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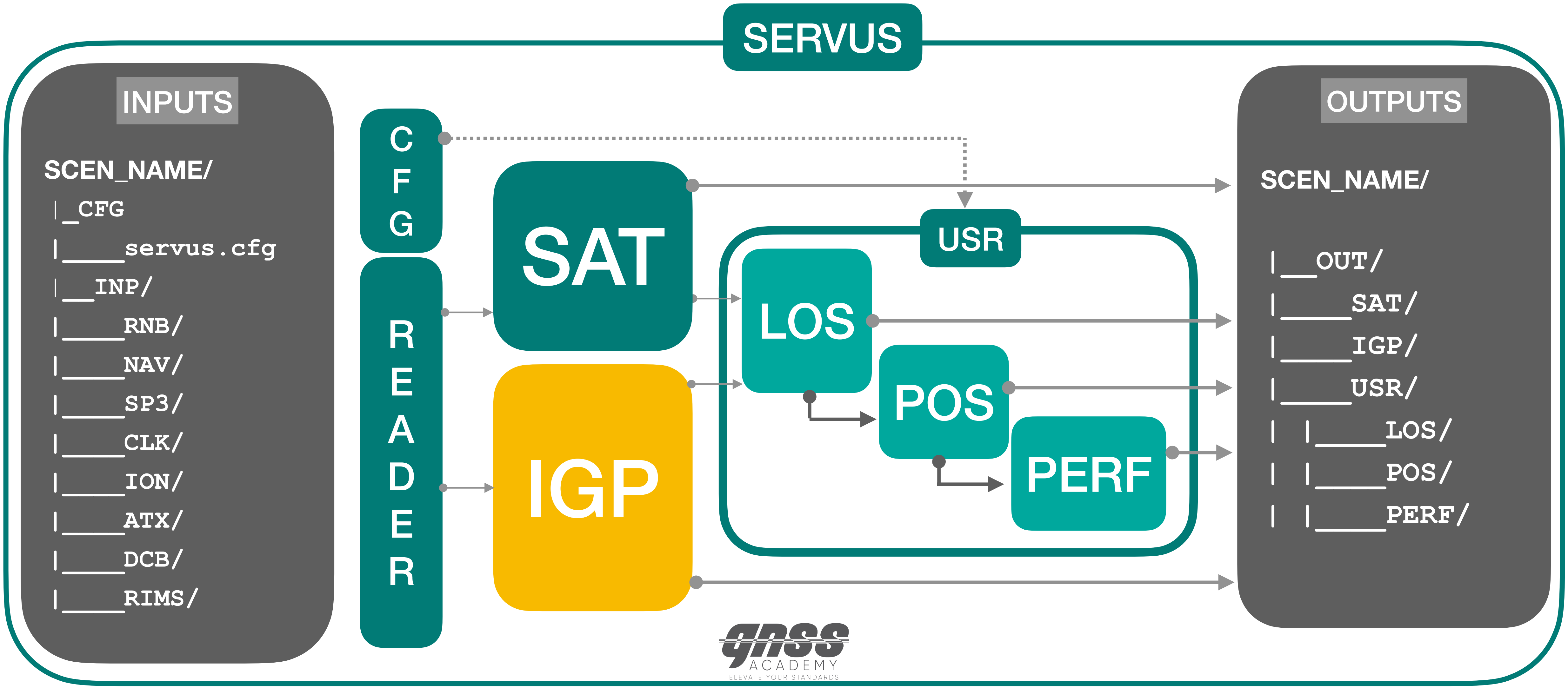
SERVUS

[IGP] MODULE

WP2 - IGP PERFORMANCE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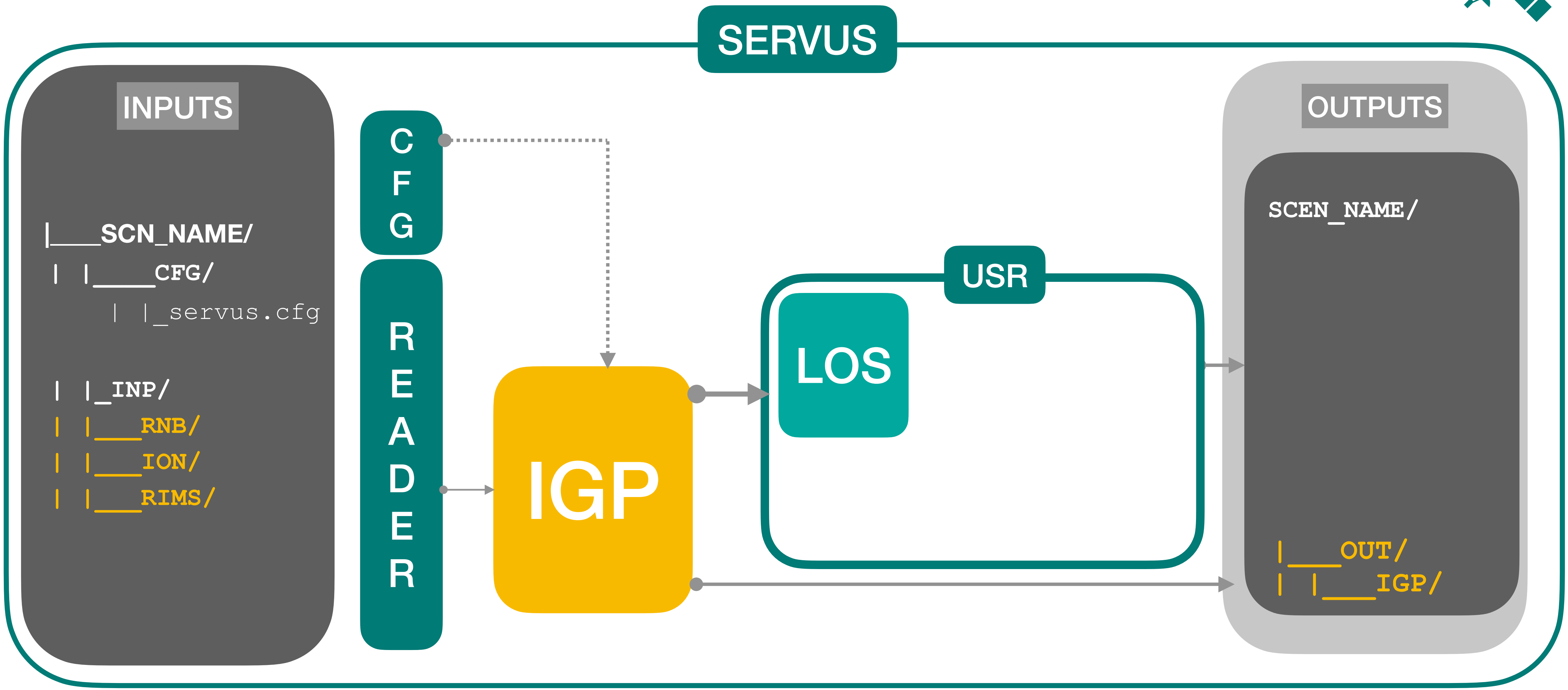
INPUTS
SCEN_NAME/
|_CFG
|____servus.cfg
|__INP/
|____RNB/
|____NAV/
|____SP3/
|____CLK/
|____ION/
|____ATX/
|____DCB/
|____RIMS/
CFG
READER
SAT
IGP
USR
LOS
POS
PERF
OUTPUTS
SCEN_NAME/
|__OUT/
|_____SAT/
|_____IGP/
|_____USR/
| |_____LOS/
| |_____POS/
| |_____PERF/

[IGP MODULE]


SERVUS
INPUTS
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| |____CFG/
| |_servus.cfg
| |_INP/
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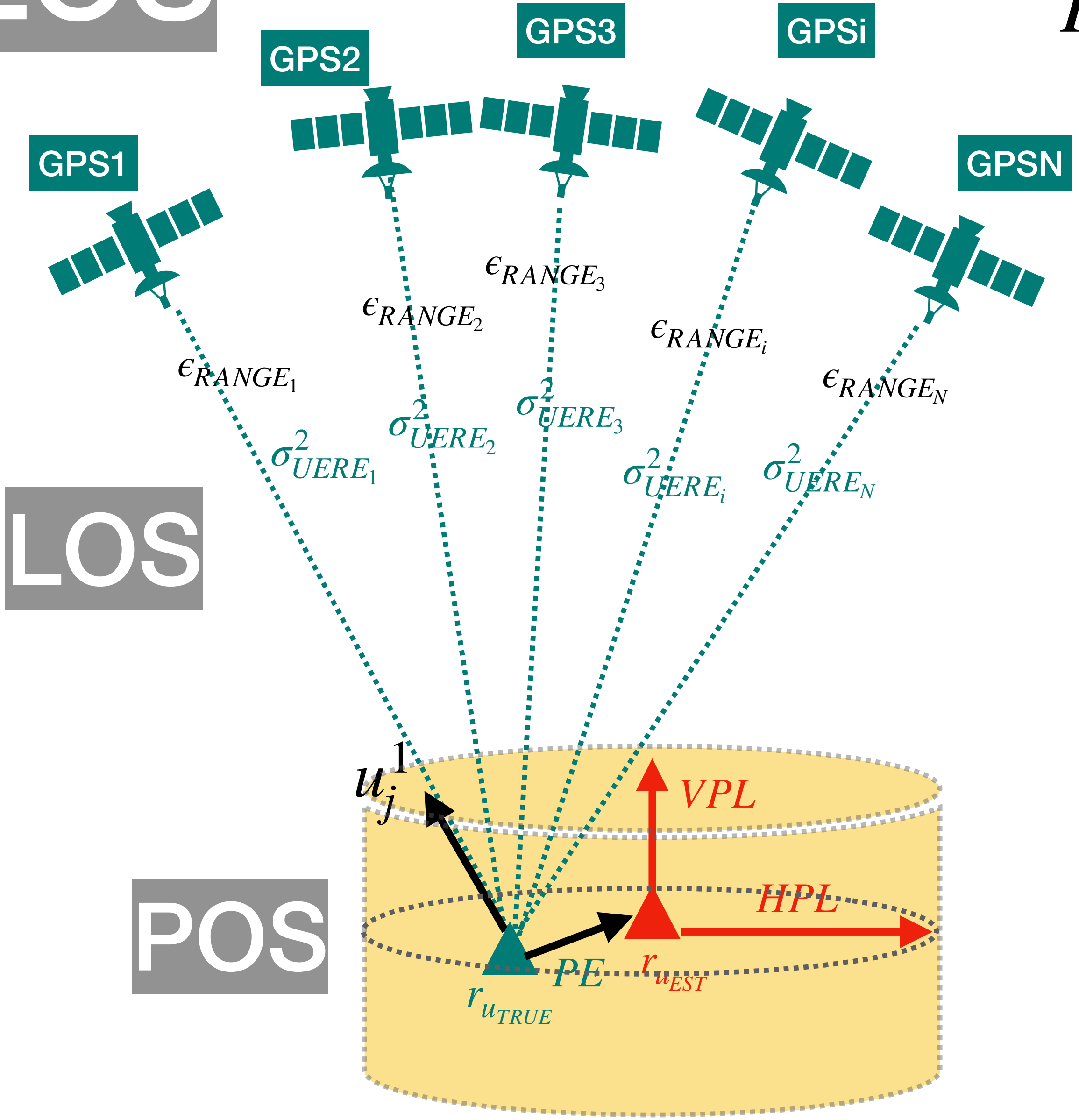
CFG
READER
IGP
USR
LOS
OUTPUTS
SCEN_NAME/
|___OUT/
| |___IGP/

LOS



$$PE = (G^T \mathbf{W} G)^{-1} G^T \mathbf{W} \{\epsilon\}$$

$$G = \begin{bmatrix} -cos(E_1)sin(Az_1) & -cos(E_1)cos(Az_1) & -sin(E_1) & 1 \\ -cos(E_2)sin(Az_1) & -cos(E_2)cos(Az_2) & -sin(E_2) & 1 \\ -cos(E_3)sin(Az_3) & -cos(E_3)cos(Az_3) & -sin(E_3) & 1 \\ \dots & & & \\ -cos(E_N)sin(Az_N) & -cos(E_N)cos(Az_N) & -sin(E_N) & 1 \end{bmatrix}$$

$$W = \begin{bmatrix} 1/(\sigma^1_{UERE})^2 & 0 & 0 & \dots & 0 \\ 0 & 1/(\sigma^2_{UERE})^2 & 0 & \dots & 0 \\ 0 & 0 & 1/(\sigma^3_{UERE})^2 & \dots & 0 \\ \vdots & & & & \\ 0 & 0 & 0 & 0 & 1/(\sigma^N_{UERE})^2 \end{bmatrix}$$

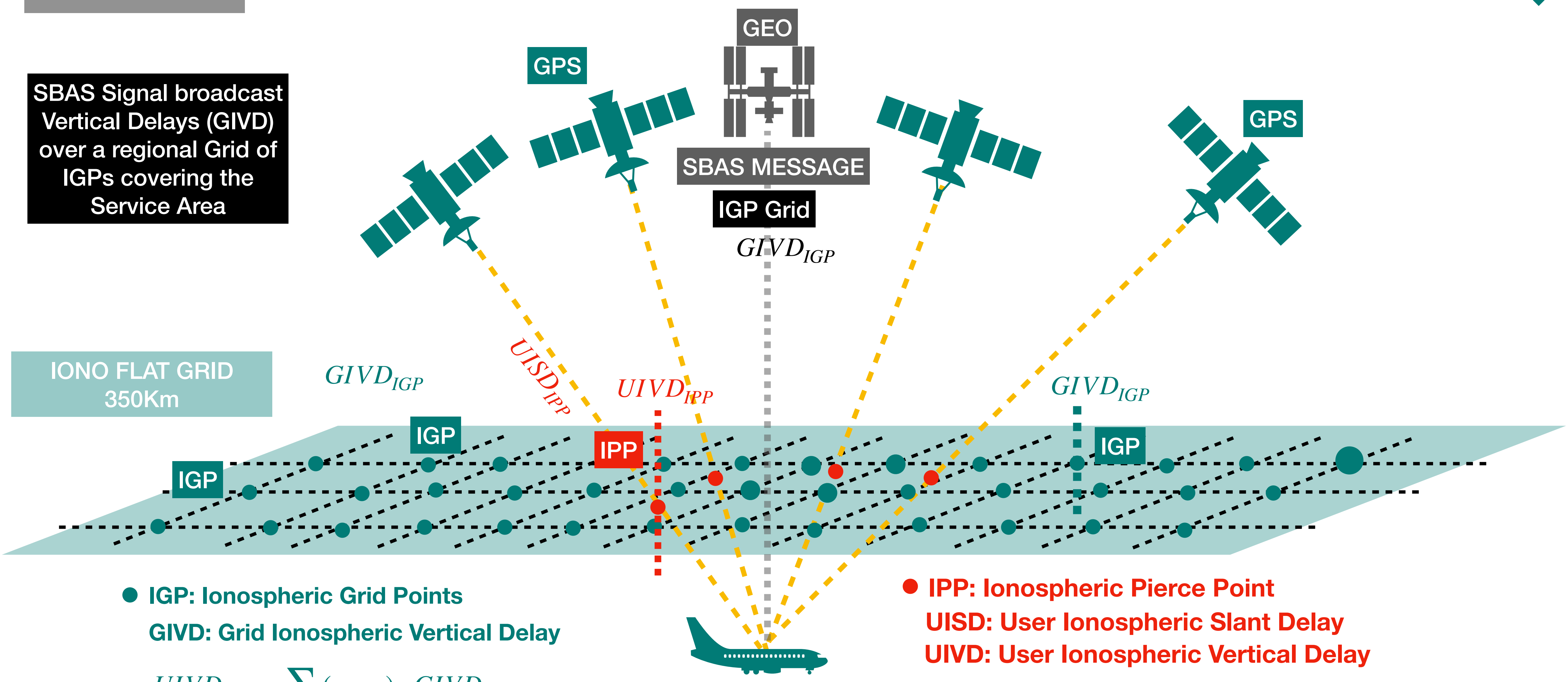
$$\epsilon_{RANGE} = SREU + UISDE + TROPO_E + AIR_E$$

$$(\sigma^i_{UERE})^2 = (\sigma^i_{FLT})^2 + (\sigma^i_{UIRE})^2 + (\sigma^i_{TROPO})^2 + (\sigma^i_{AIR})^2$$

