Considerations for using observations to guide numerical model development

Presenter: Katia Lamer

Brookhaven National Laboratory, Upton NY, USA

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Main challenges for comparing model and observations

1. Hydrometeor properties defined in terms of different moments (i.e., mass vs. radar reflectivity)

2. Scale differences between model output and observations

3. Discrepancies in performance (i.e., ability to detect/simulate small amounts of liquid or ice)

4. Ill-defined evaluation metrics
   What does one mean by cloud layer depth in mixed-phase clouds?
   How much liquid is required for a hydrometeor population to be labeled as “mixed-phase”?

5. What is a suitable evaluation spatiotemporal scale?

6. What level of accuracy between model and observations is acceptable?

Forward simulators can help overcome some of these barriers

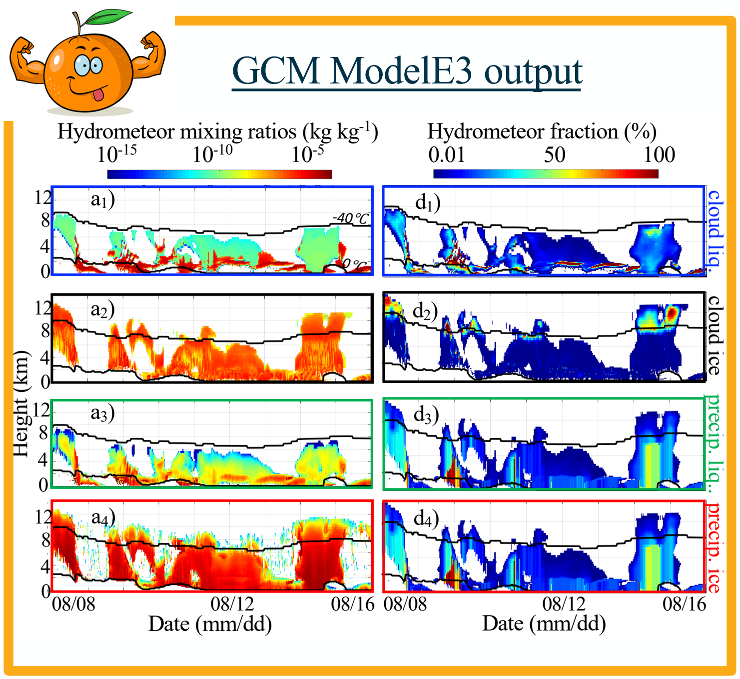
1. Hydrometeor properties defined in terms of different moments

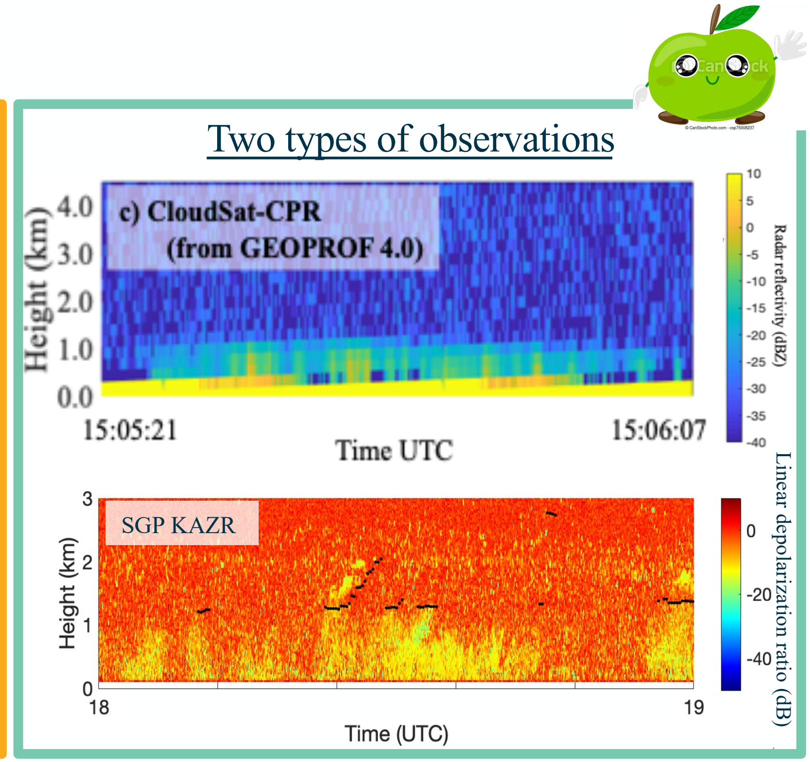
1- Models simulate each hydrometeor species separately, remote sensors cannot readily isolate hydrometeor species
=> model output information about all species must be combined.
2- Observations are sensitive to hydrometeor moments that do not necessary strongly affect process rates in models.
=> missing key hydrometeor properties need to be retrieved or assumed.

