Model Output and Evaluation

Andrew Gettelman
Dani Coleman
NCAR

Outline

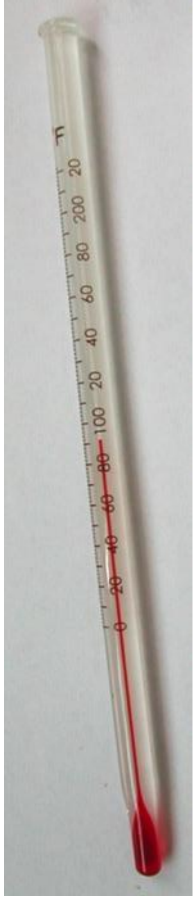
1. How to evaluate a model with observations (ideas)
   - What is a measurement?
   - Comparing observations to models (apples and oranges).
   - Satellite simulators (COSP): Concept and implementation in CAM.
2. Diagnostic packages (show examples)
   - Mean: AMWG
   - Climate Variability: CVDP
   - Variability/Processes: MDTF
3. Model output
   - ‘Standard output’: how to get it out of the model
   - Look in the user guide: ‘fancy’ output (sathist, single point, regional).
   - How to output a new variable (needs to be a cam interface level, copy existing)

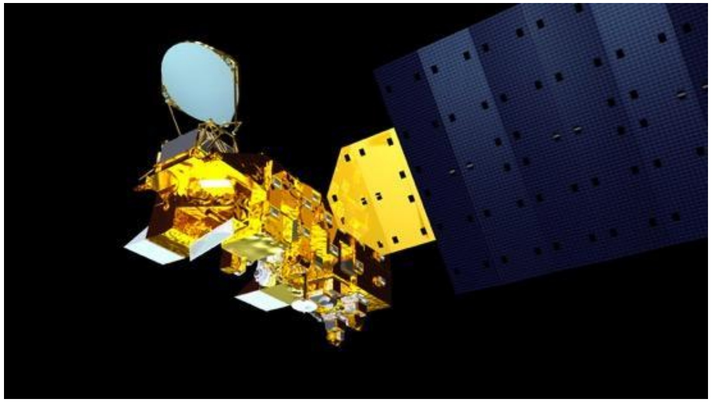
Observations: What is a cloud?
How do we compare models and observations?

Example: Measuring temperature

What do the following REALLY measure?

- Liquid (alcohol, red) thermometer?
- Thermocouple (digital thermometer)
- Infrared camera
- Satellite infrared imager



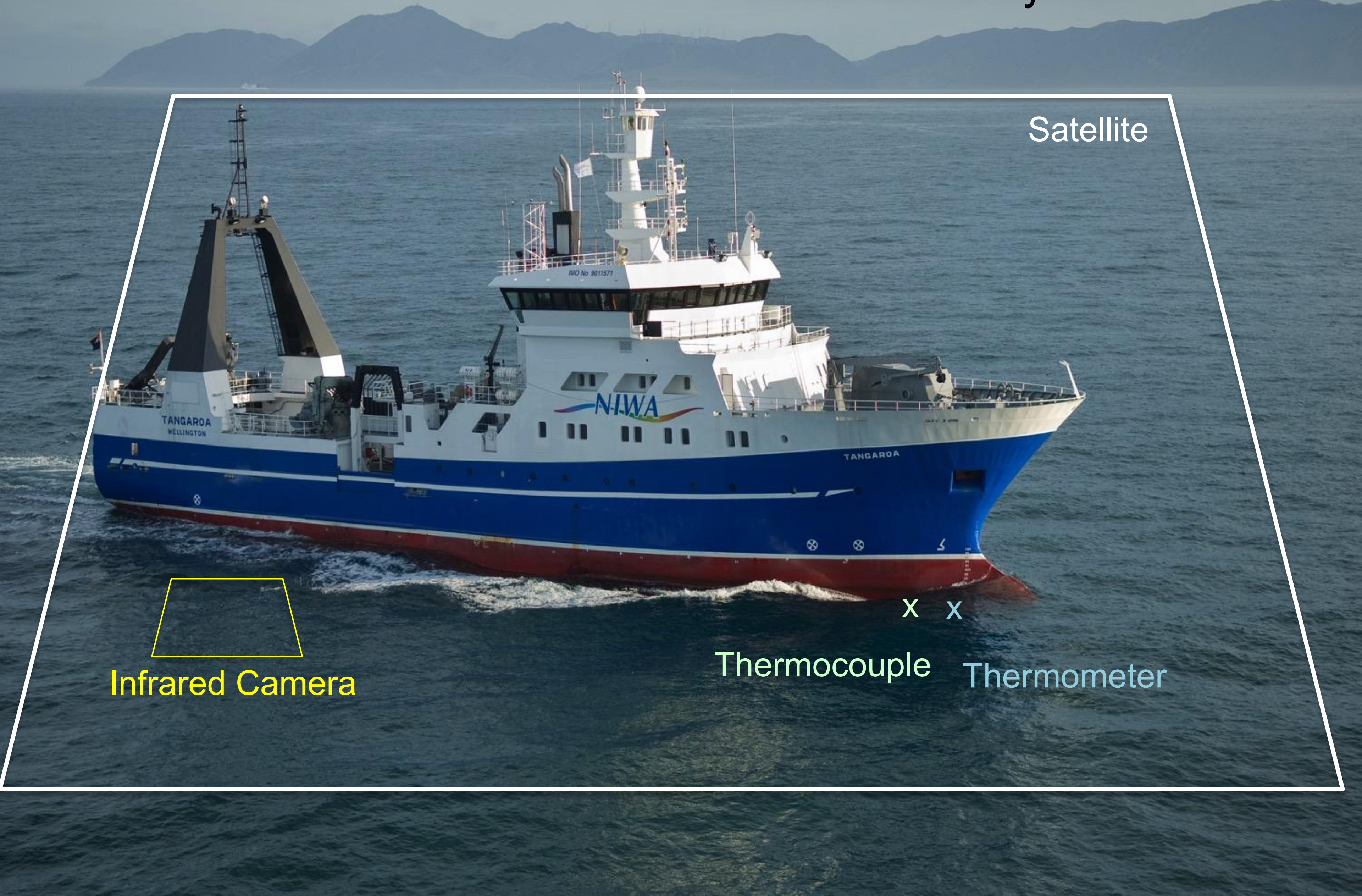


What is the error in a temperature measurement

- Image: ocean surface with a ship.
  - Liquid Thermometer
  - Thermocouple
  - Infrared camera
  - Satellite instrument
- What is the error? What are they measuring?

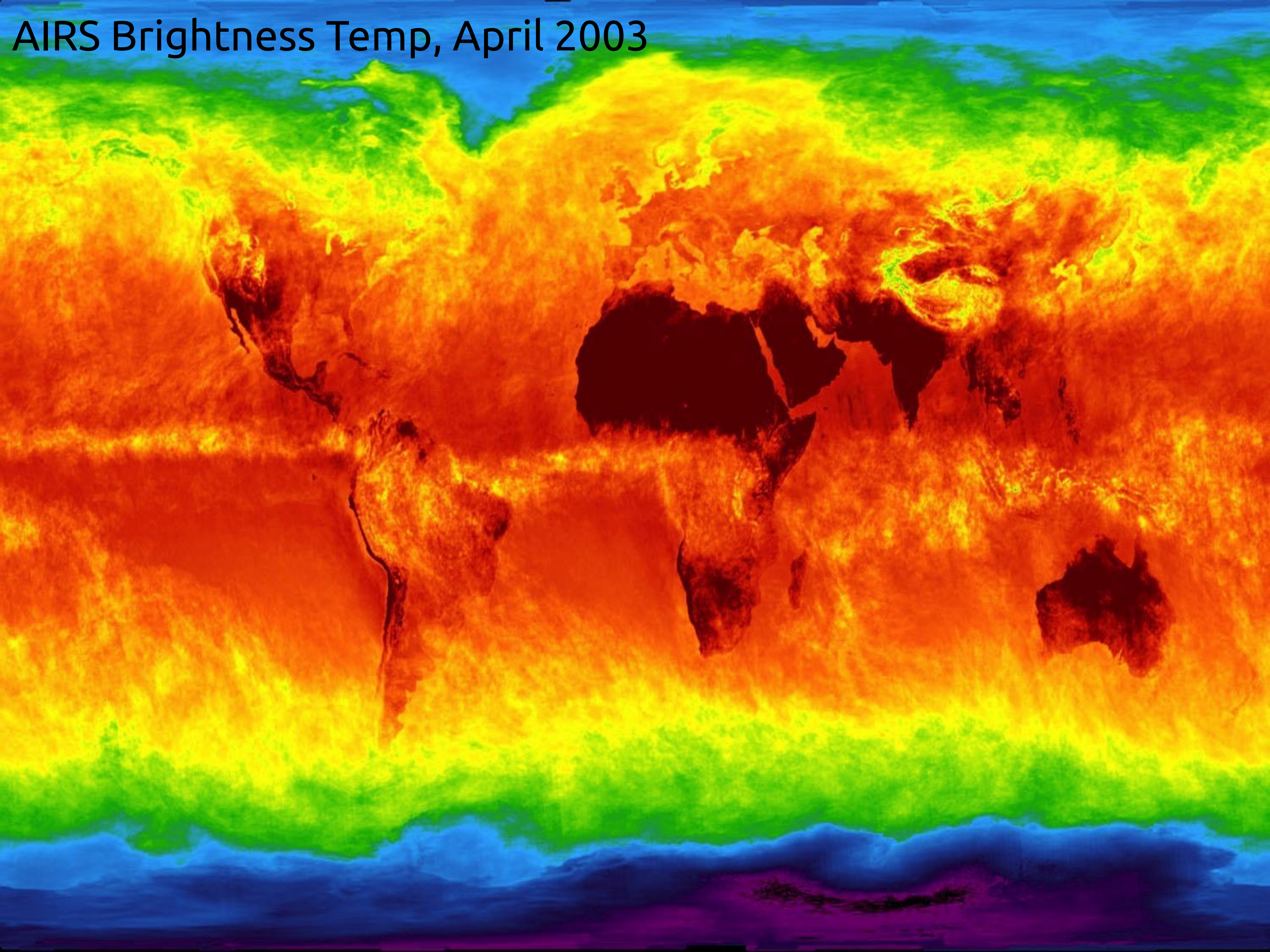
Measuring the 'Same' Temperature in a Scene

What is the error in the measurement? Uncertainty?



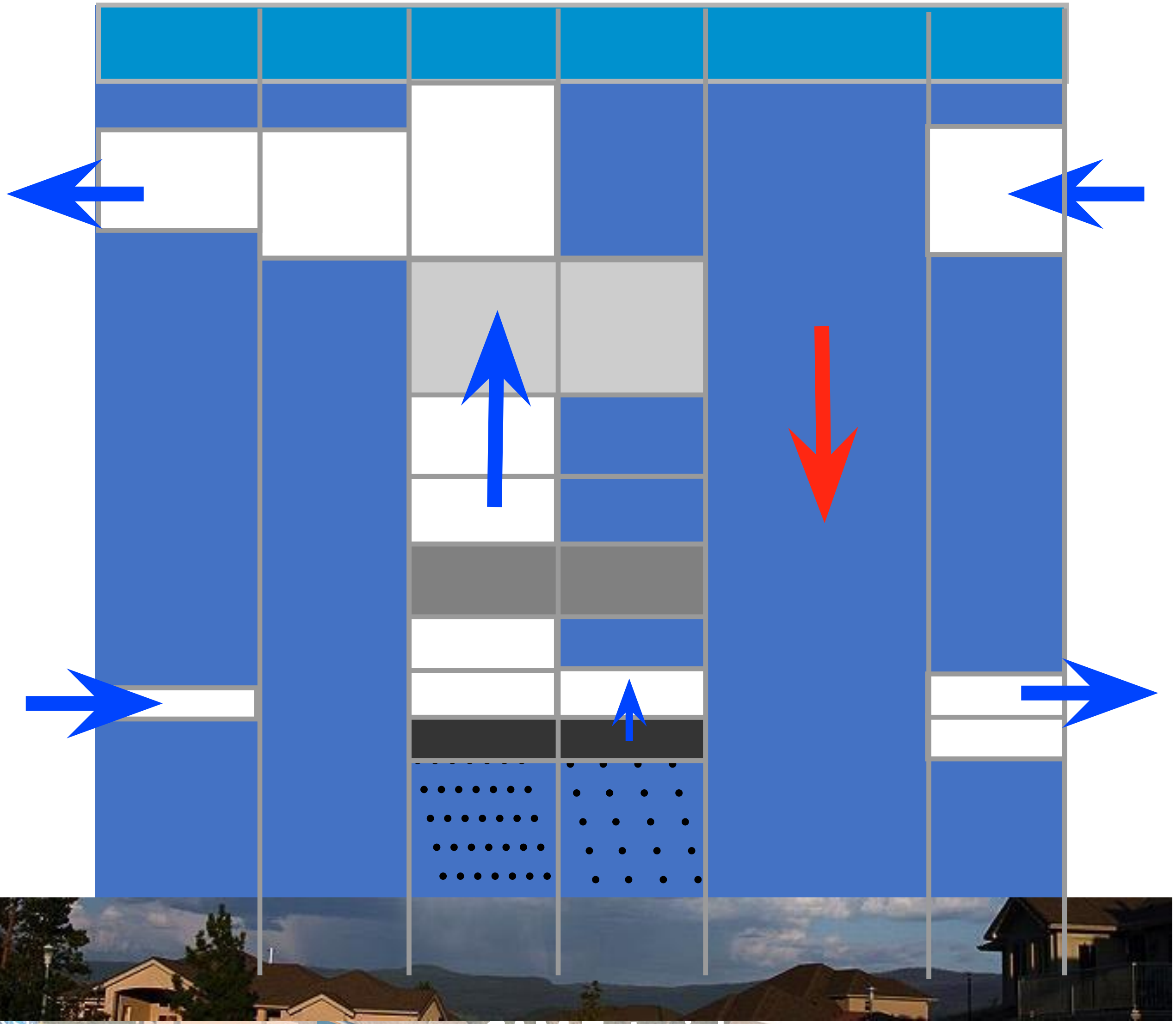
Issues

- Instrument bias (the instrument model is wrong)
- Instrument noise (unbiased, but scatter)
- Sampling volume: what is being compared.
- Bottom line: mostly we have apples and oranges. As long as we are still dealing with fruit and we know this, maybe okay.
- Almost all observations have a model embedded in them!

