An 89 GHz Passive Microwave Warm Rain Product Calibrated Using the CloudSat CPR

Ryan Eastman\textsuperscript{1}, Matthew Lebsock\textsuperscript{2}, Robert Wood\textsuperscript{1}

University of Washington Dept. of Atmospheric Sciences\textsuperscript{1}, Jet Propulsion Laboratory\textsuperscript{2}
CloudSat/CALIPSO, April 2018
Inferring precipitation from 89 GHz Tb

- Brightness Temperature (Tb) retrieved by AMSR/E is highest where cloud liquid water path (LWP) is greatest and where clouds are thickest.

- These bright regions see a much greater likelihood of precipitation.

- Variance in AMSR/E 89 GHz Tb corresponds to LWP variations on spatial scales equivalent to individual boundary layer cloud cells.
• Currently studying the subtropics where warm rain/drizzle are frequent while overlying ice is uncommon.

• These regions are chosen because they contain the maxima in stratiform cloud cover as well as the declining gradient offshore where stratiform clouds give way to trade cumulus.
Collocated CloudSat and AMSR/E observations

- The A-Train allows us to directly compare rain rate to Tb.
- CloudSat observations coincide with AMSR/E 89 GHz Tb retrievals in both space and time.
- Rain-Profile rain rate estimates coinciding with Tb values can be used to discern rain rate from Tb.
The CloudSat footprint is much smaller than the AMSR/E 89 GHz Tb footprint

- Roughly 9 CloudSat observations coincide with an AMSR/E pixel
- ‘Collocated’ observations are joined by a blue line

- Can treat each individual collocated observation independently
- Can derive statistics within each AMSR/E Tb pixel
Collocated CloudSat and AMSR/E observations

• Using data from all of 2007
• Treating each individual collocated observation independently
• Rain rate is greater when Tb is warm
• Considerable spread is shown in the individual points (blue dots), two likely reasons:
  • Varying background emissions from other variables
  • Spread in CloudSat rain rates within each Tb pixel
Differences in background variables

• There are many other emitters of microwaves, not just cloud LWP.
  • Column Water Vapor
  • Sea Surface Temperature
  • Wind speed alters surface roughness, microwave emission.

• The rain rate/Tb relationship differs depending on these other variables.
  • Equivalent rain rates show differing Tb values with differing background states

• Overlying ice can also alter retrieved Tb, so must be accounted for.
Differences in background variables

• The relationship between \( T_b \) and rain rate is modified by the column water vapor \( (CWV) \), sea surface temperature \( (SST) \), and 10-meter wind speed \( (WSP) \)
  • For each collocated observation, these variables are determined and are plotted against one-another in a 3-dimensional grid
    • x-axis: \( CWV \), y-axis: \( SST \), z-axis: \( WSP \)
• 2-dimensional projections are shown here
• Cube is divided into cubic bins
  • Width: 1 standard deviation of each variable
  • \( T_b \) – rain rate is determined for each bin
Rain rate statistics within each pixel

• Multiple CloudSat soundings actually coincide with each Tb pixel

• Allows us to compute several statistics for each pixel, rather than treat each CloudSat observation independently
Rain rate statistics within each pixel

- **Probability of rain**
  - 0 if no precip is observed
  - 1 if any CloudSat rain is seen

- **Mean rain rate**
  - The mean of all CloudSat rain rates, drizzling or not

- **Mean rate when raining**
  - The mean of only the drizzling CloudSat obs

- **Maximum rain rate**
  - The highest observed CloudSat rain rate
Rain rate statistics within each CWV/SST/WSP bin

- Within each CWV/SST/WSP bin we compute these statistics as a function of Tb, apply fits.
  - Noise is reduced by calculating the mean statistics for every 20 pixels along x (red dots)
  - Pixels are only included if no overlying ice is observed
- The fit for probability of rain as a function of Tb is done using the function $T_b = \text{logit}(p)$

\[
\text{logit}(p) = \log \left( \frac{p}{1 - p} \right)
\]

- $T_b = \text{logit}(p)$ is linear, so a linear least squares fit is computed.
- Function asymptotes to 0 and 1 at low and high $T_b$. 
Rain rate statistics within each CWV/SST/WSP bin

- The fit to the rain rates as a function of 
  Tb is done using a power law relationship:

  \[ \text{rate} = A \times T_b^B + C \]

- Coefficients A, B, and C are determined 
  using a robust fitting routine.

