P2.15 SATELLITE-DERIVED PRECIPITATION VERIFICATION ACTIVITIES WITHIN THE INTERNATIONAL PRECIPITATION WORKING GROUP (IPWG)

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1. INTRODUCTION

In recent years, the requirements for climate modelling, data assimilation, nowcasting, and hydrological applications have created the need for daily and sub-daily precipitation analyses and their associated accuracy. The development of blended, high resolution precipitation products derived from satellite observations (typically blends of low Earth orbiting (LEO) passive microwave radiometric (MW) and geostationary Earth orbiting (GEO multispectral visible/infrared (VIS/IR) imagers) has rapidly advanced to a point where a thorough analysis of their performance across space and time scales, seasons, and weather regimes is both possible and necessary. In early 2004, the International Precipitation Working Group (IPWG) started a satellite precipitation algorithm validation and intercomparison project over three domains (continental United States, Australia, and northern Europe) covered by quality-controlled surface networks (raingauge networks and operational weather radars). Its aim is to provide information to users on the daily-scale performance metrics (bias, RMSE, skill score, etc.) relative to these ground networks, and give algorithm developers a better understanding of the strengths and weaknesses of different algorithmic approaches and satellite data blends. A secondary, but also important aim is to investigate when and where satellite rainfall estimates generally perform better or worse than short-term rainfall predictions from numerical weather prediction (NWP) models.

Building upon this initial effort, the IPWG has initiated the Pilot Evaluation of High Resolution Precipitation Products (PEHRPP). PEHRPP is a joint effort among scientists who develop and produce High Resolution Precipitation Products (HRPPs), those who provide the basic data (observations from earth orbiting satellites and surface radar and rain gauge reference networks), and scientists requiring high resolution precipitation fields to conduct their research. PEHRPP aims to characterize as clearly as possible the errors in various HRPPs across varying spatial and temporal scales, variable surfaces (cold surfaces, complex terrain), and climatic regimes. Furthermore, errors of and differences between HRPPs are meaningful in that they can be systematically related to precipitation characteristics and/or algorithm methodology, thereby potentially improving HRPPs by combining products or methods based on the observed errors and differences. This article provides an overview of the validation strategies and summarizes results and findings to date.

2. CURRENT VALIDATION EFFORTS

A major recommendation from the working groups at both the first and second IPWG workshops (Levizzani and Gruber, 2003; Turk and Bauer, 2005) was the development of a validation/intercomparison of various HRPP and model datasets focusing on various operational and semi-operational satellite precipitation estimates. The first analysis was started in 2002 over Australia and is coordinated by the Australian Bureau of Meteorology. A second analysis was initiated over the continental US (coordinated by NOAA Climate Prediction Center) in 2003, and in 2004 a northern European site was added (coordinated by the University of Birmingham). Each region has a website with access to near real-time validation statistics from several techniques, which are contributed by the developers. The IPWG Validation website is at: http://www.bom.gov.au/bmrc/SatRainVal/validation-intercomparison.html**.** The project aims to validate and intercompare operational and semi-operational satellite rainfall estimates in near real time. This study focuses on the large-scale

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validation of daily rainfall estimates, for two reasons. First, the large number of rainfall observations from rain gauges at the 24-hour time scale provides good quality verification data on a large scale. Second, daily rainfall estimates are required as input to a large number of climate and other applications. For comparison, 24-hour precipitation forecasts from a limited number of NWP models (currently ECMWF, the US NCEP, the US Navy NOGAPS global model, and the Australian regional mesoscale model) are also verified.

An example output from this effort is depicted in Figures 1 and 2. Box-and-whiskers figures representing multiplicative bias and correlation coefficient between 24-hour accumulations and the gauge-based ground validation network over the Australian continent (Ebert, 2005) are shown for a collection of datasets spanning nearly 900 days ending in mid-2005. The results for individual algorithms are composited according to the type of data used to produce the rainfall estimates (merged passive microwave only techniques, infrared only techniques, blended MW+IR satellite techniques, and NWP models) to show how the skill depends on the strategy taken. Data are binned into 3-month intervals (recall that DJF is summer season) for middle latitudes (south of 25°S latitude). In general, all three types of satellite estimates begin to underestimate (bias < [illegible]s the seasons move toward winter (JJA) whereas the NWP models remain nearly unbiased. The upper 25% of the satellite estimates contain many extreme high biases as indicated by the long upper whiskers. As best represented by the summer (DJF) months, the blended satellite techniques add value by balancing the over biased MW-only and the under biased IR-only techniques. The improvement in correlation coefficient is not as dramatic, and the MW-only and blended MW+IR are not significantly different except during winter (JJA). The NWP models have their highest skill during winter, which is opposite the trend noted in the satellite estimates.