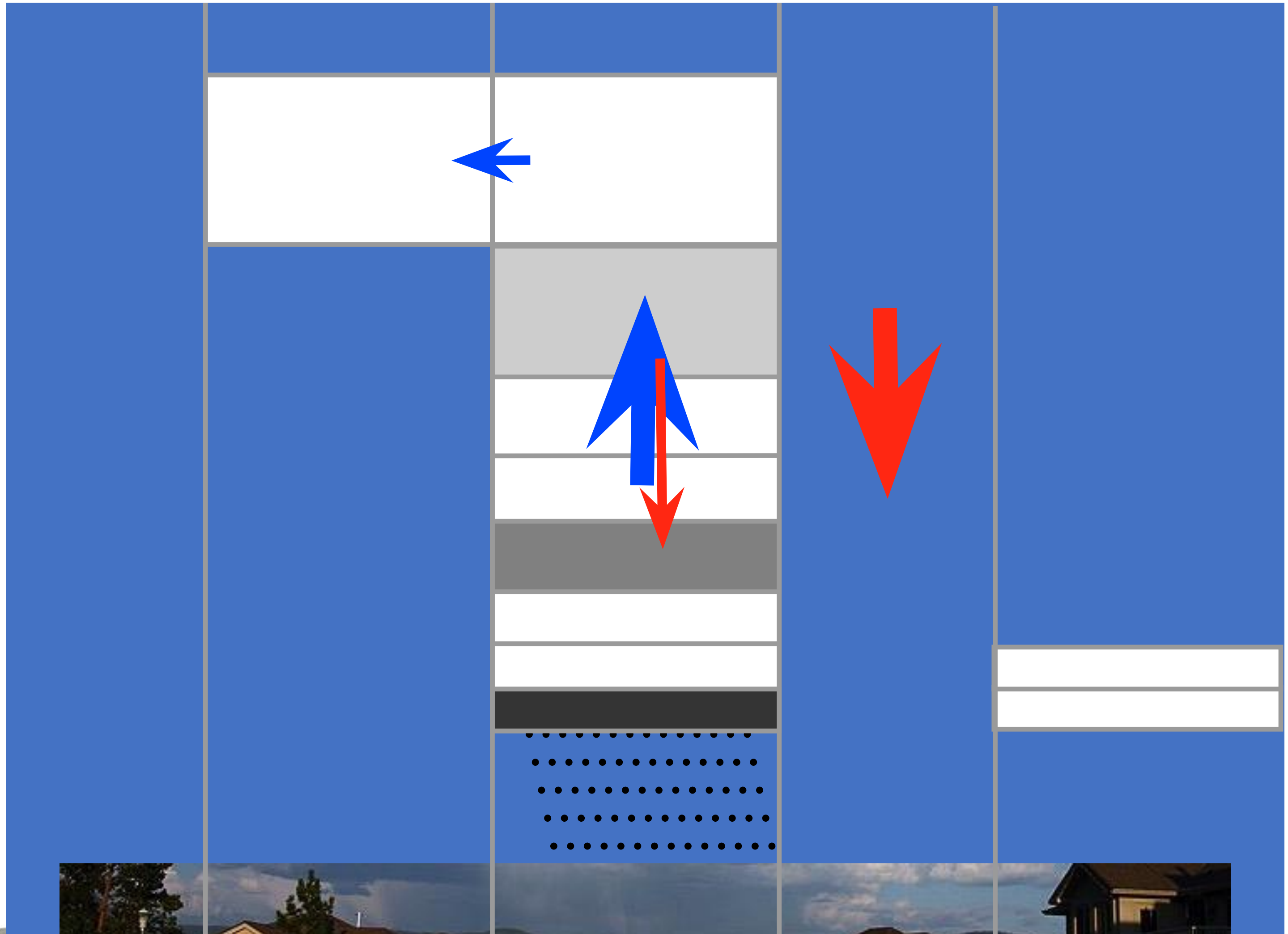

AIRS Brightness Temp, April 2003

How does a model see clouds?

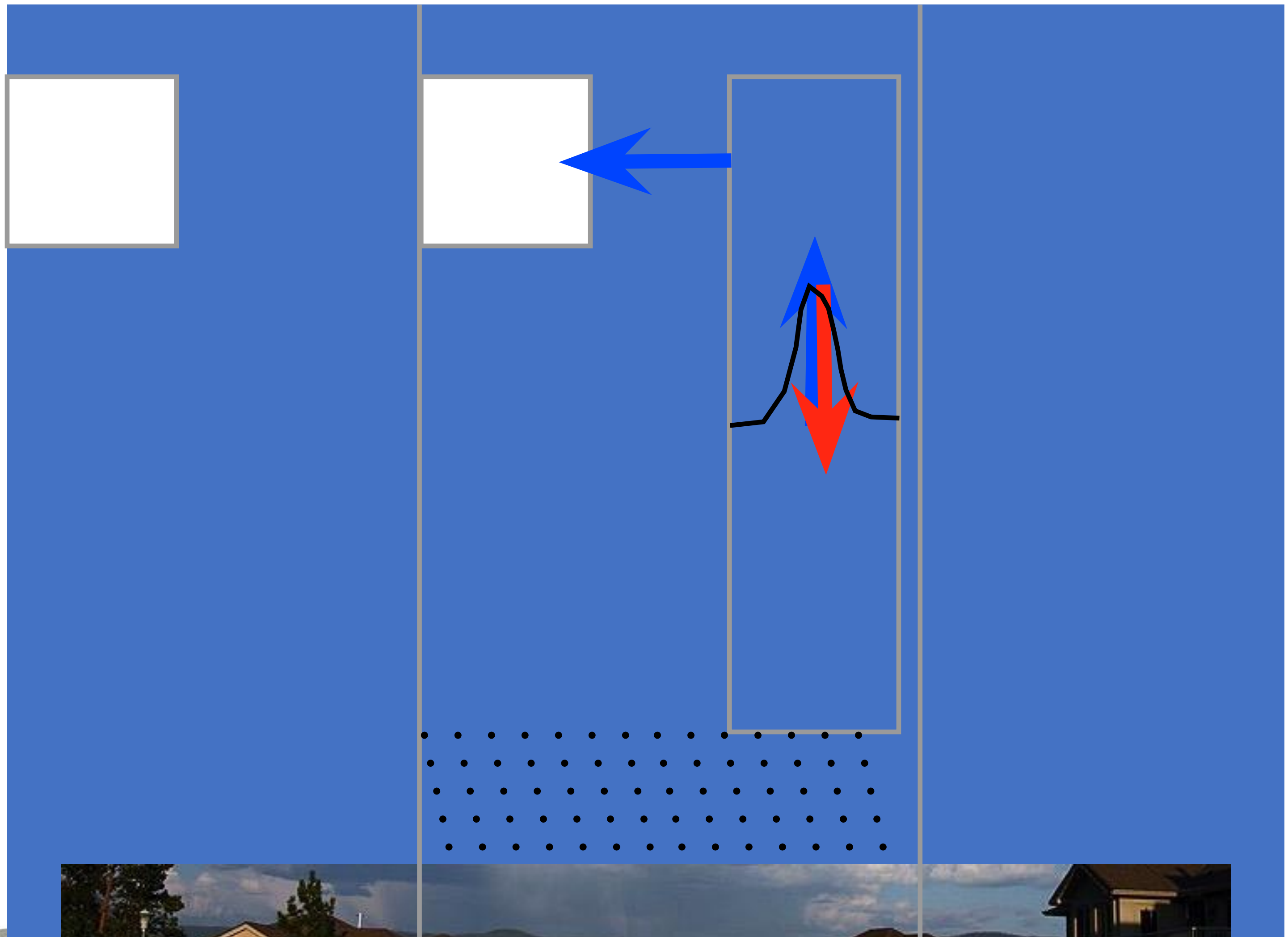
CRM/LES Convective Cloud



Mesoscale Convective Cloud



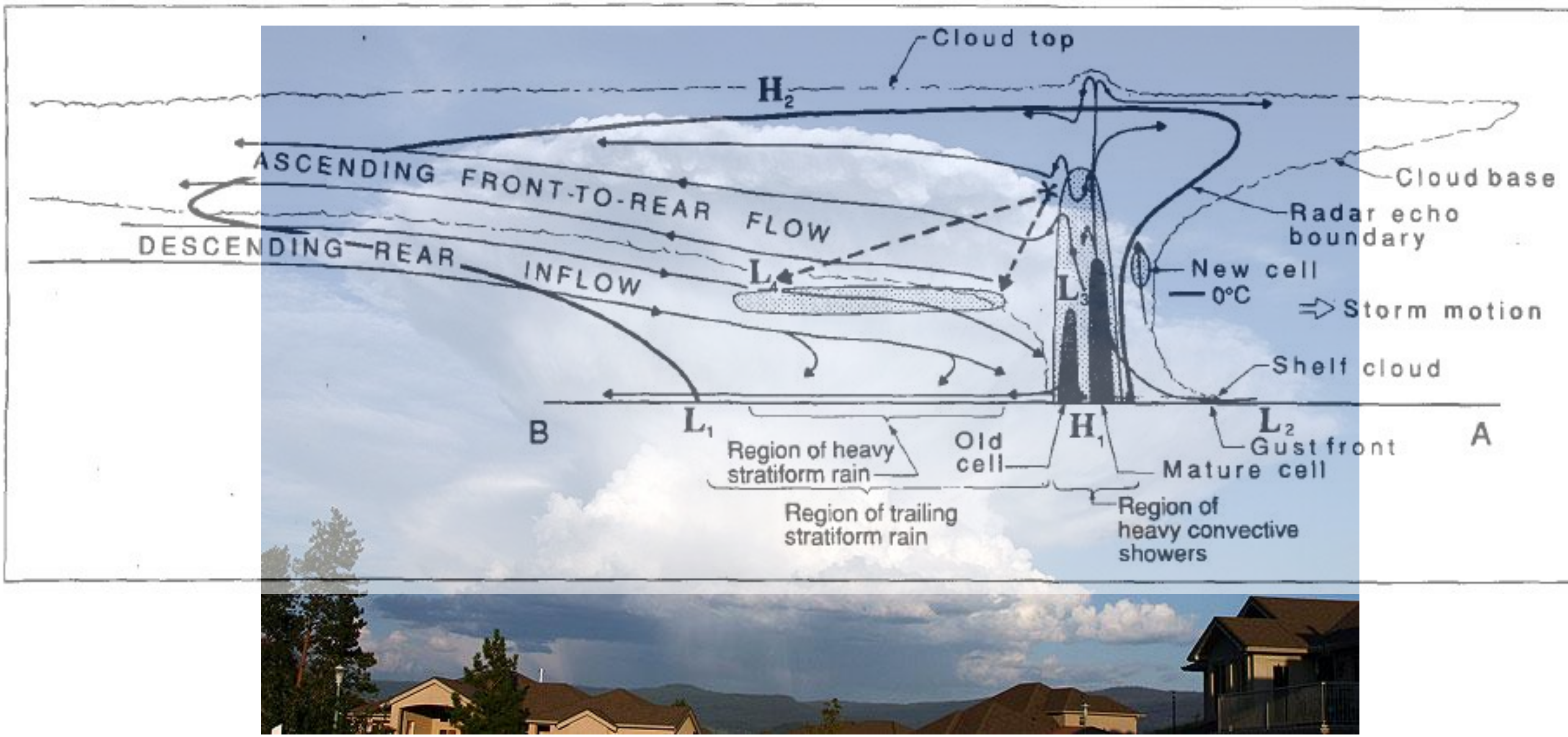
GCM Convective Cloud



This is a (picture of a) Cloud

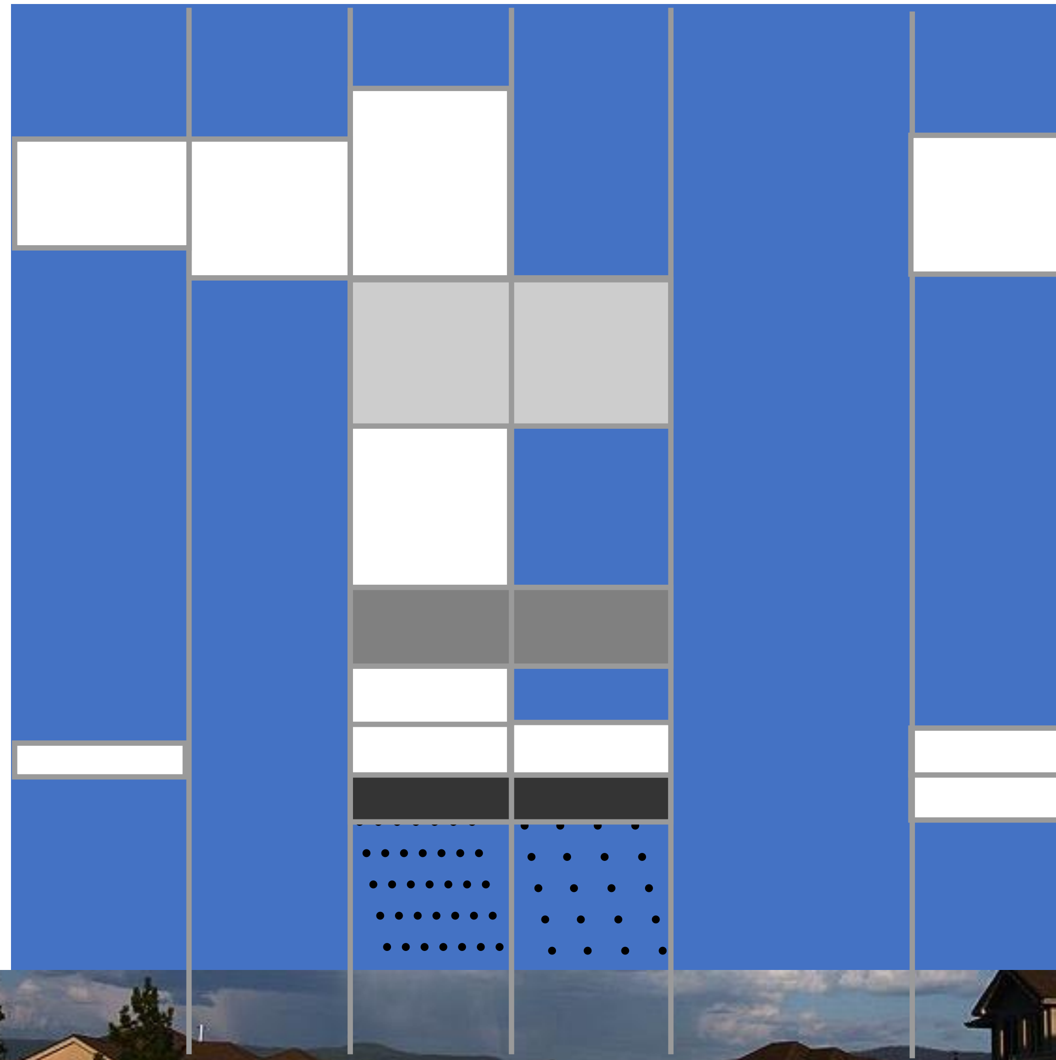
How do we observe it?

