COORDINATION GROUP FOR METEOROLOGICAL SATELLITES (CGMS)
INTERNATIONAL PRECIPITATION WORKING GROUP

FIRST SESSION

CSU TAMASAG CONFERENCE FACILITY
FORT COLLINS, COLORADO, USA

20-22 JUNE 2001

FINAL REPORT

Participants at the First International Precipitation Working Group

(*First row, left to right*, Dr A. Gruber, Dr J. Schmetz, Dr V. Levizzani, Mr K. Ohta, Dr D.Easterling, Ms T. Koyama, Dr D. Hinsman)

(*Second row, left to right*, Dr E. Smith, Mr R. Carbone, Dr C. Kummerow, Dr T. Vonder Haar, Dr J. Purdom, Dr P. Menzel)

1. OPENING OF THE MEETING *(agenda item 1)*

1.1 Opening of the meeting *(agenda item 1.1)*

The first session of the Coordination Group for Meteorological Satellites (CGMS) International Precipitation Working Group was held at the CSU Tamasag Conference Facility, Fort Collins, Colorado, USA, 20-22 June 2001. The session was opened at 09H:00 The list of participants is attached as Annex II.

1.2 Adoption of the Agenda *(agenda item 1.2)*

The agenda for the session was adopted and is reproduced in Annex I.

1.3 Working arrangements for the meeting (*Agenda item 1.3*)

The working arrangements for the session were agreed upon.

2. ELECTION OF CHAIRMAN *(agenda item 2)*

The Working Group elected Dr James Purdom as Chairman for the first session of the CGMS International Precipitation Working Group.

3. REVIEW ACTIONS TOWARDS ESTABLISHMENT OF AN INTERNATIONAL PRECIPITATION WORKING GROUP (IPWG) (*agenda item 3*)

3.1 The first session reviewed actions leading towards the establishment of an International Precipitation Working Group (IPWG). It was informed that CGMS-XXVIII (October 2000) had agreed upon the need to foster further development of focused science groups. The success of both the International TOVS Working Group (ITWG) and the CGMS Winds Working Group in focusing the scientific community on a specific application area's issues and problems, strongly suggested similar benefits could be gained by development of science teams and workshops that could deal with application areas of satellite meteorology such as quantitative precipitation estimates, NWP and ocean and land surface properties. The current existence of many scientific groups operating in these areas could facilitate this task. For example, in the area of quantitative precipitation estimation, groups of scientists were currently involved in the World Climate Research Programme (WCRP) and in particular the Global Precipitation Climatology Project (GPCP) and had already exchanged information on data requirements and algorithm development.

3.2 The first session also noted that the fifty-second session of the WMO Executive Council (2000) had recommended involving relevant science groups in a systematic manner and the positive indication from the GPCP for WCRP's GEWEX to serve as a nucleus for such a working group. Thus, WMO had strongly encouraged the formation of an International Precipitation Working Group with active participation by WMO and GPCP within the framework of CGMS.

3.3 Finally, the first session noted that CGMS-XXVIII agreed to initiate the establishment of a Working Group on Precipitation, with co-sponsorship of WMO and CGMS, and to report to CGMS-XXIX on the progress made.

3.4 The first session then reviewed the activities leading to the formation and terms of reference for the IRC International TOVS Working Group (ITWG) and the CGMS Winds Working Group.

4. REVIEW CURRENT STATUS OF PRECIPITATION ESTIMATION FROM SATELLITE-BASED OBSERVING SYSTEMS, AND PLANS AND CAPABILITIES OF FUTURE SATELLITE-BASED SYSTEMS *(agenda item 4)*

4.1 The first session reviewed the current status of precipitation estimation from satellite-based observing systems and the plans and capabilities of proposed future satellite systems as contained in Annex IV. Additionally, the first session discussed the importance of the WMO Virtual Laboratory for Education and Training in Satellite Meteorology and the relevance of the IPWG towards helping it achieve its goals.

4.2 In conducting the review, the first session noted several issues that should be considered in the formation of the IPWG:

- validation and independent verification of precipitation estimates in the context of the scale of observation and the type of precipitation phenomena being characterized;
- the importance of the full implementation of the GCOS Surface Network (GSN) to help in the validation effort;
- the importance of water vapour and cloud micro-physics in the development of precipitation systems;
- the relevance of planned field experiments within the World Weather Research Programme especially for warm season precipitation events and the assimilation of precipitation observations in forecast models;
- the relevance of missions including the Global Precipitation Measurement (GPM) mission that would tie together active and passive instruments on polar-orbiting satellites with the high temporal observing capabilities afforded by geostationary satellites;
- the importance of international cooperation in the areas of missions, validation, algorithms, new techniques, and education and training;
- the importance of the IPWG covering the needs of various communities including hydrometeorology, weather and climate.

5. REVIEW DRAFT TERMS OF REFERENE FOR AN IPWG *(agenda item 5)*

5.1 The first session reviewed the draft terms of reference for an International Precipitation Working Group. The session was guided by the terms of reference for the ITWG and CGMS Winds Working Group and the issues identified in its review of the current status of precipitation estimation from satellite-based observing systems.

5.2 The first session developed terms of reference as shown in Annex III for consideration by CGMS XXIX.

5.3 The first session agreed that the IPWG will be served by two Co-Chairmen and a Rapporteur to CGMS. The Co-Chairmen for IPWG are Dr Arnold Gruber (USA) and Dr Vincenzo Levizzani (Italy).

6. DEVELOP RECOMMENDATIONS FOR CGMS AND FOR THE SECOND SESSION OF THE INTERNATIONAL PRECIPITATION WORKING GROUP *(agenda item 6)*

6.1 The first session recommended that CGMS review and give favourable consideration to the structure and terms of reference as contained in Annex III for the IPWG.

6.2 The first session suggested that the Co-Chairmen take into consideration the terms of reference contained in Annex III and the following points in developing the second session:

- Identify producers of routine (or operational) rainfall products and engage them in quarterly reporting of remote sensing product comparisons with other rainfall estimates in a standard format;

- Address compatible and interchangeable algorithms, as appropriate, early-on with a group of specialists from both the research and operations community. This will facilitate the early transition from research to operations

- Consider validation, with a group of specialists involving standard and specialized measuring systems,

- Consider new techniques that include water vapour, cloud microphysics and the utilization of new multi-spectral data;

- Consider frequency allocation and protection activities for current and future instruments;

- Consider the role of IPWG in direct assimilation of precipitation and related observations in NWP models at all scales. WWRP/THORPEX is important to the IPWG in this context.

7. ANY OTHER BUSINESS *(agenda item 7)*

The first session requested that the Co-Chairmen make an initial indication of the time and venue for the second session of the IPWG and to inform CGMS-XXIX. The first session requested that the Chairman of the OPAG IOS inform CGMS-XXIX of the proposal for the formation of the International Precipitation Working Group as contained in Annex III.

8. CLOSURE OF THE MEETING *(agenda item 8)*

The first session thanked CIRA for providing the venue, excellent facilities and outstanding hospitality for the session. The session closed at 12H00 on 22 June 2001.

ANNEX I

AGENDA

1. OPENING OF THE MEETING

2. ELECTION OF CHAIRMAN

3. REVIEW ACTIONS TOWARDS ESTABLISHMENT OF AN IPWG

4. REVIEW CURRENT STATUS OF PRECIPITATION ESTIMATION FROM SATELLITE-BASED OBSERVING SYSTEMS, AND PLANS AND CAPABILITIES OF FUTURE SATELLITE-BASED SYSTEMS

5. REVIEW DRAFT TERMS OF REFERENCE FOR AN IPWG

6. DEVELOP RECOMMENDATIONS FOR CGMS AND FOR THE SECOND SESSION OF THE INTERNATIONAL PRECIPITATION WORK GROUP

7. ANY OTHER BUSINESS

8. CLOSURE OF THE MEETING

ANNEX II

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ANNEX III

DRAFT TERMS OF REFERENCE FOR THE INTERNATIONAL PRECIPITATION WORKING GROUP (IPWG)

BACKGROUND

It was proposed at the first session of the IPWG (20-22 June 2001) to establish the International Precipitation Working Group (IPWG) as a permanent Working Group of the Coordination Group for Meteorological Satellites (CGMS). The IPWG will focus the scientific community on operational and research satellite based quantitative precipitation measurement issues and challenges. It will provide a forum for operational and research users of satellite precipitation measurements to exchange information on methods for measuring precipitation and the impact of space borne precipitation measurements in numerical weather and hydrometeorological prediction and climate studies.

PURPOSE

In the area of quantitative precipitation estimation, the IPWG intends to build upon the expertise of scientists who are currently involved in precipitation measurements from satellites with emphasis on derivation of products. The IPWG is established to foster the:

- Development of better measurements, and improvement of their utilization;
- Improvement of scientific understanding;
- Development of international partnerships.

OBJECTIVES

The objectives of the IPWG are:

(a) to promote standard operational procedures and common software for deriving precipitation measurements from satellites;

(b) to establish standards for validation and independent verification of precipitation measurements derived from satellite data; including:

- reference standards for the validation of precipitation for weather, hydrometeorological and climate applications;

- standard analysis techniques that quantify the uncertainty of ground-based measurements over relevant time and space scales needed by satellite products;

(c) to devise and implement regular procedures for the exchange of data on inter-comparisons of operational precipitation measurements from satellites;

(d) to stimulate increased international scientific research and development in this field and to establish routine means of exchanging scientific results and verification results;

(e) to make recommendations to national and international agencies regarding the utilization of current and future satellite instruments on both polar and geostationary platforms; and

(f) to encourage regular education and training activities with the goal of improving global utilization of remote sensing data for precipitation measurements.

MEMBERSHIP

The Working Group shall be comprised of representatives nominated by the satellite operators of the CGMS, other members of CGMS and relevant research satellite operators. The CGMS or the IPWG may invite other experts from the community to participate in the activities of the group.

WORKING ARRANGEMENTS

The Working Group will be co-chaired by two chairpersons appointed by the plenary of the CGMS. The Chairs shall compile a report on relevant activities for the scheduled plenary meetings of the CGMS. The interactive connection with satellite operators will be performed through the use of a Rapporteur who will attend and report to the CGMS meetings.

