EarthCARE L2 validation

ALGORITHM DEVELOPER NEEDS

25 May 2021

2nd EarthCARE calibration/validation workshop

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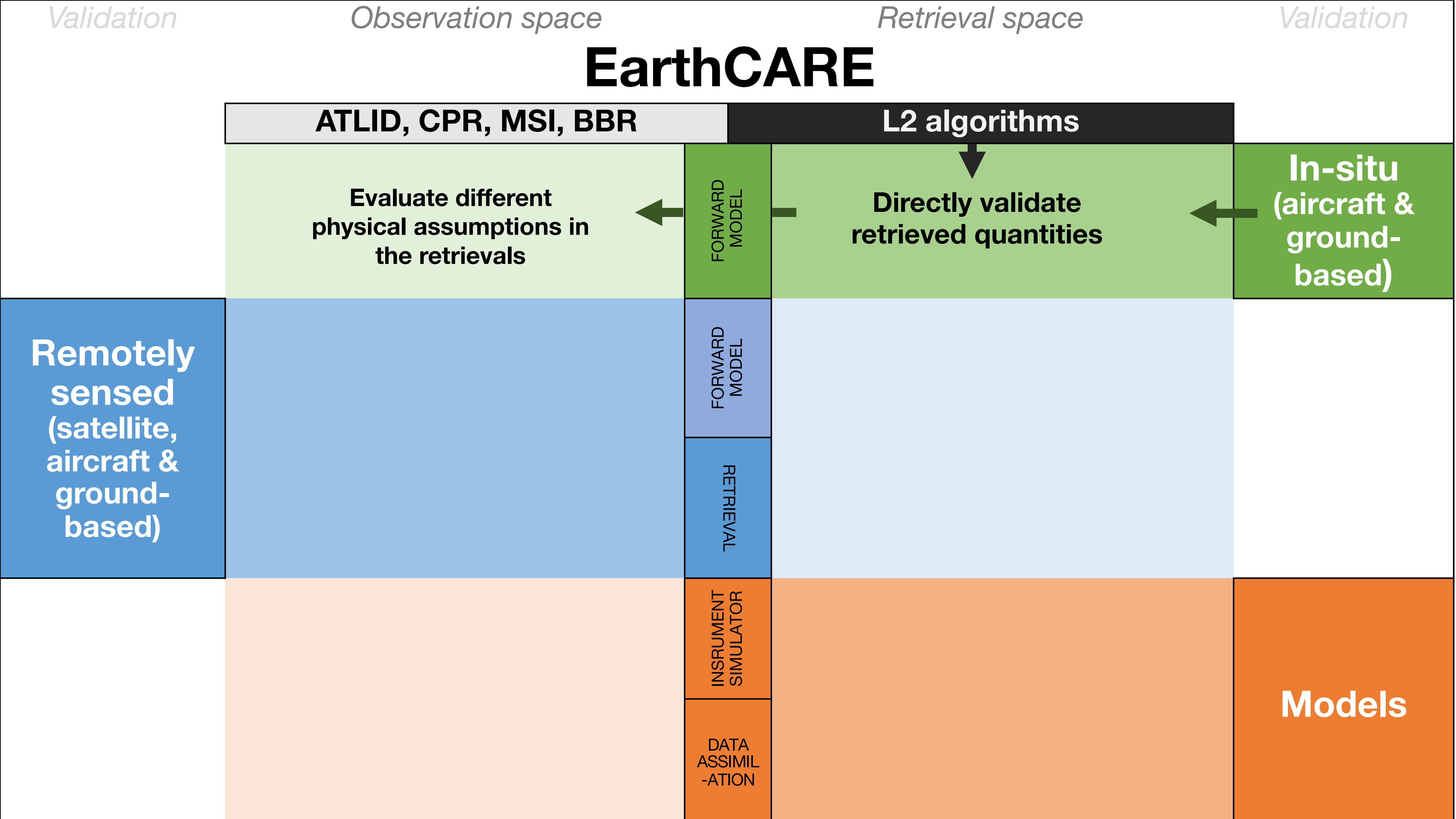
OUTLINE

- Mapping L2 products to physical quantities
- Survey of L2 processor developers' needs (responses are available here)
  1. Critical physical assumptions in processors
  2. Major retrieval uncertainties
  3. Validation needs
- Examples across validation paradigms: observation vs retrieval space
- Summary of validation needs: common themes
- What can L2 algorithms provide?

	Cloud-top, vertically integrated and layerwise			Vertical profiles	
	Quantity	**At nadir**	**Across-track**	**Quantity**	**At nadir**
Macrophysics	**Cloud-top height**	M-COP, A-CTH, A-TC, C-TC, AC-TC	M-COP, AM-CTH	**Cloud/precipitation fraction**	A-TC, C-TC, AC-TC
	Cloud-top phase & type	M-CM, A-TC, C-TC, AC-TC	M-CM, AM-CTH	**Cloud/precipitation classification**	A-TC, C-TC, AC-TC
	Aerosol layer height/depth	A-ALD, A-TC	AM-ACD	**Aerosol fraction**	A-TC, ACM-COM
	Aerosol layer classification	A-ALD, A-TC	AM-ACD	**Aerosol species**	A-TC, ACM-COM
Ice cloud & snow	**Optical thickness**	M-COP, A-EBD, ACM-CAP	M-COP	**Extinction**	A-EBD, ACM-COM, ACM-CAP
	Effective radius	M-COP, A-ICE, ACM-CAP	M-COP	**Effective radius**	A-ICE, ACM-COM, ACM-CAP
	Water path	M-COP, A-ICE, C-CLD, ACM-CAP	M-COP	**Water content**	A-ICE, ACM-COM, ACM-CAP
	Surface snow rate*	C-CLD, ACM-CAP		**Snow rate**	C-CLD, ACM-CAP
				Snow median diameter	C-CLD, ACM-CAP
				Extinction-to-backscatter ratio	A-EBD, ACM-CAP
Liquid cloud	**Optical thickness**	M-COP, A-EBD, ACM-CAP	M-COP	**Extinction**	A-EBD, ACM-COM, ACM-CAP
	Effective radius	M-COP, ACM-CAP	M-COP	**Effective radius**	ACM-COM, ACM-CAP
	Water path	M-COP, ACM-CAP	M-COP	**Water content**	C-CLD, ACM-COM, ACM-CAP
Rain	**Surface rain rate***	C-CLD, ACM-CAP		**Rain rate**	C-CLD, ACM-CAP
	Rain water path	C-CLD, ACM-CAP		**Rain water content**	C-CLD, ACM-CAP
				Median drop size	C-CLD, ACM-CAP
Aerosol (per species)	**Aerosol optical thickness**	M-AOT, A-ALD, A-AER, A-EBD, ACM-CAP	M-AOT, AM-ACD	**Aerosol extinction**	A-AER, A-EBD, ACM-COM, ACM-CAP
	Layer-mean extinction-to-backscatter ratio	A-ALD		**Extinction-to-backscatter ratio**	A-AER, A-EBD, ACM-CAP*
	Layer-mean particle linear depolarisation ratio	A-ALD		**Particle linear depolarisation ratio**	A-AER, A-EBD
	Ångström exponent	M-AOT (670/865nm), AM-ACD (355/670nm)	M-AOT (670/865nm), AM-ACD (355/670nm)		
Radiation	**Broadband radiances @TOA**		BM-RAD, ACM-RT	**Broadband radiances**	ACM-RT
	Radiative fluxes @TOA		BMA-FLX, ACM-RT	**Radiative fluxes**	ACM-RT
				Heating rates	ACM-RT

