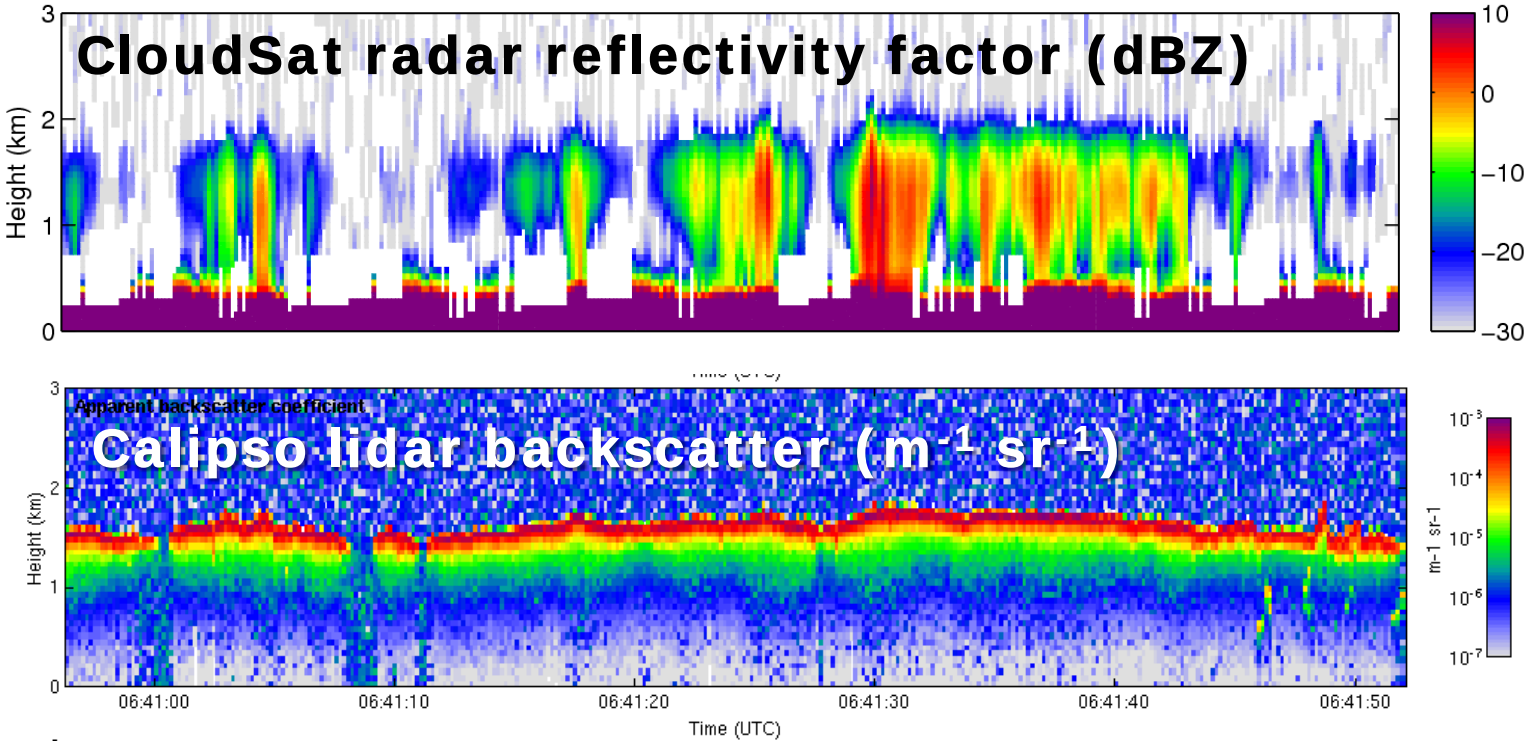
Exploiting multiple scattering in CALIPSO measurements to retrieve liquid cloud properties

Nicola Pounder, Robin Hogan,
Lee Hawkness-Smith, Andrew Barrett
University of Reading, Assimila Ltd., Met Office, ECMWF

The problem with liquid clouds

- 90% of liquid clouds over the oceans; 90% of those contain drizzle
- Lidar signal strongly attenuated & contaminated by multiple scattering

