CGMS-XXXIII
WMO WP-14
Prepared by WMO
Agenda item II/4

INTERNATIONAL PRECIPITATION WORKING GROUP

(Submitted by WMO)

Summary and purpose of document

To inform CGMS Members on the status of activity related to International Precipitation Working Group (IPWG).

ACTION PROPOSED

(1) CGMS Members to note the status of activity related to the International Precipitation Working Group (IPWG);

(2) CGMS Members to provide and update the inventory of routinely produced precipitation estimates, either operational or experimental/research, to the IPWG co-chairs, as explained in the second workshop report below;

(3) CGMS Members to note and support the IPWG science meeting scheduled to take place in Melbourne Australia in October 2006;

(4) CGMS Members to note and support the ongoing Validation activities as brought forth in the Second IPWG Working Group Workshop; reported on below.

(5) CGMS Members to provide information to the IPWG Rapporteur on areas for future consideration by the IPWG.

Appendix Detailed meeting summary “Second International Precipitation Working Group Workshop”, Monterey, California, USA, 25-28 October 2004.

DISCUSSION

Background

1. CGMS-XXVIII initiated the establishment of a Working Group on Precipitation, with co-sponsorship by WMO and CGMS.

2. CGMS-XXIX noted the successful organizational session of the International Precipitation Working Group (IPWG) and approved the terms of reference for the IPWG.

3. CGMS-XXX received with enthusiasm the report of the First International Precipitation Working Group (IPWG) Workshop and noted the establishment of three working groups: Operational Applications, Research Activities, and Validation Activities with their plans for future activities with short term, intermediate and long term goals.

4. CGMS-XXXI was updated on algorithm activities and developed Action item 31.29 requesting CGMS members to provide and update the inventory of routinely produced precipitation estimates, either operational or experimental/research, along with training information for the IPWG web page.

5. CGMS-XXXII noted the imminent IPWG science meeting to be held in October 2004 in Monterey, California, and looked forward to its success.

Second International Precipitation Working Group (IPWG) Workshop (IPWG-2)

6. During IPWG-2, held during 25-28 October 2004 in Monterey, California, two days of formal 20-minute presentations were followed by intensive working group sessions. The meeting was hosted by the Naval Research Laboratory (NRL) Marine Meteorology Division (MMD) and Drs Joe Turk (NRL) and Peter Bauer (European Centre for Medium-Range Weather Forecasts, ECMWF) co-organized the meeting. Over 50 participants from 19 countries took part in this 3½ day workshop. The workshop resulted in a series of action items, both existing ones from the first meeting as well as new ones. Specific actions suggested to the IPWG during the 32nd CGMS session, which was held in Sochi, Russia, 21-27 May 2004, were presented by Dr Jim Purdom and discussed. These recommendations included addressing the following science issues: 1) GPCP assessment; 2) solid precipitation; 3) precipitation over complex terrain; and, 4) ongoing validation studies. We report on these (and other) activities below. IPWG-2004 Proceedings have been published by EUMETSAT in hard copy and CD-R, and are available from EUMETSAT. A detailed summary of the meeting is given in Appendix A.

7. **GPCP Assessment:** IPWG2 was informed that a workshop was held in August 2004 at the Cooperative Institute of Climate Studies, ESSIC, University of Maryland to discuss a plan for the assessment of global precipitation data sets. The workshop concluded that the assessment should focus on the GPCP data set but include other sources of data as needed to support the analyses and conclusions of the assessment. The assessment will review the procedures and input data to the development of the GPCP data set, its spatial and temporal variability, the future outlook for new and improved data sets and recommendations about the quality and use of these data for studying the climate.

8. **Subsequently,** a follow-up meeting for preparation of the final GPCP assessment was held in Bologna, Italy during April 2005, at the Italian Institute for Atmospheric Sciences and Climate. Subsequently, the basic plan was generated in the form of an outline with lead authors for each Chapter, contributors and reviewers selected, and all chapters have been written and are being reviewed. The final draft is planned for completion in late 2005.
See http://cics.umd.edu/~yin/GPCP//ASSESSMENT/assessment.html for more information.

