P3A.11 ON THE CHARACTERISTICS OF PRECIPITATION IN THE FLORIDA KEYS:
THE KEYS AREA PRECIPITATION PROJECT (KAPP)

D. B. Wolff[1,2], J. Gerlach[3], D. Marks[1,4], A. Tokay[1,5], B. Fisher[1,2], D. Silberstein[1,4], and J. Wang[1,2]

[1]NASA Goddard Space Flight Center, Code 912, Greenbelt, Maryland 20771
[2]Science Systems and Applications, Inc., 5900 Princess Garden Parkway, Lanham, Maryland 20706
[3]NASA Wallops Flight Facility, Wallops Island, Virginia 23337
[4]George Mason University, Center for Earth Observing and Space Research, Fairfax, Virginia 22030
[5]Joint Center for Earth Systems Technology, UMBC, Baltimore, Maryland 21250

1. Introduction

The Keys Area Precipitation Project (KAPP) was sponsored by NASA's Tropical Rainfall Measuring Mission (TRMM) Satellite Validation Office (TSVO) and ran from August 1 through October 9, 2002. The principal goals of the project were: 1) to study the feasibility of using the Keys area as a primary ground validation site for TRMM and possibly other precipitation missions; and 2) to complement the data set collected in the summer of 2001 during the Keys Area Microphysics Project (KAMP), which was part of the Fourth Convection and Moisture Experiment (CAMEX-IV). While CAMEX-IV-KAMP involved researchers from multiple agencies and universities located over the entire Florida peninsula, KAPP was designed more specifically to study the precipitation characteristics along the lower-, middle- and upper-Keys.

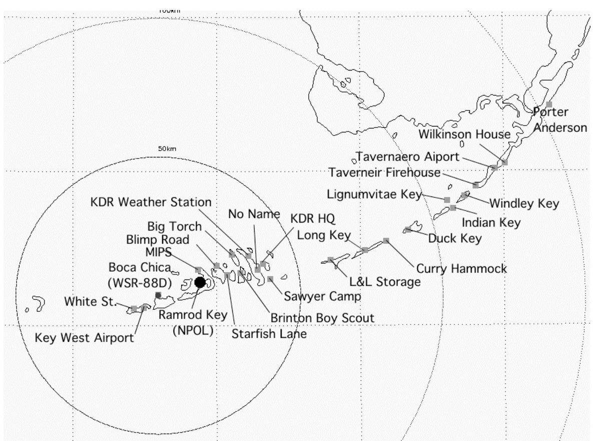

Fig. 1: Illustration of the KAPP observational network. The NPOL radar was located on Ramrod Key. The WSR-88D radar was located on Boca Chica Key. Two disdrometers were also deployed on Big Pine Key and Duck Key.

KAPP was planned, staffed and coordinated by TSVO and NASA/Wallops Observational Sciences Branch (OSB). The experiment would not have been successful without the enthusiastic and dedicated participation of the Florida Parks and Recreation Service, the National Key Deer Refuge Center, Key West National Weather Service Office and several local residents. The TSVO provided a network of rain gauges and disdrometers and collected radar data from the National Weather Service (NWS) WSR-88D radar located on Boca Chica Key. The OSB provided 24 hour observations from the NASA Polarimetric (NPOL) radar. Figure 1 provides an illustration of the gauge, disdrometer and radar network deployed for the experiment.

2. Data Collection

2.1 Gauge data

A total of 24 gauge sites were established. Two gauges were deployed at each site in order to provide the best possible measurements. New gauge data loggers were used in this experiment. TRMM has previously used loggers from Qualimetrics, Inc.; however, it has been observed that these loggers are not reliable over long periods of time, and that they are quite expensive ($700 each). The new loggers, from MadgeTech, Inc. are smaller and less expensive ($179 each) and thus far have shown to be considerably more reliable. One of the major advantages of the new loggers is their small size, which makes it possible to place them in airtight containers within the gauge housing, effectively sheltering them from the harsh tropical environment in which they are deployed.