For all simulated species:
Stratiform & Convective
Clouds & Precipitation
Liquid & Ice & *Graupel*

PSD information
- mass
- size
- *shape of the distribution*

Particle properties
- *density*
- *shape*
- *fall speed*
- *water coating*





1. Hydrometeor properties defined in terms of different moments

⇒Scattering calculations and empirically derived relationships allow us to convert simulated hydrometeors properties (~D^3) to observables (~D^6 and ~D^2). Weather/climate model complexity influences the choice of scattering models

COMPLEX

Discrete Dipole Approximation for non-spherical particles *(Draine et al 1994)*

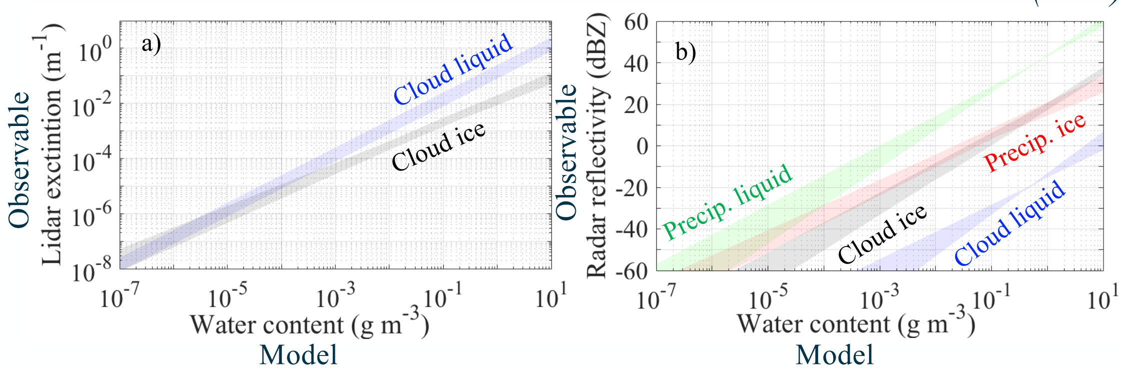
Mie theory for spherical particles (e.g., QuickBeam (*Haynes et al. 2007*) for COSP-CloudSat and for ARM CRS)

Ensemble of empirical relationship between water content – radar reflectivity (e.g., (GO)^2-SIM *(Lamer et al. 2018)*)

SIMPLE

(GO)^2-SIM scattering model

Lamer (2018)



2. Scale differences between model output and observations

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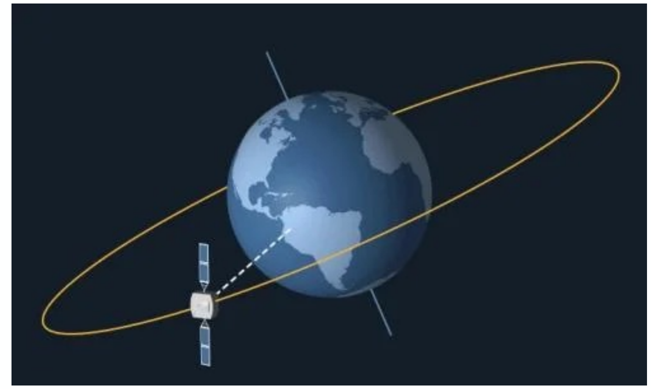
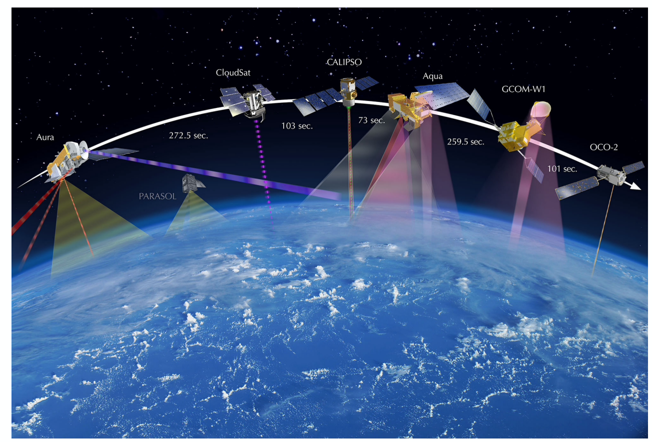
1- While models may provide 4D global or limited domain simulations, sensors collect dimensionally challenged measurements either at a fixed location or along an orbit/swath.