	Uncertainty	Locations/scenes/regimes	Measurements needed	Products
Macrophysics	Aerosol layer detection	• Multiple aerosol layers • Aerosol layers with strong internal structure • Attributing aerosol plumes at nadir to features in the across-track imagery	• Ground-based (& scanning?) and airborne lidars	A-ALD, AM-ACD, A-TC
	Aerosol/cloud discrimination	• Cloud embedded in aerosol layers	• Ground-based lidars	A-ALD, AM-ACD, A-TC
	Cloud layer detection and structure	• Multiple cloud layers • Cirrus over liquid cloud • Non-precipitating liquid clouds	• Ground-based (& scanning?) lidars & radiometers	M-CLD, AM-CTH, A-TC, C-TC, AC-TC
	Liquid clouds not fully resolved by radar/lidar synergy	• Physical depth of liquid clouds (i.e. cloud base height) • Mixed-phase layers embedded in ice • Liquid (& liquid-topped mixed-phase) clouds below optically thick ice clouds • Warm liquid clouds within cold rain	• Ground-based ceilometers/lidars • Multiple-frequency radars to constrain W-band attenuation • Microwave radiometers for LWP • Aircraft profiles of LWC	A-TC, C-TC, AC-TC
	CPR surface clutter removal	• Range of surface types	• Ground-based radars	C-TC, C-FMR
Ice cloud & snow	Snow microphysics (e.g. PSDs, microwave scattering, density & fallspeed)	• Stratiform vs convective • Rimed snow	• Bulk precipitation and particle imaging measurements at surface • Profiles of in-situ particle properties in ice clouds	C-CLD, ACM-CAP
	Ice microphysics (e.g. PSDs, ice optics, mass-size rel'n)	• Cloud-tops across range of temperatures, locations & cloud types	• In situ aircraft measurements • Visible & IR radiances	A-ICE, ACM-CAP
	Surface snow rate	• Range of meteorological conditions	• Ground-based radars and in-situ at surface	C-CLD, ACM-CAP
Liquid cloud	How to account for radiatively-important liquid clouds not detected by ATLID	• Deep ice clouds: embedded mixed-phase layers • Layered cloud scenes • Warm liquid clouds within cold rain	• Microwave radiometer for LWP • Profiles of liquid water content	ACM-CAP
Rain	Relation between rain rate and drop size distribution	• Warm rain (maritime) • Convective/stratiform rain	• Ground-based multiple-frequency radars • Dual-pol weather radars over ocean	C-CLD, ACM-CAP
	Melting layer structure & radar attenuation	• Dependence on snow properties aloft • Continuity of mass flux & size distributions across melting layer	• Ground-based & airborne multiple-frequency radar	C-CLD, ACM-CAP
Aerosol	Large AOT uncertainties over land; sensitivity to aerosol classification	• Range of different land classes (biomes) & ocean • Range of different aerosol classes	• Ground-based, e.g. AERONET(-OC) • Ship-based sun photometers, e.g. MAN • Satellite imagers, e.g. MODIS, VIIRS, 3MI	M-AOT
Radiation	Detection of and/or representation of fluxes over snow-covered surfaces	• Range of snow-covered surfaces	• High-latitude ground stations	BM-RAD, BMA-FLX

