Response of Marine Boundary Layer Cloud Properties to Aerosol Perturbations Associated with Meteorological Conditions from the 19-month AMF-Azores Campaign

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1. Background

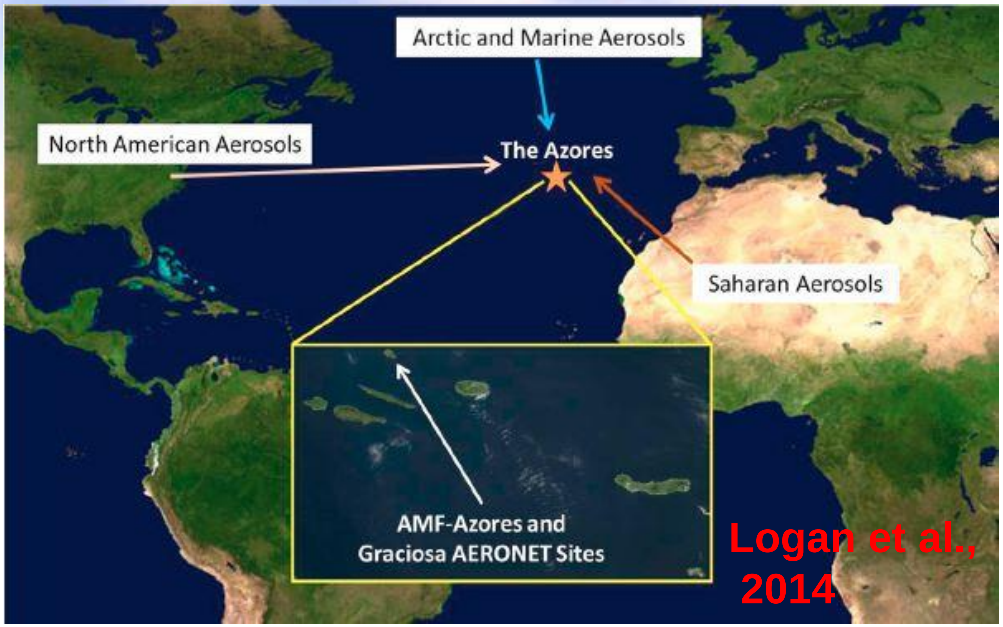
- The microphysical, structural and dynamic properties of marine boundary layer (MBL) clouds all show a sensitivity to aerosol loading, but the responses are not uniform. What processes control the diversity in the sensitivity of warm clouds to aerosol perturbations is an important science question to answer when studying aerosol-cloud-precipitation interactions.

Goal:

Investigate the responses of MBL cloud properties to changes in aerosol loading and determine how large-scale dynamics and thermodynamics affect the diversity in the MBL clouds to aerosol perturbations and affect the magnitude of the aerosol indirect effect.

2. Site, Data and Methods

May 2009 to December 2010



Logan et al., 2014

Graciosa Island (39.1°N, 28.03°W)
- typically clean, but with periodic influxes of polluted air from surrounding regions

Cloud base and top heights (Clothiaux et al., 2000; Wang and Sassen, 2001)

Aerosol number concentrations **(N_a)**

LWP (Liljgren and Lesht, 2004)

Layer-mean DER, N_C and COD (Dong et al., 1998)

