The Effect of Anthropogenic Aerosols on Cloud Properties and Climate Forcings



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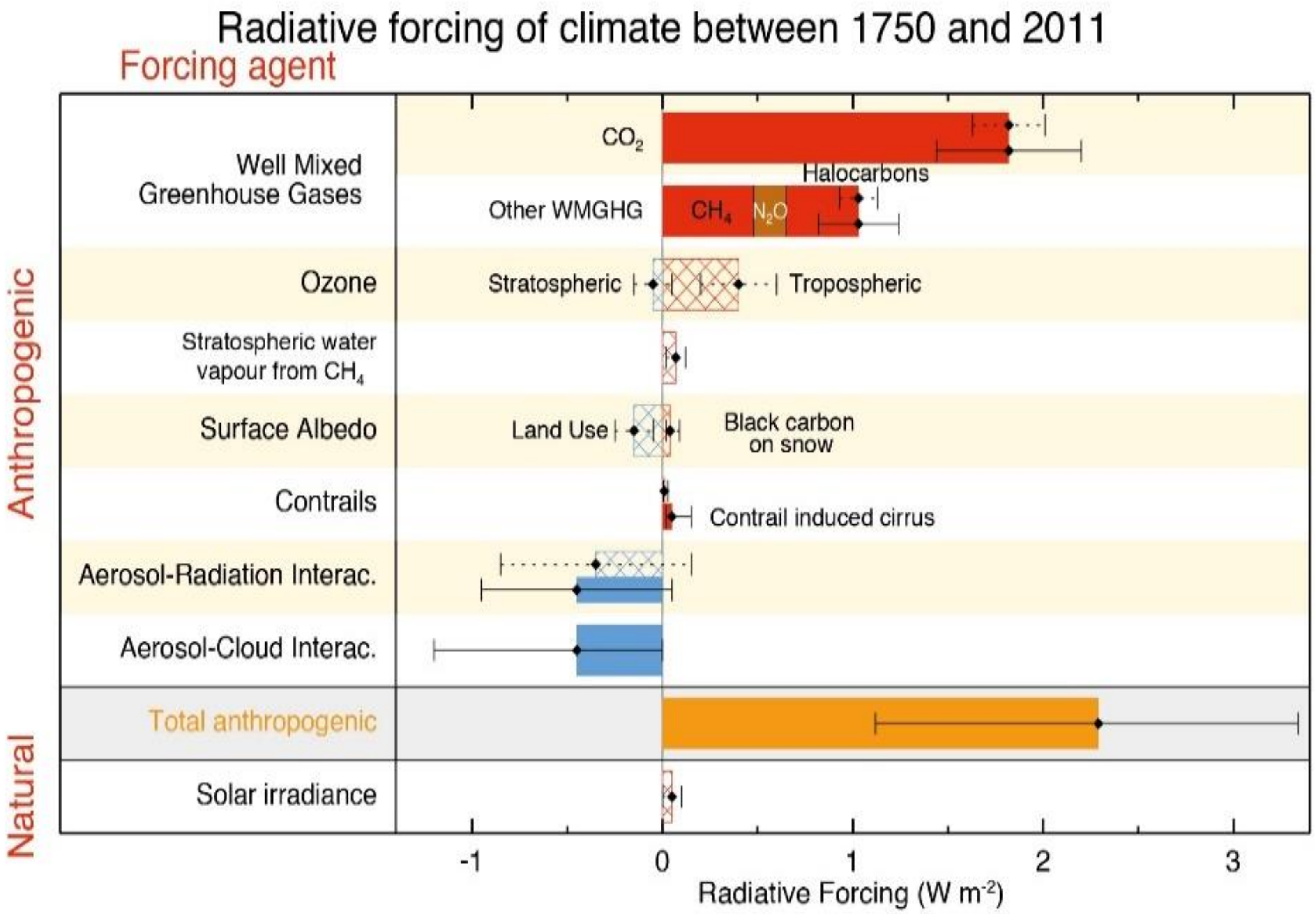
Motivation

- GHG's are well known factors that lead to heat capture and a resultant heating of the atmosphere
- On the other hand, Aerosols are known to have a direct effect on global climate but the result is much more uncertain
  - Non-Absorbing aerosols scatter radiation into space making them a cooling mechanism
  - Absorbing (Bio Mass Burning Aerosols) absorb radiation resulting in a heating mechanism
- Besides aerosol direct effects, Aerosols can interact with clouds changing their properties (Cloud Indirect Effects).
  - ***Twomey effect***: Increased aerosols loading modifies cloud optic properties such as cloud optical depth (τ_{cod}) and cloud droplet effective radius (R_{eff})
    - In particular, it is theorized that increased aerosol uptake leads to a reduction in water droplet diameters resulting in a stronger cloud reflection thereby acting as a cooling mechanism.
  - *Albrecht effect*: Increased in aerosol concentration over the region may increase the amount of low level clouds through a reduction in drizzle (Not considered here)

Uncertainty of Climate Forcing

- Climate change impact Earth's bio-sphere [*IPCC AR5*]
- Greenhouse gases play vital role in overall global energy balance
- GHG contributions well understood and quantified
- However, the effects of aerosols loading and its interaction with clouds is far less understood and drives the uncertainty in overall energy balance

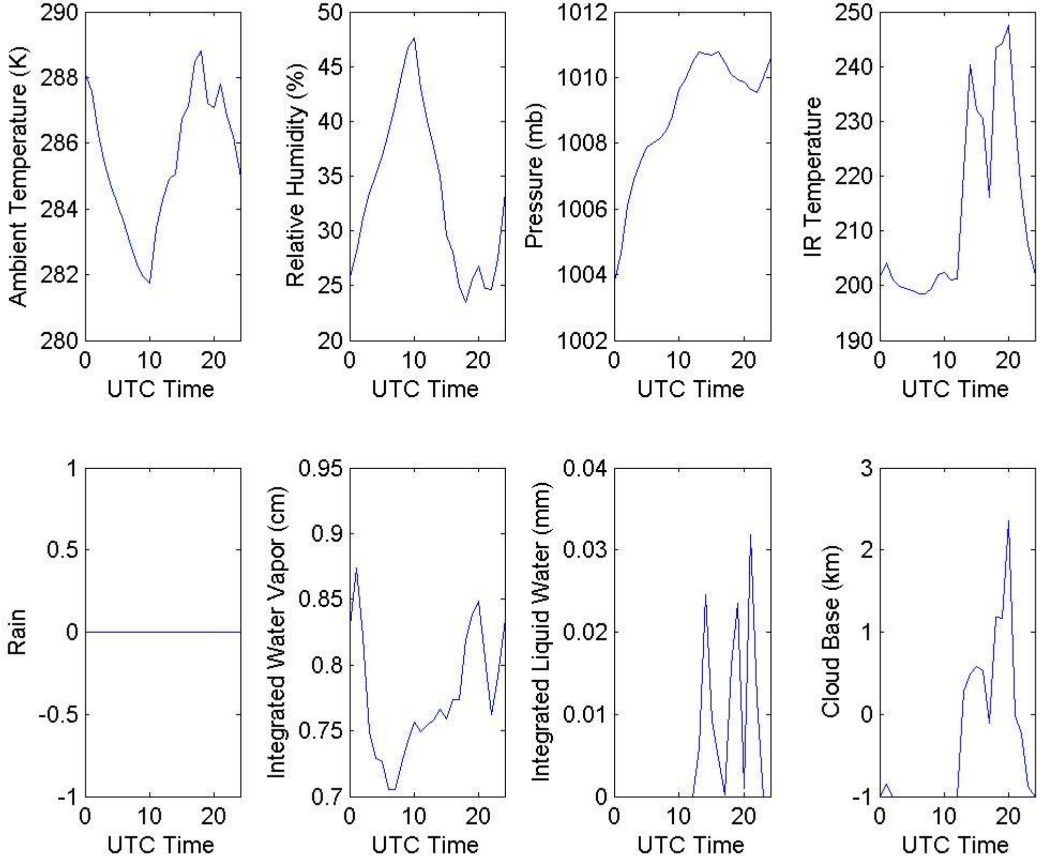


Uncertainty of climate forcing. (IPCC AR5)

