GPM/DPR Level-3 for V07
Algorithm Theoretical Basis Document

Revised July 2021

1) Overview of the Level 3 data

The Level-3 radar products provide daily and monthly global statistics of the Level-2 Ku, Ka and DPR products on a latitude-longitude grid. In version 7 (V07), the organization of the products has changed with the highest-level categorization into FS (full swath), MS (matched or inner swath) and HS (high sensitivity) swath products. The next level of division is into high and low spatial resolution grids that are defined such that the low-resolution grid (G1) is $5^0\times5^0$ (lat×lon) while the high-resolution grid (G2) is $0.25^0\times 0.25^0$. For variables defined on the low-resolution grid, the statistics include mean, standard deviation, counts and histogram. For variables defined on the high-resolution grid, the same statistics are computed except for a histogram, which is omitted. Figure 1 shows the monthly mean of the precipitation rate near the surface over the G1 and G2 grids for June 2018. The version history of L3 is given in section 3.

The level 3 code is written so that the 15 or 16 orbits of Level-2 DPR data produced daily can be processed in two runs, where one output file contains statistics from the ascending orbital passes while the other file contains statistics from the descending passes. Since all orbits for the day are processed in each run, there is no need for intermediate files. What is produced are two daily level 3 HDF files. Nominally, the standard Level 3 product is obtained by processing the twice-daily HDF files over a calendar month; however, this is not required. Output products can be generated from any set of daily HDF files. It should be noted that the daily files contain a mean square statistic rather than the standard deviation. For the monthly (or multi-day) file, however, the mean square statistic is replaced by the standard deviation.

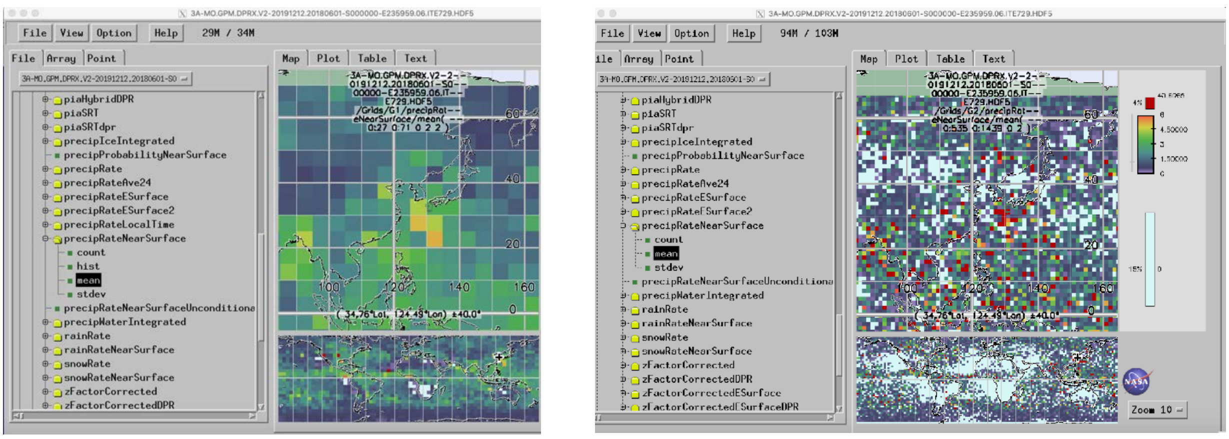

Figure 1. These plots in orbit viewer (Thor) for June 2018 show the structure of Level-3 products in HDF5. Global products include the monthly mean of near surface precipitation rate (mm/hr) on the G1 grid (Left) and on the G2 grid (Right).

Unlike the Level-2 data that are stored in separate HDF files for Ku, Ka, and DPR products, the Level-3 file combines all products and stores them under the channel dimension array in a single HDF file. As of 21 May 2018, the scan pattern of the Ka radar was changed by redirecting the 24 interleaved FOVs (fields of view) of the high sensitivity (KaHS) channel to the outer swath so that the 49 beams of the Ku- and Ka-band became approximately matched in space and time. (**Figure 2**). This means that after May 2018, full swath (FS) Ka and DPR products could be computed.

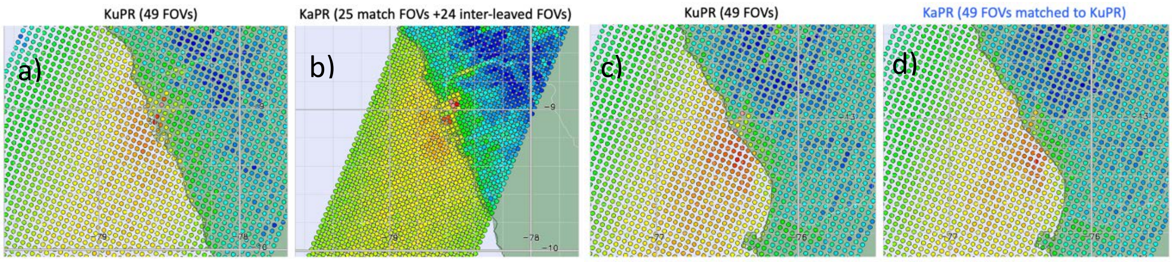

Figure 2. The left two panels show the fields of view (FOV) before the scan pattern change (a) Ku-band and (b) Ka- band where the Ka-band (MS) data were available over the inner swath. The right two panels show the FOVs at (c) Ku- and (d) Ka-band after the scan pattern change. The swath width of the Ka radar is now matched to that of the Ku-band radar where the FOVs in the outer swath are those from the high sensitivity mode, previously used in the interleaved scan pattern.

2) Variable Types

The following tables show the list of variable types in the G1 grid for V06X and V07. In version V06X, there were a total of 47 products for G1 and 42 products for G2. In version V07, the number was reduced to 39 in the FS and MS swaths, and to 37 in the HS swath.