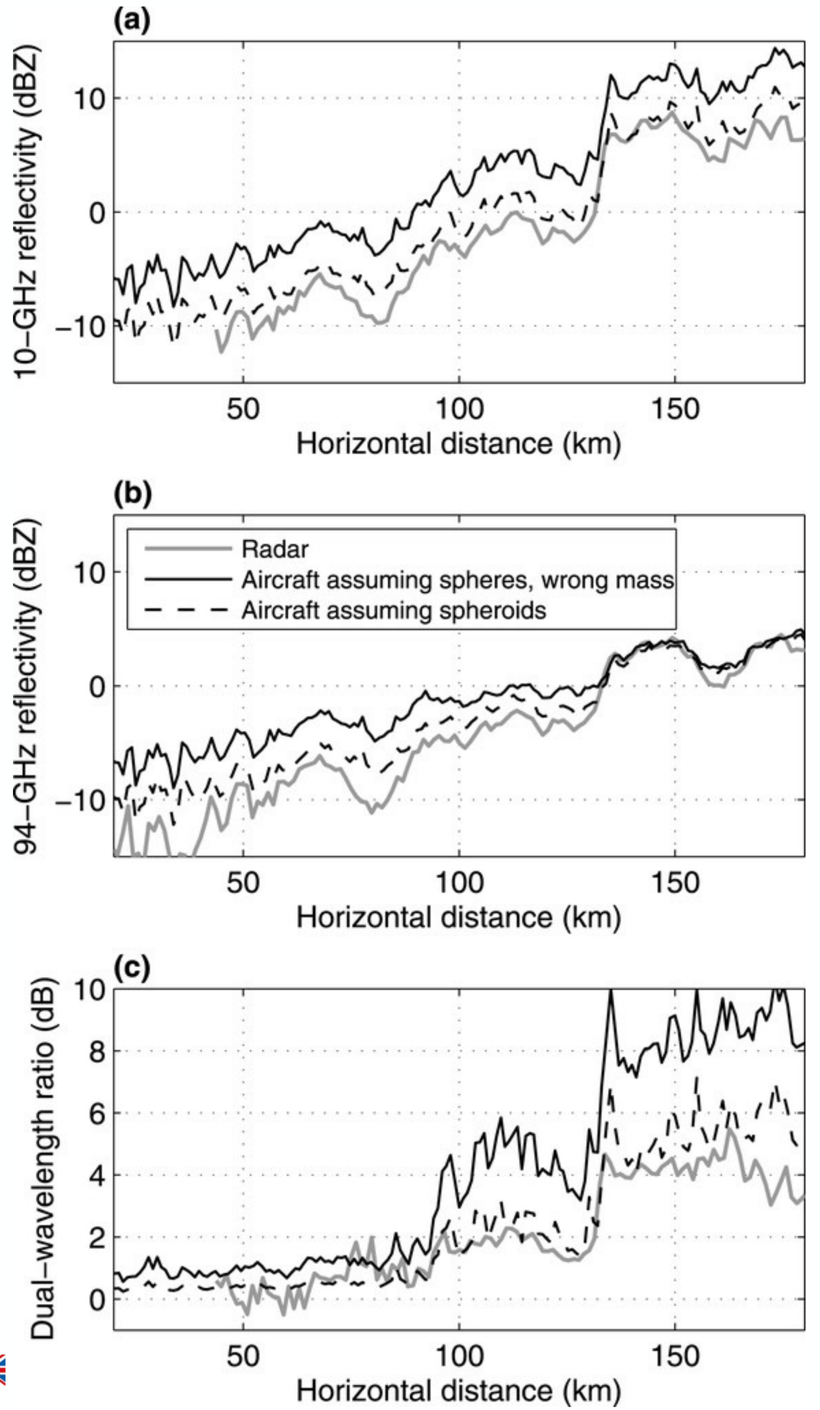


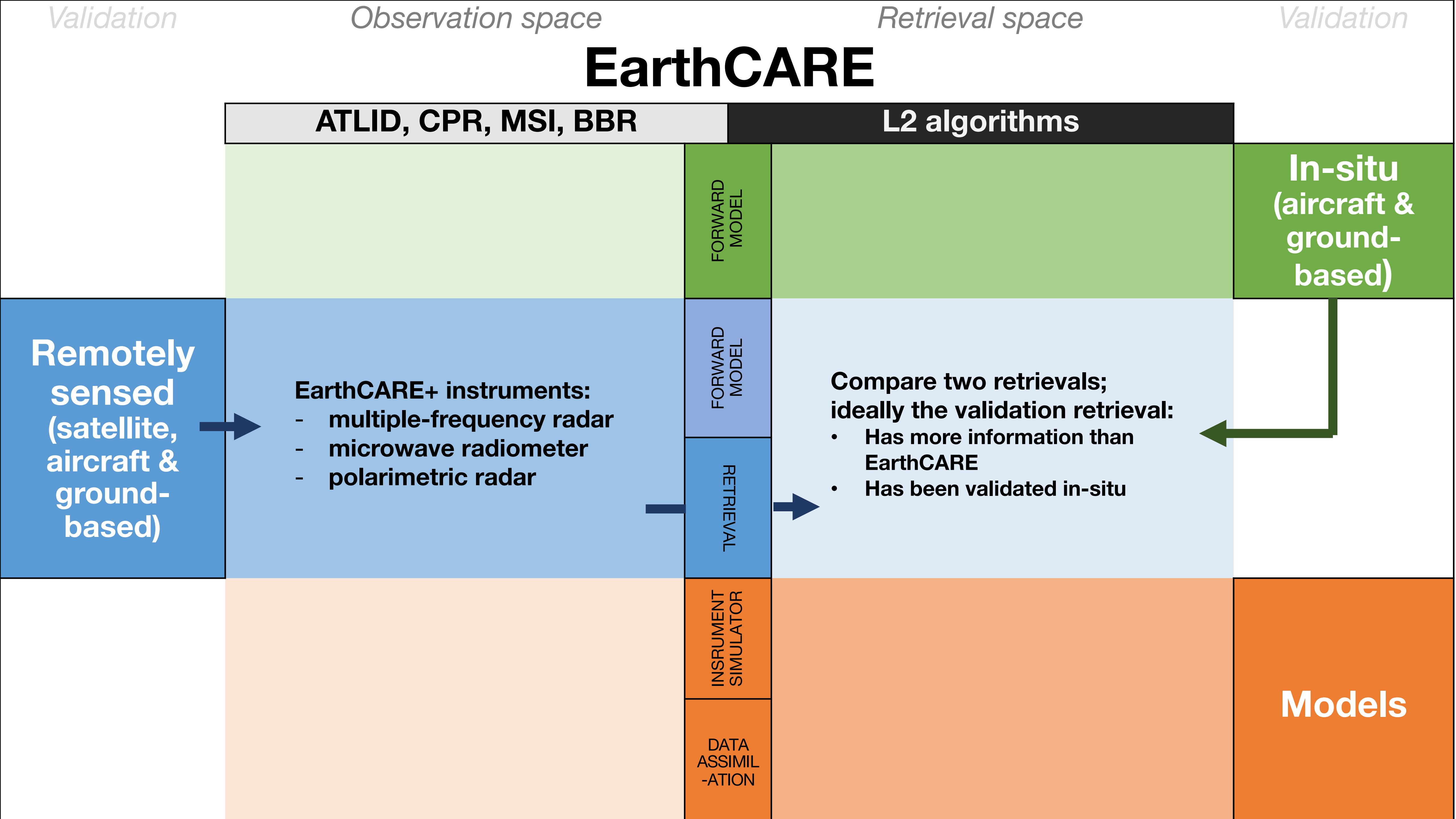
Validation
Observation space
Retrieval space
Validation
EarthCARE
ATLID, CPR, MSI, BBR
L2 algorithms
Evaluate different physical assumptions in the retrievals
FORWARD MODEL
Directly validate retrieved quantities
In-situ (aircraft & ground-based)
Remotely sensed (satellite, aircraft & ground-based)
FORWARD MODEL
RETRIEVAL
INSRUMENT SIMULATOR
DATA ASSIMIL -ATION
Models

Evaluation of ice microphysics assumptions using aircraft measurements

Hogan et al. (2012) used ground-based and airborne radars collocated with in-situ aircraft measurements to show that the mass-size relationship of Brown & Francis (1995) needs to be applied using the average particle diameter rather than the maximum diameter; **the latter implicitly assumes ice particles are spheres**.

