Assessment of NESDIS GOES-R QPE and CIRA LPW Products in Alaska and Puerto Rico to Estimate Precipitation in Data-Void Regions in Summer and Fall of 2013

Introduction

This report describes an assessment by NASA's Short-term Prediction, Research, and Transition (SPoRT) Center of NESDIS GOES-R Quantitative Precipitation Estimate (QPE) and CIRA Layered Precipitable Water (LPW) product suites. This assessment was administered by NASA-SPoRT in collaboration with GOES-R Proving Ground activities and as part of the ROSES 2010 funded collaboration with CIRA/CSU.

National Weather Service Weather Forecast Offices (NWS-WFOs) that were selected to participate in this product evaluation were primarily from high latitudes to test the utility of the products there, namely the Anchorage (AFC), Fairbanks (AFG), and Juneau (AJK) WFOs and the Alaska Pacific River Forecast Center (APRFC), as well as the WFO in San Juan, Puerto Rico (SJU). Alaska has a limited number of radars providing coverage, mostly near the southern shore, and supplements its rain data with rain and river gauges and satellite and model data. The terrain in Alaska is mountainous, which contributes to forecast problems in terms of orographically-induced precipitation processes and impacts diagnostics by compromising radar range and model precipitation estimates. The terrain and vast territorial coverage further impacts the APRFC, whose area of responsibility is the entire state. The APRFC relies heavily on river and rain gauges spread across Alaska to provide forecast products related to river forecasts and QPE. The inclusion of the San Juan office (SJU) offered an additional unplanned evaluation opportunity in a distinctly different environment owing to its tropical latitude, notable for short-duration convective events in the summer. A network of shallow rivers crisscross the island, resulting in a flood-prone environment. Radar coverage in Puerto Rico is somewhat compromised by beam blockage from the Cordillera Central, or Central Mountain Range. These similar forecast issues allow a unique opportunity to investigate the value of GOES-R QPE and CIRA LPW in vastly different environments concurrently.

This assessment took place from 15 July to 15 September 2013, which coincides with the primary convective seasons in Alaska and Puerto Rico. During this assessment, 77 evaluations were submitted by 17 different forecasters in the five offices (Table 1). This is a follow-up of an assessment of these products that focused on WFOs on the West Coast of the United Stated in March and April 2013. Participation in that assessment was hindered by a climatologically anomalous dry period. However evaluations suggested that GOES-R QPE did not perform well in mountainous regions, and CIRA LPW, while accurate and viewed as having high value over standard PW, was often used as a supplement to other data sources and was not regarded as having a high impact by West Coast forecasters.

Assessments were conducted via a survey posted on SPoRT's webpage. Surveys are brief (about ten questions), comprising mostly multiple choice questions about the product performance. Forecasters may submit feedback anytime throughout the assessment period, and they are provided the option to ask SPoRT personnel, and occasionally product developers, questions via e-mail, phone, or online chat room.

This report is intended for NOAA and NASA program managers, operational forecasters, product developers, other institutions participating in GOES-R Proving Ground and research-to-operations activities, and the general satellite remote sensing community.

NWS Office	No. Participants	No. Surveys	Forecast Problem
AFC-Anchorage	2	3	Regional precip estimates in complex terrain in mostly data-sparse regions
AFG-Fairbanks	1	3	
AJK-Juneau	6	15	
APRFC-Alaska Pacific River Forecast Center	3	14	Alaska-wide 24-hr QPE from sparse gauge network
SJU-San Juan	5	42	Flood-prone tropical island with partially beam-blocked radar
Total	**17**	**77**	

Table 1

Product Description

NESDIS GOES-R Quantitative Precipitation Estimate (QPE) is a proxy (QPE) product for the GOES-R baseline QPE product and currently uses GOES infrared and passive microwave data (from MHS on NOAA 18/19 and METOP-A, and TMI on TRMM) to estimate rainfall in a domain covered by GOES (and the GOES-R) domains. It is produced at a temporal resolution of 15 minutes and a spatial resolution of 4 km. This product was developed by Dr. Bob Kuligowski at NOAA-NESDIS-STAR (Kuligowski 2002) and transitioned to selected end users by NASA-SPoRT for evaluation.

The transitioned product suite consisted of a 15-minute instantaneous rain rate estimation, and several accumulation products (1-hr, 3-hr, 6-hr, 12-hr, 24-hr, 3-day, and 7-day) that are consistent with other radar and gauge estimates of QPE available to these end users. The instantaneous product provides a rain rate in inches per hour. The accumulation products composite the previous rainfall amounts and indicate how many inches of rain fell in the given timeframe. The products were available for use in the users' native display system (i.e., AWIPS/D2d), with the exception of SJU, who accessed data via web graphics.

A previous assessment in the West Coast mainly showed that GOES-R QPE did not accurately detect rainfall in heavy terrain; it underestimated precipitation in coastal regions and overestimated precipitation in the mountains. The early assessment did indicate that there was value from using the product offshore, where forecasters have little or no other data. No major adjustments for these terrain challenges were made prior to this evaluation.

The CIRA LPW, or Layered Precipitable Water, is a microwaved-based precipitable water product that separates the PW values into discrete layers. The product combines Microwave Integrated Retrieval System (MIRS) retrievals produced operationally at NOAA/NESDIS from NOAA-18, NOAA-19, Metop-A, and DMSP F-18 and AIRS Version 6 retrievals made available via the NASA Land Atmospheric Near real-time Capability for EOS (LANCE) system (Kidder and Jones, 2007). Coverage for LPW is near-global, and the product is updated with new swath information every three hours. This product was developed by Dr. Stan Kidder and Mr. John Forsythe at CIRA as part of the ROSES 2010 solicitation.

CIRA LPW was also assessed previously in the West Coast and forecasters were confident in this product and found it to have value over standard PW products. However, forecasters rated the product suite as having low impact overall on their forecast process.

The transitioned product suite was composed of total column-integrated precipitable water and precipitable water values in four individual layers: surface-850 mb, 850-700 mb, 700-500 mb, and 500-300 mb. These products were also made available on end users' AWIPS/D2d systems and web graphics.

