Global Precipitation Mission (GPM)

Ground Validation

Science Implementation Plan

DRAFT
July 10, 2008

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1. Overview and Rationale

The Global Precipitation Measurement mission (GPM) Ground Validation (GV) Science Implementation Plan (GVSIP) applies three overarching approaches to validation of GPM satellite constellation measurements, products, and algorithms. These approaches include:

- *National Networks:* Contributions of calibrated ground observations from operational and research instruments, regional and continental scale precipitation and hydrological products with associated error models, the development of downscaling models, and other related activities on large regional or continental scales;
- *Physical Process studies and field campaigns:* Contributions of targeted ground and aircraft measurements of cloud microphysical properties, precipitation, radar reflectivity, and radiances; modeling activities related to atmospheric simulation and retrieval algorithm testing; other relevant observations on local to regional scales
- *Integrated hydrometeorology applications:* Contributions related to assessment of satellite precipitation products at integrated hydrological sites using stream gauges and other hydrological measurements, formulation and application of downscaling methodologies, and analysis of the utility of satellite precipitation products for basin-scale water budget studies.

These approaches represent a culmination of GPM GV Science Panel and GPM Project inputs summarized in Kummerow and Petersen (2006). Within the framework of these three primary approaches, five interdependent satellite, algorithm, and modeling validation activities were specified and subsequently targeted to quantify and understanding measurement and algorithm uncertainties, propagation of those uncertainties through the product development chain, and ultimately the impact on applications (i.e., end-to-end validation). These five validation activities include: (1) core satellite error characterization; (2) constellation satellite validation; (3) assessment of radar/radiometer retrieval uncertainties; (4) cloud resolving model validation; and (5) coupled atmosphere/land surface model validation.

Relative to the five identified activities, validating rainfall products from the GPM Core satellite is expected to be difficult because the high quality of products from the combination of dual frequency radar and radiometer is expected to exceed the quality of most operational networks. As such, this effort will make use of physical approaches to divide the problem into its component pieces. For example, the first step will be to validate measured reflectivity, derived attenuation, and diagnosed median Volume Diameter (D0). This can be accomplished using the National Network approach, via direct comparison to networks of existing polarimetric and well calibrated Doppler radars across the world (i.e., within the national network approach). The second part consists of comparisons between the radar observables (attenuation and D0) and the surface rainfall as measured by very dense rain gauge and disdrometer networks. This activity combines components of both the National Network and Process Study GV approaches in that an international complement of GPM GV sites possessing the requisite instrumentation and measurement methodologies can physically reconstruct a statistically large sample of the relevant satellite observables in the absence of the core satellite itself. The Integrated Hydrology approach is designed to fully connect GPM to the potential user community by assessing uncertainties in the satellite products, but to compare these uncertainties to ground radar and rain gauge networks that are in broad use today. The process helps quantify core satellite uncertainties, and yields improved uncertainties/measures of ground based rainfall estimation as well.

In keeping with GPM science philosophy, the Constellation Satellite Validation activity relies heavily upon statistical comparisons between temporally and spatially coincident constellation and core satellite measurements. Existing national network radar and rain gauge networks will be used to assess the quality of the accumulated products. To the extent that physical schemes can be improved from the constant check and cross check of intermediate results against those derived by the core satellite, the validation is expected not only to quantify uncertainties, but aid in the algorithm improvement as well. This is particularly true over oceans where the algorithms have a strong physical foundation. It is less likely to immediately impact the land portion of the radiometer algorithms as these algorithms are still rather statistical in nature. To help construct the physical basis needed for these algorithms to improve their short space/time scale capabilities, and in particular, those capabilities over landmasses, the validation effort directly incorporates Cloud Resolving and Coupled Atmosphere/Land models as tools to better understand the relationship between observables (ice scattering signal) and the surface rainfall characteristics.

The assessment of radar/radiometer algorithm sensitivities represents a parallel but important method for verifying uncertainties and improving the algorithms themselves. Here, it is acknowledged that not all parameters affecting both precipitation and radar/radiometer observations can be directly retrieved and/or observed. Some sources of uncertainty remain because geophysical parameters of secondary importance have been assumed constant despite knowledge that these parameters do indeed vary with cloud types and meteorological regimes. Hence validation activities will be carried out at GV sites[1] specifically designed to measure these parameters; e.g., parameters such as cloud water, particle size distribution variability, or the nature of the melting layer etc. — in such a way that their natural variability may be included in the theoretical uncertainty computations. The uncertainties computed in this fashion should generally reflect those that are directly measured in core-constellation comparisons, and thus provide an important redundancy.

The final two activities, related to Cloud Resolving Model verification and Coupled Atmosphere/Land surface models serve dual purposes. These two modeling efforts provide key inputs and synthetic datasets to the development and testing of radiometer land-retrieval algorithms, helping to validate assumptions and procedures related to building more physically based algorithms. In particular, the radiometer algorithm over land requires a better understanding of the variability in ice and mixed-phase microphysics (addressed via use of CRMs) and of the land emissivity (addressed using coupled land/atmosphere models). Importantly, the ability of

[1] The word "site" is used somewhat generically here, applying to both specific activities and/or locations

coupled models to close the water budget forms another independent means of validating rainfall products, including how these products affect the overall water and energy budget. Finally, validation of these models supports the future development of combined rainfall prediction packages consisting of a mixture of numerical model and observational inputs.

The three observational and two modeling activities all revolve around the use of a finite number of GPM validation sites and/or leveraged field activities. These sites are instrumented with state of the art cloud and precipitation observational infrastructure (polarimetric radars, profilers, rain gauges, disdrometers) and are capable of meteorological characterization through soundings and radiative measurements. These sites/activities serve as focal points for extended measurement activities augmented by Intensive Observation Periods (IOPs) consisting of aircraft carrying GPM-like instruments as well as aircraft capable of in-situ microphysical measurements. To support the required validation activities—in particular, detailed process studies—a significant component of GPM GV ground-based infrastructure will be designed to be transportable. Having transportable GV infrastructure will enable participation in numerous GPM-specific and joint-agency/international external field efforts, providing a means to sample numerous targeted meteorological regimes both prior to and during the lifetime of the GPM satellite constellation.

1.1 Ground Validation Implementation

The nature of the GPM mission dictates that the GV system (GVS) provide four-dimensional precipitation measurement capabilities (time and space) that span a broad spectrum of precipitation rates (i.e., light to heavy) and types (liquid and frozen). To accomplish this task the GVS will rely on a complimentary set of NASA PMM-managed facilities, ground assets provided by the GPM Flight Project, and externally leveraged instrument assets. Here the term "externally leveraged" is defined as including both national and international assets. On regional scales select national and international resources such as existing calibrated radar and rain gauge networks will provide basic datasets that enable direct statistical validation of GPM core-satellite reflectivities and core/constellation rain rate measurements (cf. Sec. 3). Currently ground-based reflectivity and rain rate data from U.S. and other international radar networks are being actively solicited, and automatically stored, and processed by the GVS using a prototype infrastructure that compares the ground-based radar and precipitation data to coincident TRMM Precipitation Radar data (GPM Proxy). The resultant "first order" statistical comparisons provide a means for algorithm developers to assess algorithm performance at regional and/or regime scales, thus identifying potential problems in the algorithms or instruments that require further investigation (calibration, algorithm physics etc.). As the GVS infrastructure is further developed prior to launch, coincident rain rate information (currently envisioned to be NOAA Q2 products) will also be available for completing similar comparisons with passive microwave components of the GPM constellation.

To facilitate the development/improvement of algorithm physics and to support the validity of existing algorithm physical assumptions, GVS "first tier" efforts will rely heavily on NASA PMM operationally-flexible and transportable radars; specifically, the NASA N-pol S-band dual-polarimetric and the NASA GPM Ka-Ku band multi-frequency/dual-polarimetric radars. The Ka-Ku band radar is currently under development and is expected to be operational in prototype form by fall 2009. The N-Pol radar is scheduled for an upgrade and refurbishment beginning in fall 2008 and will be available for deployment by early 2011 at the latest. Use of the N-pol and GPM Ka-Ku radars will provide a means to sample the entire spectrum of precipitation rates and types, while the associated platform mobility will enable sampling of precipitation in a plethora of meteorological regimes. Importantly, the multi-parameter radar measurements will be supported/calibrated using more detailed ground-based point-measurement capabilities including a new NASA GPM 2D video disdrometer network (under development), existing rain gauge arrays, existing W-band cloud-radars (ground, air and space-based), vertically pointing wind-profiling radars, and instrumented aircraft (both NASA and other agency). Collectively this particular combination of instrumentation will provide an internally consistent and calibrated means to retrieve precipitation particle type, size, and volume contents in three dimensions- all fundamental to the development and validation of the algorithms.

Concurrent with the performance of direct/statistical validation efforts and detailed microphysical measurements, formal GPM collaboration with external programs such as the NOAA Hydrometeorological Testbed-Southeast (HMT-southeast) will be exploited to address integrated hydrologic validation. Here GVS observational resources can be deployed to supplement existing high-density NOAA hydrologic and precipitation measurements to examine the full end-to-end propagation of precipitation measurement and measurement errors through hydrologic prediction systems. The integrated validation activity can also leverage currently-funded PMM Science Team and other external NASA efforts (e.g., Energy and Water Cycle, Applied Sciences) to assess satellite-based precipitation estimation scales of utility for water-budget applications.

