Maximising the continuity of synergistic cloud-aerosol-precipitation retrievals between the A-Train and EarthCare

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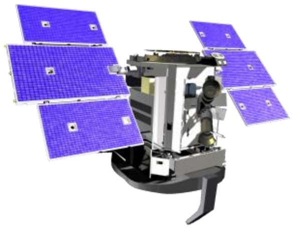
ECMWF

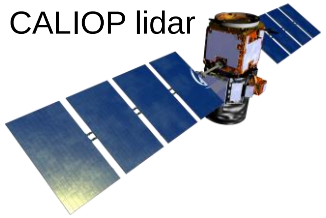
National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

A-Train

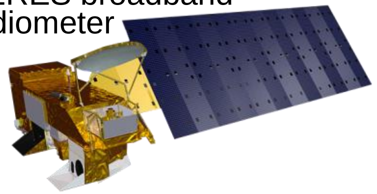
CloudSat
Cloud Profiling Radar (CPR)



CALIPSO
CALIOP lidar



Aqua
MODIS imaging radiometer
CERES broadband radiometer



ICE
PRECIP-COLUMN
RAIN-PROFILE
SNOW-PROFILE
CloudSat-only retrievals

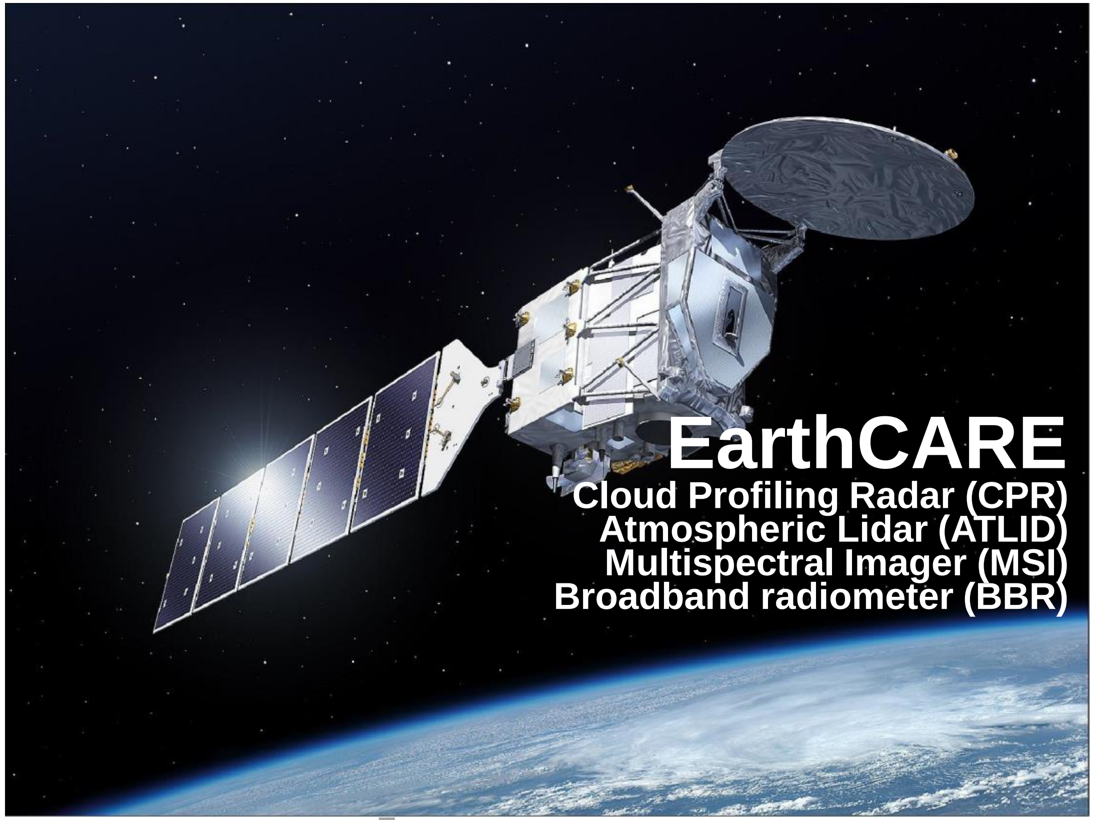
CWC-RVOD
CloudSat-MODIS retrieval of ice & liquid clouds

CALIPSO
Ice cloud and aerosol profile retrievals

DARDAR
CloudSat-CALIPSO-MODIS retrieval of ice cloud & snow

MODIS
Passive cloud and aerosol retrievals

CCCM
CERES-CloudSat-CALIPSO-MODIS composite retrievals on CERES footprint



ATLID+CPR+MSI

BBR

CCM-CAP
Unified & synergistic retrieval of cloud-aerosol-precipitation

CAPTIVATE
Clouds, Aerosol and Precipitation from mulTiple Instruments using a VAriational TEchnique

