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

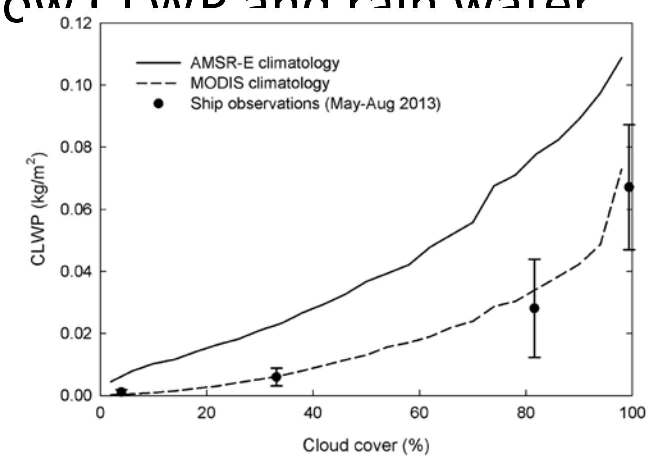
Creating an Uncertainty Data Set

- 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

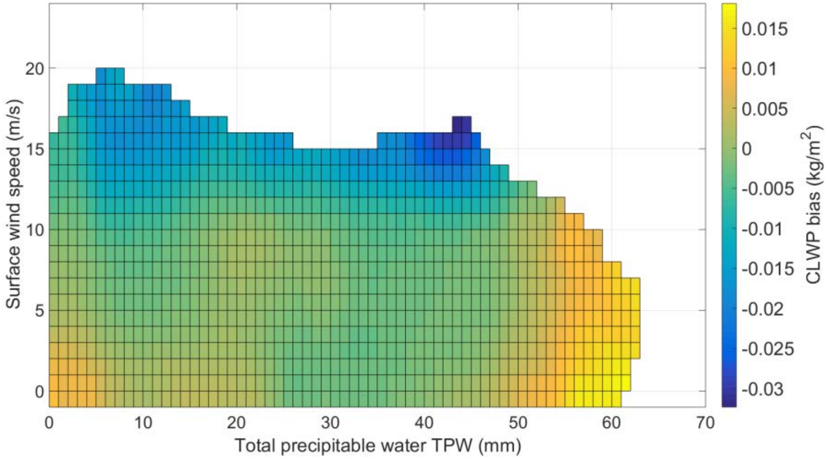
- Clear-sky bias
  - Error associated with not separating clear scenes from cloudy scenes. Bias varies due to uncertainties in gas absorption and surface emissivity; greatest impact is in partial cloudiness
- Cloud-rain partition bias
  - Relates to assumptions made in how CLWP and rain water path are separated
- Cloud temperature bias
- Cloud-fraction-dependent bias
  - Actually a combination of several biases

