Global Precipitation Mission (GPM)

Ground Validation System

Validation Network Data Product User's Guide

Volume 2 – GPM Data Products

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Document History

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1.0	October 22, 2014	Initial document and netCDF matchup file version

Contact Information

Additional information, including information on VN points-of-contact, can be obtained from the GPM Ground Validation web site:

http://pmm.nasa.gov/science/ground-validation

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1. Introduction

This document provides a basic set of documentation for the data products available from the GPM Ground Validation System (GVS) Validation Network (VN). In the GPM era the VN performs a direct match-up of GPM's space-based Dual-frequency Precipitation Radar (DPR) data with ground radar data from the U.S. network of NOAA Weather Surveillance Radar-1988 Doppler (WSR-88D, or "NEXRAD"). Ground radar networks from international partners are also part of the VN. The VN match-up will help evaluate the reflectance attenuation correction algorithms of the DPR and will identify biases between ground observations and satellite retrievals as they occur in different meteorological regimes. A prototype of the capability performed a match-up of Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar (PR) data with ground-based radar (GR) measurements from a subset of the WSR-88D sites now included in the VN operational radar data network (Fig. 1-1). TRMM data and their matching GR observations continue to be part of the VN operations in the GPM era. Volume 1 of the Validation Network Data User's Guide describes the TRMM-based VN data set.

The approaches to the DPR-to-GR data matching developed for the VN is a *geometry matching technique* based on determining the intersection of the individual DPR rays with each of the elevation sweeps of the circularly-scanning ground radar. The horizontal and vertical locations and number of data points in the geometry matching technique are different for each case due to the randomness of the ray-to-sweep intersections. Section 5 of this document describes the algorithm used to generate geometry-matched data. Data output from the geometry matching technique are stored as netCDF files, with each netCDF file being specific to the GPM overpass of an individual GR site.

A separate but nearly identical matchup technique performs a geometry matching of GR data to the GPM 2B-DPRGMI "Combined" product. A slightly different set of variables is included in the GRtoDPRGMI matchup, but the basic algorithm is the same as for the DPR-to-GR data matching.

A prototype GPM Microwave Imager (GMI)-to-GR geometry matching technique has also been developed. For this product, the GMI near-surface rain rate field from the 2A-GPROF algorithm is matched to the GR reflectivity and dual-polarization fields in two manners. First, the GR data are matched to the GMI at the intersections of the GMI line-of-sight with the GR elevation sweeps, in a similar manner to how the DPR ray intersections with the GR sweeps are computed. Second, the GR sweep intersections along a vertical column above the GMI surface footprint are computed to give the vertical profile of GR reflectivity above the location where the GMI rain rate estimate is assigned in the GPM 2A-GPROF product. This technique will also work with any GPM constellation satellite Microwave Imager data processed with the 2A-GPROF algorithm (e.g. TRMM/TMI, GCOMW1/AMSR2, F15/SSMIS, F16/SSMIS, F17/SSMIS, F18/SSMIS, METOPA/MHS, NOAA18/MHS, NOAA19/MHS). The utility of the GPROF-GR geometry match data has not been vetted by the GPM GMI algorithm developers and is to be considered an experimental product.

For purposes of this document, the term DPR data refers to any of the following products: 2A-DPR, 2A-Ka, and 2A-Ku. Any of these products may be used as valid input to the DPR-to-GR volume-matching algorithm, and the output data format is the same regardless of the GPM DPR Level 2A product used.

1.1 Data Availability

VN match-up, input, and ancillary data are available via anonymous ftp from the site: **ftp://hector.gsfc.nasa.gov/gpm-validation/data**. The site provides access to the raw GPM DPR and GMI data, raw ground radar data, quality controlled ground radar data, as well as geometrically matched DPR-GR, GMI-GR, and DPRGMI-GR data. The directory structure of the ftp site is described in detail in Section 4 of this document. GPM and constellation satellite data products are documented in "PRECIPITATION PROCESSING SYSTEM, GLOBAL PRECIPITATION MEASUREMENT, File Specification for GPM Products". The naming convention for these products is documented in "PPS File Naming Convention for Precipitation Products for The Global Precipitation Measurement (GPM) Mission." The current version of each of these documents is available from http://pps.gsfc.nasa.gov/GPMprelimdocs.html .

1.2 Software Availability

Software to perform the DPR-to-GR, DPRGMI-to-GR, and GMI-to-GR geometry matching, and to display and compute DPR-GR reflectivity and rainrate and GMI-GR rainrate statistics and analysis products from the data is available. Contact a member of the GPM GV team listed at http://pmm.nasa.gov/science/ground-validation.

1.3 Period of Record

The current period of record for the VN match-up datasets starts on 4 March 2014 (GMI) and 8 March 2014 (DPR, Ka, Ku, DPRGMI) and runs to the present. Data for all dates are reprocessed for the latest version of the products, where earlier version of the products are terminated on the date the version is superseded. Because the input ground radar data for the VN match-ups are quality controlled by a human analyst there may be a time lag of several days up to several weeks from observation to VN product generation.

1.4 Match-up Sites

At present, 70 WSR-88D sites are included in the VN operational network (Figure 1-1). Table 1-1 lists the VN site identifiers, long names, and the latitude and longitude of each. The VN short names are used in the VN product file naming convention described in Section 2 of this document. Although the list below was current at the time that this document was written, it is expected that additional routine VN sites will be added from time to time. In addition to these WSR-88D sites, there will be additional GR sites with selected periods/dates of data included in the VN data set. More up-to-date information may be available on the GPM GV web site:

http://pmm.nasa.gov/science/ground-validation

Check with the GPM GV points-of-contact for current status.

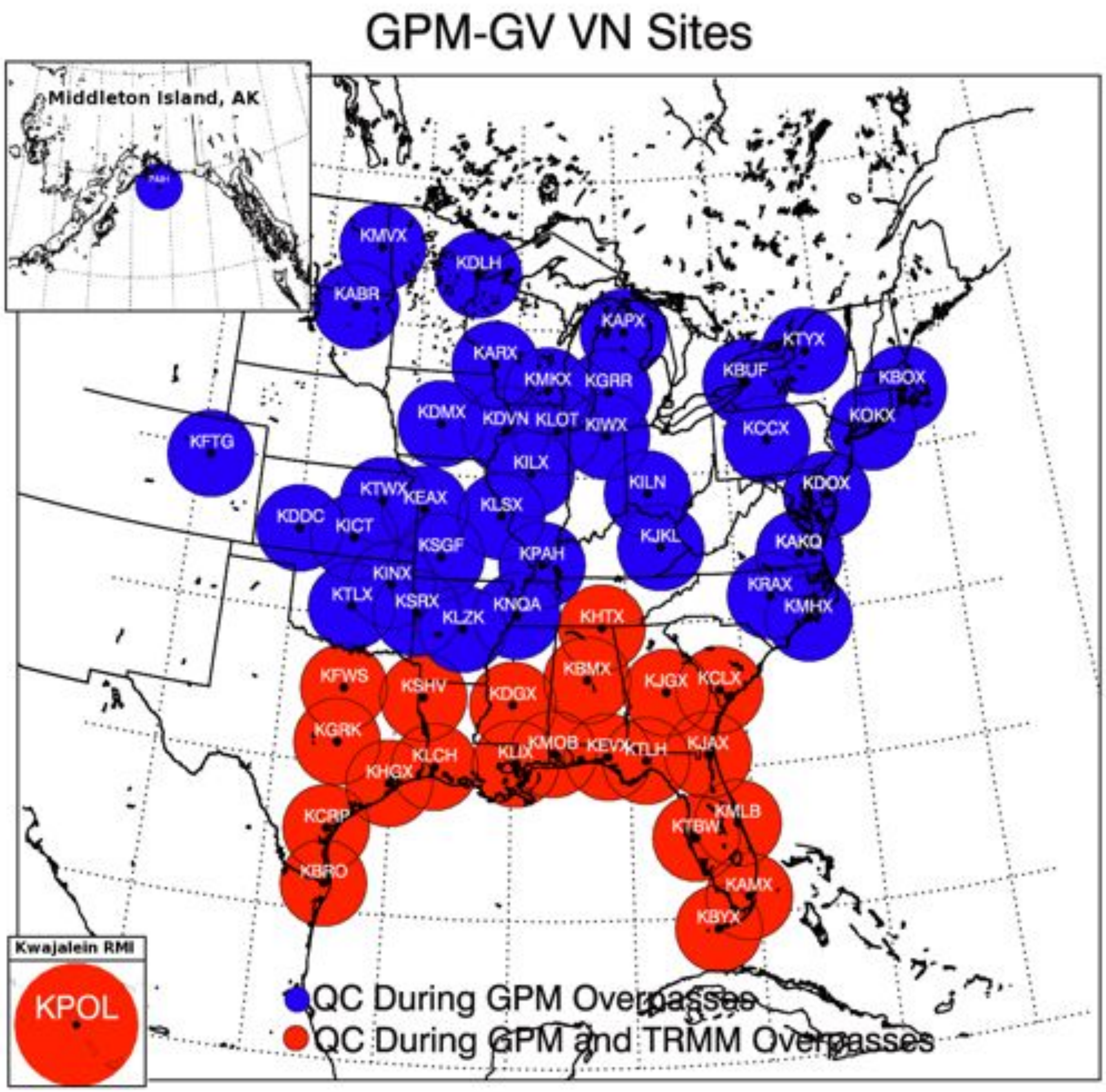

Figure 1-1. Location of VN match-up sites in the U.S. For each site, ground radar observation limits are also illustrated.

Table 1-1. WSR-88D and other (in italics) ground radar sites routinely used in the GPM GVS Validation Network.

Site ID	Site Name	Latitude (N)	Longitude (E)
KABR	Aberdeen, SD	45.4558	-98.4131
KAKQ	Wakefield, VA	36.9839	-77.0072
KAMX	Miami, FL	25.6111	-80.4128
KAPX	North Central Lower Michigan, MI	44.9072	-84.7197
KARX	La Crosse, WI	43.8228	-91.1911
KBHX	Eureka/Humboldt County, CA	40.4983	-124.292
KBMX	Birmingham/Alabaster, AL	33.1722	-86.7697

Site ID	Site Name	Latitude (N)	Longitude (E)
KBOX	Boston/Taunton, MA	41.9558	-71.1369
KBRO	Brownsville, TX	25.9161	-97.4189
KBUF	Buffalo/Cheektowaga, NY	42.9489	-78.7367
KBYX	Miami/Boca Chica Key, FL	24.5975	-81.7031
KCCX	Central Pennsylvania/Rush, PA	40.9231	-78.0036
KCLX	Charleston/Grays, SC	32.6556	-81.0422
KCRP	Corpus Christi, TX	27.7842	-97.5111
KDDC	Dodge City, KS	37.7608	-99.9689
KDFX	Austin/San Antonio/Us Hwy 90, TX	29.2728	-100.281
KDGX	Brandon, MS	32.2797	-89.9842
KDLH	Duluth, MN	46.8369	-92.2097
KDMX	Des Moines/Johnston, IA	41.7311	-93.7228
KDOX	Wakefield/Ellendale State Fo, DE	38.8256	-75.4397
KDVN	Quad Cities/Davenport, IA	41.6117	-90.5808
KEAX	Kansas City/Pleasant Hill, MO	38.8103	-94.2644
KEPZ	El Paso/Santa Teresa, TX	31.8731	-106.698
KEVX	Tallahassee/Eglin AFB, FL	30.5644	-85.9214
KFTG	Denver/Boulder, CO	39.7867	-104.546
KFWS	Dallas/Fort Worth, TX	32.5731	-97.3031
KGRK	Dallas/Fort Worth/Ft Hood, TX	30.7219	-97.3831
KGRR	Grand Rapids, MI	42.8939	-85.5447
KHGX	Houston/Galveston/Dickinson, TX	29.4719	-95.0792
KHTX	Birmingham/Northeastern Al, AL	34.9306	-86.0833
KICT	Wichita, KS	37.6547	-97.4428
KILN	Cincinnati/Wilmington, OH	39.4203	-83.8217
KILX	Central Illinois/Lincoln, IL	40.1506	-89.3369
KINX	Tulsa/Inola, OK	36.175	-95.5647
KIWX	Northern Indiana/North Webster, IN	41.4086	-85.7
KJAX	Jacksonville, FL	30.4847	-81.7019
KJGX	Atlanta/State Hwy 96, GA	32.6753	-83.3511
KJKL	Jackson/Noctor, KY	37.5908	-83.3131
KLCH	Lake Charles, LA	30.1253	-93.2158
KLGX	Langley Hill NW WA, WA	47.1158	-124.107
KLIX	New Orleans/Baton Rouge/Slidell, LA	30.3367	-89.8256
KLOT	Chicago/Romeoville, IL	41.6047	-88.0847
KLSX	St. Louis/St Charles, MO	38.6989	-90.6828
KLZK	Little Rock/N Little Rock, AR	34.8364	-92.2622
KMBX	Bismarck/Mchenry County, ND	48.3925	-100.865
KMHX	Morehead City/Newport, NC	34.7761	-76.8761
KMKX	Milwaukee/Dousman, WI	42.9678	-88.5506
KMLB	Melbourne, FL	28.1133	-80.6542
KMOB	Mobile, AL	30.6794	-88.2397
KMUX	San Francisco Bay Area/Santa, CA	37.1553	-121.898
KMVX	Eastern North Dakota/Mayville, ND	47.5278	-97.3256

Site ID	Site Name	Latitude (N)	Longitude (E)
KNQA	Memphis/Millington, TN	35.3447	-89.8733
KOKX	New York City/Upton, NY	40.8656	-72.8639
KOTX	Spokane, WA	47.6803	-117.627
KPAH	Paducah, KY	37.0683	-88.7719
KRAX	Raleigh/Durham/Clayton, NC	35.6656	-78.4897
KSGF	Springfield, MO	37.2353	-93.4006
KSHV	Shreveport, LA	32.4508	-93.8414
KSRX	Tulsa/Western Arkansas, AR	35.2906	-94.3617
KTBW	Tampa Bay Area/Ruskin, FL	27.7056	-82.4017
KTFX	Great Falls, MT	47.4597	-111.385
KTLH	Tallahassee, FL	30.3975	-84.3289
KTLX	Oklahoma City/Norman, OK	35.3331	-97.2778
KTWX	Topeka/Alma, KS	38.9969	-96.2325
KTYX	Montague/Fort Drum, NY	43.7558	-75.68
KVTX	Los Angeles/Ventura County, CA	34.4117	-119.179
KWAJ (KPOL)	*Kwajalein, Marshall Islands*	*8.71796*	*167.733*
KYUX	Phoenix/Yuma, AZ	32.4953	-114.657
PAIH	Anchorage/Middleton Island, AK	59.4614	-146.303

1.5 The "100-in-100" Criterion

In all cases, data products generated by the VN adhere to the "100-in-100" criterion. That is, event files described in subsequent sections of this document have 100 or more gridpoints indicating "Rain_Certain," as defined by the GPM DPR 2A-Ku product, that fall within 100 km of a ground radar. For this purpose, selected 2A-Ku variables are analyzed to temporary 4-km-resolution grids of 300x300 km extent, one centered on each GR site overpassed in a given orbit. Metadata concerning the precipitation and DPR/GR overlap statuses of each overpass event are computed from the temporary grids and stored in the GPM GV database, which can be queried to determine which events meet the "100-in-100" criterion, or other user-defined criteria. Matched-up DPR and GR data products and GMI and GR data products in the form of netCDF files are generated and stored on the VN ftp directory **`data/gpmgv/netCDF/geomatch/`** for any event that meets the DPR 100-in-100 criterion (see Section 4 for a complete description of the VN ftp directory structure and file naming conventions).

The VN's internal database actually stores GPM DPR, DPRGMI and GMI, TRMM PR and TMI, and ground radar data for *all* coincident events where the TRMM or GPM passes within 200 km of the ground radar, whether it is raining or not. Ground radar data are stored in the **`data/gpmgv/gv_radar`** directory and GPM and TRMM data are stored in the **`data/gpmgv/orbit_subsets`** directory of the VN ftp site. See Section 4 for a complete description of the VN ftp directory structure and file-naming conventions.

1.6 Validation Network data product netCDF format

The DPR-GR, DPRGMI-GR, and GMI-GR geometry match data products are formatted according to the network Common Data Format (netCDF) standard. The netCDF is maintained by the Unidata Program of the University Corporation for Atmospheric Research (UCAR). More information on netCDF can be found on the Unidata website:

`http://www.unidata.ucar.edu/software/netcdf`

There are three basic components of the netCDF files termed *attributes, dimensions* and *variables*, which are described briefly below.

Attributes contain auxiliary information about each netCDF *variable*. Each *attribute* has a name, data type and length associated with it. netCDF also permits the definition of *global attributes*, which typically apply to the data set as a whole, rather than to individual variables in the data. The PR-GR netCDF matchup files contain seven *global attributes*, and the GMI-GR netCDF matchup files contain four.

Dimensions are named integers that are use to specify the size (dimensionality) of one or more *variables*.

Variables are scalars or multidimensional arrays of values of the same data type. Each *variable* has a size, type and name associated with it. *Variables* also typically have *attributes* that describe them.

2. Geometry-Matched Data Products

2.1 Archive site directory

As previously described in Section 1.1, VN match-up data are available via anonymous ftp from:

`ftp://hector.gsfc.nasa.gov/gpm-validation/data/gpmgv`

Data from the geometry-matching techniques are located under the subdirectory **`netcdf/geo_match`**. The geometry-matching technique allows for comparison of actual space and ground network measurements (i.e., data are **not** resampled in 3 dimensions). This method has replaced the heritage gridding technique, which is no longer used as a primary VN data comparison method.

2.2 File Name Convention

Geometry matching data in the **`netcdf/geo_match`** directory are stored as netCDF gzip-ped files by site (4-letter site ID, see Table 1-1), event date, and orbit number (see Section 4). The data volume of each file varies depending on the numbers of GR sweep elevations and DPR/GR "overlap" points in each file, but files of 10 to 100 or more MByte are typical (larger for DPRGMI matchup files due to the inclusion of all scan types in the 2B-DPRGMI file).

The site-specific gzip file unpacks to a netCDF-format file identifiable by matchup GPM data type (DPR, DPRGMI, or GMI), GR site, date, GPM orbit number, product version, DPR 2A data type (DPR, KA, or KU), DPR swath type used (HS, MS, or NS) and geometry match file version according to the file naming conventions:

`GRtoDPR.SHORTNAME.YYMMDD.ORBIT.Vnnv.TT.SS.F_f.nc.gz`

`GRtoDPR.SHORTNAME.YYMMDD.ORBIT.Vnnv.TT.SS.F_f.RHI.nc.gz`

`GRtoDPRGMI.SHORTNAME.YYMMDD.ORBIT.Vnnv.F_f.nc.gz`

`GRtoGMI.SHORTNAME.YYMMDD.ORBIT.Vnnv.F_f.nc.gz`

where:

GRtoXXX	= matchup type, literally either GRtoDPR or GRtoGMI
SHORTNAME	= GR site identifier (see Table 1-1)
YY	= 2-digit year
MM	= 2-digit month
DD	= 2-digit day (in UTM)
ORBITNUMBER	= GPM orbit number
Vnnv	= GPM product algorithm major (nn) and minor (v) version,

	beginning with literal "V" character, e.g., V02B
`TT`	= DPR 2A data type (DPR, KA, or KU). Field does not apply to GRtoGMI or GRtoDPRGMI matchup filenames
`SS`	= type of swath used in the GR-DPR matchup (HS, MS, or NS). N/A to GRtoGMI and GRtoDPRGMI matchup filenames
`F_f`	= Geometry match file Major/minor file version indicator, e.g. 2_1 for version 2.1 matchup file
`RHI`	Literal "RHI" to indicate that the GR data used in the matchup are from a Range-Height Indicator (RHI) vertical sweep volume scan rather than the usual Plan Position Indicator (PPI) horizontal sweep volume scan
`.nc`	Literal ".nc" characters indicating a netCDF file format
`.gz`	Literal ".gz", only present if the file is compressed using *gzip*

The .nc designation indicates that the files are in the netCDF format. The .gz extension, if present, indicates that the file is compressed using the gzip utility.

Each GRtoDPR file type includes GPM DPR and ground radar data stored in netCDF format as described in Section 3 of this document. DPR reflectivity and rain rate profile data are obtained from the standard Level 2A GPM DPR products. A surface type flag, near-surface rain rate, bright band height, rain type, rain/no-rain flag and other variables are also included from these DPR products. See the geometry-match netCDF file summary in Section 3.

Each GRtoDPR matchup file uses DPR data from only one of the available scan types (stored in the 2A HDF5 files as separate "swaths") of data present in the Level 2A DPR product. The 2A-DPR contains all three of the swath types: high-resolution scan (HS), matched scan (MS), and normal scan (NS). The 2A-KA contains HS and MS swaths, and the 2A-KU contains only the NS swath. In contrast, the GRtoDPRGMI file contains volume-matched data for all instrument/swath combinations present in the 2B-DPRGMI dataset.

Ground radar data included in these files are normally derived from the horizontal-sweep-scanning (PPI) radar data that has been quality-controlled and processed into an intermediate 1C-UF product data file in Universal Format (UF). An alternate matchup method for the GRtoDPR product uses vertically-scanned (RHI) data from the ground radar in the UF format. The output GRtoDPR netCDF file format is the same for either type of GR scan.

Geometry matchup of the DPR and ground radar data is performed using methods based on those described by Bolen and Chandrasekar[1]. Matchup of ghe DPRGMI and ground radar data follows an identical method. Matchup of the GMI and ground radar data uses a similar approach to the DPR matchups, with modifications for the GMI viewing geometry. See Section 5 for algorithm details.

2.3 DPR-GR Geometry Matching Data Characteristics

The single- and multi-level spatial data fields in the geometry match data are not at fixed locations. Their horizontal locations are defined by the location of the DPR rays within the DPR scans. The number of DPR rays whose data are included in the product depends on the number of rays whose surface location is within 100 km (by default -- range is configurable) of the corresponding ground radar location. The vertical locations of the data points are defined by the intersections of the DPR ray with each of the elevation sweeps of the ground radar. See Figure 2-1 for an illustration of the intersection of DPR footprints with GR echoes. The DPRGMI geometry is essentially the same as the DPR geometry, so these descriptions apply to both datasets.

The multi-level, spatial data variables are stored as 2-D arrays in the geo-match products, with dimensions of [elevationAngle, fpdim], where elevationAngle is the number of elevation sweeps (or elevation steps in the cae of an RHI scan) in the ground radar volume scan, and fpdim is the number of DPR rays (footprints) within the 100 km of the ground radar location. The variables holding the x- and y-locations of the four corners of the DPR footprints (used only for plotting the data as images) with the additional dimension 'xydim', and the variable 'GR_HID' for GR hydrometeor type with the additional dimension 'hidim' are the only multi-level variables in the file requiring 3 dimensions.

The single-level, spatial data variables stored as 2-D (ray,scan) fields in the satellite data products are stored as 1-D arrays in the geo-match products, with dimension of [fpdim]. Each single-level and multi-level "science" variable has an associated scalar 'flag' variable (e.g., have_TypePrecip) that indicates whether the variable is populated with actual values (flag = 1) or is just initialized with "Fill" values (flag = 0).

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1 Bolen, S.M. and V. Chandrasekar. 2003. Methodology for aligning and comparing spaceborne radar and ground-based radar observations. Journal of Atmospheric and Oceanic Technology 20:647-659.

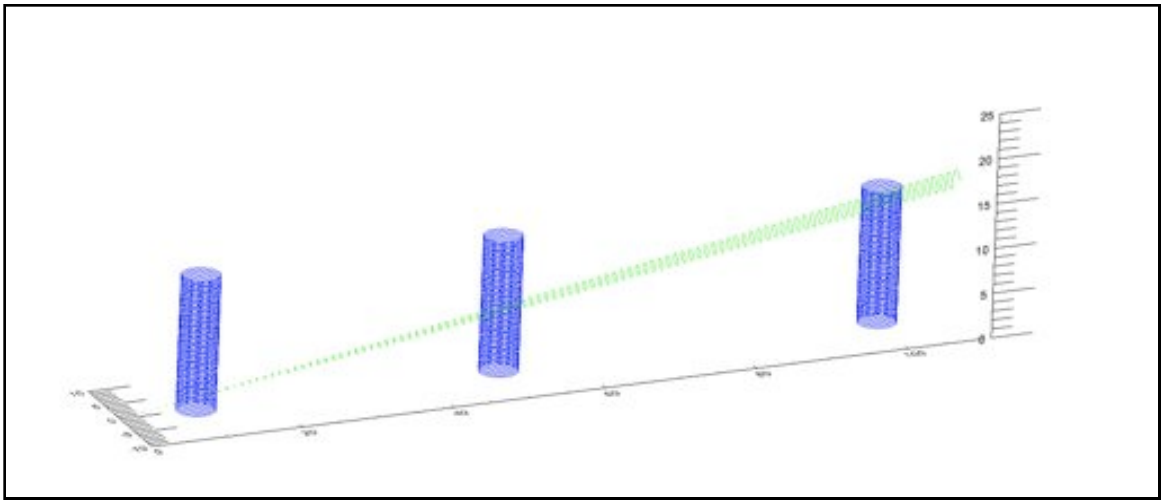

Figure 2-1. An illustration of the intersection between Ground Radar sweeps and Precipitation Radar footprints. Only a select number of radar echoes are illustrated in either case.

Since the horizontal and vertical positions of each data point in the geometry matching data set are essentially random, each data value of the spatial data variables has a set of associated horizontal and (for the multi-level variables) vertical position variables. All points have both a latitude and a longitude value, corrected for viewing angle in the case of the multi-level variables. The multi-level variables also have associated variables specifying the x- and y-corners of the DPR footprint **for data plotting purposes** (in km, relative to a Cartesian coordinate system centered at the location of the ground radar, with the +y axis pointing due north), and the top and bottom height of the ground radar elevation sweep at the DPR ray intersection point, in km above the surface. A summary is provided in Section 3 of this document of all *dimensions, attributes,* and *variables* in the Geometry Matching netCDF files.

