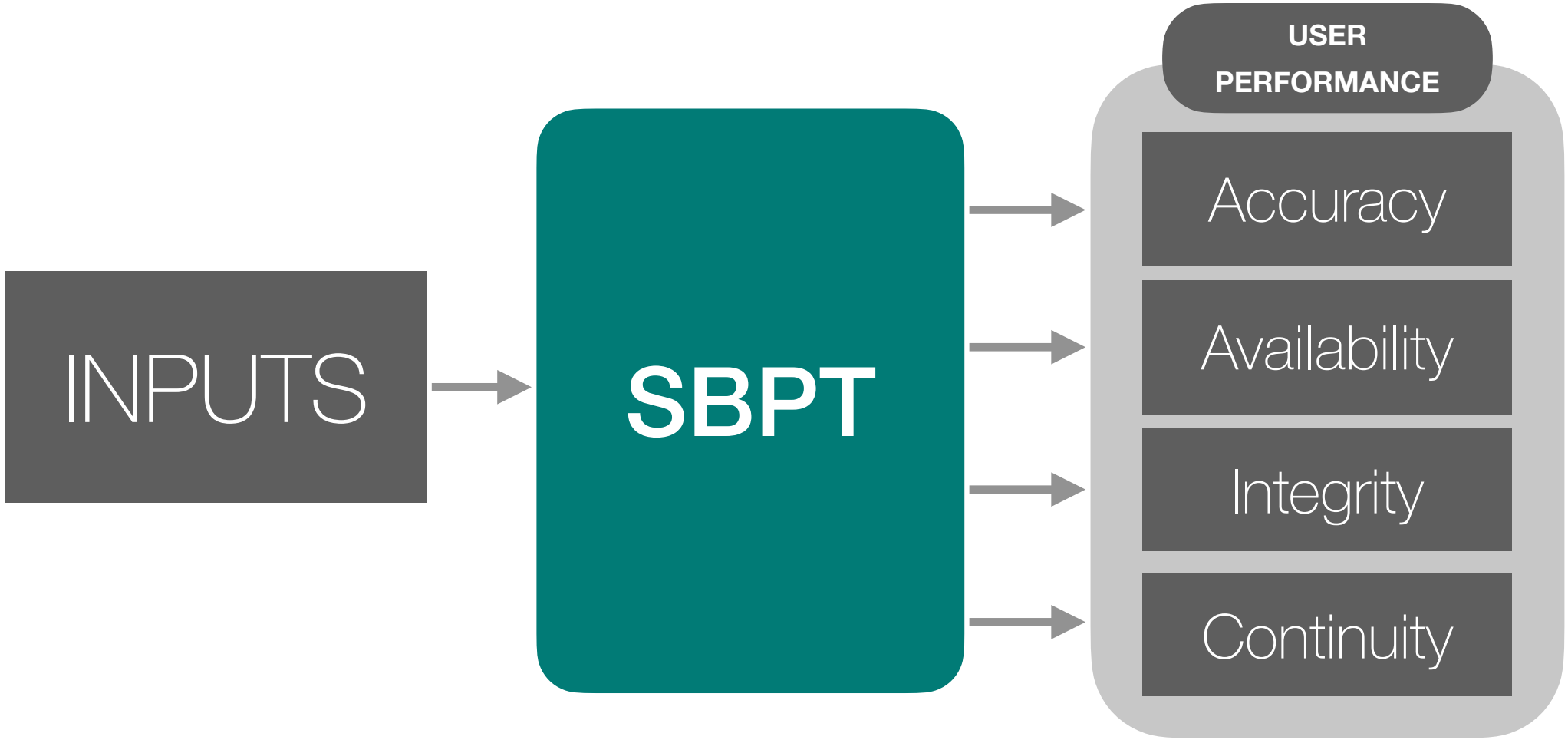
SERVUS

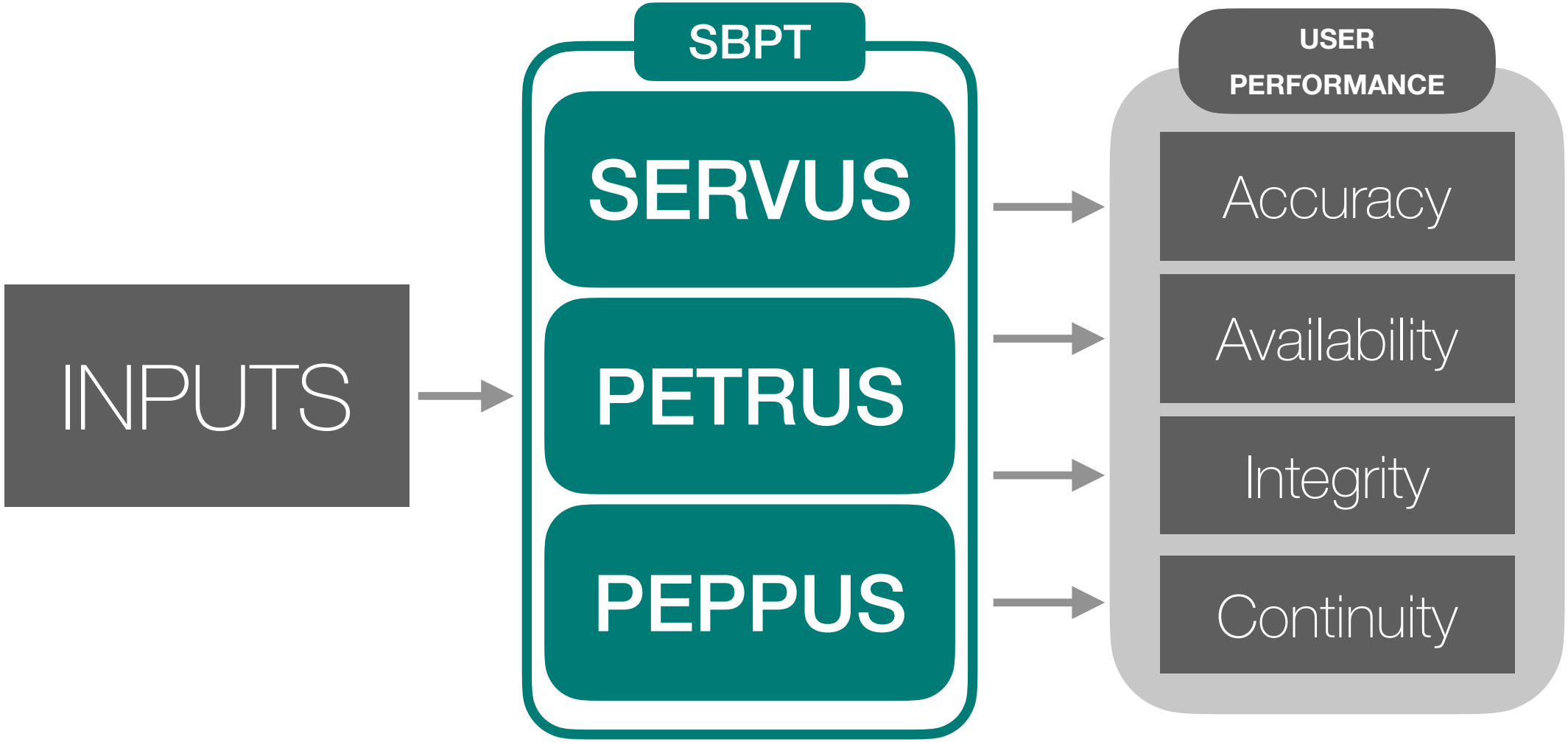
[USR] MODULE

WP3 - USR PERFORMANCE

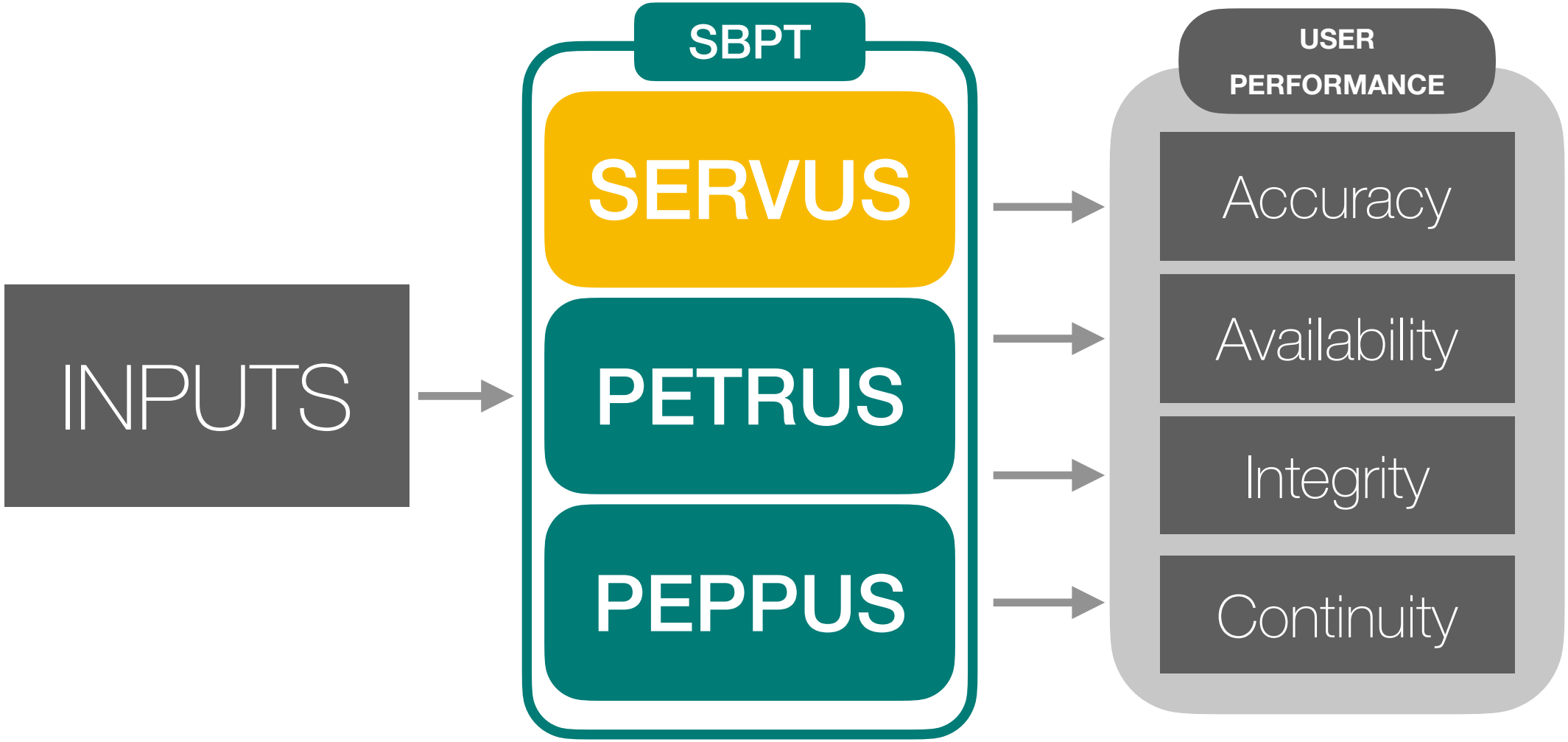
SBPT


INPUTS
SBPT
USER PERFORMANCE
Accuracy
Availability
Integrity
Continuity

SBPT

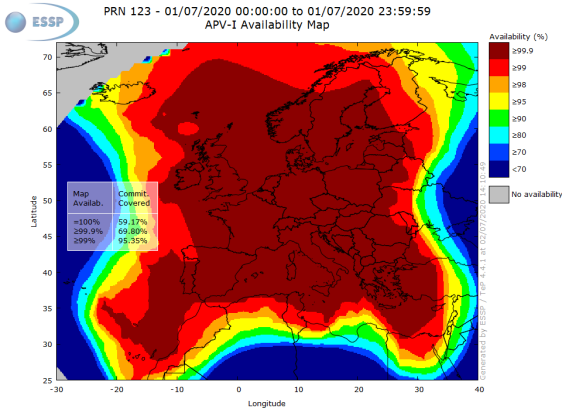

INPUTS
SBPT
SERVUS
PETRUS
PEPPUS
USER PERFORMANCE
Accuracy
Availability
Integrity
Continuity

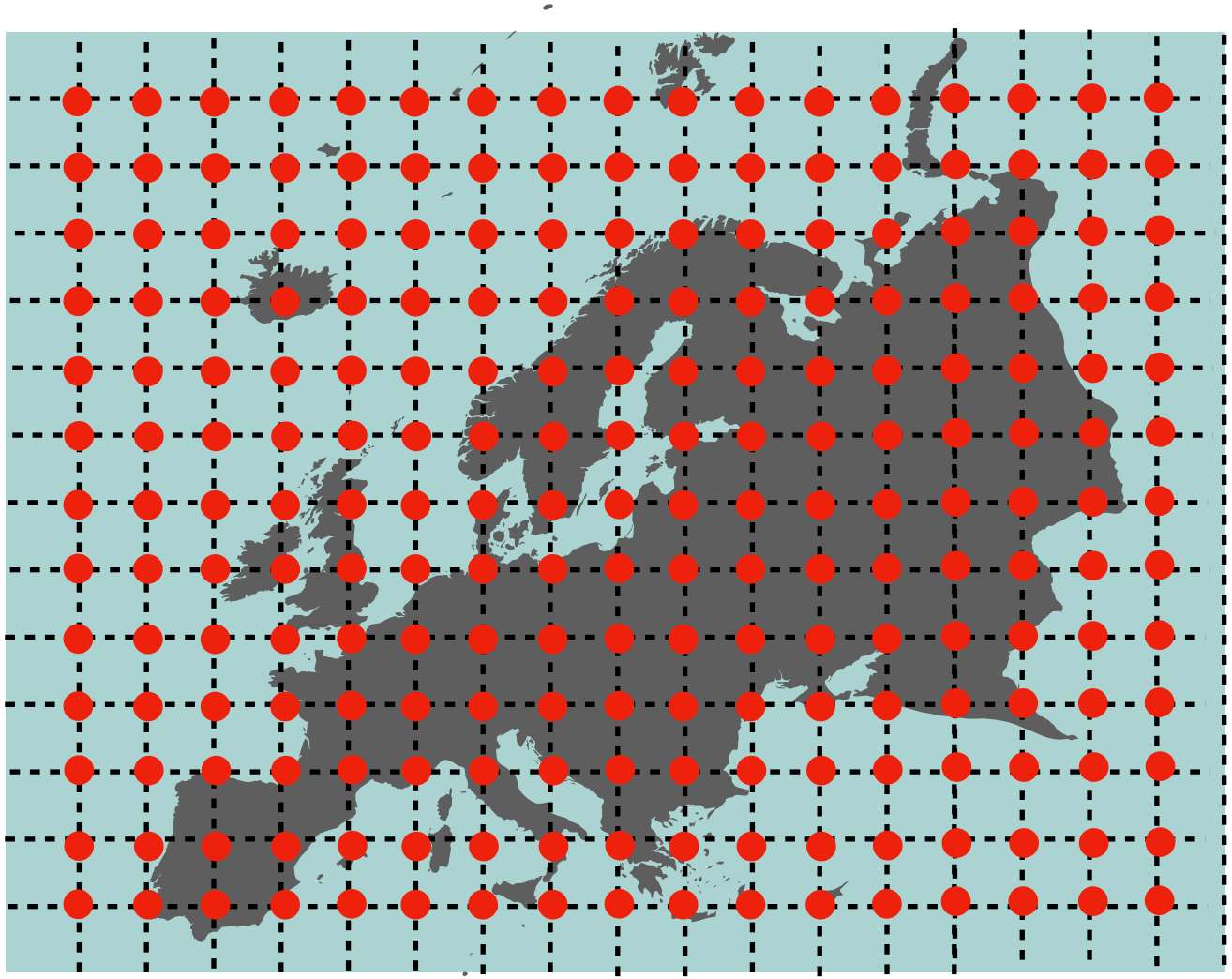
SBPT


INPUTS
SBPT
SERVUS
PETRUS
PEPPUS
USER PERFORMANCE
Accuracy
Availability
Integrity
Continuity

SERVICE VOLUME (SERVUS)

User Grid Along a Service Volume LON/LAT/GRID SIZE





AVAILABILTY

CONTINUITY

INTEGRITY

ACCURACY

RECEIVER (PETRUS)