2. Sites, Data and Methods

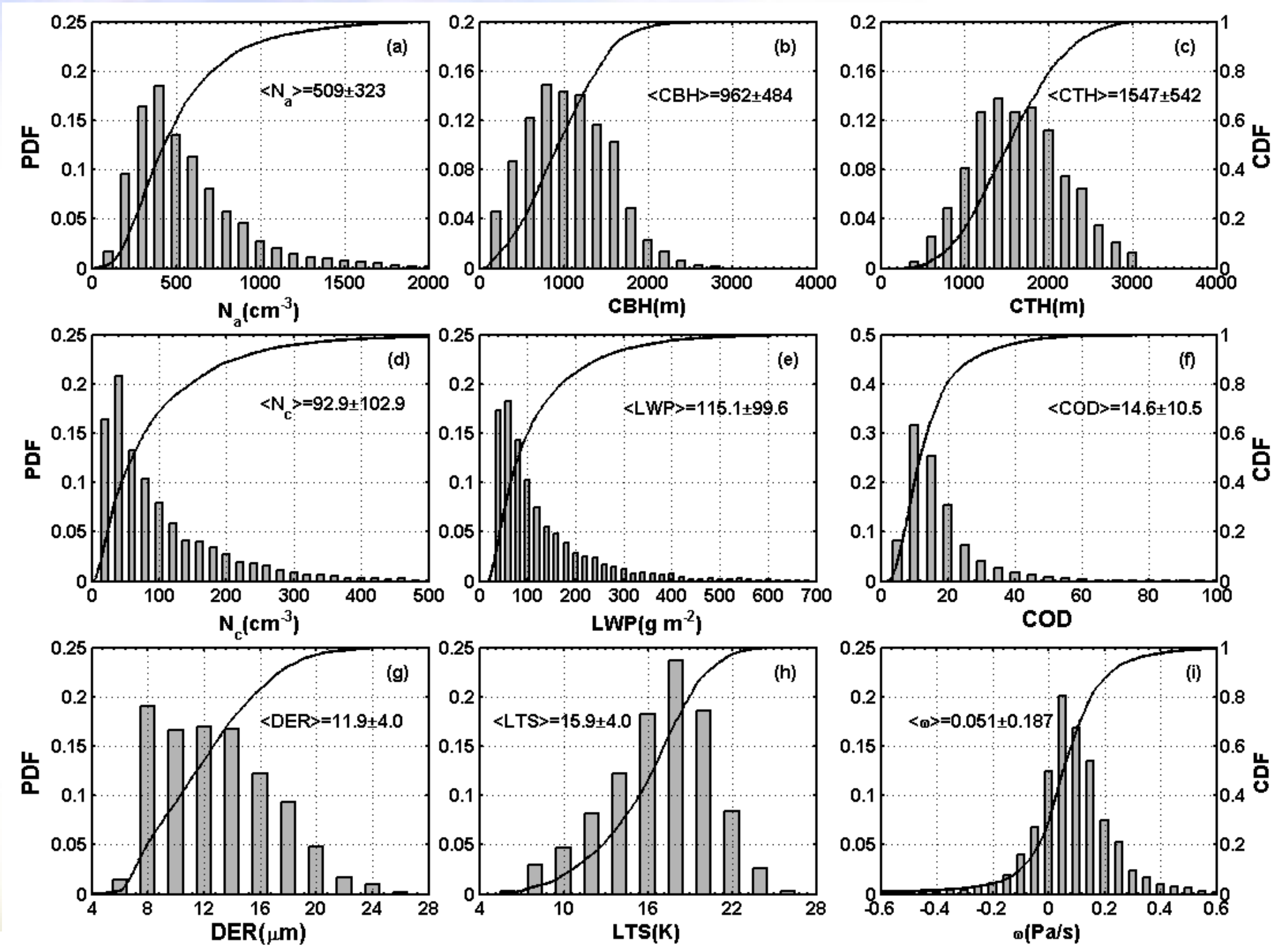
- MBL clouds: defined as clouds with top heights < 3 km (Dong et al., 2014)
- LWP observations less than 20 g m^{-2} and greater than 700 g m^{-2} were excluded to avoid very thin or broken clouds, as well as post-precipitation conditions (McComiskey et al., 2009) and potential precipitation contamination (Dong et al., 2008).

ECMWF reanalysis data (one-hour averages) from the ARM archive:

- Vertical velocity at 700 hPa (**ω**): used as a proxy for large-scale ascending and descending motions and for constraining dynamic regimes (Bony et al., 2004; Medeiros and Stevens, 2010; Sun et al., 2010)
- Lower tropospheric stability (**LTS**): used to constrain the thermodynamic state (Matsui et al., 2004; Lebsock et al., 2008)

