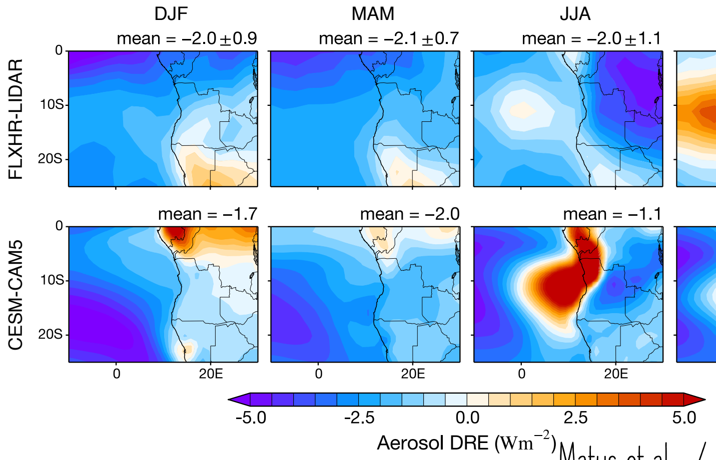
EARTHCARE'S POTENTIAL FOR CONSTRAINING MODELS: LEARNING FROM THE A-TRAIN

Tristan L'Ecuyer

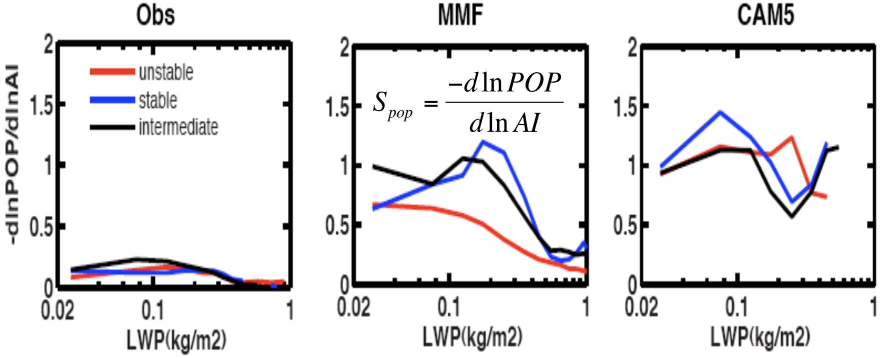
EXAMPLES

Cloud Biases Influence the Seasonality of Aerosol Radiative Forcing



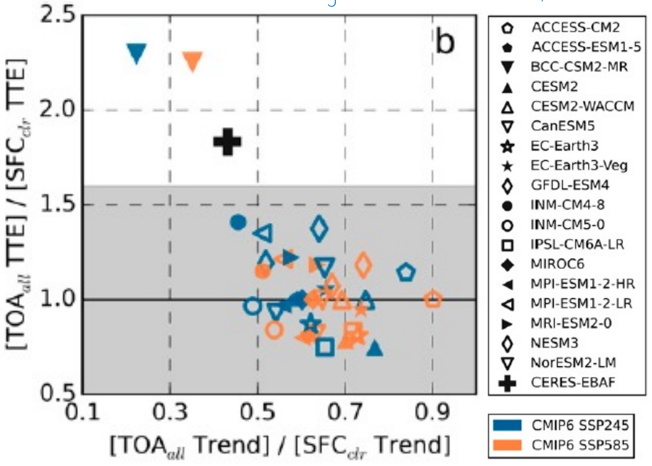
Matus et al., *J. Climate* (2015)

Precipitation Susceptibility to Aerosol Influences Warm Cloud Feedbacks



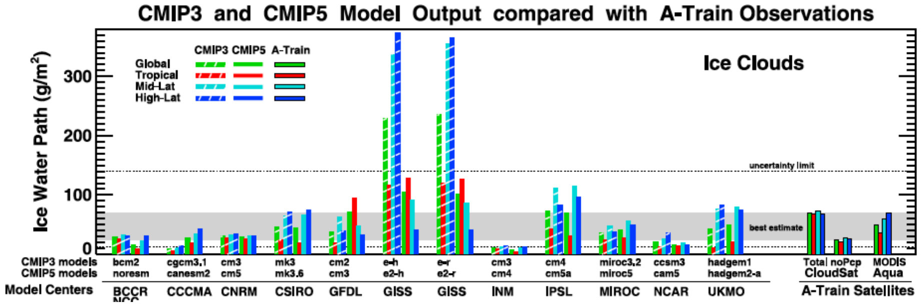
Wang et al., *GRL* (2012)

Many Models Underestimate Cloud Modulation of Arctic SW Absorption Trends (About Half Predict Cloud Changes Enhance Trends)



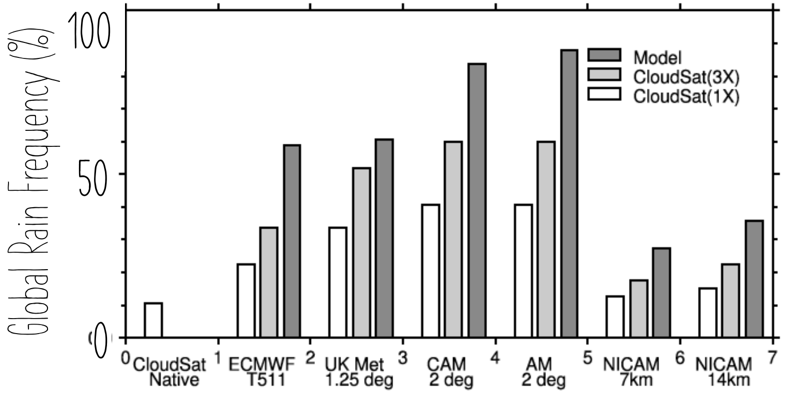
Sledd and L'Ecuyer, *J. Climate* (2021)

Large and Varied Ice Water Path Biases Across Models



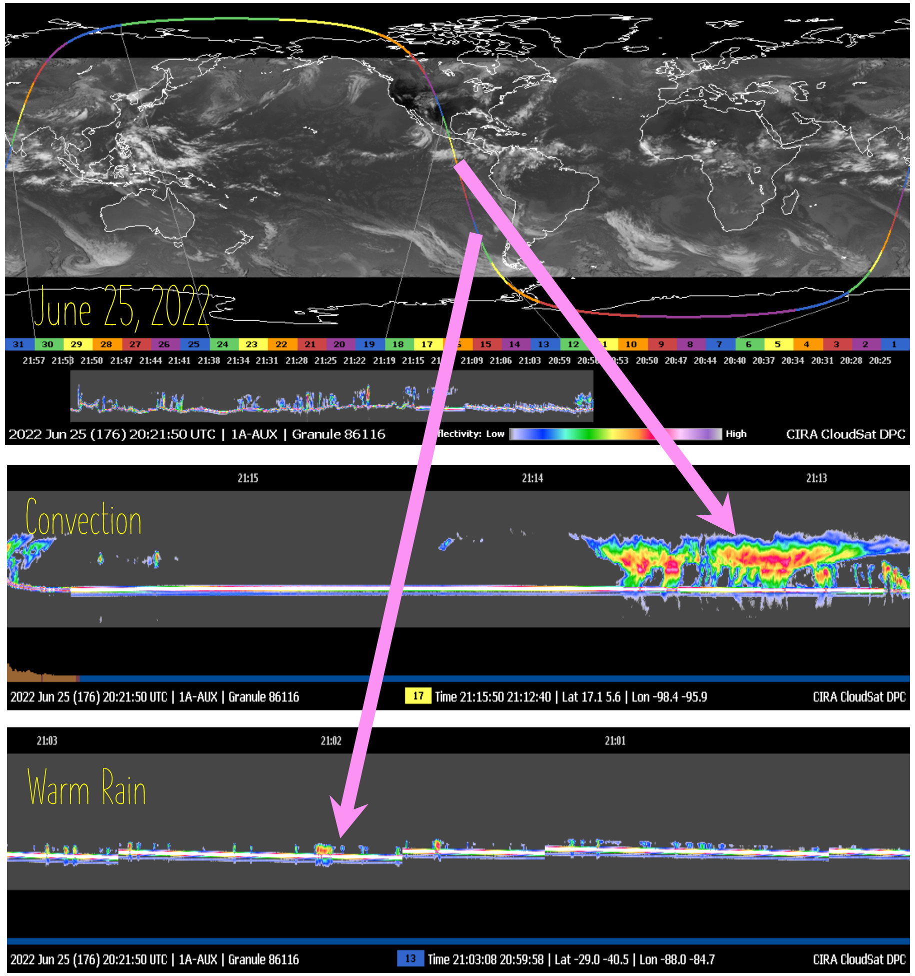
Jiang et al, *J. Geophys. Res.* (2012)

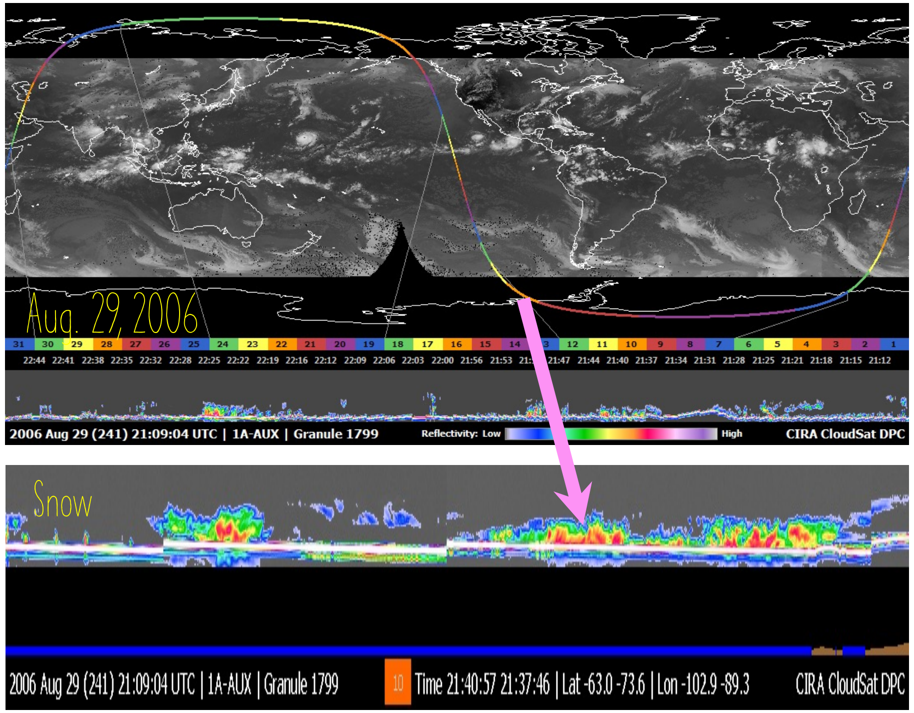
Precipitation Frequency Impacts Intensity Distribution