Under the lead of the two Co-Chairs, the IPWG will organize Workshops, co-sponsored by CGMS and WMO, approximately every two years. The Workshops will promote the exchange of scientific and operational information between the producers of precipitation measurements, the research community, and the user community.

ANNEX IV

CURRENT STATUS OF PRECIPITATION ESTIMATION FROM SATELLITE-BASED OBSERVING SYSTEMS, AND PLANS AND CAPABILITIES OF FUTURE SATELLITE-BASED SYSTEMS

TRMM and microwave estimation of precipitation

(Additional PowerPoint Presentation available)

1. Precipitation products vary widely based upon the applications for which they were developed. Nonetheless, the algorithms may be categorized into two broad types: climate and short-term applications.

2. The climate products are based primarily upon passive microwave sensors and, with the recent launch of the TRMM satellite, upon radar observations. While the sampling from these sensors is poor, the observed radiances are physically related to the rainfall and thus offer the best chance to obtain long term trends. Despite the emphasis on physical solutions, problems do exist. The TRMM passive and active microwave sensors have a bias of approximately 20% and their interannual trends, especially during the El Niño/La Niña transition do not agree. These issues are receiving attention in the TRMM programme but validation data does not currently exist to help this effort.

3. A second category of products uses the more frequent, but less physically related IR (and to some extent visible) observations from geostationary platforms. By themselves, these schemes generally require a number of assumptions and additional data before valid estimates can be obtained. This category also includes a number of polar orbiting sensors (such as MSU) which can detect some signal related to rainfall but is not directly related to the rainfall.

4. A blend of the two methods is also possible and used in the GEWEX data product. Here, geostationary IR data is calibrated by one of the climate products (coincident passive microwave data) on a monthly time scale. Once calibrated, the geostationary data may then be used to make 3-hourly estimates which are finally merged with rain gauge data to produce one best estimate of global precipitation. This product is also produced by TRMM.

5. Three topics pertinent to the IPWG relate to the above discussion:

(a) the willingness of the community to consider a community precipitation algorithm (for passive as well as combined passive/active microwave) that deals with climate products while setting the framework for regional algorithms that incorporate more indirect data sources;

(b) the recognition in TRMM that ground based validation often lacks the quality needed to validate the space-borne estimates and that classical validation practices need to be rethought;

(c) the development of an infrastructure to quantify uncertainties from both the satellite as well as ground based rainfall estimates.

European Space Agency (ESA) precipitation related missions

(Additional PowerPoint Presentation available)

6. ESA (1998) provides the background for the European Space Agency's strategy in Earth Observation for the new millennium. It marks a new era for European Earth Observation based on smaller more focused missions and a programme that is user driven, covering the whole spectrum of interests ranging from scientific research-driven Earth Explorer missions through to application-driven Earth Watch missions. The user community is, therefore, now able to look forward to a

programme of more frequent but very specific missions directed at the fundamental problems of Earth system sciences.

7. For the post-2000 time-frame two general classes of Earth Observation missions have been identified to address user requirements, namely:

- *Earth Watch Missions* - these are (pre-) operational missions;
- *Earth Explorer Missions* - these are research/demonstration missions.

8. In fact, there are two lines of Earth Explorer missions, namely 'core' and 'opportunity' missions. Core missions are larger requiring a longer lead-time while opportunity missions are smaller, more focused and supposed to get implemented quickly.

9. As a result of the first selection of Earth Explorer Core missions in 1999 two missions had been selected for implementation, namely the Gravity Field and Steady-State Ocean Circulation Mission (GOCE) and the Atmospheric Dynamics Mission (ADM-Aeolus).

10. The primary aim of the ADM-Aeolus mission (ESA, 1999) is to provide improved analyses of the global three-dimensional wind field by demonstrating the capability to correct the major deficiency in wind-profiling of the current Global Observing System (GOS) and Global Climate Observing System (GCOS). The ADM will provide the wind-profile measurements to establish advancements in atmospheric modelling and analysis. Such observations will be used in atmospheric transport studies.

11. Out of the five candidate missions under consideration for the second selection of Earth Explorer Core missions there are two missions with strong links to precipitation as they are targeted at water vapour and cloud. These are the EarthCARE (Earth Clouds Aerosol and Radiation Explorer) and the WALES (water vapour lidar experiment in space) missions.

12. The main scientific objective of EarthCARE is to provide data on a global scale which will improve the parameterisation of clouds and aerosols and their radiative effects in atmospheric (weather and climate) models. EarthCARE will also advance the use of cloud data in order to improve the initial conditions for short- and medium-range weather forecasting.

13. EarthCARE will meet these objectives by measuring on a global scale:

- Cloud boundaries (top and base), even of multi-layer clouds, and consequently height-resolved fractional cloud cover and cloud overlap;
- Vertical profiles of ice water content and ice particle size, and, if possible, the vertical velocity of the ice particles;
- Vertical profiles of liquid water content
- The occurrence of layers of supercooled cloud;
- Sub-grid scale (1km) fluctuations in cloud properties;
- Detection of precipitation and estimation of light precipitation;
- Detection of aerosol layers, estimates of their visible optical depth and the depth of the boundary layer;
- Short-wave (SW) and long-wave (LW) radiances at the top-of-the-atmosphere;

- Water vapour and temperature profiles above clouds;

- Spectrally resolved top of the atmosphere LW radiances extending to at least 25µm to study emission from water vapour and other gases.

14. For this purpose a payload consisting of:

- A nadir looking radar,
- A nadir looking lidar,
- A Fourier transform spectrometer,
- A multi-spectral imager, and
- A broad-band radiometer.

is planned to be embarked on a single satellite.

15. The objective of the WALES mission is to provide better insights into the distribution of atmospheric water vapour and aerosols in the troposphere and lower stratosphere with high vertical resolution. The primary objective of the present proposal is to overcome the shortcomings of present systems and to provide the capability to routinely provide water vapour data suitable for a reliable assessment of the detailed temporal and spatial evolution of the global water vapour distribution. These analyses would lead to an improved description of climate processes in GCMs and to benefit in numerical weather prediction (NWP).

16. More specifically, it is proposed to employ active remote sensing techniques as a new and innovative component of the meteorological Global (Climate) Observing System (G(C)OS):

- To directly sample the four-dimensional (spatial and temporal) variability of tropospheric water vapour over the entire globe with unprecedented accuracy;

- To improve the technological ability to quantitatively measure water vapour with high vertical and horizontal resolution;

- To make use of advanced Differential Absorption Lidar (DIAL) technology from a space-borne platform which is an inherently self-calibrating technique needing no complex radiative transfer models and calibration efforts;

- To establish a totally independent set of global water vapour profiles which will help to answer questions about the relationship among changes in atmospheric forcing, radiation budgets, and water vapour-cloud interactions;

- To deliver aerosol profiles and cloud field characteristics particularly in the UT/LS region to study particle formation processes and associated heterogeneous chemistry on a global scale;

- To improve the knowledge of upper tropospheric dynamics;

- To enable a better understanding of the response of the climate system to increases in atmospheric greenhouse gases;

- To help improving modelling capabilities necessary to predict Global Change;

- To improve the interpretation of passive satellite sounding measurements.

17. For the five candidate missions 'Reports for Assessment' which will be published in the series of ESA special publications (SPs) are in preparation. They will be available in early autumn and will be used to select those missions that will enter Phase A in 2002.

18. As a result of the first selection of Earth Explorer Opportunity missions in 1999 two missions had been selected for implementation, namely Cryosat and SMOS. The SMOS (soil moisture and ocean salinity, ESA, 2000) mission addresses two essential links in the global precipitation. The fluxes of both water and energy at the surface/atmosphere interface are very dependent on soil moisture, which is clearly an important variable for numerical weather prediction and climate models. Ocean salinity is a key variable in the determination of ocean circulation and the water cycle, as well as being an important tracer for observing the thermohaline circulation of water masses. The main objective of the SMOS mission is to demonstrate the observation from space of sea surface salinity over oceans and soil moisture over land, in order to advance climatological, meteorological, hydrological and science. In addition, the SMOS mission shall also lead to significant advances in the research fields related to the cryosphere, by improving the assessment of the snow mantle and of the multi-layered ice structures.

19. The 'Second Call for Proposals for Earth Explorer Opportunity Missions' has been released on 1 June with a final closing date in January 2002. More missions of relevance to precipitation are expected from this call.

20. In addition, based on work on-going in the context of EuroTRMM there are plans to participate in GPM, the global precipitation mission. These plans are under discussion.

21. The objectives of all these missions support the goals of the World Climate Research Programme (WCRP). In particular, they will support one of its sub-programmes, namely Global Energy and Water Experiment (GEWEX) which is aiming at an improved understanding of energy and water fluxes within the climate system to secure reliable forecasts at various scales of weather and climate.

22. At the workshop it is planned to provide more detail about the missions addressed in this extended abstract.

EURAINSAT and the European dimension of satellite rainfall estimations
(Additional PowerPoint Presentation available)

23. EURAINSAT - *European satellite rainfall analysis and monitoring at the geostationary scale* – is a shared-cost project (contract EVG1-2000-00030) co-funded by the Research DG of the European Commission within the RTD activities of a generic nature of the Environment and Sustainable Development sub-programme (5th Framework Programme).

24. The key objective of the project is the development of algorithms for rapidly-updated satellite rainfall estimations at the geostationary scale. The project aims at the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) on board METEOSAT Second Generation (MSG) to be launched in July 2002. The new channels available with SEVIRI in the visible (VIS) and infrared (IR) portion of the spectrum will provide insights into the microphysical and dynamic structure of precipitating clouds. Microwave (MW) radiometers on board polar orbiting satellites will be used since their data are more closely linked to the clouds vertical structure and precipitation microphysics.