Conceptual Picture

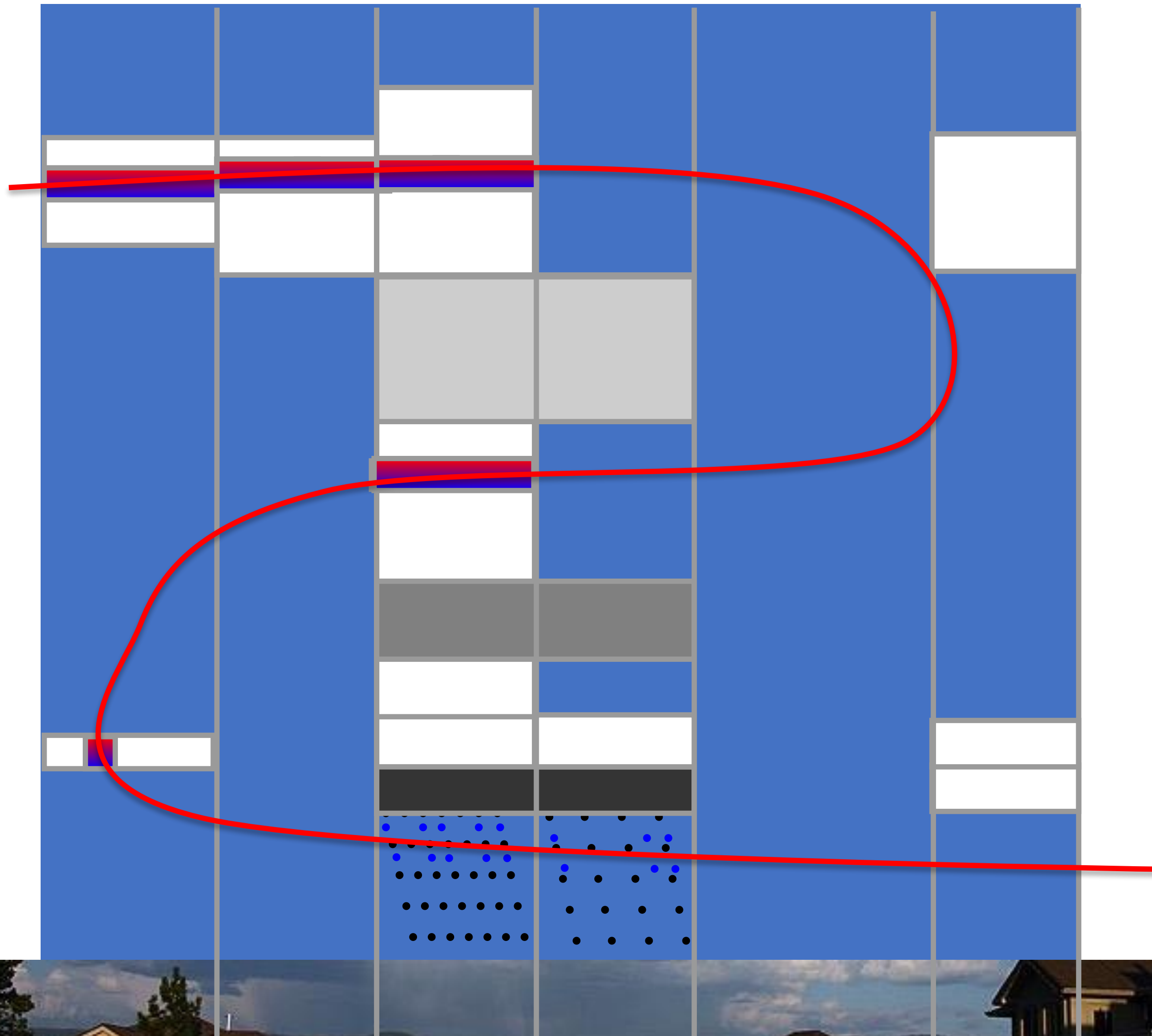


Houze et al., BAMS, 1989

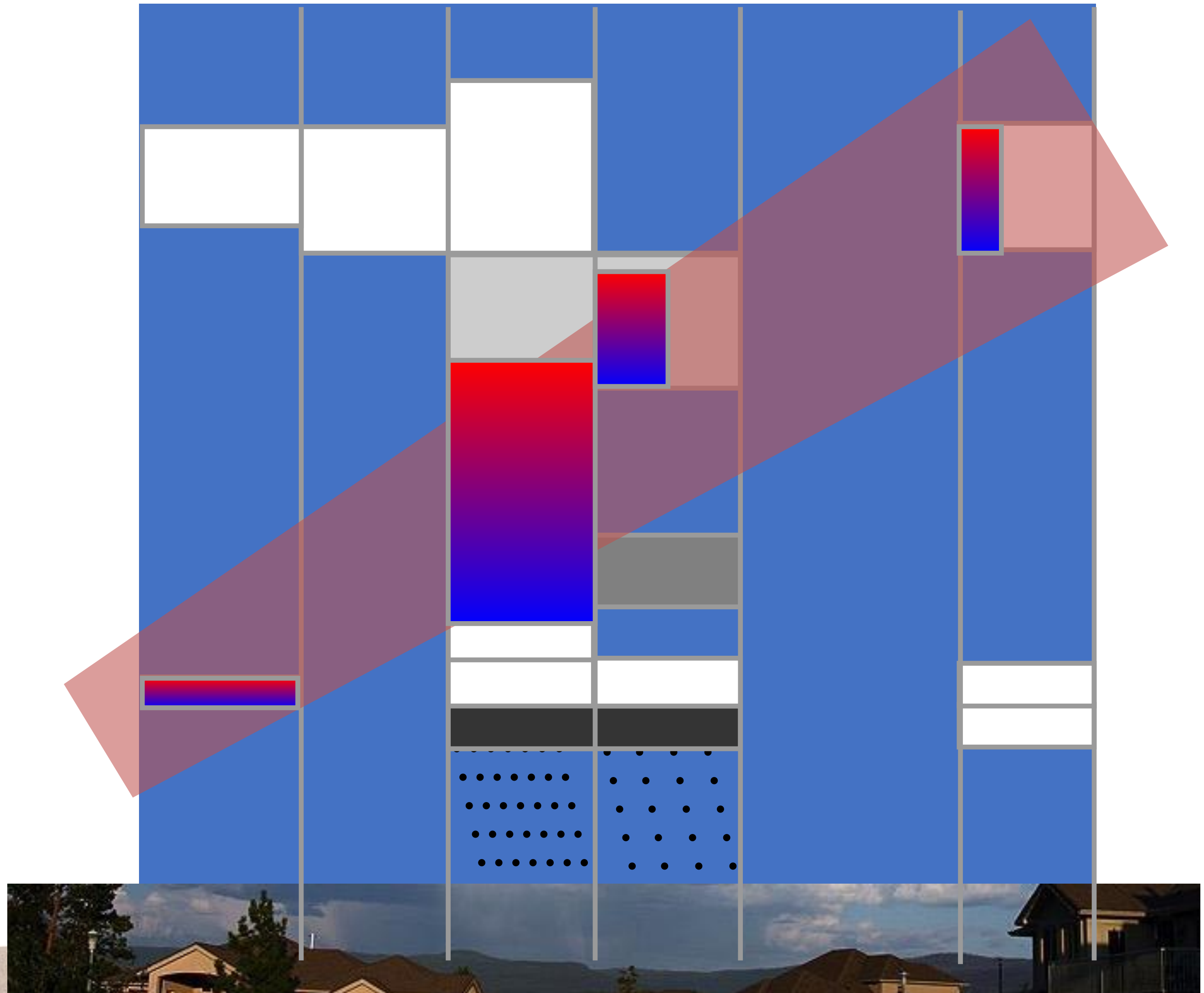
Convective Cloud (=Truth for now)