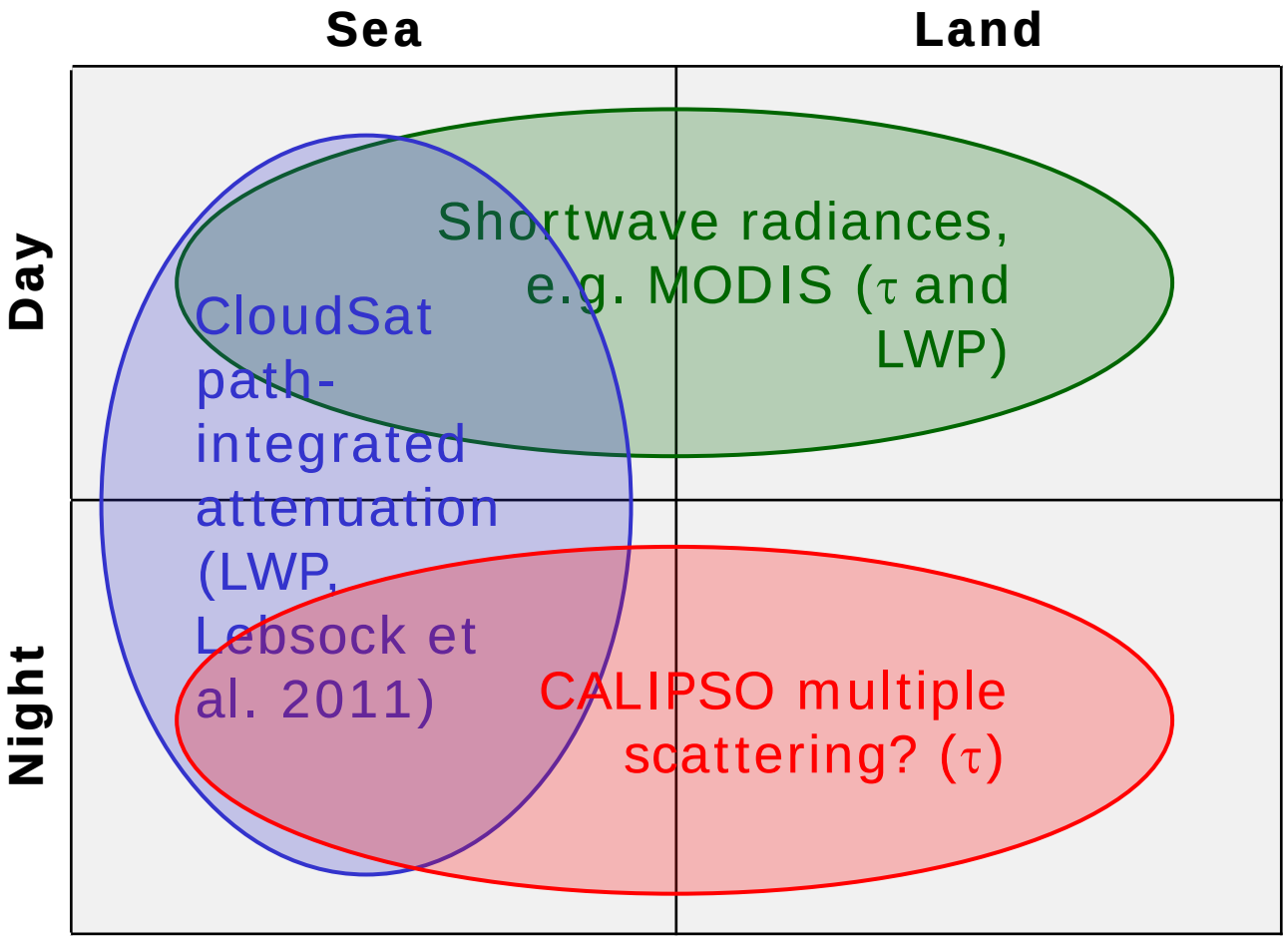


Where is cloud base?

- Can we use the lidar multiple scattering signal to estimate cloud properties (e.g. Polonsky & Davis 2004; Cahalan et al. 2005)?

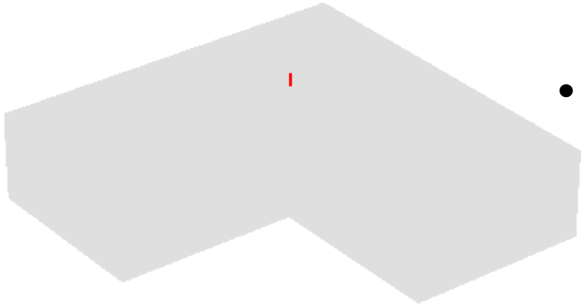
Liquid cloud properties from space

- High resolution (~1 km) integrated properties (LWP, τ) depend on:

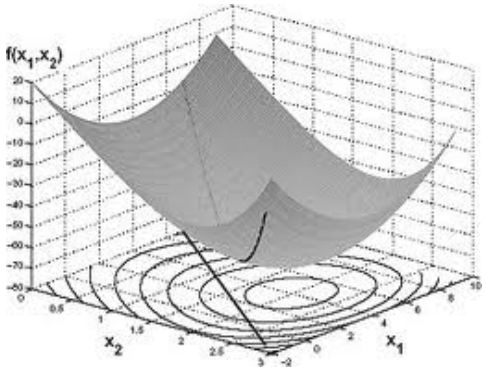


- CALIPSO multiple scattering can potentially fill a gap at night (in the day the solar background is usually too high)

