Satellite and ship-based estimates of cloud-aerosol interactions during MAGIC campaign

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Motivation: Aerosol-cloud interaction (ACI)

- Large disagreement among climate models, uncertain magnitude.

$$\mathrm{ACI}_N = \frac{d \ln N_{\mathrm{d}}}{d \ln N_{\mathrm{a}}} \leq 1$$

$\boldsymbol{N_a}$: aerosol proxy, $\boldsymbol{N_d}$: number of droplets

(Feingold et al., 2001 GRL)

- Different studies yield dissimilar ACI magnitudes:
  - Satellites: ACI<0.4 (Quaas et al., 2009 ACP)
  - NE Pacific, Point Reyes, ARM-AMF: ACI~0.48 (McComiskey et al. 2009, JGR)
  - Aircraft observations reveal stronger ACI (ACI >0.8):
    - NE Pacific DYCOMS-II: ACI~0.8-0.9 (Twohy et al., 2005 JGR)
    - SE Pacific VOCALS-REx: ACI~0.8-0.9 (Painemal and Zuidema 2013 ACP)
    - Shallow cumulus in Barbados: ACI~0.81-1.05 (Werner et al. 2014 JGR)

- **What can we learn from DOE AMF deployment during MAGIC campaign?**

MAGIC

- ARM Mobile Facility (AMF2)
- Nine months of measurements
  - Operational: Oct-Jan 2012-2013, May-Sept 2013.
  - L.A.-Honolulu: More than 30 transects (legs).
  - 6-7 days/leg

Dataset

- ***MAGIC data***:
  - Aerosols: cloud condensation nuclei (CCN), nephelometer aerosol scattering, MFRSR optical depth
  - Clouds: microphysics from a Cimel sun-photometer (Chiu et al. 2012 ACP), microwave liquid water path (Cadeddu et al., 2013, AMT)

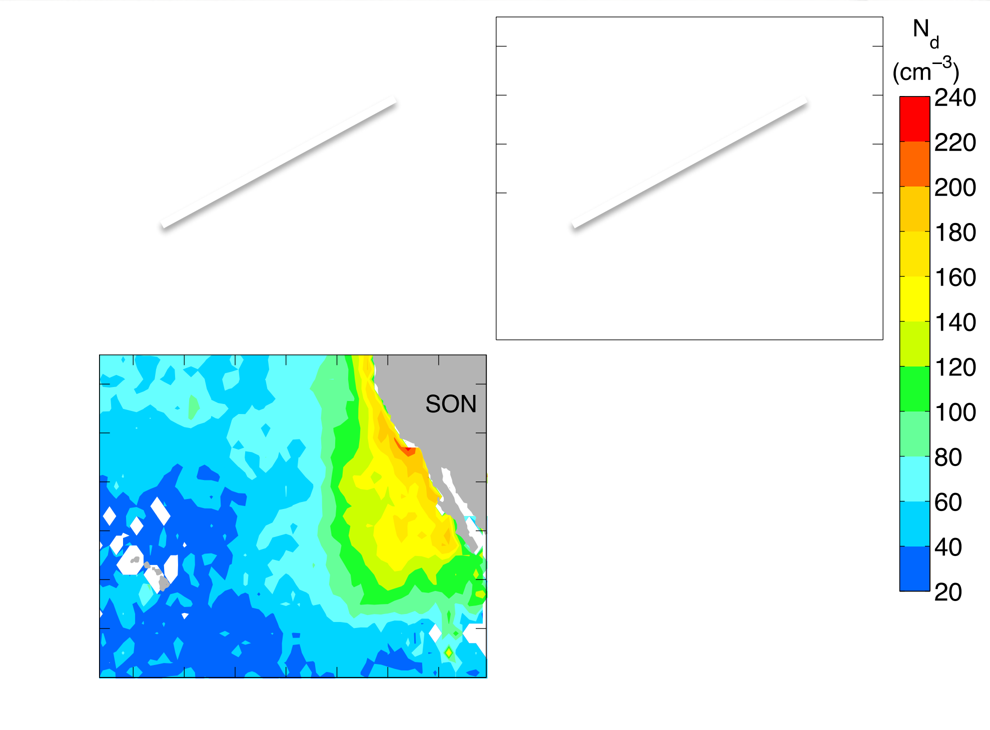
- **Satellites**:
  - Langley MODIS retrievals (Terra and Aqua), 1km pixel resolution
  - Langley GOES-15: 4km pixel resolution (nadir-view) every 30 min. Analysis constrained to samples with SZA <70˚