1.2 GPM GV Management Structure

GPM Ground Validation is implemented as an integrated element between the PMM Science Program and the GPM Flight Project. The PMM Science Program, which funds the PMM Science Team and provides a number of facility ground instruments supporting NASA missions and field campaigns related to precipitation including GPM, is managed by the TRMM/GPM Program Scientist at NASA/HQ, supported by the GPM Project Scientist at NASA/Goddard. The GPM Flight Project, which provides the GPM Ground Validation System (GVS) comprising GPM-specific ground instruments (notably the Ka-Ku-Band ground radar) and is responsible for the operation and maintenance of GPM field campaigns and GV data processing, is managed by the GPM Project Manager at NASA/Goddard under the purview of the GPM Program Executive at NASA/HQ.

The GPM Program Scientist has the overall programmatic oversight of all GV science activities. In terms of GV implementation, the GPM Project Scientist provides high-level supervision and is supported by the GPM GV Science Manager and the GPM Project GVS Manager in the planning and implementation of all aspects of GPM GV activities. The GVS Science Manager reports directly to the GPM Project Scientist and leads the coordination of members of the PMM Science Team and the GPM GV Science Panel (a sub-group of the PMM science community) in developing and implementing requisite science requirements and data collections for precipitation retrieval algorithm development and evaluation. The GPM Flight Project is responsible for the development, launch, and operations of the GPM GVS. The GPM Project Ground Validation System Manager has budget and management responsibilities for GVS observational hardware, data collection, processing, and storage funded under the GPM Project. The GPM Project GVS Manager takes directions from the GPM Project Scientist on all GV science matters but is directly responsible to GPM Project management for matters relating to GVS budget and systems engineering.

Interaction between the GPM GV Project Manager and GPM GV Science Manager

The GVS Project and Science Managers work in parallel to ensure that GPM GV Science requirements are met. The GV Science Manager continually works to identify and synthesize GV science priorities via direct communication with members of the PMM science team. In consultation with the GPM Project GVS Manager, these priorities are translated into observational system and/or data collection and processing requirements which are subsequently reviewed and approved by the GPM Project Scientist and communicated to the PMM Program Scientist for final approval as required. The GV Science Manager works with the Project GVS Manager to ensure that implementation of procedures, including development/acquisition of observational infrastructure and conducting of necessary field measurements needed to achieve GV science objectives within the available GV budget and schedule.

Role of the Precipitation Measuring Mission Science Team

The Precipitation Measuring Missions (PMM) Science Team interacts with all aspects of the GPM GV system. First, science team members overseeing the development of precipitation retrieval algorithms and/or PMM working groups provide *explicit feedback* to the GPM Project Scientist and/or GV Science Manager regarding the need for measurement of specific geophysical processes or algorithm “ingredient” parameters. This feedback (a two way interaction) helps to properly focus the scientific measurements and data collection and ensures that GV efforts directly contribute to algorithm improvements. Second, in terms of scientific instrumentation and measurement, the PMM Science Team identifies requirements for an initial set of ground/air-based instrumentation and for the algorithms needed to retrieve the aforementioned geophysical parameter in the ground-based field campaigns. Members of the science team assist with field campaign site selection, as well as the selection, delivery, and operations of GVS instrumentation. The PMM Science Team develops and provides retrieval algorithms that underpin validation network and model-based analyses. The measurement and validation/modeling components of the GV system generate data products that are stored in the GV data archive, and the PMM Science Team interacts with this archive and distribution capabilities of the GV system as needed to acquire science and data products. Over time, based on analysis activities and emerging scientific needs, members of the PMM Science Team will make further recommendations for infusion of new instrument technologies for field campaigns, new ground validation retrieval algorithms, and new validation procedures.

2. National Network Validation

The GPM GV Validation Network (VN) compares GPM satellite data and data products to similar measurements and products from the national network of operational weather radars and hydrologic measurements. The goal of the VN is to identify and resolve significant discrepancies between satellite observations of radar reflectivity and precipitation, and similar observations from ground-based national networks. The ultimate goal of such comparisons is to understand and resolve the first order variability and bias of precipitation retrievals in different meteorological/hydrological regimes at large scales.

The VN architecture is currently comprised of two specific pieces. The first piece addresses direct statistical validation of GPM DPR radar reflectivity—the fundamental (i.e., Level 1) parameter used in DPR retrieval algorithms of rainfall rate, precipitation diagnostics, and calibration of GMI retrieval algorithms. The second piece of the VN architecture addresses comparison statistics of first order retrieved parameters such as the probability distribution of rainfall rate and integrated rainfall accumulation. These "first-order" parameters will provide the basic VN comparison dataset for use not only with DPR reflectivity estimates, but for GMI and constellation passive microwave precipitation retrievals.

2.1 DPR-Ground Radar Reflectivity Intercomparison: Architecture and Method

Radar data interface. In the U.S., The VN acquires data from the national network of operational WSR-88D (NEXRAD) radars in near-real-time. This mechanism is currently used in the VN prototype (Section 3.2) to acquire WSR-88D data for specific ground radar sites. The prototype may also be extended to include targeted assets external to the continental US (e.g., Kwajalein and other national networks). In the GPM era, the VN will access and ingest data from an arbitrary number of WSR-88D and other radars within the US and internationally.

PR and DPR data interface. The VN interfaces with the Precipitation Processing System (PPS) to acquire overpass data products. Prior to the GPM launch, the VN will use comparable products from TRMM via the existing TRMM PPS interface. In the GPM era, the PPS will provide DPR overflight data for all requested ground sites.

Metadata extraction. The VN harvests metadata from the WSR-88D and PR/DPR products. Such metadata is used to help users identify and work with specific sets of GVS data. A list of metadata elements extracted or calculated from the WSR-88D and PR/DPR data is included in Appendix A.

PR/DPR resampled product. This product consists of PR/DPR satellite data and derived rainfall characteristics that have been re-sampled to a uniform Cartesian grid. The grid is centered on the location of a ground radar, and the grid has a horizontal and vertical dimension that is matched to the useful data range of the corresponding radar. There is one PR/DPR re-sampled product generated each time the PR/DPR ground track passes within 200 km of a given ground radar and precipitation echoes in the overlap area between the two instruments meet established criteria.

NEXRAD resampled product. This product consists of NEXRAD reflectivity interpolated to 4km horizontal resolution to correspond exactly to the PR/DPR re-sampled product so that they can be compared directly to one another. At a minimum, each NEXRAD product contains data for the volume scan nearest in time (within a threshold time range) to the PR/DPR overpass of the site, stored in a single product file.

Reflectivity comparisons. The VN generates statistical summaries and graphs of the results of ground-to-satellite reflectivity comparisons derived from the 3-D grids. Examples of products include:

- Scatter plots of satellite vs. ground radar reflectivity and rain rate
- Time series of mean monthly bias of WSR-88D reflectivity and rain rate relative to DPR
- Plot of mean ground-satellite reflectivity and rain rate difference vs. DPR reflectivity category
- Vertical profile of mean ground-satellite reflectivity and rain rate difference
- Probability Density Function of satellite and ground radar reflectivity at a selected height level, and of near-surface rain rate.

Other comparisons. In its at-launch configuration, the VN will allow for comparison of rain rate (R) and mean drop size diameter (Do) estimates retrieved from corresponding satellite and ground radar observations. The VN will also include GMI data and retrievals in these comparisons.

2.2 VN Prototype

A VN prototype is currently being implemented for 21 U.S. sites identified in Figure 2-1 and as a match-up dataset consisting of WSR-88D radar reflectivity and TRMM/PR reflectivity and rain rate. A similar prototype will be developed for match-up of NOAA Q2 data and TRMM/PR (proxy DPR); however, as an example, here we will focus exclusively on the prototype developed for reflectivity comparison as reflectivity is the variable from which the majority of other DPR products will originate. These comparisons build on research results published by Anagnostou et al. 2000, Bolen and Chandrasekar 2000 and by Liao et al. 2001.

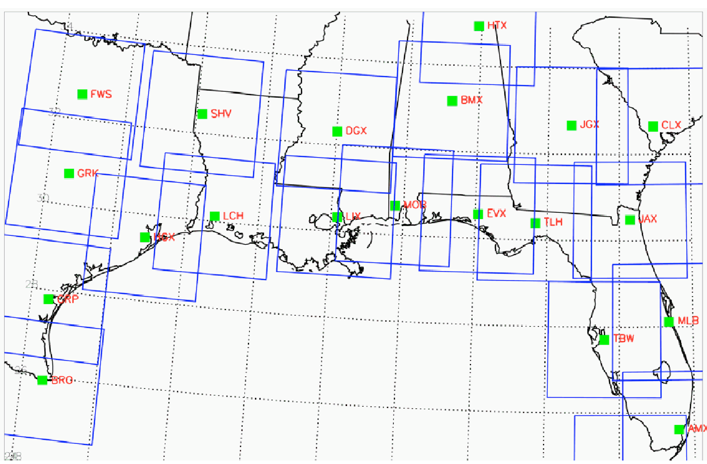

Figure 2-1. Location of VN match-up sites and associated 300x300 km grid domains in the southeastern US.