Stephens et al, *J. Geophys. Res.* (2010)

W-BAND PERSPECTIVES ON PRECIPITATION

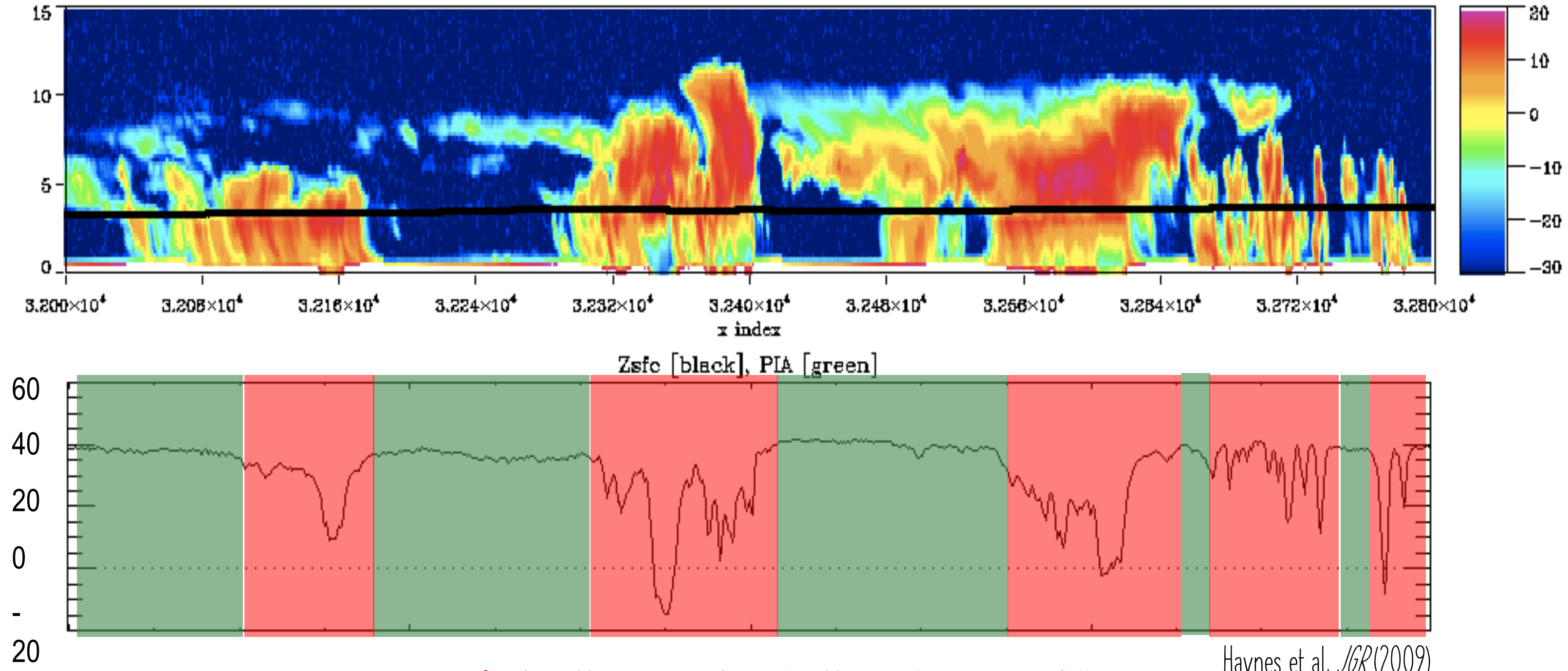




- W-band sensitivity and path-integrated attenuation provide the most comprehensive depiction of global precipitation (both rain and snow) occurrence.
- Optimal estimation algorithms that account for attenuation, non-Rayleigh scattering, and multiple-scattering have been applied to estimate rainfall and snowfall intensity.
- EarthCARE will build on this 16+ year record with better sensitivity/resolution, reduced clutter, and the addition of Doppler velocity.

DETECTING PRECIPITATION

Path-Integrated Attenuation (PIA), calculated using an estimated of clear-sky surface return (either interpolated or retrieved from wind-speed and SST), provides an indicator of rainfall and a crude intensity estimate



Haynes et al, *JGR* (2009)

Surface return significantly attenuated → rainfall

Not attenuated → No rainfall

Near-surface Z > 0 dBZ → precipitation (-15 to 0 dBZ → drizzle/light snow)

Near-surface Z < -15 dBZ → No precipitation

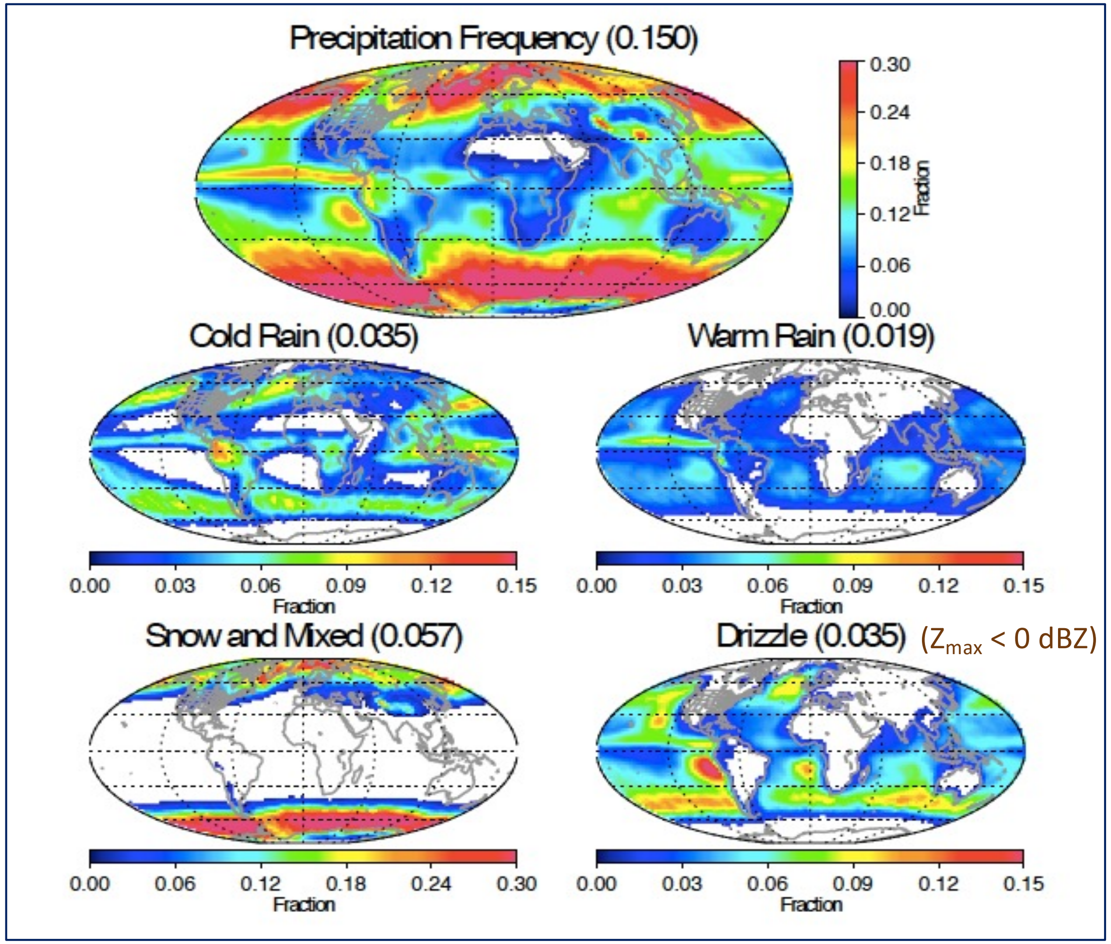
GLOBAL PRECIPITATION DISTRIBUTIONS

2007-10 Mean Precipitation Distributions

Identified using both reflectivity and attenuation (surface return).

Distinguished using cloud top height and 0 dBZ echo top height.