3. Results

Overview of aerosol and cloud properties

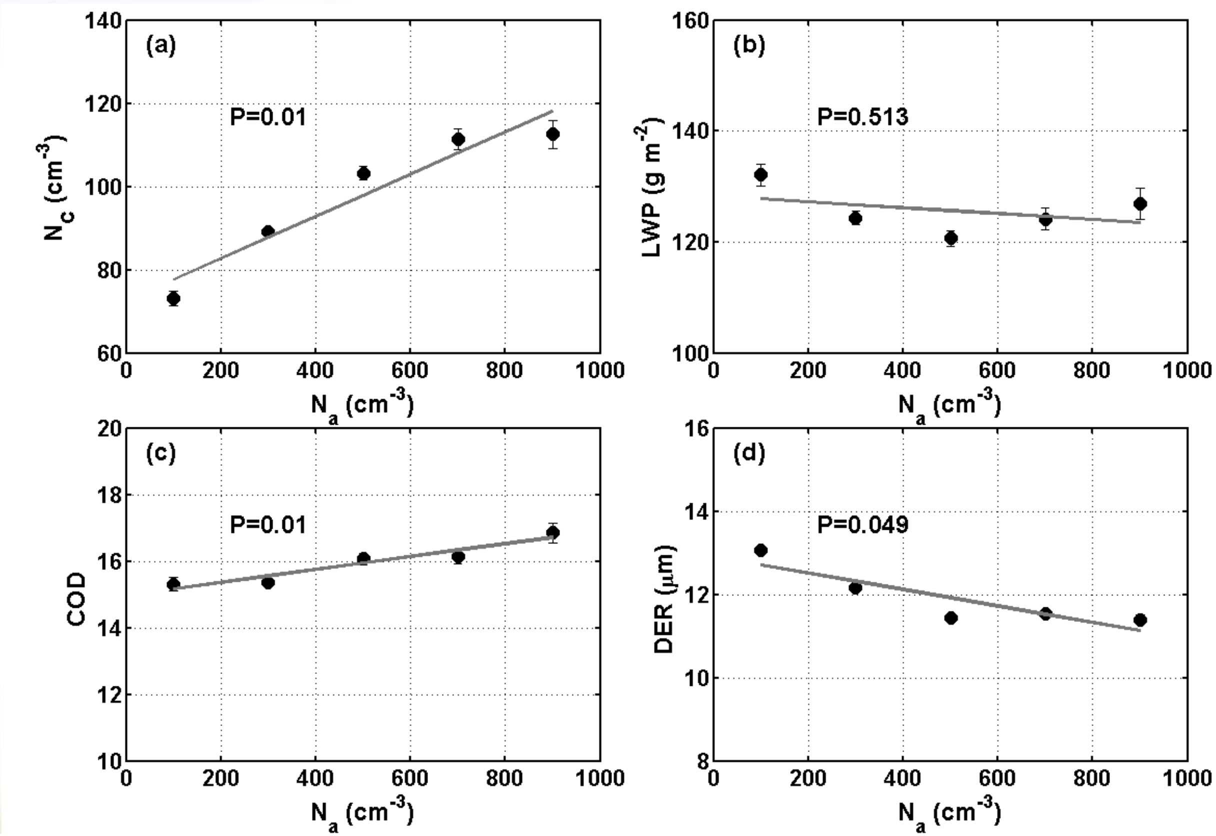


Probability Distribution Function (PDF, bar) and Cumulative Distribution Function (CDF, curve)

- 80% of N_a values are < 700 cm^{-3} with a mean value of 509 ±323 cm^{-3}
- MBL clouds generally have low CBH and CTH with mean values of 0.96±0.48 km and 1.55±0.54 km, respectively.
- Clouds have relatively small values of N_C, LWP, and COD. Most of the DER values (~65%) range from 6 to 14 μm.
- Most of the clouds have weak ascending and descending motions within them.

3. Results

Variations in cloud properties with changes in aerosol loading

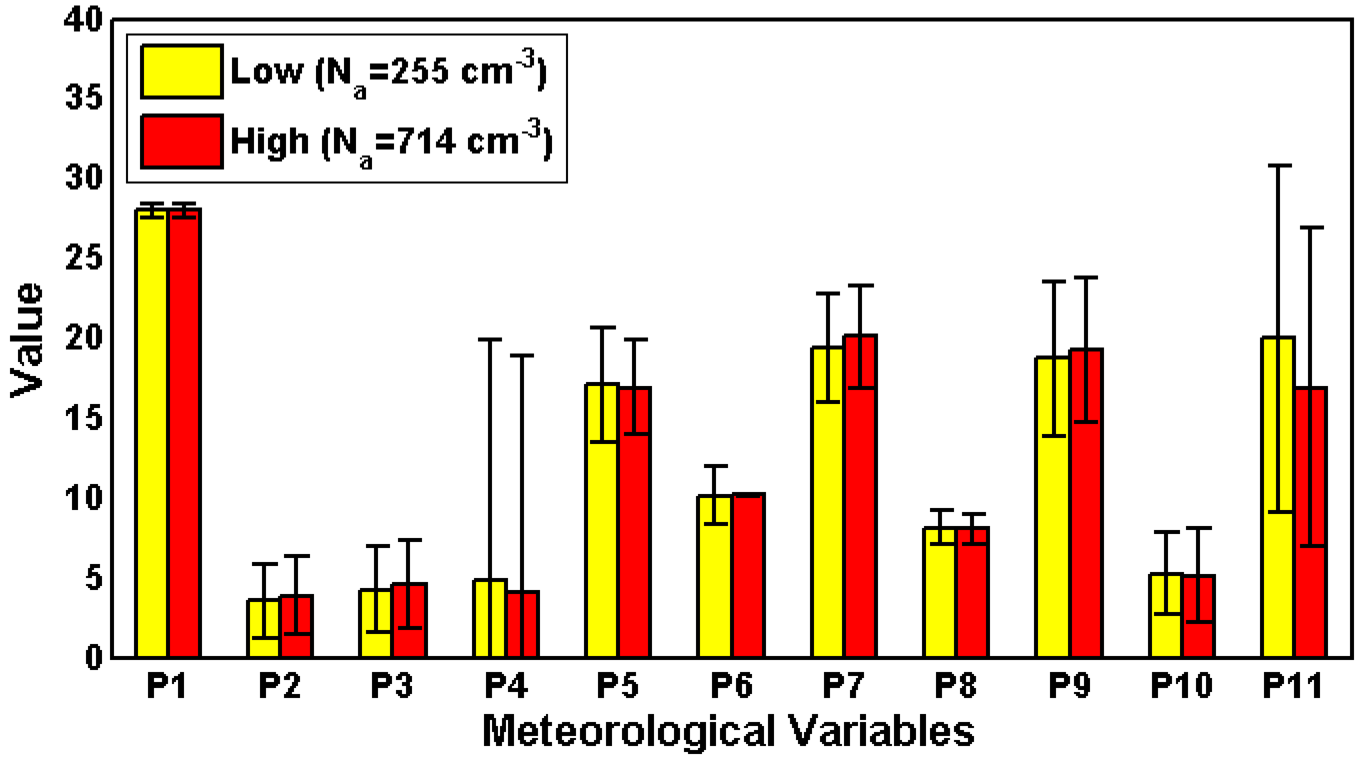


- N_C and COD increase , DER decreases as N_a increases.