⇒Instrument forward simulators allow us to extract the model grids that match the sensor sampling geometry. Those require knowledge of:

- Platform geolocation information (i.e., orbit model)
- Viewing geometry (i.e., angle, swath)
- Revisiting time (i.e., diurnal sampling)

2- Sensor sampling volume often differs from model resolution. This scale gap must be addressed. Techniques to address the scale gap generally vary with model resolution.





2. Scale gap – Model grid >> Observation volume

When model doesn't resolve cloud and precipitation features but observations do we need to decide how should hydrometeor fraction be distributed in space.

Why: Vertical overlap between cloud and precipitation layers strongly affects remote sensing measurements because signal attenuation generally increases with layer depth.

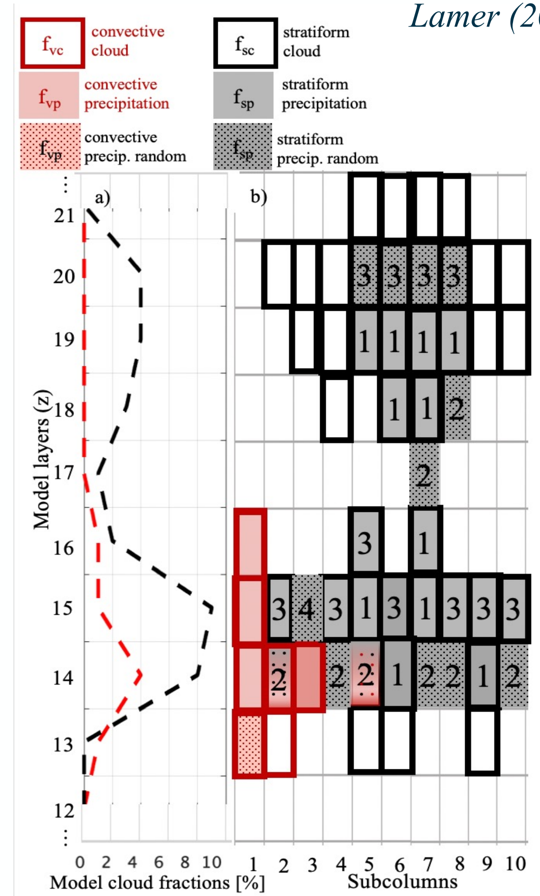
How: For example:
NASA/GISS ModelE3 horizontal resolution ~100 km
Ground-based ARM/KAZR observations: ~30 s

Approximately 12 hrs of observation within a model grid
⇒Cannot average without convoluting diurnal cycle and horizontal variability.
⇒Generate subcolumns that adheres to all overlap assumptions within the model and distribute each species. (e.g., SCOPS *(Klein and Jakob 1999; Webb et al. 2001)*, PRECIP-SCOSPS *(Zhang et al. 2010), Raisanen et al. (2004)*)

But what if overlap assumptions for different water phase species are not given?

But what if overlap assumptions differ across schemes within the same model…

Lamer (2019)

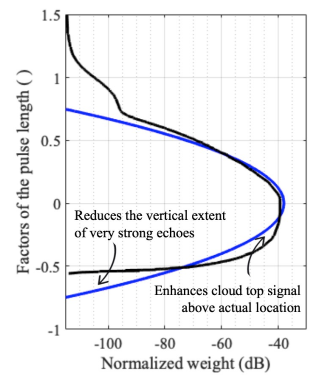


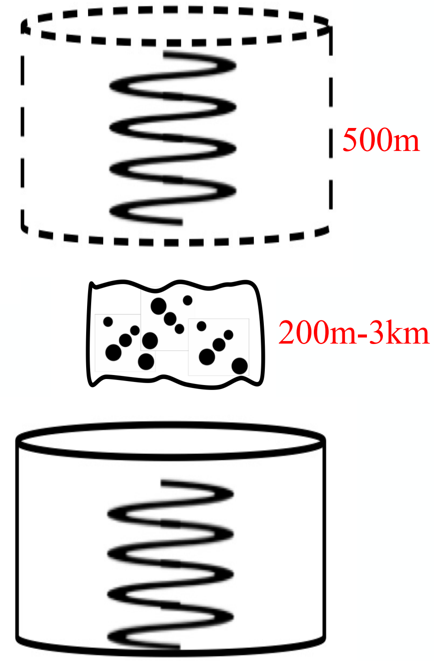
2. Scale gap – Model grid << Observation volume