25. The project team is in composed by the following institutions:

- Institute of Atmospheric and Oceanic Sciences – CNR, Bologna, Italy;
- Laboratory for Meteorology and Environmental Modelling, Florence, Italy;

- University of Ferrara, Ferrara, Italy;
- University of L’Aquila, L’Aquila, Italy;
- Deutsche Zentrum für Luft un Raumfahrt, Weßling, Germany;
- Hebrew University of Jerusalem, Jerusalem, Israel;
- University of Birmingham, Birmingham, UK;
- European and extra-European institutions participate as members of the project’s Steering Committee that actively contributes to the project science and management:
- WMO, Geneva, Switzerland;
- ECMWF, Reading UK;
- EUMETSAT, Darmstadt, Germany;
- European Space Agency, Nordwijk, The Netherlands;
- NASA, GSFC, Greenbelt, MD, USA;
- NOAA, NESDIS-ORA, Camp Springs, MD, USA;
- US Navy, NRL, Monterey, CA, USA.

26. The method(s) will work as follows: (1) microphysical characterization of precipitating clouds with VIS/IR sensors; (2) creation of microphysical and radiative databases on cloud systems using cloud model outputs and aircraft penetrations; (3) tuning of MW algorithms on different cloud systems (convective, stratiform, …); (4) combination of data from the different algorithms and application to a rapid update cycle that makes use of the different sensors at the geostationary scale.

27. The consortium wants to (a) contribute to obtaining more physical and quantitative satellite rainfall estimations using the latest generation sensors, and (b) provide a rainfall product that improves rainfall monitoring and is ready as input to the most advanced local area and global circulation NWP models. Users are to be found among national and international organizations dealing with weather analysis and forecasting:

- World Meteorological Organization (e.g., impacts in remote or insufficiently monitored areas, like Africa);
- Food and Agriculture Organization (FAO) (food production monitoring especially in developing countries);
- EUMETSAT, NOAA and other satellite exploitation organizations;
- ECMWF, NCEP and weather forecasting offices at the international, national and regional scale;
- National civil protection agencies;
- European Union benefiting from an additional powerful support to decision making authorities of its member states and from a coverage of the whole continent every 15 minutes.

28. Rainfall data are considered for direct initialization of numerical weather prediction (NWP) models. Benefits are; among others: (1) more precise mesoscale and global scale weather forecasts; (2) better monitoring of severe weather phenomena (e.g., flash floods, storm-scale events, …); (3) support to hydrology and water management; (4) support to decision making in civil protection.

29. Direct impact on the monitoring of severe events in hazardous areas, in particular, is considered of fundamental importance. Algorithms will be made available to relevant agencies as a direct output of the project.

NASDA's Precipitation related Missions
(Additional PowerPoint Presentation available)

30. The National Space Development Agency of Japan (NASDA) established the following basic policy for its Earth observation missions:

- Policy of new space development:
  - Practical contribution for society;
  - A challenge for outstanding technology;
  - Decision of priorities under limited resources.

- Principles of NASDA's Earth observation activities
  - Contribution to Earth science
  - Promotion of practical use of Earth observation data
  - Advanced technology development

31. The current and on-going projects related to precipitation mission are the following:

- TRMM (Tropical Rainfall Measuring Mission, 1997 ~ present): Joint project with NASA Precipitation Radar (PR) is provided by NASDA and CRL (Communications Research Lab.);

- ADEOS-II (Advanced Earth Observing Satellite –II, Feb. 2002)
  Satellite, Advanced Microwave Scanning Radiometer (AMSR) and Global Imager (GLI) are provided by NASDA.

- AMSR-E / EOS PM (Aqua, Dec. 2001): Satellite platform provided by NASA
  AMSR-E is provided by NASDA.

32. The future potential projects, which NASDA considers in the scenario, are the followings.

- GCOM-B1 (Global Change Observation Mission –B1, 2007-8 (TBD)): ADEOS-II follow-on mission for the material and energy cycle observation satellite, AMSR and GLI follow-on instruments are planned to be provided by NASDA.

- GPM (Global Precipitation Measurement, 2007 (TBD)): Planned joint project with NASA for the core satellite
  Dual-frequency Precipitation Radar (DPR) are planned to be provided by NASDA and CRL.
  GPM is expected to be a bridge mission to the operational system for the precipitation.

33. The major specifications of the instruments that NASDA provides are the following:

Table 1
Major Specifications of PR on TRMM

	Development Specification	**Average Value Measured during 3-years of Operation**
Frequency	13.8 GHz	Same
Peak Power	≤ 500 W	696 W
Sensitivity	S/N per pulse ≥ 0 dB for 0.7 mm/h at rain top	Up to 0.4 mm/h at 5 km altitude (Ze = $372R^{54}$ is assumed.)
Dynamic Range	≤ 70 dB	81.4 dB
Horizontal Resolution	≤ 4.4 km at nadir (3 dB one way)	Same
Range Resolution	≤ 250 m at nadir	Same
Swath Width	≥ 215 km	Same
Observable Range	From surface to height ≥ 15 km. 5-km mirror image for nadir	Same (up to 18 km?)

Table 2
Major Specifications of AMSR on ADEOS-II

Frequency (GHz)	6.9	10.65	18.7	23.8	36.5	89.0	50.3	52.8
Spatial Resolution	50 km		50 km		25 km	25 km	15 km	
Band Width (MHz)	350	100	200	400	1000	3000	200	400
Polarization	Horizontal and Vertical						Vertical	
Swath Width	1600 km							
Dynamic Range	2.7 K ~ 340 K							
Absolute Accuracy	1 K (1 sigma) / target							
NEΔT (k)	0.3 K ~ 1 K (1 sigma)						2 K (1 sigma)	
Quantization	12 bit	10 bit						

Table 3
Major Specifications of AMSR-E on Aqua

Frequency (GHz)	6.9	10.65	18.7	23.8	36.5	89.0
Spatial Resolution	43 km	29 km	16 km	18 km	8.2 km	3.5 km
Band Width (MHz)	350	100	200	400	1000	3000
Polarization	Horizontal and Vertical					
Swath Width	1450 km					
Dynamic Range	2.7 K ~ 340 K					
Absolute Accuracy	1 K (1 sigma) / target					
NE∆T (k)	0.3 K ~ 1 K (1 sigma)					
Quantization	12 bit	10 bit				

34. Currently, NASDA conducts phase A study of DPR system, and CRL conducts development & tests of critical components for Ka-band radar. The Ku-band radar is planned equivalent to TRMM/PR. The estimated specifications of DPR for GPM core satellite are the followings, however, these are to be reconsidered after the considerations of the scientific requirements.

Table 4
Estimated Major Specifications of DPR (Tentative)

	Ku-band PR	**Ka-band PR**
Scan	Active Phased Array	Active Phased Array
Frequency	13.6 GHz	35.55 GHz
Swath Width	245 km	40 – 100 km
Range Resolution	250 m	250 m
Horizontal Resolution	5 km	5 km
Peak Power	1000 W	180 W
Sensitivity (current estimate)	17 dBZ	11 dBZ (15 dBZ)
Data Rate	95 kbps	95 kbps

Precipitation and Climate Science Discussion

35. For climate monitoring and analysis, it is well recognized within the World Climate Research Programme (WCRP) that a change in "characteristics" of any moist process in the climate system may be an important indicator of regional or global climate change. Thus, the

WCRP seeks new information about precipitation and cloud occurrence, absolute amounts or values, duration of precipitation, statistics of the related physical variables, and the temporal and spatial change of all the above.

36. Previous research has lead to suggestions that Earth's precipitation systems may be characterized by distinct, physically-driven distributions of precipitation rates.

37. It is suggested that the systematic investigation of characteristic rain rates for Earth's precipitation regimes and climate zones should begin under WMO and WCRP auspices. New satellites and radar technologies now allow this to be done on a more global scale in connection with rain gauges.

38. The IPWG may wish to add the development, exploration and climatology of rain-rate PDFs to its items of international collaboration. A joint IPWG and GPCP, GEWEX, WCRP activity may be considered.

Role and Use of Surface Observations of Precipitation
(Additional PowerPoint Presentation available)

39. Surface-based precipitation measurements are available for thousands of observing sites around the world, in many cases extending back into the 19^{th} century.

40. The time resolution of these measurements varies from 15-minute observations to annual totals, however most station data are for time resolutions of daily or longer.

41. Spatial resolution of precipitation observing stations is varied, depending on the country and time period. In general as time resolution increases spatial resolution decreases. Around the globe, the highest spatial resolution is found in the mid-latitudes, decreasing both in the tropics and to a greater extent in high latitudes.

42. One of the biggest issues in comparison of satellite precipitation estimates to rain gauge observations is the problem of comparing point observations with area estimates. Typically point measurements are used to interpolate a gridded field for comparison with area estimates. However, the validity of the gridded field is constrained by the spatial resolution and areal representativeness of the point measurements used to derive the field. This is a particular problem in areas of varied topography.

43. Along with the issue of point to area comparisons are problems of homogeneity. One major issue is undercatch of precipitation by gauges , particularly solid precipitation, but also undercatch in heavy storm conditions. Furthermore, problems of time dependent biases also affect the integrity of time series data. These include station relocations, changes in gage configuration including installation of wind shields, or changing gage type, and changes in observing practices, including observing times. Observing time can be an issue when observations are taken only once per day and daily satellite estimates are being verified. For instance, take two stations near each other, one with a morning observing time and the other with an afternoon observing time. If rainfall occurs after the morning observing time, but before the afternoon time, then disparities in the daily rainfall totals between the two stations will exist.

Global Precipitation Climatology Project
(Additional PowerPoint Presentation available)

44. The Global Precipitation Climatology Project (GPCP) was formed in 1986 by the World Climate Research Programme. The goal of the GPCP was to provide a monthly mean global climatology of precipitation on a spatial scale of 2.5 x 2.5 degrees latitude/longitude. It was clearly recognized that in order to accomplish this task there would be a heavy reliance on satellite based estimates of precipitation not only for oceanic precipitation but also for land areas as well where

there was poor gauge coverage. The original objectives were to produce satellite estimates of precipitation and merge them with gauges to provide the best possible global estimates of precipitation.

45. To accomplish its objective the GPCP was organized into several international components consisting of data collection, satellite precipitation estimation, gauge data collection and analyses, merging satellite and gauge analyses, and a vigorous validation effort. Satellite estimates of rain are obtained from geostationary and polar orbiting satellites infrared radiance and from passive microwave sensors on polar orbiting satellites.