Seven basic variable types have been identified for V07. Three additional variable types were used in V06X, but not for V07.

- Type A1 variables are channel-dependent (**Table 1**)
- Type A2 variables are channel- and height(range)-dependent (**Table 2**)
- Type A3 variables are channel- and angle-dependent (**Table 3**)
- Type A4 variables are used to store products suitable for a general user (**Table 4**)
- Type A5 variables store observation counts (**Table 5**)
- Type A6 variables are time dependent (**T able 6**)
- Type A7 variables are independent of channel-, height- and angle (**Table 7**)
- Type B1, B2, B3 variables are related to dual-freq products (no longer exist in version 7) (**Table 8**)

Tables for the G2 grid are not shown here because the number of variables is same as in the G1 grid. The main differences between G1 and G2 are the number of latitude and longitude cells. For the high-resolution grid, G2, the number of latitude and longitude cells are 356 (-70 to 70 deg; 0.25 deg grid) and 1440 (-180 to 180 deg; 0.25 deg grid). For the low-resolution grid of 5 deg, G1, the number of latitude and longitude cells are 28 and 72, respectively. One other difference between the low- and high-resolution products is that histograms are computed for G1 but not for G2. A final difference is that the low resolution products are separated into surface types (all, ocean, land) while the high resolution products are not so that all surface types are included.

In the tables below, the statistics are also separated by rain type and by surface type. For the rain type, rt, index 1 (first index) includes the statistics for all rain types, index 2 includes only stratiform rain and index 3 includes only convective rain. For surface type, st, index 1 includes all surface types, index 2 only data taken over ocean, and index 3 data taken only over land. All G1 products include histograms of 30 bins where the bin definitions are given in section 5. It should be noted that for versions earlier than V07, the 'all' case was given by index=3 whereas for V07, the 'all' case is given by index=1.

Table 1 provides a list of the Type A1 variables on the G1 grid. The notation 28Lt, 72Ln is used to indicate that the number of latitude and longitude cells/indices are 28 and 72, respectively. The Table provides the dimensions for the variables in the V06X and V07 versions of the product. Information on the indices is included in the table. Note that the products in red have chn=4 (Ku, Ka, DPRKu, DPRKa) while all other products have chn=3 (Ku, Ka, DPR). Since the HS swath is used only for the single channel KaHS data, a channel dimension is unnecessary. This is also true of the HS swath products for other variable types.

Table 1. Type A1 variables: channel dependent

Type A1 (Channel-Dependent Variables) Indices: 28Lt (-70 to 70 deg; 5 deg grid), 72Ln (-180 to 180 deg; 5 deg grid), 3rt (all, stratiform, convective), 3st (all, ocean, land), 30bin 7chn (KuFS, KaMS, KaHS, DPRMS, KuMS, KaFS, DPRFS), 3chn (Ku, Ka, DPR) / 4chn (Ku, Ka, DPRKu, DPRKa)		
V06X/Grids/G1	V07/FS/G1 and V07/MS/G1	V07/HS/G1
count(28Lt,72Ln,7chn,3rt,3st) mean(28Lt,72Ln,7chn,3rt,3st) stdev(28Lt,72Ln,7chn,3rt,3st) histo(28Lt,72Ln,7chn,3rt,3st,30bin)	count(28Lt,72Ln,3chn/4chn,3rt,3st) mean(28Lt,72Ln,3chn/4chn,3rt,3st) stdev(28Lt,72Ln,3chn/4chn,3rt,3st) histo(28Lt,72Ln,3chn/4chn,3rt,3st,30bin)	count(28Lt,72Ln,3rt,3st) mean(28Lt,72Ln,3rt,3st) stdev(28Lt,72Ln,3rt,3st) histo(28Lt,72Ln,3rt,3st,30bin)
1 BBwidth	1 BBwidth	1 BBwidth
2 BBwidthNadir	2 BBwidthNadir	2 BBwidthNadir
3 Epsilon	3 epsilon	3 epsilon
4 flagHeavyIcePrecip	4 flagHeavyIcePrecip	4 flagHeavyIcePrecip
5 heightBB	5 heightBB	5 heightBB
6 heightBBnadir	6 heightBBnadir	6 heightBBnadir
7 heightStormTop	7 heightStormTop	7 heightStormTop
8 mixedPhRateNearSurface	8 mixedPhRateNearSurface	8 mixedPhRateNearSurface
9 precipIceIntegrated	9 precipIceIntegrated	9 precipIceIntegrated
10 precipRateAve24	10 precipRateAve24	10 precipRateAve24
11 precipRateESurface	11 precipRateESurface	11 precipRateESurface
12 precipRateESurface2	12 precipRateESurface2	12 precipRateESurface2
13 precipRateNearSurface	13 precipRateNearSurface	13 precipRateNearSurface
14 precipWaterIntegrated	14 precipWaterIntegrated	14 precipWaterIntegrated
15 rainRateNearSurface	15 rainRateNearSurface	15 rainRateNearSurface
16 snowRateNearSurface	16 snowRateNearSurface	16 snowRateNearSurface
17 zFactorCorrectedESurface	17 zFactorCorrectedESurface	17 zFactorCorrectedESurface
18 zFactorCorrectedNearSurface	18 zFactorCorrectedNearSurface	18 zFactorCorrectedNearSurface
19 zFactorMeasuredNearSurface	19 zFactorMeasuredNearSurface	19 zFactorMeasuredNearSurface

There are eight variables that depend on both channel and height. The statistics are taken at 5 heights (2km, 4km, 6km, 10km and 15km). The ***zFactorCorrected*** and ***zFactorMeasured*** (in red) have 4 channels (Ku, Ka, DPRKu and DPRKa) for the FS and MS swaths.

