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Global Precipitation Measurement (GPM)
Ground Validation System

Level 3 Requirements
for a
Mobile Ka-/Ku-band Radar

DRAFT

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Goddard Space Flight Center
Greenbelt, Maryland

National Aeronautics and
Space Administration

CM FOREWORD

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Global Precipitation Measurement

DOCUMENT CHANGE RECORD

Sheet: 1 of 1

REV LEVEL	DESCRIPTION OF CHANGE	APPROVED BY	DATE APPROVED

List of TBDs/TBRs

Item No.	**Location**	**Summary**	**Ind./Org.**	**Due Date**

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1 OVERVIEW

1.1 Background and Purpose

This specification defines the Level 3, system-level functional and performance requirements for NASA's Global Precipitation Measurement (GPM) mission Ground Validation System Mobile Radar (GVSMR).

1.2 Document Scope

This document sets forth requirements for NASA's GPM GVSMR including necessary ground validation measurement, data ingest, processing, archiving, and distribution.

The structure and functional breakdown of this document are used to organize the requirements only, and should not be interpreted as a physical architecture or allocation. Physical attributes and implementation approaches of the GVSMR are intentionally omitted from this document.

The GVS requirements presented in this document are traceable to the NASA GPM Level 2 Requirements.

1.3 Applicable Documents

The following is considered the controlling documents for this specification:

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

1.4 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 overall GVSMR system requirements. Section 3 defines the radar operations requirements. Section 4 defines all acronyms and symbols. Section 5 provides a work-off plan for all items that are "to be determined" (TBD) at the time this document was written.

2 KA/KU-BAND RADAR INSTRUMENT REQUIREMENTS

2.1 Instrument Measurement Requirements: Ka-band and Ku-band scanning radar

2.1.1 Electrical Performance Requirements

2.1.1.1 Ku-band scanning radar center frequency

GVSMR-18 The GVSMR Ku-band radar shall have a center frequency that operates in the range allocated to HIWRAP (13.47 GHz +/- 50 MHz, 13.91 GHz +/- 50 MHz).

Rationale: This is the frequency range allows close compatibility with HIWRAP and the GPM Dual-frequency Precipitation Radar (DPR).
Validation Method: Design and Measurement

Priority: Given suitable justification, other frequencies in the Ku-band may be considered.

Note: the frequency range is subject to approval by NTIA.

2.1.1.2 Ka-band scanning radar center frequency

GVSMR-24 The GVSMR Ka-band radar shall have a center frequency that operates in the range allocated to HIWRAP (33.72 GHz +/- 50 MHz, 35.56 GHz +/- 50 MHz).

Rationale: This is the frequency range allows close compatibility with HIWRAP and GPM DPR.
Validation Method: Design and Measurement

Priority: Given suitable justification, other frequencies in the Ku-band may be considered.

Note: the frequency range is subject to approval by NTIA.

2.1.1.3 Scanning radar beam width

GVSMR-30 The GVSMR shall have a full width half-power beam width of ≤1 degree.

Rationale: This is a nominal beam width for a research quality scanning radar. It permits approximately 500 m vertical resolution at a range of 30 km.
Validation Method: Antenna Pattern Measurement

Priority: This requirement may be traded against cost and other performance requirements

Note: This requirement applies to both the Ka and Ku bands.

2.1.1.4 Matched V & H antenna patterns in Ka-band

GVSMR-36 The GVSMR shall have Ka-band V and H antenna patterns matched to within 5% integrated power patterns over the main lobe.

Rationale: Matched V and H antenna gain patterns are required for generating various polarimetric products.
Validation Method: Measurement and Analysis

2.1.1.5 Matched V & H antenna patterns in Ku-band

GVSMR-40 The GVSMR shall have Ku-band V and H antenna patterns matched to within 5% integrated power patterns over the main lobe.

Rationale: Matched V and H antenna gain patterns are required for generating various polarimetric products.
Validation Method: Measurement and Analysis

2.1.1.6 Maximum Ka-band sidelobe

GVSMR-44 The GVSMR shall have a maximum Ka-band 1st sidelobe gain of -25 dB compared to the Ka-band main lobe.

Rationale: Needed to prevent the contamination of the signal with ground clutter and other targets outside of the 1-degree field of view.
Validation Method: Measurement

Note: this requirement applies to both H and V polarization.

Priority: This requirement may be traded against cost and other performance requirements

2.1.1.7 Maximum Ku-band sidelobe

GVSMR-50 The GVSMR shall have a maximum Ku-band sidelobe gain of -25 dB compared to the Ku-band main lobe.

Rationale: Needed to prevent the contamination of the signal with ground clutter and other targets outside of the 1-degree field of view.
Validation Method: Measurement

Priority: This requirement may be traded against cost and other performance requirements

Note: this requirement applies to both H and V polarization.

2.1.1.8 Cross-polarization isolation

GVSMR-56 The GVSMR shall have a total system cross-polarization isolation of 32 dB.

Rationale: ability to detect mixed phase precipitation
Validation Method: Receiver and antenna performance determined separately. Integrated cross-pol isolation to be calculated and verified by at least six principle plane antenna pattern measurements.

Priority: performance may be traded against cost.

Note: See GVSMR-97 for receiver isolation specification.