- $N_d = K \cdot \tau^{1/2} \cdot r_e^{5/2}$ adiabatic-like stratification

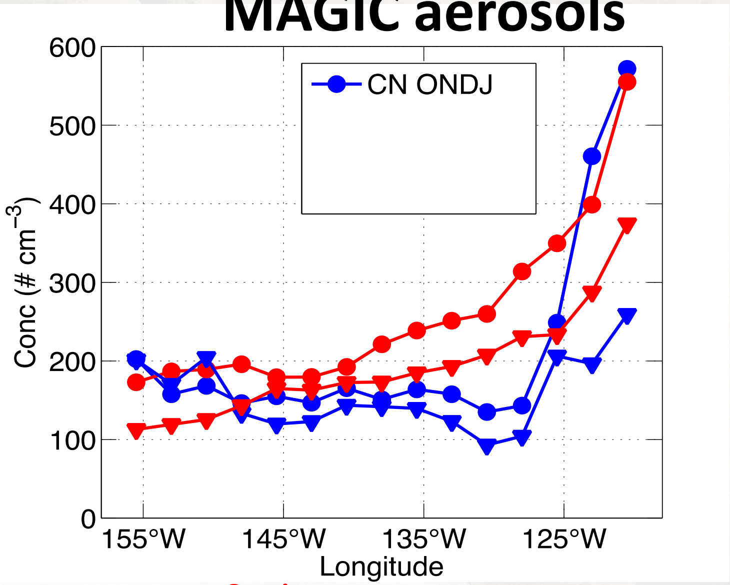
- **Aerosol-cloud interaction calculations combining different cloud microphysics estimates (ship and satellite) with the same MAGIC aerosol dataset.**

Clouds and aerosols: Seasonal view

- **MODIS N_d**



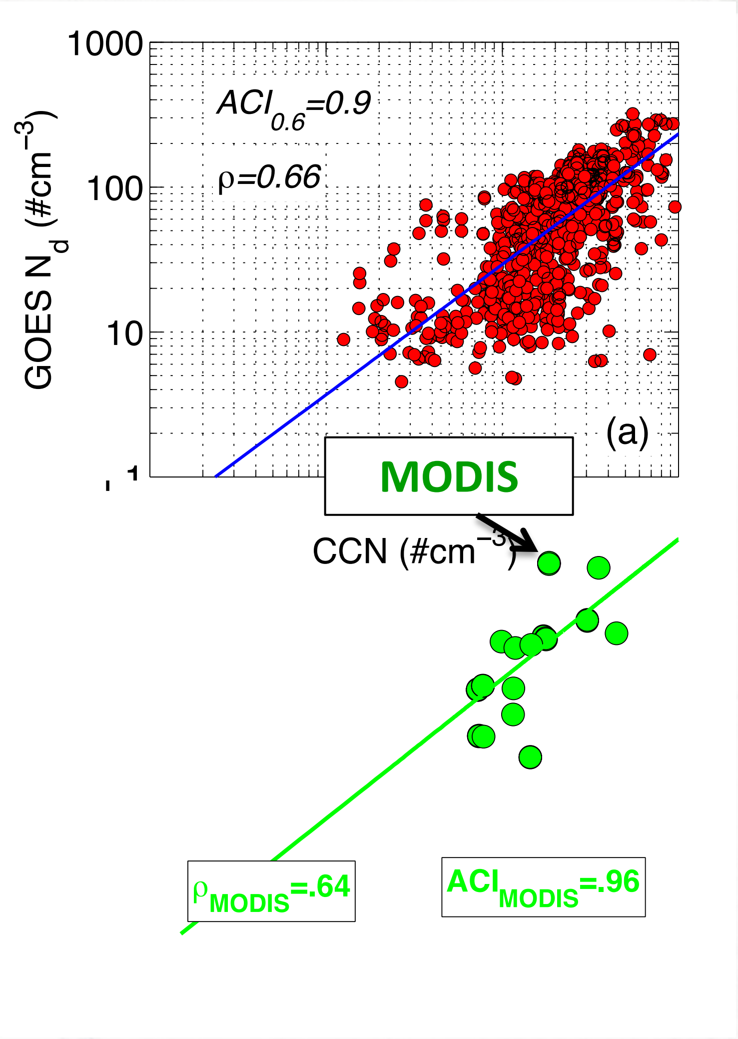
MAGIC aerosols



Spring+summer
Winter+autumn

- MODIS N_d and in-situ aerosols produce a consistent seasonal cycle

Satellites-based N_d and CCN:

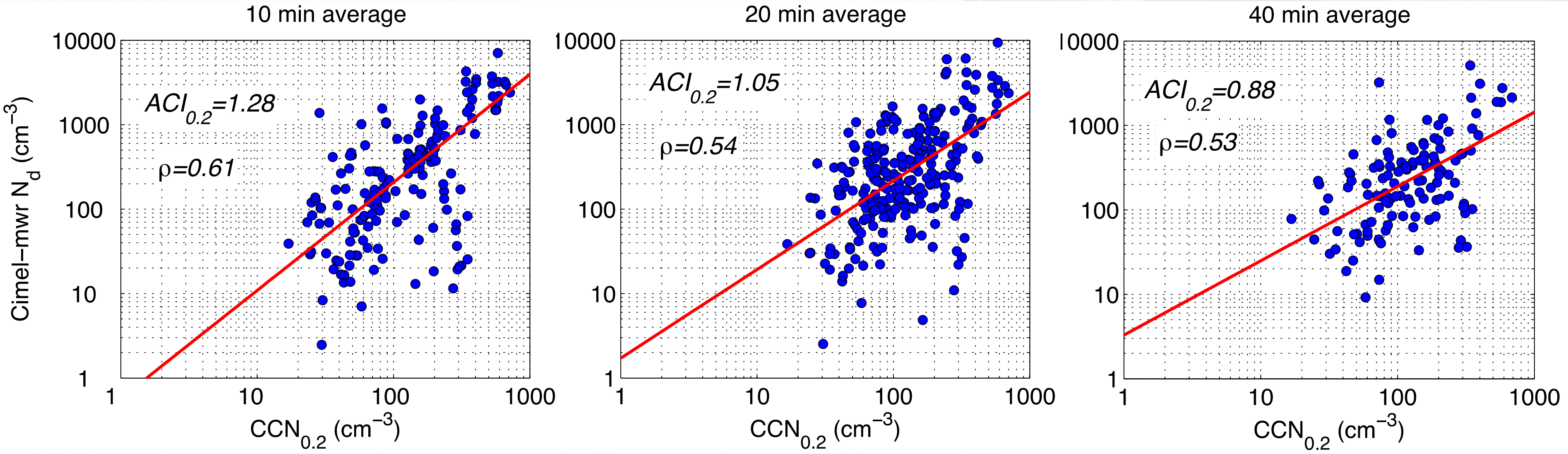


- 20 km averaged GOES/MODIS collocated with the ship location.

- Correlations higher than 0.6
- GOES and MODIS retrievals are consistent.
- $\ln(N_d)$ -ln(CCN) slope ≥0.9
- High slopes generally in agreement with aircraft observations.

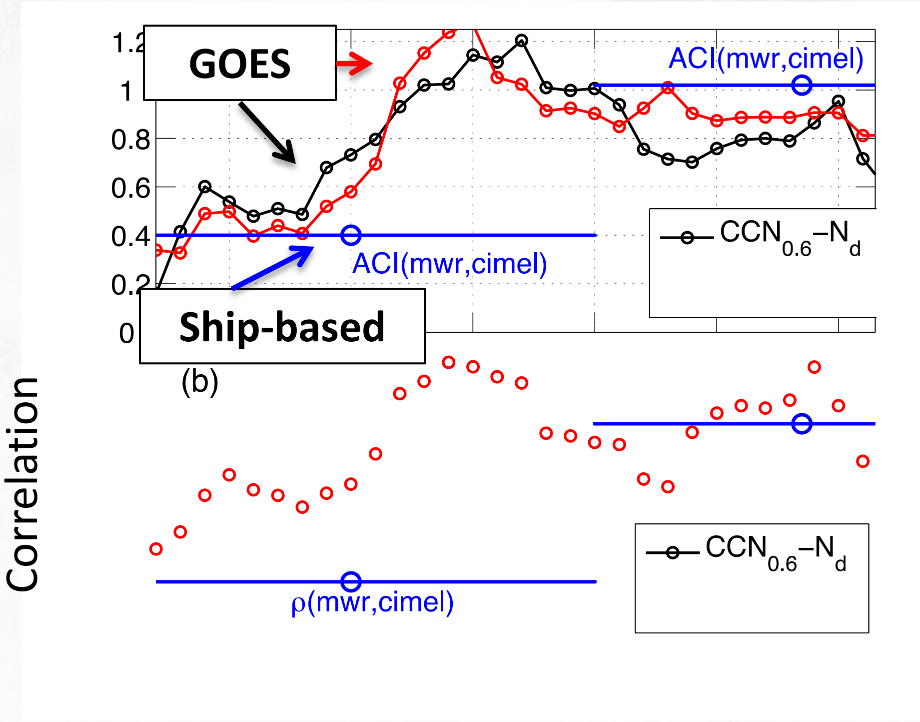
Cloud microphysics from shipborne sun-photometer