Table 2. Type A2 variables: channel- and height-dependent

Type A2 (Channel- and Height- Dependent Variables) Indices: 28Lt (-70 to 70 deg; 5 deg grid), 72Ln (-180 to 180 deg; 5 deg grid) 3rt (all, stratiform, convective), 3st (all, ocean, land), 30bin 7chn (KuFS, KaMS, KaHS, DPRMS, KuMS, KaFS, DPRFS), 3chn (Ku, Ka, DPR) / 4chn (Ku, Ka, DPRKu, DPRKa) 5hgt (2 km, 4 km, 6 km, 10 km, 15 km)		
V06X/Grids/G1	V07/FS/G1 and V07/MS/G1	V07/HS/G1
count(28Lt,72Ln,7chn,5hgt,3rt,3st) mean(28Lt,72Ln,7chn,5hgt,3rt,3st) stdev(28Lt,72Ln,7chn,5hgt,3rt,3st) histo(28Lt,72Ln,7chn,5hgt,3rt,3st,30bin)	count(28Lt,72Ln,3chn/4chn,5hgt,3rt,3st) mean(28Lt,72Ln,3chn/4chn,5hgt,3rt,3st) stdev(28Lt,72Ln,3chn/4chn,5hgt,3rt,3st) histo(28Lt,72Ln,3chn/4chn,5hgt,3rt,3st,30bin)	count(28Lt,72Ln,5hgt,3rt,3st) mean(28Lt,72Ln,5hgt,3rt,3st) stdev(28Lt,72Ln,5hgt,3rt,3st) histo(28Lt,72Ln,5hgt,3rt,3st,30bin)
20 dBNw	20 dBNw	20 dBNw
21 dm	21 dm	21 dm
22 mixedPhRate	22 mixedPhRate	22 mixedPhRate
23 precipRate	23 precipRate	23 precipRate
24 rainRate	24 rainRate	24 rainRate
25 snowRate	25 snowRate	25 snowRate
26 zFactorCorrected	26 zFactorCorrected	26 zFactorCorrected
27 zFactorMeasured	27 zFactorMeasured	27 zFactorMeasured

For the angle-dependent variables (Type A3) the angle index, ang, takes on seven values for the FS swath and four for MS and HS swaths. Taking a 4 angle-bin increment (3°), beginning with nadir (0^0) gives the following incidence angles: 0^0, ±3°, ±6°, ±9° for the MS and HS swaths. For the FS swath, this series is continued with samples at ±12°, ±15°, ±18°. ang={1, 2,..,7} $\Rightarrow$ angle bins {25, (21,29), (17,33), (13,37), (9,41), (4,45), (1,49)} . In other words, ang index 1 is used to store the nadir data, index 2 is used to store Ku-band data from angle bins 21 and 29 (abs(21-25) *0.75^0= (29-25)*0.75^0=3^0), index 3 to store data from angle bins 17 and 33 (abs(17-25)*0.75^0=(33-25)*0.75^0= 6^0), and so on. Finally, index 7 is used to store data from the farthest angles of the outer swath (abs(1-25)*0.75^0=(49-25)*0.75^0=18^0). For the HS swath we begin with the two beams closest to nadir so that: ang={1, 2, 3, 4} $\Rightarrow$ angle bins {(12,13), (8,17), (4,21), (1,24)} which correspond to incidence angles of ±0.375°, ±3.375°, ±6.375° and ±8.625°.

It will often be the case that the PIA from the SRT is considered unreliable. Since the statistics of ***piaSRT*** are taken only for those data that are considered marginally reliable or reliable, then comparisons between the PIA(SRT) and PIA(Final) statistics will be taken over different sets of data. To restrict the statistics of PIA(final) to only those cases for which the ***piaSRT*** is reliable or marginally reliable, we introduce the subsetted statistics: ***piaFinalSubset***.

Table 3. Type A3 variables: Angle-bin dependent

Type A3 (Channel- and Angel- Dependent Variables) Indices: 28Lt (-70 to 70 deg; 5 deg grid), 72Ln (-180 to 180 deg; 5 deg grid), 3rt (all, stratiform, convective), 3st (all, ocean, land), 30bin 7chn (KuFS, KaMS, KaHS, DPRMS, KuMS, KaFS, DPRFS), 4chn (Ku, Ka, DPRKu, DPRKa) 7ang (0^0, ±3°, ±6°, ±9°,±12°, ±15°, ±18°) for FS / 4 ang (0^0, ±3°, ±6°, ±9°) for MS		
V06X/Grids/G1	V07/FS/G1 and V07/MS/G1	V07/HS/G1
count(28Lt,72Ln,7chn,7ang,3rt,3st) mean(28Lt,72Ln,7chn,7ang,3rt,3st) stdev(28Lt,72Ln,7chn,7ang,3rt,3st) histo(28Lt,72Ln,7chn,7ang,3rt,3st,30bin)	count(28Lt,72Ln,4chn,7ang/4ang,3rt,3st) mean(28Lt,72Ln,4chn,7ang/4ang,3rt,3st) stdev(28Lt,72Ln,4chn,7ang/4ang,3rt,3st) histo(28Lt,72Ln,4chn,7ang/4ang,3rt,3st,30bin)	count(28Lt,72Ln,4ang,3rt,3st) mean(28Lt,72Ln,4ang,3rt,3st) stdev(28Lt,72Ln,4ang,3rt,3st) histo(28Lt,72Ln,4ang,3rt,3st,30bin)
28 piaFinal	28 piaFinal	28 piaFinal
29 piaFinalSubset	29 piaFinalSubset	29 piaFinalSubset
30 piaHB	30 piaHB	30 piaHB
31 piaHybrid	31 piaHybrid	31 piaHybrid
32 piaSRT	32 piaSRT	32 piaSRT
33 zeta	33 zeta	33 zeta