The gauge sites were operational from August 1, 2002 through October 9, 2002. Manual downloading of the data using a laptop computer was performed on a set, weekly schedule. Due to the remote nature of the some of these gauges, two staff members were used to perform the process. The data consists of ASCII records of the time of each tip, which corresponded to 0.01" (0.254 mm). Approximately four sites were serviced each day. Logging procedures were established so that post-experiment quality assurance could be performed. The data were sent via FTP to NASA/GSFC on a daily basis and were analyzed at GSFC. This procedure allowed the TSVO to detect possible problems early and deal with them accordingly so that little data was lost. There were a few problems reported, such as tidal flooding of the gauge platforms (one site), extraneous tips, and a few logger failures. Of the 43 loggers used during the experiment, there were five failures. These failures were caused by a faulty cable that was used to communicate between the logger

Corresponding author's address: David B. Wolff, NASA/GSFC, Code 912.1, Greenbelt, MD 20771
e-mail: wolff@radar.gsfc.nasa.gov

and the laptop computer. In the future, a new cable will be used at the first sign of a problem. It should be noted that the faulty loggers were sent back to the manufacturer and they were able to extract the data, so no data was lost.

The co-located gauges performed very well with respect to one another and hence provided reasonable confidence that the surface rainfall measurements were of high quality. It is noted, however, that some of the co-located gauges did indeed exhibit some differences. These differences can be contributed to one or a combination of the following: 1) calibration differences between the gauges themselves; 2) wind-induced biases; 3) timing differences; and 4) natural variability of precipitation over the ~ 1 m separation of the co-located gauges.

Both south-north and east-west gradients of rainfall were observed. At upper Sugarloaf Key, the gauges measured 0.04 to 0.1 mm h^{-1} higher rain rates than those on lower Sugarloaf Key. Similarly, the two sites at upper Big Pine Key measured 0.08 to 0.11 mm h^{-1} higher readings than the gauges at lower Big Pine Key. Lower Big Pine, No Name, and Marathon Keys, all on the east side of the gauge network, were relatively drier with unconditional rain rates of 0.14 - 0.16 mm h^{-1}. The remaining sites had rain rates higher than 0.2 mm h^{-1}. Generally, rain intensities were higher and lasted longer on the north side than on the south side of the same Key. Similarly, rain intensities were higher and lasted longer on the western Lower Keys than on the eastern Lower Keys and Marathon Key.

2.2 Disdrometer Data

Two separate disdrometer sites were established to complement the gauge and radar observations. One was located at the National Key Deer Refuge on Big Pine Key. The second was on Duck Key, at the staff residence. Preliminary results indicate that the drop size distributions obtained during KAPP are remarkably similar to those observed during KAMP (not shown).

The composite drop spectra derived from the two disdrometer records showed similar characteristics. The similar structure of size spectra was also evident between KAPP and KAMP. This indicates that the empirical relations derived from disdrometer observations were robust and representative of summer months. Interestingly, the composite spectra of the Florida Keys experiments agreed well with similar observations taken in Central Florida (TEFLUN-B) and the Amazon basin of Brazil (TRMM-LBA), but differed from observations at oceanic sites such as Kwajalein (KWAJEX) and Western Pacific warm pool (COARE). This is somewhat paradoxical because radar analysis showed that the dominant precipitation systems generally developed over the Atlantic Ocean and moved westward to the Gulf of Mexico. At a given reflectivity, more large drops than small drops were observed in continental rain, while the reverse was true for oceanic rain. Since the spectra with more small drops result in higher rain rates, the derived relations between reflectivity and rain rate ($Z = A \bullet R^b$) had a higher coefficient A, in continental rainfall than oceanic rainfall for a fixed exponent b.

2.3 Radar Data

The NPOL radar was deployed during KAPP and provided around the clock observations throughout the experiment. NPOL was deployed to provide estimates of the large-scale drop size distributions and precipitation estimates over the Keys.

