CLOSING THE DRIZZLE OBSERVATION GAP WITH CLOUDSAT

Combining Cloud Radar and Passive Observations

IPWG 11

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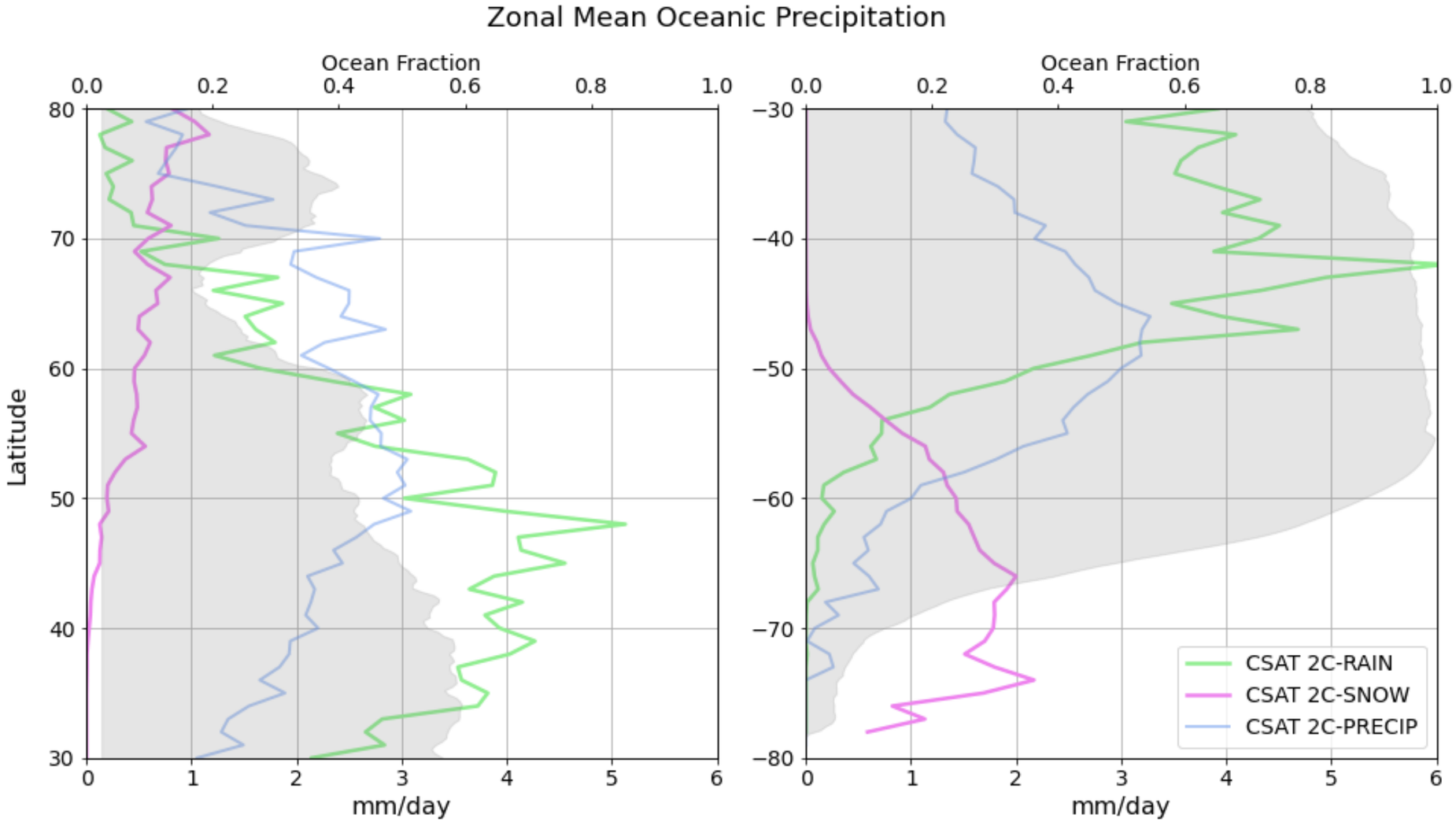
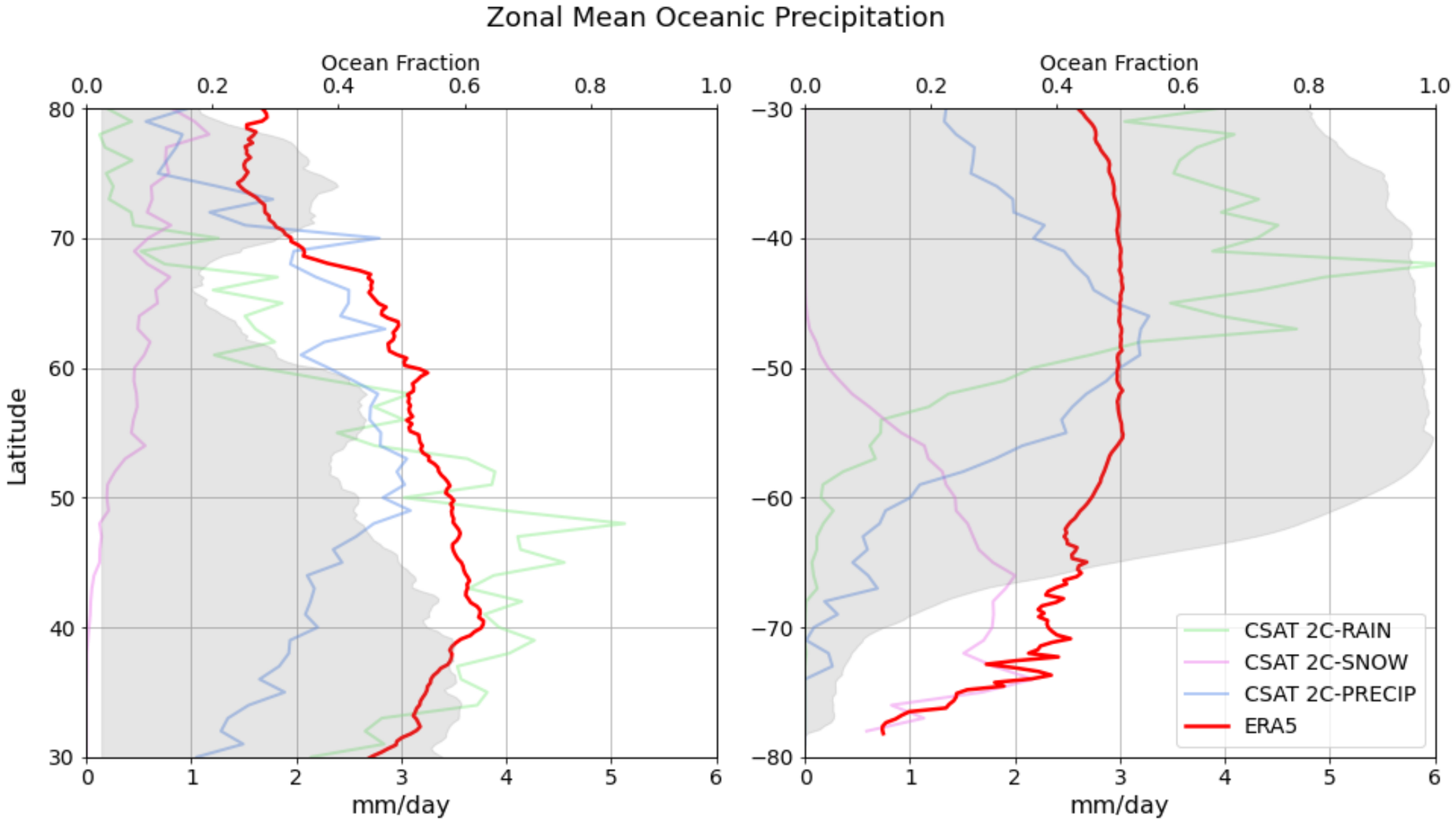
I. *Introduction: High latitude ocean precipitation is poorly constrained by current methods*

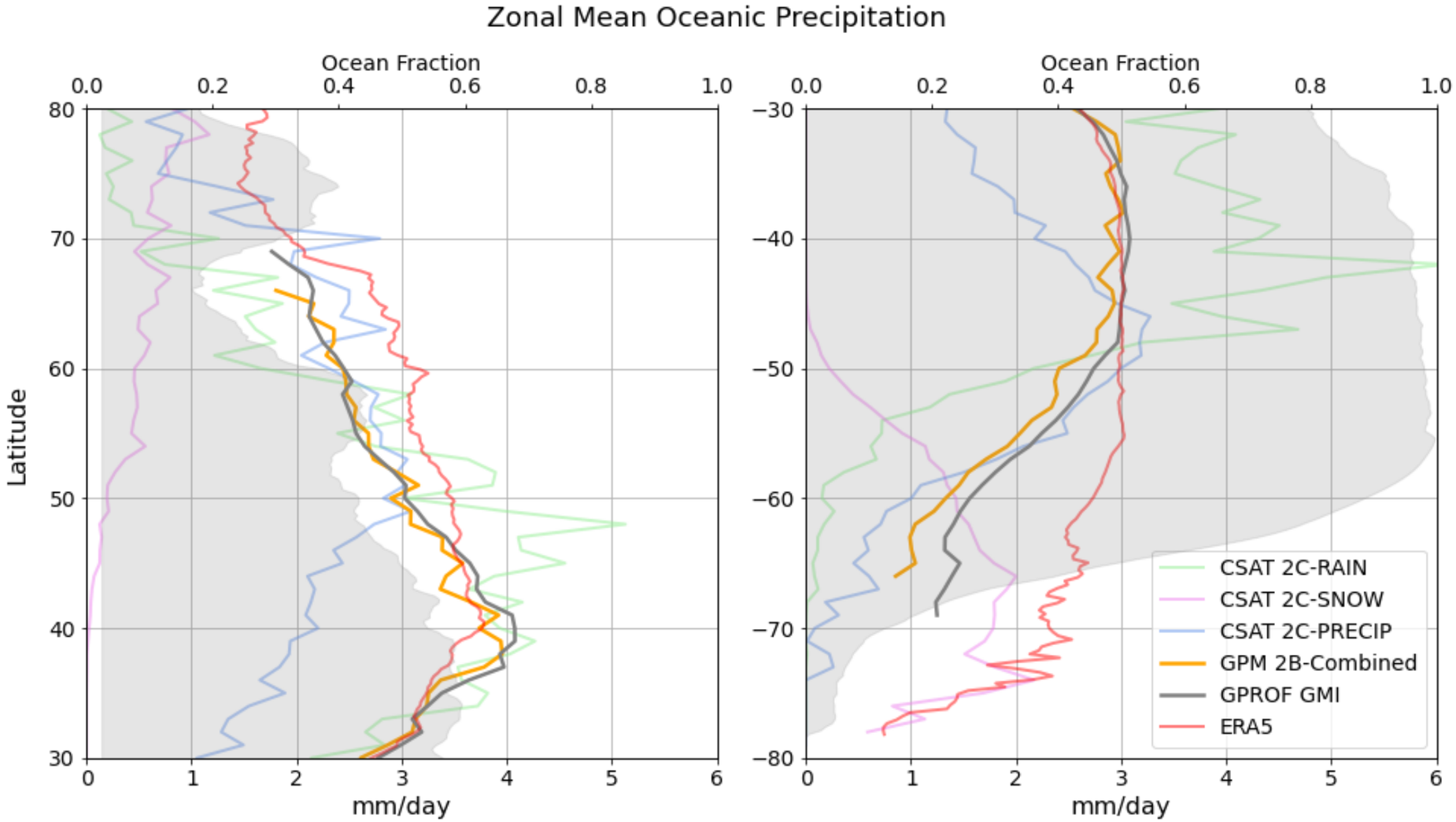
High latitude ocean precipitation is poorly constrained by current methods



