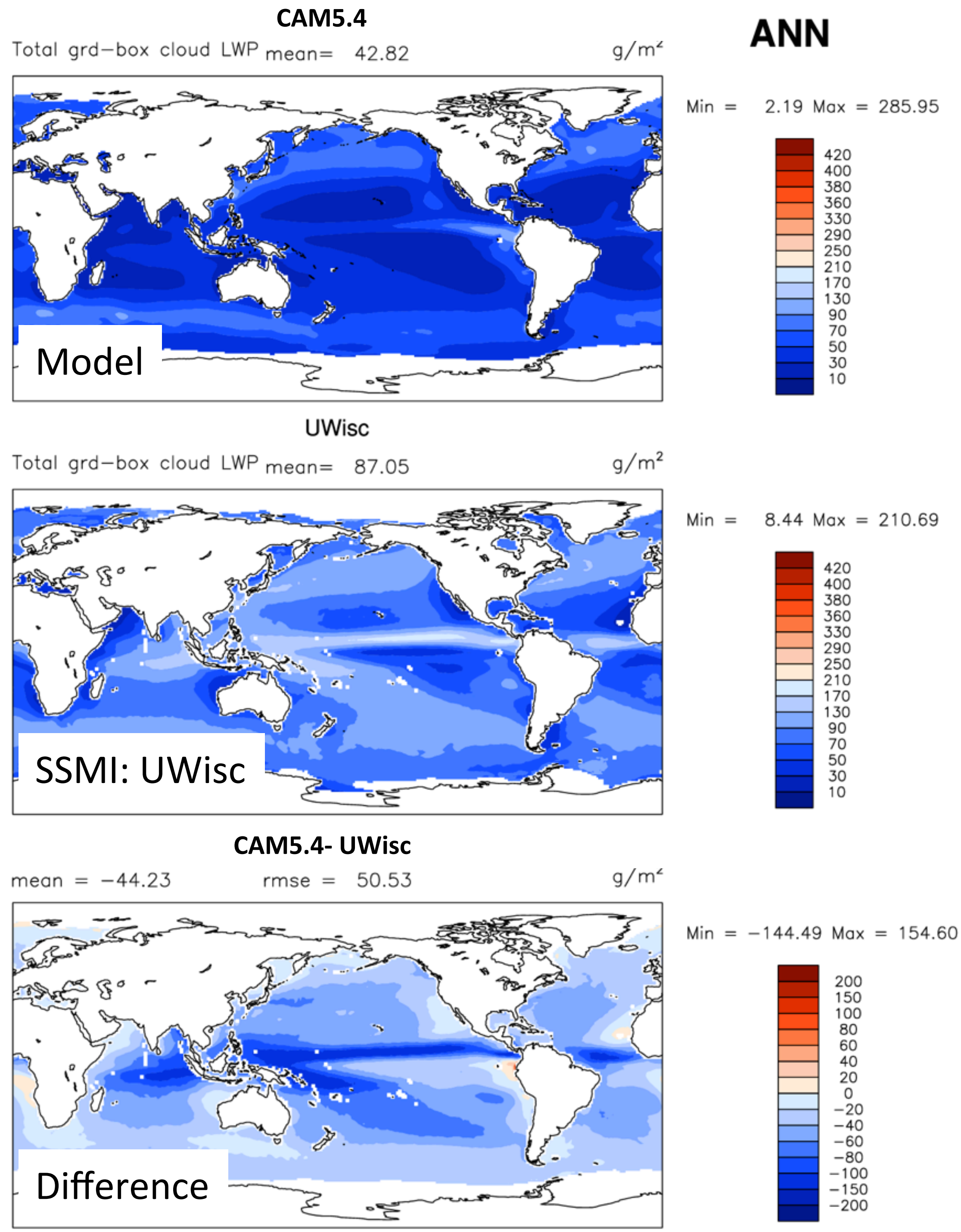
Different bias against different instruments



LWP: Wrong Message

Traditional comparison of Model LWP field against Microwave Satellite Observations of LWP. Model is low. But cloud forcing looks okay, and the cloud fraction looks okay. What is going on?