UISDE = UISD - STEC

UISD

SBAS Signal broadcast Vertical Delays (GIVD) over a regional Grid of IGPs covering the Service Area



● IGP: Ionospheric Grid Points

GIVD: Grid Ionospheric Vertical Delay

$$UIVD_{IPP} = \sum (w_{IGPi}) \cdot GIVD_{IGPi}$$

Surrounding IGPs

● IPP: Ionospheric Pierce Point

UISD: User Ionospheric Slant Delay

UIVD: User Ionospheric Vertical Delay

$$UISD_{IPP} = UIVD_{IPP} \cdot m_{pp}(elev)$$

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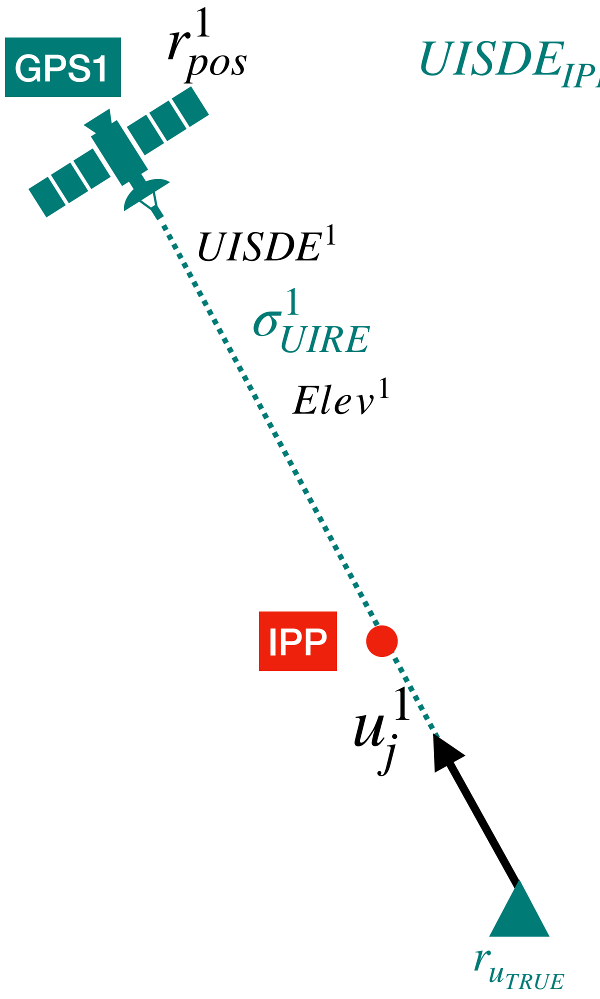
UISDE



$$UISDE_{IPP} = UISD - STEC = m_{pp}(elev) \cdot (UIVD - VTEC_{ipp}) = m_{pp}(elev) \cdot UIVDE$$

$$UISDE_{IPP} = UIVDE_{IPP} \cdot m_{pp}(elev)$$

UISDE: User Ionospheric Slant Delay Error

$$UIVDE_{IPP} = \sum (w_{IGPi}) \cdot GIVDE_{IGPi}$$

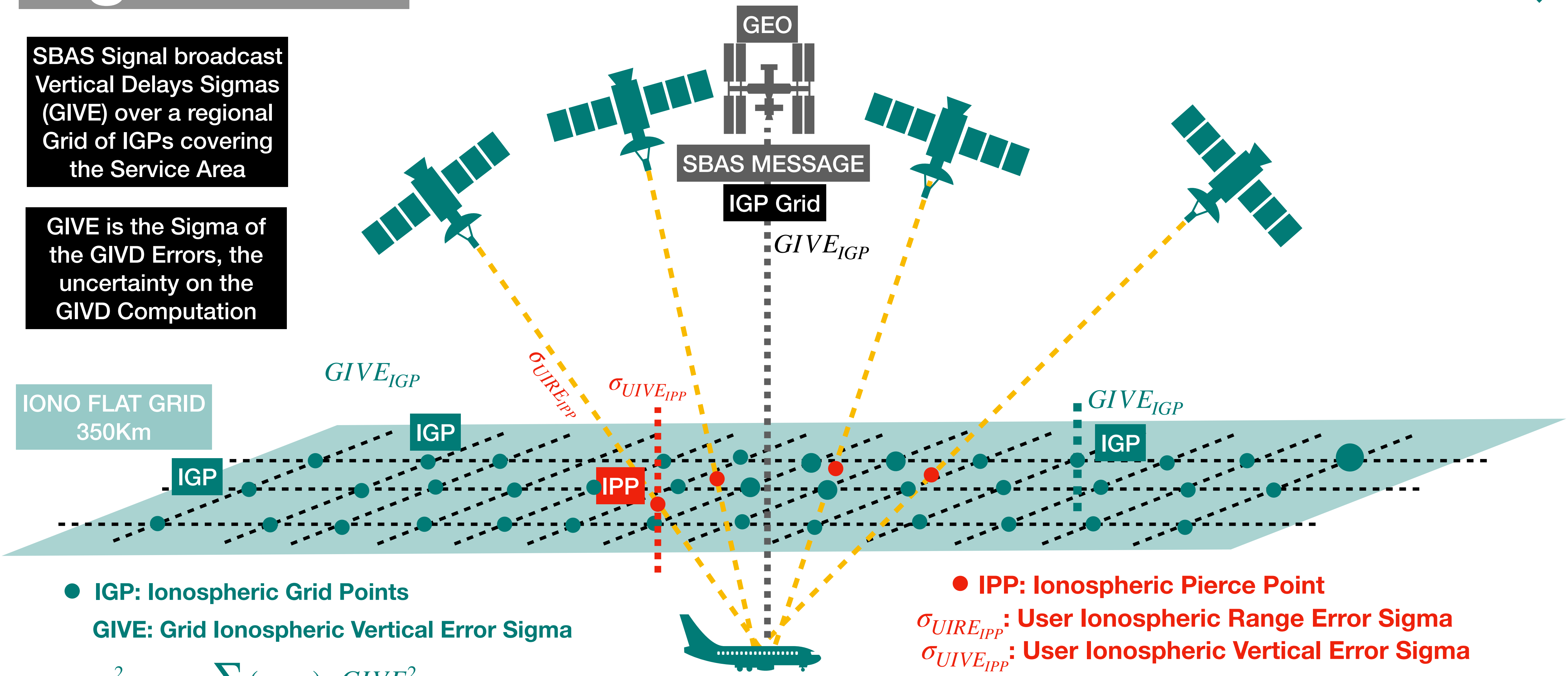
$$UIVDE_{IPP} = \sum (w_{IGPi}) \cdot (GIVD_{IGPi} - VTEC_{IGPi})$$

SigmaUIRE or UIRE

SigmaUIRE

SBAS Signal broadcast Vertical Delays Sigmas (GIVE) over a regional Grid of IGPs covering the Service Area

GIVE is the Sigma of the GIVD Errors, the uncertainty on the GIVD Computation



- IGP: Ionospheric Grid Points

GIVE: Grid Ionospheric Vertical Error Sigma

$$\sigma^2_{UIVE_{IPP}} = \sum (w_{IGPi}) \cdot GIVE^2_{IGPi}$$

Surrounding IGPs

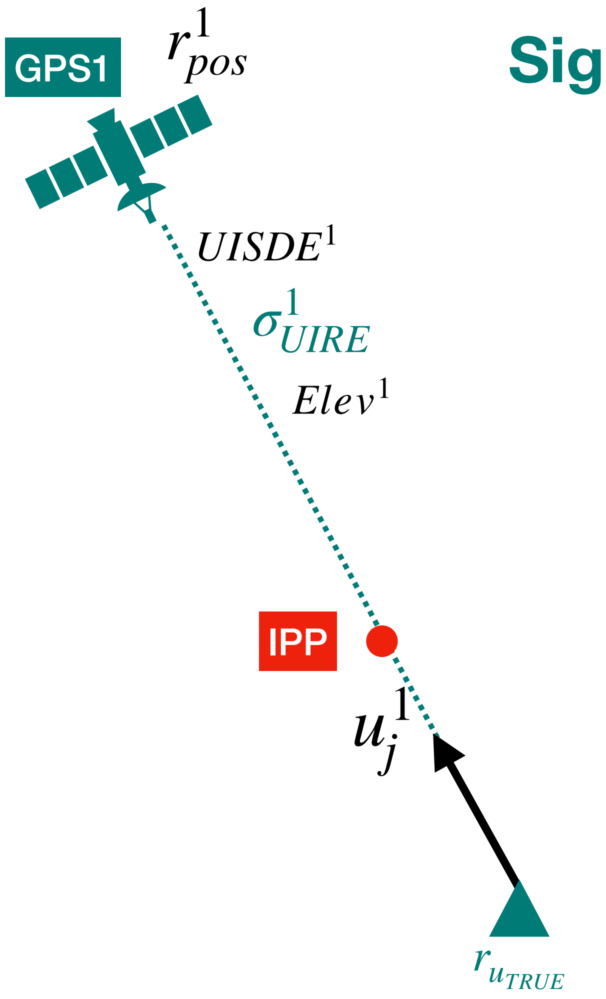
- IPP: Ionospheric Pierce Point

$\sigma_{UIRE_{IPP}}$: User Ionospheric Range Error Sigma

$\sigma_{UIVE_{IPP}}$: User Ionospheric Vertical Error Sigma

$$\sigma_{UIRE_{IPP}} = \sigma_{UIVE_{IPP}} \cdot m_{pp}(elev)$$

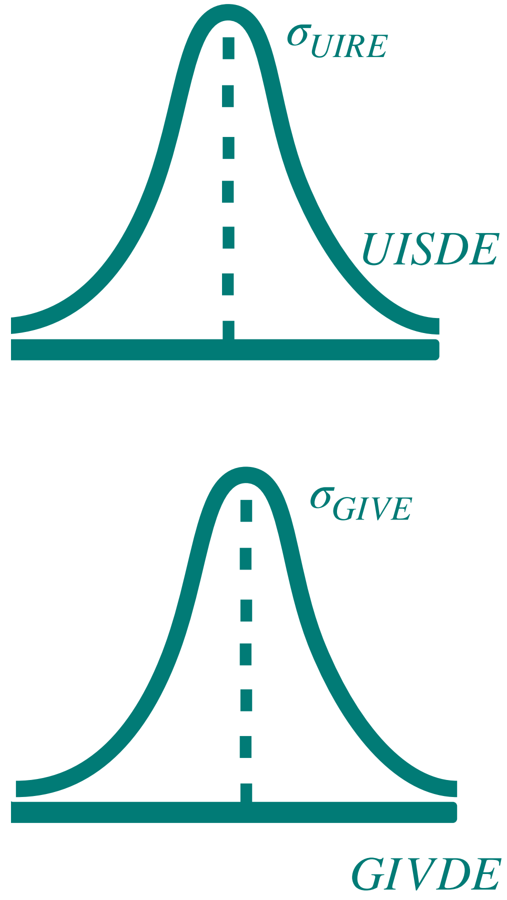
SigmaUIRE



SigmaUIRE: Sigma of the UISDE

$$\sigma_{UIRE_{IPP}} = \sigma_{UIVE_{IPP}} \cdot m_{pp}(elev)$$

$$\sigma^2_{UIVE_{IPP}} = \sum (w_{IGPi}) \cdot GIVE^2_{IGPi}$$



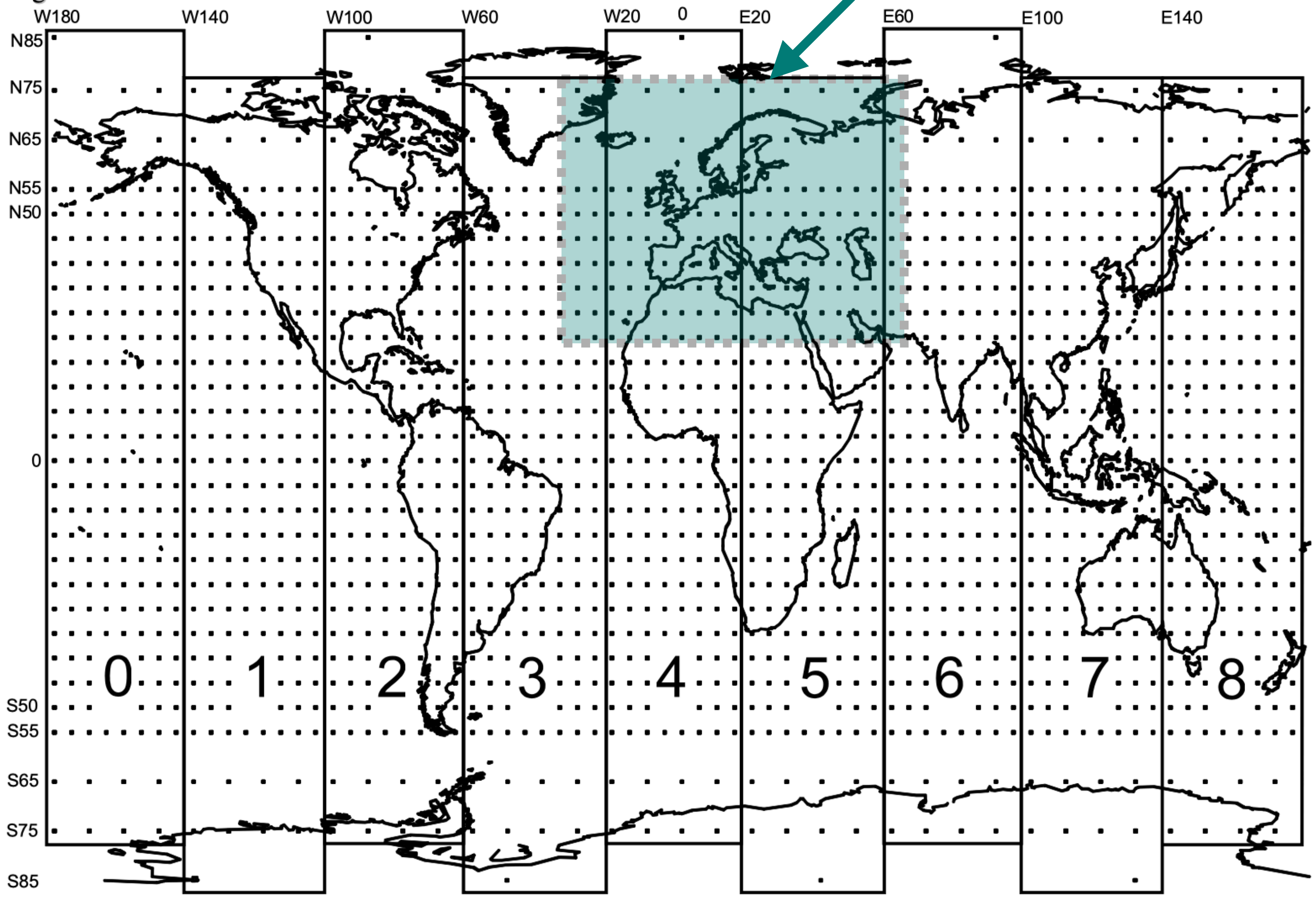
We have computed UISDE and UIRE at IPP

What about GIVDE and GIVE at IGP?