- Used in-situ particle imaging measurements to characterize average ice particle shape (oblate spheroids with aspect ratio 0.6)
- Used aircraft measurements and mass-size relation to accurately model differential radar reflectivity from the Chilbolton radar
- Used in-situ PSD and mass-size relations to model radar reflectivity at X- and W-bands measured by ER-2 during the TC4 campaign
- Showed substantial reduction in an +5 dBZ over-estimate of radar reflectivity in the Rayleigh scattering regime at X- and W-bands.



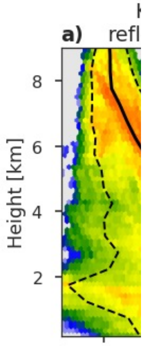

Validation
Observation space
Retrieval space
Validation
EarthCARE
ATLID, CPR, MSI, BBR
L2 algorithms
FORWARD MODEL
In-situ (aircraft & ground-based)
Remotely sensed (satellite, aircraft & ground-based)
EarthCARE+ instruments:
- multiple-frequency radar
- microwave radiometer
- polarimetric radar
FORWARD MODEL
RETRIEVAL
Compare two retrievals; ideally the validation retrieval:
• Has more information than EarthCARE
• Has been validated in-situ
INSRUMENT SIMULATOR
DATA ASSIMIL-ATION
Models

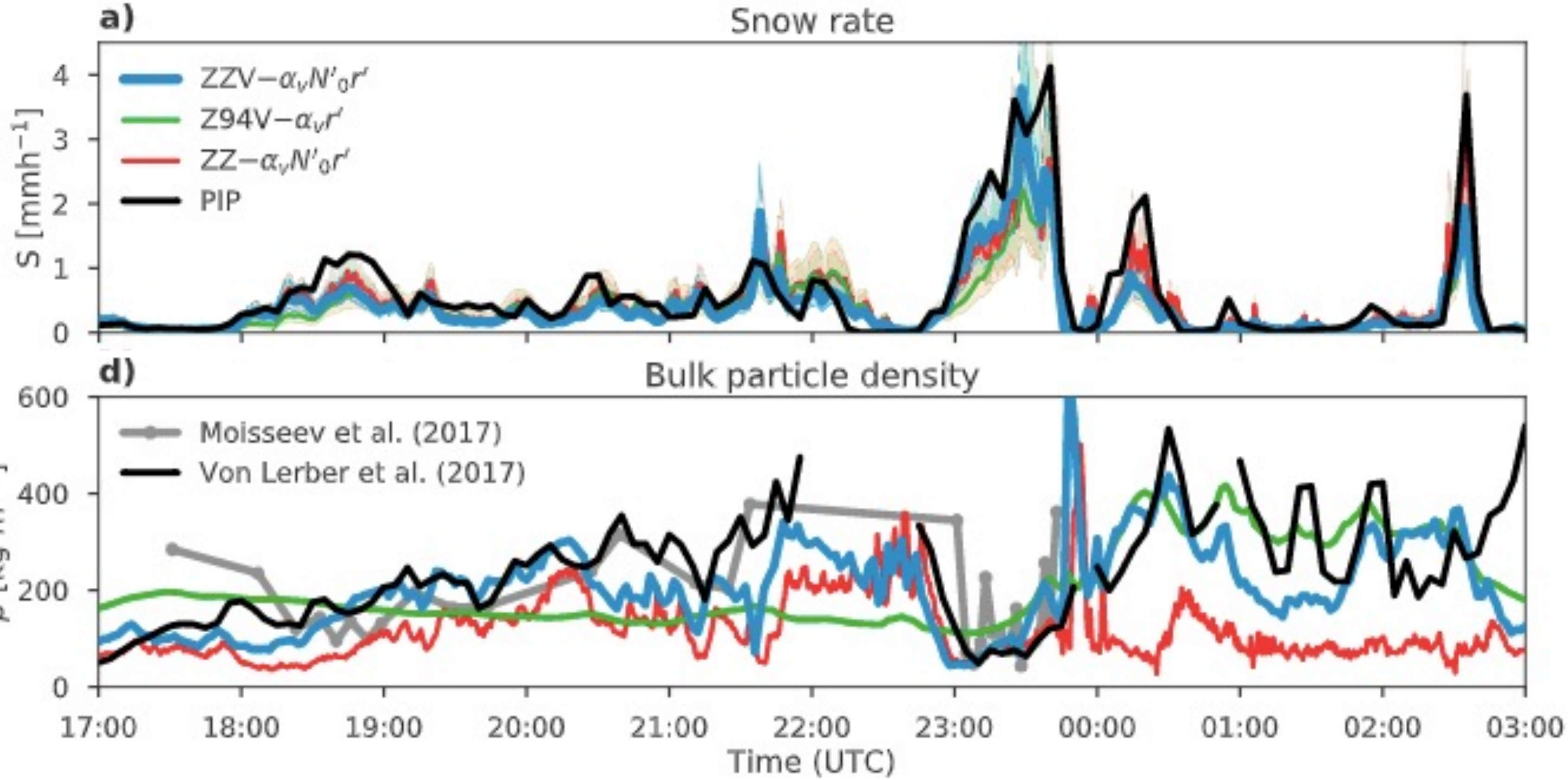
Evaluation of snow retrievals

Direct validation:

- Ground-based Doppler radar retrievals of rimed snow at Hyytiälä (BAECC 2014) are validated against in-situ estimates of snow density
- Retrieved density factor is well-correlated with liquid water path estimated from a microwave radiometer

