Developments in operational RT codes - SW

ICAP 2017

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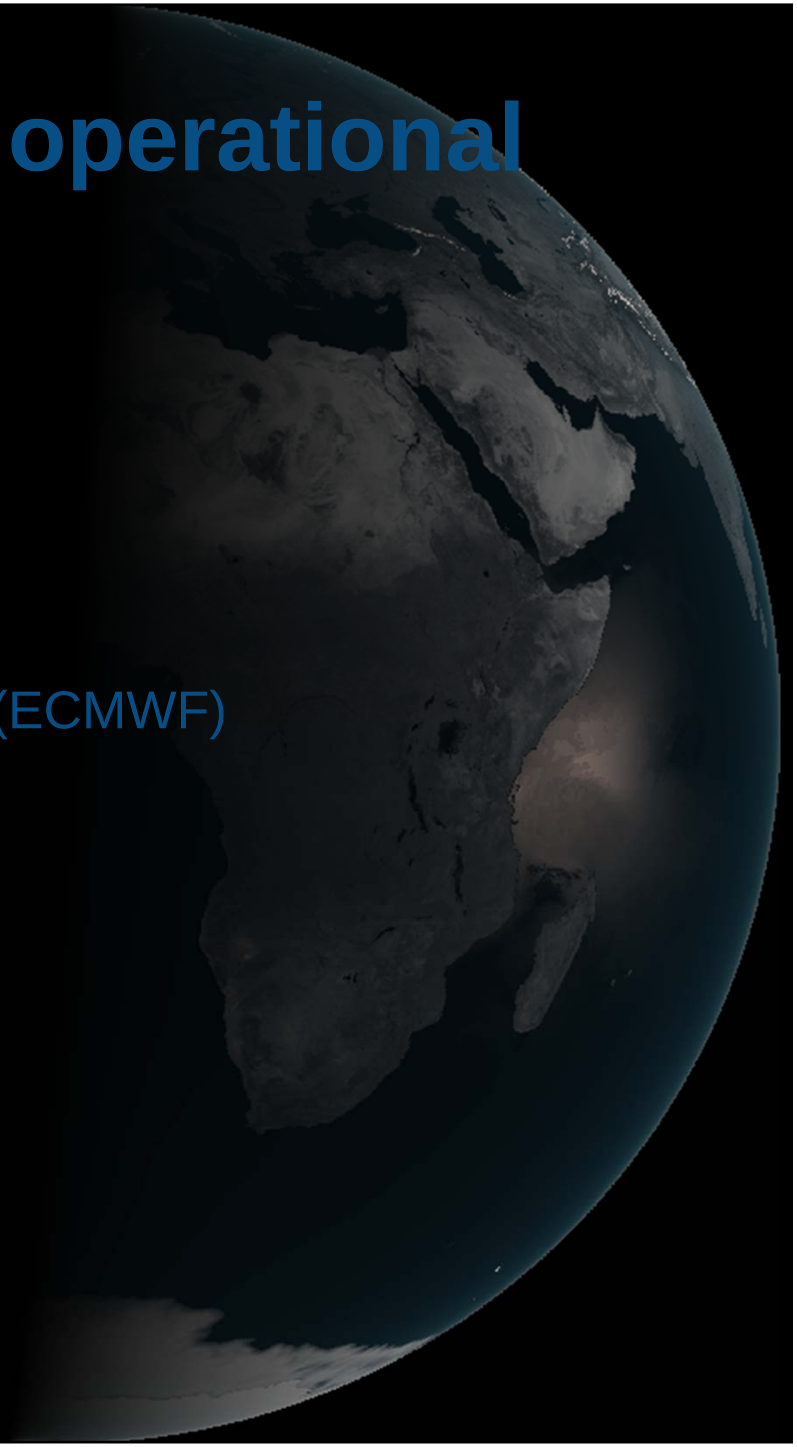
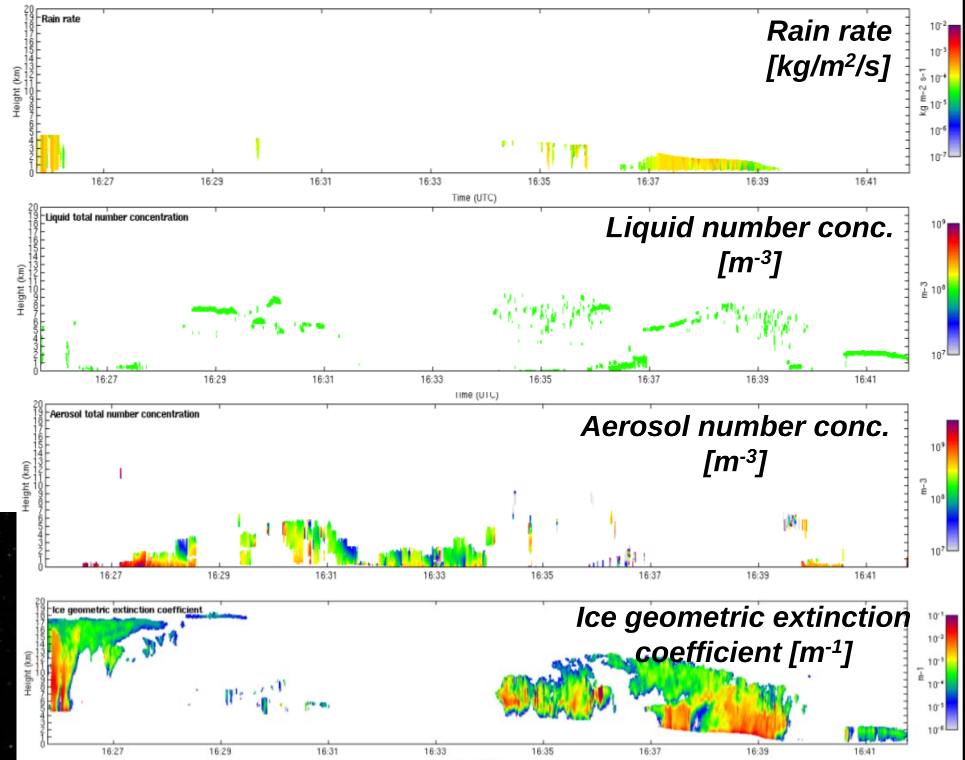


ECMWF

Synergistic retrieval algorithm for operational EarthCARE L2b products.

• Aim: to deliver the operational software to perform a synergistic retrieval of clouds, precipitations and aerosols from high-spectral resolution lidar, Doppler radar and SW-LW radiances measured on board the EarthCARE satellite (launch 2019)

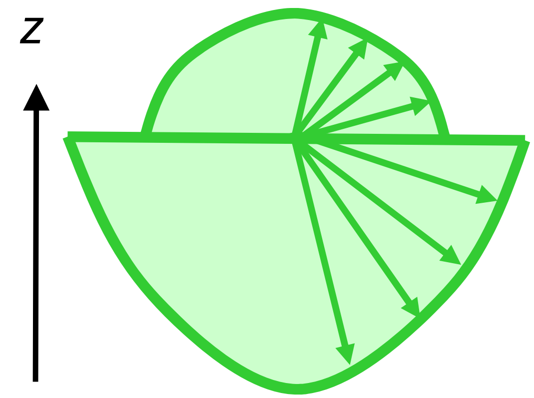
-> develop a shortwave radiance model for clouds and aerosols that is fast enough to use iteratively in a retrieval or assimilation system, but which does not need to assume just a single particle type in an atmospheric profile (like current look-up table approaches)



Retrieved liquid and aerosol number concentration, rain rate and ice extinction for a 6000 km long A-Train scene assimilating Lidar, Radar and infrared radiances