User RECEIVER over different users deployed across Europe

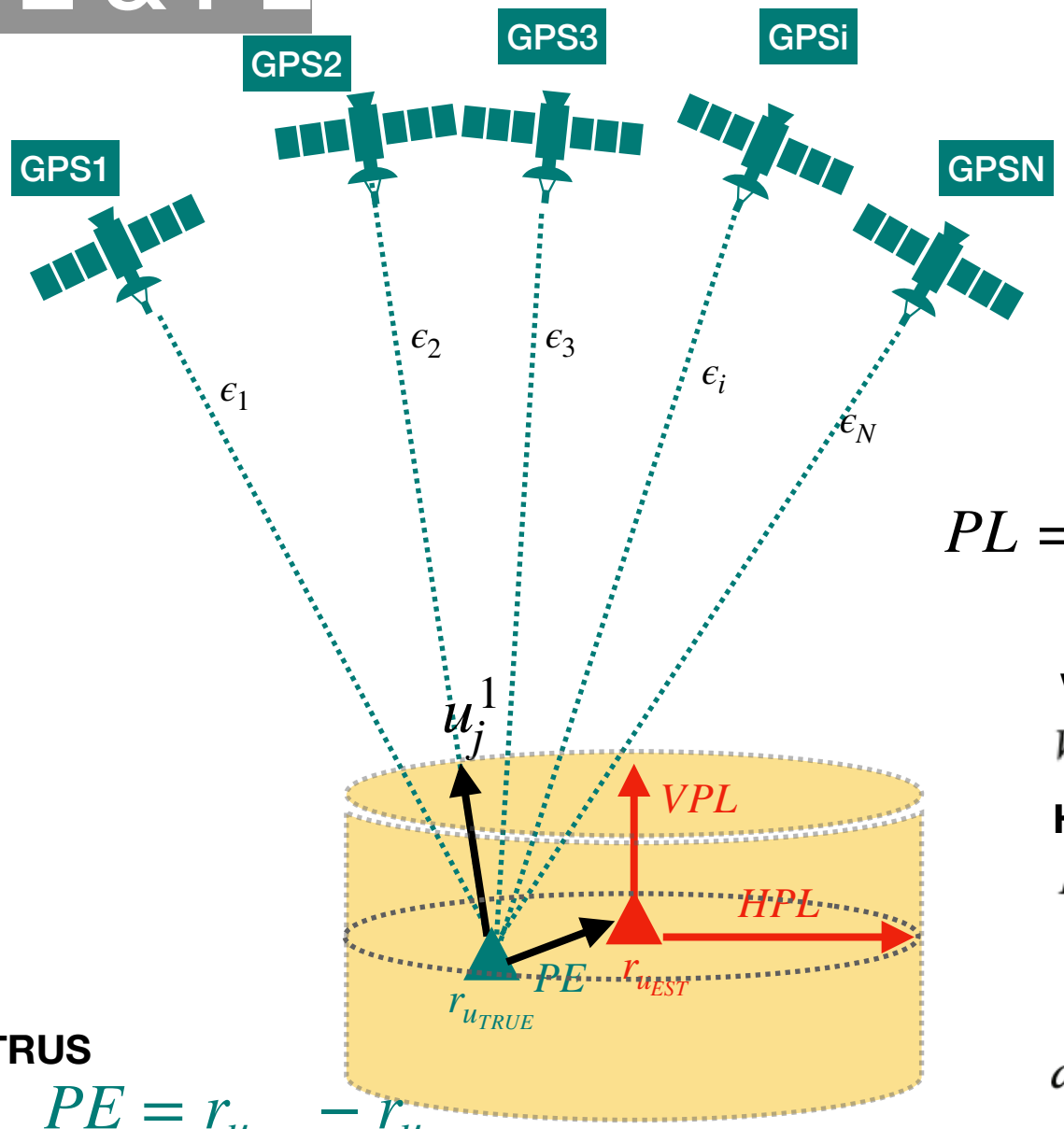
AVAILABILTY

CONTINUITY

INTEGRITY

ACCURACY

PE & PL



PETRUS

$$PE = r_{u_{EST}} - r_{u_{TRUE}}$$

SoE TO SOLVE

$$\{\Delta\rho\} = [G]\,[\Delta X] + \{\epsilon\}$$

PETRUS

$$[\Delta X_{EST}] = ([G]^T\,[W]\,[G])^{-1}[G]^T\,[W]\,\{\Delta\rho\}$$

SERVUS

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

$$W = \Sigma^{-1}$$

$$PL = (G^T\mathbf{W}G)^{-1} = \begin{bmatrix} d_{east}^2 & d_{EN} & d_{EU} & d_{ET} \\ d_{EN} & d_{north}^2 & d_{NU} & d_{NT} \\ d_{EU} & d_{NU} & d_U^2 & d_{UT} \\ d_{ET} & d_{NT} & d_{UT} & d_T^2 \end{bmatrix}$$

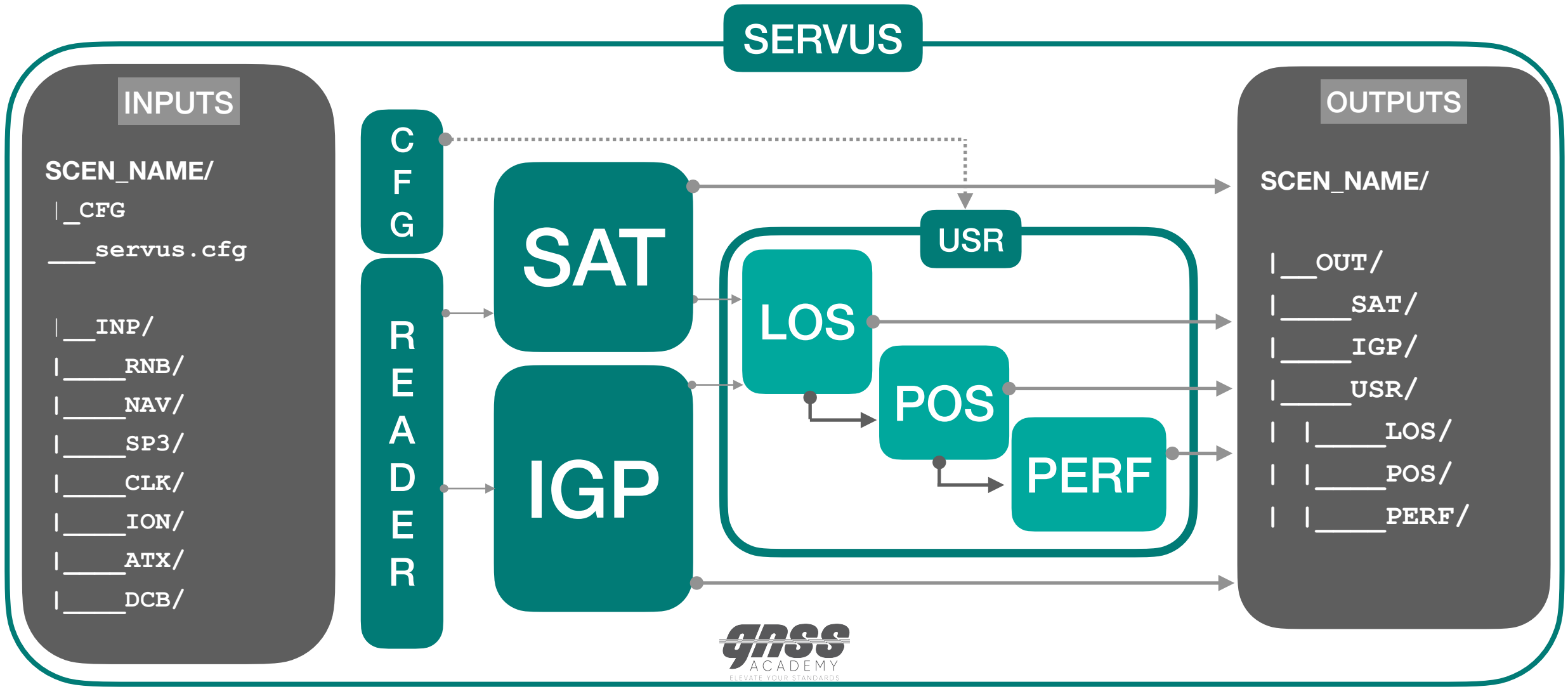
Vertical

$$VPL_{SBAS} = K_V d_U \qquad K_V = 5.33$$

Horizontal

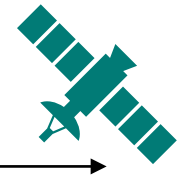
$$HPL_{SBAS} = \begin{cases} K_{H,NPA} \cdot d_{major} & K_{H,NPA} = 6.18 \\ K_{H,PA} \cdot d_{major} & K_{H,PA} = 6.0 \end{cases}$$

$$d_{major} \equiv \sqrt{\frac{d_{east}^2 + d_{north}^2}{2} + \sqrt{\left(\frac{d_{east}^2 - d_{north}^2}{2}\right)^2 + d_{EN}^2}}$$



gnss ACADEMY
ELEVATE YOUR STANDARDS

PLANNING



MONTHS

SERVUS

M1 | M2 | M3 | M4

W-3 W-2 W-1 W0 W1 W2 W3 W4 W5 W6 W7 W8 W9 W10 W11 W12 W13 W14 W15 W16

WORK-PACKAGES

WP1

WP2

WP3

WP4

T0+4W

SAT

SAT-PERF

T0+8W

IGP

IGP-PERF

T0+12W

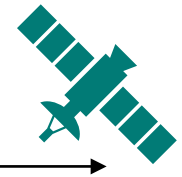
USER-LOS

POS/PERF

T0+16W

DEL

PLANNING



MONTHS

SERVUS

M1	M2	M3	M4

W-3	W-2	W-1	W0	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16

WORK-PACKAGES

WP1

T0+4W

SAT

SAT-PERF

WP2

T0+8W

IGP

IGP-PERF

WP3

T0+12W

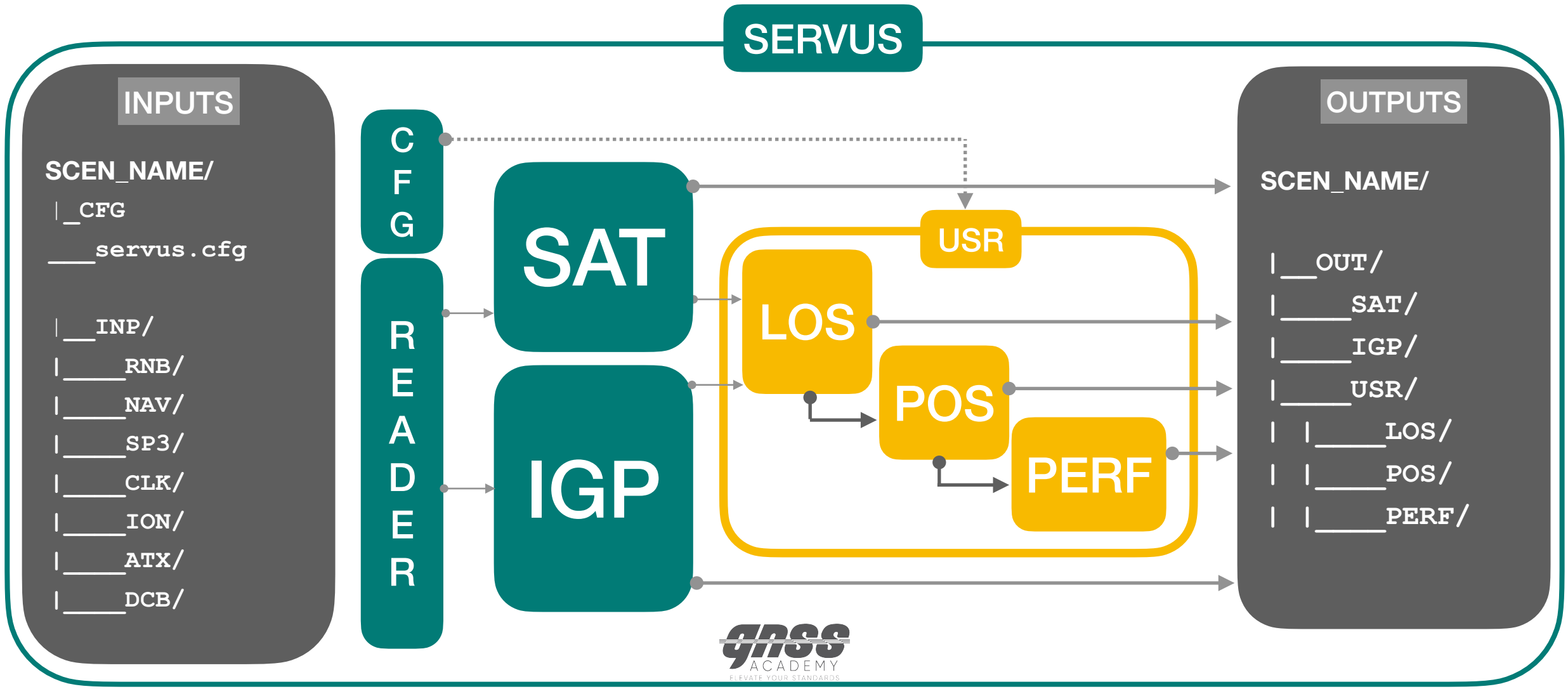
USER-LOS

POS/PERF

WP4

T0+16W

DEL



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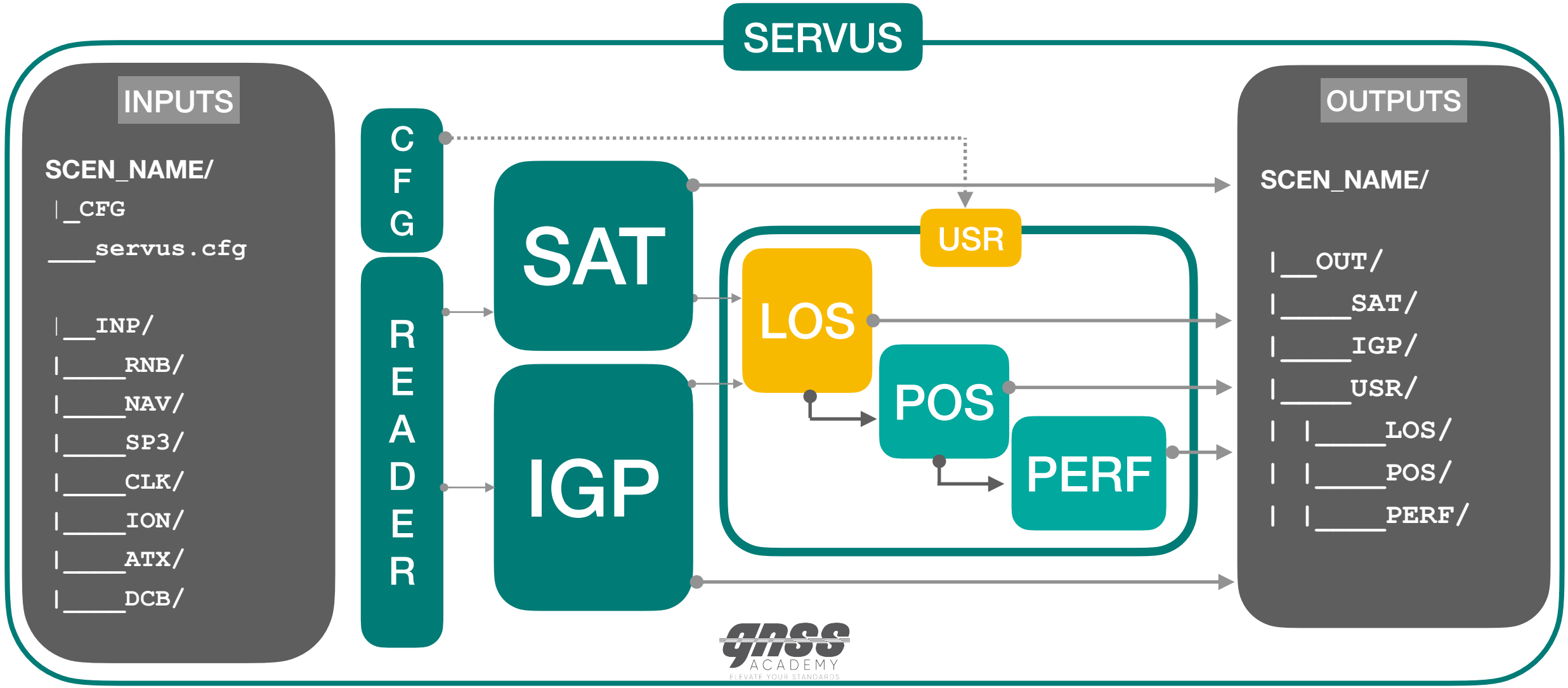
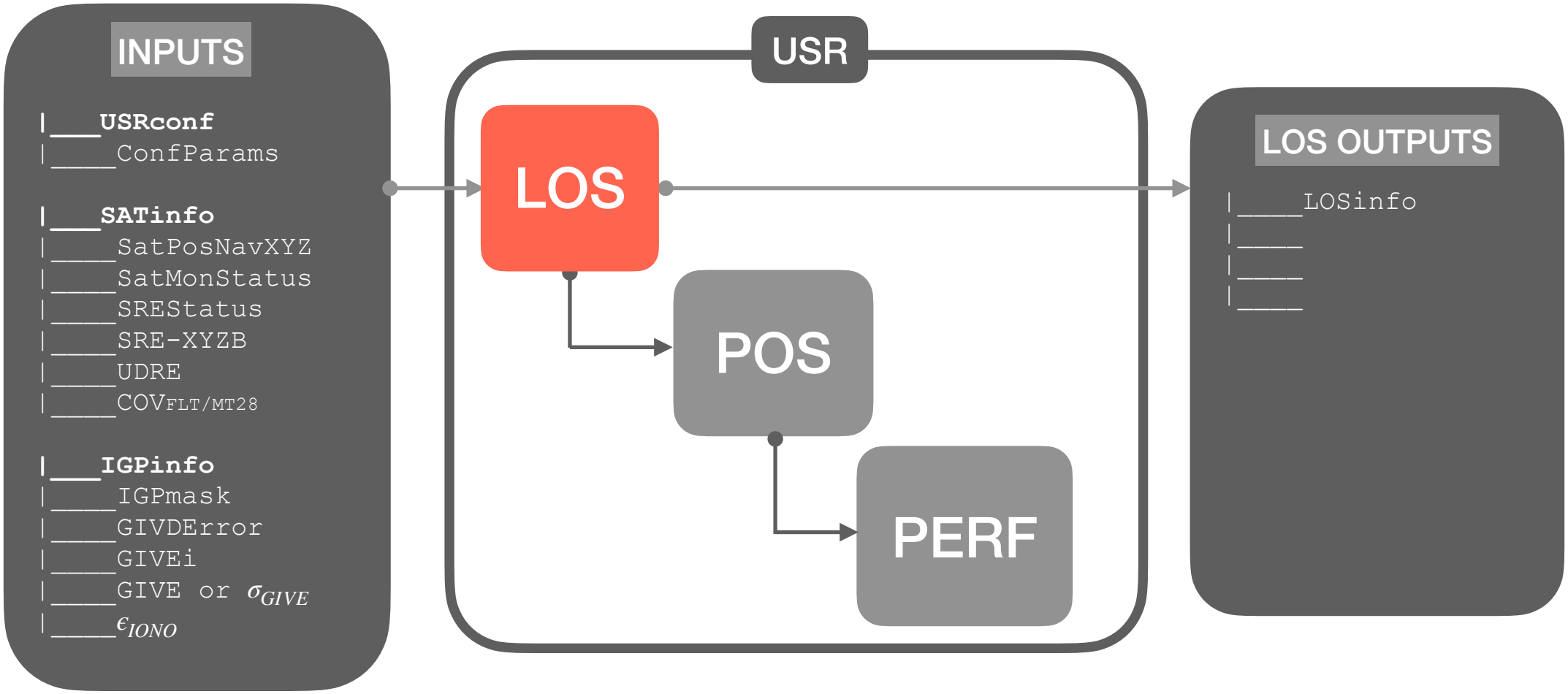
ELEVATE YOUR STANDARDS