46. Since its formation the goals of the GPCP have evolved and in addition to the monthly mean data sets a 2.5 degree pentad precipitation data set and a 1 x 1 degree daily precipitation data set have been produced and are being distributed. And plans are underway to develop high spatial and temporal resolution regional precipitation data sets that are suitable for hydrological applications. GPCP data are distributed on line through the World Data Center at the NOAA national Climatic Data Center.

47. Details of the organization and structure of the GPCP and examples of the data sets will be presented at the IPWG Workshop.

Interaction with the Virtual Laboratory for Satellite Data Utilization

48. Today, operational meteorological satellites provide essential data for meteorological and hydrological services to WMO Members across the globe. New instruments on research satellites have provided insights into future satellite systems, such that a variety of environmental applications are growing vigorously. We should expect great strides forward during the next decade with planned improvements to the space based component of the global observing system, and strive for full exploitation of that component. Updated and improved methods must be developed for preparing products for distribution to an increasingly sophisticated and diverse user community in order to accommodate the rapid-paced development cycle that informed users will demand. Maximum utilization of satellite data for environmental applications requires a strong training component.

49. Meeting the demands of this challenge is only possible because of the combined efforts of the World Meteorological Organization (WMO) and the world's producers of operational meteorological satellite data as represented through the Coordination Group for Meteorological Satellites (CGMS) in the formation of the Virtual Laboratory for Satellite Data Utilization.

50. The Virtual Laboratory for Satellite Data Utilization (VL) is a collaborative effort joining the major satellite operators across the globe with WMO "centres of excellence" in satellite meteorology. Those "centres of excellence" serve as the satellite-focused training resource for WMO Members across the globe. The "centres of excellence" are five WMO Regional Meteorological Training Centres and the Australian Bureau of Meteorology Training Centre, while the four satellite operators are the USA (NESDIS), Europe (EUMETSAT), China (NSMC), and Japan (JMA).

51. The Virtual Laboratory for Satellite Meteorology traces it origins back to work done by CIRA, the Cooperative Institute for Research in the Atmosphere, at Colorado State University in the mid 1990's. Initially aimed at providing online case study data for training US National Weather Service (NWS) offices staff to fully utilize GOES data it soon expanded to providing online case study and near real time data to the WMO RMTCs in Barbados and Costa Rica. As with the NWS effort, RAMSDIS systems, software and data were provided to those RMTCs. Using common software and hardware has allowed work done on algorithm research at CIRA and other institutes to be used by RMTC and NMS staff in Barbados and Costa Rica on real time satellite data and imagery. This cooperative arrangement has benefited the two countries and the researchers through new products, real time ground truthing and made more use of existing satellite resources.

Thus, much of the functionality of what is currently proposed for the Virtual Laboratory for Satellite Data Utilization (training in basic and advanced topics, access to tested and proven software / research and access to expertise) is borrowed from and builds upon the work done by CIRA. Recognizing the importance for a coordinated, world-wide approach to improving satellite data utilization, the WMO's CBS OPAG IOS Expert Team on Satellite Systems Utilization and Products has discussed the Virtual Laboratory concept at each of its three meetings to date. Initial discussions began in Locarno (Switzerland) in June 1999. The next meeting of the group, held in Melbourne noted that satellite training institutions and their sponsoring satellite agencies must utilize modern technology to provide a range of training opportunities and materials to WMO Members. The meeting noted that a key ingredient of the Virtual Laboratory would be to build strong links with science groups. Annex IV of the Melbourne meeting summarizes the ET's discussion on the background, objectives, status and guidelines for the Virtual Laboratory. The most recent meeting of the ET, in Lannion (France) in July 2000, identified the need for two streams of learning skills (basic and specialist) and a virtual resource library within the VL. A schematic representation of the relationships between the various components of the Virtual Laboratory is shown in Figure 1.

52. Subsequent to the Lannion meeting, the concept of the VL was brought before CGMS in October 2000. CGMS and WMO agreed to establish a Focus Group on Satellite Data Utilization and Training within the Virtual Laboratory Framework and report back to CGMS and the WMO OPAG IOS on its findings and the need for future activities in this area. A major function of the Focus Group was to help foster the VL to realize the challenges set forth by the WMO Executive Council Panel on Education and Training and in support of the WMO Strategy for Education and Training in Satellite Matters. The meeting of the Focus Group occurred during mid-May, 2001, and defined the various roles and responsibilities of participants, as well as the relationships between various components of the VL, as shown in Figure 1 (at the end of this document).

53. The immediate goal set by the Focus Group was to implement a baseline VL and to foster its logical growth. Challenges that will be met in implementing this immediate goal are set forth in the section below that addresses 0-1 year actions. Strategically, the focus group emphasized the need to provide high quality and up-to-date training resources on current and future meteorological and other environmental satellite systems, data, products and applications to improve utilization among Members; and, to enable the "centres of excellence" to facilitate and foster research and the development of socio-economic applications at the local level by the NMHS through the provision of effective training and links to relevant science groups. A component of immense strategic importance to the VL will be a Virtual Resource Library (VRL). The VRL supports all three cornerstones of the WMO strategy to improve satellite system utilization: (1) providing access to training and educational material; (2) providing software and expertise on how to the utilize data; and, (3) providing case study and near real time data. Baseline activity toward the establishment of the VRL include the establishment of web servers by EUMETSAT at their Darmstadt facility as an initial site for training resources and materials (end of September 2001) and NESDIS at CIRA for an initial set near real time data and products (end of November 2001). To facilitate this, by the end of July 2001, each member of the Focus Group agreed to prepare an inventory of which training resources and materials are presently available for the core VRL, and each satellite operator would identify what data and products could be linked into the core VRL. While it was realized that in the baseline VL that servers would be at only selected locations, a strategic goal was to have servers, with many mirrored capabilities, located at all nodes of the VL.

54. The Melbourne meeting, referred to above, noted that a key ingredient of the Virtual Laboratory would be to build strong links with science groups. The role of science groups such as the IPWG will be discussed. Topics to be addressed in the discussion include, but are not limited to:

- Contributions to the Virtual Resource Library;
- Scientist participation in VL training events;
- Development of materials for training;

- Potential roles of VL and WMO Members in supporting IPWG needs;
- Communication mechanisms (VL, IPWG, ITWG, IWWF);
  - (i) Focus Group meetings,
  - (ii) Jointly sponsored workshops,
  - (iii) Chairperson's forum.

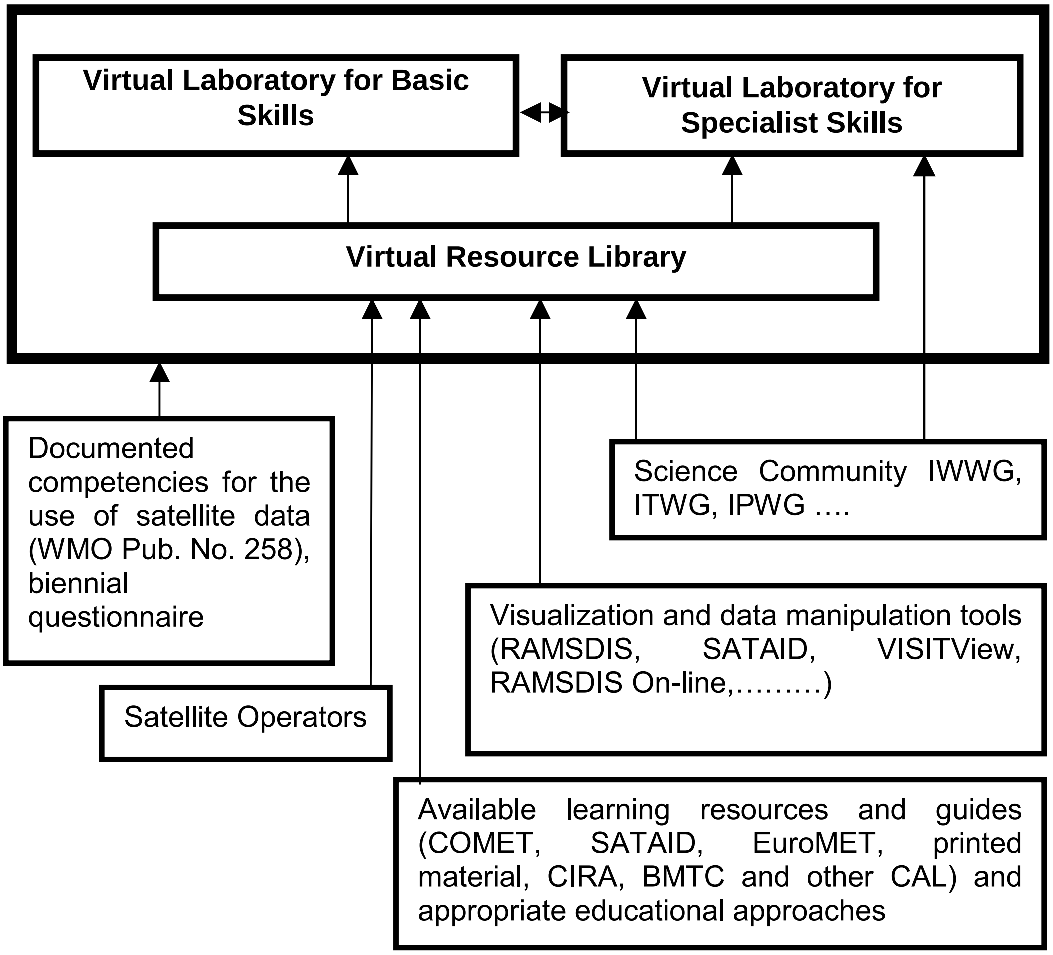

Figure 1. Schematic of the Virtual Laboratory

Rainfall Programmes at NESDIS
(Additional PowerPoint Presentation available)

55. Research and development work at NESDIS on satellite based rainfall estimation spans temporal and spatial scales ranging from severe weather to climate. Much of the work focuses on providing accurate estimates of precipitation in support of NOAA's operational missions. This includes flash flood warnings, input to NWP models, and input to river forecast models and development of precipitation data sets for climate monitoring and analysis. NESDIS scientists also participate in precipitation research supporting AMSR, TRMM and GPCP.