Table 4. contains a list of the Type A4 general user products. Since most users will not need detailed statistics, the statistics for ***precipRateNearSurfaceUnconditional*** are computed. This variable, equal to the mean, near-surface unconditional precipitation rate, is defined to be independent of rain type or surface type, i.e., all rain types and surface types are included and where the 'unconditional mean' gives the average precipitation rate with zero rain rates included. The variable ***PrecipProbabilityNearSurface*** is simply the ratio of precipitation counts (non-zero cases) to the total number of observations in the cell. The probability of rain at a particular height level, for a particular rain type and surface type, over the low-resolution grid is computed by:

$$\text{Probability of Rain}(ltL,lnL,hgt,chn,rt,st)=\frac{\text{G1\%precipRate\%count}(ltL,lnL,hgt,chn,rt,st)}{\text{G1\%ObservationCounts\%total}(ltL,lnL,hgt,chn,rt,st)}$$

Note that all rain types and all surface types are obtained by setting rt=1 and st=1. Note also that for near-surface rain rates, the height index is not needed. The conditional mean, the mean precipitation rate when precipitation is present, can be calculated from the conditional mean by multiplying by the probability of rain. The unconditioned standard deviation can also be computed from the conditional mean, conditional standard deviation and the probability of rain.

Table 4. Type A4 variables: General User Products

Type A4 (General User Variables) Indices: 28Lt (-70 to 70 deg; 5 deg grid), 72Ln (-180 to 180 deg; 5 deg grid) 7chn (KuFS, KaMS, KaHS, DPRMS, KuMS, KaFS, DPRFS), 3chn (Ku, Ka, DPR)		
V06X/Grids/G1	V07/FS/G1 and V07/MS/G1	V07/HS/G1
mean(28Lt,72Ln,7chn)	mean(28Lt,72Ln,3chn)	mean(28Lt,72Ln)
34 precipProbabilityNearSurface	34 precipProbabilityNearSurface	34 precipProbabilityNearSurface
35 precipRateNearSurfaceUnconditional	35 precipRateNearSurfaceUnconditional	35 precipRateNearSurfaceUnconditional

Table 5 gives a list of the Type A5 products related to 'Observation Counts'. This structure is used for 4 variables to store the observation counts with respect to total, local time, angle/pia, and shallow rain. The index *time* (=24) represents the local time binned by hour. Note that the G2 ***ObservationCounts structure*** is the same except the surface type ***st*** is omitted. Note that ***ObservationCounts%total*** is equal to the number of observations at a particular lat/lon box for each channel and, in the case of the G1 grid, for each surface type.

Table 5. Type A5 variables: Observation counts

Type A5 (Total Number of Observations) Indices: 28Lt (-70 to 70 deg; 5 deg grid), 72Ln (-180 to 180 deg; 5 deg grid), 3st (all, ocean, land) 7chn (KuFS, KaMS, KaHS, DPRMS, KuMS, KaFS, DPRFS), 3chn (Ku, Ka, DPR), 24time 7ang (0^0, ±3°, ±6°, ±9°,±12°, ±15°, ±18°) for FS / 4 ang (0^0, ±3°, ±6°, ±9°) for MS		
V06X/Grids/G1	V07/FS/G1 and V07/MS/G1	V07/HS/G1
total(28Lt,72Ln,7chn,3st) localTime(28Lt,72Ln,7chn,24time,3st) pia(28Lt,72Ln,7chn,7ang,3st) shallowRain(28Lt,72Ln,7chn,3st)	total(28Lt,72Ln,3chn,3st) localTime(28Lt,72Ln,3chn,24time,3st) pia(28Lt,72Ln,3chn,7ang/4ang,3st) shallowRain(28Lt,72Ln,3chn,3st)	total(28Lt,72Ln,3st) localTime(28Lt,72Ln,4ang,3st) pia(28Lt,72Ln,4ang,3st) shallowRain(28Lt,72Ln,3st)
36 observationCounts	36 observationCounts	36 observationCounts

Table 6 contains only a single Type A6 time-dependent variable: ***precipRateLocalTime***. This is used to store the time-dependent precipitation rate. Note that a height index or rain type index is not included and uses only the ***precipRateNearSurface*** variable. Both stratiform and convective rain are included – i.e., no rain type classification is used.

Table 6. Type A6 variables: time dependent

Type A6 (Time- Dependent precipRate) Indices: 28Lt (-70 to 70 deg; 5 deg grid), 72Ln (-180 to 180 deg; 5 deg grid), 3st (all, ocean, land) 7chn (KuFS, KaMS, KaHS, DPRMS, KuMS, KaFS, DPRFS), 3chn (Ku, Ka, DPR), 24time		
V06X/Grids/G1	V07/FS/G1 and V07/MS/G1	V07/HS/G1
count(28Lt,72Ln,7chn,24time,3st) mean(28Lt,72Ln,7chn,24time,3st) stdev(28Lt,72Ln,7chn,24time,3st)	count(28Lt,72Ln,3chn,24time,3st) mean(28Lt,72Ln,3chn,24time,3st) stdev(28Lt,72Ln,3chn,24time,3st)	count(28Lt,72Ln,24time,3st) mean(28Lt,72Ln,24time,3st) stdev(28Lt,72Ln,24time,3st)
37 precipRateLocalTime	37 precipRateLocalTime	37 precipRateLocalTime

Table 7 includes variables Type A7 variables that are independent of channel, angle and height. Note that ***DFRNearSurface*** is the difference of zFactorCorrectedNearSurface between DPRKu and DPRKa channels. ***DFRmNearSurface*** is equal to the Ku- and Ka-band the difference of ***zFactorMeasuredNearSurface***. For HS swath, these variables are not available.

