Long-term observations of precipitation by vertically-pointing radars

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Introduction

We have calibrated vertically-pointing, dwelling radars using collocated rain gauges (Hartten et al., 2019; Johnston et al., 2017; Hartten and Johnston, 2014). These calibrations used single events of 4 to 21 h duration. Using total rain accumulation as a calibration standard helps to average out the temporal and spatial sampling differences between these instruments.

This presentation examines longer periods using these calibrations. Questions to be answered by this research have both instrumentation and meteorological importance:

1. How accurate are the calibrations of the radars?
2. Are the calibrations stable?
3. Are the assumptions used in these calibrations valid?
4. What problems are observed that limit the usefulness of the data?

Two radar systems are examined:

- four months of data from the NOAA TOGA COARE 915-MHz wind profiler located at Manus Island, Papua New Guinea
- nine months of data from the NOAA Snow-Level Radar (SLR) operated in Plymouth, New Hampshire (PMH).

The Manus Island radar was carefully calibrated using two techniques by Hartten et al. (2019). This calibration used four events with a total accumulation of 42 mm. The PMH radar was calibrated using a stratiform rain event on 10 December 2014 (8.9 mm accumulation over 6.5 h).

Discussion

Plots of total observed precipitation accumulation (top panel) show that the calibrations are stable and close. These plots also show there are problems with the quality of the data.

One glaring problem from the Manus radar is the 70 mm jump in the 322 m range on 9 January 1993 (near the center of the plot). This jump occurred in one 30 s dwell and was caused by a strong echo (probably an airplane) that was incorrectly classified as precipitation.

PMH shows a similar large jumps on 14 May. A large interfering signal, persisting for several hours caused these jumps. Also, in the PMH radar, there is a tendency in the lowest gates for there to be apparent precipitation accumulation during periods when the rain gauge is not showing accumulation. These are caused primarily by birds and insect echoes that are mis-classified as precipitation.

The center panel shows good calibration results. The Manus example is one of the cases used for the calibration. The PMH example was chosen since the event had the most accumulation of several cases examined.

The lower panel shows examples of the main problems with these two sets of data:

- The Manus radar was deployed to measure winds, so it did not observe overhead continuously. In the period near 3:30, the rain gauge shows rain accumulation happening that is not observed by the radar.
- In the example shown for the PMH radar, the rain gauge observes 3 mm during the last half hour of the day, while the radar reports 4.2 mm prior to the last half hour due to returns from insects and birds.

Conclusions and future work

An obvious first step is to work on data quality issues. Both radars suffer from bad data values which contribute significantly to the long-term accumulations. Here are some tentative answers to the original questions, subject to improved data quality for final answers:

1. How accurate are the calibrations of the radars?

   Based on a survey of several cases, my current estimate for both radars is the reflectivity calibrations are within ±1.5 dB.

2. Are the calibrations stable?

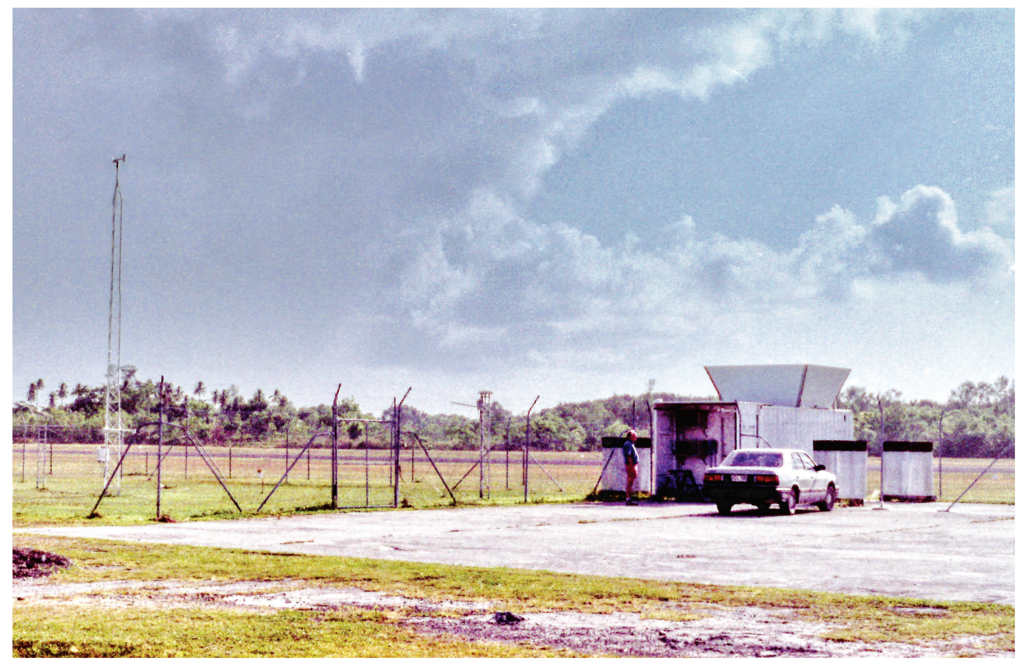
   The calibrations appear to be stable. The good example for PMH shows data 2.5 years after the calibration date.

