Observations of Aerosol-Cloud Interactions during the North Atlantic Aerosol and Marine Ecosystem Study

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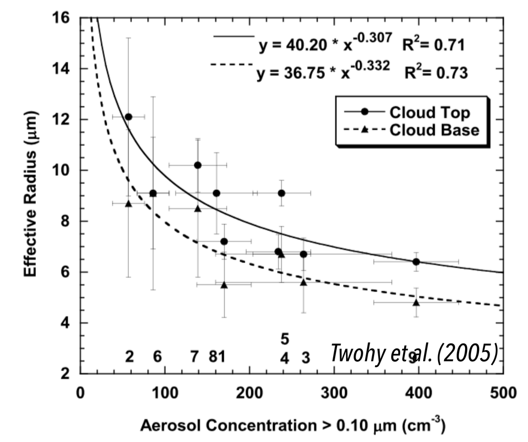
Background

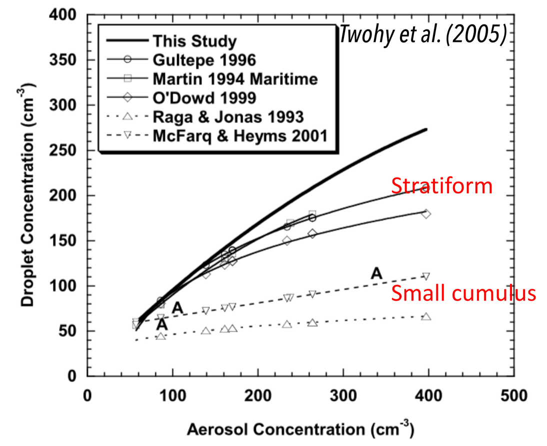
- CDNC is a cloud microphysical property that impacts radiative forcing, cloud evolution, precipitation, local and global climate and, through observation, can be used to monitor the cloud albedo effect, or the first indirect effect (Zeng et al., 2013).
- Aerosol-cloud interaction is a mechanism whereby an increase in aerosol concentration results in an increase in cloud droplet number concentration leading to changes in the radiative properties of the cloud (Twomey 1977) as well as the lifetime of the cloud (Albrecht, 1989; Liou and Ou, 1989).
- Number concentration can be related to cloud albedo through the simplified expression:

$$\frac{d\alpha}{dN_d} = \frac{\alpha(1-\alpha)}{3N_d}$$

(Platnick & Twomey, 1994)

- Aerosol-cloud interactions, or the first indirect effect, can be observed through monitoring cloud droplet number concentration.





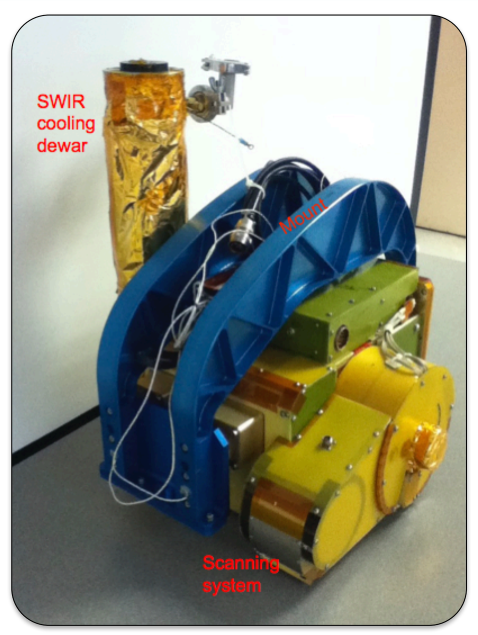
Research Objectives

1) To assess the strength of the connection between cloud properties and aerosol concentration and composition during NAAMES
2) Determine which cloud properties are least and most sensitive to aerosol concentrations
3) Explore variations in aerosol and cloud properties on daily and seasonal timescales

Instruments

Research Scanning Polarimeter

- Prototype for Aerosol Polarimetry Sensor on the Glory satellite (2011) (Cairns et al., 1999)
- Along track scanning - 152 viewing angles per scene (±60°);14 mrad field of view
- Polarimetric and full intensity measurements in the visible and shortwave infrared over 9 bands: 410, 470, 555, 670, 864, 960, 1593, 1880, 2263 nm
- Measures aerosol: OT, R_{eff}, V_{eff}, R.I., single-scattering albedo, morphology
- Measures cloud: OT, R_{eff}, V_{eff}, CTH, cloud phase, ice asymmetry parameter, CDNC