Table 7. Type A7 variables: channel, angle and height independent

Type A7 (Channel- , Angel- and Height Independent Variables)		
Indices: 28Lt (-70 to 70 deg; 5 deg grid), 72Ln (-180 to 180 deg; 5 deg grid) 3rt (all, stratiform, convective), 3st (all, ocean, land), 30bin		
V06X/Grids/G1	V07/FS/G1 and V07/MS/G1	V07/HS/G1
count(28Lt,72Ln,3rt,3st) mean(28Lt,72Ln,3rt,3st) stdev(28Lt,72Ln,3rt,3st) histo(28Lt,72Ln,3rt,3st,30bin)	count(28Lt,72Ln,3rt,3st) mean(28Lt,72Ln,3rt,3st) stdev(28Lt,72Ln,3rt,3st) histo(28Lt,72Ln,3rt,3st,30bin)	
38 DFRmNearSurface	38 DFRmNearSurface	DFRmNearSurface
39 DFRNearSurface	39 DFRNearSurface	DFRNearSurface

Table 8 contains a list of the type B1 products that depend on channel and angle. The eight variables listed in this table were in use for V06X but are no longer defined in V07. With the new structure of L3 in V07, all products with the suffix "DPR" are included under the product name. For an example, ***piaFinalDPR***(DPRchn1, DPRchn2, DPRchn3 and DPRchn4) in V06X is now saved under ***piaFinal*** where the MS dual-frequency product is saved in chn=3 and the FS dual-frequency product is saved under chn=4. The Ku-band and Ka-band estimates from ***piaFinal*** are saved in chn=1 and chn=2, respectively.

Table 8. Type B1, B2, B3 variables: channel and angle dependent DPR variables (V06X only)

Type B1 (Channel- and Angel- Dependent DPR Variables)		
Indices: 28Lt (-70 to 70 deg; 5 deg grid), 72Ln (-180 to 180 deg; 5 deg grid) 3rt (all, stratiform, convective), 3st (all, ocean, land), 30bin 4DPRchn (DPRKuMS, DPRKaMS, DPRKuFS, DPRKaFS) 7ang (0^0, ±3°, ±6°, ±9°,±12°, ±15°, ±18°)		
V06X/Grids/G1	V07/FS/G1	V07/HS/G1
count(28Lt,72Ln,4DPRchn,7ang,3rt,3st) mean(28Lt,72Ln,4DPRchn,7ang,3rt,3st) stdev(28Lt,72Ln,4DPRchn,7ang,3rt,3st) histo(28Lt,72Ln,4DPRchn,7ang,3rt,3st,30bin)		
40 epsilonDPR	epsilonDPR	epsilonDPR
41 piaFinalDPR	piaFinalDPR	piaFinalDPR
42 piaFinalDPRsubset	piaFinalDPRsubset	piaFinalDPRsubset
43 piaHybridDPR	piaHybridDPR	piaHybridDPR
44 piaSRTdpr	piaSRTdpr	piaSRTdpr

Type B2 (Channel- and Height- Dependent DPR Variables) Indices: 28Lt (-70 to 70 deg; 5 deg grid), 72Ln (-180 to 180 deg; 5 deg grid) 3rt (all, stratiform, convective), 3st (all, ocean, land), 30bin 4DPRchn (DPRKuMS, DPRKaMS, DPRKuFS, DPRKaFS), 5hgt (2 km, 4 km, 6 km, 10 km, 15 km)		
V06X/Grids/G1	V07/FS/G1	V07/HS/G1
count(28Lt,72Ln,4DPRchn,5hgt,3rt,3st) mean(28Lt,72Ln,4DRPchn,5hgt,3rt,3st) stdev(28Lt,72Ln,4DPRchn,5hgt,3rt,3st) histo(28Lt,72Ln,4DPRchn,5hgt,3rt,3st,30bin)		
45 zFactorCorrectedDPR	zFactorCorrectedDPR	zFactorCorrectedDPR
Type B3 (Channel- Dependent DPR Variables) Indices: 28Lt (-70 to 70 deg; 5 deg grid), 72Ln (-180 to 180 deg; 5 deg grid), 3rt (all, stratiform, convective) 3st (all, ocean, land), 30bin 4DPRchn (DPRKuMS, DPRKaMS, DPRKuFS, DPRKaFS)		
V06X/Grids/G1	V07/FS/G1	V07/HS/G1
count(28Lt,72Ln,4DPRchn,3rt,3st) mean(28Lt,72Ln,4DPRchn,3rt,3st) stdev(28Lt,72Ln,4DPRchn,3rt,3st) histo(28Lt,72Ln,4DPRchn,3rt,3st,30bin)		
46 zFactorCorrectedESurfaceDPR 47 zFactorCorrectedNearSurfaceDPR	zFactorCorrectedESurfaceDPR zFactorCorrectedNearSurfaceDPR	zFactorCorrectedESurfaceDPR zFactorCorrectedNearSurfaceDPR

3) Version History and Hierarchical structure

The channel combinations before the Ka-band scan pattern change (V06A) consisted of KuNS, KaMS, KaHS, DPRMS, and KuMS. In the notation adopted for V06X and above, 'normal swath' NS has been replaced by 'full swath' FS. These are identical, and both refer to the set of 49 fields of view (FOV) that comprise the swath. In particular, KuNS=KuFS. Two channels are used for Ku-band statistics: KuNS consists of level 2 products from the full swath of 49 FOVs while KuMS consists of the same products but obtained from the inner swath of 25 FOVs. Two channels are also used to store the Ka-band statistics from the 25 matched FOVs (KaMS) and from the 24 interlaced FOVs (KaHS). One channel, DPRMS, is used for the DPR products generated from the 25 matched FOVs (DPRMS). Since most of the DPR products are frequency independent, only one channel is assigned. There are, however, some frequency dependent DPR products such as path attenuation related variables (piaSRT, piaFinal, etc.) that are saved separately; for example, ***piaSRT*** (5 channels) and ***piaSRTdpr*** (2 channels, DPRKuMS and DPRKaMS).