MOPS Grid

EGNOS

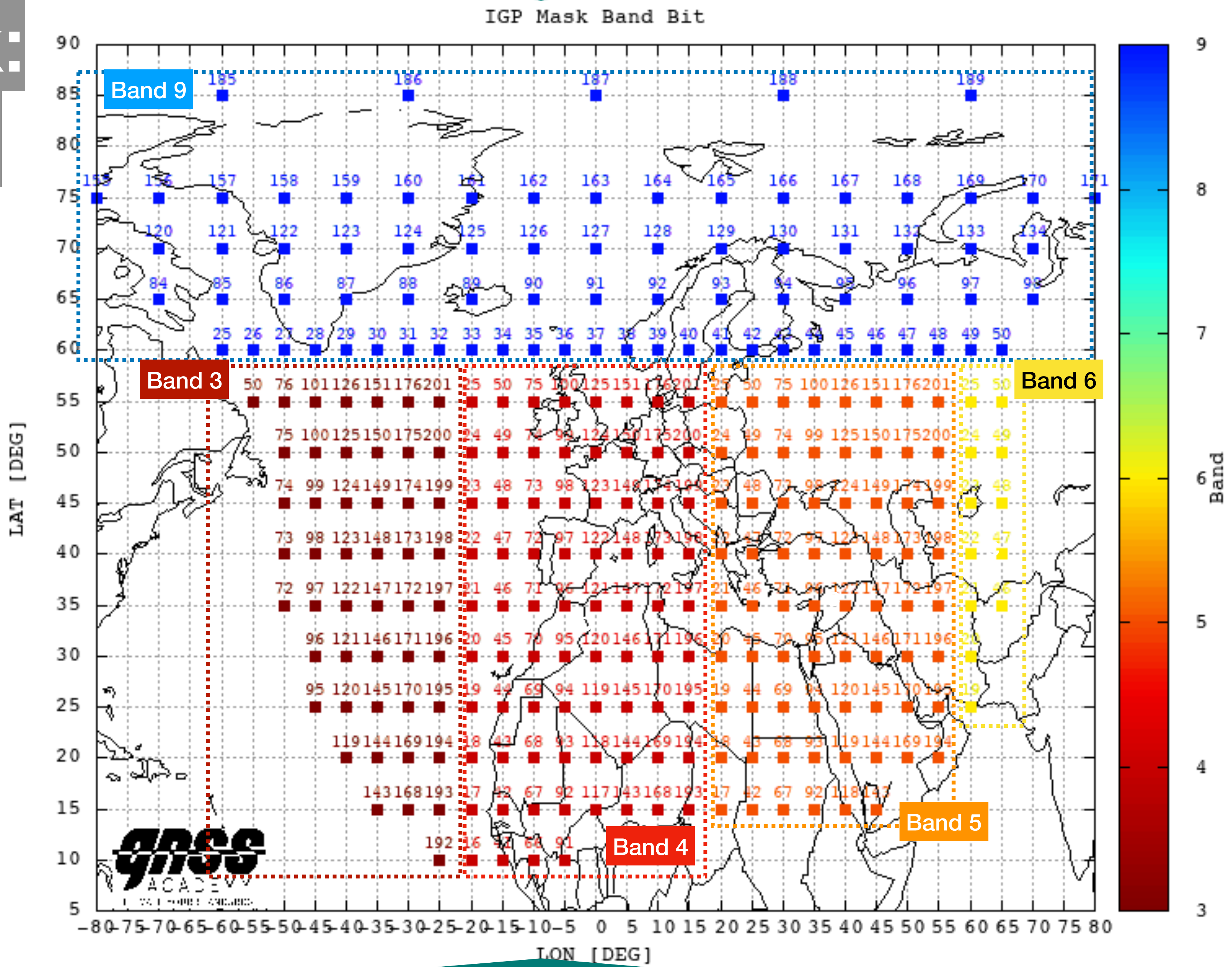
Appendix A
Page A-30



BAND		BIT
Band 3		
60 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1 to 27
55 W	55S, 50S, 45S, ..., 45N, 50N, 55N	28 to 50
50 W	85S, 75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	51 to 78
45 W	55S, 50S, 45S, ..., 45N, 50N, 55N	79 to 101
40 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	102 to 128
35 W	55S, 50S, 45S, ..., 45N, 50N, 55N	129 to 151
30 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	152 to 178
25 W	55S, 50S, 45S, ..., 45N, 50N, 55N	179 to 201
Band 4		
20 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1 to 27
15 W	55S, 50S, 45S, ..., 45N, 50N, 55N	28 to 50
10 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	51 to 77
5 W	55S, 50S, 45S, ..., 45N, 50N, 55N	78 to 100
0	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N, 85N	101 to 128
5 E	55S, 50S, 45S, ..., 45N, 50N, 55N	129 to 151
10 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	152 to 178
15 E	55S, 50S, 45S, ..., 45N, 50N, 55N	179 to 201
Band 5		
20 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1 to 27
25 E	55S, 50S, 45S, ..., 45N, 50N, 55N	28 to 50
30 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	51 to 77
35 E	55S, 50S, 45S, ..., 45N, 50N, 55N	78 to 100
40 E	85S, 75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	101 to 128
45 E	55S, 50S, 45S, ..., 45N, 50N, 55N	129 to 151
50 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	152 to 178
55 E	55S, 50S, 45S, ..., 45N, 50N, 55N	179 to 201
Band 6		
60 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1 to 27
65 E	55S, 50S, 45S, ..., 45N, 50N, 55N	28 to 50
70 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	51 to 77
75 E	55S, 50S, 45S, ..., 45N, 50N, 55N	78 to 100
80 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	101 to 127
85 E	55S, 50S, 45S, ..., 45N, 50N, 55N	128 to 150
90 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N, 85N	151 to 178
95 E	55S, 50S, 45S, ..., 45N, 50N, 55N	179 to 201
Band 9		
60 N	180W, 175W, 170W, …, 165E, 170E, 175E	1 to 72
65 N	180W, 170W, 160W, …, 150E, 160E, 170E	73 to 108
70 N	180W, 170W, 160W, …, 150E, 160E, 170E	109 to 144
75 N	180W, 170W, 160W, …, 150E, 160E, 170E	145 to 180
85 N	180W, 150W, 120W, … ,90E, 120E, 150E	181 to 192

IGP Mask: 287 IGPs

MT18



MT18

```
MESSAGE_TYPE 18 : IGP Mask                  Epoch: 1150     TIME: 14/01/19 00:19:10

IODI: 0
Number of bands:        5
Band number:            9
IGPs:
IGP(  1):  25   IGP(  2):  26   IGP(  3):  27   IGP(  4):  28   IGP(  5):  29
IGP(  6):  30   IGP(  7):  31   IGP(  8):  32   IGP(  9):  33   IGP( 10):  34
IGP( 11):  35   IGP( 12):  36   IGP( 13):  37   IGP( 14):  38   IGP( 15):  39
IGP( 16):  40   IGP( 17):  41   IGP( 18):  42   IGP( 19):  43   IGP( 20):  44
IGP( 21):  45   IGP( 22):  46   IGP( 23):  47   IGP( 24):  48   IGP( 25):  49
IGP( 26):  50   IGP( 27):  84   IGP( 28):  85   IGP( 29):  86   IGP( 30):  87
IGP( 31):  88   IGP( 32):  89   IGP( 33):  90   IGP( 34):  91   IGP( 35):  92
IGP( 36):  93   IGP( 37):  94   IGP( 38):  95   IGP( 39):  96   IGP( 40):  97
IGP( 41):  98   IGP( 42): 120   IGP( 43): 121   IGP( 44): 122   IGP( 45): 123
IGP( 46): 124   IGP( 47): 125   IGP( 48): 126   IGP( 49): 127   IGP( 50): 128
IGP( 51): 129   IGP( 52): 130   IGP( 53): 131   IGP( 54): 132   IGP( 55): 133
IGP( 56): 134   IGP( 57): 155   IGP( 58): 156   IGP( 59): 157   IGP( 60): 158
IGP( 61): 159   IGP( 62): 160   IGP( 63): 161   IGP( 64): 162   IGP( 65): 163
IGP( 66): 164   IGP( 67): 165   IGP( 68): 166   IGP( 69): 167   IGP( 70): 168
IGP( 71): 169   IGP( 72): 170   IGP( 73): 171   IGP( 74): 184   IGP( 75): 185
IGP( 76): 186   IGP( 77): 187   IGP( 78): 188   IGP( 79): 189   IGP( 80): 190
```

MT26

```
MESSAGE_TYPE 26 : IONO corrections      Epoch: 1158     TIME: 14/01/19 00:19:18

IODI: 0
Band:    4
Block:   1
 IGP  46:  Status: USE      GIVE[1Sigma]=   0.73      GIVD[m]=   0.50
 IGP  47:  Status: USE      GIVE[1Sigma]=   0.73      GIVD[m]=   0.50
 IGP  48:  Status: USE      GIVE[1Sigma]=   0.91      GIVD[m]=   0.50
 IGP  49:  Status: USE      GIVE[1Sigma]=   0.91      GIVD[m]=   0.50
 IGP  50:  Status: USE      GIVE[1Sigma]=   0.91      GIVD[m]=   0.38
 IGP  66:  Status:  NM      GIVE[1Sigma]=     NM      GIVD[m]=  63.75
 IGP  67:  Status: USE      GIVE[1Sigma]=   1.82      GIVD[m]=   1.12
 IGP  68:  Status: USE      GIVE[1Sigma]=   0.91      GIVD[m]=   0.75
 IGP  69:  Status: USE      GIVE[1Sigma]=   0.73      GIVD[m]=   0.75
 IGP  70:  Status: USE      GIVE[1Sigma]=   0.73      GIVD[m]=   1.00
 IGP  71:  Status: USE      GIVE[1Sigma]=   0.73      GIVD[m]=   0.62
 IGP  72:  Status: USE      GIVE[1Sigma]=   0.73      GIVD[m]=   0.50
 IGP  73:  Status: USE      GIVE[1Sigma]=   0.82      GIVD[m]=   0.75
 IGP  74:  Status: USE      GIVE[1Sigma]=   0.82      GIVD[m]=   0.75
 IGP  75:  Status: USE      GIVE[1Sigma]=   0.82      GIVD[m]=   0.38
```

GIVDE

GIVDE

Difference between the EGNOS GIVD and the True GIVD, here called VTEC

$$GIVDE = GIVD_{IGP} - VTEC_{IGP} = GIVD_{IGP} - (VTEC_{IONEX_{IGP}} + \epsilon_{IONEX})$$

$$GIVDE \approx GIVD_{IGP} - VTEC_{IONEX_{IGP}}$$

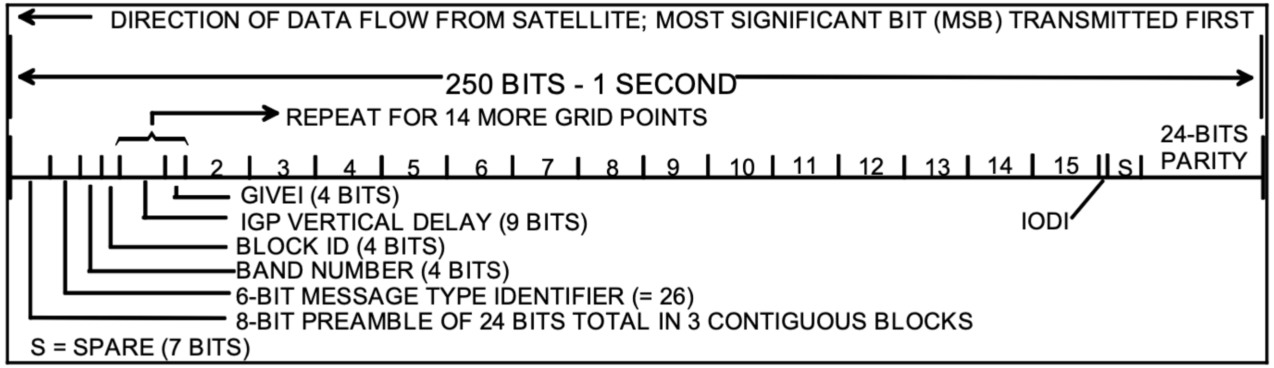
GIVD

GIVD MT26

GIVD for each IGP is extracted from MT26.

TABLE A-16 IONOSPHERIC DELAY MODEL PARAMETERS FOR MESSAGE TYPE 26

Parameter	No. of Bits	Scale Factor (LSB)	Effective Range	Units
Band Number	4	1	0 to 10	unitless
Block ID	4	1	0 to 13	unitless
For Each of 15 Grid Points	13	—	—	—
IGP Vertical Delay Estimate	9	0.125	0 to 63.875	meters
Grid Ionospheric Vertical Error Indicator (GIVEI)	4	1	0 to 15	unitless
IODI	2	1	0 to 3	unitless
Spare	7	—	—	—



The 9-bit IGP vertical delays have a 0.125 meter resolution, for a 0-63.750 meter valid range. A vertical delay of 63.875 meters (111111111) will indicate *don't use*. That is, there are no IGP vertical delays greater than 63.750 meters. If that range is exceeded, a *don't use* indication will be used.