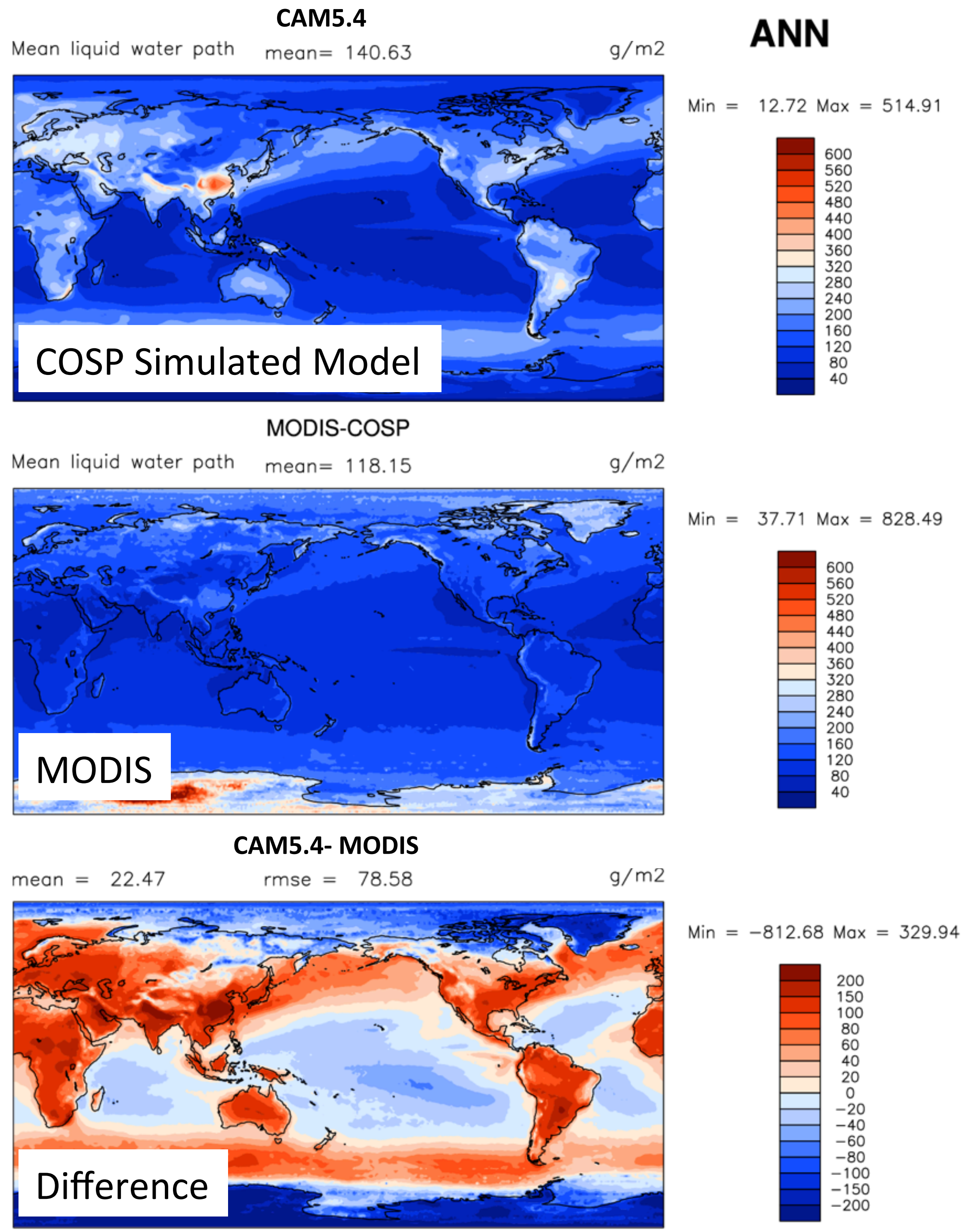
Same problem with comparison with MODIS LWP retrievals…



LWP: Correct Message

Use of the MODIS simulator for LWP: implies an Adiabatic assumption for low clouds. The model is not Adiabatic, but assuming it is Adiabatic increases LWP, especially over land and storm tracks

Now the model is slightly HIGHER than observations (+20%) rather than -50% LOW.