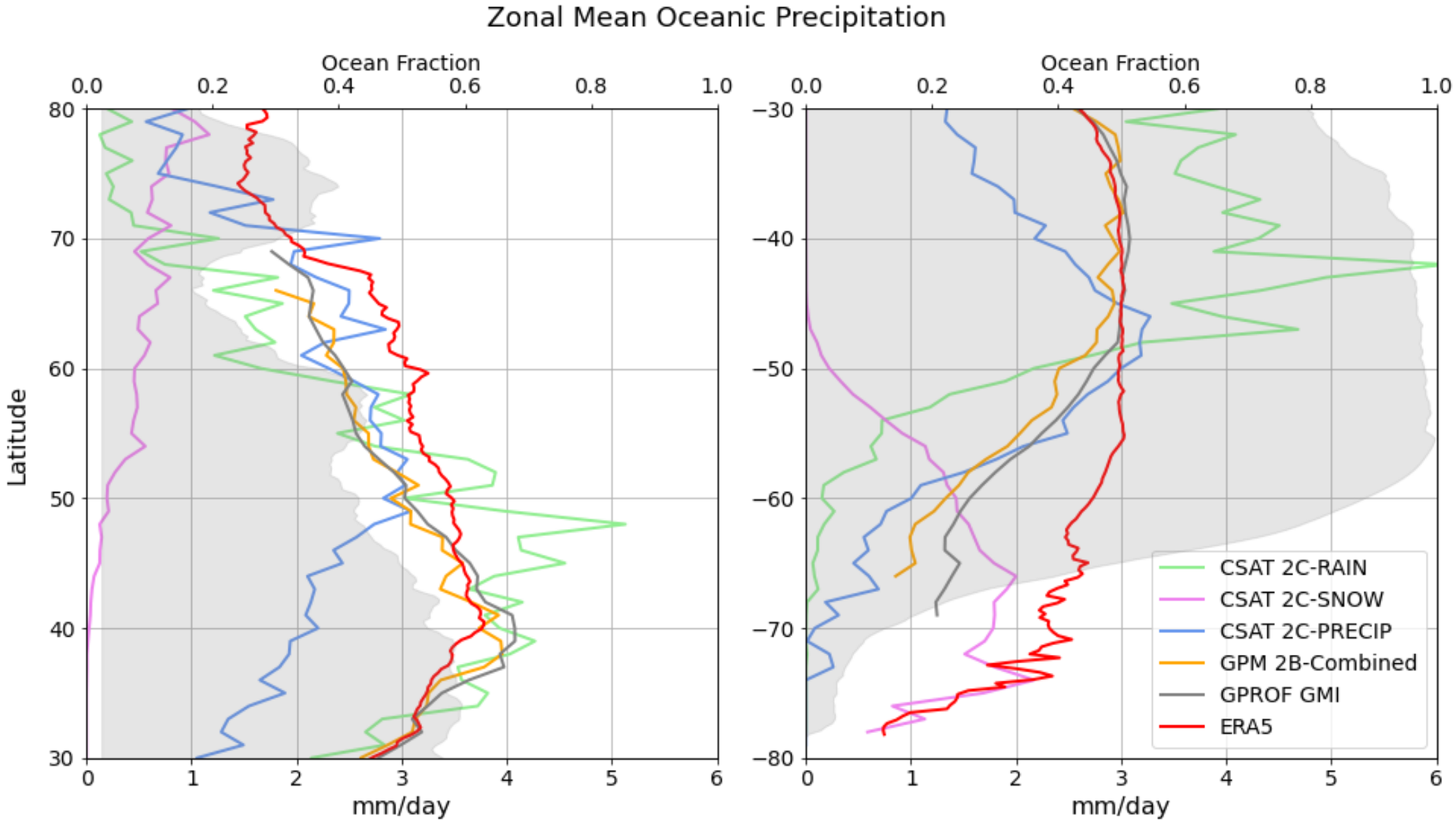
High latitude ocean precipitation is poorly constrained by current methods



High latitude ocean precipitation is poorly constrained by current methods

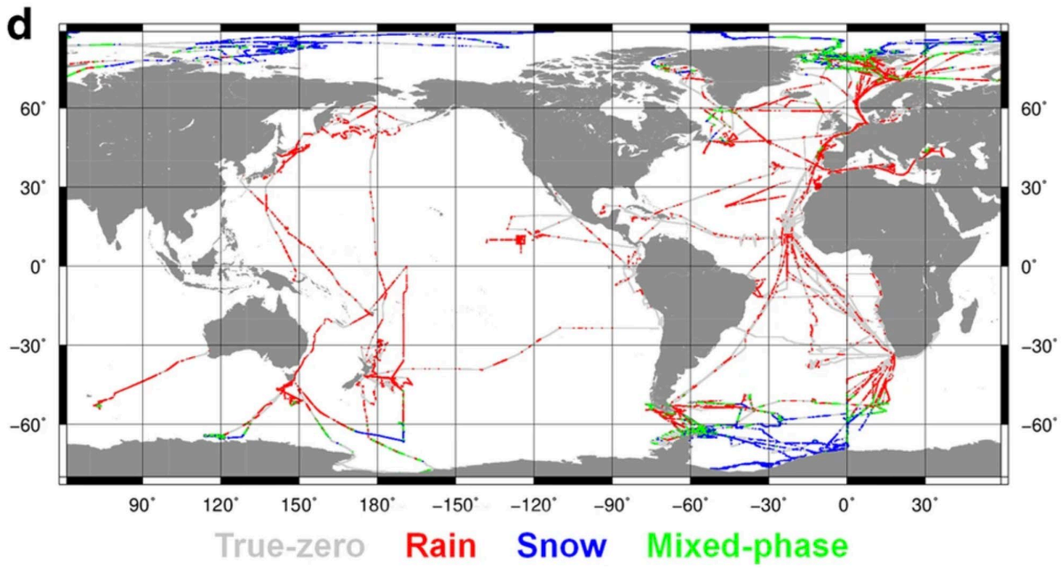


High latitude ocean precipitation is poorly constrained by current methods



Drizzle is important for high-latitude precipitation characterization

- OceanRAIN field campaign (Klepp et al. 2018):