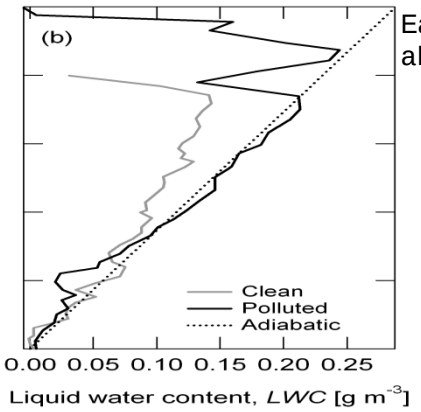
Retrieval ingredients



- Fast forward model for lidar multiple scattering
  - Hogan (2008) for small-angle scattering
  - Hogan and Battaglia (2008) for wide-angle
  - Several milliseconds to compute a profile



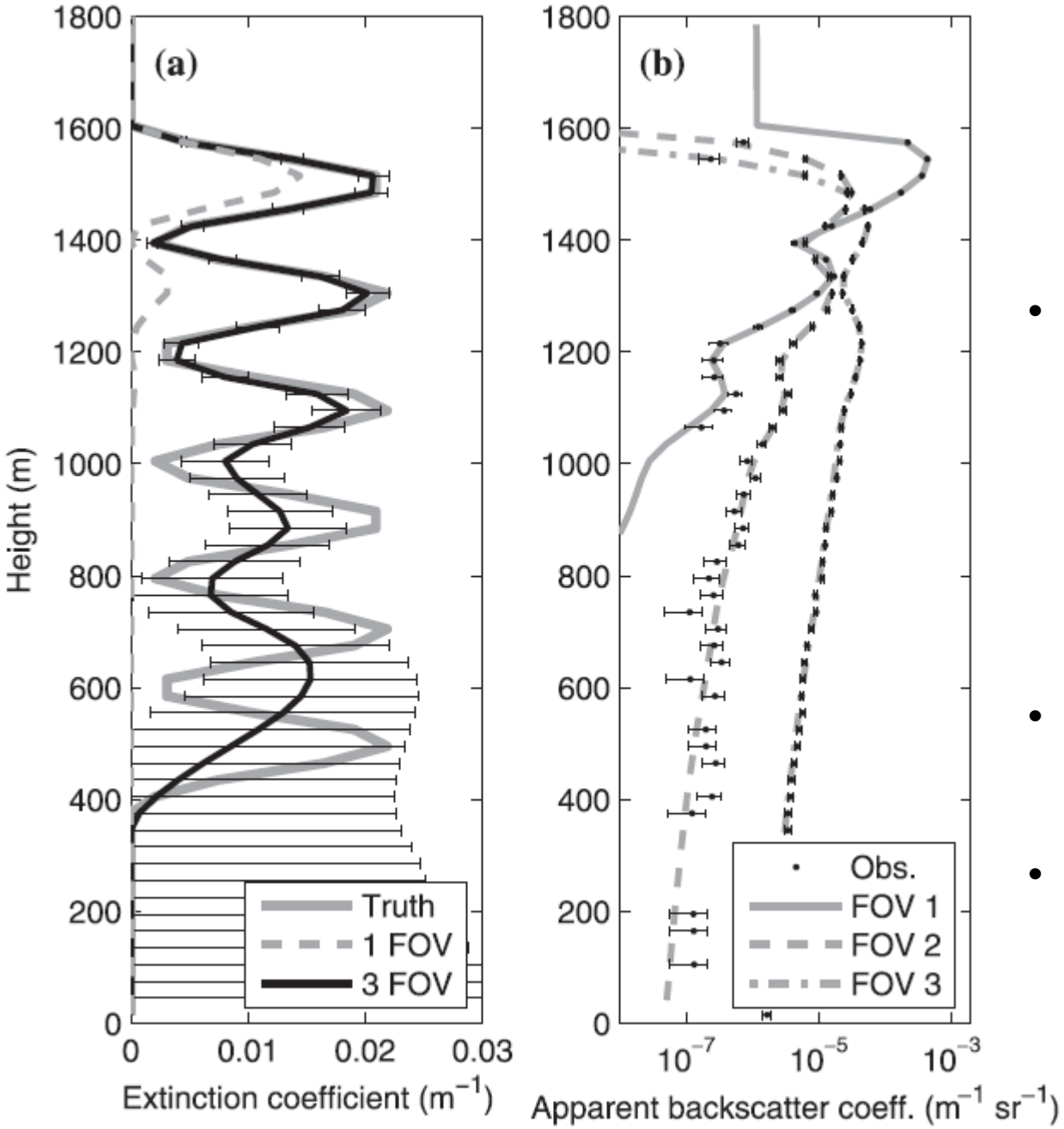
- Variational retrieval framework
  - "CAPTIVATE" (Clouds, Aerosol and Precipitation from mulTiple Instruments using a VAriational TEchnique)
  - Will generate an official product for EarthCARE



Earle et al. (2011)

