5B.1 SATELLITE PRECIPITATION ACTIVITIES OF THE INTERNATIONAL PRECIPITATION WORKING GROUP

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1. INTRODUCTION

The International Precipitation Working Group (IPWG) was endorsed during the 52nd session of the WMO Executive Council in 2000, which encouraged the Coordination Group for Meteorological Satellites (CGMS) to participate in the formation of the IPWG. The foundation meeting of the IPWG was held at Colorado State University in June 2001, and was subsequently endorsed by the CGMS in July 2001. The IPWG is the precipitation equivalent of the longstanding International TOVS Working Group (ITWG) and the International Winds Working Group (IWWG) (see Levizzani and Gruber, 2007)

The main function of the IPWG is to provide a focus for the international scientific community for operational and research satellite-based quantitative precipitation measurement, with an emphasis on the derivation of improved precipitation products through greater scientific understanding. The objectives of the IPWG include the promotion of standards for satellite precipitation measurements and subsequent validation and verification of their products; procedures for data exchange; stimulate international research and development for precipitation retrievals and encourage education and training activities. The exchange of scientific results is facilitated through the organisation of a number of international workshops at which issues relating to the observation, measurement and validation of precipitation have been discussed. The first workshop was held in Madrid, Spain, in September 2002 and focused upon operational rainfall estimates, missions and instruments, research activities and validation studies (Levizzani and Gruber, 2003). In October 2004 a second workshop was held in Monterey, California, building upon the initial workshop: data sets, error analysis, precipitation characterisation, retrievals and microphysics being he main themes (Turk and Bauer, 2005). The Bureau of Meteorology in Melbourne, Australia, hosted the third IPWG meeting in October 2006, alongside the Asia Pacific Satellite Applications Training Seminar (APSATS). The most recent meeting of the IPWG was held in Beijing in October 2008 with topics that ranged from data sets and applications through to the use of satellite retrievals with numerical models.

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2. INTERCOMPARISON ACTIVITIES

The validation and verification of precipitation data sets addresses two of the main of IPWG objectives, namely establishing standards for validation and independent verification of precipitation measurements, and fostering the exchange of data on inter-comparisons of operational precipitation measurements from satellites. Thus, one of the aims of the IPWG is the validation/verification of precipitation products to aid both the algorithm/product developers and the users to gain better insights into the operation and usability of satellite observations for quantitative precipitation estimation. A number of baseline algorithms, NWP models, quasi-operational and 'experimental' satellite algorithms (both geostationary and polar-orbiting, infrared and/or passive microwave) are available in near real time and are compared against surface reference data sets derived from gauge and/or radar observations. The near real time inter-comparisons are focused on a number of regional sites that provide at daily/0.25° inter-comparisons: Australia (co-ordinated by Beth Ebert); USA (John Janowiak); Europe (Chris Kidd) and; South America (Daniel Vila). Satellite-surface data comparisons are generated in near real-time and the results made available on the internet: links to other validation regions are provided from these main sites. Figure 1 shows the global distribution of the near real time inter-comparison regions, together with regions with limited-period comparisons: web site addresses are shown in Table 1.

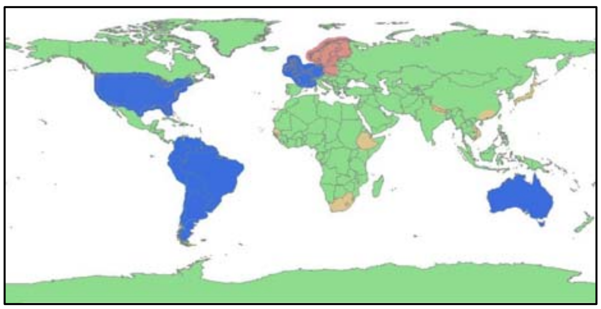

Figure 1: IPWG validation regions. Blue regions indicate near real time inter-comparisons, red areas are currently being developed as validation regions, while beige are regions where fixed-period validation work has been undertaken.