[LOS] MODULE



gnss ACADEMY
ELEVATE YOUR STANDARDS

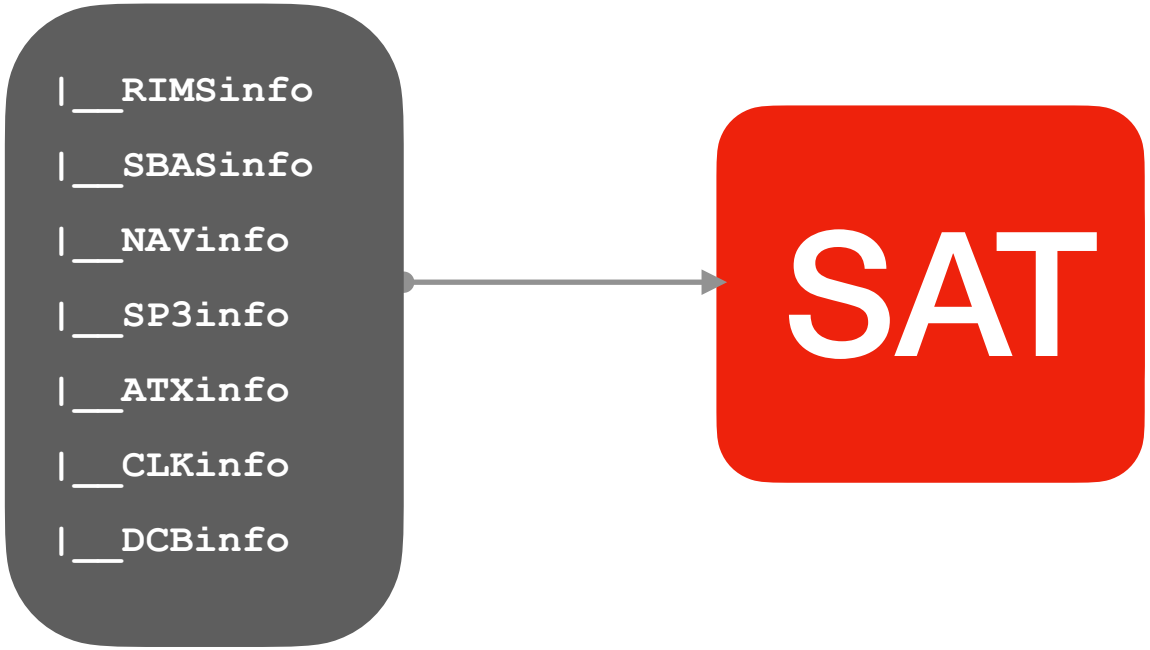
USR ARCHITECTURE



SAT

- RIMSinfo
- SBASinfo
- NAVinfo
- SP3info
- ATXinfo
- CLKinfo
- DCBinfo

SAT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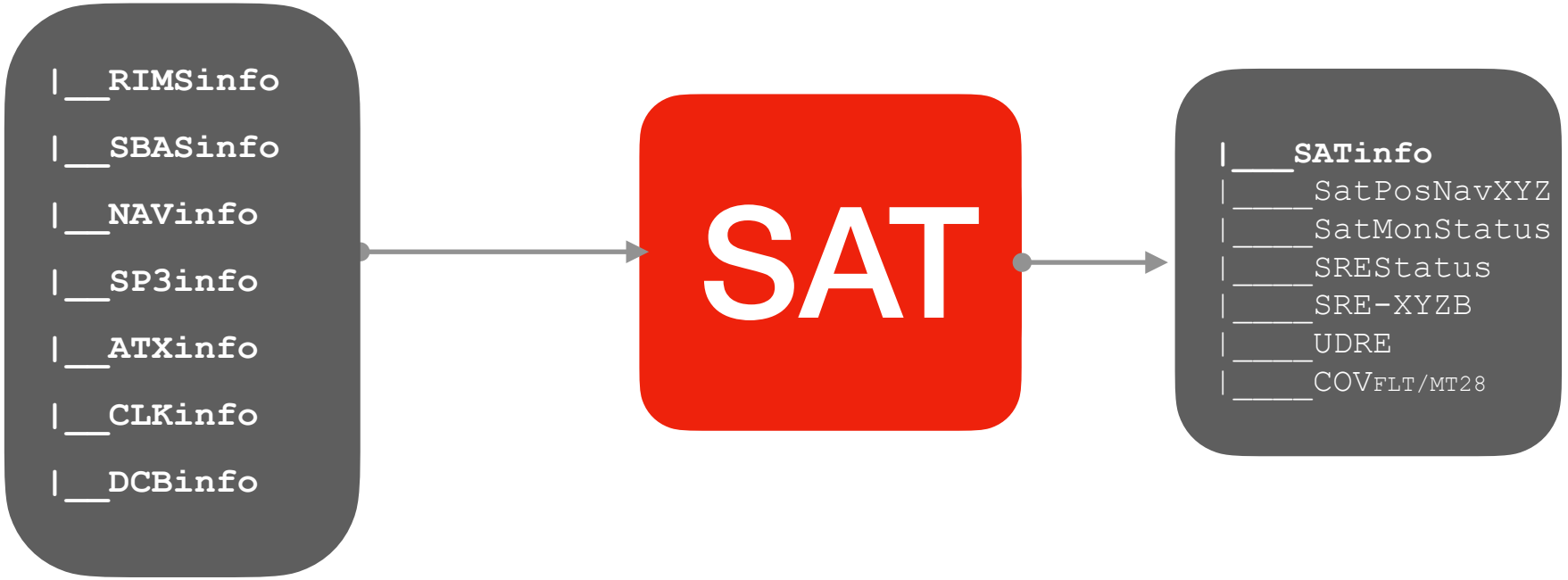
SAT

SAT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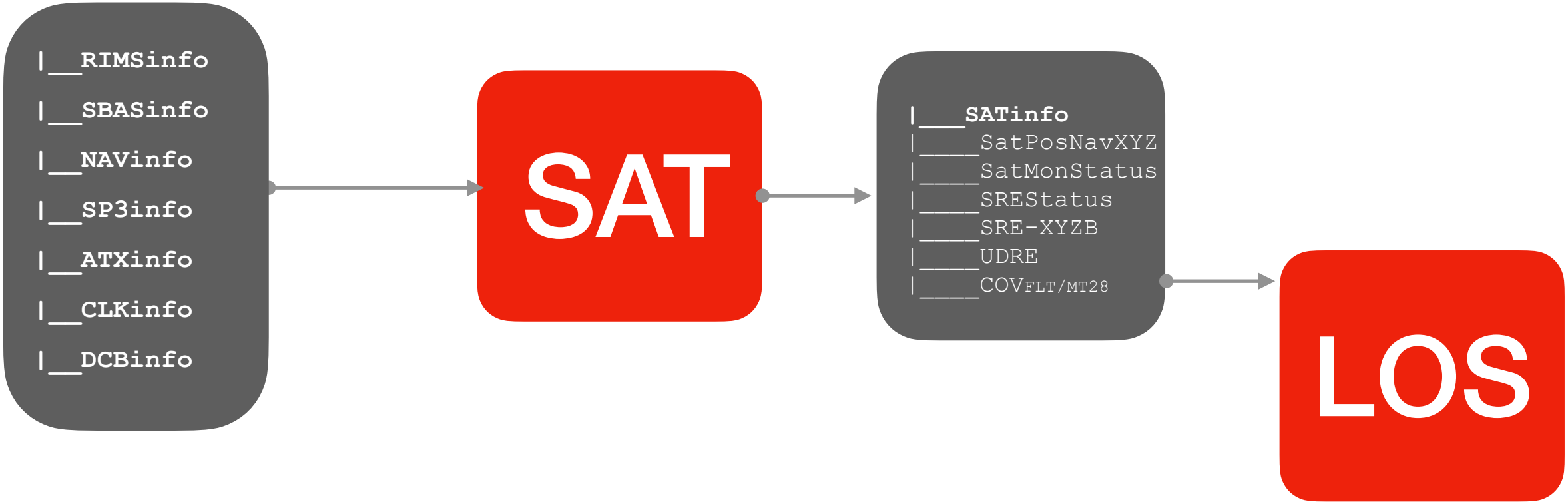
|___SATinfo
|____SatPosNavXYZ
|____SatMonStatus
|____SREStatus
|____SRE-XYZB
|____UDRE
|____COVFLT/MT28

SAT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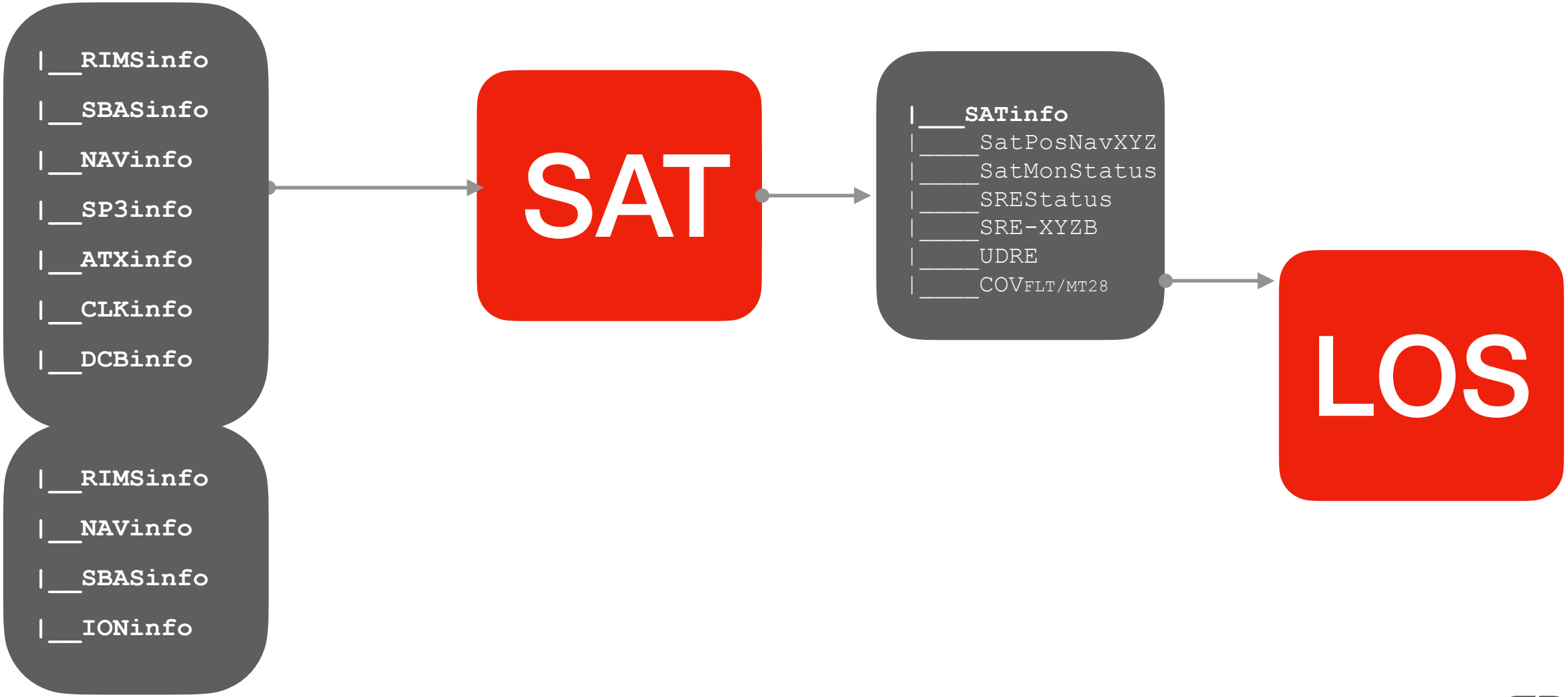
|____SatPosNavXYZ
|____SatMonStatus
|____SREStatus
|____SRE-XYZB
|____UDRE
|____COVFLT/MT28
LOS