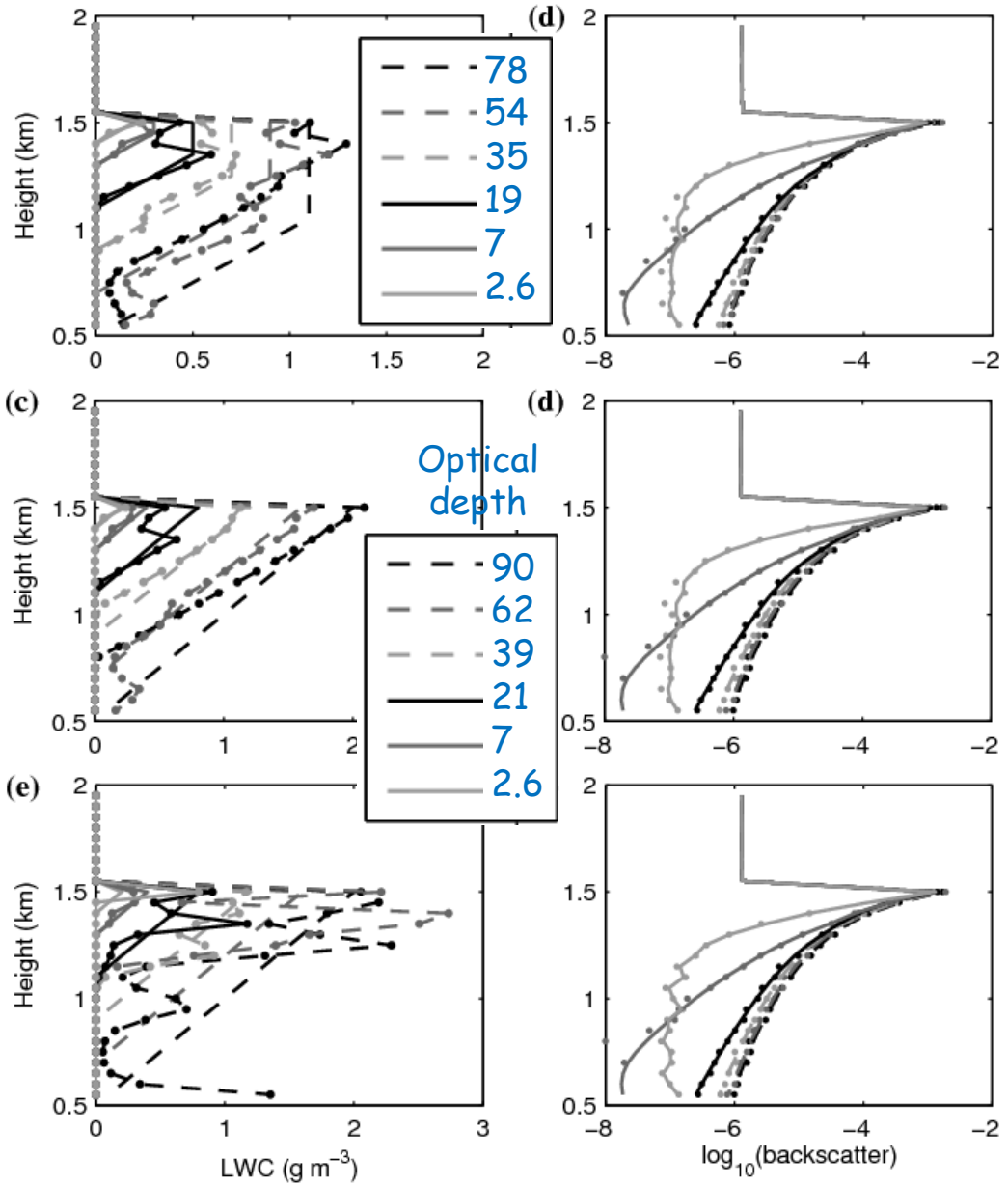
- One-sided gradient constraint
  - Add a term to the cost function to penalize LWC gradients that are steeper than adiabatic