9. **Solid Precipitation:** IPWG-2 was informed of the current status of the retrieval and quantification of snowfall and frozen precipitation was discussed. The use of passive microwave sounding channels from instruments such as the AMSU instruments was presented. It was noted that this area is also a priority area for the NASA Global Precipitation Mission (GPM). Based on this it was suggested to organize a separate workshop on this topic. Drs Ralf Bennartz (University of Wisconsin) and Ralph Ferraro (NOAA-NESDIS) agreed to co-organize with the support also of the GEWEX Radiation Panel (GRP).

10. **Subsequently**, the 1st "IPWG/GPM/GRP Workshop on Modeling of Snowfall" took place 11-13 October 2005 in Madison, Wisconsin. Over 50 participants representing 18 countries attended. The workshop was broken into three working groups: Applications, Modelling, and Validation. The workshop will be issuing and distributing a final report and a summary publication. We expect that the results and collaborations resulting from this workshop will contribute to planning and strategies for the NASA GPM ground validation (GV) program and its focus on high-latitude and frozen precipitation, as well as improvements to both satellite retrievals and NWP modeling of snow and ice.

11. **Precipitation Over Complex Terrain**: At IPWG-2 the research and algortihms working group discussed ways in which satellite precipitation techniques can identify and account for terrain effects, such as orographic enhancement of precipitation over mountainous areas. Since instantaneous satellite overpasses do not capture well dynamical conditions, the current algorithms correct for this in an ad hoc manner by using NWP model forecast low-level winds and a terrain map. It was noted that since NWP models have terrain effects and orographics "built in", that a combined satellite + model estimate would be appropriate. This was left as an action item for the technique developers and the NWP precipitation community to report on at the next IPWG workshop.

12**.** **Validation Studies**: This is the area that the group has emphasized in the time following the first IPWG meeting and received considerable attention at IPWG2 as outlined below.

13. **Organized assessment of precipitation overland:** Since the 2002 IPWG meeting, several IPWG members have undertaken an over-land (all of the gauge and radar data is currently over-land) validation/intercomparison study 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 realtime validation statistics from several techniques, which are contributed from the developers.

14. **IPWG Validation Website:** The main 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 over Australia and the US in near real time. This study focuses on the large-scale 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, 1-day forecasts from a limited number numerical weather prediction models, namely the ECMWF, the US (NCEP), and US Navy global models, and the Australian regional model, are also verified.

15. **Evaluation of High Resolution Precipitation Products:** Dr Phil Arkin of the NOAA Cooperative Institute for Climate Studies (CICS) proposed an expanded programme which is 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. 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.

16. **Subsequently,** as of October 2005, the coordinators for each of the four suites have been identified and both sat-precipitation and validation datasets are being identified and prepared. In addition to the three existing IPWG validation sites (Australia, CONUS and northern Europe, five additional validation sites have been proposed: S Korea, S. Africa, Japan and surrounding waters, Taiwan, and southern Brazil. 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 also will contribute to planning and strategies for the NASA GPM ground validation (GV) programme.

17. **Precipitation Assimilation in Numerical Weather Prediction Models:** At IPWG-2, the research group discussed the efforts that are underway in the assimilation of both passive microwave satellite-measured radiance and retrievals and related presentations were given by representatives from NASA, ECMWF and the UKMO.

18. **Subsequently, the** IPWG co-chairs (Drs Turk and Bauer) both represented the IPWG at the Joint Center for Satellite Data Assimilation (JCSDA) Workshop on the Assimilation of Clouds and Precipitation held during May 2005. The workshop was aimed at providing an up-to-date summary of satellite observations of clouds and precipitation, modelling in of these constituents in NWP, and data assimilation of satellite observations of clouds and precipitation, identification of the key impediments to progress in these areas, and the preparation of a list of recommendations to accelerate progress; (a special issue of *J. Atmos. Sci.* is planned and a workshop summary for *BAMS*).

19. **New Sensor Technology:** At IPWG-2, Dr Bizzarro Bizzarri presented the proposed GOMAS (Geostationary Observatory for Microwave Atmospheric Sounding) which is part of the iGeoLab concept proposed by WMO.