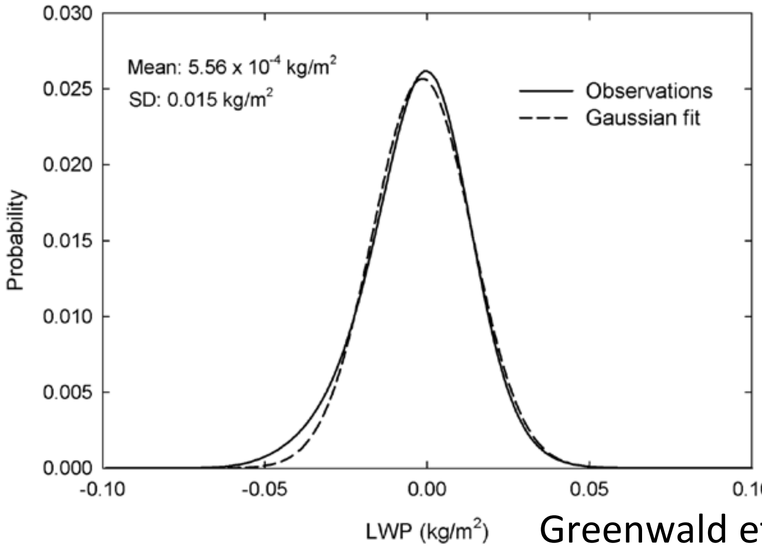


Painemal et al. 2016

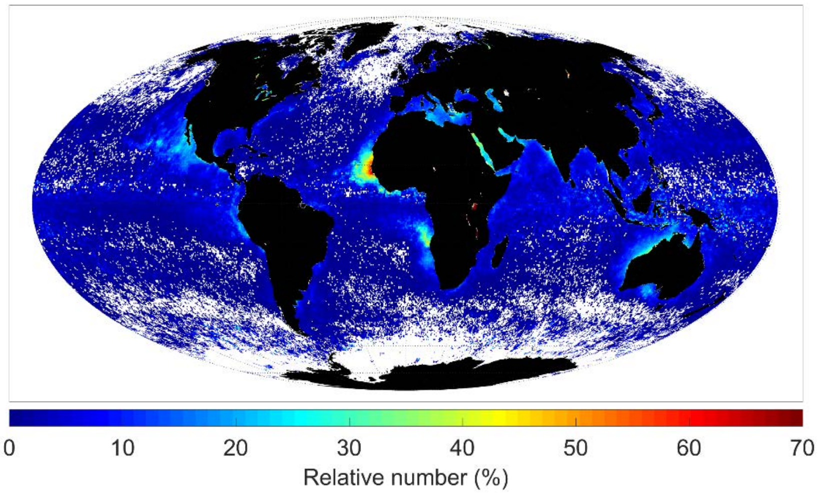
Clear-Sky Bias

- Bias varies with surface wind speed and TPW