IGP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SAT
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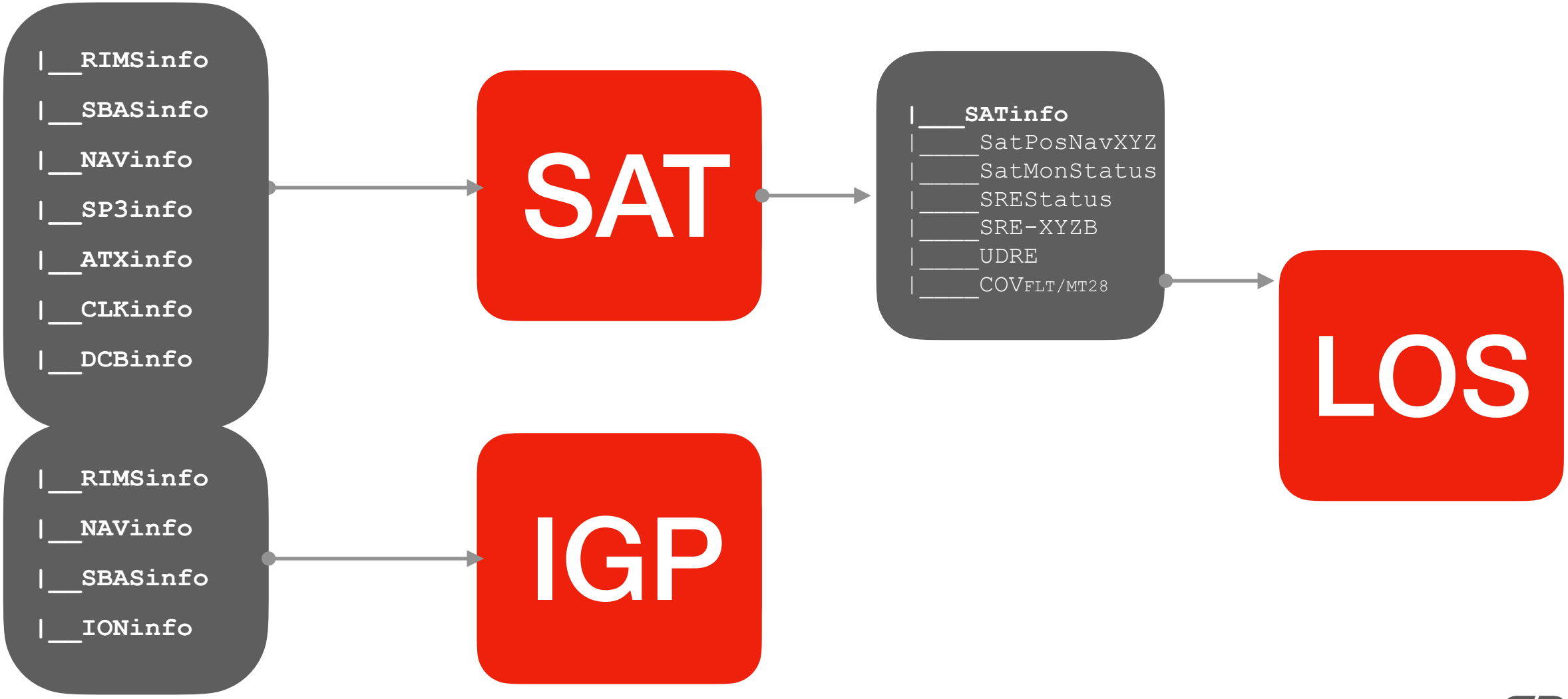
|____SRE-XYZB
|____UDRE
|____COVFLT/MT28
LOS

IGP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LOS
|__RIMSinfo
|__NAVinfo
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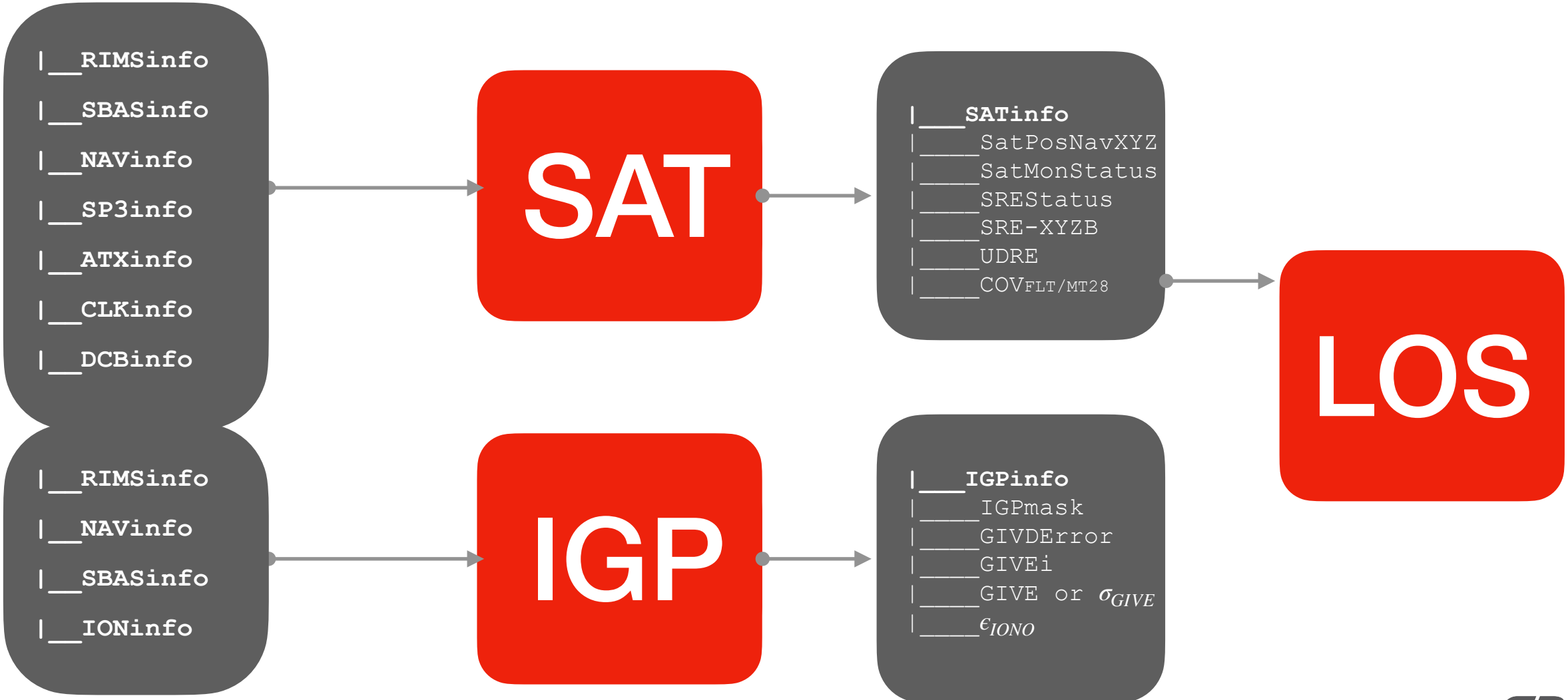
IGP

IGP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|__SBASinfo
|__IONinfo
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|____IGPmask
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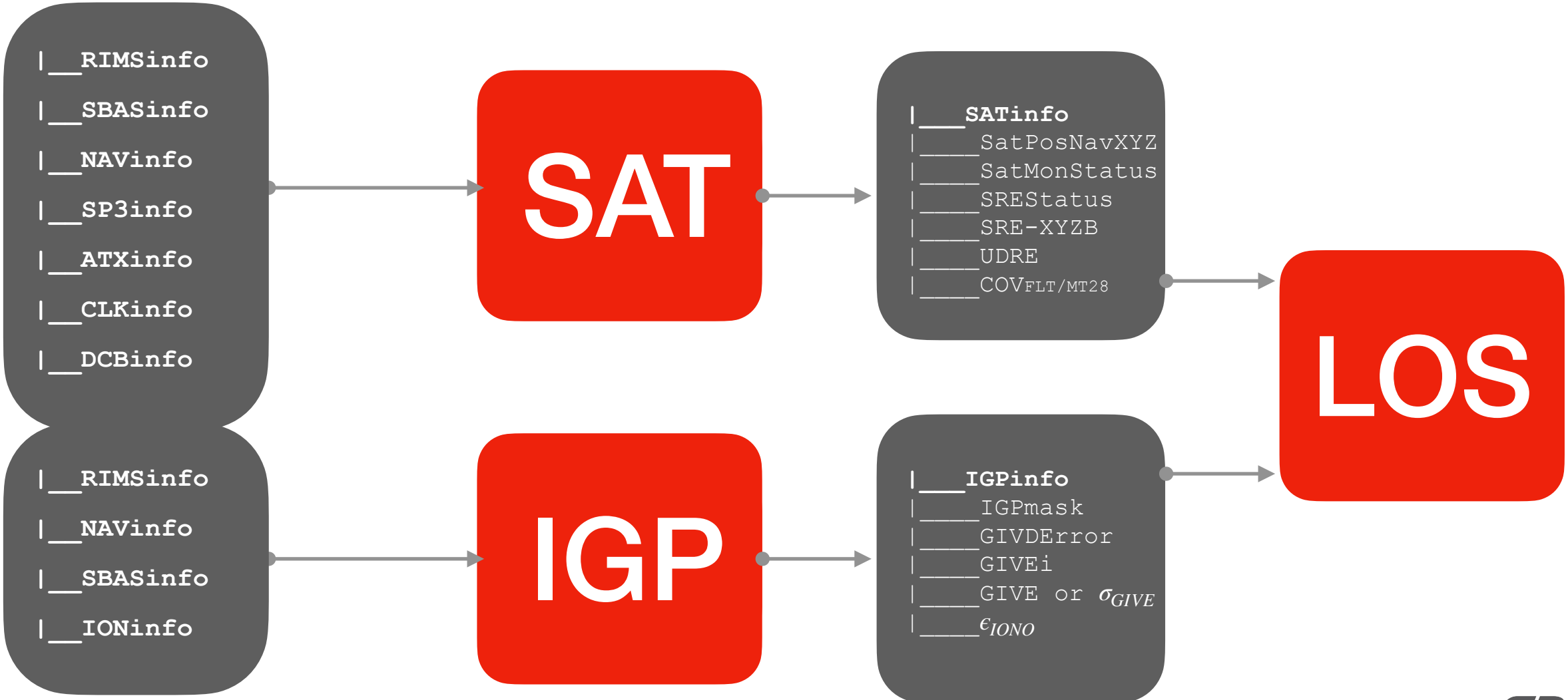
|____GIVEi
|____GIVE or σ_{GIVE}
|____ϵ_{IONO}

INPUT TO LOS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SAT
|___SATinfo
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|__RIMSinfo
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|__SBASinfo
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IGP
|___IGPinfo
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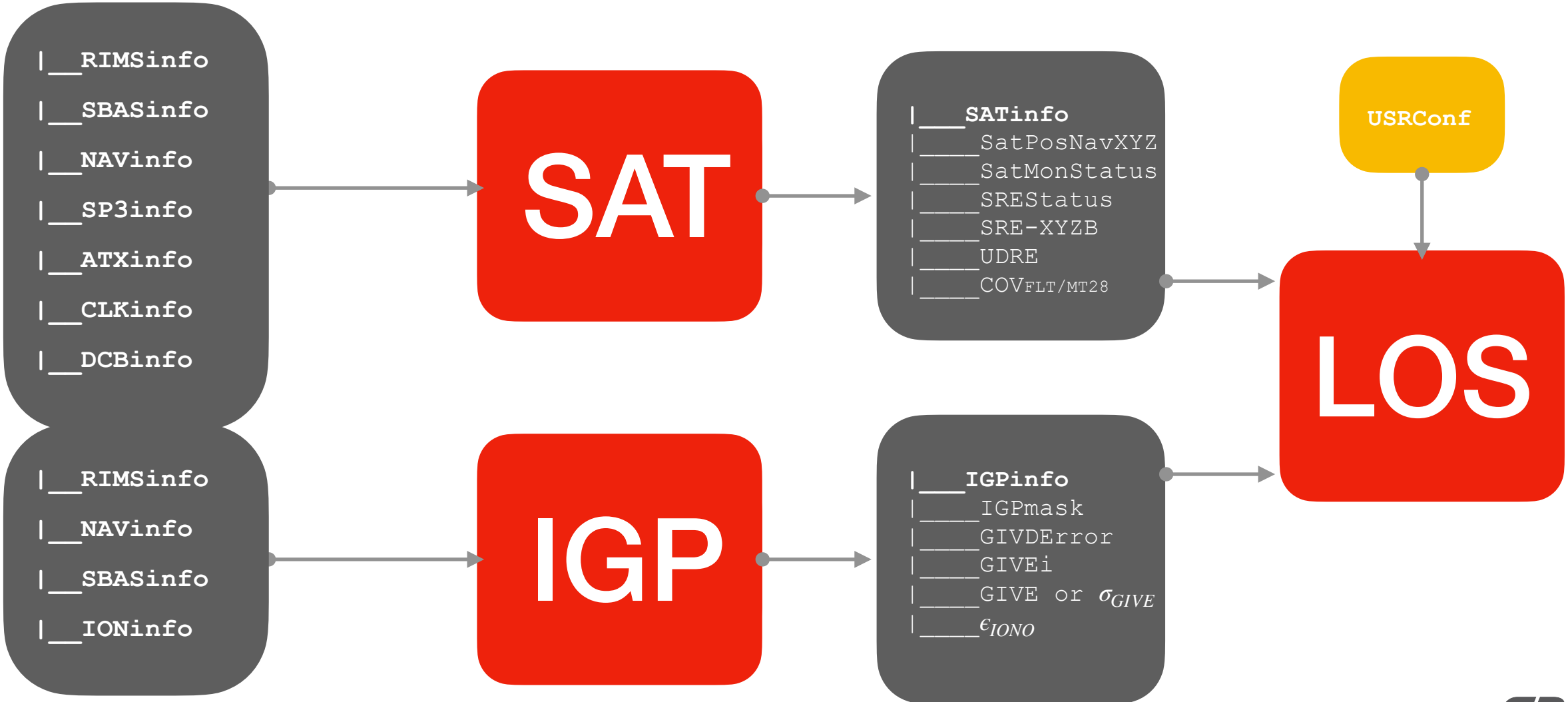
|____GIVEi
|____GIVE or σ_{GIVE}
|____ϵ_{IONO}
LOS

INPUT TO LOS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|__ATXinfo
|__CLKinfo
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SAT
|___SATinfo
|____SatPosNavXYZ
|____SatMonStatus
|____SREStatus
|____SRE-XYZB
|____UDRE
|____COVFLT/MT28
USRConf
LOS
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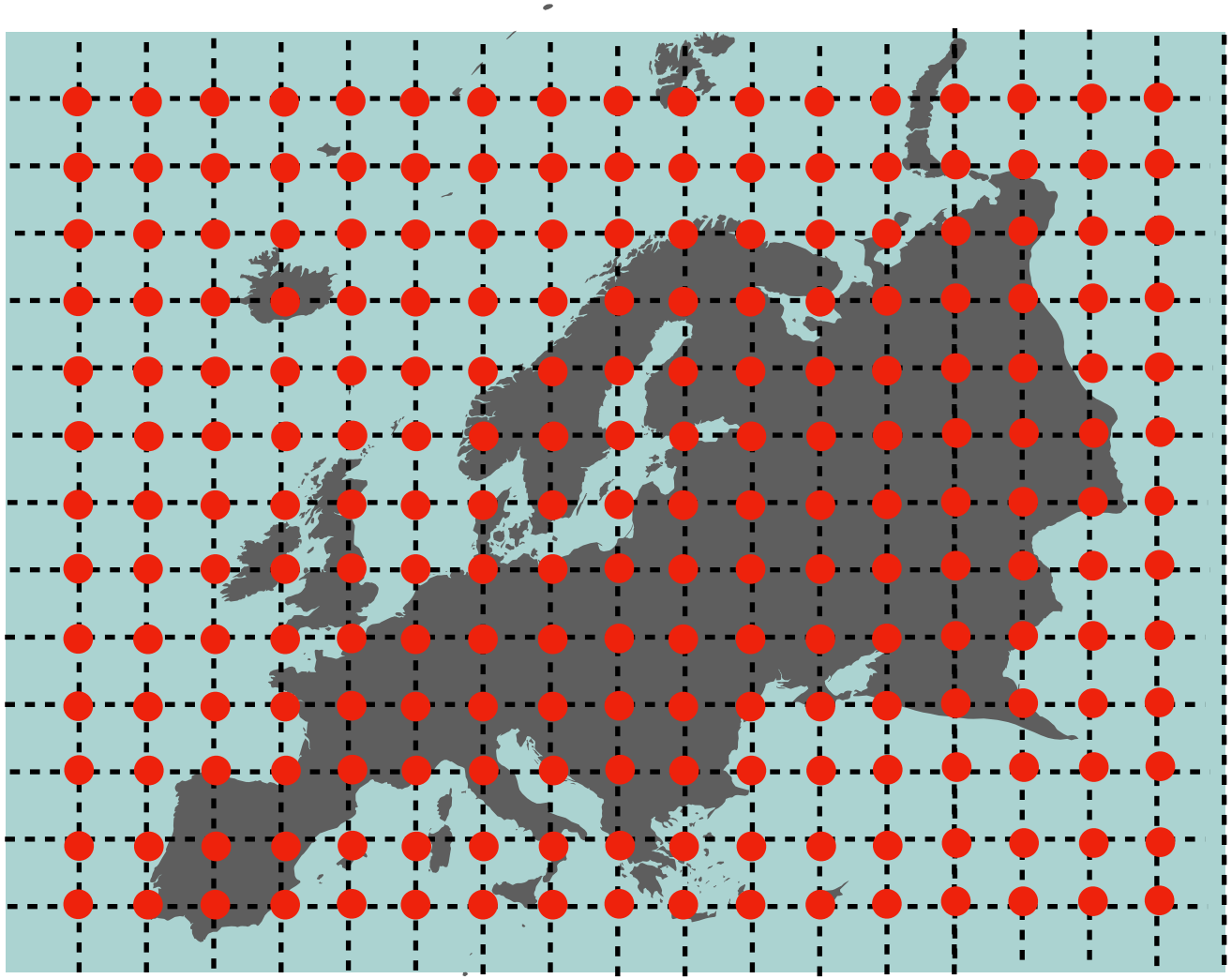
|__SBASinfo
|__IONinfo
IGP
|___IGPinfo
|____IGPmask
|____GIVDError
|____GIVEi
|____GIVE or σ_{GIVE}
|____ϵ_{IONO}

