The Effect of Anthropogenic Aerosols on Cloud Properties and Climate Forcing

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Motivation

• Greenhouse gas are well known factors that heating 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 (Aerosol Indirect Effects).
  • Twomey effect: Increased aerosols loading modifies cloud optic properties such as cloud optical depth ($\tau_{\text{cod}}$) and cloud droplet effective radius ($R_{\text{eff}}$)
Ground Based Approach

- Two measurements needed
  1) Measurement of integrated liquid water path and irradiance
  2) Measurement of aerosol properties near cloud base

- Combination of **MicroWave Radiometer (MWR)** and **MultiFilter Rotating Shadowband Radiometer (MFRSR)** offer $R_{\text{eff}}$

- **MWR** (MP-3000A, Radiometric Corporation)
  - Level 0 $\rightarrow$ voltage
  - Level 1 $\rightarrow$ brightness temperature, surface met data
  - Level 2 $\rightarrow$ integrated liquid water path and water vapor $\rightarrow$ profile (Relative Humidity, Water Vapor, Liquid Water, Temperature)

- **MFRSR** (MFR-7, Yankee Environmental System, Inc.)
  - Total, Diffuse, Direct Normal irradiance

- **Light Detection And Ranging (LIDAR)** system
  - Raman channel for aerosol extinction
  - Elastic channel for aerosol backscatter
MWR *level 1 & 2* Products

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

13 May 2013 Profiling (*level 2*)
MWR Brightness Temperature Assessment

- Brightness Temperature is very important for integrated liquid water path & water vapor and profiling data.

- Following sequences of calculation using *level 0* data (voltage) to calculate the brightness temperature ($T_{sky}$):

  1. Measured values ($V_{sky}, V_{sky\_nd}, V_{bb}, V_{bb\_nd}, T_{kBB}$)
  2. Calibrated parameters ($\alpha, T_{nd290}, K1, K2, K3, K4, dTdG$)
  3. Calculated values:
     i. $TC = K1 + K2\cdot T_{kBB} + K3\cdot T_{kBB}^2 + K4\cdot T_{kBB}^3$
     ii. $Gain\_sky = gain \text{ during sky observation} = \left( \frac{V_{sky\_nd}^{\frac{1}{\alpha}} - V_{sky}^{\frac{1}{\alpha}}}{T_{nd290} + TC} \right)^{\frac{1}{\alpha}}$
     iii. $Gain\_bb = gain \text{ during Black Body observation} = \left( \frac{V_{bb\_nd}^{\frac{1}{\alpha}} - V_{bb}^{\frac{1}{\alpha}}}{T_{nd290} + TC} \right)^{\frac{1}{\alpha}}$
     iv. $Trcv\_bb = receiver \text{ temperature during Black Body} = \left( \frac{V_{bb}}{Gain\_bb} \right)^{\frac{1}{\alpha}} - T_{kBB}$
     v. $Trcv\_sky = receiver \text{ temperature during Sky} = Trcv_{bb} + dTdG \cdot (Gain_{sky} - Gain_{bb})$
     vi. $T_{sky} = \text{Brightness Temperature} = \left( \frac{V_{sky}}{Gain_{sky}} \right)^{\frac{1}{\alpha}} - Trcv_{sky}$
One day example (1/1/2014) calculation for Brightness Temperature ($T_{sky}$)

$T_{sky}$ extracted from Level 1

$T_{sky}$ calculated from Level 0
All Channel Comparison between Level 1 and Level 0

- The result show all K band and V band agree very well
- Benefit of this assessment
  - Determine each channel measured voltage that can monitor MWR performance
  - Calculated brightness temperature from voltage that offer quality of data compare to level 1
  - Using either level 1 brightness temperature or level 0 derived brightness temperature to compute integrated liquid water path and water vapor by applying different retrieval method.
Cloud Retrieval Algorithm

Combination of MWR, MFRSR and SBDART model to compute cloud optical depth ($\tau_{\text{cod}}$) and cloud droplet effective radius ($R_{\text{eff}}$)

Aerosol measurement

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

• Demonstrate Twomey effect using Aerosol-Cloud Index (ACI)
  - ACI = slope = \( -\frac{d[\log(R_{\text{eff}})]}{d[\log(\alpha_{\text{aer}})]} \leq \frac{1}{3} \)

• Cloud effective radius \( (R_{\text{eff}}) \) calculated by cloud retrieval algorithm

• Aerosol extinction coefficient \( (\alpha_{\text{aer}}) \) computed from Raman LIDAR

Observed Twomey Effect over New York City

\[ y = -0.24071 \times + 1.2581 \]

13 May 2013, 1800 – 2000 UTC
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
Conclusions

• Investigation of potential of quantifying and observing Twomey effect is very difficult due to multiple conditions needed to observe the interaction

• We find that the Aerosol-Cloud-Index very sensitive to distance from the cloud base

• 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 (illustrate by HYSPLIT model)
  7) Updraft wind velocity (demonstrate by NCAR Rapid Refresh model)
  8) Sufficient homogeneous cloud decks

• We however able to show the Twomey effect
References