3. Are the many assumptions used in these calibrations valid?
   - The tight grouping of the ranges, esp. for Manus suggests that rain observed on the ground is closely related to the rain overhead, even 1 km above the radar.
   - In both radar time periods, stratiform rain dominated. The use of the Marshall-Palmer Z-R relationship appears to be valid for stratiform rain.
   - A cursory examination suggests Marshall-Palmer is not valid for heavy, intense rainfall, or warm rain.
4. What problems are observed that limit the usefulness of the data?
   - The Manus data has limited applicability for precipitation studies since it does not observe vertically all the time.

There are data quality issues that need to be solved in order to fully validate the calibrations. For the Manus radar, removal of one bad datum would make the upper eight ranges agree very closely. Removal of the 14 May data from the PMH radar would remove a major step in the data not observed by the rain gauge. Additionally, removal of non-atmospheric echoes could change the results significantly.

With a calibrated radar, there are many possibilities for additional studies. For the wind-profiler, knowing the calibration allows the clear-air returns to be calibrated in terms of C_n^2. For the Snow-Level Radar, knowing the calibration is stable means that there is a good possibility of using the power spectral data to determine drop size distributions.

TOGA COARE Site at Momote Airport, Manus Island, PNG



Photograph 1. TOGA COARE site at Momote, Manus Island, PNG. The 915 MHZ wind-profiling radar is mounted in the roof of the sea-container. The angled panels on top of the container shield the antenna from low-angle echoes. The tipping-bucket rain gauge is mounted on a post in the field. The surface meteorological station is mounted on a 10 m tower. Warner Ecklund is watching an airplane arrive in this photograph from 1993.