GIVD == 63.875 ==> DON'T USE

GIVE = GIVE + EpsilonIONO

MT26

TABLE A-17 EVALUATION OF GIVEIi

$GIVEI_i$	$GIVE_i$ Meters	$\sigma^2_{i,GIVE}$ Meters^2
0	0.3	0.0084
1	0.6	0.0333
2	0.9	0.0749
3	1.20	0.1331
4	1.5	0.2079
5	1.8	0.2994
6	2.1	0.4075
7	2.4	0.5322
8	2.7	0.6735
9	3.0	0.8315
10	3.6	1.1974
11	4.5	1.8709
12	6.0	3.3260
13	15.0	20.7870
14	45.0	187.0826
15	Not Monitored	Not Monitored

Degradation of Ionospheric Corrections

The residual error associated with the ionospheric corrections is characterized by the variance ($\sigma_{ionogrid}^2$) of a model distribution. This parameter is applicable at each ionospheric grid point, and must be interpolated to the user pierce point and translated to slant range (A.4.4.10). This term is computed as:

$$\sigma^2_{ionogrid} = \begin{cases} \left(\sigma_{GIVE} + \varepsilon_{iono}\right)^2, & if\ RSS_{iono} = 0\ (Message\ Type\ 10) \\ \sigma^2_{GIVE} + \varepsilon^2_{iono}, & if\ RSS_{iono} = 1\ (Message\ Type\ 10) \end{cases} \quad \text{(A-58)}$$

where:

RSS_{iono} = root-sum-square flag from Message Type 10

σ_{GIVE} = model parameter from Message Type 26 (ref. A.4.4.10)

and

$$\varepsilon_{iono} = C_{iono\_step}\left\lfloor \frac{t - t_{iono}}{I_{iono}} \right\rfloor + C_{iono\_ramp}(t - t_{iono}) \quad \text{(A-59)}$$

C_{iono_step} = the bound on the difference between successive ionospheric grid delay values determined from Message Type 10

t = the current time

t_{iono} = the time of transmission of the first bit of the ionospheric correction message at the GEO

C_{iono_ramp} = the rate of change of the ionospheric corrections determined from Message Type 10

I_{iono} = the minimum update interval for ionospheric correction messages determined from Message Type 10

$\lfloor x \rfloor$ = the floor or greatest integer less than x function

VTEC

IONEX

igsg0140.19i

HEADER

```
     1.0            IONOSPHERE MAPS     MIX                 IONEX VERSION / TYPE
cmpcmb v1.2          GRL/UWM             1-feb-19 09:08      PGM / RUN BY / DATE
ionex file containing IGS COMBINED Ionosphere maps          COMMENT
global ionosphere maps for day 014, 2019                    DESCRIPTION
IONEX file containing the COMBINED IGS TEC MAPS and DCBs    DESCRIPTION
      IONEX files of the following IAACs were combined: cod DESCRIPTION
                                                        jpl DESCRIPTION
Contact address: Andrzej Krankowski                         DESCRIPTION
                 Geodynamics Research Laboratory            DESCRIPTION
                 University of Warmia and Mazury (GRL/UWM)  DESCRIPTION
                 Oczapowski St. 1                           DESCRIPTION
                 10-957-Olsztyn, POLAND                     DESCRIPTION
                 e-mail:  kand@uwm.edu.pl                   DESCRIPTION
                                                            DESCRIPTION
  2019     1    14     0     0     0                        EPOCH OF FIRST MAP
  2019     1    15     0     0     0                        EPOCH OF LAST MAP
  7200                                                      INTERVAL
    13                                                      # OF MAPS IN FILE
  COSZ                                                      MAPPING FUNCTION
     0.0                                                    ELEVATION CUTOFF
combined TEC calculated as weighted mean of input TEC valuesOBSERVABLES USED
   322                                                      # OF STATIONS
    32                                                      # OF SATELLITES
  6371.0                                                    BASE RADIUS
     2                                                      MAP DIMENSION
   450.0 450.0   0.0                                        HGT1 / HGT2 / DHGT
    87.5 -87.5  -2.5                                        LAT1 / LAT2 / DLAT
  -180.0 180.0   5.0                                        LON1 / LON2 / DLON
    -1                                                      EXPONENT
TEC values in 0.1 tec units;  9999, if no value available   COMMENT
DCB values in nanoseconds, reference is Sum_of_SatDCBs = 0  COMMENT
```

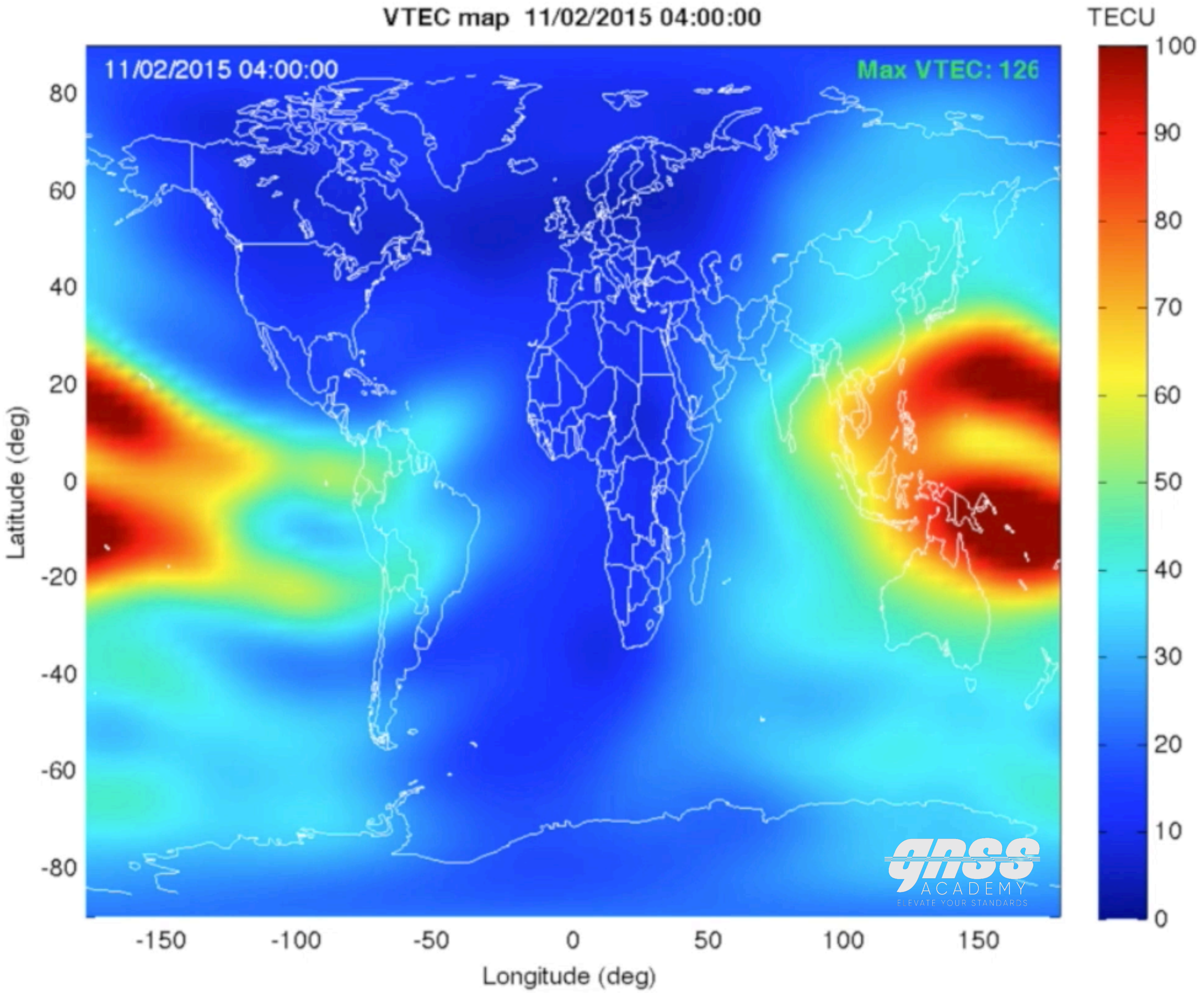
VTEC MAPS LATxLON 2.5x5deg
EVERY 2 HOURS

```
                                                            END OF HEADER
     1                                                      START OF TEC MAP
  2019     1    14     0     0     0                        EPOCH OF CURRENT MAP
    87.5-180.0 180.0   5.0 450.0                            LAT/LON1/LON2/DLON/H
   14   14   14   14   14   14   14   14   14   14   14   13   13   13   13   12
   12   12   12   11   11   11   10   10   10   10   10   10   10   10    9    9
    9    9    9    9    9    9   10   10   10   10   10   11   11   11   11   12
   12   12   12   13   13   13   13   13   13   14   14   14   14   14   14   14
   14   14   14   14   14   14   14   14   14
    85.0-180.0 180.0   5.0 450.0                            LAT/LON1/LON2/DLON/H
   17   17   18   18   18   18   18   19   19   19   19   19   18   18   18   17
   17   16   15   14   14   13   12   11   11   10   10   10    9    9    9    9
    9    9    9    9    9    9    9    9   10   11   11   12   13   14   14   15
   16   16   17   17   17   17   17   17   17   17   17   17   17   17   16   16
   16   16   16   16   16   16   16   17   17
    82.5-180.0 180.0   5.0 450.0                            LAT/LON1/LON2/DLON/H
   20   21   22   23   23   24   24   25   25   25   26   26   25   25   25   24
   23   22   21   20   19   18   16   15   13   12   11   10   10    9    9    9
    9    9    9    9    9    9   10   10   11   13   14   15   17   18   19   20
   21   21   22   22   22   22   22   21   21   20   20   19   19   18   18   18
   18   17   18   18   18   19   19   20   20
```

VTEC for an IPP is obtained by spatial bilinear interpolation with the surrounding grid points and linear interpolation between 2 hours-maps

STEC at IPP is obtained from VTEC multiplied by a mapping function elevation dependent

VTEC



VTEC map 11/02/2015 04:00:00
11/02/2015 04:00:00
Max VTEC: 126
TECU
100
90
80
70
60
50
40
30
20
10
0
Latitude (deg)
80
60
40
20
0
-20
-40
-60
-80
Longitude (deg)
-150
-100
-50
0
50
100
150
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VTEC from IONEX: SPACE Interpolation

$$E(\lambda_0 + p\,\Delta\lambda, \beta_0 + q\,\Delta\beta) = (1-p)\,(1-q)\,E_{0,0} + p\,(1-q)\,E_{1,0} + q\,(1-p)\,E_{0,1} + p\,q\,E_{1,1},$$

where $0 \leq p < 1$ and $0 \leq q < 1$. $\Delta\lambda$ and $\Delta\beta$ denote the grid widths in longitude and latitude.

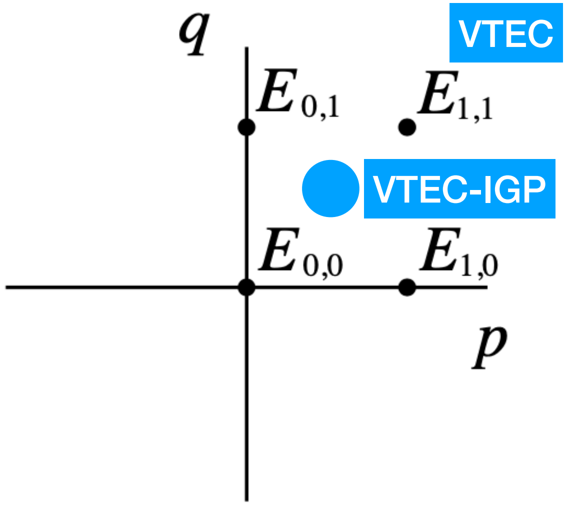

Figure 1: Bivariate interpolation using the nearest 4 TEC values $E_{i,j}$

VTEC from IONEX: TIME Interpolation

3 Methods:

1 Simply take the nearest TEC map $E_i = E(T_i)$ at epoch T_i:

$$E(\beta, \lambda, t) = E_i(\beta, \lambda), \tag{1}$$

where $|t - T_i| = \min$.

2 Interpolate between consecutive TEC maps $E_i = E(T_i)$ and $E_{i+1} = E(T_{i+1})$:

$$E(\beta, \lambda, t) = \frac{T_{i+1} - t}{T_{i+1} - T_i} E_i(\beta, \lambda) + \frac{t - T_i}{T_{i+1} - T_i} E_{i+1}(\beta, \lambda), \tag{2}$$

where $T_i \leq t < T_{i+1}$.

3 Interpolate between consecutive *rotated* TEC maps:

$$E(\beta, \lambda, t) = \frac{T_{i+1} - t}{T_{i+1} - T_i} E_i(\beta, \lambda'_i) + \frac{t - T_i}{T_{i+1} - T_i} E_{i+1}(\beta, \lambda'_{i+1}), \tag{3}$$

where $T_i \leq t < T_{i+1}$ and $\lambda'_i = \lambda + (t - T_i)$. The TEC maps are rotated by $t - T_i$ around the Z-axis in order to compensate to a great extent the strong correlation between the ionosphere and the Sun's position. Note that method (1) can be refined accordingly by taking the nearest *rotated* map: $E(\beta, \lambda, t) = E_i(\beta, \lambda')$.

GIVE

GIVE = GIVE + EpsilonIONO

MT26

TABLE A-17 EVALUATION OF GIVEIi

GIVEI$_i$	GIVE$_i$ Meters	$\sigma^2_{i,GIVE}$ Meters^2
0	0.3	0.0084
1	0.6	0.0333
2	0.9	0.0749
3	1.20	0.1331
4	1.5	0.2079
5	1.8	0.2994
6	2.1	0.4075
7	2.4	0.5322
8	2.7	0.6735
9	3.0	0.8315
10	3.6	1.1974
11	4.5	1.8709
12	6.0	3.3260
13	15.0	20.7870
14	45.0	187.0826
15	Not Monitored	Not Monitored

Degradation of Ionospheric Corrections

The residual error associated with the ionospheric corrections is characterized by the variance ($\sigma_{ionogrid}^2$) of a model distribution. This parameter is applicable at each ionospheric grid point, and must be interpolated to the user pierce point and translated to slant range (A.4.4.10). This term is computed as:

$$\sigma^2_{ionogrid} = \begin{cases} \left(\sigma_{GIVE} + \varepsilon_{iono}\right)^2, & if\ RSS_{iono} = 0\ (Message\ Type\ 10) \\ \sigma^2_{GIVE} + \varepsilon^2_{iono}, & if\ RSS_{iono} = 1\ (Message\ Type\ 10) \end{cases} \tag{A-58}$$

where:

RSS_{iono} = root-sum-square flag from Message Type 10

σ_{GIVE} = model parameter from Message Type 26 (ref. A.4.4.10)

and

$$\varepsilon_{iono} = C_{iono\_step}\left\lfloor \frac{t - t_{iono}}{I_{iono}} \right\rfloor + C_{iono\_ramp}(t - t_{iono}) \tag{A-59}$$

C_{iono_step} = the bound on the difference between successive ionospheric grid delay values determined from Message Type 10

t = the current time

t_{iono} = the time of transmission of the first bit of the ionospheric correction message at the GEO

C_{iono_ramp} = the rate of change of the ionospheric corrections determined from Message Type 10

I_{iono} = the minimum update interval for ionospheric correction messages determined from Message Type 10