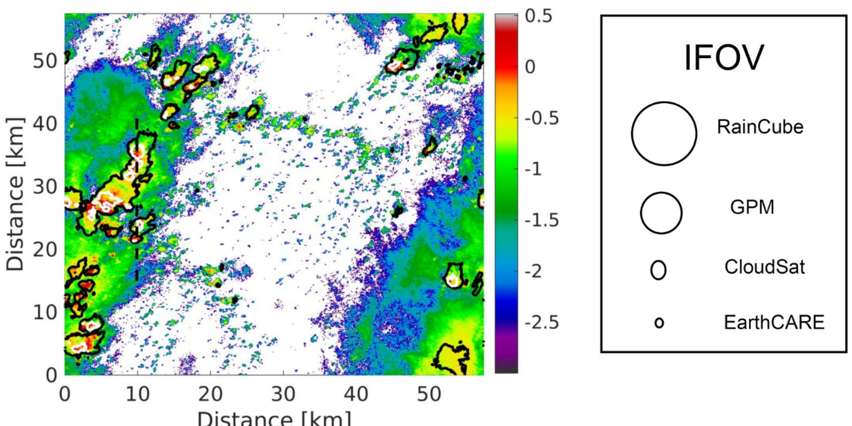
When model resolve cloud and precipitation features at a resolution higher than we can observe them
=> an option is to apply an instrument forward simulator.

Requires knowledge of:

- Radar pulse range weighting function
- Radar pulse along track weighting function
- Footprint at the ground







Battaglia et al. (2020)

Lamer et al. (2020)

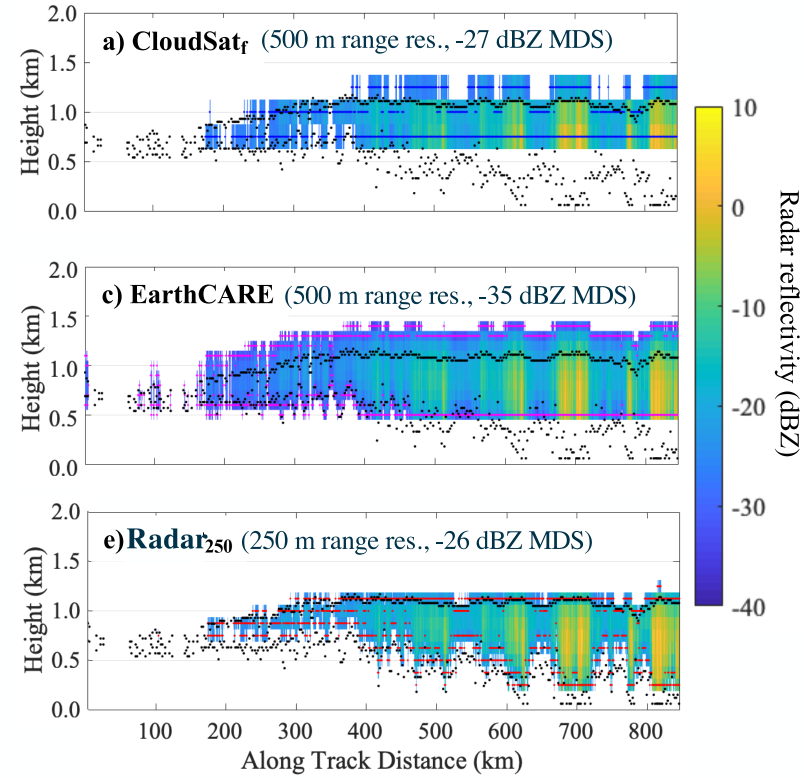
3. Sensor performance – Effects other than scattering

Models can simulate even minute hydrometeor amounts. Instead of applying a threshold on model output to match instrument performance we can reproduced more realistic height dependent sensor detection limitations in forward space.

⇒ Reproduce:

- Range dependent sensitivity loss
- Signal attenuation by liquid *(e.g., Chepfer et al. 2008)*
- Blind zone cause by outgoing pulse or surface echo

Forward simulated radar reflectivity for different spaceborne radars



Lamer et al. (2020)