IPWG home page	http://www.isac.cnr.it/~ipwg/IPWG.html
Australian validation	http://www.bom.gov.au/bmrc/SatRainVal/sat_val_aus.html
European validation	http://kermit.bham.ac.uk/~ipwgeu/
US validation	http://cics.umd.edu/~johnj/us_web.html
S. America validation	http://cics.umd.edu/~dvila/web/SatRainVal/dailyval.html

Table 1: List of IPWG home page and inter-comparison web site links

The validation/verification of products through the IPWG differ from other ground-validation campaigns in a number of ways. While many ground validation campaigns are designed specifically to investigate certain criteria, such as specific events for a new sensor or a particular physical precipitation process/regime, the IPWG validates regional-scale products on a regular quasi-operational basis. In particular, the IPWG validation relies upon the availability of existing surface precipitation observation networks to provide validation data sets: over Australia and South America these are gauge data, over Europe, radar data, while over the United States, both gauge and radar. Although the IPWG validation concentrates upon these main regional sites, one aim of the IPWG is to encourage the development of other validation regions: these are often in regions where the distribution of surface data sets may be restricted, but participants in that country can access the satellite products, validate the results locally and present these results, thus expanding the range of climatic and geographical regions. A final difference between many ground-validation campaigns and that of the IPWG is that the time/space scales tend to differ: the IPWG set the goal of validation/verification of precipitation products at 0.25/daily scales, while much specific ground validation is performed at sensor-resolution and instantaneous time scale.

3. PRECIPITATION PRODUCT ANAYSIS

3.1 Processing steps

The IPWG validation sites are organised in a similar manner: liaison between the different regional sites discussed the range of statistics that should be used to provide users with clear, yet understandable results. In addition, a common graphical display of the results was agreed upon, including the colour scale, to permit ease in the cross-comparison of products between the different validation regions.

Each of the regional sites follow a similar processing mechanism: although the programming/graphics software varies the processing sequence is listed below:

- *Initial setup*: involving the setting of the dates of data required, usually the current day minus one; clearing out of old data and any data that was deemed corrupted from previous analysis;
- *Data acquisition:* searching through existing data for a set number of data days prior to the present and listing missing data; creation of a file for use by ftp, followed by *ftp* to the data sources (note that this gets whatever the data is on the server, even if it is bad); an ftp limit of

4kB on the macro files usually requires individual *ftp* for each data set;

- *Data preparation*: Initial quality-control of data for precipitation products and surface data sets; remapping of ingested data to local regional validation grid: note that lat/lon grids are used for analysis except in the case of European region where a polar-stereographic projection (optimised by means of look up tables) is used to ensure equal area analysis from 30°N to 70°N;
- *Results generation*: generation of statistical output and incorporation into graphical output with imagery and scatterplots of data;
- *Web page generation*: generation/updating of HTML files; copying over to web-server

It should be noted that while these processing steps are executed as scheduled tasks, they are not necessary 'automatic' and require user-intervention when problems arise.

3.2 Validation output

Figure 2 shows the output for the European validation region, but the layout is common across all regional validation sites. The two main images provide a display of the surface rainfall products, whether this is radar, gauge or both, together with the satellite/model precipitation product. Zero rainfall is denoted as white, while no data regions are denoted as grey. It should be noted that only regions that have both surface and satellite/model precipitation product are analysed in the statistics. In the *lower left* is a scatterplot of the surface (observed) vs product (estimated), while in the *bottom centre* (for the European region only) is a plot of cumulative rainfall occurrence and accumulation: the closer the estimated and observed lines are the better the overall relationship between the two precipitation fields are. In the *top right* are displayed bar graphs of the distribution of rainfall by occurrence and by accumulation to allow a visual analysis of how well
the satellite/model matches the surface data for the areas covered by each rainfall category: in this case it can be seen that the overall area of precipitation retrieved by the satellite algorithm is very close to that of the surface radar, while the satellite estimate underestimates the overall rainfall slightly. Below these are the statistical