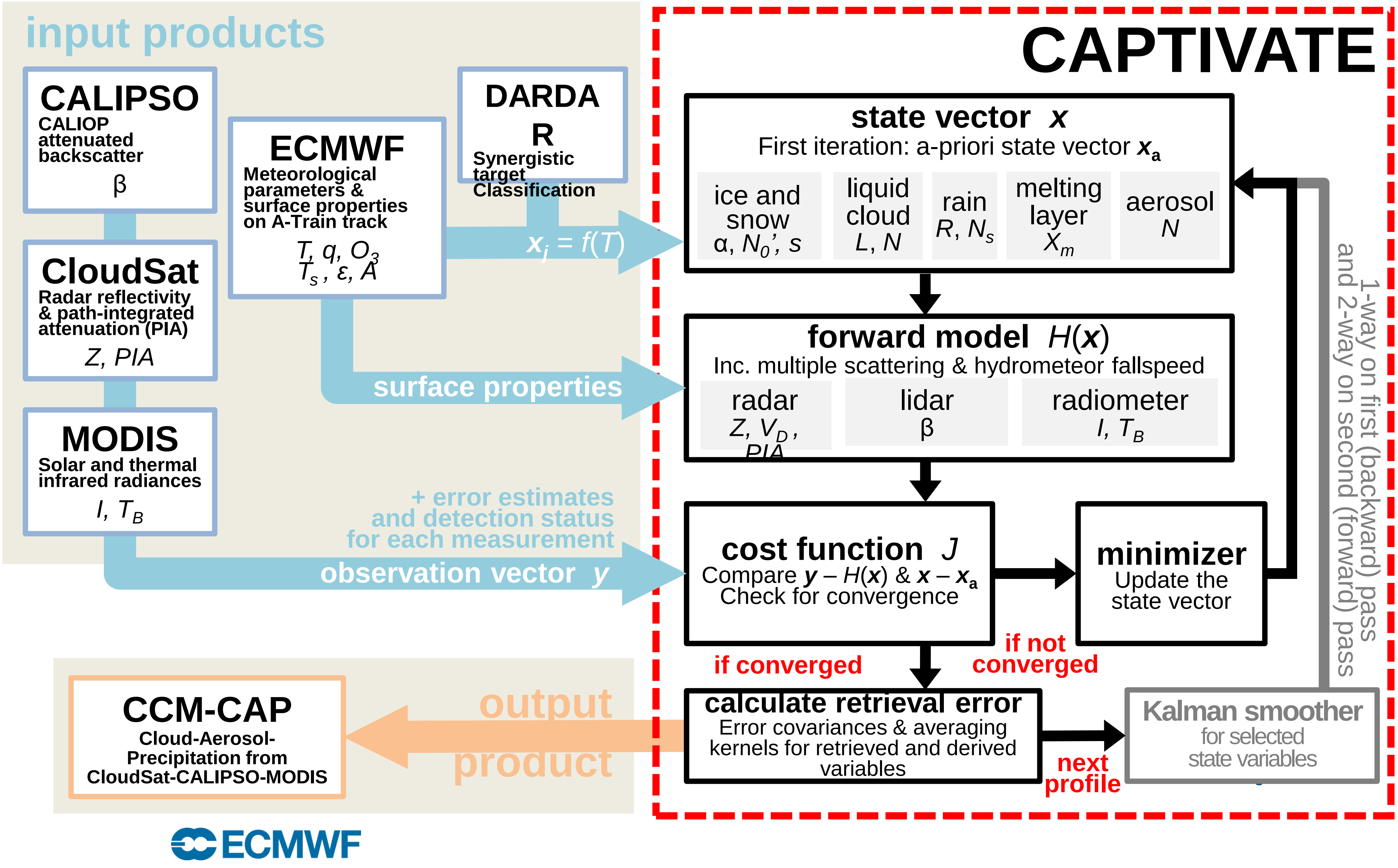
ACM-CAP
Unified & synergistic retrieval of cloud-aerosol-precipitation