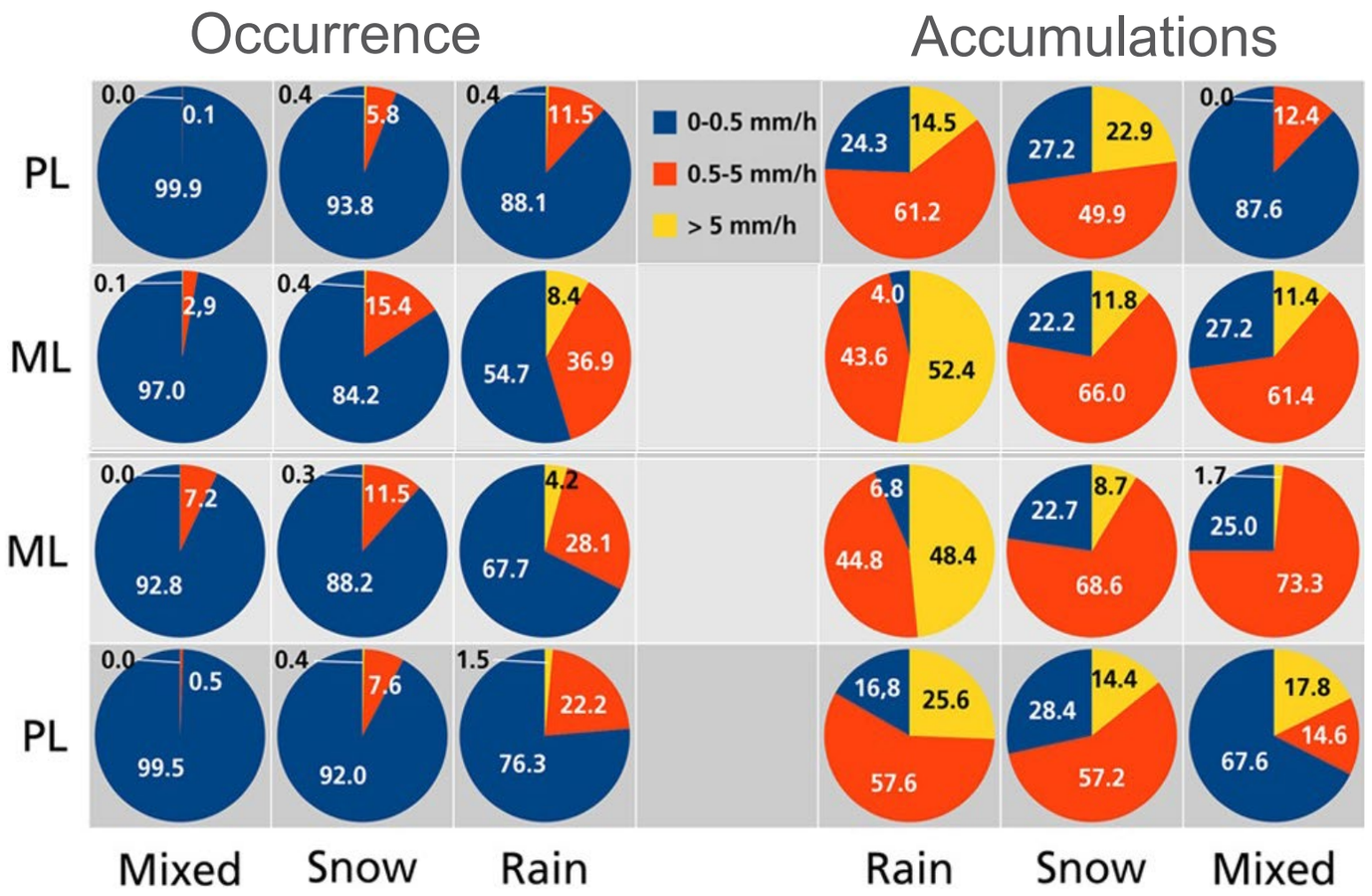
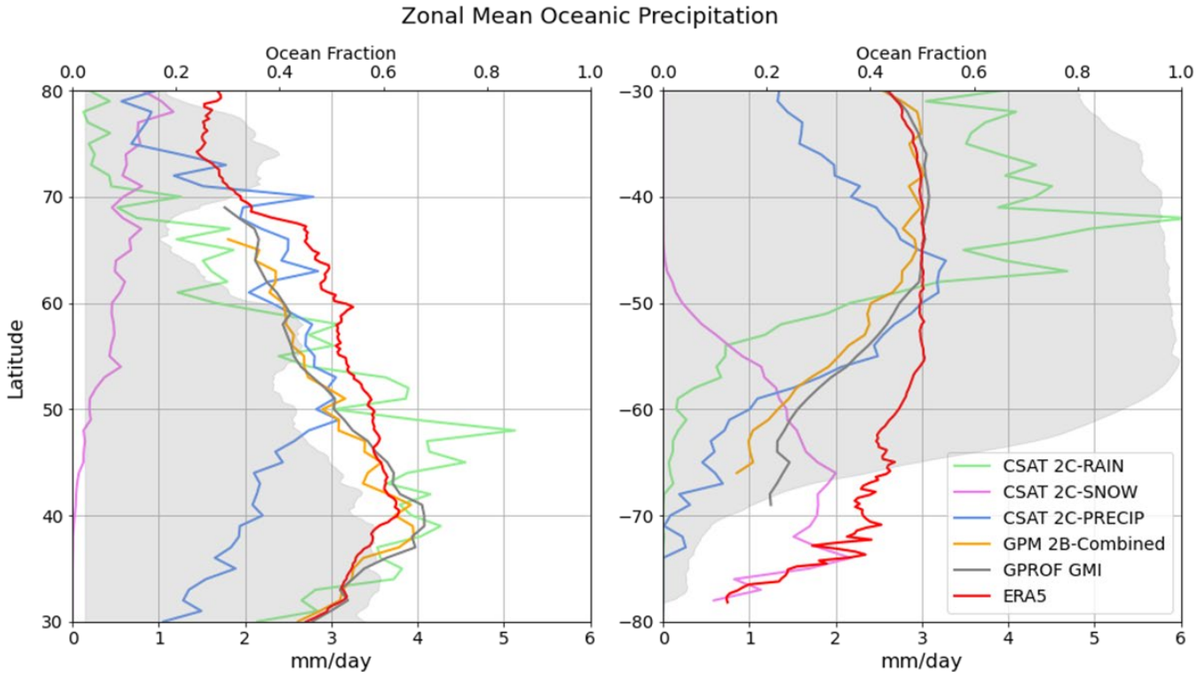
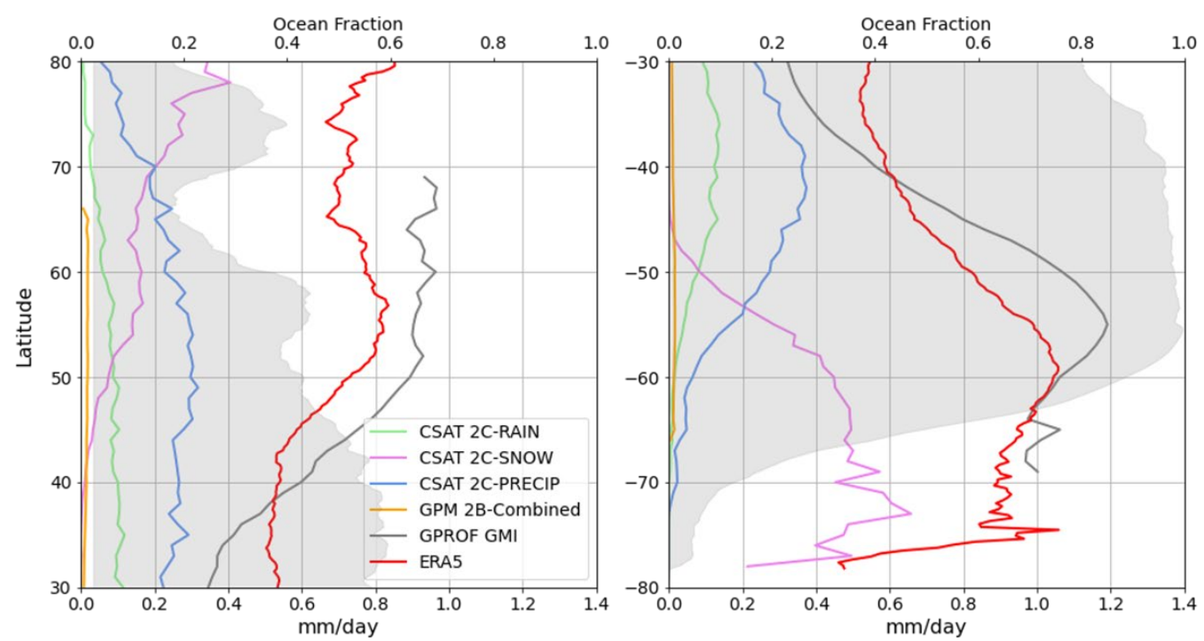


Image Credits: Adapted from Figures 2 and 3 from Klepp et al. (2018)


Zonal Mean Oceanic Precipitation
Ocean Fraction
Latitude
mm/day
CSAT 2C-RAIN
CSAT 2C-SNOW
CSAT 2C-PRECIP
GPM 2B-Combined
GPROF GMI
ERA5


Zonal Mean Oceanic Precipitation ≤ 0.25 mm/hr
Ocean Fraction
Latitude
mm/day
CSAT 2C-RAIN
CSAT 2C-SNOW
CSAT 2C-PRECIP
GPM 2B-Combined
GPROF GMI
ERA5

Satellite methods have limitations when it comes to observing drizzle:

- Precipitation Measurement Mission radars:
  - Minimum detection thresholds
    - TRMM-PR: ~1 mm/hr
    - GPM-DPR: ~0.25 mm/hr
  - Poor sampling
    - narrow, nadir-only scans
  - Assumed Particle Size Distributions (PSDs)
  - PIA/Dual Frequency doesn't add information for small drop sizes

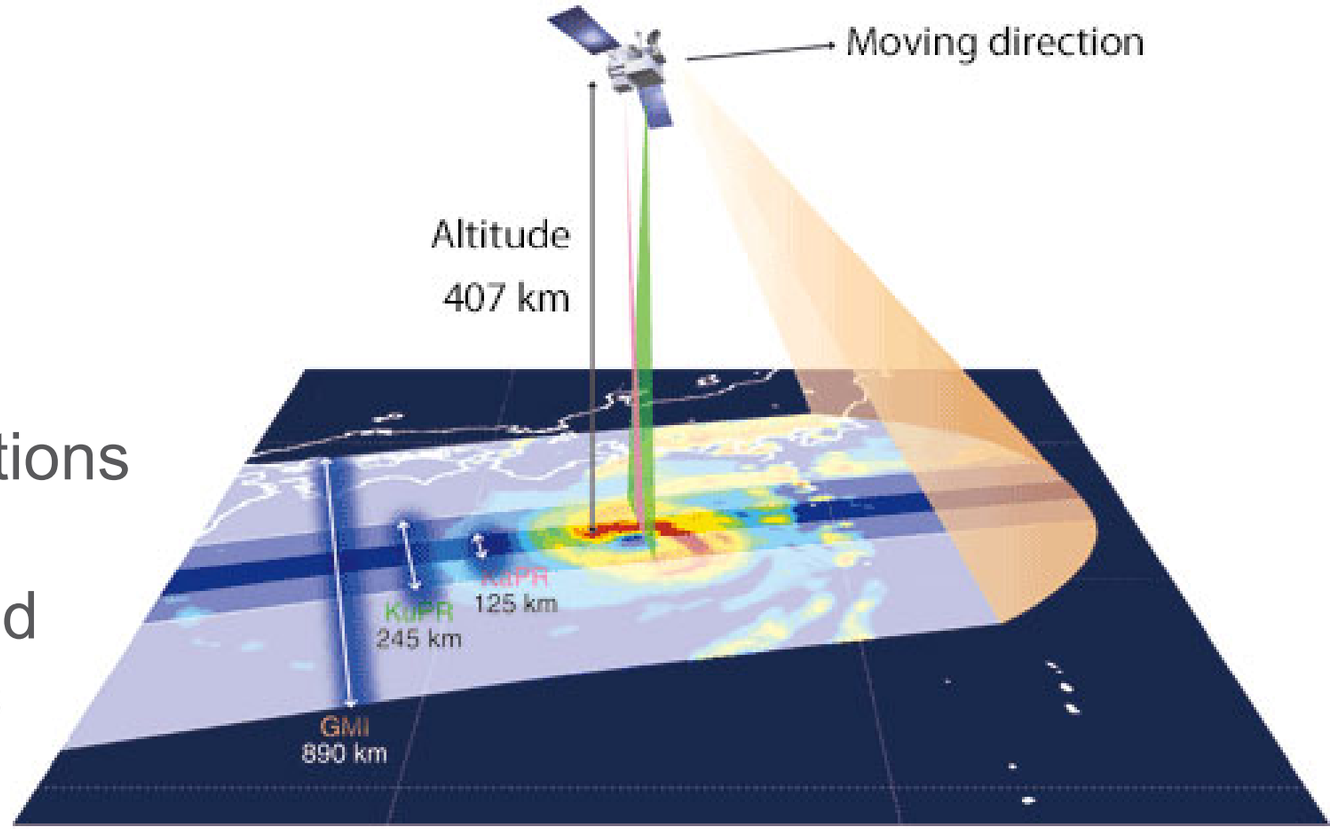


Image Credit: JAXA

Satellite methods have limitations when it comes to observing drizzle:

- Cloud Radars (CloudSat): Good for estimating drizzle, but...
  - Even poorer sampling (1-km pencil beam)
  - Too few physical constraints
  - Suffer from surface clutter
  - Attenuate easily
    - Need ancillary data to constrain PIA

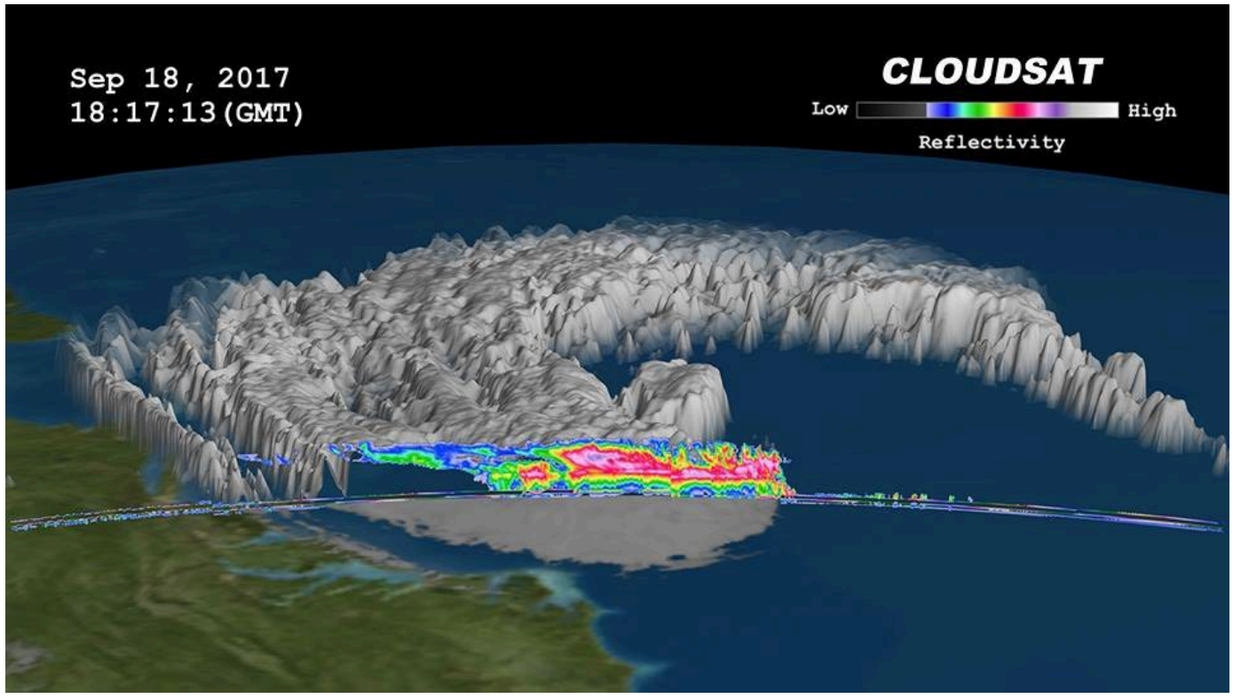


Image Credit: NASA CloudSat Project

Satellite methods have limitations when it comes to observing drizzle:

- Passive Microwave Observations: good sampling, but...
  - Nonunique solutions in inversion techniques
  - Have trouble separating light precipitation from cloud water

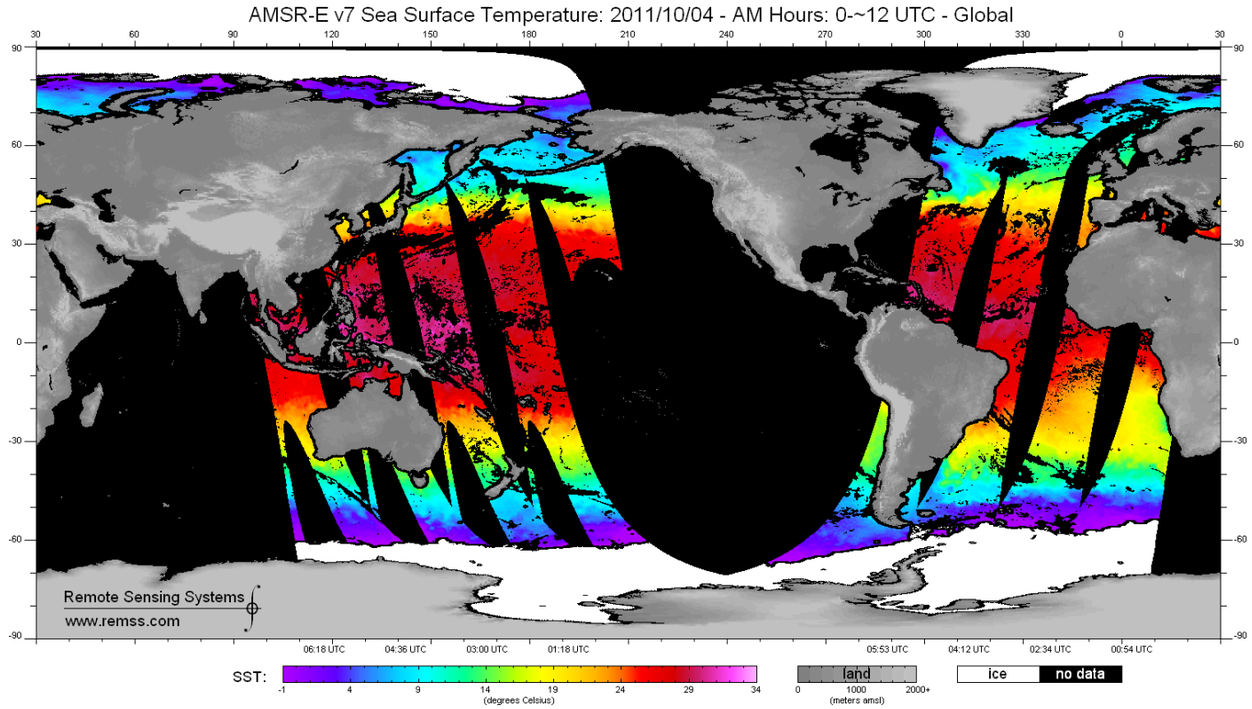


Image Credit: Remote Sensing Systems

Combined techniques:

- Uses advantages of active and passive observations
- Can give solutions to under-constrained problems

- GPM DPR-GMI Combined Algorithm (GPM-CMB):
  - Vertical distribution of hydrometeors
  - Particle sizes
  - Surface precipitation rates

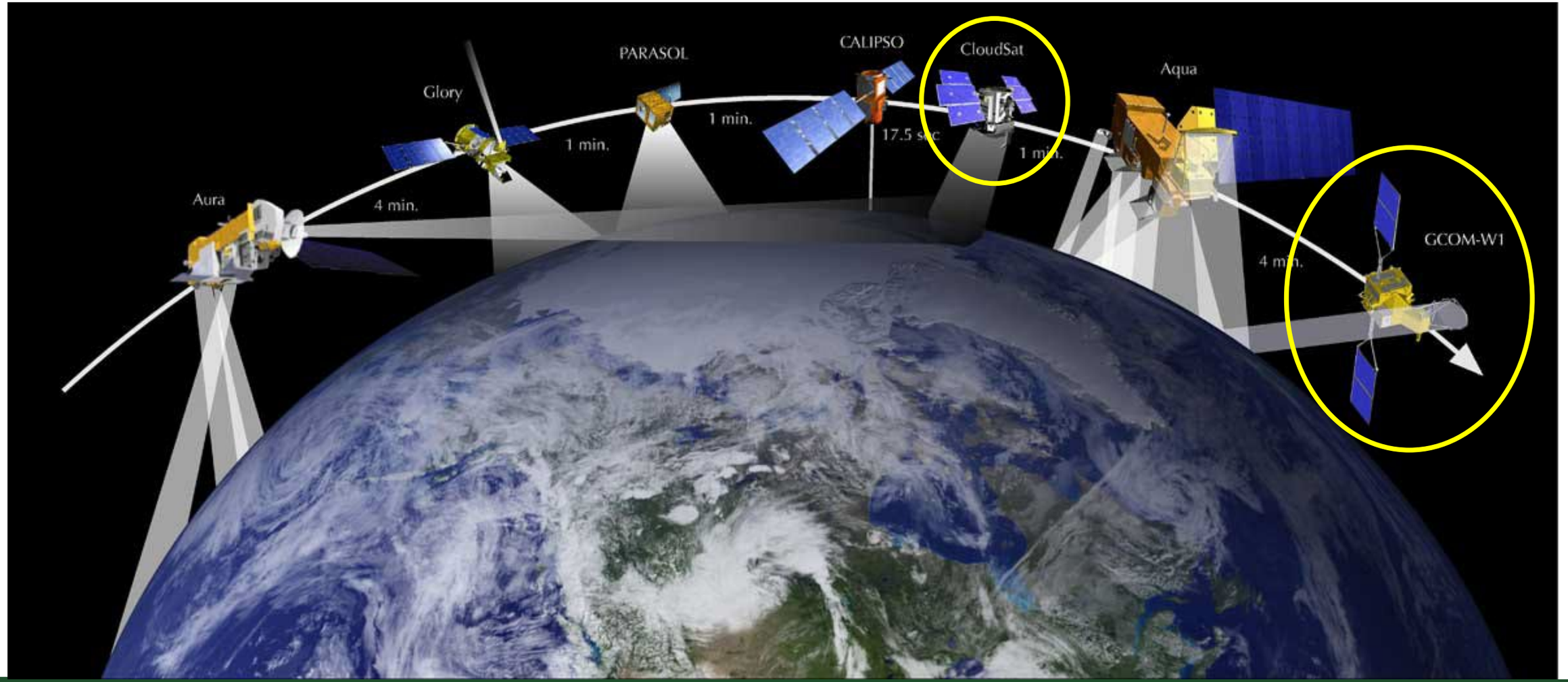
  } Physical consistency

- GPM-CMB profiles form *a priori* database for GPROF
- DPR misses light drizzle, therefore so would GPROF