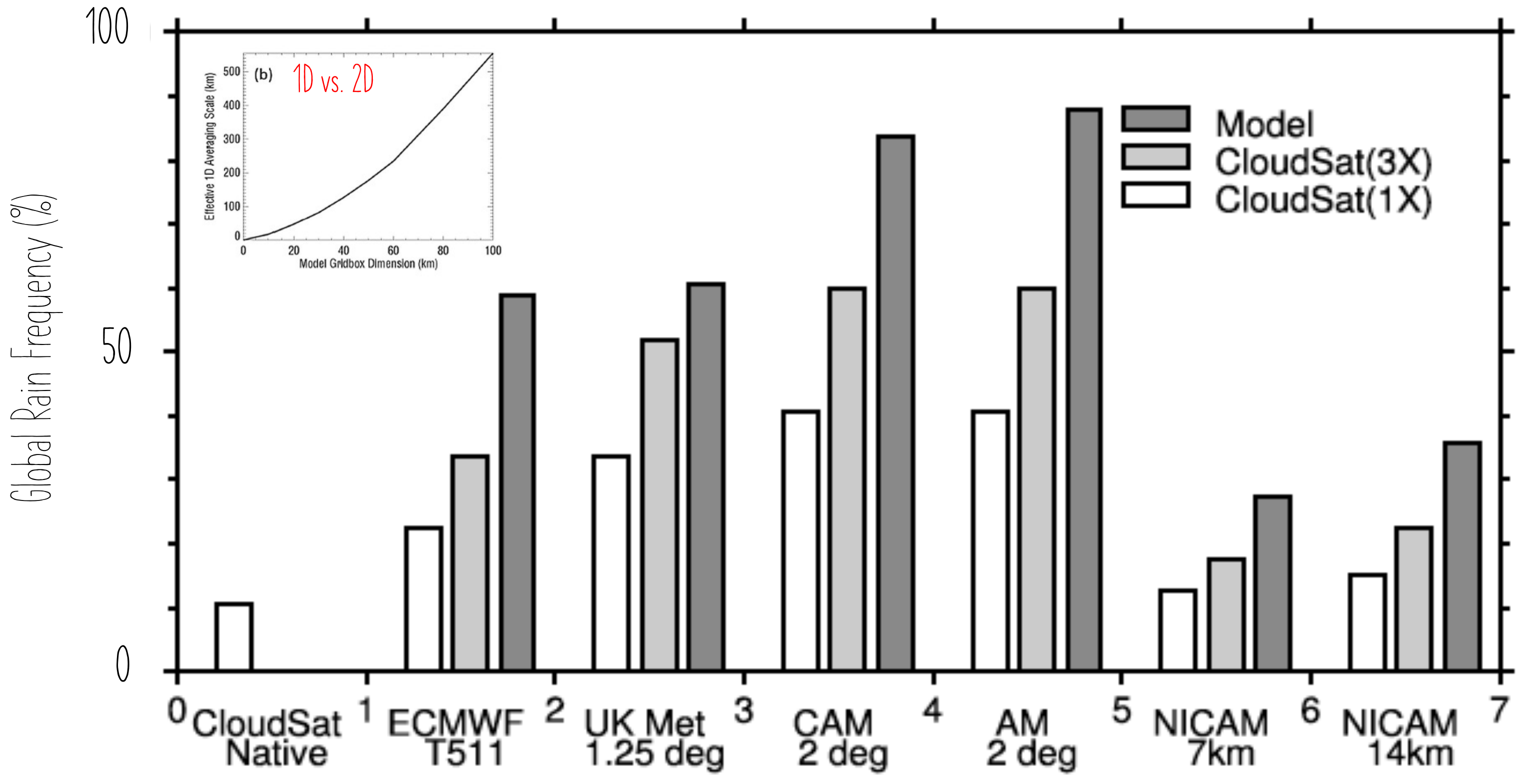
Modeled melted fraction < 90%



EarthCARE's increased sensitivity and spatial resolution will allow further refinment.

RAINFALL FREQUENCY

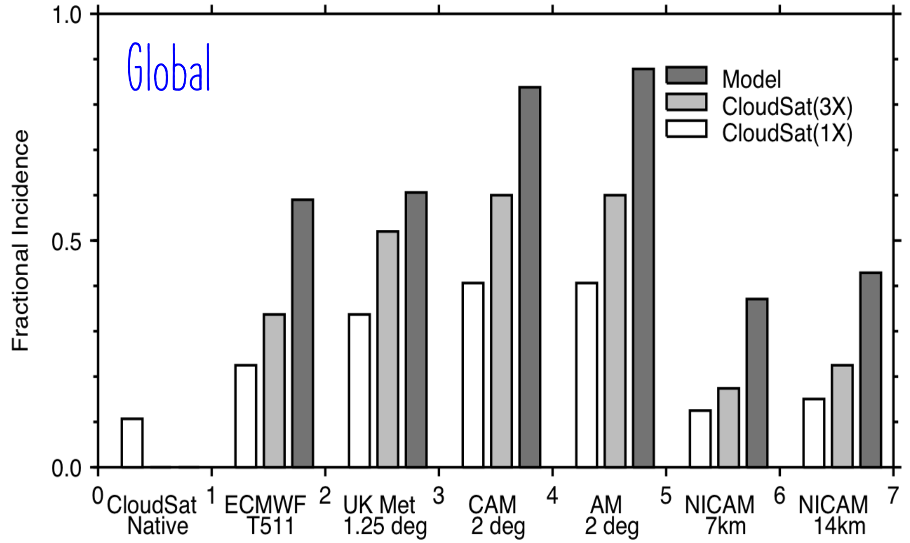
"THE *DREARY STATE OF MODELS*"



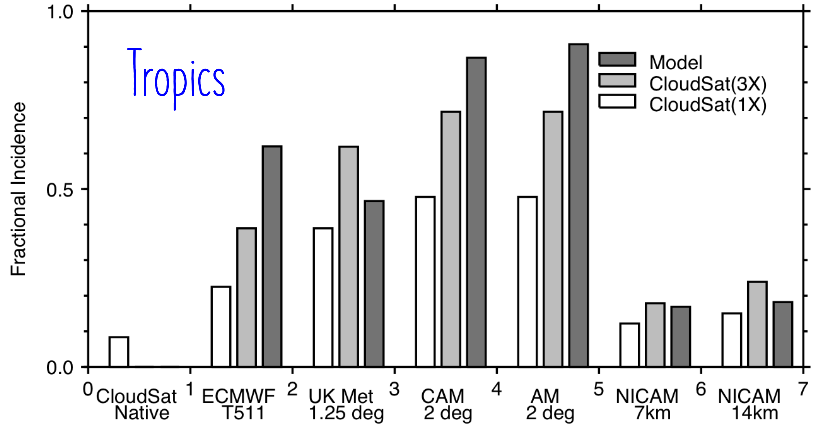
Stephens et al, *J. Geophys. Res.* (2010)

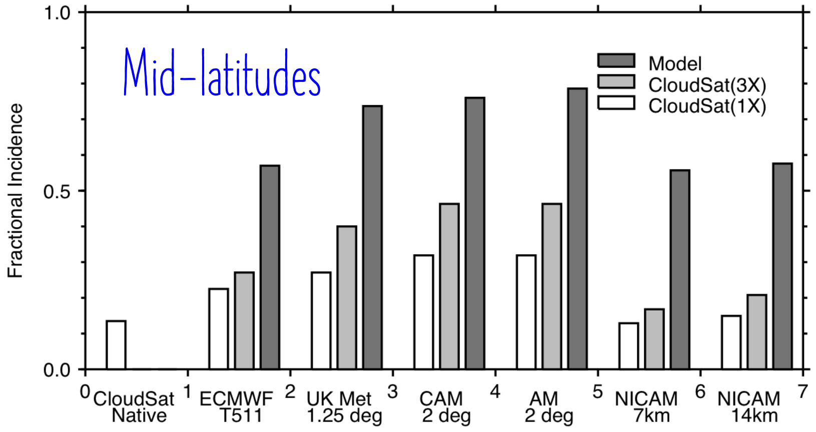
DREARY MIDLATITUDES

"THE *DREARY STATE OF MODELS*"



Stephens et al, *J. Geophys. Res.* (2010)





FALLING SNOW

Algorithm Highlights

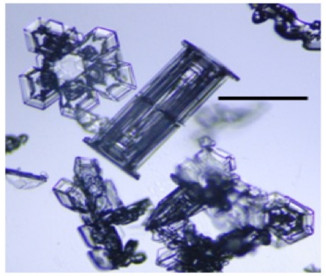
- Variational Approach
  - Allows prior information
  - Predicts uncertainties
- Retrieve intercept and slope of exponential particle size distribution

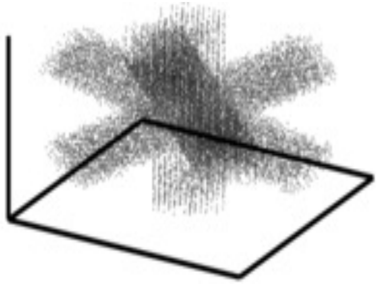
$$N(D) = N_0 e^{-\Lambda D}$$

- Scattering properties, PSD, and density based on field observations

Microphysical Assumptions

- Non- spherical scattering modeled based on in situ obs.
- Mass and projected area relationships are constrained from multi-sensor retrievals



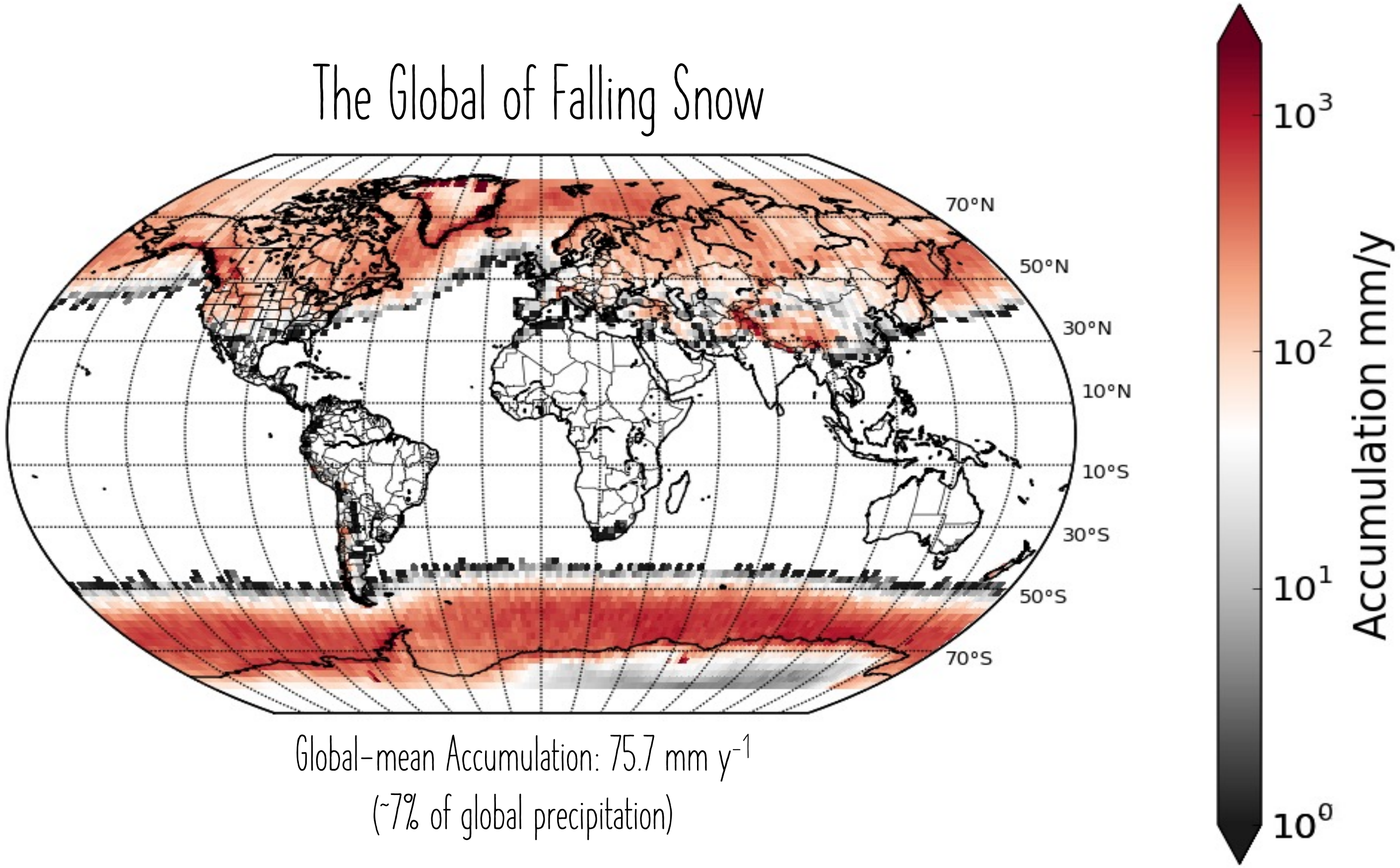


- These assumptions remain the largest source of uncertainty in CloudSat snowfall estimates