Google Maps

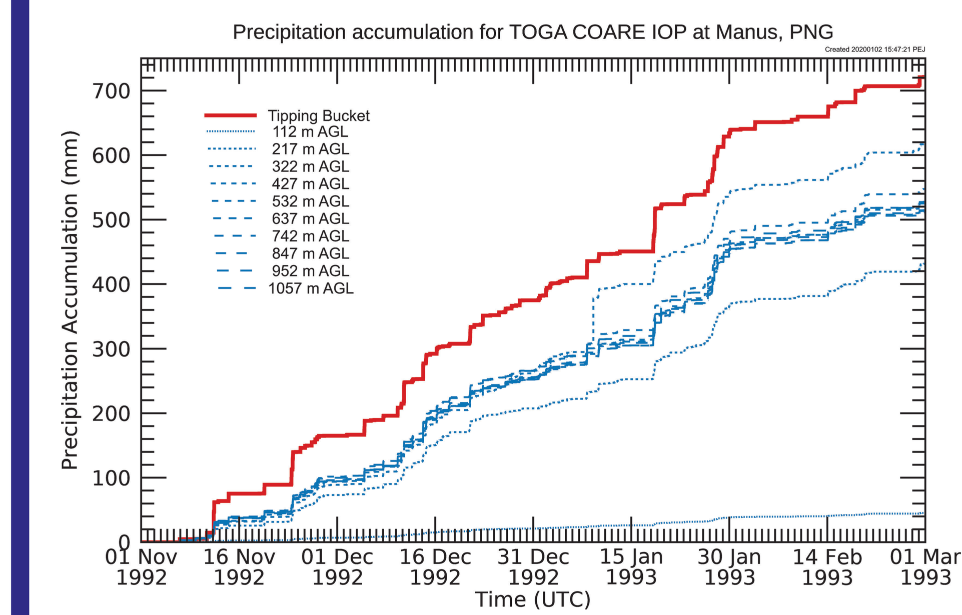
Data Methods

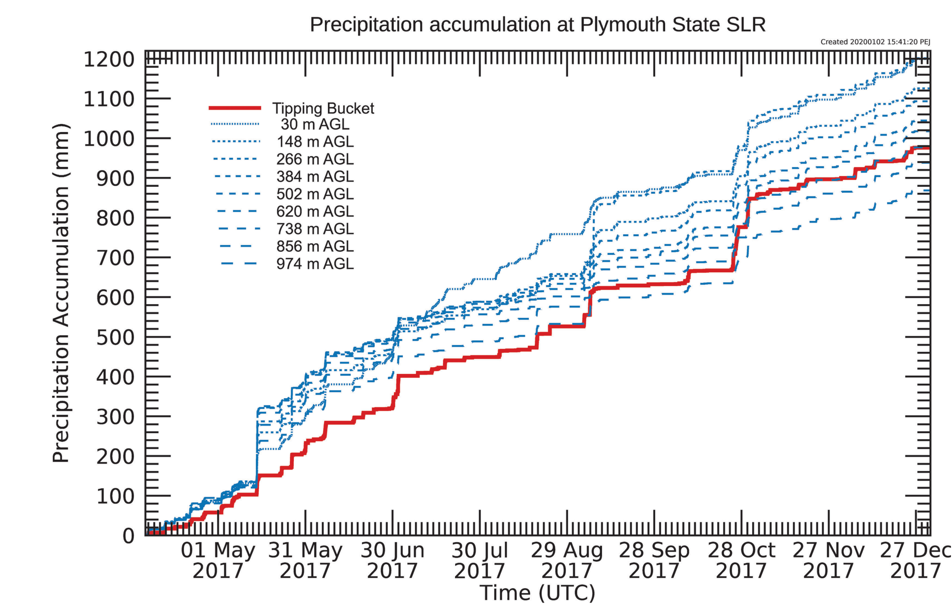
The Manus surface meteorology data was obtained from the COAPS archive. The rain gauge recorded rain in increments of 0.01". The data in the archive is saved in 0.1 mm values, so the smallest rain values are reported as 0.3 mm. This 18.1% difference results in a large total accumulation error, since most of the rain recorded at Manus was 1 tip per record (0.01"/minute). The rain gauge data were corrected to represent multiples of 0.254 mm. One issue that is not well documented is the meaning of the time stamp. My assumption is that the time stamp is the original time stamp from the Campbell CR10 datalogger, which is the end of the data observation period.

The raw spectral data from both radars was processed using the PDAprecipAll software package described in Hartten et al. (2019). This routine does some quality control of the data by classifying the data as rain or not rain. The radar precipitation accumulations only use data that have been classified as rain. The time stamp on all of the radar data records is the beginning of the observation period. Only days with accumulation by the rain gauge have been included.