In Figure 3, we present results for seven of the satellite techniques (colored boxes) (Huffman et. al, 2003; Joyce et. al, 2004; Kuligowski, 2002; Sorooshian et. al, 2000; Turk et al., 2003) and one selected NWP model (black box) that contributed to the composited statistics in Figure 2. The key facts to notice are the wide range of skill amongst the various satellite estimates, and the fact that there are some instances where the satellite correlation coefficient is commensurate with that of the NWP model correlation. In fact during the summer (DJF), the performance of the NWP model and one of the satellite estimates (red color) is essentially the same.

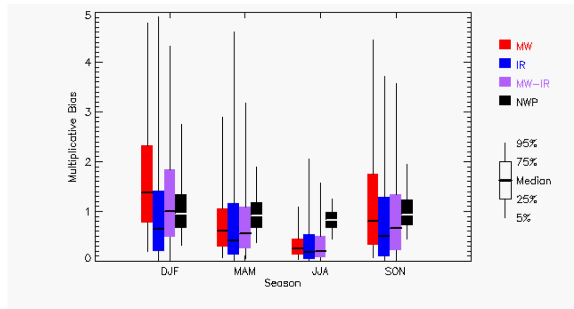

Figure 1. Box-and-whiskers figure representing multiplicative bias between 24-hour HRPP accumulations and the gauge-based ground validation network over the Australian continent. Data are binned into 3-month intervals (e.g., DJF=December+January+February) for middle latitudes (south of 25°S latitude). MW=Passive microwave only techniques, IR=Infrared-only techniques, MW+IR=Blended satellite techniques, NWP=Numerical Weather Prediction models.

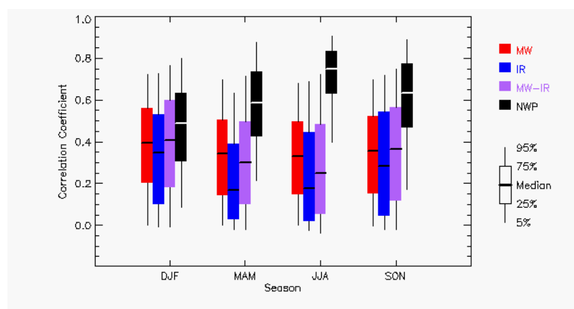

Figure 2. Same as Figure 1, but for correlation coefficient.

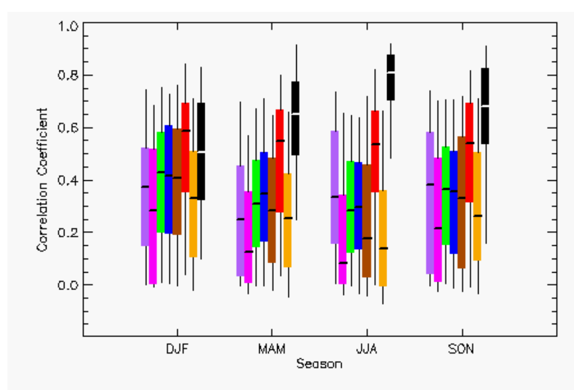

Figure 3. Same as Figure 2, but seven satellite precipitation HRPP techniques (non-black colors) and one NWP forecast model (black color) are represented from a subsetted 886 day period from 2002-2005.

Figures 4-5 present the identical set of statistics as Figures 1-2, except the data points encompass the Australian tropics (north of 25°S latitude). The satellite techniques appear to outperform the NWP models during summer (DJF) and are competitive during spring (SON), especially the blended MW+IR techniques. Two notable features are the very low correlation (< 0.2) produced by the satellite techniques during the winter dry season (JJA), and an overall marked degradation of the NWP models compared to their mid-latitude performance across all seasons, especially JJA and SON. The blended MW+IR techniques bring added information (lower overall bias, improved correlation) compared to MW or IR during the wettest DJF summer months, but in an overall sense the MW-only and MW+IR estimates perform similarly. For both satellite and model estimates, the extended 75% to 95% bias whisker lengths suggests a small number of very large overestimates occur during the drier JJA and SON seasons.

The results for individual techniques (Figure 6, the tropical latitudes equivalent of Figure 3) show these characteristics in more detail. Nearly all satellite estimates outperform the model during DJF and with higher correlations than they demonstrated for middle latitudes, and with less of a clear "winner" amongst the satellite estimates as was evident in Figure 3. For the winter (JJA) tropical latitudes, while the satellite estimates all show very overall little skill, the long upper whiskers suggest that there are a small number of cases where the correlation was indeed rather good.