Wood et al., *AMT* (2014)

GLOBAL DISTRIBUTION OF FALLING SNOW

The Global of Falling Snow

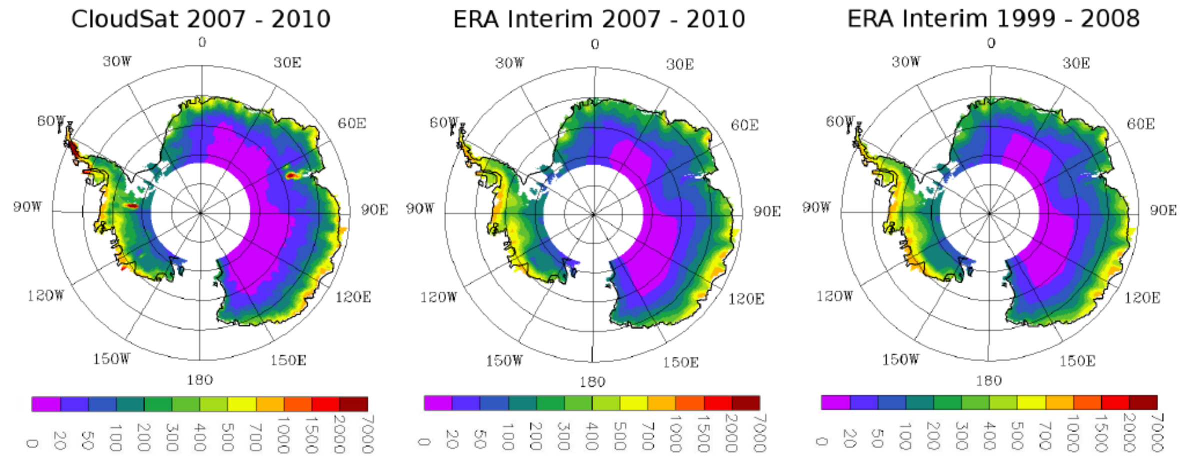


Global-mean Accumulation: 75.7 mm y^{-1}
(~7% of global precipitation)

- Unique high-latitude precipitation observations to evaluate global snowfall predictions.
- Ground clutter impacts both occurrence (shallow snow and virga) and intensity estimates.
- EarthCARE's reduced ground clutter and coincident radar/lidar measurements offer the potential to reduce uncertainties in global snowfall estimates.

Reanalyses and Climate Models

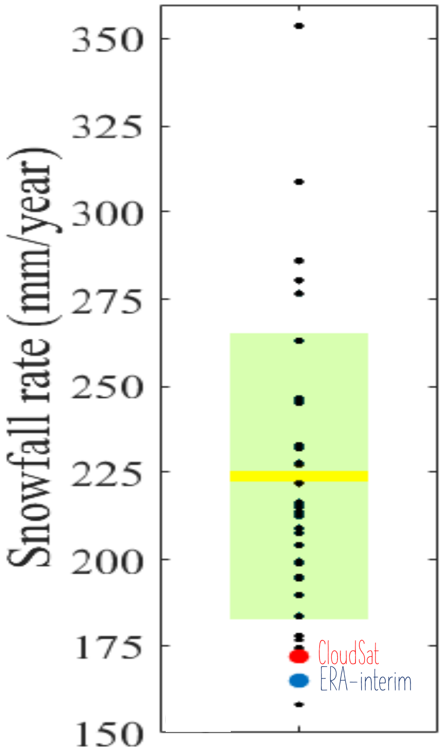
Annual Mean Accumulation



	Mean snowfall rate
CloudSat (2007-2010)	172 mm/year
ERA Interim (2007-2010)	165 mm/year
ERA Interim (1999-2008)	167 mm/year

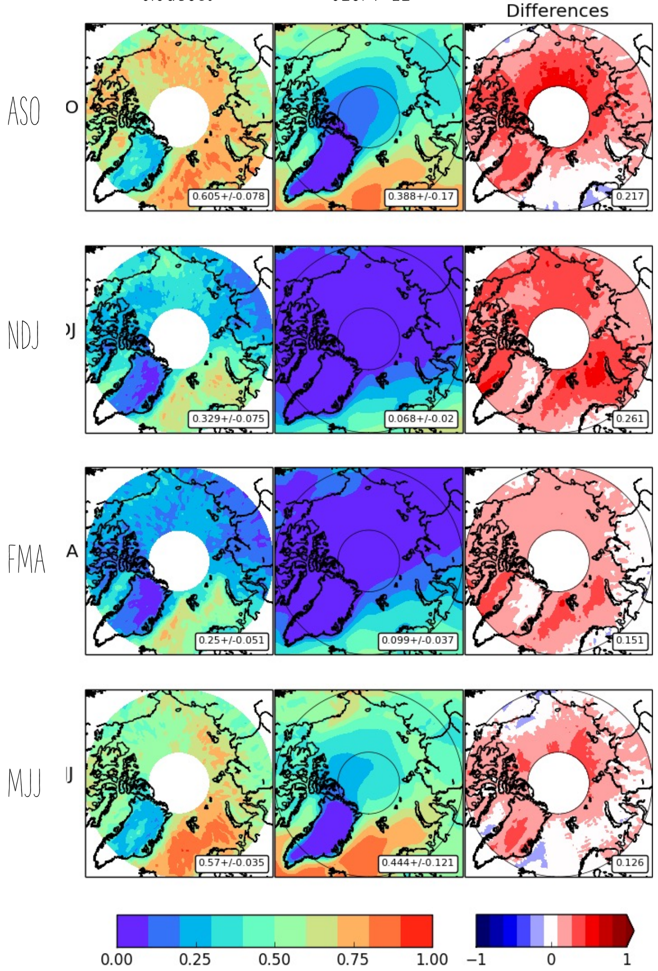
Palerme et al, *The Cryosphere* (2014)

Antarctic Mean Accumulation

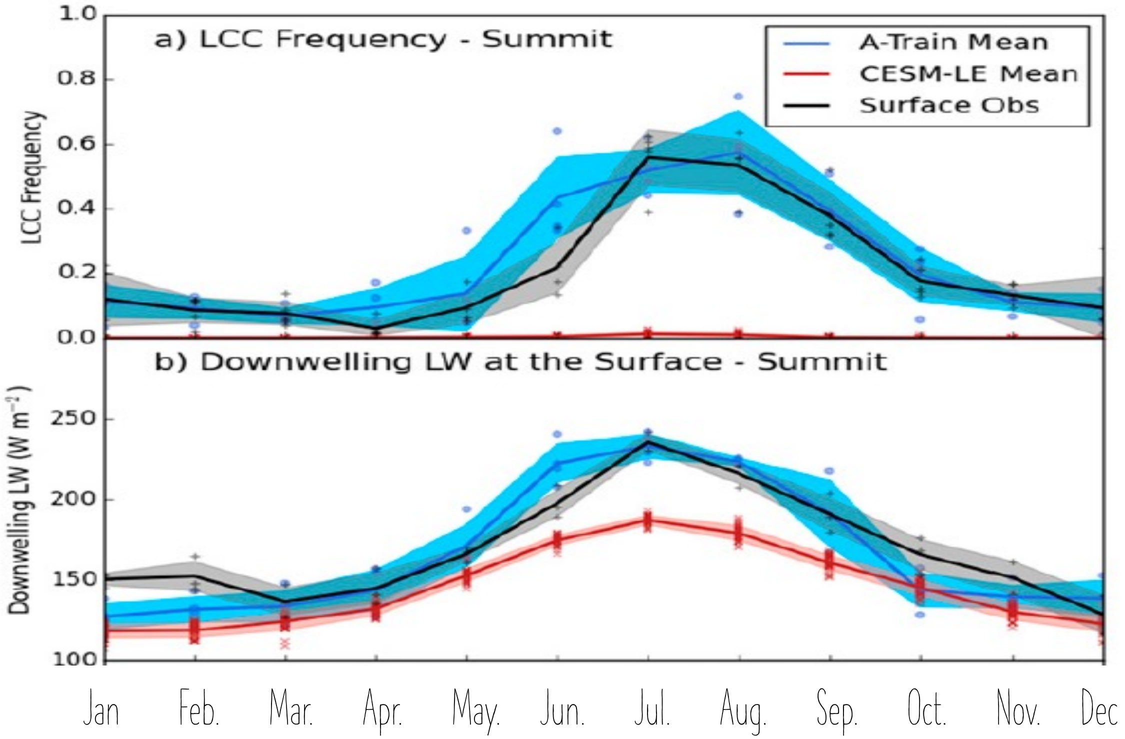


Palerme et al, *Atmos. Res.* (2017)
Palerme et al, *Climate Dynamics* (2017)