Methodology and Results

GOES-R QPE and CIRA LPW are satellite products that provide information regarding rainfall and moisture profiles, respectively, that can supplement or, if necessary, perform in the absence of radar-derived rainfall. SPoRT developed this assessment to determine the value of these products particularly in data-sparse regions to achieve their forecast objectives. The end users for each assessment are provided training for the products in the weeks leading up to the assessment, via a combination of teletraining sessions, recorded training modules, two-sided Quick Guides, and/or dedicated training sessions with individual offices. Content is made available through SPoRT's training webpage or can be downloaded to the end users' site to allow broad access to the materials throughout the assessment (http://weather.msfc.nasa.gov/sport/training/).

Prior to this QPE / LPW assessment, WFO SOOs and satellite focal points participated in one of two kick-off calls with SPoRT personnel and product developers Bob Kuligowski, Stan Kidder, and John Forsythe in which a product training session was provided and instructions for the evaluation were given. Content from this teletraining was provided to the SOOs to train their forecast staff, and two-page (single sheet) laminated "Quick Guides" on GOES-R QPE and CIRA LPW (developed by SPoRT with content provided by product developers) were sent to the offices to be used as a reference directly within the operations area. Additionally, SPoRT personnel visited the Alaska offices during the assessment and provided one-on-one training and demonstration of the products.

NASA-SPoRT assessments usually occur in the form of relatively short (on the order of 4 to 8 weeks) evaluation periods in which end users, such as National Weather Service forecasters, fill out brief questionnaires regarding the products' performance on a variety of metrics: product availability, users' confidence in the product, the product's utility compared to standard products or procedures, and any other specific questions related to the product(s) being evaluated. Often, product developers and the end users exchange emails to ask questions and discuss specific examples of product performance.

Feedback from participants was collected in the form of an online "two-minute survey" (http://weather.msfc.nasa.gov/sport/survey/qpeLpwAlaskaSurvey.html) comprising of mostly multiple choice questions and an open-ended comment section for general remarks (also see Appendix 1). SPoRT staff were automatically notified via email of submissions and typically provided a specific response to each user comment or question within 12-24 hours. Participants also directly emailed comments and questions to SPoRT personnel and the product developers, submitted screen captures of specific cases, asked questions or posted discussion points in the NASA-SPoRT NWS chat room, as well as posted product applications on the Wide World of SPoRT blog (http://nasasport.wordpress.com/).

From the five offices that participated, there were 17 forecasters who contributed survey submissions, totaling 77 surveys. Four blogs were posted by SJU describing forecast events. Numerous emails were received from the offices describing specific cases or asking questions. See Table 1 for a breakdown of participation statistics.

There were a few technical problems that resulted in data outages that lasted on the order of hours to days. When these issues arose, participants were notified via email and given an estimated outage time if known. Users were notified when the data flow was valid for evaluations again.

NESDIS GOES-R QPE

Most participants had seen or utilized the available training materials for GOES-R QPE, and out of 17 participants completing 77 surveys, about 4 participants had followed up with specific questions pertaining to GOES-R QPE beyond the material covered in the supplied training. This suggests that forecasters overall believed they received adequate training prior to this assessment.

Forecasters' perception of the utility of the GOES-R proxy QPE products varied considerably as indicated in Figure 1. The forecasters most often found the QPE products "somewhat useful" over data-deprived regions, such as mountainous terrain or over oceans; however, responses varied from "not useful at all" to "very useful". Furthermore, the forecasters viewed the utility of the products in data deprived regions more favorably toward the end of the two-month evaluation period after the same forecasters had been using the product for several events (see Figure 2). ***This trend likely indicates that the more experience the forecasters had with the product, the more useful they found the product to be, indicating the importance of training and repeated exposure by the same forecasters during the intensive evaluation period.***

At WFOs, forecasters reported that the most useful accumulation products for assessed events were the 6-hour, 3-hour, and 1-hour accumulation, respectively. Conversely, the APRFC preferred the 24-hour accumulation for their operations, likely as a supplement to their 24-hour river and rain gauge QPE product.