2.4 The "expected/rejected" Matchup Variables

One set of DPR-GR geometry match variables in the netCDF files is concerned with the coincidence of ground radar (GR) and satellite precipitation radar (DPR) range gates. These variables provide a metric that can be used to assess the "goodness" of the matchup between the radars. These "expected/rejected" variables are described in some detail below, because their content and meaning may otherwise be difficult to understand. As for the other geometry matchup variables, valid values for categorical variables are listed in Section 3 of this document. The meaning of all other variables can be deduced from the complete list of the geometry matchup variables and their associated units, which can also be found in Section 3 of this document.

For a given DPR ray, several GR range gates and rays will typically intersect several PR range gates, as illustrated in vertical cross section in Figure 2-1, above. The geometry matching algorithm converts DPR and GR dBZ to Z, and then vertically averages Z values for all DPR range gates within the vertical extent (defined by the GR beam width and range from the radar) of a GR elevation scan for those areas where a GR elevation sweep intersects a DPR ray (Fig. 2.2). In contrast, GR data are averaged only in the horizontal in the area surrounding the matched DPR field-of-view for each DPR ray, treating each GR sweep as a separate entity, as shown in Figure 2-3.

Only those gates at or above a specified reflectivity or rain rate threshold are included in the DPR and GR gate averages (variables DPR_dBZ_min, GR_dBZ_min, and rain_min). The VN algorithm calculates the number of DPR and GR gates expected (from a strictly geometric standpoint) and rejected (below the applicable measurement threshold) in generating these averages and stores them in netCDF variables as defined below.

- GR reflectivity: n_gr_expected, n_gr_rejected
- DPR uncorrected reflectivity: n_dpr_expected, n_dpr_meas_z_rejected
- DPR corrected reflectivity: n_dpr_expected, n_dpr_corr_z_rejected.

The effects of non-uniform beam filling can be minimized in cases where the number of rejected gates is zero in both of the GR and DPR match-up volumes, and where the standard deviation of GR reflectivity (GR_Z_StdDev variable in netCDF matchup file) is low. Use of the DPR-GR expected/rejected variables and cutoff thresholds and their effects on the reflectivity comparisons results is presented in detail in Appendix 1.

Only the GR expected/rejected variables are included in the GMI-GR matchup data, as there is no averaging of GMI data in the volume matching. In the GMI matching algorithm, the quasi-vertical DPR ray boundaries shown in Figs. 2-2 and 2-3 would be replaced with the highly sloping GMI line-of-sight from the satellite to the surface footprint for purposes of determining the GR intersections with the GMI. In addition to the line-of-sight matchups, GR data are also averaged along a vertical column above the GMI surface footprint, resulting in a second set of GR volume average and expected/rejected matchup variables in the GMI-GR data files.

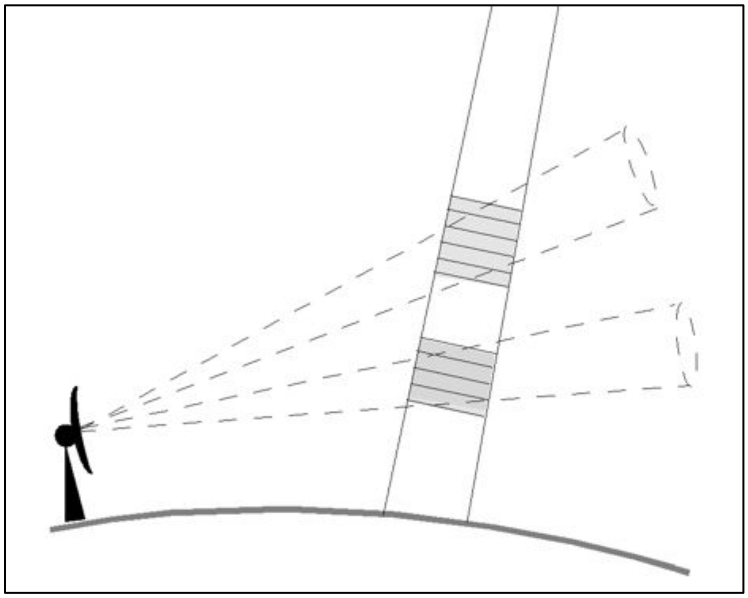

Figure 2-2. Schematic of DPR gate averaging at GR sweep intersections. Shaded areas show individual DPR gates intersecting the vertical extent of two GR sweeps (dashed) at different elevation angles. Only one DPR ray is shown. The reflectivity values of the individual DPR gates are averaged over the vertical extent of the GR sweeps, resulting (in this example) in two matching volumes.

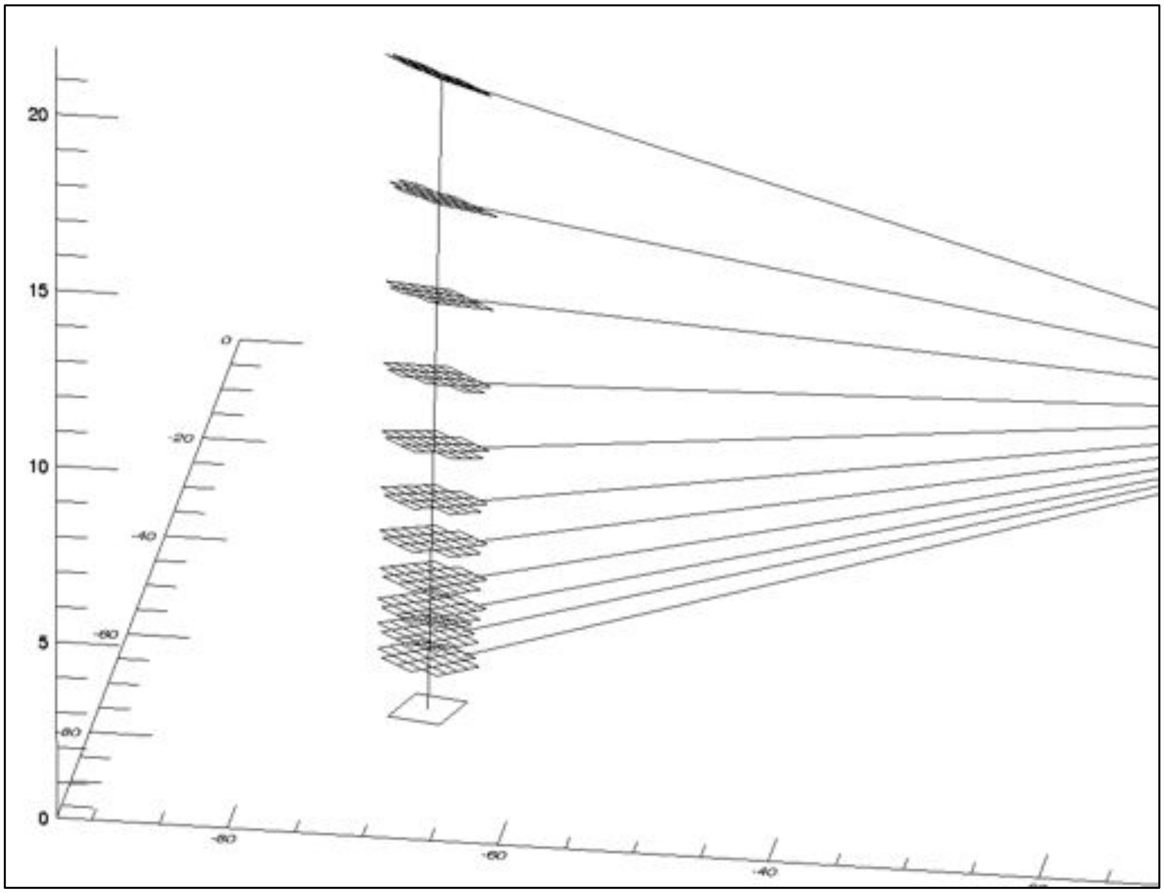

Figure 2-3. Schematic representation of GR volume matching to DPR. Square outline at surface, plotted from the x- and y-corners of the DPR footprint stored in the matchup netCDF file, shows the earth-surface location of a single DPR ray whose centerline is shown as a vertical line. The "waffle" areas show the horizontal outline of GR gates mapped to the DPR ray for each individual elevation sweep of the ground radar, which is located off the right side of the figure at X=0, Y=0, where X, Y, and Z are in km. Sloping lines are drawn between the GR sample volumes and the ground radar along the GR sweep surfaces. GR range gates are inverse-distance-weighted from the DPR ray centerline to compute the GR averages for the matching volumes. Vertical extent and overlap of the GR gates is not shown. GR azimuth/range resolution is 1° by 1 km in the plot.

3. Summary of the Geometry Match netCDF files

Geometry matching netCDF data files are formatted with 6 dimensions: 4 for data arrays, and 2 for character variables. There are 93 regular variables and 15 global attributes in the DPR-GR matchup files, and 114 regular variables and 11 global attributes in the GMI-GR matchup files. The two types of matchup files are described in detail in Sections 3.1 and 3.2, below.

3.1 DPR-GR Geometry Match netCDF file description

The format and content of the GRtoDPR-type Geometry Match netCDF file is presented below, in the form of partial netCDF file creation instructions. The values for dimensions having a fixed size for all files are specified, while those for dimensions which vary on a file by file basis by site overpass event (fpdim and elevationAngle) are left unspecified. Note that the fill values for non-int variables have a type indicator appended to the numerical value, e.g. -888.f for a FLOAT fill value, 1s for a SHORT integer fill value. The global attributes DPR_Version, DPR_Scantype, DPR_2AKU_file and GR_file have been assigned values based on a real 2A-Ku matchup for purposes of the example. A different GV_UF_Z_field value (depends on the type of GR radar site) would result if a different data field is used as the source of reflectivity data from the GR data file used as input to the geometry matching application. Other GV_UF_xxx_field global variables for GR dual-polarization derived fields (Zdr, Kdp, etc.) are left at their default values.

Table 3.1-1 summarizes the name, type, dimension, and special values (e.g., Missing Data) associated with each "science" and geolocation array variable in the GRtoDPR-type geo-match netCDF files. Table 3.1-2 provides the definitions of the values of categorical variables.

```
dimensions:
	fpdim = ;
	elevationAngle = ;
	xydim = 4 ;
	hidim = 15 ;
	len_atime_ID = 19 ;
	len_site_ID = 4 ;
variables:
	float elevationAngle(elevationAngle) ;
```

```
        elevationAngle:long_name = "Radar Sweep Elevation Angles" ;
        elevationAngle:units = "degrees" ;
    int numScans ;
        numScans:long_name = "Number of DPR scans in original datasets" ;
        numScans:_FillValue = -888 ;
    short numRays ;
        numRays:long_name = "Number of DPR rays per scan in original datasets" ;
        numRays:_FillValue = -888s ;
    float rangeThreshold ;
        rangeThreshold:long_name = "Dataset maximum range from radar site" ;
        rangeThreshold:_FillValue = -888.f ;
        rangeThreshold:units = "km" ;
    float DPR_dBZ_min ;
        DPR_dBZ_min:long_name = "minimum DPR bin dBZ required for a *complete* DPR vertical average" ;
        DPR_dBZ_min:_FillValue = -888.f ;
        DPR_dBZ_min:units = "dBZ" ;
    float GR_dBZ_min ;
        GR_dBZ_min:long_name = "minimum GR bin dBZ required for a *complete* GR horizontal average" ;
        GR_dBZ_min:_FillValue = -888.f ;
        GR_dBZ_min:units = "dBZ" ;
    float rain_min ;
        rain_min:long_name = "minimum DPR rainrate required for a *complete* DPR vertical average" ;
        rain_min:_FillValue = -888.f ;
        rain_min:units = "mm/h" ;
    short have_GR_Z ;
        have_GR_Z:long_name = "data exists flag for GR_Z" ;
        have_GR_Z:_FillValue = 0s ;
    short have_GR_Zdr ;
        have_GR_Zdr:long_name = "data exists flag for GR_Zdr" ;
        have_GR_Zdr:_FillValue = 0s ;
    short have_GR_Kdp ;
```

```
        have_GR_Kdp:long_name = "data exists flag for GR_Kdp" ;
        have_GR_Kdp:_FillValue = 0s ;
    short have_GR_RHOhv ;
        have_GR_RHOhv:long_name = "data exists flag for GR_RHOhv" ;
        have_GR_RHOhv:_FillValue = 0s ;
    short have_GR_rainrate ;
        have_GR_rainrate:long_name = "data exists flag for GR_rainrate" ;
        have_GR_rainrate:_FillValue = 0s ;
    short have_GR_HID ;
        have_GR_HID:long_name = "data exists flag for GR_HID" ;
        have_GR_HID:_FillValue = 0s ;
    short have_GR_Dzero ;
        have_GR_Dzero:long_name = "data exists flag for GR_Dzero" ;
        have_GR_Dzero:_FillValue = 0s ;
    short have_GR_Nw ;
        have_GR_Nw:long_name = "data exists flag for GR_Nw" ;
        have_GR_Nw:_FillValue = 0s ;
    short have_ZFactorMeasured ;
        have_ZFactorMeasured:long_name = "data exists flag for ZFactorMeasured" ;
        have_ZFactorMeasured:_FillValue = 0s ;
    short have_ZFactorCorrected ;
        have_ZFactorCorrected:long_name = "data exists flag for ZFactorCorrected" ;
        have_ZFactorCorrected:_FillValue = 0s ;
    short have_paramDSD ;
        have_paramDSD:long_name = "data exists flag for paramDSD variables (Dm and Nw)" ;
        have_paramDSD:_FillValue = 0s ;
    short have_PrecipRate ;
        have_PrecipRate:long_name = "data exists flag for PrecipRate" ;
        have_PrecipRate:_FillValue = 0s ;
    short have_LandSurfaceType ;
        have_LandSurfaceType:long_name = "data exists flag for LandSurfaceType" ;
```

```
        have_LandSurfaceType:_FillValue = 0s ;
    short have_PrecipRateSurface ;
        have_PrecipRateSurface:long_name = "data exists flag for PrecipRateSurface" ;
        have_PrecipRateSurface:_FillValue = 0s ;
    short have_SurfPrecipTotRate ;
        have_SurfPrecipTotRate:long_name = "data exists flag for SurfPrecipTotRate" ;
        have_SurfPrecipTotRate:_FillValue = 0s ;
    short have_BBheight ;
        have_BBheight:long_name = "data exists flag for BBheight" ;
        have_BBheight:_FillValue = 0s ;
    short have_BBstatus ;
        have_BBstatus:long_name = "data exists flag for BBstatus" ;
        have_BBstatus:_FillValue = 0s ;
    short have_qualityData ;
        have_qualityData:long_name = "data exists flag for qualityData" ;
        have_qualityData:_FillValue = 0s ;
    short have_FlagPrecip ;
        have_FlagPrecip:long_name = "data exists flag for FlagPrecip" ;
        have_FlagPrecip:_FillValue = 0s ;
    short have_TypePrecip ;
        have_TypePrecip:long_name = "data exists flag for TypePrecip" ;
        have_TypePrecip:_FillValue = 0s ;
    short have_clutterStatus ;
        have_clutterStatus:long_name = "data exists flag for clutterStatus" ;
        have_clutterStatus:_FillValue = 0s ;
    float latitude(elevationAngle, fpdim) ;
        latitude:long_name = "Latitude of data sample" ;
        latitude:units = "degrees North" ;
        latitude:_FillValue = -888.f ;
    float longitude(elevationAngle, fpdim) ;
        longitude:long_name = "Longitude of data sample" ;
```

```
        longitude:units = "degrees East" ;
        longitude:_FillValue = -888.f ;
    float xCorners(elevationAngle, fpdim, xydim) ;
        xCorners:long_name = "data sample x corner coords." ;
        xCorners:units = "km" ;
        xCorners:_FillValue = -888.f ;
    float yCorners(elevationAngle, fpdim, xydim) ;
        yCorners:long_name = "data sample y corner coords." ;
        yCorners:units = "km" ;
        yCorners:_FillValue = -888.f ;
    float topHeight(elevationAngle, fpdim) ;
        topHeight:long_name = "data sample top height AGL" ;
        topHeight:units = "km" ;
        topHeight:_FillValue = -888.f ;
    float bottomHeight(elevationAngle, fpdim) ;
        bottomHeight:long_name = "data sample bottom height AGL" ;
        bottomHeight:units = "km" ;
        bottomHeight:_FillValue = -888.f ;
    float GR_Z(elevationAngle, fpdim) ;
        GR_Z:long_name = "GV radar QC Reflectivity" ;
        GR_Z:units = "dBZ" ;
        GR_Z:_FillValue = -888.f ;
    float GR_Z_StdDev(elevationAngle, fpdim) ;
        GR_Z_StdDev:long_name = "Standard Deviation of GV radar QC Reflectivity" ;
        GR_Z_StdDev:units = "dBZ" ;
        GR_Z_StdDev:_FillValue = -888.f ;
    float GR_Z_Max(elevationAngle, fpdim) ;
        GR_Z_Max:long_name = "Sample Maximum GV radar QC Reflectivity" ;
        GR_Z_Max:units = "dBZ" ;
        GR_Z_Max:_FillValue = -888.f ;
    float GR_Zdr(elevationAngle, fpdim) ;
```

```
        GR_Zdr:long_name = "DP Differential Reflectivity" ;
        GR_Zdr:units = "dB" ;
        GR_Zdr:_FillValue = -888.f ;
    float GR_Zdr_StdDev(elevationAngle, fpdim) ;
        GR_Zdr_StdDev:long_name = "Standard Deviation of DP Differential Reflectivity" ;
        GR_Zdr_StdDev:units = "dB" ;
        GR_Zdr_StdDev:_FillValue = -888.f ;
    float GR_Zdr_Max(elevationAngle, fpdim) ;
        GR_Zdr_Max:long_name = "Sample Maximum DP Differential Reflectivity" ;
        GR_Zdr_Max:units = "dB" ;
        GR_Zdr_Max:_FillValue = -888.f ;
    float GR_Kdp(elevationAngle, fpdim) ;
        GR_Kdp:long_name = "DP Specific Differential Phase" ;
        GR_Kdp:units = "deg/km" ;
        GR_Kdp:_FillValue = -888.f ;
    float GR_Kdp_StdDev(elevationAngle, fpdim) ;
        GR_Kdp_StdDev:long_name = "Standard Deviation of DP Specific Differential Phase" ;
        GR_Kdp_StdDev:units = "deg/km" ;
        GR_Kdp_StdDev:_FillValue = -888.f ;
    float GR_Kdp_Max(elevationAngle, fpdim) ;
        GR_Kdp_Max:long_name = "Sample Maximum DP Specific Differential Phase" ;
        GR_Kdp_Max:units = "deg/km" ;
        GR_Kdp_Max:_FillValue = -888.f ;
    float GR_RHOhv(elevationAngle, fpdim) ;
        GR_RHOhv:long_name = "DP Co-Polar Correlation Coefficient" ;
        GR_RHOhv:units = "Dimensionless" ;
        GR_RHOhv:_FillValue = -888.f ;
    float GR_RHOhv_StdDev(elevationAngle, fpdim) ;
        GR_RHOhv_StdDev:long_name = "Standard Deviation of DP Co-Polar Correlation Coefficient" ;
        GR_RHOhv_StdDev:units = "Dimensionless" ;
        GR_RHOhv_StdDev:_FillValue = -888.f ;
```

```
float GR_RHOhv_Max(elevationAngle, fpdim) ;
        GR_RHOhv_Max:long_name = "Sample Maximum DP Co-Polar Correlation Coefficient" ;
        GR_RHOhv_Max:units = "Dimensionless" ;
        GR_RHOhv_Max:_FillValue = -888.f ;
float GR_rainrate(elevationAngle, fpdim) ;
        GR_rainrate:long_name = "GV radar DP Rainrate" ;
        GR_rainrate:units = "mm/h" ;
        GR_rainrate:_FillValue = -888.f ;
float GR_rainrate_StdDev(elevationAngle, fpdim) ;
        GR_rainrate_StdDev:long_name = "Standard Deviation of GV radar DP Rainrate" ;
        GR_rainrate_StdDev:units = "mm/h" ;
        GR_rainrate_StdDev:_FillValue = -888.f ;
float GR_rainrate_Max(elevationAngle, fpdim) ;
        GR_rainrate_Max:long_name = "Sample Maximum GV radar DP Rainrate" ;
        GR_rainrate_Max:units = "mm/h" ;
        GR_rainrate_Max:_FillValue = -888.f ;
short GR_HID(elevationAngle, fpdim, hidim) ;
        GR_HID:long_name = "DP Hydrometeor Identification" ;
        GR_HID:units = "Categorical" ;
        GR_HID:_FillValue = -888s ;
float GR_Dzero(elevationAngle, fpdim) ;
        GR_Dzero:long_name = "DP Median Volume Diameter" ;
        GR_Dzero:units = "mm" ;
        GR_Dzero:_FillValue = -888.f ;
float GR_Dzero_StdDev(elevationAngle, fpdim) ;
        GR_Dzero_StdDev:long_name = "Standard Deviation of DP Median Volume Diameter" ;
        GR_Dzero_StdDev:units = "mm" ;
        GR_Dzero_StdDev:_FillValue = -888.f ;
float GR_Dzero_Max(elevationAngle, fpdim) ;
        GR_Dzero_Max:long_name = "Sample Maximum DP Median Volume Diameter" ;
        GR_Dzero_Max:units = "mm" ;
```

```
        GR_Dzero_Max:_FillValue = -888.f ;
    float GR_Nw(elevationAngle, fpdim) ;
        GR_Nw:long_name = "DP Normalized Intercept Parameter" ;
        GR_Nw:units = "1/(mm*m^3)" ;
        GR_Nw:_FillValue = -888.f ;
    float GR_Nw_StdDev(elevationAngle, fpdim) ;
        GR_Nw_StdDev:long_name = "Standard Deviation of DP Normalized Intercept Parameter" ;
        GR_Nw_StdDev:units = "1/(mm*m^3)" ;
        GR_Nw_StdDev:_FillValue = -888.f ;
    float GR_Nw_Max(elevationAngle, fpdim) ;
        GR_Nw_Max:long_name = "Sample Maximum DP Normalized Intercept Parameter" ;
        GR_Nw_Max:units = "1/(mm*m^3)" ;
        GR_Nw_Max:_FillValue = -888.f ;
    float ZFactorMeasured(elevationAngle, fpdim) ;
        ZFactorMeasured:long_name = "DPR Uncorrected Reflectivity" ;
        ZFactorMeasured:units = "dBZ" ;
        ZFactorMeasured:_FillValue = -888.f ;
    float ZFactorCorrected(elevationAngle, fpdim) ;
        ZFactorCorrected:long_name = "DPR Attenuation-corrected Reflectivity" ;
        ZFactorCorrected:units = "dBZ" ;
        ZFactorCorrected:_FillValue = -888.f ;
    float PrecipRate(elevationAngle, fpdim) ;
        PrecipRate:long_name = "DPR Estimated Rain Rate Profile" ;
        PrecipRate:units = "mm/h" ;
        PrecipRate:_FillValue = -888.f ;
    float Dm(elevationAngle, fpdim) ;
        Dm:long_name = "DPR Dm from paramDSD" ;
        Dm:units = "mm" ;
        Dm:_FillValue = -888.f ;
    float Nw(elevationAngle, fpdim) ;
        Nw:long_name = "DPR Nw from paramDSD" ;
```

```
        Nw:units = "dB 1/(mm*m^3)" ;
        Nw:_FillValue = -888.f ;
    short clutterStatus(elevationAngle, fpdim) ;
        clutterStatus:long_name = "Clutter region sample adjustment status" ;
        clutterStatus:units = "Categorical" ;
        clutterStatus:_FillValue = -888s ;
    short n_gr_z_rejected(elevationAngle, fpdim) ;
        n_gr_z_rejected:long_name = "number of bins below GR_dBZ_min in GR_Z average" ;
        n_gr_z_rejected:_FillValue = -888s ;
    short n_gr_zdr_rejected(elevationAngle, fpdim) ;
        n_gr_zdr_rejected:long_name = "number of bins with missing Zdr in GR_Zdr average" ;
        n_gr_zdr_rejected:_FillValue = -888s ;
    short n_gr_kdp_rejected(elevationAngle, fpdim) ;
        n_gr_kdp_rejected:long_name = "number of bins with missing Kdp in GR_Kdp average" ;
        n_gr_kdp_rejected:_FillValue = -888s ;
    short n_gr_rhohv_rejected(elevationAngle, fpdim) ;
        n_gr_rhohv_rejected:long_name = "number of bins with missing RHOhv in GR_RHOhv average" ;
        n_gr_rhohv_rejected:_FillValue = -888s ;
    short n_gr_rr_rejected(elevationAngle, fpdim) ;
        n_gr_rr_rejected:long_name = "number of bins below rain_min in GR_rainrate average" ;
        n_gr_rr_rejected:_FillValue = -888s ;
    short n_gr_hid_rejected(elevationAngle, fpdim) ;
        n_gr_hid_rejected:long_name = "number of bins with undefined HID in GR_HID histogram" ;
        n_gr_hid_rejected:_FillValue = -888s ;
    short n_gr_dzero_rejected(elevationAngle, fpdim) ;
        n_gr_dzero_rejected:long_name = "number of bins with missing D0 in GR_Dzero average" ;
        n_gr_dzero_rejected:_FillValue = -888s ;
    short n_gr_nw_rejected(elevationAngle, fpdim) ;
        n_gr_nw_rejected:long_name = "number of bins with missing Nw in GR_Nw average" ;
        n_gr_nw_rejected:_FillValue = -888s ;
    short n_gr_expected(elevationAngle, fpdim) ;
```

```
        n_gr_expected:long_name = "number of bins in GR_Z average" ;
        n_gr_expected:_FillValue = -888s ;
short n_dpr_meas_z_rejected(elevationAngle, fpdim) ;
        n_dpr_meas_z_rejected:long_name = "number of bins below DPR_dBZ_min in ZFactorMeasured average" ;
        n_dpr_meas_z_rejected:_FillValue = -888s ;
short n_dpr_corr_z_rejected(elevationAngle, fpdim) ;
        n_dpr_corr_z_rejected:long_name = "number of bins below DPR_dBZ_min in ZFactorCorrected average" ;
        n_dpr_corr_z_rejected:_FillValue = -888s ;
short n_dpr_corr_r_rejected(elevationAngle, fpdim) ;
        n_dpr_corr_r_rejected:long_name = "number of bins below rain_min in PrecipRate average" ;
        n_dpr_corr_r_rejected:_FillValue = -888s ;
short n_dpr_dm_rejected(elevationAngle, fpdim) ;
        n_dpr_dm_rejected:long_name = "number of bins with missing Dm in DPR Dm average" ;
        n_dpr_dm_rejected:_FillValue = -888s ;
short n_dpr_nw_rejected(elevationAngle, fpdim) ;
        n_dpr_nw_rejected:long_name = "number of bins with missing Nw in DPR Nw average" ;
        n_dpr_nw_rejected:_FillValue = -888s ;
short n_dpr_expected(elevationAngle, fpdim) ;
        n_dpr_expected:long_name = "number of bins in DPR averages" ;
        n_dpr_expected:_FillValue = -888s ;
float DPRlatitude(fpdim) ;
        DPRlatitude:long_name = "Latitude of DPR surface bin" ;
        DPRlatitude:units = "degrees North" ;
        DPRlatitude:_FillValue = -888.f ;
float DPRlongitude(fpdim) ;
        DPRlongitude:long_name = "Longitude of DPR surface bin" ;
        DPRlongitude:units = "degrees East" ;
        DPRlongitude:_FillValue = -888.f ;
short LandSurfaceType(fpdim) ;
        LandSurfaceType:long_name = "DPR LandSurfaceType" ;
        LandSurfaceType:units = "Categorical" ;
```

```
        LandSurfaceType:_FillValue = -888s ;
    float PrecipRateSurface(fpdim) ;
        PrecipRateSurface:long_name = "DPR Near-Surface Precipitation Rate" ;
        PrecipRateSurface:units = "mm/h" ;
        PrecipRateSurface:_FillValue = -888.f ;
    float SurfPrecipTotRate(fpdim) ;
        SurfPrecipTotRate:long_name = "2B-DPRGMI Near-Surface Estimated Rain Rate" ;
        SurfPrecipTotRate:units = "mm/h" ;
        SurfPrecipTotRate:_FillValue = -888.f ;
    float BBheight(fpdim) ;
        BBheight:long_name = "DPR Bright Band Height above MSL" ;
        BBheight:units = "m" ;
        BBheight:_FillValue = -888.f ;
    short BBstatus(fpdim) ;
        BBstatus:long_name = "Bright Band Quality" ;
        BBstatus:units = "Categorical" ;
        BBstatus:_FillValue = -888s ;
    short qualityData(fpdim) ;
        qualityData:long_name = "DPR FLG group qualityData" ;
        qualityData:units = "Categorical" ;
        qualityData:_FillValue = -888s ;
    short FlagPrecip(fpdim) ;
        FlagPrecip:long_name = "DPR FlagPrecip" ;
        FlagPrecip:units = "Categorical" ;
        FlagPrecip:_FillValue = -888s ;
    short TypePrecip(fpdim) ;
        TypePrecip:long_name = "DPR TypePrecip (stratiform/convective/other)" ;
        TypePrecip:units = "Categorical" ;
        TypePrecip:_FillValue = -888s ;
    short scanNum(fpdim) ;
        scanNum:long_name = "product-relative zero-based array index of DPR scan number" ;
```

```
        scanNum:_FillValue = -888s ;
    short rayNum(fpdim) ;
        rayNum:long_name = "product-relative zero-based array index of DPR ray number" ;
        rayNum:_FillValue = -888s ;
    double timeNearestApproach ;
        timeNearestApproach:units = "seconds" ;
        timeNearestApproach:long_name = "Seconds since 01-01-1970 00:00:00" ;
        timeNearestApproach:_FillValue = 0. ;
    char atimeNearestApproach(len_atime_ID) ;
        atimeNearestApproach:long_name = "text version of timeNearestApproach, UTC" ;
    double timeSweepStart(elevationAngle) ;
        timeSweepStart:units = "seconds" ;
        timeSweepStart:long_name = "Seconds since 01-01-1970 00:00:00" ;
        timeSweepStart:_FillValue = 0. ;
    char atimeSweepStart(elevationAngle, len_atime_ID) ;
        atimeSweepStart:long_name = "text version of timeSweepStart, UTC" ;
    char site_ID(len_site_ID) ;
        site_ID:long_name = "ID of Ground Radar Site" ;
    float site_lat ;
        site_lat:long_name = "Latitude of Ground Radar Site" ;
        site_lat:units = "degrees North" ;
        site_lat:_FillValue = -888.f ;
    float site_lon ;
        site_lon:long_name = "Longitude of Ground Radar Site" ;
        site_lon:units = "degrees East" ;
        site_lon:_FillValue = -888.f ;
    float site_elev ;
        site_elev:long_name = "Elevation of Ground Radar Site above MSL" ;
        site_elev:units = "km" ;
    float version ;
        version:long_name = "Geo Match File Version" ;
```

```
// global attributes:
        :DPR_Version = "V01G" ;
        :DPR_ScanType = "NS" ;
        :GV_UF_Z_field = "CZ" ;
        :GV_UF_ZDR_field = "DR" ;
        :GV_UF_KDP_field = "KD" ;
        :GV_UF_RHOHV_field = "RH" ;
        :GV_UF_RR_field = "RR" ;
        :GV_UF_HID_field = "FH" ;
        :GV_UF_D0_field = "D0" ;
        :GV_UF_NW_field = "NW" ;
        :DPR_2ADPR_file = "no_2ADPR_file" ;
        :DPR_2AKU_file = "2A-CS-CONUS.GPM.Ku.V5-20140522.20140601-S200600-E201309.001465.V01G.HDF5" ;
        :DPR_2AKA_file = "no_2AKA_file" ;
        :DPR_2BCMB_file = "no_2BCMB_file" ;
        :GR_file = "KAMX_2014_0601_200509.uf.gz" ;
```