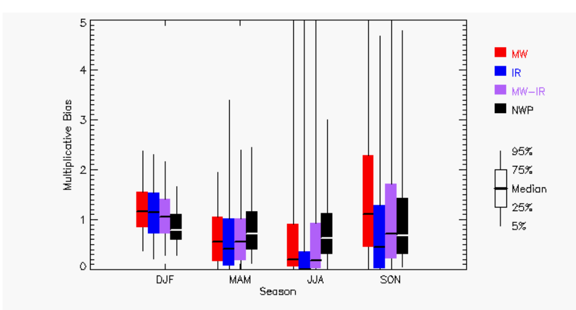

Figure 4. Same as Figure 1, but for tropical latitudes (north of 25°S latitude).

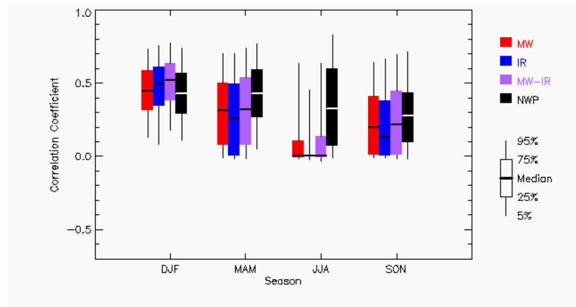

Figure 5. Same as Figure 2, but for tropical latitudes (north of 25S latitude).

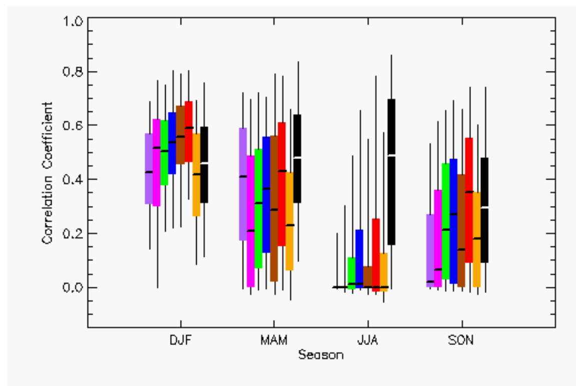

Figure 6. Same as Figure 3 but for tropical latitudes (north of 25°S latitude).

There are several possible reasons for the especially notable JJA satellite-model difference. The average daily rain rate across all Australian middle latitudes tends to be nearly constant at about 1 mm d^{-1} regardless of season, whereas the tropical latitudes are more variable, ranging from very dry (under 1 mm d^{-1} in JJA) to upwards of 5-8 mm d^{-1} in DJF (Turk et. al, 2003). This suggests that overall, the satellite techniques perform best for more frequent, intense, and dominant convective rain situations characteristic of tropical latitudes. Unlike these satellite-based techniques, the NWP models represent the dynamics and motions associated with frontal boundaries and transport the associated 3-D moisture patterns, better enabling it to trigger the precipitation fallout, its phase, and accumulation over time. This is a likely reason for the superior performance of the NWP models in the middle latitudes.

The MW+IR satellite techniques presented here all incorporate fast-refresh geostationary imaging IR channels and incorporate the IR data in either a "quantitative" fashion (where the 11 µm IR T_B is calibrated to a rain rate based upon recent, physically-based MW rain rates), or in a "qualitative" fashion (where the IR T_B structure is used to track and morph precipitation features in between time-sequential MW overpasses). A common feature to both types of techniques is that errors and artifacts in the physically-based MW estimates will manifest themselves in the final MW+IR output product. For wintertime conditions consisting of less convection and a greater percentage of shallower, fast-moving, less intense rain events, the IR cloud top temperature is a poor indicator of the underlying rain rate and produces a greater percentage of false alarms (i.e., higher bias) in the qualitative-type MW+IR estimates, especially for lighter rain rates near 1 mm hr^{-1}. The MW+IR techniques that utilize the rapid-update IR datasets in more of a qualitative sense to "track" precipitation features perform better in the middle latitudes, where a greater percentage of precipitation is associated with frontal boundaries. As evidence to this, the best performing satellite technique in the middle latitudes (Figure 3) was the qualitative transport-type technique. In general, the tropical wet months of DJF appear to be the "best case" for all of the satellite estimates, where the precipitation features are more stationary, usually convective, with cold cloud tops whose rain rates are better-characterized and quantified by the MW datasets.

Lastly, all of the satellite techniques incorporate MW-estimated rainfall with channels < 90 GHz, which is known to poorly represent over-land precipitation that does not have a convective-type ice cap. Since the overall rain accumulations from the validation datasets are much smaller during JJA (both latitudes, but especially tropics), the poor overall satellite performance may be a manifestation of the poor quality input MW-based satellite estimates that "drive" the blended MW+IR estimates. Efforts to incorporate precipitation radar (PR) estimates from the Tropical Rainfall Measuring Mission (TRMM) satellite, as well as the introduction of new higher frequency (150 window and 183 GHz moisture sounding channels) based retrieval techniques from the Advanced Microwave Sounding Unit (AMSU) and the Special Sensor Microwave Imager Special (SSMIS) are ongoing. These HF (High Frequency) based scattering retrievals have promise to extend the detection and accuracy of over-land precipitation rates to the lighter rain rates.