2.1.1.9 Ku-band minimum detectable signal

GVSMR-62 The GVSMR Ku-band shall have a minimum detectable signal of -10 dBZ at 15 km in clear air for a single pulse when measured with 150 m range resolution.

Rationale: This sensitivity is better than that provided by the space-based DPR, the system with level of sensitivity will permit testing of the DPR algorithms.
Validation Method: Analysis using Measured Values

Priority: This requirement may be traded against cost and other performance requirements

Note-1: Assuming 1-degree beamwidth and an antenna gain of 44.5 dB.

Note-2: A phase-1 version of the radar may have a sensitivity of 0 dBZ.

Note-3: There is an overall system sensitivity goal of -20 dBZ, assuming the application of pulse integration and other methods.

2.1.1.10 Ka-band minimum detectable signal

GVSMR-70 The GVSMR Ka-band shall have a minimum detectable signal -10 dBZ at 15 km in clear air for a single pulse when measured with 150 m range resolution.

Rationale: This sensitivity is better than that provided by the space-based DPR, the system with level of sensitivity will permit testing of the DPR algorithms.
Validation Method: Analysis using Measured Values

Priority: This requirement may be traded against cost and other performance requirements

Note-1: Assuming 1-degree beamwidth and an antenna gain of 44.5 dB.

Note-2: A phase-1 verion of the radar may have a sensitivity of 0 dBZ.

Note-3: There is an overall system sensitivity goal of -20 dBZ, assuming the application of pulse integration and other methods.

2.1.1.11 Measure and record transmit and receive gain

GVSMR-78 The GVSMR shall measure and record the transceiver gain on a 1-second integration to within 0.05 dB.

Rationale: required for monitoring radar calibration stability
Validation Method:

Note: this requirement applies to both Ka-band and Ku-band radars.

2.1.1.12 Ka-band receiver dynamic range

GVSMR-83 The GVSMR Ka-band receiver shall have a dynamic range of ≥90 dB.

Rationale: This dynamic range allows for 16-bit quantization of the radar signal.
Validation Method: Measurement

Priority: The first version of the Ka-band receiver may have a 14-bit quantization.

2.1.1.13 Ku-band receiver dynamic range

GVSMR-88 The GVSMR Ku-band receiver shall have a dynamic range of ≥90 dB.

Rationale: This dynamic range allows for 16-bit quantization of the radar signal.
Validation Method: Measurement

Priority: The first version of the Ka-band receiver may have a 14-bit quantization.

2.1.1.14 Ka-band and Ku-band beam co-alignment

GVSMR-93 The GVSMR shall co-align the Ka-band antenna pattern with Ku-band antenna pattern to within one-tenth of the 3 dB beamwidth.

Rationale: Both radars need to sample the same volume of space at the same time.
Validation Method: Measurement and Analysis

2.1.1.15 Receiver channel isolation

GVSMR-97 The GVSMR receiver isolation shall exceed 35 dB between channels.

Rationale: Isolation exceeds cross-polarization isolation in GVSMR-56.
Verification: Measurement

2.1.1.16 Simultaneous transmission and simultaneous reception mode

GVSMR-101 The GVSMR shall be capable of simultaneously transmitting and receiving on the H and V channels.

Rationale: This mode will typically be used as the default for radar data collection.
Validation Method: Demonstration

Note: this requirement applies to both the Ka-band and Ku-band radars

2.1.1.17 Alternate transmit simultaneous receive mode

GVSMR-106 The GVSMR shall be capable of alternating transmit H and V polarizations from pulse to pulse while receiving on both.

Rationale: This mode allows permits the measurement of the Linear Depolarization Ratio (LDR) which can be used for hydrometeor classification
Validation Method: Demonstration

Note: this requirement applies to both the Ka-band and Ku-band radars

2.1.2 Physical/Mechanical Performance Requirements

2.1.2.1 Scanning radar minimum operational range

GVSMR-112 The GVSMR shall have a minimum operational range of 100 meters when the range resolution is set to ≤50 meters.

Rationale: 100 m is a reasonable range for setting up a calibration target.
Validation Method: Analysis.

2.1.2.2 Scanning radar minimum range resolution

GVSMR-116 The GVSMR shall have a minimum range resolution of ≤30 m for all gates within the minimum and maximum range.

Rationale: 30 m is equivalent to a 0.2 _sec pulse width.
Validation Method: Demonstration

2.1.2.3 Selectable radar range resolution

GVSMR-120 The GVSMR shall have a selectable range resolution from the minimum 0.2 _sec to 1.8 _sec in 0.2 _sec steps.

Rationale: The radar data must have sufficient resolution to provide meaningful information on the spatial variability of rainfall and other products. Also, 125 m is the minimum gate size for the GPM DPR and this spec allows for a range gate to be selected that is equivalent to this.
Note: the minimum range resolution is defined in requirement GVSM-56.

2.1.2.4 Ka-band and Ku-band range gate alignment

GVSMR-124 The GVSMR Ka-band range gates shall be aligned with the Ku-band range gates to within +/- 10 meters when both radars operate at the same pulse repetition frequency.

Rationale: Needed to ensure that the same volume of the atmosphere is sampled at the same time by both radars
Validation Method: Measurement and Analysis

2.1.2.5 Scanning radar elevation pointing resolution

GVSMR-128 The GVSMR shall have an elevation pointing resolution of ≤0.1 degree.