NOTES:

1) The variables **topHeight** and **bottomHeight** are in units of km above ground level (km AGL), while **BBheight** is in units of meters above mean sea level (m above MSL). Assuming all heights are converted to units of km, then the variable **site_elev** (km above MSL) relates "Above MSL" and "AGL": `HeightAGL = HeightMSL - site_elev`

2) Actual values for the dimension variables "**fpdim**" and "**elevationAngle**" must be specified at time of netCDF file creation.

3) Only one of the global variables DPR_2ADPR_file, DPR_2AKU_file, DPR_2AKA_file will have a real file name in a given matchup file, the other variables will be set to their default "no_XXX_file" value. The variable DPR_2BCMB_file will be an actual file name if a 2B-DPRGMI data file is optionally included in the matchup processing for the DPR, Ka, or Ku matchup. Otherwise it takes the default value "no_2BCMB_file" to indicate that no 2B-DPRGMI data was included.

4) GR_HID is not an average, it is an array of values representing a histogram that counts the number of GR range gates in each hydrometeor category (integer HID code), for those GR range gates geometrically matched to the DPR footprint. The first array element is a special element that counts the number of GR range bins where the HID category is MISSING. Array elements 2-12 give the number of GR bins in each HID category: 'UC' (unclassified), 'DZ' (drizzle), 'RN' (rain), 'CR' (ice crystals), 'DS' (dry snow/aggregates), 'WS' (wet snow), 'VI' (vertical ice), 'LDG' (low density graupel), 'HDG' (high density graupel), 'HA' (hail), 'BD' (big drops). Array elements 13-15 are spares at this time.

5) clutterStatus is a code representing the state of the DPR range gates included in the geometry-match sample averages for the multi-level DPR variables. See Table 3.1-2, below.

Table 3.1-1. Variable name, type, dimensions, and interpretation of special data values for science and geolocation variables in DPR-GR Geometry Match netCDF files.

Variable Name(s)	Type	Dimension(s)	Special Value(s)
GR_Z GR_Z_StdDev GR_Z_Max ZFactorMeasured ZFactorCorrected	float	elevationAngle, fpdim	-888.0: Range edge delimiter, Fill Value -777.0: In-range PR scan edge delimiter -9999.0: Missing data -100.0: Below dBZ cutoff value
GR_Zdr GR_Zdr_StdDev GR_Zdr_Max GR_Kdp GR_Kdp_StdDev GR_Kdp_Max GR_RHOhv GR_RHOhv_StdDev GR_RHOhv_Max GR_rainrate GR_rainrate_StdDev GR_rainrate_Max GR_Dzero GR_Dzero_StdDev GR_Dzero_Max GR_Nw GR_Nw_StdDev GR_Nw_Max	float	elevationAngle, fpdim	-888.0: Range edge delimiter, Fill Value -777.0: In-range PR scan edge delimiter -9999.0: Missing data -100.0: Below threshold cutoff value, or all GR bin values are MISSING
GR_HID	short	elevationAngle, fpdim, hidim	-888.0: Range edge delimiter, Fill Value
PrecipRate	float	elevationAngle, fpdim	-888.0: Range edge delimiter, Fill Value -777.0: In-range PR scan edge delimiter -88.88: Below rain rate cutoff threshold
Dm (note 9) Nw (note 9)	float	elevationAngle, fpdim	-888.0: Range edge delimiter, Fill Value -777.0: In-range PR scan edge delimiter -9999.0: Missing data
n_gr_z_rejected n_gr_zdr_rejected n_gr_kdp_rejected n_gr_rhohv_rejected n_gr_rr_rejected n_gr_hid_rejected n_gr_dzero_rejected n_gr_nw_rejected n_gr_expected n_dpr_meas_z_rejected n_dpr_corr_z_rejected n_dpr_corr_r_rejected n_dpr_expected	short	elevationAngle, fpdim	-888: Fill Value

Variable Name(s)	Type	Dimension(s)	Special Value(s)
latitude, longitude, topHeight, bottomHeight	float	elevationAngle, fpdim	-888.0: Fill Value
xCorners, yCorners	float	elevationAngle, fpdim, xydim	-888.0: Fill Value
DPRlatitude, DPRlongitude	float	fpdim	-888.0: Fill Value
LandSurfaceType BBstatus qualityData FlagPrecip TypePrecip	short	fpdim	-888: Range edge delimiter, Fill Value
PrecipRateSurface SurfPrecipTotRate BBheight	float	fpdim	-888.0: Range edge delimiter, Fill Value
scanNum rayNum	int	fpdim	-1: Edge-of-Range indicator -2: In-range PR scan edge indicator
clutterStatus	short	fpdim	None, see Notes, above.
elevationAngle	float	elevationAngle	N/A

Notes on Table 3.1-1:

1. Special Values are values outside of the normal physical range of the data field, and which indicate a special meaning at the data point (e.g., Missing data).
2. Range edge points are the footprints of the nearest PR rays outside of, but immediately adjacent to, the range ring surrounding the ground radar at distance = **rangeThreshold**, for a given PR scan. These points form a partial circle around points for the PR rays within the **rangeThreshold** of the ground radar, where the latter points contain actual data values.
3. PR scan edge points are the footprints of single PR rays extrapolated just beyond either edge of the PR scan, and which fall within or immediately adjacent to the **rangeThreshold** distance from the ground radar.
4. The combination of the Range Edge points and the Scan Edge points serve to completely enclose the in-range PR footprints on the surface: a) defined by each elevation sweep (for multi-level variables), or b) at the earth surface (for single level variables). The purpose of these points is to prevent the extrapolation of "actual" PR data values outside of the in-range area, if the data are later analyzed to a regular grid using an objective analysis technique.
5. Range Edge points and Scan Edge points are indicated by **scanNum** and **rayNum** values of -1 and -2, respectively. **scanNum** and **rayNum** values of 0 or greater are actual array indices of PR rays within the full data arrays in the source PR product files.
6. ***Range and Scan Edge points are optional in the POLAR2DPR program that generates the GR/DPR matchup data and, as a default, are disabled from being computed and output. If the "Mark Edges" parameter's default value is***

overridden, then these types of points will then be computed and output as described above.

7. **Fill Value** is the value to which scalar or array variables in the netCDF file are initialized when the file is created. These values remain in place unless and until the data value is overwritten.
8. The variables **topHeight** and **bottomHeight** represent height above ground level (AGL) (i.e., height above the ground radar) ***in km***, while **BBheight** represents height above mean sea level (MSL; the earth ellipsoid, actually), ***in meters***. The difference between AGL height and MSL height is given by the value of the **site_elev** variable, the height above MSL of the ground radar, in km. To compare **BBheight** to **topHeight** or **bottomHeight**, first convert **BBheight** to km units. Then, either subtract **site_elev** from **BBheight** to work in AGL height units, or add **site_elev** to **topHeight** and **bottomHeight** to work in MSL height units.
9. **Dm** and **Nw** together comprise the **paramDSD** element of the Level 2A DPR products. They are stored as separate variables in the GRtoDPR matchup netCDF files.

Table 3.1-2. Values of categorical variables in the DPR-GR geometry matching technique netCDF files.

Variable	Category definitions
LandSurfaceType	0-99 = Water 100-199 = Land 200-299 = Coast 300-399 = Inland Water -9999 = Missing in DPR product -888 = Point not coincident with PR
typePrecip	Precipitation type, expressed by an 8-digit number. The three major rain categories, stratiform, convective, and other, can be obtained as follows. When typePrecip is greater than zero, then: Major rain type = typePrecip/10000000 where: 1 = stratiform 2 = convective 3 = other Otherwise, if typePrecip < 0 then: No rain = -1111 Missing data = -9999 No data = -888 (not coincident with PR)
FlagPrecip	0 = No Precipitation 1 = Precipitation -9999 = Missing Value in DPR product
BBstatus	The "BBstatus" variable in the netCDF file is an unmodified copy of the "qualityBB" variable in the 2ADPR, 2AKa, or 2AKu file. It indicates the status of the bright band detection. 1 = Good, 0 = BB not detected with rain present -1111 = No-rain value -9999 = Missing

Variable	Category definitions
clutterStatus	clutterStatus is a code representing the state of the DPR range gates included in the geometry-match sample averages for the multi-level DPR variables. It is an internally-computed variable produced as part of the geometry-matching algorithm, unlike the variables above which are simply copies of values present in the DPR data product. For those DPR range gates geometrically matched to a GR elevation sweep for the given DPR ray, the clutterStatus code values 0-2 indicate one of 3 possible situations: 0 = all geometry-matched DPR gates above clutter region, no substitution or truncation 1 = one or more geometry-matched DPR gates below lowest clutter-free gate, DPR average truncated to those in the clutter-free region 2 = all geometry-matched DPR gates below lowest clutter-free gate, average set to value of the lowest DPR clutter-free gate
GR_HID	See NOTES in preceding text box.