20. **Subsequently,** the second IGeoLab science workshop will take place in Rome in late October 2005 and Dr Turk will attend on behalf of IPWG and present contributed materials from many IPWG participants and others, to support the idea of a geostationary microwave instrument for meteorological applications, tropical cyclone forecasting and intensity applications, and NWP data assimilation. The GOMAS instrument was proposed to ESA in response to the announcement of opportunity for new core space missions.

Other Items of Interest and Future IPWG Workshop Plans

21. **Interaction with ITWG**: Several members of the IPWG are also active in the ITWG (TOVS Working Group) and an IPWG poster was presented at the ITWG workshop in Beijing in May 2005.

22. **Algorithm Inventory:** The IPWG algorithm inventory (first prepared after the initial IPWG meeting in Madrid) is being updated with a new template and information to associated links for products, datasets, and relevant publications. The website contains all latest report and documents prepared with relevant IPWG participation.

23. **Third IPWG Workshop for 2006:** The 3rd IPWG Workshop will take place in mid-October 2006, at the Australian Bureau of Meteorology in Melbourne, Australia. A portion of the workshop will overlap with the Asian Pacific Satellite Training (APSATS-2006) event that is also scheduled for that month. We envision several IPWG attendees overlapping their visits and presenting materials to APSATS attendees. IPWG also request CGMS members to support the workshop. If possible, we request financial assistance from CGMS satellite operators and requests WMO travel support for approximately 4-5 attendees from developing countries.

APPENDIX

Summary "Second International Precipitation Working Group Workshop," Monterey, California, October 25-28, 2004; for publication in the Bulletin of the Amer. Meteor. Soc.

The International Precipitation Working Group and its Role in the Improvement of Quantitative Precipitation Measurements

By Joe Turk[1] and Peter Bauer[2]

Validation experiments, algorithm status, research efforts and precipitation standards were discussed at the second workshop of the IPWG

The role of the International Precipitation Working Group (IPWG) is to foster the development of better quantitative precipitation measurements and improvement of their utilization, with a strong focus on the development of international partnerships. Rapid development of algorithms and precipitation products from the ever-expanding meteorological satellite constellation (including the Tropical Rainfall Measuring Mission (TRMM), which deployed the first spaceborne precipitation radar in 1997) provide observational data to a diverse variety of applications, including climate, hydrology, and forecasting. To better exploit these data, a recommendation was put forth by the Coordination Group for Meteorological Satellites (CGMS) in 2001, that strongly encouraged the formation of IPWG with active participation by the World Meteorological Organization (WMO) and the Global Precipitation Climatology Project (GPCP). The objectives of the IPWG involve the analysis and intercomparison of independent datasets, the establishment of standards for operational analysis procedures, validation and independent verification of precipitation measurements derived from satellite data, and the promotion of their proper usage through training and education. The first IPWG meeting took place in October 2002 at the National Meteorological Institute (INM) in Madrid, Spain (Levizzani, 2003).

To better understand the global water cycle, from basin-sized flash flood events to larger scale events such as the El Nino, there is a need for precipitation data across a wide range of spatial and temporal scales, latitudes, seasons, and over both ocean and land. For example, the GPCP, which falls under the Global Energy and Water Experiment activity of the WCRP /WMO, is charged with providing long-term global precipitation data sets for climate analysis and research (WCRP, 1986). By their very nature, low Earth-orbiting (LEO) satellite observations of precipitating clouds represent instantaneous "snapshot" observations (twice per day, at similar local times), and at a spatial resolution that is typically much coarser than the scale of the underlying spatial variability. The first operational passive microwave (PMW) sensor was the Special Sensor Microwave Imager (SSMI) onboard the Defense Meteorological Satellite Program (DMSP) satellites, which has been gathering hydrological data records since 1987. With the improvements in physically-based precipitation retrieval models, and the availability and improved time latency of satellite data, rapid developments in precipitation estimation techniques have resulted from combinations of LEO and finer spatial scale, fast-refresh visible and infrared (VIS/IR) data gathered from geostationary satellites. Depending upon the types of satellite datasets used, these multi-sensor techniques are capable of producing global precipitation products at various combinations of spatial and temporal scales. Since there are many ongoing research efforts and routinely available precipitation products, one of the actions from the first meeting of the IPWG (Levizzani, 2003) was the creation and maintenance an inventory of current precipitation datasets (updated information is available at **http://www.isac.cnr.it/~ipwg**). Since the IPWG provides an open forum for the intercomparison,

