Relationship between Clouds, Aerosols, the environment and the onset of Precipitation

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Paper by Berg, Kummerow et al., (2006) speculated that discrepancy in TRMM rainfall detection east of China was due to high aerosol concentrations increasing the liquid water content at which clouds begin to precipitate.
A straightforward example from Nauru

Surface rainfall (top), cloud liquid water (middle) and radar reflectivity (bottom) for 3 hours on 25 Nov. 1998.
A not so straightforward example from Nauru

Surface rainfall (top), cloud liquid water (middle) and radar reflectivity (bottom) for 3 hours on 07 Oct. 2004.
Objective

Determine if onset of precipitation can be parameterized as a function of relatively few thermodynamic and aerosol variables.

Procedure

☆ Started with AMF/China campaign but radar data not available for robust statistics.

☆ Start with incomplete, but global satellite data and look for specific relationships

☆ Confirm these relationships using data from Arm permanent and Mobile Facility.
A-Train

- State of the art remote sensing capabilities
- Formation flying provides spatially and temporally co-located observations
  1. CloudSat
  2. CERES
  3. MODIS
  4. AMSR-E
  5. AIRS
Evidence for decreased droplet/drop sizes in high CCN air for raining and non-raining clouds from A-train observations
Probability of Precipitation and Aerosol

POP decreases by as much as 10% with large aerosol burden
• Dependence on thermodynamic stability greater than that of aerosol
• POP decreased by ~5% in dirty air regardless of LWP
The water path effect for precipitating clouds dominates the radius effect.

\[ \tau = \frac{3LWP}{2\rho r_e} \]

\[ \alpha_{cl} \approx F(\tau) = F(r_e, LWP) \]
r_e and mean cloud Z_e tend to decrease in precipitating clouds
  • Implies decreased autoconversion rates

Stability has a greater impact on POP than aerosol concentration

For a given LWP, POP decreases by ~5% from clean to polluted state.
  • Independent of thermodynamic environment

i_{cld} and α_{cld} response in precipitating clouds is dominated by the water path effect.
Back to ARM Data

6 year

10 year

Cloud Thickness vs CN Concentration 2006-2007

Cloud Base < 1 km
1 km < Cloud Base < 2 km
2 km < Cloud Base < 4 km
Next Steps

Use SGP, Nauru and China AMF, Azores deployment with observed aerosol concentrations and precipitation from ground radar ($Z > -15$ dBZ) to verify satellite inference.

Use SGP, Nauru and China AMF, Azores deployment with observed microwave LWP & LWC, in situ aerosols, radar precipitation and in-situ measurements of stability to verify satellite inference.
Aerosol Indirect Effects
(How we think they work)

Direct Effect

1st Indirect Effect

2nd Indirect Effect

Scattering & absorption of radiation
Unperturbed cloud
Increased CDNC (constant LWC) (Twomey, 1974)
Drizzle suppression. Increased LWC
Increased cloud height (Pincus & Baker, 1994)
Increased cloud lifetime (Albrecht, 1989)

Top of the atmosphere
Surface

Direct effects
Cloud albedo effect/ 1st indirect effect/ Twomey effect
Cloud lifetime effect/ 2nd indirect effect/ Albrecht effect