3.2 GMI-GR Geometry Match netCDF file description

The format and content of the GRtoGMI-type Geometry Match netCDF file is presented below, in the form of partial netCDF file creation instructions. See Section 3.1 for details related to dimensions and netCDF variable types. Table 3.2-1 summarizes the name, type, dimension, and special values (e.g., Missing Data) associated with each "science" and geolocation array variable in the GRtoGMI-type geometry match netCDF files. While the descriptions are in terms of GR-to-GMI matchups, this same file format also applies to GR-to-GPROF matchup data for any GPM constellation satellite Microwave Imager data (e.g. TRMM/TMI, GCOMW1/AMSR2, F15/SSMIS, F16/SSMIS, F17/SSMIS, F18/SSMIS, METOPA/MHS, NOAA18/MHS, NOAA19/MHS).

```
dimensions:
    fpdim =  ;
    elevationAngle =  ;
    xydim = 4 ;
    hidim = 15 ;
    len_atime_ID = 19 ;
    len_site_ID = 4 ;
variables:
    float elevationAngle(elevationAngle) ;
        elevationAngle:long_name = "Radar Sweep Elevation Angles" ;
        elevationAngle:units = "degrees" ;
    float rangeThreshold ;
        rangeThreshold:long_name = "Dataset maximum range from radar site" ;
        rangeThreshold:_FillValue = -888.f ;
        rangeThreshold:units = "km" ;
    float GR_dBZ_min ;
        GR_dBZ_min:long_name = "minimum GR bin dBZ required for a *complete* GR horizontal average" ;
        GR_dBZ_min:_FillValue = -888.f ;
        GR_dBZ_min:units = "dBZ" ;
    float gprof_rain_min ;
        gprof_rain_min:long_name = "minimum XMI rainrate required" ;
        gprof_rain_min:_FillValue = -888.f ;
        gprof_rain_min:units = "mm/h" ;
```

```
float radiusOfInfluence ;
      radiusOfInfluence:long_name = "Radius of influence for distance weighting of GR bins" ;
      radiusOfInfluence:_FillValue = -888.f ;
      radiusOfInfluence:units = "km" ;
short have_GR_Z_slantPath ;
      have_GR_Z_slantPath:long_name = "data exists flag for GR_Z_slantPath" ;
      have_GR_Z_slantPath:_FillValue = 0s ;
short have_GR_rainrate_slantPath ;
      have_GR_rainrate_slantPath:long_name = "data exists flag for GR_rainrate_slantPath" ;
      have_GR_rainrate_slantPath:_FillValue = 0s ;
short have_GR_Zdr_slantPath ;
      have_GR_Zdr_slantPath:long_name = "data exists flag for GR_Zdr_slantPath" ;
      have_GR_Zdr_slantPath:_FillValue = 0s ;
short have_GR_Kdp_slantPath ;
      have_GR_Kdp_slantPath:long_name = "data exists flag for GR_Kdp_slantPath" ;
      have_GR_Kdp_slantPath:_FillValue = 0s ;
short have_GR_RHOhv_slantPath ;
      have_GR_RHOhv_slantPath:long_name = "data exists flag for GR_RHOhv_slantPath" ;
      have_GR_RHOhv_slantPath:_FillValue = 0s ;
short have_GR_HID_slantPath ;
      have_GR_HID_slantPath:long_name = "data exists flag for GR_HID_slantPath" ;
      have_GR_HID_slantPath:_FillValue = 0s ;
short have_GR_Dzero_slantPath ;
      have_GR_Dzero_slantPath:long_name = "data exists flag for GR_Dzero_slantPath" ;
      have_GR_Dzero_slantPath:_FillValue = 0s ;
short have_GR_Nw_slantPath ;
      have_GR_Nw_slantPath:long_name = "data exists flag for GR_Nw_slantPath" ;
      have_GR_Nw_slantPath:_FillValue = 0s ;
short have_GR_Z_VPR ;
      have_GR_Z_VPR:long_name = "data exists flag for GR_Z_VPR" ;
      have_GR_Z_VPR:_FillValue = 0s ;
short have_GR_rainrate_VPR ;
      have_GR_rainrate_VPR:long_name = "data exists flag for GR_rainrate_VPR" ;
      have_GR_rainrate_VPR:_FillValue = 0s ;
```

```
short have_GR_Zdr_VPR ;
      have_GR_Zdr_VPR:long_name = "data exists flag for GR_Zdr_VPR" ;
      have_GR_Zdr_VPR:_FillValue = 0s ;
short have_GR_Kdp_VPR ;
      have_GR_Kdp_VPR:long_name = "data exists flag for GR_Kdp_VPR" ;
      have_GR_Kdp_VPR:_FillValue = 0s ;
short have_GR_RHOhv_VPR ;
      have_GR_RHOhv_VPR:long_name = "data exists flag for GR_RHOhv_VPR" ;
      have_GR_RHOhv_VPR:_FillValue = 0s ;
short have_GR_HID_VPR ;
      have_GR_HID_VPR:long_name = "data exists flag for GR_HID_VPR" ;
      have_GR_HID_VPR:_FillValue = 0s ;
short have_GR_Dzero_VPR ;
      have_GR_Dzero_VPR:long_name = "data exists flag for GR_Dzero_VPR" ;
      have_GR_Dzero_VPR:_FillValue = 0s ;
short have_GR_Nw_VPR ;
      have_GR_Nw_VPR:long_name = "data exists flag for GR_Nw_VPR" ;
      have_GR_Nw_VPR:_FillValue = 0s ;
short have_surfaceTypeIndex ;
      have_surfaceTypeIndex:long_name = "data exists flag for surfaceTypeIndex" ;
      have_surfaceTypeIndex:_FillValue = 0s ;
short have_surfacePrecipitation ;
      have_surfacePrecipitation:long_name = "data exists flag for surfacePrecipitation" ;
      have_surfacePrecipitation:_FillValue = 0s ;
short have_pixelStatus ;
      have_pixelStatus:long_name = "data exists flag for pixelStatus" ;
      have_pixelStatus:_FillValue = 0s ;
short have_PoP ;
      have_PoP:long_name = "data exists flag for PoP" ;
      have_PoP:_FillValue = 0s ;
float latitude(elevationAngle, fpdim) ;
      latitude:long_name = "Latitude of data sample" ;
      latitude:units = "degrees North" ;
      latitude:_FillValue = -888.f ;
```

```
float longitude(elevationAngle, fpdim) ;
        longitude:long_name = "Longitude of data sample" ;
        longitude:units = "degrees East" ;
        longitude:_FillValue = -888.f ;
float xCorners(elevationAngle, fpdim, xydim) ;
        xCorners:long_name = "data sample x corner coords." ;
        xCorners:units = "km" ;
        xCorners:_FillValue = -888.f ;
float yCorners(elevationAngle, fpdim, xydim) ;
        yCorners:long_name = "data sample y corner coords." ;
        yCorners:units = "km" ;
        yCorners:_FillValue = -888.f ;
float topHeight(elevationAngle, fpdim) ;
        topHeight:long_name = "data sample top height AGL" ;
        topHeight:units = "km" ;
        topHeight:_FillValue = -888.f ;
float bottomHeight(elevationAngle, fpdim) ;
        bottomHeight:long_name = "data sample bottom height AGL" ;
        bottomHeight:units = "km" ;
        bottomHeight:_FillValue = -888.f ;
float topHeight_vpr(elevationAngle, fpdim) ;
        topHeight_vpr:long_name = "data sample top height AGL along local vertical" ;
        topHeight_vpr:units = "km" ;
        topHeight_vpr:_FillValue = -888.f ;
float bottomHeight_vpr(elevationAngle, fpdim) ;
        bottomHeight_vpr:long_name = "data sample bottom height AGL along local vertical" ;
        bottomHeight_vpr:units = "km" ;
        bottomHeight_vpr:_FillValue = -888.f ;
float GR_Z_slantPath(elevationAngle, fpdim) ;
        GR_Z_slantPath:long_name = "GV radar QC Reflectivity" ;
        GR_Z_slantPath:units = "dBZ" ;
        GR_Z_slantPath:_FillValue = -888.f ;
float GR_Z_StdDev_slantPath(elevationAngle, fpdim) ;
        GR_Z_StdDev_slantPath:long_name = "Standard Deviation of GV radar QC Reflectivity" ;
```

```
        GR_Z_StdDev_slantPath:units = "dBZ" ;
        GR_Z_StdDev_slantPath:_FillValue = -888.f ;
    float GR_Z_Max_slantPath(elevationAngle, fpdim) ;
        GR_Z_Max_slantPath:long_name = "Sample Maximum GV radar QC Reflectivity" ;
        GR_Z_Max_slantPath:units = "dBZ" ;
        GR_Z_Max_slantPath:_FillValue = -888.f ;
    float GR_rainrate_slantPath(elevationAngle, fpdim) ;
        GR_rainrate_slantPath:long_name = "GV radar QC Rain Rate" ;
        GR_rainrate_slantPath:units = "dBZ" ;
        GR_rainrate_slantPath:_FillValue = -888.f ;
    float GR_rainrate_StdDev_slantPath(elevationAngle, fpdim) ;
        GR_rainrate_StdDev_slantPath:long_name = "Standard Deviation of GV radar QC Rain Rate" ;
        GR_rainrate_StdDev_slantPath:units = "dBZ" ;
        GR_rainrate_StdDev_slantPath:_FillValue = -888.f ;
    float GR_rainrate_Max_slantPath(elevationAngle, fpdim) ;
        GR_rainrate_Max_slantPath:long_name = "Sample Maximum GV radar QC Rain Rate" ;
        GR_rainrate_Max_slantPath:units = "dBZ" ;
        GR_rainrate_Max_slantPath:_FillValue = -888.f ;
    float GR_Zdr_slantPath(elevationAngle, fpdim) ;
        GR_Zdr_slantPath:long_name = "DP Differential Reflectivity" ;
        GR_Zdr_slantPath:units = "dB" ;
        GR_Zdr_slantPath:_FillValue = -888.f ;
    float GR_Zdr_StdDev_slantPath(elevationAngle, fpdim) ;
        GR_Zdr_StdDev_slantPath:long_name = "Standard Deviation of DP Differential Reflectivity" ;
        GR_Zdr_StdDev_slantPath:units = "dB" ;
        GR_Zdr_StdDev_slantPath:_FillValue = -888.f ;
    float GR_Zdr_Max_slantPath(elevationAngle, fpdim) ;
        GR_Zdr_Max_slantPath:long_name = "Sample Maximum DP Differential Reflectivity" ;
        GR_Zdr_Max_slantPath:units = "dB" ;
        GR_Zdr_Max_slantPath:_FillValue = -888.f ;
    float GR_Kdp_slantPath(elevationAngle, fpdim) ;
        GR_Kdp_slantPath:long_name = "DP Specific Differential Phase" ;
        GR_Kdp_slantPath:units = "deg/km" ;
        GR_Kdp_slantPath:_FillValue = -888.f ;
```

```
float GR_Kdp_StdDev_slantPath(elevationAngle, fpdim) ;
    GR_Kdp_StdDev_slantPath:long_name = "Standard Deviation of DP Specific Differential Phase" ;
    GR_Kdp_StdDev_slantPath:units = "deg/km" ;
    GR_Kdp_StdDev_slantPath:_FillValue = -888.f ;
float GR_Kdp_Max_slantPath(elevationAngle, fpdim) ;
    GR_Kdp_Max_slantPath:long_name = "Sample Maximum DP Specific Differential Phase" ;
    GR_Kdp_Max_slantPath:units = "deg/km" ;
    GR_Kdp_Max_slantPath:_FillValue = -888.f ;
float GR_RHOhv_slantPath(elevationAngle, fpdim) ;
    GR_RHOhv_slantPath:long_name = "DP Co-Polar Correlation Coefficient" ;
    GR_RHOhv_slantPath:units = "Dimensionless" ;
    GR_RHOhv_slantPath:_FillValue = -888.f ;
float GR_RHOhv_StdDev_slantPath(elevationAngle, fpdim) ;
    GR_RHOhv_StdDev_slantPath:long_name = "Standard Deviation of DP Co-Polar Correlation Coefficient" ;
    GR_RHOhv_StdDev_slantPath:units = "Dimensionless" ;
    GR_RHOhv_StdDev_slantPath:_FillValue = -888.f ;
float GR_RHOhv_Max_slantPath(elevationAngle, fpdim) ;
    GR_RHOhv_Max_slantPath:long_name = "Sample Maximum DP Co-Polar Correlation Coefficient" ;
    GR_RHOhv_Max_slantPath:units = "Dimensionless" ;
    GR_RHOhv_Max_slantPath:_FillValue = -888.f ;
short GR_HID_slantPath(elevationAngle, fpdim, hidim) ;
    GR_HID_slantPath:long_name = "DP Hydrometeor Identification" ;
    GR_HID_slantPath:units = "Categorical" ;
    GR_HID_slantPath:_FillValue = -888s ;
float GR_Dzero_slantPath(elevationAngle, fpdim) ;
    GR_Dzero_slantPath:long_name = "DP Median Volume Diameter" ;
    GR_Dzero_slantPath:units = "mm" ;
    GR_Dzero_slantPath:_FillValue = -888.f ;
float GR_Dzero_StdDev_slantPath(elevationAngle, fpdim) ;
    GR_Dzero_StdDev_slantPath:long_name = "Standard Deviation of DP Median Volume Diameter" ;
    GR_Dzero_StdDev_slantPath:units = "mm" ;
    GR_Dzero_StdDev_slantPath:_FillValue = -888.f ;
float GR_Dzero_Max_slantPath(elevationAngle, fpdim) ;
    GR_Dzero_Max_slantPath:long_name = "Sample Maximum DP Median Volume Diameter" ;
```

```
        GR_Dzero_Max_slantPath:units = "mm" ;
        GR_Dzero_Max_slantPath:_FillValue = -888.f ;
    float GR_Nw_slantPath(elevationAngle, fpdim) ;
        GR_Nw_slantPath:long_name = "DP Normalized Intercept Parameter" ;
        GR_Nw_slantPath:units = "1/(mm*m^3)" ;
        GR_Nw_slantPath:_FillValue = -888.f ;
    float GR_Nw_StdDev_slantPath(elevationAngle, fpdim) ;
        GR_Nw_StdDev_slantPath:long_name = "Standard Deviation of DP Normalized Intercept Parameter" ;
        GR_Nw_StdDev_slantPath:units = "1/(mm*m^3)" ;
        GR_Nw_StdDev_slantPath:_FillValue = -888.f ;
    float GR_Nw_Max_slantPath(elevationAngle, fpdim) ;
        GR_Nw_Max_slantPath:long_name = "Sample Maximum DP Normalized Intercept Parameter" ;
        GR_Nw_Max_slantPath:units = "1/(mm*m^3)" ;
        GR_Nw_Max_slantPath:_FillValue = -888.f ;
    short n_gr_expected(elevationAngle, fpdim) ;
        n_gr_expected:long_name = "number of bins in GR slantPath averages" ;
        n_gr_expected:_FillValue = -888s ;
    short n_gr_z_rejected(elevationAngle, fpdim) ;
        n_gr_z_rejected:long_name = "number of bins below GR_dBZ_min in GR_Z_slantPath average" ;
        n_gr_z_rejected:_FillValue = -888s ;
    short n_gr_rr_rejected(elevationAngle, fpdim) ;
        n_gr_rr_rejected:long_name = "number of bins below gprof_rain_min in GR_rainrate_slantPath average" ;
        n_gr_rr_rejected:_FillValue = -888s ;
    short n_gr_zdr_rejected(elevationAngle, fpdim) ;
        n_gr_zdr_rejected:long_name = "number of bins with missing Zdr in GR_Zdr_slantPath average" ;
        n_gr_zdr_rejected:_FillValue = -888s ;
    short n_gr_kdp_rejected(elevationAngle, fpdim) ;
        n_gr_kdp_rejected:long_name = "number of bins with missing Kdp in GR_Kdp_slantPath average" ;
        n_gr_kdp_rejected:_FillValue = -888s ;
    short n_gr_rhohv_rejected(elevationAngle, fpdim) ;
        n_gr_rhohv_rejected:long_name = "number of bins with missing RHOhv in GR_RHOhv_slantPath average" ;
        n_gr_rhohv_rejected:_FillValue = -888s ;
    short n_gr_hid_rejected(elevationAngle, fpdim) ;
        n_gr_hid_rejected:long_name = "number of bins with undefined HID in GR_HID_slantPath histogram" ;
```

```
        n_gr_hid_rejected:_FillValue = -888s ;
    short n_gr_dzero_rejected(elevationAngle, fpdim) ;
        n_gr_dzero_rejected:long_name = "number of bins with missing D0 in GR_Dzero_slantPath average" ;
        n_gr_dzero_rejected:_FillValue = -888s ;
    short n_gr_nw_rejected(elevationAngle, fpdim) ;
        n_gr_nw_rejected:long_name = "number of bins with missing Nw in GR_Nw_slantPath average" ;
        n_gr_nw_rejected:_FillValue = -888s ;
    float GR_Z_VPR(elevationAngle, fpdim) ;
        GR_Z_VPR:long_name = "GV radar QC Reflectivity along local vertical" ;
        GR_Z_VPR:units = "dBZ" ;
        GR_Z_VPR:_FillValue = -888.f ;
    float GR_Z_StdDev_VPR(elevationAngle, fpdim) ;
        GR_Z_StdDev_VPR:long_name = "Standard Deviation of GV radar QC Reflectivity along local vertical" ;
        GR_Z_StdDev_VPR:units = "dBZ" ;
        GR_Z_StdDev_VPR:_FillValue = -888.f ;
    float GR_Z_Max_VPR(elevationAngle, fpdim) ;
        GR_Z_Max_VPR:long_name = "Sample Maximum GV radar QC Reflectivity along local vertical" ;
        GR_Z_Max_VPR:units = "dBZ" ;
        GR_Z_Max_VPR:_FillValue = -888.f ;
    float GR_rainrate_VPR(elevationAngle, fpdim) ;
        GR_rainrate_VPR:long_name = "GV radar QC Rain Rate along local vertical" ;
        GR_rainrate_VPR:units = "dBZ" ;
        GR_rainrate_VPR:_FillValue = -888.f ;
    float GR_rainrate_StdDev_VPR(elevationAngle, fpdim) ;
        GR_rainrate_StdDev_VPR:long_name = "Standard Deviation of GV radar QC Rain Rate along local vertical" ;
        GR_rainrate_StdDev_VPR:units = "dBZ" ;
        GR_rainrate_StdDev_VPR:_FillValue = -888.f ;
    float GR_rainrate_Max_VPR(elevationAngle, fpdim) ;
        GR_rainrate_Max_VPR:long_name = "Sample Maximum GV radar QC Rain Rate along local vertical" ;
        GR_rainrate_Max_VPR:units = "dBZ" ;
        GR_rainrate_Max_VPR:_FillValue = -888.f ;
    float GR_Zdr_VPR(elevationAngle, fpdim) ;
        GR_Zdr_VPR:long_name = "DP Differential Reflectivity along local vertical" ;
        GR_Zdr_VPR:units = "dB" ;
```

```
        GR_Zdr_VPR:_FillValue = -888.f ;
    float GR_Zdr_StdDev_VPR(elevationAngle, fpdim) ;
        GR_Zdr_StdDev_VPR:long_name = "Standard Deviation of DP Differential Reflectivity along local vertical" ;
        GR_Zdr_StdDev_VPR:units = "dB" ;
        GR_Zdr_StdDev_VPR:_FillValue = -888.f ;
    float GR_Zdr_Max_VPR(elevationAngle, fpdim) ;
        GR_Zdr_Max_VPR:long_name = "Sample Maximum DP Differential Reflectivity along local vertical" ;
        GR_Zdr_Max_VPR:units = "dB" ;
        GR_Zdr_Max_VPR:_FillValue = -888.f ;
    float GR_Kdp_VPR(elevationAngle, fpdim) ;
        GR_Kdp_VPR:long_name = "DP Specific Differential Phase along local vertical" ;
        GR_Kdp_VPR:units = "deg/km" ;
        GR_Kdp_VPR:_FillValue = -888.f ;
    float GR_Kdp_StdDev_VPR(elevationAngle, fpdim) ;
        GR_Kdp_StdDev_VPR:long_name = "Standard Deviation of DP Specific Differential Phase along local vertical" ;
        GR_Kdp_StdDev_VPR:units = "deg/km" ;
        GR_Kdp_StdDev_VPR:_FillValue = -888.f ;
    float GR_Kdp_Max_VPR(elevationAngle, fpdim) ;
        GR_Kdp_Max_VPR:long_name = "Sample Maximum DP Specific Differential Phase along local vertical" ;
        GR_Kdp_Max_VPR:units = "deg/km" ;
        GR_Kdp_Max_VPR:_FillValue = -888.f ;
    float GR_RHOhv_VPR(elevationAngle, fpdim) ;
        GR_RHOhv_VPR:long_name = "DP Co-Polar Correlation Coefficient along local vertical" ;
        GR_RHOhv_VPR:units = "Dimensionless" ;
        GR_RHOhv_VPR:_FillValue = -888.f ;
    float GR_RHOhv_StdDev_VPR(elevationAngle, fpdim) ;
        GR_RHOhv_StdDev_VPR:long_name = "Standard Deviation of DP Co-Polar Correlation Coefficient along local vertical" ;
        GR_RHOhv_StdDev_VPR:units = "Dimensionless" ;
        GR_RHOhv_StdDev_VPR:_FillValue = -888.f ;
    float GR_RHOhv_Max_VPR(elevationAngle, fpdim) ;
        GR_RHOhv_Max_VPR:long_name = "Sample Maximum DP Co-Polar Correlation Coefficient along local vertical" ;
        GR_RHOhv_Max_VPR:units = "Dimensionless" ;
        GR_RHOhv_Max_VPR:_FillValue = -888.f ;
    short GR_HID_VPR(elevationAngle, fpdim, hidim) ;
```

```
        GR_HID_VPR:long_name = "DP Hydrometeor Identification along local vertical" ;
        GR_HID_VPR:units = "Categorical" ;
        GR_HID_VPR:_FillValue = -888s ;
    float GR_Dzero_VPR(elevationAngle, fpdim) ;
        GR_Dzero_VPR:long_name = "DP Median Volume Diameter along local vertical" ;
        GR_Dzero_VPR:units = "mm" ;
        GR_Dzero_VPR:_FillValue = -888.f ;
    float GR_Dzero_StdDev_VPR(elevationAngle, fpdim) ;
        GR_Dzero_StdDev_VPR:long_name = "Standard Deviation of DP Median Volume Diameter along local vertical" ;
        GR_Dzero_StdDev_VPR:units = "mm" ;
        GR_Dzero_StdDev_VPR:_FillValue = -888.f ;
    float GR_Dzero_Max_VPR(elevationAngle, fpdim) ;
        GR_Dzero_Max_VPR:long_name = "Sample Maximum DP Median Volume Diameter along local vertical" ;
        GR_Dzero_Max_VPR:units = "mm" ;
        GR_Dzero_Max_VPR:_FillValue = -888.f ;
    float GR_Nw_VPR(elevationAngle, fpdim) ;
        GR_Nw_VPR:long_name = "DP Normalized Intercept Parameter along local vertical" ;
        GR_Nw_VPR:units = "1/(mm*m^3)" ;
        GR_Nw_VPR:_FillValue = -888.f ;
    float GR_Nw_StdDev_VPR(elevationAngle, fpdim) ;
        GR_Nw_StdDev_VPR:long_name = "Standard Deviation of DP Normalized Intercept Parameter along local vertical" ;
        GR_Nw_StdDev_VPR:units = "1/(mm*m^3)" ;
        GR_Nw_StdDev_VPR:_FillValue = -888.f ;
    float GR_Nw_Max_VPR(elevationAngle, fpdim) ;
        GR_Nw_Max_VPR:long_name = "Sample Maximum DP Normalized Intercept Parameter along local vertical" ;
        GR_Nw_Max_VPR:units = "1/(mm*m^3)" ;
        GR_Nw_Max_VPR:_FillValue = -888.f ;
    short n_gr_vpr_expected(elevationAngle, fpdim) ;
        n_gr_vpr_expected:long_name = "number of bins in GR_Z_VPR, GR_rainrate_VPR averages" ;
        n_gr_vpr_expected:_FillValue = -888s ;
    short n_gr_z_vpr_rejected(elevationAngle, fpdim) ;
        n_gr_z_vpr_rejected:long_name = "number of bins below GR_dBZ_min in GR_Z_VPR average" ;
        n_gr_z_vpr_rejected:_FillValue = -888s ;
    short n_gr_rr_vpr_rejected(elevationAngle, fpdim) ;
```

```
        n_gr_rr_vpr_rejected:long_name = "number of bins below gprof_rain_min in GR_rainrate_VPR average" ;
        n_gr_rr_vpr_rejected:_FillValue = -888s ;
    short n_gr_zdr_vpr_rejected(elevationAngle, fpdim) ;
        n_gr_zdr_vpr_rejected:long_name = "number of bins with missing Zdr in GR_Zdr_VPR average" ;
        n_gr_zdr_vpr_rejected:_FillValue = -888s ;
    short n_gr_kdp_vpr_rejected(elevationAngle, fpdim) ;
        n_gr_kdp_vpr_rejected:long_name = "number of bins with missing Kdp in GR_Kdp_VPR average" ;
        n_gr_kdp_vpr_rejected:_FillValue = -888s ;
    short n_gr_rhohv_vpr_rejected(elevationAngle, fpdim) ;
        n_gr_rhohv_vpr_rejected:long_name = "number of bins with missing RHOhv in GR_RHOhv_VPR average" ;
        n_gr_rhohv_vpr_rejected:_FillValue = -888s ;
    short n_gr_hid_vpr_rejected(elevationAngle, fpdim) ;
        n_gr_hid_vpr_rejected:long_name = "number of bins with undefined HID in GR_HID_VPR histogram" ;
        n_gr_hid_vpr_rejected:_FillValue = -888s ;
    short n_gr_dzero_vpr_rejected(elevationAngle, fpdim) ;
        n_gr_dzero_vpr_rejected:long_name = "number of bins with missing D0 in GR_Dzero_VPR average" ;
        n_gr_dzero_vpr_rejected:_FillValue = -888s ;
    short n_gr_nw_vpr_rejected(elevationAngle, fpdim) ;
        n_gr_nw_vpr_rejected:long_name = "number of bins with missing Nw in GR_Nw_VPR average" ;
        n_gr_nw_vpr_rejected:_FillValue = -888s ;
    float XMIlatitude(fpdim) ;
        XMIlatitude:long_name = "Latitude of XMI surface bin" ;
        XMIlatitude:units = "degrees North" ;
        XMIlatitude:_FillValue = -888.f ;
    float XMIlongitude(fpdim) ;
        XMIlongitude:long_name = "Longitude of XMI surface bin" ;
        XMIlongitude:units = "degrees East" ;
        XMIlongitude:_FillValue = -888.f ;
    short surfaceTypeIndex(fpdim) ;
        surfaceTypeIndex:long_name = "2A-GPROF surfaceTypeIndex" ;
        surfaceTypeIndex:units = "Categorical" ;
        surfaceTypeIndex:_FillValue = -888s ;
    float surfacePrecipitation(fpdim) ;
        surfacePrecipitation:long_name = "2A-GPROF Estimated Surface Rain Rate" ;
```

```
        surfacePrecipitation:units = "mm/h" ;
        surfacePrecipitation:_FillValue = -888.f ;
    short pixelStatus(fpdim) ;
        pixelStatus:long_name = "2A-GPROF pixelStatus" ;
        pixelStatus:units = "Categorical" ;
        pixelStatus:_FillValue = -888s ;
    short PoP(fpdim) ;
        PoP:long_name = "2A-GPROF probabilityOfPrecip" ;
        PoP:units = "percent" ;
        PoP:_FillValue = -888s ;
    int rayIndex(fpdim) ;
        rayIndex:long_name = "XMI product-relative ray,scan IDL 1-D array index" ;
        rayIndex:_FillValue = -888 ;
    double timeNearestApproach ;
        timeNearestApproach:units = "seconds" ;
        timeNearestApproach:long_name = "Seconds since 01-01-1970 00:00:00" ;
        timeNearestApproach:_FillValue = 0. ;
    char atimeNearestApproach(len_atime_ID) ;
        atimeNearestApproach:long_name = "text version of timeNearestApproach, UTC" ;
    double timeSweepStart(elevationAngle) ;
        timeSweepStart:units = "seconds" ;
        timeSweepStart:long_name = "Seconds since 01-01-1970 00:00:00" ;
        timeSweepStart:_FillValue = 0. ;
    char atimeSweepStart(elevationAngle, len_atime_ID) ;
        atimeSweepStart:long_name = "text version of timeSweepStart, UTC" ;
    char site_ID(len_site_ID) ;
        site_ID:long_name = "ID of Ground Radar Site" ;
    float site_lat ;
        site_lat:long_name = "Latitude of Ground Radar Site" ;
        site_lat:units = "degrees North" ;
        site_lat:_FillValue = -888.f ;
    float site_lon ;
        site_lon:long_name = "Longitude of Ground Radar Site" ;
        site_lon:units = "degrees East" ;
```

```
        site_lon:_FillValue = -888.f ;
    float site_elev ;
        site_elev:long_name = "Elevation of Ground Radar Site above MSL" ;
        site_elev:units = "km" ;
    float version ;
        version:long_name = "Geo Match File Version" ;

// global attributes:
        :PPS_Version = "V01A" ;
        :GV_UF_Z_field = "CZ" ;
        :GV_UF_ZDR_field = "Unspecified" ;
        :GV_UF_KDP_field = "Unspecified" ;
        :GV_UF_RHOHV_field = "Unspecified" ;
        :GV_UF_RR_field = "Unspecified" ;
        :GV_UF_HID_field = "Unspecified" ;
        :GV_UF_D0_field = "Unspecified" ;
        :GV_UF_NW_field = "Unspecified" ;
        :2AGPROF_file = "Some_2AGFROF_file" ;
        :GR_file = "Some_1CUF_file" ;
```

NOTES:

1) The variables **topHeight** and **bottomHeight** are in units of km above ground level (km AGL). Assuming all heights are in units of km, then the variable **site_elev** (km above MSL) relates heights above mean sea level (MSL) and AGL:

`HeightAGL = HeightMSL - site_elev`

2) Actual values for the dimension variables "**fpdim**" and "**elevationAngle**" must be specified at time of netCDF file creation.

Table 3.2-1. Variable name, type, dimensions, and interpretation of special data values for science and geolocation variables in GMI-GR Geometry Match netCDF files.

Variable Name(s)	Type	Dimension(s)	Special Values
GR_Z_slantPath GR_Z_StdDev_slantPath GR_Z_Max_slantPath GR_Z_VPR GR_Z_StdDev_VPR GR_Z_Max_VPR	float	elevationAngle, fpdim	-888.0: Range edge delimiter, Fill Value -777.0: In-range GMI scan edge delimiter -9999.0: Missing data -100.0: Below dBZ cutoff value
GR_rainrate_slantPath GR_rainrate_StdDev_slantPath GR_rainrate_Max_slantPath GR_rainrate_VPR GR_rainrate_StdDev_VPR GR_rainrate_Max_VPR	float	elevationAngle, fpdim	-888.0: Range edge delimiter, Fill Value -777.0: In-range GMI scan edge delimiter -9999.0: Missing data -100.0: Below rainrate cutoff value
GR_Zdr_slantPath GR_Zdr_StdDev_slantPath GR_Zdr_Max_slantPath GR_Kdp_slantPath GR_Kdp_StdDev_slantPath GR_Kdp_Max_slantPath GR_RHOhv_slantPath GR_RHOhv_StdDev_slantPath GR_RHOhv_Max_slantPath GR_Dzero_slantPath GR_Dzero_StdDev_slantPath GR_Dzero_Max_slantPath GR_Nw_slantPath GR_Nw_StdDev_slantPath GR_Nw_Max_slantPath GR_Zdr_VPR GR_Zdr_StdDev_VPR GR_Zdr_Max_VPR GR_Kdp_VPR GR_Kdp_StdDev_VPR GR_Kdp_Max_VPR GR_RHOhv_VPR GR_RHOhv_StdDev_VPR GR_RHOhv_Max_VPR GR_Dzero_VPR GR_Dzero_StdDev_VPR GR_Dzero_Max_VPR GR_Nw_VPR GR_Nw_StdDev_VPR GR_Nw_Max_VPR	float	elevationAngle, fpdim	-888.0: Range edge delimiter, Fill Value -777.0: In-range PR scan edge delimiter -9999.0: Missing data -100.0: Below threshold cutoff value, or all GR bin values are MISSING
GR_HID_slantPath GR_HID_VPR	short	elevationAngle, fpdim, hidim	-888.0: Range edge delimiter, Fill Value

Variable Name(s)	Type	Dimension(s)	Special Values
surfacePrecipitation PoP (note 9)	float	fpdim	-888.0: Range edge delimiter, Fill Value -777.0: In-range GMI scan edge delimiter -9999.9: Missing data
n_gr_expected n_gr_z_rejected n_gr_rr_rejected n_gr_zdr_rejected n_gr_kdp_rejected n_gr_rhohv_rejected n_gr_hid_rejected n_gr_dzero_rejected n_gr_nw_rejected n_gr_vpr_expected n_gr_z_vpr_rejected n_gr_rr_vpr_rejected n_gr_zdr_vpr_rejected n_gr_kdp_vpr_rejected n_gr_rhohv_vpr_rejected n_gr_hid_vpr_rejected n_gr_dzero_vpr_rejected n_gr_nw_vpr_rejected	short	elevationAngle, fpdim	-888: Fill Value
latitude, longitude, topHeight, bottomHeight topHeight_vpr, bottomHeight_vpr (see note 8)	float	elevationAngle, fpdim	-888.0: Fill Value
xCorners, yCorners	float	elevationAngle, fpdim, xydim	-888.0: Fill Value
XMIlatitude, XMIlongitude	float	fpdim	-888.0: Fill Value
surfaceTypeIndex pixelStatus	short	fpdim	-888: Range edge delimiter, Fill Value -777: In-range GMI scan edge delimiter -99: Missing data
rayIndex	int	fpdim	-1: Edge-of-Range indicator -2: In-range GMI scan edge indicator
elevationAngle	float	elevationAngle	N/A

Notes on Table 3.2-1:

1. Special Values are values outside of the normal physical range of the data field, and which indicate a special meaning at the data point (e.g., Missing data).
2. Range edge points are the nearest GMI footprints lying outside of, but immediately adjacent to, the range ring surrounding the ground radar at distance =

rangeThreshold, for a given GMI scan. These points form a partial circle around points for the GMI footprints within the **rangeThreshold** of the ground radar, the latter which contain actual data values.

3. In-range GMI scan edge points are the computed positions single GMI footprints extrapolated just beyond either edge of the GMI scan, and which fall within or immediately adjacent to the **rangeThreshold** distance from the ground radar.
4. The combination of the Range Edge points and the Scan Edge points serve to completely enclose the in-range GMI footprints on the surface: a) defined by each elevation sweep (for multi-level variables), or b) at the earth surface (for single level variables). The purpose of these points is to prevent the extrapolation of "actual" GMI data values outside of the in-range area, if the data are later analyzed to a regular grid using an objective analysis technique.
5. Range Edge points and Scan Edge points are indicated by **rayIndex** values of -1 and -2, respectively. **rayIndex** values of 0 or greater are actual 1-D equivalent array indices of GMI footprints within the full data arrays in the 2A-GPROF data files.
6. ***Range and Scan Edge points are optional and, as a default, are disabled from being computed and output. If the "Mark Edges" parameter's default value is overridden, then these types of points will then be computed and output as described above.***
7. **Fill Value** is the value to which scalar or array variables in the netCDF file are initialized when the file is created. These values remain in place unless and until the data value is overwritten.
8. The variables **topHeight, bottomHeight**, **topHeight_vpr,** and **bottomHeight_vpr** represent height above ground level (AGL) (i.e., height above the ground radar) ***in km***.
9. **PoP** values are assigned only for GMI footprints with **surfaceType** "water", and are undefined (-99) over land and coast.

Table 3.2-2. Values of categorical variables in the GMI-GR geometry matching technique netCDF files.

Variable	Category definitions
surfaceTypeIndex	1 : Ocean 2 : Sea-Ice (3-12 are 'land classification') 3 : Maximum Vegetation 4 : High Vegetation 5 : Moderate Vegetation 6 : Low Vegetation 7 : Minimal Vegetation 8 : Maximum Snow 9 : Moderate Snow 10 : Low Snow 11 : Minimal Snow 12 : Standing Water and Rivers 13 : Water/Land Coast Boundary 14 : Water/Ice Boundary 15 : Land/Ice Boundary -99 : Missing value
pixelStatus	0 : Valid pixel 1 : Boundary error in landmask 2 : Boundary error in sea-ice check 3 : Boundary error in sea surface temperature 4 : Invalid time 5 : Invalid latitude/longitude 6 : Invalid brightness temperature 7 : Invalid sea surface temperature -99 : Missing value
GR_HID_slantPath GR_HID_VPR	See GR_HID description for GRtoDPR matchup file.

3.3 DPRGMI-GR Geometry Match netCDF file description

The format and content of the GRtoDPRGMI-type Geometry Match netCDF file is presented below, in the form of partial netCDF file creation instructions. See Section 3.1 for details related to dimensions and netCDF variable types. Special values associated with each "science" and geolocation array variable in the GRtoDPRGMI-type geometry match netCDF files follow those for similarly named variables in the DPRtoGR matchup files, as listed in Table 3.1-1. Exceptions are those variables with special values defined in the 2B-DPRGMI file itself, as documented in ***PRECIPITATION PROCESSING SYSTEM, GLOBAL PRECIPITATION MEASUREMENT, File Specification for GPM Products***, available from http://pps.gsfc.nasa.gov/ppshome/GPMprelimdocs.html. The DPRGMI product contains data for two swaths in the HDF5 data files: the narrower MS swath for Ka scans matched to inner Ku footprints, and the wider NS swath for Ku footprints. Note that both the MS and NS swaths are processed in the GR-DPRGMI matchup and are included in the GRtoDPRGMI netCDF files, with the same variables repeated, one with an '_MS' indicator in the name and one with an '_NS' indicator in the name, where there is a difference between swath types for the data in the variable. Note also that for certain MS swath variables there is an additional dimension "nKuKa" in the variable as compared to the NS swath version of the variable, indicating that there are both Ka- and Ku-derived values in the variable.