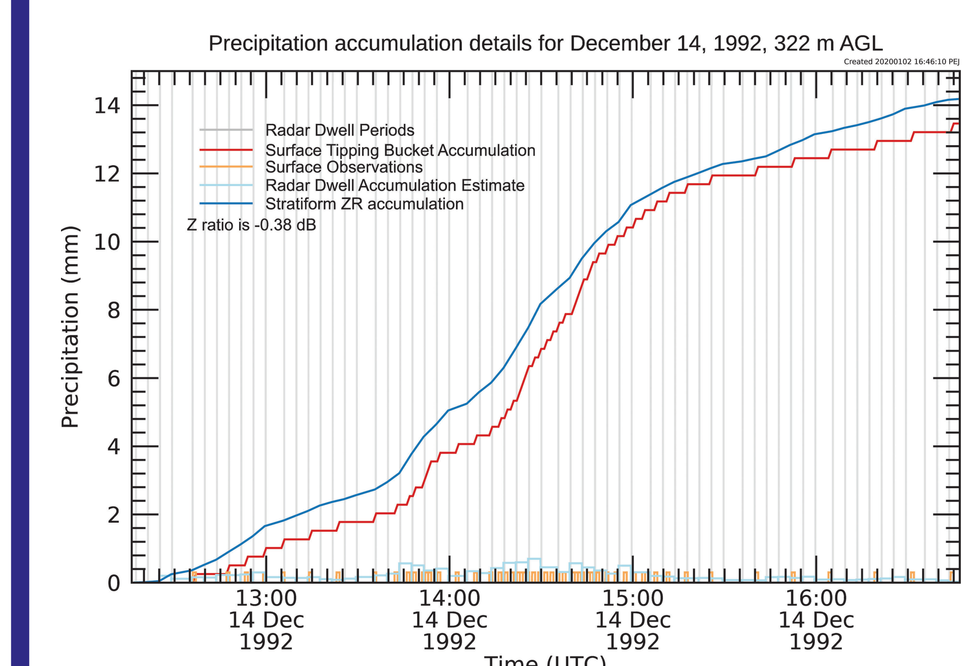
The data from the surface stations and the radar was manipulated and visualized using IDL. This included displaying the data properly relative to the time stamps.