Rationale: Needed to ensure that the radar can accurately point at calibration targets.
Validation Method: Demonstration

2.1.2.6 Scanning radar azimuth pointing resolution

GVSMR-132 The GVSMR shall have an azimuth pointing resolution of ≤0.1 degree.

Rationale: Needed to ensure that the radar can accurately point at calibration targets.
Validation Method: Demonstration

2.1.2.7 Scanning radar elevation pointing knowledge uncertainty

GVSMR-136 The GVSMR shall have an elevation pointing uncertainty of ≤0.2 degree.

Rationale: It maintains a beam height error upper limit of ~100 m at the radar maximum range of 30 km.
Validation Method: Design and Analysis

2.1.2.8 Scanning radar azimuth pointing knowledge uncertainty

GVSMR-140 The GVSMR shall have an azimuth pointing uncertainty of ≤0.2 degree.

Rationale: It maintains a beam height error upper limit of ~100 m at the radar maximum range of 30 km.
Validation Method: Design and Analysis

2.1.2.9 Azimuth radar scan rates

GVSMR-144 The GVSMR shall provide a maximum azimuthal scan rate of at least 36° sec-1.

Rationale: These rates allow the GVSMR to be scan-synchronized with any WSR-88D unit.
Validation Method: Demonstration

2.1.2.10 Elevation radar scan rates

GVSMR-148 The GVSMR shall provide a maximum elevation scan rate of at least 4° sec-1.

Rationale: These rates allow the GVSMR to be scan-synchronized with any WSR-88D unit.
Validation Method: Demonstration

2.1.2.11 Scanning radar minimum and maximum elevation

GVSMR-152 The GVSMR shall have a range of elevation look angles from -0.5° to 90°.

Rationale: The stated elevation range is required for the radar to scan, as near as practical, a full 3-D volume.
Validation Method: Demonstration

2.1.2.12 Scanning radar azimuth range

GVSMR-156 The GVSMR shall be capable of scanning a full 360 degrees of azimuth.

Rationale: The stated elevation range is required for the radar to scan, as near as practical, a full 3-D volume.
Validation Method: Demonstration

Priority: Moderate. Some blind spots are permitted if required by the integration of the radar onto the platform that carries it.

2.2 Instrument Product Generation Requirements

2.2.1 Scanning radar equivalent reflectivity factor product

GVSMR-162 The GVSMR shall generate Ka-band and Ku-band calibrated horizontal and vertical equivalent reflectivity factor (Zh and Zv) products (in dB) to an accuracy of ≤1.0 dB for measurements at all ranges and elevations, independent of any attenuation correction.

Rationale: An accuracy of 1.0 dBZ is necessary to provide sufficient accuracy of the rain rate derived from reflectivity, and to match the reflectivity accuracy requirements of the GPM DPR.
Validation Method: Measurement.

2.2.2 Scanning radar differential reflectivity product

GVSMR-166 The GVSMR shall generate Ka-band and Ku-band calibrated differential reflectivity (Zdr) products (in dB) with an accuracy ≤ 0.2 dB independent of any attenuation correction.

Rationale: As in GVSMR-2.2.05, but in the native range, azimuth coordinates of the radar.
Validation Method: Measurement.

Note: Solar observation and test pulses can be used for validation.

2.2.3 Scanning radar differential propagation phase product

GVSMR-171 The GVSMR shall generate Ka-band and Ku-band differential propagation phase (_dp in degrees) products with an accuracy of ≤3.0 degrees for any measurement in the entire radar scan volume where the radar signal has not been completely attenuated.

Rationale: As in GVSMR-166, but in the native range, azimuth coordinates of the radar. Differential propagation is also used to eliminate ground clutter from the scan.
Validation Method: Measurement.

2.2.4 Scanning radar co-polar correlation coefficient product

GVSMR-175 The GVSMR shall generate Ka-band and Ku-band correlation coefficient products (unitless) of the horizontal and vertical return signal (_hv) with an accuracy of ≤0.005 for any measurement in the entire radar scan volume.

Rationale: The correlation coefficient is needed in concert with other measured and derived parameters to help distinguish between precipitation types and to help eliminate ground clutter.
Validation Method: Measurement.

2.2.5 Scanning radar linear depolarization ratio product (optional)

GVSMR-179 The GVSMR shall generate Ka-band and Ku-band linear depolarization ratio (LDR) products (in dB) to an accuracy of ≤1.0 dB (when averaged over distances of 1 km) for both horizontal transmit/vertical receive and vertical transmit/horizontal receive conditions for any measurement in the entire radar scan volume.

Rationale: LDR is a good indicator of regions where a mixture of precipitation types occur and can be used as a hydrometeor identification discriminator.
Validation Method: Measurement.

GVSMR-182 Note: the default mode of data collection for the GVSMR will be simultaneous transmission and simultaneous reception (STSR) and depolarization information will not be collected. As required, the GVSMR shall operate in a mode capable of measuring the depolarization ratio (e.g., simultaneous transmit alternate reception - STAR mode).

Rationale:

2.2.6 Scanning radar Doppler radial velocity product

GVSMR-184 The GVSMR shall generate Doppler radial velocity products (in m/sec) with an uncertainty of +/- 1 m/sec for any measurement in the entire radar scan volume.