- LWP decreases slightly with increasing N_a, but not significantly so.

3. Results

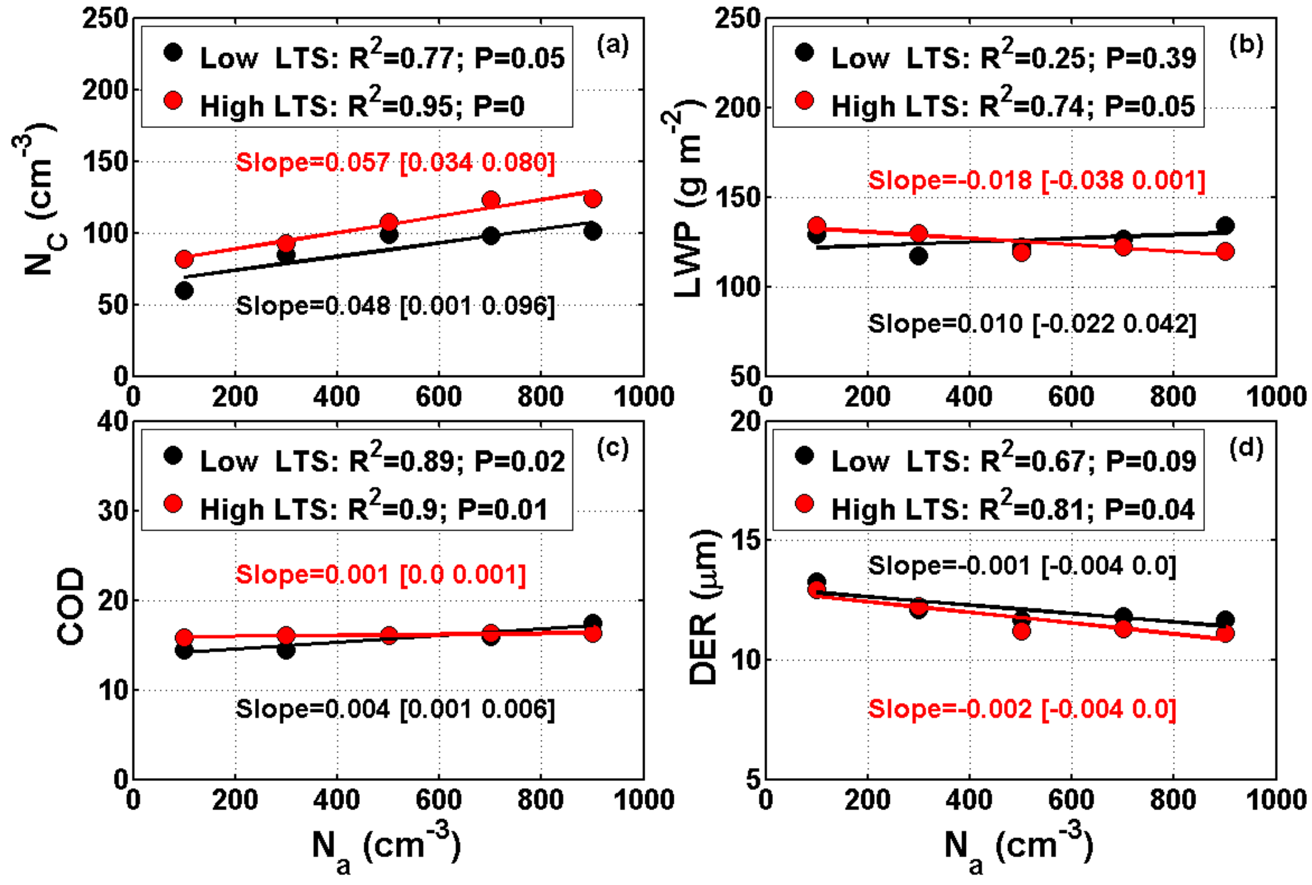
Variations in meteorological variables with changes in aerosol loading



P1- temperature at 750 hPa (/10, K),
P2 - specific humidity at 750 hPa (*1000, g/kg)
P3 - relative humidity at 750 hPa (/10, %)
P4 - vertical velocity at 700 hPa (*100, Pa/s)
P5 - lower tropospheric stability (K)
P6 - surface pressure (/100, hPa)
P7 - surface temperature (^{o}C)
P8 - surface relative humidity (/10, %)
P9 - surface water vapor pressure (hPa),
P10 - surface wind speed (m/s)
P11 - surface wind direction (/10, degrees).