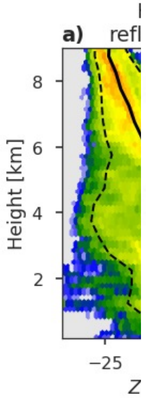
Mason et al. (2018), JGR-Atmospheres

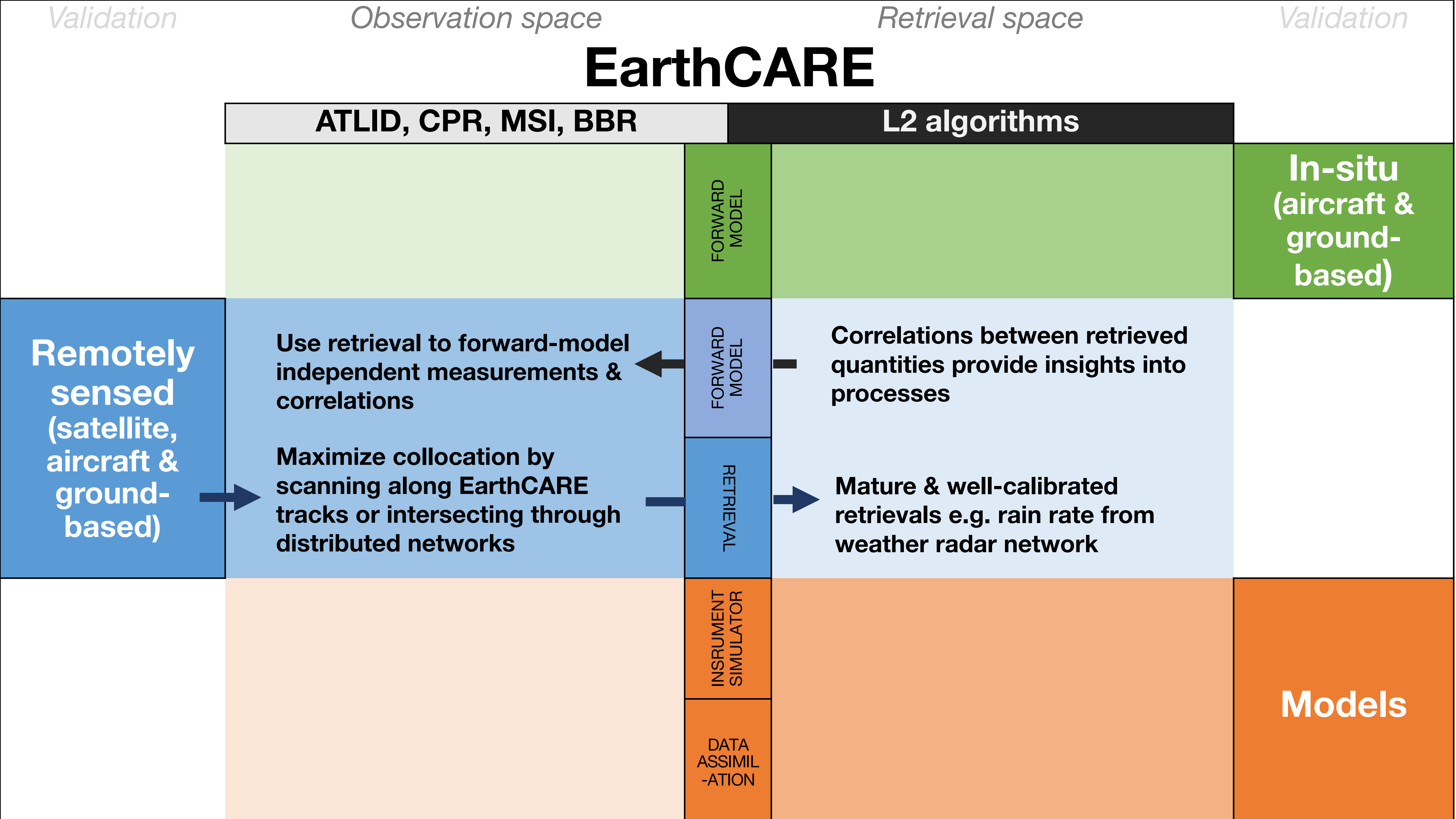




Statistical validation:

- LWP used as a proxy to generate CFADs of observed and retrieved quantities in unrimed and rimed snow regimes (low vs high LWP)




Validation
Observation space
Retrieval space
Validation
EarthCARE
ATLID, CPR, MSI, BBR
L2 algorithms
FORWARD MODEL
In-situ (aircraft & ground-based)
Remotely sensed (satellite, aircraft & ground-based)
Use retrieval to forward-model independent measurements & correlations
FORWARD MODEL
Correlations between retrieved quantities provide insights into processes
Maximize collocation by scanning along EarthCARE tracks or intersecting through distributed networks
RETRIEVAL
Mature & well-calibrated retrievals e.g. rain rate from weather radar network
INSRUMENT SIMULATOR
DATA ASSIMIL -ATION
Models