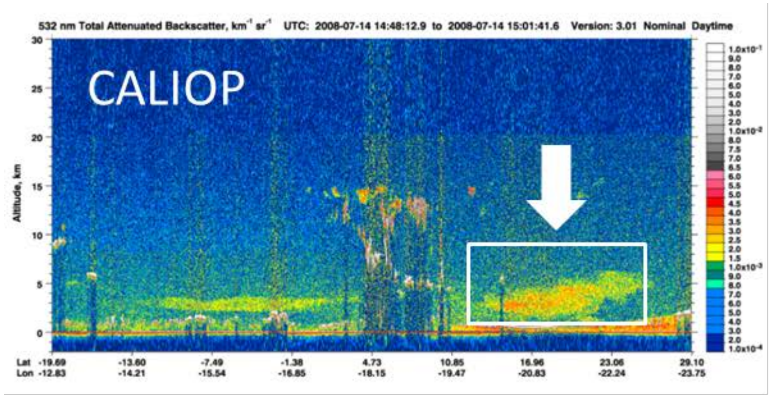


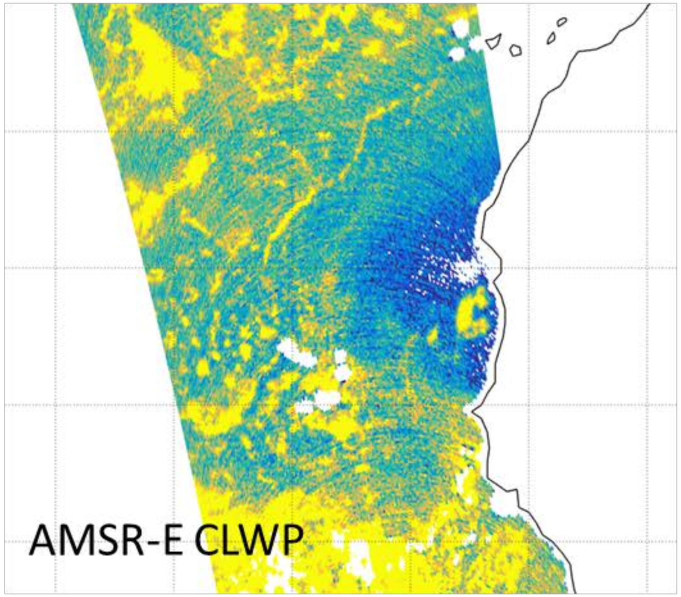


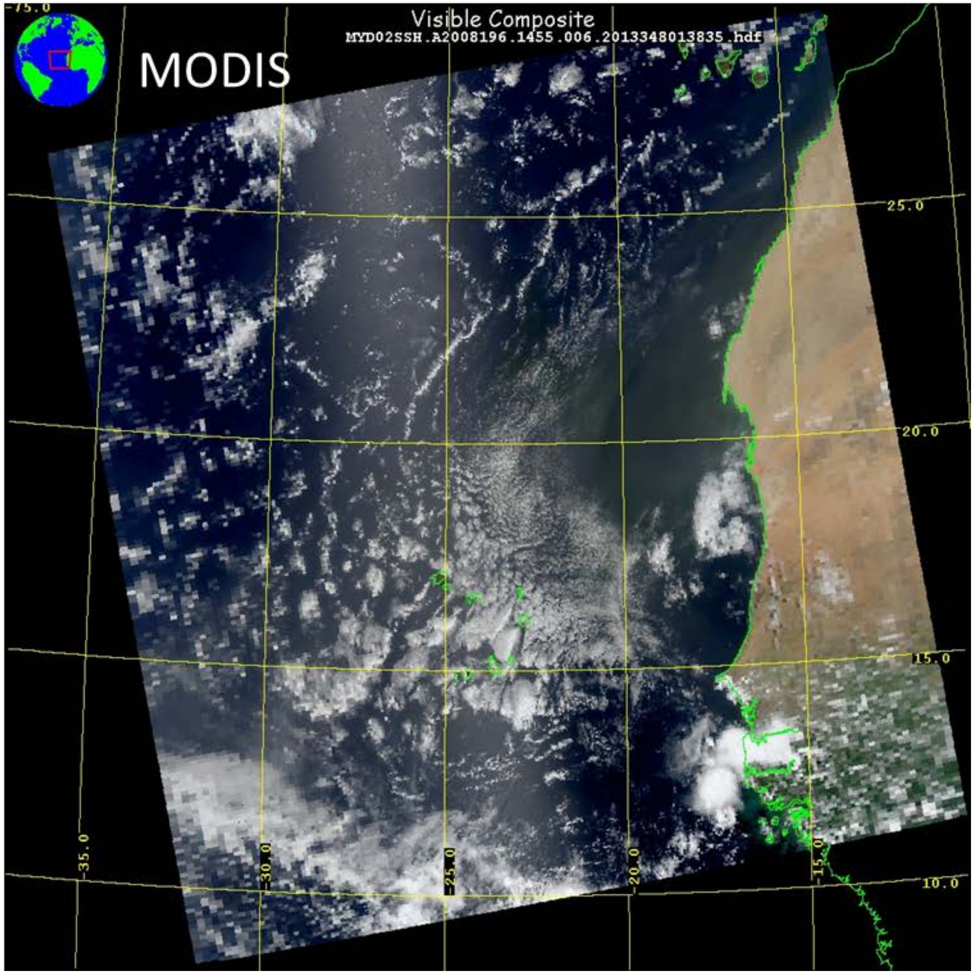
Greenwald et al. 2018



Dust: A New Source of Error?