ARCTIC MIXED PHASE CLOUD BIASES



Summit Station Greenland

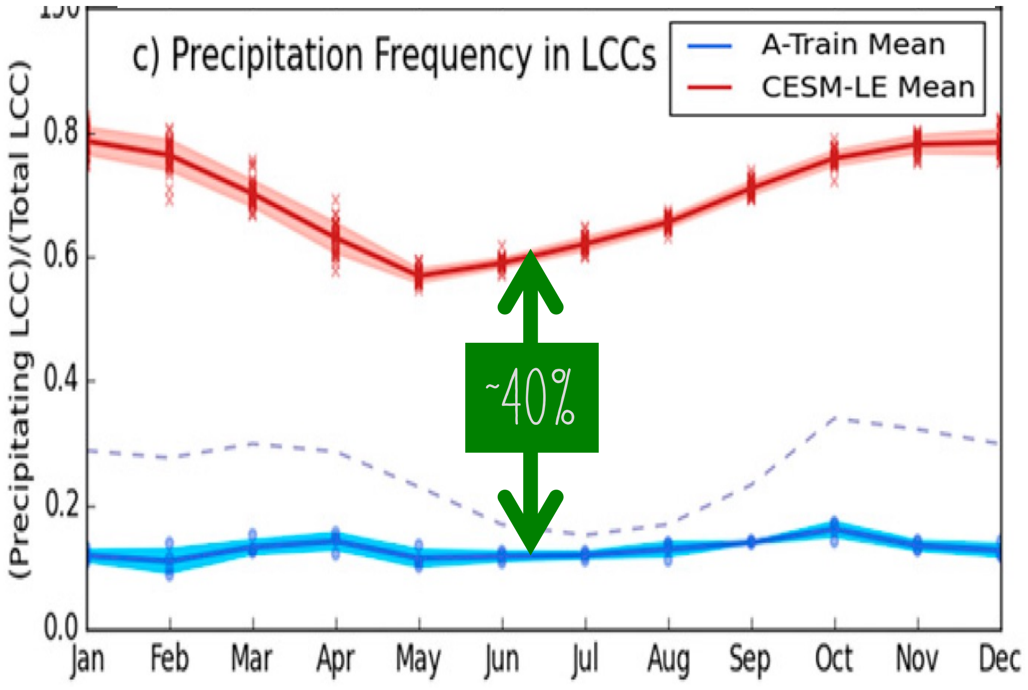


McIlhattan et al, *J. Climate* (2017)

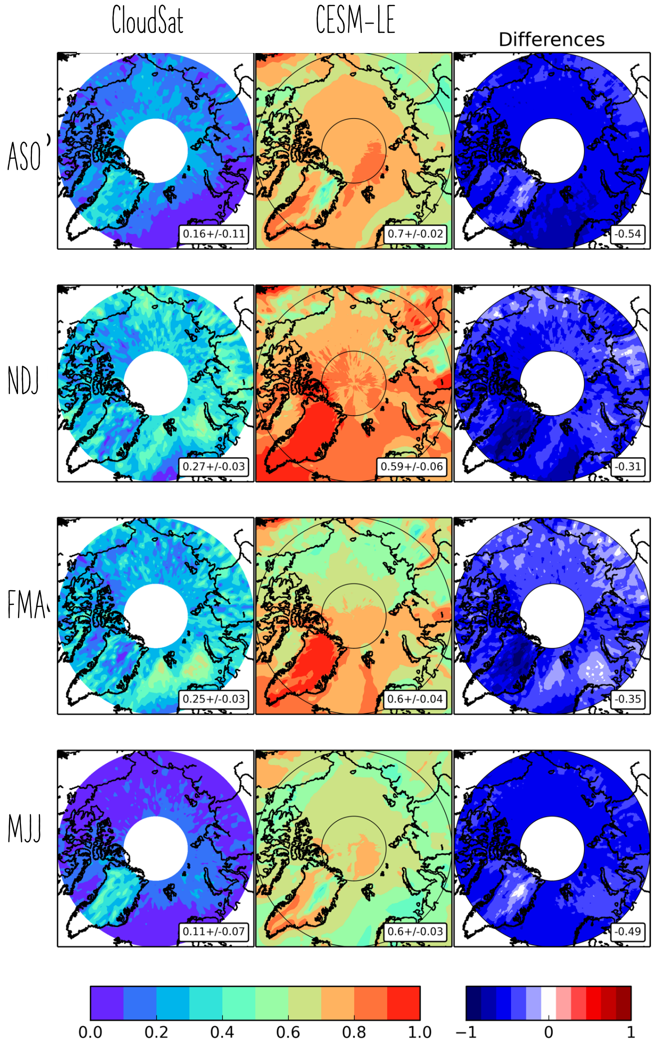
See also: Cesana et al, *Geophys. Res. Letters* (2012)

A CONNECTION TO SNOW FORMATION PROCESSES?

Fraction of Arctic Liquid Containing Clouds That Snow



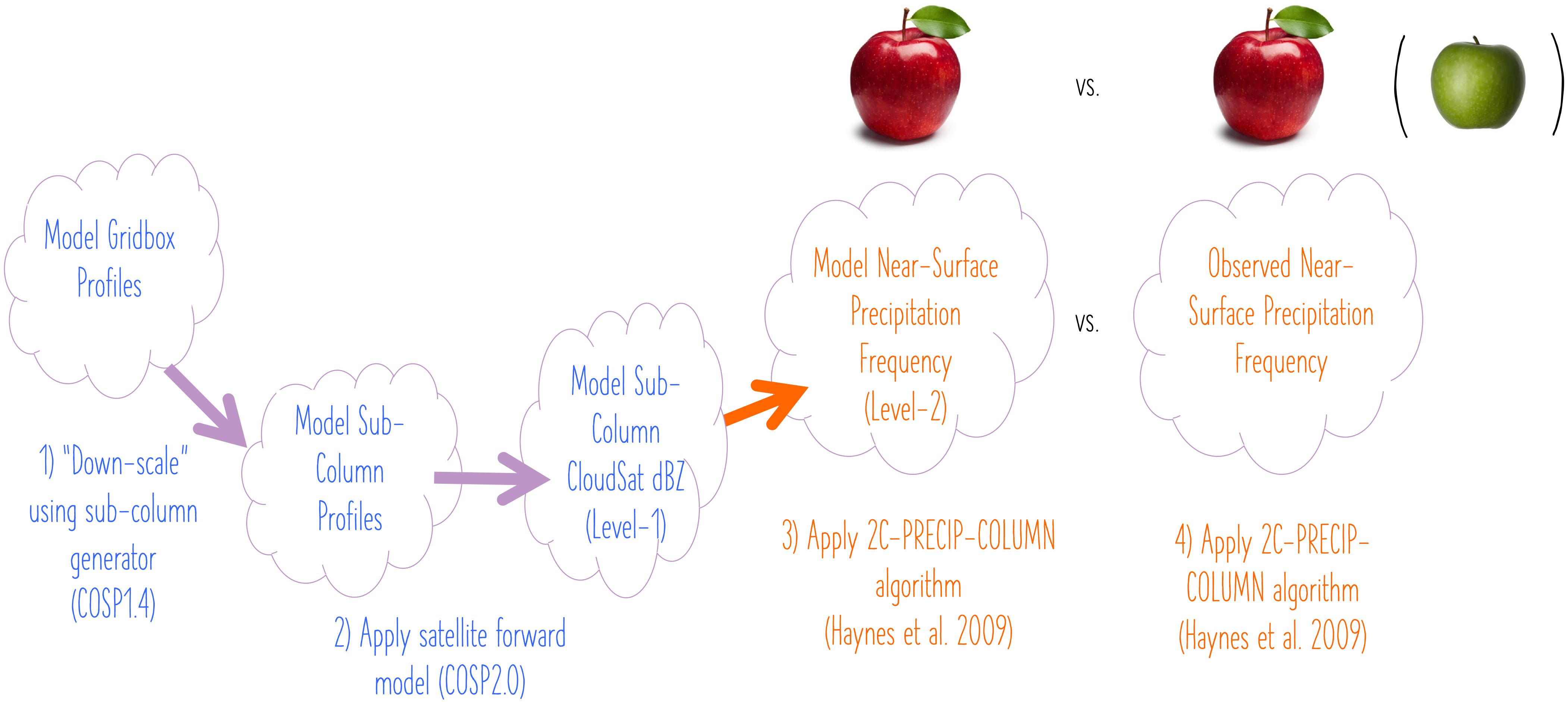
McIlhattan et al, *J. Climate* (2017)



- Combining these two independent parameters provides a metric that connects to precipitation processes: Arctic liquid containing clouds precipitate much too frequently in CESM1