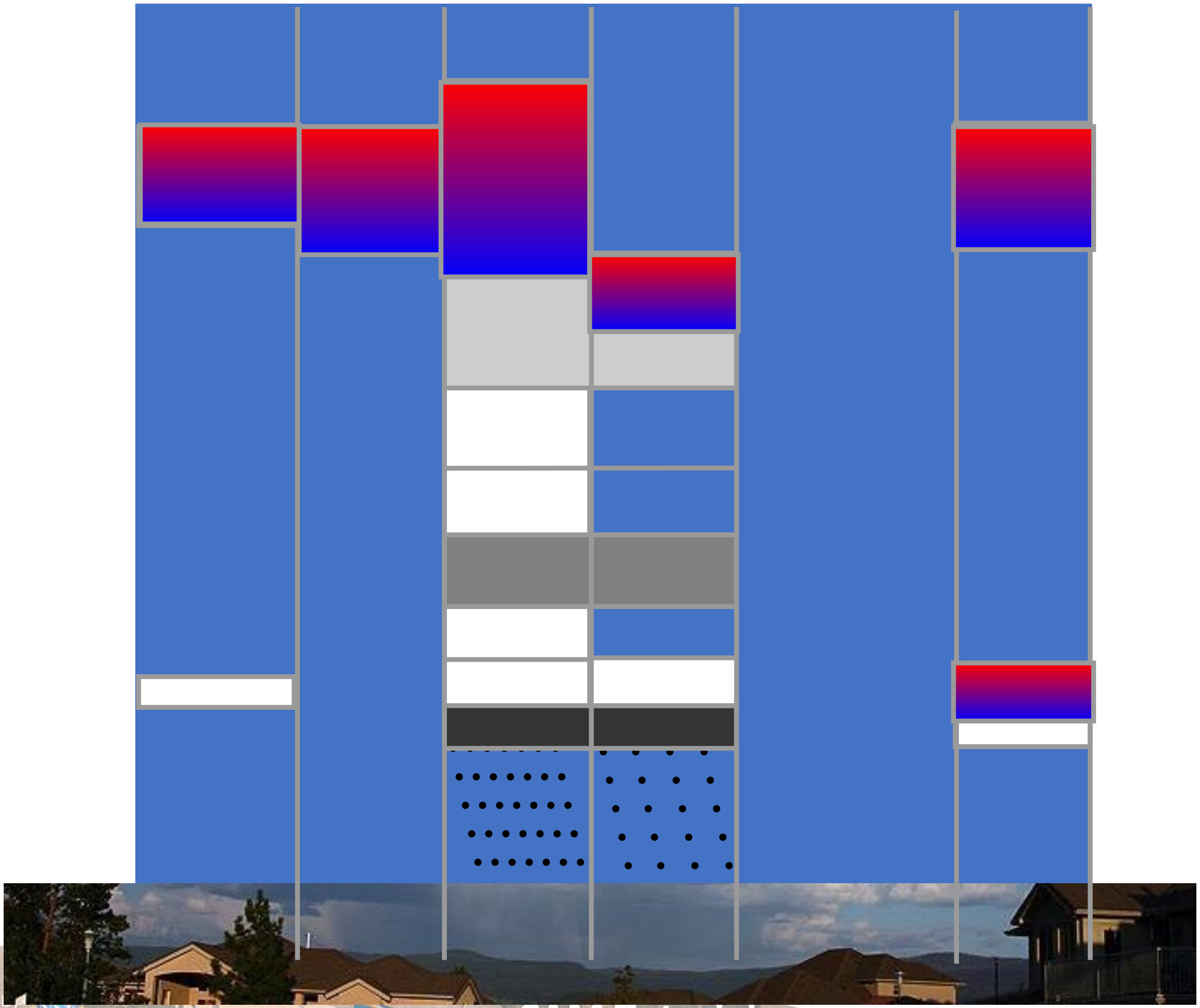
Aircraft Convective Cloud



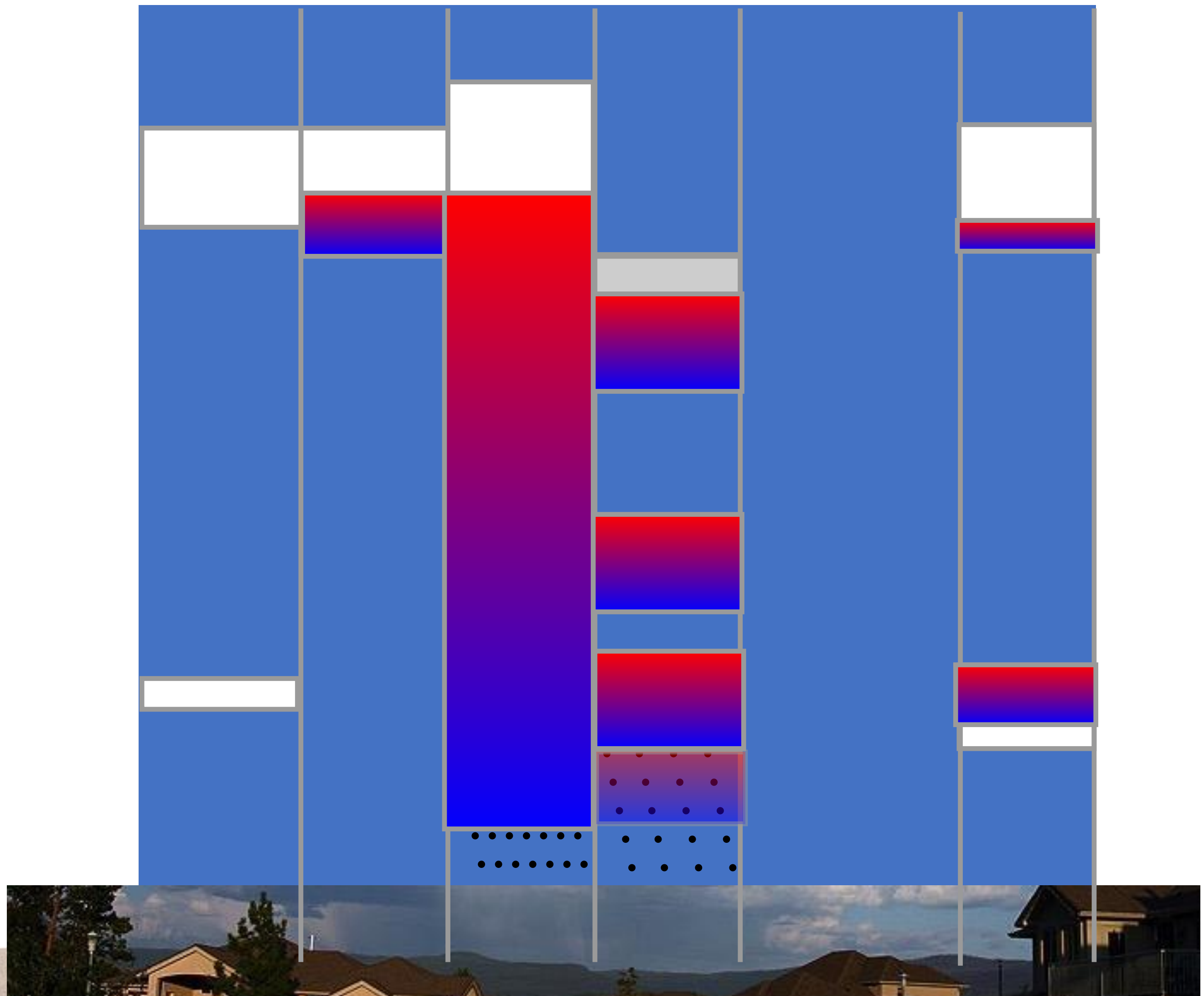
Radar Convective Cloud



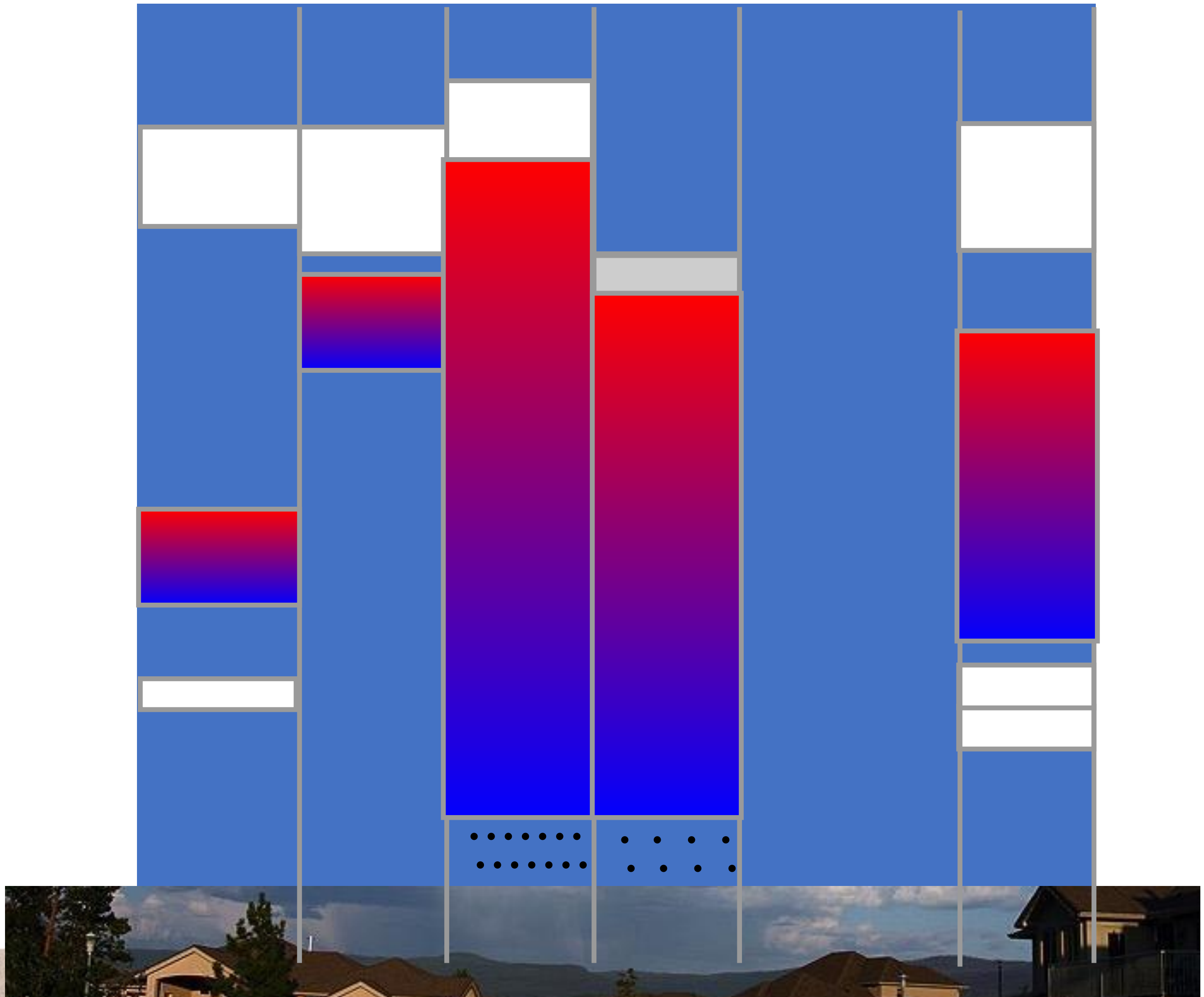
Lidar (CALIPSO) Convective Cloud



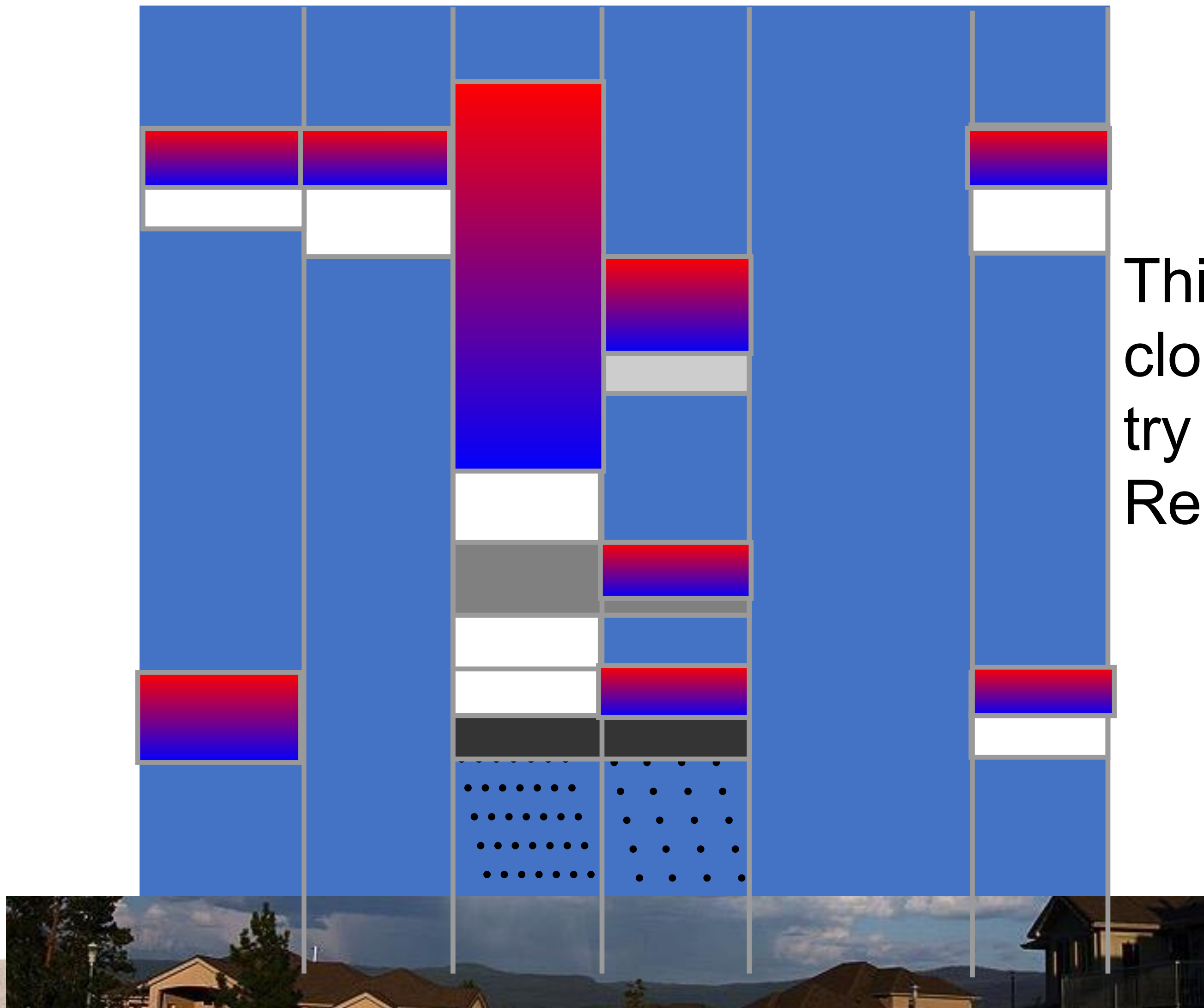
Radar (CloudSat) Convective Cloud



IR (MODIS) Convective Cloud



Vis/IR (MISR) Convective Cloud



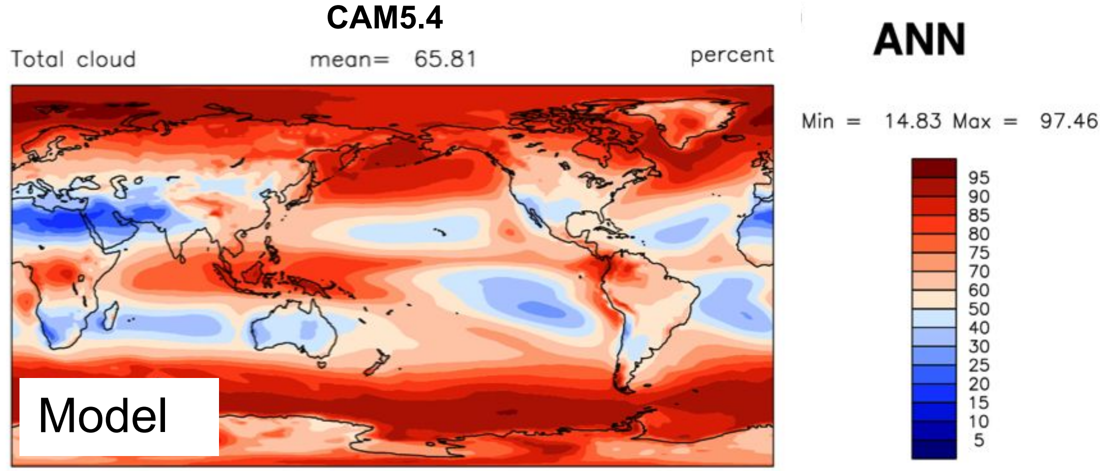
This is just cloud fraction: try it with LWP, Re, etc !

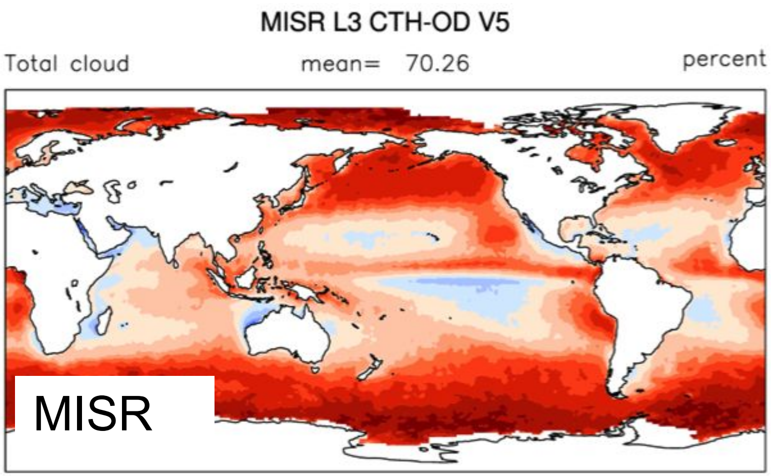
Traditional Evaluation Methods

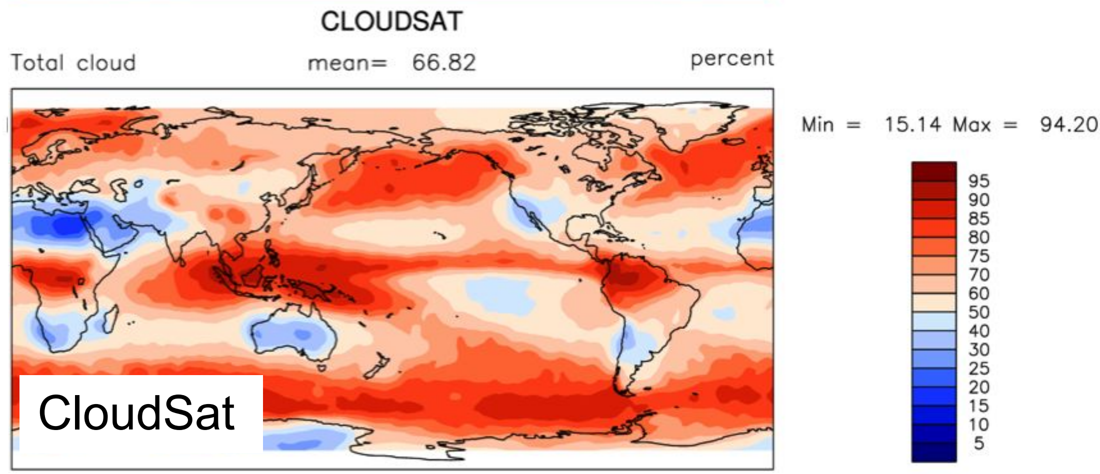
- Climate Evaluation
  - Use the easy variables: Cloud Fraction
  - Means or Climatology
- Weather Evaluation
  - Forecast: Looks okay
  - Composites
  - Forecast Skill Metrics

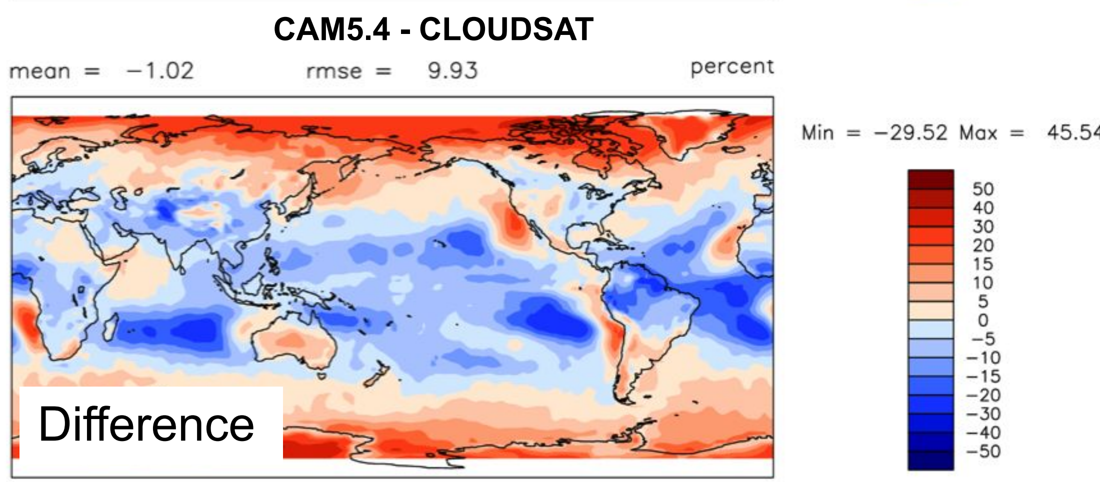
Climate Evaluation: Cloud fraction…

Traditional View: Model – CloudSat (Radar+ Lidar)





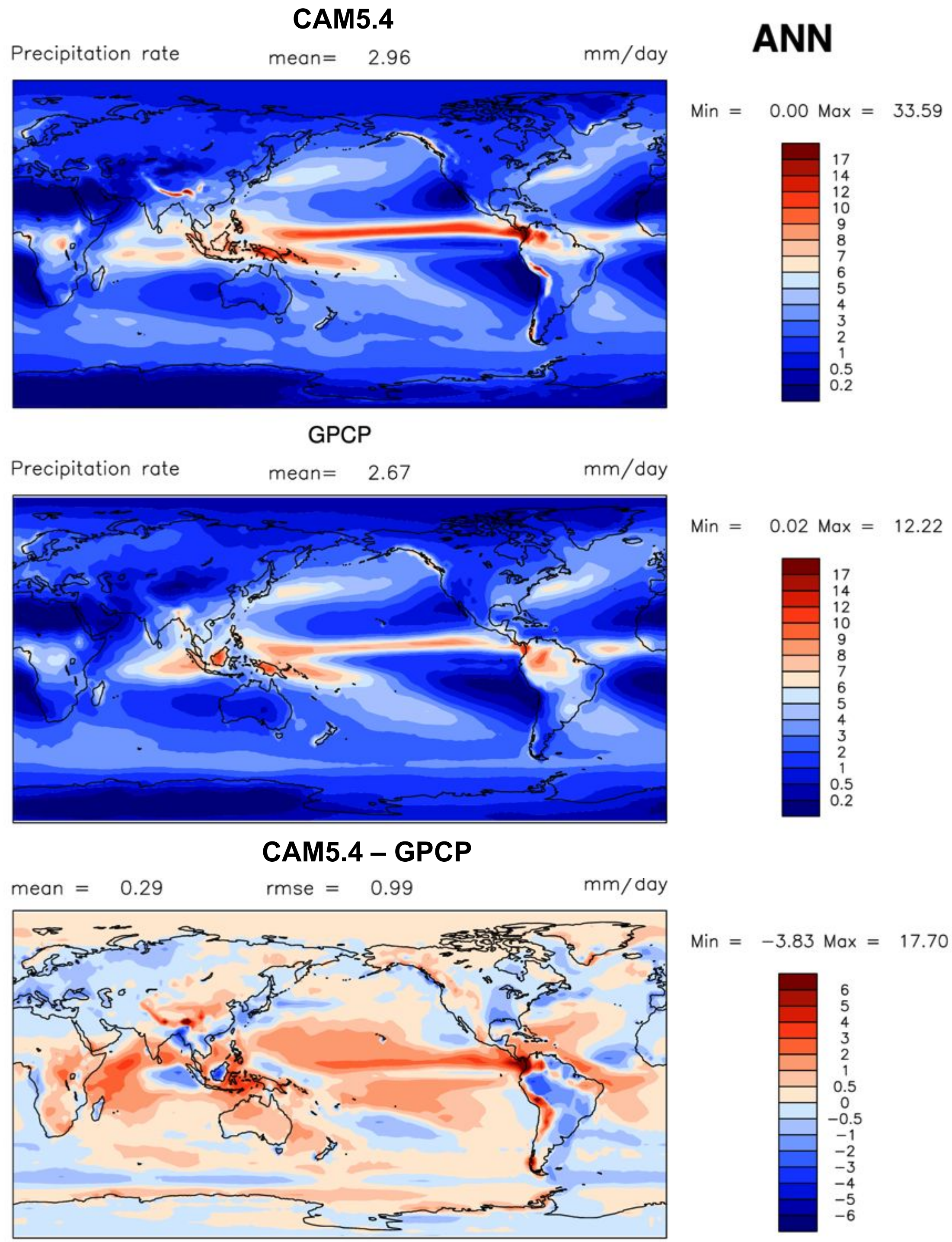




Biases change with data set.
May even change sign!

Mean Metrics

Example: Precipitation



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

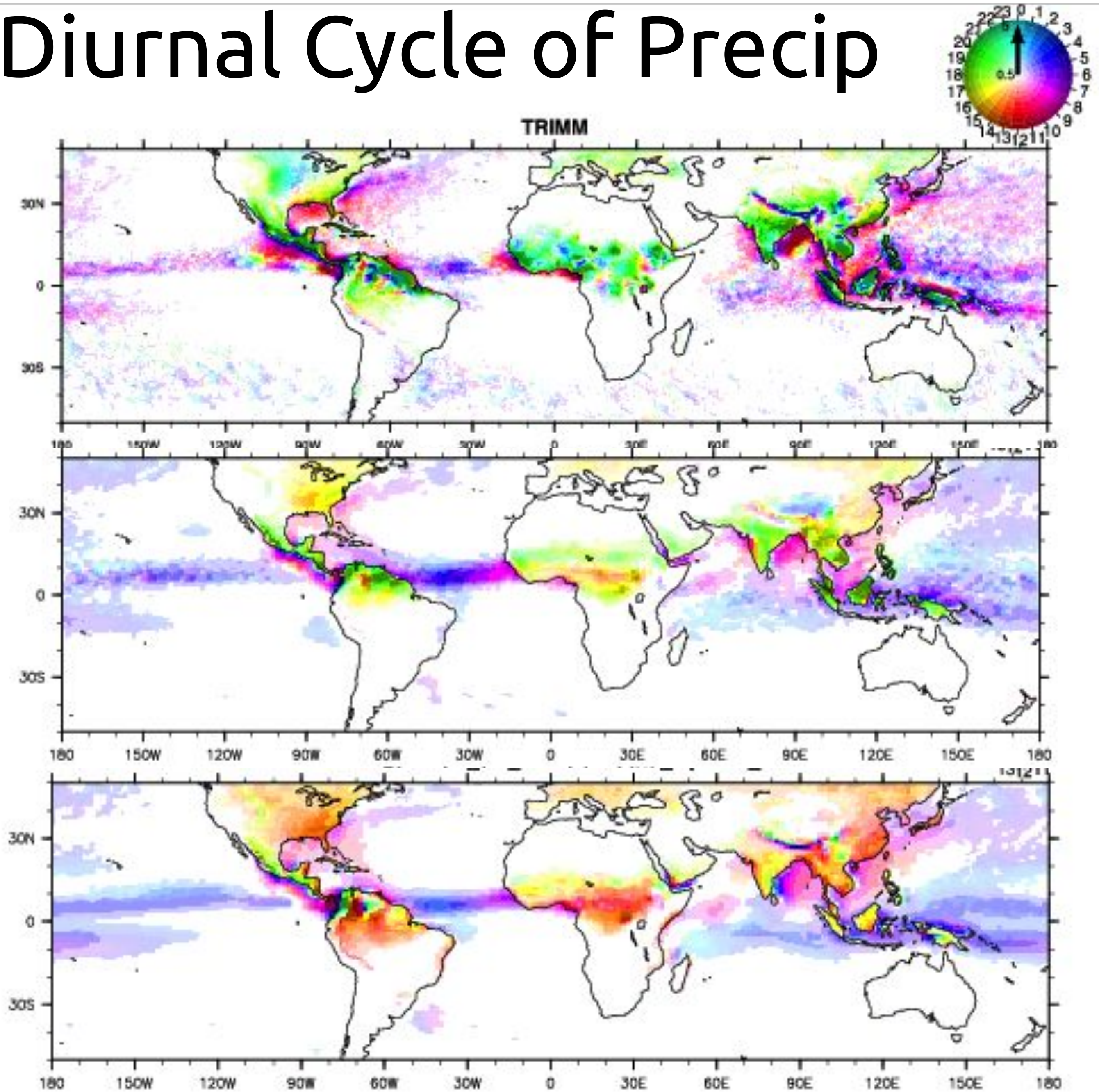
Variability: Diurnal Cycle of Precip

JJA Precipitation Rate

TRMM: OBS

CAM5.5 (new)