CCM-RAD
Radiative fluxes, heating rates and radiative closure at nadir

CCM-3D
3D scene reconstruction
CCM-RT
Radiative transfer

ACM-3D
3D scene reconstruction
ACM-RT
Radiative transfer

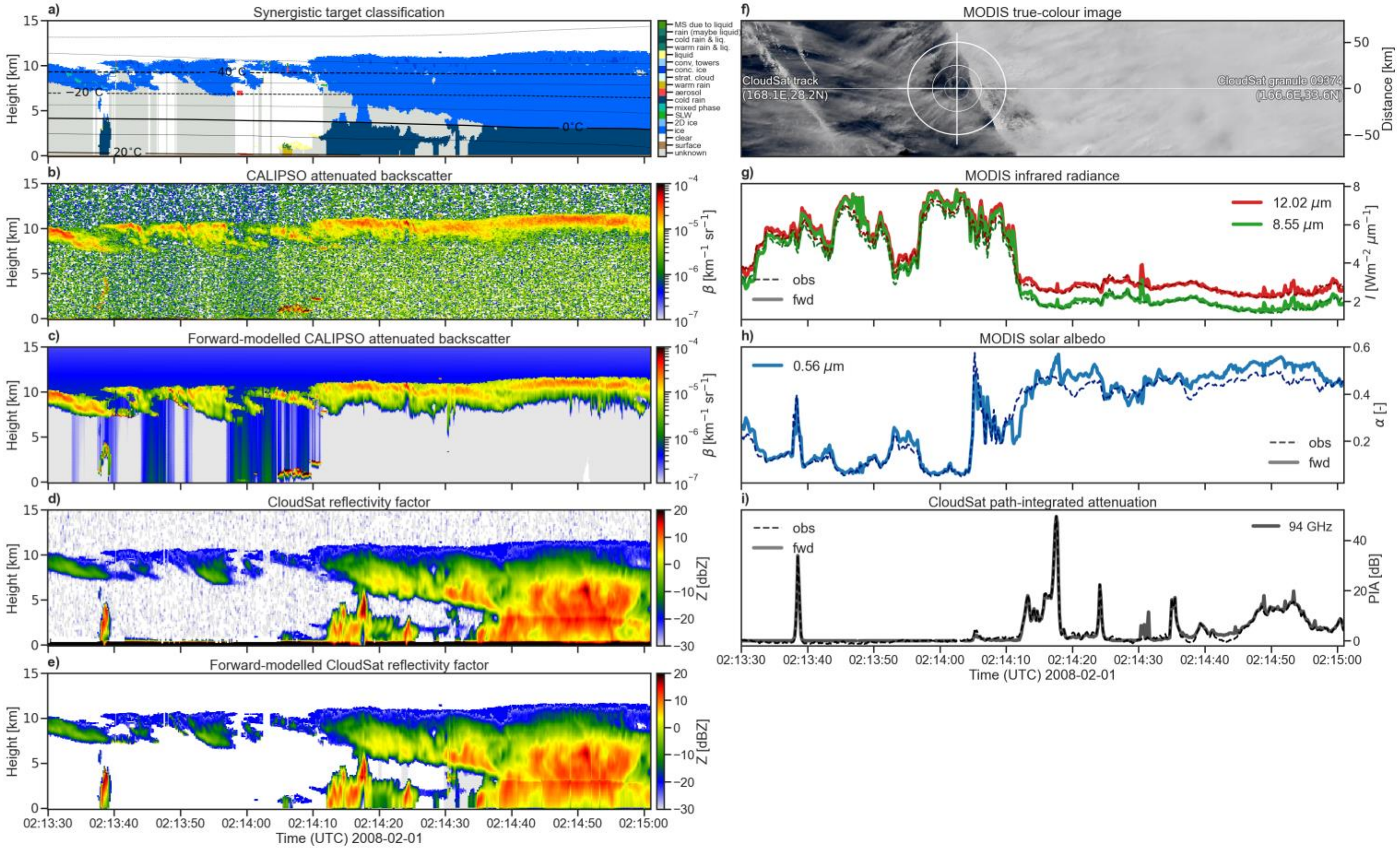
ACMB-DF
Top-of-atmosphere radiative closure assessment



input products
CALIPSO
CALIOP attenuated backscatter
β
CloudSat
Radar reflectivity & path-integrated attenuation (PIA)
Z, PIA
MODIS
Solar and thermal infrared radiances
I, T_B
ECMWF
Meteorological parameters & surface properties on A-Train track
T, q, O_3
T_s, ε, A
DARDAR
Synergistic target Classification
x_j = f(T)
surface properties
+ error estimates and detection status for each measurement
observation vector y
CAPTIVATE
state vector x
First iteration: a-priori state vector x_a
ice and snow
α, N_0', s
liquid cloud
L, N
rain
R, N_s
melting layer
X_m
aerosol
N
forward model H(x)
Inc. multiple scattering & hydrometeor fallspeed
radar
Z, V_D, PIA
lidar
β
radiometer
I, T_B
cost function J
Compare y – H(x) & x – x_a
Check for convergence
minimizer
Update the state vector
if converged
if not converged
calculate retrieval error
Error covariances & averaging kernels for retrieved and derived variables
next profile
Kalman smoother
for selected state variables
1-way on first (backward) pass and 2-way on second (forward) pass
output product
CCM-CAP
Cloud-Aerosol-Precipitation from CloudSat-CALIPSO-MODIS
ECMWF