USER GRID

User Grid Along a Service Volume LON/LAT/GRID SIZE

LONxLAT = 5degx5deg



Mission

- *Computation of User-Sat **LOS** information Parameters for each User and Each Satellite:*

1. **Satellite Geometry User LOS**: Unitary vectors, Elevation, Azimuth, IPP longitude and latitude, Visibility
2. **Computation of Range Errors** of all contributors per User-Sat **LOS** (SREU, UISDE, STDE, AIRE)
   - **SREU** Projection of Satellite Orbit and Clock Error (SRE and SRE-B) to the LOS direction
   - **UISDE** Projection of the IGP VTEC Model error into the LOS (Slant Direction)
   - **STDE** using a random shooting on a Gaussian distribution with Sigma=**SigmaTROPO**
   - **AIRError** using a random shooting on a Gaussian distribution with Sigma=**SigmaAIR**

$$RANGE_{ERROR} = SREU + UISDE + TROPO_E + AIR_E$$

3. **Computation of the Sigmas** for all error contributors (ORB, IONO, TROPO, AIRBORNE)
   - **SigmaFLT:** Projection of the Satellite Covariance Matrix (UDRE, COVFLT) into the User LOS direction.
   - **SigmaUIRE** Projection of the Ionospheric Interpolated Vertical Sigma (GIVE) at IGPs into the User LOS
   - **SigmaTROPO** Sigma of the Tropo Model Error from MOPS Appendix J
   - **SigmaAir** Sigma of the Airborne Model Error from MOPS Appendix J

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

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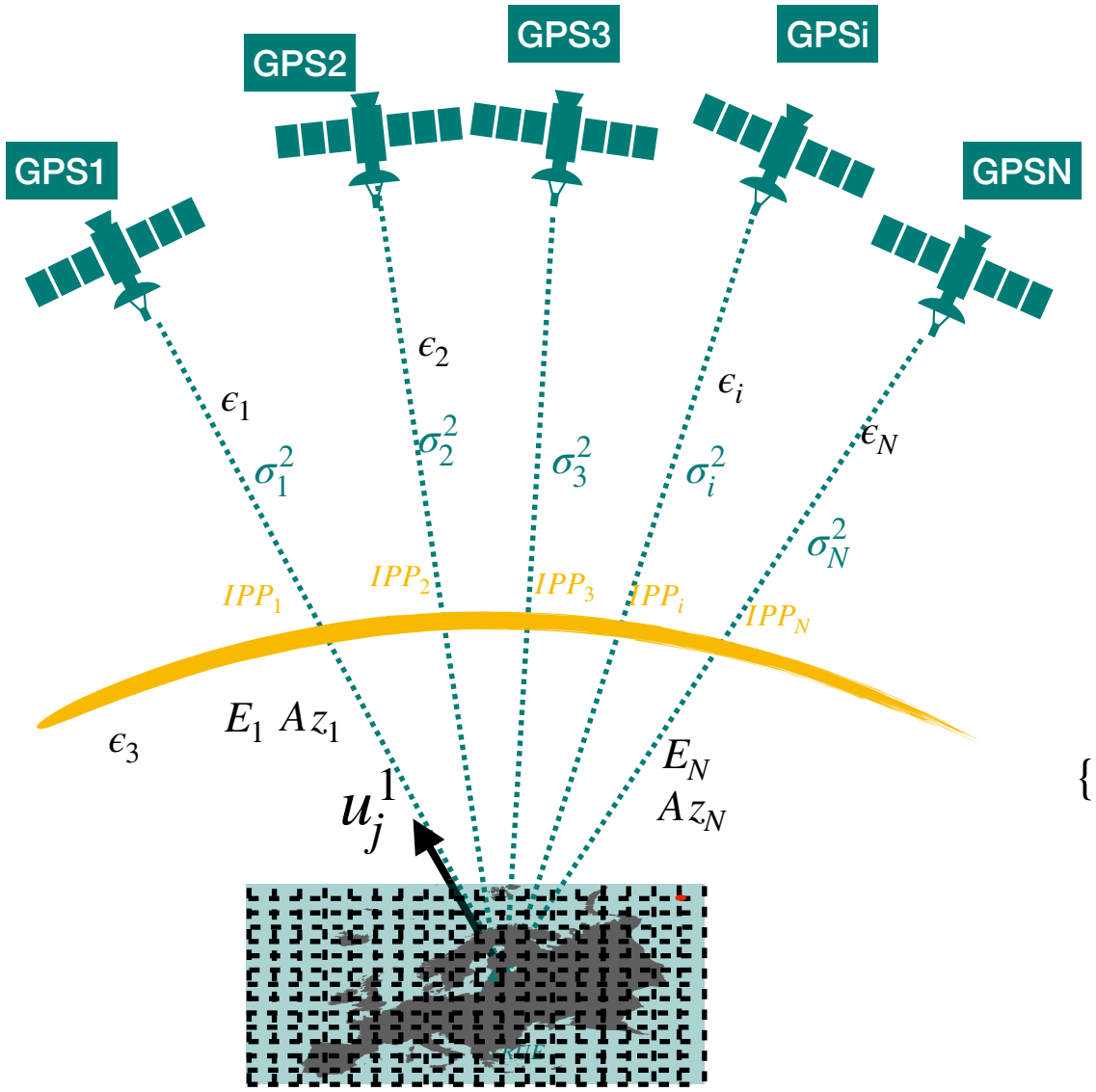
ELEVATE YOUR STANDARDS

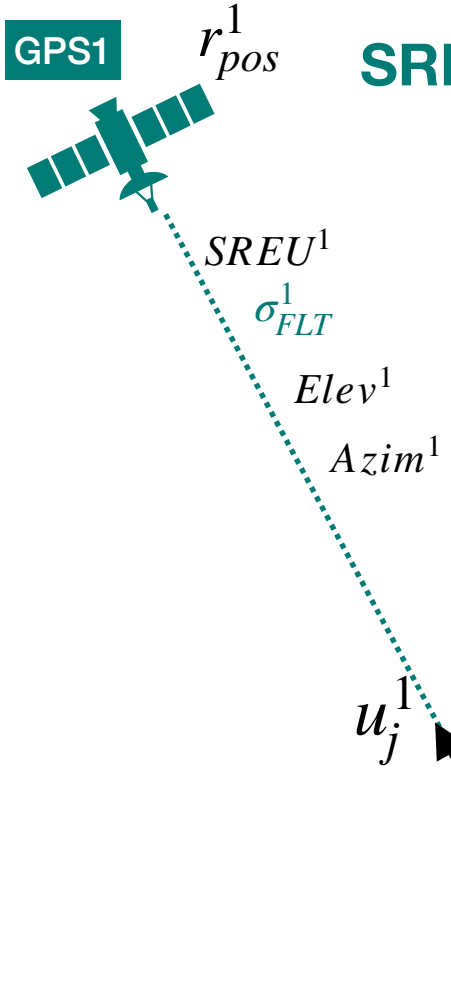
LOS-GEOM



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

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

SREU SigmaFLT



SREU: Satellite Residual Error projected into the User Direction

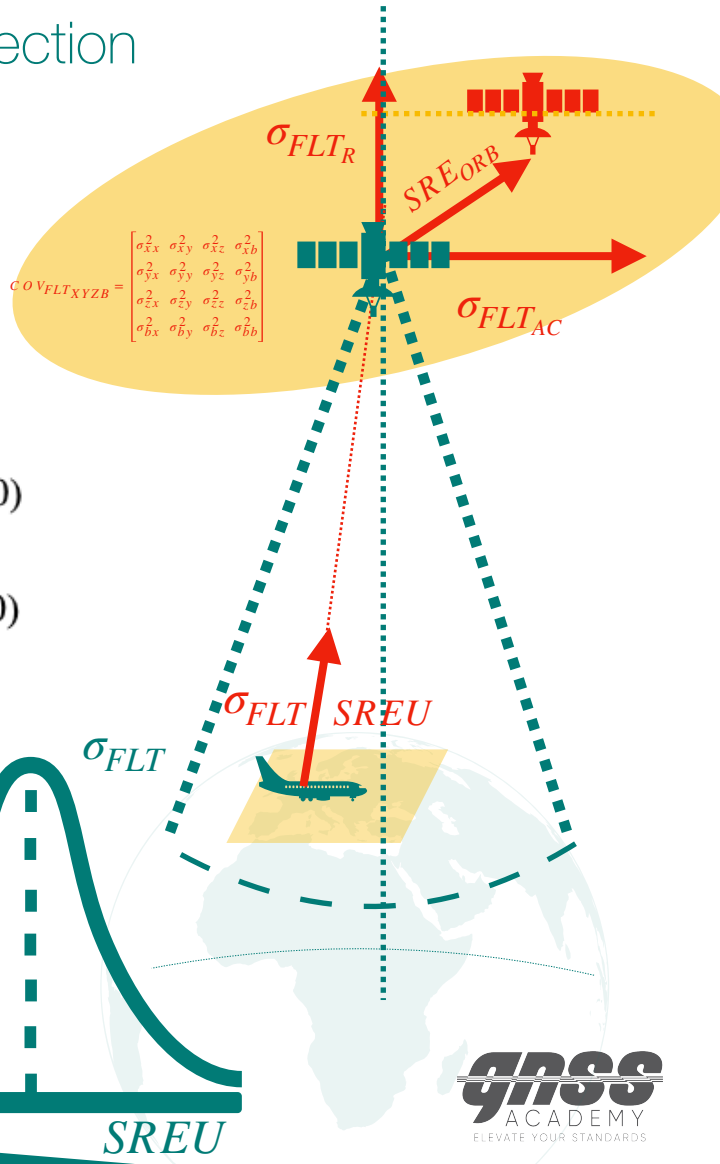
$$SREU = SRE_{XYZ} \cdot u^i_u - SRE_B$$

SigmaFLT: Sigma of the SREU

$$\sigma^2_{flt} = \begin{cases} \left[(\sigma_{UDRE}) \cdot (\delta UDRE) + \varepsilon_{fc} + \varepsilon_{rrc} + \varepsilon_{ltc} + \varepsilon_{er}\right]^2, & if\ RSS_{UDRE} = 0 (MessageType 10) \\ \left[(\sigma_{UDRE}) \cdot (\delta UDRE)\right]^2 + \varepsilon^2_{fc} + \varepsilon^2_{rrc} + \varepsilon^2_{ltc} + \varepsilon^2_{er}, & if\ RSS_{UDRE} = 1 (MessageType 10) \end{cases}$$

$$\delta_{UDRE^i_j} = \sqrt{u^i_j \cdot COV_{FLT} \cdot u^i_j}$$

$$\delta_{UDRE^i_j} = 1$$ (Within ECAC in EGNOS V2)



UDRE

MT-2to6

TABLE A-6 EVALUATION OF UDREIi

$UDREI_i$	$UDRE_i$ Meters 3.29Sigma	$\sigma^2_{i,UDRE}$ $Meters^2$
0	0.75	0.0520
1	1.0	0.0924
2	1.25	0.1444
3	1.75	0.2830
4	2.25	0.4678
5	3.0	0.8315
6	3.75	1.2992
7	4.5	1.8709
8	5.25	2.5465
9	6.0	3.3260
10	7.5	5.1968
11	15.0	20.7870
12	50.0	230.9661
13	150.0	2078.695
14	Not Monitored	Not Monitored
15	Do Not Use	Do Not Use

UDRE indicator is sent as part of the Fast Corrections Messages, updated every 6 seconds

SigmaUDRE is obtained with this table by dividing the Second Column by 3.29.

COV-MT28 (EGNOS V3 and WAAS)

1

$$\mathbf{R}=\mathbf{E}\cdot\mathbf{SF}, \qquad E = \begin{bmatrix} E_{1,1} & E_{1,2} & E_{1,3} & E_{1,4} \\ 0 & E_{2,2} & E_{2,3} & E_{2,4} \\ 0 & 0 & E_{3,3} & E_{3,4} \\ 0 & 0 & 0 & E_{4,4} \end{bmatrix}$$

$$\text{and } \mathbf{SF} = 2^{(\text{scale exponent} - 5)}.$$

2

$$C = R^T \cdot R$$

3

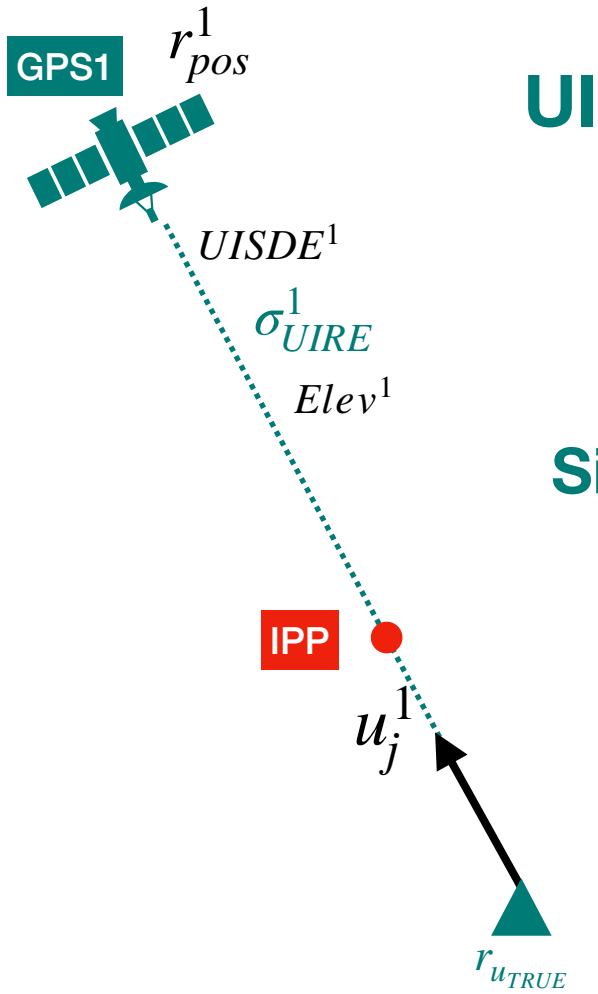
$$\delta UDRE = \sqrt{I^T \cdot C \cdot I} + \varepsilon_C$$

I is the 4-D line of sight vector from the user to the satellite

$$\sigma_{flt}^2 = \begin{cases} \left[(\sigma_{UDRE}) \cdot (\delta UDRE) + \varepsilon_{fc} + \varepsilon_{rrc} + \varepsilon_{ltc} + \varepsilon_{er}\right]^2, & if\ RSS_{UDRE} = 0 (MessageType 10) \\ \left[(\sigma_{UDRE}) \cdot (\delta UDRE)\right]^2 + \varepsilon_{fc}^2 + \varepsilon_{rrc}^2 + \varepsilon_{ltc}^2 + \varepsilon_{er}^2, & if\ RSS_{UDRE} = 1 (MessageType 10) \end{cases}$$

Parameter	No. of Bits (Note 1)	Scale Factor (LSB)	Effective Range (Note 1)	Units
IODP	2	1	0 to 3	unitless
PRN Mask No.(Note 2)	6	1	0 to 51	---
Scale exponent	3	1	0 to 7	unitless
$E_{1,1}$	9	1	0 to 511	unitless
$E_{2,2}$	9	1	0 to 511	unitless
$E_{3,3}$	9	1	0 to 511	unitless
$E_{4,4}$	9	1	0 to 511	unitless
$E_{1,2}$	10	1	±512	unitless
$E_{1,3}$	10	1	±512	unitless
$E_{1,4}$	10	1	±512	unitless
$E_{2,3}$	10	1	±512	unitless
$E_{2,4}$	10	1	±512	unitless
$E_{3,4}$	10	1	±512	unitless
PRN Mask No.(Note 2)	6	1	0 to 51	---
Scale exponent	3	1	0 to 7	unitless
$E_{1,1}$	9	1	0 to 511	unitless
$E_{2,2}$	9	1	0 to 511	unitless
$E_{3,3}$	9	1	0 to 511	unitless
$E_{4,4}$	9	1	0 to 511	unitless
$E_{1,2}$	10	1	±512	unitless
$E_{1,3}$	10	1	±512	unitless
$E_{1,4}$	10	1	±512	unitless
$E_{2,3}$	10	1	±512	unitless
$E_{2,4}$	10	1	±512	unitless
$E_{3,4}$	10	1	±512	unitless