56. This work is characterized by high resolution in both space and time primarily from geostationary satellites but does include polar orbiting data. Our operational rain estimation is based on GOES infrared data, called Auto-estimator (AE). It is used primarily for heavy precipitation estimates. However, there are several experimental algorithms, developed either in house or by others who are cooperating with us, run in real time for evaluation and testing as possible improvements to the operational algorithms. The ultimate goal is to evaluate various

algorithm and select the ones that work best for a given synoptic situation. Clearly the IPWG will help facilitate this effort.

57. In addition to combining geo and polar orbiting satellites rain estimates instantaneous estimates are available from AMSU A, B, and SSM/I and a microwave algorithms is being developed for use over land by AMSR and TRMM.

58. Most of the climate effort has focused on development of monthly mean precipitation estimates from SAM/I, and contributions to GPCP. Plans call for including AMSU as part of the climate product suite. Other related climate products include snow cover, sea ice and total column water vapour and recently we have developed algorithms for cloud liquid water and ice water content.

59. Areas needing improvement, are cold season estimates including solid precipitation rate, lake effect snow, and precipitation estimates in complex terrain. These are challenging problems that can be addressed by the IPWG.

Evaluation of Basin Area Averaged Rainfall from the GOES Auto-Estimator for Flash Flood Monitoring

(Additional PowerPoint Presentation available)

60. Infrared window brightness temperatures have been regressed in a non-linear formulation to estimate hourly or more frequent rain rates; an infrared power law rain rate (IPR) algorithm is derived from a statistical analysis of surface radar derived instantaneous rainfall estimates and satellite infrared cloud top temperatures collocated in space and time. The rainfall rate estimates are adjusted for different moisture regimes using recent fields of precipitable water vapour. In addition, rain is restricted to regions with positive cloud top temperature growth and distinct isolated cold cores within the cloud. NESDIS has implemented an Auto-estimator operationally for applications to flash flood forecasting, numerical modelling, and operational hydrology. Evaluations of the GOES Auto-estimator reveal utility for 1 to 6 hour estimates for flash flood monitoring, but exaggeration of the area of precipitation; there also appears to be an underestimate of rainfall rates in warm-top stratiform cloud systems.

61. Auto-estimator rainfall estimates from GOES are being evaluated as areal averages over drainage basins and compared to averages from the combined radar/satellite/gauge product (Quantitative Precipitation Estimates (QPE) Segregation Using Multiple Sensors (SUMS)) being developed at NSSL. Accurate estimates of basin averaged rainfall is important to forecasting the stream flow, especially in complex terrain. Comparisons of rainfall at available rain gauges may not be representative of basin averages and hence, flash flood potential. Basins are being delineated on a flash flood scale (roughly 10 square miles and smaller). This approach facilitates comparison of accumulated rainfall with thresholds for flash flooding in the basin (flash flood guidance). Evaluations of the Auto-estimator and QPE SUMS are being made for winter and spring precipitation regimes in Arizona and Oklahoma.

62. This paper presents early work on a flash flood case from Arizona on 22 Oct 2000. The Auto-estimator rainfall has been reprocessed at 15-minute intervals. The data has been used in Areal Mean Basin Estimated Rainfall (AMBER) for comparison with the radar and radar plus satellite estimates. On this day, the NWS reported that 4 to 6 inches of rain fell in the headwaters of Centennial Wash, near Wenden AZ. Resulting runoff reached depths of 12 feet and discharge exceeded 20,000 cubic feet per second. 125 mobile homes were inundated and transported downstream. One migrant worker was killed and property damage exceeded $6M.

63. Figure 2 shows the instantaneous and accumulated rainfall from the Auto-estimator averaged over a basin along the Santa Mari river during a 6-hr period. In this case, both remain below the thresholds for flooding in this basin. It appears that the Auto-estimator underestimated rainfall amounts at 2 inches compared to NWS reports at 4 to 6 inches. The majority of rain fell

well upstream of Centennial Wash suggesting that flood routing with a hydrologic model may be necessary for this kind of event.

64. These data are displayed in real time on the Quantitative Precipitation Estimator Interactive Web Interface (QIWI). It offers flexibility, efficient web-based interface (any platform), lists basin attributes (flash flood potential), configurable thresholds on-the-fly, and displays of underlying terrain/geopolitical features.

65. Future work will engage radar and combine radar/satellite/gauge estimates as input to QIWI. Additionally rainfall amounts will be evaluated using stream flow measurements, and eventually, a stream flow prediction model will be coupled to the QIWI interface. Results from this other flash flood case studies indicates QIWI can provide about 1 hour of lead time (time between rainfall peak and flood peak)

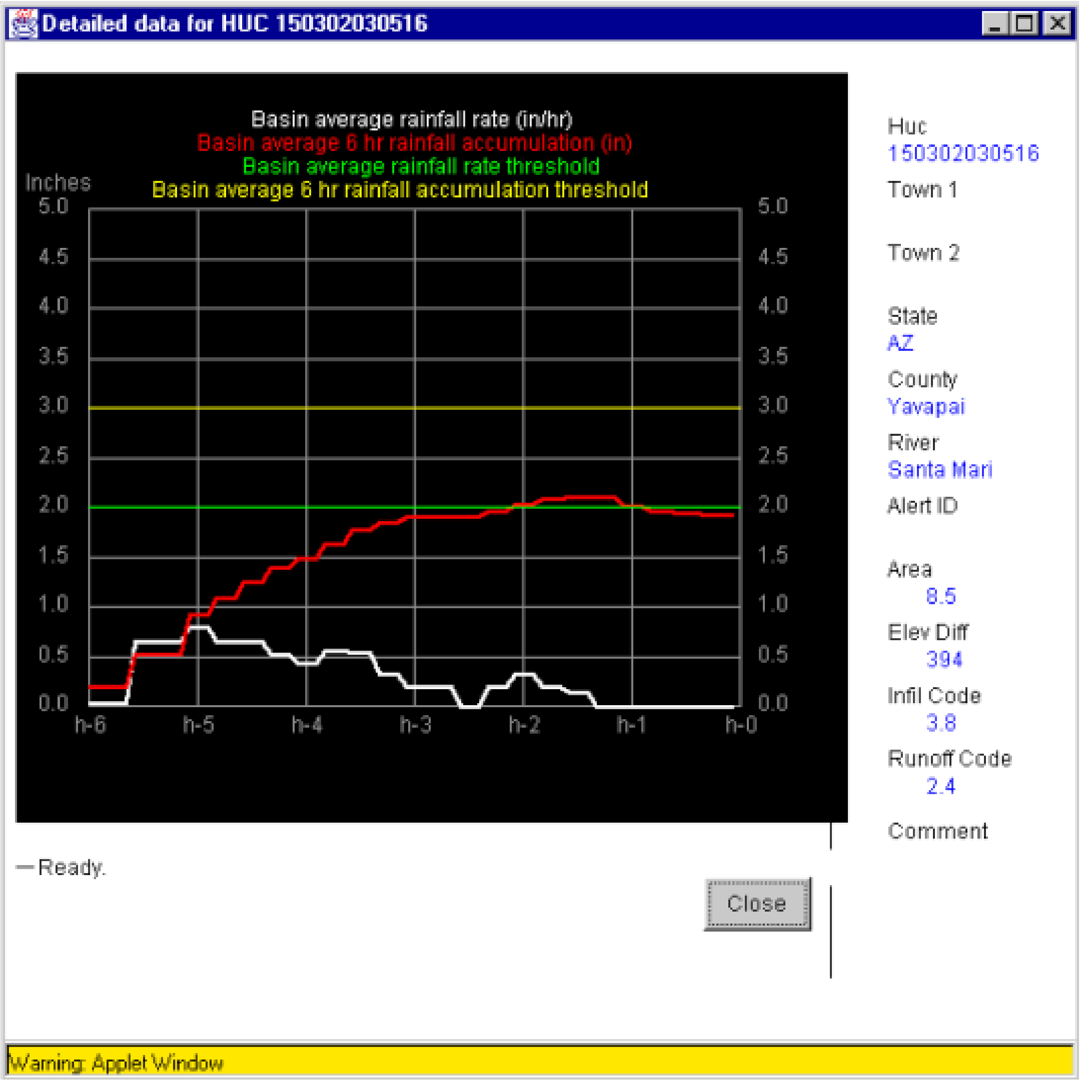

Figure 2. Instantaneous (white) and accumulated (red) rainfall from the Auto-estimator averaged over a basin along the Santa Mari river during a 6-hr period; in this case, the instantaneous and accumulated rainfall is below the thresholds for flooding (green and yellow, respectively) in this basin.

World Weather Research Programme (WWRP), WME CAS
(Additional PowerPoint Presentation available)

66. The WWRP has numerous R&D and Forecast Demonstration Projects within which improved quantitative precipitation estimation (QPE) and/or quantitative precipitation forecasting (QPF) are principal goals. While the long-term objectives of the WWRP include all deterministic forecast ranges and slightly beyond, the near term focus is on very short through medium range prediction. Moreover, such goals are heavily emphasized in populated regions where precipitation events have high economic and social impact.

67. The more important role of satellite observations of precipitation to most WWRP projects will be related to improved initialization of forecast models at all scales and ranges of prediction. That is to say, we must properly initialize forecast models with knowledge of where precipitation is falling and, to the extent possible, represent the diabatic heating/cooling effects. This is a major challenge in 4-D data assimilation where the favoured approach for the future is to have models predict satellite and radar observations and then use radiances or reflectivity differences to adjust the models. We are a long way from accomplishing this for precipitation at the global scale, however limited area applications at the mesoscale are on the operational horizon.

68. Another application, especially of geosynchronous satellites, is the detection of cloud motion and vertical growth in rule-based nowcasting (0-6 h). Such non-dynamical and hybrid schemes for heavy rainfall and flood prediction are extremely important in high impact weather. In this sphere, satellite imagery and ground-based radar in tandem are the core observations and the primary basis for rule-based nowcasts. Increasingly, these observations are being assimilated via adjoint models with dynamical and thermodynamical constraints imposed in the non-linear dynamical setting. Very high rates of sampling are required and forecast specificity (resolution) is of the essence, including the urban scale.

