Global Precipitation Mission (GPM)

Ground Validation System

Level 3 Operations Concept

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Goddard Space Flight Center
Greenbelt, Maryland 20771

CM FOREWORD

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1. GVS Overview

1.1 Introduction

This specification defines the Level 3 functional and performance requirements for NASA's Global Precipitation Measurement (GPM) mission Ground Validation System (GVS). Overall, the GPM mission has defined a series of scientific objectives which include improvement in predicting terrestrial weather, climate, and hydrometeorology through a better observational understanding of the global water cycle. The purpose of the GPM GVS is rooted in the need for independent and objective evaluation of the precipitation products generated by the GPM mission. For its part, the GVS provides an independent means of evaluation, diagnosis, and ultimately improvement of the GPM spaceborne measurements and precipitation retrievals. These goals are more completely defined as follows:

- Evaluation—Quantify the uncertainties in GPM standard precipitation retrieval algorithms
- Diagnosis—Understand the time and space error characteristics of GPM precipitation products generated by these algorithms, and
- Improvement—Contribute to the improvement of GPM precipitation retrieval algorithms throughout the mission.

Achieving these goals is seen as a necessary step for improved GPM data products and for increased utilization of these products in Global Climate Models (GCMs), Numerical Weather Prediction (NWP) models, and hydrometeorological models for climate and weather forecasting.

1.2 Document Scope

This document defines the Operations Concept for the GPM GVS. It includes a high-level description of the GVS, its interfaces and interactions with other entities, and some expected operational scenarios. It serves as a roadmap for GVS development and testing.

1.3 GVS Definition

The Global Precipitation Measurement (GPM) mission is a partnership between the National Aeronautics and Space Administration (NASA) and the Japanese Aerospace Exploration Agency (JAXA). NASA's Goddard Space Flight Center (GSFC) has the lead management responsibility for GPM mission. The GPM mission definition includes the following elements:

- GPM core satellite carrying the JAXA-provided Dual-frequency Precipitation Radar (DPR) and a NASA-provided, passive GPM microwave imager (GMI)
- A GMI instrument intended for flight on a "constellation" satellite provided by a partner to be determined
- A Precipitation Processing System (PPS) to generate near-real-time precipitation products and a final time series of global precipitation measurements

- A Mission Operations System for the operation of the NASA-provided spacecraft
- A Ground Validation System (GVS), consisting of several system elements employed in the independent validation of the instruments on the GPM core satellite and the associated data products generated from them.

The high-level roles within the GPM mission, and the GVS portions of them, are illustrated in Figure 1-1.

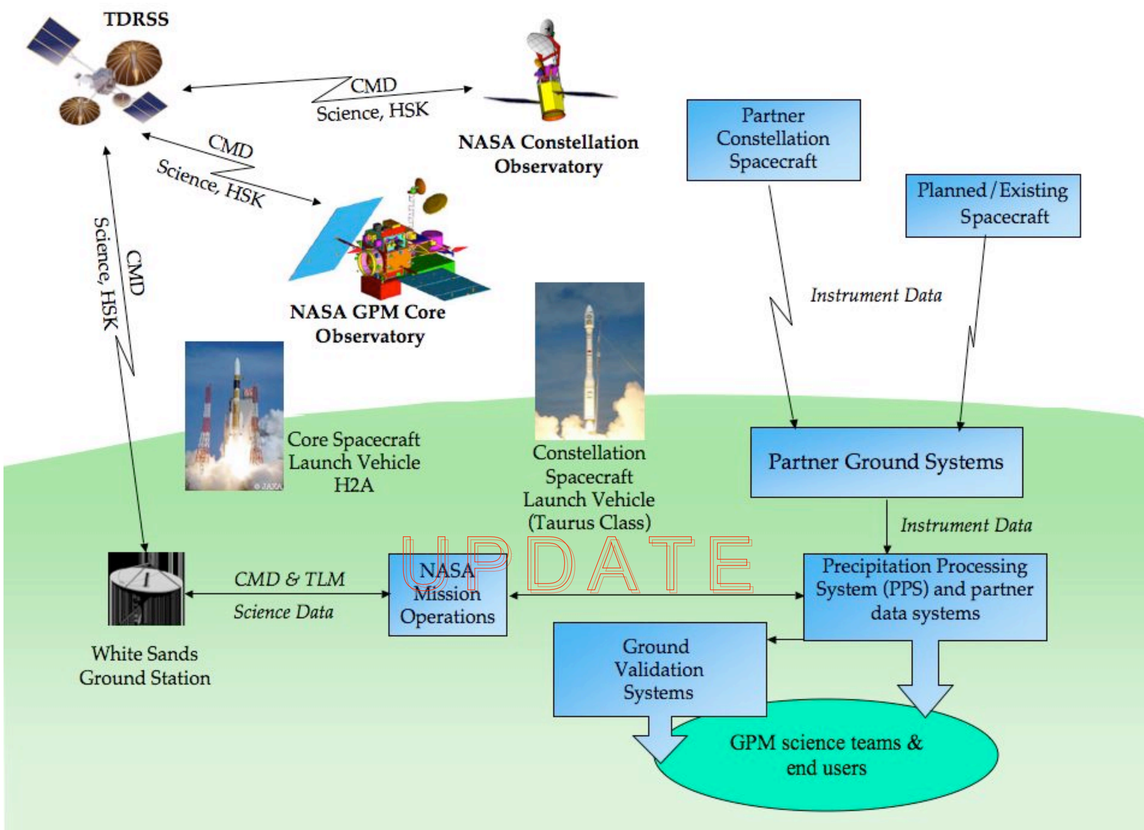

Figure 1-1. GPM Mission Architecture

1.4 Applicable Documents

The following are considered the controlling documents for this operations concept:

- NASA GPM Project Level 1 Requirements.
- NASA Global Precipitation Measurement (GPM) Mission (L2) Requirements Document (420.2-REQS-013001A).

1.5 Document Organization

Section 1 of this document provides introduction and background information on the GVS, including an overview of the GVS and its operations. Section 2 defines the operations of the overall GVS. Section 3 defines GVS in the context of external entities and interfaces. Sections 4-8 define operations for each major functional element of the

GVS. Section 9 defines the pre-launch and post-launch operations of the GVS while Section 10 describes several operations scenarios.

2. GVS Overall Framework and System Description

The conceptual framework for GVS is based on the notion of statistical and physical validation of GPM satellite data products. *Statistical validation*, often referred to as "ground truth," is used to identify random and systematic errors in the satellite data products. *Physical validation* is concerned with understanding the origin of these errors. In the GPM GVS, physical validation will verify the assumptions of the radiative transfer models at the core of the retrieval algorithms that generate GPM data products.

GVS statistical validation relies primarily on a series of field campaigns that collect meteorological and atmospheric measurements in a variety of precipitation regimes. The field campaigns will be equipped with various ground- and aircraft-based instruments to make direct and remote sensing measurements. The operations concept for the Field Measurements and Product Generation function is described in Section 4.

Additional data for GVS statistical validation is provided by the GVS Validation Network. This capability matches up ground radar data from the US network of NOAA Weather Surveillance Radar-1988 Doppler (WSR-88D, or "NEXRAD"). The purpose of the Validation Network is to evaluate the reflectance attenuation correction algorithms of the GPM Dual-frequency Precipitation Radar (DPR) and to identify biases between ground observations and satellite retrievals as they occur in different meteorological regimes. Since the Validation Network will help identify locations where the GPM precipitation algorithms exhibit significant bias and error, the results of the Validation Network will also be used to help direct the selection of field campaign locations for detailed study of the origins of these errors. The operations concept for the GVS Validation Network function is described in Section 5.

GVS physical validation is executed through the capabilities provided by the Satellite Simulator Model (SSM). The SSM uses ground measurements from the Validation Network and field campaigns along with land surface and cloud resolving model output to drive forward radiative transfer models that simulate GPM Dual-frequency Precipitation Radar (DPR) and GPM Microwave Instrument (GMI) satellite observations. During operations, an iterative process of measurement and simulation will be used to identify the causes of error and bias in GPM algorithm retrievals, and to identify opportunities for algorithm updates. In the pre-launch phase, the SSM will simulate ground and aircraft radar and radiometer instrument observations to assist in the planning and execution of field campaigns. The operations concept for the SSM function is described in Section 6.

The GVS system is built on the integration of the three elements described above (field campaigns and products, the Validation Network, and the SSM) together with capabilities for archive and distribution of GVS data (including metrics). Sections 7 – 9 describe the operations concept for system A&D of GVS data and metrics, and for pre- and post-launch GVS operations. Figure 2-1 illustrates the GVS in the context of its GVS external elements, which are described briefly below, and in detail in Section 3.

- The Precipitation Measuring Mission (PMM) Science Team interacts with the GVS by receiving data, and by providing algorithms and technologies that are infused into field campaigns and products, into the Validation Network, and into the SSM throughout the GVS lifecycle

- The Precipitation Processing System (PPS) provides schedule information of co-observation opportunities between the GPM GVS measurement sites and the GPM Core and Constellation spacecraft, as well as subsets of satellite data collected over the GVS sites
- A set of science community users receive GVS data and products through interaction with the archive and distribution capabilities of the GVS
- Ancillary data products, including NOAA WSR–88D radar data, are acquired by the GVS
- An interface to GPM Management is available for queries and reports as needed to assess GVS metrics. Such metrics allow management to assess the operations and performance of the distributed elements of the GVS
- At the end of the GPM mission lifecycle all GVS data are transferred to a long-term archive at a non-GPM long-term archive.

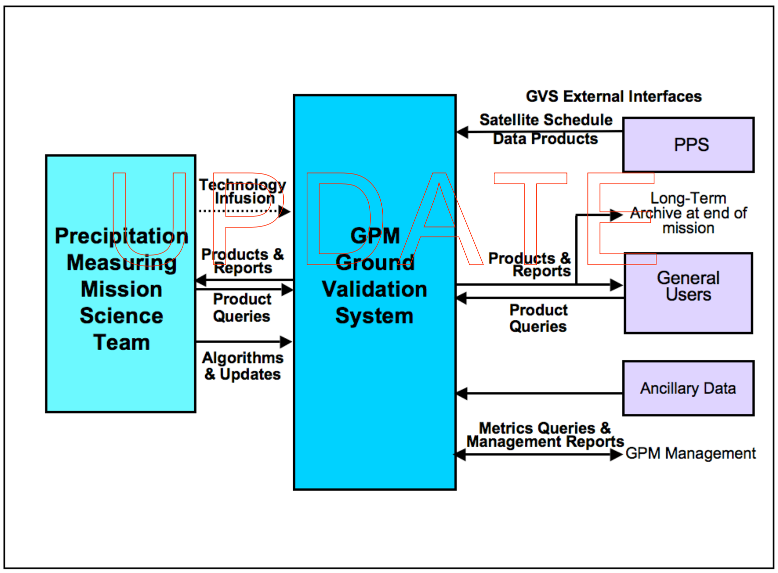

Figure 2-1 Context diagram for GPM GVS and related elements

2.1 General Features of the GPM GVS

Development and operations of the GPM GVS will be managed by GPM Project at GSFC. To the greatest extent possible, the development of the GPM GVS will be based on re-use of current instrumentation, methodologies, best practices, and near-term research results of the precipitation ground validation community.