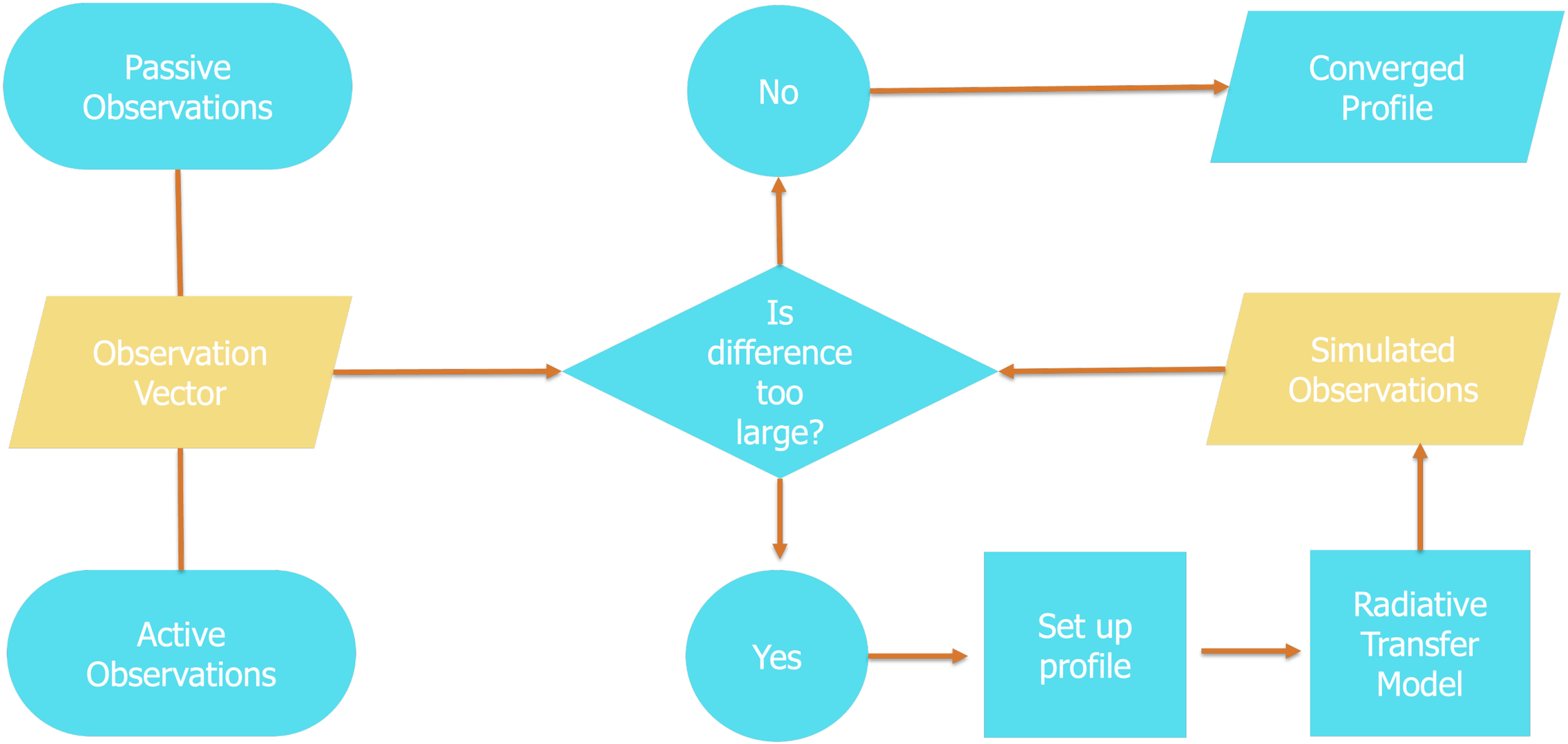
II. *Can we combine cloud radar and passive observations to constrain drizzle with mutual consistency?*

The A-Train:

Advanced Scanning Microwave Radiometer 2 (AMSR2)
Cloud Profiling Radar (CPR)



Combined optimal estimation (OE) retrieval



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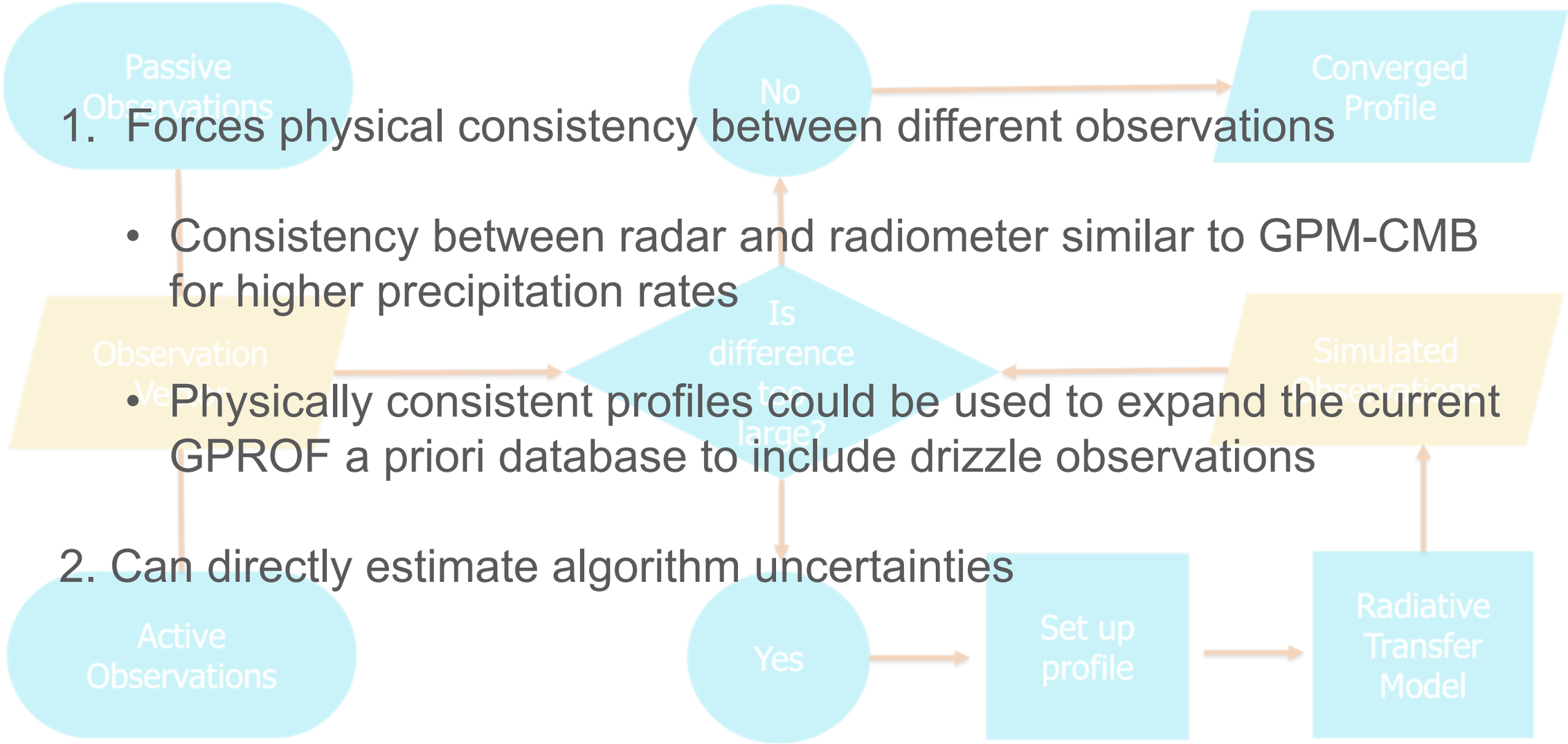
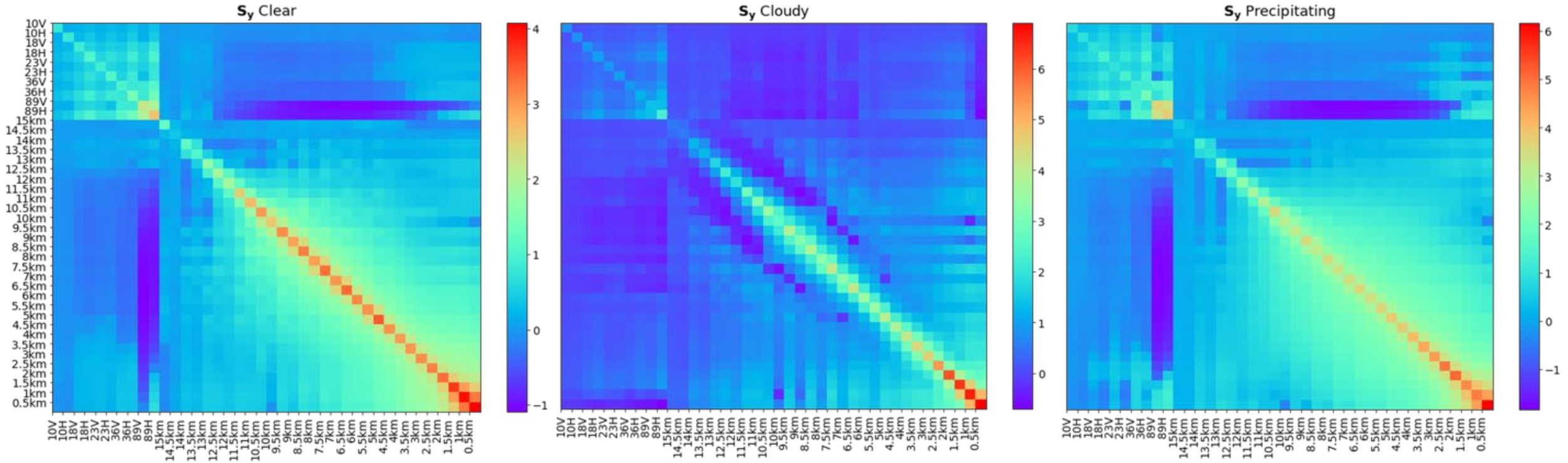