3. Results

Cloud property-N_a relationships under different stability conditions



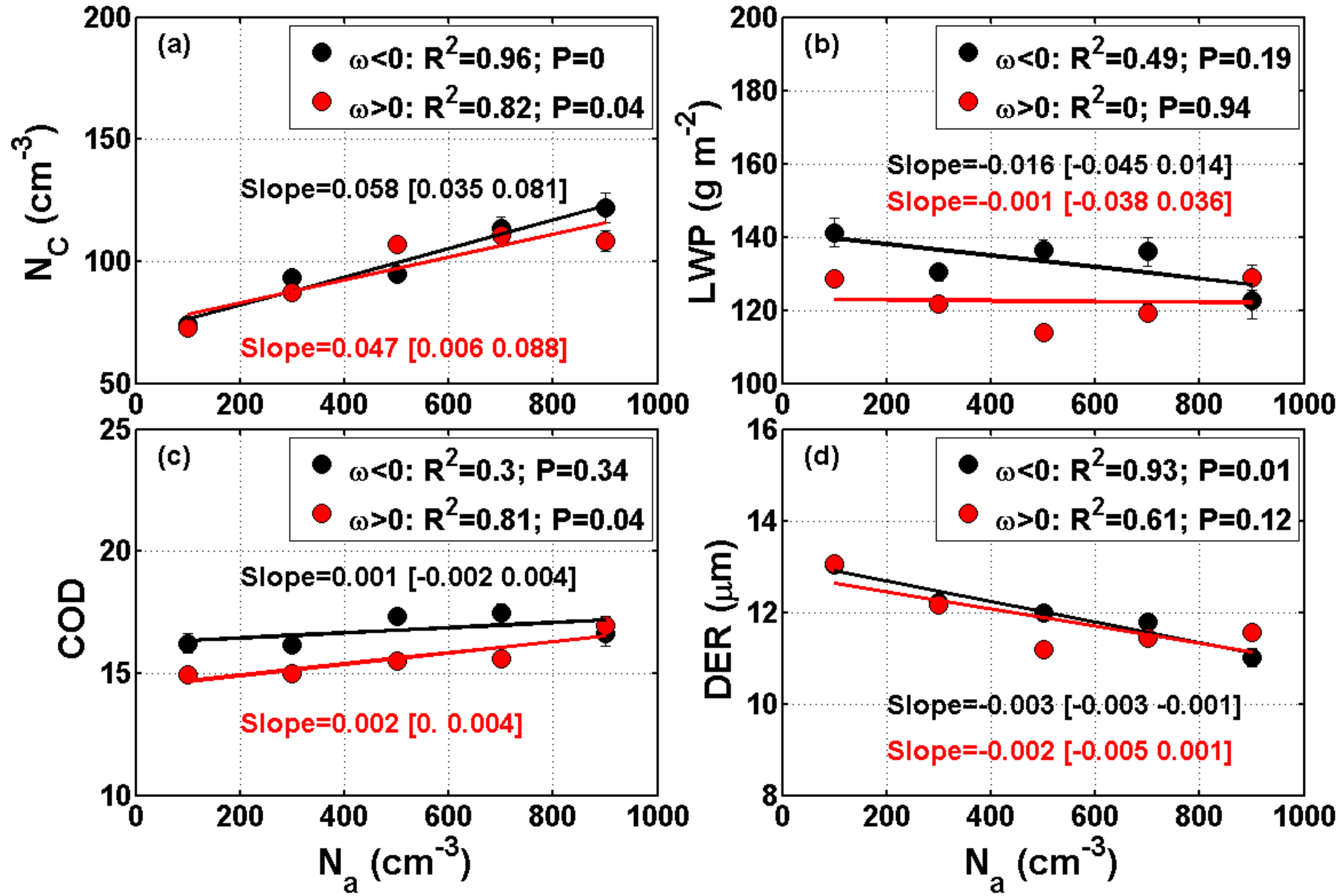
Low LTS:
< 16.8 K

High LTS:
> 16.8 K

- N_c and COD increase, and DER decreases with increasing N_a under all LTS conditions.
- The relationship between N_c (DER) and N_a is stronger under high stability conditions.
- LWP significantly decreases with increasing N_a under high stability conditions and shows little change under low stability conditions.

3. Results

Cloud property-N_a relationships under ascending and descending motion conditions