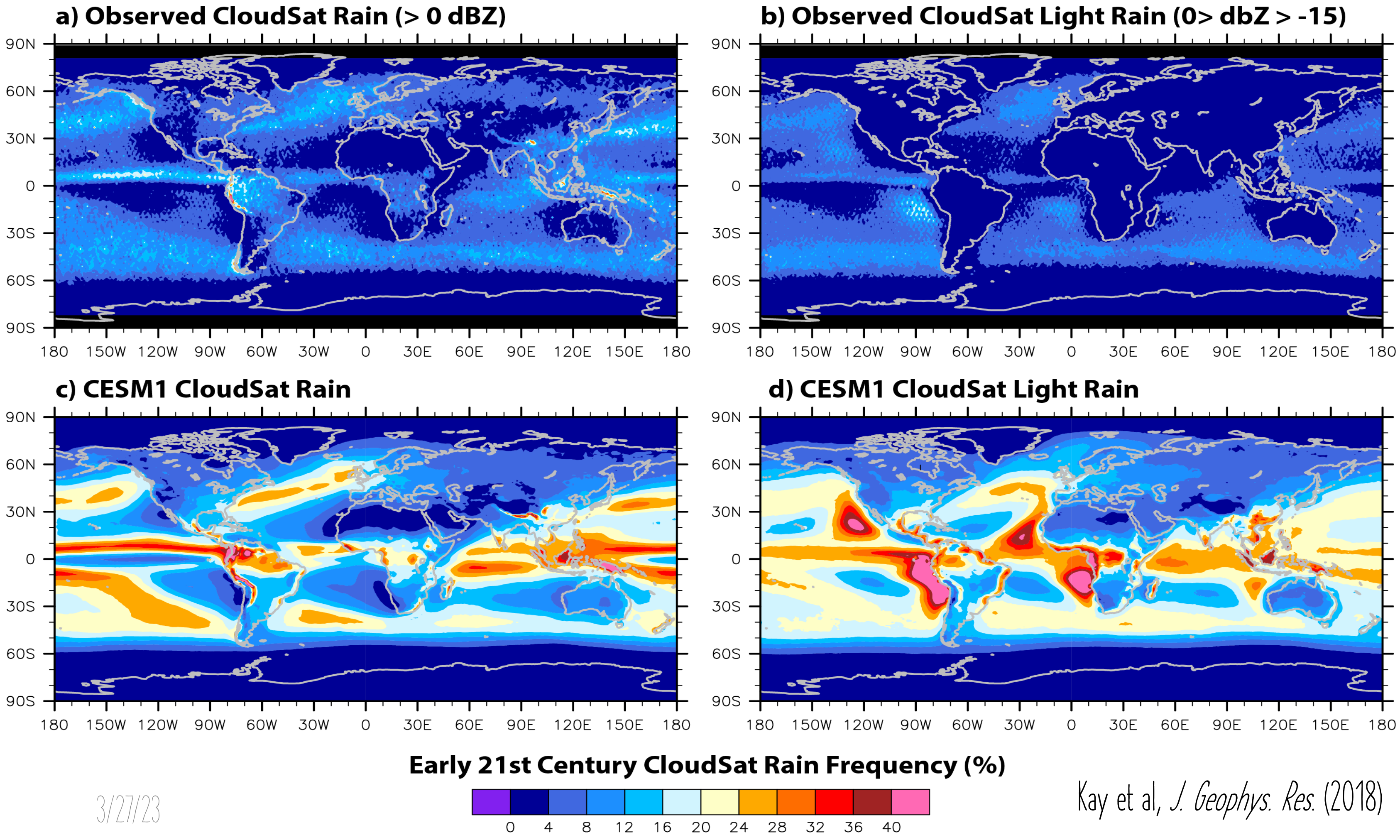
- Snowfall detection is impossible in the blind zone.
- EarthCARE's higher vertical resolution radar mitigates blind zone effects.

THE CLOUDSAT LEVEL-2 PRECIPITATION SIMULATOR



Courtesy: Jen Kay

DREARY MODELS REVISITED



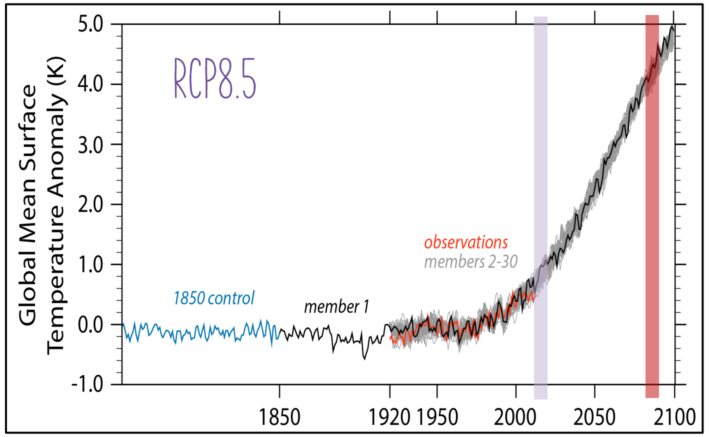
Kay et al, *J. Geophys. Res.* (2018)

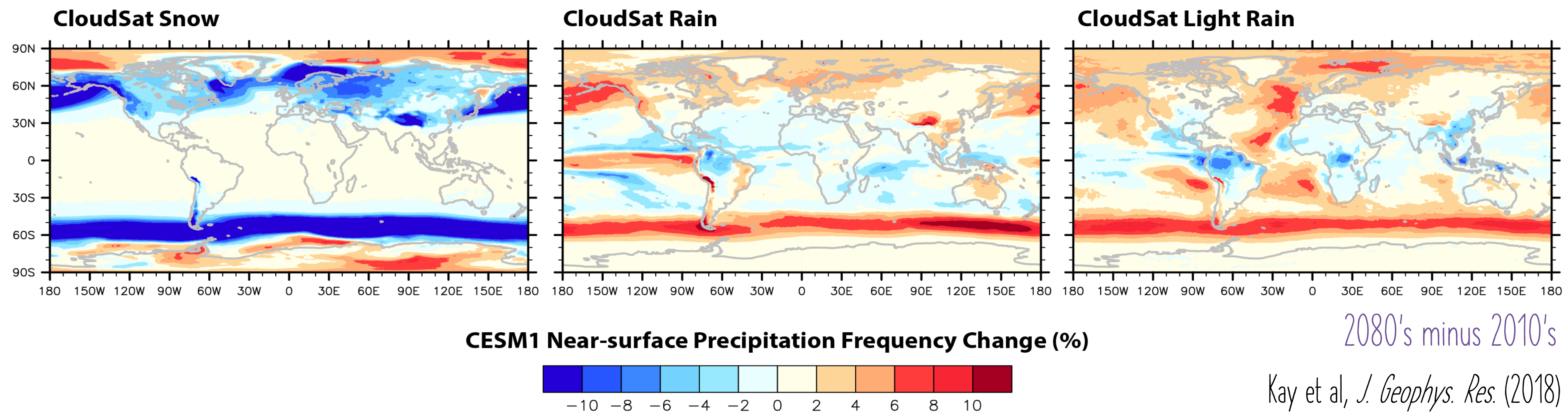
- Simulators are essential to account for instrument sensitivity, resolution, limitations (e.g. blind zone).
- Defining robust metrics linked to observable quantities increase confidence in biases.
- Consistent definitions (e.g. reflectivity thresholds or ice/liquid fractions) can be applied to simulator output to ensure apples-to-apples comparisons against Level-2 products.

A SATELLITE VIEW OF FUTURE PRECIPITATION

Three CESM1 Predictions:

- Snow transition to Rain (esp. in mid-latitude storm tracks)
- Narrowing of Equatorial Rain Band (esp. in Pacific)
- Increase in Sub-tropical Light Rain Frequency





2080's minus 2010's

Kay et al, *J. Geophys. Res.* (2018)

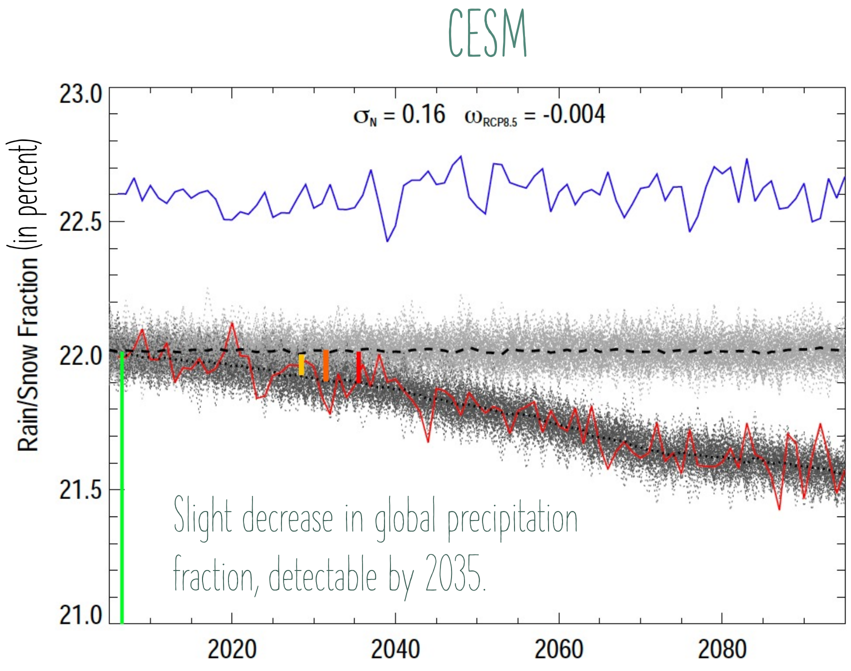
L'Ecuyer et al, *J. Climate* (in prep)

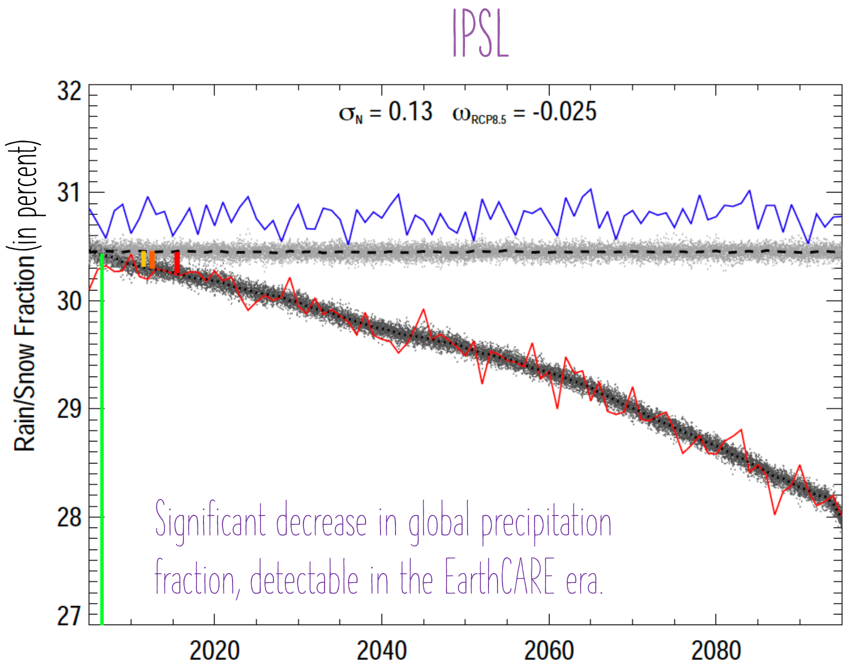
See also:

Chepfer et al, *J. Geophys. Res.* (2018)

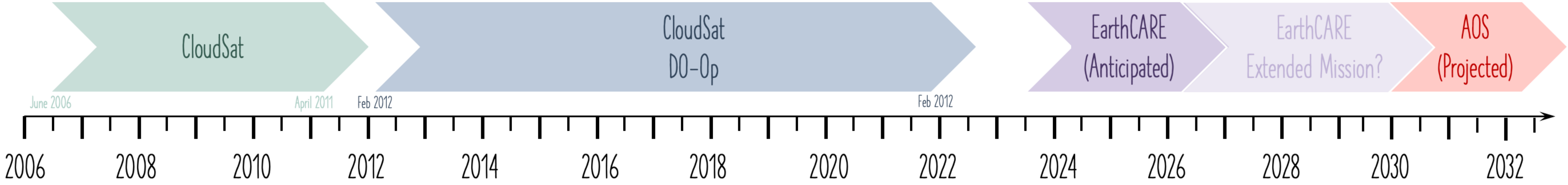
Sledd and L'Ecuyer, *J. Climate* (2021)

CAN WE TEST THESE PREDICTIONS?