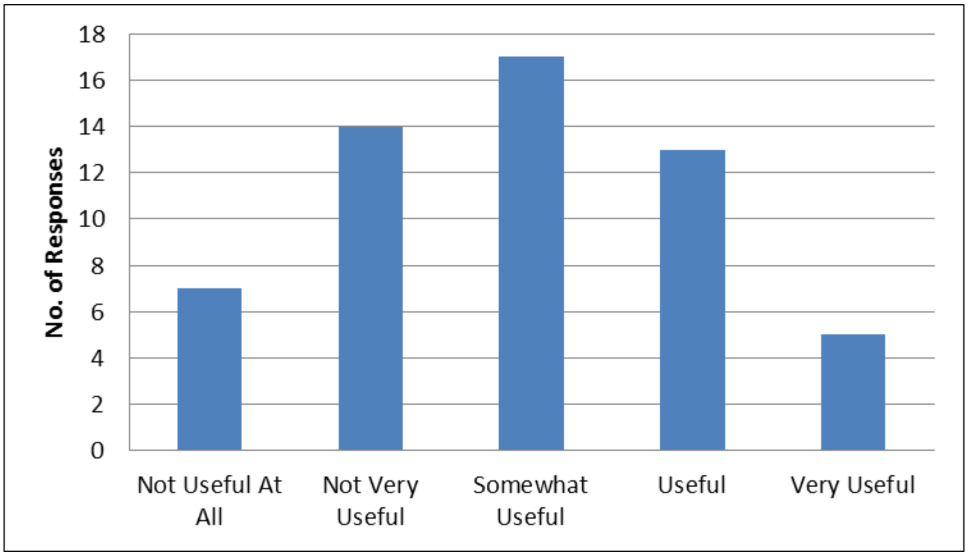

Figure 1 Utility of GOES-R QPE in data-sparse regions

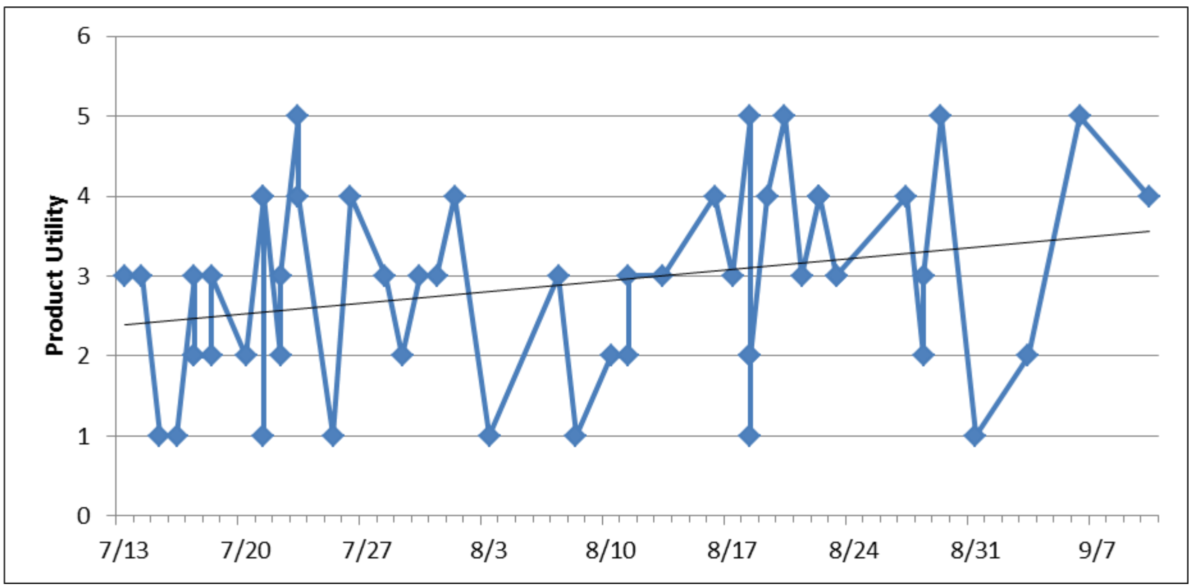

Figure 2 Time trend of QPE utility, where 1 is "Not Useful at All" and 5 is "Very Useful"

Participants were also asked to compare GOES-R QPE to other rainfall estimates. In SJU, for most events, regardless of precipitation type (e.g. Terrain-Influenced, Atmospheric River, Convective, etc.) or accumulation product used, the forecasters responded that GOES-R QPE underestimated precipitation and typically QPE estimated half as much precipitation as other precipitation point observations. Figure 3 shows that, when compared to either radar-derived rainfall or rain gauges, GOES-R QPE in SJU most often only observed about half as much rainfall (indicated by the" ~<=0.5x obs." column) as the other observation methods. The graph also shows that there were events (terrain-influenced, convective, offshore, and 1-, 3- and 6-hr accumulations) in which forecasters indicated that GOES-R QPE reported 1.5 times the amount of rainfall, or even twice the amount of rainfall as other observations, but for most events, GOES-R QPE under-estimated rainfall when compared to other observations. Forecasters from

SJU described and sent examples of several cases in which the GOES-R QPE observation matched the spatial extent of the actual rainfall, as reported by gauges and radar estimates, but was underestimated by sometimes as much as a third. One case was a record-setting rainfall in Puerto Rico which flooded rivers and streams in the San Juan area and caused the San Juan Airport to divert air traffic for a few hours. Approximately 8 to 10 inches fell in 24 hours, and 8.91 inches were reported at the San Juan Airport in a 6 hour period starting at 11 am. Despite IR cloudtop temps of -80C, GOES-R QPE reported rainfall amounts in the 24-hour period of only 3.14 inches in San Juan (see Figure 4). There were other locations on the island for this event where GOES-R QPE was accurate, or even over-estimated in a location where less than an inch of rain had fallen (see Figure 5). However, the heavy rains in Puerto Rico often exceed 3 inches per hour for several minutes, which is not well-resolved by either the IR or microwave instrumentation. Additionally, there were also cases in SJU in which small, intense convective event occurred, which were also not thoroughly observed by current GOES instrumentation. The combination of temporal and spatial resolution of the product on current GOES was likely a contributing factor in the under-estimates of rainfall in SJU, as diagnosed in discussions between forecasters at SJU and Dr. Kuligowski, and it is likely that improving the spatial and temporal resolution (e.g., utilizing the highest available resolutions on GOES-R ABI) will improve upon this.