The GPM GVS is planned to begin operations at least 6 months prior to launch of the GPM core satellite. To meet this goal, the GVS will conduct pre-operational testing of all its elements, nominally beginning 12 months prior to GPM core satellite launch. The

GVS will then continue operational testing up to GPM satellite launch, and will operate as designed for the full 3-year core mission and 2-year constellation mission. This argues for a relatively simple and flexible GVS design that can be operated in a fashion that is as automated as possible. Indeed, the GVS will nominally require attended operations on a 5-day per week 8-hour per day work schedule, with unattended operations after hours, on weekends, and on holidays.

During the GVS operational lifetime it is expected that the ground validation research community will make continuous improvements in instrumentation and methodology. Thus, an approach that allows critical new measurement components to be incorporated in the data stream is essential. The GPM GVS will therefore account for both routine maintenance and sustaining engineering as well as infusion of new instrumentation and methodologies as they migrate from research to a state that is "ready for operations."

During its development and operations, the GPM GVS will observe all of the applicable NASA/GSFC Mission Assurance Requirements (MAR), NASA Program Requirements (NPRs) and Goddard Project Requirements (GPRs). In particular, the GPM GVS will adhere to the best practices of systems engineering to ensure configuration control over internal systems and software, data holdings (including computer code), and external interfaces. All necessary steps will be take to secure rights to data products, reports, documentation and computer code that the GVS makes available for archive and distribution. The GVS will also document, archive, and distribute its data policies and procedures to ensure seamless and secure access to its data holdings. Finally, the GVS will ensure the safety of all its system elements and personnel.

2.2 Major GVS Functions

As illustrated in Figure 2-2, the major GVS functions are Field Measurements and Product Generation (FMPG), the Validation Network (VN), the Satellite Simulator Model (SSM), GVS Archive and Distribution (A&D), and the Metrics Database (MD). Sections 3 – 8 describe the operations concepts for these functions. Section 9 describes the GVS pre- and post-launch operations. Section 10 describes several GVS operational scenarios.

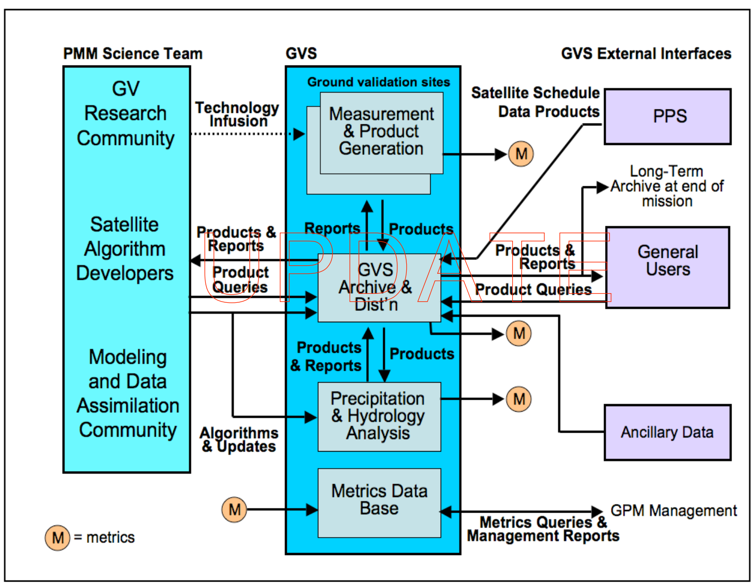

Figure 2-2 GVS Operational Data Flow

3. GVS Interfaces

The GPM GVS has a number of interfaces with external elements as described briefly in Section 2, and as illustrated in Figure 2-2. These interfaces are described in greater detail below.

3.1 Precipitation Measuring Mission Science Team

The Precipitation Measuring Mission (PMM) Science Team interacts with all aspects of the GPM GVS. First, in terms of instrumentation and measurement, the PMM Science Team identifies requirements for an initial set of ground-based instrumentation and for the algorithms needed to retrieve atmospheric parameters from the ground-based measurements. Members of the science team also assist with validation site selection, as well as the selection, delivery, and operations of GVS instrumentation. The PMM Science Team provides algorithms that drive the validation and model-based analysis, which forms the basis of the GVS physical validation. The measurement and validation/modeling components of the GVS generate data products that are stored in the GVS, and the PMM Science Team interacts with the archive and distribution capabilities of the GVS as needed to acquire GVS data products. Using previously established "standing orders," PMM Science Team members can receive data products as they are generated by the GVS, including products that match-up GVS data products with satellite observations and model output. Team members may also search for and receive current and historical versions of data products stored within the GVS. Team members with questions about GVS data and services can send email to a GVS customer service representative and subsequently receive an email reply. Over time, members of the PMM Science Team will make recommendations to the GVS on infusion of new instrument technologies for field campaigns, new ground validation retrieval algorithms, and new validation procedures.

3.2 Precipitation Processing System

The Precipitation Processing System (PPS) provides overflight schedules to the GVS. This scheduling information enables GVS ground sites to coordinate instrument and measurement operations with the GPM core and constellation spacecraft. Analysis has shown that the probability of a precipitation event occurring during a core satellite overflight of a given ground site is on the order of about 2 times per month. Thus, capturing precipitation events during overflights is an important target-of-opportunity for GPM GVS operations. The PPS also delivers GPM core spacecraft data to the GVS that are processed to Level 1 and Level 2. These satellite data products will be used in the cross-comparison with GVS observations and model output.

3.3 General Users

A world-wide community of users may access GPM GVS data products via the archive and distribution capabilities of the GVS. Users can query and search the historical archive of GVS data products and request data delivery via the Internet. Users can also set up "standing orders" for routine receipt of GVS data products.

3.4 GPM Management

During operations the GVS routinely generates metrics on ground-based instrument performance, validation and characterization processes, product generation, and on the performance of GVS archive and distribution capabilities. These metrics are recorded and stored in a GVS database. Routine reports generated by the metrics database are distributed to GPM Management for analysis of overall GVS performance, as well as for detection and mitigation of anomalies. GPM Management may also query the GVS metrics database. The database can generate unique reports for GPM Management in response to these queries on an as-needed basis.

3.5 Ancillary Data

The VN element of the GVS acquires ancillary data from NOAA's Weather Surveillance Radar-1988 Doppler (WSR-88D, or "NEXRAD") collected at ground stations throughout the continental United States. See Section 5 for additional details on this interface.

3.6 Long-Term Archive

At the end of the operational life-time of the GPM Core Satellite the GVS will prepare a copy of all current versions of its data products and product generation software for delivery to a non-GPM long term archive.

4. Field Measurement and Product Generation (FMPG) Function

GVS observations for statistical validation of GMP products will be made in a series of investigator-led field measurement campaigns, known as Extended Observation Periods, (EOPs). Several EOPs envisioned, each lasting several months, with each EOP punctuated by one or more Intensive Observation Periods (IOPs). Each subsequent EOP will move from one climatic region to another, as determined by the GPM Project in consultation with members of the PMM Science Team and other representatives of the atmospheric community.

A primary goal of the FMPG function is to capture atmospheric measurements for all precipitation events over the GPM ground validation sites. Of particular importance to the GVS are those precipitation events that coincide with GPM core and constellation satellite overpasses. As described in Section 3.2, the PPS provides scheduling information for overpass events. While operations of the GVS ground sites are continuous, operators are available nominally on a 5-day per week, 8-hours per day work schedule. Operations are unattended after hours and during holidays.

4.1 Overall FMPG Tasks

Each GVS ground site operates an experiment and data collection protocol. Part of the protocol calls for all FMPG instruments at all sites to be calibrated and routinely validated. Calibration is traced to a defined standard, and the calibration is tracked throughout the operational life-time of each instrument. Instrument validation is performed by inter-comparison with other instruments and with proxy measurements on a routine basis. As for operations, the FMPG generates products and associated error characteristics from ground-based instruments as necessary to support the modeling and simulation elements of GPM physical validation (see Section 6).

As described in Section 3.1, the Precipitation Measuring Mission Science Team assists in the specification and deployment of FMPG instruments and algorithms. The science team receives FMPG products for the purpose of research and analysis, and the science team also recommends improvements in the FMPG products via the introduction of new instrumentation and algorithms.

Process and performance metrics are be captured and recorded during FMPG activities to assist in the management of the numerous, heterogeneous and distributed elements of the GVS. Such metrics record, for example, ground instrument outage and malfunction; instrument noise, drift, accuracy and precision; error characteristics of derived data products; and characteristics of instrument validation. The FMPG also compiles metrics on the delivery performance and quality of data received from the PPS, and on the performance of data delivery to the GVS archive. Metrics are delivered by the FMPG to the GVS Metric Database (see Section 8).

4.1.1 GV-specific Instrumentation

Specific instrumentation requirements for GPM GVS are detailed in the document "Global Precipitation Mission Ground Validation System Level 3 Requirements for Ground Validation Field Campaign Instruments and Products." With the exception of the instrumented aircraft, which are only deployed for an IOP, all GVS instrumentation will operate in both EOPs and IOPs, and all except the aircraft and the rawinsonde network will operate and collect data continuously. All NASA-owned GVS instrumentation will be portable and redeployable. Additional details on the GVS instruments are provided in subsequent sections of this document.

4.1.2 FMPG Operations

The FMPG sub-system operations concept is presented as a set of functions and processes required for GPM GVS instrument observations and data product generation during field campaigns. The allocation of functions and processes in this document is not meant to constrain the detailed architecture and implementation plans of GVS field campaigns. Rather, the objective of this operations concept is to capture all of the necessary functionality of the FMPG operations. It is understood that some functions and processes may ultimately be reallocated within the overall GPM GVS.

Figure 4-2 illustrates the concept of the FMPG operated as a series of Extended Observation Periods (EOPs), each with a number of associated Intensive Observation Periods (IOPs). It is expected that the first EOP and IOP will be executed prior to GPM launch. Some complement of GVS instrumentation will be fielded and run during each EOP. Additional instrumentation will be fielded during IOPs including, for example, aircraft-based instruments. EOPs will be conducted for a period of time in a given location. Periodically, field campaigns will move from one climatic regime to another, as determined by the GPM Project in consultation with members of PMM Science Team and other representatives of the atmospheric community.