The VN prototype ingests NEXRAD radar and rain rate data from 21 radar sites (Figure 2-1), performs quality control on the NEXRAD reflectivity fields, transforms the NEXRAD and PR data to a common grid, harvests metadata and performs statistical comparisons. The VN prototype was designed to be scalable, and adding additional WSR-88D radar sites within the US is relatively simple. Further, the software has been adapted to compare radars from other international and national sites (e.g., the K-Pol radar on Kwajalein, the ARMOR radar at the Univ. of Alabama-Huntsville, radars in Australia and S. Korea, etc.). More up-to-date information on the set of individual radars now included in the VN is available on the GPM GV web site http://gpm.gsfc.nasa.gov/groundvalidation.html.

Prototype product archive and distribution. VN data are available at the GPM password-protected ftp site. Methods for access to the ftp site are described on the GPM GV web page http://gpm.gsfc.nasa.gov/groundvalidation.html. A User's Guide is also available on the web site that describes the format and content TRMM Precipitation Radar and NEXRAD match-up dataset.

VN Future Development

As needs arise, the VN architecture will be expanded to incorporate more WSR-88D or other radars. In particular, subsets of 88D radar sites located in meteorologically "interesting" or particularly challenging regions from a retrieval standpoint and within the extended mid-latitude coverage of the GPM core satellite will be added to the VN. Indeed, discussions have been held, and radar data exchanged, between GPM GV and representatives from meteorological agencies from Brazil, S. Korea, and Taiwan. As needed, the VN software can be exported for approved international activities related to GPM GV. Complimenting both the national and international activities over land, the VN will also continue to rely upon TRMM Kwajalein validation site activities over the tropical ocean as currently maintained by the PMM, to include Kwaj.-Pol radar and atoll and precipitation data.

Also of importance to expansion of the VN is consideration of the impending dual-polarimetric upgrade of the WSR-88D network (planned for 2009-2011). The upgraded network will yield internally consistent reflectivity calibration and generate superior rain rate estimates. Relative to expanding the VN architecture, this upgrade will require the coding and implementation of further dual-polarimetric radar data quality control procedures (reflectivity calibration consistency and attenuation corrections) on the front end of 2A-55 product (or similar product) generation. Currently the TRMM Ground Validation Office is developing dual-polarimetric archive and quality control capabilities using both KOUN WSR-88D and Kwajalein Atoll K-pol dual-polarimetric radar datasets as prototypes. It is expected that the processing stream used for these prototypes will comprise the initial version of dual-polarimetric VN processing.

2.3 VN Rainrate Statistics

Rainrate and rainfall validation in the VN architecture will rely heavily on the use of existing high resolution, quality controlled national network rain rate products created in the NOAA Q2 (to become the basis of the NOAA Multi-platform Precipitation Estimator; MPE) operational suite of products. NOAA Q2 products provide 3-D gridded, rain gauge-adjusted radar estimates of rainfall rate and reflectivity over spatial scales of ~ 2 x 2 x 1 km and temporal scales of 5 minutes (the resolution of individual NEXRAD radar volume scans). For this effort, upscaling of the Q2 gridded data and subsequent comparison between probability distributions of rainfall rate measured by coincident Q2 and DPR pixels will be accomplished. The upscaled Q2 products will also clearly be available for use in comparisons with passive microwave instruments such as the GMI on the core satellite, and where/when necessary, other select GPM constellation members that fly over VN network radar foci.

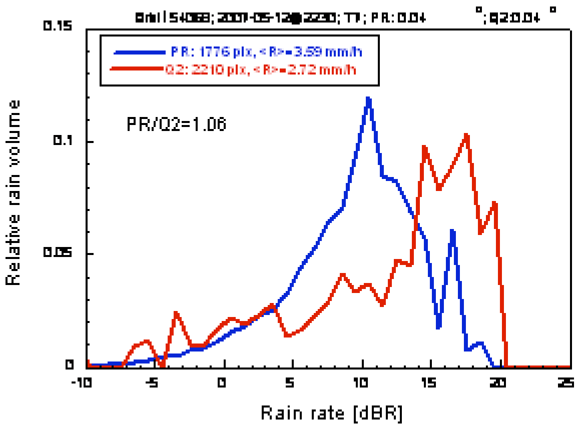

Figure 2-2. Comparison of TRMM Precipitation Radar and NOAA Q2 rain rate PDFs for a storm over the southeastern U.S (courtesy, E. Amitai, 2008).

These comparisons will provide a robust statistical means to verify/validate the instantaneous and accumulated rain rate products produced by the DPR and constellation passive microwave instruments.

This effort requires the development of automated ingest of Q-2 data files (details still TBD), upscaling of Q-2 spatial resolution to match that of the DPR/GMI (work being accomplished by E. Amitai), and the development of software to perform statistical comparisons (also being developed by E. Amitai). Development of the required ingest, storage and processing infrastructure to accomplish the comparisons is currently underway and is encompassed in the software architecture of the VN. Results of these comparisons, especially "large" departures in various regions of the CONUS, will be provided directly to U.S. DPR and GMI Algorithm leads.

~~Finally, the same type of statistical comparison using Q2 data (rainfall rate/ n-hour rain accumulation) will also be developed for Level II GMI rain rate products.~~

3. Field Campaigns

Field campaigns account for the majority of the effort and resources expended by GPM GVS. These field campaigns are not an end in and of themselves. They are a means to further GPM algorithm development in the pre-launch era, and a means for GPM product validation following the launch of the GPM Core and LEO satellites.

A key lesson learned from the Tropical Rainfall Measurement Mission (TRMM) is that precipitation algorithm retrieval errors are not universal, but have a strong dependence on meteorological regimes. As such, the GPM Ground Measurements Advisory Panel recommended that GPM direct its GV measurements to selected meteorological regimes, particularly those where there are large errors or large uncertainties in retrieval of precipitation estimates from satellite observations (Kummerow and Petersen 2006). In choosing which regimes to study, it is noted that the number of "regimes" and the difficulty of representing them in physically-based algorithm retrievals (see Table 3-1) has increased greatly since the TRMM era's emphasis on the tropical oceans. The increased sampling of continental regions combined with the hydrological objectives of GPM place greater demands on the success of retrieval algorithms over land surfaces—and in particular, on passive microwave retrievals. However, while the land-surface emphasis is recognized, it is recognized with the caveat that there may still be a need for some field work to be completed over water (in particular, cold season mid-latitude water surfaces).

Table 3-1. Physical process validation.

Dual Frequency Precipitation Radar	Passive Microwave Radiometer
Detection: Precipitation (rain/snow) Rain type (convective/stratiform) Algorithm Physics: PIA Algorithm: Errors/Accuracy Impacts of cloud water, water vapor, DSD and assumed DSD models DSD retrieval: DFR algorithm and DSD model for 3-D retrieval of rain and snow as f(regimes, temporal / spatial variability, precipitation rate) Z-R at light rain rates Sub-pixel variability Impact of external a priori regime ID Melting level ID, variability, extinction Hydrometeor typing and profile	Detection: Snowfall detection thresholds and surface/atmospheric emission characteristics Rain no rain (especially light rain) Rain type (convective/stratiform) Algorithm Physics: Single/bulk ice scattering vs. precipitation rate and type Surface emissivity impacts Melting layer extinction Water vapor, cloud water, and mixed phase impacts/models Impacts of a priori "regime" ID Models: Utility of "synthetic" of cloud profile databases Coupled CRM/LSM physical inputs and associated parameterizations

In order to satisfy physical process study needs, this implementation plan calls for a series of field deployments to different regimes prior to and following the GPM launch. The current deployment schedule calls for at least 5 GPM-led field campaigns with periodicity of approximately 18 months (3 pre-launch and 2 post launch, see Table 3-2 and Appendix B). These deployments do not represent "catch-all" opportunities, but are designed to solve specific high priority problems in both core and constellation satellite retrieval algorithms, as identified by algorithm developers, who directly participate in GV field campaign planning and execution.

Table 3-2. Notional GPM GV field campaign deployment schedule.

Objective	Date
Physical basis for GMI and DPR rainfall retrievals over land surfaces	Spring/early summer 2011
Cold-season retrieval of frozen and mixed precipitation over land surfaces	Winter 2011/2012
Physical/Integrated hydrological validation	2013
Cold season product validation	2015
Integrated hydrological product validation	2016

The GPM GV Advisory Panel recommended that validation activities consider products made from retrieval of individual instruments, the merged precipitation products based on cloud resolving models, and coupled land surface/cloud resolving models used in hydrologic applications. Therefore, to the degree possible, field measurement campaigns will be designed to address both model and satellite validation objectives.

3.1 Field Campaign Implementation Methodology

Given the approximate decade long period between GPM pre and post launch operations it is not possible, at present, to definitively list the scope and content of all pre- and post-launch GV field campaigns. Nevertheless, at the time of writing, GPM has already participated as a collaborator in a field campaign directed toward snowfall retrieval algorithm development, and other pre-launch campaigns are in the planning stages (see Table 3-2). Over the longer period of the mission the location and duration of GV field measurements will be made as a series of adaptive decisions prior to and during the GPM mission. In this regard the Precipitation Measurement Mission (PMM) Science Team, its working groups, and the GPM GV Science Advisory Panel will play a coordinated role in making recommendations about the scientific priority, focus, and location of each field campaign deployment. Final decisions on deployments will be the responsibility of GPM management.