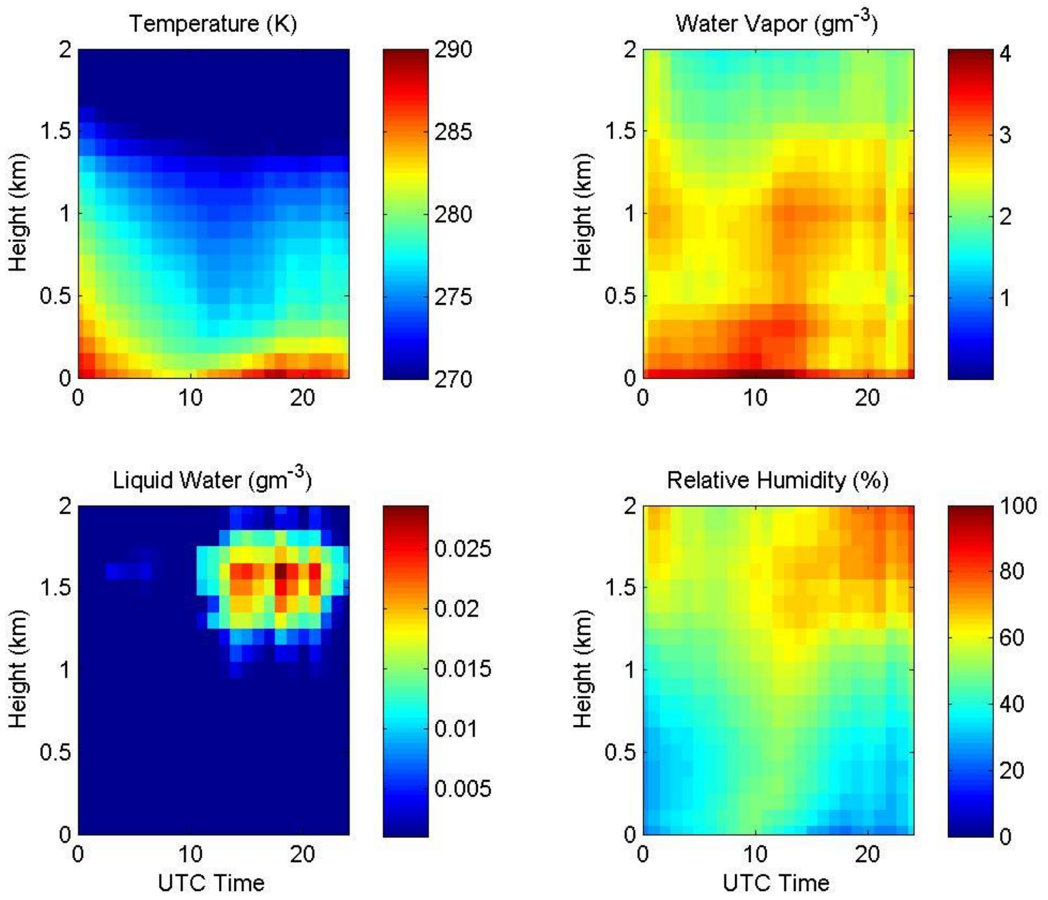
Ground Based Approach

- Two components necessary
  1) Measurement of cloud droplet R_{eff}
  2) Need aerosol properties near cloud base
- Combination of **m**icro**w**ave **r**adiometer (MWR) and **m**ulti**f**ilter **r**otating **s**hadowband **r**adiometer (MFRSR) offer cloud droplet effective radius
- **Li**ght **D**etection **A**nd **R**anging (LIDAR) system can provide the aerosol properties
  - Raman Lidar for aerosol extinction
  - Elastic Lidar for aerosol backscatter

MWR *level 1 & 2* Products Retrieved by Neural Network

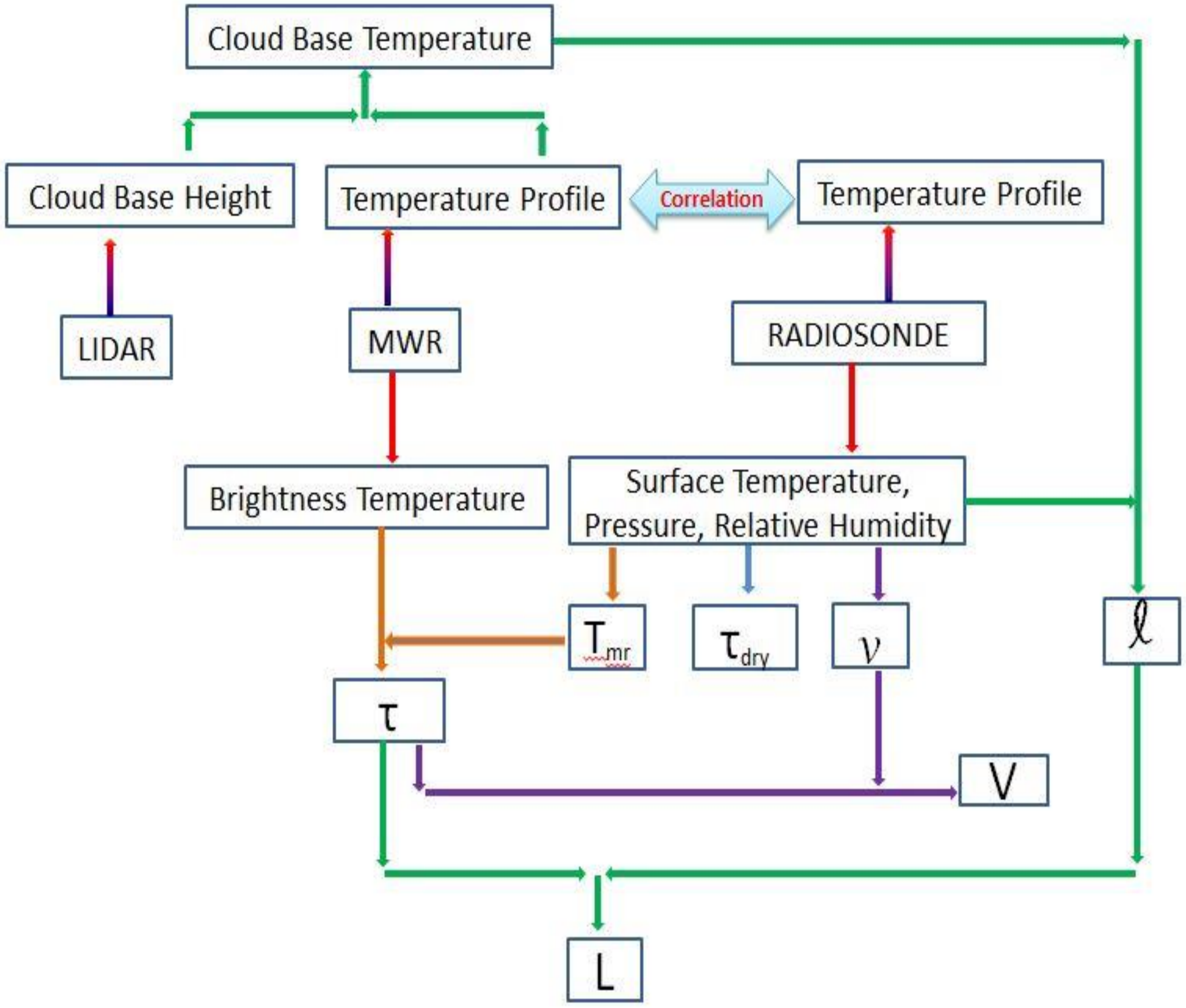


13 May 2013 Surface (*level 1*) and Integrated (*level 2*)



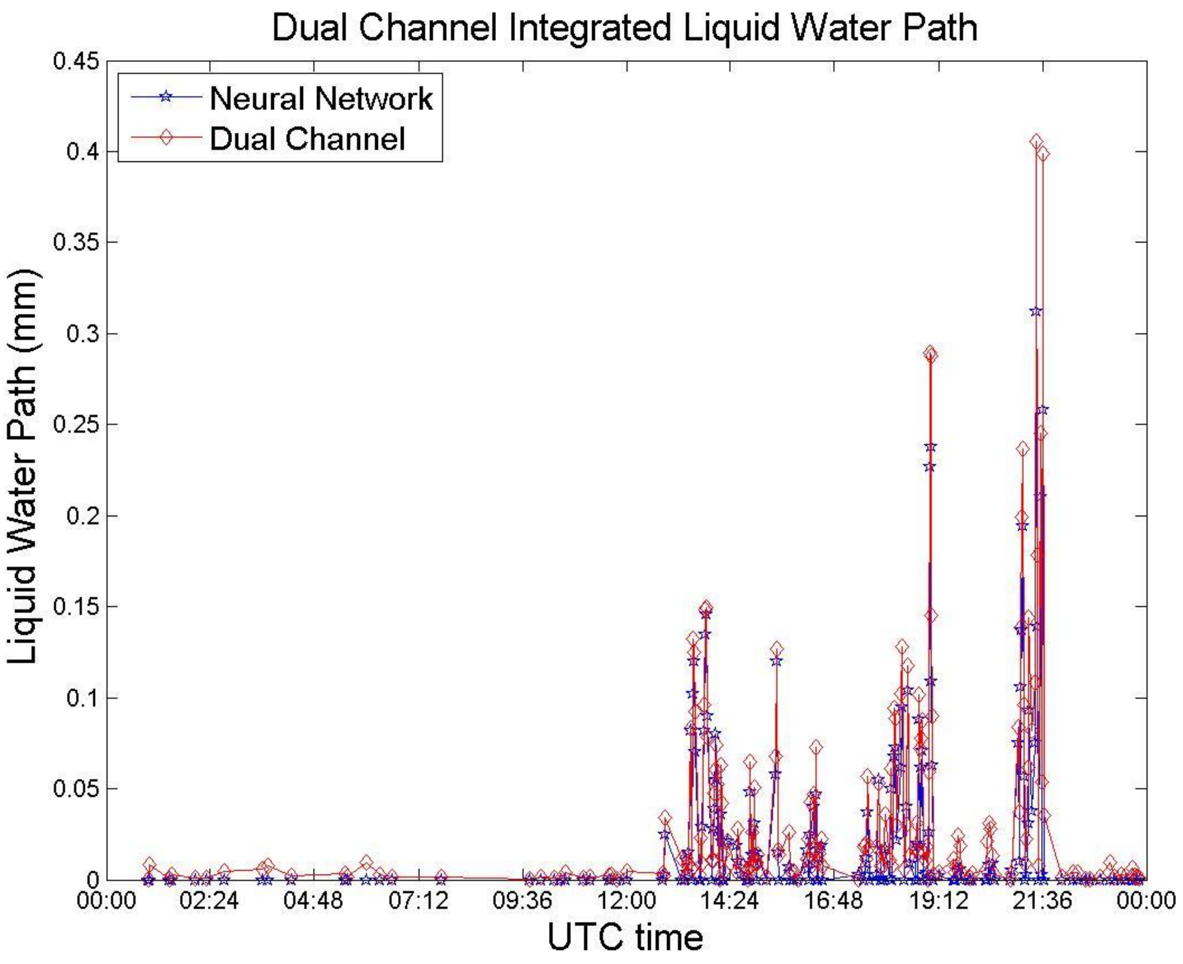
13 May 2013 Profiling (*level 2*)