1. Forces physical consistency between different observations
   - Consistency between radar and radiometer similar to GPM-CMB for higher precipitation rates
   - Physically consistent profiles could be used to expand the current GPROF a priori database to include drizzle observations
2. Can directly estimate algorithm uncertainties

We can predetermine observational uncertainty estimates based on category

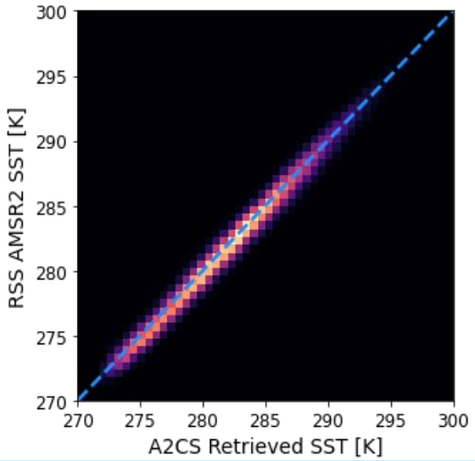


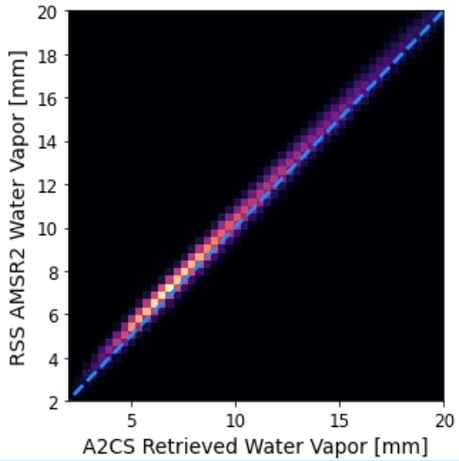
III. *Results: improved constraints for drizzle estimates*