69. Recently, it has been revealed that long space/time coherence is associated with major convective precipitation events over continents. This attribute should increase the potential utility of radar observations of precipitation from space for short-term forecasts.

70. The WWRP was approved by CAS in March 1998, resulting from a consolidation of two Working Groups that had focused on prediction from very-short through the long ranges. Since then the Science Steering Committee has met annually, once each at Hong Kong, Innsbruck, and Vancouver, Canada. In 2001 it will hold its fourth session at the WMO in Geneva.

71. WWRP has adopted a “project” or topical approach to research, forecast demonstration, technology transfer, and training objectives. A total of 10 projects are at some stage of implementation or development and these are very briefly summarized below. One project (MAP) was “grandfathered” into the WWRP in that it was a well-established programme prior to WWRP’s inception. However, most of the projects have been initiated or stimulated by the SSC itself. A few project ideas and proposals have been initiated externally and reviewed as potential WWRP projects. Six projects have received at least some level of SSC approval; three projects are actively in progress; and each of these has completed at least one episode of field experimental activity. My presentation in Guilin will go into more detail on each of these projects.

72. One symposium and two workshops have been organized:

- The Sydney 2000 Nowcasting Workshop was held from 30 October to 9 November 2000 for the purpose of education and training of senior forecasters from various WMO members. Forecasters from around the world participated in an experiential course of study that included assessment of the nowcasting potential of advanced forecast systems; the forecast process relationship to current scientific understanding; political/decision-making aspects; and societal impacts of improved prediction. Ian Bell, AU Bureau of Meteorology Training Centre, organized the workshop with the assistance and participation of experts from each of the forecast systems being demonstrated during the Sydney 2000 Forecast Demonstration Project.

- A Workshop on the Verification of Quantitative Precipitation Forecasts will be held in Prague 14-16 May 2001. This workshop, mainly through invitations and recommended participants, will be kept to a group of 20-25 experts, including six invited speakers. The emphasis is on mesoscale and convective scale verification of heavy rainfall amounts but also including winter precipitation. There is an impact component to this workshop to ensure societal meaningful and useful verification criteria.
  (Radmila Bubnova, Programme Chairperson).

- The International Conference on QPF will be held at Reading University, 2-6 September 2002). The emphasis will be on high impact weather including heavy rain events. Participation is expected to be approximately 300 people. The Conference will have sessions pertinent to predictions at all forecast ranges (nowcasting through seasonal). It will consider both physical and social science aspects of precipitation forecast information, including the importance, communication and use of QPF predictions.
  (Keith Browning, Programme Chairperson). Eleven prominent speakers have accepted invitations for keynote talks.

73. Projects in progress included:

Mesoscale Alpine Programme (MAP)
Research and Development Project, P. Bougeault, P. Binder and R. Smith (leaders)

Airflow and precipitation in steep terrain and within the extra-tropical cyclone context. Field phase was completed in November 1999. Major observing facilities including numerous research aircraft from the EC and US. Objectives range from fundamental studies in dry and moist dynamics under topographical influences, to experimental prediction of heavy precipitation and flash floods. The field phase was highly successful and research findings are beginning to emerge.

Sydney 2000 (S2K)
Forecast Demonstration Project, T. Keenan, Project Director

Very short range prediction and nowcasting of high impact weather in large metro areas during and after the Sydney 2000 Olympics. Rule-based forecast and decision support systems; limited area model. Verification and impacts research components in addition to forecast systems demonstration. Training workshop. Pilot trials September 1999, February 2000. Field phase completed 2 September through 18 November 2000 with extensions by most participants through 31 December. A highly successful demonstration, compromised only by the relatively small number of severe weather events. A special issue of Weather & Forecasting is planned.

Aircraft In-Flight Icing (AIFI)
Research and Development Project, G. Isaac and J-L Brenguier, SSC Co-Chairs

Coordination and consolidation of numerous national and regional efforts related to understanding of icing conditions in water and mixed-phase clouds. This includes regional climatologies of freezing precipitation and upper air conditions associated with same; development of *in situ* instrumentation and acquisition of microphysical data in icing conditions; interpretation and use of remote sensing data; numerical model representations and predictions of icing. Involves all sectors of aviation industry and users of icing forecast information. Alliance Icing Research Study (AIRS) field campaign successfully completed in Canada.

74. Approved Projects included:

Tropical Cyclone Landfall (TCL)
G. Holland, organizer and Acting SSC Chair

In cooperation with the WMO Tropical Meteorology Research Programme and the USWRP, an ambitious sequence of RDP (N. Atlantic) and FDPs (Australia-Asia regions) to improve predictions of wind, rainfall and use/impact of forecast information associated with landfall of tropical cylcones.

The Hemispheric Observing system Research and Predictability Exp. (THORpex)
R&D and Forecast Demonstration, A. Thorpe and R. Gall, SSC Co-Chairs

With the WMO Working Group on Numerical Experimentation (WGNE), a programme of research related to predictability and prediction of cyclones of oceanic (or remote-continent) origin given the present sparsity of *in situ* observations and the under-utilization of remote sensing data from space. Components include data assimilation technique development, interpretation of theory, observational strategies, observing platform tests, observing system simulations. Field campaigns envisioned for the Arctic-N. Atlantic and Arctic-N. Pacific. Preliminary Science Plan was approved in 2000 and Full Science Plan to be reviewed October 2001.

Mediterranean Cyclones Experiment (MEDEX)
Research and Development Project, A. Jansa, P. Alpert, A. Buzzi Co-leaders SSC

High impact weather events in Mediterranean region with emphasis on high winds, heavy precipitation and flooding. Includes unique aspects of cyclogenesis peculiar to region with very warm water, steep terrain, high frequency of cyclogenesis. Western and eastern region aspects initially documented through establishment of dynamically-based climatology from existing and augmented data. Science Plan approved for climatological and forecast sensitivity studies only. Field campaigns may be considered upon further definition of forecast problem and limitations.

75. Developing projects included:

Warm Season Rainfall & Flooding
Research and Development Project, coordination by R. Carbone

On several continents, including Africa, the Americas, Australia, China and the Indian subcontinent, mesoscale convective systems are known to have lifetimes up to 24 h, indicative of a dynamical up-scaling from ordinary forms of convection. Recently, coherent warm season precipitation episodes, essentially continental in zonal extent, have been identified over North America. Such findings are suggestive of a heretofore unrecognized intrinsic predictability of heavy warm season rainfall. Goals of proposed project are to markedly increase skill of quantitative precipitation forecasts in the warm season over continents (at ranges from 6 to 72 h) and to demonstrate the utility and benefit of improved QPF information in the prediction of floods and other applications.

Sand and Dust Storms
Research and Development Project, with the Arab League

This project is currently undergoing some rethinking and broadening of participation within and beyond Arab League Members. As originally proposed, the ASAPRO initiative called for improved observational infrastructure for soil uptake, atmospheric surface and boundary layer structures, upper air observations, and limited area model experimentation.

Urban Environment & Flooding
Category of Project not yet determined. O. Massambani, organizer

Heavy rain and urban flooding are the likely foci of this developing project with Sao Paulo Brazil being a candidate city to host it.

Athens 2004
Forecast Demonstration Project, Lalas, organizer

Advanced version of Sydney 2000 – urban nowcasting with stronger NWP component. Likely increased emphasis on advanced data assimilation and ultra-high resolution dynamical model forecasts of convection, winds and air quality.

76. Future directions for WWRP included:

The WWRP/SSC has worked diligently to formulate a programme with vigorous elements of meteorological R&D, advanced forecast demonstration, verification, impacts research and training. It has accomplished this mainly through initiatives of the SSC membership and ad hoc funding.

During the next four years it is essential that the programme of activities achieve a steady state, with a relatively small number of high priority projects advocated, guided and supported through critical review and publication. Our premise is that the number of programmes need not be increased but rather a greater coherence and critical mass of effort can be achieved through international collaboration and coordination. More systematic and integrated procedures should be developed to obtain funds for conduct of these activities at a level that can be sustained for a period of years.

The WWRP must also develop more effective mechanisms to attract unsolicited proposals for worthy projects and to more thoroughly engage developing-nation participants at the forefront of research and demonstration. A greater emphasis should be placed on the use of operational data in WWRP research together with specialized or advanced numerical models. TCL, THORpex and the developing Warm Season projects offer the potential to achieve major advances in forecast skill for problems with widespread global application.

NASA PERSPECTIVE ON GLOBAL PRECIPITATION MEASUREMENT (GPM) MISSION

(Additional PowerPoint Presentation available)

OVERVIEW

Project Definition

77. The GPM mission will measure precipitation on a global basis with sufficient quality, Earth coverage, and sampling to improve prediction of the Earth's climate, weather, and specific components of the global water cycle (GWC).

Science Objectives

78. The GPM mission is a science-based R & D programme with the fundamental objective of advancing prediction skill in the aforementioned geophysical disciplines. This will be accomplished by making substantive improvements in global precipitation observations, specifically improvements in measurement accuracy, precision, sampling frequency, spatial coverage, and spatial resolution. The GPM mission shall also pursue a long term goal of moving toward a space-based global precipitation observing system motivated by its identity under the NASA Earth Science Division's post-EOS Systematic Measuring Mission programme.

79. Ongoing scientific research within the Tropical Rainfall Measuring Mission (TRMM) and interpretation of results from that mission by affiliated scientists have determined that a more comprehensive precipitation measuring programme utilizing various advanced radar-radiometer instrument technologies will lead to such improved predictability.