$\lfloor x \rfloor$ = the floor or greatest integer less than x function

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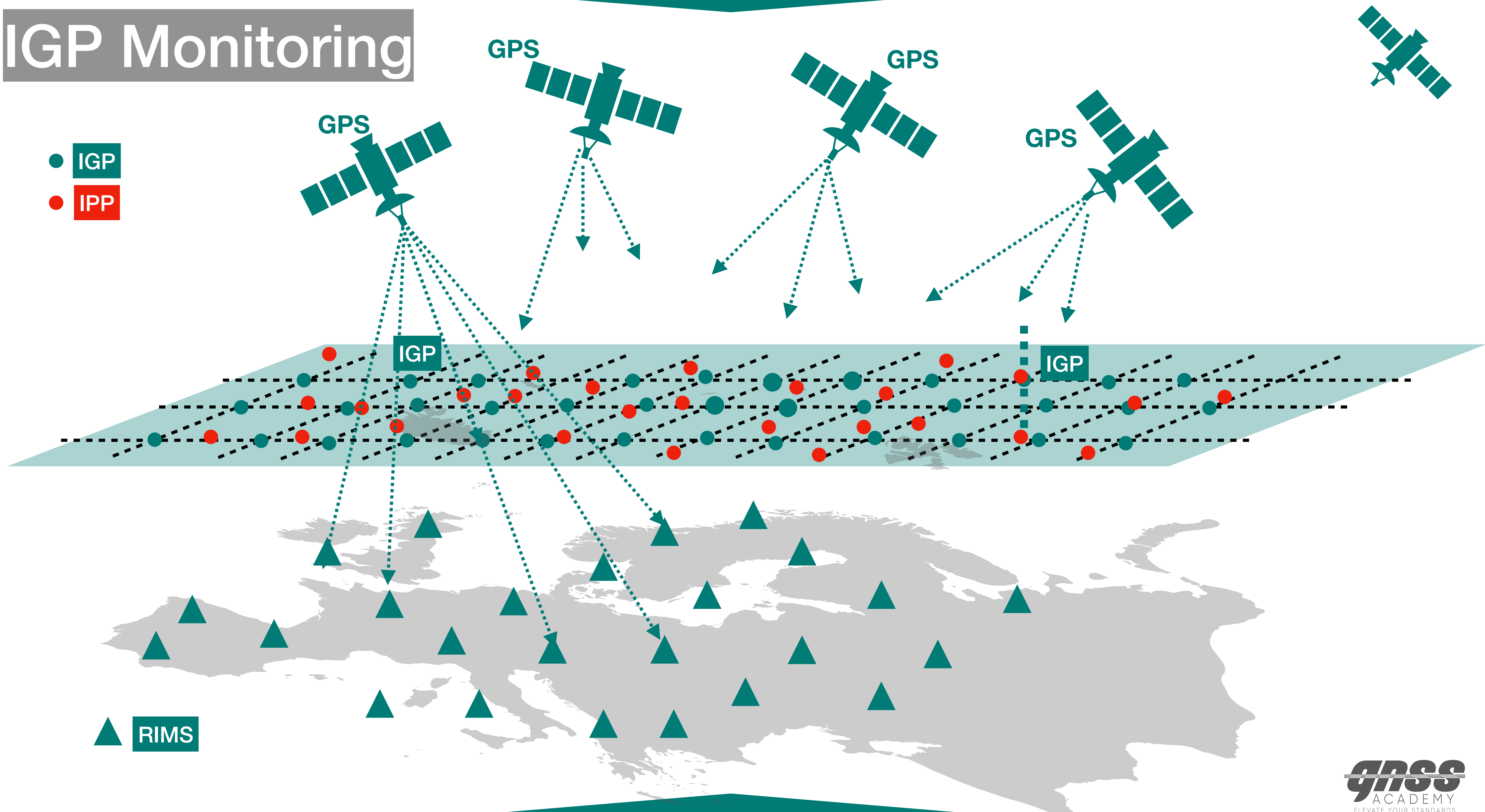
MT26

```
MESSAGE_TYPE 26 : IONO corrections      Epoch: 1158     TIME: 14/01/19 00:19:18

IODI: 0
Band:    4
Block:   1
 IGP   46:   Status: USE       GIVE[1Sigma]=   0.73       GIVD[m]=    0.50
 IGP   47:   Status: USE       GIVE[1Sigma]=   0.73       GIVD[m]=    0.50
 IGP   48:   Status: USE       GIVE[1Sigma]=   0.91       GIVD[m]=    0.50
 IGP   49:   Status: USE       GIVE[1Sigma]=   0.91       GIVD[m]=    0.50
 IGP   50:   Status: USE       GIVE[1Sigma]=   0.91       GIVD[m]=    0.38
 IGP   66:   Status:  NM       GIVE[1Sigma]=     NM       GIVD[m]=   63.75
 IGP   67:   Status: USE       GIVE[1Sigma]=   1.82       GIVD[m]=    1.12
 IGP   68:   Status: USE       GIVE[1Sigma]=   0.91       GIVD[m]=    0.75
 IGP   69:   Status: USE       GIVE[1Sigma]=   0.73       GIVD[m]=    0.75
 IGP   70:   Status: USE       GIVE[1Sigma]=   0.73       GIVD[m]=    1.00
 IGP   71:   Status: USE       GIVE[1Sigma]=   0.73       GIVD[m]=    0.62
 IGP   72:   Status: USE       GIVE[1Sigma]=   0.73       GIVD[m]=    0.50
 IGP   73:   Status: USE       GIVE[1Sigma]=   0.82       GIVD[m]=    0.75
 IGP   74:   Status: USE       GIVE[1Sigma]=   0.82       GIVD[m]=    0.75
 IGP   75:   Status: USE       GIVE[1Sigma]=   0.82       GIVD[m]=    0.38
```

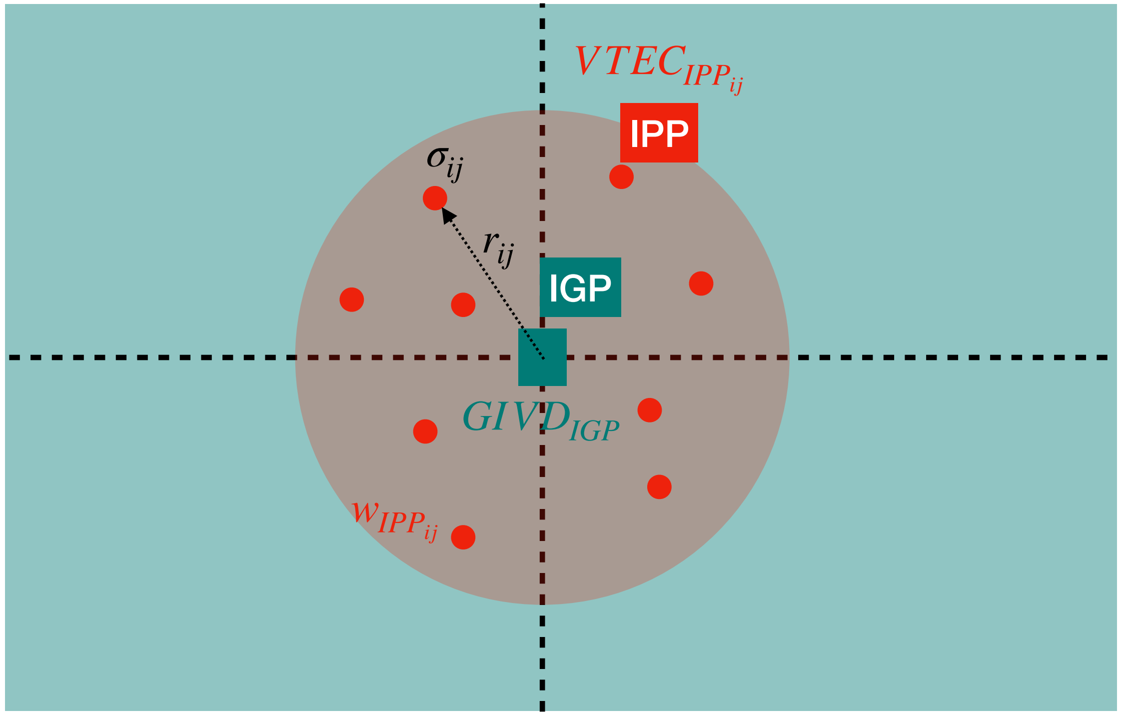
IGP Monitorability

IGP Monitoring



VTEC@IPP to GIVD@IGP

- $GIVD_{IGP}$ can be approximated as a weighted average of the surrounding RIMS-SAT IPP $VTEC_{IPP_{ij}}$ using a weighting function dependent of the radial spherical distance and the associated sigma of the measurement



$$GIVD_{IGP} = \sum w_{IPP_{ij}}(r_{ij}, \sigma_{ij}) \cdot VTEC_{IPP_{ij}}$$

MISSION

Mission IGP1

1. Provide **LOS** module with the necessary information at IGP level.
   - IGP Vertical Delay Errors: GIVDE to later compute the UISDE.
   - IGP Sigmas Information: GIVE later compute the SigmaUIRE projecting along the users.
   - IGP Monitoring Status:
     - **M**: Monitored (GIVE<15)
     - **NM**: Not Monitored (GIVE=15)
     - **DU**: Don’t Use (GIVD=63.875m)

Mission IGP2

2. **Assess and Characterize the related IONO performances.**

Report and/or to display the following type of analyses:

- IGP **Monitoring** Analyses
- IGP **Accuracy** Analyses: GIVDE figures
- IGP **Upper-bound** Analyses: GIVE figures
- IGP **Integrity** Analyses through SI=(GIVDE/5.33GIVE)
- Other …

INPUTS

EXTERNAL INPUTS to IGP Module

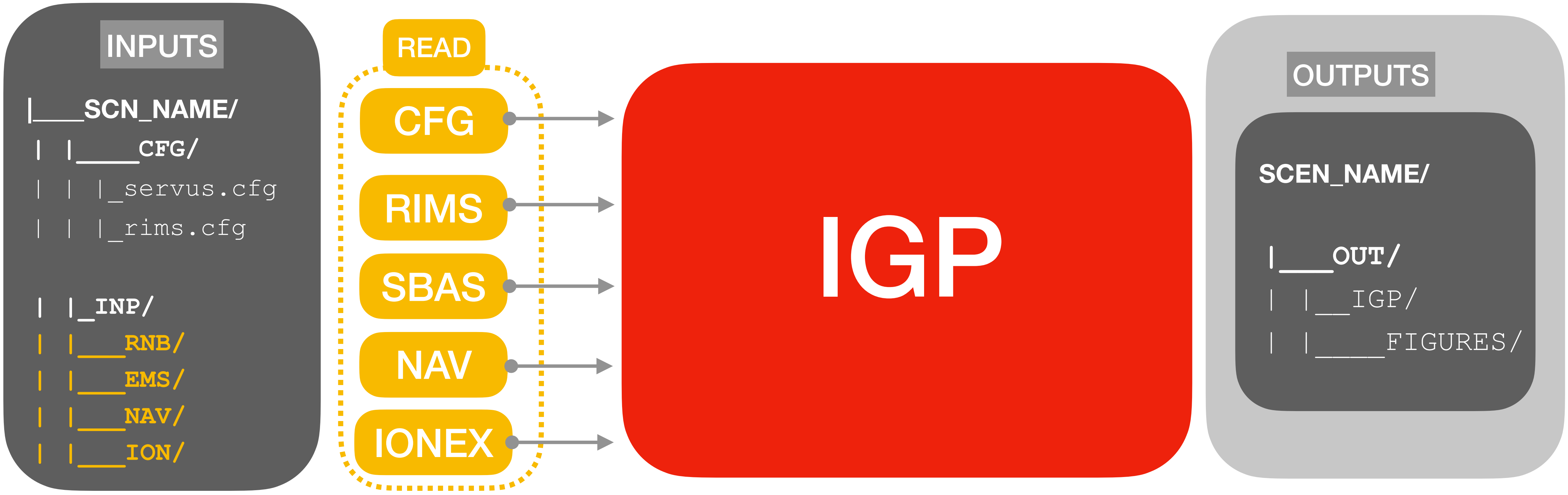
INTERFACE	FORMAT	SCEN/INP	DESCRIPTION
SBAS MESSAGES	RINEX B or EMS	RNB or EMS	Files containing the SBAS SIS Navigation message 250 bits per second with all the different Messages Types broadcast by the SBAS GEO. RINEX B format ftp://serenad-public.essp-sas.eu/SERENAD0/FROM_ESSP/MSG/
GPS NAVIGATION	RINEX NAV.	NAV/	Files containing the GPS Navigation Message with the Ephemeris and clock model parameters information. Satellite positions referred to APC and P1P2 Clocks. ftp://cddis.gsfc.nasa.gov/gps/data/daily/
PRECISE ORBITS	SP3	SP3/	IGS files containing very precise satellite positions (XYZ) in WGS84 reference frame referred to the Satellite Center of Masses with a typical sampling time of 10-15min. ftp://cddis.gsfc.nasa.gov/gps/products/
PRECISE CLOCKS	RINEX CLK	CLK/	IGS files containing very precise satellite clock offsets in GPS/IGSs Time scale reference frame bi-frequency P1P2 with a typical sampling time of 30s or 300s. ftp://cddis.gsfc.nasa.gov/gps/data/daily/
ANTENNA OFFSETS	ANTEX	ATX/	IGS ANTEX files contains the Satellite Antenna Phase Offsets (CoM to APC) in meters. APC depends on the Code and the frequency. ftp://ftp.gfz-potsdam.de/GNSS/metadata/satellite/ANTEX/
CODE BIASES	DCB	DCB/	IGS Monthly Files including the differential Code Biases (DCBs), P1P2 and C1P1 for each satellite GPS. ftp://ftp.aiub.unibe.ch/CODE/
PRECISE IONOSPHERE	IONEX	ION/	IGS Daily files including a precise 2D Global Ionosphere Maps (GIM) with the VTEC information across the Globe with a typical sampling rate of 2 hours. ftp://cddis.gsfc.nasa.gov/pub/gps/products/ionex/

EXTERNAL INPUTS to IGP Module

INTERFACE	FORMAT	SCEN/INP	DESCRIPTION
SBAS MESSAGES	RINEX B or EMS	RNB or EMS	Files containing the SBAS SIS Navigation message 250 bits per second with all the different Messages Types broadcast by the SBAS GEO. RINEX B format ftp://serenad-public.essp-sas.eu/SERENAD0/FROM_ESSP/MSG/
GPS NAVIGATION	RINEX NAV.	NAV/	Files containing the GPS Navigation Message with the Ephemeris and clock model parameters information. Satellite positions referred to APC and P1P2 Clocks. ftp://cddis.gsfc.nasa.gov/gps/data/daily/
PRECISE ORBITS	SP3	SP3/	IGS files containing very precise satellite positions (XYZ) in WGS84 reference frame referred to the Satellite Center of Masses with a typical sampling time of 10-15min. ftp://cddis.gsfc.nasa.gov/gps/products/
PRECISE CLOCKS	RINEX CLK	CLK/	IGS files containing very precise satellite clock offsets in GPS/IGSs Time scale reference frame bi-frequency P1P2 with a typical sampling time of 30s or 300s. ftp://cddis.gsfc.nasa.gov/gps/data/daily/
ANTENNA OFFSETS	ANTEX	ATX/	IGS ANTEX files contains the Satellite Antenna Phase Offsets (CoM to APC) in meters. APC depends on the Code and the frequency. ftp://ftp.gfz-potsdam.de/GNSS/metadata/satellite/ANTEX/
CODE BIASES	DCB	DCB/	IGS Monthly Files including the differential Code Biases (DCBs), P1P2 and C1P1 for each satellite GPS. ftp://ftp.aiub.unibe.ch/CODE/
PRECISE IONOSPHERE	IONEX	ION/	IGS Daily files including a precise 2D Global Ionosphere Maps (GIM) with the VTEC information across the Globe with a typical sampling rate of 2 hours. ftp://cddis.gsfc.nasa.gov/pub/gps/products/ionex/