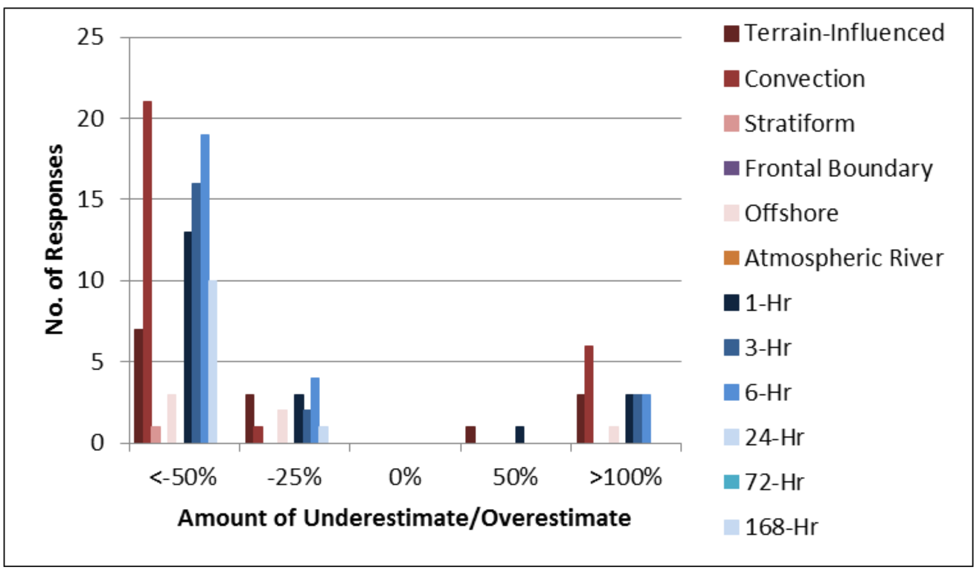

Figure 3 QPE bias as estimated by SJU forecasters

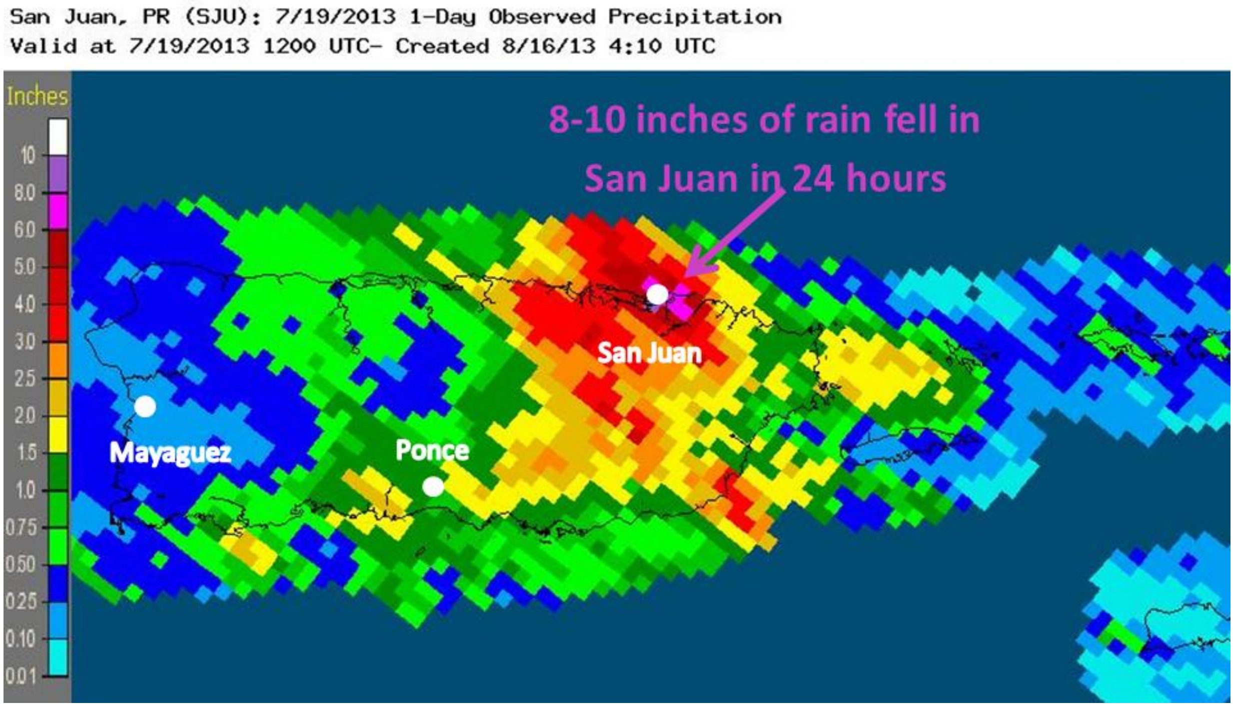

Figure 4 24-hr radar analysis of precipitation indicating locations of highest rainfall on 19 July fell in San Juan.

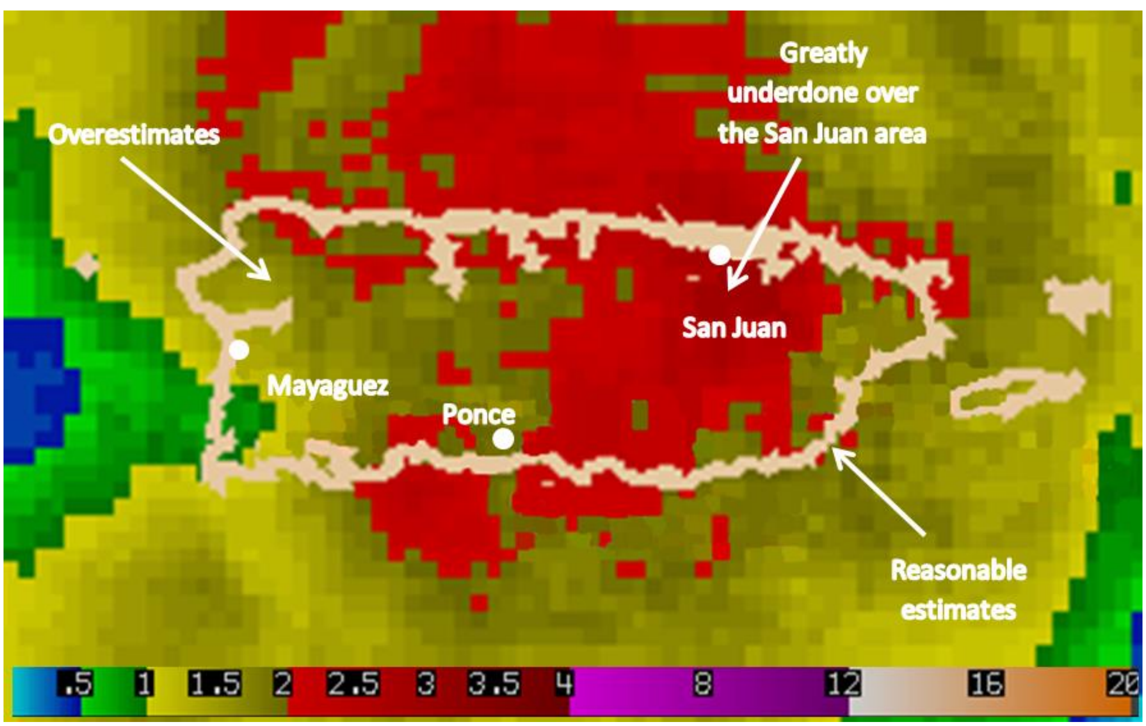

Figure 5 Adapted from an image in Luis Rosa's World Wide of SPoRT Blog Post, "Tropical Wave Brings Historic Rains to San Juan, PR- July 18, 2013"