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exchange and analysis of both existing and research-oriented precipitation data, another recommendation from the first meeting of the IPWG was the need to collect high-quality ground validation datasets in order to properly assess, validate and better understand the sources of error and uncertainty in satellite-derived precipitation datasets. Therefore, the IPWG divides its actions into three main working groups: operational applications and techniques, validation, and research activities.

During the second IPWG workshop, held during 25-28 October 2004 in Monterey, California, two days of formal 20-minute presentations were followed by intensive working group sessions. The meeting was hosted by the Naval Research Laboratory (NRL) Marine Meteorology Division (MMD) and Drs. Joe Turk (NRL) and Peter Bauer (European Centre for Medium-Range Weather Forecasts, ECMWF) co-organized the meeting. Over 50 participants from 19 countries took part in this 3 ½ day workshop. The workshop resulted in a series of action items, both existing ones from the first meeting as well as new ones. Specific actions suggested to the IPWG during the 32nd CGMS session, which was held in Sochi, Russia, May 21-27, 2004, were discussed and will be articulated on below. The recommendations from this second IPWG meeting will be considered at the 33rd session of CGMS (CGMS-XXXIII) to be held in Japan in November 2005.

OPERATIONAL PRECIPITATION DATASETS

PMW-based satellite rainfall algorithms and techniques which derive precipitation utilize data from low-Earth orbiting satellite sensors, which sample wide swaths of Earth in either a conical or across-track scan pattern. The current operational constellation includes the Tropical Rainfall Measuring Mission (TRMM) microwave imager (TMI) and its companion precipitation radar (PR), three Advanced Microwave Sounding Units (AMSU; NOAA-15/16/17), the Advanced Microwave Scanning Radiometer (AMSR-E, onboard EOS-Aqua), three SSMI (DMSP F-13/14/15), Windsat (Coriolis), SSMIS (DMSP F-16). With the delay in the deployment of the NASA Global Precipitation Mission (GPM), the recent decision by NASA to extend the life of TRMM through 2004 and possibly longer is encouraging, since TRMM is currently the only LEO satellite in a non-sun-synchronous orbit. The current TMI rainfall algorithm (2A12) is now Version 6 and has shown much better agreement with the results from the PR. In the future (Version 7 and beyond), more attention will be given to the a-priori database of cloud structures to make it more consistent with the PR-derived rain characterization. It will have to be adapted to work with the above sensors and more, and provide physical error models and rainfall probabilities that reflect the inherent uncertainty in the precipitation measurement. The AMSU-B algorithm was discussed, including the recent adaptation of a falling snow detection capability. While the AMSU-B instruments were designed for moisture profiling, they have several sounding channels appropriate for high latitude precipitation.

The various blended techniques that were presented utilize geostationary satellite-based VIS/IR data together with the PMW data. The current operational geostationary constellation includes Geostationary Operational Environmental Satellite (GOES) satellites (GOES-9 at 155E, GOES-10 at 135W, GOES-12 at 75W), Meteosat Second Generation (MSG) at 5E, and Meteosat-5 at 63E. The discussion centered around the various means to tie together the intermittent, high-quality PMW precipitation observations with the fast-refresh, fine-scale VIS/IR data from the geostationary satellites. The GPCP has been producing a one-degree daily (1DD) global product since October 1996, and the effort was expanded in 2002 to include a 0.25-degree, three-hourly global product known as the Multi-satellite Precipitation Algorithm (MPA). The presentations focused not only upon algorithms, but also on the sources of error in the estimated values, and means to better quantify them. The focus of the blended satellite presentations was on means to add new data sources, such as multispectral satellite datasets, PMW-based satellite precipitation datasets with very different observing characteristics, radar data, and raingauges. Several presentations focused on using geostationary data to advect precipitation systems in-between revisits of the intermittent PMW data, including a morphing approach and another which uses a cloud motion winds diffusion scheme. These techniques have the advantage of using the IR data purely for cloud motion and not precipitation quantification, but were shown to suffer for situations where the