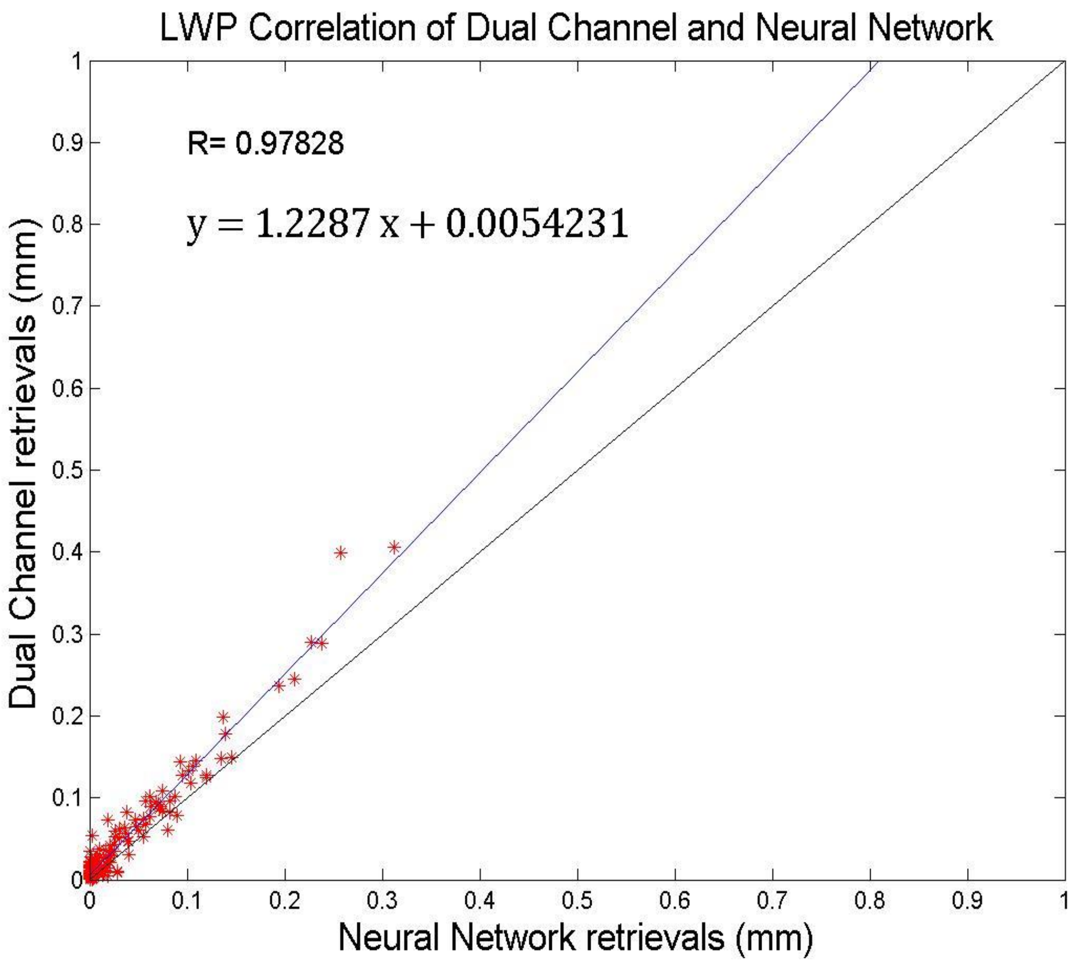
Dual Channel LWP Retrievals Algorithm



1. Obtain temperature profile from MWR and Radiosonde
2. Acquire brightness temperature from MWR
3. Attain surface meteorological data from ground instruments
4. Calculate optical depth for both channels and Subtract closest clear-sky period [*Wang, 2007*]
5. Retrieved integrated liquid water path and water vapor *[Liljegren et al., 2001*]
6. Estimate cloud base temperature from LIDAR

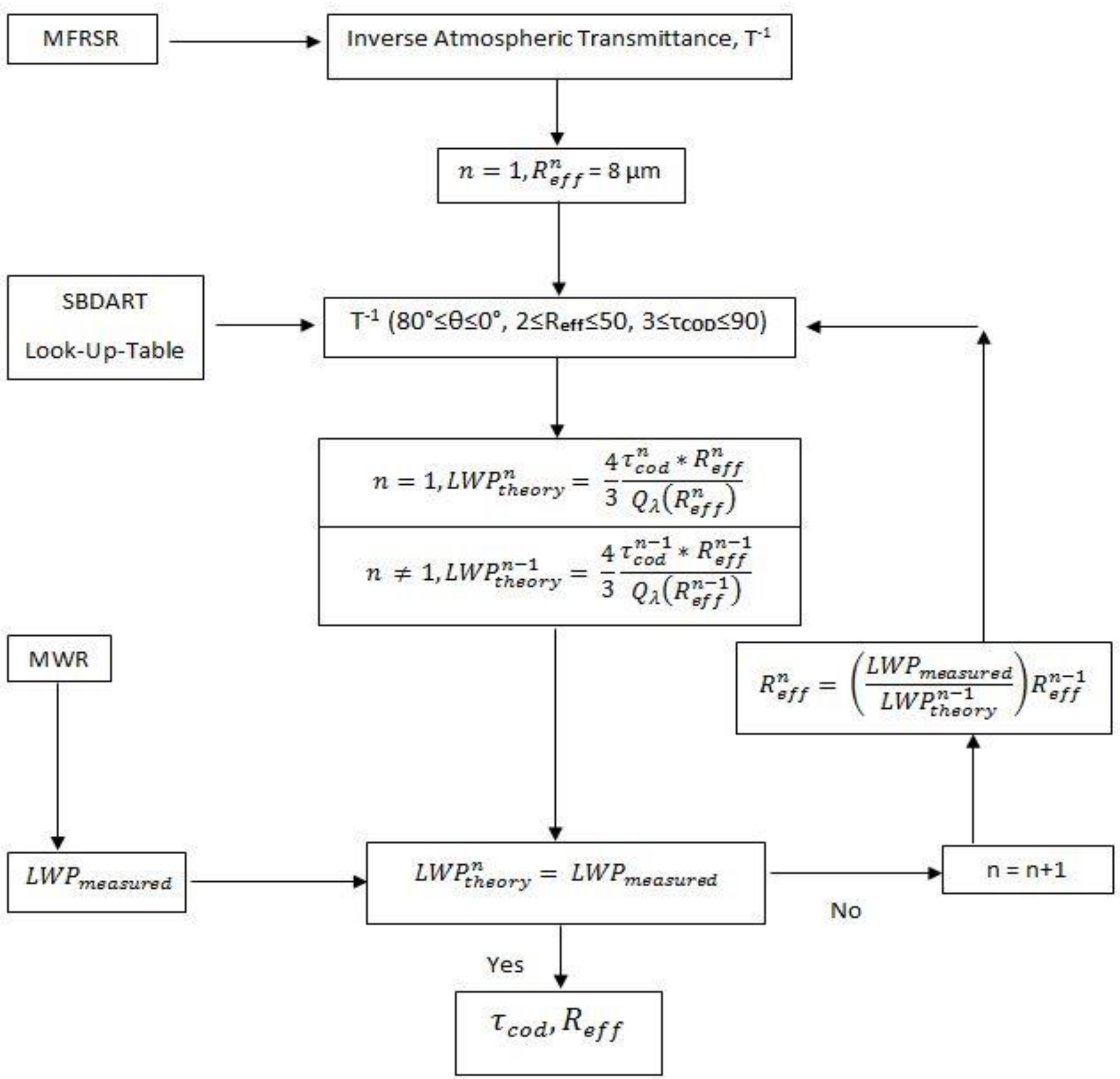
LWP Retrievals by Dual Channel (DC) Method