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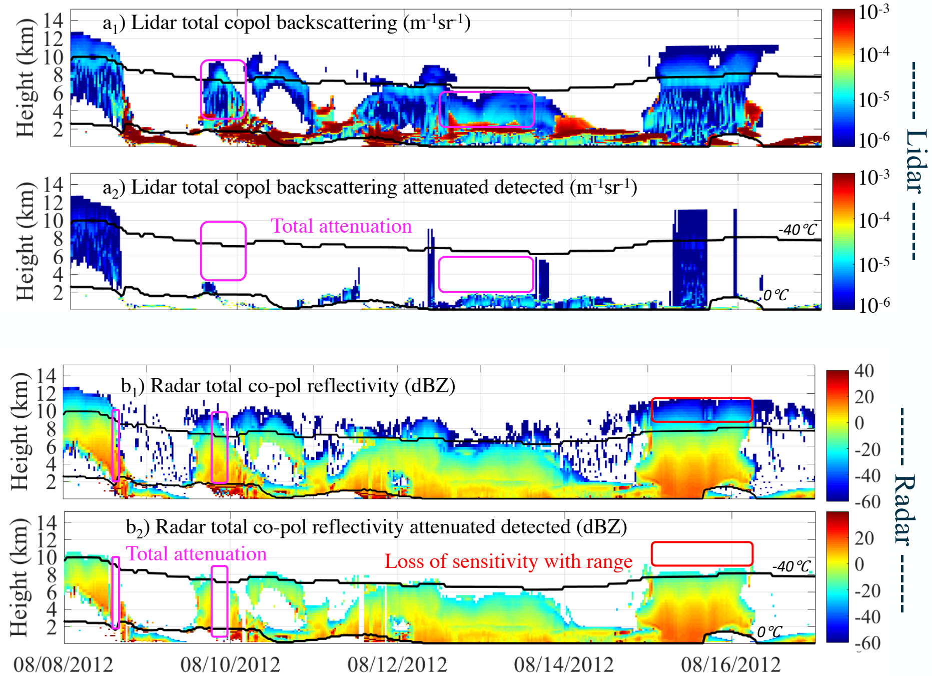
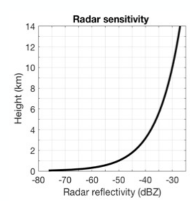
Forward simulated
lidar backscatter and radar reflectivity
with and without instrument model



Lamer et al. (2018)

Within (GO)2-SIM, we a stratiform clouds and precipitation case we found that only ~78 % of simulated grid boxes could be observed/assessed by real sensors.

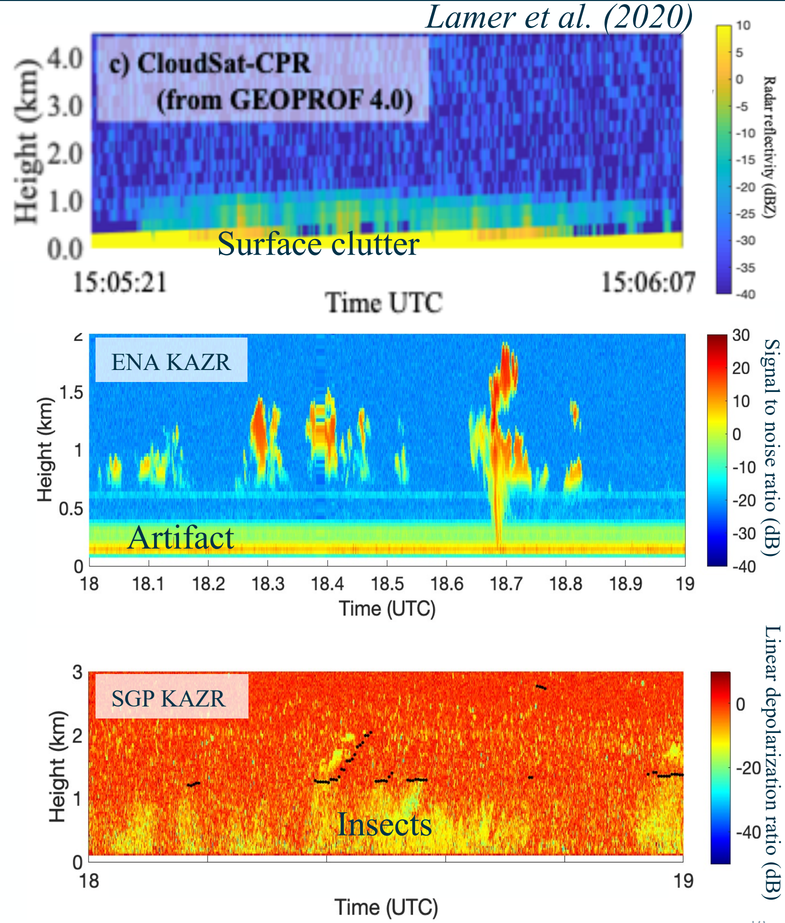


3. Sensor performance – Non-meteorological echoes

One must remain mindful that forward simulators do not represent instrument noise, surface clutter, insects and other non-meteorological targets.

⇒As such it is essential that observations be rigorously quality controlled, filtered and calibrated before they can be used to guide model development.