The challenge of modelling shortwave radiances

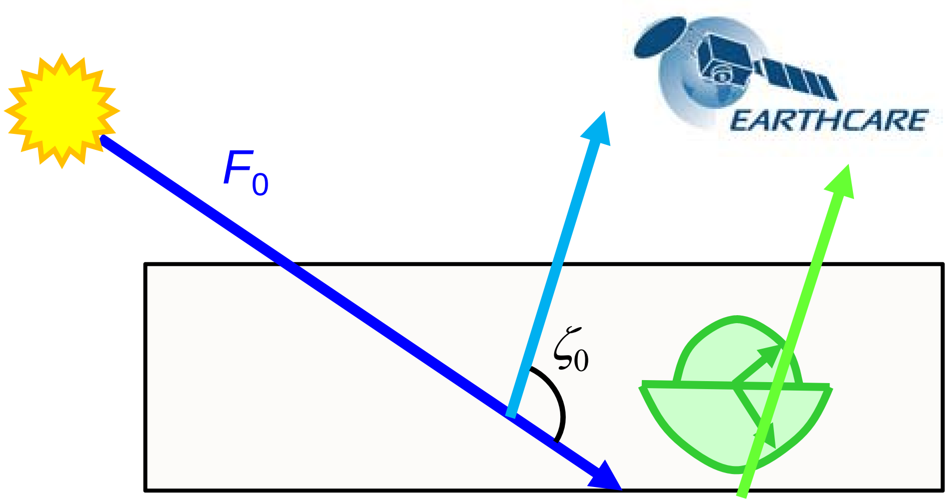
- State-of-the-art is the *discrete ordinate method* e.g. DISORT
  - Discretize radiance distribution in *elevation* by *N* streams
  - Expand the radiance distribution in *azimuth* as a cosine series
  - For each cosine term, solve large matrix problem for multiple layers
  - Computational cost proportional to N^3
  - Probably too expensive to run iteratively in a retrieval
  - Challenging to code the adjoint of such a model



- Typically calculations performed offline to generate a 5D lookup table as a function of solar zenith angle, instrument zenith angle, optical depth, particle effective radius, surface albedo
  - Not feasible to represent multiple layers containing different particle types (e.g. thin ice clouds over aerosol or liquid cloud), even if information on such layering is available from active instruments

The two-stream source function technique (Toon et al. 1989)

First try to adapt the Toon et al. (1989) infrared model to the shortwave



- Compute profile of direct solar radiation
- Two-stream scheme for diffuse fluxes
- Single-scattering contribution to radiance simply reading off phase function at ζ_0
- For multiple-scattering contribution to radiance, perform 1D radiance calculation using diffuse fluxes as the source function

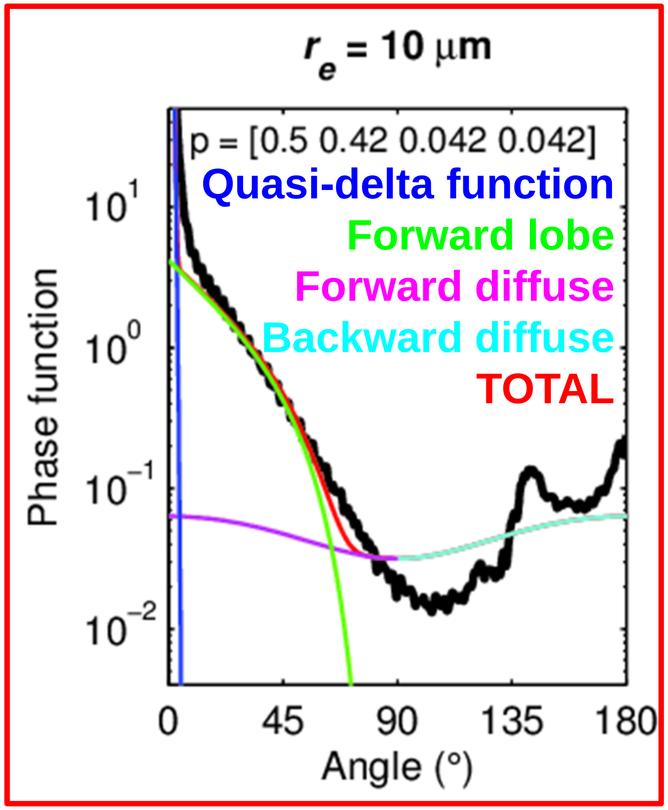
Direct beam obeys: $$\frac{dF_0}{d\tau} = -\frac{F_0}{\cos(\theta_0)}$$

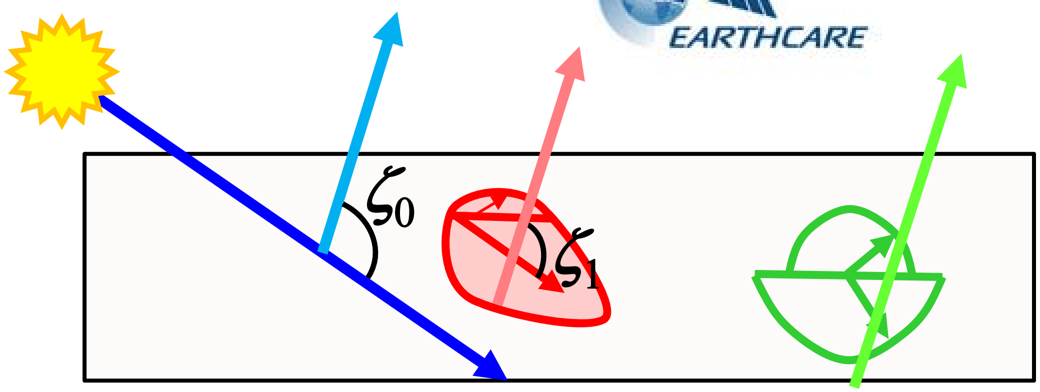
Very fast, accuracy adequate for fluxes (used in weather and climate models)

Not very accurate for radiances due to *wide forward lobe* in the phase function

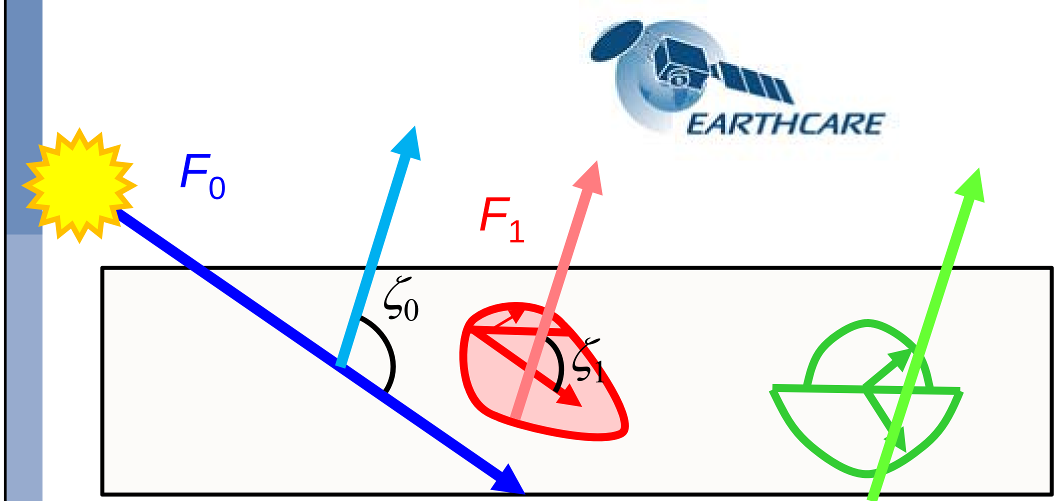
Forward-Lobe Two-Stream rAdiance Model (FLOTSAM)

- Cloud and aerosol phase functions have a wide forward lobe and can be parameterized as the weighted sum of four components
- Propagation of radiation scattered by wide forward lobe is treated as a separate stream
- Single scattering treated exactly
- Much faster than discrete ordinate method
- Potentially more accurate than look-up table when multiple particle types present in profile





Forward-Lobe Two-Stream rAdiance Model (FLOTSAM)



- Compute profile of direct solar radiation
- Compute profile of radiation in the forward lobe with effective zenith angle θ_1
- Two-stream scheme for diffuse fluxes
- Single-scattering contribution to radiance
- Lobe contribution to radiance by reading off smoothed phase function at ζ_1
- Multiple-scattering contribution to radiance
- Also treat lobe in path to satellite