LOW LEVEL DESIGN

IGP ARCHITECTURE



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IGP ARCHITECTURE

INPUTS

|___CFGinfo
|___RIMSinfo
|___NAVinfo
|___SBASinfo
|___IONinfo

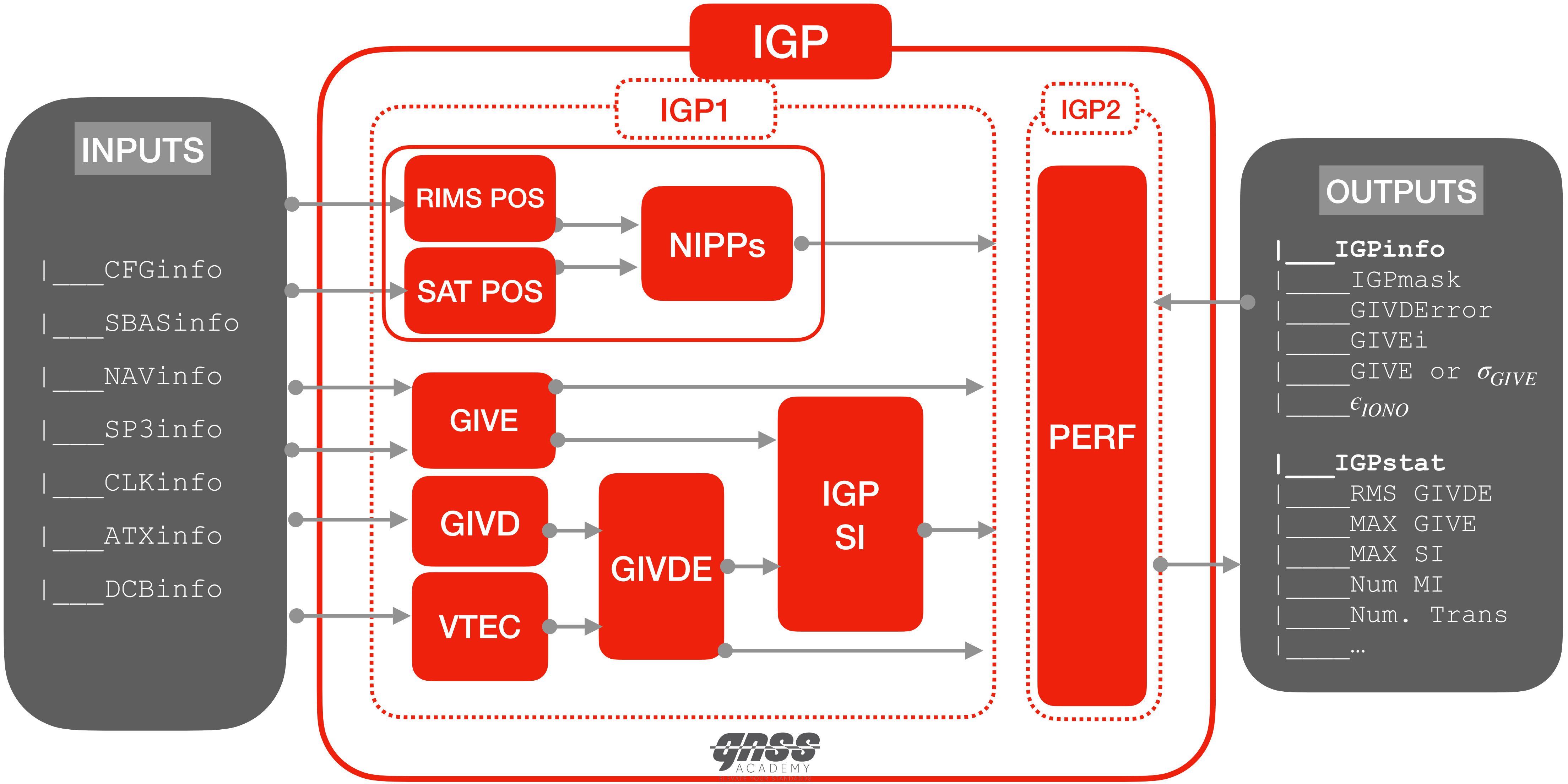
IGP

OUTPUTS

|___IGPinfo
|_____IGPmask
|_____GIVDError
|_____GIVEi
|_____GIVE or σ_{GIVE}
|_____ϵ_{IONO}

|___IGPstat
|_____RMS GIVDE
|_____MAX GIVE
|_____MAX SI
|_____Num MI
|_____Num. Trans
|_____…

LOW LEVEL DESIGN



OUTPUTS

OUTPUTS

INTERFACE	FORMAT	SCEN/OUT	DESCRIPTION
IGP INSTANTANEOUS	IGP_INFO.dat	IGP/	Daily Files and Figures containing for all IGPs in the EGNOS mask: • IGP instantaneous info
IGP STATISTICS	IGP_STAT.dat	IGP/	Daily files containing IGP Statistics • IGP Performances Statistics (e.g: …)
GIVDE HISTOGRAM	IGP_GIVDE_HIST.dat	IGP/	Daily files containing GIVDE Histogram
LATBANDS STAT	IGP_LATBANDS_GIVDE_STAT.dat	IGP/	Statistics per Latitude Band bin
NIPP STATISTICS	IGP_NIPP_BINS_STAT.dat	IGP/	Statistics per Number of IPPs bins
IGP FIGURES	.png	IGP/ FIGURES	Delay Figures containing for all IGP timing information and statistics

IGP1

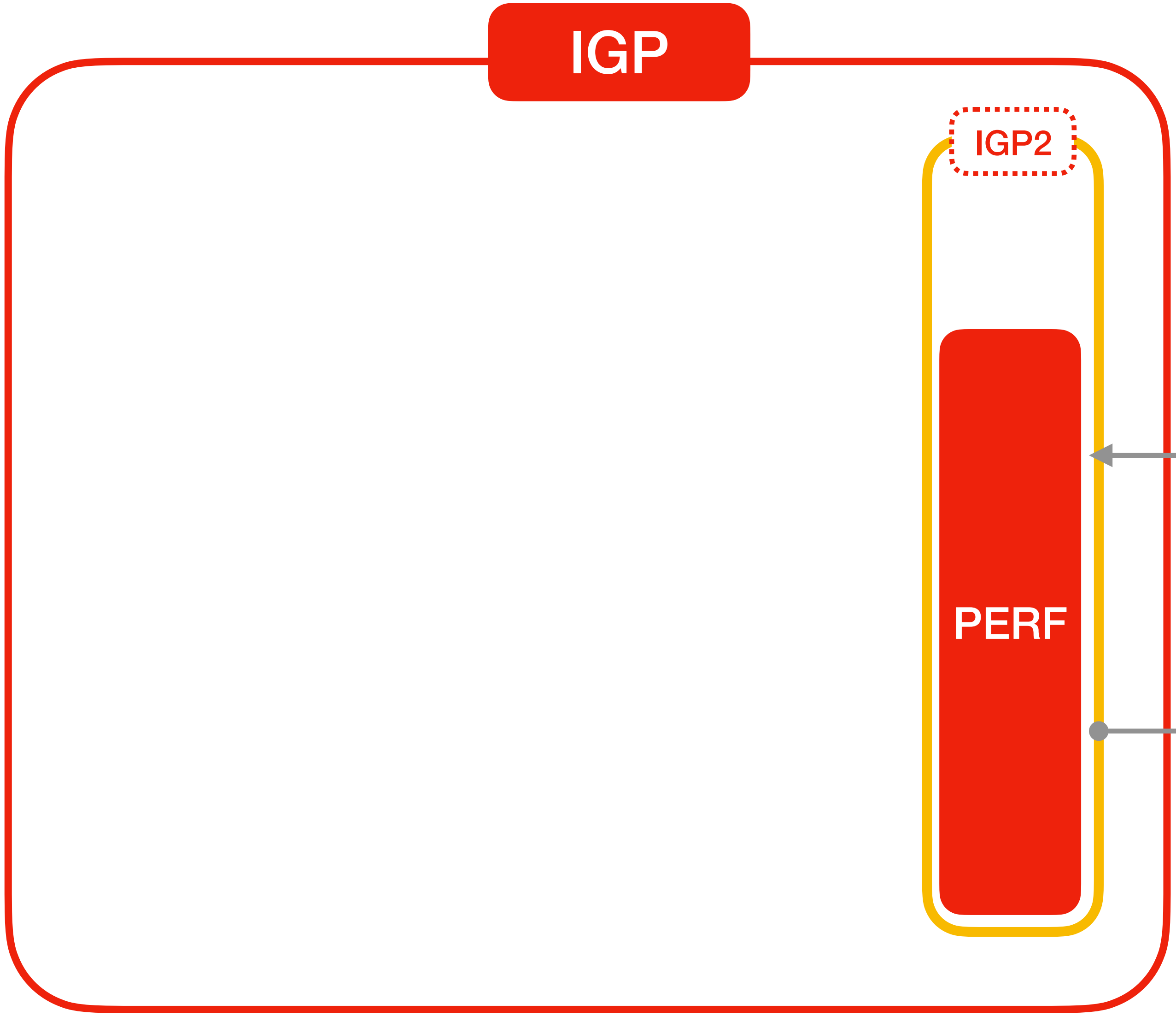
OUTPUTS: IGP INFO

IGP_INFO_Y19D014_GEO123.dat

Col	Content	Forma	Units	Description
C1	**SOD**	%05d	SEC	Second of Day
C2	**DOY**	%03d	No Units	Day of the Year
C3	**IGP ID**	%d	No Units	IGP ID
C4	**IGP BAND**	%d	No Units	IGP Band
C5	**IGP BIT**	%d	No Units	IGP Bit in Band
C6	**IGP LON**	%f	DEG	IGP Longitude
C7	**IGP LAT**	%f	DEG	IGP Latitude
C8	**STATUS**	%d	No Units	IGP Monitoring Status (0:NM; 1:M; -1;DU)
C9	**GIVEI**	%f	No Units	Grid Ionospheric Vertical Error Sigma Index
C10	**GIVE**	%f	METER	Grid Ionospheric Vertical Error Sigma
C11	**GIVD**	%f	METER	Grid Ionospheric Vertical Delay
C12	**GIVDE STATUS**	%d	No Units	Computation Status of the GIVDE Error.
C13	**GIVDE**	%f	METER	Grid Ionospheric Vertical Delay Error
C14	**SI**	%f	No Units	IGP Safety Index (GIVDE/5.33*GIVE)
C15	**VTEC**	%f	METER	IGP VTEC from IONEX reference files
C16	**NIPP**	%f	No Units	Number of IPPs surrounding the IGP for a given spherical angle (e.g: 8 Deg)
C17	**MMFLAG**	%d	No Units	GIVE Status from MacroModel
C18	**IONMMRATIO**	%f	No Units	Ratio between GIVE and GIVE from MacroModel.

WP2: IGP2 (IGP-PERF)

LOW LEVEL DESIGN



INPUTS

|__CFGinfo

|__RIMSinfo

|__SBASinfo

|__NAVinfo

|__IONinfo

OUTPUTS

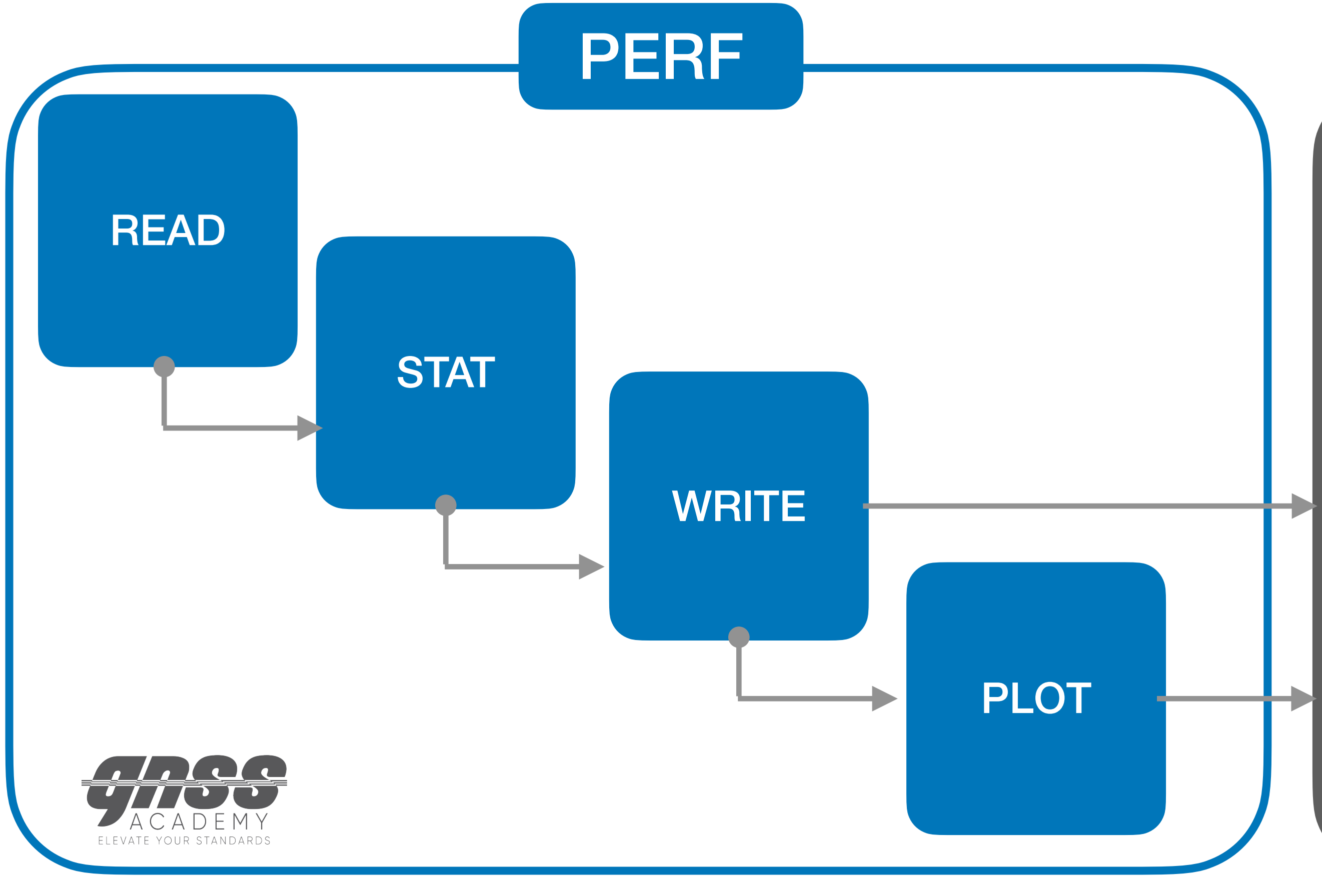
|___IGPinfo
|_____IGPmask
|_____GIVDError
|_____GIVEi
|_____GIVE or σ_{GIVE}
|_____ϵ_{IONO}

|___IGPstat
|_____RMS GIVDE
|_____MAX GIVE
|_____MAX SI
|_____Num MI
|_____Num.Trans

Submodule-PERF

INPUTS

```
|__IGPinfo FILE
|____
```



OUTPUTS

|___**IGPinfo**
|_____IGPmask
|_____GIVDError
|_____GIVEi
|_____GIVE or σ_{GIVE}
|_____ϵ_{IONO}

|___**IGPstat**
|_____RMS GIVDE
|_____MAX GIVE
|_____MAX SI
|_____Num MI
|_____Num. Trans
|_____…

WP2: Develop IGP-PERF Submodule

- **READ** IGP_INFO file with instantaneous IGP information
- **COMPUTE** IGP Performances as daily statistics of some indicators:
  - ➡ Monitoring
  - ➡ Accuracy
  - ➡ Integrity
  - ➡ Upper-bound
  - ➡ Continuity
- **WRITE** daily files on these indicators per IGP
- **PLOT** IGP Performance Figures in terms of Accuracy, Integrity, Monitorability and Upper-bound based on previous Indicators.