Participants in the AK offices did not find a strong bias in any given accumulation product or circumstance, but they experienced general inconsistent performance that hindered their use of the data, resulting in fewer responses to this set of questions from AK forecasters (Figure 6). In the Alaska WFOs and the APRFC, forecasters often used the comments section and email rather than the multiple choice questions to describe specific conditions in their vast CWAs, frequently citing terrain issues as having an impact on the accuracy of GOES-R QPE. For example, in one comment representative of this situation, a forecaster noticed that GOES-R QPE over-estimated rainfall on a mountain range where downslope evaporation was likely occurring, but otherwise observed accurate estimates by GOES-R QPE. In other examples, forecasters described under-estimates or "misses" in the mountains in shallow precipitation events or relatively warm-cloudtop events. However, feedback indicated under- or over-estimates in various mountain ranges for cold cloud top events. Another forecaster stated for a single shift that, *"For terrain-influenced/stratiform rain in NW AK, probably similar amounts to what fell, but terrain-influenced/stratiform rain in the central and eastern Brooks Range was severely underestimated. Rain indicated in upper Yukon basin was over estimated in coverage. Light stratiform/terrain influenced rain in SW AK was missed."*

Note that there were several events in which the product did an excellent job of observing rainfall amounts and locations, as compared to gauges and available radar; however the general trend was toward inconsistency in Alaska during the evaluation period. In one example from the APRFC, the GOES-R QPE 24 hour product was being compared to a 24 hour Remote Automatic Weather Station (RAWS) rain gauge value. The precipitation type was identified as "convective", and most of the 24 hour rain gauge values in AK matched well to the QPE for this day. One RAWS value, however, seemed anomalously high to the forecaster. Salmon Trout RAWS (lat 66.48.45, lon 141.37.12) reported 1.00 inch for the 24 hour period, and the next closest gauge, at the Porcupine River at the Mouth of the Coleen River, registered just 0.18 inches. Indeed, no RAWS or river gauge in the vicinity had reported more than 0.20 inches in the 24 hour period. GOES-R QPE data, however, showed a localized region of heavy rainfall near the area in locations in which there are no gauges to verify, allaying the forecaster's suspicions that the gauge report was faulty (see the circled areas in Figures 7-9). Participants were also asked to indicate how the GOES-R QPE product suite was used in their forecast process for the event evaluated. Out of the respondents who chose to answer this question, the most common response was "Influenced the issuance of a Nowcast or a Flood product", and most of those respondents were from the SJU WFO (18 out of 20).

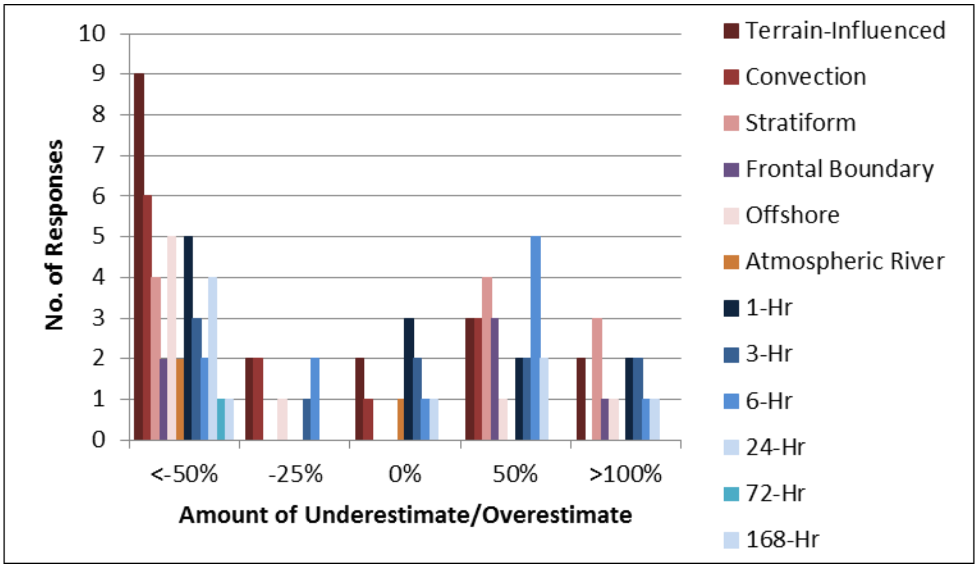

Figure 6 QPE bias as estimated by AK forecasters

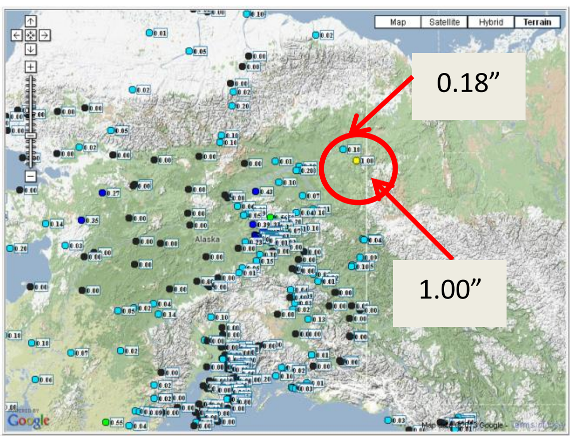

Figure 7 Gauge report of 1.00 inch of rain.

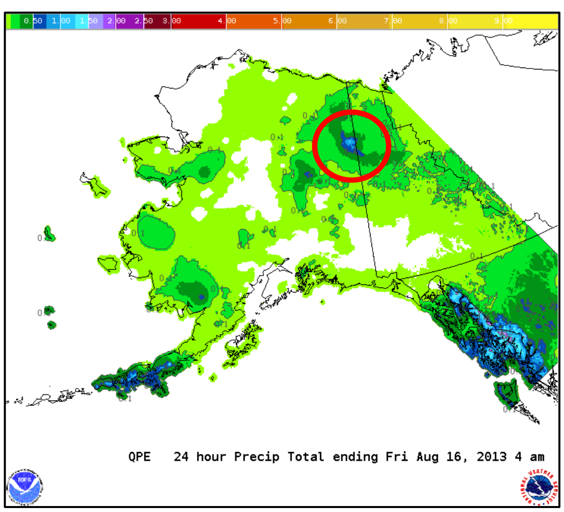

Figure 8 24-hr APRFC Precip Analysis.