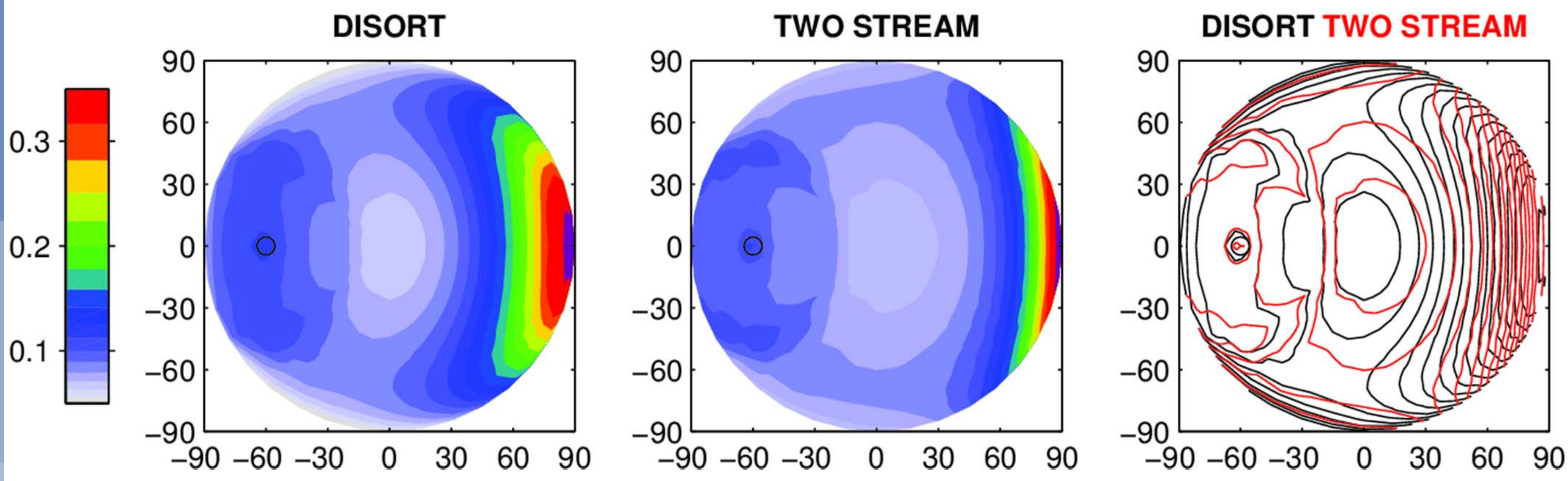
Lobe flux obeys: $$\frac{dF_1}{d\tau} = pF_0 - q\frac{F_1}{\cos(\theta_1)}$$

Very fast, straightforward to code up adjoint

Some flexibility in how the forward lobe is specified

Is it accurate?

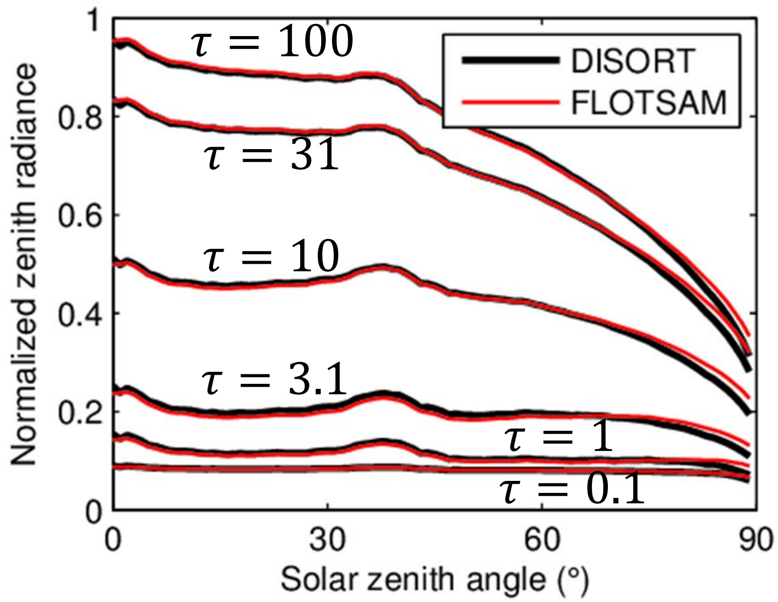
Full radiance field: Two-stream source function

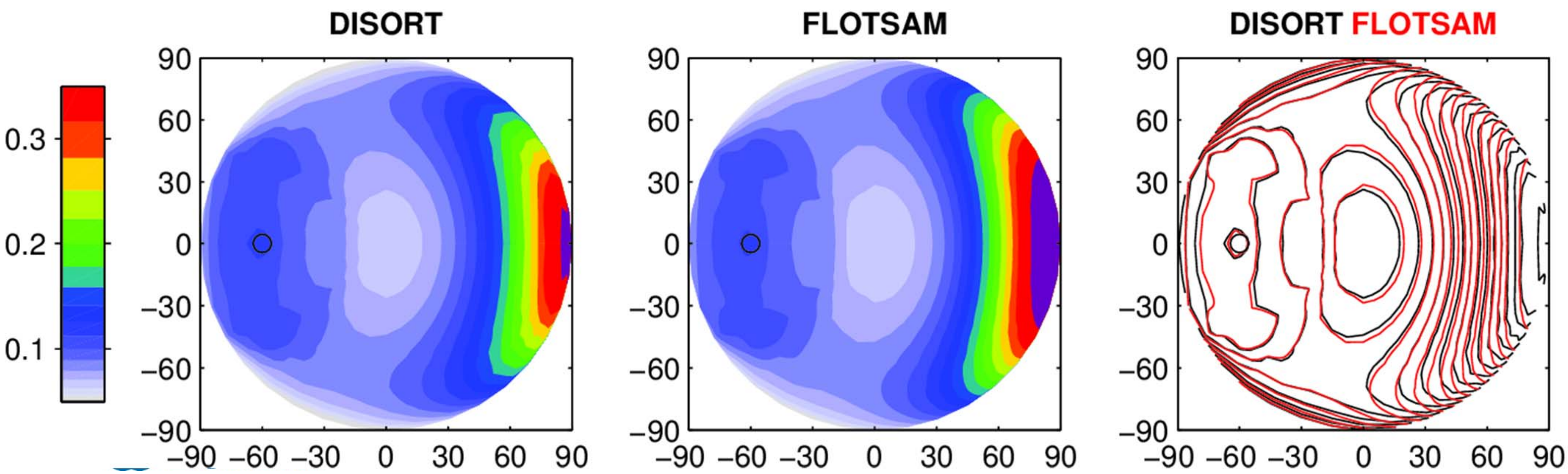


radiance pattern for solar zenith angle of 60 degrees

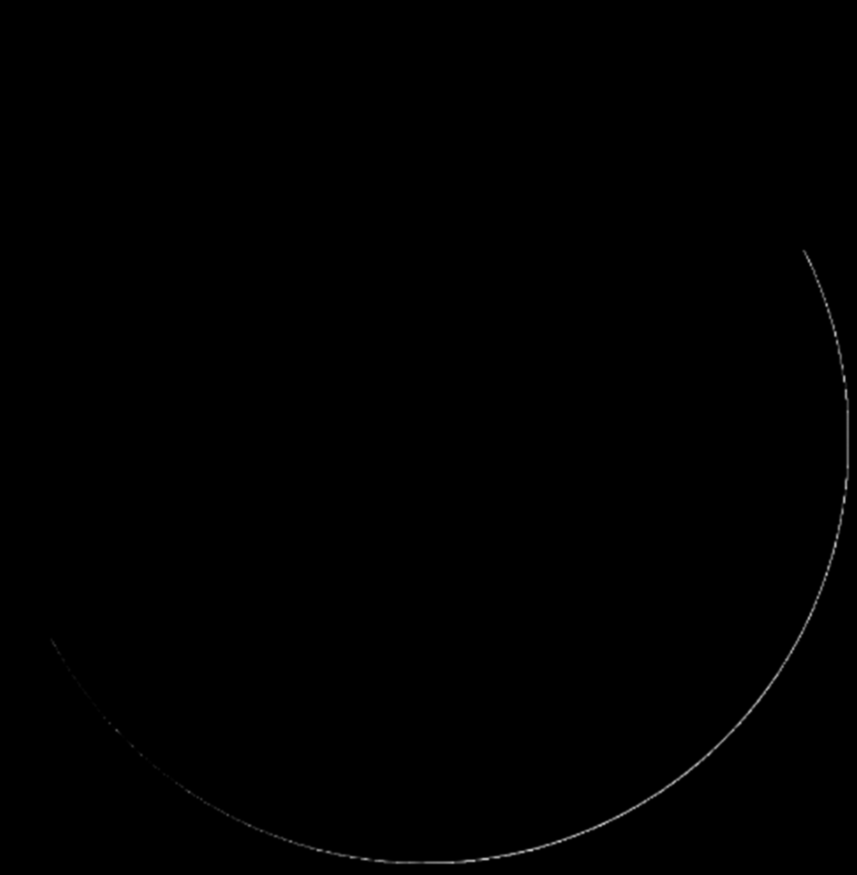
Validation against DISORT

- Liquid cloud phase function effective radius 10 microns
- (right) nadir viewing sensor
- (bottom) radiance pattern for solar zenith angle of 60 degrees