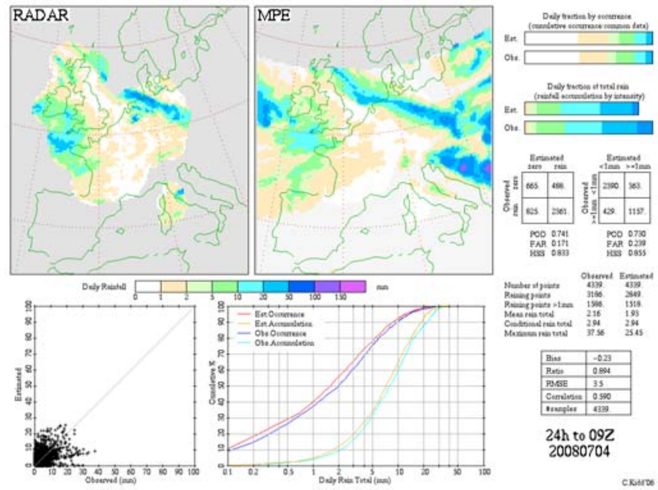

Figure 2: Typical output of IPWG daily/0.25 degree satellite-surface validation for the European region for the MSG Multi-satellite Precipitation Estimate (MPE) technique: note the polar-stereographic projection used.

output which include simple categorical analysis of the rainfall for both rain/no-rain and for rain>1mm/rain<1mm, together with the associated scores for the probability of detection (POD), false-alarm ratio (FAR) and Heidke skill score (HSS). Below these are descriptive statistics, including the total number of points analysis, number of raining points, number of raining points >1mm/day, mean daily rainfall, mean conditional rainfall (i.e. mean rain-only data) and the maximum daily rainfall. Finally in the *lower right* are the standard statistical measures including the bias (estimated-observed), the ratio (estimated/observed), the root mean squared error (RMSE) and the correlation coefficient (Pearson's product moment correlation coefficient).

To further aid the intercomparison of the products the regional validation sites may include further tables or analysis. The European site also generates tables for each of the basic statistics (bias, ratio, RMSE and correlation) to allow algorithm developers and users to cross-compare the performance of the precipitation products easily. Figure 3 shows the table for the correlation: across the top are the different algorithms, while each row relates to each of the previous 30 days of data. To further aid comparisons each cell in the table is color coded: for the correlations a good positive correlation is indicated as a green, fading through to yellow and white for no correlation, then orange and reds for negative correlation. It can be seen from Figure 3 that some precipitation products produce generally positive correlations for most cases – in this case the NOGAPS model. However, it can also be noted that the good correlations are often stratified more by dates than by product, indicating that the type and form of precipitation within the validation region is often critical in achieving good statistical score: high correlations tend to occur on days with widespread rainfall across the whole region.

IPWG European Validation

00-24Z correlation statistics

date	NOGAPS	3B40RT	3B41RT	3B42RT	AMSU	CMORPH	CPCMW	HYDRO-E	PMIR	FDA	NRLGEO	NRLPMW
071129	-	0.129	0.179	0.196	-	-	-	-	-	-	-	-
071128	0.644	0.065	0.191	0.132	0.353	0.342	0.307	0.410	-	-	0.103	0.074
071127	0.412	-0.081	0.185	-0.077	0.133	-0.063	-0.065	0.450	-	0.027	0.018	-0.059
071126	0.394	0.369	-0.056	0.222	0.150	0.040	0.166	0.055	-99.000	0.109	0.313	0.330
071125	0.593	0.023	0.290	0.095	0.077	0.012	0.030	0.022	0.157	0.268	0.032	0.031
071124	0.564	0.085	0.230	0.328	0.268	0.282	0.235	0.204	0.375	0.194	0.184	0.186
071123	0.454	0.111	0.129	0.247	0.497	0.367	0.342	0.301	0.574	0.235	0.583	0.436
071122	0.436	0.409	0.333	0.419	0.483	0.553	0.408	0.530	0.607	0.472	0.751	0.672
071121	0.480	0.250	-0.008	0.201	0.228	0.304	0.287	0.325	0.117	0.282	0.303	0.278
071120	0.453	0.218	-0.034	0.020	0.296	0.431	0.294	0.114	0.255	0.208	0.234	0.229
071119	-	-0.010	-0.126	-0.025	-0.175	0.155	0.062	0.182	0.025	0.087	0.036	0.094
071118	-	0.274	0.550	0.603	-0.104	0.622	0.561	0.605	0.474	0.347	0.413	0.431
071117	0.773	0.298	0.619	0.576	-0.046	0.681	0.536	0.666	0.646	0.477	0.511	0.492
071116	0.088	-0.005	-0.009	0.038	-0.019	0.101	0.026	0.053	-	-0.021	0.040	0.026
071115	0.199	0.138	-0.030	0.063	0.023	0.025	0.057	0.189	-0.049	0.146	0.154	0.163
071114	0.349	0.235	0.330	0.313	0.028	0.138	0.249	0.479	-	0.103	0.143	0.195
071113	0.459	0.105	0.241	0.198	-0.010	0.046	0.043	0.462	0.171	0.162	0.055	0.062
071112	0.377	0.286	0.168	0.302	0.181	0.270	0.183	0.336	0.158	0.435	0.194	0.211
071111	0.582	0.124	0.435	0.344	0.278	0.316	0.274	0.379	-99.000	0.063	0.345	0.265
071110	0.718	0.305	0.479	0.486	0.208	0.268	0.211	0.597	0.040	0.011	0.261	0.241
071109	0.536	0.157	0.233	0.239	0.128	0.120	0.124	-	0.147	0.295	0.164	0.187

