Validation and research applications of MODIS edition 4 cloud properties in marine clouds

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Satellite retrievals validation

- Validation of satellite retrievals hampered by the lack of reliable in-situ data.
- Aircraft data: detailed microphysical observations, but limited sampling.
- Ground-based: Adequate temporal sampling but very limited spatial sampling. Retrieving cloud properties can be challenging.
- Ship-based data: Adequate temporal sampling and better spatial coverage.
• ARM Mobile Facility (AMF2): radars, lidars, microwave and visible radiometers, sondes, and aerosol probes.

• Nine months of measurements
  – ~6 days/leg
Dataset

- **MAGIC data:**
  - Clouds microphysics from a Cimel sun-photometer (Chiu et al. 2012 ACP): cloud optical depth ($\tau$) and effective radius ($r_e$)
  - Three-channel microwave liquid water path (Cadeddu et al., 2013, AMT)
  - Cloud radar and radiosondes: cloud height and temperature

- **Satellites:**
  - Edition 4 MODIS retrievals (Terra and Aqua), 1km pixel resolution.
  - Daytime GOES-15: 4km pixel resolution (nadir-view) every 30 min with SZA<60°.
  - MODIS/GOES liquid water path (LWP): adiabatic-like assumption: $LWP=\frac{5}{9}\rho_w r_e \tau$
  - Satellite microwave liquid water path from AMSR2 (0.25°x 0.25°)
Satellite vs Satellite: AMSR2-MODIS

- Afternoon pass ~ 1:30 pm, overcast scenes
- AMSR2, Wentz algorithm at 0.25° x 0.25°
- LWP estimates based on 3.7 μm and 2.1 μm effective radius

- MODIS2.1μm-AMSR2: r=0.89, bias=5.5 g/m² (9.3%)
- MODIS3.7μm-AMSR2: r=0.85, bias=0.81 g/m² (1.3 %), nearly unbiased!!
Ship-based data: Cloud microphysics and liquid water path

- LWP: Ship-based 3-channel µwave radiometer
- Cloud optical depth (τ): sun-photometer (Chiu et al., 2012)

\[ r=0.94, \text{ bias}=9.1 \text{ g/m}^2, \text{ rsme}=18.9 \text{ g/m}^2 \]

\[ r=0.85, \text{ bias}=1.5, \text{ rsme}=3.21 \]

- Cloud effective radius? Comparison is uncertain, ground-based \( r_e \) is less robust than τ.
Cloud temperature and height

- MODIS cloud temperature vs inversion temperature (radiosonde)
- MODIS cloud height: linear fit from Painemal et al. 2013, that relates $T_{\text{top}}$ – SST to cloud height.
- Ship-based cloud top height from a k-band radar (three months)
Applications: Boundary layer evolution

- Adiabatic approximation for computing cloud base height
- Boundary layer degree of turbulent mixing: Difference between cloud base height (CBH) and lifting condensation level (LCL).

**MODIS and Reanalysis**

**CBH–LCL**

**In-situ, transect between L.A. and Hawaii**

![Map diagram showing cloud base height (CBH) and lifting condensation level (LCL) over the NE Pacific, with a transect between LA and Hawaii. The map includes a color gradient for CBH–LCL differences, and a graph showing the mean and median cloud base height (H_{base}) compared to the lifting condensation level (LCL) across different longitudes.]
Regional patterns of aerosol transport

MAGIC cloud condensation nuclei CCN observations

Satellite-based cloud number of droplets \( (N_d) \), \( N_d = K \cdot r_e^{-5/2} \cdot \tau^{-1/2} \)

- Periods with high CCN consistent with back-trajectories originated near the coast
- Aerosol changes during MAGIC associated with synoptic changes in circulation

Painemal et al. (JGR, 2015)
Aerosol indirect effect

- Quantification of the relationship between aerosol and cloud microphysics
- Cloud droplet number concentration $N_d = K \cdot r_e^{-5/2} \cdot \tau^{-1/2}$

- Co-variability between aerosol (cloud condensation nuclei) and $N_d$ (Painemal et al. 2016, in prep.)
Partially cloudy scenes: LWP

• Are satellite cloud data reliable in partially cloudy scenes for climate applications?

• MODIS LWP=LWP_{cloudy}\cdot CF_M

• Data binned as a function of satellite cloud frequency (CF) and MODIS cloud fraction (CF_M)

• AMSR-2 and MODIS(2.1\mu m) overestimate the ship-based data

• MODIS(3.7\mu m) is nearly unbiased !!!

Painemal et al 2016 (GRL, under review)
Future satellite-aircraft intercomparisons

- CSET: Northeast Pacific
- ORACLES and LASIC: Northeast Atlantic
Concluding remarks

• MODIS LWP and ship-based retrievals are highly correlated.
  – For broken scenes, MODIS LWPxCF reproduces the LWP dependence on cloud cover
• MODIS $\tau$ correlates well with sun-photometer $\tau$.
• Lapse rate technique is adequate for deriving cloud height using cloud temperature and SST

• Current research activities:
  – Marine boundary layer evolution: boundary layer coupling, cloud top longwave cooling, and entrainment.
  – Evaluation of satellite microwave retrievals in broken scenes.
  – Quantification of the aerosol indirect effect:
    • Co-variability between cloud and aerosol properties.
    • Albedo perturbations associated with changes in cloud microphysics.

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Partially cloudy scenes II: Cloud effective radius

- CF: Cloud fraction
- $H_\sigma$: heterogeneity factor, $\sigma_{0.64 \mu m}/\mu_{0.64 \mu m}$ (Liang et al., 2009, JGR)
- $r_{e3.78}$ less sensitive to CF and $H_\sigma$
- Painemal et al. (2013 ACP)