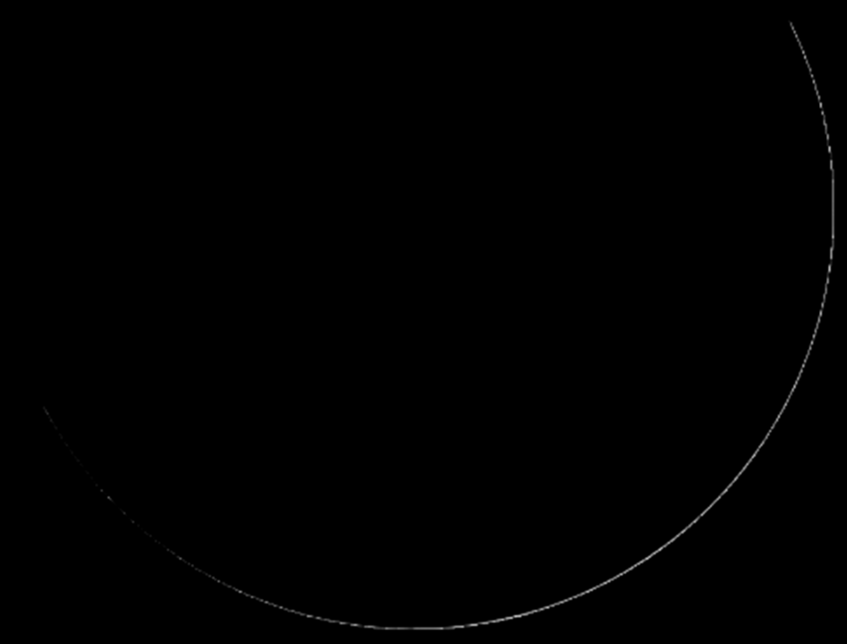


Simulation of geostationary visible imagery at 0.5 microns clear sky



- ECMWF cloud, albedo and surface winds fields at 1/8 degree resolution
- Rayleigh scattering but neglect aerosols and gas absorption
- Merge clear-sky layers for speed
- Cost ~0.5 ms per profile
- Adjoint/Jacobian from automatic differentiation
- Cox and Munk-type parametrization of ocean sun glint

Simulation of geostationary visible imagery at 0.5 microns total sky (static cloud field)



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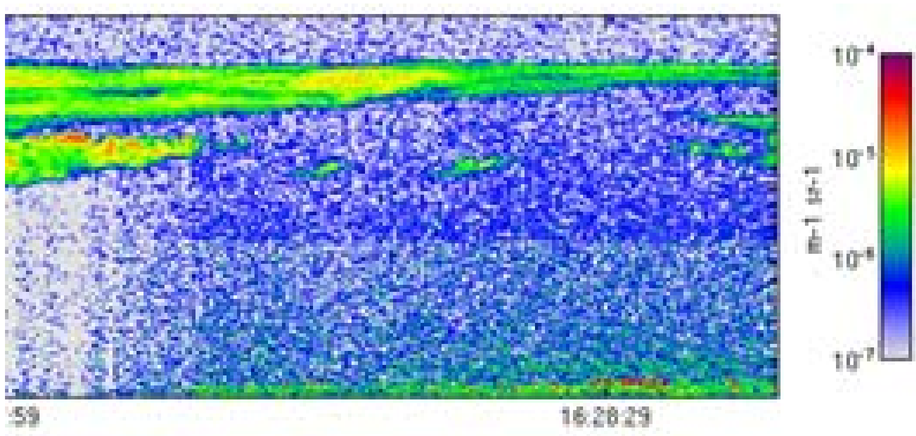
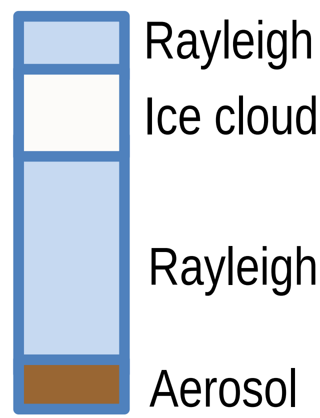
Summary – new SW model

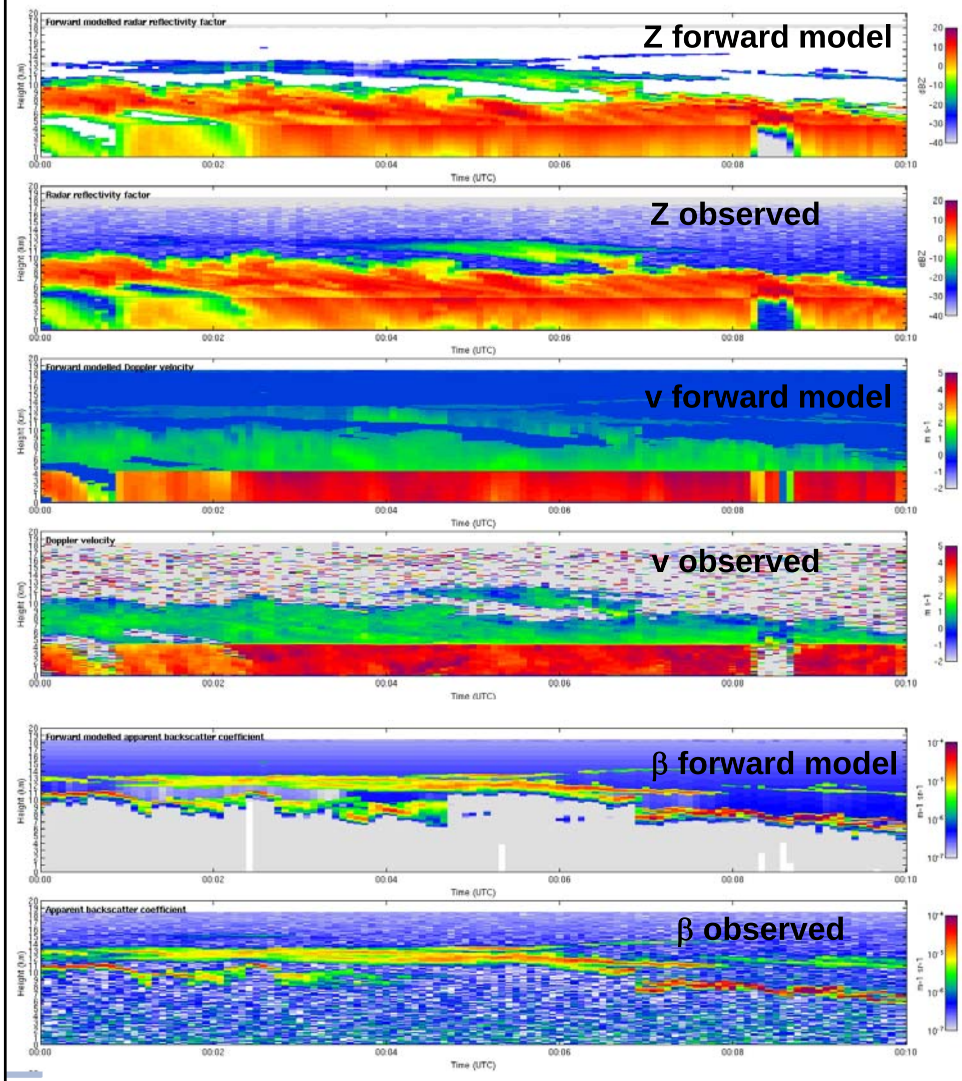
- New fast shortwave radiance model “FLOTSAM” under development
- Explicitly estimates the fraction of radiation in the forward lobe
- Work required to improve representation of the forward lobe and hence radiances looking towards the sun
- Coded in C++ using Adept library (Hogan 2014) for automatic differentiation
- Additional speed-up possible for shortwave radiances because layers with similar phase functions can be combined