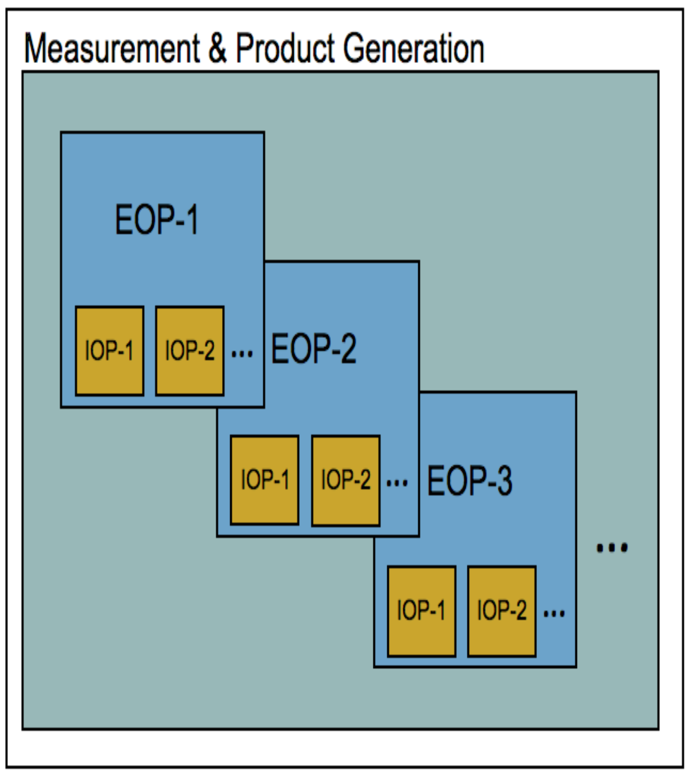

Figure 4-2. Illustration of the EOP and IOP concepts.

Figure 4-2 presents a schematic illustration of the organization and operation of PI instruments in EOP and IOP campaigns. Each PI is responsible for the Deploy Instrument and Product Generation functions during a FMPG field campaign. Each GVS instrument will be managed by a Principal Investigator (PI), who will be responsible for all aspects of the instrument's deployment and operations. All PI instruments will have a common source for time synchronization, and each will make raw observations in the native

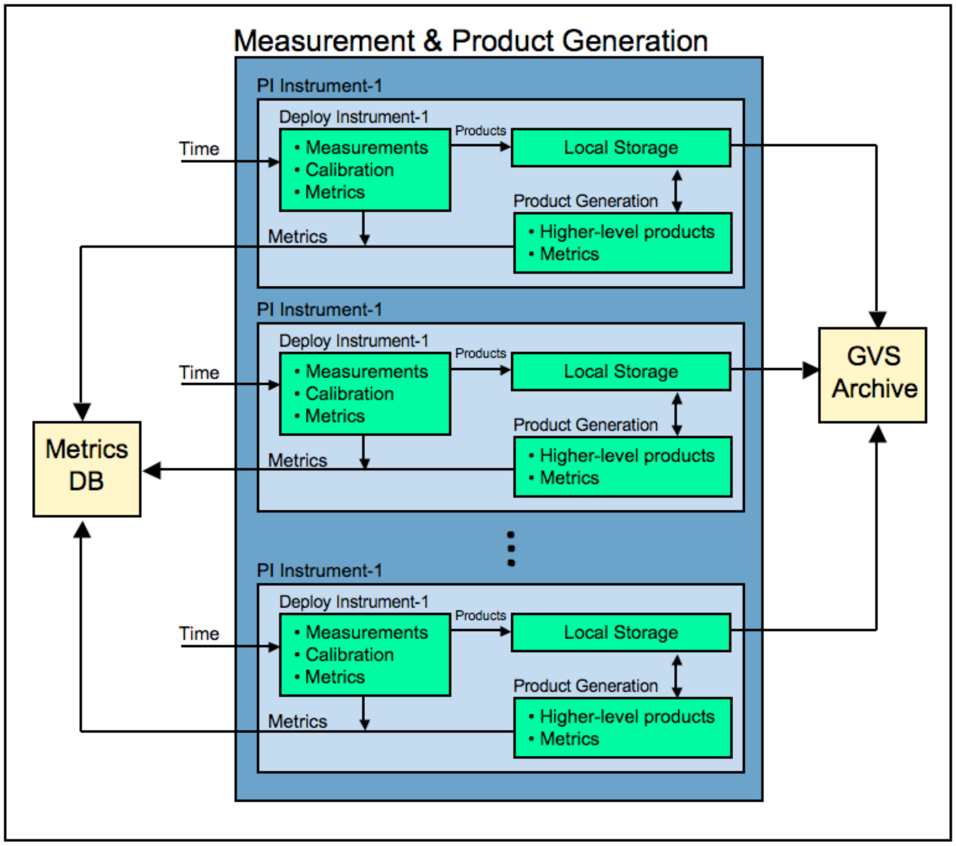

Figure 4-3. Schematic illustration of the Instrument Deployment and Product Generation functions during EOPs and IOPs.

format of the instrument. These data will be maintained in a local storage archive, and will be made available for higher-level processing under the PI's management. Higher-level products will be stored locally, and will also be made available to the GVS Archive and Distribution (A&D) sub-system. Metrics will be generated by the Deploy Instrument and Product Generation functions, and will be transmitted to a GVS Metrics Database (DB).

4.2 Interfaces

As shown schematically in Fig. 4.2, each GVS instrument system will collect and archive data locally within the system (data collection), and provide data products to the GVS Archive and Distribution (A&D) function (data transfer). Where possible, data transfer from the instrument system to the A&D function on the central GVS server will be in real or near-real time over available communications networks, and will be automated. Both science data and instrument and instrument product status data and metrics will be sent to the A&D function from the instrument systems. Near-real-time ingest into the GVS A&D system of quick-look images from the X-band and S-band scanning radars and the S-band and UHF-band profilers, whichever is/are active in an active EOP/IOP study, is the minimum set of real-time data to be transferred. These data are necessary to facilitate remote control over operations of these radar systems by the PI or other GVS operational personnel.

Data collection and local storage and archive will be internal to the GVS instrument systems. The data transfer component will be distributed between the instrument system and the centralized GVS A&D server. The detailed design of the data transfer means and methods will dictate the interface between the field systems and the central system, and will likely vary from one instrument system to another, and possibly from one site location to another. Specific Interface Control Documents (formal or informal) between the individual instrument systems and the GVS A&D system will be developed once the instrument systems are identified, developed, and acquired.

For instrumentation at existing ground validation sites, the data collection function typically will exist and be controlled by another organization. In these cases, only a data transfer function from the external ground validation system to the GPM GVS A&D function will be developed, and only if the data from the external ground validation system need to be duplicated within the GPM GVS archive. Otherwise, the GVS will provide only a data link or availability information needed to obtain the data from the external ground validation system. The GPM GVS may maintain a catalog of available data from the external system in order to provide details on matching data sets for ground validation precipitation and coincident overpass events.

4.3 Product Generation

Each GVS instrument executes the Product Generation function (see Figure 4-3). Since each GVS instrument is under the control of a unique PI, each Product Generation function associated with a given instrument will have a number of unique characteristics. The unique characteristics of the Product Generation function are described for each instrument in Sections 4.3.1 though 4.3.7, below. There are also a number of characteristics to the Product Generation function that are common to all instruments. These common characteristics are described in the following paragraphs.

All PI-provided instruments create two types of data products: those comprising raw or lightly-processed instrument observations generated by the Instrument Observation function, and derived products generated by the Product Generation function which, depending on the data type, have been re-sampled in time or space, reformatted, quality-controlled, post-processed to derive additional parameters, and/or created from two or more parent data sets. In all cases, each PI instrument stores its results in storage that is specific and local to the instrument system and under control of the instrument PI.

Product Formats. Data products from each instrument's Product Generation function should be provided to the GVS Archive and Distribution subsystem in data files in one of the well-defined hydrometeorological or data-sharing file formats. ASCII data will be in one of the encoded Hydrometeorological text formats [e.g., Standard Hydrological Exchange Format (SHEF), etc.], or an easily-parsed and convertible format, such as comma-separated values (CSV). Binary encoded data normally will be in either Binary Universal Format for Reports (BUFR) [for point observations such as rain gauges or rawinsonde] or Gridded Binary (GRIB) [for gridded products]. Post-processed data will be stored in GRIB, Network Common Data Format (netCDF), Hierarchical Data Format (HDF), or eXtensible Markup Language (XML). Scanning radar data will be in native NEXRAD Stage II product format for S-band PPI data originating from WSR-88D radars. X-band PPI data from the NASA-owned radar as well as other agency or university radars are expected to be provided in the Universal Format (UF) or HDF file format. Where necessary, the GVS A&D function will decode and/or convert instrument data sets into netCDF, HDF, or XML.

Product File Identification. A file naming convention will be adopted for data provided by the instrument Product Generation function. The file name will indicate the nominal UTC date-time of the data in the file, the instrumentation and/or product type, and the instrument or network location ID. The instrument system needs no external information (orbit number, etc.) to generate a unique file name for the GVS. The GVS A&D function needs no information beyond the product file name to identify the type, nominal time, and site location of data in the file. Nominal time of the product data will vary by instrument and product. In the case of rain gauges or disdrometers, it may be the nearest hour for an aggregated hourly data file, as an example. For scanning radar, it could be the time of the volume scan (either the start, middle, or end time, by agreed convention).

Data transfer. Data from each instrument will be made available to the GVS A&D function via the most appropriate and cost-effective method. In most cases, this will be via secure file transfer over the internet in a push/pull configuration between the onsite data system for the instrument and the central GVS A&D system, as shown in Fig. 2.2. In extreme cases such as network unavailability or low bandwidth with large data volumes or rates, data transfer will be by shipment of removable recording media containing a copy of the data. Data transfers internal to the overall instrument system (e.g., from individual rain gauges) will be the responsibility of the instrument PI. Where possible, existing data transfer and storage mechanisms such as those of the DOE Atmospheric Radiation Measurement (ARM) Climate Research Facility (ACRF) or the TRMM GVS will be leveraged directly or by duplication of the capability.

4.3.1 X-band re-sampled products

A common Cartesian grid has been defined specifically for Product Generation functions that generate the spatially re-sampled X-band and S-band scanning radar products. The common Cartesian grid allows for routine inter-comparison of these and other GVS data products. Each 3-dimensional grid is constructed so that the scanning radar is located at the grid center and the grid extends for 30 km (X-band) or 60 km (S-band) in the x (east-west) and y (north-south) directions. The grids extend in the z (vertical) direction from 0.5 km to 18 km above ground level. The resolution of the grid in all directions is uniform, with the resolution not exceeding the actual radar beam resolution at maximum horizontal range.

The X-band resampled products include a reflectivity factor product (rZ_h and rZ_v in dB), with an accuracy of 2.0 dB or better for all grid elements in the resampled radar scan volume. An X-band re-sampled differential reflectivity factor product (rZ_{dr} in dB) will also be generated; this product will have an accuracy of 0.4 dB or better for any grid element in the entire resampled radar volume. Finally, an X-band scanning radar specific differential phase product (K_{dp}) will be generated from a polar coordinate product with an accuracy of 0.3 degrees/km over a minimum distance of 3 km. The polar coordinate K_{dp} product will be resampled to the common Cartesian grid for all measurements in the entire scan volume where reliable differential propagation phase measurements can be obtained.