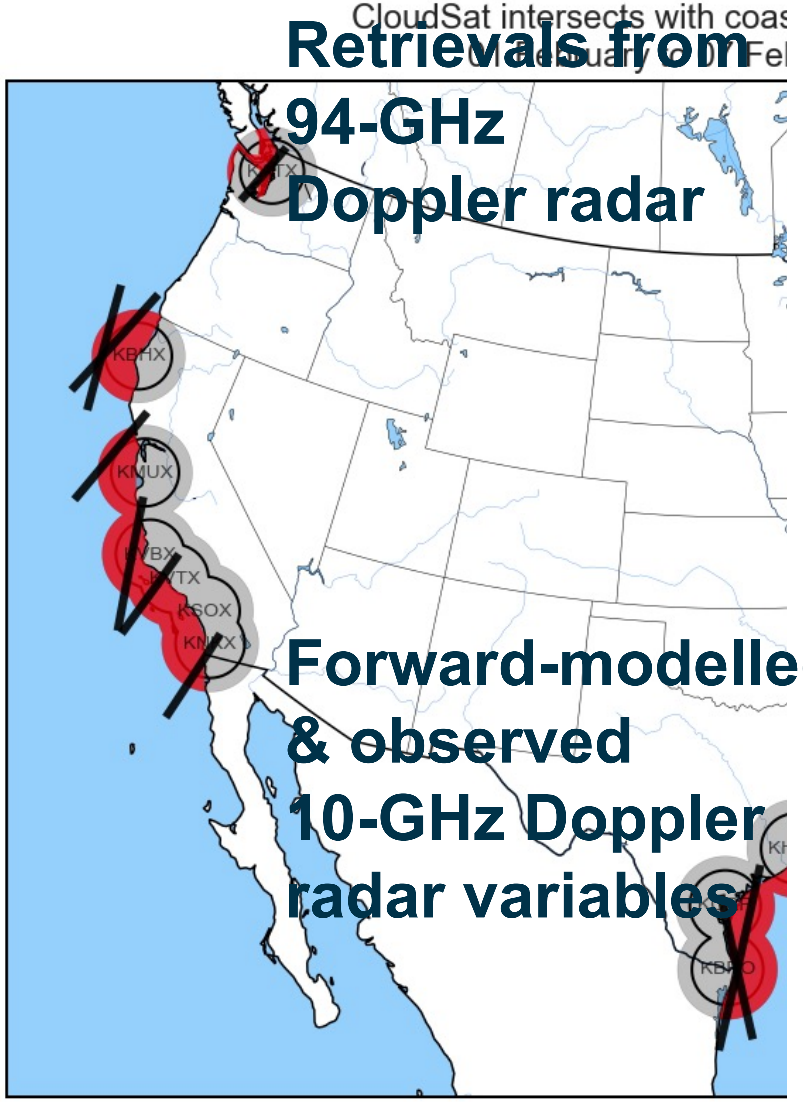
Validation of rain retrievals

Direct validation:

- Maximizing correlative data:
  - EarthCARE tracks intersecting weather radar network for validating rain retrievals over oceans
  - Ground-based remote sensing: scans along EarthCARE tracks rather than vertically-pointing
- Forward-modelling independent X-band radar from ER-2 aircraft during TC4 campaign
  - Mason et al. (2017), *ACP*

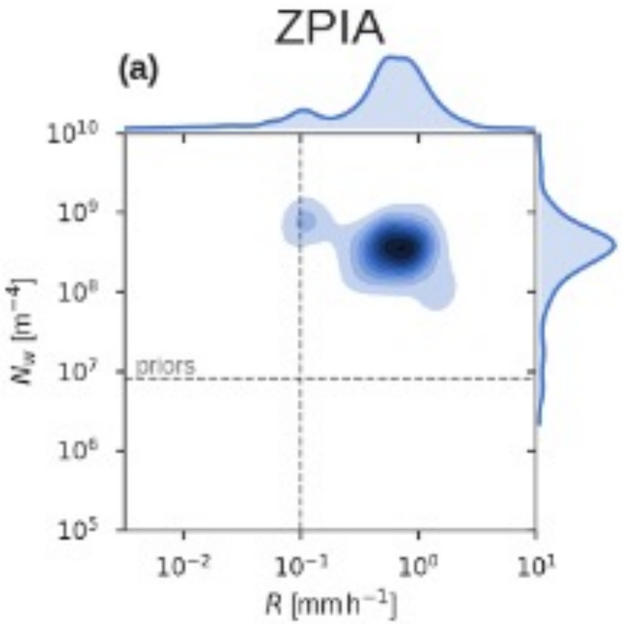
Statistical validation:

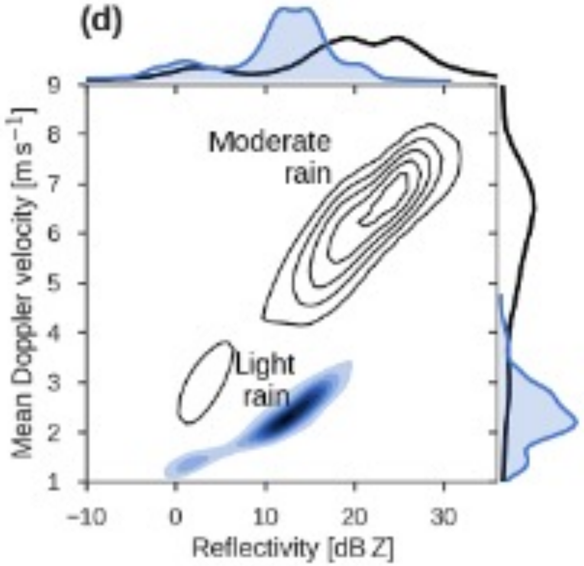
- joint histograms (correlations between quantities); can map precipitation regimes between observation and retrieval space