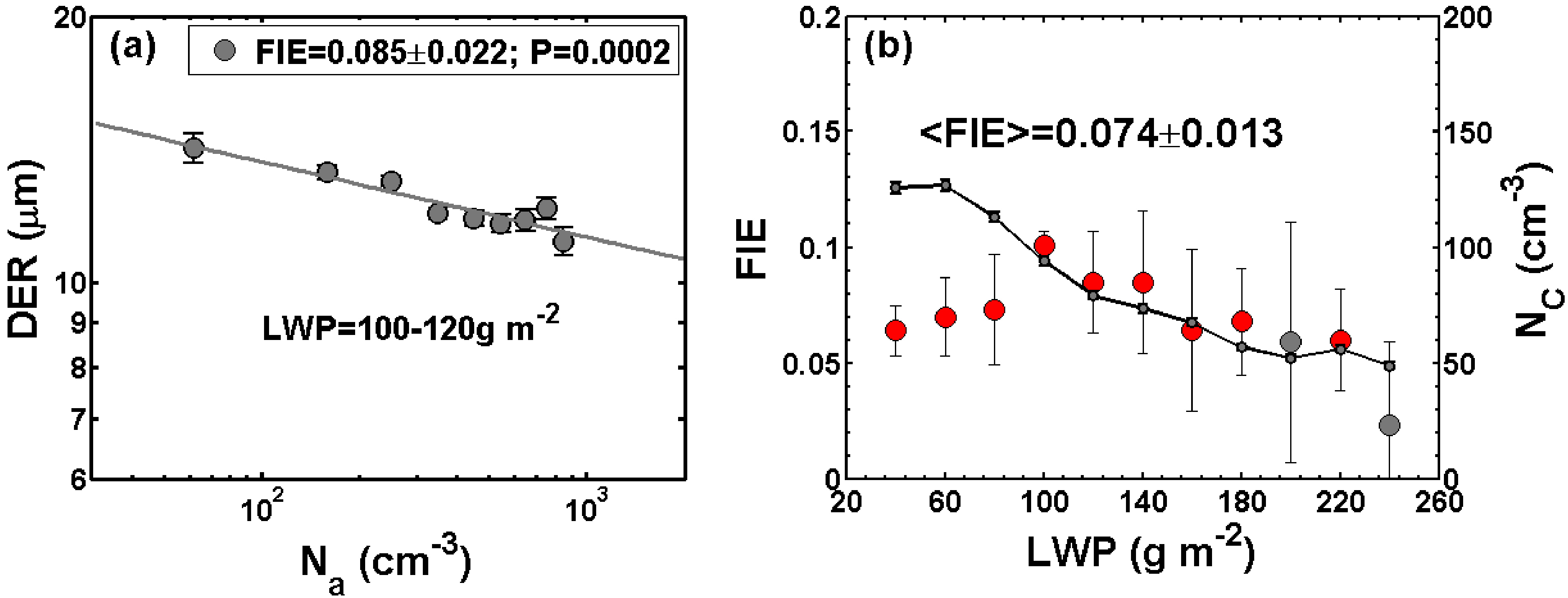


As N_a increases:
- N_c shows a significant increase. A stronger slope is found when $\omega < 0$.
- LWP changes little when $\omega > 0$ and decreases when $\omega < 0$.
- COD significantly increases when $\omega > 0$ and DER significantly decreases when $\omega < 0$.

3. Results

The aerosol first indirect effect (FIE)