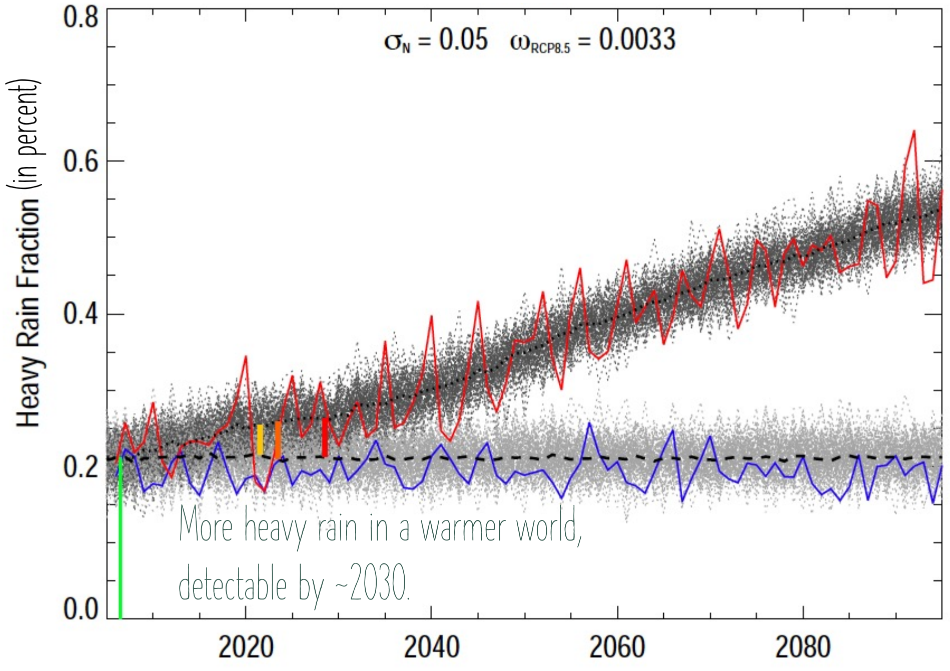


- Diagnostics tied to observables and simulators provide robust tests.
- Inter-calibration possible using surface returns.
- W-band precipitation record could be extended to > 25 years with EarthCARE and AOS.

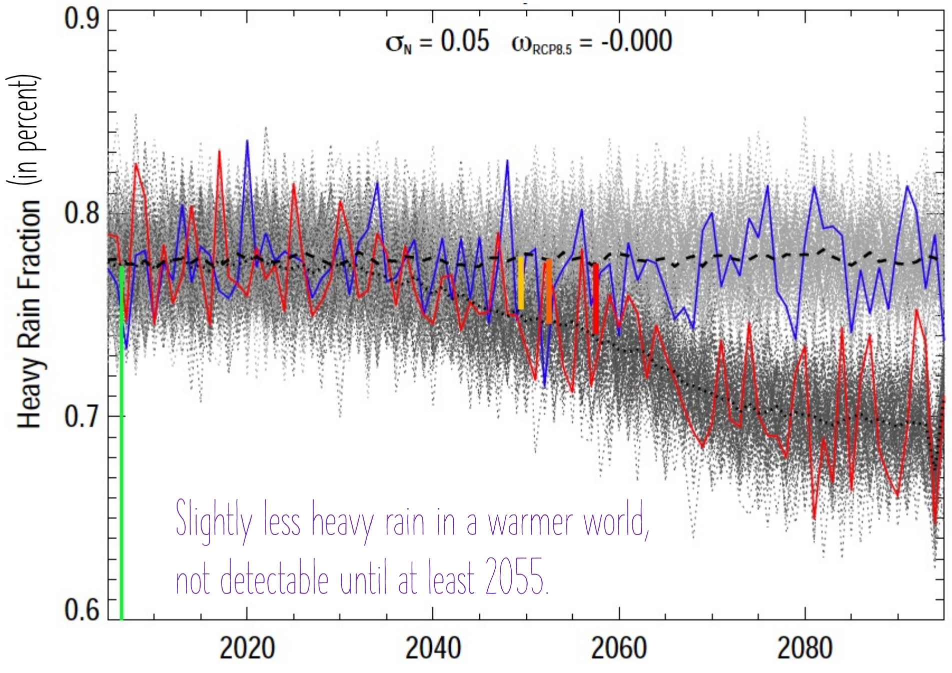


HEAVY RAIN (W-BAND FULLY ATTENUATED)

CESM



IPSL



L'Ecuyer et al, *J. Climate* (in prep)

- Robust metric: "Can the radar see the surface?" (analogous to CALIPSO opaque cloud occurrence).
- Time-to-emergence analyses show that these models have opposite trends in heavy rain frequency.
- CESM trend could be verifiable within AOS timeframe provided EarthCARE bridges the gap.

LOOKING AHEAD TO THE ERA OF EARTHCARE AND K-SCALE MODELS

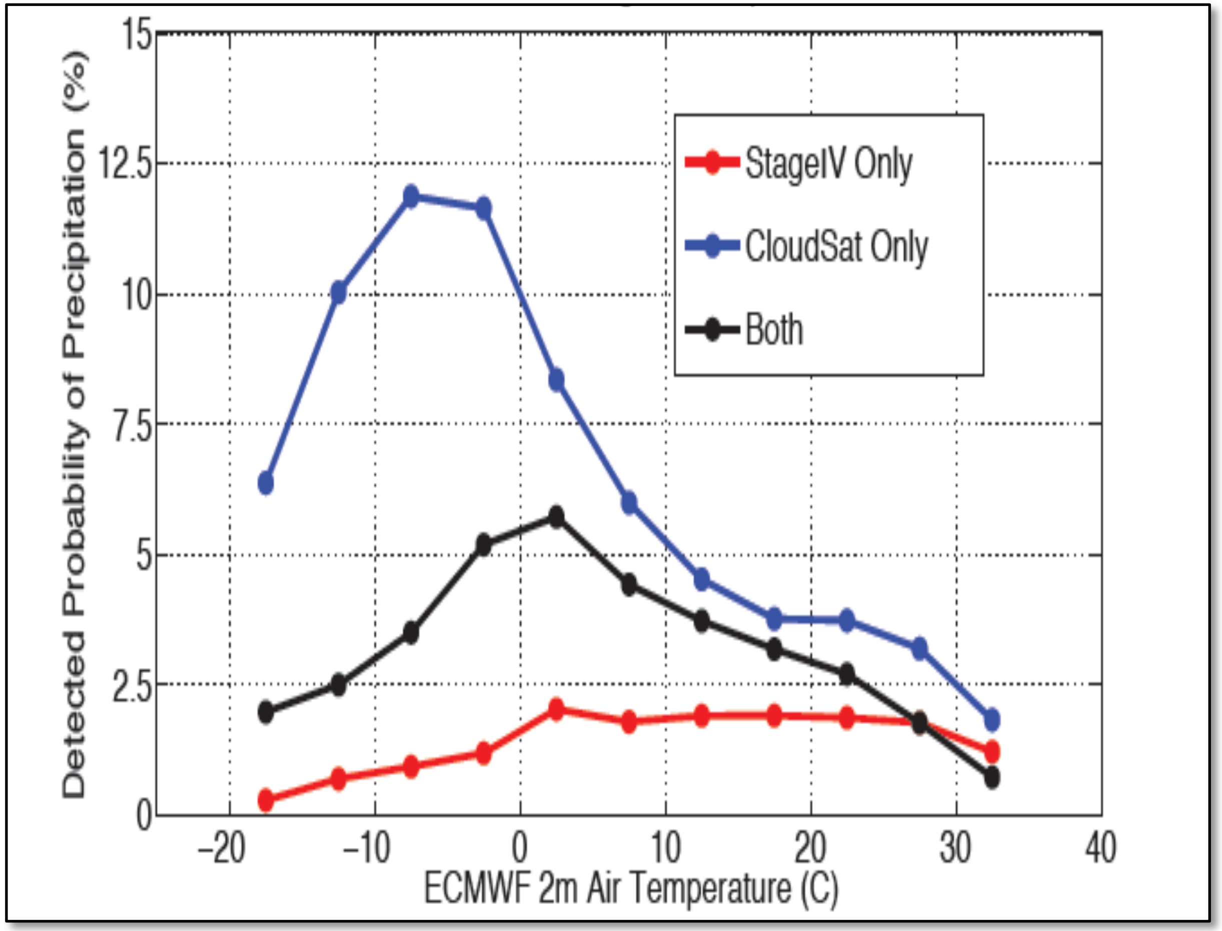
- EarthCARE advances
  - Increased sensitivity
  - Smaller FOV
  - Reduced ground clutter
  - Vertical motion
  - Continuing active sensor data records (absolute calibration/robust metrics)
- k-scale models better suited to applying measurement simulators
  - Resolution more comparable to precipitation scales
  - Explicit microphysics
  - Minimize need to statistically generate sub-columns
  - Spatial information preserved

Messages

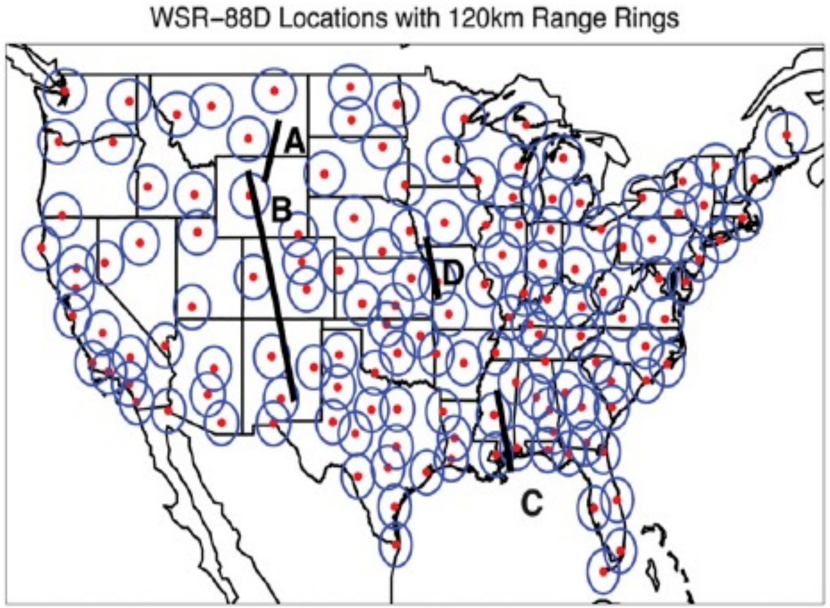
- Simulating instrument characteristics (spatial resolution, sensitivity, blind zone, etc.) is essential for meaningful comparisons.
- Simulating Level-2 products offers diagnostics ofen easier to interpret than Level-1.
- Diagnostics directly tied to observables provide the most robust tests.
- W-band precipitation record could be extended to > 25 years with EarthCARE and AOS.