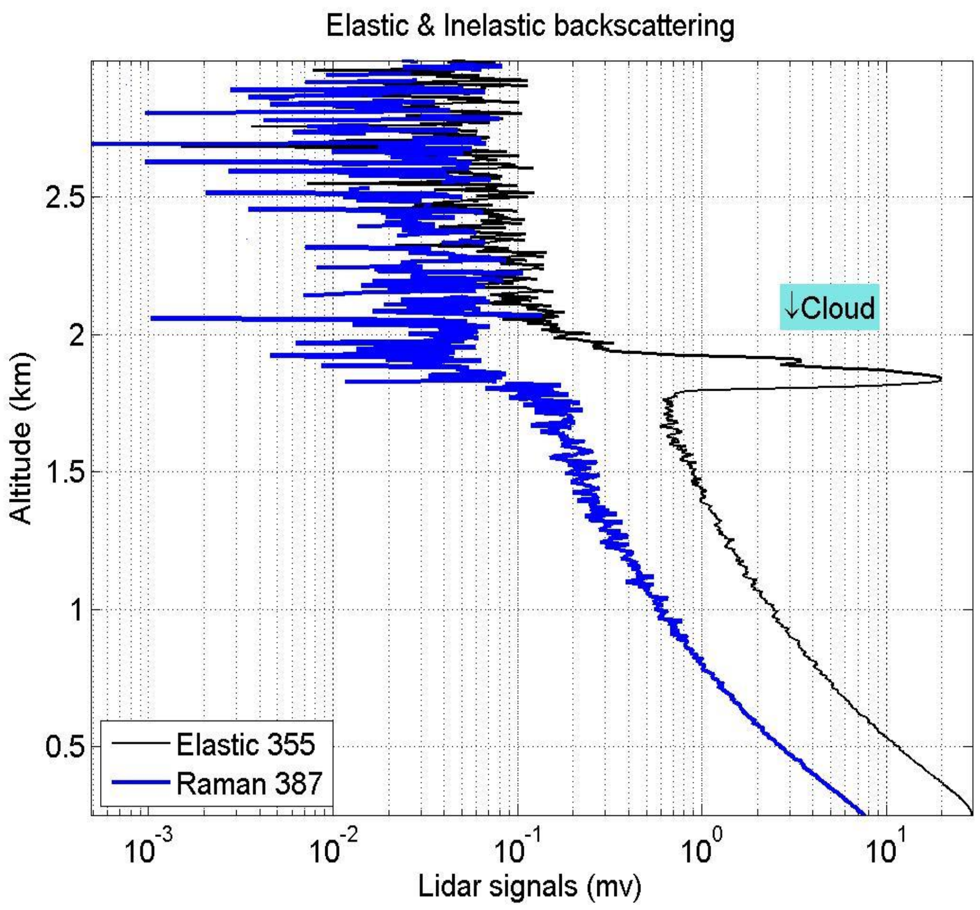
DC LWP→ $L = \upsilon_{23.834}\tau_{23.834} + \upsilon_{30}\tau_{30}$, $where, \tau$ **= optical depth,** υ **= retrieval coefficient (Liljegren et al., 2001)**

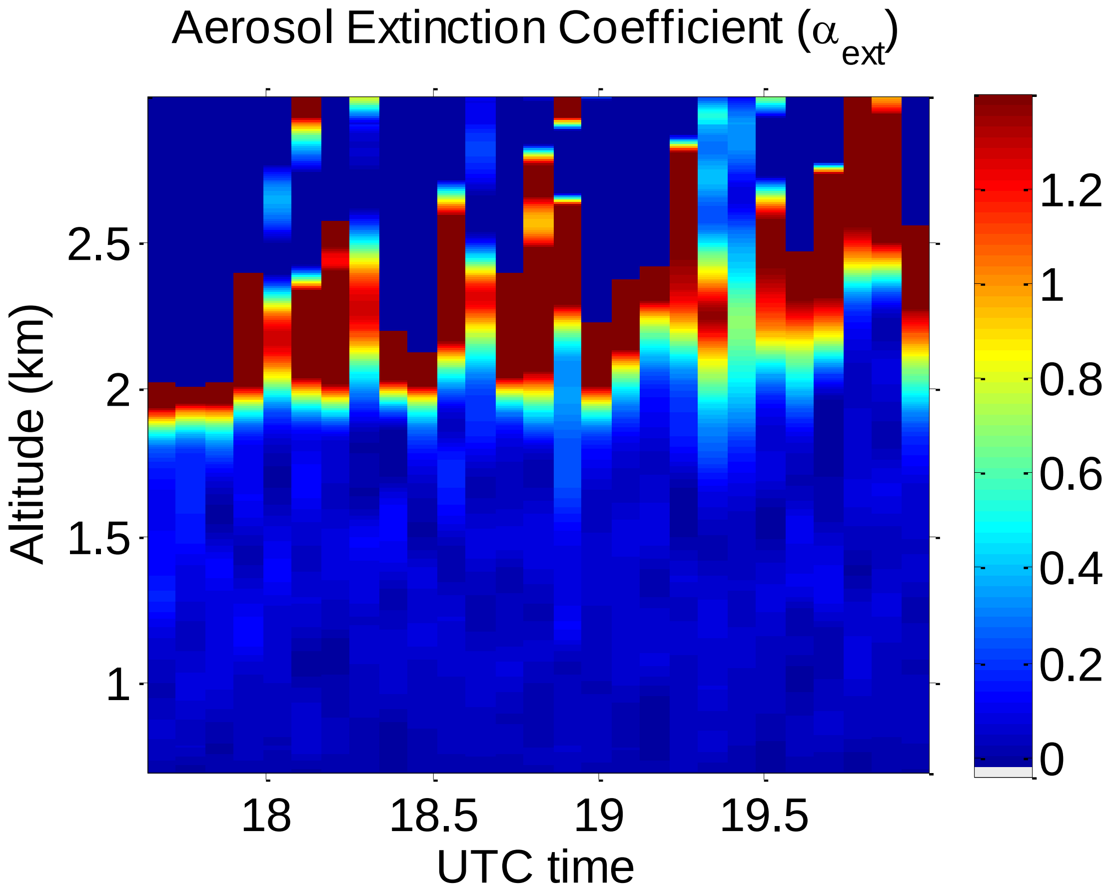
Iterative Cloud Optic Retrieval Algorithm



- $T_{diff}(\tau_{cod}, R_{eff}, \theta)$
- $LWP(\tau_{cod}, R_{eff})$
- $LWP = \frac{2}{3}\tau_{cod}R_{eff}$
- For given angle, we have two constraints to simultaneously solve τ_{cod}, R_{eff}

Aerosol Extinction Coefficients





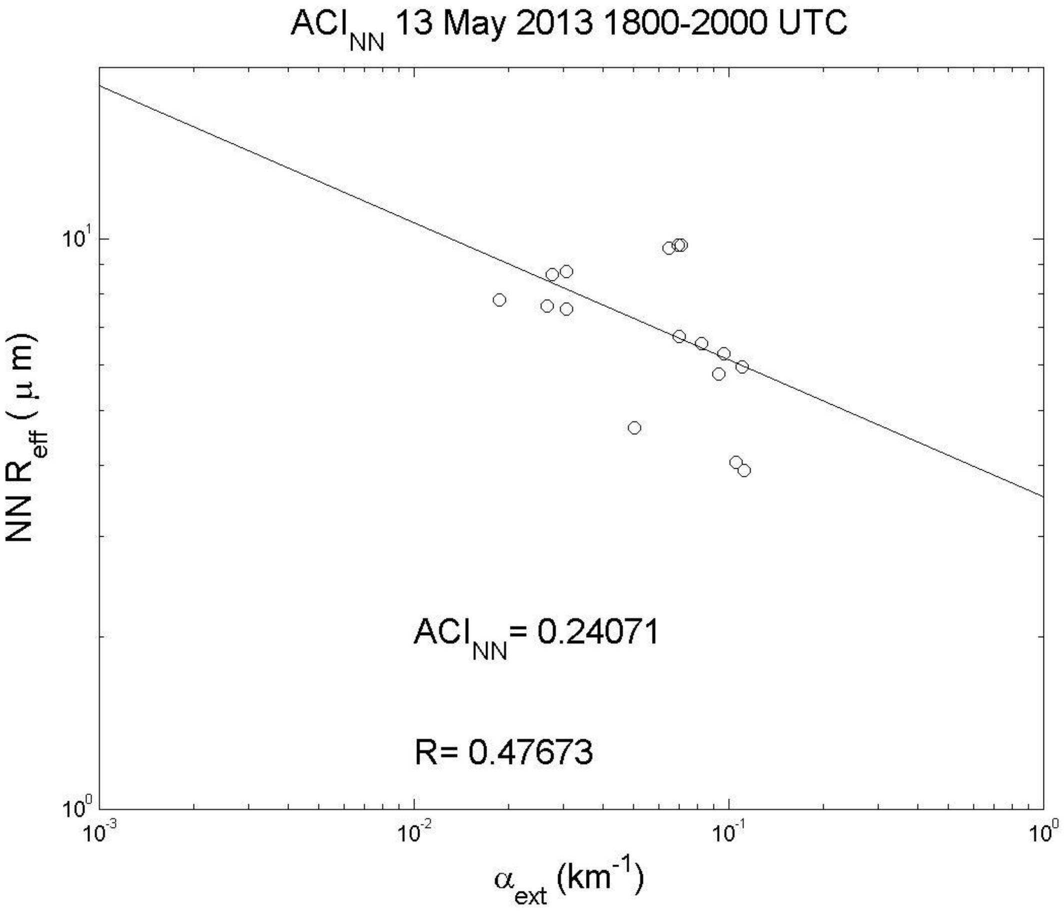
One minute backscattering return for elastic (355 nm) and Raman (N_2, 387 nm) for 5/13/2015.
[Ansmann et al.,1990,1992]