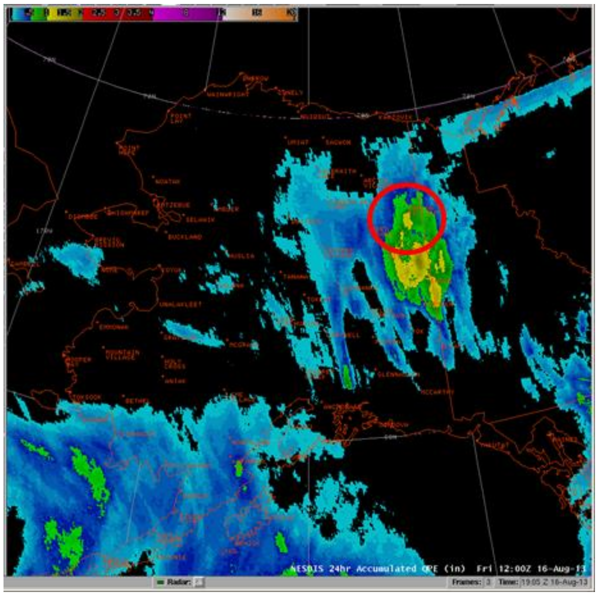

Figure 9 Location of gauge report matches with GOES-R QPE 24-hr accumulation of locally high (up to 1 inch) rain fall.

CIRA LPW

As previously stated, the CIRA LPW assessment also took place from July 15 to September 15 and was assessed by the AK and SJU forecasters. Some of the underlying goals of this assessment were to determine how this unique product suite could be used, either alone or in conjunction with existing products, to interrogate a vertical profile for moisture and its impacts, especially over data-sparse regions. The majority of participants utilized the basic training available for CIRA LPW, and relatively few made further inquiries or comments strictly regarding training throughout assessment period. This suggests that the forecasters felt they received adequate training to use LPW properly.

The majority of SJU forecasters stated that they had “high” confidence in the LPW product, while the AK forecasters had “medium” confidence in LPW (Figure 10). Having higher confidence in the product is likely an indication of the product’s perceived accuracy, and SJU forecasters, one forecaster specifically, immediately observed accuracy for events from the start of the assessment. Forecasters in AK, however, observed non-uniformity in the product’s appearance from different satellite overpasses and were less certain about its accuracy early in the assessment.

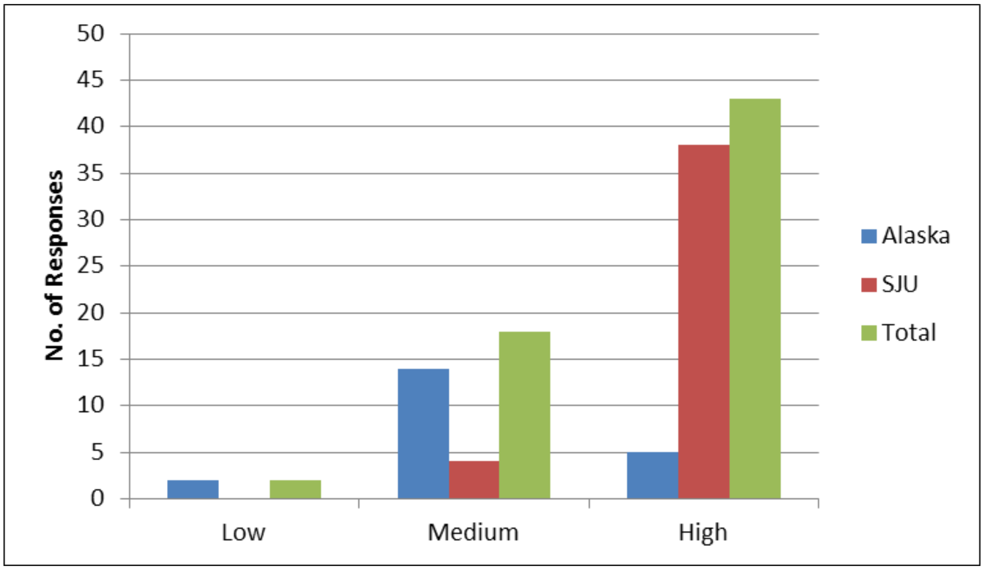

Figure 10 Confidence in LPW values

Most SJU forecasters also stated that LPW had a "large" impact on their process (Figure 11) to address the forecast problems stated, such as determining the amount and depth of moisture in the atmosphere to ascertain whether convection may be suppressed or if there is a likelihood of flooding. AK forecasters said that LPW provided "some" impact on their forecast issues (Figure 11), which tended to focus on orographic precipitation, flooding, and atmospheric river events. However, in a specific case involving an atmospheric river event in September that impacted most of the southern coast of Alaska, most forecasters evaluating CIRA LPW found "large" or "very large" impact on their forecast process, "high" confidence in the LPW values, and "large" or "very large" value over standard PW products, which is more favorable than AK forecasters viewed CIRA LPW for rain events as a whole.