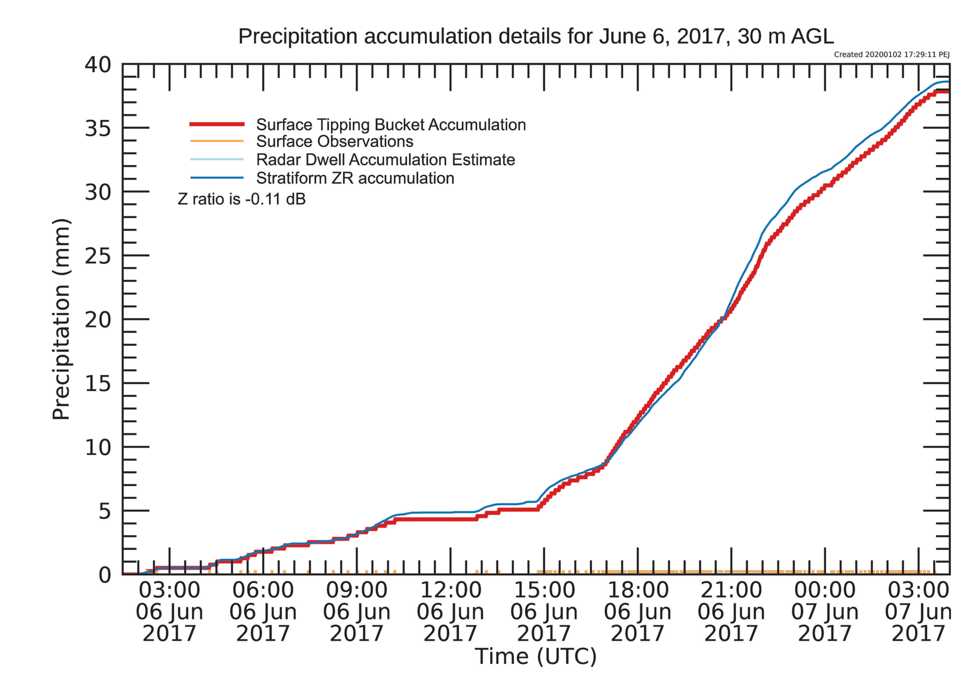
Total observed rain accumulation



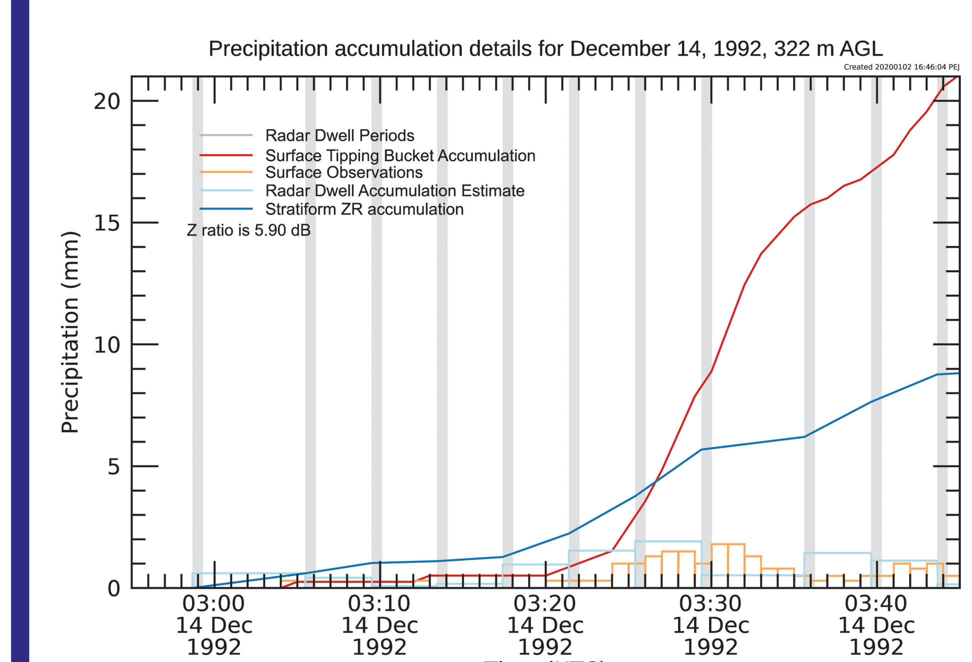


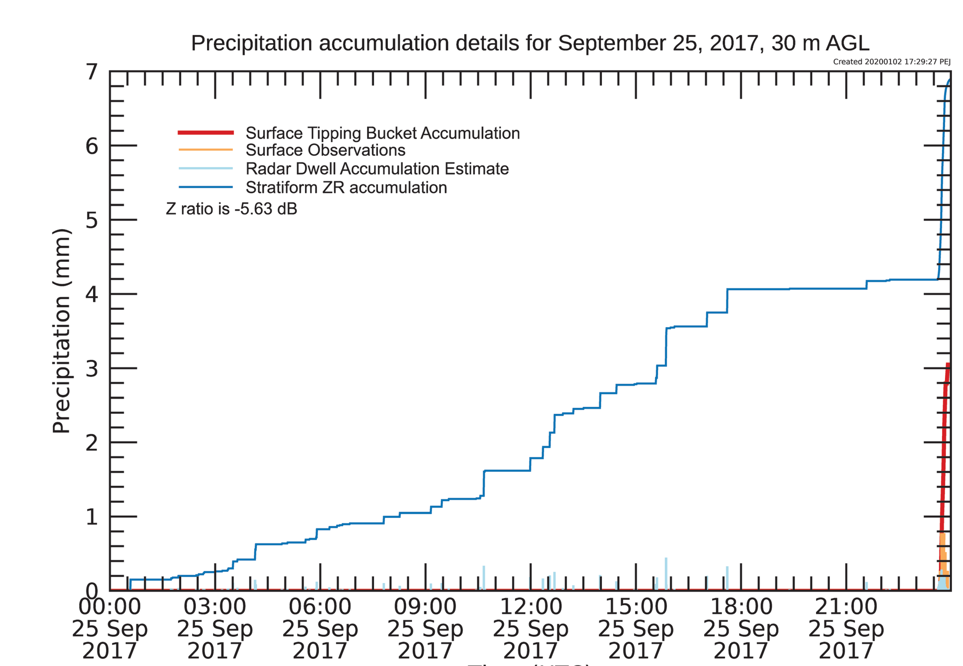
Examples of well calibrated radars





Data problem examples





Pertinent relationships used in this work.