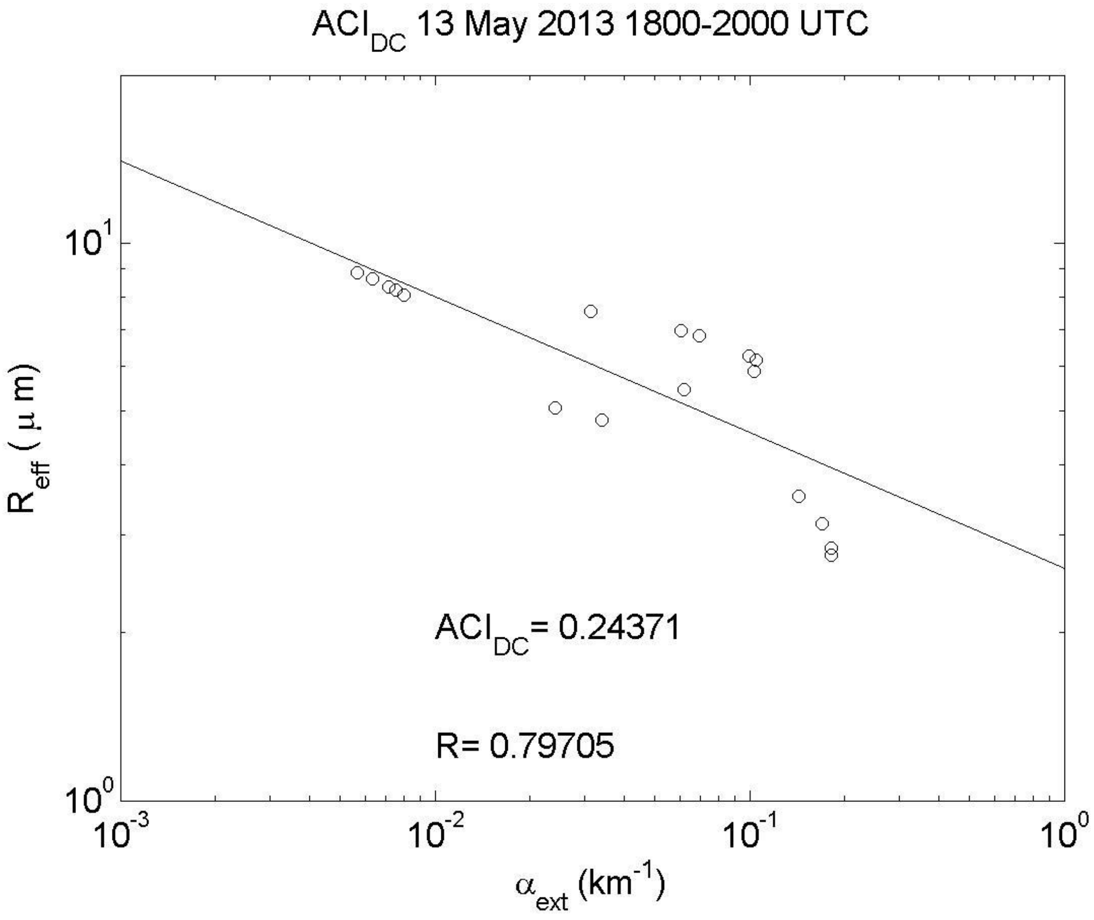
Aerosol extinction coefficient profile for 1800-2000 UTC 5/13/2013

Results

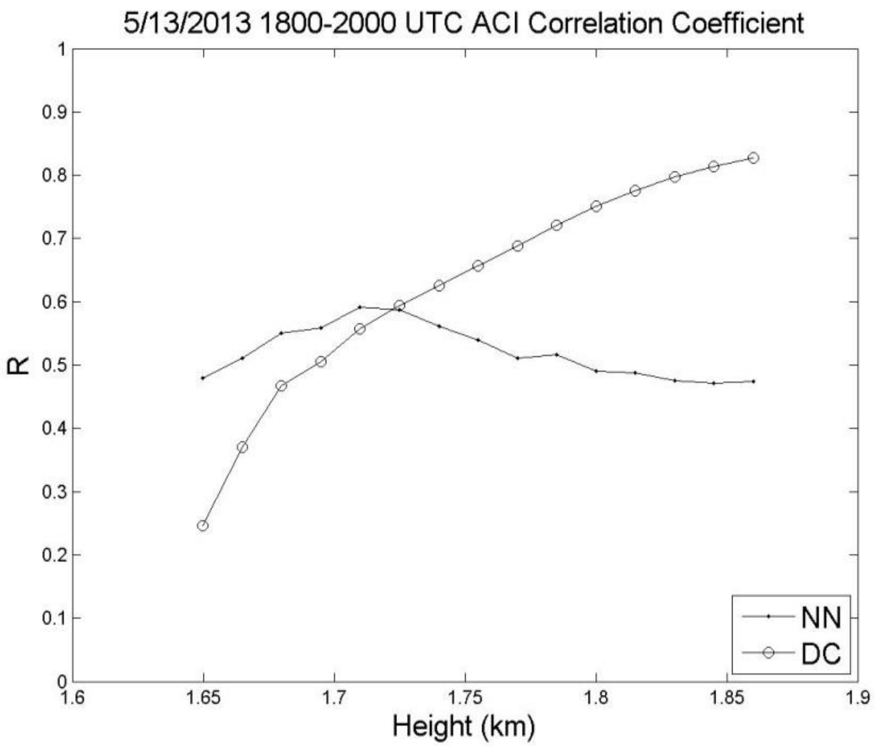
- Aerosol-Cloud Index, ACI =-$\left\{\frac{d[log(R_{eff})]}{d[log(\propto_{aer})]}\right\}$
- Cloud effective radius (R_{eff}) calculated by iterative algorithm
- Aerosol extinction coefficient (α_{aer}) computed from Raman LIDAR
- Following requirements limits the number of observations
  1) Fine mode aerosol determined by Angstrom coefficient (AERONET website)
  2) High single scattering albedo (AERONET website)
  3) Cloud base height less than 2 km
  4) Overall liquid water path constraint ($50 < LWP < 90$)
  5) Strong aerosol loading
  6) Significant vertical wind uptake (HYSPLIT model)
  7) Updraft wind velocity (NCAR Rapid Refresh model)
  8) Sufficient homogeneous cloud decks
- Demonstrate Twomey Effect