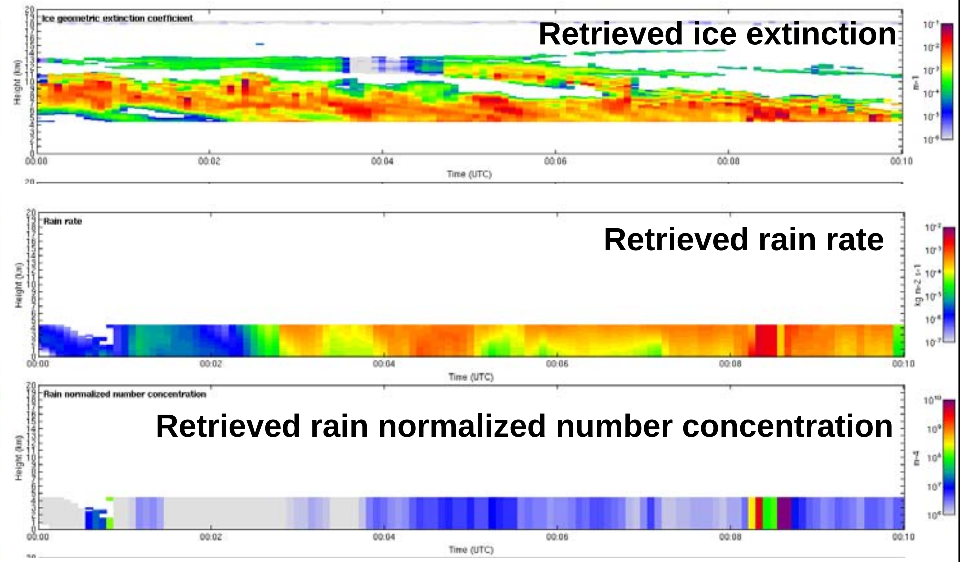




NASA ER-2 test data

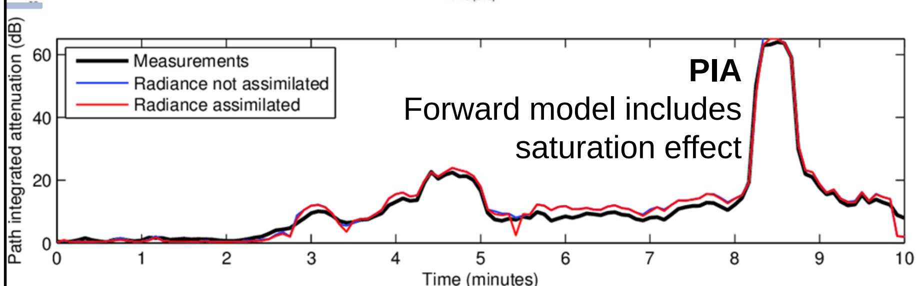
- Excellent platform to test EarthCARE algorithms:
  - CRS 94-GHz radar: reflectivity, Doppler velocity and path-integrated attenuation
  - CPL lidar: we use 532-nm backscatter but 355-nm and 1064-nm also available
  - MAS 50-channel radiometer: solar, near-IR and thermal-IR channels
  - EDOP 10-GHz radar: reflectivity & Doppler velocity – use for validation
- Two contrasting cases from TC-4 campaign over Pacific ocean near Panama:
  - Ice cloud & stratiform rain
  - Warm rain from thick liquid cloud