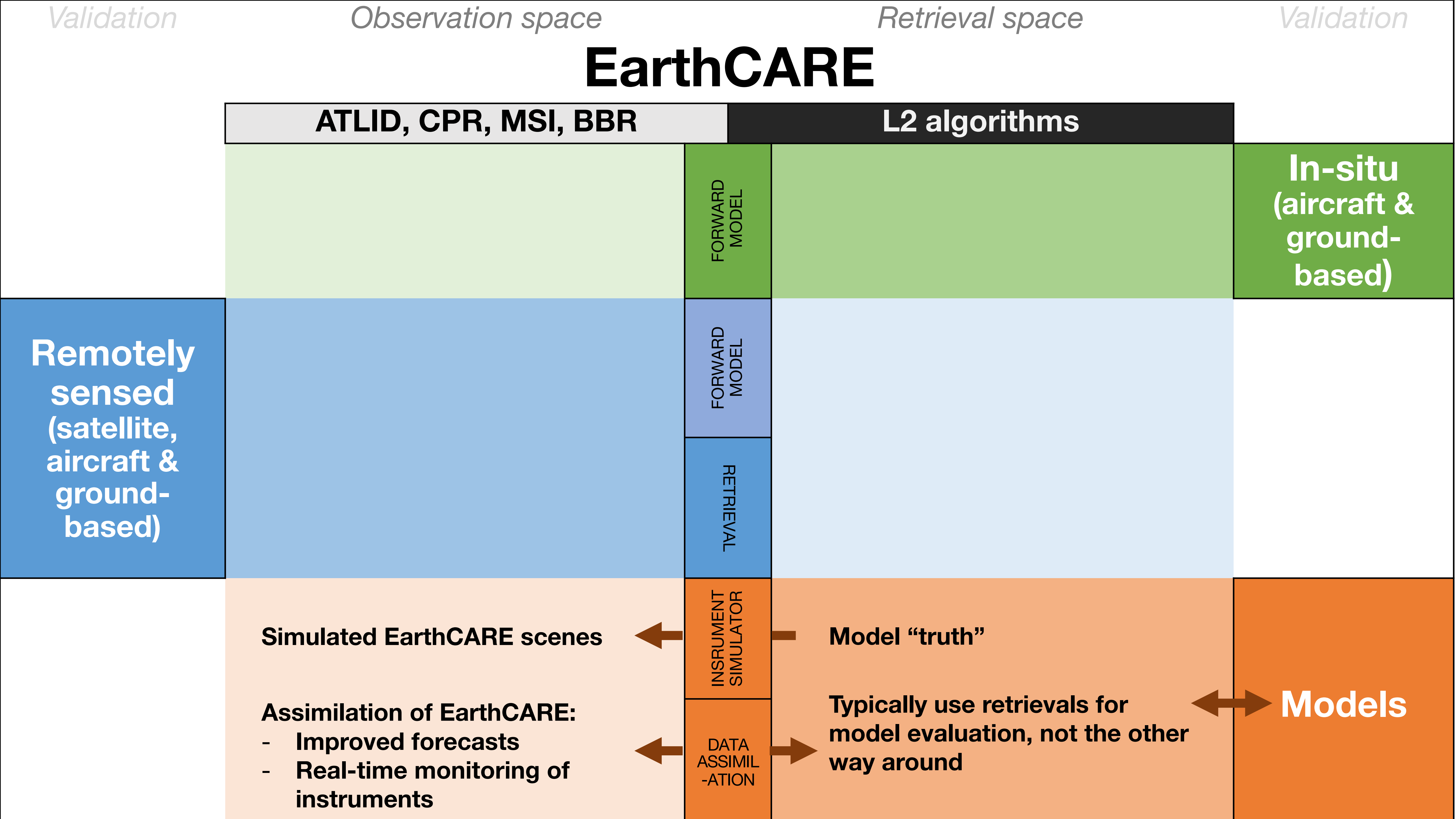


Retrievals from 94-GHz Doppler radar

Forward-modelled & observed 10-GHz Doppler radar variables



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FORWARD MODEL
In-situ (aircraft & ground-based)
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FORWARD MODEL
RETRIEVAL
INSRUMENT SIMULATOR
Simulated EarthCARE scenes
Model “truth”
Assimilation of EarthCARE:
- Improved forecasts
- Real-time monitoring of instruments
DATA ASSIMIL -ATION
Typically use retrievals for model evaluation, not the other way around
Models

Target classification evaluation using simulated EarthCARE scenes

ATLID (A-TC):

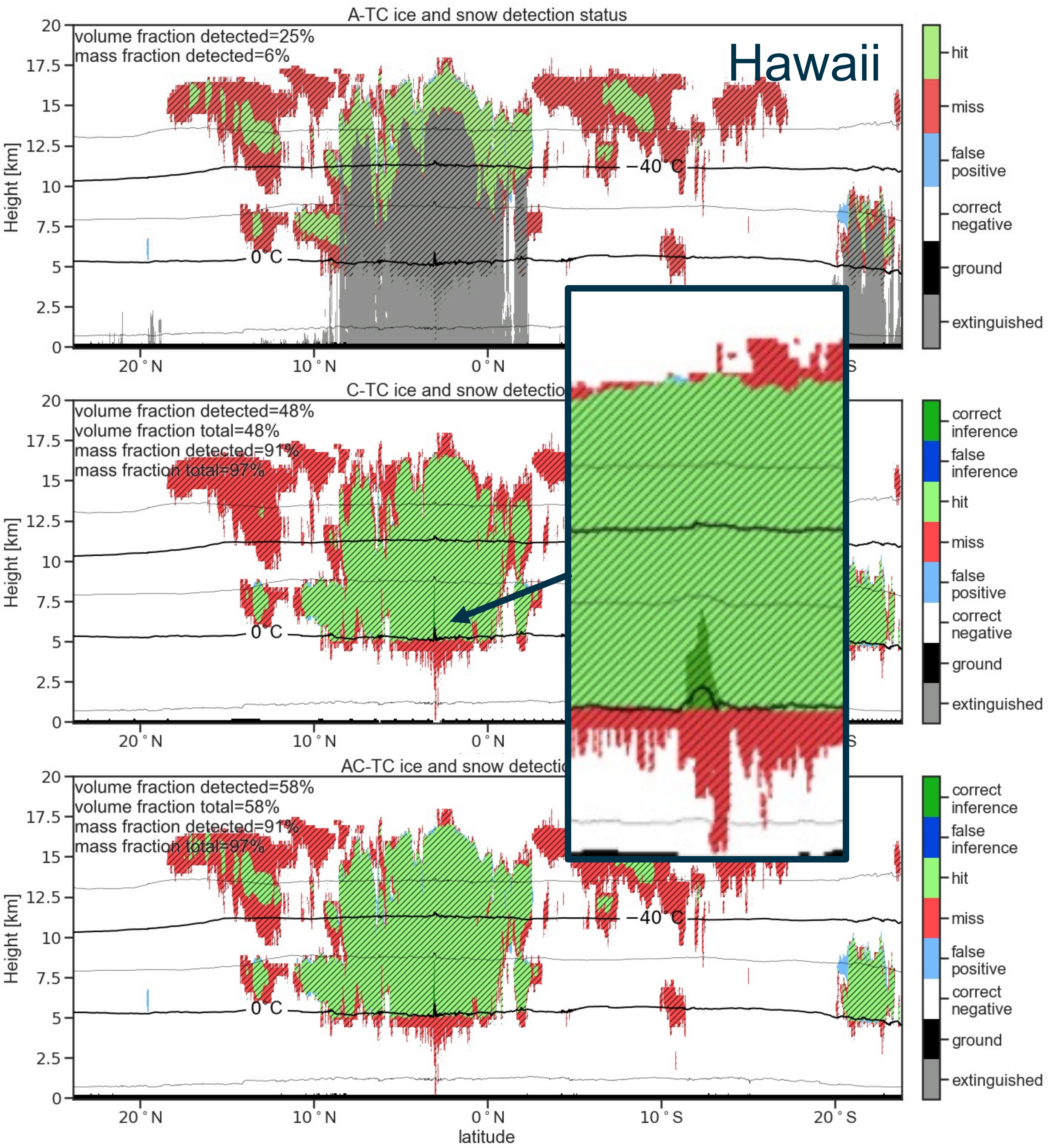
- Detects about 25% of ice cloud by volume
- Around 5% by mass

CPR (C-TC):

- Around 50% by volume (missing cloud-tops & cirrus)
- +90% by mass (sensitive to snow)
- Up to 97% including where CPR is extinguished