UISDE



UISDE: User Ionospheric Slant Delay Error

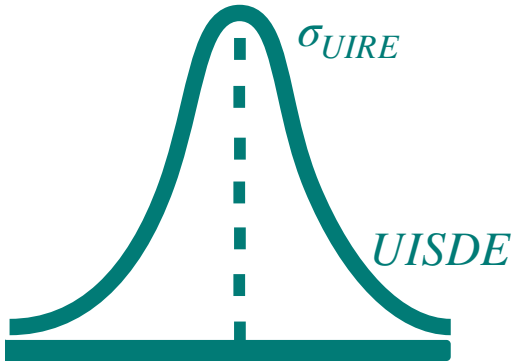
$$UISDE_{IPP} = m_{pp}(elev) \cdot \sum (w_{IGPi}) \cdot GIVDE_{IGPi}$$

MOPS Interpolation

SigmaUIRE: Sigma of the UISDE

$$\sigma^2_{UIRE_{IPP}} = m_{pp}(elev)^2 \cdot \sum (w_{IGPi}) \cdot GIVE^2_{IGPi}$$

MOPS Interpolation



$$\rho^i_{jSMOOTH} = (r^i_{SBAS} - r_j) \cdot u^i_j - b^i_{SBAS} + b_j + I^i_{iSBAS} + T^i_{jMODEL} + (\epsilon_{ORB_{SBAS}} \cdot u^i_j + \epsilon^i_{b_{SBAS}} + \epsilon_{IONO_{SBAS}} + \epsilon_{TROPO_{MODEL}} + \epsilon_{TN} + \epsilon_{MP} + \epsilon_{DIV})$$

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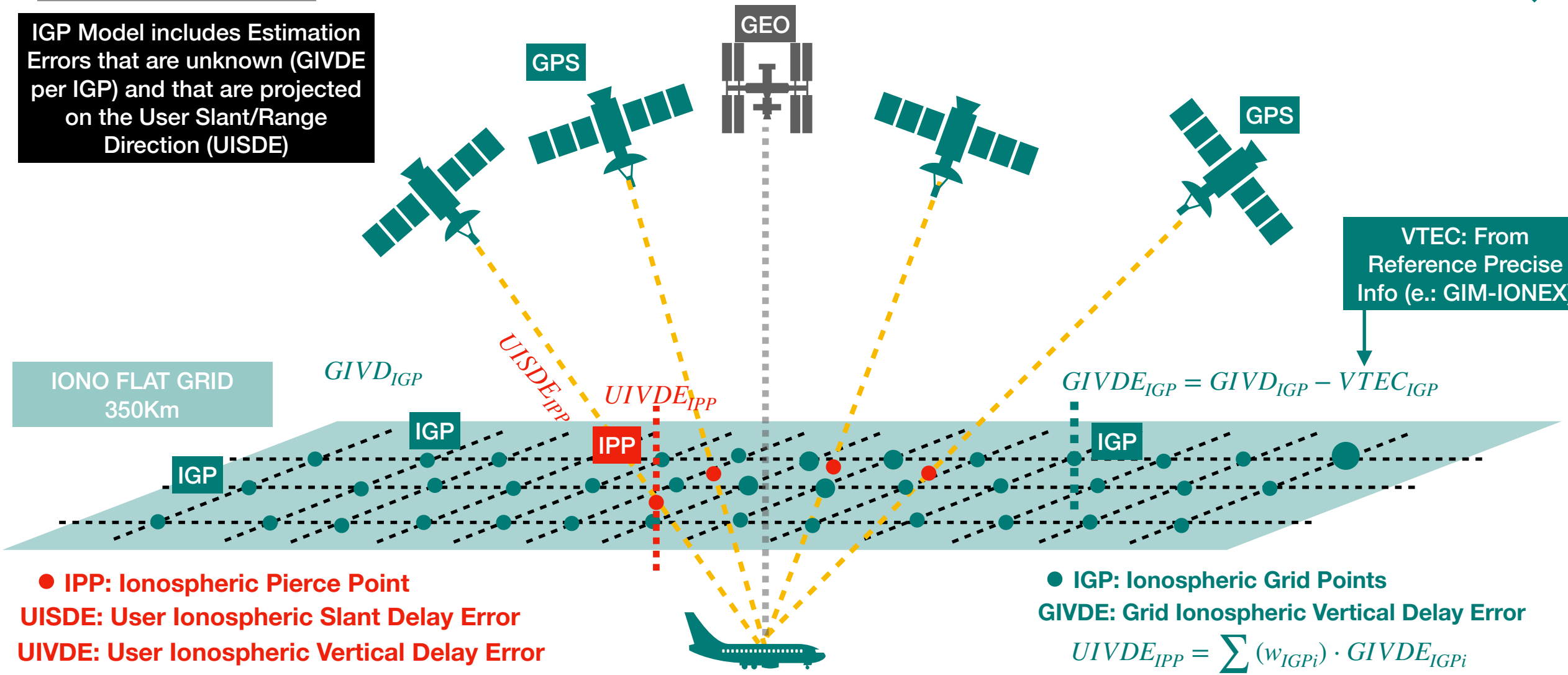
UISDE

IGP Model includes Estimation Errors that are unknown (GIVDE per IGP) and that are projected on the User Slant/Range Direction (UISDE)



- **IPP: Ionospheric Pierce Point**

UISDE: User Ionospheric Slant Delay Error

UIVDE: User Ionospheric Vertical Delay Error

$$UISDE_{IPP} = UISD_{IPP} - STEC_{IPP}$$

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

- **IGP: Ionospheric Grid Points**

GIVDE: Grid Ionospheric Vertical Delay Error

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

Surrounding IGPs

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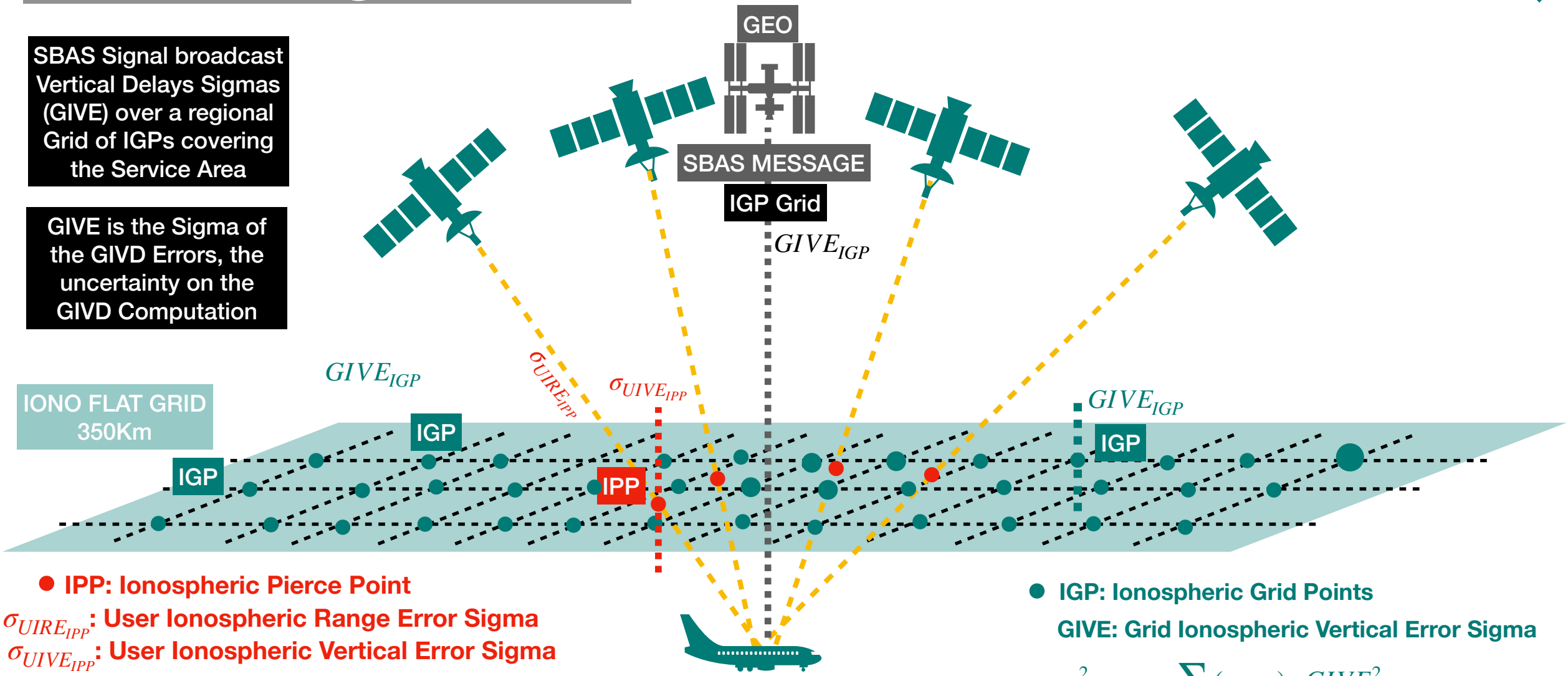
UIRE or SigmaUIRE

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



- **IPP: Ionospheric Pierce Point**

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

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

$$\sigma^2_{UIRE_{IPP}} = \sigma^2_{UIVE_{IPP}} \cdot m_{pp}(elev)^2$$

- **IGP: Ionospheric Grid Points**

GIVE: Grid Ionospheric Vertical Error Sigma

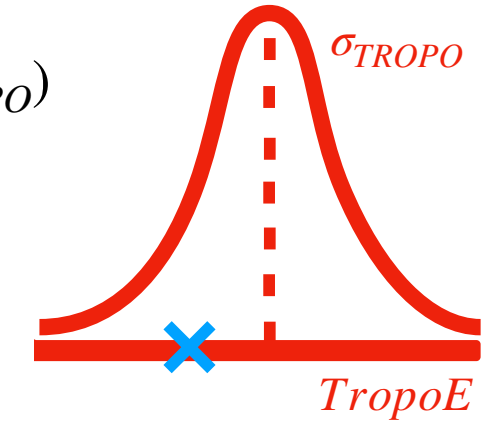
$$\sigma^2_{UIVE_{IPP}} = \sum (w_{IGPi}) \cdot GIVE^2_{IGPi}$$

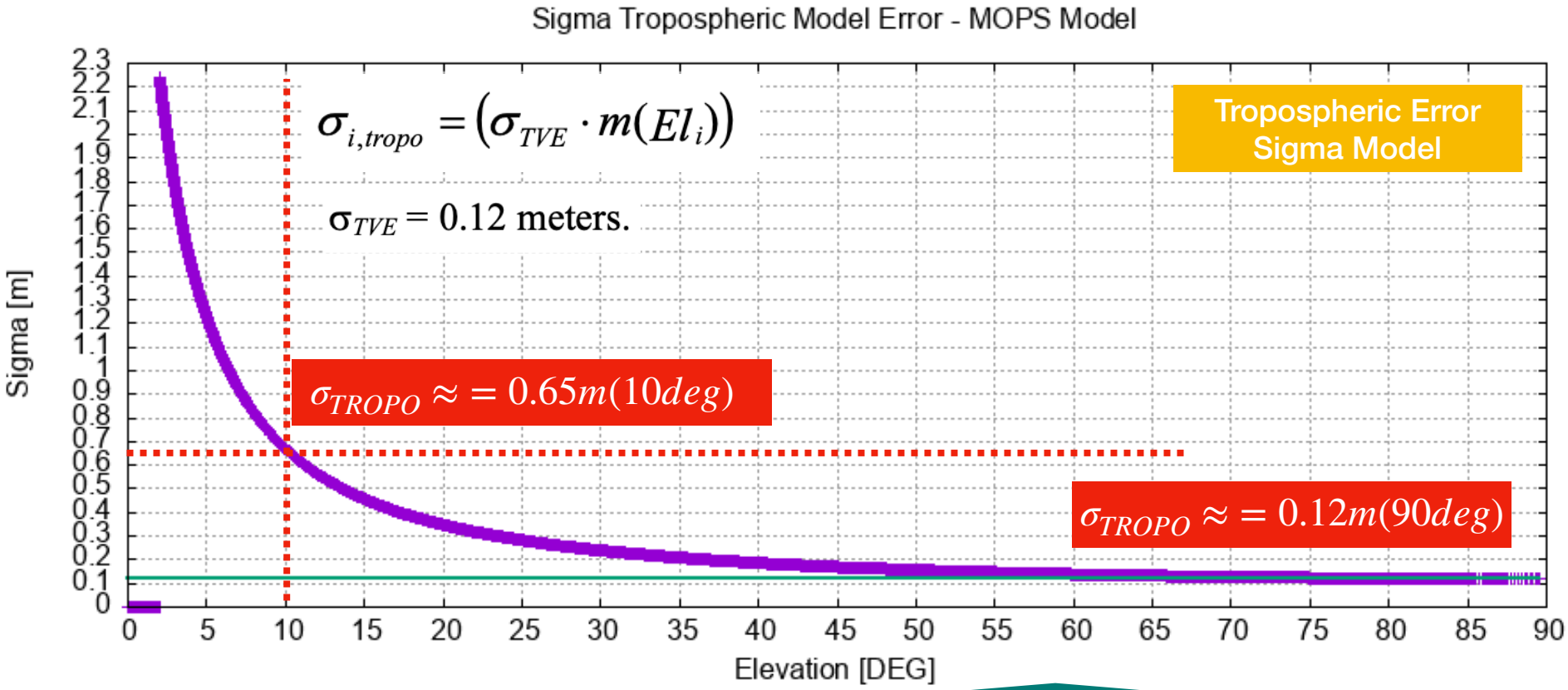
Surrounding IGPs

Slant Tropo Error (STDE) and SigmaTropo

STDE Random Shooting to a Gaussian distribution of null mean and Sigma the Sima of Tropo Error Model

$$TropoE \approx N(0,\sigma_{TROPO})$$

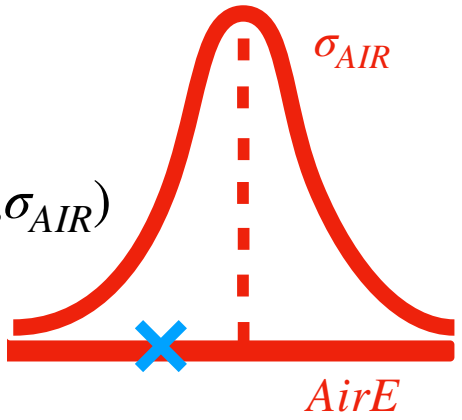


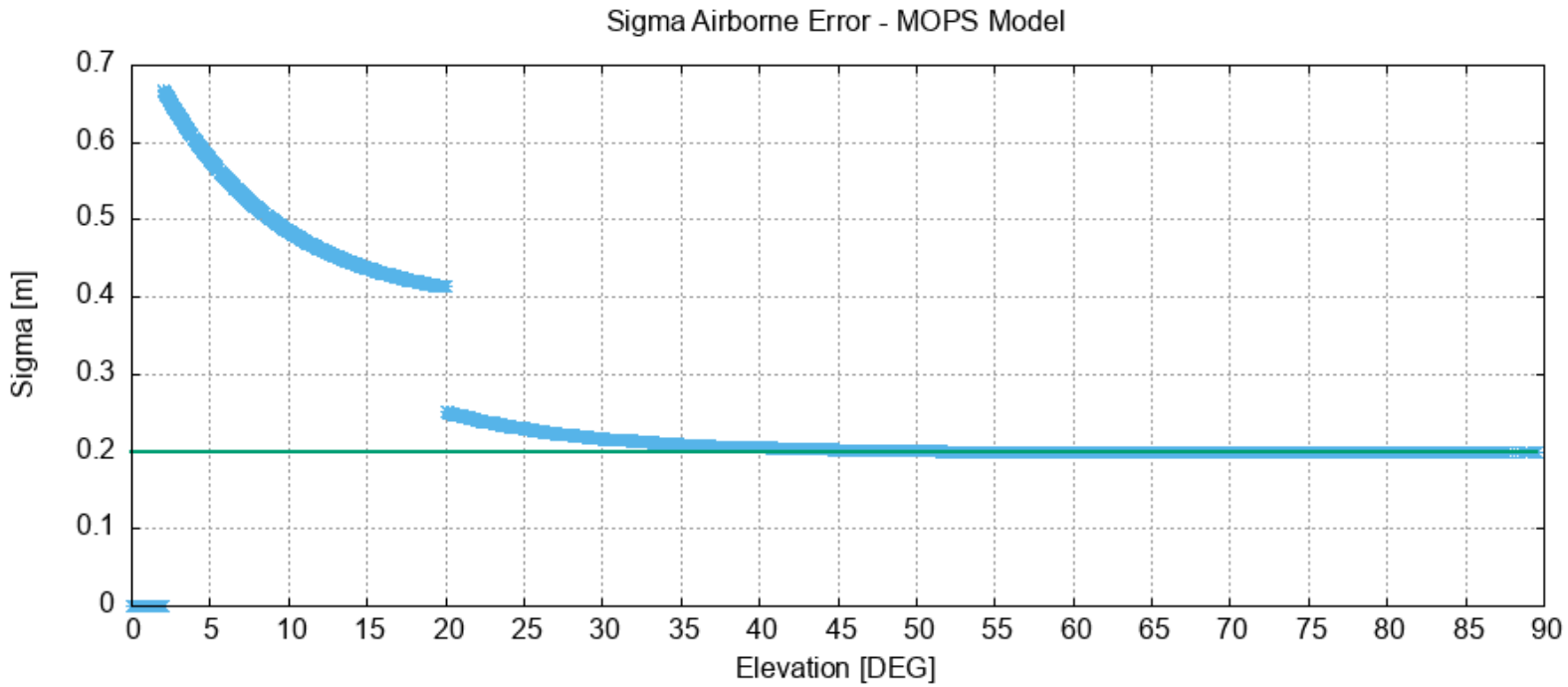


Sigma AIR and Airborne Error (AirE)