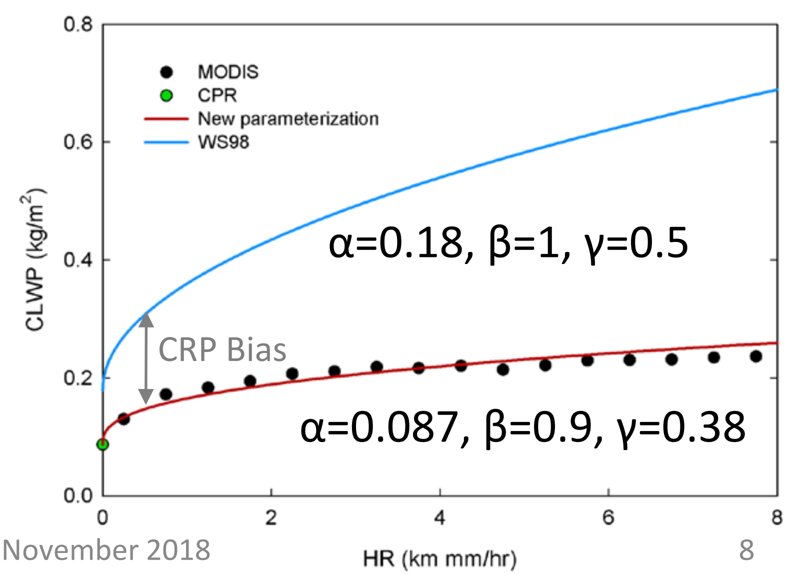




Cloud-Rain Partition Bias

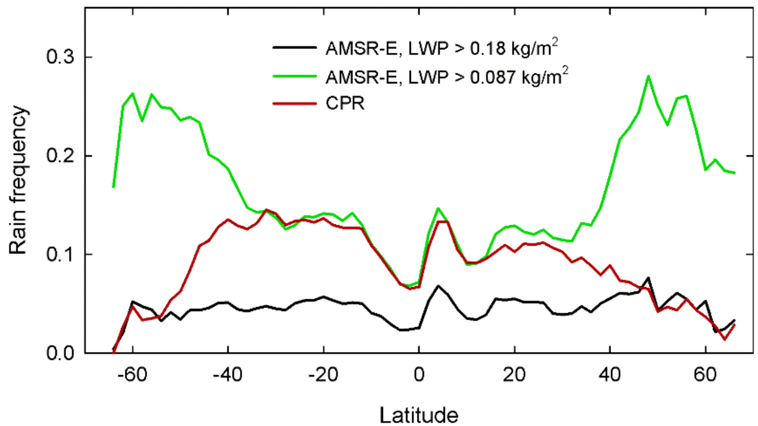
- Improved cloud-rain partition parameterization for warm clouds using the 2008 collocated multisensor dataset
  - MODIS cloud mask, $CLWP_{0.86/3.7}$
  - AMSR-E R, 36.5 GHz τ
  - CPR RWC, H, CLWP
  - CALIOP CTT
- Restrictions
  - Overcast AMSR-E FOVs
  - SZA < 45^{o}

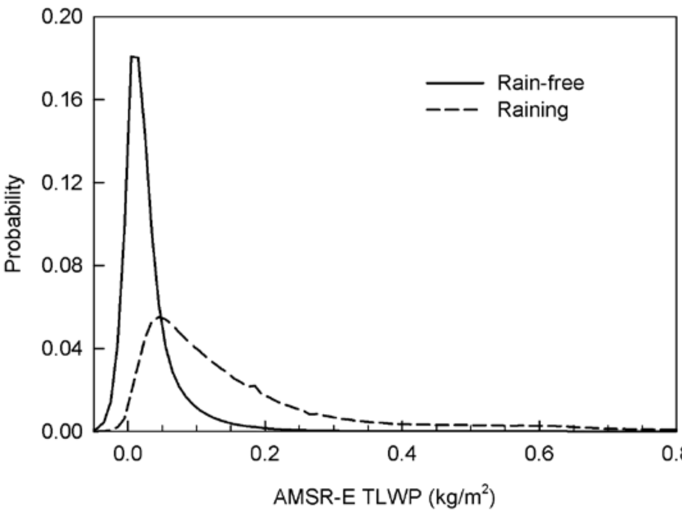
$$CLWP = \alpha\,(1+\beta(HR)^{\gamma})$$



Limits of Drizzle/Rain Detection

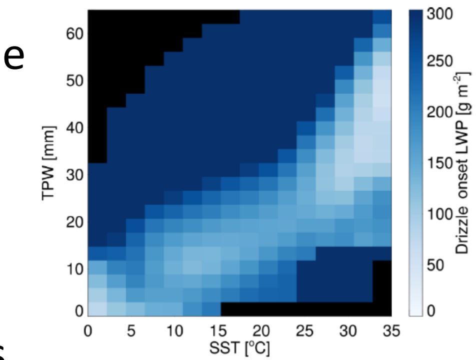
Greenwald et al. (2018)