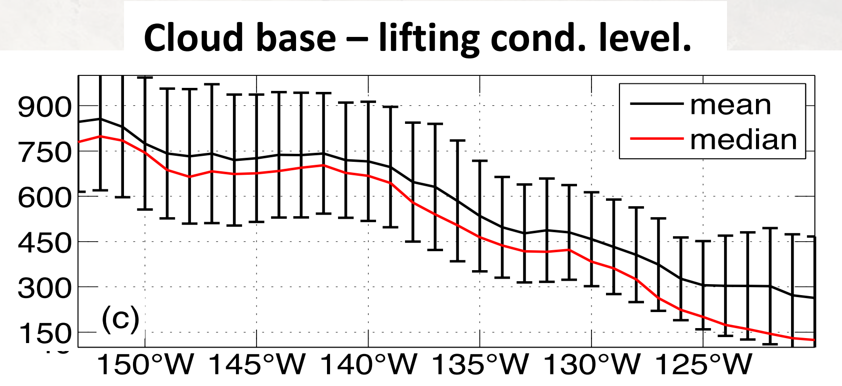
- Sun-photometer retrievals of r_e and τ. τ is generally more robust than r_e
- $N_d = N_d(\tau, LWP_{MWR})$, under a vertically stratified (adiabatic) assumption

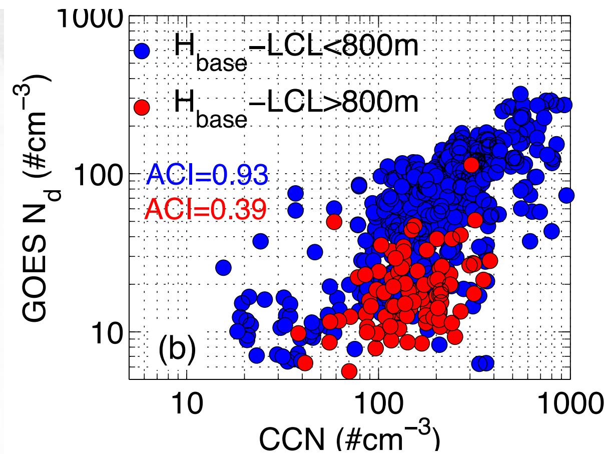


- High ln(N_d)-ln(CCN) slopes, near the upper physical limit 1
- Values close to the GOES/MODIS-shipbased estimates.

Westward transect and MBL decoupling







Painemal et al.2015 JGR, under review

- Satellite/ship-based ACI is higher near the coast.
- $CCN_{surface} \neq CCN_{cloud\ base}$ for decoupled conditions.

Cloud adiabaticity?

- Adiabatic liquid water path (LWP_{ad}) against the 3-ch microwave radiometer (MWR)

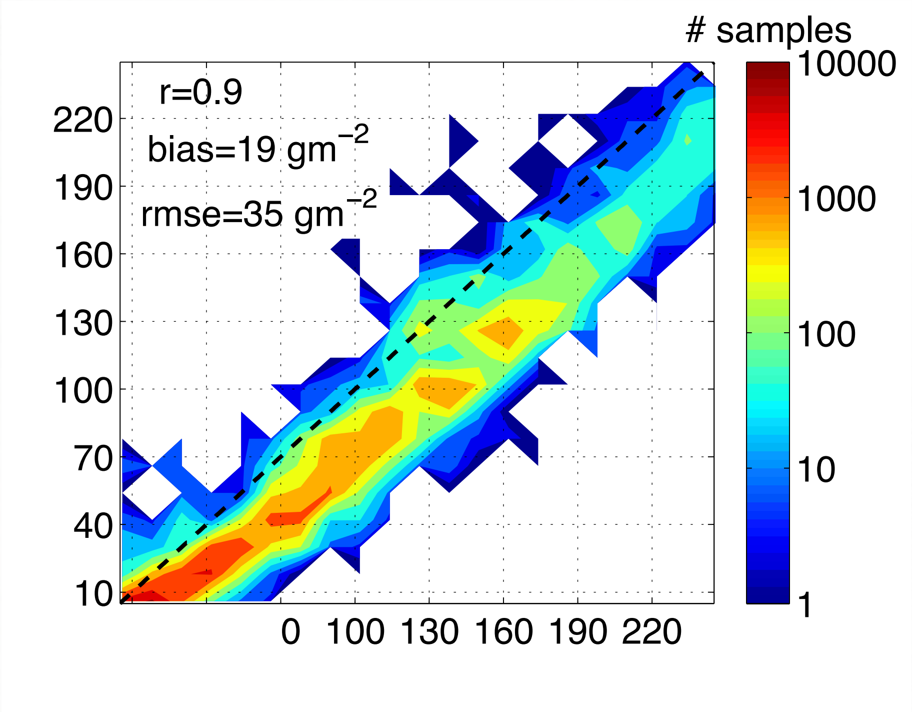
$$LWP_{ad} = K \cdot \frac{(Z_{top} - Z_{base})^2}{2}$$

$$K = K(P_c, T_c)$$

Ka-band radar, courtesy of X. Zhou/P. Kollias (McGill U.)