Depending on the rangeThreshold used and the proximity of the GPM orbit to the ground radar, there may be no overlap of the narrower MS swath with the matchup domain. In this case, the **have_swath_MS** flag variable is zero, and the various "_MS" variables are dimensioned to only one footprint (**fpdim_MS** = 1) and their data values are populated with the netCDF FillValue.

```
dimensions:
    fpdim_MS =  ;
    fpdim_NS =  ;
    elevationAngle =  ;
    xydim = 4 ;
    hidim = 15 ;
    nPSDlo = 2 ;
    nBnPSDlo = 9 ;
    nKuKa = 2 ;
    nPhsBnN = 5 ;
```

```
        timedimid_MS =   ;
        timedimid_NS =   ;
        len_atime_ID = 19 ;
        len_site_ID = 4 ;
variables:
        float elevationAngle(elevationAngle) ;
                elevationAngle:long_name = "Radar Sweep Elevation Angles" ;
                elevationAngle:units = "degrees" ;
        short have_ swath_MS;
                have_ swath_MS:long_name = "data exists flag for MS swath'" ;
                have_ swath_MS:_FillValue = 0s ;
        short Year_MS(timedimid_MS) ;
                Year_MS:long_name = "Year of DPR MS scan" ;
                Year_MS:_FillValue = -888s ;
        byte Month_MS(timedimid_MS) ;
                Month_MS:long_name = "Month of DPR MS scan" ;
                Month_MS:_FillValue = -88b ;
        byte DayOfMonth_MS(timedimid_MS) ;
                DayOfMonth_MS:long_name = "DayOfMonth of DPR MS scan" ;
                DayOfMonth_MS:_FillValue = -88b ;
        byte Hour_MS(timedimid_MS) ;
                Hour_MS:long_name = "Hour of DPR MS scan" ;
                Hour_MS:_FillValue = -88b ;
        byte Minute_MS(timedimid_MS) ;
                Minute_MS:long_name = "Minute of DPR MS scan" ;
                Minute_MS:_FillValue = -88b ;
        byte Second_MS(timedimid_MS) ;
                Second_MS:long_name = "Second of DPR MS scan" ;
                Second_MS:_FillValue = -88b ;
        short Millisecond_MS(timedimid_MS) ;
                Millisecond_MS:long_name = "Millisecond of DPR MS scan" ;
                Millisecond_MS:_FillValue = -888s ;
        short Year_NS(timedimid_NS) ;
                Year_NS:long_name = "Year of DPR NS scan" ;
```

```
        Year_NS:_FillValue = -888s ;
    byte Month_NS(timedimid_NS) ;
        Month_NS:long_name = "Month of DPR NS scan" ;
        Month_NS:_FillValue = -88b ;
    byte DayOfMonth_NS(timedimid_NS) ;
        DayOfMonth_NS:long_name = "DayOfMonth of DPR NS scan" ;
        DayOfMonth_NS:_FillValue = -88b ;
    byte Hour_NS(timedimid_NS) ;
        Hour_NS:long_name = "Hour of DPR NS scan" ;
        Hour_NS:_FillValue = -88b ;
    byte Minute_NS(timedimid_NS) ;
        Minute_NS:long_name = "Minute of DPR NS scan" ;
        Minute_NS:_FillValue = -88b ;
    byte Second_NS(timedimid_NS) ;
        Second_NS:long_name = "Second of DPR NS scan" ;
        Second_NS:_FillValue = -88b ;
    short Millisecond_NS(timedimid_NS) ;
        Millisecond_NS:long_name = "Millisecond of DPR NS scan" ;
        Millisecond_NS:_FillValue = -888s ;
    int startScan_MS ;
        startScan_MS:long_name = "Starting DPR MS overlap scan in original dataset, zero-based" ;
        startScan_MS:_FillValue = -888 ;
    int endScan_MS ;
        endScan_MS:long_name = "Ending DPR MS overlap scan in original dataset, zero-based" ;
        endScan_MS:_FillValue = -888 ;
    short numRays_MS ;
        numRays_MS:long_name = "Number of DPR MS rays per scan in original datasets" ;
        numRays_MS:_FillValue = -888s ;
    int startScan_NS ;
        startScan_NS:long_name = "Starting DPR NS overlap scan in original dataset, zero-based" ;
        startScan_NS:_FillValue = -888 ;
    int endScan_NS ;
        endScan_NS:long_name = "Ending DPR NS overlap scan in original dataset, zero-based" ;
        endScan_NS:_FillValue = -888 ;
```

```
short numRays_NS ;
        numRays_NS:long_name = "Number of DPR NS rays per scan in original datasets" ;
        numRays_NS:_FillValue = -888s ;
float rangeThreshold ;
        rangeThreshold:long_name = "Dataset maximum range from radar site" ;
        rangeThreshold:_FillValue = -888.f ;
        rangeThreshold:units = "km" ;
float DPR_dBZ_min ;
        DPR_dBZ_min:long_name = "minimum DPR bin dBZ required for a *complete* DPR vertical average" ;
        DPR_dBZ_min:_FillValue = -888.f ;
        DPR_dBZ_min:units = "dBZ" ;
float GR_dBZ_min ;
        GR_dBZ_min:long_name = "minimum GR bin dBZ required for a *complete* GR horizontal average" ;
        GR_dBZ_min:_FillValue = -888.f ;
        GR_dBZ_min:units = "dBZ" ;
float rain_min ;
        rain_min:long_name = "minimum DPR rainrate required for a *complete* DPR vertical average" ;
        rain_min:_FillValue = -888.f ;
        rain_min:units = "mm/h" ;
short have_GR_Z ;
        have_GR_Z:long_name = "data exists flag for GR_Z" ;
        have_GR_Z:_FillValue = 0s ;
short have_GR_Zdr ;
        have_GR_Zdr:long_name = "data exists flag for GR_Zdr" ;
        have_GR_Zdr:_FillValue = 0s ;
short have_GR_Kdp ;
        have_GR_Kdp:long_name = "data exists flag for GR_Kdp" ;
        have_GR_Kdp:_FillValue = 0s ;
short have_GR_RHOhv ;
        have_GR_RHOhv:long_name = "data exists flag for GR_RHOhv" ;
        have_GR_RHOhv:_FillValue = 0s ;
short have_GR_rainrate ;
        have_GR_rainrate:long_name = "data exists flag for GR_rainrate" ;
        have_GR_rainrate:_FillValue = 0s ;
```

```
short have_GR_HID ;
        have_GR_HID:long_name = "data exists flag for GR_HID" ;
        have_GR_HID:_FillValue = 0s ;
short have_GR_Dzero ;
        have_GR_Dzero:long_name = "data exists flag for GR_Dzero" ;
        have_GR_Dzero:_FillValue = 0s ;
short have_GR_Nw ;
        have_GR_Nw:long_name = "data exists flag for GR_Nw" ;
        have_GR_Nw:_FillValue = 0s ;
float latitude_MS(elevationAngle, fpdim_MS) ;
        latitude_MS:long_name = "Latitude of 3-D data sample" ;
        latitude_MS:units = "degrees North" ;
        latitude_MS:_FillValue = -888.f ;
float longitude_MS(elevationAngle, fpdim_MS) ;
        longitude_MS:long_name = "Longitude of 3-D data sample" ;
        longitude_MS:units = "degrees East" ;
        longitude_MS:_FillValue = -888.f ;
float xCorners_MS(elevationAngle, fpdim_MS, xydim) ;
        xCorners_MS:long_name = "data sample x corner coords." ;
        xCorners_MS:units = "km" ;
        xCorners_MS:_FillValue = -888.f ;
float yCorners_MS(elevationAngle, fpdim_MS, xydim) ;
        yCorners_MS:long_name = "data sample y corner coords." ;
        yCorners_MS:units = "km" ;
        yCorners_MS:_FillValue = -888.f ;
float topHeight_MS(elevationAngle, fpdim_MS) ;
        topHeight_MS:long_name = "data sample top height AGL" ;
        topHeight_MS:units = "km" ;
        topHeight_MS:_FillValue = -888.f ;
float bottomHeight_MS(elevationAngle, fpdim_MS) ;
        bottomHeight_MS:long_name = "data sample bottom height AGL" ;
        bottomHeight_MS:units = "km" ;
        bottomHeight_MS:_FillValue = -888.f ;
float GR_Z_MS(elevationAngle, fpdim_MS) ;
```

```
        GR_Z_MS:long_name = "GV radar QC Reflectivity" ;
        GR_Z_MS:units = "dBZ" ;
        GR_Z_MS:_FillValue = -888.f ;
    float GR_Z_StdDev_MS(elevationAngle, fpdim_MS) ;
        GR_Z_StdDev_MS:long_name = "Standard Deviation of GV radar QC Reflectivity" ;
        GR_Z_StdDev_MS:units = "dBZ" ;
        GR_Z_StdDev_MS:_FillValue = -888.f ;
    float GR_Z_Max_MS(elevationAngle, fpdim_MS) ;
        GR_Z_Max_MS:long_name = "Sample Maximum GV radar QC Reflectivity" ;
        GR_Z_Max_MS:units = "dBZ" ;
        GR_Z_Max_MS:_FillValue = -888.f ;
    float GR_Zdr_MS(elevationAngle, fpdim_MS) ;
        GR_Zdr_MS:long_name = "DP Differential Reflectivity" ;
        GR_Zdr_MS:units = "dB" ;
        GR_Zdr_MS:_FillValue = -888.f ;
    float GR_Zdr_StdDev_MS(elevationAngle, fpdim_MS) ;
        GR_Zdr_StdDev_MS:long_name = "Standard Deviation of DP Differential Reflectivity" ;
        GR_Zdr_StdDev_MS:units = "dB" ;
        GR_Zdr_StdDev_MS:_FillValue = -888.f ;
    float GR_Zdr_Max_MS(elevationAngle, fpdim_MS) ;
        GR_Zdr_Max_MS:long_name = "Sample Maximum DP Differential Reflectivity" ;
        GR_Zdr_Max_MS:units = "dB" ;
        GR_Zdr_Max_MS:_FillValue = -888.f ;
    float GR_Kdp_MS(elevationAngle, fpdim_MS) ;
        GR_Kdp_MS:long_name = "DP Specific Differential Phase" ;
        GR_Kdp_MS:units = "deg/km" ;
        GR_Kdp_MS:_FillValue = -888.f ;
    float GR_Kdp_StdDev_MS(elevationAngle, fpdim_MS) ;
        GR_Kdp_StdDev_MS:long_name = "Standard Deviation of DP Specific Differential Phase" ;
        GR_Kdp_StdDev_MS:units = "deg/km" ;
        GR_Kdp_StdDev_MS:_FillValue = -888.f ;
    float GR_Kdp_Max_MS(elevationAngle, fpdim_MS) ;
        GR_Kdp_Max_MS:long_name = "Sample Maximum DP Specific Differential Phase" ;
        GR_Kdp_Max_MS:units = "deg/km" ;
```

```
        GR_Kdp_Max_MS:_FillValue = -888.f ;
    float GR_RHOhv_MS(elevationAngle, fpdim_MS) ;
        GR_RHOhv_MS:long_name = "DP Co-Polar Correlation Coefficient" ;
        GR_RHOhv_MS:units = "Dimensionless" ;
        GR_RHOhv_MS:_FillValue = -888.f ;
    float GR_RHOhv_StdDev_MS(elevationAngle, fpdim_MS) ;
        GR_RHOhv_StdDev_MS:long_name = "Standard Deviation of DP Co-Polar Correlation Coefficient" ;
        GR_RHOhv_StdDev_MS:units = "Dimensionless" ;
        GR_RHOhv_StdDev_MS:_FillValue = -888.f ;
    float GR_RHOhv_Max_MS(elevationAngle, fpdim_MS) ;
        GR_RHOhv_Max_MS:long_name = "Sample Maximum DP Co-Polar Correlation Coefficient" ;
        GR_RHOhv_Max_MS:units = "Dimensionless" ;
        GR_RHOhv_Max_MS:_FillValue = -888.f ;
    float GR_rainrate_MS(elevationAngle, fpdim_MS) ;
        GR_rainrate_MS:long_name = "GV radar DP Rainrate" ;
        GR_rainrate_MS:units = "mm/h" ;
        GR_rainrate_MS:_FillValue = -888.f ;
    float GR_rainrate_StdDev_MS(elevationAngle, fpdim_MS) ;
        GR_rainrate_StdDev_MS:long_name = "Standard Deviation of GV radar DP Rainrate" ;
        GR_rainrate_StdDev_MS:units = "mm/h" ;
        GR_rainrate_StdDev_MS:_FillValue = -888.f ;
    float GR_rainrate_Max_MS(elevationAngle, fpdim_MS) ;
        GR_rainrate_Max_MS:long_name = "Sample Maximum GV radar DP Rainrate" ;
        GR_rainrate_Max_MS:units = "mm/h" ;
        GR_rainrate_Max_MS:_FillValue = -888.f ;
    short GR_HID_MS(elevationAngle, fpdim_MS, hidim) ;
        GR_HID_MS:long_name = "DP Hydrometeor Identification" ;
        GR_HID_MS:units = "Categorical" ;
        GR_HID_MS:_FillValue = -888s ;
    float GR_Dzero_MS(elevationAngle, fpdim_MS) ;
        GR_Dzero_MS:long_name = "DP Median Volume Diameter" ;
        GR_Dzero_MS:units = "mm" ;
        GR_Dzero_MS:_FillValue = -888.f ;
    float GR_Dzero_StdDev_MS(elevationAngle, fpdim_MS) ;
```

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        GR_Dzero_StdDev_MS:long_name = "Standard Deviation of DP Median Volume Diameter" ;
        GR_Dzero_StdDev_MS:units = "mm" ;
        GR_Dzero_StdDev_MS:_FillValue = -888.f ;
    float GR_Dzero_Max_MS(elevationAngle, fpdim_MS) ;
        GR_Dzero_Max_MS:long_name = "Sample Maximum DP Median Volume Diameter" ;
        GR_Dzero_Max_MS:units = "mm" ;
        GR_Dzero_Max_MS:_FillValue = -888.f ;
    float GR_Nw_MS(elevationAngle, fpdim_MS) ;
        GR_Nw_MS:long_name = "DP Normalized Intercept Parameter" ;
        GR_Nw_MS:units = "1/(mm*m^3)" ;
        GR_Nw_MS:_FillValue = -888.f ;
    float GR_Nw_StdDev_MS(elevationAngle, fpdim_MS) ;
        GR_Nw_StdDev_MS:long_name = "Standard Deviation of DP Normalized Intercept Parameter" ;
        GR_Nw_StdDev_MS:units = "1/(mm*m^3)" ;
        GR_Nw_StdDev_MS:_FillValue = -888.f ;
    float GR_Nw_Max_MS(elevationAngle, fpdim_MS) ;
        GR_Nw_Max_MS:long_name = "Sample Maximum DP Normalized Intercept Parameter" ;
        GR_Nw_Max_MS:units = "1/(mm*m^3)" ;
        GR_Nw_Max_MS:_FillValue = -888.f ;
    short n_gr_z_rejected_MS(elevationAngle, fpdim_MS) ;
        n_gr_z_rejected_MS:long_name = "number of bins below GR_dBZ_min in GR_Z average" ;
        n_gr_z_rejected_MS:_FillValue = -888s ;
    short n_gr_zdr_rejected_MS(elevationAngle, fpdim_MS) ;
        n_gr_zdr_rejected_MS:long_name = "number of bins with missing Zdr in GR_Zdr average" ;
        n_gr_zdr_rejected_MS:_FillValue = -888s ;
    short n_gr_kdp_rejected_MS(elevationAngle, fpdim_MS) ;
        n_gr_kdp_rejected_MS:long_name = "number of bins with missing Kdp in GR_Kdp average" ;
        n_gr_kdp_rejected_MS:_FillValue = -888s ;
    short n_gr_rhohv_rejected_MS(elevationAngle, fpdim_MS) ;
        n_gr_rhohv_rejected_MS:long_name = "number of bins with missing RHOhv in GR_RHOhv average" ;
        n_gr_rhohv_rejected_MS:_FillValue = -888s ;
    short n_gr_rr_rejected_MS(elevationAngle, fpdim_MS) ;
        n_gr_rr_rejected_MS:long_name = "number of bins below rain_min in GR_rainrate average" ;
        n_gr_rr_rejected_MS:_FillValue = -888s ;
```

```
short n_gr_hid_rejected_MS(elevationAngle, fpdim_MS) ;
        n_gr_hid_rejected_MS:long_name = "number of bins with undefined HID in GR_HID histogram" ;
        n_gr_hid_rejected_MS:_FillValue = -888s ;
short n_gr_dzero_rejected_MS(elevationAngle, fpdim_MS) ;
        n_gr_dzero_rejected_MS:long_name = "number of bins with missing D0 in GR_Dzero average" ;
        n_gr_dzero_rejected_MS:_FillValue = -888s ;
short n_gr_nw_rejected_MS(elevationAngle, fpdim_MS) ;
        n_gr_nw_rejected_MS:long_name = "number of bins with missing Nw in GR_Nw average" ;
        n_gr_nw_rejected_MS:_FillValue = -888s ;
short n_gr_expected_MS(elevationAngle, fpdim_MS) ;
        n_gr_expected_MS:long_name = "number of bins in GR_Z average" ;
        n_gr_expected_MS:_FillValue = -888s ;
float precipTotPSDparamHigh_MS(elevationAngle, fpdim_MS) ;
        precipTotPSDparamHigh_MS:long_name = "2B-DPRGMI precipTotPSDparamHigh for MS swath" ;
        precipTotPSDparamHigh_MS:units = "mm_Dm" ;
        precipTotPSDparamHigh_MS:_FillValue = -888.f ;
float precipTotPSDparamLow_MS(elevationAngle, fpdim_MS, nPSDlo) ;
        precipTotPSDparamLow_MS:long_name = "2B-DPRGMI precipTotPSDparamLow for MS swath" ;
        precipTotPSDparamLow_MS:units = "Nw_mu" ;
        precipTotPSDparamLow_MS:_FillValue = -888.f ;
float precipTotRate_MS(elevationAngle, fpdim_MS) ;
        precipTotRate_MS:long_name = "2B-DPRGMI precipTotRate for MS swath" ;
        precipTotRate_MS:units = "mm/h" ;
        precipTotRate_MS:_FillValue = -888.f ;
float precipTotWaterCont_MS(elevationAngle, fpdim_MS) ;
        precipTotWaterCont_MS:long_name = "2B-DPRGMI precipTotWaterCont for MS swath" ;
        precipTotWaterCont_MS:units = "g/m^3" ;
        precipTotWaterCont_MS:_FillValue = -888.f ;
short n_precipTotPSDparamHigh_rejected_MS(elevationAngle, fpdim_MS) ;
        n_precipTotPSDparamHigh_rejected_MS:long_name = "number of bins below rain_min in precipTotPSDparamHigh
            average for MS swath" ;
        n_precipTotPSDparamHigh_rejected_MS:_FillValue = -888s ;
short n_precipTotPSDparamLow_rejected_MS(elevationAngle, fpdim_MS, nPSDlo) ;
        n_precipTotPSDparamLow_rejected_MS:long_name = "number of bins below rain_min in precipTotPSDparamLow
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            average for MS swath" ;
        n_precipTotPSDparamLow_rejected_MS:_FillValue = -888s ;
    short n_precipTotRate_rejected_MS(elevationAngle, fpdim_MS) ;
        n_precipTotRate_rejected_MS:long_name = "number of bins below rain_min in precipTotRate average for MS swath" ;
        n_precipTotRate_rejected_MS:_FillValue = -888s ;
    short n_precipTotWaterCont_rejected_MS(elevationAngle, fpdim_MS) ;
        n_precipTotWaterCont_rejected_MS:long_name = "number of bins below rain_min in precipTotWaterCont
            average for MS swath" ;
        n_precipTotWaterCont_rejected_MS:_FillValue = -888s ;
    int precipitationType_MS(fpdim_MS) ;
        precipitationType_MS:long_name = "2B-DPRGMI precipitationType for MS swath" ;
        precipitationType_MS:units = "Categorical" ;
        precipitationType_MS:_FillValue = -888 ;
    float surfPrecipTotRate_MS(fpdim_MS) ;
        surfPrecipTotRate_MS:long_name = "2B-DPRGMI surfPrecipTotRate for MS swath" ;
        surfPrecipTotRate_MS:units = "mm/h" ;
        surfPrecipTotRate_MS:_FillValue = -888.f ;
    float surfaceElevation_MS(fpdim_MS) ;
        surfaceElevation_MS:long_name = "2B-DPRGMI surfaceElevation for MS swath" ;
        surfaceElevation_MS:units = "m" ;
        surfaceElevation_MS:_FillValue = -888.f ;
    int surfaceType_MS(fpdim_MS) ;
        surfaceType_MS:long_name = "2B-DPRGMI surfaceType for MS swath" ;
        surfaceType_MS:units = "Categorical" ;
        surfaceType_MS:_FillValue = -888 ;
    short phaseBinNodes_MS(fpdim_MS, nPhsBnN) ;
        phaseBinNodes_MS:long_name = "2B-DPRGMI phaseBinNodes for MS swath" ;
        phaseBinNodes_MS:units = "None" ;
        phaseBinNodes_MS:_FillValue = -888s ;
    float DPRlatitude_MS(fpdim_MS) ;
        DPRlatitude_MS:long_name = "Latitude of DPR surface bin for MS swath" ;
        DPRlatitude_MS:units = "degrees North" ;
        DPRlatitude_MS:_FillValue = -888.f ;
    float DPRlongitude_MS(fpdim_MS) ;
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        DPRlongitude_MS:long_name = "Longitude of DPR surface bin for MS swath" ;
        DPRlongitude_MS:units = "degrees East" ;
        DPRlongitude_MS:_FillValue = -888.f ;
    short scanNum_MS(fpdim_MS) ;
        scanNum_MS:long_name = "product-relative zero-based DPR scan number for MS swath" ;
        scanNum_MS:_FillValue = -888s ;
    short rayNum_MS(fpdim_MS) ;
        rayNum_MS:long_name = "product-relative zero-based DPR ray number for MS swath" ;
        rayNum_MS:_FillValue = -888s ;
    float ellipsoidBinOffset_MS(fpdim_MS, nKuKa) ;
        ellipsoidBinOffset_MS:long_name = "2B-DPRGMI Ku and Ka ellipsoidBinOffset for MS swath" ;
        ellipsoidBinOffset_MS:units = "m" ;
        ellipsoidBinOffset_MS:_FillValue = -888.f ;
    short lowestClutterFreeBin_MS(fpdim_MS, nKuKa) ;
        lowestClutterFreeBin_MS:long_name = "2B-DPRGMI Ku and Ka lowestClutterFreeBin for MS swath" ;
        lowestClutterFreeBin_MS:units = "None" ;
        lowestClutterFreeBin_MS:_FillValue = -888s ;
    int precipitationFlag_MS(fpdim_MS, nKuKa) ;
        precipitationFlag_MS:long_name = "2B-DPRGMI Ku and Ka precipitationFlag for MS swath" ;
        precipitationFlag_MS:units = "Categorical" ;
        precipitationFlag_MS:_FillValue = -888 ;
    short surfaceRangeBin_MS(fpdim_MS, nKuKa) ;
        surfaceRangeBin_MS:long_name = "2B-DPRGMI Ku and Ka surfaceRangeBin for MS swath" ;
        surfaceRangeBin_MS:units = "None" ;
        surfaceRangeBin_MS:_FillValue = -888s ;
    float correctedReflectFactor_MS(elevationAngle, fpdim_MS, nKuKa) ;
        correctedReflectFactor_MS:long_name = "2B-DPRGMI Ku and Ka Corrected Reflectivity Factor for MS swath" ;
        correctedReflectFactor_MS:units = "dBZ" ;
        correctedReflectFactor_MS:_FillValue = -888.f ;
    float pia_MS(fpdim_MS, nKuKa) ;
        pia_MS:long_name = "2B-DPRGMI Ku and Ka Path Integrated Attenuation for MS swath" ;
        pia_MS:units = "dB" ;
        pia_MS:_FillValue = -888.f ;
    short n_correctedReflectFactor_rejected_MS(elevationAngle, fpdim_MS, nKuKa) ;
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        n_correctedReflectFactor_rejected_MS:long_name = "numbers of Ku and Ka bins below DPR_dBZ_min in
            correctedReflectFactor average for MS swath" ;
        n_correctedReflectFactor_rejected_MS:_FillValue = -888s ;
    short n_dpr_expected_MS(elevationAngle, fpdim_MS, nKuKa) ;
        n_dpr_expected_MS:long_name = "numbers of expected Ku and Ka bins in DPR averages for MS swath" ;
        n_dpr_expected_MS:_FillValue = -888s ;
    float latitude_NS(elevationAngle, fpdim_NS) ;
        latitude_NS:long_name = "Latitude of 3-D data sample" ;
        latitude_NS:units = "degrees North" ;
        latitude_NS:_FillValue = -888.f ;
    float longitude_NS(elevationAngle, fpdim_NS) ;
        longitude_NS:long_name = "Longitude of 3-D data sample" ;
        longitude_NS:units = "degrees East" ;
        longitude_NS:_FillValue = -888.f ;
    float xCorners_NS(elevationAngle, fpdim_NS, xydim) ;
        xCorners_NS:long_name = "data sample x corner coords." ;
        xCorners_NS:units = "km" ;
        xCorners_NS:_FillValue = -888.f ;
    float yCorners_NS(elevationAngle, fpdim_NS, xydim) ;
        yCorners_NS:long_name = "data sample y corner coords." ;
        yCorners_NS:units = "km" ;
        yCorners_NS:_FillValue = -888.f ;
    float topHeight_NS(elevationAngle, fpdim_NS) ;
        topHeight_NS:long_name = "data sample top height AGL" ;
        topHeight_NS:units = "km" ;
        topHeight_NS:_FillValue = -888.f ;
    float bottomHeight_NS(elevationAngle, fpdim_NS) ;
        bottomHeight_NS:long_name = "data sample bottom height AGL" ;
        bottomHeight_NS:units = "km" ;
        bottomHeight_NS:_FillValue = -888.f ;
    float GR_Z_NS(elevationAngle, fpdim_NS) ;
        GR_Z_NS:long_name = "GV radar QC Reflectivity" ;
        GR_Z_NS:units = "dBZ" ;
        GR_Z_NS:_FillValue = -888.f ;
```