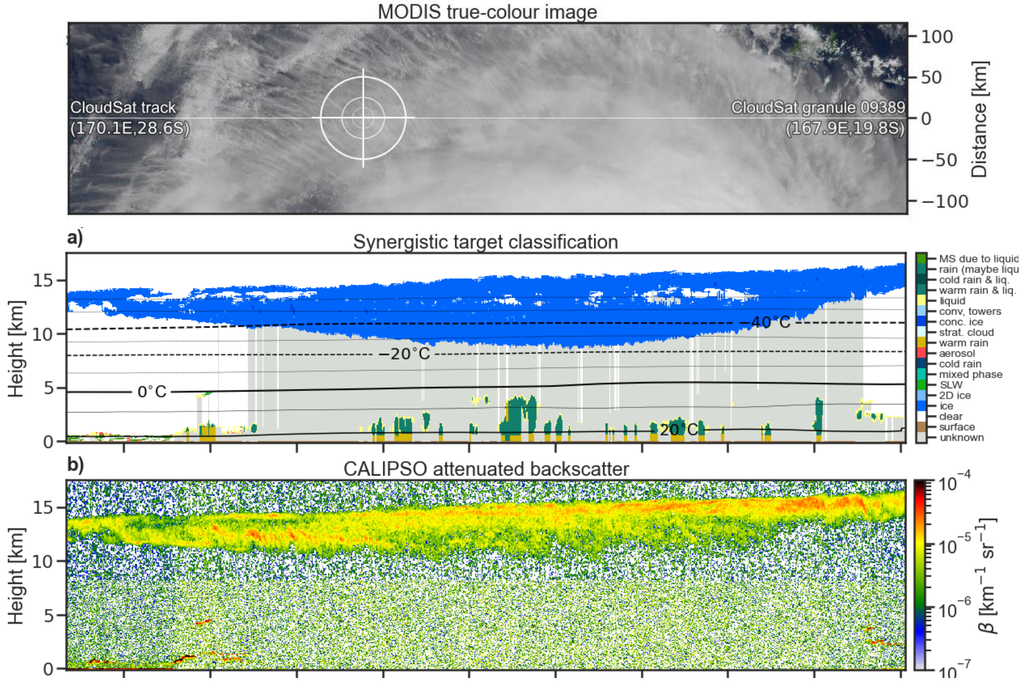
CAPTIVATE: key features

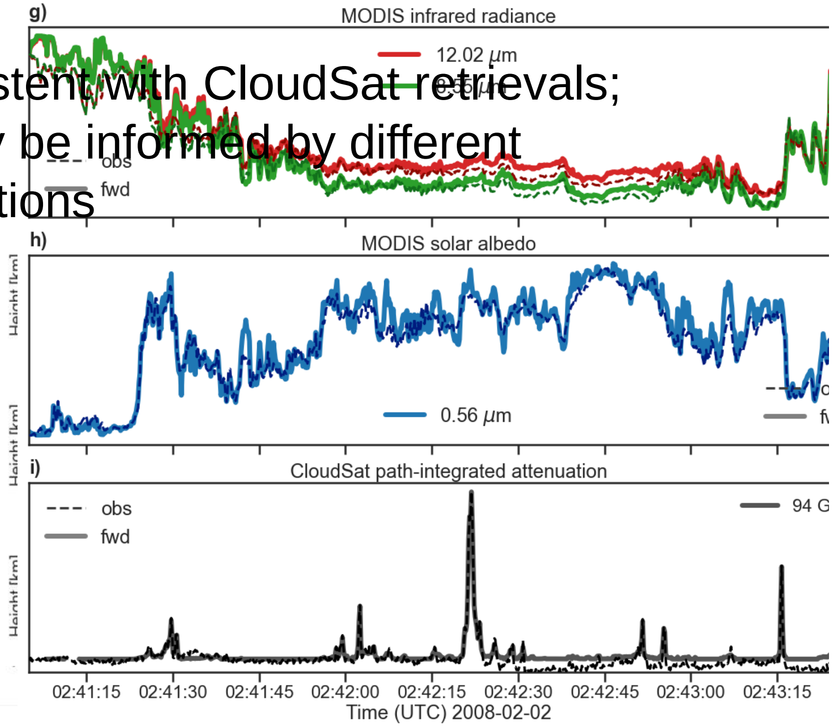
- Advantages of synergistic retrievals are well-established:
  - radar-lidar synergy is greatest for ice cloud; most other components rely on one or the other active sensor
  - But some measurements act as integrated constraints with contributions from different components of the atmosphere (radar PIA from liquid cloud and rain; solar radiances from ice and liquid cloud)
- Advantages of a unified retrieval in complex and layered cloud scenes
  - Mass flux conserved across the melting layer
  - Mixed-phase/supercooled liquid layers
  - Ice clouds over warm liquid cloud
  - Drizzle/rain colocated with liquid cloud

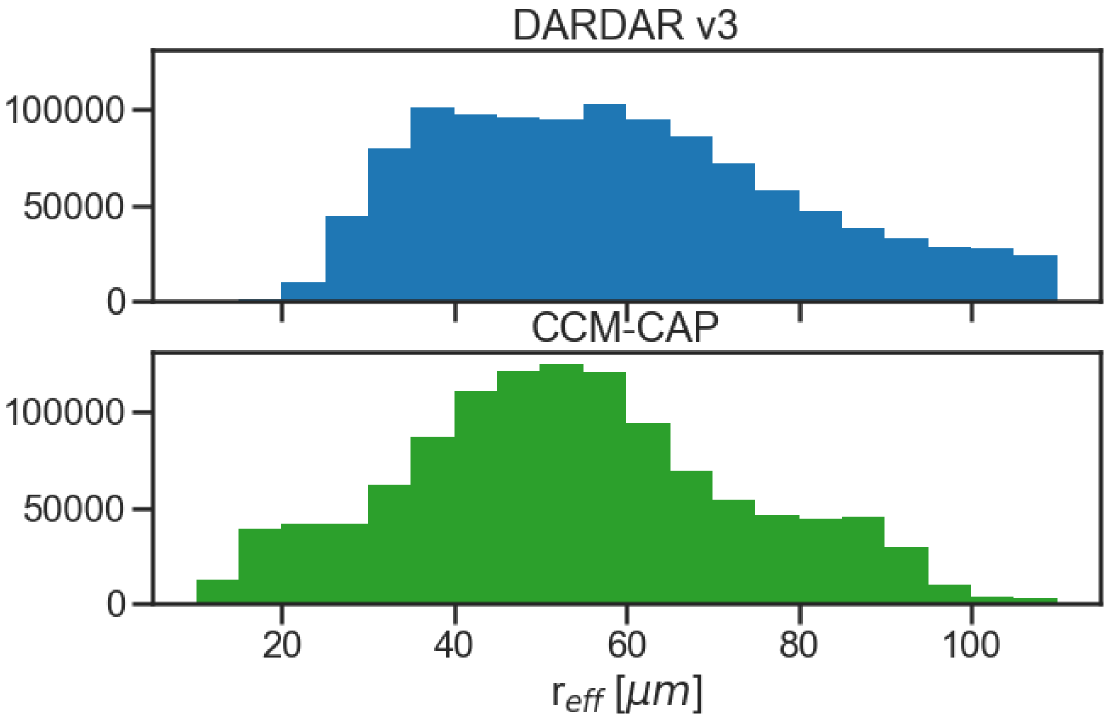


CCM-CAP: Ice and snow

- Retrievals of optically thin ice at cloud-top are under-constrained (lidar-only)
  - Assimilating the radar noise floor provides an upper limit on the forward-modelled radar reflectivity of ice clouds retrieved from lidar-only measurements
  - Results in an overall reduction in effective radius compared to previous retrievals (e.g. DARDAR), consistent with very high-sensitivity airborne radar-lidar retrievals, but not previously
- Ice water path consistent with CloudSat retrievals; higher snow rates may be informed by different microphysical assumptions