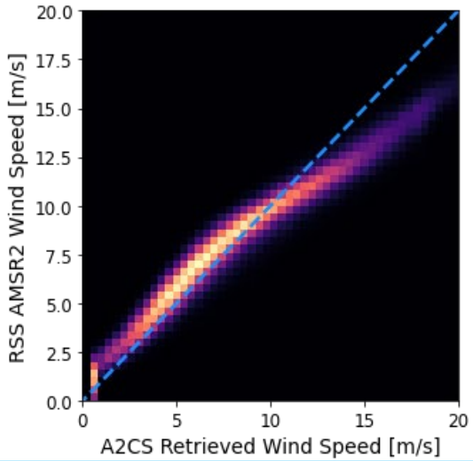
Remote Sensing Systems AMSR2*

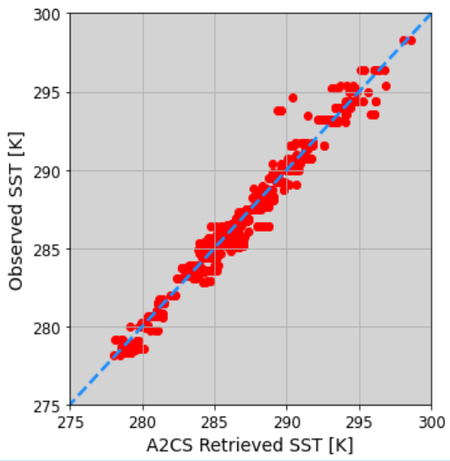
In-situ Buoys and Ships**

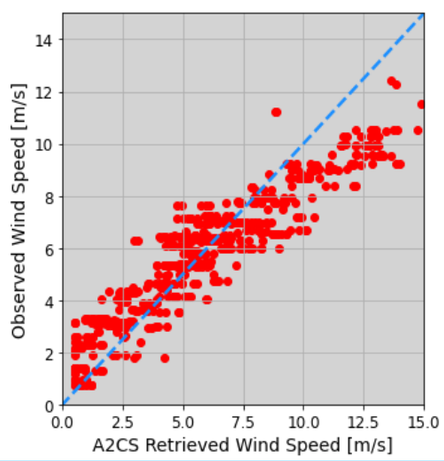
Clear



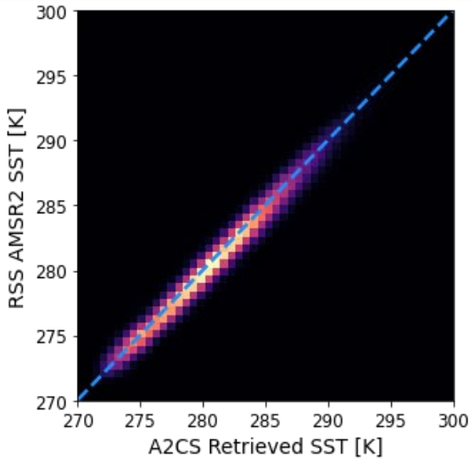


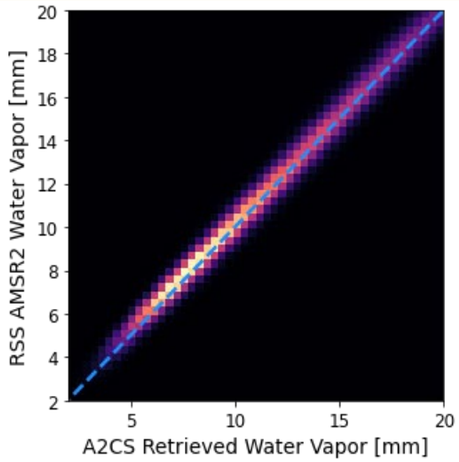


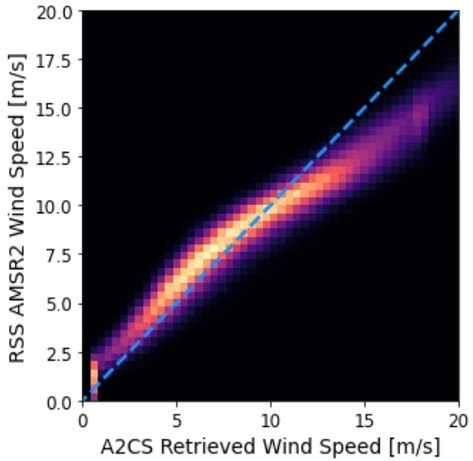


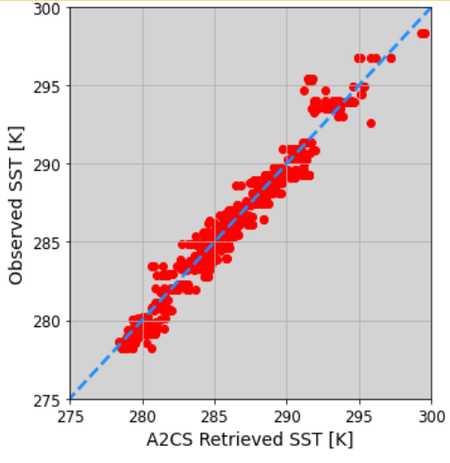


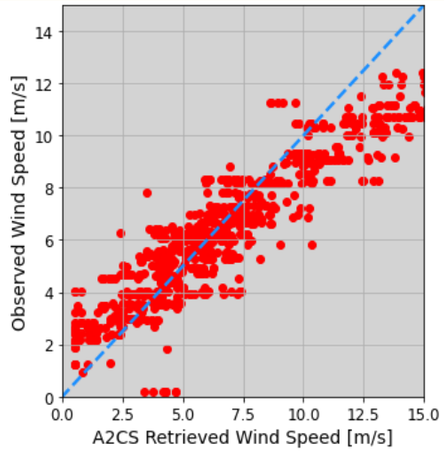
Cloudy









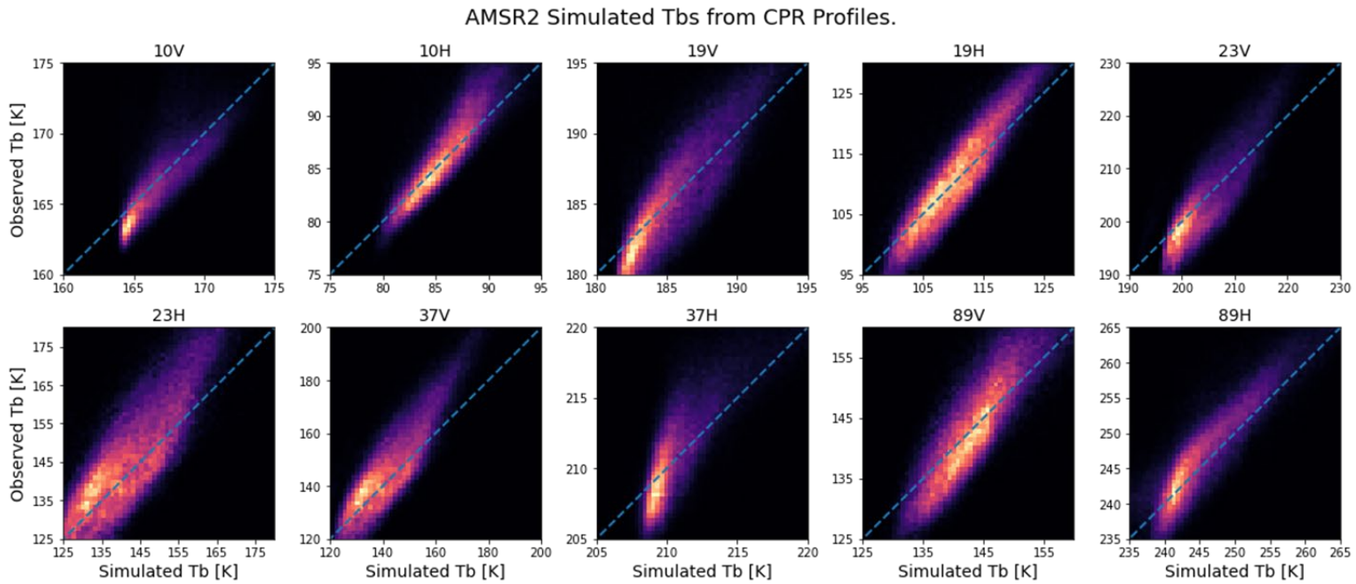


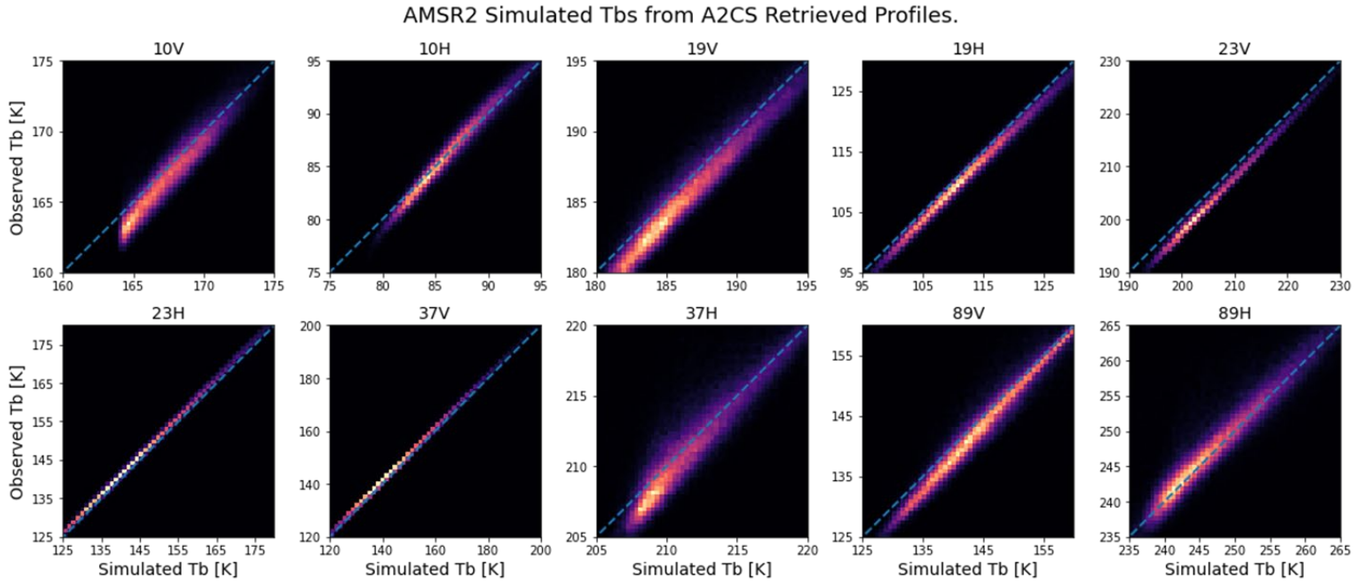
*Wentz et al., 2014: www.remss.com/missions/amsr.

**www.oceansites.com

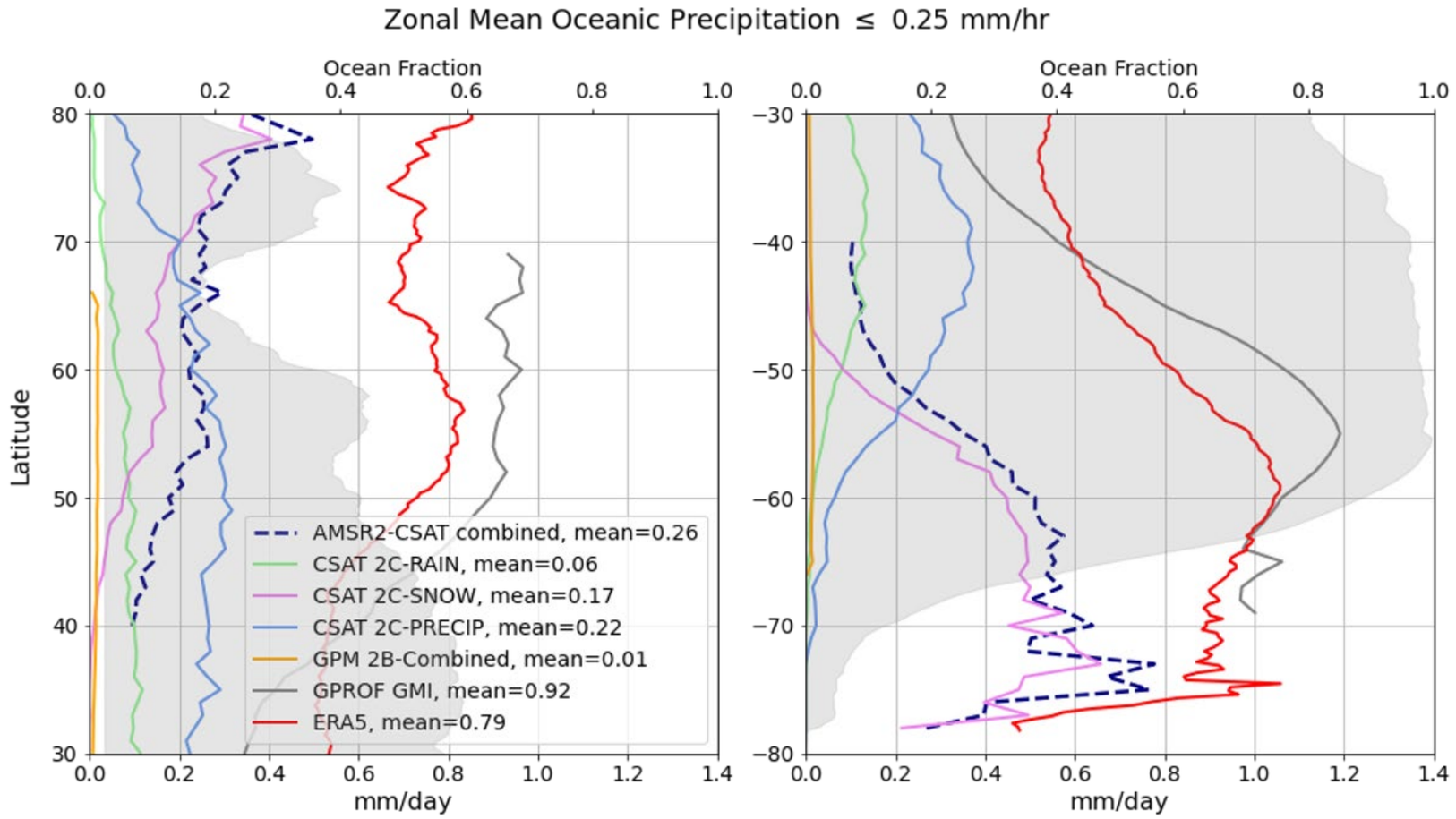
Retrieved profiles are physically consistent

- Simulated Tbs from retrieved states align with AMSR2 observed Tbs
- 25% of converged passive-only retrievals were found to be precipitating by combined retrieval





Zonal drizzle estimates slightly overestimate CloudSat

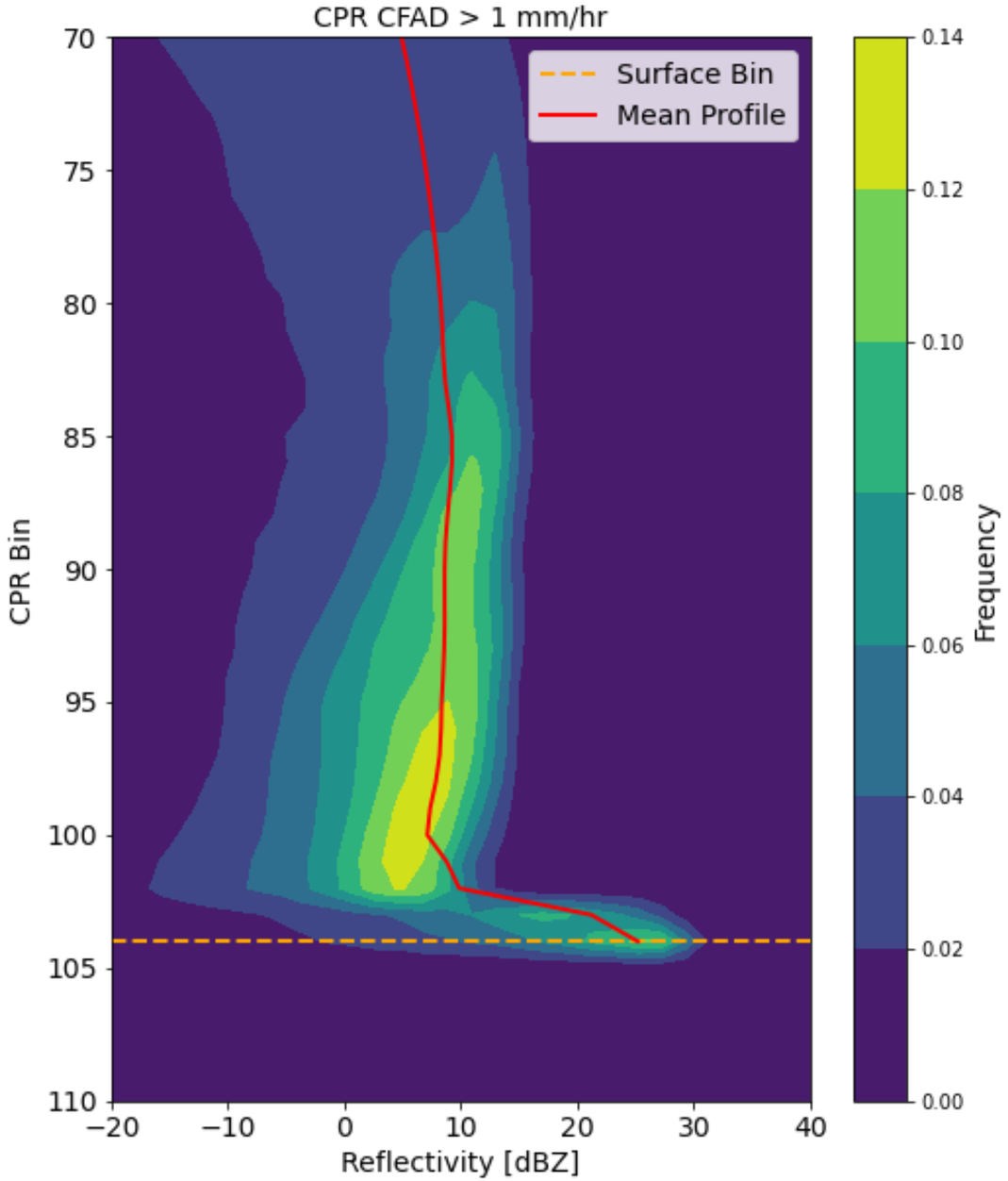


Conclusions:

- Retrieved drizzle profiles are physically consistent with both sets of observations
- Radiometer is able to constrain water vapor for improved radar attenuation estimates
- Retrieved surface parameters validate well against passive-only and in-situ
  - (but validation is difficult in this regime)

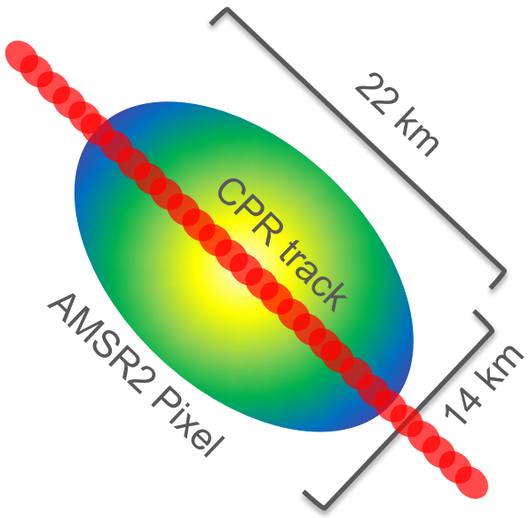
Thank you.

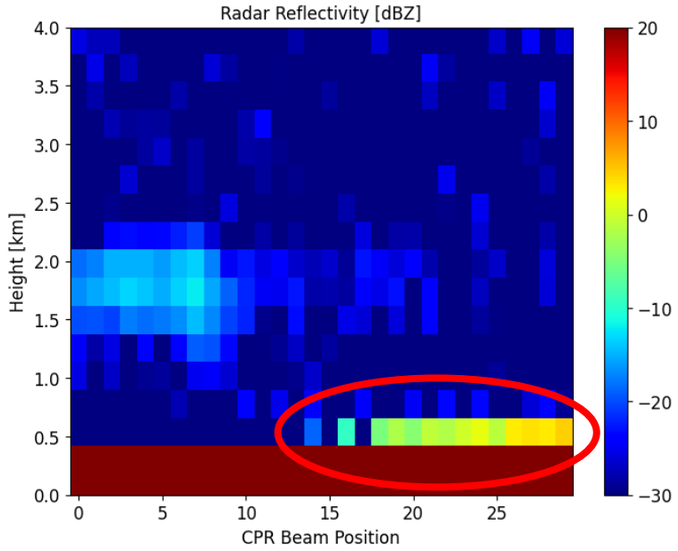
Supplementary Slides

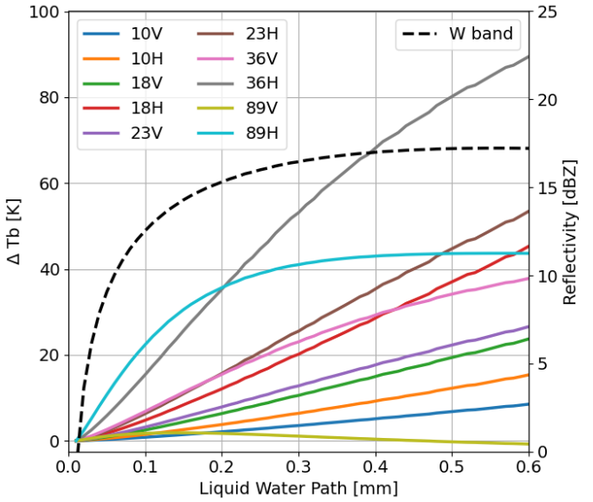

CPR CFAD > 1 mm/hr
Surface Bin
Mean Profile
CPR Bin
70
75
80
85
90
95
100
105
110
−20
−10
0
10
20
30
40
Reflectivity [dBZ]
Frequency
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00

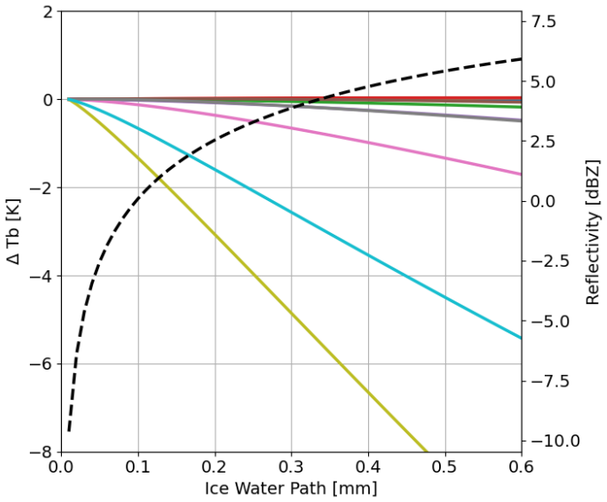
Caveats

- Spatial resolution mismatch
  - Along-track average CPR observations
- Inhomogeneous beam filling
  - Radiometer seems to be able to correct for low intensities
- Unresolved surface clutter
  - Use ERA5 cloud base
- Limited validation

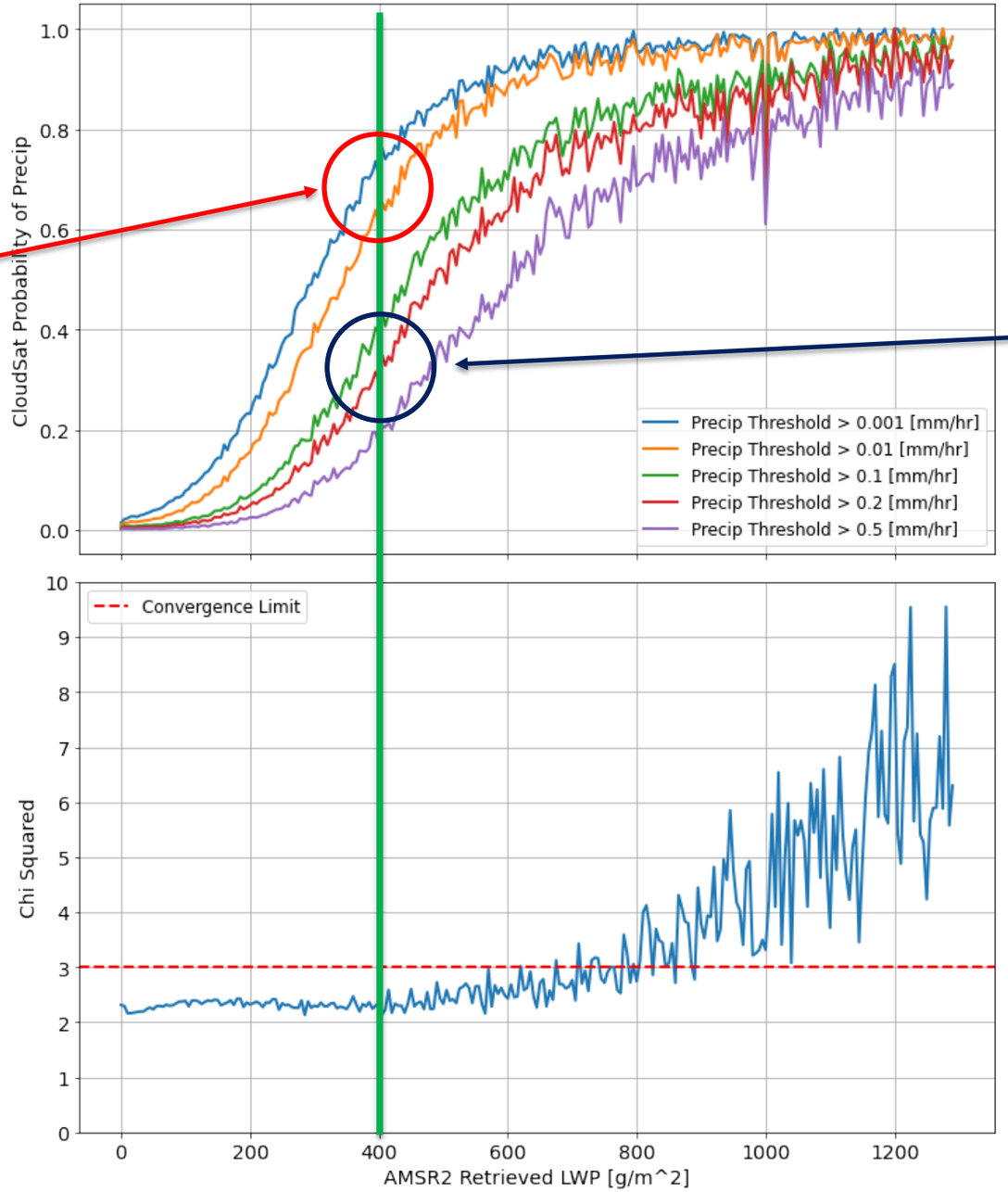








CloudSat



DPR