BACKUP SLIDES

COMPARISONS TO GROUND RADAR NETWORKS

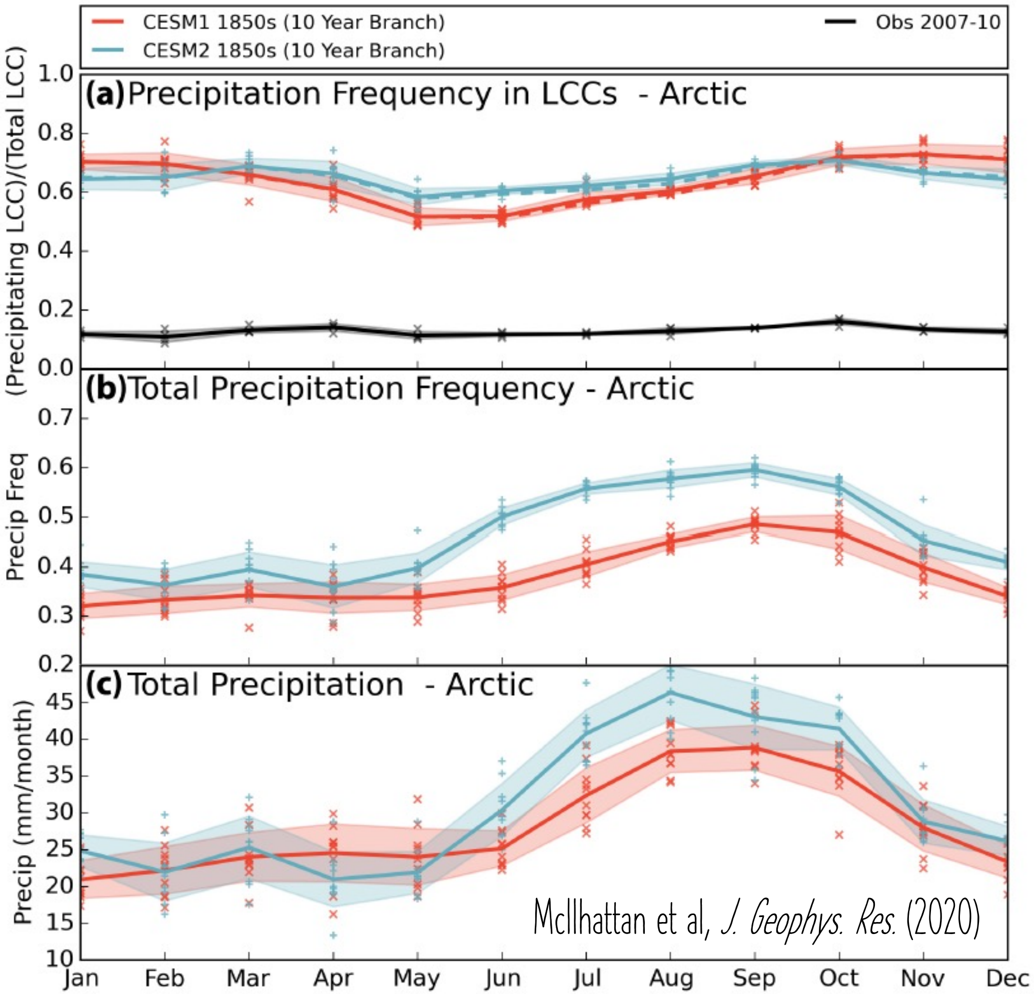


Smally et al, *J. Hydro.* (2014)



Satellite-based W-band radar measurements mitigate beam curvature, limited sensitivity, and calibration differences that impact precipitation detection from scanning ground-based radar networks.

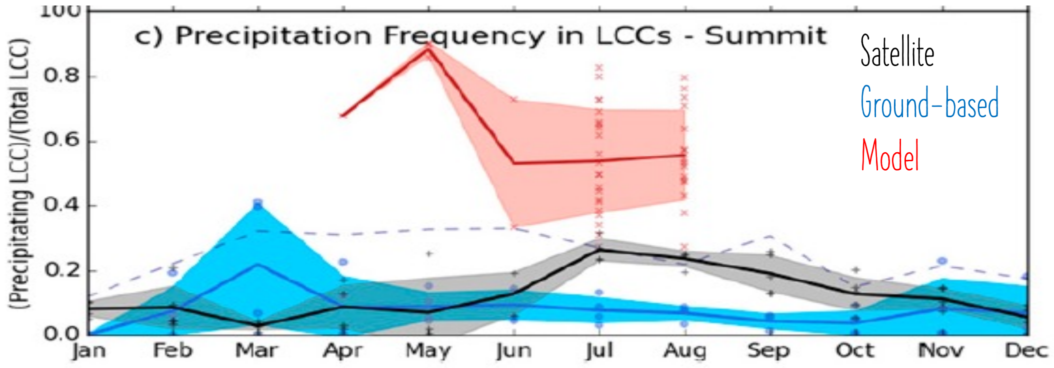
TESTING MODEL ADVANCES



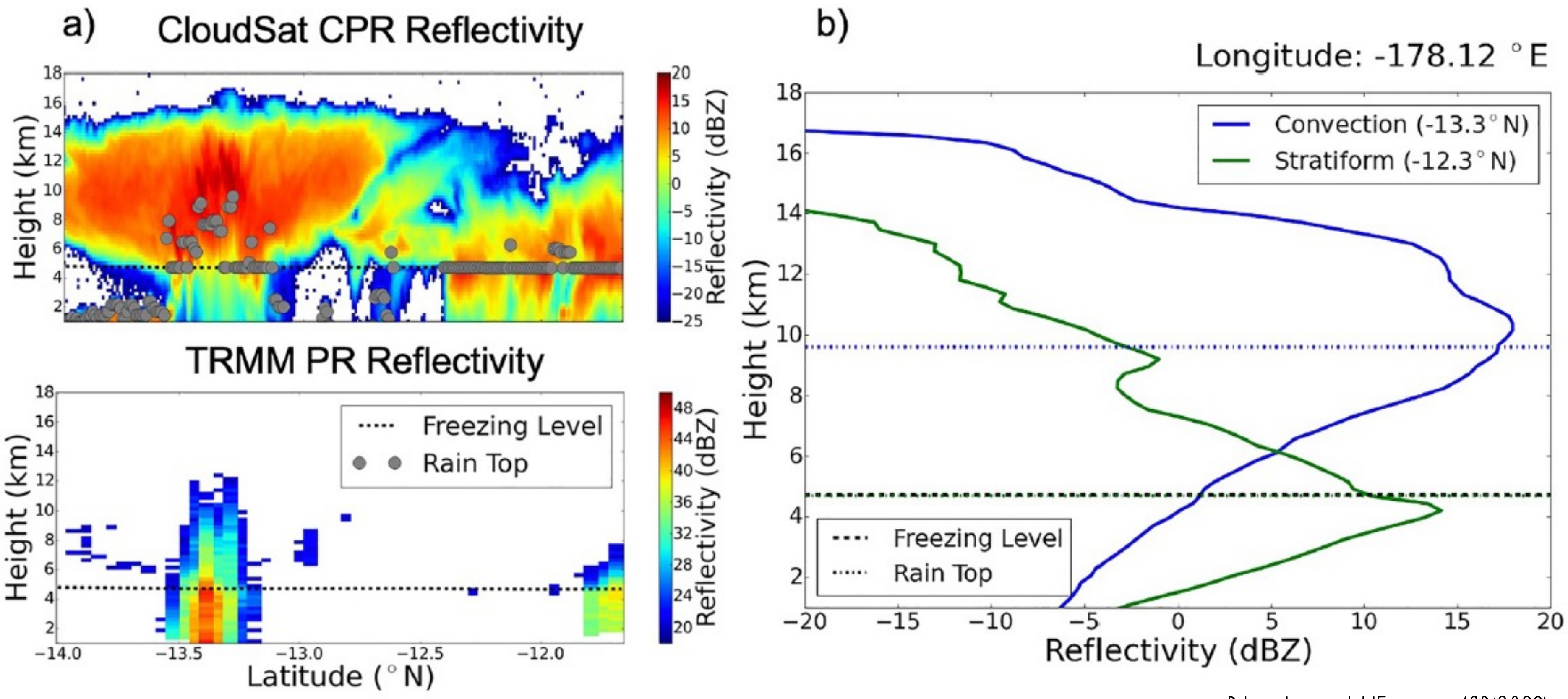
McIlhattan et al, *J. Geophys. Res.* (2020)

- The constraint that about 15% of Arctic super-cooled liquid containing clouds produce snow (closely linked to observables and verifiable against ground observations) provides a metric for testing model improvements.

Summit Station Greenland



IDENTIFYING CONVECTION



Pilewskie and L'Ecuyer, *JGR* (2023)

- CloudSat uses attenuation to identify updrafts where raindrops are observed above the freezing level (at the 1.5 km scale of the field of view).
- EarthCARE should resolve cores with even greater spatial resolution
- Doppler velocity may help constrain updraft strength in larger cores.