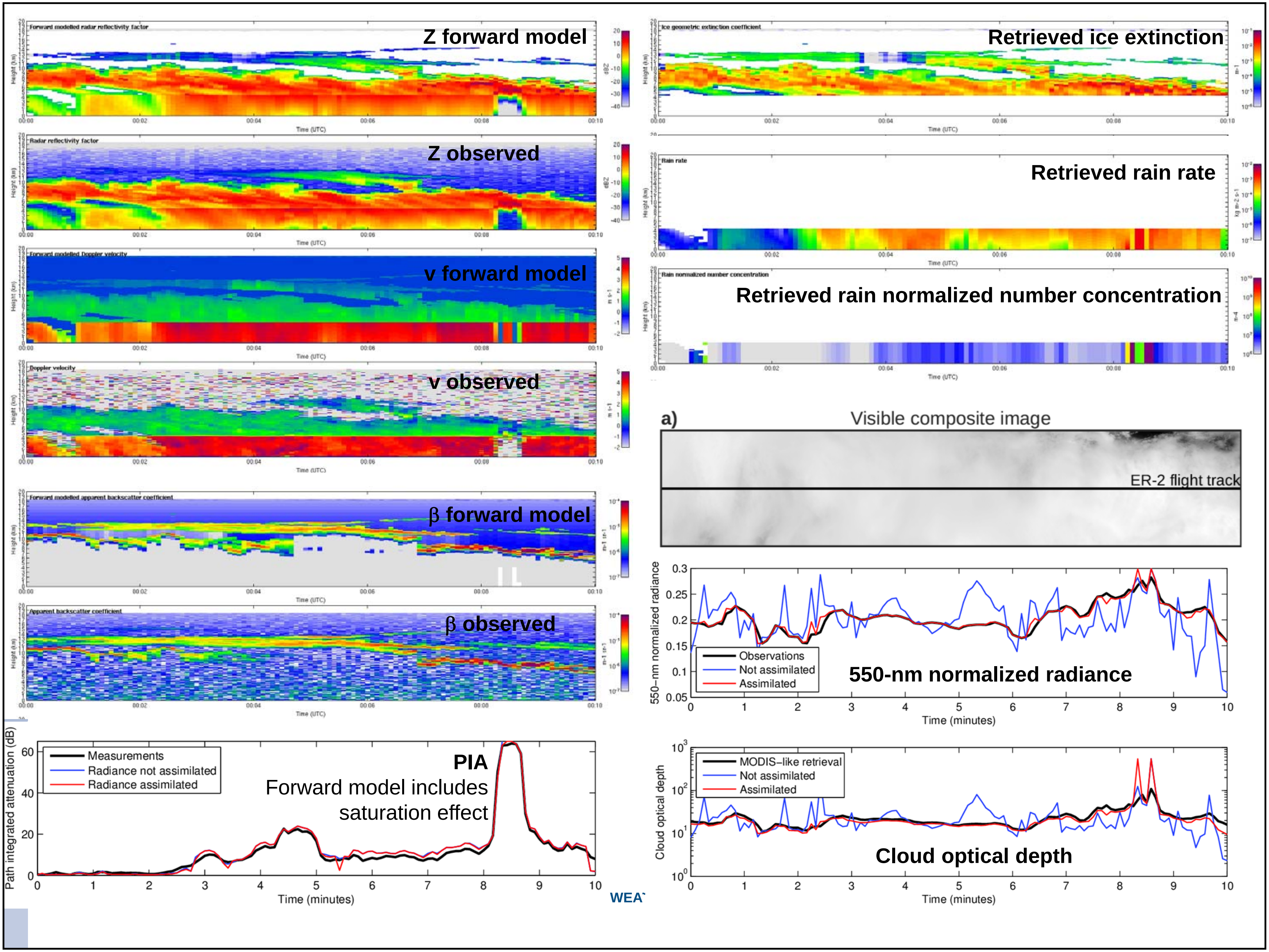


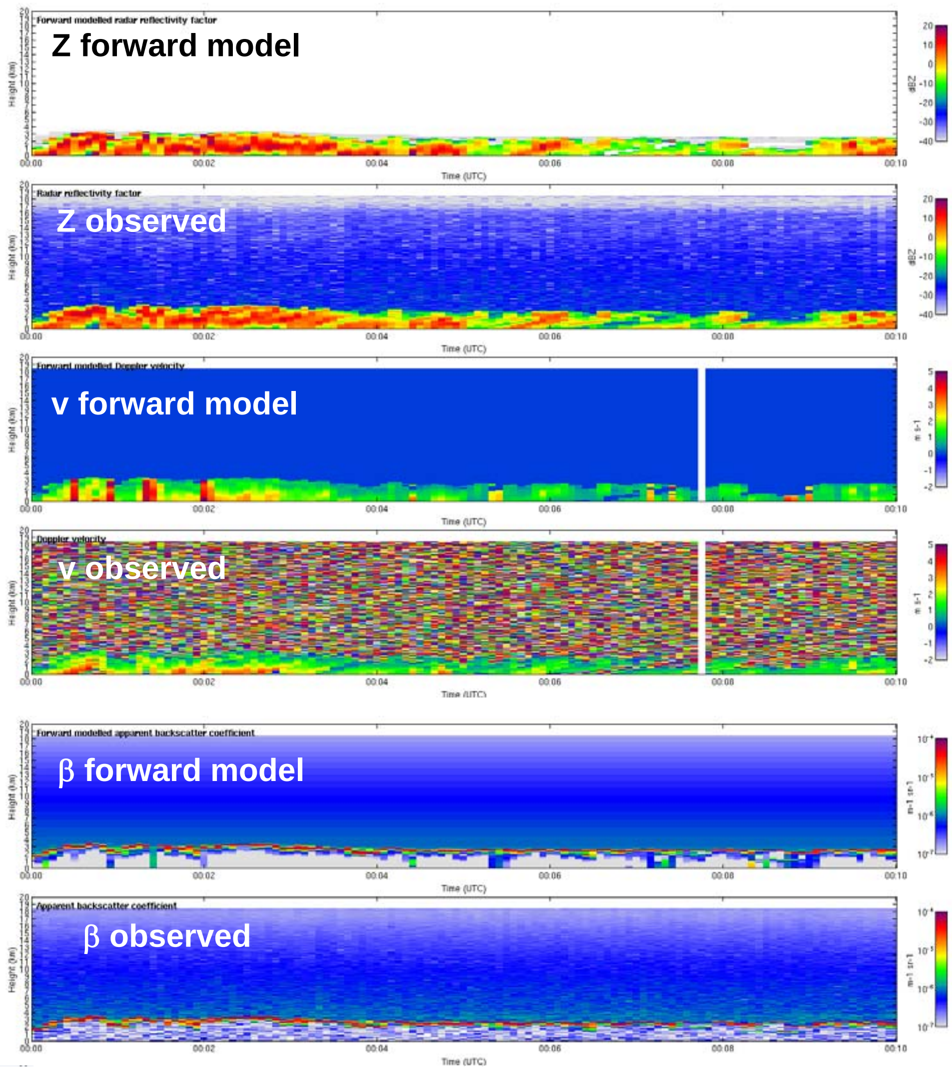


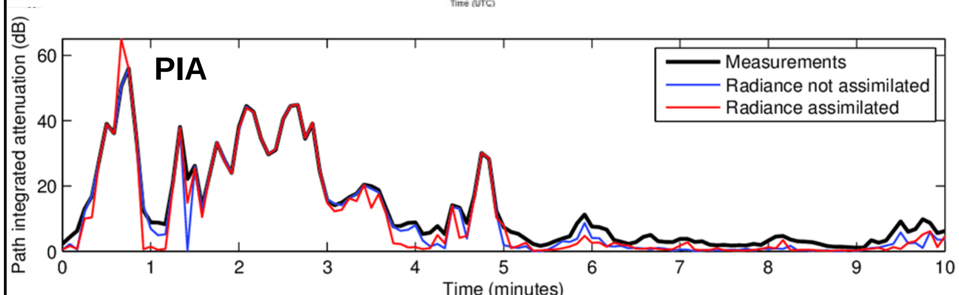
Case 1: ice cloud and rain

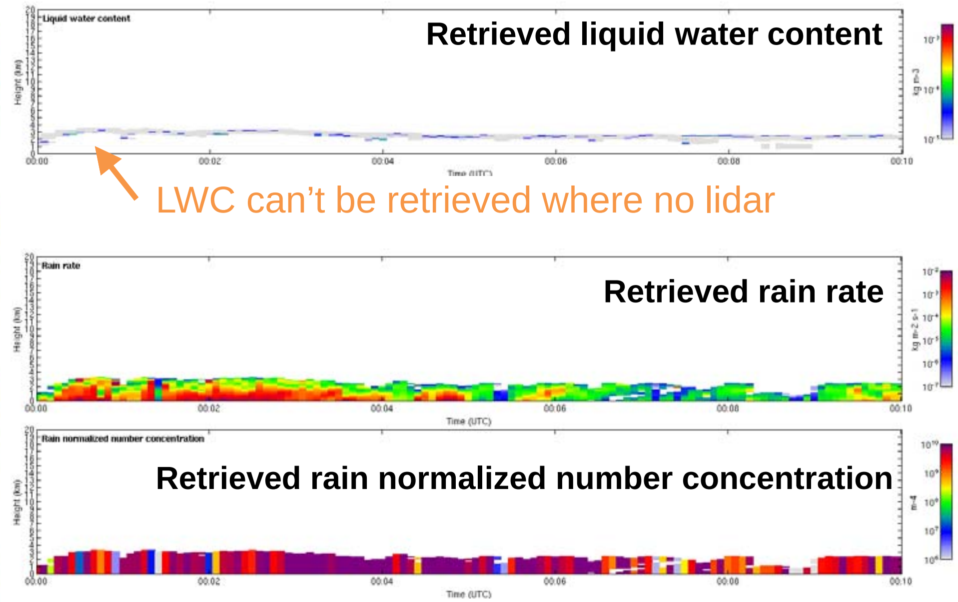
- Assimilate Z, v, PIA, β
- Retrieve ice extinction, ice Nw, lidar ratio, rain rate, rain Nw
- Rain rates of 1-10 mm h^{-1}
- What happens if we assimilate 550-nm radiance as well?




Z forward model
Z observed
v forward model
v observed
β forward model
β observed
Retrieved ice extinction
Retrieved rain rate
Retrieved rain normalized number concentration
a)
Visible composite image
ER-2 flight track
550-nm normalized radiance
Observations
Not assimilated
Assimilated
Time (minutes)
PIA
Forward model includes
saturation effect
Measurements
Radiance not assimilated
Radiance assimilated
Path integrated attenuation (dB)
Cloud optical depth
MODIS-like retrieval
Not assimilated
Assimilated
Time (minutes)