Given the current state of GV development and the stated needs of algorithm developers (Kummerow and Petersen 2006; Table 3-1), it is reasonable to define a "field campaign archetype"—a general model, or "reference architecture" of what constitutes a successful field campaign. In this case, the archetype provides enough information to estimate field campaign costs, but does not necessarily specify particular dates, locations, deployed instruments, or specific investigations that will take place during each campaign. This approach allows for some degree of detail in budgeting and scheduling, but it also allows for adaptive decisions to be made about the location and timing of any particular campaign as new knowledge is gained and as scientific priorities become clear.

A comprehensive list of instruments that the GVS will employ during field campaigns is provided in other documentation[2]. While the listing of instruments in these documents is intended to be comprehensive, each Intensive Operations Period (IOP) is unique and some instruments may not be deployed in any given campaign. Conversely, some campaigns may require additional instruments that are provided by NASA or by other collaborators.

Overall, the reference architecture for GV field campaigns is based on a series of investigator-led Extended Observation Periods (EOPs) and Intensive Observation Periods (IOPs) as described in the paragraphs below.

Extended Observation Periods. The duration of an EOP is expected to last for 6-12 months or more. The EOP plan is currently modeled on the structure of NOAA's Hydrometeorological Testbed (HMT; most recently HMT-West), especially in its emphasis on mobility and adaptive remote sensing. In general EOPs supplement *existing* network and/or operational instrumentation and datasets (e.g., radar, gauge, lightning, etc.) to provide expanded, more detailed sampling for longer duration. As such, the GPM GV instrument suite nominally includes a truck-mounted multi-frequency (Ka-Ku band) polarimetric radar, radar profiler, along with a deployable ground-based radiometer, disdrometers and rain gauges. In the near future, it is also anticipated that the NASA N-Pol S-band dual-polarimetric radar facility will be upgraded to full research capability. When this occurs, N-pol will become a robust EOP tool (especially in heavy convective precipitation regimes). The instrument suite is principally directed toward three-dimensional measurement of multi-parameter radar variables (i.e., in addition to just reflectivity), estimation of precipitation rates and contents, and diagnosis of drop/particle size distributions across the complete spectrum of precipitation occurrence (e.g., precipitation initiation in the cloud stage, to heavy rainfall/deep ice-phase production). At least three geographically and meteorologically diverse EOPs are planned for the GPM Core and Constellation missions.

Note that an EOP may utilize a specific subset of GV instrumentation or the entire GV instrument suite as needs dictate. Also, depending on available community instrumentation the concept of an EOP can be extended to include targeted measurement campaigns for which no NASA GV instruments are deployed, but acceptable community instruments and PMM investigators are

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[2] See ""Global Precipitation Measurement (GPM) Ground Validation System Level 3 Requirements" and "Global Precipitation Measurement (GPM) Ground Validation System Level 3 Requirements for a Mobile Ka-/Ku-band Radar."

funded/leveraged to collect and/or distribute relevant datasets. Several examples (not a comprehensive list) of U.S. mainland regions where advanced measurement infrastructure exists, measurements are routinely made and could potentially be employed in an EOP include the Front Range of Colorado; NASA-MSFC/University of Alabama Huntsville in Northern Alabama; Wallops Flight Facility, Maryland; the DOE SGP site in Oklahoma; CASA IP-1 network in southwestern Oklahoma, Melbourne, Florida; Grand Forks, North Dakota; NOAA HMT-west and east location in California and North Carolina respectively, and several others.

Intensive Observation Periods. IOPs are relatively short duration (4-6 week), targeted field campaigns conducted with a dense complement of instrumentation that may or may not occur in conjunction with an EOP. IOPs are generally characterized by the deployment of aircraft equipped with instruments that support specific physical validation objectives of the IOP (i.e., priority measurements required for algorithm validation). Examples of such ground and airborne instrumentation are specifically listed in Sec. 3.2 under "Field Observing Facilities" and include in-situ microphysical probes as well as radar and radiometric remote sensing.

Investigator-Led Measurements. EOP and IOP field campaigns will be managed by a competitively selected Principal Investigator (PI) who will operate under NASA's direction. Additional Co-Investigators (CoIs) will be selected to participate in each campaign. Selection criteria for PIs and CoIs will be based in large measure on their ability to contribute field campaign operations expertise, specific instrument measurements, and/or relevant analysis and data products.

Instrumentation Deployment Strategies. GVS instrumentation deployments will vary by ground validation activity to best achieve science objectives (e.g., validation of cloud or land surface models, hydrology, or direct comparison with satellite observations). The number, type, location, and arrangement of the instrumentation will be customized by site under guidance of the IOP/EOP science teams, and as driven by site geographic constraints, deployment logistics, the availability of existing instrumentation, and funding. As the GPM mission proceeds, it is expected that results from the GPM GVS VN study will help to further delineate regions and/or regimes where specific ground validation measurements are required to investigate the differences between the ground and space-based measurements.

Coordination with Other Agencies (National or International). It is recognized from the outset that the U.S. component of GPM GV needs to leverage relevant activities conducted by external research and/or operational organizations to more completely meet the needs of global algorithm development and validation. In these cases, GPM will cooperate with national or international agencies to develop joint strategies that enable synergistic, "gap-filling" datasets to be collected and analyzed toward the goal of facilitating a more complete validation of targeted algorithm physics. One key aspect of this coordination involves the development of a research and organization template that details the specific scientific objectives, infrastructure, principal investigators, detailed work plans and tasks, and a management plan. Several examples of this type of interaction are in planning or initial development stages including cold season snowfall validation near the Helsinki, Finland testbed (physical process and national network use), snowfall retrieval validation in Toronto, Canada (and future activities planned therein), integrated validation activities in the U.S. that leverage GPM participation in the NOAA Hydrometeorological Testbed program, ongoing national network validation coordination with several other countries (EU, Australia, Brazil etc.), and coordination with the U.S. DOE on a mid-latitude continental convective clouds experiment (MC3E), etc.

Achieving "Success" in Field Campaign Activities: EOP and IOP efforts are undertaken with specific algorithm validation needs in mind (e.g., validating the physics and output of a selected retrieval algorithm). These activities will be organized and conducted with the explicit participation of algorithm developers. Hence, following each EOP/IOP, datasets relevant to examination and formulation of physical processes in the algorithms will have been collected. In the post EOP/IOP observation phase, EOP/IOP science/instrument team members, algorithm developers and other interested members of the PMM science team will undertake significant quality control, data reduction, and analysis efforts related to the EOP/IOP. These efforts will be coordinated by the GV Science Manager under the direction of the GPM/PMM Project Scientist in such a way as to maximize the scientific return. *The specific EOP/IOP validation activity will be deemed a success when the results either: a) affect a measurable positive change in a given algorithm quantity; and/or b) result in validation of an assumed or parameterized physical process represented within the algorithm (i.e. validating the algorithm science).*

3.2 Prototype Pre-Launch Cold-Season Field Campaign: Canadian CloudSat Calipso Validation Project (C3VP)

GPM algorithm development (PMW and DPR) and Ground Validation (GV) teams need snowfall datasets to: 1) develop and validate physical models that convert the physical characteristics of single snowflakes (shape, size distribution, density, ice-air-water ratio) to their radiative properties (asymmetry factor, absorption, scattering, and backscattering coefficients); and 2) relate bulk layer radiative properties to calculated and observed passive microwave radiances and radar reflectivities.

Implicit to items 1) and 2) is the ability to effectively observe and quantify the characteristics of falling snow (rate, density, particle habit etc.) over domains the size of at least a single satellite and/or radar-pixel (on the order of 10-100 km2). However, a cost-effective and optimal set of methodologies to perform these measurements, indeed, even a determination of what measurements are most relevant has yet to be developed. Accordingly, during the winter of 2006-2007 members of the GPM/PMM science team participated in the Canadian CloudSat/Calipso Validation Project (C3VP; Hudak et al., 2006a,b; Petersen et al., 2007). C3VP was a multi-national, multi-agency field experiment hosted by Environment Canada (EC) and centered on the Centre of Atmospheric Research Experiments (CARE) site, located near Egbert, Ontario, Canada (Fig. 3-1).

Figure 3-1. Location of C3VP CARE site (red dot) in Ontario, Canada.

GPM/PMM scientific objectives for C3VP included: a) Collection of measurements enabling development of models that convert microphysical properties of snow to observed radiative properties (i.e., GPM dual-frequency radar reflectivity, passive microwave imager radiances); b) support of cloud resolving model (CRM) microphysics validation for simulations of lake effect and synoptic snowfall events in support of retrieval algorithm testing and development; c) testing of prototypes and further assessment of GPM GV ground-based instrumentation needs and methods for measuring snowfall and validating spaceborne snowfall measurements; and d) collection of datasets supporting development of satellite simulator models (e.g., coupled CRM, Land-Surface, and radiative transfer models).