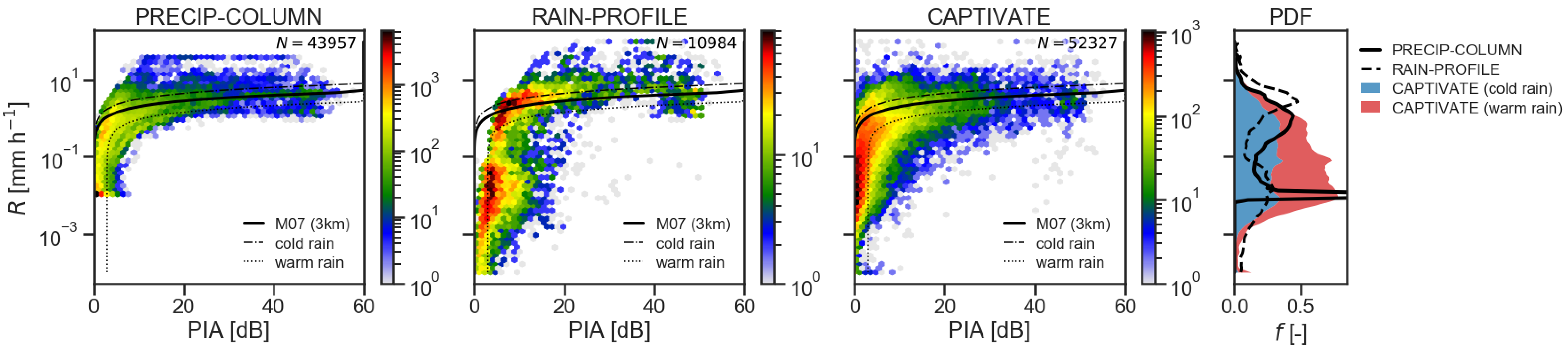






CCM-CAP: Drizzle & rain

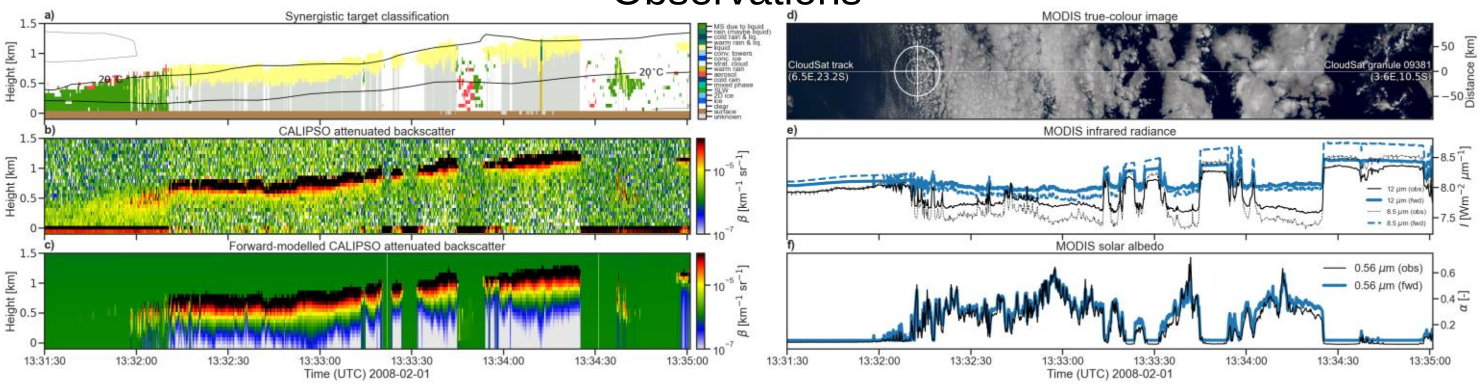
- Rain drop size distribution (DSD) scales as a function of rain rate (Abel & Boutle, QJRMS, 2012), but can also retrieve deviations from this relation when constrained by observations
  - PIA can provide a strong constraint on retrieving DSDs with high concentrations of small drops in warm rain (Mason et al., *ACP*, 2017)
- Rain rate and liquid cloud both contribute to PIA
- Compared with CloudSat rain products
  - PRECIP-COLUMN doesn't resolve features within the profile (e.g. evaporation or collision-coalescence), but is well-constrained by PIA
  - RAIN-PROFILE has distinct attenuating and non-attenuating regimes