Condensation Nuclei Counter (CNC)

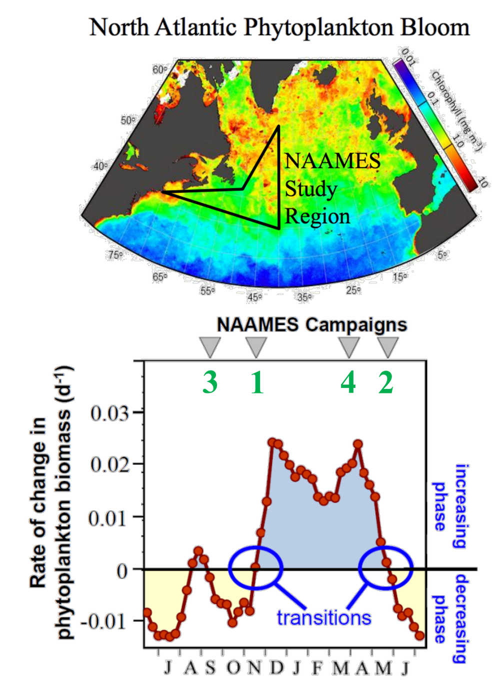
- CNC measures the concentration of cloud condensation nuclei (CCN) at several superstation levels
- Supersaturation levels range from 0.07% to as high as 2%
- Droplet sizes from 0.75 – 10 µm across 20 size bins and operates at a 1 Hz sampling rate

Aerosol Mass Spectrometer (AMS)

- Provides organic aerosol analysis of aerosol size and chemical mass loading information
- Particle size range: 0.04 to ~ 1.0 micrometers

Measurements

- **North Atlantic Aerosols and Marine Ecosystems Study (NAAMES)**
  - 4 aircraft and ship measurement campaigns over 5 years (Each campaign is aligned to a specific annual event in the plankton cycle)
- Goals
  - Characterize plankton ecosystem properties during primary phases of the annual cycle in the North Atlantic and their dependence on environmental forcings
  - Determine how marine aerosols and boundary layer clouds are influenced by plankton ecosystems in the North Atlantic (and their feedbacks)



Behrenfeld, M., "NAAMES Confirmation Review.' 28 Aug 2015

N_d Retrieval Method

$$N_d = \frac{5}{3}\frac{\tau}{\overline{\sigma_e}H}$$

1) Cloud Optical Thickness, τ
2) Mean extinction cross-section at cloud top, $\overline{\sigma_e}$
3) Cloud Geometrical Thickness, H

Assumptions

1) Linearly increasing LWC. $L = c\,h$,
2) Constant N_d profile $N_d(h) = c$

- Mean droplet extinction cross section is estimated from polarized reflectances in the cloud-bow near cloud top (figure 1)
- Geometric thickness is estimated by relating in-cloud water vapor absorption to physical thickness
  - This could also be retrieved from polarimetric oxygen A-band
- The method has been validated using data from the NAAMES 1 and 2 campaigns (figure 2)
- It is expected that a polarimeter aboard PACE would be capable of using this method

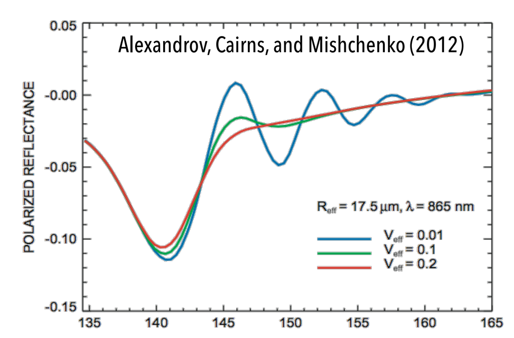


Fig: Polarized reflectance as a function of scattering angle for several V_{eff}

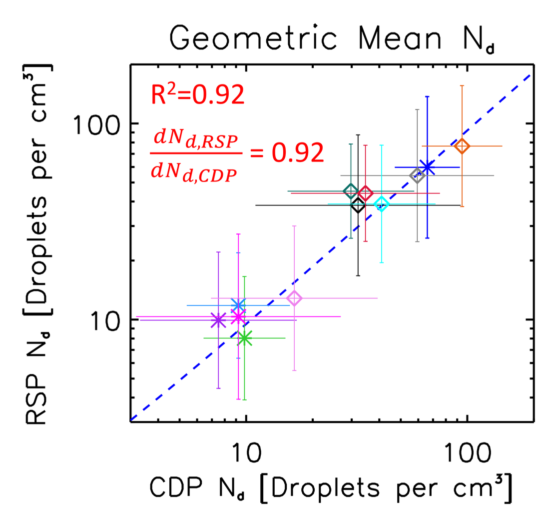


Fig: 12 daily mean N_d values from the RSP and in situ Cloud Droplet Probe (CDP) collected during the NAAMES 1 and 2 campaigns