Marshall-Palmer ZR relationship for converting reflectivity to rain rate: $Z = 200R^{1.6}$ or rain rate: $R = \left(\frac{Z}{200}\right)^{1/1.6}$

Total rain accumulation is the sum of individual measurments: $C = \sum_{i=1}^{m} R\Delta t$ So accumulation is $C_{Radar} = \sum_{i=1}^{m}\left(\frac{Z_i}{200}\right)^{1/1.6}\Delta t$

Assuming Z and period are constant, then this can be rewritten as:

$$C_{radar} = \sum_{i=1}^{m}\left(\frac{Z_i}{200}\right)^{1/1.6}\Delta t \approx m\Delta t\left(\frac{\overline{Z}}{200}\right)^{1/1.6}$$ and the equivalent accumulation $$C_{gauge} = n\Delta t_{gauge}\left(\frac{Z_{new}}{200}\right)^{1/1.6}$$

$$\frac{C_{gauge}}{C_{radar}} = \frac{n\Delta t_{gauge}\left(\frac{Z_{new}}{200}\right)^{1/1.6}}{m\Delta t\left(\frac{Z_{radar}}{200}\right)^{1/1.6}}$$ but $n\Delta t_{gauge} = m\Delta t$ so simplifying gives $$\frac{C_{gauge}}{C_{radar}} = \frac{(Z_{new})^{1/1.6}}{(Z_{radar})^{1/1.6}}$$

$$\Rightarrow Z_{new} = Z_{radar}\left(\frac{C_{gauge}}{C_{radar}}\right)^{1.6}$$ so the approximate ratio is $$10\log\left(\frac{Z_{new}}{Z_{radar}}\right) = 10\log\left(\frac{C_{gauge}}{C_{radar}}\right)^{1.6} = 16\log\left(\frac{C_{gauge}}{C_{radar}}\right)$$

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Snow-level Radar (SLR) at Plymouth State University

Photograph 2. The NOAA Snow-level Radar (SLR) installed near the Grafton Residence Hall on the Plymouth State University campus, Plymouth, New Hampshire. The SLR is an FM-CW radar. The right antenna shroud contains the transmit antenna. The receive antenna is on the left. All radar electronics are inside the enclosure between the antennas. The meteorological surface station is mounted on a tripod near the radar. The tipping-bucket rain gauge is on the crossarm opposite the temperature and relative humidity sensors.

Google Maps

Data Sources

The TOGA COARE surface station data was obtained from the TOGA COARE Surface Meteorology Data Center maintained by the Center for Ocean Atmospheric Prediction Studies (COAPS) at Florida State University (https://www.coaps.fsu.edu/COARE/). The TOGA COARE Manus Island original radar spectral data, and all of data from the SLR from Plymouth State University were obtained from the internal archives at the NOAA/ESRL/ Physical Science Division.

Both photographs were taken by the author.

References

Hartten, L. M., and P. E. Johnston. 2014. 'Stratocumulus-Topped Marine Boundary Layer Processes Revealed by the Absence of Profiler Reflectivity', *Journal of Applied Meteorology and Climatology*, 53: 1775-89.

Hartten, Leslie M., Paul E. Johnston, Valerie M. Rodríguez Castro, and Paola S. Esteban Pérez. 2019. 'Postdeployment Calibration of a Tropical UHF Profiling Radar via Surface- and Satellite-Based Methods', *Journal of Atmospheric and Oceanic Technology*, 36: 1729-51.

Johnston, Paul E., James R. Jordan, Allen B. White, David A. Carter, David M. Costa, and Thomas E. Ayers. 2017. 'The NOAA FM-CW Snow-Level Radar', *Journal of Atmospheric and Oceanic Technology*, 34: 249-67.

Miller, E. R., and A. C. Riddle. June 1994. 'TOGA COARE Integrated Sounding System Data Report- Volume 1A Revised Edition. Available at NCAR/UCAR Earth Observing Laboratory.

Zhang, Jian, Kenneth Howard, Carrie Langston, Steve Vasiloff, Brian Kaney, Ami Arthur, Suzanne Van Cooten, Kevin Kelleher, David Kitzmiller, Feng Ding, Dong-Jun Seo, Ernie Wells, and Chuck Dempsey. 2011. 'National Mosaic and Multi-Sensor QPE (NMQ) System: Description, Results, and Future Plans', *Bulletin of the American Meteorological Society*, 92: 1321-38.

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