After the scan pattern change (V06X), the total number of channels increased from five to seven. The two additional channels were needed to store the Ka full swath (KaFS) and the DPR full swath products (DPRFS). Table 9 shows in more detail the channel index information and the array dimensions before and after the scan pattern change. Note that frequency dependent DPR products, such as ***piaSRTdpr***, also require two additional DPR channels for the full swath (DPRKuFS and DPRKaFS) along with the existing DPR channels for the inner swath (DPRKuMS and DPRKaMS). To store these data, we use the following convention for the channel dimension array: DPRKuMS (DPRchn=1), DPRKaMS (DPRchn=2), DPRKuFS (DPRchn=3) and DPRKaFS (DPRchn=4).

The structure of L3 has been reorganized in V07 to simplify a complex set of products produced by single and dual-frequency data and stored over high- and low-resolution grids. The hierarchical structures for the Level 3 in V06X and V07 are shown schematically in Figure 3. The highest level of organization in V07 is into one of 3 swaths: full swath (FS), matched or inner swath (MS) and high resolution swath (HS). The next level of organization is into low (G1) and high resolution (G2) grids. This organization makes it possible to reduce the number of channels or products relative to that used in V06X. For example, in the diagram shown below under the product 'precipRateNearSurface' (near-surface precipitation rate), the statistics, that include counts, mean, standard deviation and histogram (not shown), are computed from the Ku-band data over the full swath (KuFS), from the Ka-band data over the full swath (KaFS) and from both frequencies over the full swath (DPRFS). Similar statistics (KuMS, KaMS and DPRMS) for 'precipRateNearSurface' can be found under the MS swath where only data from the matched or inner swath are used. Under the HS swath, the statistics (KaHS) for 'precipRateNearSurface' are computed from the high sensitivity Ka-band data.

Most products are similar to 'precipRateNearSurface' in the sense that only 3 'channels' or product types are needed. Exceptions to this rule include frequency-dependent variables such as 'piaSRT' as shown below, under the FS (or MS and HS) swath, where '***piaSRT***' is the path attenuation as determined by the surface reference technique (SRT). For these variables, 4 channels are needed: path attenuation at Ku-band using the Ku-band data (KuFS), Ka-band path attenuation derived from the Ka-band data (KaFS), Ku-band path attenuation as estimated by using both frequencies (DPRKuFS) and, finally, Ka-band path attenuation derived by using both frequencies (DPRKaFS). Therefore, a total of 9 possible channel combinations are as follows. KuFS, KaFS, DPRKuFS, DPRKaFS, KuMS, KaMS, DPRKuMS, DPRKaMS, KaHS. As shown in the version V06X structure of Figure 3, estimates from single wavelengths were stored in piaSRT (KuFS, KaFS, KuMS, KaMS and KaHS) and estimates from the dual-frequency data (DPRKuMS, DPRKaMS, DPRKuFS and DPRKaFS) were stored in ***piaSRTdpr***, respectively. In version V07, the ***piaSRTdpr*** product was integrated into the piaSRT product. piaSRT has 4 channels under full swath (KuFS, KaFS, DPRKuFS and DPRKaFS), 4 channels under MS swath (KuMS, KaMS, DPRKuMS, DPRKaMS), and 1 channel under HS swath (KaHS), respectively. Table 9 shows the channel combination of products from Ku, Ka and DPR and the order of product for version 6, versions V06X and version V07.

Table 9. The channel combination of products from Ku, Ka and DPR and the order of product for version 6, version 6X and version 7. The 4th channel in V07 is allocated only for the products that have 2 DPR estimates from DPRKu and DPRKa (in red) such as the ***piaSRT, zFactorMeasured,*** and ***zeta***.

V06			**V06X**			**V07**		
Before Scan Pattern Change			**After Scan Pattern Change**			**Before/After Scan Pattern Change**		
Swath Name	Channel Name	Statistics At Freq.	Swath Name	Channel Name	Statistics At Freq.	Swath Name	Channel Name	Statistics At Freq.
Grids	Chn 1	KuFS	Grids	Chn 1	KuFS	FS	Chn 1	KuFS
	Chn 2	KaMS		Chn 2	KaMS		Chn 2	KaFS
	Chn 3	KaHS		Chn 3	KaHS		Chn 3	DPRFS
	Chn 4	DPRMS		Chn 4	DPRMS			DPRKuFS
	Chn 5	KuMS		Chn 5	KuMS		Chn 4	DPRKaFS
				Chn 6	KaFS	MS	Chn 1	KuMS
				Chn 7	DPRFS		Chn 2	KaMS
							Chn 3	DPRMS
								DPRKuMS
							Chn 4	DPRKaMS
						HS		KaHS