Rationale: Single or multiple Doppler wind retrievals will be used to validate CRM kinematic structure.
Validation Method:

2.2.7 Time series data collection

GVSMR-188 The GVSMR shall be capable of recording complete time series on request by the operator such that:
a. the system has the capacity to store up to 2 hours of contiguous time series data.
b. Doppler spectra may be calculated.

Rationale: Needed for checking out and development of algorithms.
Validation Method: Demonstration

Priority: performance of this requirement can be traded against cost, and performance of other requirements

Note: this requirement applies to both the Ka-band and Ku-band radars

2.2.8 Unambiguous velocity requirement

GVSMR-196 The GVSMR unambiguous Doppler velocity shall be 25 m/sec at Ka-band and 25 m/sec at Ku-band.

Rationale: The unambiguous Doppler velocity is based on an acceptable maximum measurement range of 30 km. This range will provide adequate spatial coverage and

Nyquist velocity range for precipitation retrievals. Based on the formula v_max*r_max=c*lambda/8.
Validation Method: Analysis

2.3 General Instrument Requirements

2.3.1 Communications

GVSMR-201 The GVSMR shall generate quick-look images at least every 15 minutes and these images will be available to other computers in the local network.

Rationale: An image display generation capability is necessary to locally and remotely monitor the instrument data quality and for weather situational awareness in GV field operations.
Validation Method: Demonstration

Note: These images will show low-level Plan Position Indicators (PPIs) of radar reflectivity, differential reflectivity, and specific differential phase.

2.3.2 Mobility

GVSMR-206 The GVSMR shall be a transportable, self contained system capable of traveling from one field site location to another on demand.

Rationale: The GVS operations concept calls for a series of filed campaigns to be held in different climatic regimes. The Ka-/Ku-band radar needs to easily moved from one field site to another.
Validation Method: Demonstration.

2.3.3 Set up

GVSMR-210 The GVSMR shall be capable of performing full operations within 72 hours of delivery to a field site.

Rationale: See Requirement GVSMR-206.
Validation Method: Demonstration.

2.3.4 Tear down

GVSMR-214 The GVSMR shall be capable of transitioning from operations to a state ready for transport given 72 hours of prior notification.

Rationale: See Requirement GVSMR-206.
Validation Method: Demonstration.

2.3.5 Thermal regime

GVSMR-218 The GVSMR shall operate in a range of ambient temperatures from +40 C to -40 C.

Rationale: These are the range of temperatures expected during field campaigns held in Finland in the winter and Oklahoma in the summer.
Validation Method: Analysis

2.3.6 Wind load operations

GVSMR-222 The GVSMR shall operate in a range of wind velocities up to a maximum sustained velocity of 25 m/sec.

Rationale: This is the maximum wind velocity (equal to about 50 knots, a strong gale) considered safe for operating the radar.
Validation Method: Analysis

Note: this requirement applies to both Ka-band and Ku-band radars.

2.3.7 Wind load survivability

GVSMR-227 The GVSMR shall be capable of surviving a sustained wind velocity of up to a maximum of 35 m/sec.

Rationale: This is the maximum wind velocity (equal to about 70 knots, a hurricane) considered safe for storing the radar.
Validation Method: Analysis

Note: this requirement applies to both Ka-band and Ku-band radars.

Priority: This requirement may be traded for cost against a lower performance.

2.3.8 Precipitation regime

GVSMR-233 The GVSMR shall be capable of operations in rain of up to 50 mm per hour, snow of up to 4 cm per hour, and freezing rain.

Rationale: These precipitation rates approach the useful range of operations
Validation Method: Analysis and demonstration.

Note: this requirement applies to both Ka-band and Ku-band radars.

2.3.9 Metrics capability

GVSMR-238 The GVSMR shall, at a minimum, monitor and record ground instrument up time, outage and/or malfunction others metrics TBD-1.

Rationale:
Validation Method: Demonstration.

2.3.10 Unattended operations (TBD-2)

GVSMR-244 The GVSMR shall be capable of unattended operations with, at a minimum, the following capabilities:
a. the ability to operate the radar from a remote location via electronic networks, including the ability to modify and execute scan sequences from remote locations
b. the ability to distribute a selectable list of products in near-real-time over wired & wireless electronic networks
c. the ability to operate autonomously (without human support or intervention) for a minimum of 72 hours
d. the ability to transmit notifications to selected destinations in the event of non-nominal conditions.

Rationale: Needed to reduce operations costs.
Validation Method: Demonstration.

2.3.11 Check validity of data recorded

GVSMR-252 The GVSMR shall perform automated verification of data formats and ranges for all data recorded.

Rationale: Useful in identifying anomalous conditions during operations.
Validation Method: Demonstration.

2.3.12 Check validity of data distributed

GVSMR-256 The GVSMR shall perform automated verification of data formats and checksums on all data distributed.

Rationale: Useful in identifying anomalous conditions during operations.
Validation Method: Demonstration.

2.3.13 Local archive capability

GVSMR-260 The GVSMR shall implement a local archive capability with, at a minimum, the following characteristics:
a. maintain the integrity of all data collected
b. maintain data acquired from TBD-23 hours of continuous operations
c. manage multiple versions of the same data.

Rationale: Local storage will be needed during operations.
Validation Method: Demonstration.

2.3.14 Data format

GVSMR-267 The GVSMR shall generate data products that conform to at least one standard science data format.