CAM5.3 (Old)

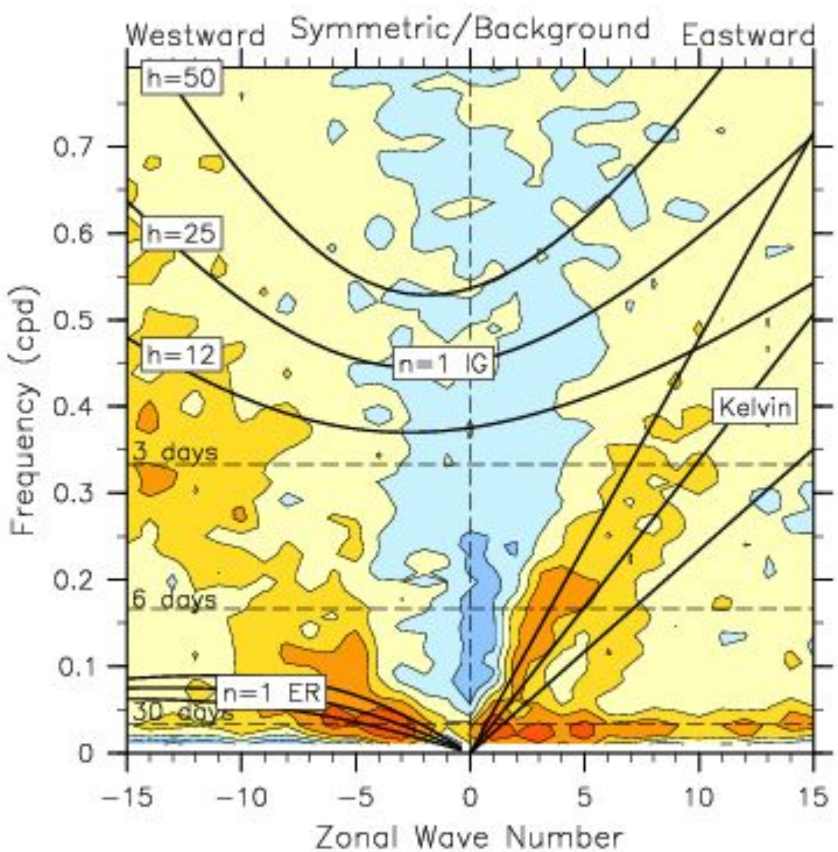


Thanks to R. Neale, C-C. Chen

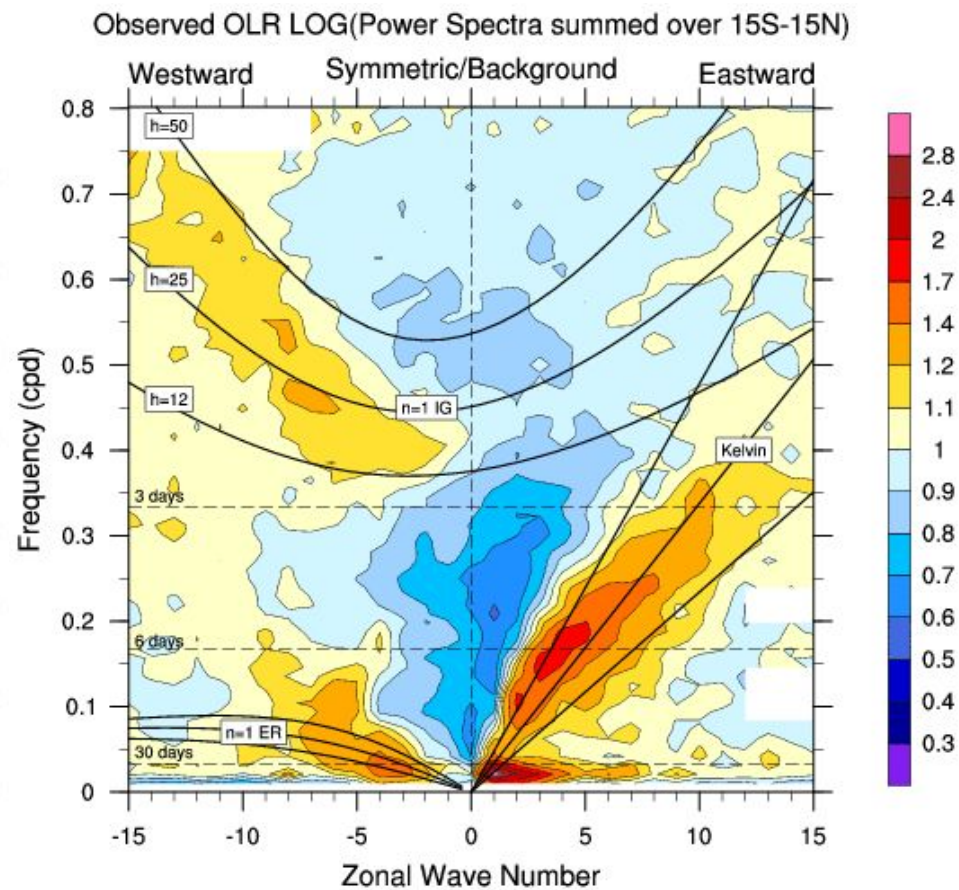
Variability: Tropical Waves

Symmetric OLR Spectrum (Wheeler & Kiladis, 1999)