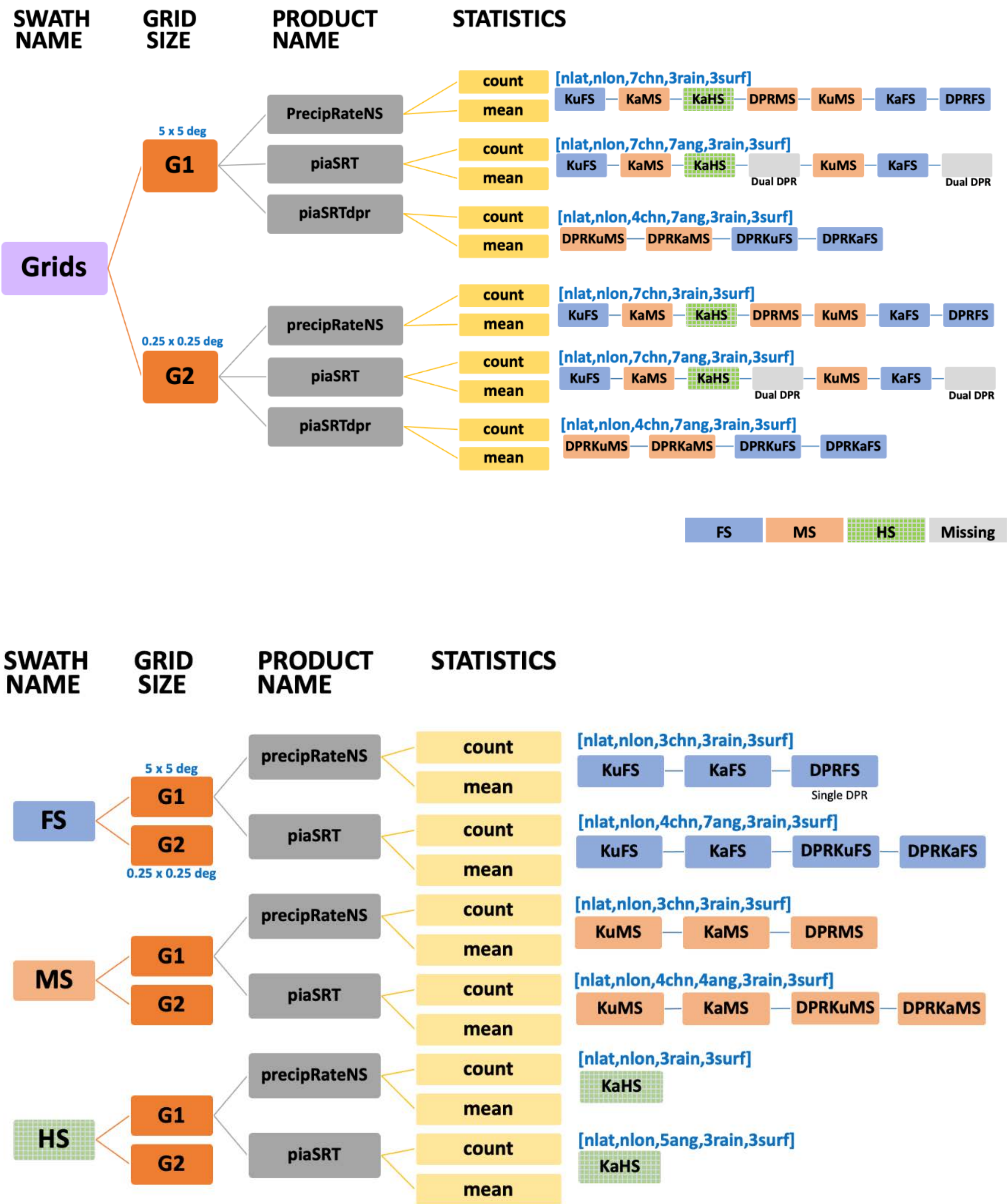

Figure 3. The organization for Level 3 in V06X (upper) and in V07 (lower).

4) Definition of Variables (see level 2 documentation for detailed descriptions)

Unless otherwise indicated, the variables below are such that the mean and standard deviations are 4-byte real, the counts and histograms are 4-byte integers. Except for ObservationCounts and precipRateNearSurfaceUnconditional, all statistics are conditioned on the presence of precipitation. Unless otherwise noted, all variables are defined on both low and high-resolution grids. Variables in blue color no longer exist in V07.

BBwidth: width of bright-band (m) [classification]
BBwidthNadir: width of bright-band (m) at nadir incidence [classification]
DFRNearSurface: Z(Ku)-Z(Ka), in dB, evaluated near the surface [solver]
DFRmNearSurface: Zm(Ku)-Zm(Ka), in dB, evaluated near the surface [preparation]
dBN$_w$: 10 log10 of the particle number concentration (m^{-3}) [solver]
dm: mass-weighted diameter (mm) [solver]
epsilon: dimensionless scale factor on α in $k=\alpha Z^{\beta}$ (where k is the specific attenuation in dB/km) [solver]
epsilonDPR: same as above except height dependent using dual-freq data [solver]
flagHeavyIcePrecip: flag to indicate the presence of hail or graupel in the column [classification]
heightBB: height from ellipsoid to 'bright-band' (m) [classification]
heightBBnadir: height from ellipsoid to 'bright-band' for nadir incidence (m) [classification]
heightStormTop: height from ellipsoid to storm top (m) [preparation]
mixedPhRate: precip rate of mixed phase particles as a function of height (mm/h) [solver]
mixedPhRateNearSurface: precip rate of mixed phase particles near surface (mm/h) [solver]
ObservationCount%localTime: total number of observations categorized into local hour. Note that this variable is only computed on the low-resolution grid.
ObservationCount%pia: total number of observations categorized into incidence angle
ObservationCount%shallowRain: number of observations of shallow rain [classification]
ObservationCount%total: total number of observations
piaFinal: path-integrated attenuation (dB), obtained from single-freq methods [solver]
piaFinalDPR: path-integrated attenuation (dB), obtained from dual-freq method [solver]
piaFinalDPRSubset path-integrated attenuation (dB), obtained from dual-freq method using only those observations for which the SRT-derived pia is considered reliable or marginally reliable [SRT, solver]
piaFinalSubset: path-integrated attenuation (dB), obtained from single-freq methods using only those observations for which the SRT-derived pia is considered reliable or marginally reliable [SRT, solver]
piaHB: path-integrated attenuation (dB) derived from the Hitschfeld-Bordan method
piaHybrid: path-integrated attenuation (dB) derived from the weighted sum of the HB and SRT
piaHybridDPR: path-integrated attenuation (dB) derived from the weighted sum of the HB, SRT, and the standard dual-wavelength method
piaSRT: path-integrated attenuation (dB), obtained from single-freq methods [SRT]
piaSRTdpr: path-integrated attenuation (dB), obtained from dual-freq method [SRT]
precipIceIntegrated: precipitation ice content integrated along the column (g/m^2) [solver]
precipProbabilityNearSurface: probability of rain near surface, low-resolution only [preparation]
precipRate: height-dependent precipitation rate (mm/h). Note that all 'precipRate' variables include all types of precipitation [solver] (note that precipRate is the sum of rainRate, mixedPhrate, and snowRate.)
precipRateAve24: average precipitation rate (mm/h) between 2-4 km above ellipsoid [solver]
precipRateESurface: estimated precip rate at surface (mm/h) [solver]
precipRateESurface2: estimated precip rate at surface (mm/h), using a statistical approach [solver]
precipRateLocalTime: near-surface precip rate (mm/h) categorized into local hour; low-resolution only [solver]
precipRateNearSurface: precip rate (mm/h) near surface [solver]