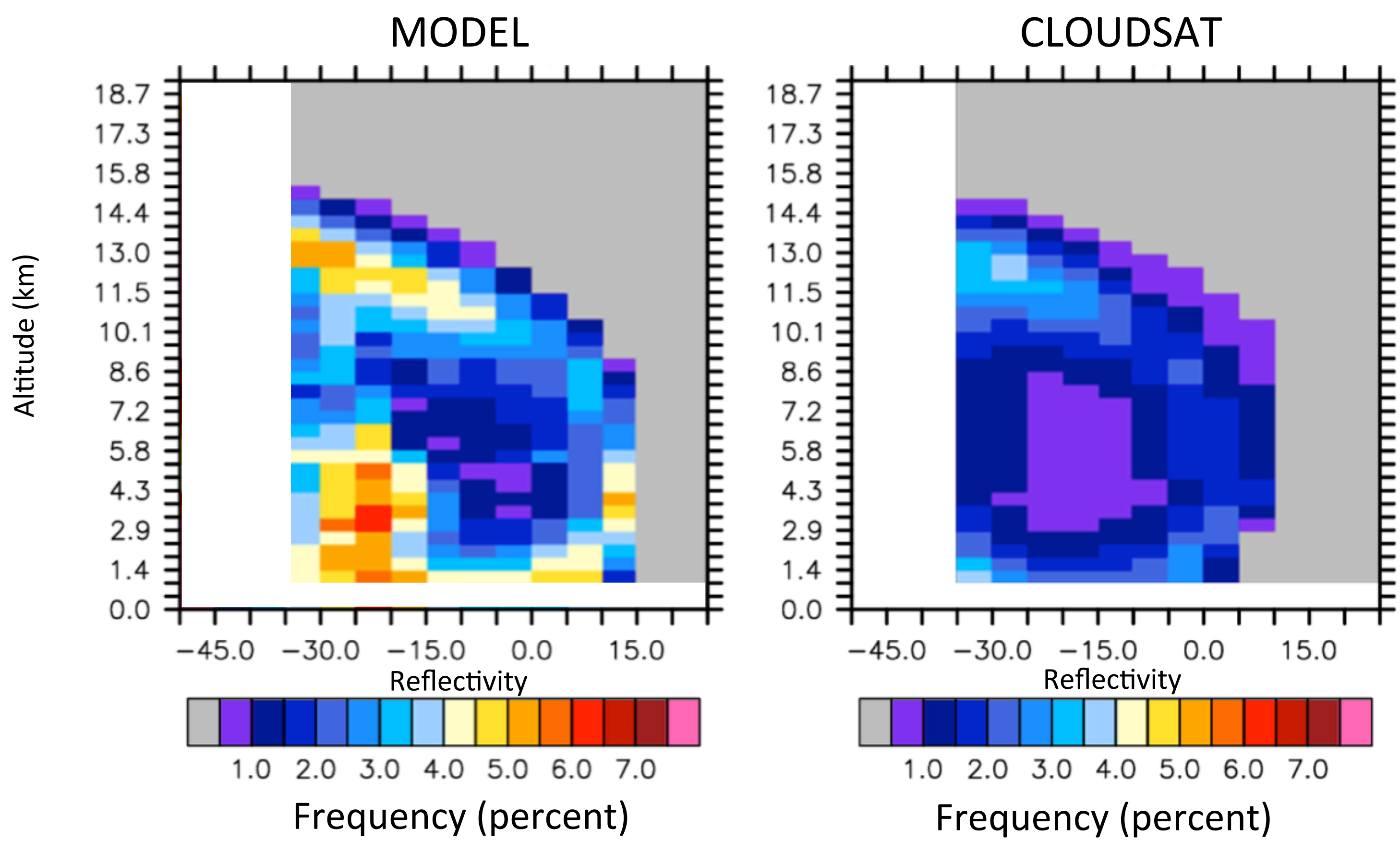
Simulate Reflectivity

Simulate observed quantities: in this case, Reflectivity ($Z \propto D^{-6}$)

Cumulative Frequency by Altitude Diagram (CFAD)

Shows modes of variability and regimes in models and observations

Here: thin, low clouds too extensive and high, too much moderate drizzle



Complexities

- Sub-grid scales are hard to observe
  - Hard to make model and observations consistent
- Global constraints on clouds are good (& bad)
  - Benefit of the climate scale
  - Integral of regimes: zero in on regimes, analogues
  - Easy to get the right clouds for the wrong reasons
- Simulators provide an integrated view
  - Sometimes hard to disentangle processes

Summary

Best practices for cloud observations:

1. Use forecast mode for verification
2. Simulate the observation with the model (simulators). Find the critical processes: focus on these processes (field studies). Here: mixed phase, auto-conversion

Challenges

- Scales: Cloud scales hard to observe, harder to simulate
- No easy way to get simulations to work across scales
  - We are trying: Some dogs are better than others for this
  - Fewer dogs may be better (less plumbing)
- Improving processes sometimes breaks key metrics: the challenge of rippling compensating errors
  - Some dogs work/play better with others

Thanks!

This is how René Magritte sees a cloud…

The Empire of Lights, R. Magritte, Peggy Guggenheim Museum, Venice