CAM5.5

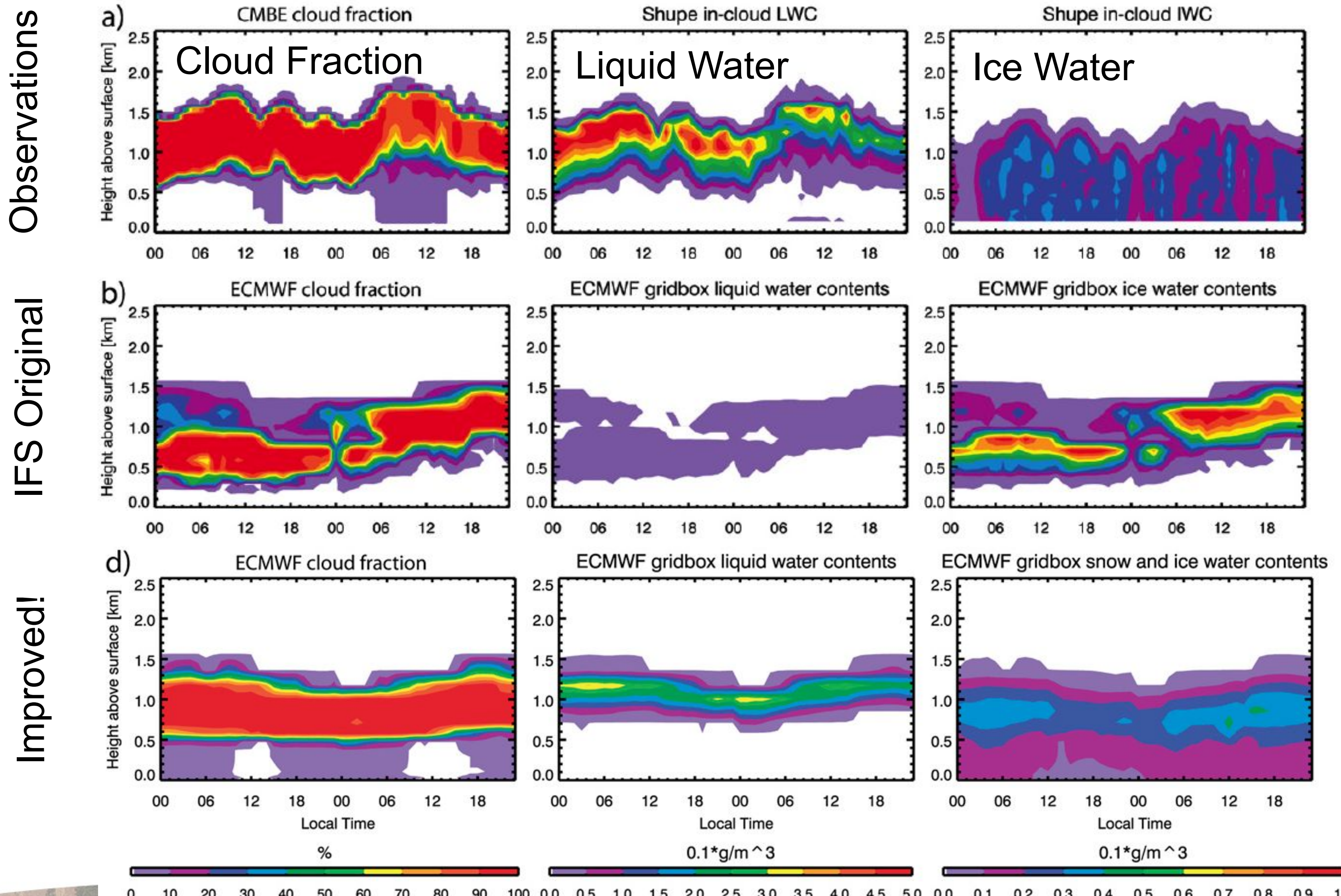


NOAA-OLR



Weather Model Forecasts: Case Study

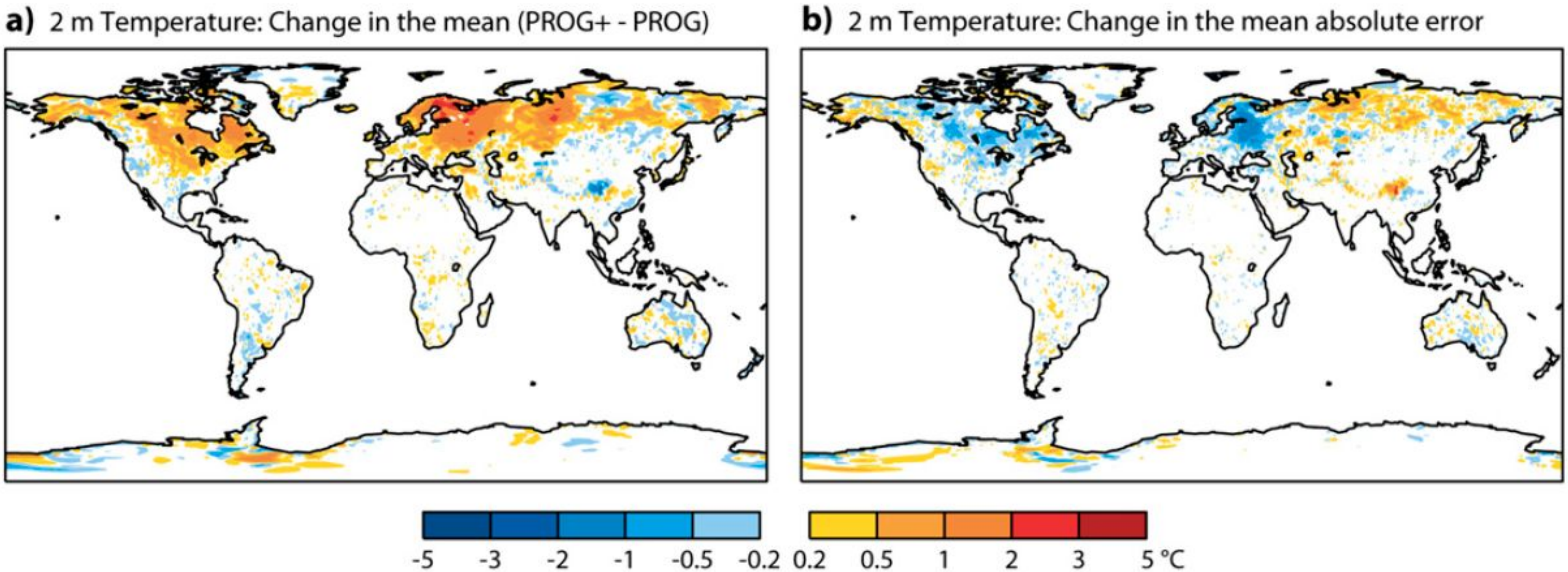
Mixed Phase Arctic Clouds



Forbes and Ahlgrimm, 2014, MWR

Show it works globally

Warmer Temps = Reduced Mean Error



Goal was to reduce a temperature bias

Forbes and Ahlgrimm, 2014, MWR

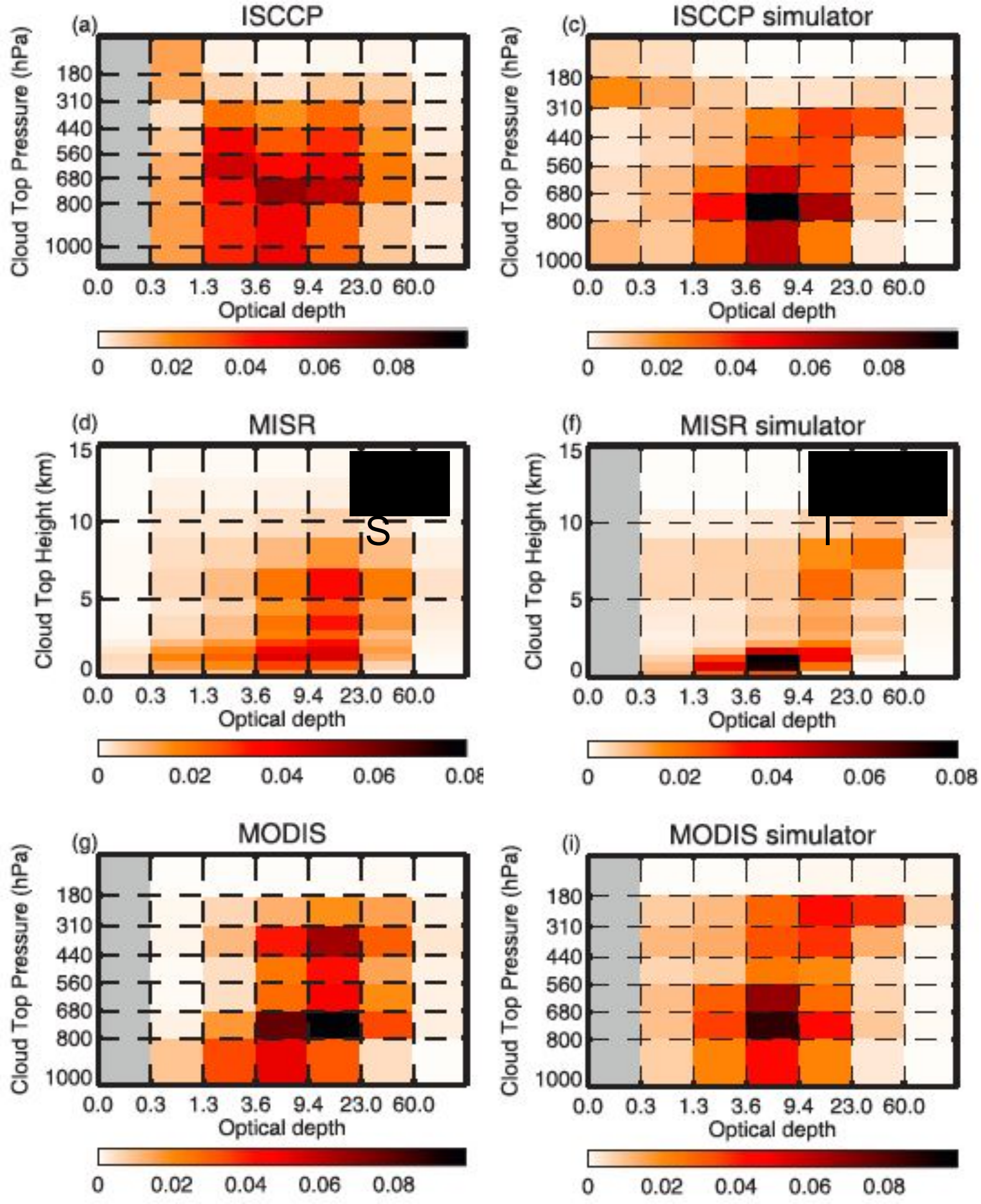
Instrument Simulators

- 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

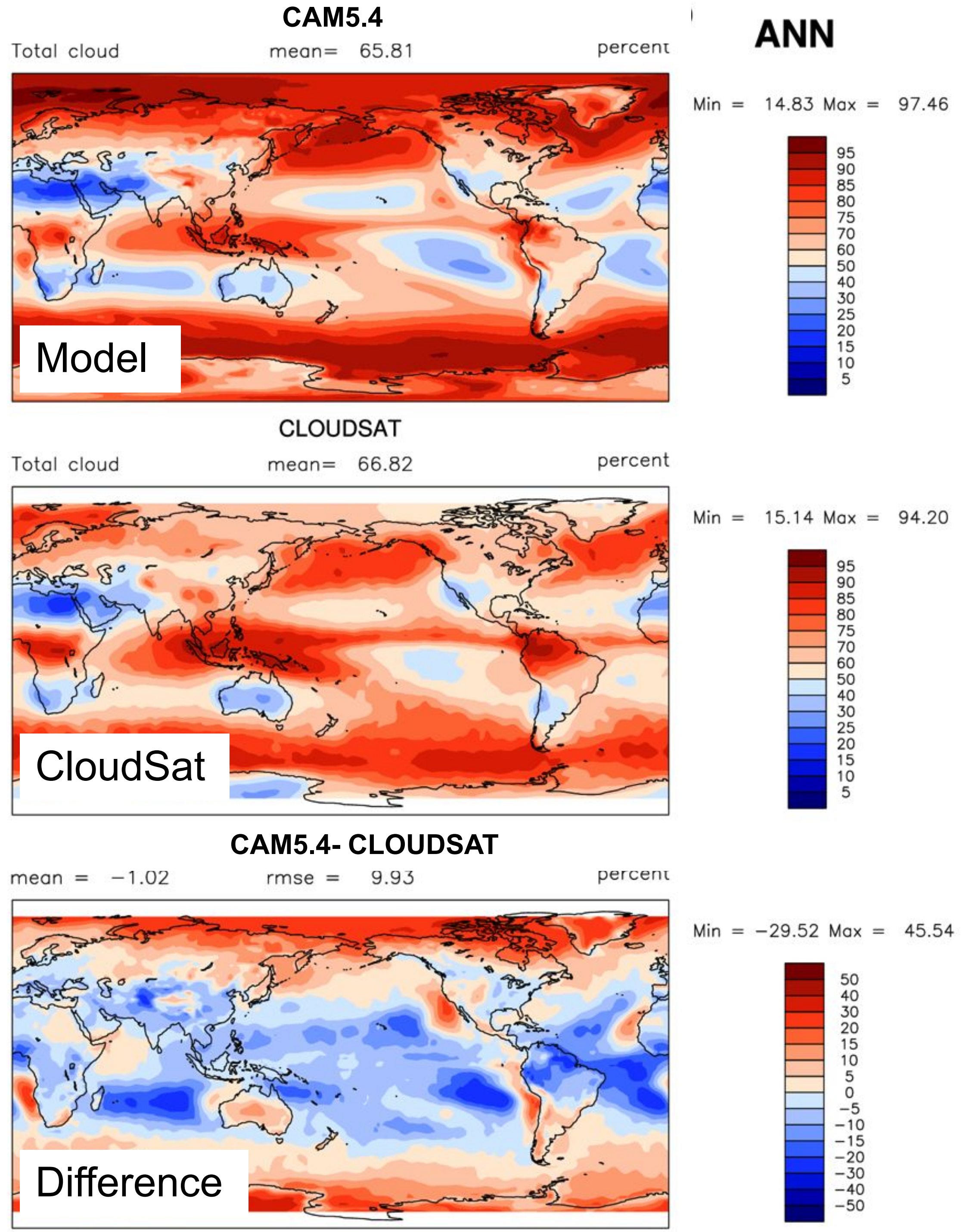
Simulator Examples: UM



Bodas-Salcedo et al (2012)

Cloud fraction…

Traditional View: Model – CloudSat (Radar+ Lidar)

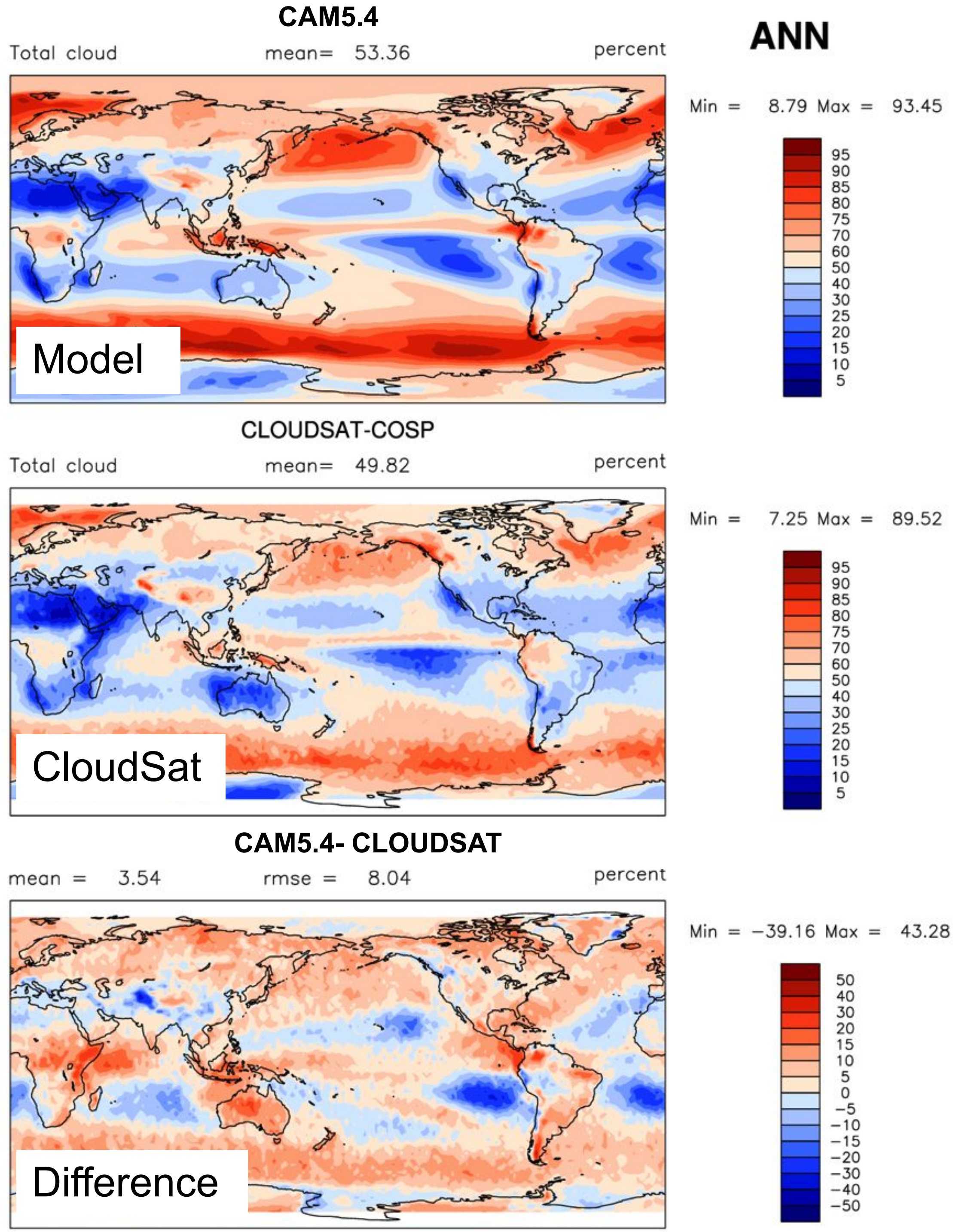


Cloud Fraction

SIMULATOR VIEW Model – CloudSat

CloudSat Product only. Fewer clouds (no Lidar). Model higher in tropics. Also removes some low clouds near surface (higher latitudes).

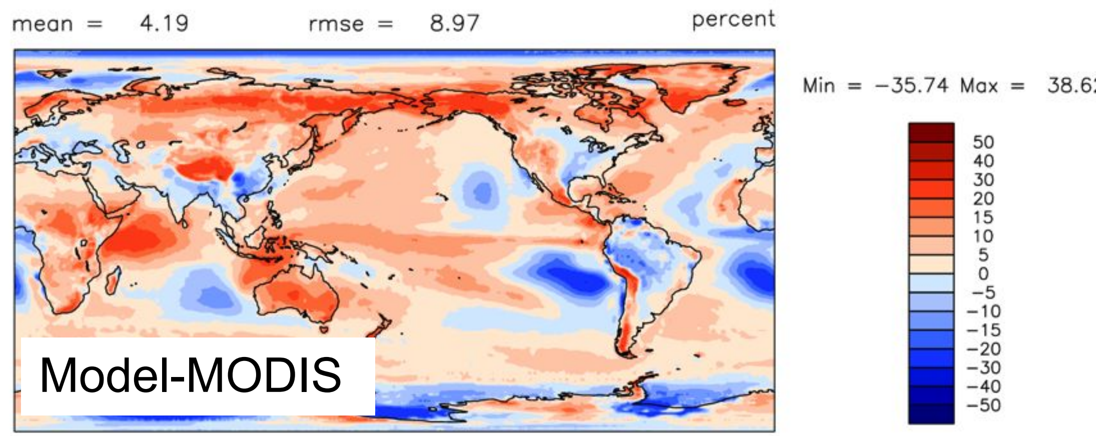
- Simulated cloud fraction is lower.
- Bias is a different sign.

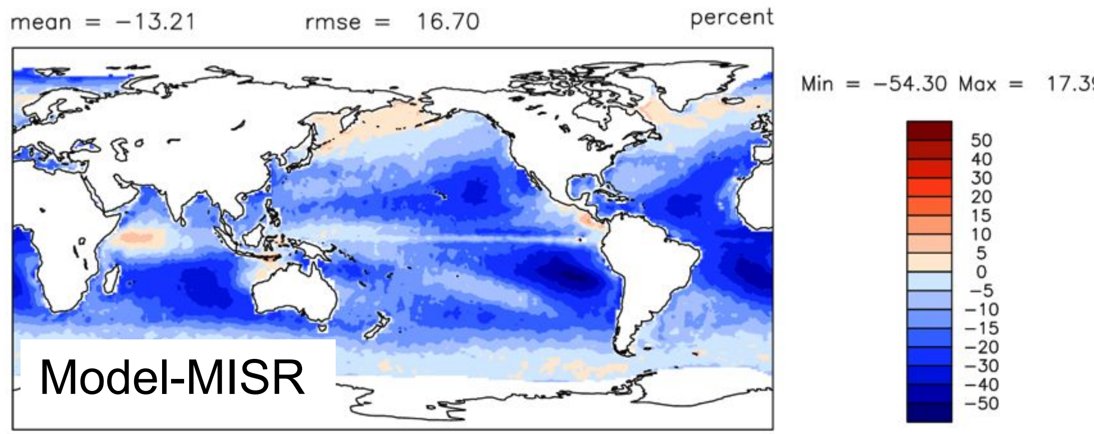


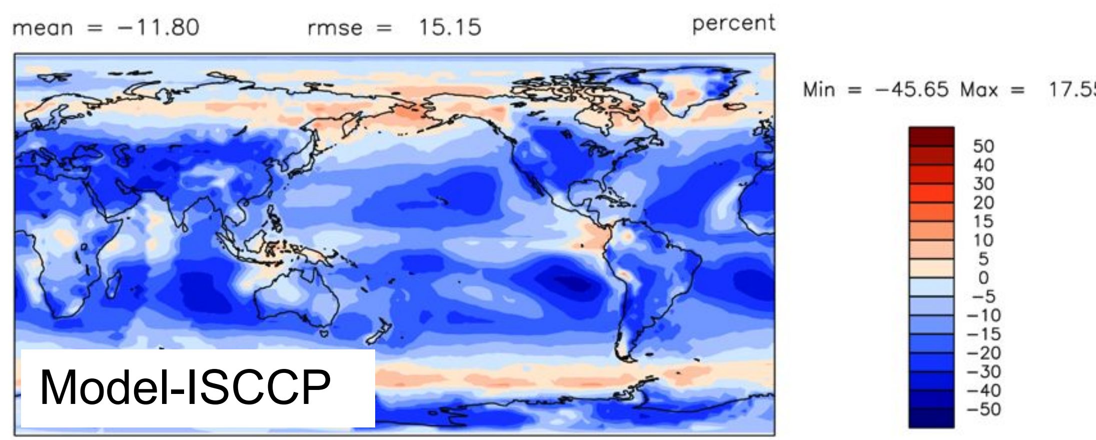
Cloud Fraction Differences (τ>0.3)

Different bias against different instruments

This is the same model run!







LWP: Wrong Message

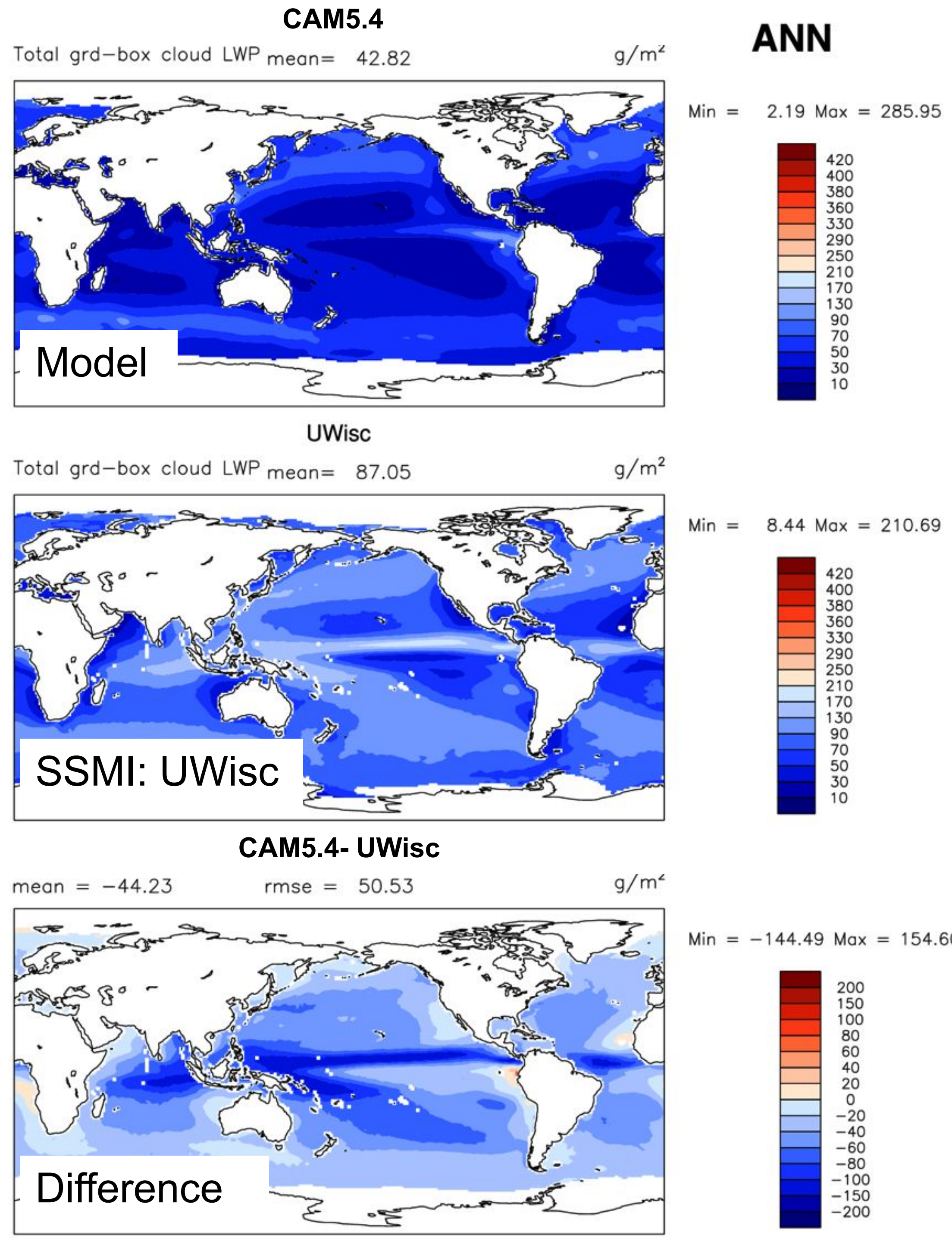
Traditional comparison of Model LWP field against Microwave Satellite Observations of LWP.