```
float GR_Z_StdDev_NS(elevationAngle, fpdim_NS) ;
	GR_Z_StdDev_NS:long_name = "Standard Deviation of GV radar QC Reflectivity" ;
	GR_Z_StdDev_NS:units = "dBZ" ;
	GR_Z_StdDev_NS:_FillValue = -888.f ;
float GR_Z_Max_NS(elevationAngle, fpdim_NS) ;
	GR_Z_Max_NS:long_name = "Sample Maximum GV radar QC Reflectivity" ;
	GR_Z_Max_NS:units = "dBZ" ;
	GR_Z_Max_NS:_FillValue = -888.f ;
float GR_Zdr_NS(elevationAngle, fpdim_NS) ;
	GR_Zdr_NS:long_name = "DP Differential Reflectivity" ;
	GR_Zdr_NS:units = "dB" ;
	GR_Zdr_NS:_FillValue = -888.f ;
float GR_Zdr_StdDev_NS(elevationAngle, fpdim_NS) ;
	GR_Zdr_StdDev_NS:long_name = "Standard Deviation of DP Differential Reflectivity" ;
	GR_Zdr_StdDev_NS:units = "dB" ;
	GR_Zdr_StdDev_NS:_FillValue = -888.f ;
float GR_Zdr_Max_NS(elevationAngle, fpdim_NS) ;
	GR_Zdr_Max_NS:long_name = "Sample Maximum DP Differential Reflectivity" ;
	GR_Zdr_Max_NS:units = "dB" ;
	GR_Zdr_Max_NS:_FillValue = -888.f ;
float GR_Kdp_NS(elevationAngle, fpdim_NS) ;
	GR_Kdp_NS:long_name = "DP Specific Differential Phase" ;
	GR_Kdp_NS:units = "deg/km" ;
	GR_Kdp_NS:_FillValue = -888.f ;
float GR_Kdp_StdDev_NS(elevationAngle, fpdim_NS) ;
	GR_Kdp_StdDev_NS:long_name = "Standard Deviation of DP Specific Differential Phase" ;
	GR_Kdp_StdDev_NS:units = "deg/km" ;
	GR_Kdp_StdDev_NS:_FillValue = -888.f ;
float GR_Kdp_Max_NS(elevationAngle, fpdim_NS) ;
	GR_Kdp_Max_NS:long_name = "Sample Maximum DP Specific Differential Phase" ;
	GR_Kdp_Max_NS:units = "deg/km" ;
	GR_Kdp_Max_NS:_FillValue = -888.f ;
float GR_RHOhv_NS(elevationAngle, fpdim_NS) ;
	GR_RHOhv_NS:long_name = "DP Co-Polar Correlation Coefficient" ;
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```
        GR_RHOhv_NS:units = "Dimensionless" ;
        GR_RHOhv_NS:_FillValue = -888.f ;
    float GR_RHOhv_StdDev_NS(elevationAngle, fpdim_NS) ;
        GR_RHOhv_StdDev_NS:long_name = "Standard Deviation of DP Co-Polar Correlation Coefficient" ;
        GR_RHOhv_StdDev_NS:units = "Dimensionless" ;
        GR_RHOhv_StdDev_NS:_FillValue = -888.f ;
    float GR_RHOhv_Max_NS(elevationAngle, fpdim_NS) ;
        GR_RHOhv_Max_NS:long_name = "Sample Maximum DP Co-Polar Correlation Coefficient" ;
        GR_RHOhv_Max_NS:units = "Dimensionless" ;
        GR_RHOhv_Max_NS:_FillValue = -888.f ;
    float GR_rainrate_NS(elevationAngle, fpdim_NS) ;
        GR_rainrate_NS:long_name = "GV radar DP Rainrate" ;
        GR_rainrate_NS:units = "mm/h" ;
        GR_rainrate_NS:_FillValue = -888.f ;
    float GR_rainrate_StdDev_NS(elevationAngle, fpdim_NS) ;
        GR_rainrate_StdDev_NS:long_name = "Standard Deviation of GV radar DP Rainrate" ;
        GR_rainrate_StdDev_NS:units = "mm/h" ;
        GR_rainrate_StdDev_NS:_FillValue = -888.f ;
    float GR_rainrate_Max_NS(elevationAngle, fpdim_NS) ;
        GR_rainrate_Max_NS:long_name = "Sample Maximum GV radar DP Rainrate" ;
        GR_rainrate_Max_NS:units = "mm/h" ;
        GR_rainrate_Max_NS:_FillValue = -888.f ;
    short GR_HID_NS(elevationAngle, fpdim_NS, hidim) ;
        GR_HID_NS:long_name = "DP Hydrometeor Identification" ;
        GR_HID_NS:units = "Categorical" ;
        GR_HID_NS:_FillValue = -888s ;
    float GR_Dzero_NS(elevationAngle, fpdim_NS) ;
        GR_Dzero_NS:long_name = "DP Median Volume Diameter" ;
        GR_Dzero_NS:units = "mm" ;
        GR_Dzero_NS:_FillValue = -888.f ;
    float GR_Dzero_StdDev_NS(elevationAngle, fpdim_NS) ;
        GR_Dzero_StdDev_NS:long_name = "Standard Deviation of DP Median Volume Diameter" ;
        GR_Dzero_StdDev_NS:units = "mm" ;
        GR_Dzero_StdDev_NS:_FillValue = -888.f ;
```

```
float GR_Dzero_Max_NS(elevationAngle, fpdim_NS) ;
        GR_Dzero_Max_NS:long_name = "Sample Maximum DP Median Volume Diameter" ;
        GR_Dzero_Max_NS:units = "mm" ;
        GR_Dzero_Max_NS:_FillValue = -888.f ;
float GR_Nw_NS(elevationAngle, fpdim_NS) ;
        GR_Nw_NS:long_name = "DP Normalized Intercept Parameter" ;
        GR_Nw_NS:units = "1/(mm*m^3)" ;
        GR_Nw_NS:_FillValue = -888.f ;
float GR_Nw_StdDev_NS(elevationAngle, fpdim_NS) ;
        GR_Nw_StdDev_NS:long_name = "Standard Deviation of DP Normalized Intercept Parameter" ;
        GR_Nw_StdDev_NS:units = "1/(mm*m^3)" ;
        GR_Nw_StdDev_NS:_FillValue = -888.f ;
float GR_Nw_Max_NS(elevationAngle, fpdim_NS) ;
        GR_Nw_Max_NS:long_name = "Sample Maximum DP Normalized Intercept Parameter" ;
        GR_Nw_Max_NS:units = "1/(mm*m^3)" ;
        GR_Nw_Max_NS:_FillValue = -888.f ;
short n_gr_z_rejected_NS(elevationAngle, fpdim_NS) ;
        n_gr_z_rejected_NS:long_name = "number of bins below GR_dBZ_min in GR_Z average" ;
        n_gr_z_rejected_NS:_FillValue = -888s ;
short n_gr_zdr_rejected_NS(elevationAngle, fpdim_NS) ;
        n_gr_zdr_rejected_NS:long_name = "number of bins with missing Zdr in GR_Zdr average" ;
        n_gr_zdr_rejected_NS:_FillValue = -888s ;
short n_gr_kdp_rejected_NS(elevationAngle, fpdim_NS) ;
        n_gr_kdp_rejected_NS:long_name = "number of bins with missing Kdp in GR_Kdp average" ;
        n_gr_kdp_rejected_NS:_FillValue = -888s ;
short n_gr_rhohv_rejected_NS(elevationAngle, fpdim_NS) ;
        n_gr_rhohv_rejected_NS:long_name = "number of bins with missing RHOhv in GR_RHOhv average" ;
        n_gr_rhohv_rejected_NS:_FillValue = -888s ;
short n_gr_rr_rejected_NS(elevationAngle, fpdim_NS) ;
        n_gr_rr_rejected_NS:long_name = "number of bins below rain_min in GR_rainrate average" ;
        n_gr_rr_rejected_NS:_FillValue = -888s ;
short n_gr_hid_rejected_NS(elevationAngle, fpdim_NS) ;
        n_gr_hid_rejected_NS:long_name = "number of bins with undefined HID in GR_HID histogram" ;
        n_gr_hid_rejected_NS:_FillValue = -888s ;
```

```
short n_gr_dzero_rejected_NS(elevationAngle, fpdim_NS) ;
        n_gr_dzero_rejected_NS:long_name = "number of bins with missing D0 in GR_Dzero average" ;
        n_gr_dzero_rejected_NS:_FillValue = -888s ;
short n_gr_nw_rejected_NS(elevationAngle, fpdim_NS) ;
        n_gr_nw_rejected_NS:long_name = "number of bins with missing Nw in GR_Nw average" ;
        n_gr_nw_rejected_NS:_FillValue = -888s ;
short n_gr_expected_NS(elevationAngle, fpdim_NS) ;
        n_gr_expected_NS:long_name = "number of bins in GR_Z average" ;
        n_gr_expected_NS:_FillValue = -888s ;
float precipTotPSDparamHigh_NS(elevationAngle, fpdim_NS) ;
        precipTotPSDparamHigh_NS:long_name = "2B-DPRGMI precipTotPSDparamHigh for NS swath" ;
        precipTotPSDparamHigh_NS:units = "mm_Dm" ;
        precipTotPSDparamHigh_NS:_FillValue = -888.f ;
float precipTotPSDparamLow_NS(elevationAngle, fpdim_NS, nPSDlo) ;
        precipTotPSDparamLow_NS:long_name = "2B-DPRGMI precipTotPSDparamLow for NS swath" ;
        precipTotPSDparamLow_NS:units = "Nw_mu" ;
        precipTotPSDparamLow_NS:_FillValue = -888.f ;
float precipTotRate_NS(elevationAngle, fpdim_NS) ;
        precipTotRate_NS:long_name = "2B-DPRGMI precipTotRate for NS swath" ;
        precipTotRate_NS:units = "mm/h" ;
        precipTotRate_NS:_FillValue = -888.f ;
float precipTotWaterCont_NS(elevationAngle, fpdim_NS) ;
        precipTotWaterCont_NS:long_name = "2B-DPRGMI precipTotWaterCont for NS swath" ;
        precipTotWaterCont_NS:units = "g/m^3" ;
        precipTotWaterCont_NS:_FillValue = -888.f ;
short n_precipTotPSDparamHigh_rejected_NS(elevationAngle, fpdim_NS) ;
        n_precipTotPSDparamHigh_rejected_NS:long_name = "number of bins below rain_min in precipTotPSDparamHigh
            average for NS swath" ;
        n_precipTotPSDparamHigh_rejected_NS:_FillValue = -888s ;
short n_precipTotPSDparamLow_rejected_NS(elevationAngle, fpdim_NS, nPSDlo) ;
        n_precipTotPSDparamLow_rejected_NS:long_name = "number of bins below rain_min in precipTotPSDparamLow
            average for NS swath" ;
        n_precipTotPSDparamLow_rejected_NS:_FillValue = -888s ;
short n_precipTotRate_rejected_NS(elevationAngle, fpdim_NS) ;
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        n_precipTotRate_rejected_NS:long_name = "number of bins below rain_min in precipTotRate average
            for NS swath" ;
        n_precipTotRate_rejected_NS:_FillValue = -888s ;
    short n_precipTotWaterCont_rejected_NS(elevationAngle, fpdim_NS) ;
        n_precipTotWaterCont_rejected_NS:long_name = "number of bins below rain_min in precipTotWaterCont
            average for NS swath" ;
        n_precipTotWaterCont_rejected_NS:_FillValue = -888s ;
    int precipitationType_NS(fpdim_NS) ;
        precipitationType_NS:long_name = "2B-DPRGMI precipitationType for NS swath" ;
        precipitationType_NS:units = "Categorical" ;
        precipitationType_NS:_FillValue = -888 ;
    float surfPrecipTotRate_NS(fpdim_NS) ;
        surfPrecipTotRate_NS:long_name = "2B-DPRGMI surfPrecipTotRate for NS swath" ;
        surfPrecipTotRate_NS:units = "mm/h" ;
        surfPrecipTotRate_NS:_FillValue = -888.f ;
    float surfaceElevation_NS(fpdim_NS) ;
        surfaceElevation_NS:long_name = "2B-DPRGMI surfaceElevation for NS swath" ;
        surfaceElevation_NS:units = "m" ;
        surfaceElevation_NS:_FillValue = -888.f ;
    int surfaceType_NS(fpdim_NS) ;
        surfaceType_NS:long_name = "2B-DPRGMI surfaceType for NS swath" ;
        surfaceType_NS:units = "Categorical" ;
        surfaceType_NS:_FillValue = -888 ;
    short phaseBinNodes_NS(fpdim_NS, nPhsBnN) ;
        phaseBinNodes_NS:long_name = "2B-DPRGMI phaseBinNodes for NS swath" ;
        phaseBinNodes_NS:units = "None" ;
        phaseBinNodes_NS:_FillValue = -888s ;
    float DPRlatitude_NS(fpdim_NS) ;
        DPRlatitude_NS:long_name = "Latitude of DPR surface bin for NS swath" ;
        DPRlatitude_NS:units = "degrees North" ;
        DPRlatitude_NS:_FillValue = -888.f ;
    float DPRlongitude_NS(fpdim_NS) ;
        DPRlongitude_NS:long_name = "Longitude of DPR surface bin for NS swath" ;
        DPRlongitude_NS:units = "degrees East" ;
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        DPRlongitude_NS:_FillValue = -888.f ;
    short scanNum_NS(fpdim_NS) ;
        scanNum_NS:long_name = "product-relative zero-based DPR scan number for NS swath" ;
        scanNum_NS:_FillValue = -888s ;
    short rayNum_NS(fpdim_NS) ;
        rayNum_NS:long_name = "product-relative zero-based DPR ray number for NS swath" ;
        rayNum_NS:_FillValue = -888s ;
    float ellipsoidBinOffset_NS(fpdim_NS) ;
        ellipsoidBinOffset_NS:long_name = "2B-DPRGMI ellipsoidBinOffset for NS swath" ;
        ellipsoidBinOffset_NS:units = "m" ;
        ellipsoidBinOffset_NS:_FillValue = -888.f ;
    short lowestClutterFreeBin_NS(fpdim_NS) ;
        lowestClutterFreeBin_NS:long_name = "2B-DPRGMI lowestClutterFreeBin for NS swath" ;
        lowestClutterFreeBin_NS:units = "None" ;
        lowestClutterFreeBin_NS:_FillValue = -888s ;
    int precipitationFlag_NS(fpdim_NS) ;
        precipitationFlag_NS:long_name = "2B-DPRGMI precipitationFlag for NS swath" ;
        precipitationFlag_NS:units = "Categorical" ;
        precipitationFlag_NS:_FillValue = -888 ;
    short surfaceRangeBin_NS(fpdim_NS) ;
        surfaceRangeBin_NS:long_name = "2B-DPRGMI surfaceRangeBin for NS swath" ;
        surfaceRangeBin_NS:units = "None" ;
        surfaceRangeBin_NS:_FillValue = -888s ;
    float correctedReflectFactor_NS(elevationAngle, fpdim_NS) ;
        correctedReflectFactor_NS:long_name = "2B-DPRGMI Corrected Reflectivity Factor for NS swath" ;
        correctedReflectFactor_NS:units = "dBZ" ;
        correctedReflectFactor_NS:_FillValue = -888.f ;
    float pia_NS(fpdim_NS) ;
        pia_NS:long_name = "2B-DPRGMI Path Integrated Attenuation for NS swath" ;
        pia_NS:units = "dB" ;
        pia_NS:_FillValue = -888.f ;
    short n_correctedReflectFactor_rejected_NS(elevationAngle, fpdim_NS) ;
        n_correctedReflectFactor_rejected_NS:long_name = "number of bins below DPR_dBZ_min in
            correctedReflectFactor average" ;
```

```
        n_correctedReflectFactor_rejected_NS:_FillValue = -888s ;
    short n_dpr_expected_NS(elevationAngle, fpdim_NS) ;
        n_dpr_expected_NS:long_name = "number of expected bins in DPR averages for NS swath" ;
        n_dpr_expected_NS:_FillValue = -888s ;
    double timeNearestApproach ;
        timeNearestApproach:units = "seconds" ;
        timeNearestApproach:long_name = "Seconds since 01-01-1970 00:00:00" ;
        timeNearestApproach:_FillValue = 0. ;
    char atimeNearestApproach(len_atime_ID) ;
        atimeNearestApproach:long_name = "text version of timeNearestApproach, UTC" ;
    double timeSweepStart(elevationAngle) ;
        timeSweepStart:units = "seconds" ;
        timeSweepStart:long_name = "Seconds since 01-01-1970 00:00:00" ;
        timeSweepStart:_FillValue = 0. ;
    char atimeSweepStart(elevationAngle, len_atime_ID) ;
        atimeSweepStart:long_name = "text version of timeSweepStart, UTC" ;
    char site_ID(len_site_ID) ;
        site_ID:long_name = "ID of Ground Radar Site" ;
    float site_lat ;
        site_lat:long_name = "Latitude of Ground Radar Site" ;
        site_lat:units = "degrees North" ;
        site_lat:_FillValue = -888.f ;
    float site_lon ;
        site_lon:long_name = "Longitude of Ground Radar Site" ;
        site_lon:units = "degrees East" ;
        site_lon:_FillValue = -888.f ;
    float site_elev ;
        site_elev:long_name = "Elevation of Ground Radar Site above MSL" ;
        site_elev:units = "km" ;
    float version ;
        version:long_name = "Geo Match File Version" ;

// global attributes:
```

```
:DPR_Version = "V02A" ;
:GV_UF_Z_field = "CZ" ;
:GV_UF_ZDR_field = "DR" ;
:GV_UF_KDP_field = "KD" ;
:GV_UF_RHOHV_field = "RH" ;
:GV_UF_RR_field = "RR" ;
:GV_UF_HID_field = "FH" ;
:GV_UF_D0_field = "D0" ;
:GV_UF_NW_field = "NW" ;
:DPR_2BCMB_file = "2B-CS-CONUS.GPM.DPRGMI.CORRA2014.20140311-S213153-E214032.000190.V02A.HDF5" ;
:GR_file = "KARX_2014_0311_213816.uf.gz" ;
```

NOTES:

1) The variables **topHeight** and **bottomHeight** are in units of km above ground level (km AGL). Assuming all heights are in units of km, then the variable **site_elev** (km above MSL) relates heights above mean sea level (MSL) and AGL:

```
HeightAGL = HeightMSL - site_elev
```

2) Actual values for the dimension variables "**fpdim_MS**", "**fpdim_NS**", "**elevationAngle**", "**timedimid_MS**", and "**timedimid_NS**" must be specified at time of netCDF file creation. The fpdim dimensions represent the number of DPR footprints in the DPR/GR overlap area for the indicated swath type. The timedimid dimensions represent the number of DPR scans in the overlap area for the indicated swath type.

4. Directory Structure of the VN ftp site

This section describes the directory structure for the VN data ftp site:

ftp://hector.gsfc.nasa.gov/gpm-validation/data/gpmgv

In the directory structures shown below, all directory and filename values and/or fields indicated in regular text are literal fields that never vary from those shown. The fields shown in ***bold italics*** vary according to the value of the field code they represent. Fields enclosed in [brackets] are optional, and the brackets are not part of the file names. The field codes are defined in Table 4-1.

/coincidence_tables (Note-1)
    /***YYYY***
        /***MM***
            /***DD***/
                CT***.SSSS.YYYYMMDD.jjj***.txt
                CT***.SSSS.YYYYMMDD.jjj***.unl

/db_backup/ (Note-2)
    gpmgvDBdump.gz
    gpmgvDBdump.old.gz

/gv_radar (Note-3)
    /finalQC_in (Note-3)
        /***xxxx***
            /1CUF
                /***YYYY***
                    /***MMDD***/
                        XXXX_YYYY_MMDD_hhmmss.uf.gz (Note-6)
                        XXXX_YYYY_MMDD_hhmmss_rhi.uf.gz (Note-6)
            /images
                /***YYYY***
                    /***MMDD***/
                        XXXX _YYYY_MMDD_hhmmss_FF.swe***e***_PPI.png
            /raw
                /***YYYY***
                    /***MMDD***/
                        XXXXYYYYMMDD_hhmmss.gz

/mosaicimages (Note-4)
    /archivedmosaic/
        YYYY-MM-DD_hhmm.gif

/netcdf (Note-5)
/geomatch/
GRtoDPR.***XXXX.YYMMDD.#####.version.type.scan.V_v.***nc.gz
GRtoDPR.***XXXX.YYMMDD.#####.version.type.scan.V_v.***RHI.nc.gz
GRtoDPRGMI.***XXXX.YYMMDD.#####.***nc.gz
GRtoGMI.***XXXX.YYMMDD.#####.***nc.gz

/orbit_subset
/SSSS
/instrument
/algorithm
/version
/UUUU
/YYYY
/MM
/DD/
PPS_filename

Table 4-1. Field Definitions for Directory and Filename Conventions

Field Code or Name	Definition
#####	Satellite orbit number, 1 to 6 digits
algorithm	Product algorithm (For GPM: 2ADPR, 2AKa, 2AKu, 2AGPROF, 2BDPRGMI)
ee	sequential elevation sweep number, zero-based
FF	radar field variable: DZ (reflectivity), CZ (post-QC reflectivity), VR (radial velocity), DR (differential reflectivity), KD (Kdp), PH (Differential Phase), RH (RHOhv), SD (), ZZ ()
hhmm	2-digit hour (hh) and minute (mm)
hhmmss	2-digit hour (hh), minute (mm), and second (ss)
instrument	Satellite instrument ID: DPR, Ka, Ku, GMI, DPRGMI, SSMIS, TMI, etc.
MM	2-digit month
MMDD	2-digit month (MM) and day of month (DD)
N	nominal hour of data, from rounding up (1-24)
PPS_filename	Data file name formatted according to the PPS File Naming Convention. Refer to the document: ***File Naming Convention for Precipitation Products For the Global Precipitation Measurement (GPM) Mission, PPS_610.2_P550.*** EXAMPLE: 2A-CS-CONUS.GPM.Ku.V5-20140617.20140704-S230210-E230826.001980.V02A.HDF5

Field Code or Name	Definition
SSSS	Satellite identifier (F15, F16, F17, F18, GCOMW1, GPM, METOPA, NOAA18, NOAA19, TRMM)
scan	DPR scan type used in the GR-DPR matchup: HS, MS, or NS
type	DPR product subtype: DPR, Ka, or Ku
UUUU	CS (Coincidence Subset) Product Subset ID for products from the PPS
version	product algorithm major/minor version, e.g., V02B
V_v	Volume matching file major (V) and minor (v) version number, e.g., 2_1
xxxx	lower-case version of XXXX
XXXX	radar station ID (e.g., Table 1-1)
YYMM	2-digit year (YY) and month (MM)
[YY]YYMMDD	2- or 4-digit year (YY or YYYY), month (MM), and day of month (DD)
YYYY	4-digit year

Note-1. Files in the **coincidence_tables** directory are satellite-specific Daily Coincidence Table (CT) files from the Precipitation Processing Subsystem (PPS). The tables contain the orbit number, date, time, distance, and direction of the satellite orbital subtrack's nearest approach to the ground radar sites configured for this purpose in the PPS. The CT cutoff distance is 700 km. Files in the form CT***.SSSS.YYYYMMDD.jjj***.txt are the complete, original CT files from the PPS. Those with the ".unl" file extension contain CT data reformatted in a form to be loaded in the GPM GV PostgreSQL database, for only the ground radar sites used in the GPM Validation Network.

Note-2. Files in the **db_backup** directory contain a backup (dump) of the GPM VN's PostgreSQL database 'gpmgv', created using the pg_dump utility, and compressed using gzip. The latest dump of the database is in the file 'gpmgvDBdump.gz'. This file is renamed to 'gpmgvDBdump.old.gz' as each new backup is performed. Only the current and previous dumps are retained.

Note-3. The files in under the top-level **gv_radar** directory contain ground radar data in multiple file formats. These radar data come mostly from U.S. domestic WSR-88D radars, but data from other ground radars are also located in this directory structure. Files that fall under the directory **raw** are original-format radar data files for the given radar site. Files under the higher-level directory **1CUF** are those that were subject to both automated and human quality control and, optionally, computation of additional dual-polarization data fields. The files in the **1CUF** subdirectories contain a full volume scan of ground radar data conforming to the "Universal Format" (UF) data format. Each data file contains data for one ground radar volume scan. Within the individual data file names, the fixed field "uf " designates that this is a radar file in Universal Format.

Files in the **images** subdirectories are Plan Position Indicator (PPI) display images of various data fields from the ground radar, for selected elevation sweeps. The variable fields FF in the individual file names indicate the data field plotted in the PPI image. Within the individual data file names, the fixed field "png" designates that the image file is in PNG image format.

Files in the **raw** subdirectory are the original radar data files in their native format, as obtained from the data source. For the WSR-88D sites, the files are in the NEXRAD Level-II archive format, not to be confused with the TRMM GV Level 2 gridded radar products (refer to Vol.1 of this document).

Note-4. Files under the **mosaicimages** directory are National Weather Service (NWS) WSR-88D national-scale radar mosaic images (RIDGE mosaics). RIDGE national mosaics are produced every 10 minutes by the NWS. Only those mosaics corresponding to the time of GPM and TRMM overpasses of the GPM Validation Network area in the continental U.S. are contained in the **archivedmosaic** subdirectory.

Note-5. The two types of GPM-specific files in the **netcdf/geo_match** directory structure contain (1) geometrically-matched ground radar and GPM Precipitation Radar (GRtoDPR) data, and (2) geometrically matched ground radar and GPM Microwave Imager (GRtoGMI) data, in netCDF format as described above in Section 2 of the VN Data User's Guide. Each file corresponds to single ground radar volume scan taken nearest in time to where a GPM satellite orbit's subtrack passes within 200 km of the ground radar during a "significant" rainfall event. . The addition of the "**.RHI**" designator in the file name indicates use of an RHI volume scan for the GR data.

Note-6. The filename convention for the 1CUF files changed beginning with the inclusion of dual-polarimetric variables in the data files. Prior to the dual-pol upgrade, the name convention followed the ***YYMMDD.N.TTTT.V.hhmm***.uf.gz pattern. After the upgrade and once TRMM GV began to include the dual-polarization data variables in the files, the name convention changes to the ***XXXX_YYYY_MMDD_hhmmss***.uf.gz pattern. The dual-polarization file names include the NWS site identifiers (XXXX field) in the 1CUF file names and directory trees, such that the legacy TRMM GV site IDs for the WSR-88D sites are no longer used in the 1CUF file names. The date of the changeover to dual-polarization data files differs by site, but predates the GPM era. The addition of the "**_rhi**" designator in the file name following ***hhmmss*** indicates an RHI scan type.

Note-7. The Coincidence Subset (CS) product subset identifiers are short descriptive names for the rectangular latitude/longitude area boundaries defining the area of coverage for the product subset. The identifiers and the latitude/longitude boundaries defining the CS areas are defined in Table 4-2. The orbit subset products are produced for a given CS area and instrument whenever one or more "surface footprints" in the instrument's scan strategy lies within the latitude/longitude rectangle defining the CS region. Complete scan lines for all scans with at least one footprint in the CS area are included in the CS product, regardless of the fraction of the scan that overlaps the CS area. That is, the scan data are not strictly clipped to the CS rectangle.

Table 4-2. Coincidence Subset geographical definitions for VN orbit subsets

CSI Name	Description	North latitude bound	South latitude bound	West longitude bound	East longitude bound
AKradars	PAIH WSR-88D radar (Middleton Island, Alaska)	66.5 N	55.0 N	-167.0 E	-134.0 E
CONUS	Contiguous 48 United States	50.0 N	23.0 N	-126.0 E	-66.0 E
DARW	Darwin, Australia CPOL radar	-14.5 N	-10.0 N	128.74 E	133.35 E
KOREA	Korean radars	32.5 N	39.0 N	124.5 E	130.5 E
KWAJ	Kwajalein KPOL radar	6.47 N	10.97 N	165.47 E	170.01 E

5. Geometry Matching Algorithm Descriptions

The following sections provide a high-level schematic of the DPR-GR and TMI-GR geometry matching algorithms. The DPRGMI-GR is essentially identical to the DPR-GR algorithm. Detailed documentation of the algorithms is contained in the source code.

5.1 DPR match-up sampling to GR

The basic DPR-to-GR data processing algorithm is as follows:

1. For each DPR ray in the product, compute the range of the ray's earth intersection point from the ground radar location. If greater than 100 km (adjustable at run time; see ***rangeThreshold*** variable in netCDF matchup file), ignore the ray. If within 100 km, proceed as follows:
2. Examine the corrected reflectivity values along the DPR ray. If one or more gates are at or above a specified threshold (18 dBZ by default, see ***DPR_dBZ_min*** variable in netCDF matchup file), proceed with processing the ray, otherwise set the DPR and GR match-up values to "below threshold" and proceed to the next DPR ray.
3. Using the range from step 1, determine the height above ground level where the DPR ray intersects the centerline of each of the elevation sweeps of the GR, and the width (as a vertical distance) of the GR beam at this range;
4. Compute a parallax-adjusted location of the DPR footprint center at each GR sweep intersection height from step 3, as a function of height, the DPR ray angle relative to nadir, and the orientation (azimuth) of the DPR scan line. Retain these adjusted horizontal locations for the processing of the GR data;
5. Using the beam heights and widths from step 3, compute the upper and lower bound heights of each GR sweep at its intersection with the DPR ray, correcting for height above MSL (the earth ellipsoid) as required for the DPR height definition;
6. For each GR sweep intersection, determine the total number, and along-ray positions, of the DPR range gates geometrically located between the upper and lower bound heights from step 5, accounting for DPR scan angle away from nadir in computing the DPR gate heights;
7. For the DPR 3-D fields, perform a simple average of values over the set of range gates identified in step 6, for each GR sweep intersection (Figure 2-2). If any of these DPR range gates is below the lowest clutter-free gate, leave them out of the computation. If ALL of these gates are below the lowest clutter-free gate, then take the lowest clutter-free gate reflectivity value as the sample average DPR reflectivity. Set the clutterStatus variable value according which of these three actions were taken. Reflectivity is converted from dBZ to Z before averaging, then the average Z is converted back to dBZ. Only those gates with values at or above specified reflectivity (18 dBZ) or rain rate (0.01 mm h^{-1}) thresholds are included in the average. Keep track of the number of below-threshold DPR gates *rejected* from the vertical averages, and the number of gates *expected* in the

averages from a geometric standpoint (from step 6);

8. For the 2-D DPR field values (e.g., surface rain rate, bright band height), simply extract or derive the scalar field value for the given DPR ray.
9. Using the parallax-adjusted locations of the DPR footprints from step 4, compute the four x- and y-corners of the DPR footprint, which can be used to plot the DPR data on a map or image in a contiguous, non-overlapping manner. Each corner point is computed as the midway point between the DPR footprint center x,y coordinates and those of the four diagonally-adjacent DPR footprints (extrapolated if at the edge of the DPR scan). These corner coordinates do not represent the area of the actual DPR measurement in any physical manner.

The 3-D DPR fields which are vertically averaged, yielding one value per intersected GR sweep per DPR ray, include:

- Raw DPR reflectivity (ZFactorMeasured in 2A product)
- Attenuation-Corrected DPR reflectivity (ZFactorCorrected in 2A product)
- Rain rate (mm/h) (PrecipRate in 2A product)

The 2-D DPR variables which are taken unaveraged, one value per DPR ray, include:

- Surface type (land/ocean/coastal) flag (LandSurfaceType)
- Near-surface rain rate, mm/h (PrecipRateSurface)
- Bright band height and status (BBheight, BBstatus)
- Rain type categorization (convective, stratiform, other) (TypePrecip)
- Rain/no-rain flag (FlagPrecip).

These scalar values are directly extracted and/or derived from data fields within DPR level 2A products (2A-DPR, 2A-Ka, 2A-Ku).

5.2 GR match-up sampling to DPR

The basic GR-to-DPR data processing algorithm is as follows:

1. For each DPR ray processed (i.e., not skipped in Step 2, above), and for each elevation sweep of the GR, repeat the following:
2. Compute the along-ground distance between each GR bin center and the parallax-adjusted DPR footprint center (from DPR step 4);
3. Flag the GR bins within a fixed distance of the DPR center. The fixed distance is equivalent to the maximum radial size of all the DPR footprints processed. Ignore GR bins above 20 km above ground level
4. Examine the reflectivity values of the flagged GR bins from step 3. If all values fall below 0.0 dBZ, then skip processing for the point and set its match-up value to "below threshold". Otherwise:
5. Perform an inverse distance weighted average of the GR reflectivity values over the bins from step 4 (Figure 2-3), using a Barnes gaussian weighting. Reflectivity

is converted from dBZ to Z before averaging, then the average Z is converted back to dBZ. All GR bins with values at or above 0.0 dBZ are included in the average. Keep track of the total number of bins included in the average, and the number of these GR bins with values meeting a specified reflectivity threshold (GR_dBZ_min variable in netCDF file; 15 dBZ by default). Also compute the maximum and the standard deviation of reflectivity among the bins included in the average.

6. Repeat steps 4 and 5 for the ground radar dual-polarization variables except hydrometeor type (GR_HID), but doing a simple arithmetic average of all non-missing data values (no conversion to/from dBZ). For GR_HID, just determine the number of bins in each HID category and save the array of counts.

5.3 GMI match-up sampling

The only computations that take place on the GMI data are to determine which GMI footprints are within a given range threshold of the GR site, and for each in-range GMI footprint, to compute the intersection of the GMI instrument field-of-view with each of the GR sweeps. The basic GMI-to-GR data processing algorithm is as follows:

1. For each GMI footprint in the product, compute the range of the footprint's earth intersection point from the ground radar location. If greater than 100 km (adjustable), ignore the ray. If within 100 km, proceed as follows:
2. Compute the azimuth between the GMI footprint and the GPM satellite's nadir subpoint. This gives the earth-relative direction along which the GMI is viewing.
3. Using the range and azimuth from steps 1 and 2, and the fixed GMI scan incidence angle relative to the ground, determine the height above ground level where the GMI view centerline intersects the centerline of each of the elevation sweeps of the GR, and the width (as a vertical distance) of the GR beam at this range;
4. Compute a parallax-adjusted location of the GMI footprint center at each GR sweep intersection height from step 3, as a function of height, the GMI incidence angle, and the orientation (azimuth) of the GMI scan line. Retain these adjusted horizontal locations for the processing of the GR data;
5. Using the beam heights and widths from step 3, compute the upper and lower bound heights of each GR sweep at its intersection with the GMI scan sample;
6. Taking the GMI footprint's surface position, and ignoring GMI viewing parallax, project the GMI footprint along the local vertical to the earth surface and determine the height above ground level where local vertical intersects the centerline of each of the elevation sweeps of the GR, and the width (as a vertical distance) of the GR beam at this range. Retain the unadjusted surface footprint locations for the processing of the GR data;
7. Using the beam heights and widths from step 6, compute the upper and lower bound heights of each GR sweep at its intersection with the local vertical above the GMI surface footprint;
8. For the 2-D GMI field values (e.g., surface rain rate), simply extract the scalar

field value for each in-range GMI footprint.

9. Using the parallax-adjusted locations of the GMI footprints from step 4, compute the four x- and y-corners of the GMI footprint, which can be used to plot the GMI data on a map or image in a contiguous, non-overlapping manner. Each corner point is computed as the midway point between the GMI footprint center x,y coordinates and those of the four diagonally-adjacent GMI footprints (extrapolated if at the edge of the GMI scan). These corner coordinates do not represent the area of the actual GMI measurement in any physical manner.

The GMI 2A-GPROF variables which are included in the matchups, one value per GR-GMI overlapping footprint, include:

- Surface rain rate, mm/h (surfacePrecipitation)
- GMI latitude (surface footprint center position) (XMIlatitude)
- GMI longitude (ditto) (XMIlongitude)
- Surface type (land/ocean/coast: surfaceTypeIndex)
- Data flag (pixelStatus)
- Probability of Precipitation (PoP)

These values are directly extracted from data fields within the GMI 2A-GPROF product.

5.4 GR match-up sampling to GMI

The GR-to-GMI algorithm is nearly identical to the GR-to-DPR algorithm, except for GMI we compute two sets of GR matchup samples, one along the sloping GMI instrument scan line-of-sight (Fig. 5.4-1), and one along the local vertical above the GMI surface footprint position (Fig. 5.4-2). The basic GR-to-GMI data processing algorithm is as follows:

1. For each in-range GMI footprint processed, and for each elevation sweep of the GR, repeat the following:
2. Compute the along-ground distance between each GR bin center and the parallax-adjusted GMI footprint center (from GMI step 4);
3. Flag the GR bins within a fixed distance of the GMI footprint center (Figure 5.4-1). The fixed distance is equivalent to the spacing between adjacent GMI surface footprints along a diagonal. Ignore GR bins above 20 km above ground level.
4. Examine the reflectivity values of the flagged GR bins from step 3. If all values fall below a 0.0 dBZ threshold, then skip processing for the point and set its match-up value to "below threshold". Otherwise:
5. Perform an inverse distance weighted average of the GR reflectivity values over the bins from step 4, using a Barnes gaussian weighting. Reflectivity is converted from dBZ to Z before averaging, then the average Z is converted back to dBZ. All GR bins with values at or above 0.0 dBZ are included in the average. Keep track of the total number of bins included in the average, and the number of these GR bins with values meeting a specified reflectivity threshold (15 dBZ by

default).

6. Repeat step 2, but for the unadjusted GMI footprint center (along the local vertical, from GMI step 6).
7. Repeat step 3 for the GMI footprint center in step 6, as shown in Fig. 5.4-2.
8. Repeat steps 4 and 5 for the GR bins flagged in step 7.

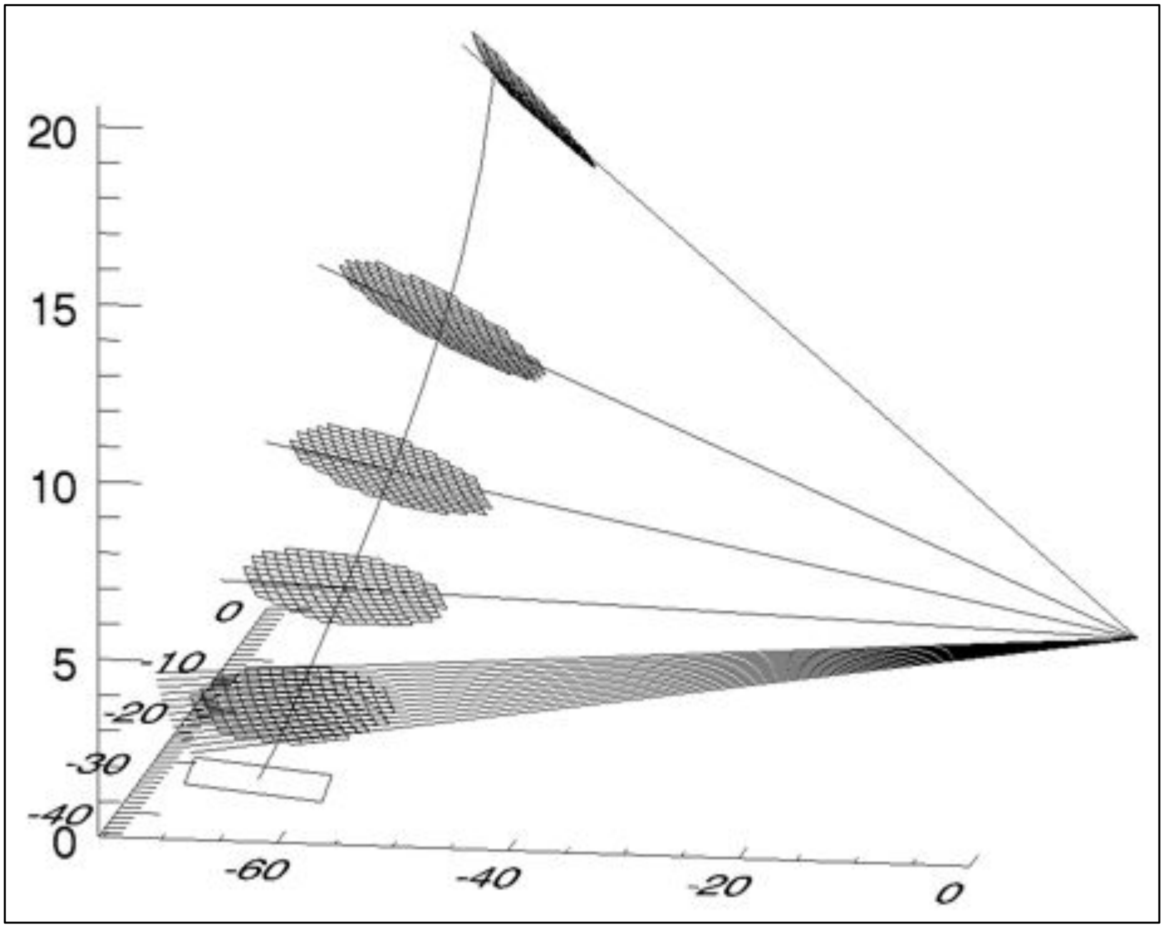

Figure 5.4-1. Schematic representation of GR volume matching to GMI along the GMI line-of-sight. Rectangular outline at surface locates the surface intersection of a single GMI surface footprint whose field-of-view centerline is shown as a slightly curving vertical line (due to the projection of the curved earth onto a flat surface). The "waffle" areas show the horizontal outline of GR gates mapped to the GMI footprint for individual elevation sweeps of the ground radar, which is located in the figure at X=0, Y=0, Z=0, where X, Y, and Z are in km. Sloping lines are drawn between the GR sample volumes and the ground radar along the sweep surfaces, where the lowest sweep shows the GR ray centers for each ray mapped to the GMI footprint. GR range gates are inverse-distance-weighted from the GMI field-of-view center to compute the GR averages for the matching volumes. Vertical extent and overlap of the GR gates is not shown, and only every third GR sweep is plotted for clarity. GR azimuth/range resolution is 1° by 1 km in the plot.

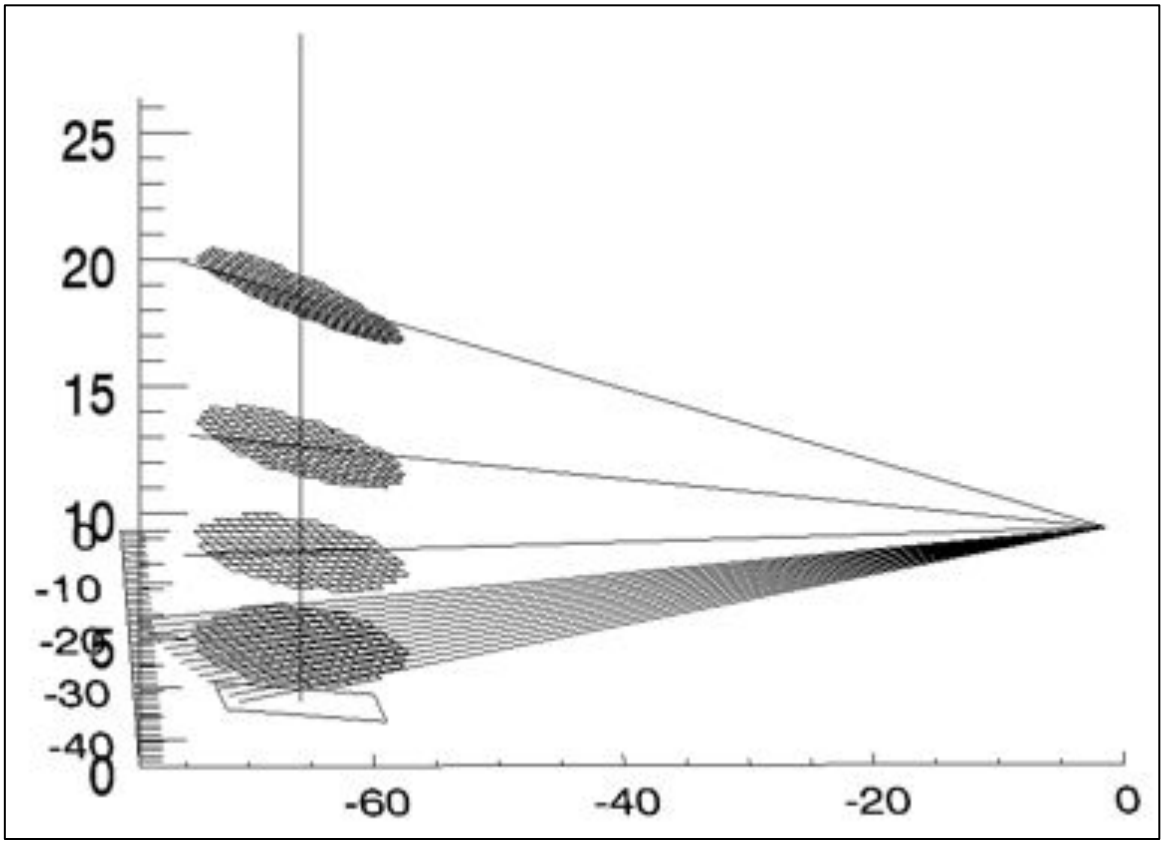

Figure 5.4-2. As in Figure 5.4-1, except GR averaging is along the local vertical above the GMI surface footprint center rather than along the GMI instrument line-of-sight.

6. Acronyms and Symbols

ACRONYM	DEFINITION
3-D	3-Dimensional
AGL	Above Ground Level
CSI	Coincident Subsetted Intermediate
DAAC	Distributed Active Archive Center
dBZ	Decibels (dB) of radar Reflectivity (Z)
DISC	(Goddard Earth Sciences) Data and Information Center
DP	Dual Polarization (radar)
DPR	(GPM) Dual-frequency Precipitation Radar
GMI	GPM Microwave Imager
GPM	Global Precipitation Measurement
GR, gr	Ground Radar (a.k.a. GV radar)
GSFC	Goddard Space Flight Center
GV	Ground Validation
GVS	Ground Validation System
HDF	Hierarchical Data Format (HDF-4 or HDF-5)
HID	Hydrometeor ID
ID	Identification, Identifier
IDL	Interactive Data Language
km	kilometers
m	meters
mm/h	millimeters (mm) per hour (h)
MSL	(above) Mean Sea Level
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research (part of UCAR)
netCDF	network Common Data Form
NEXRAD	Next-generation Weather Radar (a.k.a. "WSR-88D")
NOAA	National Oceanic and Atmospheric Administration
PMM	Precipitation Measuring Missions
PoP	Probability of Precipitation

ACRONYM	DEFINITION
PPI	Plan Position Indicator
PPS	Precipitation Processing Subsystem
PR	(TRMM) Precipitation Radar
QC	Quality Control
TMI	TRMM Microwave Imager
TRMM	Tropical Rainfall Measuring Mission
UCAR	University Corporation for Atmospheric Research
UF	(radar) Universal Format
US	United States
UTC	Coordinated Universal Time
VN	Validation Network
VPR	Vertical Profile of Reflectivity
WSR-88D	Weather Surveillance Radar - 1988 Doppler (a.k.a. "NEXRAD")

7. Appendix

Extended Abstract

SENSITIVITY OF SPACEBORNE AND GROUND RADAR COMPARISON
RESULTS TO DATA ANALYSIS METHODS AND CONSTRAINTS

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P68 SENSITIVITY OF SPACEBORNE AND GROUND RADAR COMPARISON RESULTS TO DATA ANALYSIS METHODS AND CONSTRAINTS

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1. INTRODUCTION

Numerous studies have compared reflectivity and derived rain rates from the space-based Precipitation Radar (PR) on board the Tropical Rainfall Measuring Mission (TRMM) satellite to similar observations from ground-based weather radars (GR), using a variety of algorithms to compute matching PR and GR volumes for comparison. Most studies have used a fixed 3-dimensional grid centered on the ground radar (e.g., Schumacher and Houze, 2000; Anagnostou et al., 2001; Liao et al., 2001; Wang and Wolff, 2009), onto which the PR and GR data are interpolated using a proprietary approach and/or commonly available GR analysis software (SPRINT, REORDER). Other studies have focused on the intersection of the PR and GR viewing geometries either explicitly (Bolen and Chandrasekar, 2000), or using a hybrid of the fixed grid and PR/GR common fields of view. For the Dual-Frequency Precipitation Radar (DPR) of the upcoming Global Precipitation Measurement (GPM) mission, a prototype DPR/GR comparison algorithm based on TRMM PR data has been developed that defines the common volumes in terms of the geometric intersection of PR and GR rays, where smoothing of the PR and GR data are minimized and no interpolation is performed (Schwaller and Morris, 2011).

The mean reflectivity differences between the PR and GR can differ between data sets produced by the different volume matching methods; and for the GPM prototype, by the type of constraints and categorization applied to the data. In this paper, we will show results comparing the 3-D gridded analysis "black box" approach to the GPM prototype geometry-matching approach, using matching TRMM PR and WSR-88D ground radar data. The effects of applying data constraints and data categorizations on the volume-matched data to the results, and explanations of the differences in terms of data and analysis algorithm characteristics are presented below. Implications of the differences to the determination of PR/DPR calibration differences and use of ground radar data to evaluate the PR and DPR attenuation correction algorithms are also discussed.

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2. DATA AND ANALYSIS CHARACTERISTICS

The geometry matching algorithm calculates PR and GR averages at the geometric intersection of the PR rays with the individual GR radar elevation sweeps. The along-ray PR data are averaged only in the vertical, between the top and bottom height of each GR elevation sweep it intersects (Figure 1). GR range bins are horizontally averaged over an area of coverage defined by the half-power points of each PR ray intersected, distance-weighted from the parallax-adjusted center of the PR beam. Each GR elevation sweep is treated separately. The volume-matched data are a set of conical surfaces retaining the vertical coverage defined by the elevation sweeps of the GR volume scan, but with horizontal resolution and location redefined by the PR's scan/ray coordinates. The data gaps between GR sweeps and the "cone of silence" above the highest sweep angle are retained in the geometry-match data set.