$$FIE = -\frac{d\ln(DER)}{d\ln(\alpha)}$$

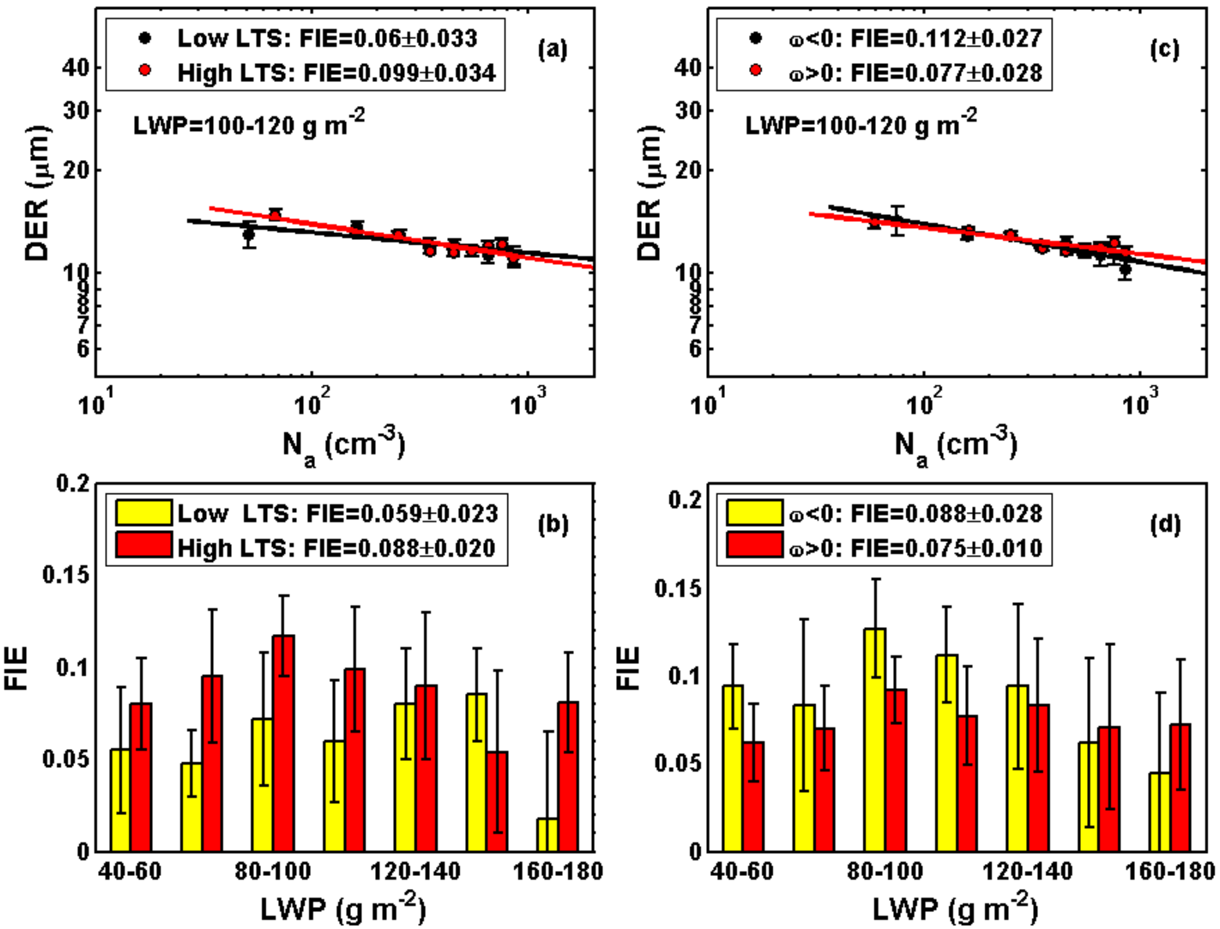


FIE ranges from 0.060±0.022 to 0.101±0.006 in different LWP bins with a clear decreasing trend as LWP increases.

3. Results

Aerosol FIE under different stability and vertical velocity conditions

FIE estimates based on ground-based measurements of aerosol and cloud properties

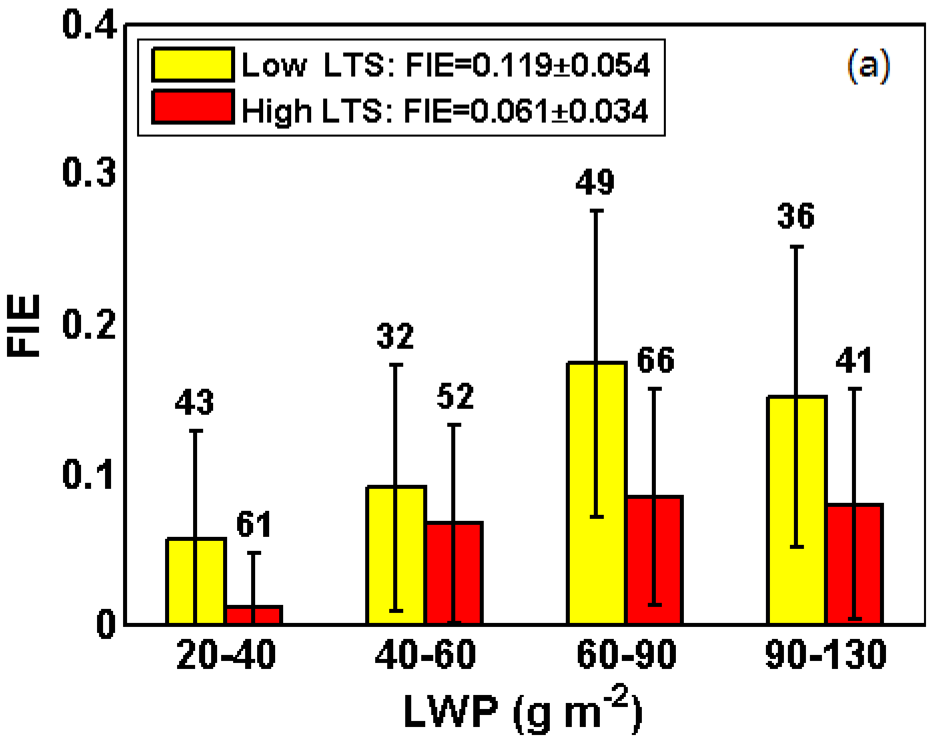


FIE is larger under high stability conditions.

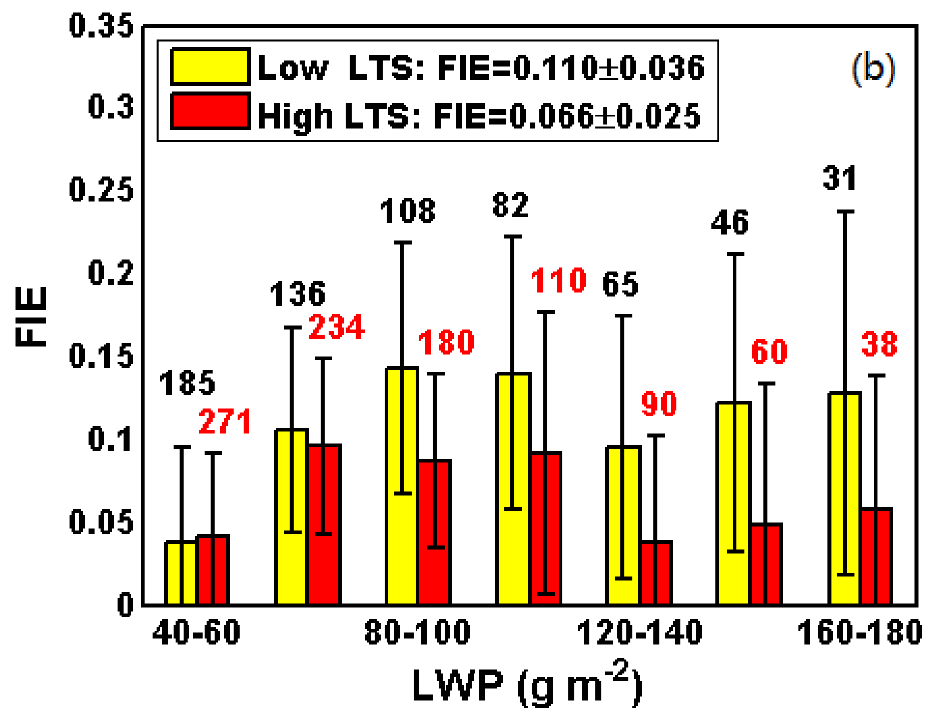
FIE appears to be higher under ascending motion conditions for clouds with low LWP and under descending motion conditions for clouds with high LWP.