Lamer et al. (2020)



4. Evaluation metrics

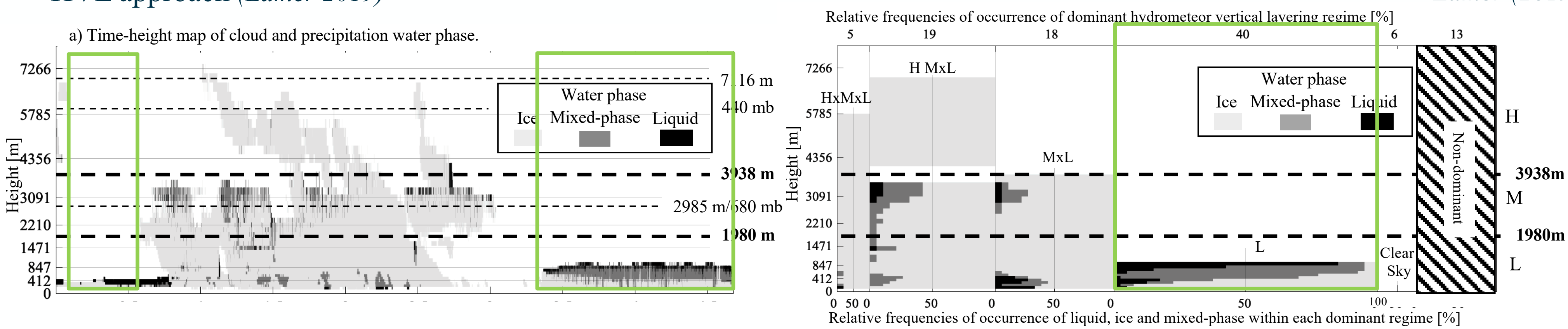
Quality controlled observations and forward simulated model output can be compared to estimate model performance, but it may be difficult to track back the cause of any discrepancy

A more informative way is to apply the same retrieval to observations and forward simulated model output and compare the retrieved property. Useful for ill defined properties like hydrometeor layer depth or liquid fraction in mixed-phase systems.

⇒For cloud layering, a possibility is to first establish if cloud are distributed correctly across 3 fundamental level

- GOCCP approach *(Cesana and Chepfer 2013; Chepfer et al 2010),*
- ISCCP approach *(Rossow and Schiffer 1991)*
- CVS approach *(Remillard and Tselioudis 2013, 2015)*
- HVL approach *(Lamer 2019)*

Lamer (2019)



Preliminary model evaluation of ModelE3 against ARM obs. at the North Slope of Alaska