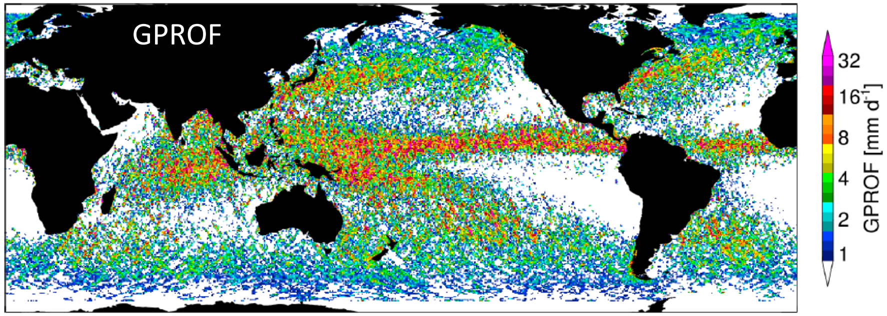


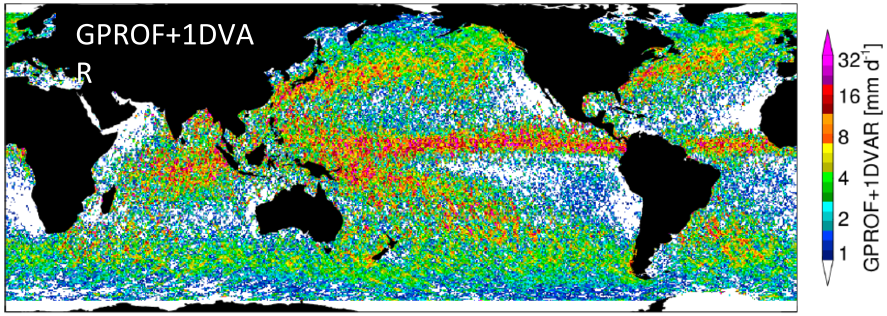
Improved sensitivity to drizzle and light rain:

- Variable LWP threshold
- 1DVAR with error co-variances derived from in situ dropsize distributions



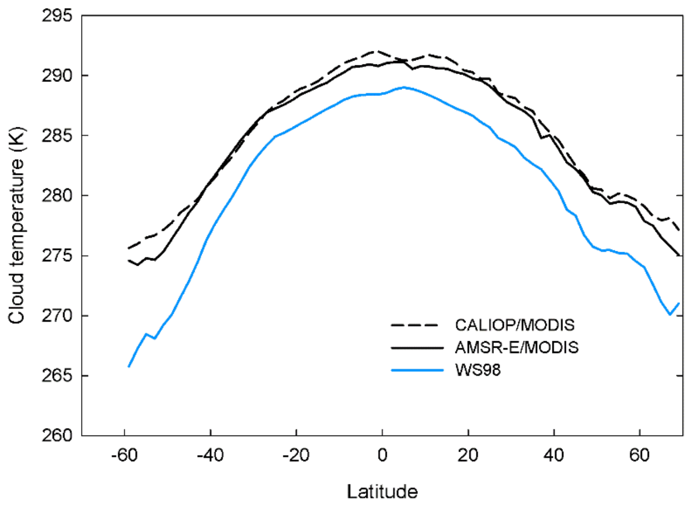
Duncan et al. (2018)