time in-between PMW revisits is sufficiently long compared to the evolution of the rain system. More IR-quantitative blending approaches were presented, such as the MPA and others, are more robust but which rely upon previous overpasses of PMW data and work best for tropical, convective-type rain systems. A third type of rainfall retrieval that was presented depends upon multispectral cloud observations to estimate near-cloud top properties such as optical depth and effective radius, which are related to the phase, formation and lifecycle of precipitation.

The group reviewed the status of the IPWG website and commented that the precipitation algorithm inventory, while it has grown significantly since the first meeting, needs to be updated to reflect technique modifications and new methods. While the main focus of these new and improved operational techniques is aimed at improving the time resolution of derived precipitation products, there has to date been little usage of numerical weather prediction (NWP) data in the blended techniques. The types of satellite data currently used do not provide useful information on atmospheric dynamics. It was recognized that there is a need for better knowledge of low level moisture and winds in order to account for orographic effects in the satellite techniques. The blended techniques reflect the quality of the PMW datasets that went into them, and so satellite improvements in high latitude precipitation will depend upon related improvements in the PMW algorithms.

The group discussed the possibility of standardizing Level-2 (level 2 refers to data products derived on the high resolution sensor-swath coordinates) precipitation data content. The recommendation from this group dealt with very specific issues relative to Level-2 type products (blank-filling for missing scanlines, information on earlier Level-1 calibration source, inclusion of highest-resolution geolocation fields, precipitation quality estimates, etc.). In particular, the precipitation quality estimate(s) should be provided, but at this point the types of quality information are informal and not well-established. Certain other quantities should be provided if the algorithm allows it (e.g., precipitation type and the probability of non-zero precipitation). A common documentation format was also encouraged. The working group encouraged further evaluation of the high-resolution blended precipitation products, however the details of the implementation of such an effort (science plan, funding, etc) were not well enough defined at this point to make any further recommendations.

During 2-4 August 2004, the Global Precipitation Climatology Program (GPCP) Intergovernmental Panel on Climate Change (IPCC) workshop on precipitation assessment took place. A discussion of the workshop was presented and the assessment is currently being formalized and drafted, with a final copy due in 2005.

VALIDATING PRECIPITATION DATASETS

There are distinct main users of satellite-derived precipitation products: algorithm developers, hydrological applications, climate applications, numerical weather prediction (NWP) data assimilation, and operational nowcasting. Each of these applications has a distinct requirement on the accuracy of the input precipitation data, some more stringent than others. To properly assess and determine error characteristics of satellite precipitation algorithms, validation datasets should be collected over a long enough period of time in order to properly assess the efficacy of the technique(s) across precipitation types, seasons, and to judge detection efficiency and performance across a wide variety of rainfall intensities. During the 32nd CGMS session, which was held in Sochi, Russia, May 21-27, 2004, the CGMS suggested that the IPWG consider validation of satellite-derived precipitation as one of their key actions. Since the 2002 IPWG meeting, several IPWG members have undertaken an over-land (all of the gauge and radar data is over-land) validation/intercomparison study 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 realtime validation statistics from several techniques, which are contributed from the developers.

