Joint Variability of Airborne Passive Microwave and Ground-based Radar Observations Obtained in the TRMM Kwajalein Experiment

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Introduction

**Goal:** Use field experiment observations to evaluate the underlying physical theory of passive microwave precipitation retrieval that relates brightness temperatures (Tb) to surface rainfall (R).

- Satellite passive microwave precipitation retrievals, particularly over the tropical ocean, are key components of merged precipitation products such as the GPCP annual average map (above left).
- The detailed pattern of passive microwave precipitation rate (TMI) is often at odds with measurements from more accurate radar sensors (PR).

The Tropical Rainfall Measuring Mission (TRMM) Kwajalein Experiment (KWAJEX) was held from July-September 1999 in the west Pacific and was designed to obtain an empirical physical characterization of precipitating convective clouds over the tropical ocean.

- Coordinated data sets were obtained from aircraft and ground-based sensors including passive microwave measurements from the Advanced Microwave Precipitation Radiometer (AMPR) on the NASA DC-8 aircraft and volumetric radar reflectivity data from a ground-based S-band radar (KPOL).
- AMPR and KPOL measurements were processed to yield over 24,000 temporal and spatial matching observations within 6 min coincidence.
  - The raining subset of 5 along-track x 4 cross-track AMPR super-pixels were averaged to yield 7 cross-track AMPR super-pixels (4 x 3.2 km²).
  - Each AMPR super-pixel was matched to the nearest 2 x 2 km² interpolated KPOL radar pixel in 1.5 km altitude layers starting at 1.5 above sea level.

**Table 1.** Sample size of coincident AMPR and KPOL super-pixels categorized by subsets obtained within convective and stratiform regions and by incidence angle.

<table>
<thead>
<tr>
<th>Incidence Angles</th>
<th>Convective Precipitation</th>
<th>Stratiform Precipitation</th>
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</thead>
<tbody>
<tr>
<td>Angles</td>
<td></td>
<td></td>
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<tr>
<td>25.2° to -25.2°</td>
<td>7399</td>
<td>17370</td>
</tr>
<tr>
<td>Nadir only (0°)</td>
<td>1066</td>
<td>2553</td>
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Passive microwave Tb are the result of column scattering and absorption properties of precipitation, cloud and water vapor. At frequencies < 22 GHz absorption by liquid water dominates. For a given freezing level height, absorption and associated Tb increase with increasing layer-average rain rate until about 20 mm/hr (42 dBZ). At frequencies > 60 GHz, ice scattering dominates and yields decreasing Tb for increasing ice particle concentration and size. Based on model output, the impact of partially melted particles on measured Tb is estimated to account for increases of up to 43 K at 9.7 GHz, 28 K at 19 GHz and 10 K at 85 GHz (Olson et al., 2001).

Several recently recognized sources of uncertainty in the relationship between passive microwave brightness temperatures and surface rainfall are minimized in the KWAJEX data sets:

- The freezing level height (rain layer depth) is nearly constant at 4787 m ± 35 km (35 km, 85 GHz: 7.7 km).
- AMPR nadir pixels observe the atmospheric column at 0° incidence angle used as a proxy for surface rain rate (R) dBz/10 = log10(a) + b log10(R) a=160 and b=1.5 based on Kwajalein disdrometer data (Houze et al., 2005).
- Distribution of super-pixel rain layer reflectivities (left) and a map (left) showing objectively classified convective (green) and stratiform (blue) regions. Light gray indicates z < 15 dBz and dark gray in echo.

Results

<table>
<thead>
<tr>
<th>Convective</th>
<th>Stratiform</th>
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<tr>
<td>19 GHz</td>
<td>10.7 GHz</td>
</tr>
<tr>
<td>85 GHz</td>
<td>85 GHz</td>
</tr>
</tbody>
</table>

Scatterplots of super-pixel KPOL rain layer reflectivity and AMPR radar-only Tb for indicated channels. (left column) convective precipitation regions, (right column) stratiform precipitation regions. Horizontal lines indicate mode in distribution of all AMPR super-pixels in that category. Distributions for all AMPR points (not shown) are similar to radar points.

Conclusions

- **For tropical, open ocean, deep convection observed in KWAJEX,** there is a factor of 4 variation in R for a given Tb when relating aircraft-observed Tb to rain-layer rain rate.
- **Observed variation in 19 GHz Tb for a given R is equivalent to ~4 km variability in freezing level height in Wihlet et al. (1977) calculations.**
- **Uncertainties in relating Tb to R are larger in convective precipitation regions compared to stratiform regions which have narrower melting layers and more large ice particles (D > 2 mm).**
- **Model-based estimates of the impact of partially melted particles account for less than half of the observed Tb variation.**
- **The current use of TMI 85 GHz Tb for the detailed rain rate pattern in TRMM products is likely a large source of error in these patterns since higher spatial resolution 85 GHz Tb at 0° incidence contain little information on the rain-layer rain rates.**
- **The practical impact of the poor instantaneous correlations between Tb and R and resulting uncertainties in rainfall retrieval will be difficult to mitigate unless satellite sensors can distinguish among precipitation structures that yield different sub-ranges of Tb for a given R.**
- **Satellite passive microwave may be better suited to area-threshold methods of precipitation estimation (e.g. GPI) rather than quantitative rain rate retrieval.**

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