First metric: Dominant regimes types

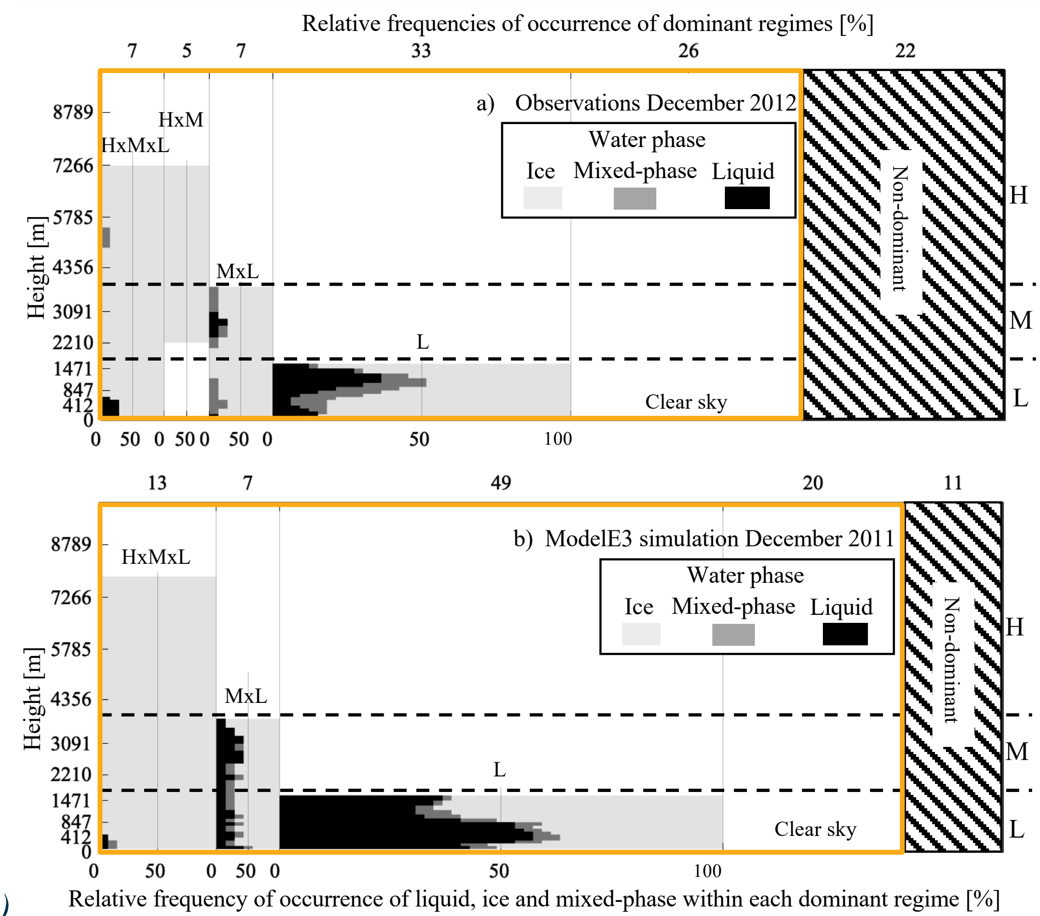
December 2012 ARM observations

5 dominant regimes

December 2011 NASA ModelE3 simulation

✓ 4 dominant regimes were simulated

X Missing deep elevated layers (HxM)



Lamer (2019)

Preliminary model evaluation of ModelE3 against ARM obs. at the North Slope of Alaska

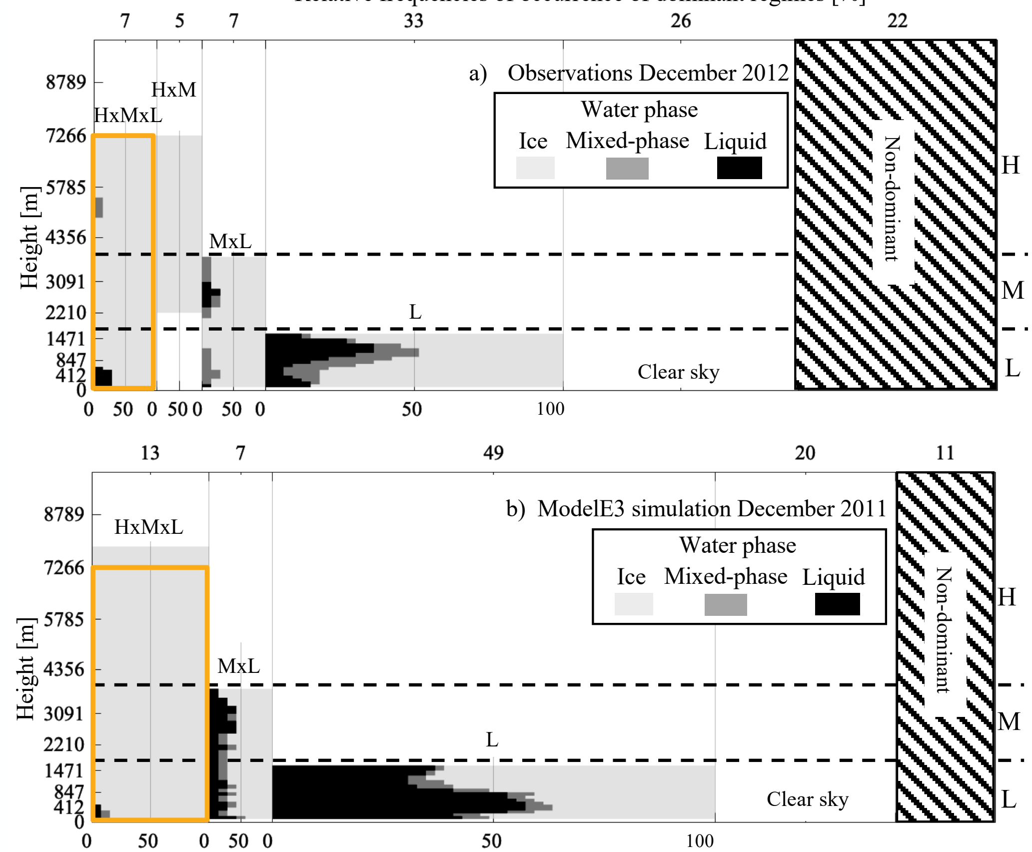
Second metric: Dominant regimes thickness

December 2012 ARM observations

Deep systems (HxMxL) extend to 7266m

December 2011 NASA ModelE3 simulation

X Deep systems (HxMxL) are too deep



Lamer (2019)

Preliminary model evaluation of ModelE3 against ARM obs. at the North Slope of Alaska