3. Results

Aerosol FIE under different stability and vertical velocity conditions



FIE estimates based on ground-based retrievals of aerosol properties and **MODIS-retrieved cloud properties**



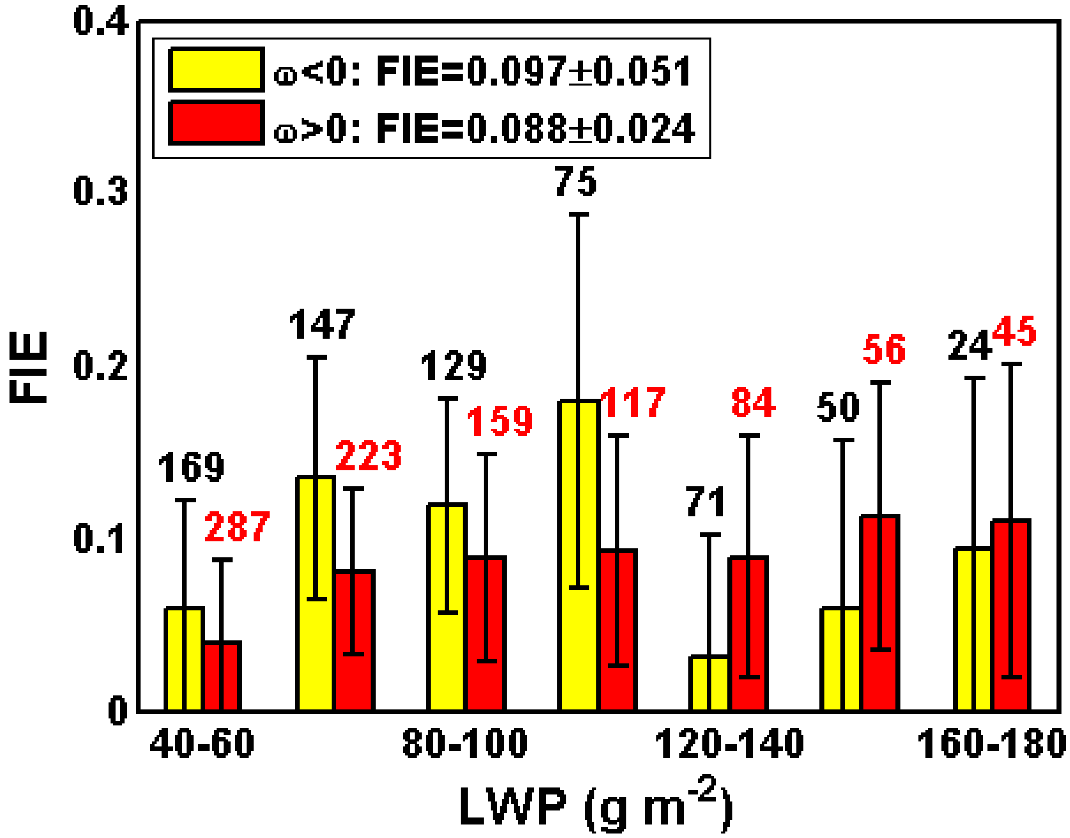
FIE estimates based on 10 years of **MODIS-retrieved aerosol and cloud properties**

FIE is larger under low stability conditions.

A contrasting dependence of FIE on atmospheric stability estimated from surface and satellite cloud property retrievals is found.

3. Results

Aerosol FIE under different stability and vertical velocity conditions



FIE appears to be higher under ascending motion conditions for clouds with low LWP and under descending motion conditions for clouds with high LWP.

FIE estimates based on 10 years of **MODIS-retrieved aerosol and cloud properties** under different vertical velocity conditions.

4. Conclusions

- The correlations between cloud microphysical properties (N_c, LWP, DER) and N_a were stronger under more stable conditions and under ascending motion conditions.
- The magnitude and corresponding uncertainty of the FIE ranged from 0.060 ± 0.022 to 0.101 ± 0.006 depending on the LWP values with a clear decreasing trend as LWP increased.
- A contrasting dependence of FIE on atmospheric stability estimated from surface and satellite cloud property retrievals was found.
- The magnitude of the FIE tended to be higher under ascending motion conditions for clouds with low LWP and under descending motion conditions for clouds with high LWP.

Acknowledgments

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Thank you for your attention