Synergy (AC-TC):

- ATLID provides +10% by volume not detected by CPR
- ATLID-only detections makes negligible contribution by mass of ice
- **But cloud-tops & cirrus are critical to radiation**



Target classification evaluation using simulated EarthCARE scenes

ATLID (A-TC):

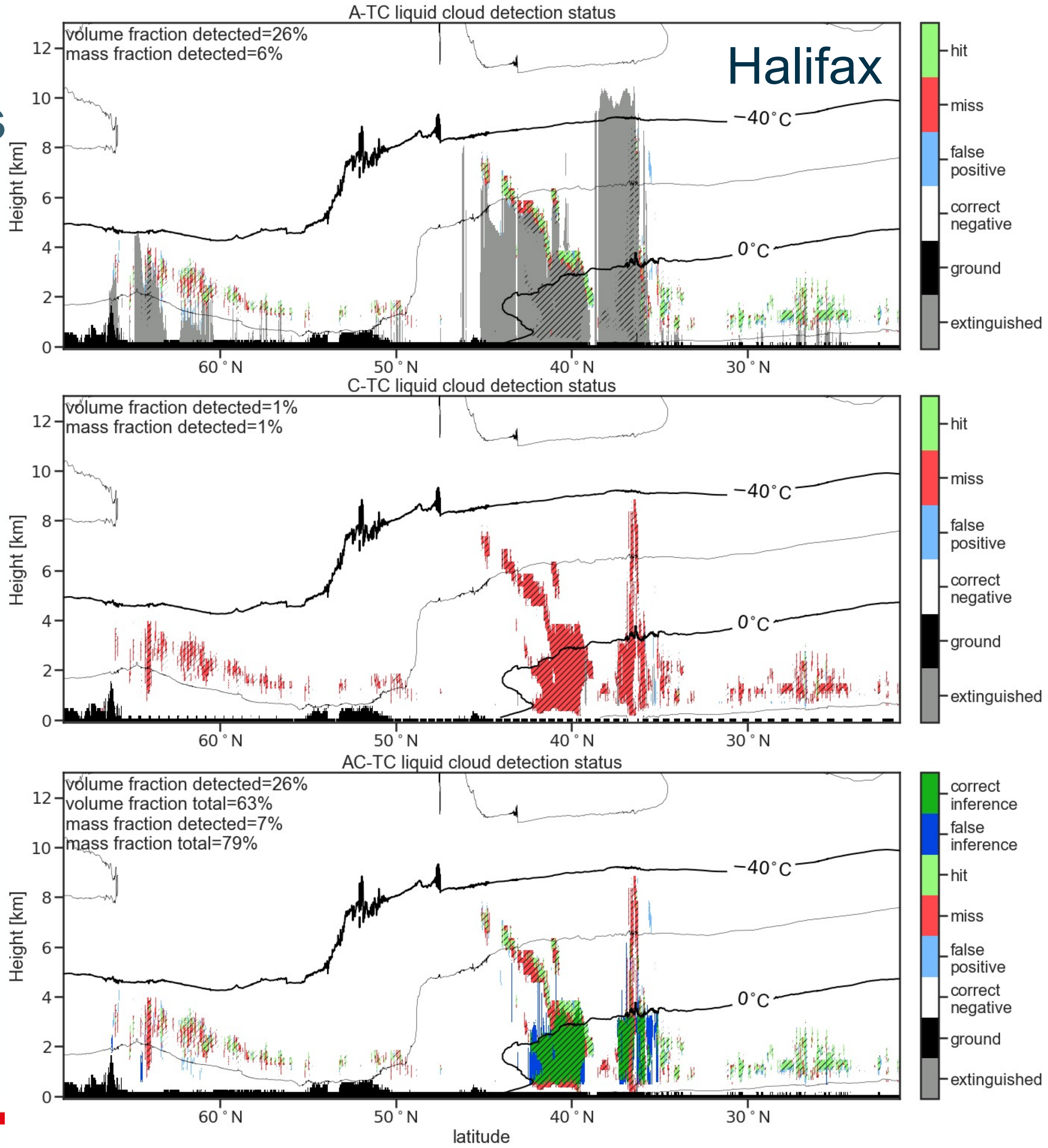
- Detects about 25% of liquid cloud by volume
- Around 5% by mass
- Scattered shallow liquid clouds are well-represented
- Missing 95% of liquid in deeper layers, convective cores, and collocated with rain

CPR (C-TC):

- Liquid cloud detection is very rare

Synergy (AC-TC):

- Same as ATLID
- Is it possible to make a sensible assumption?
    - Assuming liquid cloud in cold rain resolves almost 80% of liquid by mass
- **Improves ACM-CAP assimilation of MSI solar radiances; downstream improvement in ACM-RT**



SUMMARY OF DEVELOPER NEEDS

- An incomplete survey of developer needs: detailed discussions in ATLID/Aerosols, CPR/Clouds and Radiation sessions
- Identified two major kinds of retrieval uncertainties:
  - Dependence on upstream target classification products: **are the features we're trying to retrieve adequately resolved?**
    - Complex & layered cloud and aerosol scenes
    - Identifying and characterizing surface types for passive and active instruments
    - Ground-based validation: "bottom-up" remote-sensed view of aerosol & cloud layers alongside in-situ measurements at surface, to complement EarthCARE's blind zones
  - Universality: **how well do our physical assumptions hold in other locations/regimes?**
    - Physical assumptions may be mature, but often based on specific/limited studies
    - Opportunity to identify gaps, and target locations/regimes with campaigns
    - For statistical validation we need to be able to isolate processes: selecting/sub-setting data by location, correlated measurements, weather regime, cloud/precipitation type, etc.

HOW CAN L2 ALGORITHMS BE LEVERAGED?

- EarthCARE L2 algorithms run with inputs from airborne and ground-based instruments
  - Benefit of validating in “retrieval space” without introducing a second retrieval
  - But requires a high level of pre-processing:
    - Calibration & correction
    - Common grid for synergistic measurements
    - Contextual information (instrument status, surface characterization, atmospheric profiles from re-analysis)
    - Description and metadata

- Can EarthCARE algorithms be used to generate validation data in “observation space”?
  - Forward-model non-EarthCARE instruments (e.g. X-band Doppler radar)
  - Forward-model EarthCARE-like instruments from ground-based configurations?