Although the production of 3-dimensional grids of radar data fields is specified as a derived product requirement of the X-band and S-band radars, it is more likely to be implemented as a function of the central GVS radar data post-processing. It makes sense to produce the 3-dimensional grids only after the radar data has undergone quality control and review.

Additional X-band radar derived product parameters include hydrometeor type, median drop diameter and number concentration, and rain rate.

4.3.2 S-band re-sampled products

In a similar fashion to the products described in Section 4.1, several S-band products will be resampled and interpolated to a common Cartesian grid, but at a coarser grid resolution as a result of the larger 60 km area of coverage for the S-band grids. The set of S-band scanning radar products to be resampled is identical to the X-band's in type and in the accuracies required.

4.3.3 Scanning radar combined products

TBD-1

4.3.4 S-band and UHF-band profiler products

The S-band and UHF-band profiler will operate as a pair and sample a common volume of the atmosphere to produce vertical profiles of mean reflectivity, mean reflectivity-weighted Doppler velocity, and velocity variance at each range gate. Derived product parameters will include vertical air motion, mean cloud/precipitation particle diameter and concentration, raindrop Gamma shape parameter, and raindrop size distribution.

4.3.5 Disdrometer and rain gauge products

The GVS disdrometer products are mean particle diameter, particle number concentration, and equivalent rain rate and radar reflectivity derived from the first two products, with a minimum time resolution of one minute. Rain gauge products are precipitation rate and precipitation accumulation over fixed intervals including 1-minute, 5-minute, and 1-hour. All rain gauge and disdrometer products represent a point measurement at the surface. The disdrometer will be co-located with one or more rain gauges.

4.3.6 Profiling microwave radiometer products

The GVS profiling microwave radiometer will provide vertical profiles of temperature and water vapor from the ground level to 10 km above ground level at 15-minute or smaller time intervals above a fixed-point location. It is expected to be able to operate continuously and have a rain mitigation capability to operate in active precipitation. These products help to interpolate the vertical state of the atmosphere in between rawinsonde launch times.

4.3.7 Rawinsonde products

The basic GVS rawinsonde product consists of vertical soundings of wind speed (ms^{-1}), wind direction (degrees), temperature (K), pressure (mb), relative humidity (percent), and altitude (m) in ≤2-second-intervals, beginning at the surface and extending to at least 100 mb. The GPM GVS rawinsonde system will have Global Positioning Satellite (GPS) tracking capabilities. The basic sounding products will be interpolated to regular pressure levels for use in model initialization. Rawinsonde soundings will be taken only during selected precipitation events in an IOP or an EOP.

4.4 X-band scanning radar

Recent studies[1] have shown that polarimetric techniques at X-band can be used to provide accurate rain rates as low as ~2 mm hr^{-1}; polarimetric-based rain estimates at S-band (see Section 4.5) begin at 5-7 mm hr^{-1}. Under high rain rate conditions (rates of several tens of mm hr^{-1}) X-Band signals are subject to severe attenuation losses. While X-Band attenuation procedures have been developed, complete signal extinction can occur, rendering precipitation estimation impossible. Therefore S-Band and X-Band form a complimentary combination that can apply the more accurate polarimetric rain estimators to a wider range of rainfall rates than either could handle alone.

The X-band radar will be a NASA-acquired and -owned mobile system with doppler and dual polarimetric capability. It will provide Plan Position Indicator (PPI) products of at least the following parameters:

- Reflectivity (horizontal and vertical polarization)

[1] Matrosov. S.Y., R. Cifelli, P.C. Kennedy, S.W. Nesbitt, and S.A. Rutledge, 2006: A comparative study of rainfall rate retrievals based on specific differential phase shift measurements and X- and S-band radar frequencies. *J. Atmos. Oceanic Technol.*, in press.

- Radial velocity
- Spectrum width
- Differential reflectivity
- Differential phase.

The X-band radar processor will also provide additional derived products (e.g., rainfall rate and particle size distribution information), quick-look images, and 3-dimensional gridded representations of selected parameters. The X-band radar will serve multiple GVS purposes including:

- independently evaluating GPM Dual-frequency Precipitation Radar (DPR) reflectivity calibration and DPR attenuation corrections
- determining the location and intensity of precipitation in the GVS area
- determining the characteristics and types of precipitation and cloud particles in a 3-dimensional volume
- providing data to initialize Cloud Resolving Model (CRM) runs and validating the results.

4.5 S-band scanning radar

A considerable body of research has demonstrated that polarimetric techniques can be applied to S-band radar data to retrieve reliable rain rates in storms with rainfall greater than 5-7 mm hr^{-1}. These S-band radars also have the advantage of performing these observations over a range on the order of 150-200 km, compared to the 50-100 km range of X-band systems. The GVS S-band scanning radar will have capabilities and uses similar to the X-band scanning radar, and will provide a similar set of of products. The primary difference is that the S-band scanning radar (likely a NEXRAD WSR-88D of the NWS, or a university-owned radar of similar design) will likely be owned and operated by another agency. As noted above, the combination of X-band and S-band radars forms a complementary combination that can apply the most accurate polarimetric rain estimators to a wider range of rainfall rates than either could handle alone.

4.6 S-band profiler

The purpose of the S-band and UHF-band profilers is twofold: to provide reliable estimates of drop size distribution (DSD) parameters, and to provide a means for calibration and validation of the scanning radar estimates of precipitation. The S-band profiler is relatively sensitive to hydrometerors through the properties of Mie and Rayleigh scattering off of these hard targets. In contrast, radars at the longer UHF frequencies are sensitive to vertical air motion through scattering off of refractivity turbulence (Bragg scattering). In principal, the profiler Doppler spactra (containing the combination of Bragg and Rayleigh/Mie scattering components) can be used to retrieve the DSD. The retrieval of DSD is very sensitive to vertical air motion because DSDs uncorrected for air motion shift the spectra toward larger drops in downdrafts and smaller drops in updrafts. The use of two profilers operating in two frequencies enables air motion to be estimated with one profiler and the precipitation motion to be estimated with the other under a variety of meteorological conditions, thus providing a better estimate of DSD than with either instument operating alone.

The S-band profiler is a mobile, non-scanning, vertically-pointing active radar. The GVS instrument will be acquired and owned by NASA. The S-band Profiler will be co-located and used in conjunction with the UHF Profiler (below) to produce vertical profiles of measured and derived parameters including:

- Mean reflectivity
- Mean reflectivity-weighted Doppler velocity
- Velocity variance
- Median particle diameter
- Mean particle concentration
- Gamma shape parameter
- Vertical air motion.

The primary uses of the profiling radars are to determine estimates of drop size distributions and rain rates and their variation with altitude. The co-location of the S-band and the UHF profilers give a dual-frequency capability which improves the estimates of the derived parameters. These measurements assist in development and evaluation of microware precipitation retrieval algorithms and validation of CRM microphysics. The profiler reflectivities may also be compared with DPR reflectivities through the full altitude range of the DPR, from the surface to 18 km in order to assess the variability of precipitation at spatial scales below the detection threshold of the scanning radars.

4.7 UHF-band profiler

The UHF Profiler have capabilities and objectives similar to the S-band profiler, but operate at a much lower frequency. The two profilers will be co-located and used in a complementary manner as described above. The GVS instrument will be acquired and owned by NASA.

4.8 Precipitation gauge and disdrometer network

Rain gauges remain the standard by which all other precipitation measurements and estimates are evaluated, and a precipitation gauge network will be a major component of the GVS instrumentation suite. GVS rain gauges will have a 1-minute sampling capability to estimate instantaneous rain rates, and will be deployed singly, to maximize areal coverage, or in pairs, to maximize quality and accuracy of the measurements. For GVS sites where validation of DPR and ground radar reflectivity and derived rain rates are a primary goal, paired gauges will be deployed in a dense cluster to try to capture the within-pixel or within-bin variability of precipitation. For GVS sites where the areal-average or integrated rainfall amount is required, rain gauges will be deployed evenly over the study area (e.g., the river or stream basin). Gauges will be either NASA-owned, owned by another agency, or a mix of the two, depending on the GVS site.

Disdrometers will measure drop size distribution (DSD) and derived rain rate and reflectivity at a fixed point on the groun surface. They will provide the only direct measurement of DSD except in the rare events when instrumented aircraft are operating. DSD is a critical measurement affecting the accuracy and validity of all remotely-sensed rain estimates. Disdrometers will be deployed in a similar manner to, and co-located with, the rain gauges, though will be many fewer in number. A disdrometer will also be co-located with the S-band and UHF profilers to provide DSD surface coverage and ground truth for these instruments. Disdrometers will be either NASA-owned, owned by another agency, or a mix of the two, depending on the GVS site.

4.9 Profiling microwave radiometer

The profiling microwave radiometer will be a NASA-acquired and -owned instrument. It will provide near-continuous, surface-based vertical soundings of temperature and water vapor at a point location. These measurements will be useful to validate and improve the passive microwave precipitation retrieval algorithms and provide inputs to the CRM. They will help to estimate vertical atmospheric profiles at times between rawinsonde launches.

4.10 Rawinsonde Network

The GVS rawinsonde network will consist of up to 5 rawinsonde launch and tracking sites. The rawinsondes will provide atmospheric soundings and Global Positioning Satellite (GPS) tracked winds from the surface up through at least 100 mb at ≤2-second intervals. The rawinsondes will be deployed in a pattern which best serves to initialize the CRMs in the GVS study area. Rawinsondes will be launched only when precipitation events are occurring or are expected in conjunction with a GPM or TRMM overpass. Soundings will be taken more frequently during an IOP than in an EOP. It is expected that NASA will acquire rawinsonde equipment, and that NASA will also be able to aquire data from soundings collected by agencies operating in the vicinity of the GVS field campaign.

4.11 Aircraft-based measurements

The GPM GVS airborne observation instrumentation and operations concept has not been fully defined. Due to costs and coordination issues, aircraft observations will be taken only as a part of an IOP, and only for a subset of these. The aircraft will be contracted to NASA. Some of the onboard instrumentation may be NASA-provided. The primary purpose behind the aircraft observations is to gather detailed, in-situ, microphysical data on precipitation and cloud particles, liquid water, water vapor, condensation nuclei, winds, and radiation in a 3-dimensional volume of the atmosphere to support precipitation process studies. The most likely scenarios for aircraft operations in the GPM GVS are in mid-latitude and snow and frozen precipitation regime site studies. Where possible, GPM GVS will piggy-back off of other field studies taking aircraft observations for hydrometeorological purposes.