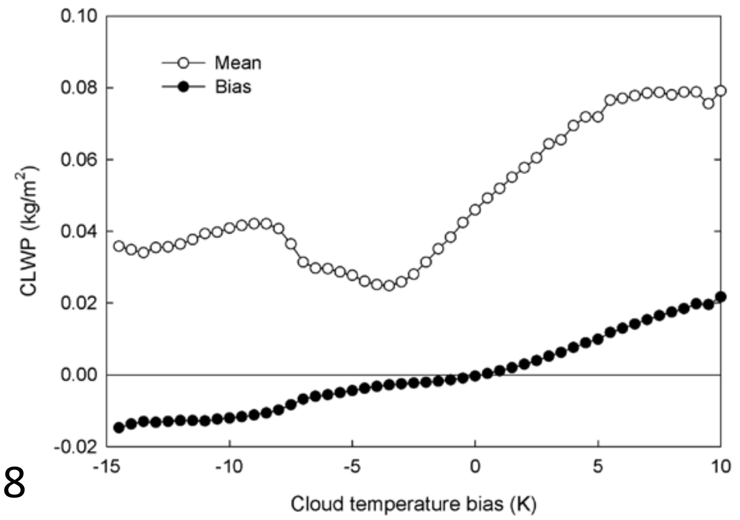




Cloud Temperature Bias

- 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

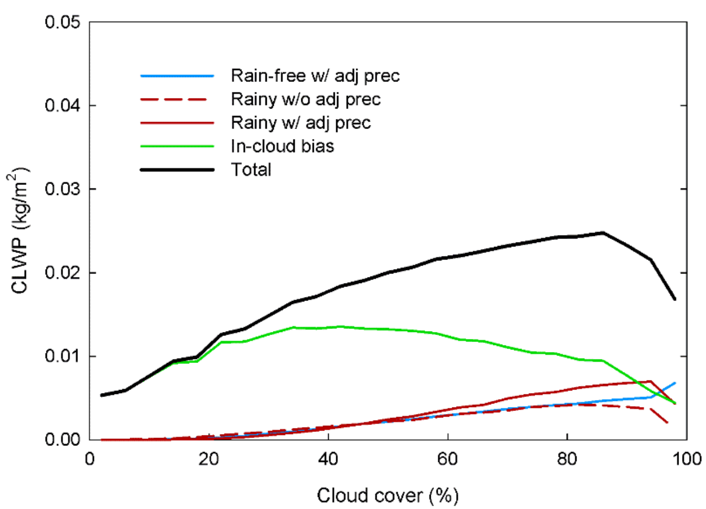




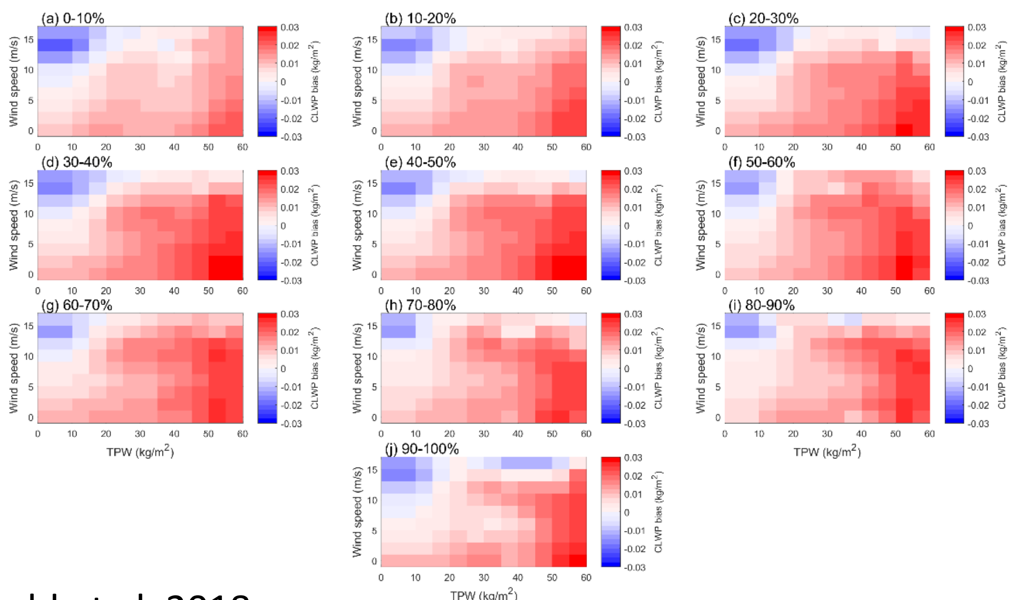
Greenwald et al. 2018

Cloud-Fraction-Dependent Bias

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



In-cloud bias characteristics



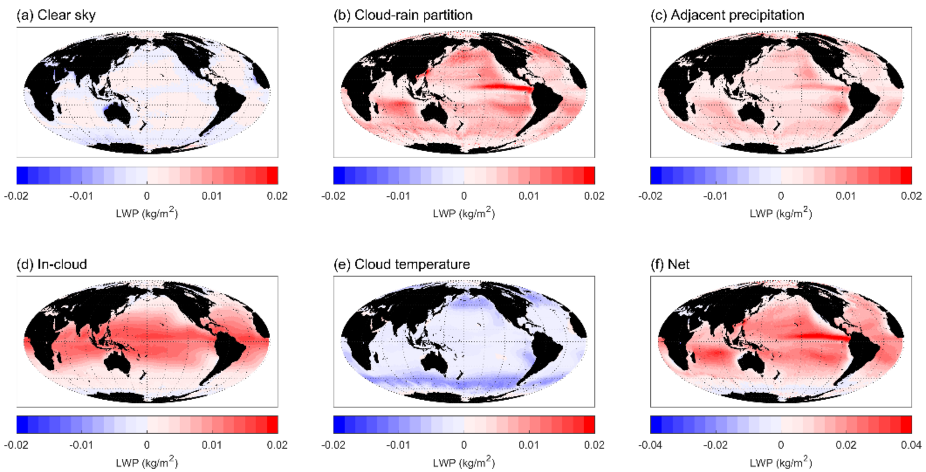
Greenwald et al. 2018

Applying the Error Analysis

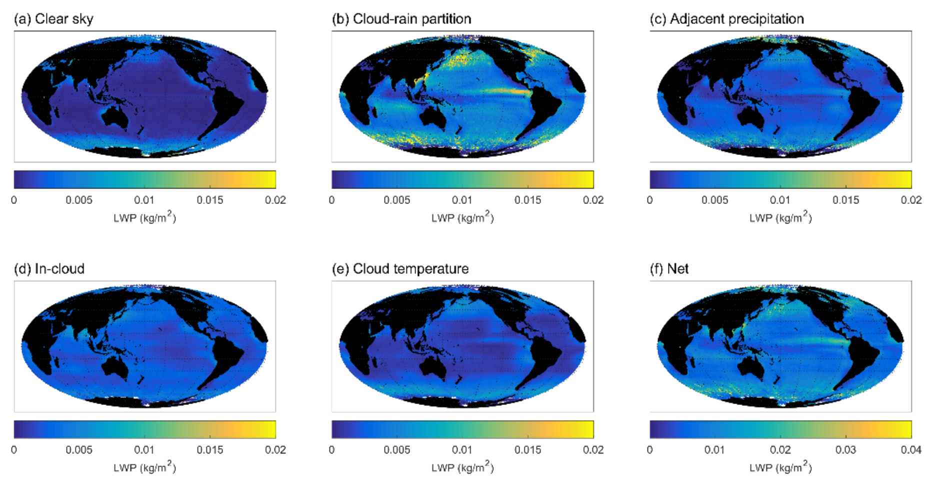
- Clear-sky bias