Figure 3: Table of correlation statistics for all products for previous analysis period to allow intercomparison of product performance.

3.3 Surface data sets

As noted above, different validation regions use either radar and/or gauge data for verification of the satellite/model precipitation products. However, the quality-control of these can at times be problematic. Often, the need to acquire the verification data within near real time limits the type of data available, and the amount of cross-checking to ensure the highest quality control of the data sets. A good example of some of difficulties that are encountered, and therefore should be borne in mind in interpreting the results, is described.

For the European region radar data from across Europe is acquired by the UK Meteorological Office and processed to form a 5 km product every 15 minutes: these 15 minute estimates are then accumulated into daily estimates for use within the IPWG validation site. Gauge data is generally only fully available one month (or more) in arrears and therefore cannot be used for the near real time analysis of the satellite/model data sets. The upper pair of images shown in Figure 4 shows the radar data (left) and the corresponding gauge data (right) for a significant rainfall event. Note that over the UK land areas the agreement between the radar and the gauge is good, not least because the radar undergoes real time adjustment from selected gauge data within each radar domain. However, the effects of range are seen over the sea areas and over France, thus questioning the usefulness of such data. In particular, as shown in the lower two images in Figure 4, there are occasions when atmospheric conditions produce significant amounts of anaprop errors (false rain echoes, including that from shipping) in the radar signal – while the gauge data show no rainfall.

4. FUTURE DIRECTIONS

The main IPWG validation regional sites (Australia, United States and Europe) were established at the start of 2003 and have be ingesting, processing and displaying surface-product comparison each day since then. After this five year period it is an opportune time to review the work of the validation sites and to map out future directions. Some of the key questions include:

What are the key requirements in the future to make best of our own limited resources? The current validation sites are unfunded and rely upon resources provided by their host institutions. This includes the daily upkeep of the sites, which can be significant at times when software or communication problems occur requiring manual intervention.

What are the requirements of the algorithm/product developers? The algorithm/product developers are one of the main drivers of the validation sites: they can view the performance of their particular product in relationship to other precipitation products and to the surface reference data sets – do the current set of displays/statistics adequately reflect what they require?

What are the requirements of the user community? The other main interested group are the “users” – these may range from hydrologists interested in river flows or for soil moisture etc. Does the analysis of the products and the verification of them match their requirements?

What new sources of data are available? Are we using the best available sets of data available, for both the satellite/model data sets, as well as the surface verification data sets? There are several encouraging short-term regional intercomparisons available – should be these be expanded further?

Should we go beyond daily regional comparisons (local-global, instantaneous-seasonal)? At present the IPWG validation sites have concentrated upon the daily 0.25 degree comparisons. However, there is a perceived requirement for statistical analysis over other time periods and regions. For example, local scale to global scale is feasible, particularly since the precipitation products currently available are generally available on a global basis (or at least 60°N to 60°S). Similarly, many instantaneous products are available – and are the subject of the Program for the Evaluation of High-Resolution Precipitation Products (PEHRPP; Turk et al. 2008), but, should we also consider seasonal analysis too?

In terms of the representativeness of the current sites, the IPWG should pursue the expansion of the existing validation area to regions poorly represented by the IPWG and other intercomparisons/validation studies. Possible regions include the well-instrumented BALTEX region, high-latitude oceanic regions, as well as expansion of existing regions (e.g. United States into Canada, and Europe into Eastern Europe).