Multiple-FOV lidar



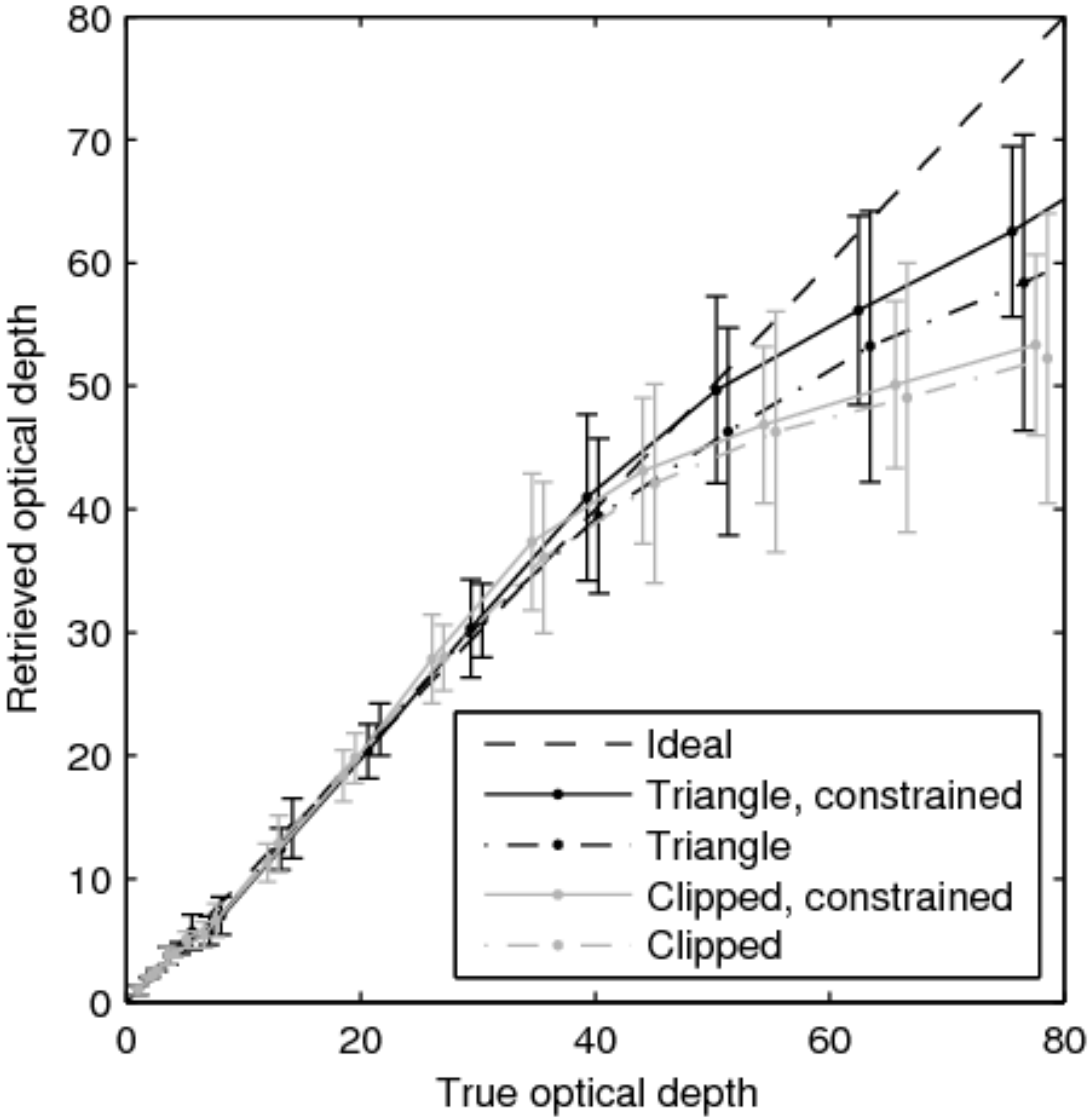
- Pounder et al. (2012) showed that this approach with three fields of view could retrieve the vertical extinction profile down to around 6 optical depths
- Good constraint on much higher optical depths
- Applied to airborne THOR lidar

Single FOV lidar (e.g. CALIPSO)?



- Simulated clipped triangular profile
  - with gradient constraint
- Triangular profile
  - with gradient constraint
- Triangular profile
  - without gradient constraint
  - Much poorer profile