Rationale: Use of a standard data format will increase the ease of use of the radar data.
Validation Method: Demonstration.

Note: netCDF is a science data format that is commonly used by the atmospheric sciences community.

2.3.15 Product metadata

GVSMR-272 The GVSMR data products shall include descriptive metadata including, at a minimum:
a. the version identifier of the software that generated the product
b. the time and date that the product was generated.

Rationale: Product metadata increases the usability of the product.
Validation Method: Demonstration.

2.3.16 Interface to standard analysis and display tools

GVSMR-278 The GVSMR shall generate data products that can be used directly by Sigmet IRIS.

Rationale: Sigmet IRIS is a commonly used radar data analysis and display package.
Validation Method: Demonstration.

2.3.17 Commercial electrical power

GVSMR-282 The GVSMR shall be capable of operations from commercial power sources, including those with the following characteristics:
a. single or 3-phase
b. 100 V to 240 V
c. 50 Hz to 60 Hz.

Rationale: The radar may operate in the US or internationally and may encounter a variety of commercial power sources.

Validation Method: Demonstration.

2.3.18 Electrical generator

GVSMR-289 The GVSMR shall generate sufficient electrical power to meet all of its autonomous operational requirements, including radar operations, air conditioning/heating, and associated computer resources, for up to 6 weeks of continuous operations.

Rationale: The radar may operate in the US or internationally and may encounter situations where no commercial power source is available.
Validation Method: Demnstration.

Note: Re-fueling is of course permitted during those 6 weeks of operations.

2.3.19 Generation of measured products

GVSMR-294 The GVSMR shall generate all measured products listed in Section 2.2 within 24 hours of observations.

Rationale: Needed to prevent data backlog during continuous operations.
Note: See section 2.2 for measured products.

Validation Method: Demonstration.

2.4 GVSMR Instrument Contractor Requirements

2.4.1 Documentation

GVSMR-300 The GVSMR contractor shall deliver documentation in print and electronic media of, at a minimum, the following:
a. a design document, including as-built specifications and comprehensive schematics

b.an operator's manual, including operating instructions, set-up and tear-down instructions, operating procedures, and maintenance instructions

Rationale: Documentation needed to operate and maintain the radar.
Validation Method: Demonstration.

2.4.2 Training

GVSMR-306 The GVSMR contractor shall provide training in the operations and maintenance of the GVSMR radar and support equipment.

Rationale: Training is needed to operate and maintain the radar.
Validation Method: Demonstration.

2.4.3 Maintenance and spare parts (TBD-21)

3 KA/KU-BAND OPERATIONS REQUIREMENTS

3.1 Derived Products

3.1.1 Scanning radar product Cartesian grid

GVSMR-313 The GVSMR operator shall generate Ka-band and Ku-band radar products (defined below) interpolated from polar coordinates to a 3-dimensional Cartesian grid with, at a minimum, the following characteristics:
a. Cartesian grid center located on the scanning radar
b. Cartesian grid extending 30 km in the X,Y (east-west ,north-south) direction from the location of the radar
c. Cartesian grid extending in the Z (vertical) direction from 0.5-18km above ground level
d. Resolution of the Cartesian grid in all dimensions not to exceed the actual radar beam resolution at maximum horizontal range.

Rationale: The radar components need to be mapped to a Cartesian grid, since the original polar-coordinate product data are incompatible with requirements for use of the data. The 3-D Cartesian gridded data will be used as input to Satellite Simulation Models (SSM), for validation of Cloud Resolving Models (CRM), and to evaluate the calibration and attenuation correction of the satellite-borne PR/DPR. The domain and resolution of the 3-D grid are driven by the radar characteristics, sampling theory, and product usage.
Validation Method: Demonstration

3.1.2 Re-sampled equivalent reflectivity factor product

GVSMR-321 The GVSMR operator shall generate Ka-band and Ku-band resampled horizontal and vertical equivalent reflectivity factor (rZh and rZv in dB) products with, at a minimum, the following characteristics:
a. The rZh and rZv product is resampled to the Cartesian grid defined in Requirement GVSMR-3.1.35 for each PPI-volume scan of radar data
b. The rZh and rZv product shall have an accuracy of 2.0 dB or better for any grid element in the entire resampled radar scan volume.

Rationale: GVSMR reflectivity will be compared to satellite radar reflectivity on a common grid to validate the calibration of each instrument and the effectiveness of the PR/DPR attenuation corrections. It will also be used in computation of rain rates using the traditional Z-R as well as polarimetric relationships. 2 dB is the minimum accuracy required for these purposes.
Validation Method: Demonstration for GVSMR-321a, analysis for GVSMR-321b.

Note: 2 dB refers to the re-sampling error of the product

3.1.3 Re-sampled differential reflectivity product

GVSMR-328 The GVSMR operator shall generate Ka-band and Ku-band resampled differential reflectivity factor (rZdr in dB) products with, at a minimum, the following characteristics:
a. The rZdr product is resampled to the Cartesian grid defined in Requirement GVSMR-313 for each PPI-volume scan of radar data.
b. The rZdr product has an accuracy of 0.4 dB or better for any grid element in the entire resampled radar scan volume.

Rationale: Differential reflectivity is needed to estimate Drop Size Distributions, detect the presence of hail, and estimate rainfall using polarimetric parameters.
Validation Method: Demonstration for GVSMR-328a, analysis for GVSMR-328b.