80. The mainstream scientific objectives of the GPM mission are as follows:

- *For Climate*, to accurately measure the global-regional variability of rainfall, relate those variations to concomitant variations in global-regional temperature, detect the presence or absence of a speculated acceleration in the global water cycle due to global temperature change, and improve global climate datasets and climate prediction through data assimilation of global rainfall measurements into global climate models (i.e., global climate re-analyses and simulation experiments);

- *For Weather*, to improve the accuracy of global and regional numerical weather prediction models through data assimilation of precipitation measurements, with emphasis on improving predictability of hurricanes and severe local storms, and verification of such models with globally continuous and consistent rainfall measurements;

- *For Global* Water *Cycle*, to improve the understanding and predictability of relevant components of the Earth’s water cycle -- which includes water in the atmosphere, within the land surface, in the oceans, and in the cryosphere -- by achieving substantive accuracy improvement in basin-scale water balance across the relevant space-time scales, with particular emphasis on improving the prediction of damaging floods and the availability of fresh water resources.

Mission Strategy

81. The science objectives and framework for research will develop from a rationale projection of global water cycle-based science strategies articulated in the 2001 NASA Earth Science Enterprise Strategic Plan and NASDA's Science Implementation Plan for their ATMOS-A1 mission which is how they identify the core satellite - onto the GPM mission's Science Implementation Plan (the latter due out in February-2002). The GPM programme will be recognized as the satellite mission centre-piece of NASA's initiative in the Global Water & Energy Cycle (GWEC) programme.

82. In order to achieve measurement accuracy, consistency, and coverage across the Earth, including the oceans, continents, and snow-ice fields, a space-based measuring system is required made up of a constellation of low orbiting satellites carrying passive and active microwave measuring instruments. One of these satellites (referred to as the "GPM core satellite") will be similar to the TRMM observatory insofar as its carrying an advanced combined radar-radiometer instrument payload. This enables the highest quality rain measurements and thus a source of transfer calibration information to the rest of the constellation members (referred to as "drone satellites").

83. The constellation system must be technically and financially feasible. Because TRMM demonstrated much of the technical capacity needed by the GPM mission, development of space hardware will be low risk by definition. In order to be financially responsible, the GPM mission will use the vehicles of international participation and international partnership.

84. The central spacecraft of the constellation will be the "GPM core satellite" to be developed under the primary GPM partnership involving NASA and the National Aeronautics and Space Development Agency (NASDA) of Japan. The core spacecraft will carry a NASA-provided passive microwave rain radiometer and a NASDA-provided dual-frequency rain radar.

85. The drone satellites will carry a variety of partner-contributed passive microwave multichannel radiometers. These satellites will consist of a collection of ongoing operational/experimental platforms provided by GPM partners (including NASDA and DOD/IPO) and new dedicated "GPM drone satellites". NASA will be required to provide one or more new dedicated constellation members. Other national and international partnerships will be developed under flexible arrangements to increase the population of the constellation and to provide ground-based calibration-validation sites to ensure high quality space measurements and an understanding of their uncertainties.

86. Scientific research is to be conducted by a competed international science team. Whereas individual international partners are expected to develop their own sovereign science teams, a Joint GPM Science Team made up of selected members of the individual partner teams will act as a governance body for programme-level decisions affecting the scientific research.

87. Whereas precipitation is the major unresolved term in the water budget equations whose improved measurement will guarantee improvement in atmospheric and hydrologic predictability, and thus must be given high priority, this mission recognizes that global water cycle research is highly multi-disciplinary and inter-disciplinary. Thus, the GPM mission endorses complimentary missions and data gathering programmes focused on other key elements of the global water cycle. Of particular additional interest to GPM are improved global datasets of tropospheric wind, atmospheric water vapour, non-precipitating cloud physics, soil moisture, upper layer ocean salinity, freeze-thaw cycling, snow-ice accumulation, river runoff, and lake-sea levels. The GPM programme also recognizes that auxiliary payloads may be required on both core and constellation spacecraft to fulfil some of the more difficult science requirements.

Mission Components

88. In summary, the GPM mission is made up of the following components:

(1) a consortium of partner-based science teams and a down-selected Joint GPM Science Team largely dedicated to use of a global precipitation measuring system and additional synergistic global measurements to better understand hydrological processes and to advance predictability of climate, weather, and the GWC itself,

(2) a core spacecraft mission based on a partnership between NASDA,

(3) a scalable partnership-based constellation of radiometers that provide precipitation data streams,

(4) a multi-mission operations system,

(5) various GPM-centric high quality ground calibration and validation sites sponsored by NASA and additional partners, and,

(6) a science data processing system with multiple centres which coordinate to produce near-real-time "broadcast quality" rainfall products and a final time series of "climate quality" global precipitation measurements plus associated accuracy and precision uncertainties.

MISSION SEGMENTS

Core Spacecraft

89. The core spacecraft will produce measurements which improve our understanding of the microphysics of precipitation and the relationship between precipitation and the vertical structure of latent heating. Improved understanding of precipitation microphysics and its relationship to

diabatic heating is critical to the accuracy and precision requirements of the mission. The measurement requirements needed to produce this understanding and fulfil the level 1 GPM science requirements have been stipulated in preliminary form and will be under continuous refinement until the core satellite's Mission Confirmation Review in the 2nd quarter of 2003.

Sensitivity to Liquid/Ice Water Content

90. The core satellite shall carry a multichannel-polarized passive microwave radiometer system supplied by the NASA/Goddard Space Flight Center (GSFC) to provide measurements of the liquid/ice water content of precipitating clouds. The main radiometer shall be of the conical scanning type to ensure consistency with the scanning modes to be used by most radiometers in the constellation. The radiometer(s) will measure brightness temperatures at notional rain frequencies selected across the 10-150 GHz cm-mm radio spectrum.

91. Based on past analysis of Special Sensor Microwave Imager (SSM/I) measurements from the Defense Military Satellite Program (DMSP) and from TRMM Microwave Imager (TMI) measurements from the TRMM satellite, the nominal required frequencies are 10.7, 19, 22, 37, and 85 GHz with a 150 GHz frequency now deemed "highly desirable" for detection of snow as determined from the AMSU-B sensors flown on the current generation of NOAA polar orbiting satellites. The lower frequency measurements (10-37 GHz) detect the presence and amount of liquid water mass in the atmosphere because they are a measure of liquid water absorption-attenuation, while the higher frequency measurements (37-150) detect the presence and amount of ice mass through sensitivity to ice scattering-attenuation.

Sensitivity to Drop Size Distribution

92. The core satellite shall carry a dual-frequency (Ku-Ka band) non-coherent rain radar system supplied by NASDA and its affiliate partner, the Communications Research Laboratory (CRL) of Japan, to provide measurements of the rainfall drop size distribution (DSD) within focused areas of precipitation. The radars will measure attenuated radar reflectivities at 13.6 and 35 GHz within the radio spectrum. The DSD is one of the two fundamental measures of precipitation (the other being fall velocity which the DSD adequately predicts), in which a dual-frequency bore-sighted radar is the first order means by which to characterize the DSD properties of precipitating clouds. This is possible because a dual-frequency radar measures differential reflectivity (not possible on the single frequency Ku-band radar of TRMM) which is in turn sensitive to variations in the drop size spectra of precipitation-size particles.

Discrimination of Storm Type

93. The core spacecraft shall make measurements which enable the discrimination between convective and stratiform precipitation and "GPM core satellite" retrieval algorithms will provide explicit classification of precipitation type. This information is critical to numerical weather and climate prediction models which formulate convective and stratiform cloud processes separately and distinctly. This can be done because first, the radar can detect the presence or absence of the bright band (melting layer) which is generally considered as a feature which differentiates between convective-stage and stratiform-stage of precipitation (a pronounced bright band indicating stratiform rain), and second because the radiometer can detect the degree of heterogeneity in the rain field (convective rain generally being more heterogeneous).

Measurement of Precipitation Over Land

94. The core spacecraft shall improve the measurement of precipitation over land by taking advantage of its measurements to sensitivity to the DSD spectrum, and the fundamental difference between DSD properties over land and ocean environments.

Calibration of Radiometer Measurements

95. The core spacecraft shall make precipitation measurements which enable the calibration of measurements produced by the constellation radiometers. The core spacecraft will be able to synthesize radiometer measurements, which produce liquid/ice water content factors, with radar measurements, which produce DSD and vertical structure factors, ensuring the highest quality rain measurements for which the accuracy can be passed on to the remainder of the constellation through "calibration transfer". This process adjusts "raw" measurements from the constellation radiometers to "normalized" measurements free of bias relative to the core spacecraft, thus achieving spatial and temporal consistency in the global rain datasets. In this process, it would be highly desirable that a portion of the radar and radiometer measurements be bore-sighted within a common space-time framework.

Detection of Snow

96. The core spacecraft shall be capable of detecting dry snow over water and wet snow over land. The more variable properties of a land background makes it more difficult to detect dry snow falling above it, except for intense events in which large snow flakes and large crystal-flake aggregates are present. The measurement of atmospheric snowfall rate and its follow up accumulation will be considered as a forefront topic in new research.

Mission Lifetime

97. The core spacecraft shall be designed to operate for three (3) years with limited-life items and expendables, including the battery and solar array, sized to a five (5) year goal.

Launch

98. The core spacecraft shall be designed for launch on a NASDA provided H2-A launch vehicle.

Data Delivery

99. Level 0 radiometer and radar data streams will be available to GPM-designated processing centres in a near-real time mode, a 3-hour mode, and as daily quality controlled rain products. All level 0 data will be archived. GPM will process the level 0 near-real time data to a “broadcast quality” continuously updated global rain image and the 3-hour data to “broadcast quality” sequential 3-hour global rain maps. Designated instrument processing centres will convert the daily products to level 1 “climate quality” products. The GPM data processing centre will then process the level 1 “climate quality” products to final level 2 and 3 products as the required input data become available. All level 1, 2, and 3 products will be archived. The “climate quality” products will undergo multiple reprocessing throughout mission operations to ensure continuous refinement of the accuracy and precision of the measurements.

End-of-Life Re-entry Requirements

100. The design and operation of the NASA-NASDA core spacecraft will comply with the re-entry policies of NASA.

Radio Spectrum Requirements

101. Active radio frequency (RF) emitters shall use assigned portions of the RF spectrum. Passive microwave radiometers shall use portions of the RF spectrum to the greatest extent possible reserved for exclusive use by Earth Remote Sensing (first priority), or for shared use (second priority). Whereas the use of shared and non-protected bands is required, bandwidths and channel centre frequencies shall be selected so as to minimize potential interference.