4.12 Site Selection and Instrument Deployment

A key lesson learned from the Tropical Rainfall Measurement Mission (TRMM) is that errors in precipitation data products are not universal, but have a strong dependence on meteorological regimes. As such, the GPM Ground Measurements Advisory Panel recommended that GPM should direct its GVS measurements to selected meteorological regimes, particularly those where there are large errors or large uncertainties in retrieval of precipitation estimates from satellite observations. Consequently, the FMPG will be executed as a series of deployments to different regimes throughout the mission lifetime. The advisory panel also recommended that GPM validation activities consider not only the satellite products, but also the merged precipitation products based on cloud resolving models and coupled land surface/cloud resolving models used in hydrologic applications. Therefore, field measurement campaigns will be designed to address both model and satellite validation objectives.

The location and duration of GVS field measurements will be made as a series of adaptive decisions prior to and during the GPM mission. The Precipitation Measurement Missions (PMM) Science Team and the GPM Ground Measurements Advisory Panel will play a role in making decisions about the scientific focus and location of each deployment. Final decisions on deployments will be the responsibility of GPM Project management. These deployments can be defined in terms of Extended Observation Periods (EOPs) and Intensive Observation Periods (IOPs).

Extended Observation Periods. The duration of an EOP is expected to last for 18 months or more. The EOP plan is modeled on the structure of NOAA's Hydro-Meteorological Testbed (HMT), especially in its emphasis on mobility. As such, the GVS instrument suite nominally includes a truck-mounted X-band dual polarization radar and S-band radar profiler, along with a deployable ground-based radiometer, disdrometers and rain gauges. The instrument suite is principally directed toward measurement of radar reflectivity, estimation of precipitation, and drop/particle size distribution. At least 3 geographically and meteorologically diverse EOPs are planned for the GPM Core and Constellation missions, as illustrated in Figure 4-1.

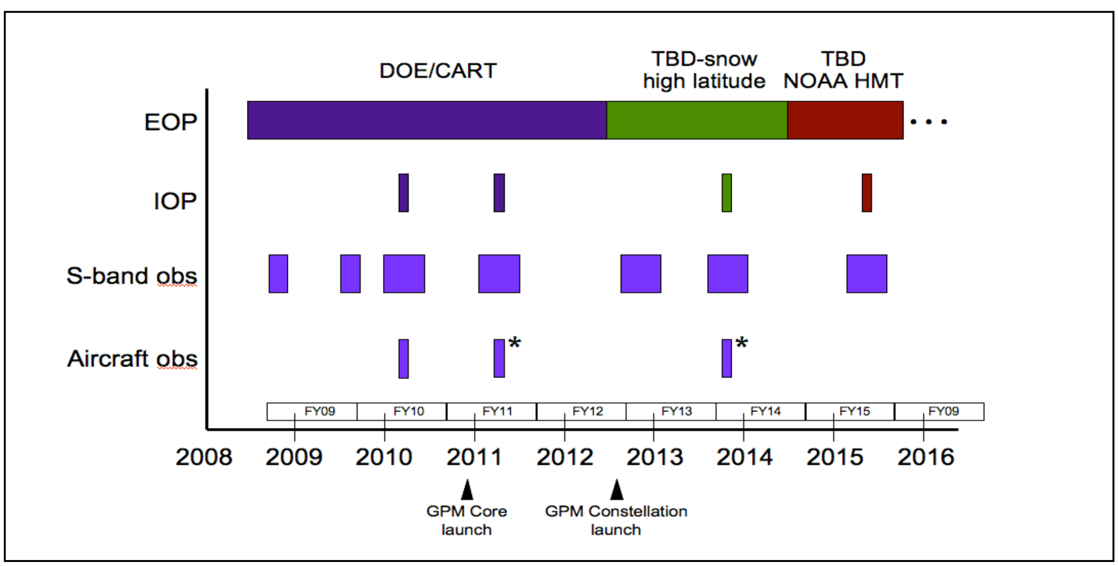

Figure 4-4. GVS deployments and observation periods.

Intensive Observation Periods. As illustrated in Figure 1, IOPs are relatively short duration, intensive campaigns that are conducted in conjunction with EOPs. IOPs are characterized by the deployment of aircraft equipped with instruments that support the specific physical validation objectives of the EOP. Such instrumentation would include in-situ microphysical measurements as well as radar and radiometric remote sensing.

4.12.1 Investigator-Led Measurements

EOP and IOP field campaigns will be funded by NASA's GPM Project. Each EOP 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 specific instrument measurements and data products defined in GVS instruments and data product requirements documents. The PIs and CoIs will also adhere to the operations concepts and scenarios defined in this document.

4.12.2 Instrumentation Deployment Strategies

GVS instrumentation deployments will vary by ground validation site in order to best achieve the science goals for the selected site (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 science teams, and as driven by site geographic constraints and the availability of existing instrumentation. Also, results from the GPM GVS VN studies are expected to point to areas where specific ground validation measurements are required to investigate the differences between the ground and space-based measurements.

For example, one candidate for GVS EOP/IOP deployment is the Department of Energy (DOE) Clouds and Radiation Testbed (CART) site located near Ponca City, Oklahoma. This is a microphysics and radiation study site where precipitation regimes are fairly well understood and a large suite of instrumentation and infrastructure already exists, and where it may only be necessary to deploy a subset of GPM GVS instrumentation to augment the available measurements. For a hydrologic study site, GVS rain gauges and radars would be optimally deployed to best measure the basin-average precipitation, whereas for a coastal or orographically-influenced site, radars and rain gauges may be placed to best capture the variability of precipitation traversing inland, or by elevation and exposure. GVS may sacrifice pairing of rain gauges at these latter types of sites in favor of distributing the gages one-by-one at as many points as possible in the study area. For oceanic sites, GPM will likely utilize the existing TRMM ground validation locations and instrumentation to extend the historical record and (if possible) compare measurements from the two satellite instrumentation systems.

GVS sites for snow and frozen precipitation regimes are likely to be outside the conterminous U.S. In these cases, GPM will cooperate with international agencies to deploy and manage the instrumentation. Manual observations are an important component of snow and frozen precipitation identification and measurement, and must be taken into account in site selection and instrument co-location.

5. Validation Network (VN) Function

The GVS VN operations concept describes the data, systems, processing, and phased development involved in the implementation of VN requirements. The VN requirements for GPM at the most basic level are to compare calibrated, attenuation-corrected reflectivity from the Tropical Rainfall Measurement Mission (TRMM) Precipitation Radar (PR) and the GPM Dual-Frequency Precipitation Radar (DPR) to space- and time-coincident ground-based radar reflectivity, primarily from the Weather Surveillance Radar-1988 Doppler (WSR-88D, or "NEXRAD"), over the Continental United States (CONUS). The aims of the reflectivity comparisons are to:

- Evaluate the effectiveness of the PR/DPR attenuation correction algorithms in various precipitation situations by comparison to unattenuated ground radar reflectivity at low altitudes and/or in heavy precipitation;
- Evaluate the accuracy of the WSR-88D reflectivity calibrations at each ground site by comparison to the well-calibrated PR/DPR reflectivity with precipitation echoes at higher altitudes or in situations where PR/DPR attenuation at lower altitudes is minimal.
- Provide a data set that can be used for assessing GPM data product algorithm accuracy in various precipitation regimes.

The methodologies envisioned for the VN reflectivity comparisons derive in large measure from published investigations of TRMM PR reflectivity to ground-based radar reflectivity. The VN will extend these methods to the full national network of WSR-88D radars in a near-real-time, semi-automated environment. For details, refer to the GPM GVS Level 3 Requirements.

5.1 VN System Description

This operations concept is presented as a set of functions and processes required for the operations of the GVS VN. The allocation of functions and processes in this document is not meant to constrain the detailed GVS system architecture that will be defined later in the GVS development cycle. The objective of this operations concept is to capture all of the necessary functionality of the GVS VN operations, but it is understood that some functions and processes may ultimately be reallocated within the GPM GVS.

Figure 5-1 presents a schematic overview of the functions and processes involved in the GPM GVS VN. The data ingest function acquires WSR-88D Level II products and GPM Precipitation Processing System (PPS) Site Overpass and Level 1 and 2 data products from GVS-external systems. The Data Pre-processing function processes is shown in green in the figure. The Data Post-processing and Analysis function is in orange, the Interactive and Scheduling function is in pink, and the Manual Quality Control function is in blue. Each of these functional areas is described in the sections below.

The GVS VN will operate subject to the overall GPM GVS functional, operational, archive, and performance requirements, which are described elsewhere in this document and in the Global Precipitation Mission (GPM) Ground Validation System Level 3 Requirements.

Definitions: System, function, process <<to be added>>

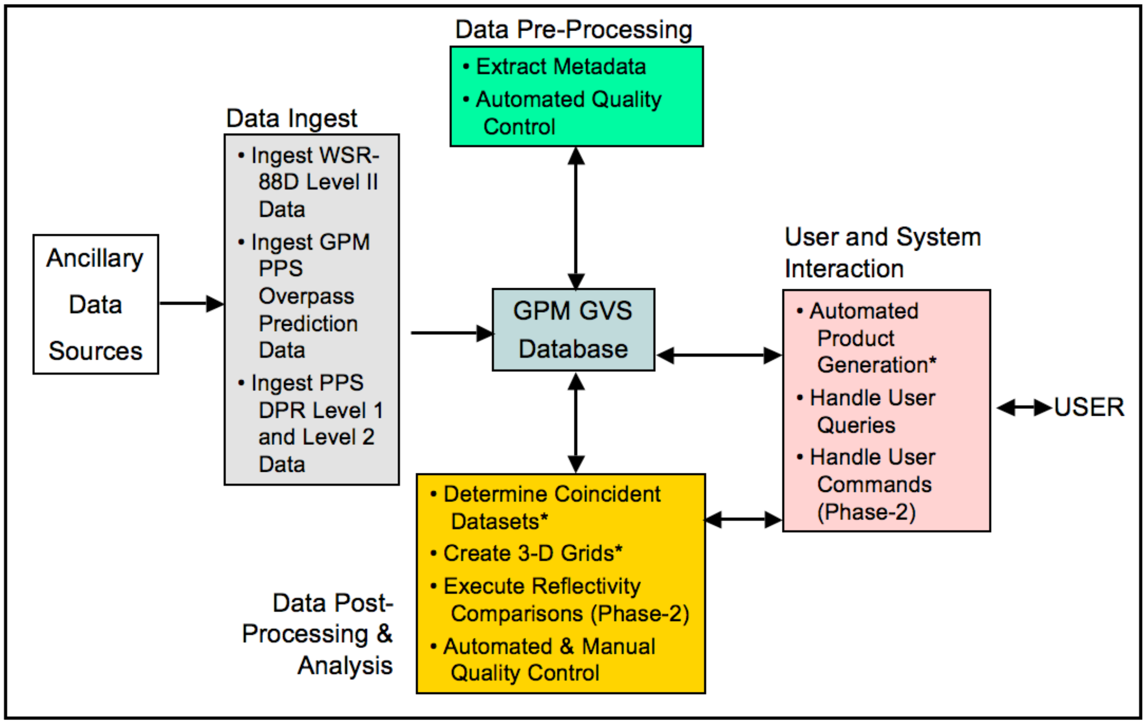

Figure 5-1. Overview of major functions and processes of the GPM GVS VN. Processes that have expanded Phase-2 capabilities are noted with an asterisk (*).