precipRateNearSurfaceUnconditional : unconditional rain rate (mm/h) near surface, low-resolution only [solver]
precipWaterIntegrated: precipitation water content integrated along the column (g/m^2) [solver]
rainRate: height-dependent rain rate (mm/h) [solver].
rainRateNearSurface: rain rate near the surface (mm/h) [solver]
snowRate: height-dependent snow rate (mm/h) [solver].
snowRateNearSurface: snow rate near surface (mm/h) [solver]
zFactorCorrected: height-dependent radar reflectivity factor (mm^6/m^3) in dB, using single-freq attenuation correction [solver]
zFactorCorrectedDPR: height-dependent radar reflectivity factor (mm^6/m^3) in dB, using dual-freq attenuation correction [solver]
zFactorCorrectedESurface: estimated at-surface radar reflectivity factor (mm^6/m^3) in dB, using single-freq attenuation correction [solver]
zFactorCorrectedESurfaceDPR: estimated at-surface radar reflectivity factor (mm^6/m^3) in dB, using dual-freq attenuation correction [solver]
zFactorCorrectedNearSurface: near-surface radar reflectivity factor (mm^6/m^3) in dB, using single-freq attenuation correction [solver]
zFactorCorrectedNearSurfaceDPR: near-surface radar reflectivity factor (mm^6/m^3) in dB, using dual-freq attenuation correction [solver]
zFactorMeasured: height-dependent measured radar reflectivity factor (mm^6/m^3) in dB [preparation]
zFactorMeasuredNearSurface: measured radar reflectivity factor near surface (mm^6/m^3) in dB [preparation]

5) Histogram Bin Definitions

! mm/h (logarithmic steps) used for all rain rate & related variables
cat_rain = [0.01, 0.10, 0.13, 0.17, 0.23, 0.30, 0.40, 0.52, 0.69, 0.91, 1.20, 1.58, 2.08,
2.75, 3.62, 4.77, 6.29, 8.29, 10.92, 14.40, 18.97, 25.00, 32.95, 43.43, 57.24,
75.44, 99.43, 131.04, 172.71, 227.63, 300.00]

! dBZ, used for all radar reflectivity-related variables where Z is in units of mm^6/m^3
cat_Z = [0.01, 6.0, 8.0, 10.0, 12.0, 14.0, 16.0, 18.0, 20.0, 22.0, 24.0, 26.0, 28.0, 30.0,
32.0, 34.0, 36.0, 38.0, 40.0, 42.0, 44.0, 46.0, 48.0, 50.0, 52.0, 54.0, 56.0, 58.0,
60.0, 62.0, 64.0]

! kg/m^2
cat_integratedWater = [0.0, 200.0, 400.0, 600.0, 800.0, 1000.0, 1200.0, 1400.0, 1600.0, 1800.0,
2000.0, 2200.0, 2400.0, 2600.0, 2800.0, 3000.0, 3200.0, 3400.0, 3600.0,
3800.0, 4000.0, 4200.0, 4400.0, 4600.0, 4800.0, 5000.0, 5200.0, 5400.0,
5600.0, 5800.0, 6000.0]

! meters
cat_bbhgt = [10.0, 250.0, 500.0, 750.0, 1000.0, 1250.0, 1500.0, 1750.0, 2000.0, 2250.0, 2500.0,
2750.0, 3000.0, 3250.0, 3500.0, 3750.0, 4000.0, 4250.0, 4500.0, 4750.0, 5000.0,
5250.0, 5500.0, 5750.0, 6000.0, 6250.0, 6500.0, 6750.0, 7000.0, 7500.0,20000.0]

! meters
cat_bbwdth = [0.0, 125.0, 250.0, 375.0, 500.0, 625.0, 750.0, 875.0, 1000.0, 1125.0, 1250.0,
1375.0, 1500.0, 1625.0, 1750.0, 1875.0, 2000.0, 2125.0, 2250.0, 2375.0, 2500.0,
2625.0, 2750.0, 2875.0, 3000.0, 3125.0, 3250.0, 3375.0, 3500.0, 3625.0, 3750.0]

! km (convert m > km)
cat_stormh = 1000.0*[0.01, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0,
6.5, 7.0, 7.5, 8.0, 8.5, 9.0, 9.5, 10.0, 10.5, 11.0, 11.5, 12.0,
12.5, 13.0, 14.0, 15.0, 16.0, 20.0]

cat_epsilon = [0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3,
1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7,
2.8, 2.9, 3.0]

cat_nubf = [1.0, 1.05, 1.1, 1.15, 1.2, 1.25, 1.3, 1.35, 1.4, 1.45, 1.5, 1.55, 1.6, 1.65,
1.7, 1.75, 1.8, 1.85, 1.9, 1.95, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7,
2.8, 2.9, 3.0]

! dB
cat_pia = [0.01, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, 2.0, 2.5,
3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 7.0, 8.0, 9.0, 10.0, 15.0, 20.0, 25.0,
30.0, 100.0]

! N_w: m^{-3} mm^{-1}
cat_dBNw = [0.1, 1.0, 2.0, 4.0, 6.0, 8.0, 10.0, 12.0, 14.0, 16.0, 18.0, 20.0, 22.0,
24.0, 26.0, 28.0, 30.0, 32.0, 34.0, 36.0, 38.0, 40.0, 42.0, 44.0, 46.0,
48.0, 50.0, 52.0, 54.0, 56.0, 60.0]

! mm
cat_Dm = [0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5,
1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3.0,
4.0]