Model is low.

But cloud forcing looks okay.
Cloud fraction looks okay.

What is going on?

Same problem with comparison with MODIS LWP retrievals…

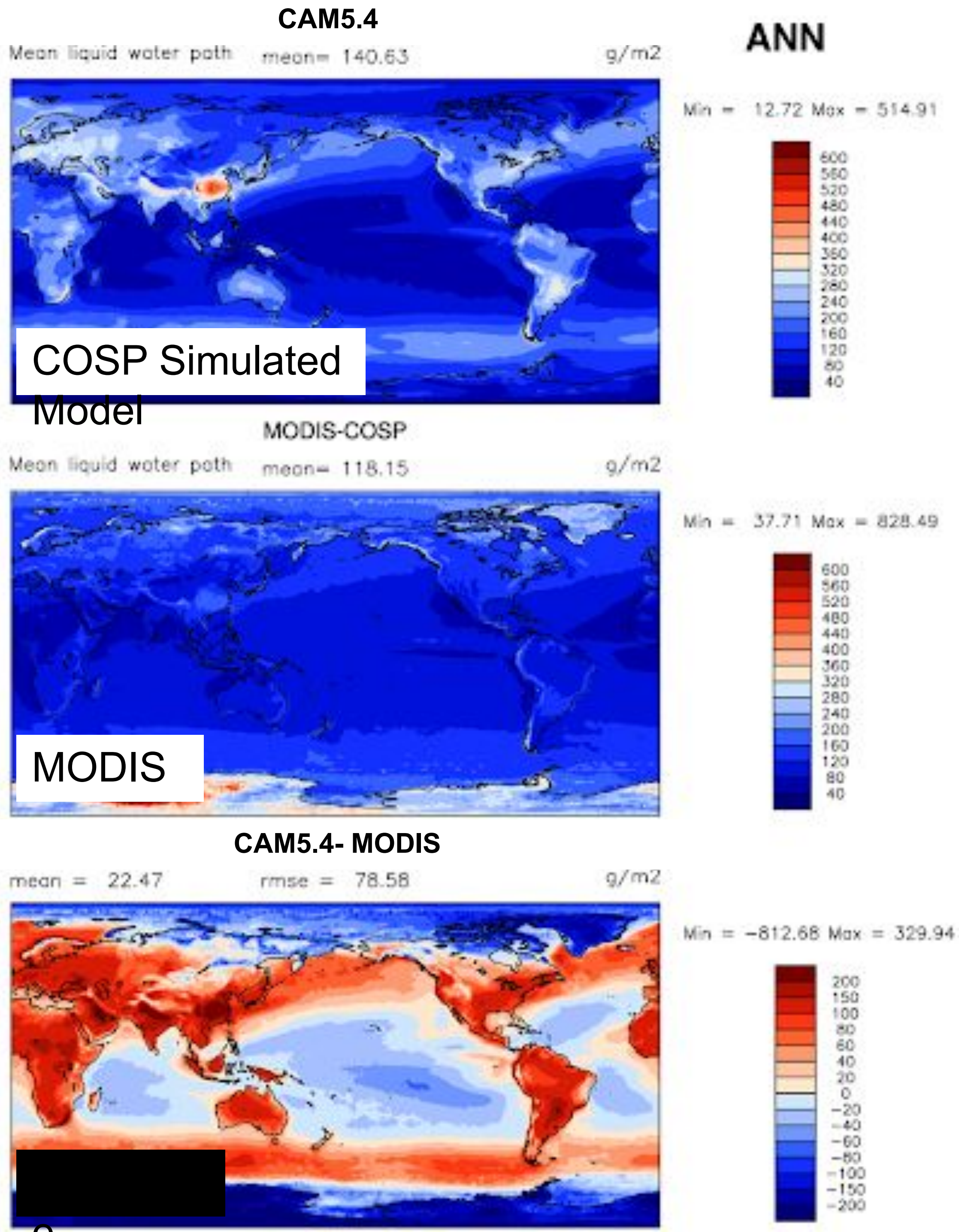


LWP: Correct Message

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 ($Z \propto D^{-6}$)

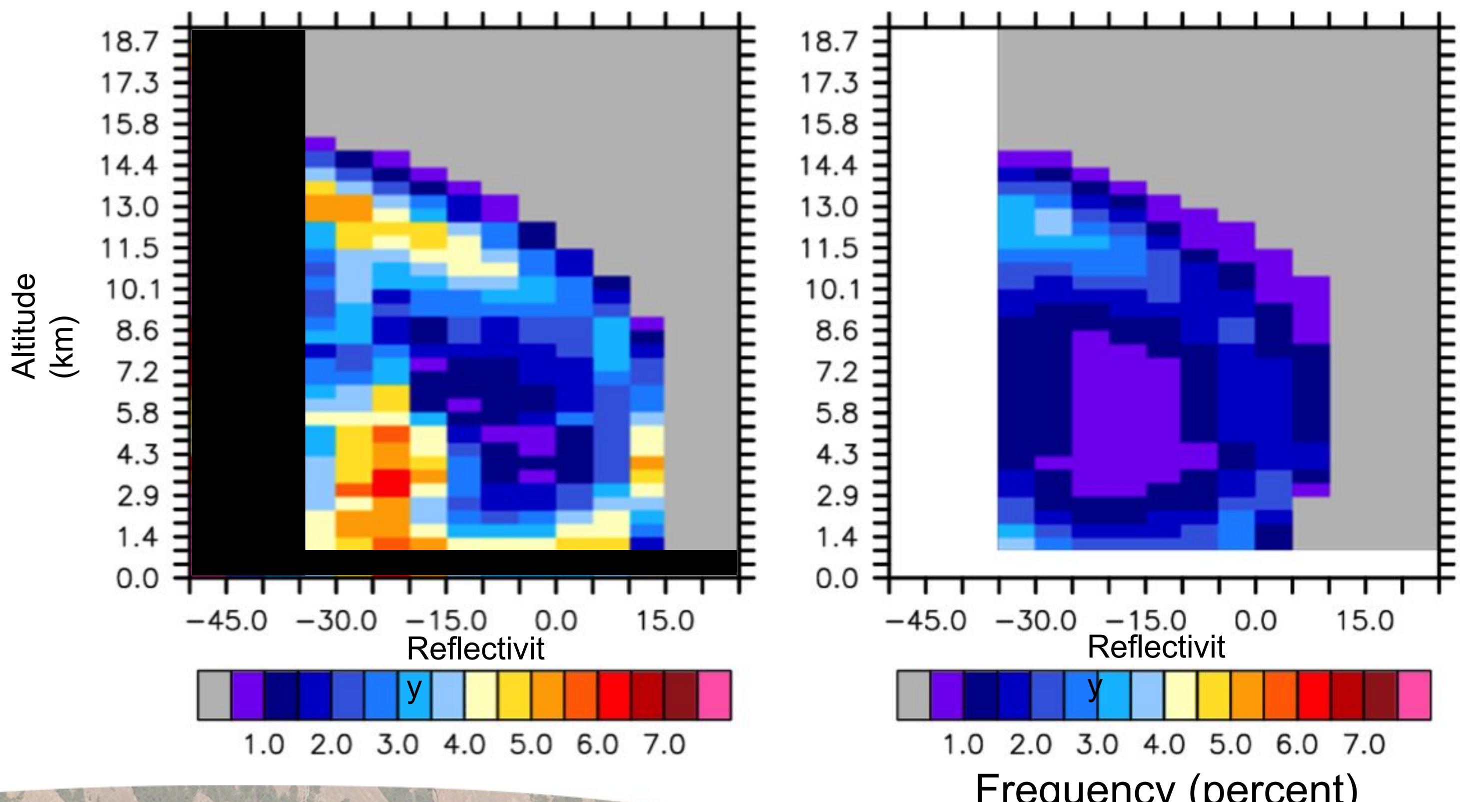
Cumulative Frequency by Altitude Diagram (CFAD)

Shows modes of variability and regimes in models and observations

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

MODEL

CLOUDSAT

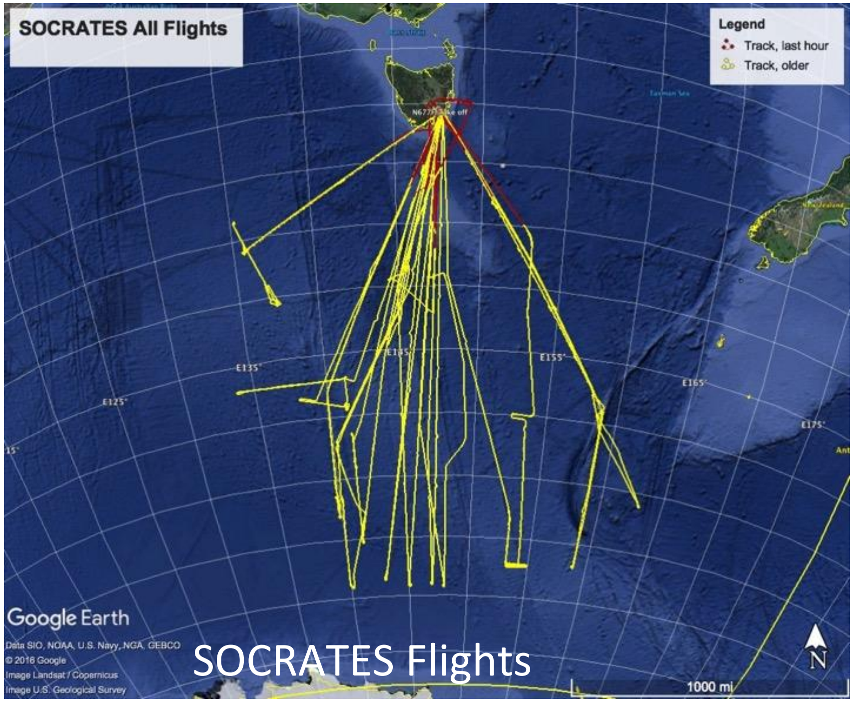


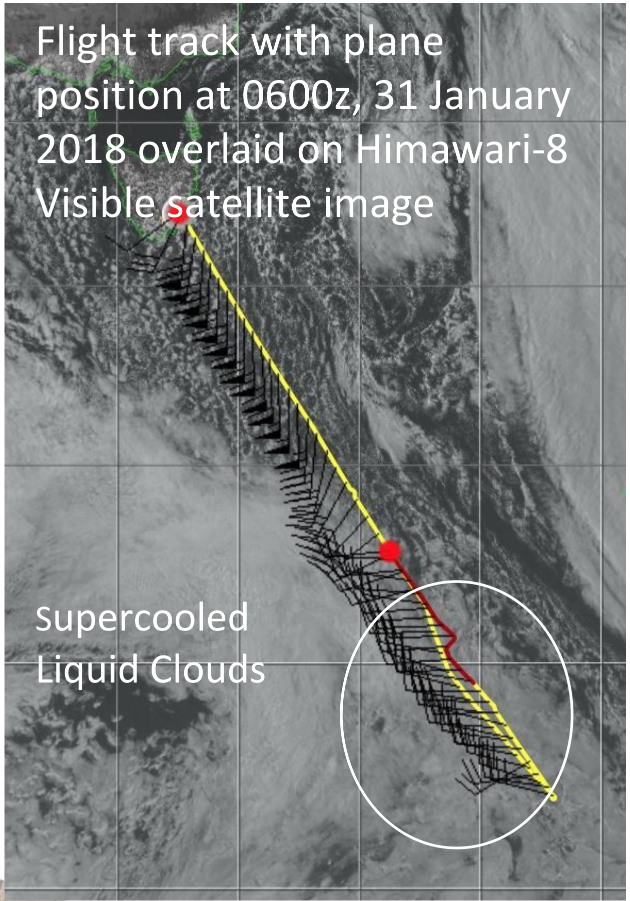
Complexities

- 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

In Situ Observations

The 2018 SOCRATES project used Southern Ocean aircraft and ship observations to sample clouds. Simulate details of cloud drop size distributions



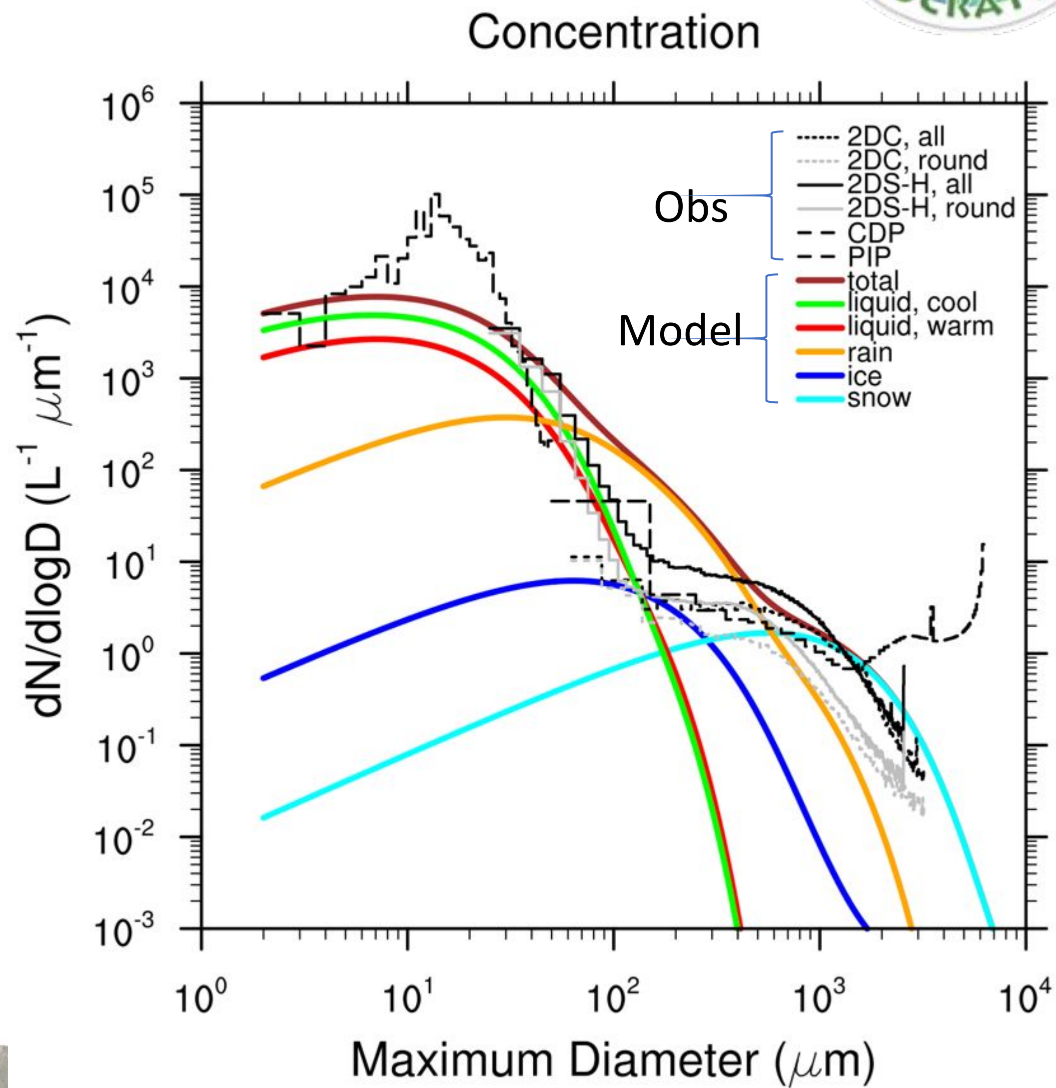


Model v. Obs Size Distributions

Model (CAM6) nudged to observations and sampled along SOCRATES flight tracks over the S. Ocean.