Results – Aerosol Mass

Aerosol Type & Mass

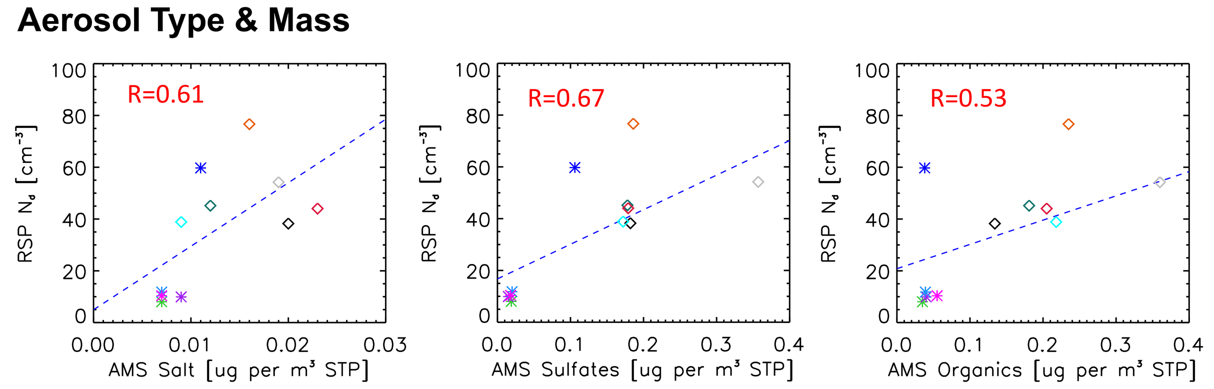


Fig: RSP N_d measurements are compared with AMS measured salt, organic and sulfate aerosol masses.

Results N_d and CCN

N_d and CCN

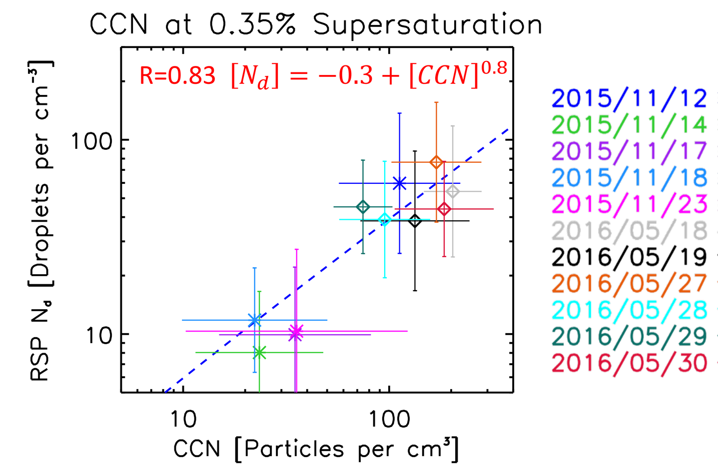


Figure: RSP N_d and LARGE in situ CCN geometric means and geometric SD factor (bars) collected during cloud modules

> ***Key finding:*** *Boundary layer CCN has a strong positive correlation with N_d*

- The strength of all correlations are dependent on *supersaturation* with weaker correlations being associated with low and high supersaturations