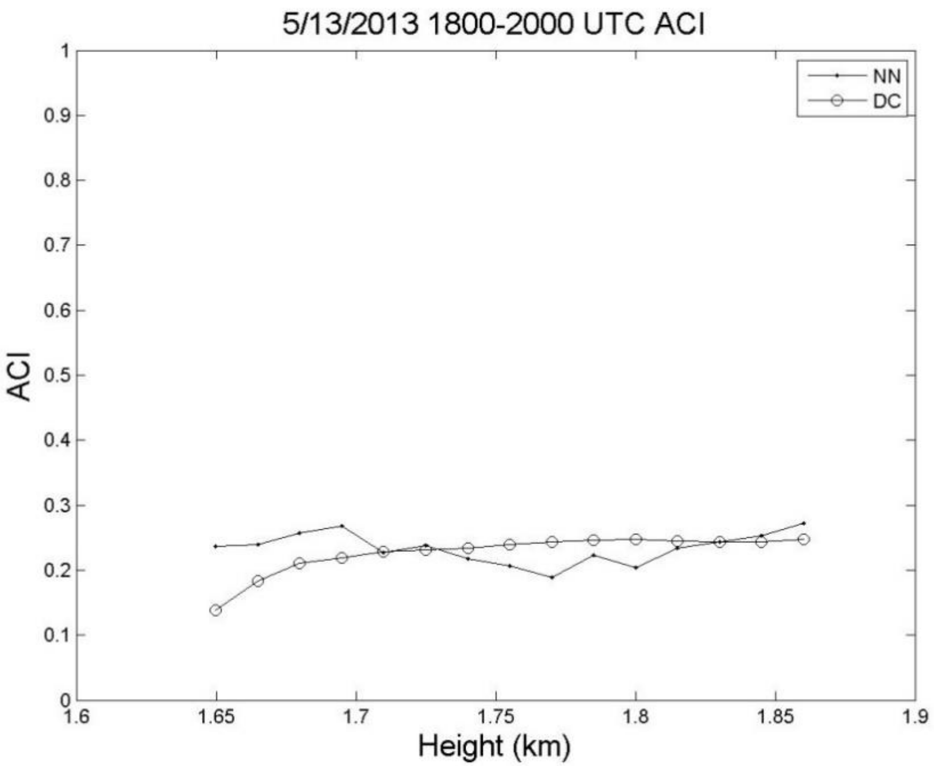
Observed Twomey Effect





Sensitivity of Twomey Effect

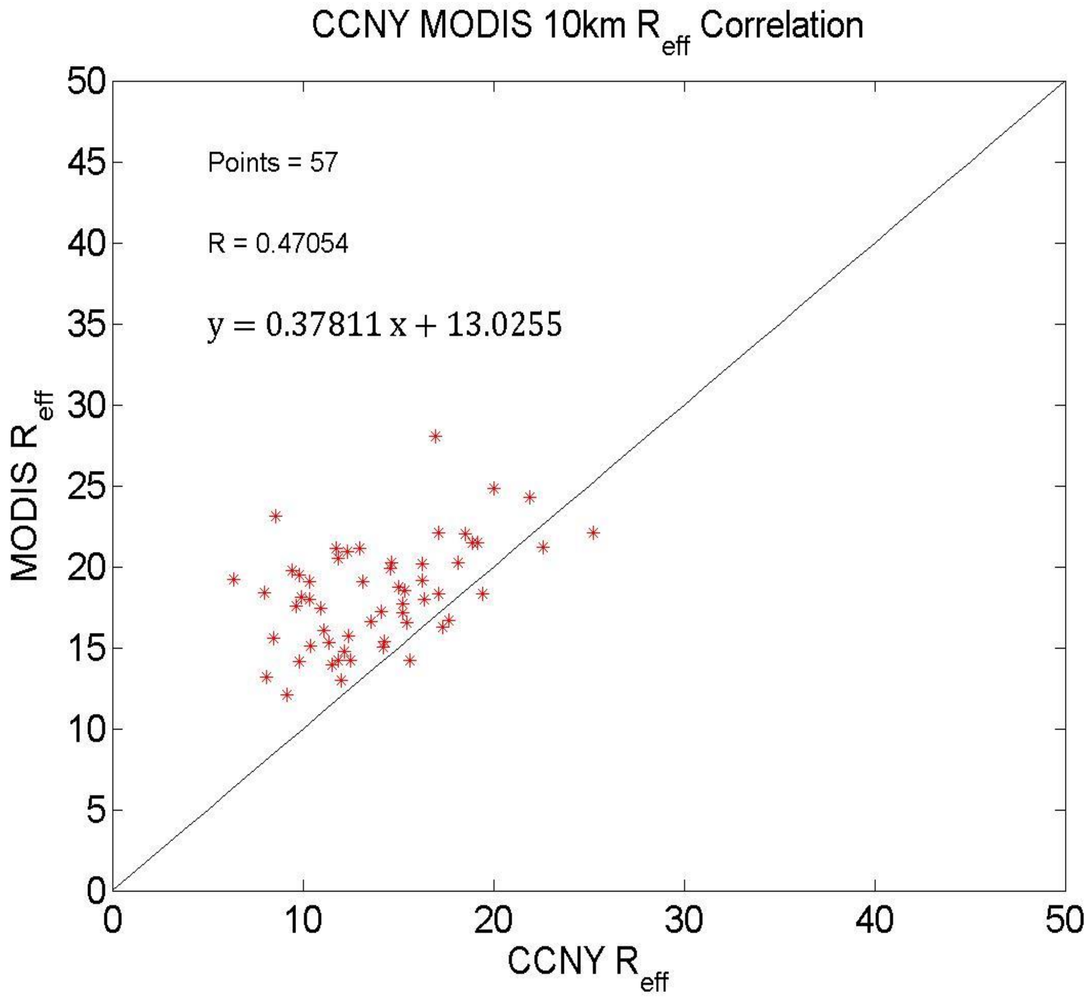




- Aerosol extinction below cloud base height
- Make sure without including any of cloud fields
- At least 100 – 150 meters gap necessary to avoid cloud contamination
- If far away from cloud base height (~200 meters)
  - Magnitude of ACI change dramatically
- Height is important

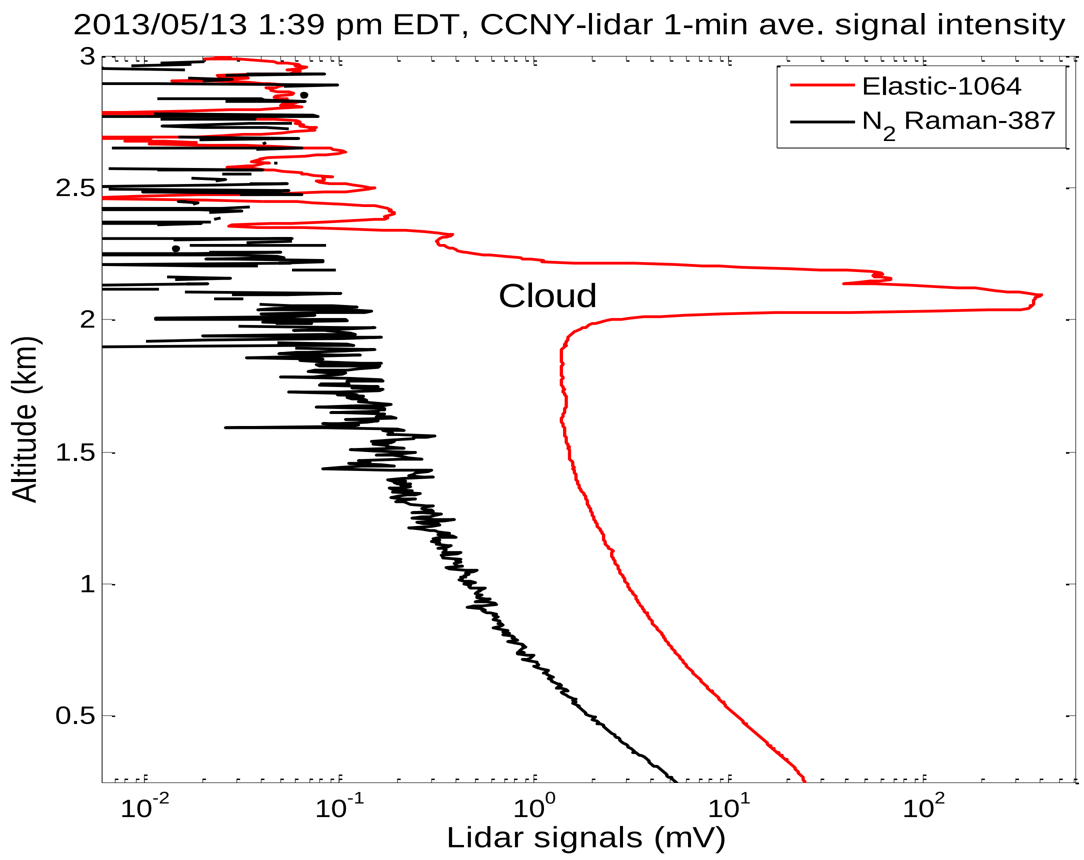
R_{eff} Assessment between Ground and Satellite Retrievals

- Select same day and time for both ground and satellite retrievals for May, June, and July 2013
- 10 km x 10 km with 30 minutes averaging for comparison
- Even though space and ground based different approaches with a few month data
- Show significant agreement
- But bias in MODIS
- Due to overall increase of R_{eff} towards the top of the cloud that satellite actually probes when using solar reflection measurements