5.2 *Data Ingest Sub-Function*

The data ingest processes of Fig. 5-1 are general components of the GPM GVS, with VN enhancements to acquire these specific data over the entire CONUS rather than just at a few GPM GVS EOP and IOP sites. Only those data components of the GPM GVS pertinent to the VN are described here.

The Ingest WSR-88D Level II Data process will acquire data from the national network in near-real-time from the Internet-II data source using the Local Data Manager (LDM) software package, or their equivalents in the GPM mission time frame. This mechanism is currently used in the TRMM GVS to acquire WSR-88D data for specific ground radar sites. GPM will expand this mechanism to include data acquisition for all WSR-88D sites in the CONUS.

During the GPM era, the Ingest GPM PPS Overpass Prediction Data process and the Ingest PPS DPR Level 1 and Level 2 Data process will interface with the PPS to acquire overpass data products. Prior to the GPM launch, the GVS will acquire comparable products for TRMM via the existing TRMM PPS interface. The PPS will provide the necessary products to the GVS from a ftp server. During VN operations the PPS will provide PR/DPR overflight data corresponding to every WSR-88D in the CONUS. Once acquired, the VN Data Ingest Function will conduct basic format checking on the ingested products and pass them to the GPM GVS database as illustrated in Figure 5-1.

5.3 Data Preprocessing Sub-Function

The Data Pre-processing function extracts additional metadata from the WSR-88D Level II and GPM DPR data products, and executes automated quality control (QC) procedures on the WSR-88D reflectivity data. These processes are shown in the light green box in Fig. 5-1.

The Automated Quality Control process applies automated QC algorithms to all the data and stores the associated QC results in the GVS database.

The Extract Metadata process harvests additional metadata from the WSR-88D and PR/DPR products. Such metadata will be used to help users identify and work with specific sets of GVS data. For example, extraction of pertinent precipitation state metadata and its linkage to data products in the database will allow a rapid determination of whether one, both, or neither of the coincident ground and satellite radar data for an overpass indicate the presence of precipitation echoes. Data for precipitation events and non-precipitating events could then be stored in separate databases, e.g. offline for non-events, and online for precipitating events. A more complicated user search and data selection scenario might be to identify and fulfill a user request for the subset of data where both the ground and space radar indicate stratiform precipitation covering over 50% of the overlap area between the two radars, the ground/satellite radar overlap area itself is 75% or more of the VN 3-D grid volume centered on the ground radar, and the location of the bright band is less than or equal to 3 km above ground level (AGL). This latter scenario will require additional metadata to be produced and stored in the database as the ingested products are processed within the GVS (see following section).
Useful metadata elements to be extracted or calculated from the WSR-88D Level II data potentially include:

- 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.

The VN reads and quality controls PR/DPR data, and extracts metadata. Useful metadata elements to be extracted or calculated from the GPM PPS PR/DPR Level 1 and 2 data products potentially include:

- 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

A GPM GVS data model accounting for the available and desired metadata for the various GVS data will support the types of data queries and processing envisioned by the GPM science team. The GVS database will support the users’ needs as defined by the GVS data model, and system requirements. In the context of the VN Operations Concept, the GVS database of Figure 5-1 includes both the science data for the VN, and the GVS Metrics database described in the GPM GVS Level 3 Requirements.

5.4 Data Post-Processing and Analysis Sub-Function

The Data Post-Processing and Analysis sub-function includes three high-level processes: Determine Coincident Datasets, Create 3-D Grids, and Execute Reflectivity Comparisons. The Determine Coincident Datasets and Create 3-D Grids processes will be part of the Phase-1 or initial core functionality of the VN system. The Execute Reflectivity Comparisons process will be implemented as a Phase-2 capability. In Phase-1, The Determine Coincident Datasets and Create 3-D Grids processes are executed automatically under system control. In Phase-2, these processes may be initiated either under system control (routine, default) or user control (non-routine).

5.4.1 Determine Coincident Datasets Process

For VN Phase-1 operations, and in routine, scheduled operations during Phase-2, the Determine Coincident Datasets process will use a set of default area-of-coverage overlap and time offset rules to match up PR/DPR products to WSR-88D products, at the granularity of a given overpass of an individual ground radar site. Information linking the matching products will be stored in the GVS database to allow easy identification, retrieval, and processing of the paired data. In essence, the Coincident Dataset is simply a set of links between products stored in the GVS database, for a given set of matchup rules. The links may exist as tables in a relational database or in a set of tabular files, depending on how the GVS is implemented. It does not require the duplication or prepackaging of the radar data themselves. The Determine Coincident Datasets process for the default case will be automated and triggered either by the receipt of necessary input data or at fixed times (e.g., by the crontab).

VN Phase-2 will permit non-routine operations such as a user-initiated operation. For example, in Phase-2 operations of the VN the Determine Coincident Datasets process will permit users to specify custom parameters that define the areal overlap and time offset thresholds to be applied to determine the matching satellite and ground radar products. Other parameters, such as the time period (begin and end dates), precipitation regime, or region of the U.S. may be specified to bound the data for which custom, coincident data sets are determined in the non-routine case. These custom match-ups may be stored in the GVS database separate from the default match-ups. Only authorized users will have the permissions necessary to define, create, and store custom matchup datasets during Phase-2 operations of the VN.

In either operating mode, depending on how the satellite and ground radar data are broken out in time and space, there may be up to two each of the satellite and radar granules/products in the matchup, though the norm will be a one-to-one match. For instance, if a DPR overpass of a WSR-88D occurs exactly between volume scans of the ground radar, the higher-elevation sweeps of the preceding volume scan and the lower-elevation sweeps of the succeeding volume scan will be the best match in time to the DPR data, as the WSR-88D volume scan strategies are one-way, from low to high elevations.

5.4.2 Create 3-D Grids Process

The Create 3-D Grids process is a Phase-1 capability that conducts coordinate transformation and interpolation to map the polar-coordinate, fixed-elevation-angle, ground radar data and the line-scan, height-AGL-binned, satellite radar data to common three-dimensional grid volumes. This process will be based on the methods currently used in the TRMM GV processing of PR data and ground radar data for specific TRMM GV locations (see http://trmm-fc.gsfc.nasa.gov/trmm_gv/), enhanced to include GPM DPR data, coverage over the national network of WSR-88D ground radars, and VN metadata extraction and storage. The details of the specific transformation algorithm to be used will not be presented here. Specification of the algorithm will be left to the GPM Science Team.

A single pair of 3-D reflectivity grids, one of satellite-based data and one of ground-based data, will be routinely produced by the Create 3-D Grids process for each PR or DPR overpass of a WSR-88D national network site in the CONUS, when the overpass meets the default criteria for overlap of the satellite and ground based radar areas of coverage, i.e., when they are determined to be coincident. The Create 3-D Grids process for the routine, default case will be automated and triggered either by the availability of necessary input data (i.e., as each coincident dataset is identified by Determine Coincident Datasets) or at fixed times (e.g., by the crontab). The resulting 3-D grids will be stored in the GVS database along with links to the coincident dataset from which they were produced.

In VN Phase-2, non-routine capabilities such as a user-initiated operation will be possible. In this phase of operations the Create 3-D Grids process will accept custom parameters to define the underlying map projection, gridpoint spacing and dimensions for the 3-D grid. Other parameters, such as the time period (begin and end dates), precipitation regime, region of the U.S., and the matchup dataset to be used to determine the matching satellite and ground radar products may be specified to bound the data for which custom, 3-D grid sets are generated in the non-routine case. Only authorized users will have the permissions necessary to define and create custom 3-D grid datasets within the GVS during Phase-2 operations of the VN.

In all phases of VN operations, the Create 3-D Grids process will include ancillary functions to analyze some basic characteristics of data in the 3-D grids and produce descriptive metadata based on these analyses. The metadata elements so produced will be stored in the GVS database with links to the related 3-D grids, and by association, to the matchup radar products from which the 3-D grids are produced. Storage retention of the metadata elements in the database will match those of the 3-D grids from which they were derived. The types of metadata to be derived from the data in the 3-D grids may include:

- Percentage of the horizontal grid area within which precipitation is present, based on a reflectivity threshold, for each vertical level in the 3-D grid
- Percentage of the 3-D grid in which overlapping PR or DPR data are available (partial overlap coverage will be allowed and is likely to be the norm)
- Maximum and minimum vertical grid levels where the bright band occurs within the 3-D grid
- Percent missing data in each level of the 3-D grid
- Type(s) of precipitation (convective, stratiform, etc.) present in the 3-D grid (this in itself may be a 2-D array indicating the dominant precipitation type in each vertical column of the 3-D grid)

3-D grids may not be produced, and will not be stored, for the NULL case where no precipitation echoes are present in either the PR/DPR or ground radar data, or where one or both of the satellite and ground radar data sets are missing or flagged as bad by QC. In the NULL case, only a metadata flag will be stored to indicate the condition responsible for the NULL case. Other than basic error checking of the input data, the Create 3-D

Grids process will not perform any quality control on the output grid data. However, QC flags will be associated with each 3-D grid stored in the database, with values initialized to "no QC performed". In VN Phase-2, these values can be reset by analysis and processing of the Execute Reflectivity Comparisons process, or manually.

The resolution of the default 3-D grids in the horizontal should not be finer than the largest dimension of the satellite or ground radar data samples within the grid domain. For the WSR-88D and a nominal grid domain of ±100 km from the radar, the driving resolution is the PR or DPR instantaneous field of view (IFOV) of approximately 5 km, and so this will be the default resolution of the 3-D grids. The WSR-88D resolution within this domain is 2.5 km or better, which would result in undesirable subsampling of the PR/DPR data and increased data storage and transmittal requirements.

Note: If satellite-to-radar grid co-registration, warping. morphing, etc. are implemented as a supported algorithm in the Execute Reflectivity Comparisons process, then a much smaller horizontal grid domain (±25 km) and gridpoint spacing (0.5 km) may be used for the common 3-D grid, or a second set of 3-D grids at this higher resolution may be produced.

5.4.3 Execute Reflectivity Comparisons Process (Phase-2)

The Phase-2 GPM GVS VN will include an Execute Reflectivity Comparisons process to produce statistical summaries and graphs of the results of ground-to-satellite reflectivity comparisons derived from the 3-D grids. Examples of products to be created possibly include, but are not limited to:

- Scatter plots of satellite vs. ground radar reflectivity (Figure 5-2)
- Time series of mean monthly bias of WSR-88D reflectivity relative to PR/DPR (Figure 5-3)
- Plot of mean ground-satellite reflectivity difference vs. PR/DPR reflectivity category (Figure 5-4)
- Vertical profile of mean ground-satellite reflectivity difference (Figure 5-5).