In addition to the inclusion of new regions, new analysis/comparison techniques need to be investigated. For example. high temporal/spatial resolution comparisons will need to rely upon more descriptive statistics due to the non-linear nature of high-resolution precipitation products. However, the implementation of fuzzy-logic statistical techniques might provide useful, informative analysis of such data sets.

The analysis of the performance of satellite/model precipitation products on longer-time scales has been somewhat limited, although seasonal performance of daily estimates was discussed by Ebert et al. (2007). Intercomparison of results over Australia are available at a number of results on the Australia IPWG validation web page, and exemplify what can be achieved. Figure 5 shows the results of a seasonal intercomparison of precipitation products for December, January, and February 2006-07 for the TMPA-RT algorithm alongside other precipitation products.

5. CONCLUSIONS

The IPWG provides a focus and support for precipitation research through and number of activities, including workshops, meetings and education. Through these it encourages the development, exploitation and testing of new techniques, together with the inter-comparison of techniques for operational applications. It also provides a means to represent the precipitation scientific community, and to make recommendations to the national and international agencies responsible for overseeing precipitation-related programmes.

A main focus of the IPWG activities is the inter-comparison of precipitation products: analysis of the precipitation products at daily/0.25 degree scales is performed in near real time to provide algorithm developers and the user community with an indication of the performance of the different products over the regional validation sites. Future direction of the intercomparisons is a balance of community-driven requirements and achievable goals.

6. REFERENCES

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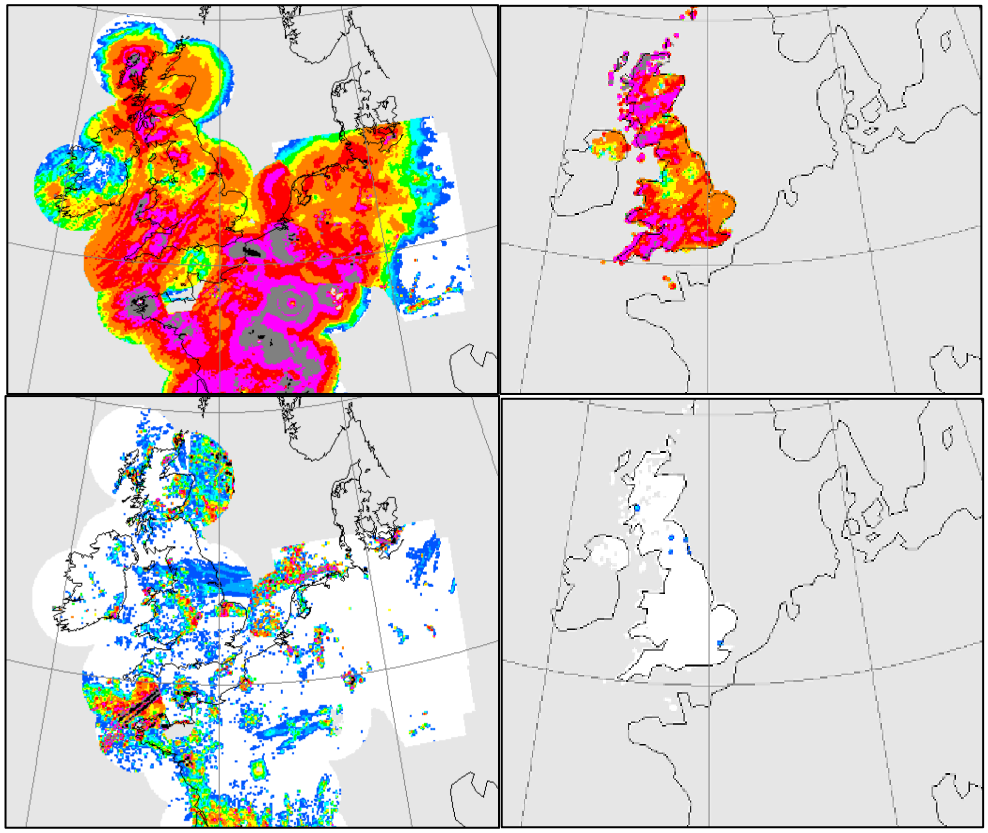
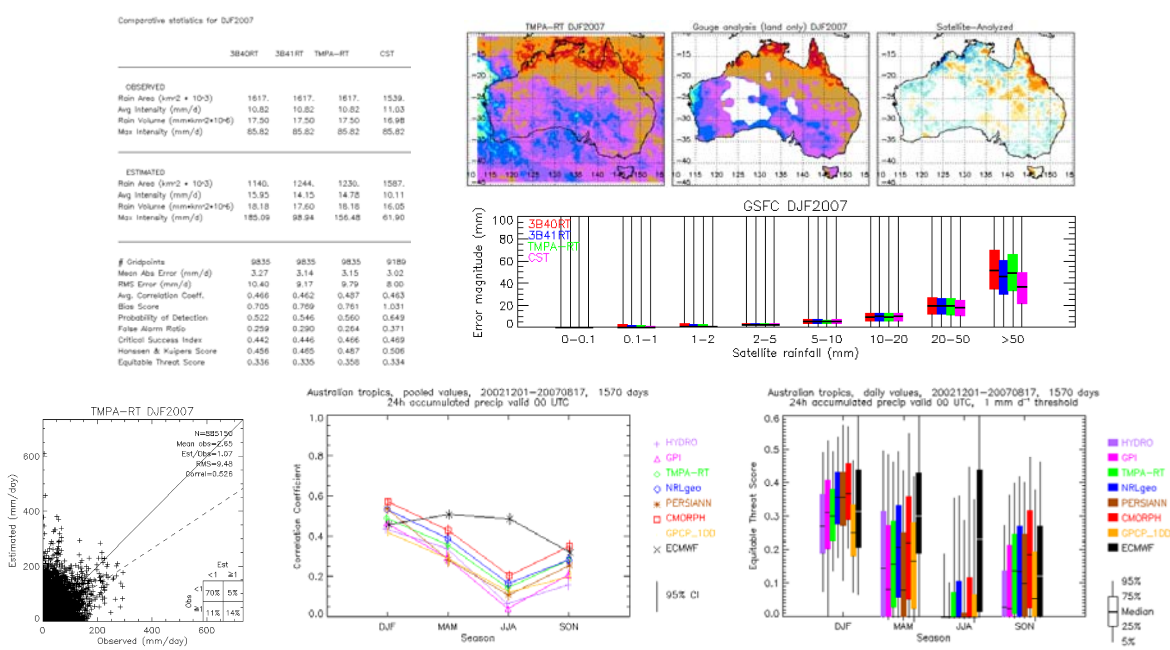