Cloud Property Correlations

> ***Key finding:*** *Liquid water path is **uncorrelated** with N_d*

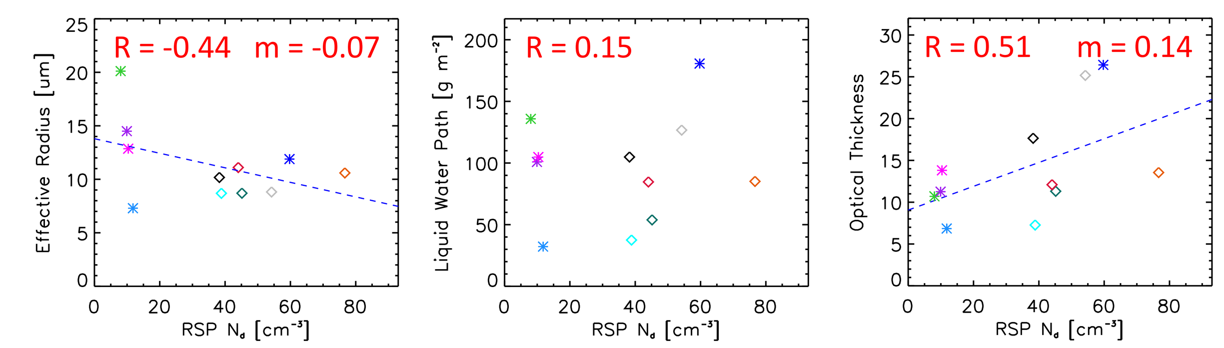


Figure: Cloud property variability is compared with CCN concentrations. A linear fit is shown if correlation is over 0.5.

Meteorological Properties

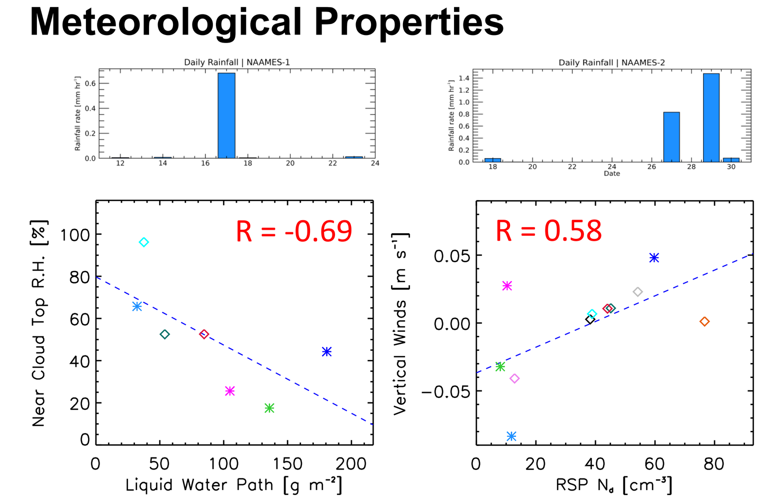


Figure: Horizontal and vertical winds, above and below cloud relative humidity and precipitation data are assessed to determine meteorological contributions to cloud property variability

> ***Key finding:*** *Above cloud relative humidity has a **robust** inverse correlation with liquid water path*

- Vertical winds can explain some variability in the N_d-CCN relationship
- A low number of data points complicates analyzing precipitation data
- Boundary layer relative humidity did not have a detectable effect on cloud properties