OUTPUTS: IGP STAT

IGP_STAT_Y19D014_GEO123.dat

Column	Content	Format	Units	Description
C1	IGP ID	%d	No Units	IGP ID
C2	IGP BAND	%d	No Units	IGP Band
C3	IGP BIT	%d	No Units	IGP Bit in Band
C4	IGP LON	%f	DEGREES	IGP Longitude
C5	IGP LAT	%f	DEGREES	IGP Latitude
C6	MON	%f	No Units	IGP Monitoring Percentage during the day
C7	MIN-IPP	%d	No Units	Minimum Number of IPPs surrounding the IGP
C8	MAX-IPP	%d	No Units	Maximum Number of IPPs surrounding the IGP
C9	NTRANS	%d	No Units	Number of Transitions from M to NM and M to DU
C10	RMSGIVDE	%f	METER	RMS of GIVD Error
C11	MAXGIVD	%f	METER	Maximum GIVD
C12	MAXGIVE	%f	METER	Maximum GIVE
C13	MAXGIVEi	%f	No Units	Maximum GIVE Indicator
C14	MAXVTEC	%f	METER	Maximum VTEC
C15	MAXSI	%f	No Units	Maximum Safety Index (SI=GIVDE/kf*GIVE)
C16	NMI	%d	No Units	Number of MIs on IGP

OUTPUTS: IGP GIVDE HIST

IGP_GIVDE_HIST_Y19D014_GEO123.dat

Column	Content	Format	Units	Description
C1	**BINID**	%d	No Units	Bin ID (0,1,…)
C2	**BINMIN**	%f	METER	Bin Minimum. The bin contains samples in [BINMIN, BINMAX)
C3	**BINMAX**	%f	METER	The bin step is configured using GIVDE_BIN configuration parameter (recommended value: 0.1) Bin Maximum. The bin contains samples in [BINMIN, BINMAX)
C4	**NUMSAMP**	%d	No Units	Number of samples of the bin
C5	**FREQ**	%f	No Units	Relative frequency of the bin

OUTPUTS: IGP LATBANDS GIVDE STAT

IGP_LATBANDS_GIVDE_STAT_Y19D014_G123.dat

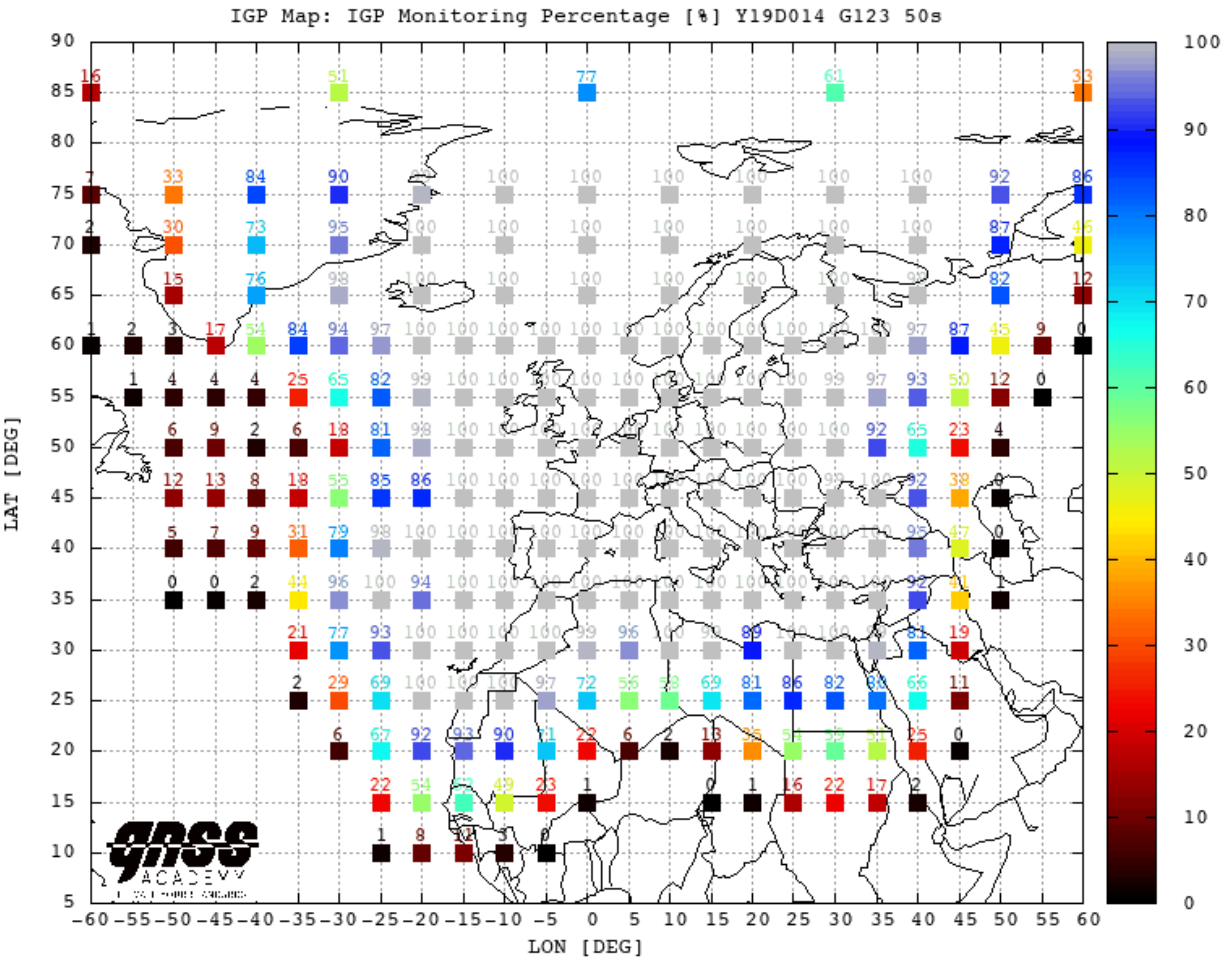
Column	Content	Format	Units	Description
C1	**BINID**	%d	No Units	Bin ID (0,1,…)
C2	**LATBAND**	%s	METER	Latitude bands (check **IGP latitude** against the following thresholds): ✳**EQUATOR:** Equatorial band |Latitude|<=20 ✳**MIDLOW:** Mid-low latitudes 20<|Latitude|<=32 ✳**MID:** Mid latitudes 32<|Latitude|<=50 ✳**MIDHIGH:** Mid-high latitudes 50<|Latitude|<=61 ✳**NORTH:** Polar latitudes 61<|Latitude|
C3	**NUMSAMP**	%d	No Units	Number of samples of the bin
C4	**GIVDERMS**	%f	METER	RMS of the GIVDE of the bin
C5	**GIVDEMAX**	%f	METER	Maximum of the GIVDE of the bin

OUTPUTS: IGP NIPP BINS STAT

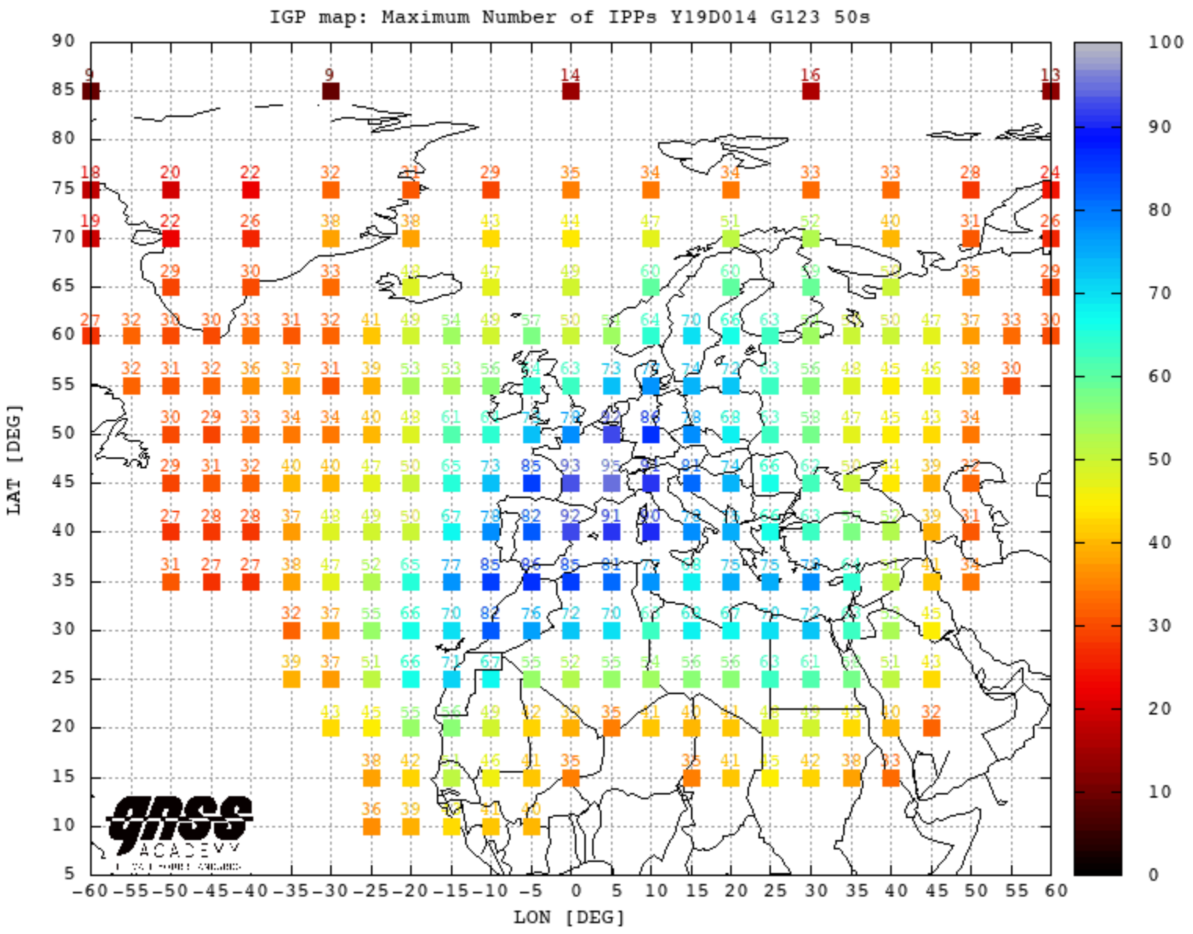
IGP_NIPP_BINS_STAT_Y19D014_GEO123.dat

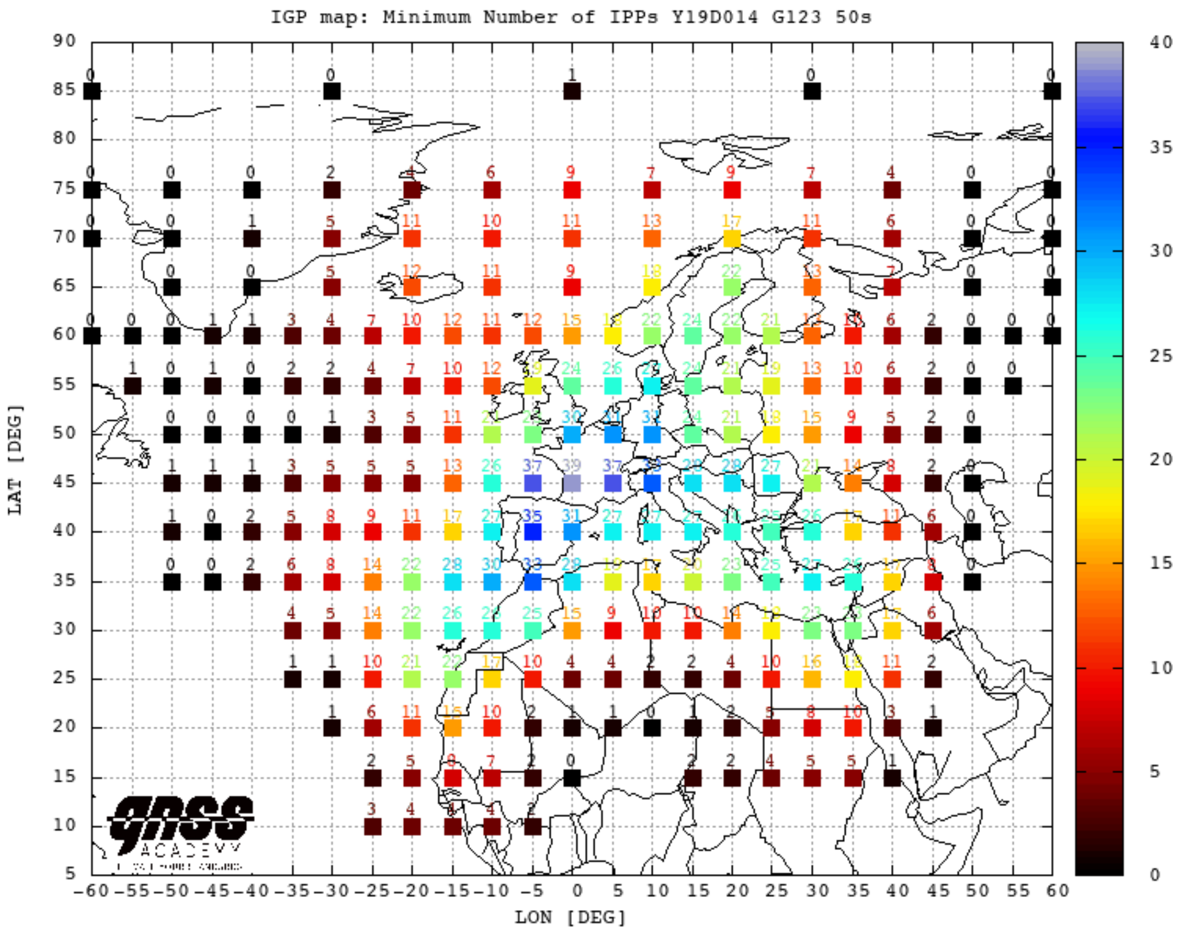
Column	Content	Format	Units	Description
C1	**BINID**	%d	No Units	Bin ID (0,1,…)
C2	**BINMIN**	%f	METER	Bin Minimum. The bin contains samples in [BINMIN, BINMAX)
C3	**BINMAX**	%f	METER	Number of IPPs bin. The bin step is configured using NIPPS_BIN configuration parameter (recommended value: 5) Bin Maximum. The bin contains samples in [BINMIN, BINMAX)
C4	**NUMSAMP**	%d	No Units	Number of samples of the bin
C5	**GIVEMIN**	%f	METER	Minimum of the GIVE of the bin
C6	**GIVEMAX**	%f	METER	Maximum of the GIVE of the bin
C7	**GIVDERMS**	%f	METER	RMS of the GIVDE of the bin
C8	**GIVDEMAX**	%f	METER	Maximum of the GIVDE of the bin
C9	**SIMIN**	%f	No Units	Minimum of the SI of the bin
C10	**SIRMS**	%f	No Units	RMS of the SI of the bin
C11	**SIMAX**	%f	No Units	Maximum of the SI of the bin