C3VP Experiment design and GPM/PMM Instrumentation

The C3VP field campaign was organized around four intensive aircraft observation periods (IOPs). Each IOP was conducted for a duration of ~10 days. In turn the IOPs were embedded within an extended period of continuous surface-based observations collected from October 2006 through April 2007. Operations during IOPs were organized around three specific scientific thrusts. The first and primary emphasis of C3VP consisted of GV activities related to CloudSat/Calipso (CC) science and algorithm retrieval validation. The second component (Cloud-Layer Experiment-10; CLEX-10) involved process studies of mixed-phase non-precipitating mid-level layered. Both the CC and CLEX components of C3VP focused heavily on cloud particle measurements (ice and mixed phase) via ground (CARE site) and airborne radar and cloud microphysical measurements (see Appendix C for a list of C3VP instrumentation).

The third component of C3VP was the NASA GPM/PMM GV snowfall measurement component. For this effort NASA-GPM/PMM augmented C3VP instrumentation listed in Appendix C with the University of Massachusetts Advanced Multi-Frequency Radar (Ka, Ku, W bands; first ever field deployment), the Colorado State University 2D Video Disdrometer (2DVD), two NASA Parsivel disdrometers, and the NASA snow video imager (SVI) (see Appendix C). Particular emphasis on intensive radar sampling of snow by scanning multi-frequency radars (e.g., AMFR) was accomplished during the third IOP (January 8-28, 2007).

During IOP3 the GPM/PMM science team requested specific flight patterns to be flown over/near the CARE site within range of the AMFR radar (~20 km). Concomitantly, the King City radar (WKR) conducted RHI scans every 10-20 minutes that were oriented over the CARE site and AMFR radar, (331°) and through the flight pattern (when applicable). Spiral descents were centered just upstream of CARE, and over the AMFR radar and disdrometer suite, which were located on the downwind edge of the spiral. Even when there were no flight operations, WKR multi-parameter RHI scans were collected over the CARE site (occasional time-series data collection at several fixed elevation angles was also performed at WKR).

Collectively, numerous snow events including both synoptic and lake effect snow bands were sampled in a coordinated fashion by C3VP airborne and ground-based instrumentation. These cases provide the backbone of detailed microphysical, radiative transfer and cloud-resolving model analyses. More detailed examples of observations and analyses are presented in Tokay et al. (2007), and Petersen et al. (2007). Core analysis for the C3VP data set has focused on disdrometer and polarimetric radar retrievals of equivalent melted particle diameter, techniques for measuring snow water equivalent, and airborne and ground-based (e.g., radar and profiler) retrieval of hydrometeor phase, mass content, and particle size distribution in the column.

Use of CRMs: An algorithm tool for snowfall retrieval?

One period of the IOP (20-22 January 2006) afforded the opportunity to collect a two day sequence of polarimetric multi-frequency radar, aircraft and disdrometer data in rapidly changing snowfall regimes: During this period a transition from heavy lake-effect snow bands to a more widespread moderate intensity synoptic snow event occurred. The two day period was modeled by W. K. Tao et al (NASA GSFC) using a nested high-resolution WRF CRM dynamic core with several different microphysical schemes. The C3VP observational data form a verification or “consistency” dataset against which the model can be compared (e.g., CFADs of radar reflectivity, snowfall rates, snow water equivalent, hydrometeor profiles, AMSU-B/MHS observed brightness temperatures, etc.). In turn, the CRM can be coupled to a radiative transfer model to simulate PMW and DPR radiances and reflectivities respectively. The simulated radiances and reflectivities provide a means to test specific aspects of the snowfall retrieval algorithms in two very different snowfall regime types. Conversely, the observations themselves form a type of “truth” against which the fidelity of the model simulations and simulated radiances can be tested.

C3VP Extended Observational Dataset

Snowfall observations were collected via WKR polarimetric radar, precipitation gauges, and the 2DVD and Parsivel disdrometers for the entire winter of 2006-2007. This longer duration dataset will be analyzed to provide a winter season time series of snowfall in the form of radar constrained estimates of melted snow water equivalent at the CARE site, and area wide snowfall estimates derived from the radar-disdrometer diagnosed Z-M relationships. The combined analysis will provide a means to determine occurrence and threshold statistics for high frequency (e.g., 85 - 183 GHz) passive microwave detection of snowfall over land via coincident AMSU-B and MHS overpasses on NOAA polar orbiting satellites (proxies for GMI frequencies).

Extending the C3VP field campaign model

It is important to note that the C3VP proxies for microwave radiometer remote sensing of snowfall were garnered from target of opportunity overpasses of existing satellite platforms (e.g., NOAA and NASA polar orbiters). Relative to applying and extending the C3VP field campaign model to future GPM cold-season science and algorithm needs, it may be necessary to include at least one aircraft capable of carrying a suite of instruments comparable to that being flown on the GPM core satellite (i.e., dual-frequency radar, radiometers). This aircraft would ideally act as the GPM "simulator" flying over both the in situ microphysics aircraft and ground-based instrumentation. From a GV science perspective, including such an aircraft would complete the validation requirements.

3.3 Pre-Launch Plans for a 2011 Mid-latitude Continental Campaign

GPM GV activities must vigorously address the issue of physically-based PMW, DPR, and combined PMW-DPR precipitation retrievals, *with special emphasis placed on over-land retrievals, and must do so early in the pre GPM-launch phase.* By extension, this activity requires 1) the collection of new observational datasets that extend and improve current microphysical descriptions of the 3-D distribution and character (e.g., sizes, phases, rates etc.) of precipitation; and 2) observational datasets suitable to initialize/force our best CRMs and to provide robust statistical verification of the simulated clouds and precipitation. Arguably, these activities should also culminate in the clear establishment, early-on, of the capability/fidelity/limitation of CRMs to support precipitation retrieval algorithm development. To support these requirements in the pre-GPM-launch era, near-term implementation of leveraged joint research collaboration between NASA GPM and the DOE ARM program is planned. This collaboration will take the form of an intensive field campaign termed the Mid-latitude Convective Clouds Experiment (MC^3E). Specifically, it is suggested that DOE and GPM GV jointly conduct the MC^3E IOP during the late spring/early summer of 2011 within the CASA IP-1 X-band radar network located in southwestern Oklahoma. Importantly, this site is within the field of view of *both* the TRMM[3] (TMI, VIRS, *and* PR) and CloudSat platforms. Appendix E lists a comprehensive set of instruments that are under consideration for the MC^3E campaign.

Collaboration with the the Department of Energy (DOE) Clouds and Radiation Testbed (CART) activity is especially advantageous to this effort. The CART activity spread across a large section of Oklahoma provides a set of microphysics and radiation study sites where precipitation regimes are fairly well understood and a large suite of instrumentation and supporting infrastructure already exists. The DOE sites maintain a strong and complimentary emphasis in cloud-remote sensing and are in the process of expanding their instrumentation to both precipitation remote sensing (via use of the NSF CASA IP-1 X-band radar network in southwestern OK) and the construction of a dual-frequency Ka-W band radar (to be completed in 2009). The DOE infrastructure can be readily supplemented with GPM GV instrumentation including the NASA N-pol dual-polarimetric radar, the NASA Ka-Ku band mobile scanning polarimetric radar (precipitation physics and DPR-frequency matched), D-scale disdrometer network, and NASA airborne instrumentation. Further, NOAA platforms such as the KOUN research dual-polarimetric NEXRAD radar are also favorably located to provide valuable GV data. Collectively, this suite of instrumentation can provide the means to address, in a very comprehensive fashion, physically-based passive microwave (PMW) retrieval algorithm development over land (empirical and cloud-resolving

[3] Assuming TRMM and CloudSat are both still operational in 2011- which current projections suggest.

model-based approaches), and testing of DPR drop size distribution and path-integrated attenuation retrieval algorithms at frequencies both complimentary to, and matching those of, the orbiting GPM DPR.

GPM MC^{3}E Science Objectives. GPM and ARM interests (discussed above) motivate the design of a synergistic, multi-agency, process-oriented field project that addresses issues related to observations over land of cloud and precipitation processes (including latent heating), cloud modeling, and the construction of both PMW and DPR precipitation retrieval algorithms. MC^{3}E will provide both the DOE-ARM and NASA-GPM communities a means to further establish linkages between macro and microphysical characteristics of precipitating clouds and their associated radiative characteristics as sensed by passive and active microwave instruments deployed on the ground by ARM, on current orbiting NASA satellite platforms such as TRMM and CloudSat, and on the GPM core and constellation satellites. This field project will also provide a framework to directly test GPM ground validation logistics, instruments and methods. Specific GPM objectives for the MC^{3}E include:

(1) Collection of cloud microstructure, microphysics (cloud water, cloud ice, liquid, mixed and solid precipitation phases), particle sizes, shapes and distributions, high resolution melting layer characteristics, rainfall rates, and aerosol characteristics (e.g., CCN and IN concentrations to the extent possible) in a mid-latitude land environment during the varying "regimes" of the boreal spring and summer transition under the TRMM and CloudSat fields of view.
(2) Collection of high resolution drop size distribution and rain rate information to statistically quantify sub satellite-pixel precipitation characteristics.
(3) Quantification of surface multi-channel microwave emissivity as a function of the land surface state/type, sensible and latent heat fluxes (including soil moisture). A small portion of the proposed sampling domain of MC^{3}E will cover the of the USDA-ARS Little Washita watershed. This watershed is well instrumented with a micronet of ~20 rain gauge and soil temperature/moisture probes, and from a land surface perspective it is a well studied/characterized hydrologic testbed.
(4) Construction of accurate large-scale forcing environments for CRM simulations (i.e., to remove the issue of quality forcing datasets as an issue for the accuracy of the CRM)
(5) Testing of CRM simulation fidelity via intensive statistical comparisons of simulated to observed cloud properties and latent heating fields (e.g., using radar and ARM-SGP sounding array data) in a variety of case types (leveraging seasonal transition in regimes over Oklahoma).
(6) Further establishment of CRM space-time integrating and data assimilation capability for quantitative precipitation estimation.
(7) Evaluation of the core complement of GPM GV instrumentation (radars, profilers, disdrometers etc.) to specifically include sampling/measurement methodologies and assessment of associated error characteristics as applied to mid-latitude temperate-climate precipitation measurements.
(8) Supported by (1-6) development and refinement of a physically-based GPM passive microwave retrieval algorithm for use over land (this objective could also test empirical approaches).