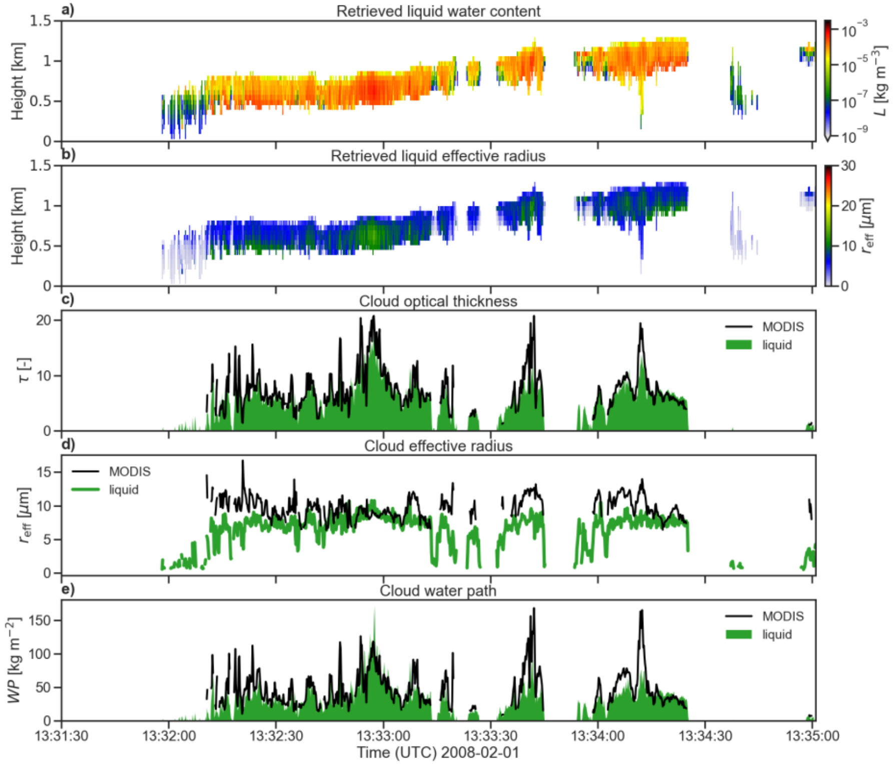
CCM-CAP: liquid cloud

- Retrievals of non-precipitating liquid cloud closely resemble MODIS cloud retrievals
- But it's likely that a majority of liquid cloud goes undetected by spaceborne radar-lidar
  - radar is sensitive to precipitating hydrometeors, while lidar is quickly extinguished near cloud-top
  - Missing liquid clouds have a strong shortwave/solar radiance signal, so can't be ignored from a cloud-radiation perspective
  - Have demonstrated some success by coarsely represent missing liquid cloud with the assumption that liquid cloud is colocated with rain.