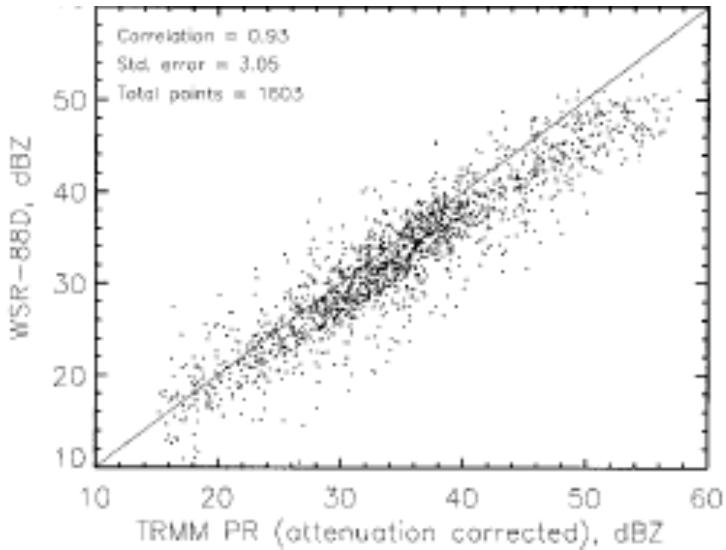

Figure 5-2. Example scatterplot of WSR-88D vs. TRMM PR attenuation-corrected reflectivity. From Liao, et al. (2001).

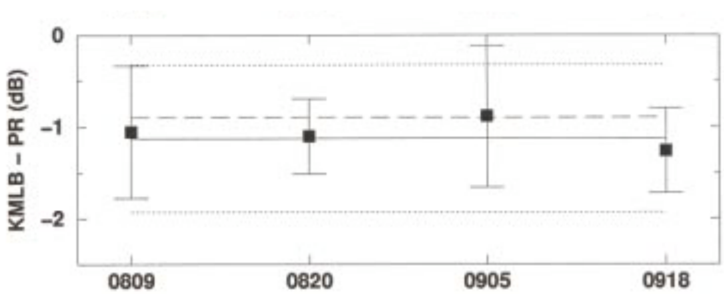

Figure 5-3. Example time series of WSR-88D – TRMM PR attenuation-corrected reflectivity. From Anagnostou et al. (2001).

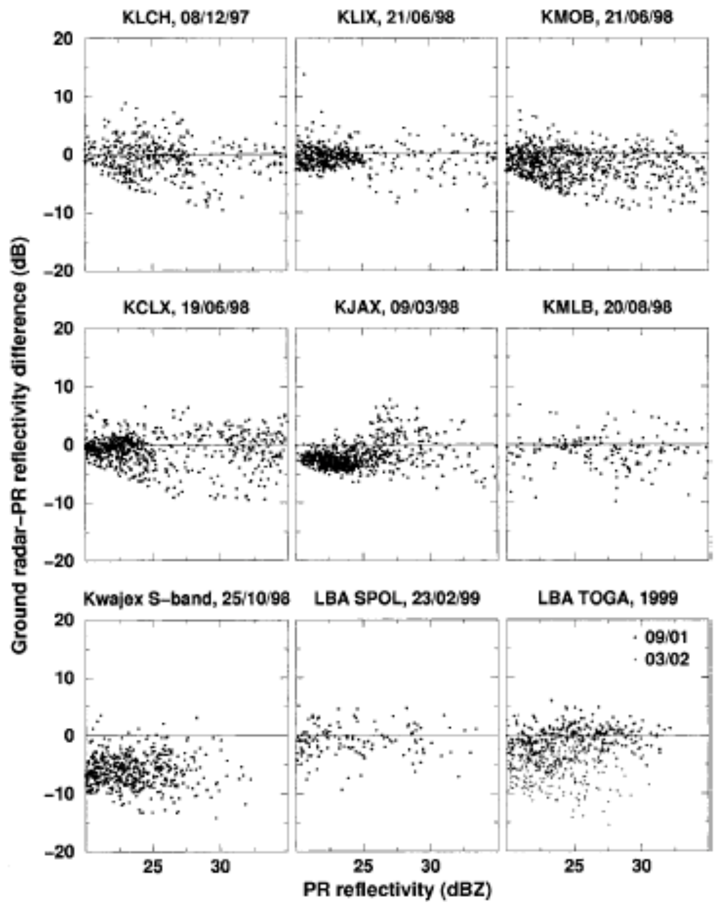

Figure 5-4. Example of WSR-88D –TRMM PR attenuation-corrected reflectivity difference vs. PR reflectivity category. From Anagnostou et al. (2001).

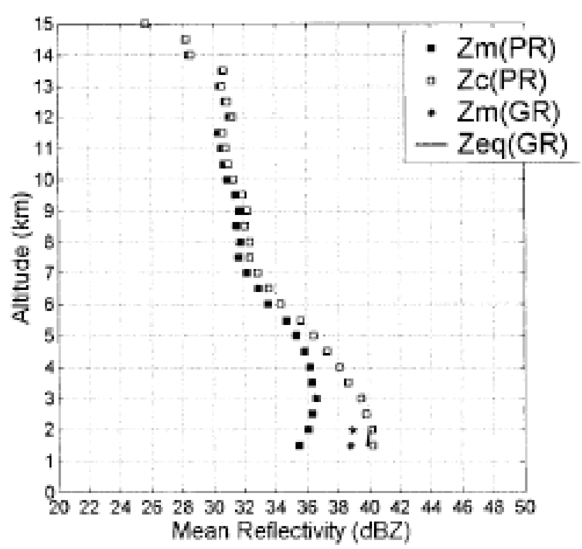

Figure 5-2. Example vertical profiles of WSR-88D and TRMM PR reflectivites. From Bolen and Chandra (2000).

The Phase-2 VN will produce a default set of reflectivity comparison products on a scheduled basis. The default products will be for individual WSR-88D locations over a statistically meaningful time period (monthly or longer). If feasible, an attempt will be made to produce default products specific to precipitation regime (convective, stratiform, light rain, snow, etc.), elevation (above bright band; below bright band), or other predefined situations by applying metadata rules limiting the input 3-D grid data to those meeting the desired criteria.

The Phase-2 Execute Reflectivity Comparisons process will perform quality control on the reflectivity comparisons to determine, as best as possible, whether there are significant geolocation errors (for PR/DPR reflectivity) or anomalous echoes (anomalous propagation, ground clutter, etc.) from the ground radar. Where possible errors exceed defined thresholds, the affected 3-D grids will be flagged in the database and excluded from the product results. A summary (Datetime, data type, QC check failed) of excluded grid data will be produced for the default output product and stored in the database as metadata associated with the product. The output display products will indicate, at a minimum, the number of grid pairs excluded from the results due to failure of QC checks.

In Phase-2, an option will be provided to manually override the individual 3-D grid QC flags which result from the automated reflectivity comparison QC checks from a prior product generation run. In the case where the manual override value indicates to force inclusion of 3-D grid data otherwise flagged for rejection by the QC, the output display product may be regenerated with the flagged data included in the results.

The Phase-2 default products of the Execute Reflectivity Comparisons process will be stored in the GVS. The GVS will provide an online catalog of reflectivity comparison display products, from which products may be selected, viewed, and downloaded. These products will be publicly available online.

Authorized users will have the capability to specify the parameters and criteria used to produce reflectivity comparisons supported by the capability to created customized comparison displays. These users will be able to use either default- or custom-produced 3-D reflectivity grids as input to the reflectivity comparison display generation.

The Manual Quality Control process is executed during both Phases of the VN, but only in cases where it is determined from coincident WSR-88D and satellite data that a rainfall event has occurred. Analysis has shown that the probability of a rainfall event over a WSR-88D site coinciding with a GPM DPR overpass occurs on the order of about 2 times per month per site. When a joint event such as this occurs, the GVS will conduct a manual review and QC of the WSR-88D reflectivity data. Following the QC step, the GVS will either store a modified version of the reflectivity product and applied QC results to the database, or the GVS will flag the data as good (use as-is) or bad (data rejected), depending on the nature and location of the data problems within the product. The original, unmodified WSR-88D data will be retained in either case.

5.5 Scheduled and Interactive Tasks Sub-Function

In Phase-1 of VN operations, users will be able to search coincident PR/DPR and NEXRAD radar reflectivity data (both raw data and data resampled to a common grid) using search criteria for metadata attributes such as those defined in Section 5.2. Users will also be able select data from search results for download via the online access capabilities of the GPM GVS.

Routine data ingest and storage, pre- and post-processing, and generation of the common grid product will be fully automated for Phase-1 operations. Depending on the child process, initiation of the Automated Product Generation process will be either triggered by receipt of necessary input data or scheduled by the system. A default set of parameters to define coincidence of data sets, generation of 3-D grid volumes, time periods covered in the output display products, and stratification of the data contained in the output products will be defined. The default parameters will be retrieved and applied in the routine processing of the VN data.

Phase-2 routine operations will have all the capabilities of Phase-1. In addition, users will be able to select pre-generated products for display or download from the online access to the GPM GVS. This is indicated by the Handle Data Queries process shown in Figure 5-1. This capability will follow the general data accessibility and interactivity requirements for the overall GPM GVS.

The Phase-2 Handle User Commands process illustrated in Figure 5-1 will provide interactive capabilities for authorized users to specify different sets of parameter values to control the operation of various other processes that create customized, non-routine products on demand. It will also provide the interfaces to run QC procedures and manually modify QC flags in the database to override the results of the built-in QC functions.

The Automated Product Generation process shown in Figure 5-1 is the parent process which controls the child processes to determine coincident data sets, and to create the 3-D reflectivity grids. In Phase-2, the capabilities of this process will be expanded to generate the reflectivity comparison display products during routine operations.

5.6 VN Performance and Operations Scenarios

<<to be added>>

6. Satellite Simulator Model (SSM) Function

The SSM performs physical validation of GPM products—by extension it also performs physical validation on the algorithms and models that form the basis for these products. The SSM uses ground measurements from the Validation Network and field campaigns along with land surface and cloud resolving model output to drive forward radiative transfer models that simulate GPM Dual-frequency Precipitation Radar (DPR) and GPM Microwave Instrument (GMI) satellite observations. During operations, an iterative process of measurement and simulation identifies the causes of error and bias in GPM algorithm retrievals and identifies opportunities for algorithm updates. In the pre-launch phase, the SSM simulates ground and aircraft radar and radiometer instrument observations to assist in the planning and execution of field campaigns.