(9) Supported by (1-6) and use of ground-based (GPM-GV) and airborne Ku-Ka band radars with other available radar frequencies (S, X, W etc.) and CRM simulations, further develop/refine GPM DPR attenuation correction and precipitation retrieval algorithm.

3.4 Integrated Validation: Field collaboration with the NOAA HMT

The integrated modeling and observational needs of this particular approach make all of the aforementioned cloud and precipitation observations highly relevant to this GV effort. Specifically, the majority of the observations (e.g., multi-parameter radar, radiosonde, precipitation rate etc.) form the basis for physical validation of the CRM/LSM applications proposed for this effort. However, there are observations in this particular validation approach that form a more specific and heretofore non-traditional complement for use in precipitation mission validation. These added measurements include: measurement of land surface water and energy budget terms, including surface energy fluxes (downward shortwave, longwave and net radiation, sensible, latent and ground heat), surface water fluxes (stream flow), state variables such as soil moisture and temperature profiles, groundwater levels, land cover, vegetation, and soil properties. The majority of these special observation types are likely to be obtained via leveraged participation in field campaign collaborations already making use of some significant fraction of these instruments in existing hydrologic and energy budget networks, or through GPM GV funding of specific investigators/instruments on an “as needed” basis.

Relative to integrated hydrological validation and EOP/IOP phases, the NOAA HMT program serves as both a potential model and vehicle for GPM GV integrated validation activities. NOAA HMT is planning for intensive observational hydrology studies to be conducted over the Tar River catchment in North Carolina beginning sometime after 2010 and extending to at least 2013. Based on previous HMT-West EOPs and IOPs conducted in the American River basin, the expected compliment of observations provided by NOAA includes stream flow gauges, a dense rain gauge network, wind profilers, and both C and X-band scanning Doppler/dual-polarimetric radars. NOAA also conducts distributed hydrologic modeling in support of the HMT. Relative to participation of NASA GPM GV, NASA participation would add further coupled CRM/Land surface modeling capability and select instrumentation (mobile radar, disdrometers, a profiler) as a partner in the HMT-East IOP/EOP. This would provide access to the HMT dataset and provide for analysis related to both validation and application of high resolution satellite precipitation products over complex terrain and their assimilation into operational hydrologic forecasting. To the extent that the HMT project involves a “mountain to coast” philosophy, at the North Carolina hydrologic study site, GV rain gauges and radars would be optimally deployed to best measure the basin-average precipitation, whereas for a coastal or orographic sites, radars and rain gauges would be placed to best capture the variability of precipitation traversing inland, or by elevation and exposure. The HMT-GPM interaction has yet to be formally defined and the HMT-East dates of operation have yet to be finalized. However, based on discussions with the NOAA HMT Manager it is reasonable to project GPM GV participation in an HMT East IOP to be held no sooner than late 2012 (fall/winter season campaign).

3.5 Longer-Term Implementation

Passive microwave algorithm developers have stressed the need for observations that further develop key physical components of retrieval algorithms for both liquid and frozen precipitation over land surfaces (prior to launch). Additionally, there is a need to better represent the microphysics of the melting process as it relates to microwave detection of underlying rainfall or mixed phase precipitation over the northern latitude oceans, especially if the height of the melting layer is close to the sea surface. Accordingly, current GV planning calls for specific involvement in at least one future cold-season IOP and one future hydrological validation IOP, both to be completed *prior to launch of the GPM Core Satellite*, which is currently scheduled for July 2013.

As for the cold-season IOP, current planning is focusing on a collaborative effort with the Finnish Meteorological Association (FMA) for a field campaign to be conducted near Helsinki, Finland and the adjacent Baltic Sea. This location was chosen to exploit the resources of the Helsinki Testbed (HTB). The HTB is a cooperative Finnish Government, University and industry endeavor that helps to develop, refine and test advanced instrumentation and methods for observing and forecasting mesoscale weather phenomena in high-latitude conditions, e.g. on the south coast of Finland. As currently configured the HTB hosts a C-band research grade dual-polarimetric radar, three other Doppler radars, a vertically pointing wind profiler, a plethora of snow and precipitation gauges, numerous meteorological stations and ceilometers (on and offshore). As such, participants in the HTP have developed a great deal of experience in observing/measuring cold-season weather and are already in possession of many robust datasets relevant to GPM. The target date for a joint field campaign that leverages HTB assets is still to be scheduled, but would likely follow the MC3E experiment. GPM GV contributions to a cold-season field campaign are still to be determined, but could include ground radars and other instrumentation, and potentially aircraft observations. In any event, the planning processes leading to the campaign—and its execution—will mirror the planning and execution processes used in the MC3E experiment.

GPM GV may also participate in cold-season and other appropriate filed campaigns as opportunities arise, subject to the availability of resources. For example, GPM GV is planning for guest participation in a CloudSat study that is scheduled for the fall/winter of 2009 over Helsinki and the Baltic Sea. GPM GV has also been invited to participate in a Canadian-led IOP located near Vancouver. In addition, it is clear that several international GPM efforts will be held to validate algorithm retrievals over land (e.g., in support of contributed GPM constellation satellites, land-based campaigns are in the planning stages in other countries including numerous member states of the EU, Brazil, Korea, Japan etc.). Via coordination between these efforts and our efforts in the U.S., many additional quality datasets will arise to support validation of the GPM retrieval algorithms.

4. International Collaboration

Leveraging of international research activities and infrastructure will enable coordinated global ground validation activities to be conducted. Here, global refers to more than just geography—it also refers to precipitation regime. Because the problem of identifying observational gaps, organizing relevant datasets, and finally validating satellite products over a global domain is so daunting, a great degree of focus, coordination and organization are required. Set in this framework, specific and targeted collaborations have been sought with international partners. One such venue used for these collaborations was the 3rd International GPM Ground Validation Workshop held in Buzios, Brazil in March of 2008. The primary objective of this workshop was to identify, develop, and organize a structure for collaborative ground validation (GV) research activities between international GPM partners and the U.S. Precipitation Measurement Mission Science Team. The international response to the meeting was quite strong as 24 different planned or ongoing GPM GV activities were presented by approximately 19 different countries. Following the suite of presentations an extensive discussion took place regarding algorithm validation needs, available instruments and data standards, and methods for infusion of relevant GV results into the retrieval algorithms. The combined result of the presentations and associated discussion was the establishment of a draft member framework for international GV collaboration. This framework identifies individual GV activities by country and GV approach. Following identification of activities, each country was invited to submit a formal proposal to the PMM Program for membership on the PMM Science Team. The structure of the proposals contained science objectives, infrastructure, personnel and a management plan. Importantly, each proposal also identifies which members of the PMM Science Team were to collaborate with the international members of a given proposal. Currently, proposals from Finland, the United Kingdom, Canada, France, Germany, Australia, and Brazil have been submitted and have been already been accepted or are in the process of being accepted. Each of these proposals leverages national network infrastructure and also specific physics expertise to address multiple targeted emphases ranging from cold-season precipitation validation in Finland and Canada, to algorithm development for tropical warm/cold-cloud precipitation physics in Australia and Brazil. Several other proposals (Italy, Israel, Spain, Ecuador, Cyprus, South Korea) are in preparation.

5. GVS Archive and Distribution

The GPM GV web site has been developed as a focus for ground validation data archive and distribution. At present, the site provides access to GPM GV data from the Validation Network (VN) prototype (see Section 2.2 of this document), as well as links to ground validation web sites maintained by international partners and other US domestic agencies. As described in Section 2 of this document, the VN data are made available for distribution as soon as the VN products are generated. GPM GV manages these data via a password protected ftp site. As described on the GPM GV website, this password is freely available to anyone who requests it.

Although GPM GV conducts data management for the VN, a general principle for GPM GV data archive and distribution is to avoid duplication of effort provided by partner agencies. This principle applies in particular to the archive and distribution of field campaign data by GPM GV partners in the operational agencies. Such agencies include Environment Canada (EC) for C3VP, DOE for MC3E, and NOAA for HMT. In all cases, the operational agencies have extensive experience in data quality control, archive and distribution, and in the development and maintenance of data systems to manage field campaign data (e.g., Macduff and Egan, 2004). Thus, in cases where GPM GV collaborates with the operational agencies, the GV website will provide links to the data maintained by the operational agencies. In these cases, GPM GV will *not* provide storage or otherwise manage the field campaign data unless there is a compelling reason to do so.