Observations

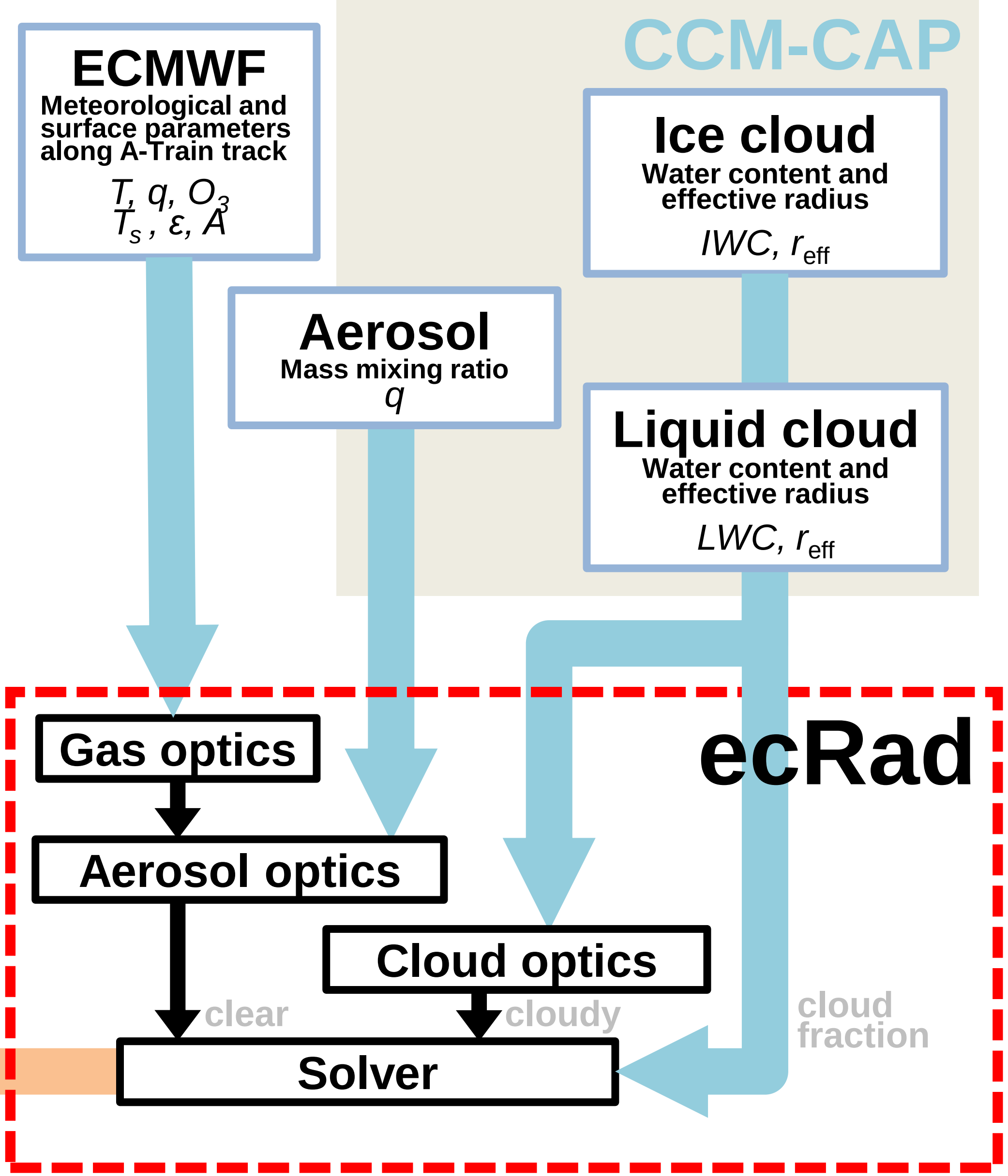


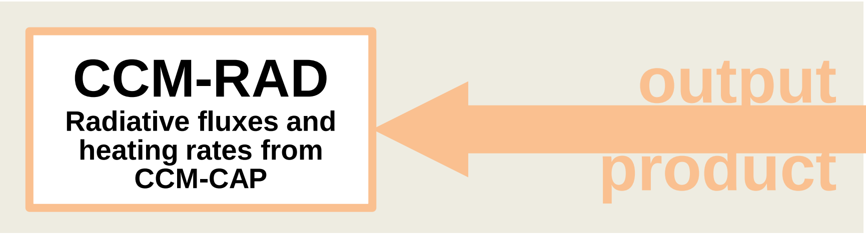
Retrievals



CCM-RAD: radiative transfer at nadir

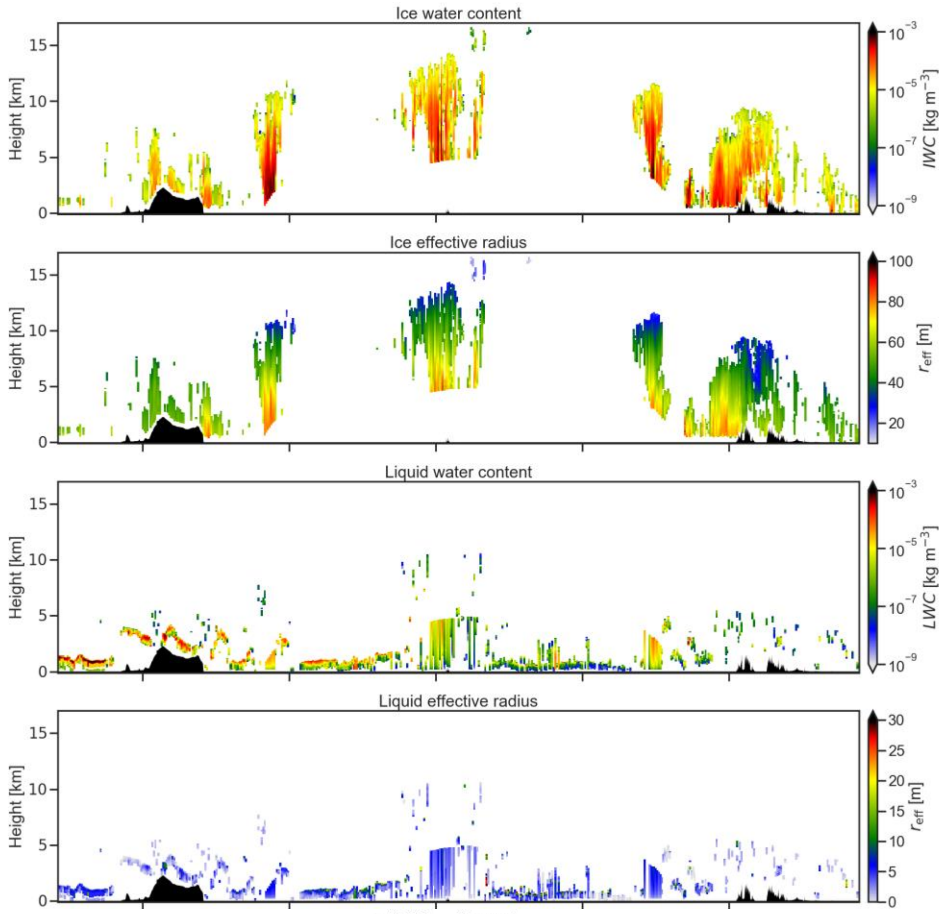
- CCM-CAP retrieved cloud and aerosol properties are inputs to radiative transfer model
- Radiative transfer model is the offline version of the ECMWF forecast model's fast and accurate radiation scheme, *ecRad* (Hogan and Bozzo, 2018)
- Unlike the EarthCARE radiative product (ACM-RT), the radiative transfer is currently run just at nadir, not across the MODIS swath
- We also use CCM-CAP as the inputs for a more robust radiative closure assessment across the MODIS swath using the method of Barker et al. (2011), which underpins the ACM-3D & ACM-RT products for EarthCARE