Australia: **http://www.bom.gov.au/bmrc/wefor/staff/eee/SatRainVal/sat_val_aus.html**
US: **http://www.cpc.ncep.noaa.gov/products/janowiak/us_web.shtml**
Europe: **http://kermit.bham.ac.uk/~kidd/ipwg_eu/ipwg_eu.html**

Maps of the various validation regimes, the types of validation data and statistics used, and summaries from the data that have been validated so far were shown. These validation efforts are currently focused on validating satellite (and several weather prediction model precipitation forecasts) datasets at a daily time scale (24-hour accumulations), but efforts are being directed on gathering data from densely spaced, finer time sampling resolution gauge and/or radar networks. For ease of intercomparison and less confusion, the validation sites all utilize identical statistical metrics (see **http://www.bom.gov.au/bmrc/wefor/staff/eee/verif/verif_web_page.html**). The satellite-based techniques tended to perform best in convective situations during summer seasons, but their performance dropped off considerably when moving into winter and higher latitudes where light drizzle and colder surfaces are frequently encountered. The NWP models outperformed the satellite algorithms in winter seasons and at high latitudes. Not surprisingly, two main research areas (see below) suggested at this IPWG meeting were solid precipitation and the estimation of precipitation over cold surfaces.

While the data used in the current validation efforts was fairly-well quality-controlled, there remained the need for further improvement in the reference datasets used for the validation, i.e., instrument error, raingauge undercatch, sampling errors. Additional information from orographic precipitation, snow and drizzle were difficult to measure. The validation working group agreed upon the need to search for and collect high quality datasets from agencies that may wish to be involved in these IPWG activities. This also includes data from Arctic and Antarctic networks, as well as observations from international experiments, the North American Monsoon Experiment (NAME) and the South American Monsoon Low Level Jet Experiment (SALJET), both of which will include rain gauge transects over steep terrain. Several possible locations and existing networks were discussed, as well as possible adoption of newer diagnostic validation techniques which are currently being developed for mesoscale quantitative precipitation forecasts (QPF). Several of these metrics are still being defined for the various users, which will require additional input and interaction with the various precipitation dataset users.

It was recognized that since direct validation against high-quality surface reference data is not possible throughout much of the globe, alternative approaches such as physical error modeling and validation of rain probability distribution functions (PDF) will be required. The group suggested that there was a need for more representation from the precipitation assimilation and NWP community at future IPWG meetings, in order that the types of error modeling being performed with the satellite estimates could be better aligned with the types of statistics the NWP user will require. The need to advertise and publish articles on the IPWG validation efforts was agreed upon and action items set up.

CURRENT RESEARCH EMPHASIS

Spaceborne observations of precipitating clouds represent the top-of-atmosphere upwelling radiation emerging from scattering and emission processes within the three-dimensional cloud microphysical structure. Early SSMI-era statistical algorithms that related PMW brightness temperatures (T_B) to underlying rainfall rates have given way to physical-statistical techniques, which rely upon mesoscale cloud-resolving models and a Bayesian approach to converge upon cloud structures (including surface rain) that are consistent with the satellite observations. To best describe the natural variability inherent in the microphysics of rain, cloud, graupel, and other hydrometeors, cloud-resolving mesoscale models are used to construct the *a-priori* databases. It is recognized that the complexity of the global precipitation process is much greater than that

which can be described by any set of *a-priori* databases, leading to a natural uncertainty in the estimation of rain rate, liquid water contents, etc. Two main issues in precipitation-related research were identified: the ongoing uncertainty that exists in quantitative precipitation estimation from purely passive remote sensing instruments alone, and the weakness of these same instruments in the detection and quantification of snow over land surfaces. These topics were also suggested to the IPWG during the 32nd CGMS session referred to above. To fully address these areas, the research working group supported and recommended the deployment of next-generation spaceborne radar systems, and the addition of sounding-based channels (i.e., non-window channels) on passive microwave instruments.

Three research areas were identified as crucial for the adequate use of existing and future spaceborne precipitation observations: an open architecture rainfall retrieval algorithm format; combined PMW-IR models; and transportable ("transporting" rainfall using fast-refresh IR data) rainfall estimation techniques. The open architecture framework would combine the strengths of the various international research groups. Ongoing research in the known deficient areas (frozen precipitation, drizzle, orographic rain, cold surfaces, etc.) could best be combined and analyzed within this paradigm. Related to this was an effort to cooperate and share software libraries (e.g., radiative transfer codes, etc.) and associated documentation, and the establishment of a framework for physical algorithm development, dataset fusion, and validation.