CCN and Cloud Properties

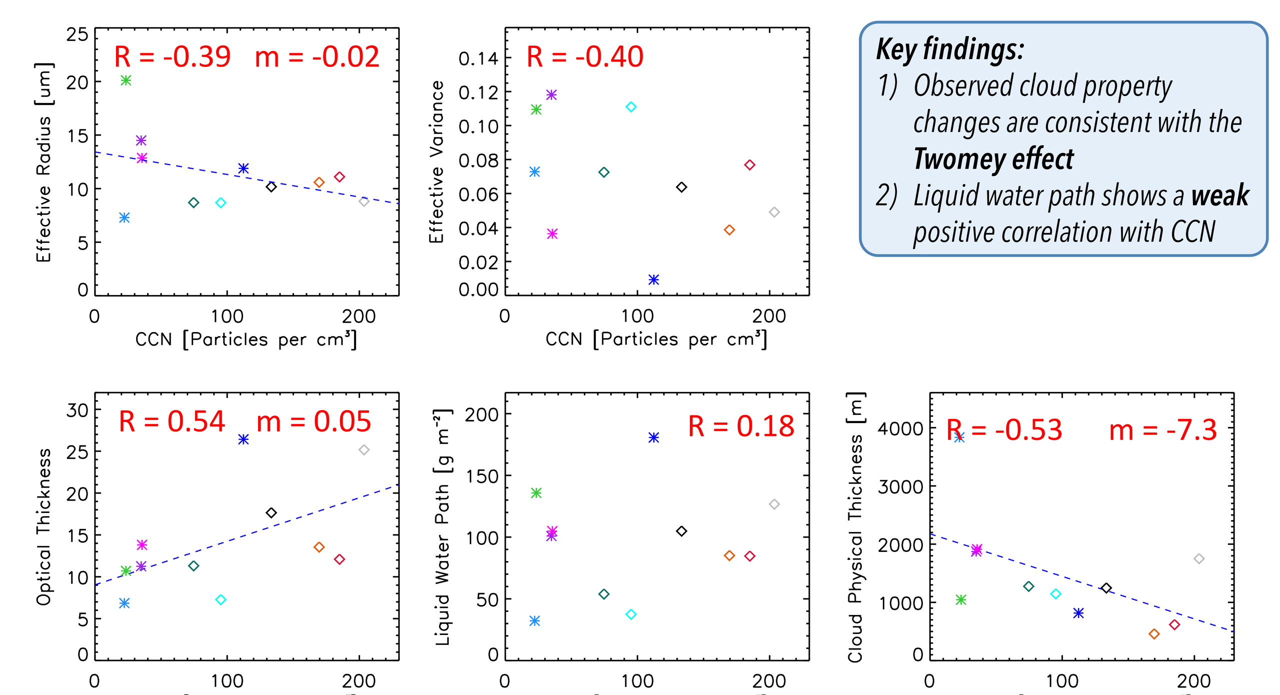


Figure: Cloud property variability is compared with CCN concentrations. A linear fit is shown if correlation is over 0.5.

> ***Key findings:***
> 1) *Observed cloud property changes are consistent with the **Twomey effect***
> 2) *Liquid water path shows a **weak** positive correlation with CCN*

Results – Seasonal

Seasonal Comparisons

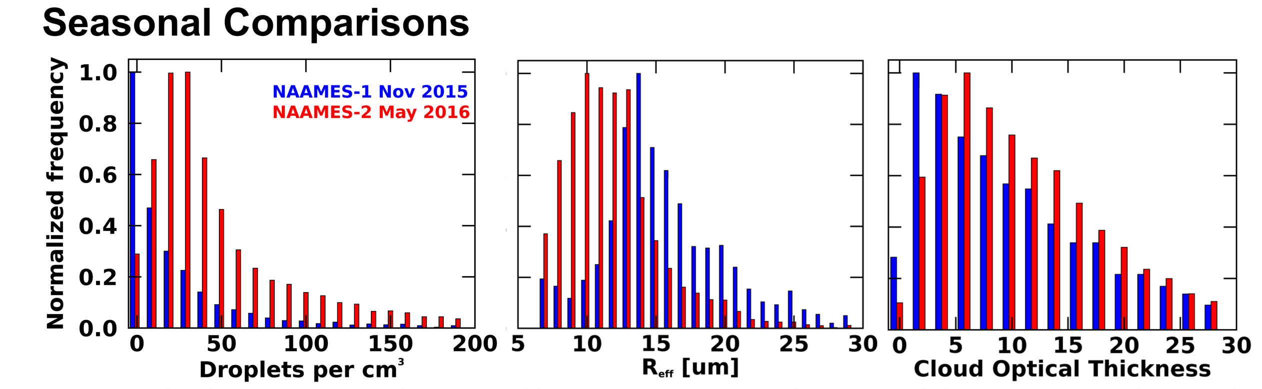


Figure: Cloud property retrievals separated by season (campaign), showing N_d (left), R_{eff} (center) and COT (right)

> ***Key findings:*** Through seasons 1) N_d increases 156% 2) R_{eff} decreases 23% 3) τ increases 8%

Conclusions

1. Meteorological conditions can explain some variability of aerosol's effect on cloud properties
   - Strongest influence was found with the above cloud relative humidity (-0.69) and updraft velocity (0.58)
   - Precipitation was not found to have a detectable effect
2. A strong (0.83) correlation is found between N_d and CCN
   - High correlations also for R_{eff} (-0.39), V_{eff} (-0.40), τ (0.54) and P.T. (-0.53)
   - Only weak correlations are found between liquid water path with CCN (0.18) and N_d (0.15)
3. Cloud property and aerosol concentration changes are found to be consistent with the ***Twomey effect***
4. Above cloud relative humidity has a ***robust*** inverse correlation with liquid water path and therefore plays an important role
5. A seasonal change in aerosol chemical composition is observed, which correlates with a seasonal change in cloud properties
   - A cloud ***brightening*** is found with τ increasing 8% between campaigns

Future Work

A. Use a LES model to better determine cloud property dependencies on meteorological properties
B. Use the in situ UHSAS instrument to assess aerosol size distribution and hygroscopicity on CCN-N_d sensitivity

Acknowledgements

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