Note: Based on Rob Cifelli's 12/17/07 email, the consensus is that the interpolation uncertainty should be no more than double the uncertainty of the parameter in radar space. For example, a 0.2 dB measurement uncertainty in Zdrwould translate into a 0.4 dB uncertainty after interpolation. However, these values should probably be regarded as targets, and additional testing should be done to confirm that they can be met.

3.1.4 Specific differential phase product

GVSMR-335 The GVSMR operator shall generate Ka-band and Ku-band differential phase (Kdp in degrees/km) products with, at a minimum, the following characteristics:
a. The Kdp product measured in polar coordinates with an accuracy of 0.3 degrees/km or better over a minimum distance of 3 km for any measurement in the entire radar scan volume where reliable differential propagation phase measurements can be obtained
b. The Kdp product generated in polar coordinates re-sampled to the Cartesian grid specified in requirement GVSMR-313.

Rationale: Differential phase is needed to estimate rainfall intensity and accumulation, especially in the presence of hail. It is highly immune to radar calibration errors and partial beam blockage
Validation Method: Demonstration for GVSMR-335b, analysis for GVSMR-335a.

3.1.5 Liquid water content profiles

GVSMR-341 The GVSMR operator shall generate estimates of the vertical profile of atmospheric precipitation liquid water content (g/m3) sampled to a 3-dimensional grid with a horizontal resolution not to exceed the actual radar beam resolution for each PPI-volume scan of radar data.

Rationale: Vertical profiles of atmospheric liquid water are needed as input to and validation of SSMs, and for validation and initiation of Cloud-system Resolving Models (CRMs). These data will supplement moisture profiles collected by upper air soundings. Accuracies are based on the instrument measurement requirements. Temporal resolution

is the minimum required to provide a representative measurement in changing atmospheric conditions.
Validation Method: Demonstration.

3.1.6 Scanning radar hydrometeor identification product

GVSMR-345 The GVSMR operator shall estimate hydrometeor types with the subsequent product having at a minimum, the following characteristics:
a. The hydrometeor type product estimates the most likely hydrometeor types sampled to a 3-dimensional grid with a horizontal resolution not to exceed the actual radar beam resolution for each PPI-volume scan of radar data
b. The hydrometeor type product classifies hydrometeors into at least the following types: light rain, moderate rain, heavy rain, rain mixed with precipitation-sized ice, and precipitation-sized ice only (warm season) and low density snow, high density snow, and mixed precipitation (cold season).

Rationale: Knowledge of actual hydrometeor types is needed to model and validate microwave precipitation retrievals and CRM microphysics, and improve active radar attenuation algorithms.
Validation Method: Demonstration.

3.1.7 Scanning radar median drop diameter product

GVSMR-351 The GVSMR operator shall generate a median drop diameter D0 product (in mm) with, at a minimum, the following characteristics:
a. The D0 product sampled to a 3-dimensional grid with a horizontal resolution not to exceed the actual radar beam resolution for each PPI-volume scan of radar data
b. The D0 product with an accuracy of ≤0.2 mm.

Rationale: This requirement, along with GVSMR-357 and GVSMR-363 are related and interdependent. D0 in combination with number concentration of liquid droplets (GVSMR-363) is needed to make accurate determination of rain rates from radar and to compute attenuation estimates.
Validation Method: Demonstration for GVSMR-351a, analysis for GVSMR-351b.

3.1.8 Scanning radar instantaneous rain rate product

GVSMR-357 The GVSMR operator shall generate a rain intensity product (in mm/hr) with, at a minimum, the following characteristics:
a. The rain intensity product shall be sampled to a 3-dimensional grid with a horizontal resolution not to exceed the actual radar beam resolution for each PPI-volume scan of radar data
b. The rain intensity product shall have an accuracy of ±20%.

Rationale: Rain rate is the primary measured element to be validated in GPM. Rain rate estimates from scanning radar will be one of the validating measurements.

Validation Method: Demonstration for GVSMR-357a, analysis for GVSMR-357b.

3.1.9 Scanning radar number concentration - liquid product

GVSMR-363 The GVSMR operator shall shall generate a drop number concentration product that estimates of the number of liquid water drops per volume (in m-3) sampled to a 3-dimensional grid with a horizontal resolution not to exceed the actual radar beam resolution for each PPI-volume scan of radar data.

Rationale: See GVSMR-351.
Validation Method: Demonstration for GVSMR-363a, analysis for GVSMR-363b.

3.2 Project/Program General Requirements

3.2.1 Participate in pre-operational training

GVSMR-368 The GVSMR operator shall participate pre-operational training provided by the GVSMR contractor.

Rationale: See requirement GVSMR-306.
Validation Method: Demonstration.

3.2.2 Conduct configuration management

GVSMR-372 The GVSMR operator shall maintain configuration control, at a minimum over
a. Internal systems and software
b. Data holdings, including products, reports, documentation and computer code
c. External interfaces.

Rationale: Ensures “best practices” in terms of system operations.

Validation Method: Demonstration.

3.2.3 Interface to GVS Archive and Distribution Element

GVSMR-379 The GVSMR operator shall provide all data, including products, reports, documentation and computer code to the GVS Archive and Distribution Element.