Finally, we note that there have been no over-water IPWG validation efforts to date. Given the superiority of the MW estimates over water, one would expect that the satellite estimates would show superior performance than they currently do over land. We hope to plan some validation using coastal radars and ship radar data during upcoming efforts, as discussed in the next section.

3. PROPOSED NEW VALIDATION EFFORTS

The IPWG has proposed an expanded validation program named PEHRPP (Proposed Evaluation of High Resolution Precipitation Products). PEHRPP is an effort that will bring together scientists who develop and produce High Resolution Precipitation Products (HRPP), those who provide the basic data (observations from earth orbiting satellites and surface radar and rain gauge reference networks), and those who have a need for high resolution precipitation fields to conduct their research. The principal goal of PEHRPP is to characterize as clearly as possible the errors in various high resolution precipitation products (HRPP) on many spatial and temporal scales, over varying surfaces and climatic regimes. By including both satellite and model estimates we intend to demonstrate that using NWP forecasts can improve an HRPP. This will require including a number of such forecasts in PEHRPP and testing one or more HRPP that use them in some way.

PEHRPP consists of four suites of validation activities: (a) regional daily and sub-daily validation, (b) high time resolution comparisons over limited domains, (c) validation against very high quality data from field programs, and (d) "big picture" monthly comparisons. For each set, the initial tasks will be identical: identify the space and time domains and scales, obtain the appropriate validating observations and HRPP, and carry out a suite of statistical comparisons. The results of these calculations will be examined and described, and recommendations for the development of improved HRPP and retrospective processing will be fashioned. A summary will be prepared and discussed at the next IPWG meeting in 2006, with associated reports and publications. As of October 2005, the coordinators for each of the four suites have been identified and both satellite-precipitation and validation datasets are being identified and prepared. In addition to the three existing IPWG validation sites, additional validation sites have been proposed in Asia, Africa, and South America. Coordinated Enhanced Observing Period (CEOP) datasets have also been identified and are being examined, as well as a re-analysis/validation of models and satellite precipitation using the KWAJEX radar datasets that were collected for TRMM ground validation. We expect that the results of PEHRPP will contribute not only to GEWEX goals and programs, but may also fit into planning and strategies for the NASA GPM ground validation (GV) program.

The 3rd IPWG Workshop will take place in mid-October 2006, at the Australian Bureau of Meteorology in Melbourne, Australia. The workshop will take place adjacent to the Asia-Pacific Satellite Application Training Seminar (APSATS). For further information, the IPWG website http://www.isac.cnr.it/~ipwg contains all latest report and documents from workshops and news on upcoming events and meetings.

4. CONCLUSIONS

The current state of the IPWG Precipitation Validation Effort was presented. Given that the validation so far has all been conducted on a daily time scale and is comprised of entirely over-land situations, there are several main conclusions to be drawn so far:

1. The limited capability of MW-based sensors to adequately assess over-land precipitation, especially during winter season situations is a major limiting factor in improving the performance of MW and MW+IR satellite-based techniques.

2. In middle latitudes the capability of an NWP model to represent the dynamics and motion associated with frontal boundaries and transport of the associated 3-D moisture patterns currently allows it to achieve much better performance in short-term forecasted precipitation than provided by the satellite estimates.

3. Conversely, in tropical summer seasons where a large percentage of the precipitation totals derive from moisture-laden environments which generate vigorous convection, the satellite estimates appear to perform somewhat better. The NWP models used here do not explicitly carry clouds, and diagnose precipitation largely based upon how well they handle the moisture structure and temperature. On the other hand, the window channels used in the MW sensors directly “sense” the deep columnar hydrometeors within the presence of the moist atmosphere, thereby better positioning the precipitation and its intensity.

4. The performance of all of the satellite estimates appears to be rain rate-dependent. More frequent and intense rain storms, especially those of a convective nature, typical in a tropical environment, produce better performance statistics. The skill of the satellite estimates during the drier months is dominated by the poor performance handling drizzle and light rain.

5. For middle latitudes, blended satellite precipitation techniques that utilize the fast-refresh geostationary IR data to track/morph precipitation appear to outperform the quantitative techniques which specifically calibrate IR T_B values into equivalent rain rates. However this conclusion needs to be further substantiated with additional cases and situations where the revisit time between MW overpasses is insufficient to capture the appearance and/or disappearance of new rain cells.

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