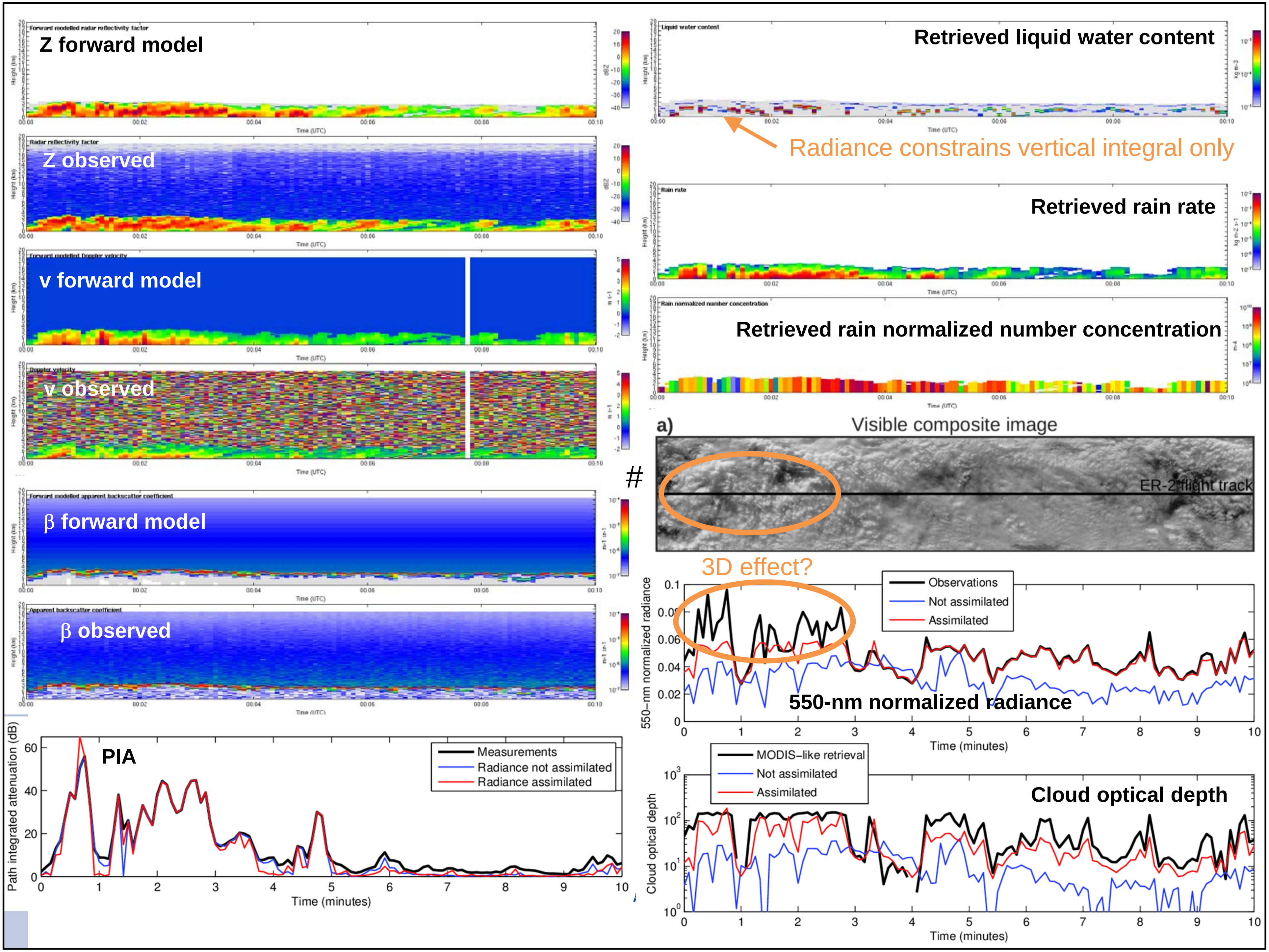






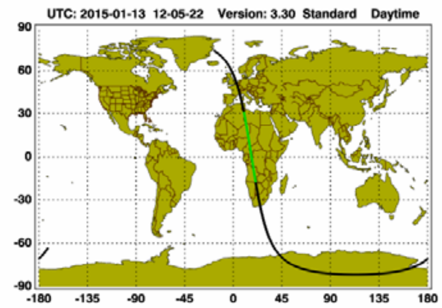
Case 2: liquid cloud and warm rain

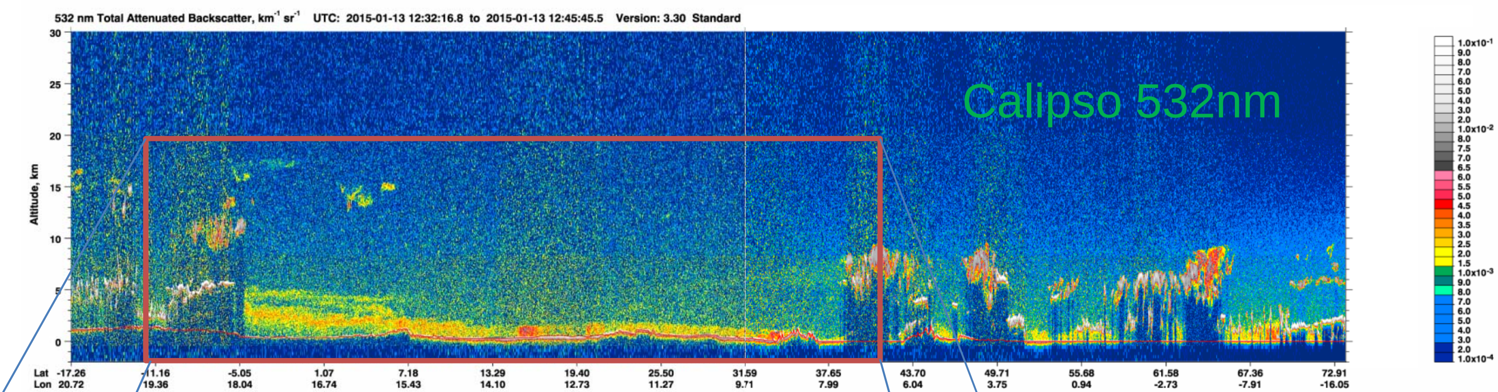
- Assimilate Z, v, PIA, β
- Retrieve liquid water content, rain rate, rain Nw
- Much higher Nw retrieved compared to rain from melting ice
- Rain rates of 0.1-10 mm h^{-1}
- Assimilating 550-nm radiance allows liquid cloud to be assimilated to the ground

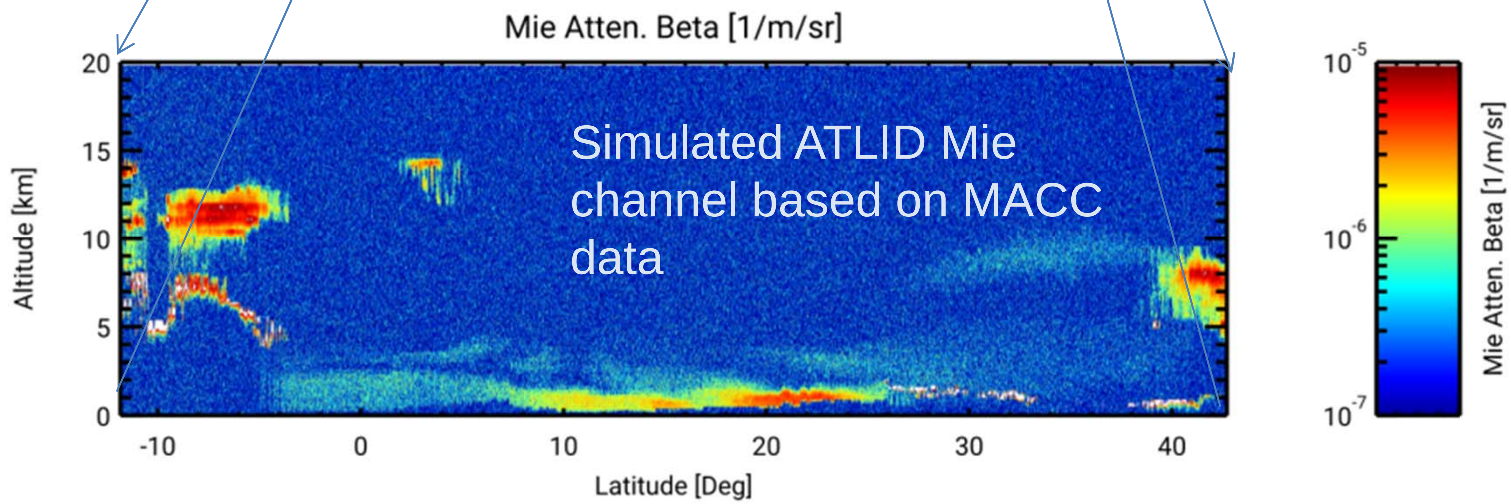

Z forward model
Z observed
v forward model
v observed
β forward model
β observed
Time (UTC)
Retrieved liquid water content
Radiance constrains vertical integral only
Retrieved rain rate
Retrieved rain normalized number concentration
a)
Visible composite image
ER-2 flight track
#
3D effect?
Observations
Not assimilated
Assimilated
550-nm normalized radiance
550–nm normalized radiance
Time (minutes)
PIA
Path integrated attenuation (dB)
Measurements
Radiance not assimilated
Radiance assimilated
Time (minutes)
MODIS–like retrieval
Not assimilated
Assimilated
Cloud optical depth
Cloud optical depth
Time (minutes)