Model does a good job at reproducing obs, with some caveats.

Hints at fundamental issues with modal formulations (Exponential and Gamma functions.



CAM Diagnostic 'Packages'

- **Mean Climate**: Atmospheric Model Working Group (AMWG) Diagnostic Package
- **Atmospheric Processes:** NOAA Model Diagnostics Task Force (MDTF) Package
- **Climate Variability:** Climate Variability Diagnostic Package (CVDP)

Mean Climate

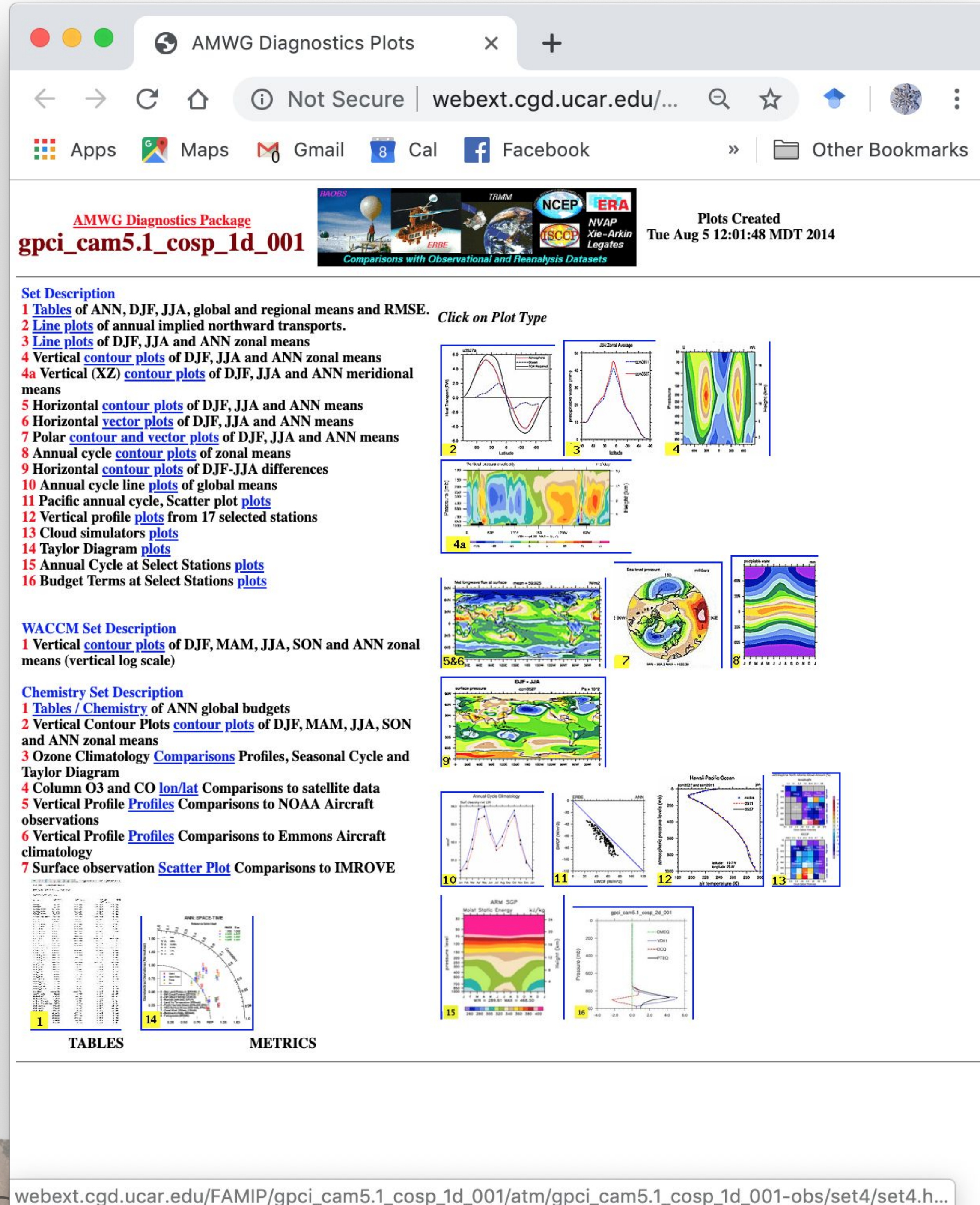
http://www.cesm.ucar.edu/working_groups/Atmosphere/amwg-diagnostics-package/

- AMWG Diagnostic Package
- Shell script that Calls NCL
- Set analysis
  - Model v. Obs
  - Model v. Model
  - Works on monthly mean model output
- Extensions for:
  - Chemistry
  - WACCM (Stratosphere and Mesosphere)

AMWG Example

Model v. Obs

[Link to example]



Atmospheric Processes

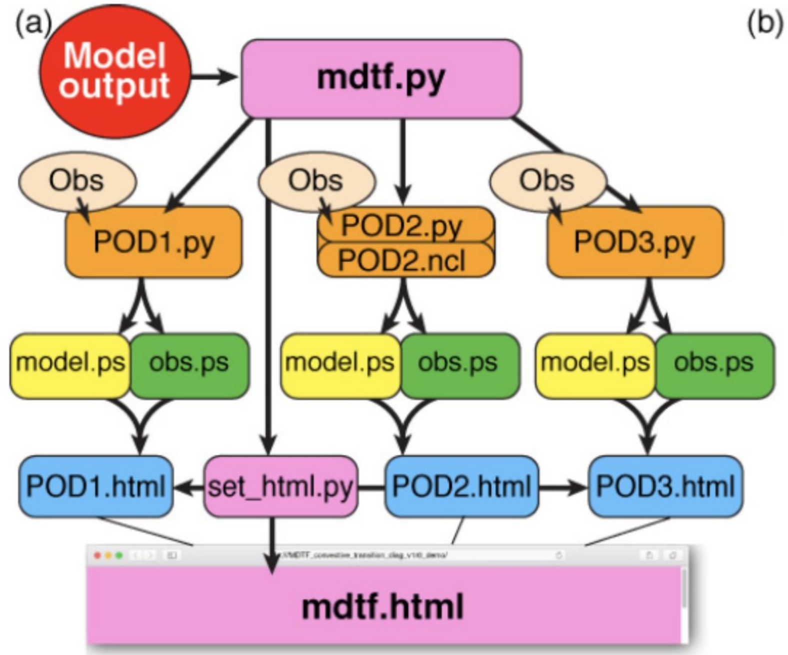
http://www.cesm.ucar.edu/working_groups/Atmosphere/mdtf-diagnostics-package/

Model Diagnostics Task Force (MDTF) diagnostic package

Designed to validate physical processes in climate models.

- Focus on model development through Process-Oriented Diagnostics (PODs)
- **Sub-monthly model output** (daily -> 3hr, different for different PODs)
  - *Latest incarnation of AMP's variability package: contains MJO, Wheeler-Kiladis and Diurnal cycle figures*
- For Model Developers
- Runs on CESM, GFDL and CMIP model output
  - *Once a diagnostic is implemented, can run easily on other model output*
- Modular, portable, extensible, open-source, community*
  - *Run on your data: 6 implemented modules + 3 in testing + > 7 in development*

MDTF Design

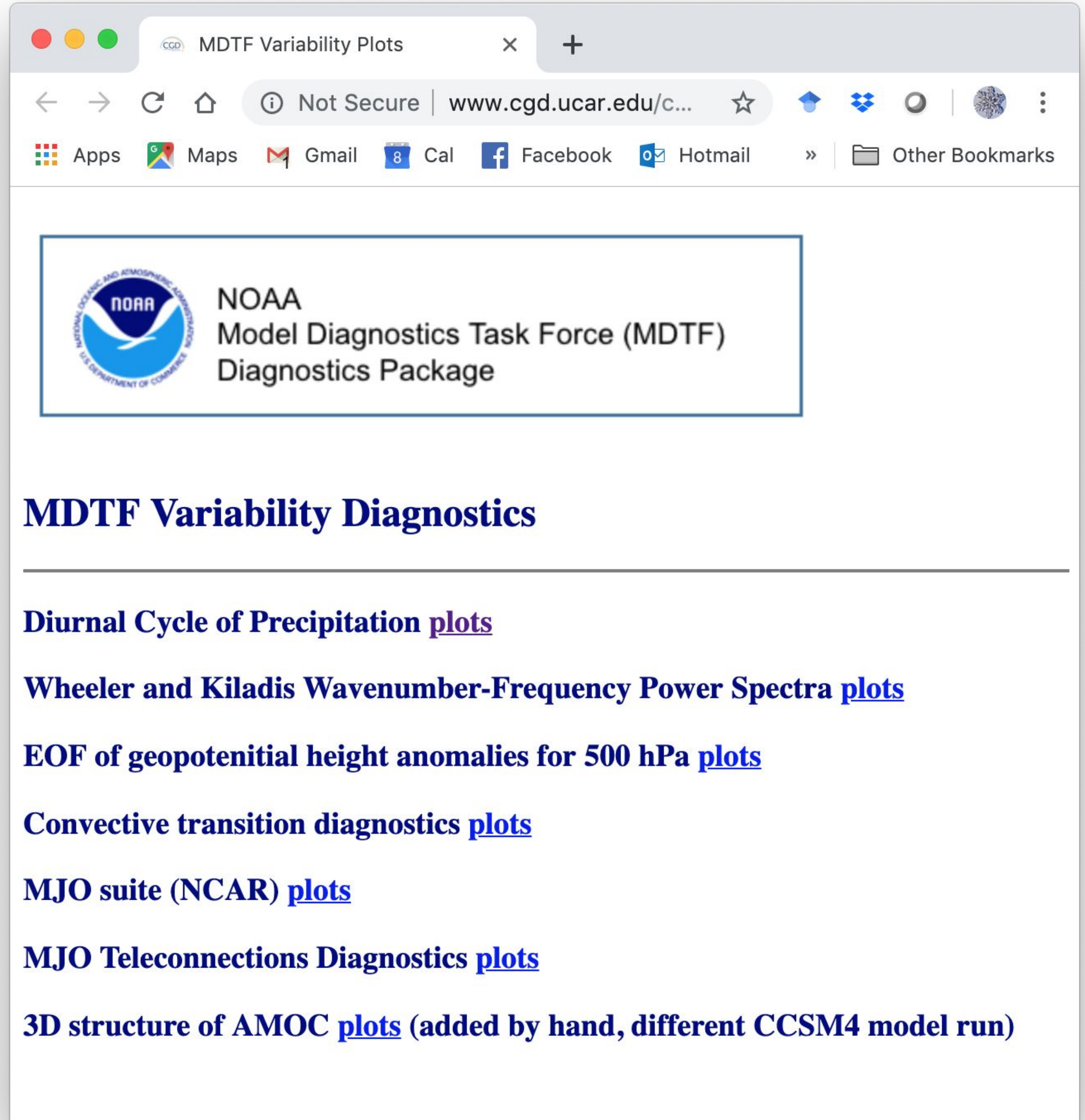


- Open-source and distributed under the LPGLv.3 license
- Python driver *mdtf.py*
  - Establishes file paths, variable names, output location
  - Calls individual PODs
    - Written in any open-source language, currently all are NCL or python
    - Currently provides its own observatio
    - Each creates a web page to display its output
    - Independent from each other within the framework
  - Writes a top-level webpage with links to the individual pages

MDTF example

Analysis CAM6 v. Obs

[Link to example]()



Climate Variability

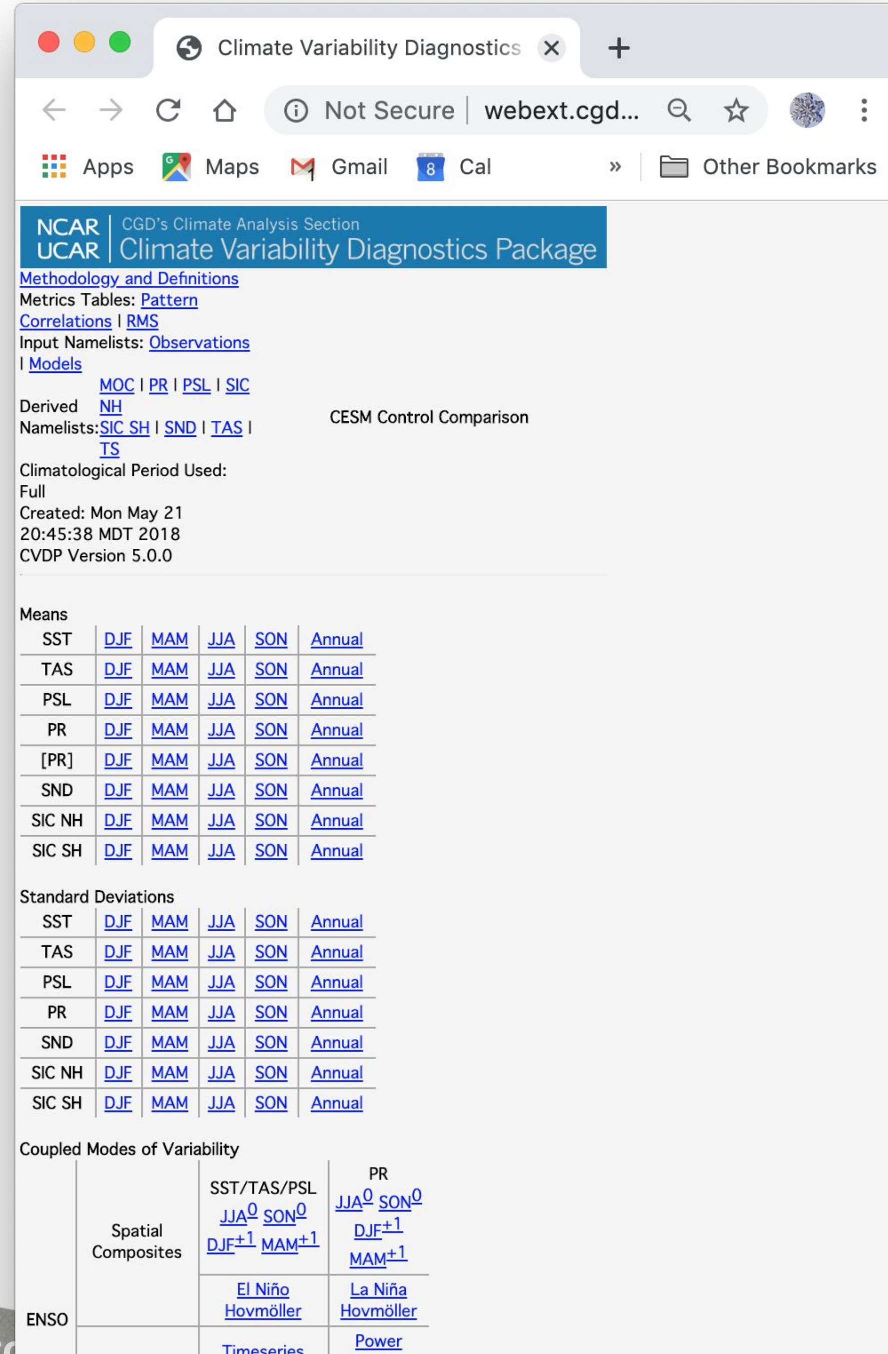
http://www.cesm.ucar.edu/working_groups/CVC/cvdp/

- CVDP uses monthly mean data to analyze climate variability
- Means, Standard Deviations
- Modes of variability (PDO, ENSO)
- Multiple model simulations against observations (separate panels)

CVDP Example

CESM Simulations

[Link to Example]



Summary: Diagnostics

- Measurements have models in them
- Try to compare Apples to Apples
- Often better to bring the model to the observations
- Satellite simulators are a way forward
- Sometimes you need in-situ data
- CAM diagnostics:
  - Mean Climate
  - Atmospheric Processes
  - Climate Variability