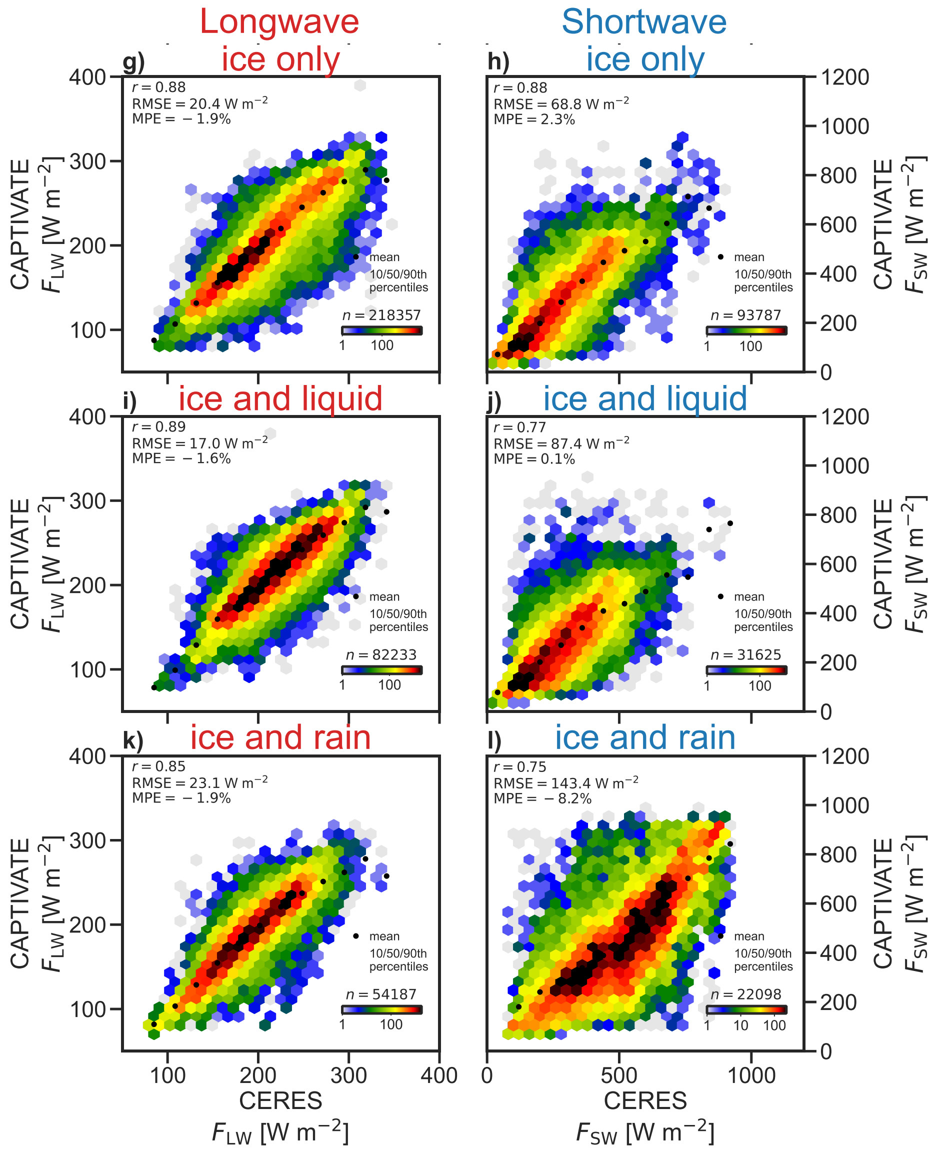
CCM-RAD: radiative fluxes & heating rates

- ecRad computes LW & SW radiative fluxes through the atmosphere
- Radiative heating rates calculated from net radiative flux over each layer
- Top-of-atmosphere (TOA) fluxes vs CERES measurements
- LW radiative closure well-constrained; determined by cloud-top height/temperature
- SW radiative closure more sensitive to cloud phase, retrieved properties and surface albedo
- Assumption of liquid cloud in rain improves shortwave fluxes at TOA, but drastically changes heating rates in the lower atmosphere
  - Cloud base height assumption from spaceborne radar-lidar could be evaluated using surface fluxes



CCM-RAD: radiative closure

- With coarse distinctions between cloud regimes; more careful selection could be made to target specific processes
- Radiative closure assessment provides a built-in evaluation of biases in the radiative properties of clouds retrieved by CCM-CAP. This can be used to quantify improvements, e.g. in microphysical properties of ice clouds
- Increased noise attributed to inherent mismatch between the ~1km scale of CloudSat-CALIPSO measurements and the ~20km CERES footprint.
    - Should be substantially reduced by carrying out across-track radiative closure assessment (Barker et al. 2011 & ACM-RT)
- SW closure more challenging than LW



Summary

- CCM-CAP: unified and synergistic retrieval of clouds, aerosols and precipitation from the A-Train
  - Advantages over a patchwork of single-instrument and synergistic retrievals, especially in complex and layered scenes
  - Continuity with EarthCARE synergistic retrievals
  - Current applications:
    - Testing and development of EarthCARE synergistic retrievals
    - Evaluation of ECMWF integrated forecast system
    - Forward-modelling of novel microwave/radar sensors
- Downstream products: radiative fluxes and heating rates
  - CCM-RAD at nadir using ECMWF radiation scheme; Radiative closure vs CERES provides a built-in evaluation of CCM-CAP
  - Also providing CCM-CAP as input to 3D radiative transfer methodology (Barker et al.
- Paper and initial dataset to follow
  - Starting with 1 year of A-Train data (2008)
  - To expand to first 5 years of A-Train (2006 to 2011); period of optimal CloudSat-CALIPSO performance
  - Looking for users!
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