Third metric: Dominant regimes occurrence

December 2012 ARM observations

7 % deep systems (HxMxL)

5 % deep elevated layers (HxM)

7 % deep low-level layers (MxL)

33 % low-level layers (L)

26 % clear sky

December 2011 NASA ModelE3 simulation

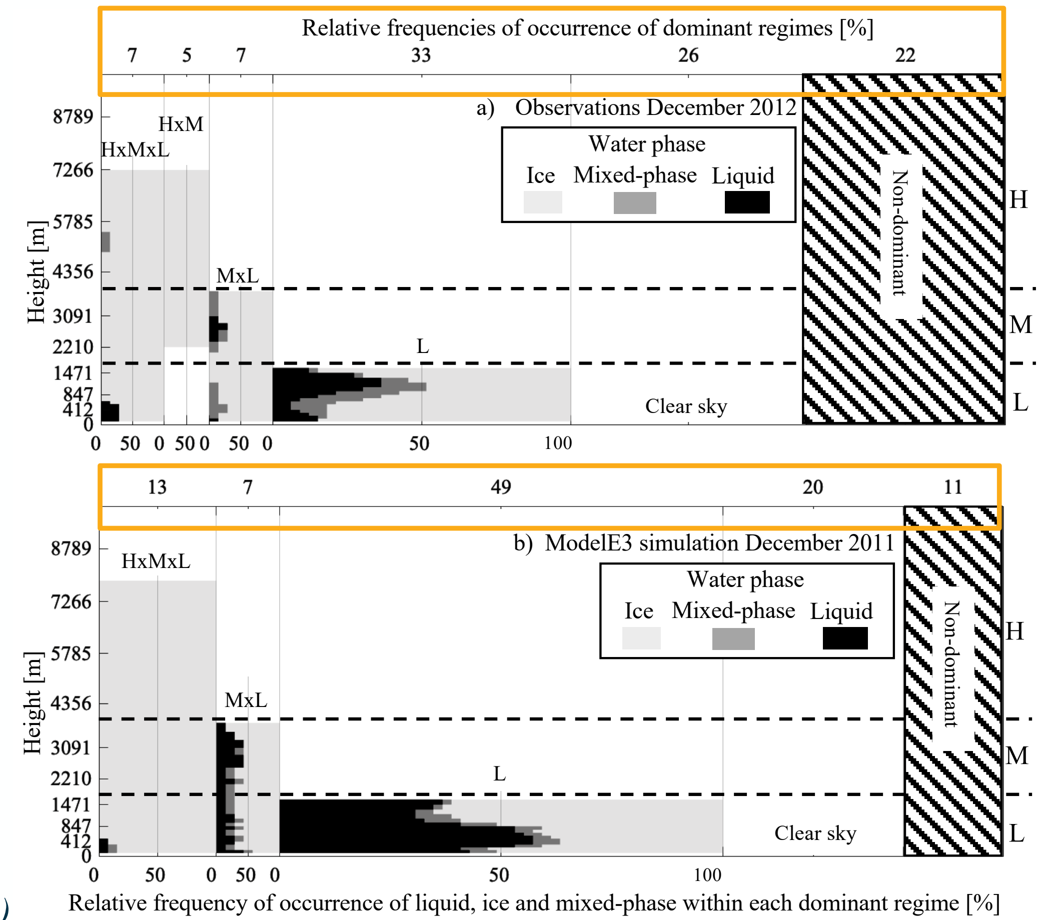
OK deep systems (HxMxL)

- deep elevated layers (HxM)

✓ deep low-level layers (MxL)

+ 16 % low-level layers (L)

OK clear sky



Lamer (2019)

Main challenges for comparing model and observations

1. Define hydrometeor properties in terms of the same moments (i.e., mass vs. radar reflectivity)
⇒ Apply scattering forward simulator to model output (mass => radar reflectivity, lidar backscatter)

2. Account for the scale differences
Model output scale << Measurement scale => Average model output using instrument IFOV weighting functions
Model output scale >> Measurement scale => Create model sub-columns that follow model assumptions

3. Objectively filter data for performance difference
⇒ Forward simulate effects other than scattering (attenuation, sensitivity drop with range, blind-zone)
⇒ Filter observations for non meteorological echoes (e.g., noise, surface clutter, insects) and calibrate them

4. Define an objective evaluation metric
⇒ Apply the same retrieval on forward simulated model output and observations
(e.g., hydrometeor layer depth, hydrometeor population phase)

5. Identify a suitable evaluation timescale
⇒ Case study vs. statistical analysis

6. Define what level of discrepancy is acceptable or not given the uncertainty in the process