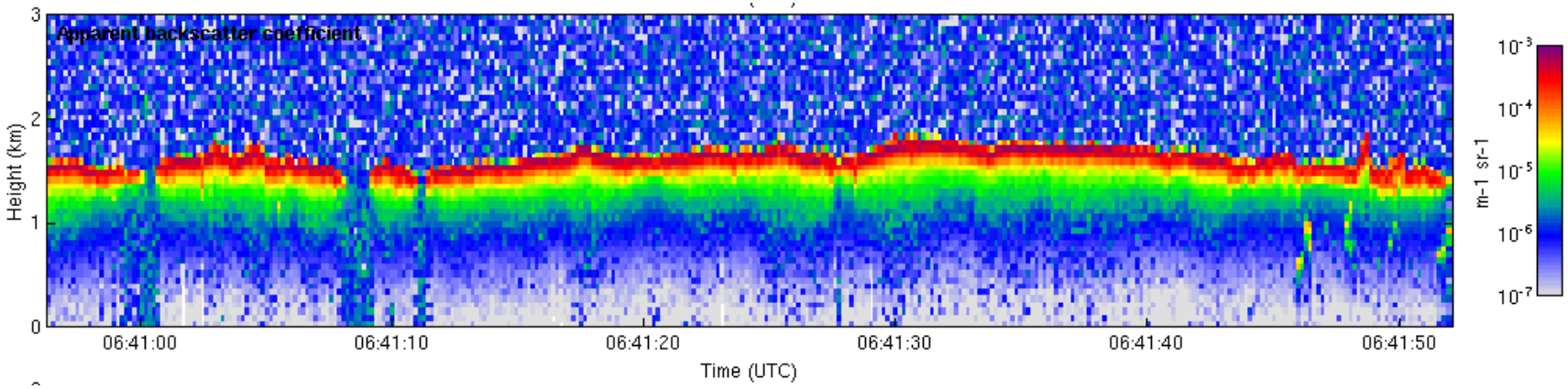
Optical depth



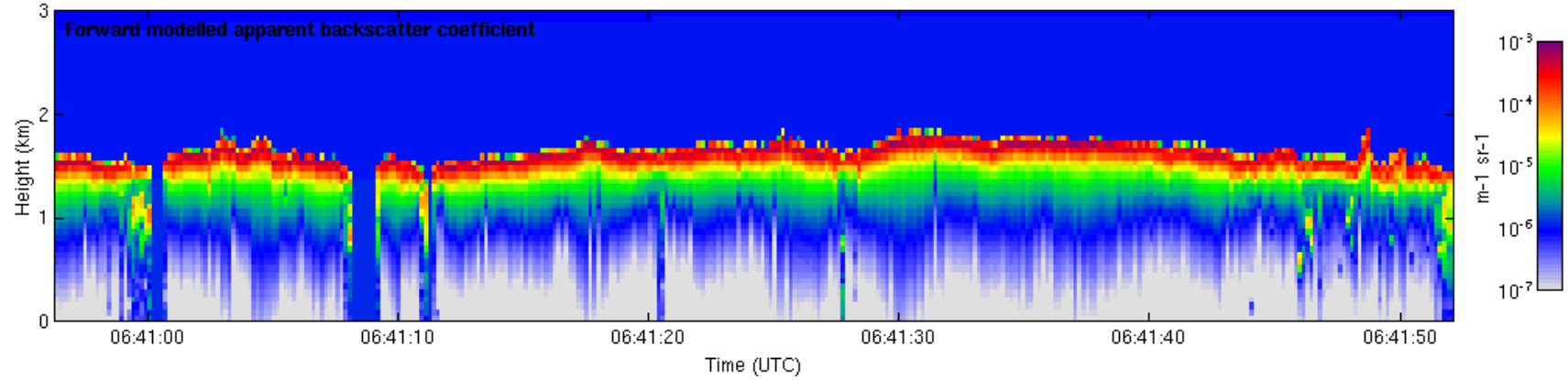
- Retrieved optical is unbiased up to around 50
- Larger values tend to be underestimated
  - Not many photons get back from this deep in the cloud
- If gradient constraint turned off:
  - Much poorer extinction profile
  - But retrieved optical depth only slightly poorer

Application to real CALIPSO data

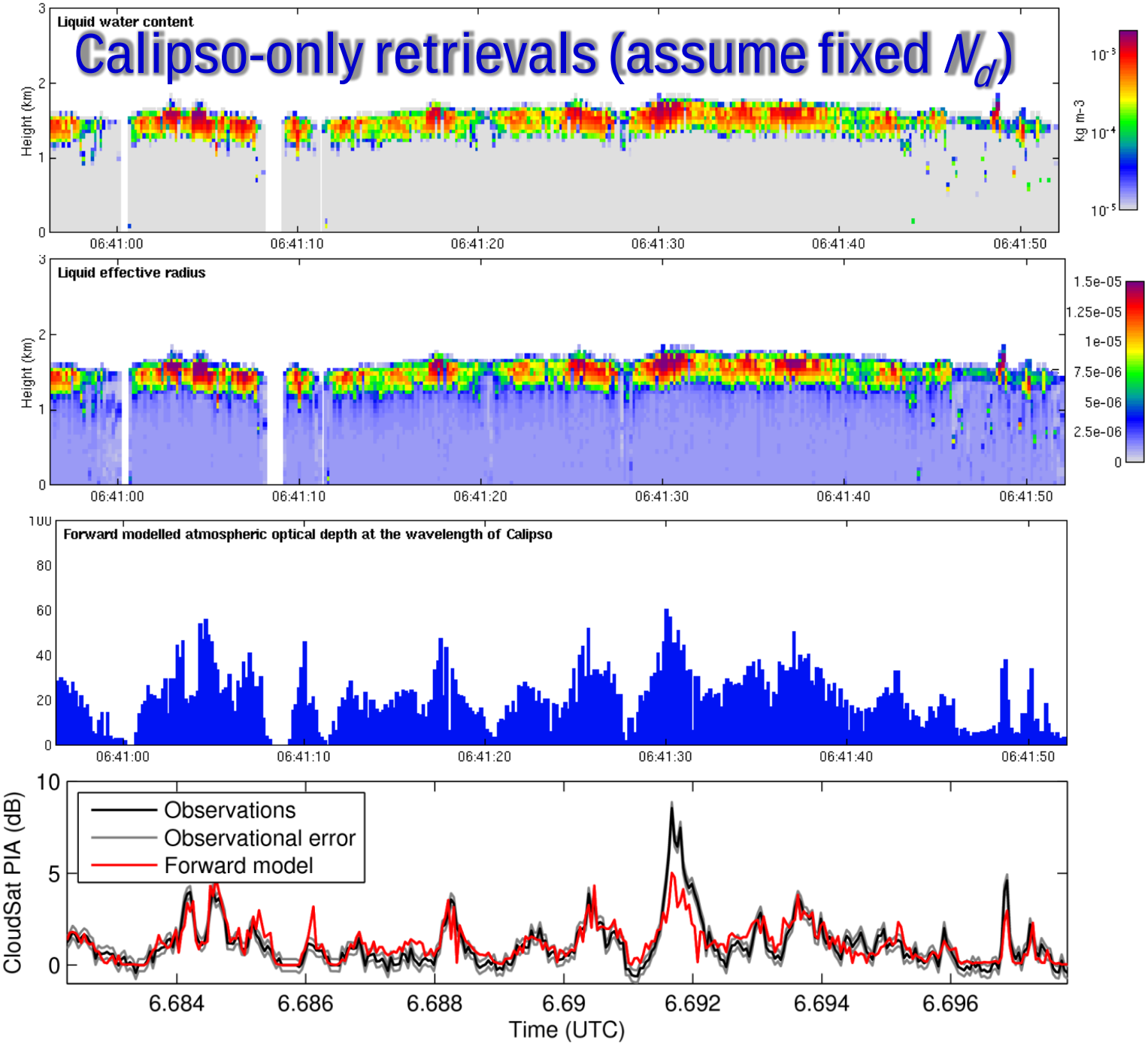
- CALIPSO attenuated backscatter observations:



- At final iteration of retrieval, forward-modelled backscatter looks like:

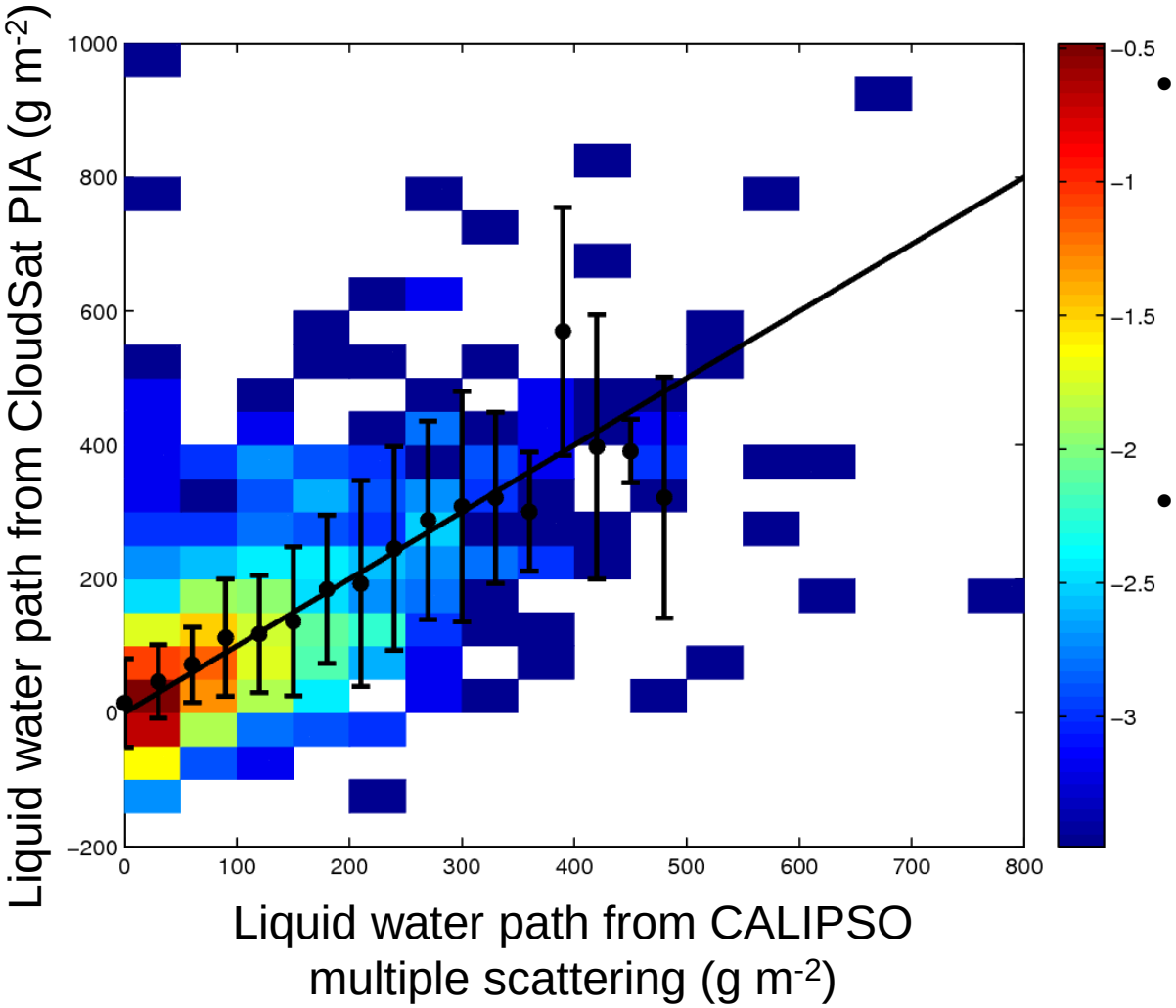


Calipso-only retrievals (assume fixed N_d)