The NPOL antenna is a Malibu Research Inc. "FLAPS" antenna consisting of crossed dipole reflectors at the vertices of an open mesh flat surface. The phase of the reflected signal reaching the feed horn is a function of the length of the dipole. By adjusting the size of the dipoles the antenna was designed to duplicate the characteristics of a standard solid parabolic reflector. The open mesh greatly reduces wind resistance and eliminates the need for a massive pedestal. The dual channel receiver has matched low noise amplifiers and nearly identical wave guide paths for the horizontal (H) and vertical (V) channels. The dual receivers are part of the SIGMET RVP-7 processor. The transmitter is an Enterprise Electronics Corporation S-Band magnetron rated at 850 KW peak power. NPOL is designed to operate in several modes: 1) simultaneously transmitting both H and V, 2) transmitting either H or V or 3) alternating on a pulse to pulse basis between H and V. In all modes, the dual receivers continuously receive power in both the H and V channels.

The WSR-88D radar located on Boca Chica Key also provided an important dataset for validation estimates. A Digital Subscriber Line (DSL) modem was installed at the Key West NWS Forecast Office and was used to transfer the radar data to GSFC in near real-time. Actually, the data was first sent to the National Climate Data Center in Asheville, NC and then was piped to GSFC. The latency for the data transfer was on the order of 5-10 minutes. During the KAMP program, nearly 25% of the data observed by the radar was lost due to the then-current archival system's repeated failures. The new DSL approach used during KAPP allowed for a nearly complete dataset.

3. Data Analysis

Once the radar, gauge and disdrometer data were collected and quality controlled, the standard Level I-III TRMM Standard Products (TSP) were produced (Marks et al, 2000). Table 1 provides a description of the TSP generated from the KAPP data.

These products, as well as some ancillary products, are used to generate relationships between what the radar observed (radar reflectivity) and what the gauges measured at the surface (rain rate). The methodology to generate these Z-R relationships by TSVO is known as the bulk adjustment method. In essence, the column of reflectivity above each gauge, for each volume scan, is extracted, and is paired with the gauge-observed rain rate near the time of the radar scan (± 7 minutes). These radar/gauge comparisons are written to an intermediate file (IF). One such intermediate file is written per month of observed radar data. Accumulations of rain rates from the radar and accepted gauges (average seven-minute gauge rain rate centered at volume-scan time) are calculated and used to derive independent bulk-adjustments to Z-R coefficients for convective and stratiform rain types.

Approximately one radar volume scan is performed over the gauge locations within the seven-minute time average. Initially, a single Z-R relationship, $Z = 300R^{1.4}$, is used for derived rainfall over the gauges for both rain types. Bulk-adjusted dual classification coefficients are derived from the initial Z-R relationship using the following equations:

$$A_{strat} = 300(R_{strat}/G_{strat})^{1.4}$$

$$A_{conv} = 300(R_{conv}/G_{conv})^{1.4}$$

R_{strat} (R_{conv}) is the stratiform (convective) rain rate accumulation from the radar over all the gauge locations combined, and G_{strat} (G_{conv}) is the stratiform (convective) rain rate accumulation from the gauges. Note that a fixed exponent of 1.4 is used for both rain types. The justification of using a fixed exponent is discussed in Smith and Joss (1997). This bulk-adjustment method of forcing the radar-estimated accumulations to match those from the gauges is justified in order to account for known and unknown adjustments in the radar calibration. The derived bulk-adjusted convective and stratiform Z-R relationships are then applied to quality-controlled reflectivity data (from the lowest beam) to obtain instantaneous surface rainfall rates within 15-150 km of the radar (TSPN 2A-53). Z-R relationships are derived from radar and gauge data from 15-99 km range from the radar, but applied to create rainfall products from 15-150 km range.