ceilometer

radiosondes



- High linear correlation between adiabatic and MWR estimates.
- Constant positive bias of MWR needs further investigation
- Degree of adiabaticity is difficult to address due to retrievals uncertainties
- **Adiabatic assumption appears to be appropriate**

CCN, aerosol scattering (β), and optical depth (AOD)

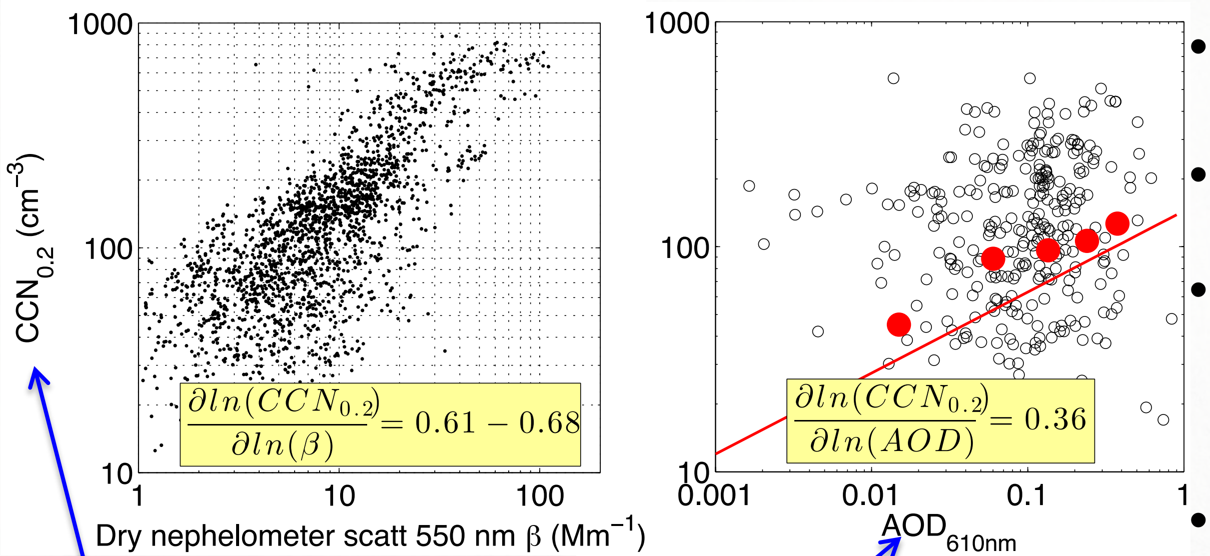
- The aerosol parameter selection matters:

$$\frac{\partial \ln(CCN)}{\partial \ln(AOD)} \neq \frac{\partial \ln(CCN)}{\partial \ln(\beta)} \neq 1$$

→

$$ACI = \frac{\partial \ln (N_d)}{\partial \ln (CCN)} \neq \frac{\partial \ln (N_d)}{\partial \ln (AOD)} \neq \frac{\partial \ln (N_d)}{\partial \ln (\beta)}$$

Andreae et al., 2009 ACP, Shinozuka et al. 2015 ACPD



surface

column

- $ACI_{AOD} < ACI_{\beta} < ACI_{CCN} \approx 1$
- $2.7 \cdot ACI_{AOD} \approx 1.5 \cdot ACI_{\beta} \approx ACI_{CCN}$
- **β**: aerosol particle size, refr. Index matter
- **AOD**: vertical structure, humidification, particle size, refr. index matter.
- Relationship can partially explain the small MODIS ACI(N_d,AOD)

Conclusions

- Satellite and shipborne remote sensing cloud retrievals yield consistently high aerosol-cloud interactions, in agreement with aircraft-based estimates over the ocean.
- MAGIC ACI is higher than other ARM-based estimates, likely associated with a more coupled boundary layer.

- Aerosol optical depth produces noisy and small ACI.
- Satellite cloud microphysics and in-situ CCN offer an intermediate solution.

- Aerosol vertical structure requires further analysis

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