Figure 4: Radar (left) versus gauge (right) comparisons over the UK for a widespread rainfall event (top) and for an anomalous radar rainfall event (bottom).



Comparative statistics for DJF2007

	3B40RT	3B41RT	TMPA–RT	CST
OBSERVED				
Rain Area (km^2 * 10^3)	1617.	1617.	1617.	1539.
Avg Intensity (mm/d)	10.82	10.82	10.82	11.03
Rain Volume (mm*km^2*10^6)	17.50	17.50	17.50	16.98
Max Intensity (mm/d)	85.82	85.82	85.82	85.82
ESTIMATED				
Rain Area (km^2 * 10^3)	1140.	1244.	1230.	1587.
Avg Intensity (mm/d)	15.95	14.15	14.78	10.11
Rain Volume (mm*km^2*10^6)	18.18	17.60	18.18	16.05
Max Intensity (mm/d)	185.09	98.94	156.48	61.90
# Gridpoints	9835	9835	9835	9189
Mean Abs Error (mm/d)	3.27	3.14	3.15	3.02
RMS Error (mm/d)	10.40	9.17	9.79	8.00
Avg. Correlation Coeff.	0.466	0.462	0.487	0.463
Bias Score	0.705	0.769	0.761	1.031
Probability of Detection	0.522	0.546	0.560	0.649
False Alarm Ratio	0.259	0.290	0.264	0.371
Critical Success Index	0.442	0.446	0.466	0.469
Hanssen & Kuipers Score	0.456	0.465	0.487	0.506
Equitable Threat Score	0.336	0.335	0.358	0.334

Figure 5: Results of a seasonal intercomparisons of precipitation products for December 2006 – February 2007.