A recommendation was made to generate the framework for a "multi-frequency simulator" which could be optimized with orbit configurations, frequency channels, etc., in order to optimize future sensor design and deployment, including potential impacts due to interference within frequency bands.

The group encouraged the combined PMW-IR precipitation techniques to adopt this sort of open and modular framework philosophy. For example, the "transportable" techniques generally separate into those that use the fast-refresh IR data quantitatively, and those that use these IR data for rainfall advection. A modular framework would work well, since the techniques were all using the same "input" dataset and produce similar output products. It would also facilitate the use of numerical forecast model data into the retrieval algorithms, which only a few algorithms currently utilize. More rigorous ways of blending and merging datasets (e.g., blending rainfall estimates from one type of satellite with another, whether PMW or IR) were encouraged (an action for the operational applications WG), that could consider NWP-type data assimilation techniques and be a framework to combine different precipitation estimates from different sensors with different error structures. This was left as an action item for the operational applications group.

COOPERATION WITH OTHER PROGRAMS

In order to assure that the types of error modeling being performed with the satellite estimates could be better aligned with the types of statistics that users will require, increased representation from the precipitation assimilation and NWP community at future IPWG meetings was encouraged. The establishment of an IPWG liaison with the International TOVS Working Group (ITWG) was proposed. The research working group also recommended the planning of a workshop, coordinated with the GPCP, dedicated to frozen precipitation physics and observations, which will be further discussed and announced in 2005.

The IPWG also supported the introduction of Level-2 precipitation content standards, which was proposed to the IPWG by representatives from NASA headquarters. Precipitation standards for products beyond level-2 (e.g., level 3 products such as blended satellite precipitation over various space and time scales) were determined to be at a sufficiently early stage and not yet ready for standardization. The formation of a working group under the auspices of the NASA Global Precipitation Mission (GPM) program was suggested in order to discuss the format issues in more detail.

None of the precipitation products being generated would be very useful without proper training and educational materials to go along with them. The IPWG will work together to provide updated information to the CGMS Virtual Laboratory (VL) for Training in Satellite Meteorology. The VL is a networked system of meteorological satellite operators, six "centres of excellence" at WMO Regional Meteorological Training Centres in Barbados, Costa Rica, Niger, Kenya, China and the Bureau of Meteorology in Australia, and the WMO. Furthermore, the IPWG website is constantly being updated with more specific technique-related information, including links to developers' websites, data and imagery access sites, and related documentation which describes the technique implementation and description. For the latest inventory of precipitation techniques, see http://www.isac.cnr.it/~ipwg/algorithms/algorithms-invent.html.

CONCLUDING COMMENTS

The IPWG meeting ended with a formal presentation of letters of appreciation from the WMO (presented by Dr. Hinsman of the WMO) to the outgoing IPWG co-chairs, Dr. Vincenzo Levizzani and Dr. Arnold Gruber. The new incoming IPWG co-chairs were announced, who will be Dr. Joe Turk and Dr. Peter Bauer. The location for the next IPWG meeting was discussed and will be announced at a later date, but the meeting is tentatively planned for autumn 2006. The local host, Dr. Joe Turk of NRL, formally closed the meeting with a special thank-you to the outgoing IPWG co-chairs, to the meeting sponsors and also to WMO. The complete IPWG meeting program with links to presentations and abstracts is available online at the IPWG website under **http://www.isac.cnr.it/~ipwg/meetings/monterey/monterey2004.html.**

Acknowledgments We express our sincere thanks to the outgoing IPWG co-chairs, Drs. Vincenzo Levizzani and Dr. Arnold Gruber, who have dedicated and volunteered much time since the IPWG inception in 2001. We also thank Dr. Donald Hinsman (WMO) for his efforts in securing travel support for several participants, and Dr. James F.W. Purdom for his role as the IPWG Rapporteur to the CGMS. Special recognition is given to Dr. Elizabeth Ebert for initiating and developing much of the validation project, and her assistance with the IPWG website. We acknowledge the generous support from the Naval Research Laboratory (NRL), the National Environmental Satellite Data and Information Service (NESDIS), the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), and the World Meteorological Organization (WMO).

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