Random Shooting to a Gaussian distribution of null mean and Sigma the Sigma of Airborne Error Model (MOPS)

$$AirE \approx N(0,\sigma_{AIR})$$





Low Level Architecture

INPUTS

- **USRconf**
  - UserGrid
- **SATinfo**
  - SatPosNavXYZ
  - SatMonStatus
  - SREStatus
  - SRE-XYZB
  - UDRE$_{MT2to5}$
  - COV$_{FLT/MT28}$
  - DEG$_{MT7/MT10}$
- **IGPinfo**
  - IGPmask
  - GIVDError
  - GIVEi
  - GIVE or σ_{GIVE}
  - ϵ_{IONO}

LOS

- GEO
  - UVect
  - Elev
  - Azim
  - IPP
- SREU SigmaFLT
- UISDE SigmaUIRE
- STDE SigmaTropo
- AirE SigmaAir
- RangeError
- SigmaUERE

LOS OUTPUTS

- **LOS info**
  - Time SOD,
  - User Lon/Lat
  - Ulos UxUyUz
  - Sat PRN
  - Sat Elev, Azim,
  - IPP Lon/Lat
  - SV Used in SOL
  - SREU
  - UISDE
  - STropoDelayError
  - AirError
  - **RANGError**
  - SigmaFLT
  - SigmaUIRE
  - SigmaTropo
  - SigmaAir
  - **SigmaUERE**

Processing Logic

- Read **USRcfg** information to define a grid of user coordinates across the service area with the configured size spacing or reading an external file (if possible)
- Extract **SATinfo** and **IGPinfo** from SAT and IGP Modules.
- **For each second or time step during.**
  - **For each USER in the grid.**
    - **For each MONITORED SATELLITE (UDREi<12 PA) with valid FLT Corrections:**
      - **Estimate the LoS Geometrical Properties**.
        - ✓ Elevation and Azimuth
        - ✓ IPP Longitude and Latitude
        - ✓ Unitary Vector from user to the satellite
        - ✓ Visibility Flag (OK if elevation is above a minimum user masking angle)
      - **If satellite is Visible**:
        - Estimate the LoS Range Error (SREU, UISDE, TROPOE, AIRE)
        - Estimate the LoS Sigma UERE (SigmaFLT, SigmaUIRE, SigmaTropo, SigmaAIR)

LOS FILE

FILENAME: LOS_INFO_Y19014_GEO123.dat

Column	Content	Format	Units	Description
C1	SOD	%05d	SEC	Second of Day
C2	DOY	%03d	DAYS	Day of Year
C3	USER ID	%5d	-	User ID as a number
C4	ULON	%f	DEG	User Longitude
C5	ULAT	%f	DEG	User Latitude
C6	FLAG	%d	-	Flag to indicate if this LOS can be used for PA or NPA or any
C7	CONST	%s	-	Satellite Constellation (G: GPS, E:Galileo)
C8	PRN	%02d	-	Satellite PRN
C9	ELEV	%f	DEG	Satellite Elevation angle
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C11	IPPLON	%f	DEG	IPP Longitude
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C14	UERE1	%f	METER	UERE from the Orbit&Clock and ionospheric component
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C16	RERROR	%f	METER	Total Range Error with all the contributors
C17	SigmaUERE	%f	METER	Sigma UERE including all the contributors
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C20	UDREI	%f	-	Satellite UDRE Index
C21	SFLT	%f	METER	Satellite SigmaFLT (Sigma of the Satellite Orbit and Clock
C22	STROPOE	%f	METER	Slant Tropospheric Model Error
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C28	UISD	%f	METER	User Ionospheric Slant Delay
C29	SIGMAMP	%f	METER	Sigma of Multipath Error
C30	SIGMANOISE	%f	METER	Sigma of Receiver Noise

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C28	UISD	%f	METER	User Ionospheric Slant Delay
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C30	SIGMANOISE	%f	METER	Sigma of Receiver Noise

LOS FILE

FILENAME: LOS_INFO_Y19014_GEO123.dat

USER

Column	Content	Format	Units	Description
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C3	USER ID	%5d	-	User ID as a number
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C28	UISD	%f	METER	User Ionospheric Slant Delay
C29	SIGMAMP	%f	METER	Sigma of Multipath Error
C30	SIGMANOISE	%f	METER	Sigma of Receiver Noise

SATELLITE

LOS FILE

FILENAME: LOS_INFO_Y19014_GEO123.dat

ULOS

Column	Content	Format	Units	Description
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C5	ULAT	%f	DEG	User Latitude
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C7	CONST	%s	-	Satellite Constellation (G: GPS, E:Galileo)
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ERROR

LOS FILE

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ORBIT CLOCK

LOS FILE

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TROPO

LOS FILE

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C22	STROPOE	%f	METER	Slant Tropospheric Model Error
C23	SIGMTROPO	%f	METER	Sigma of the Troposphere Model Error
C24	AIRERR	%f	METER	Airborne Error including Multipath, Receiver Noise and the
C25	SIGMAIR	%f	METER	Sigma Airborne including Multipath, Receiver Noise and the
C26	UISDE	%f	METER	User Ionosphere Slant Delay Error
C27	UIRE	%f	METER	User Ionospheric Range Error
C28	UISD	%f	METER	User Ionospheric Slant Delay
C29	SIGMAMP	%f	METER	Sigma of Multipath Error
C30	SIGMANOISE	%f	METER	Sigma of Receiver Noise

AIR

LOS FILE

FILENAME: LOS_INFO_Y19014_GEO123.dat

Column	Content	Format	Units	Description
C1	SOD	%05d	SEC	Second of Day
C2	DOY	%03d	DAYS	Day of Year
C3	USER ID	%5d	-	User ID as a number
C4	ULON	%f	DEG	User Longitude
C5	ULAT	%f	DEG	User Latitude
C6	FLAG	%d	-	Flag to indicate if this LOS can be used for PA or NPA or any
C7	CONST	%s	-	Satellite Constellation (G: GPS, E:Galileo)
C8	PRN	%02d	-	Satellite PRN
C9	ELEV	%f	DEG	Satellite Elevation angle
C10	AZIM	%f	DEG	Satellite Azimuth angle
C11	IPPLON	%f	DEG	IPP Longitude
C12	IPPLAT	%f	DEG	IPP Latitude
C13	RERROR1	%f	METER	Range Error Orbit and Ionospheric Component
C14	UERE1	%f	METER	UERE from the Orbit&Clock and ionospheric component
C15	SI1	%f	-	Safety Index at Range level from Orbit&Clock plus Ionosphere
C16	RERROR	%f	METER	Total Range Error with all the contributors
C17	SigmaUERE	%f	METER	Sigma UERE including all the contributors
C18	Range SI	%f	-	Safety Index at Range level with all the contributors
C19	SREU	%f	METER	Satellite Residual Error at the User Position
C20	UDREI	%f	-	Satellite UDRE Index
C21	SFLT	%f	METER	Satellite SigmaFLT (Sigma of the Satellite Orbit and Clock
C22	STROPOE	%f	METER	Slant Tropospheric Model Error
C23	SIGMTROPO	%f	METER	Sigma of the Troposphere Model Error
C24	AIRERR	%f	METER	Airborne Error including Multipath, Receiver Noise and the
C25	SIGMAIR	%f	METER	Sigma Airborne including Multipath, Receiver Noise and the
C26	UISDE	%f	METER	User Ionosphere Slant Delay Error
C27	UIRE	%f	METER	User Ionospheric Range Error
C28	UISD	%f	METER	User Ionospheric Slant Delay
C29	SIGMAMP	%f	METER	Sigma of Multipath Error
C30	SIGMANOISE	%f	METER	Sigma of Receiver Noise

IONO

LOS FILE

FILENAME: LOS_INFO_Y19014_GEO123.dat

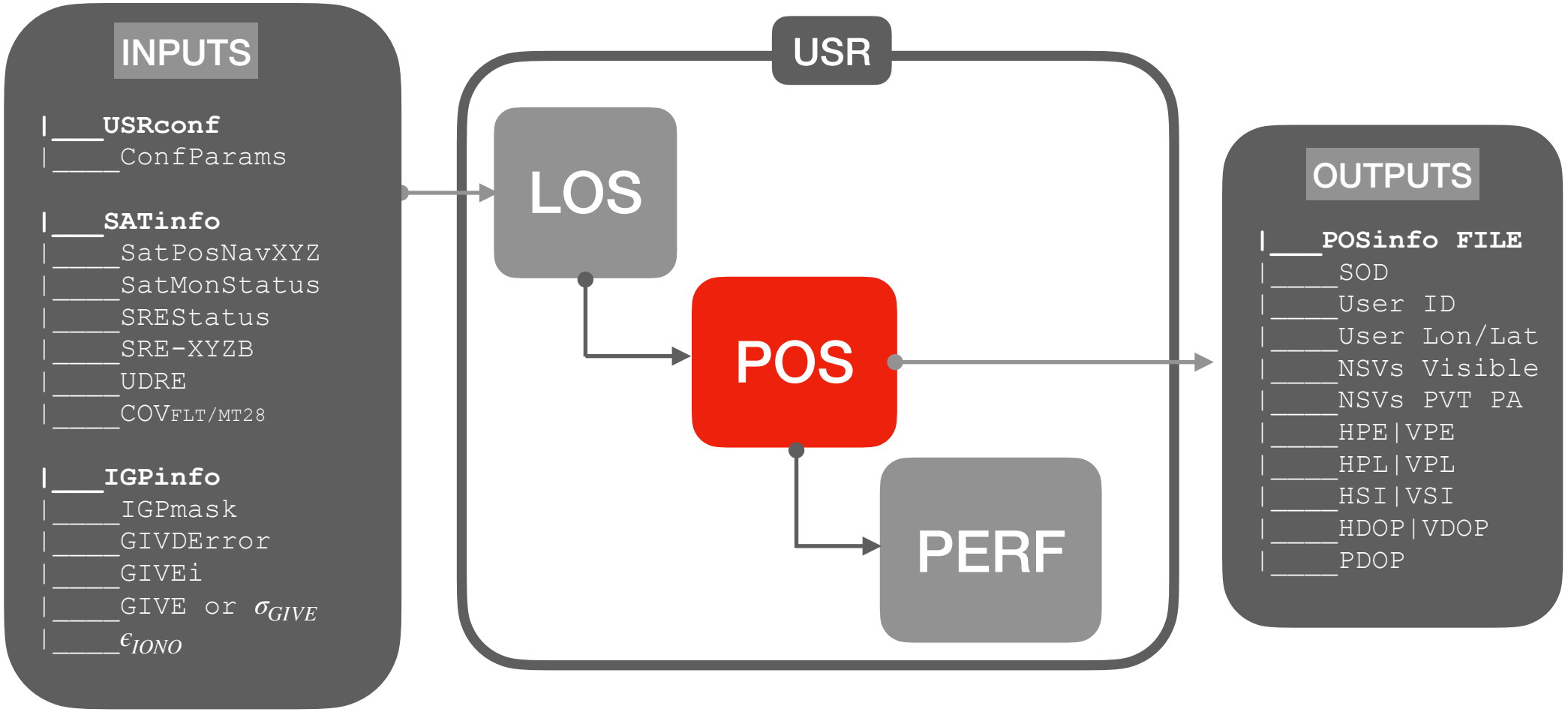
FLAG

ELEV

Column	Content	Format	Units	Description
C1	SOD	%05d	SEC	Second of Day
C2	DOY	%03d	DAYS	Day of Year
C3	USER ID	%5d	-	User ID as a number
C4	ULON	%f	DEG	User Longitude
C5	ULAT	%f	DEG	User Latitude
C6	FLAG	%d	-	Flag to indicate if this LOS can be used for PA or NPA or any
C7	CONST	%s	-	Satellite Constellation (G: GPS, E:Galileo)
C8	PRN	%02d	-	Satellite PRN
C9	ELEV	%f	DEG	Satellite Elevation angle
C10	AZIM	%f	DEG	Satellite Azimuth angle
C11	IPPLON	%f	DEG	IPP Longitude
C12	IPPLAT	%f	DEG	IPP Latitude
C13	RERROR1	%f	METER	Range Error Orbit and Ionospheric Component
C14	UERE1	%f	METER	UERE from the Orbit&Clock and ionospheric component
C15	SI1	%f	-	Safety Index at Range level from Orbit&Clock plus Ionosphere
C16	RERROR	%f	METER	Total Range Error with all the contributors
C17	SigmaUERE	%f	METER	Sigma UERE including all the contributors
C18	Range SI	%f	-	Safety Index at Range level with all the contributors
C19	SREU	%f	METER	Satellite Residual Error at the User Position
C20	UDREI	%f	-	Satellite UDRE Index
C21	SFLT	%f	METER	Satellite SigmaFLT (Sigma of the Satellite Orbit and Clock
C22	STROPOE	%f	METER	Slant Tropospheric Model Error
C23	SIGMTROPO	%f	METER	Sigma of the Troposphere Model Error
C24	AIRERR	%f	METER	Airborne Error including Multipath, Receiver Noise and the
C25	SIGMAIR	%f	METER	Sigma Airborne including Multipath, Receiver Noise and the
C26	UISDE	%f	METER	User Ionosphere Slant Delay Error
C27	UIRE	%f	METER	User Ionospheric Range Error
C28	UISD	%f	METER	User Ionospheric Slant Delay
C29	SIGMAMP	%f	METER	Sigma of Multipath Error
C30	SIGMANOISE	%f	METER	Sigma of Receiver Noise

WP3.1: USR-POS

POS


INPUTS
|___USRconf
|____ConfParams
|___SATinfo
|____SatPosNavXYZ
|____SatMonStatus
|____SREStatus
|____SRE-XYZB
|____UDRE
|____COVFLT/MT28
|___IGPinfo
|____IGPmask
|____GIVDError
|____GIVEi
|____GIVE or σ_{GIVE}
|____ϵ_{IONO}
USR
LOS
POS
PERF
OUTPUTS
|___POSinfo FILE
|____SOD
|____User ID
|____User Lon/Lat
|____NSVs Visible
|____NSVs PVT PA
|____HPE|VPE
|____HPL|VPL
|____HSI|VSI
|____HDOP|VDOP
|____PDOP