  - AMSR-E CLWP
  - MODIS cloud mask
- Cloud-rain-partition bias
  - AMSR-E R, $\tau_{36.5}$
  - MODIS cloud mask, CTT/CTH
- Cloud temperature bias
  - AMSR-E CLWP, SST
  - MODIS cloud mask, CTT/CTH
- Cloud-fraction-dependent bias
  - AMSR-E CLWP, TPW, wind speed
  - MODIS cloud mask, CTT

Space/Time Variability of Errors

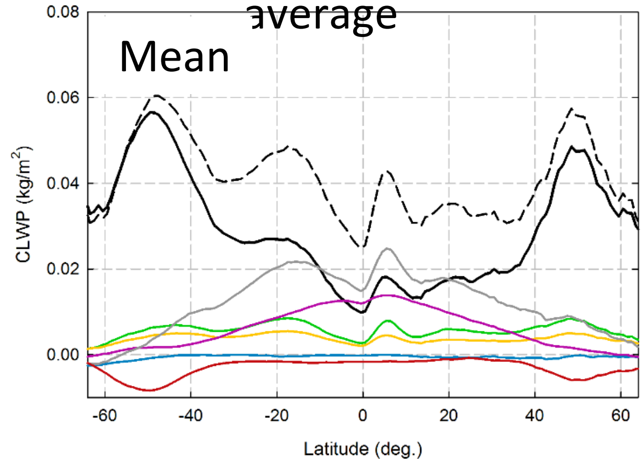
9-yr Mean

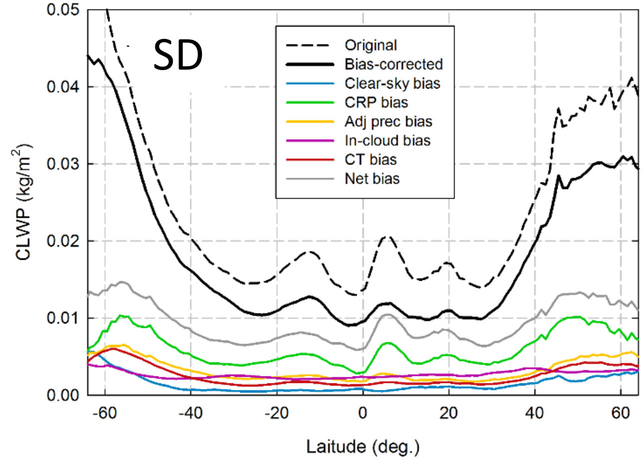


Interannual SD



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