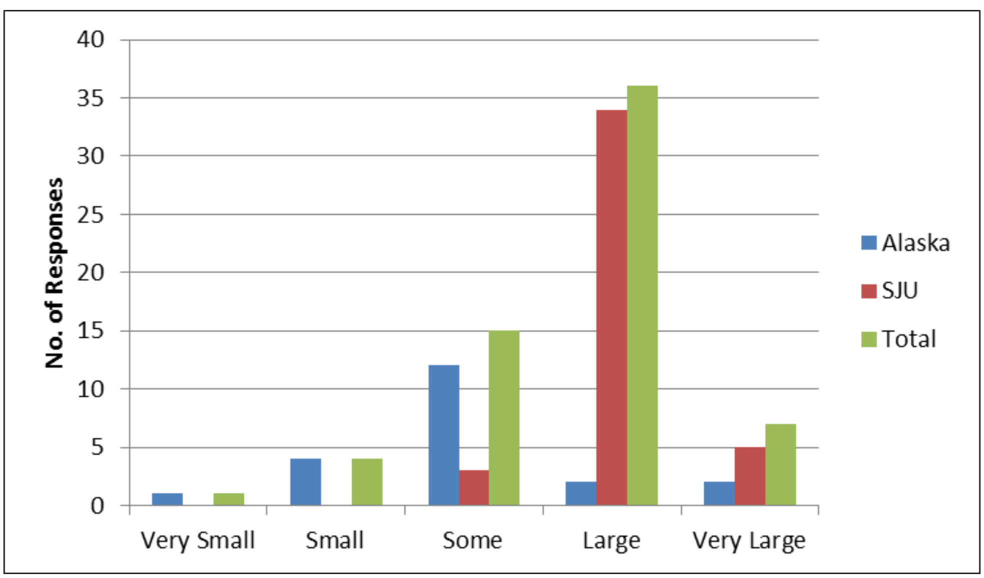

Figure 11 Impact of LPW on the forecast process

Figure 12 shows a four-panel display of three layers, 850-700 mb, 700-500 mb, and 500-300 mb, and the total PW for 3 September at 15Z. Forecasters for this AR event used LPW to determine how deep the moist plume was and whether the moisture was distributed throughout the height of the column or concentrated lower with respect to locations of orographic lifting. For example, the relative intensity of the AR in the 500-300 mb layer was helpful for one forecaster who mentioned CIRA LPW in an Area Forecast Discussion and stated that the product "partly influenced" that forecaster's issuance of a flood watch. Another forecaster later wrote, *"The layered PW product was very useful in identifying the AR moving up along the front over the gulf and issuing a RVS for river rises. Most of the moisture was in the lower levels and this would be the area of high orographic lifting."* During this event, some forecasters compared the actual rainfall totals from gauges to the available Total PW given by the product and typically found the values to be very similar. As with GOES-R QPE, participants using CIRA LPW gave the product a higher impact rating later in the assessment, suggesting possibly that they were more comfortable using it, had become familiar with the available training, or had otherwise learned over time how to effectively integrate this product into their forecast process.

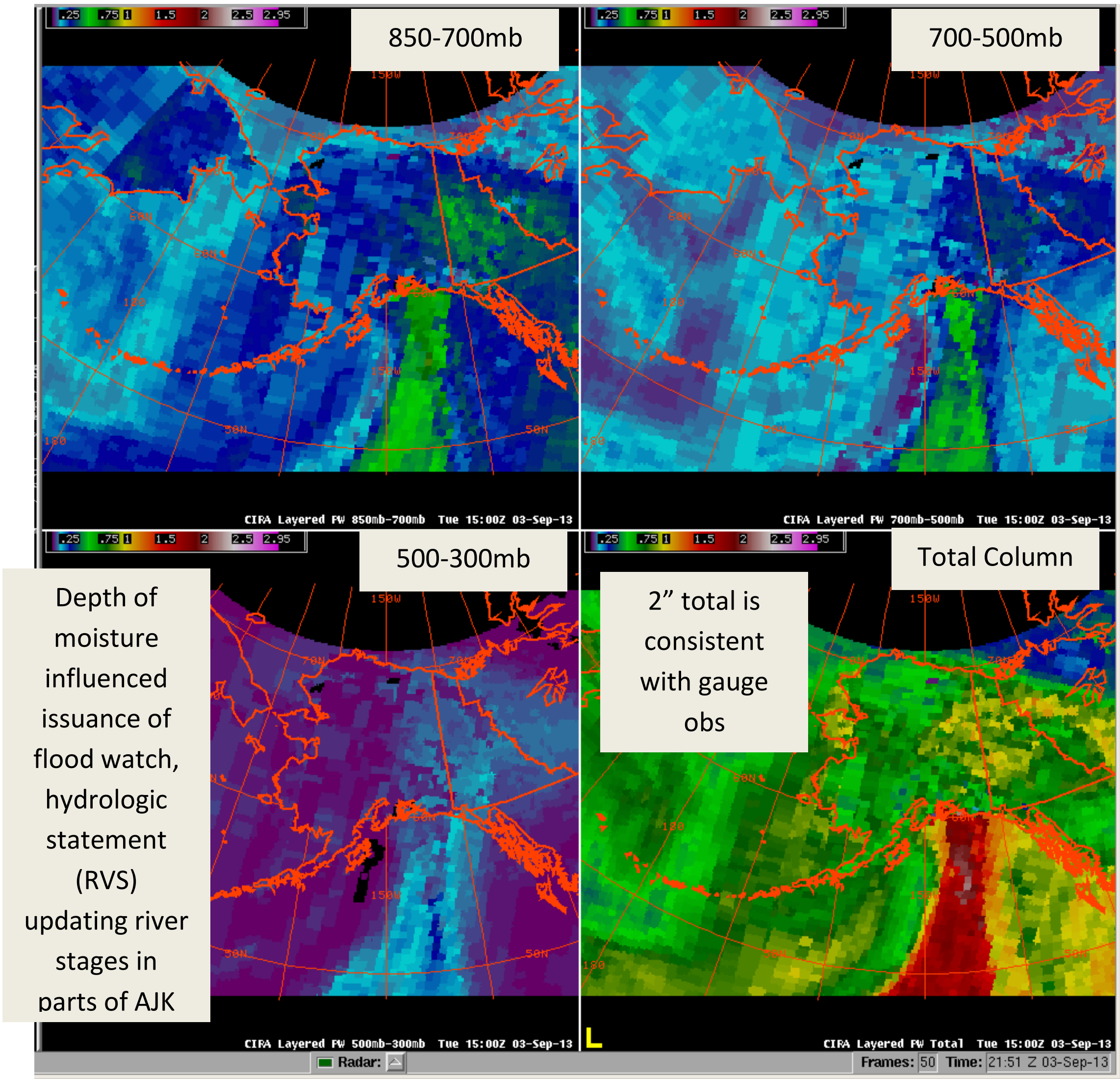

Figure 12 CIRA LPW in AWIPS showing atmospheric river at 15Z on 3 September.