An example of the principle described above can be found in the archive and distribution of data for the C3VP experiment. In this case, EC funds the Meteorological Service of Canada (MSC) to maintain a website which includes a password protected archive of data collected during the C3VP EOP and IOP campaigns. GPM-funded investigators provided their quality-controlled data to the C3VP archive managers, and their data are now maintained by EC/MSC under a data protocol developed by EC/MSC and approved by GPM. In exceptional cases GPM-funded data sets are not archived by EC/MSC, and one such example is the WRF/GCE model output generated by Tao (2007) and coworkers. In this case, the model output is relatively voluminous (>80 GB) and subject to change as new model runs are completed. It is expected, however, that a version of the model output will be included as part of the C3VP archive when the conclusive version of the dataset is compiled. It is also expected that a similar approach to archive and distribution will be followed for field campaigns planned with DOE (ARM) and NOAA (HMT). The URLs for all relevant websites are included in Table 6-1, below.

Table 5-1. Websites for archive and distribution of ground validation data.

GPM GV	http://gpm.gsfc.nasa.gov/groundvalidation.html
EC/MSC C3VP	http://c3vp.org/index.html
DOE ARM	http://www.archive.arm.gov/
NOAA HMT	http://www.etl.noaa.gov/et7/data/

Another important aspect of the C3VP campaign was the agreement by all participants to adhere to a joint data protocol. The data protocol consists of common-sense principles, such as the right of PIs to be included as co-authors (and the right to refuse co-authorship) on papers generated from unpublished versions of their data, and agreement to acknowledge funding agencies in publications. The data protocol also describes the C3VP expectations for documentation and quality control, and it includes target dates for delivering data to the C3VP archive, as well as target dates for data release to other C3VP investigators. The target date for the ultimate public release of the data is also defined in the protocol. A copy of the C3VP data protocol is included as Appendix D of this document. Similar protocols will be developed for each field campaign conducted with other GPM GV partners.

6. References

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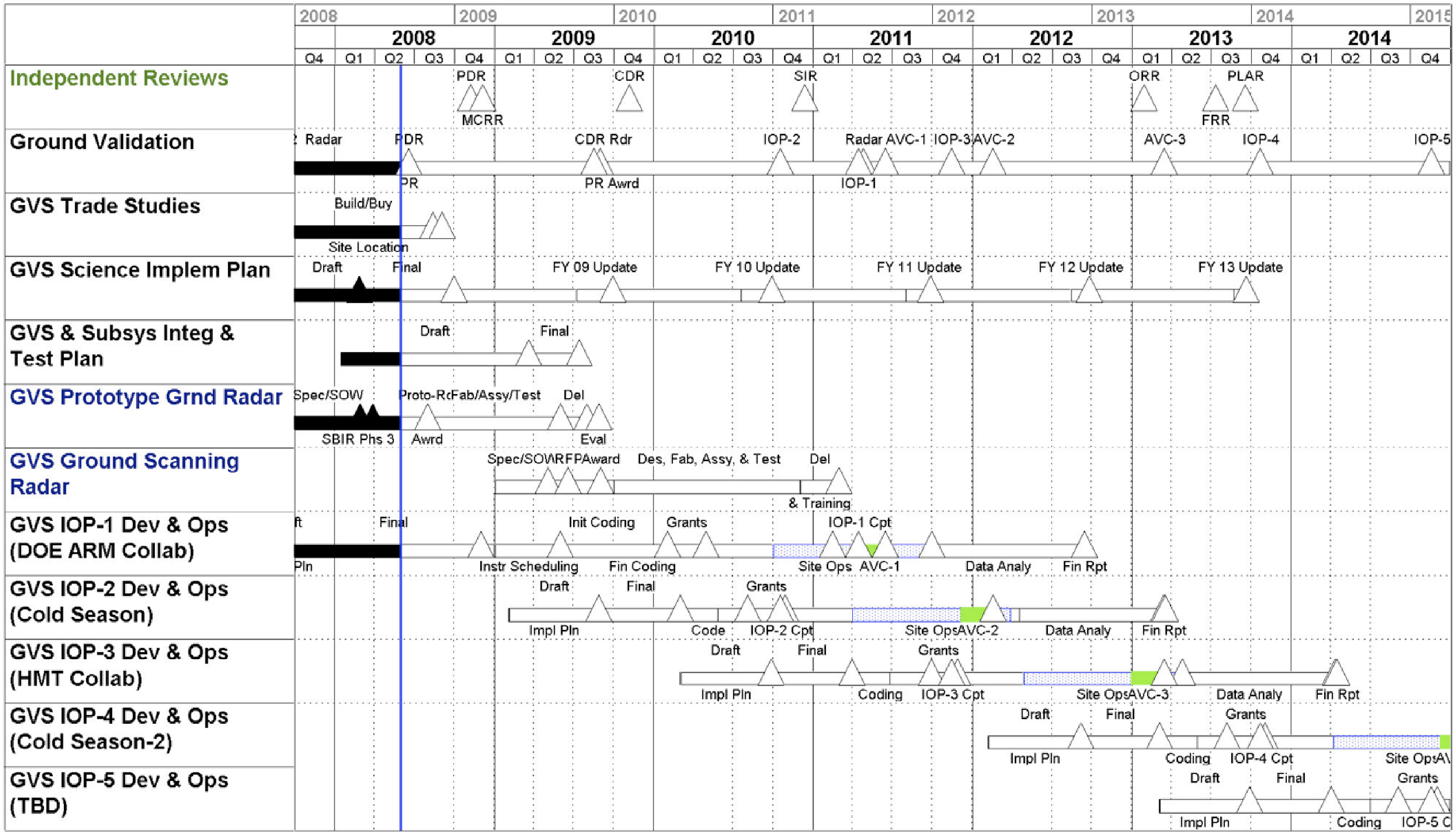
Validation Network Data Product User's Guide. http://gpm.gsfc.nasa.gov/ground_direct.html

7. Appendix A: Validation Network Metadata

At a minimum, the following metadata will be included in operational VN data products.

- Nominal volume scan time, e.g. begin time of the volume scan
- Volume Coverage Pattern (VCP) ID number – defines elevations present in the volume, sampling mode, and time to complete the volume scan
- Begin time and elevation of each elevation sweep
- System gain calibration constant
- Percent of range bins above a reflectivity threshold for precipitation
- Results of automated QC algorithms
- Data quality and availability metrics for the GVS Metrics Database.
- Datetime and nadir-to-site distance of nearest approach to, and location ID of, each ground radar overpassed in a given orbit number
- DPR Level 1 and 2 data granule(s) or product identifier(s) included within the overlap area for each location overpass event described by the previous bullet
- A flag indicating actual or empty data for each data element of the preceding bullet
- Geolocation accuracy estimates for each DPR overpass data product
- A flag indicating whether or not precipitation is indicated in the DPR overpass data product
- Flags indicating the conditional type(s) of precipitation characterizations indicated in each DPR overpass data product (Level 2 -- can link back to matching Level 1 product); e.g., convective, stratiform
- For each ground radar location overpass event, percentage of each "standard" 3-D grid volume covered by:
  - Ku-band PR
  - Ka-band PR
- Average height (AGL) of the bright band within the overlap area as detected by the PPS DPR Level 2 algorithm
- Algorithm version number for each original and reprocessed PPS data product provided
- Data quality and availability metrics for the GVS Metrics Database

8. Appendix B: Schedule for GVS Field Campaign and Related Activities



This schedule identifies the major milestones and activities related to the GVS field campaigns that will be held prior and following the launch of the GPM Core satellite. Field campaigns are scheduled on an approximately 18-month intervals starting in calendar year 2011.

9. Appendix C: C3VP Instruments

Organization/Instrument	Air/Ground
NRC Convair-580 (State parms, full suite of 2-D, 1-D microphysics, W/Ka band radars, G-band radiometer)	Air
NASA JPL W-band radar	Ground
King City C-band dual-pol radar (WKR)	Ground
McGill U. Verti-X, X-band Doppler radar	Ground
EC 915 MHz Wind Profiler	Ground
Prof. Radiometer (23, 30, 51-59 GHz)	Ground
NASA GRC Radiometer (89, 150 GHz)	Ground
EC Surface Met. Stations	Ground
EC Ceilometer	Ground
EC Rawinsonde	Ground
EC POSS Radar	Ground
EC/DRI Hot Plate	Ground
McGill U. HVSD (Hydrometeor/Velocity Shape Detector)	Ground
EC/Penn. St. suite of IR radiometers	Ground
EC FD12P Visibility meter	Ground
EC Snow and Precip. Gauges (DFIR, NIPHER, Geonor, pit gauge etc.).	Ground
McGill U. Ground Precip. Photography	Ground
Organization/Instrument	**Air/Ground**
U. Mass. AMFR (Ka/Ku/W Radar)	Ground
CSU 2D Video Disdrometer	Ground
NASA WFF Parsivel Disdrometers (2)	Ground
NASA WFF Snow Video Imager	Ground

10. Appendix D: C3VP Data Protocol

Canadian CloudSat/CALIPSO Validation Project (C3VP)
Data Protocol

1. The tentative list of C3VP participants below are to agree to the C3VP protocol.

• MSC	• U. of Alaska	• CCRS
• NRC	• Penn State	• UQAM
• CSU	• McGill	• NASA PMM

2. All publications using C3VP data will be required to acknowledge the funding agencies. All publications should be listed on the C3VP web site.