It should be noted that the TSVO Version 5 products, which are currently being released, do not use the bulk-adjustment scheme, as it has been determined that use of the Window Probability Matching Method (WPMM) (Rosenfeld, 1994) provides superior estimates on both monthly and shorter time scales (Marks et al, 2003).

3.1 Rainfall Estimates

Figure 5 provides the derived monthly rainfall map for the Keys area using the WSR-88D radar data for August 2001. Each pixel in this map covers a 2 km x 2 km area and the map provides estimates extending 150 km from the radar. There is a noticeable south-to-north gradient, with the heaviest amounts located over the Florida peninsula. In order to evaluate the quality of these rain estimates, the observed radar estimates can be compared to the gauge-measured rates. Figure 6 provides a scatter-plot of radar vs. gauge estimates for August, 2002. On these dependent data, we see that the Mean Absolute Error (MAE) is about 0.19 or 19%. They are also well correlated with a correlation coefficient (r) of 0.90. Figures 7 and 8 similarly provide the monthly rainfall map and scatter-plots for September 2001. Figure 8 illustrates the increased rainfall observed over the Gulf of Mexico (NW quadrant), due to the presence of Tropical Storms Lilly and Isidore. Although the correlations are a bit lower in September, the MAE was reduced to 17%.

Table 1: TRMM Science Data Product descriptions. All products are stored in Hierarchical Data Format (HDF).

Product	*Description*
1C-51	Quality-controlled reflectivity. Non-precipitating echo removed.
2A-53	Area rain rate map. 2 km x 2 km horizontal resolution. 151 x 151 pixels, extending 150 km from the radar.
2A-54	Stratiform/Convective rain type map. 2 km x 2 km horizontal resolution. 151 x 151 pixels, extending 150 km from the radar.
2A-55	3-D Gridded reflectivity. 2 km x 2 km horizontal resolution. 1.5 km vertical resolution (13 levels from 1.5-19.5 km above ground height). 151 x 151 pixels, extending 150 km from radar.
3A-54	Monthly rain accumulation map (mm). 2 km x 2 km horizontal resolution. 151 x 151 pixels, extending 150 km from the radar.

4. Summary and Conclusions

NASA's Tropical Rainfall Measuring Mission (TRMM) conducted the Keys Area Precipitation Project (KAPP) during August-September, 2002. The purpose of the program was to further the characterization of precipitation in the Keys area, and to determine the viability of using the Keys area as a long-term site for TRMM Ground Validation. A total of 24 gauge sites were established. Additionally, NASA's NPOL radar was deployed to provide estimates of drop-size distributions and improved rainfall estimates. Data from the Key West WSR-88D radar was also used for rainfall estimation.

North-South and West-East gradients of precipitation were observed by both radar and gauge measurements. Rain drop size spectra, somewhat surprisingly, agreed well with the similar observations taken in Central Florida (TEFLUN-B) and Amazon basin of Brazil (TRMM-LBA), but differed from the observations taken in oceanic sites such as Kwajalein (KWAJEX) and Western Pacific warm pool (COARE).

Both goals were achieved and it is envisaged that the Keys area will be a highly useful site, both meteorologically and logistically, for further validation studies.

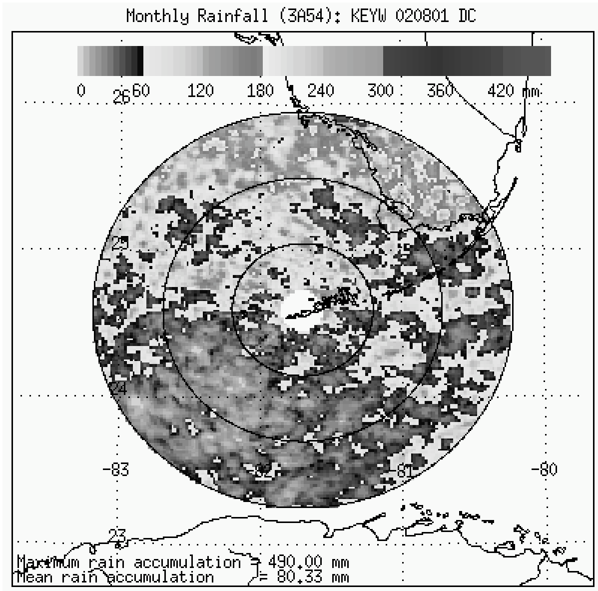

Fig. 5: Monthly WSR-88D rainfall estimate for August 2002. The accumulations were generated using the TRMM GV bulk-adjustment scheme (explained further in the text).