Most participants stated that this layered product provided either "large" value or "very large" value over standard total precipitable water (TPW) products. Regionally, Alaskan participants chose "some" or "large" value, and SJU participants chose "large" or "very large" value most often (Figure 13). Furthermore, forecasters stated that they had compared the total PW product made available in this product suite to model forecasts of column PW in order to gauge accuracy. In their follow-up comments, participants also stated that they compared CIRA LPW values to RAOBs to determine accuracy when they were available, generally with favorable results.

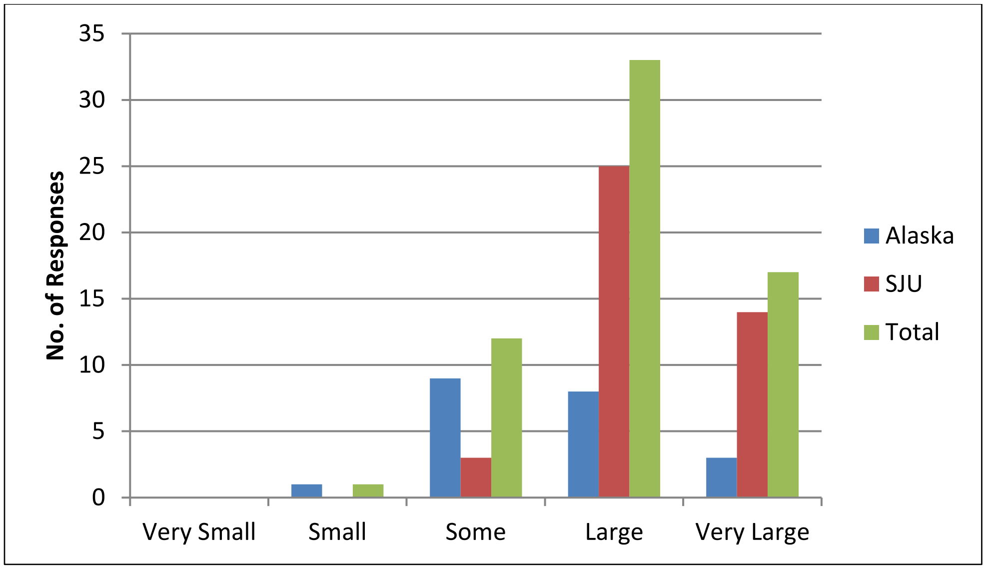

Figure 13 Value of layered PW product compared to a standard TPW product

Summary and Recommendations

While the quantitative results presented above are valuable performance metrics, the comments stated by forecasters provide insight into product usage. They often contain recommendations for improvements to the products to increase product utility. A brief summary of the products' performance and those forecaster recommendations are included herein.

NESDIS GOES-R QPE

Overall, when NESDIS GOES-R QPE was not performing well, it usually underestimated precipitation in SJU and was inconsistent in rainfall amounts in AK, although forecasters found it "somewhat useful" and found it more useful the longer they worked with it. Many forecasters used language in their descriptions stating that they were becoming accustomed to the bias and continuing to find utility in the product, particularly in SJU. A comment typical of this is, *"The fact that NESDIS QPE showed some areas receiving up to 0.5 inches and the fact that is has greatly underestimated past few days convinced me to issue a flood advisory…"* The recommendations for this product going forward are:

- Develop a method to account for orographic influence to cloud features and resulting precipitation. For example, one option may include using CIRA's Orographic Rain Index (ORI),
- Utilize the highest possible temporal and spatial resolution in the GOES-R era,
- Filter out or better accommodate cirrus cloud influence.

CIRA LPW

Assessors in SJU found "large" impact to their forecast process in using CIRA LPW, had higher confidence in the product, and rated it to have larger value than standard PW products than AK assessors, who mostly chose centric answer choices. A forecaster in SJU wrote, *"Overall, this product to me is of great value and should be made operational."* An AK forecaster who was using the product for multiple events at once was specifically pleased with the appearance of the product, saying the *"visual quality is alone a help on a busy shift."*

Although the feedback was not exclusively positive, users in both regions often described the benefits of the CIRA LPW product to their forecast with positive language, stating that it was usually accurate and provided value in atmospheric river events, tropical waves, examining the Saharan air layer, and examining the depth of available moisture in other events.

Specific suggestions for CIRA LPW going forward are:

- Develop a percent of total, percent of normal, or anomaly version of the product,
- Add layers representing 925-850 or 925-800 mb to better capture rapid changes near the surface,
- Create an additional 850-500 layer to examine the Saharan air layer.

Appendix: Assessment Questions

Please indicate if you have seen/used basic training materials on the Layered Precipitable Water (LPW) and GOES-R Quantitative Precipitation Estimate (QPE) products:
Indicate timeliness of product application for operations:
1. Indicate the precipitation mode/synoptic regime(s) present during this time period:
2. Rank the impact of the LPW on the forecast process:
3. Rate your confidence level in LPW values:
4. Were the total PW values of the layers (separate product) compared to model initialization/forecasts of total column PW to gauge accuracy of total moisture?
5. How would you rate the value of having this layered PW product compared to a standard TPW product?
6. What was the utility of GOES-R QPE suite in data-deprived regions, such as mountainous terrain and off-shore?
7. Click the radio button for the precipitation mode, in order to indicate how QPE compares to other observations that were available to you. Estimate based on comparisons you have already made to other observations.
8. Which QPE accumulation products were the most useful?
9. For the accumulation products chosen in the previous question, click the radio button in order to indicate how the QPE accumulation compares to other observations.
10. How did GOES-R QPE influence your forecast process?
11. Other feedback about these products can be written here:

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Kuligowski, Robert J., 2002: A Self-Calibrating Real-Time GOES Rainfall Algorithm for Short-Term Rainfall Estimates. *J. Hydrometeor*, **3**, 112–130.

Kidder, Stanley Q., Andrew S. Jones, 2007: A Blended Satellite Total Precipitable Water Product for Operational Forecasting. *J. Atmos. Oceanic Technol.*, **24**, 74–81.