3. C3VP participating organizations will have free and timely access to the data acquired during the project. The normal vehicle for data dissemination will be a transfer of data via the main archive established at MSC; however, direct transfer of data between investigators (organizations) is also encouraged. It may be necessary for some organizations to archive some specialized data sets, and retain them within their organizations. In that case, a summary of that data, and the procedures for obtaining copies, would be transmitted to the C3VP Archive.

4. The types of data to be provided to the C3VP archive and their attached rights will be agreed upon at a special meeting of participating scientists before the field campaign.

5. All data in the C3VP Archive, and sub-archives of participating organizations, shall be comprised of the following components,
   - **Instrument abstract**: A short document describing the instrument, its placement, and data collection method(s).
   - **Data listing**: A listing of each available data segment and its attributes, e.g. filename, start/stop times, duration, data/scan type, etc.
   - **Quality control (QC) report**: Documentation of the calibration and QC procedures including a PI assessment of the data's quality.
   - **Graphical overview**: Time-series multimedia product(s) to yield a quick look at the data.
   - **Data guide**: Documentation of the final data file format(s).

6. Organizations that collect C3VP data are responsible for the reduction, quality control, analysis, interpretation, and publication of their data and research results.

7. Any data sets resulting from collaborative investigations among C3VP participants will be made available to the C3VP Archive. This includes all collaborative efforts both within and outside the C3VP organizations. Any re-processed or combined dataset containing C3VP data should go to the C3VP archive.

8. Each investigator retains private ownership of the data until they either appear in publication or the C3VP archive is released to the scientific community.

9. An investigator whose unpublished data are to be used in an investigation has the right to be included among the authors of any resulting publication. The investigator may refuse co-authorship but not the use of this data. Exception is granted to student thesis, as they are recognized as not carrying co-authorship. The investigator must provide information concerning the quality of the data and may require that suitable caveats regarding the data be included in the publication.

10. C3VP participating organizations may release their own data to whomever they wish. They may not release the data of other organizations (investigators) without consent.

11. "Outside" investigators not employed by C3VP participating organizations may participate and/or have access to unpublished C3VP data provided they,
    - are sponsored by an C3VP organization.
    - declare which data they plan to use prior to participation.

12. It is the responsibility of the sponsoring investigator to solicit the participation of the data investigator to process their data.

13. First cuts of reduced data obtained by investigators participating in collaborative research will be made available "internally" to C3VP participants within 6 months following acquisition.

14. Each "data collecting agency" will issue data status reports every 6 months, or until the data reside in the Archive.

The C3VP Archive, and the archives of individual organizations, will be made publicly available, with nominal charges for filling requests, after 3 years after

11. Appendix E: MC3E Field Observing Facilities

Relative to *both* DOE and GPM science objectives deployment of the following instrumentation[4] is desirable:

Ground-Based:

1. Radar Systems:
   a. Scanning and/or vertically pointing network of Ka/Ku/W bands (DOE, NASA GPM GV)
   b. CASA IP-1 X-band network (DOE-funded use in 2011)
   c. S-band dual-polarimetric Doppler radar [NASA N-Pol or KOUN dual-pol]
2. Radiosonde and enhanced surface network for model forcing [DOE-ARM]
3. High resolution video disdrometer and rain gauge network observations: Deployment of a D-scale video disdrometer network capable of resolving variations in rain rate type, intensity, and size distributions (e.g., D_0) on scales ≤ 4 km (order of the GPM footprint) within a 100 km^2 area under optimal coverage of ground multi-parameter radars [NASA GPM / DOE-ARM]
4. Enhanced soil moisture array observations (leverage existing Oklahoma mesonet and ARS-micronet observations to increase spatial resolution).

Airborne (2-3 Aircraft)

1. In-situ microphysics: 1-D, 2-D PMS particle suite plus IN counter and aerosol probes (Wyoming King Air) [NASA GPM]
2. High altitude satellite simulator with W/Ka/Ku Radar (HIRAP, EDOP), PMW radiometers, ground emissivity, (NASA ER-2) [NASA PMM]
3. Low altitude aerosol sampling aircraft [DOE-ARM].

The field campaign will leverage a subset of existing cloud, aerosol, radiation and atmospheric state measurements being made routinely at the ARM Central Facility site and migrated to the CASA IP-1 site [at the time of writing it is not clear how many platforms will be moved to the CASA IP-1 network location]. Potential instruments/measurements include:

[4] It is assumed that DOE-ARM would support existing science instrumentation currently available at the ARM Central Facility (see description below).

Aerosols:
- Continuous ground-based Aerosol Observation System, occasional aircraft profiling via ARM Cessna in-situ aerosol profiling system

Atmospheric Profiling
- Radiosonde sites: Up to 4 launches per day at six surrounding locations
- Column water vapor and cloud liquid water: High frequency (90-150 GHz) microwave radiometer
- Vertical profiles of water-vapor, cloud- and aerosol-related quantities (Raman Lidar)
- 50 and 915 MHz Wind Profiler and RASS

Clouds/Cloud water/Cloud ice
- Ka-band vertically pointing radar (MMCR)
- W-band vertically pointing radar (WACR)
- Ka/W band scanning radar (to be completed by 2009)
- Cloud base height (Vaisala Ceilometer)
- Cloud base and PBL height (Micropulse Lidar)

Precipitation
- IP-1 X-band Doppler radar network (3-4; if DOE acquires IP-1 network as planned)
- Distromet RD80 (Joss-Waldvogel) Disdrometer

Surface Energy Flux
- Eddy Correlation Flux, Surface Bowen Ratio

Surface Meteorology
- 60 m meteorological tower, precipitation and snow depth gauges
- Oklahoma Mesonet
- Numerous broadband radiometers (net radiation, long wave etc.)

12. Acronyms and Symbols

ACRONYM	DEFINITION
1-D, 2-D, 3-D	1-, 2-, 3-Dimensional
2DVD	2-Dimensional Video Disdrometer
AMFR	Advanced Multi-Frequency Radar
AMSU-B/MHS	Advanced Microwave Sounding Unit-B/Microwave Humidity Sounder
ARM	Atmospheric Radiation Measurement
C3VP	Canadian Cloudsat/CALIPSO Validation Programme
CARE	Centre for Atmospheric Research Experiments
CASA	Center for Collaborative Adaptive Sensing of the Atmosphere
CART	Clouds and Radiation Testbed
CFAD	Contoured Frequency by Altitude Diagram
CLEX	Cloud Layer Experiments
CLM	Community Land Model
CNN	Cloud Condensation Nuclei
CoI	Co-Investigator
CRM	Cloud Resolving Model
Do	Mean Drop Size Diameter
DOE	Department of Energy
DPR	Dual-frequency Precipitation Radar
EC	Environment Canada
EDOP	ER-2 Doppler Radar
EOP	Extended Operation Period
ftp	File Transfer Protocol
GCE	Goddard Cumulus Ensemble
GLDAS	Global Land Data Assimilation System
GHz	Giga Hertz

ACRONYM	DEFINITION
GMI	Global Microwave Imager
GPM	Global Precipitation Measurement
GSFC	Goddard Space Flight Center
GV	Ground Validation
GVS	Ground Validation System
GVSIP	Ground Validation Science Implementation Plan
HMT	HydroMeteorology Testbed
HTB	Helsinki Testbed
IOP	Intensive Operation Period
IN	Ice Nuclei
IP-1	Integrative Project #1 (X-band radar network)
km	kilometer
LES	Large-scale Eddy Simulation
LSM	Land Surface Model
MC3E	Mid-latitude Convective Clouds Experiment
MMCR	Millimeter wave Cloud Radar
NASA	National Aeronautics and Space Administration
netCDF	network Common Data Form
NEXRAD	NEXt Generation Doppler weather RADar
NOAA	National Oceanic and Atmospheric Administration
Noah	
NSF	National Science Foundation
PI	Principal Investigator
PMM	Precipitation Measuring Missions
PMW	Passive Microwave
PPS	Precipitation Processing System
PR	Precipitation Radar
PR2	NASA JPL airborne dual-frequency radar (Ka-Ku bands)
RASS	Radio Acoustic Sounding System

ACRONYM	DEFINITION
RHI	Range Height Indicator
SGP	Southern Great Plains
SSM	Spacecraft Simulation Model
SVI	Snow Video Imager
TBD	To Be Determined
TOA	Top-Of-Atmosphere
TRMM	Tropical Rainfall Measuring Mission
TSDIS	TRMM
URL	Universal Resource Locator
US	United States
VCP	Volume Coverage Pattern
VIC	Variable Infiltration Capacity
VN	Validation Network
WACR	W-band Airborne Cloud Radar
WKR	King City Radar
WRF	Weather Research and Forecasting Model
WSR-88D	Weather Surveillance Radar - 1988 Doppler
Zc	Corrected Radar Reflectivity Factor
Zr	Raw Radar Reflectivity Factor