Constellation Spacecraft

Precipitation Sampling

102. The constellation spacecraft are to provide sufficient sampling of precipitation to enable resolving hydrologic processes taking place at the diurnal time scale (i.e., the daily solar cycle). The geophysicist's convention is that three (3) hours is a minimal allowable time step to resolve diurnal scale processes and thus the goal of the GPM mission is to develop a constellation count through the tool of international partnering that enables no worse than 3-hour sampling at any point on the Earth. Under an orthodox constellation orbit architecture, this sampling capability could be achieved with one core spacecraft and 7-8 constellation members. Given that the orbit profiles will be heterogeneous because the individual partners operate under individual orbit profile constraints, it is likely that 9-10 constellation members will be needed to achieve the 3-hour sampling goal.

Calibration of Radiometer Measurements

103. The constellation spacecraft shall make "raw" precipitation measurements which will later be bias-adjusted into "normalized" measurements on the basis of calibration-quality measurements provided by the core spacecraft. The calibration adjustments will be determined by dataset time series specific to individual constellation satellite members gathered during times when a given constellation member and the core satellite overlap in coverage. This procedure ensures spatial and temporal consistency in the final global rain datasets.

Data Delivery

104. Level 0 radiometer data streams will be available to GPM-designated processing centres in a near-real time mode, a 3-hour mode, and as daily quality controlled rain products. All level 0 data will be archived. GPM will process level 0 near-real time data to a “broadcast quality” continuously updated global rain image and the 3-hour data to "broadcast quality" 3-hour global rain maps integrating data from all GPM partners. Designated instrument processing centres will convert the daily products to level 1 “climate quality” products. The GPM data processing centre will then process the level 1 "climate quality products to final level 2 and 3 products as the required input data become available. All GPM partners will have open access to both "broadcast quality" products and "climate quality" products. All level 1, 2, and 3 products will be archived. The “climate quality” products will undergo multiple reprocessing throughout mission operations to ensure continuous refinement of the accuracy and precision of the measurements.

NASA Contributed Constellation Spacecraft

Mission Lifetime

105. Any NASA constellation spacecraft shall be designed to operate for three (3) years with limited-life items and expendables, including the battery and solar array, sized to a five (5) year goal.

Launch

106. Any NASA constellation spacecraft shall be designed for launch on a commercial launch vehicle sanctioned by use by NASA.

End-of-Life Re-entry Requirements

107. The design and operation of any NASA constellation spacecraft will comply with the re-entry policies of NASA.

Radio Spectrum Requirements

108. All NASA constellation spacecraft passive microwave radiometers shall use portions of the RF spectrum to the greatest extent possible reserved for exclusive use by Earth Remote Sensing (first priority), or for shared use (second priority). Whereas the use of shared and non-protected bands is required, bandwidths and channel centre frequencies shall be selected so as to minimize potential interference.

Mission Operations System

109. The GPM mission shall include the operations of the core spacecraft and any NASA-provided constellation spacecraft. These spacecraft will be operated by NASA, with the operations costs considered in mission design trades and included within the scope of the programme.

Ground Calibration & Validation Sites

Purpose

110. The GPM programme will require 8-10 local-area and regional validation sites which will provide independent measurements of rainfall reaching the surface to be used to assess the accuracy and precision uncertainties of the satellite measurements. These sites must remain in operation for a minimum of five (5) years commencing at least two (2) years before launch of the core spacecraft and continuing for at least three (3) years after launch of the core spacecraft. The foremost users of these measurement uncertainty factors are specialists in NWP data assimilation who require what are called "error covariances" determined by the uncertainty factors, and climate specialists who must carefully understand the accuracy uncertainties of the space-based precipitation measurements before drawing conclusions regarding climate trends and amplitudes of interannual anomalies in the context of the global water cycle.

Functionality

111. Two types of validation sites will be needed. The first is called a local area validation supersite which is to consist of a research quality multiparameter ground radar, surrounded by a dense network of research quality rain gauges and disdrometers. In addition, situated away from the radar's ground clutter zone will be an upward looking radiometer-radar system at matched frequencies to the core spacecraft, and a 95 GHz cloud radar capable of detecting the pre-precipitation stage of a developing rain storm. Finally, a meteorological tower system equipped to measure the surface radiation, energy, water, and carbon budgets will be deployed near the radiometer-radar site. Such an instrument complement would ensure high caliber calibration-validation analysis of the satellite measurements at the local area scale of approximately 200 km.

112. In order to qualify as a validation supersite, a local area site will have to operate the above instrumentation in conjunction with an on-site science data processing facility staffed with 4-6 scientists and equipment technicians. A supersite must be capable of ingesting the satellite data streams and report, on an up-to-date basis, a continuous time series of accuracy and precision factors as well as error covariance information suitable for use at experimental and operational forecast centres employing rainfall data assimilation. A validation supersite must also be situated in an area which can accommodate specialized field programmes to be operated under GPM auspices, focused on particular GPM science problems.

113. The second type of validation site is called a regional rain gauge network made up of a densely populated network of research quality rain gauges but spread over a regional area (order 600 km) to address calibration-validation situations whose rainfall characteristics cannot be adequately sampled by a local area validation site. Whereas this type of validation site is not as high calibre as the validation supersite in terms of assessing accuracy and precision of the satellite

measurements, it resolves these factors at the regional scale which represents important information in calculating error covariance statistics for data assimilation users.

Implementation

114. NASA will provide two validation supersites, the first a tropical open ocean site, the second a mid-latitude continental site. It will also provide one regional validation site based on the rain gauge network deployed around and west of the Kennedy Space Center (KSC) in central Florida. Because development and operation of all 8-10 sites is expensive and should not be the sole responsibility of NASA, NASA will negotiate partnerships with other agencies both nationally and internationally to ensure the total number of validation sites adequately samples the variety of environmentally distinct rain systems distributed over the Earth.

Data Processing Centre

Data System Architecture

115. The GPM science data system shall be compliant with the NEWDISS concepts and science data centres shall be structured using heterogeneous architecture.

Data System Functionality

116. The GPM science data system shall include functions for: (1) data acquisition; (2) data preservation, (3) data dissemination; (4) algorithm improvement/testing; & (5) data stewardship.

Input Data Streams

117. The GPM science data system shall accommodate the minimum number of data streams required to meet the temporal sampling resolution goal of 3 hours.

Schedule

Mission Start

118. The operating capability of the GPM mission is expected to begin in 2007.

Ongoing Mission Period

119. There are no hard lifetime requirements for the GPM mission as it concerns NASA, other than dictated by the survivability of the core spacecraft and the availability of science funding. Moreover, there are no requirements on launch phasing by partners who introduce drone satellite members into the constellation during the useful life of the mission. This eliminates the need to plan satellite launches with respect to a pre-ordained launch schedule.

120. It will be the responsibility of the Joint GPM Science Team to coordinate and direct science-related activity for the assimilation of new constellation spacecraft into the mission, and to provide advice and counsel on orbital architecture issues to the partner agencies in seeking the most optimal data gathering design vis-á-vis the constellation satellite orbits.

CONSTELLATION ORBIT INTEGRITY

Strategy

121. It is recognized that in defining the orbit configuration strategy for the GPM mission that no single agency will be able to select the orbit profiles of all satellites included in the complete constellation. These decisions are the responsibilities of the individual agencies that operate the

individual satellites, in some cases according to constraints outside of the domain of GPM. Therefore, it will not be possible to design an orthodox constellation orbit architecture that would create ideal sampling for GPM purposes. Moreover, because the expected set of constellation members will fly at different altitudes and inclinations and will consist of a mix of sun-synchronous and non-sun-synchronous satellite orbits, the notion of an idealized orthodox orbit architecture for "perfect sampling" capability is precluded. By the same token, the expected orbit profiles of the shared constellation members and the flexibility available in designing orbit profiles for the dedicated drones in moving toward an optimal orbit architecture, allows for a number of robust orbit architecture solutions insofar as GPM's temporal sampling goals.

122. However, all of these architectures will require fairly rigid specifications insofar as keeping the orbit profiles nearly invariant. This is because any orbit architecture solution designed to optimize sampling according to some type of GPM optimization metric will quickly deteriorate if any constellation member becomes slightly perturbed out of its pre-defined orbit profile, as characteristic of satellites flying at low altitude undergoing residual atmospheric drag.

Autonomous Orbit Control

123. It is possible to achieve near invariance in orbit profiles through a relatively recent technology called "autonomous orbit control", which consists of an onboard software package continuously making orbit adjustment by commanding thrusters according to the pre-defined orbit parameters for a given satellite, only requiring for hardware an onboard GPS receiver to enable continuous navigation fixes. NASA will likely require this capability on any GPM satellite which it will operate, and will strongly recommend that this capability be included on any constellation satellite(s) provided by a GPM partner.

PUBLIC OUTREACH & EDUCATION

General Theme

124. The GPM mission shall provide a means to disseminate information to the general public in a manner that promotes outreach and provides a significant educational benefit across a full range of education and age levels. This is predicated on the ability of the GPM data information system to provide continually updated rain imagery on a near-real-time basis through internet interfaces designed to provide the touch and feel of communicating directly with satellites within the GPM constellation. For a number of outreach applications, a data latency for "broadcast quality" products of no later than 45 minutes would be desirable (e.g., by the Japanese JMA); for most other outreach applications, a data latency for "broadcast quality" products of no later than 3 hours is needed.

Priorities for Outreach

125. Based on the TRMM experience, current high priority recipients and their presumed information interfaces would consist of: (1) students, teachers, and researchers within all types of educational institutions by virtue of direct network access to GPM level 1, 2, and 3 data and derived products; (2) commercial and public television enterprises by virtue of direct network access to near-real time graphical rain imagery suitable for weathercasting programming; (3) National Weather Service and affiliated operational forecast centres by virtue of direct network access to data assimilation level "near-real-time-products"; and (4) any government, private sector, and academic data user agency as well as private homes that would find global rain products of value for their institutional and/or personal initiatives by virtue of direct network access to all near-real-time and archival products (note USDA, USGS, and the FAA are good examples of such U.S. government institutions).