Comparisons against model-generated scenes

2015-01-13:
Approx. 12 UTC

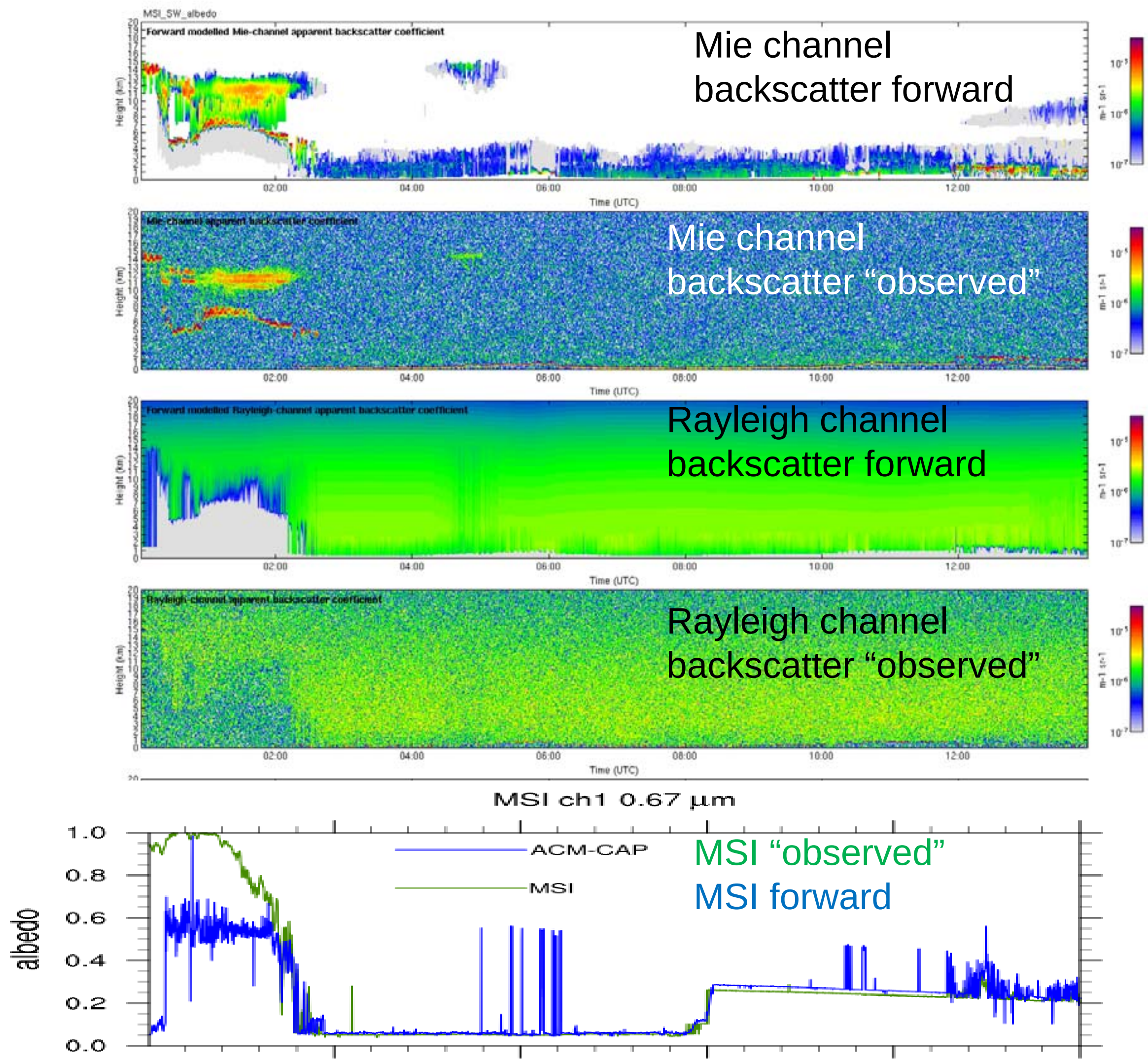




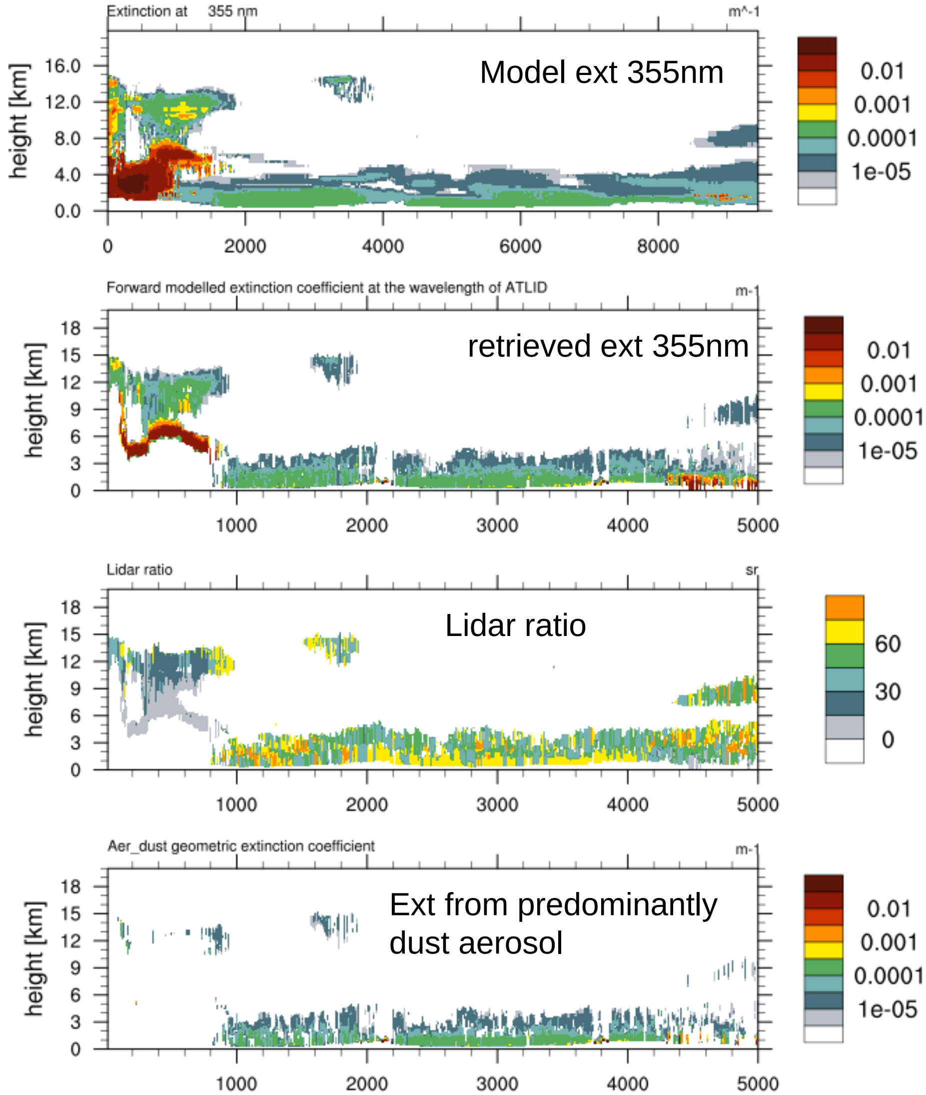


KNMI

Comparisons against model-generated scenes



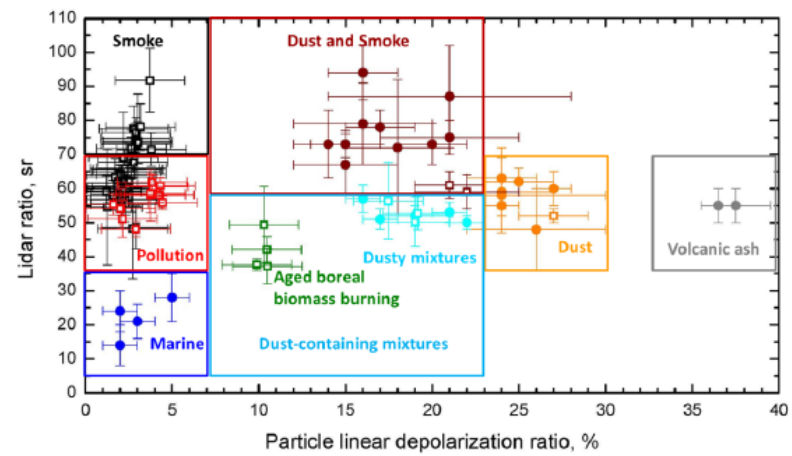
Comparisons against model-generated scenes



Assimilated HSRL and SW radiances

Combined lidar-radar input target classification

Mixture aerosol model



U. Wandinger, TROPOS, Leibniz

Summary and future work

- FLOTSAM is promising shortwave radiance model for retrievals and assimilation
- Developments to expect in the next 6 months
  - Evaluate against DISORT using aerosol phase functions
  - Test aerosol retrievals using A-Train (MODIS+CALIPSO) observations
  - Optimize code - e.g. not thread-safe at the moment
  - Submit a paper
  - Release under a free-software license
- Improvements to consider if used for NWP
  - Represent sub-grid cloud structure
  - Add gas absorption if to be used for near-IR wavelengths
  - If “Adept” automatic differentiation too slow, could recode in Fortran

FLOTSAM on
ECMWF data

JMA's
Himawari-8