The initial operations of the SSM focuses on creating validation data sets for a series of meteorological events of interest in specific climatic regimes. Each validation data set is a snapshot of the meteorological event, equivalent in duration and extent to a satellite overpass. SSM data set development starts with Cloud-system Resolving Model (CRM) or Large-Eddy Simulation model (LES) output. Based on model output, atmospheric properties are defined consistently for wavelengths applicable the GPM radar and radiometer, as well as ground-based instruments. Radiative transfer calculations are performed to simulate the atmospheric radiation (for the radiometer) and reflectivity (for the radar) arriving at the space-based and ground-based instruments. These data are then acted on by retrieval algorithms to produce inferred atmospheric properties (e.g., rain rate and drop size distribution), which can be compared directly to the input fields and to ground/aircraft measurements. The goal of the SSM is thus an internally consistent set of observations, simulations and retrievals. Deviations from internal consistency are indicative of errors that stem from the measurement/modeling/inversion process.

The SSM represents a relatively novel approach to validation. There is little precedence or heritage for it, and there is considerable risk in system development and in the ultimate acceptance of SSM products. For these reasons an incremental development approach will be pursued, starting with a set of prototypes early in the development lifecycle, an initial core operating capability at launch, and incremental enhancements throughout the GPM operational phase.

6.1 Pre- and At-Launch SSM Product Generation

CRM output. In the pre-launch and initial operating phases the SSM will be executed as a series of case studies in a number of climatic regimes. CRM output for these case studies can be based on quality controlled observational networks (e.g., sounding arrays) or reanalysis. Both of these approaches have been found to be particularly successful in modeling convective systems. For shallow convection and stratiform clouds, large-eddy simulation models (LES), rather than CRMs, are generally used in cloud process studies, owing to requirements for higher resolution in simulating these cloud systems. Since GPM will place more emphasis on higher-latitude cloud systems than TRMM, it may be necessary to employ LESs if CRMs are unable to meet the case study success criteria.

Simulation of GPM GMI and DPR. Data produced by the state-of-the-art, high-resolution CRMs and/or LESs serve as the basis for creating `scenes' that will be used as input to various radiative transfer programs and instrument simulation modules. This provides the basis for simulating satellite overpasses and ground/aircraft measurements. Forward microwave radiative transfer models will be used to generate radiances (TOA and at specific heights corresponding to aircraft observations) and column reflectivities that match the characteristics of the GPM GMI and DPR instruments for the time(s) and date(s) of the available model atmosphere. Output from the simulations will be generated in conformity with the community standards. Initially, the CRM fields alone will be used to set the initial conditions for the radiance and reflectivity simulation. Over time, an effort will be made to include land surface characteristics (e.g., surface emissivity, temperature, aspect and orientation) in the simulations.

Precipitation retrieval. Simulated GMI TOA radiances and DPR column reflectivities will be used as input to one or more standard precipitation retrieval algorithms. The algorithms will generate precipitation fields in conformity with dataset standards. The retrieved values will be subject to validation and constraint-checking by comparison with actual aircraft- and ground-based instrument data from FMPG EOP and IOP campaigns.

Simulate ground- and aircraft-based radars and radiometers. On an as-needed basis, forward microwave radiative transfer models will be used to generate radiances and reflectivities simulating ground- and aircraft-based instruments in use or planned for use in FMPG field campaigns.

6.2 Post-Launch Enhancements

Forward modeling sensitivity analysis. Upon establishing a baseline or reference set of model outputs that suitably match the observations, this activity will seek to perturb different boundary characteristics in the coupled model system (land surface, CRM, radiative) to isolate parameters that produce the largest sensitivity in simulated results. The results of this analysis will form a framework for assessing weaknesses in the algorithm performance and also provide direction as to specific measurement types that can isolate the most sensitive algorithm parameters.

Assimilation. The vision for the SSM involves the eventual use of observational data assimilation into the coupled modeling system to provide “real time” validation, diagnosis, and interpretation of algorithm products from the space-borne measurements. At this stage it is recognized that considerable work in data assimilation methodology is still required.

6.3 Metrics

The SSM generates performance and process metrics on the full scope of its activities, including: ingest of atmospheric measurements and satellite observations from the A&D; setting initial conditions for the CRM or LES; atmospheric radiative transfer modeling; retrieval of precipitation and related values; and cross-comparison of simulations, retrievals, and instrument measurements. All SSM metrics are all delivered to the GVS Metrics Database (MD).

6.4 Interfaces

The SSM directly interfaces with the A&D for the receipt of all the data and products it needs to conduct its modeling, simulation, retrieval, and cross-comparison. Data and products from the PPS, FMPG, and any ancillary data sources are first delivered to the A&D and then transferred to the SSM as needed.

7. GVS Archive and Distribution

The GVS Archive and Distribution (A&D) capability maintains the integrity of its data holdings by providing secure and reliable storage of, and access to: GVS data, products, documentation, and reports. It is also the site for archive of the computer code used in product generation by the SSM and FMPG. As such, the A&D provides an interface to the SSM and FMPG capabilities for the receipt of data products, reports, documentation and computer code. The A&D also provides the interface to the PPS for delivery of GVS data products required by the PPS.

The A&D capability provides Internet-based search and order capabilities that allows all users access to all versions of its holdings. Similarly, products are distributed from the A&D via the Internet. Data distribution may be the result of a search and order session or it may be the result of a standing order. The performance of the A&D is such that data will be available for search and delivery within 24 hours of receipt during nominal operations.

The A&D also provides a limited customer service for science team members. This service allows science team members to send email to the A&D with questions about data products and services, and a reply is generated by A&D staff. This service will not be available to general users.

During its operations, the GVS A&D will generate performance metrics related to, for example, data quality checks, the data volume and number of products ingested and distributed, the numbers of searches and orders, customer service requests, and replies.

8. GVS Metrics Database Function

The Metrics Database (MD) is a tool for management of the heterogeneous and distributed elements of the GVS. As described above, the FMPG, A&D and SSM elements of the GVS all generate performance and process metrics, and these metrics are delivered to the MD for safe and reliable storage. The MD allows GPM management to establish “standing orders” for database reports that can be triggered by date or event. The MD also allows management to search the metrics in the database and to generate one-time, user-defined reports.

9. Operational Phases

9.1 Pre-Launch

9.2 Operations

10. GPM GVS Operational Scenarios

This section explores two use scenarios in which the GVS is employed in accomplishing basic GPM requirements for algorithm improvement and error estimation for global data products.

10.1 Operational Data Flow

This section provides a time-line that illustrates the nominal operations and data flow in the GVS. Section 4 examines GVS operations in the context of two use scenarios.

1. The PPS determines and periodically distributes scheduling information on GPM constellation and core spacecraft overflights of GPM GVS ground site locations. The GVS FMPG and the spacecraft measure the same precipitation events at the same time.
2. The GVS FMPG, the GPM core spacecraft, and the GPM constellation spacecraft measure precipitation events on an ongoing basis; the spacecraft measure events across the globe, while the GVS measures the events at local sites.
3. The PPS generates L1 and L2 data products for core and constellation spacecraft, extracts subsets of the data corresponding to GVS ground site locations, and delivers the subsets to the GVS A&D.
4. The FMPG sites generate data products that characterize the atmospheric state during a precipitation event. These data products are delivered to the GVS A&D.
5. The A&D distributes FMPG data products to Precipitation Measuring Mission Science Team members and to the general user community according to previously established standing orders or in response to searches and orders.
6. The GVS SSM acquires PPS and FMPG products from the A&D and conducts various analyses on the data. The SSM uses the FMPG atmospheric state data to calculate TOA Tb and Z, and compares these values to PPS observations. The SSM also uses these data to parameterize its precipitation retrieval algorithm, and to calculate a “constrained” precipitation estimate. This estimate is compared to direct measurement of precipitation at the GVS sites and to the precipitation estimated by PPS data products. Reports are generated on these comparisons and sent to the A&D.
7. The A&D distributes SSM data products to Precipitation Measuring Mission Science Team members and to the general user community according to previously established standing orders or in response to searches and orders.
8. The Precipitation Measuring Mission Science Team reviews and analyzes data received from the GVS A&D. Over time, the PMM Science Team proposes new GVS instrumentation and algorithms, which are tested and integrated into the GVS.

11. Acronyms and Symbols

ACRONYM	DEFINITION
3-D	3-Dimension
A&D	Archive and Distribution
ACRF	ARM Climate Research Facility
AGL	Above Ground Level
ARM	Atmospheric Radiation Measurement
ASCII	American Standard Code for Information Interchange
BUFR	Binary Universal Format for Representation of meteorological data
CART	Clouds and Radiation Testbed
CM	Configuration Management
CMO	Configuration Management Office
CoI	Co-Investigator
CONUS	Continental United States
CRM	Cloud Resolving Model
CSV	Comma-Separated Values
dB	Decibel
DOE	Department of Energy
DPR	Dual-frequency Precipitation Radar
DSD	Drop Size Distribution
EOP	Extended Operation Period
FMPG	Measurement and Product Generation Function
GCM	Global Climate Model
GMI	Global Microwave Imager
GPR	Goddard Project Requirement
GPM	Global Precipitation Measurement
GPS	Global Positioning System
GRIB	GRIdded Binary
GSFC	Goddard Space Flight Center
GV	Ground Validation
GVS	Ground Validation System
HDF	Hierarchical Data Format
HMT	HydroMeteorology Testbed
hr	Hour
ICD	Interface Control Document
ID	Identification
IFOV	Instantaneous Field Of View
IOP	Intensive Operation Period
JAXA	Japanese Aerospace Exploration Agency t
K	Kelvin
Kdp	Specific Differential Phase
km	kilometer
km	Kilometer

L2	Level-2
LDM	Local Data Manager
LES	Large-scale Eddy Simulation
m	Meter
MAR	Mission Assurance Requirements
mb	Millibar
MD	Metrics Database
mm	Millimeter
ms^{-1}	Meters per second
NASA	National Aeronautics and Space Administration
netCDF	network Common Data Form
NEXRAD	
NOAA	National Oceanic and Atmospheric Administration
NPR	NASA Program Requirement
NWP	Numerical Weather Prediction
NWS	National Weather Service
PI	Principal Investigator
PMM	Precipitation Measuring Missions
PPI	Plan Position Indicator
PPS	Precipitation Processing System
PR	Precipitation Radar
QC	Quality Control
RT	Radiative Transfer
rZdr	Resampled differential reflectivity factor
rZh	Resampled equivalent reflectivity factor horizontal polarization
rZv	Resampled equivalent reflectivity factor vertical polarization
SHEF	Standard Hydrometeorological Exchange Format
SSM	Model-Based Analysis
Tb	Brightness Temperature
TOA	Top-Of-Atmosphere
TRMM	Tropical Rainfall Measuring Mission
UF	Universal Format
UHF	Ultra High Frequency
US	United States
UTC	
VCP	Volume Coverage Pattern
VN	Validation Network
WSR-88D	Weather Surveillance Radar - 1988 Doppler
XML	Extended Markup Language
Z	Reflectivity Factor