Rationale: Needed to ensure long-term storage of radar data products
Validation Method: Demonstration

APPENDIX A - ACRONYMS AND SYMBOLS

ACRONYM	DEFINITION
3-D	3-Dimension
AGL	Above Ground Level
CM	Configuration Management
CMO	Configuration Management Office

ACRONYM	**DEFINITION**
CRM	Cloud Resolving Model
D0	Median drop diameter
dB	Decibel
dBZ	Reflectivity in decibels
DOE	Department of Energy
DPR	Dual-frequency Precipitation Radar
DSD	Drop Size Distribution
G	Gram
GHz	GigaHertz
GMI	Global Microwave Imager
GPR	Goddard Project Requirement
GPM	Global Precipitation Measurement
GSFC	Goddard Space Flight Center
GV	Ground Validation
GVS	Ground Validation System
GVSMR	Ground Validation System Mobile Radar
HIWRAP	High-Altitude Imaging Wind and Rain Airborne Profiler
Hr	Hour
IOP	Intensive Operations Period
IFOV	Instantaneous Field of View
Kdp	Specific Differential Phase
Km	Kilometer
LDR	Linear Depolarization Ratio
M	Meter
MAR	Mission Assurance Requirements
MC^3E	Midlatitude Continental Convective Clouds Experiment
Mm	Millimeter
ms^{-1}	Meters per second
NASA	National Aeronautics and Space Administration
NITA	National Telecommunications and Information Administration
NPR	NASA Program Requirement
PMM	Precipitation Measuring Missions
PPI	Plan Position Indicator
PR	Precipitation Radar
QC	Quality Control
rZdr	Resampled differential reflectivity factor
rZh	Resampled equivalent reflectivity factor horizontal polarization
rZv	Resampled equivalent reflectivity factor vertical polarization
s, sec	Second
SSM	Model-Based Analysis
STSR	Simultaneous Transmission and Simultaneous Reception

ACRONYM	**DEFINITION**
STAR	Simultaneous Transmission Alternate Reception
TBD	To Be Determined
WSR-88D	Weather Surveillance Radar - 1988 Doppler
Z	Reflectivity Factor
Z-R	Reflectivity Factor-Rain
Zdr (rZdr)	Differential reflectivity factor (resampled)
Zh (rZh)	Equivalent reflectivity factor horizontal polarization (resampled)
Zv (rZv)	Equivalent reflectivity factor vertical polarization (resampled)
_dp	Differential propagation phase
_vh	Correlation coefficient of the horizontal and vertical return signal

APPENDIX B - WORK-OFF ITEMS

Item No.	Description
TBD-1	Metrics to be recorded by GVSMR
TBD-2	Maybe more detail is needed to define what unattended operations means
TBD-3	CLOSED
TBD-4	CLOSED
TBD-5	Time-line for delivery of derived products
TBD-6	CLOSED
TBD-7	CLOSED
TBD-8	CLOSED
TBD-9	CLOSED
TBD-10	CLOSED
TBD-11	CLOSED
TBD-12	CLOSED
TBD-13	CLOSED
TBD-14	CLOSED
TBD-15	CLOSED
TBD-16	CLOSED
TBD-17	CLOSED
TBD-18	CLOSED
TBD-19	CLOSED
TBD-20	CLOSED
TBD-21	Requirement for maintenance and spares
TBD-22	CLOSED
TBD-23	Number of hours of local storage

Open: 5, Closed: 18

APPENDIX C - TRACEABILITY

Parent Requirement	Requirement
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-18 2.1.1.1.0-1 Ku-band scanning radar center frequency
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-24 2.1.1.2.0-1 Ka-band scanning radar center frequency
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-30 2.1.1.3.0-1 Scanning radar beam width
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-36 2.1.1.4.0-1 Matched V & H antenna patterns in Ka-band
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-40 2.1.1.5.0-1 Matched V & H antenna patterns in Ku-band
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-44 2.1.1.6.0-1 Maximum Ka-band sidelobe
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-50 2.1.1.7.0-1 Maximum Ku-band sidelobe
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-56 2.1.1.8.0-1 Cross-polarization isolation
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-62 2.1.1.9.0-1 Ku-band minimum detectable signal
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-70 2.1.1.10.0-1 Ka-band minimum detectable signal
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-78 2.1.1.11.0-1 Measure and record transmit and receive gain
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-83 2.1.1.12.0-1 Ka-band receiver dynamic range
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-88 2.1.1.13.0-1 Ku-band receiver dynamic range
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-93 2.1.1.14.0-1 Ka-band and Ku-band beam co-alignment
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-97 2.1.1.15.0-1 Receiver channel isolation
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-101 2.1.1.16.0-1 Simultaneous transmission and simultaneous reception mode

