Advances in Quantifying Uncertainties in Passive Microwave Observations of Cloud Liquid Water for Climate Applications

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Motivation

• Observations of CLWP – an essential climate variable – can provide important constraints on climate model simulations

• Multisensor Advanced Climatology of Liquid Water Path (MAC-LWP) CDR (30 year record)
  • Strengths: combines all conically scanning sensors (intercalibrated); includes sampling errors
  • Weaknesses: Lacks inherent uncertainties and validation

• Numerous studies have investigated CLWP errors using multi-sensor satellite data but these errors are not easily used by data users

• NASA MEaSUREs 5-yr project: “A Data Record of the Cloudy Boundary Layer” (PI: Teixiera, JPL)
  • Enhanced MAC-LWP (Elsaesser et al. 2017)
  • Developed an extended uncertainty data set for passive microwave observed CLWP (Greenwald et al. 2018)
Content

• Development of a CLWP uncertainty data set
• Main sources of systematic error
• Space/time characteristics of errors
• Conclusions
Creating an Uncertainty Data Set

• Focus on warm clouds (easier problem)
• Use reasonably long record from a single well-calibrated microwave sensor (e.g., AMSR-E)
• Use of merged satellite observations for deriving cloud properties and quantifying CLWP errors:
  • 2008 collocated multisensor data set (AMSR-E/MODIS*/CPR/CALIOP)
  • Combined AMSR-E/MODIS* L2C 9.25-yr data set; fast collocation algorithm developed at SSEC (Nagle & Holz 2009)

*Collection 6
Main Sources of Systematic Error

• Clear-sky bias
  • Error associated with not separating clear scenes from cloudy scenes. Bias varies due to uncertainties in gas absorption and surface emissivity; greatest impact is in partial cloudiness

• Cloud-rain partition bias
  • Relates to assumptions made in how CLWP and rain water path are separated

• Cloud temperature bias

• Cloud-fraction-dependent bias
  • Actually a combination of several biases

Painemal et al. 2016
Clear-Sky Bias

• Bias varies with surface wind speed and TPW
Dust: A New Source of Error?

CALIOP

MODIS

AMSR-E CLWP
Cloud-Rain Partition Bias

• Improved cloud-rain partition parameterization for warm clouds using the 2008 collocated multisensor dataset
  • MODIS cloud mask, CLWP_{0.86/3.7}
  • AMSR-E R, 36.5 GHz $\tau$
  • CPR RWC, H, CLWP
  • CALIOP CTT

• Restrictions
  • Overcast AMSR-E FOVs
  • SZA < 45°

$$CLWP = \alpha (1+\beta(HR)^\gamma)$$

$\alpha=0.18$, $\beta=1$, $\gamma=0.5$

$\alpha=0.087$, $\beta=0.9$, $\gamma=0.38$
Improved sensitivity to drizzle and light rain:
- Variable LWP threshold
- 1DVAR with error covariances derived from in situ dropsize distributions

Greenwald et al. (2018)

Duncan et al. (2018)
Cloud Temperature Bias

• Apply adiabatic theory and use MODIS cloud top properties
• Adiabatic assumption valid for Sc in a well-mixed BL but slightly underestimates bias for Cu
• Overall impact of cloud temperature bias is rather small for warm clouds

Greenwald et al. 2018
Cloud-Fraction-Dependent Bias

- Adjacent precipitation bias ("rain-free" scenes)
- Cloud-rain partition bias
- In-cloud bias

Greenwald et al. 2018
Applying the Error Analysis

• Clear-sky bias
  • AMSR-E CLWP
  • MODIS cloud mask

• Cloud-rain-partition bias
  • AMSR-E R, $\tau_{36.5}$
  • MODIS cloud mask, CTT/CTH

• Cloud temperature bias
  • AMSR-E CLWP, SST
  • MODIS cloud mask, CTT/CTH

• Cloud-fraction-dependent bias
  • AMSR-E CLWP, TPW, wind speed
  • MODIS cloud mask, CTT
Space/Time Variability of Errors

9-yr Mean

Interannual SD

Zonal average

Greenwald et al. 2018
Conclusions

• Combining passive microwave and visible-infrared data is essential in quantifying errors and improving the accuracy of these observations

• Uncertainties in passive microwave-derived CLWP observations are dominated by cloud-rain partition and in-cloud biases

• Plan is to extend the error analysis to other cloud types and sensors for CDRs like MAC-LWP
  • ISCCP HX series cloud data sets (~10 km; 3 hourly)
  • Develop CRP schemes using dual-frequency radars (DPR)
  • Improved rain detection methods (e.g., Duncan et al. 2018)
Backup slides

![Graph showing CLWP (kg/m²) vs Cloud cover (%)]

- AMSR-E climatology (bias-corrected)
- Ship observations (May-Aug 2013)