- Using these fits, rain rates and 
  probabilities can be estimated directly as 
  a function of Tb within each 
  CWV/SST/WSP bin.
Rain rate statistics for all available CWV/SST/WSP bins

• These fits are done for all possible CWV/SST/WSP bins.
  • Fits are only calculated for the range of temperatures seen in our collocated data.
    • Fits only used for interpolation, NOT extrapolation.
  • CWV/SST/WSP bins need to have at least 60 observations in order to compute a fit, though most have substantially more.

• The coefficients that produce these probabilities and rates as a function of Tb are then applied to all Tb data in our subtropical regions to estimate rain rates.
Case study: Precipitation in NE Pacific, January 23 2007
Case study: Precipitation in NE Pacific, January 23 2007
Verifying against CloudSat

• Compare AMSR/E statistics back against collocated CloudSat observations.
  • Mean CloudSat statistics for all CloudSat observations within a 0.1 mm/hr bin of AMSR/E rain rate data.
  • Agreement is strong, especially at rates below 1 mm/hr.
  • Variance increases with rain rate until around ~2mm/hr, when variance decreases
    • Possibly because heavier rates are associated with larger cells?
• Standard error continues to increase with rate due to declining #’s of obs
Comparing with existing AMSR/E RAIN

- Existing rain rate data from AMSR/E (AMSR/E RAIN)
  - Uses lower frequency channels and offers resolution at 0.25° lat/lon.
  - Existing product is sensitive to higher rain rates and more convective rainfall, but misses most drizzle,
- In the subtropics, the 89 GHz data appears much more sensitive than the currently available product
Comparing with existing AMSR/E RAIN

- Spatial comparison shows differences in resolution and sensitivity
  - 89 GHz assumed to be drizzling if probability > 0.5
  - Existing product misses ~70% of the drizzle seen by 89 GHz
  - 89 GHz misses 19% of existing products rainfall
    - Mostly due to removal of ice clouds
- RAIN misses most light drizzle
Comparing with existing AMSR/E RAIN

- % of co-occurring RAIN observations per bin of 89 GHz drizzle rate
- RAIN misses most light drizzle seen by 89 GHz rain product.
  - At low rain rates (<0.3 mm/hr), RAIN detects <25% of the drizzle seen by our 89 GHz product
  - Agreement improves substantially at rates greater than ~0.75 mm/hr.
Conclusions

• The collocation of CloudSat and AMSR/E in the A-Train allow us to directly compare CloudSat rain rates to 89 GHz brightness temperatures (Tb), which are warmer for higher LWP.

• After controlling for other variables that modify Tb, the relationship between rain rate and Tb becomes clearer
  • Column Water Vapor (CWV)
  • Sea Surface Temperature (SST)
  • 10-meter Wind Speed
  • Ice clouds are filtered out
Conclusions

• Numerous CloudSat observations within each Tb pixel allows for the calculation of several statistics associated with each Tb value:
  • Probability of rain
  • Mean rain rate
  • Mean rate when raining
  • Maximum rain rate

• Statistics for each Tb value are calculated within CWV/SST/WSP bins using fits to collocated data, and are available for all available subtropical AMSR/E 89 GHz Tb values in 2007.

• Data for light rain compare favorably with CloudSat, near 1:1.

• 89 GHz drizzle outperforms existing AMSR/E RAIN product, particularly when rain rates are less than 0.75 mm/hr.
Acknowledgements

• NASA Grant # NNXBAQ35G
• Peter Blossey, Matt Wyant, Hans Mohrmann, Andy (Kuan Ting) O, Sam Pennypacker, Isabel McCoy, Michael Diamond, Sarah Doherty