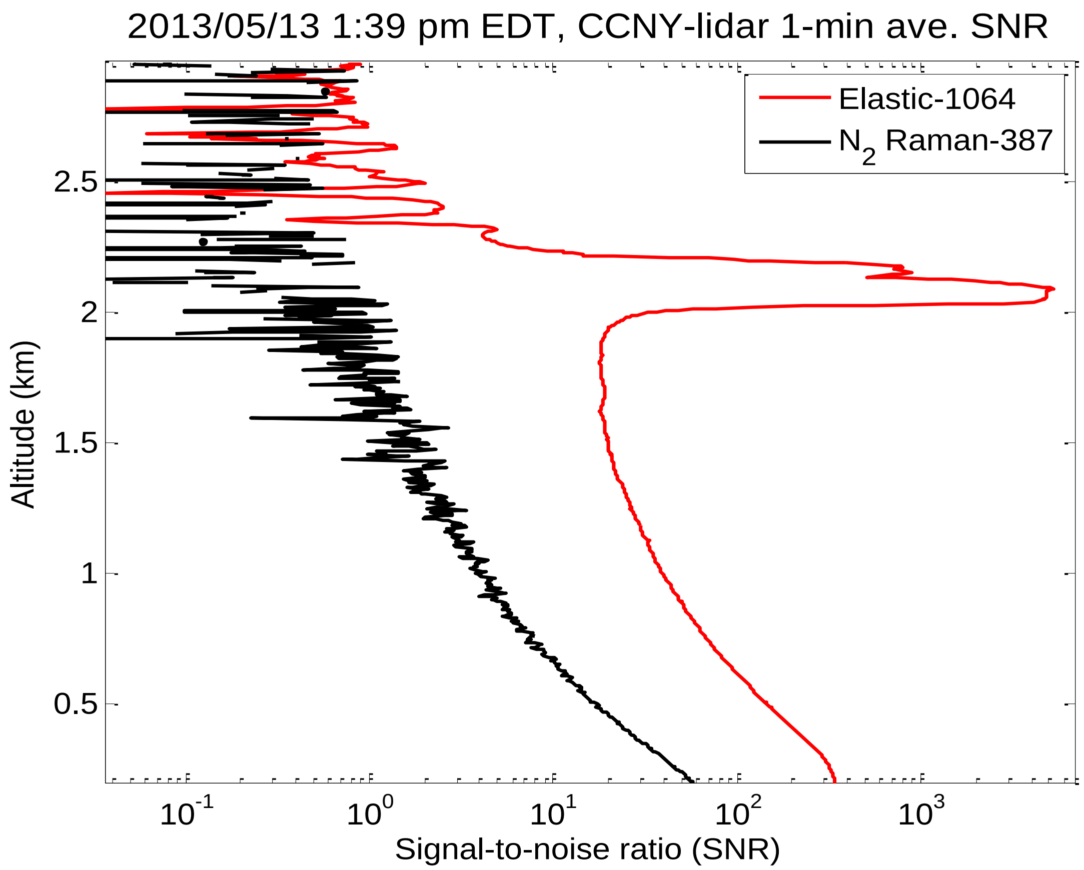


Exploring Potential use of 1064nm Backscattering

Noise Reduction using Elastic Backscatter

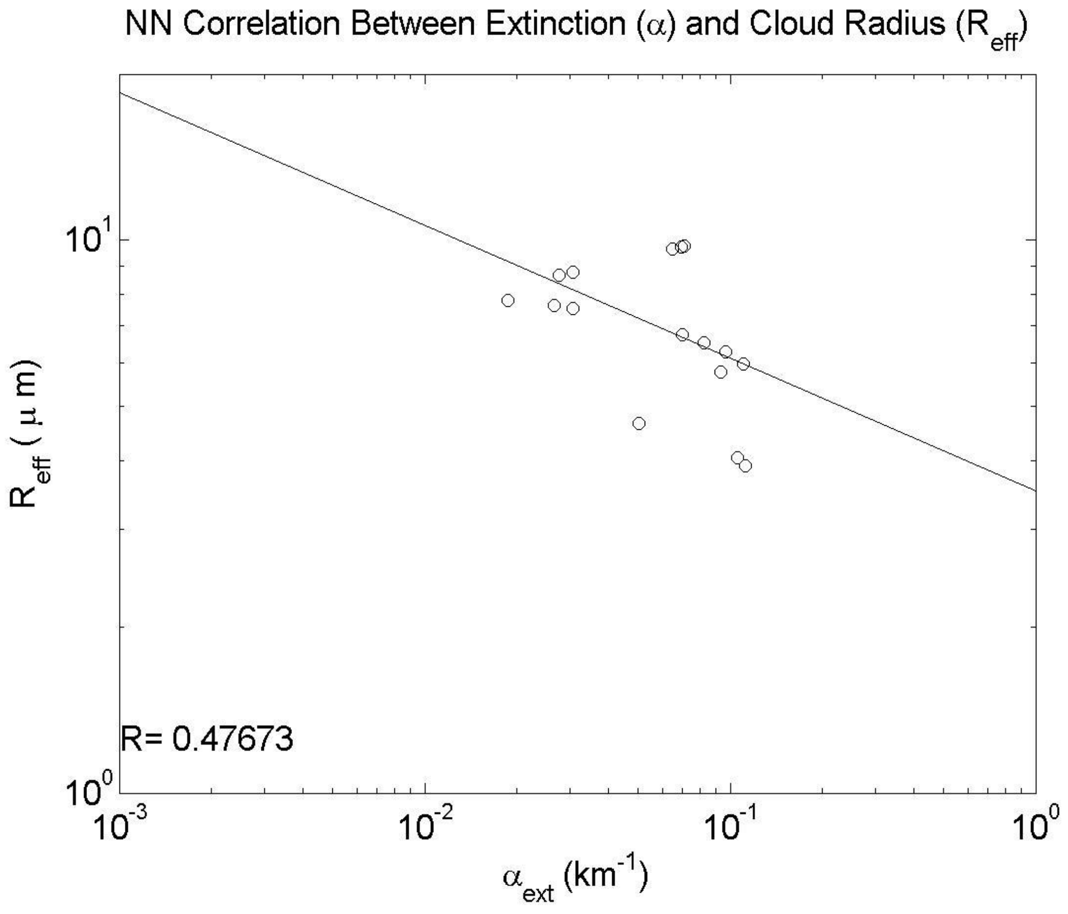


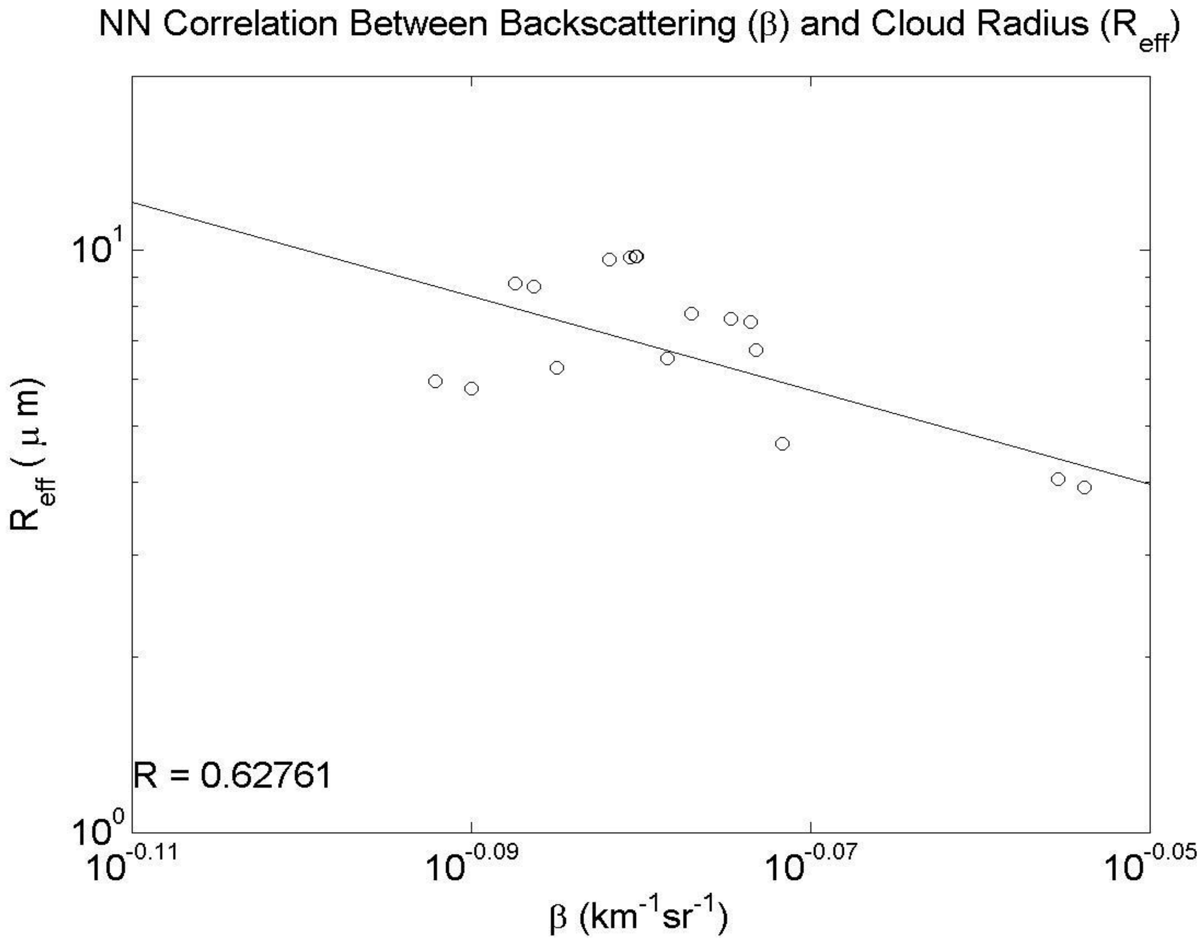
Lidar 1-min average signal intensity



SNR at the elastic-1064 and N_2-Raman channel

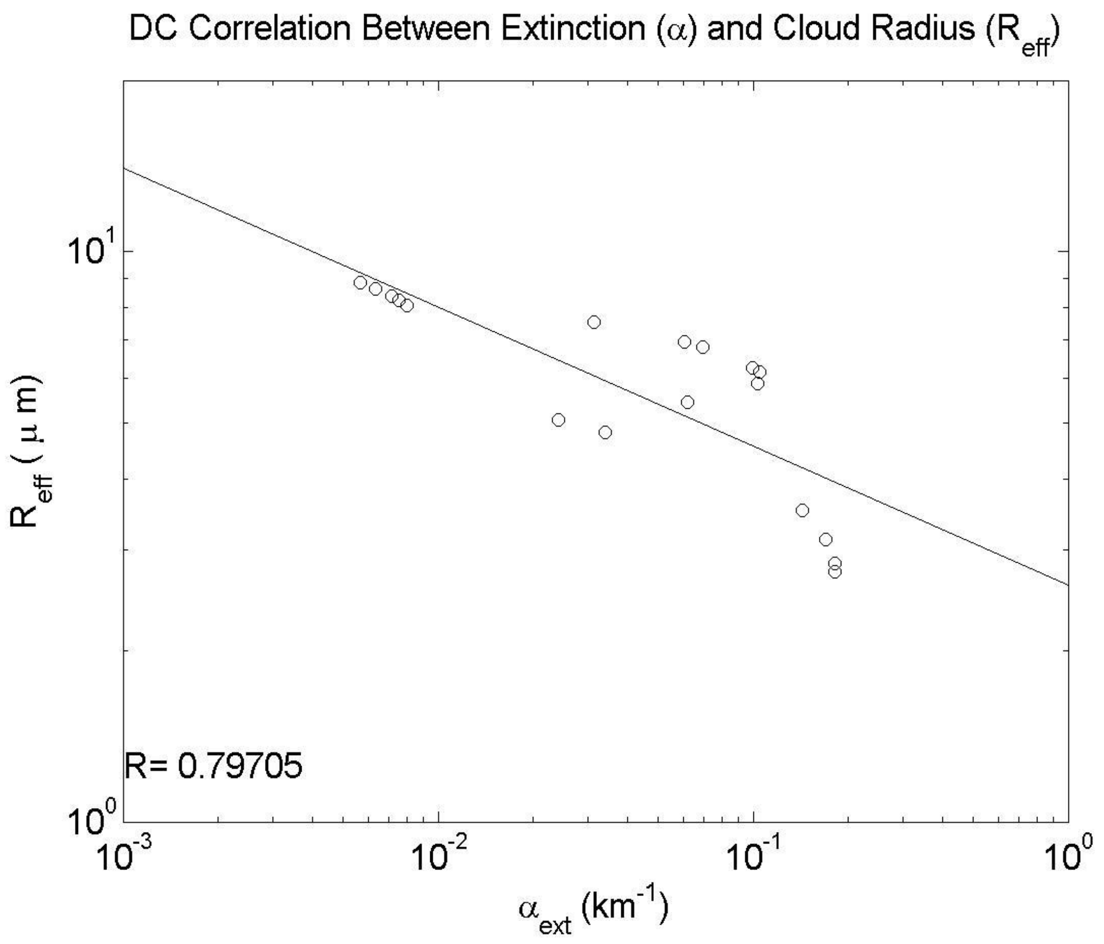
Twomey Effect Comparison of Extinction and Backscatter

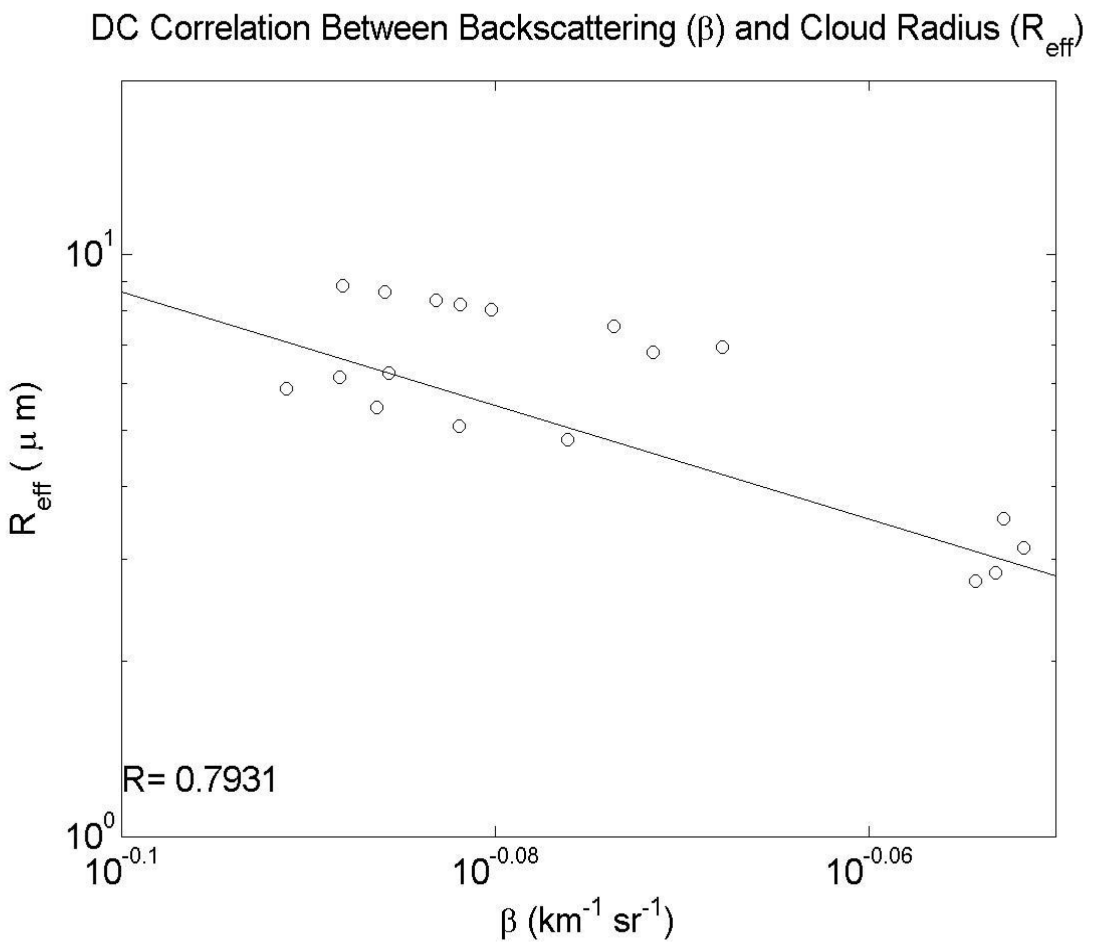




For neural network (NN) 5/13/2013 1800 -2000 UTC

Twomey Effect Comparison of Extinction and Backscatter





For dual channel (DC) 5/13/2013 1800 -2000 UTC

Conclusions

- Investigation of potential of quantifying and observing 1st Aerosol Indirect Effect (Twomey effect) is very difficult due to multiple conditions needed to observe the interaction
- The condition include : aerosols hygroscopic growth, homogeneous water phase cloud with fairly small liquid water path, stable cloud base height, vertical wind uptake, no precipitation
- We however able to show the Twomey effect
- Demonstrate Aerosol-Cloud-Index using two different LWP retrievals approaches
- We find that the Aerosol-Cloud-Index very sensitive to distance from the cloud base
- We also investigate the possibility of using the backscatter instead of the extinction to improve the noise inherent in Raman Lidar
- Preliminary result seem to show better correlation between backscatter and R_{eff} due most likely to better SNR

Future Work

- More measurements needed using synergetic ground based instruments
- Explore in more detail Backscatter approach to allow for more data per event improving the statistical assessment of ACI
- Exploring hygroscopic growth models of aerosols using combined lidar extinction/backscatter ratios and MWR RH
- Use direct vertical wind velocity measurements from Doppler LIDAR at CCNY.

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