MON

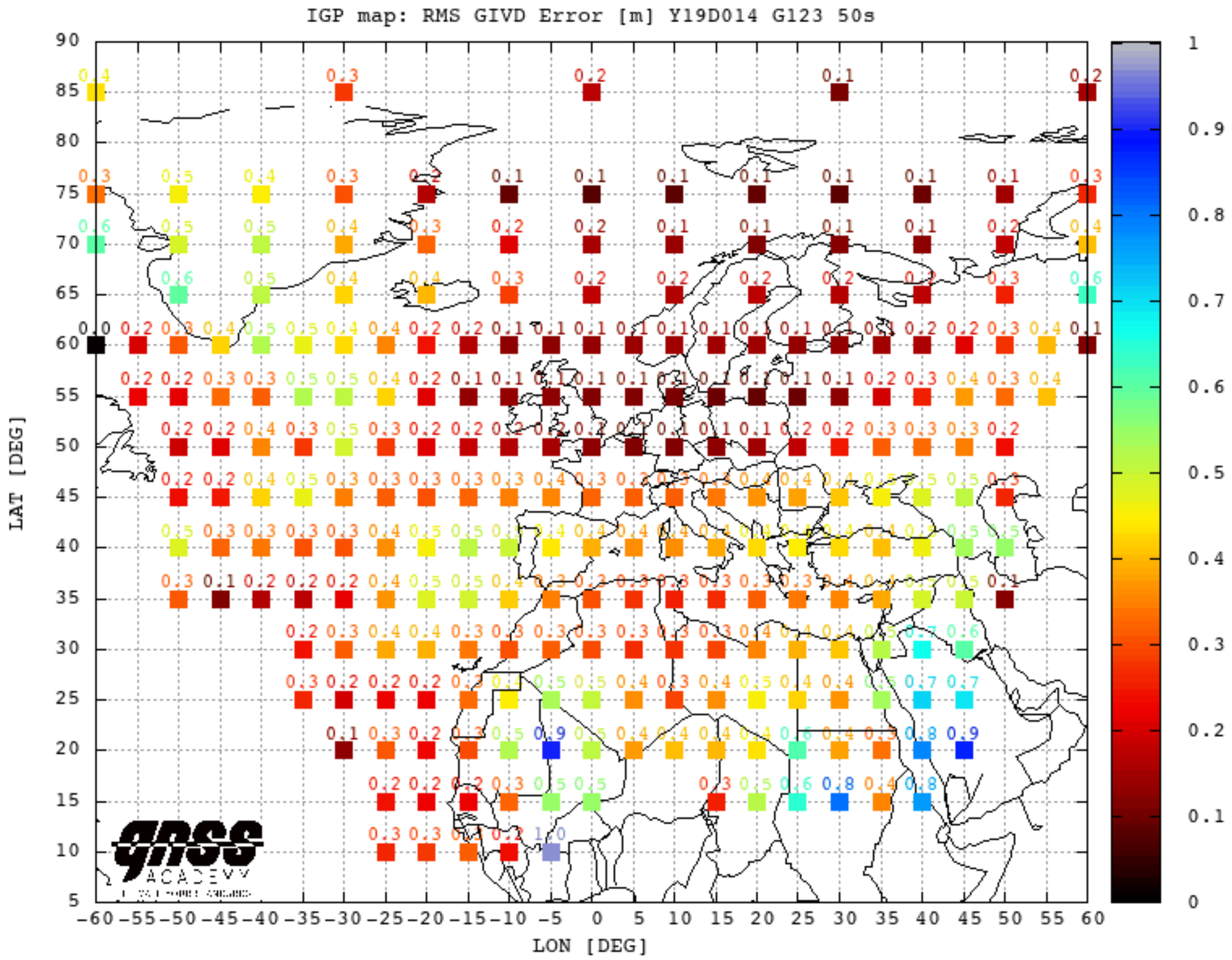

IGP Map: IGP Monitoring Percentage [%] Y19D014 G123 50s
LAT [DEG]
LON [DEG]
90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5
-60 -55 -50 -45 -40 -35 -30 -25 -20 -15 -10 -5 0 5 10 15 20 25 30 35 40 45 50 55 60
100 90 80 70 60 50 40 30 20 10 0

MON


IGP map: Maximum Number of IPPs Y19D014 G123 50s
LAT [DEG]
LON [DEG]

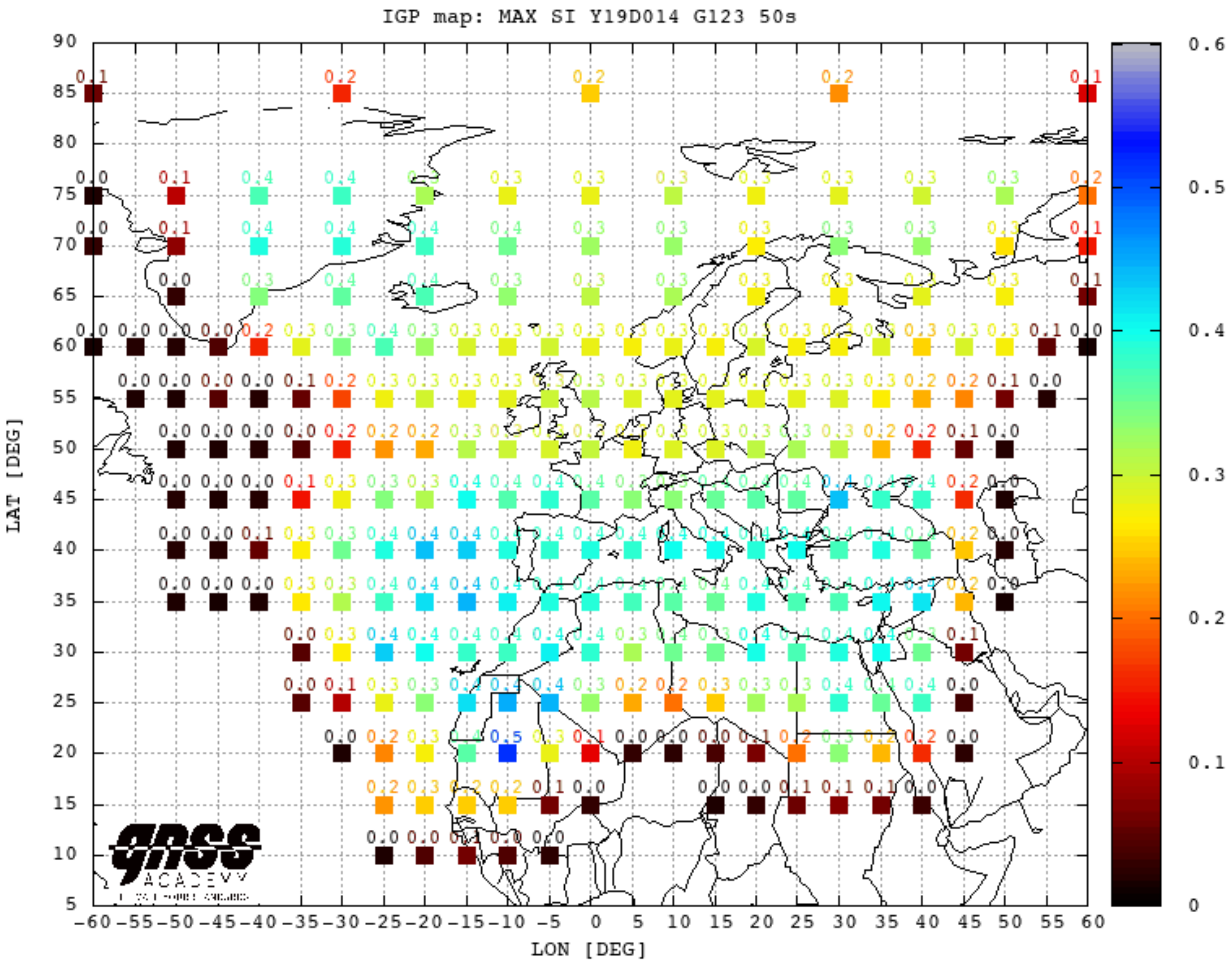

IGP map: Minimum Number of IPPs Y19D014 G123 50s
LAT [DEG]
LON [DEG]

ACC



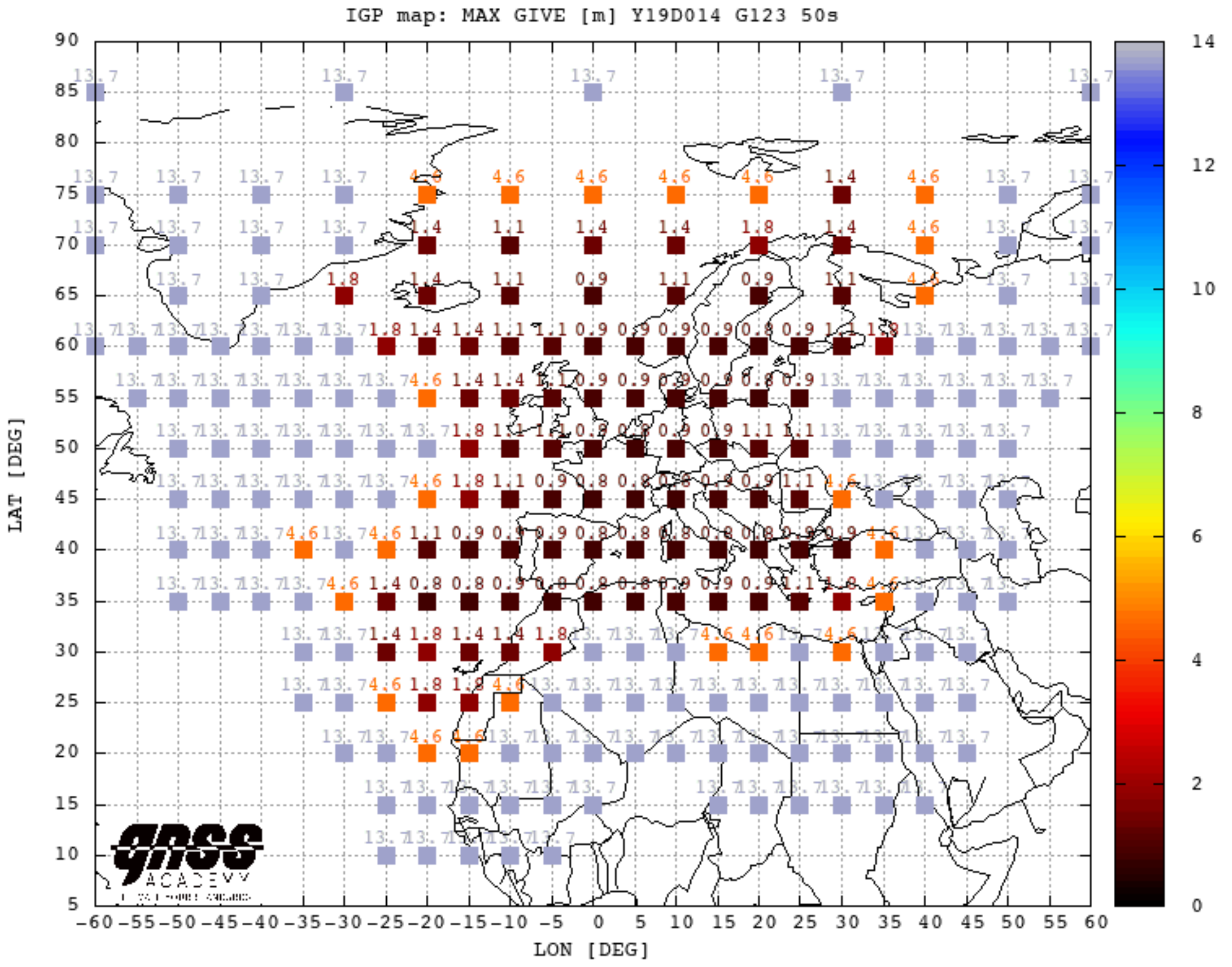
INT

- SI=(GIVDE/5.33GIVE)
- If SI>1 —> MI



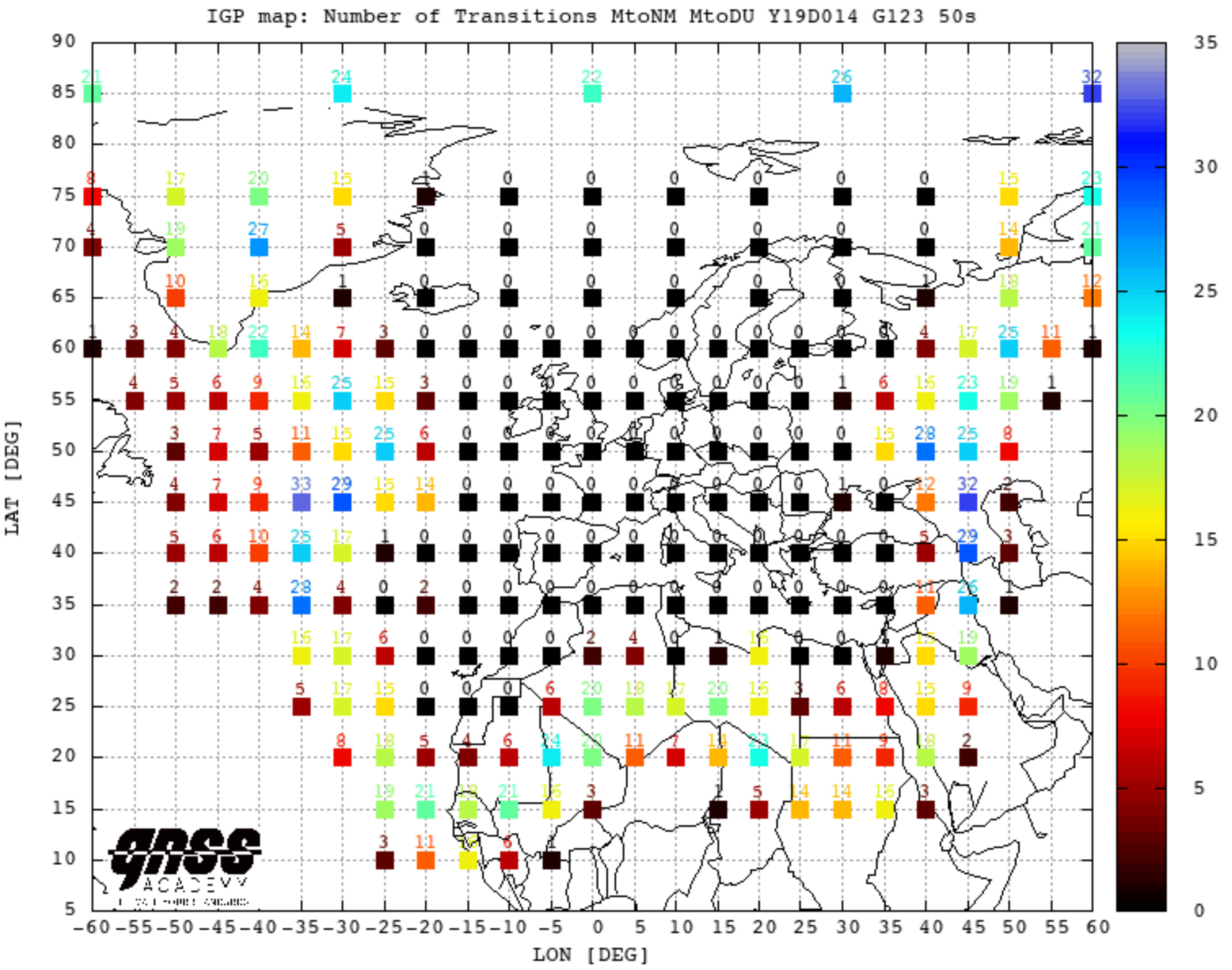
UPP Upperbound => Availability

- The higher GIVE the higher PL and then it can lead to PL>AL
- Need of monitoring the maximum values of GIVE.



CONT

- Number of Transitions from MtoNM or MtoDU.
- Each time an IGP gets NM or DU, this can lead to a continuity problem at user level, since DOP increases and PL can exceed > Alert Limit.



SEE WORK-PACKAGE DESCRIPTION:

SERVUS-WP2-IGP-PERF_Module.pdf