- LWC
- Effective radius
- Optical depth
- CloudSat PIA

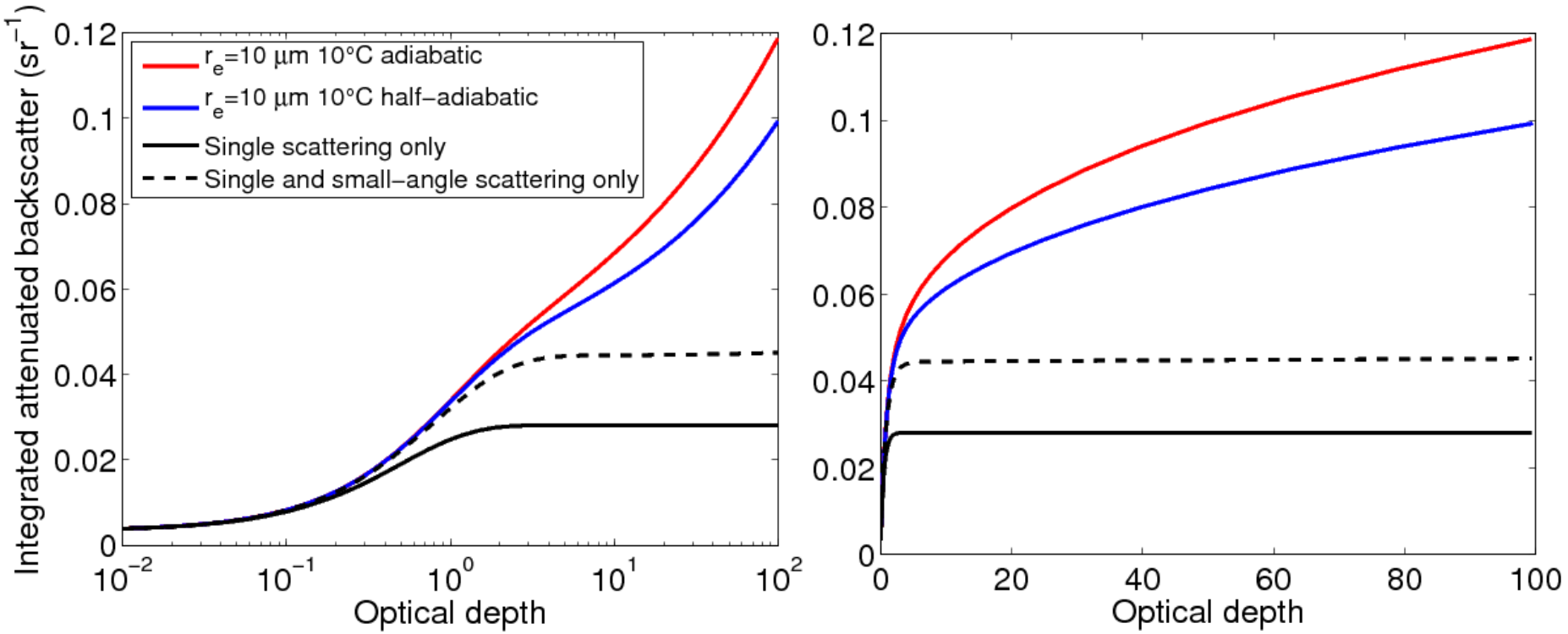
Comparison to CloudSat-estimated LWP



- Hawkness-Smith (PhD, 2010) derived LWP from CloudSat path-integrated attenuation over oceans
  - Similar to Lebsock et al. (2011)
- Unbiased agreement with CALIPSO multiple scattering retrieval for assumed number concentration
  - Some scatter!

A simpler approach?

- Optical depth can be estimated simply from integrated backscatter B!
  - Some dependence on the shape of the extinction profile



  - Ground-based lidar: weak wide-angle multiple scattering leads to constant B with optical depth so can use for calibration (O'Connor et al. 2004)

Summary and outlook

- Via a fast multiple scattering model, we can interpret CALIPSO backscatter at night to retrieve optical depth and to some extent the vertical profile of extinction
- This capability is part of “unified” CAPTIVATE retrieval scheme that will be applied to A-Train and EarthCARE data
- Will be more difficult with EarthCARE due to narrower field of view

- Recently developed a fast forward model for lidar *depolarization* due to multiple scattering, which could provide an additional constraint
- The extinction coefficient profile would be retrieved much better from a future spaceborne lidar with *multiple fields of view*!