Parent Requirement	Requirement
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-106 2.1.1.17.0-1 Alternate transmit simultaneous receive mode
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-112 2.1.2.1.0-1 Scanning radar minimum operational range
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-116 2.1.2.2.0-1 Scanning radar minimum range resolution
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-120 2.1.2.3.0-1 Selectable radar range resolution
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-124 2.1.2.4.0-1 Ka-band and Ku-band range gate alignment
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-128 2.1.2.5.0-1 Scanning radar elevation pointing resolution
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-132 2.1.2.6.0-1 Scanning radar azimuth pointing resolution
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-136 2.1.2.7.0-1 Scanning radar elevation pointing knowledge uncertainty
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-140 2.1.2.8.0-1 Scanning radar azimuth pointing knowledge uncertainty
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-144 2.1.2.9.0-1 Azimuth radar scan rates
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-148 2.1.2.10.0-1 Elevation radar scan rates
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-152 2.1.2.11.0-1 Scanning radar minimum and maximum elevation
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-156 2.1.2.12.0-1 Scanning radar azimuth range
MRD523 7.4.1.1.0-1 Direct assessment of satellite precipitation estimates MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-162 2.2.1.0-1 Scanning radar equivalent reflectivity factor product
MRD523 7.4.1.1.0-1 Direct assessment of satellite precipitation estimates MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-166 2.2.2.0-1 Scanning radar differential reflectivity product
MRD525 7.4.1.2.0-1 Precipitation physics measurements	GVSMR-171 2.2.3.0-1 Scanning radar

Parent Requirement	Requirement
for satellite observation simulation	differential propagation phase product
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation	GVSMR-175 2.2.4.0-1 Scanning radar co-polar correlation coefficient product
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation	GVSMR-179 2.2.5.0-1 Scanning radar linear depolarization ratio product (optional)
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation	GVSMR-184 2.2.6.0-1 Scanning radar Doppler radial velocity product
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation	GVSMR-188 2.2.7.0-1 Time series data collection
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation	GVSMR-196 2.2.8.0-1 Unambiguous velocity requirement
MRD532 7.4.2.2.0-1 Product Generation	GVSMR-201 2.3.1.0-1 Communications
MRD532 7.4.2.2.0-1 Product Generation	GVSMR-206 2.3.2.0-1 Mobility
MRD530 7.4.2.1.0-1 Measurement	GVSMR-210 2.3.3.0-1 Set up
MRD530 7.4.2.1.0-1 Measurement	GVSMR-214 2.3.4.0-1 Tear down
MRD530 7.4.2.1.0-1 Measurement	GVSMR-218 2.3.5.0-1 Thermal regime
MRD530 7.4.2.1.0-1 Measurement	GVSMR-222 2.3.6.0-1 Wind load operations
MRD530 7.4.2.1.0-1 Measurement	GVSMR-227 2.3.7.0-1 Wind load survivability
MRD530 7.4.2.1.0-1 Measurement	GVSMR-233 2.3.8.0-1 Precipitation regime
MRD540 7.4.2.6.0-1 Metrics	GVSMR-238 2.3.9.0-1 Metrics capability
MRD530 7.4.2.1.0-1 Measurement	GVSMR-244 2.3.10.0-1 Unattended operations (TBD-2)
MRD534 7.4.2.3.0-1 Archive	GVSMR-252 2.3.11.0-1 Check validity of data recorded
MRD534 7.4.2.3.0-1 Archive	GVSMR-256 2.3.12.0-1 Check validity of data distributed
MRD534 7.4.2.3.0-1 Archive	GVSMR-260 2.3.13.0-1 Local archive capability
MRD534 7.4.2.3.0-1 Archive	GVSMR-267 2.3.14.0-1 Data format
MRD534 7.4.2.3.0-1 Archive	GVSMR-272 2.3.15.0-1 Product metadata
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation	GVSMR-278 2.3.16.0-1 Interface to standard analysis and display tools
MRD530 7.4.2.1.0-1 Measurement	GVSMR-282 2.3.17.0-1 Commercial electrical power
MRD530 7.4.2.1.0-1 Measurement	GVSMR-289 2.3.18.0-1 Electrical generator
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation	GVSMR-294 2.3.19.0-1 Generation of measured products
MRD530 7.4.2.1.0-1 Measurement	GVSMR-300 2.4.1.0-1 Documentation
MRD530 7.4.2.1.0-1 Measurement	GVSMR-306 2.4.2.0-1 Training
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-313 3.1.1.0-1 Scanning radar product Cartesian grid
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-321 3.1.2.0-1 Re-sampled equivalent reflectivity factor product
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-328 3.1.3.0-1 Re-sampled differential reflectivity product
MRD525 7.4.1.2.0-1 Precipitation physics measurements	GVSMR-335 3.1.4.0-1 Specific differential

Parent Requirement	Requirement
for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	phase product
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-341 3.1.5.0-1 Liquid water content profiles
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-345 3.1.6.0-1 Scanning radar hydrometeor identification product
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-351 3.1.7.0-1 Scanning radar median drop diameter product
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-357 3.1.8.0-1 Scanning radar instantaneous rain rate product
MRD525 7.4.1.2.0-1 Precipitation physics measurements for satellite observation simulation MRD532 7.4.2.2.0-1 Product Generation	GVSMR-363 3.1.9.0-1 Scanning radar number concentration - liquid product
MRD543 7.4.3.1.0-1 Ready for operations MRD545 7.4.3.2.0-1 Operations lifetime	GVSMR-368 3.2.1.0-1 Participate in pre-operational training
MRD543 7.4.3.1.0-1 Ready for operations MRD545 7.4.3.2.0-1 Operations lifetime	GVSMR-372 3.2.2.0-1 Conduct configuration management
MRD534 7.4.2.3.0-1 Archive MRD536 7.4.2.4.0-1 Archive search and order MRD538 7.4.2.5.0-1 Distribution	GVSMR-379 3.2.3.0-1 Interface to GVS Archive and Distribution Element