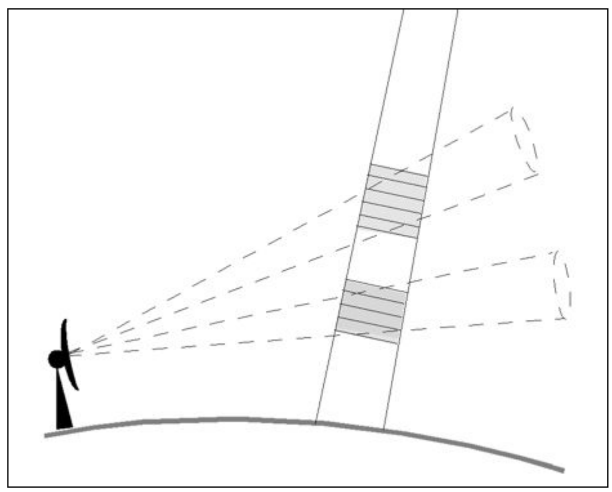

Figure 1. Schematic of PR ray /GR sweep intersections. Shaded areas are "matching volumes" showing the PR gates for one PR ray intersecting GR sweeps (dashed) at two different elevation angles. PR gates are 250 m along-ray by ~5 km in the horizontal.

Unlike the gridded approaches there is no interpolation, extrapolation, or oversampling of data, so matching volumes only exist at somewhat random locations where both the PR and GR instruments have taken actual observations. However, other than for the averaging required to produce the matching volumes, the data are not smoothed; and each sample volume is accompanied by metadata describing the variability and maximum of the reflectivity within the sample volume, and the fraction of range gates in the PR and GR sample averages having reflectivity values above an adjustable detection threshold (typically taken to be 18 dBZ for the PR). Sample volumes are further characterized by rain type (Stratiform or Convective), proximity to the melting layer, underlying surface (land/water/mixed), and the time difference between the PR and GR observations.

The approaches using analysis of PR and GR data to a fixed 3-dimensional grid centered on the GR treat the PR and GR data separately. While offering the simplicity of a regular coordinate system of fixed location and size, grids represent the scan pattern of neither instrument and thus require some amount of smoothing, interpolation, and extrapolation to attempt to fill as many grid points as possible with data values and fill reasonable gaps in the GR volume scan. All resulting non-missing data points are treated equally, whether or not one or both instruments made observations in the volume represented by the grid box.

In this study, we consider matched PR and GR reflectivity data from the grid-based volume matching algorithm and the geometry-match algorithm. PR data are from the TRMM 2A-25 attenuation-corrected reflectivity product, Version 6. GR data originate from the WSR-88D Level II Archive reflectivity product, which has been quality-controlled to remove non-precipitating echoes (Wolff et al, 2005). Only data samples within 100 km of the ground radar and the overlap of the PR data swath are evaluated. The 3-D grids used are of 4-km horizontal resolution and 1.5-km vertical resolution, with 13 levels centered between 1.5 and 19.5 km height above the GR.

PR data are analyzed to the grid following the methods applied by Liao, et al. (2001). Two different grid analysis methods are applied to the GR data. The first method takes the 2-km-resolution 2A-55 standard TRMM GV product and reduces it to 4 km resolution, as in Liao, et al. (2001). The second method analyzes the Level-II data to the 4-km, 13-level grid using the REORDER radar analysis software. For purposes of comparison to the gridded data, the geometry-match data are grouped into the same 13 vertical levels based on the midpoint height of each sample volume. A mean bright band height is computed for each coincident PR/GR rain case from information provided by the PR bright band detection algorithm, in order to subdivide the data by proximity to the bright band (above, within, or below).

In computing the mean reflectivity differences between the PR and GR, the matched volumes are subdivided into categories based on combinations of the following attributes common to both the grid-based and geometry-match data sets:

- TRMM orbit number (defines date and time of the event)
- GR site identifier
- height layer (13 layers, 1.5-19.5 km)
- proximity to bright band: above, within, or below
- rain type: stratiform, convective, or unknown
- distance from the GR (0-50, 51-100 km)

For each of the data categories defined by the permutations of these attributes, the mean difference between, and standard deviation of, the PR and GR reflectivity for the non-missing sample volumes in the category is computed separately for the grid data and the geometry match data and stored in a data table, along with the identifying attributes and the number of data samples included in the category.

Geometry-match data are subdivided by an additional attribute defined as the fraction of the sample with reflectivity above a minimum instrument detection threshold, defined as 18 dBZ for PR and 15 dBZ for the GR (to match the PR detection threshold but allow for a 3 dBZ calibration difference). The geometry matching algorithm determines, from a pure geometric standpoint, the locations of the PR and GR range bins that are "coincident", and the number of each (number PR expected, number GV expected). Then the reflectivity values of each range gate are evaluated before averaging. The number of PR bins below the 18 dBZ threshold (number PR rejected) and the number of GR bins below 15 dBZ (number GV rejected) are computed and related to each PR and GR sample volume. To compute the PR volume average, the algorithm leaves out those range bins below 18 dBZ and averages the remaining (the same approach is taken in determining the vertically-averaged PR reflectivity for a fixed layer in the grid-based algorithm). No range bins are left out in computing the reflectivity average, maximum, and standard deviation for the GR sample volumes, but those bins below 0.0 dBZ are set to 0.0 dBZ.

From these attributes, a percentage of each sample volume that is above its respective detection threshold is computed for the geometry-match PR and GR. Samples where both the PR and GR percent-above-threshold is non-zero includes all data points with a non-missing reflectivity value, and is akin to the grid-based approach. Restricting the data to samples with a PR and GR percent-above-threshold constraint of 100% provides the best and fairest comparison between the PR and GR instruments, where the entire PR sample volume is above the PR detection threshold, and the entire GR sample volume is filled with echoes above the PR detection threshold. One of the major goals of this study is to show the effects of varying the percent above threshold criteria on the PR-GR mean reflectivity differences. This study computed mean differences from the geometry-matched data for 11 categories of percent-above-threshold cutoff, ranging between 0 and 100%, by 10% steps.

3. SENSITIVITY TO FRACTION OF SAMPLE VOLUME ABOVE DETECTION THRESHOLD

Figures 2-5 show mean PR-GR reflectivity differences for all rainy overpasses at the KMLB (Melbourne, Florida) WSR-88D site from 13 August 2006 to 30 June 2008. KMLB was selected since previous studies have shown it to be closely calibrated to the PR and to have a stable calibration over time (Liao et al., 2001; Liao and Meneghini, 2009a). Figure 2 shows the differences for the convective rain, above bright band category, where the differences based on the geometry-match data have been further subdivided on a sample-by-sample basis by their percent of gates above threshold as described in the previous section. Outside of the percent above threshold, the grid-based results are for the matching categories (orbits, site, rain type, proximity to bright band). Data at height levels above the bright band are merged. Categories where no geometry match samples meet the percent above threshold criteria are eliminated from both the gridded and geometry match data for that percentage, but the gridded data are not otherwise filtered on a sample-by-sample basis.

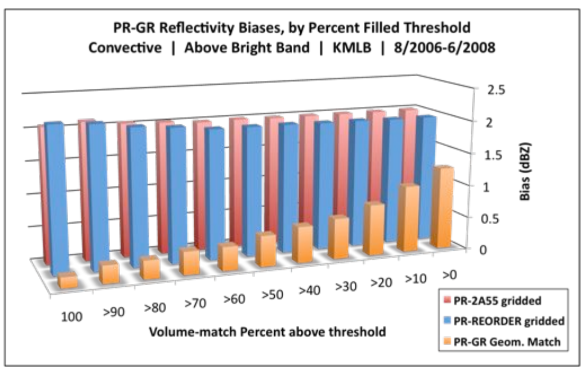

Figure 2. PR-GR reflectivity mean differences at KMLB for convective rain samples above the bright band, by percent above threshold category (see text). PR-2A55 and PR-REORDER series are based on gridded analyses. PR-GR series is from geometry-matched data, using percent above threshold categories from 0 to 100%.

Note the effect of varying the percent above threshold criteria on the PR and GR geometry-match results. As the percent of the sample volume filled with above-detection-threshold reflectivity bins increases, the high bias of the PR to the GR decreases, and vice versa. Much of this is explained by the averaging technique, where only PR bins of 18 dBZ or greater are included in the PR average, while for the GR, all bins are included in the volume average, though the GR percent above threshold measurement for the geometry-matched data is based on the fraction of the GR bins at 15 dBZ or greater. Thus, regardless of the percent above threshold criterion applied to the PR, the lowest PR reflectivity will always be 18 dBZ or greater. The lowest possible geometry-match GR reflectivity included in the mean difference calculation will increase with percent above threshold from just above 0.0 dBZ at percentage values above 0, to 15 dBZ or greater at for samples where 100% of the GR bins in the average are above threshold. The mean differences computed from the gridded data takes all matched PR and GR grid points in the category where the reflectivity values for both are 18 dBZ or greater.

Figure 2 shows that the PR is high biased relative to the GR by about 2 dBZ in the grid-based analyses, and by 1 dBZ or less in the geometry-match analyses. The high bias of the PR relative to the GR in the latter data lowers from 1.26 dBZ to 0.16 dBZ in the geometry-match data as the percent-above-threshold constraint increases from 0 to 100 and the “floor” reflectivity for the GR sample volumes included increases to 15 dBZ, closer to the PR cutoff at 18 dBZ. The grid-based analyses do not change significantly with the change in the percent threshold since the all sample volumes are included for each category. Minor changes occur where grid data for some orbits are excluded when the geometry-match data for the same orbit have no sample volumes meeting the percent-above-threshold criterion of the data category.

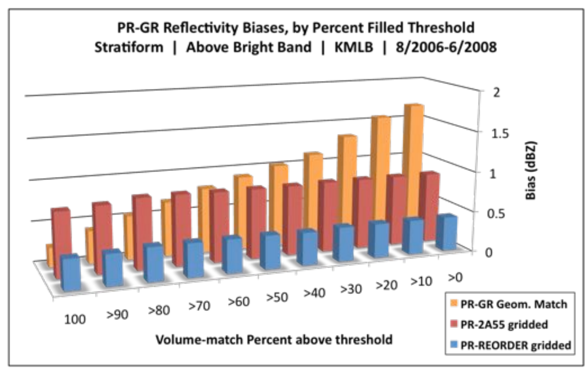

Figure 3. As in Fig. 2, but for stratiform rain type. Order of series is changed from Fig. 2, for visibility.

Figure 3 shows the results for the stratiform rain, above bright band Category. In this case the grid-based PR-GR bias based on the 2A-55 GR product is smaller than the bias based on the REORDER analysis of the GR volume scan, while the geometry match data exhibits the same tendencies but slightly higher PR-GR bias than the convective case. The smaller mean reflectivity differences for the grid-based results compared to the convective case are due to the lower overall reflectivity in the stratiform rain areas, where imposition of an 18 dBZ minimum for the gridpoint sample volumes included in the mean difference calculation puts the grid data in situation approaching the 100% above-threshold constraint applied to the geometry-matched data. There is also likely to be some contamination of the bright band in the grid case, where the bright-band-influenced data are filtered by excluding those fixed layers whose centers lie within 1000 m of the mean bright band, but, for greater ranges from the radar, the vertical extent of GR bins contributing to such layers may overlap the bright band, raising the GR reflectivity with respect to the PR. The actual top and bottom of each geometry-match sample volume is compared to the mean bright band height when determining whether the sample volume is above, below, or affected by the bright band, so bright band contamination is less likely for these data.

It is this category (stratiform, above bright band) that is used to evaluate calibration differences between the PR and ground radars, as attenuation of the PR at Ku band is at its minimum, and strong horizontal gradients of reflectivity are not present, minimizing the non-uniform beam filling effects. Figure 2 shows that the calibration offset is highly sensitive to the method used to calculate matching PR and GR sample volumes, as well as to the parameters used to select the data samples included in the calculations.

Figures 4 and 5 show the mean differences below the bright band for the convective and stratiform rain rate categories, respectively. The stratiform case in Fig. 5 follows a similar trend to the above-bright-band categories with respect to the change with percent above threshold and the relative biases of the three data sets. The geometry match data for the convective case in Fig. 4 break the pattern of monotonically decreasing PR-GR biases with increasing percent above threshold. In this category, the PR and GR reflectivities change in a similar manner with percent above threshold, perhaps due to the attenuation corrections applied to the PR data.

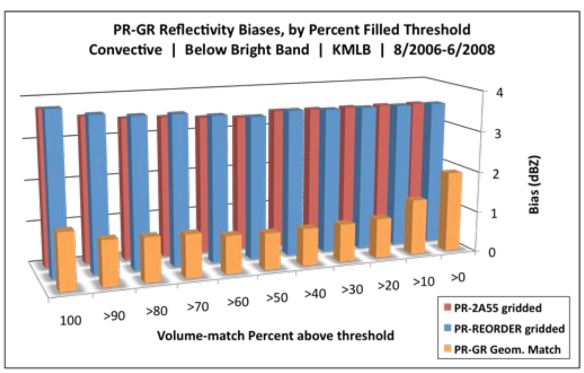

Figure 4. As in Fig. 2, but for convective samples below the bright band.

The overall high bias of the convective samples for the gridded analyses relative to the geometry match data is due primarily to a few cases of very high convective reflectivities. The mean reflectivity differences are weighted by the number of gridpoints in the category, not case-by-case, so a few cases with high PR-GR biases over large areas are driving up the grid-based biases. The difference between the gridded data and geometry match data in these cases is due to the objective analysis scheme used for the PR spreading of the high PR reflectivities over a wider area than they are observed, resulting in high PR reflectivities being differenced against lower GR reflectivities. Since the PR data are averaged only in the vertical in the geometry-match analysis, this source of bias is not present in these data.

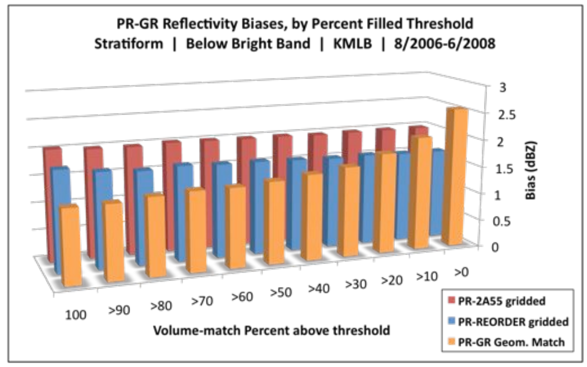

Figure 5. As in Fig. 2, but for stratiform rain samples below the bright band.

4. SENSITIVITY TO PR-GR TIME DIFFERENCES

The time matching rule for PR and GR data selects the GR volume scan with the earliest begin time in a 9-minute window centered on the time of the PR's closest approach to the GR site. The time offset between the PR and GR data has little effect on the mean reflectivity differences, as the mean PR and GR reflectivities do not change significantly in the range of time offsets resulting from this rule. However, the point-to-point reflectivity differences for fast-moving or evolving precipitation echoes should be expected to increase as the time difference increases. To investigate these differences, the standard deviation of the point-to-point differences was computed for each category, and averaged over the full data set. Figure 6 shows these results for the gridded and geometry-match data sets, for the 100% above-threshold category.

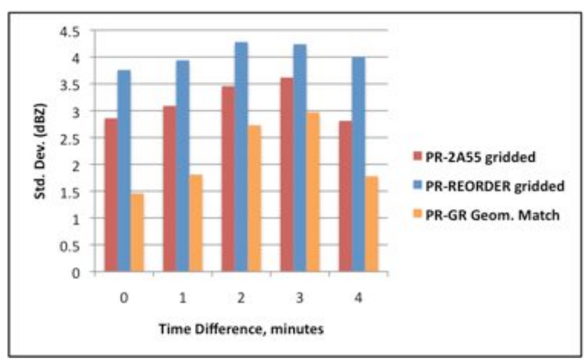

Figure 6. Standard Deviation of PR-KMLB reflectivity differences by time offset between PR and KMLB, for all categories shown in Figs. 2-5, combined.

The standard deviation of the reflectivity differences increases for all 3 data sets as the time difference between the PR and GR increases from 0 to 3 minutes. The reduction in the standard deviation at 4 minutes time offset is probably a data sampling effect due to the smaller number of data points in this group.

5. SENSITIVITY TO MINIMUM REFLECTIVITY THRESHOLD

By default, the geometry matching algorithm uses a PR threshold of 18 dBZ and a GR threshold of 15 dBZ in determining the fraction of a volume filled with above-threshold reflectivity. The sensitivity of the mean reflectivity differences to changes in these threshold values is demonstrated by changing the GR threshold to 18 dBZ, to match the PR threshold. Table 1 shows mean PR-GR reflectivity differences for the two GR thresholds, split out into stratiform and convective rain regimes both above and below the bright band, limited to those samples 100% filled with above-threshold reflectivity. The data include all cases in years 2008 and 2009 at KMLB. As expected, the PR-GR mean differences for the 18 dBZ GR threshold are lower than for the 15 dBZ threshold, but only by about 0.3 (0.1) dBZ above (below) the bright band, and fewer samples (N) qualify for the higher GR threshold.

Table 1. PR-KMLB mean reflectivity differences (dBZ) for 2008 and 2009 from geometry-match data with GR reflectivity thresholds of 15 dBZ and 18 dBZ. Separate results are shown for convective (C) and stratiform (S) rain, above and below the bright band (BB).

Rain Type / Location	15 dBZ GR threshold		18 dBZ GR threshold	
	mean PR-GR	N	mean PR-GR	N
C / Above BB	0.27	1922	-0.01	1269
C / Below BB	1.03	1154	0.92	1006
S / Above BB	-0.27	2894	-0.63	1566
S / Below BB	2.17	3174	2.10	2382

6. SENSITIVITY TO RANGE FROM GR

Table 2 shows the PR-GR geometry match mean reflectivity differences for KMLB for the data periods used in Figs. 2-6, divided into range categories of 0-50 and 50-100 km from the GR. The sense in which the differences change with distance reverses between stratiform rain, where the differences increase with distance, and convective rain, where the differences decrease with increasing distance. The reason for this difference in behavior is not immediately clear, as both the PR and GR volume averages are affected by the increase in the GR range gate height and width with distance. In either case, away from the bright band the difference between near and far distances in less than 0.4 dBZ for both convective and stratiform rain. The cause of the large differences with distance for the within-bright-band categories needs further investigation, but may be a sampling issue due to the smaller number of samples in the 0-50 km category.

Table 2. PR-KMLB mean reflectivity differences (dBZ) for the geometry match data included in Figs. 2-6, split out by distance from the GR. Separate results are shown for convective (C) and stratiform (S) rain, above, below, and within the bright band (BB).

Rain Type / Location	0-50 km		50-100 km	
	mean PR-GR	N	mean PR-GR	N
C / Above BB	0.30	165	0.14	1182
C / Below BB	1.55	445	1.17	443
C / Within BB	3.04	85	0.37	840
S / Above BB	-0.03	237	0.28	1497
S / Below BB	1.19	1540	1.53	1100
S / Within BB	-2.40	105	-0.66	2818

7. EFFECTS OF S-Ku FREQUENCY MATCHING ADJUSTMENTS

All the comparisons shown up to this point have matched Ku-band PR reflectivity against S-band GR reflectivity, not accounting for expected reflectivity differences due to the different operating frequencies of each instrument. Liao and Meneghini (2009b) provide S- to Ku-band reflectivity corrections for the ice phase (above bright band) and rain phase (below bright band) based on theoretical considerations. Table 3 shows the results obtained comparing the geometry-match unadjusted (S-band) and Ku-adjusted GR reflectivities against the PR, for the same data period as in Table 2 and Figs. 2-6. Note that no correction is attempted for the within-bright-band layer, due to the unknown particle sizes and types in this layer.

Table 3. PR-KMLB mean reflectivity differences (dBZ) for the geometry match data in Table 2, for both unadjusted and frequency-adjusted GR. Separate results are shown for convective (C) and stratiform (S) rain, above and below the bright band (BB).

Rain Type / Location	Unadjusted GR		Ku-adjusted GR	
	mean PR-GR	N	mean PR-GR	N
C / Above BB	0.16	1347	1.35	1347
C / Below BB	1.36	888	-0.30	888
S / Above BB	0.24	1734	0.73	1734
S / Below BB	1.33	2640	0.61	2640

Note that the stratiform rain areas both above and below the melting layer show almost identical PR-GR mean reflectivity differences after the S-to-Ku GR adjustment. The S-to-Ku adjustment relationships are quadratic in terms of Z_e, the reflectivity factor, resulting in larger adjustments to the convective cases. Assuming that the stratiform/above bright band difference represents the residual calibration offset between the PR and GR, then applying this offset to the Ku-adjusted differences shows stratiform differences of 0.1 dBZ or less between PR and GR. A mean PR bias of approximately -1.0 dBZ exists for convective cases below the bright band, indicating an undercorrection for attenuation of the Version 6 PR at low levels in convective rain where PR attenuation is significant. These results are similar to those computed by Liao and Meneghini (2009b) for KMLB, for post-orbital-boost cases between September 2001 and February 2004.

8. CASE-BY-CASE VARIABILITY

Statistics shown thus far represent averages over all the cases in the time period. For comparison, Table 4 presents mean PR-GR differences on a case-by-case basis (a raining TRMM overpass of the KMLB radar), for the stratiform rain, above bright band category, limited to those points with a percent above threshold of 100%. The results are ordered by the mean value of the maximum PR reflectivity in each remaining non-fixed sub-category (height and distance in this case) and secondarily by orbit number. These data run from August 2006 to June 2008, as in Figs. 2-6. As seen in the results, the mean PR-GR differences for the geometry match data are insensitive to the mean reflectivity, with the exception of two outlier cases for orbits 60537 and 59408. However, the number of samples in the cases tends to increase with the maximum observed reflectivity in stratiform rain.

Table 4. Case-by-case PR-KMLB mean reflectivity differences (dBZ) for stratiform rain, above the bright band. ***PR-2A55*** and ***PR-REORDER*** results are based on gridded PR and GR analyses. ***PR-GR Geo. Match*** results are from geometry-matched data, for the 100% above threshold category.

Orbit #	Mean Max. PR	PR-2A55 gridded		PR-REORDER gridded		PR-GR Geo. Match	
		Mean Diff.	N	Mean Diff.	N	Mean Diff.	N
49886	22	0.76	30	-0.10	18	-0.08	5
56068	22	1.28	23	-0.54	19	0.09	6
54645	23	-0.48	46	-0.72	46	-1.06	10
56248	23	0.16	37	-0.31	32	-0.06	8
49837	23	0.48	149	-0.01	128	-0.27	50
50249	24	-0.08	167	-0.38	140	-0.69	53
56019	24	0.08	40	-0.62	38	-0.70	10
54691	24	0.33	72	-0.07	61	-0.41	40
52676	25	-0.17	5	-0.77	5	1.44	7
50234	25	0.15	27	-0.25	25	-0.15	10
55332	25	0.23	87	-0.37	74	-0.14	56
55668	25	0.34	88	0.03	76	-0.50	43
54752	25	0.64	328	0.30	277	-0.47	132
58751	25	0.79	82	0.51	73	-1.7	19
58049	25	1.14	200	0.61	169	0.09	61
53943	25	3.31	19	3.93	19	0.31	5
50344	26	0.33	20	0.03	16	0.27	6
59136	26	0.37	43	-0.37	39	-1.06	20
56141	26	0.38	390	0.05	318	-0.23	142
50405	27	0.70	502	0.08	412	-0.10	269
59209	27	0.84	83	0.27	77	-0.02	21
60537	27	3.19	158	2.10	152	2.50	164
54908	28	1.55	442	1.13	370	1.06	288
57457	29	0.31	247	0.45	220	0.36	50
54847	30	0.52	314	0.41	285	-0.26	215
59197	30	1.48	117	0.54	99	0.15	44

Table 5 presents the case-by-case results for the convective rain, above bright band category. For this subset of data a pair of strong outlier cases appear for orbits 60537 and 51916 for all three analysis types. It is the large biases and numbers of samples for these cases that contribute to the high values of the PR-GR mean reflectivity differences for convective rain seen in the preceding figures. The reasons for these outlier cases is a subject for further study.

Table 5. As in Table 4, but for convective rain, above the bright band.

Orbit #	Mean Max. PR	PR-2A55 gridded		PR-REORDER gridded		PR-GR Geo. Match	
		Mean Diff.	N	Mean Diff.	N	Mean Diff.	N
49837	27	1.29	15	0.71	14	1.98	5
57457	29	1.84	32	2.08	26	2.73	10
58049	29	1.85	75	1.56	63	0.76	33
50344	30	1.46	39	1	29	1.96	12
56370	32	0.85	42	-0.66	33	-0.59	13
54908	32	1.73	68	1.67	57	1.68	26
54569	35	1.14	16	1.33	15	0.25	8
59209	35	1.54	134	2.35	126	0.08	65
54691	35	1.95	111	1.01	78	0.14	22
56068	36	1.37	23	1	25	2.91	5
56248	36	1.78	54	1.63	43	2.21	16
59957	38	2.71	117	0.91	72	0.28	14
55717	39	1.71	104	1.43	80	-0.39	34
59194	40	0.96	107	2.25	90	-1.06	48
58751	41	1.79	92	2.19	89	0.09	50
59136	42	1.06	83	1.48	60	-1.37	23
50405	42	1.77	394	2.09	316	-0.1	246
54752	42	2.26	164	2.82	140	1.38	78
54847	43	0.83	335	1.51	259	-0.79	251
59148	43	1.5	105	2.09	91	0.65	33
53943	43	1.6	265	2.28	233	-0.95	151
59197	43	2.52	235	2.26	173	-0.55	92
60537	43	5.98	215	5.21	143	3.67	85
51916	44	5.43	53	6.33	50	3.86	27

It is clear from Tables 4 and 5 that the case-by-case variability in the mean reflectivity difference between the PR and GR exceeds that of the effects of sample percent above threshold, minimum GR reflectivity threshold, range from the GR, and S-to-Ku frequency adjustments, and not all of this variation can be ascribed to the size of the data sample in each case.

9. CONCLUSIONS

A new volume-matching algorithm to compare space-based and ground-based radar observations has been developed for the upcoming GPM mission. It allows comparisons to be limited to locations where both systems observe echoes, with no interpolation or extrapolation of the data, and allows the quality of the matching volumes to be controlled in terms of beam filling aspects. The geometry-matched data from this algorithm are compared to traditional grid-based analyses of the same data and are shown to produce a closer comparison between the TRMM PR and the Melbourne, Florida WSR-88D radar.

The two attributes that most affect the geometry-match comparison results are shown to be the percent of the matching volumes filled with reflectivity values above the PR detection threshold of approximately 18 dBZ, and the application of S- to Ku-band frequency adjustments to the ground radar data, each of which can change the long-term mean reflectivity differences by up to 1.5 dBZ. Geometry-match and grid-based comparison results for stratiform rain were similar, however for convective rain the PR was much more high-biased against the GR for gridded analysis when compared to the geometry-match result.

Mean reflectivity differences were relatively insensitive to the time difference between the PR and GR for the range of time differences allowed in the data set, though the scatter of the point-to-point differences is seen to increase with increasing time differences. Mean PR-GR reflectivity differences as a function of distance from the ground radar trended in opposite directions for stratiform and convective rain, with a maximum absolute difference of about 0.4 dBZ for each. The case-by-case variability of the mean reflectivity differences was shown to exceed the variability in the full data set's differences resulting from any of the data analysis, categorization, and frequency adjustment methods applied in the study.

10. RESOURCES

Time-matched TRMM PR and KMLB WSR-88D data files in original formats, geometry match netCDF data files produced from these data, and the Data User's Guide for the geometry match data are freely available for download, as is open source code used to perform the geometry matching and generate displays and statistical comparisons between the PR and GR. Refer to the online links within the *Validation Network Software and Data Products* section of:

http://pmm.nasa.gov/science/ground-validation

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