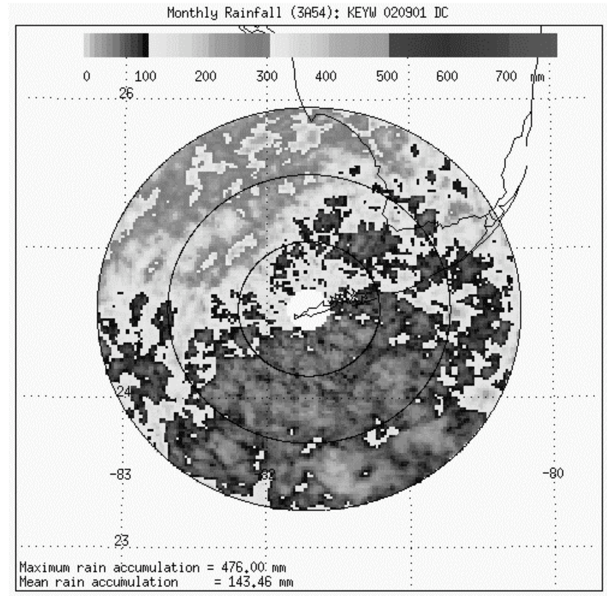

Fig 7: Same as Fig. 5, except for September 2002.

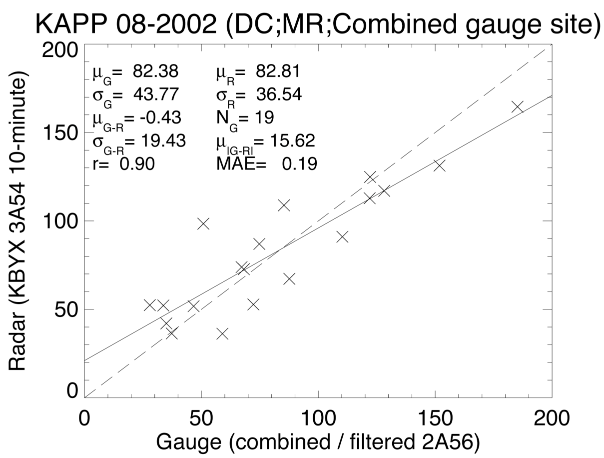

Fig. 6: Scatter-plot of gauge vs. radar monthly rainfall estimates for August 2002. The correlation coefficient and mean absolute error (MAE) are also shown.

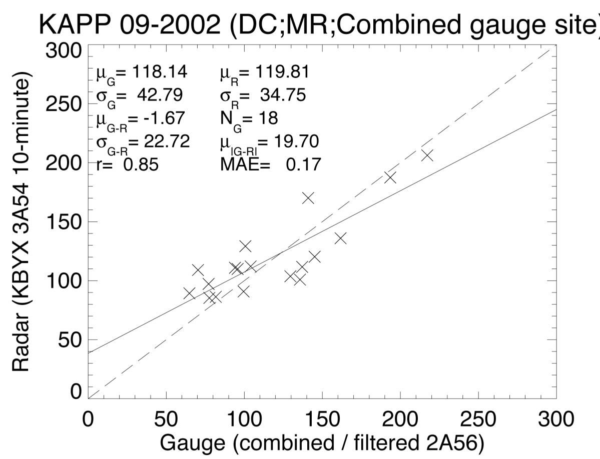

Fig. 8: Same as Fig. 6, except for September, 2002

References

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