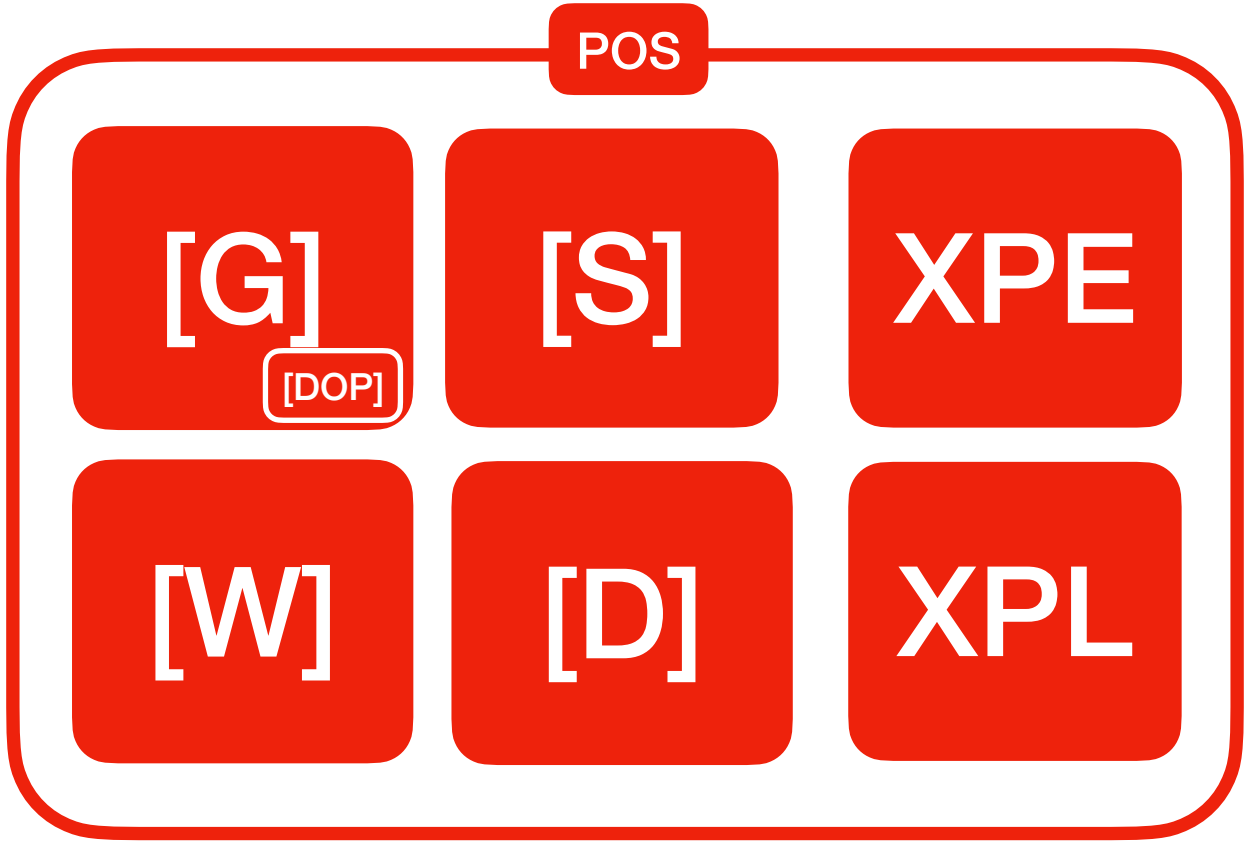
WP3.1: Develop USR-POS Sub-Module

- **READ** LOS_INFO file with instantaneous LOS information
- **BUILD** [G], [W], [S], [D] and [DOP] Matrices
- **COMPUTE**
  - ➡ Position Errors: HPE(t), VPE(t)
  - ➡ Protection Levels: HPL(t), VPL(t)
  - ➡ DOPs: HDOP(t), VDOP(t), PDOP(t)
  - ➡ NSVs: Number of Satellite used(t)
- **Write** a POS file with all the instantaneous information per user.

Low Level Design

LOS INPUTS

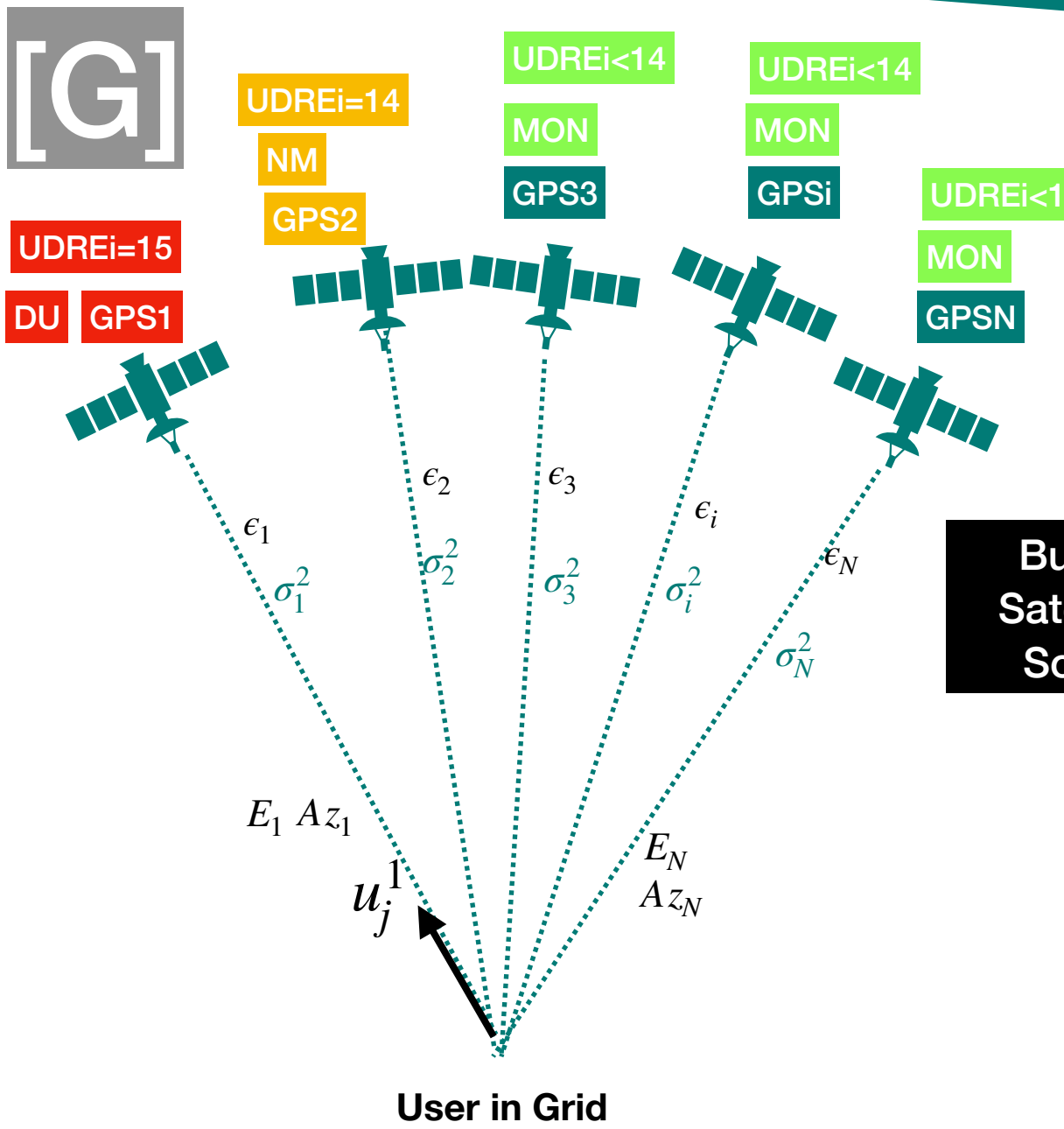
- **LOS info**
  - Time SOD,
  - User Lon/Lat
  - Ulos UxUyUz
  - Sat PRN
  - Sat Elev, Azim,
  - IPP Lon/Lat
  - SV Used in SOL
  - SREU
  - UISDE
  - STropoDelayError
  - AirError
  - **RANGError**
  - SigmaFLT
  - SigmaUIRE
  - SigmaTropo
  - SigmaAir
  - **SigmaUERE**



POS OUTPUTS

- **POSinfo FILE**
  - SOD
  - User ID
  - User Lon/Lat
  - NSVs Visible
  - NSVs PVT PA
  - HPE|VPE
  - HPL|VPL
  - HSI|VSI
  - HDOP|VDOP
  - PDOP

gnss ACADEMY
ELEVATE YOUR STANDARDS



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

Build [G] Matrix from Satellites usable on PA Solution (UDREi<12)

Note that NPA solution allows using satellites UDREi>=12 (12,13)

Check PA Flag and Elevation Angle > 5deg

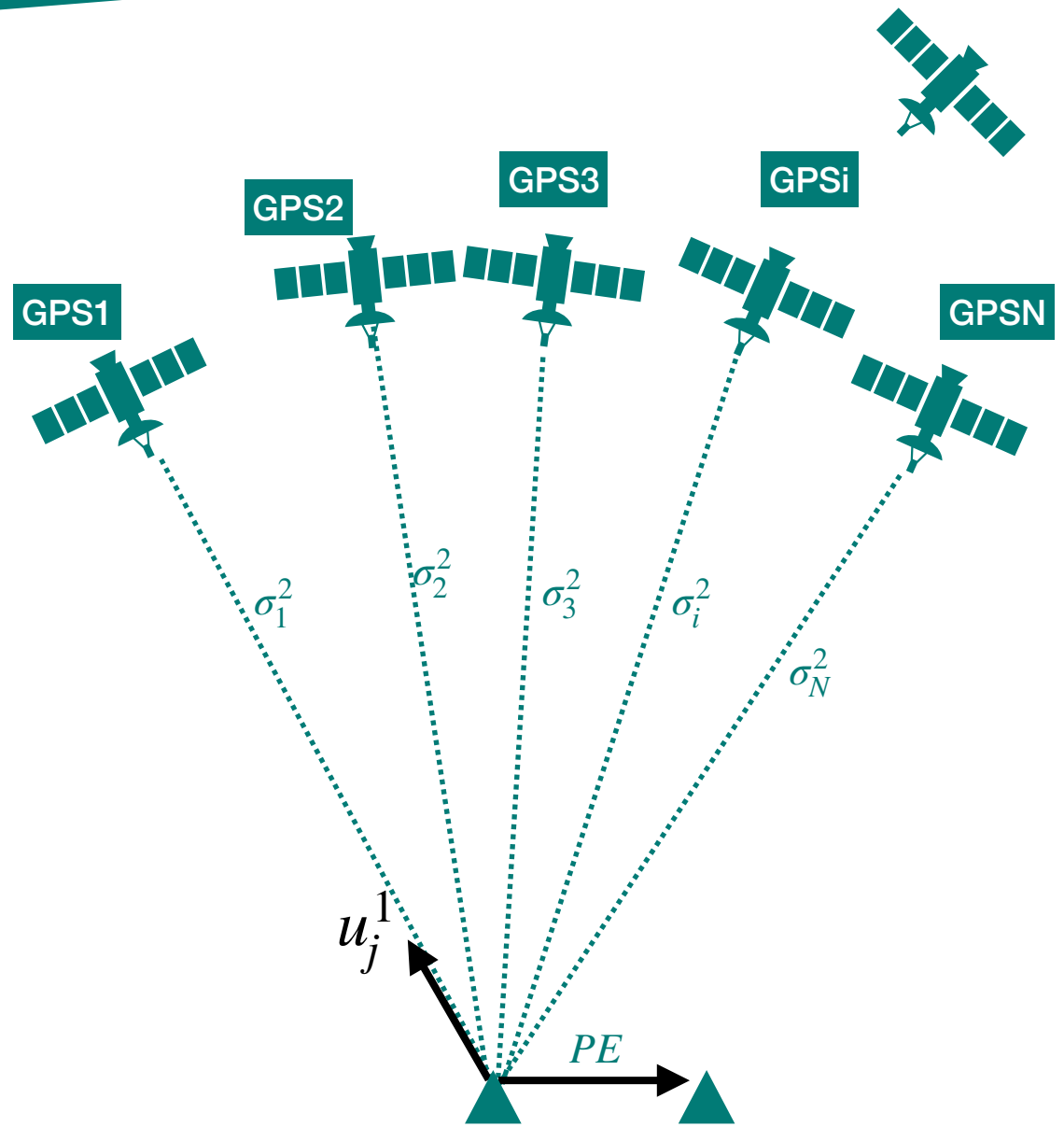
[W]

$$W = \Sigma^{-1}$$

$$W = \begin{bmatrix} w_1 & 0 & \cdots & 0 \\ 0 & w_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & w_N \end{bmatrix}$$

$$\Sigma = COV(\epsilon) = \begin{bmatrix} (\sigma^2_{UERE})^2 & 0 & 0 & 0 & 0 \\ 0 & (\sigma^2_{UERE})^2 & 0 & \cdots & 0 \\ 0 & 0 & (\sigma^3_{UERE})^2 & \cdots & 0 \\ \cdots & & & & \\ 0 & 0 & 0 & \cdots & (\sigma^N_{UERE})^2 \end{bmatrix}$$

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



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

gnss ACADEMY
ELEVATE YOUR STANDARDS

[S]

$$[S] = (G^T \mathbf{W} G)^{-1} G^T \mathbf{W}$$

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

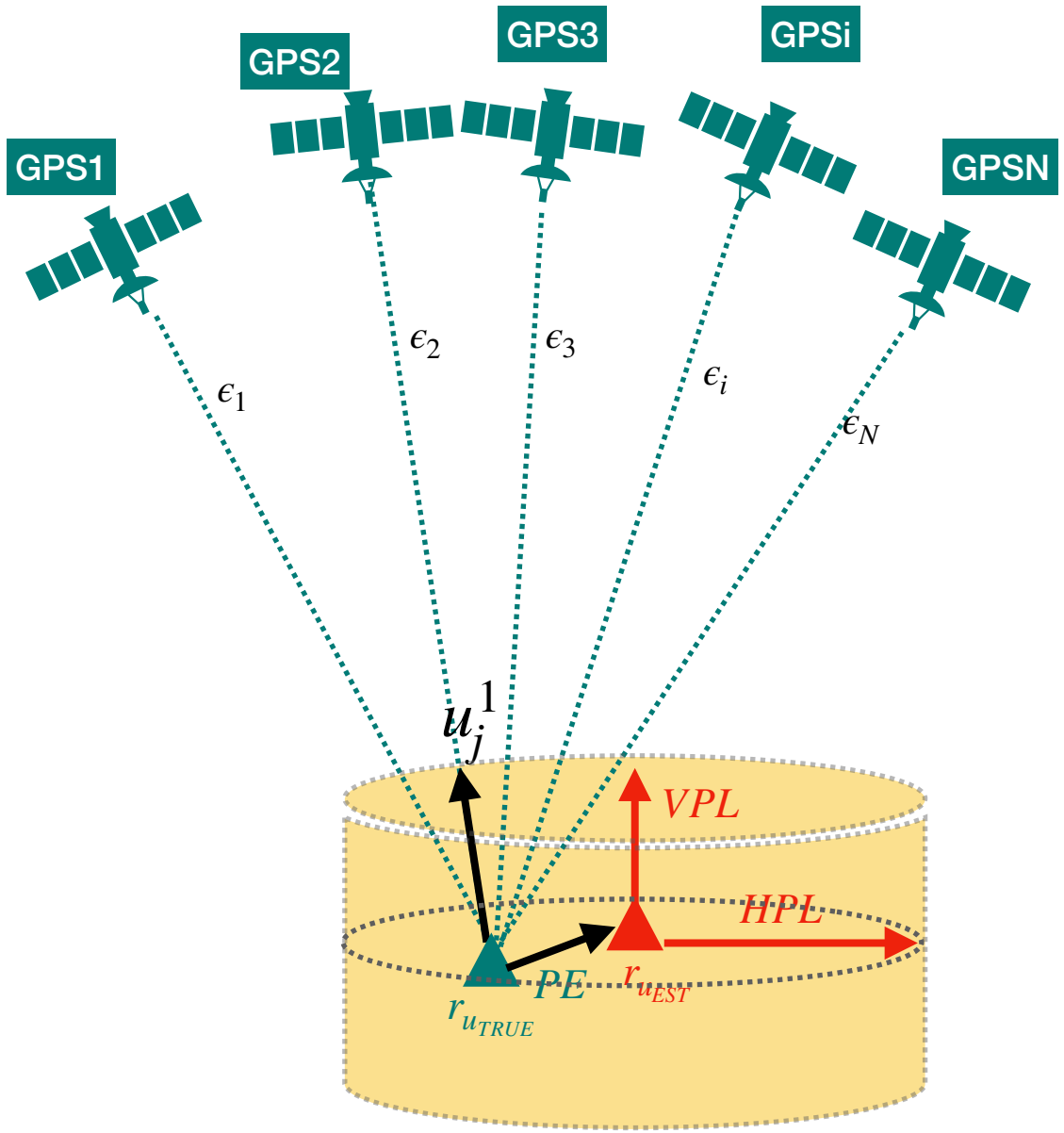
[D]

$$[D] = (G^T \mathbf{W} G)^{-1}$$

[DOP]

$$[DOP] = (G^T G)^{-1}$$

Compute XPE, XPL, XDOPS



EQ. TO SOLVE

$$\{\Delta\rho\} = [G]\,[\Delta X] + \{\epsilon\}$$

$$W = \Sigma^{-1}$$

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

$$[D] = (G^T \mathbf{W} G)^{-1} = \begin{bmatrix} d_{east}^2 & d_{EN} & d_{EU} & d_{ET} \\ d_{EN} & d_{north}^2 & d_{NU} & d_{NT} \\ d_{EU} & d_{NU} & d_U^2 & d_{UT} \\ d_{ET} & d_{NT} & d_{UT} & d_T^2 \end{bmatrix}$$

Vertical

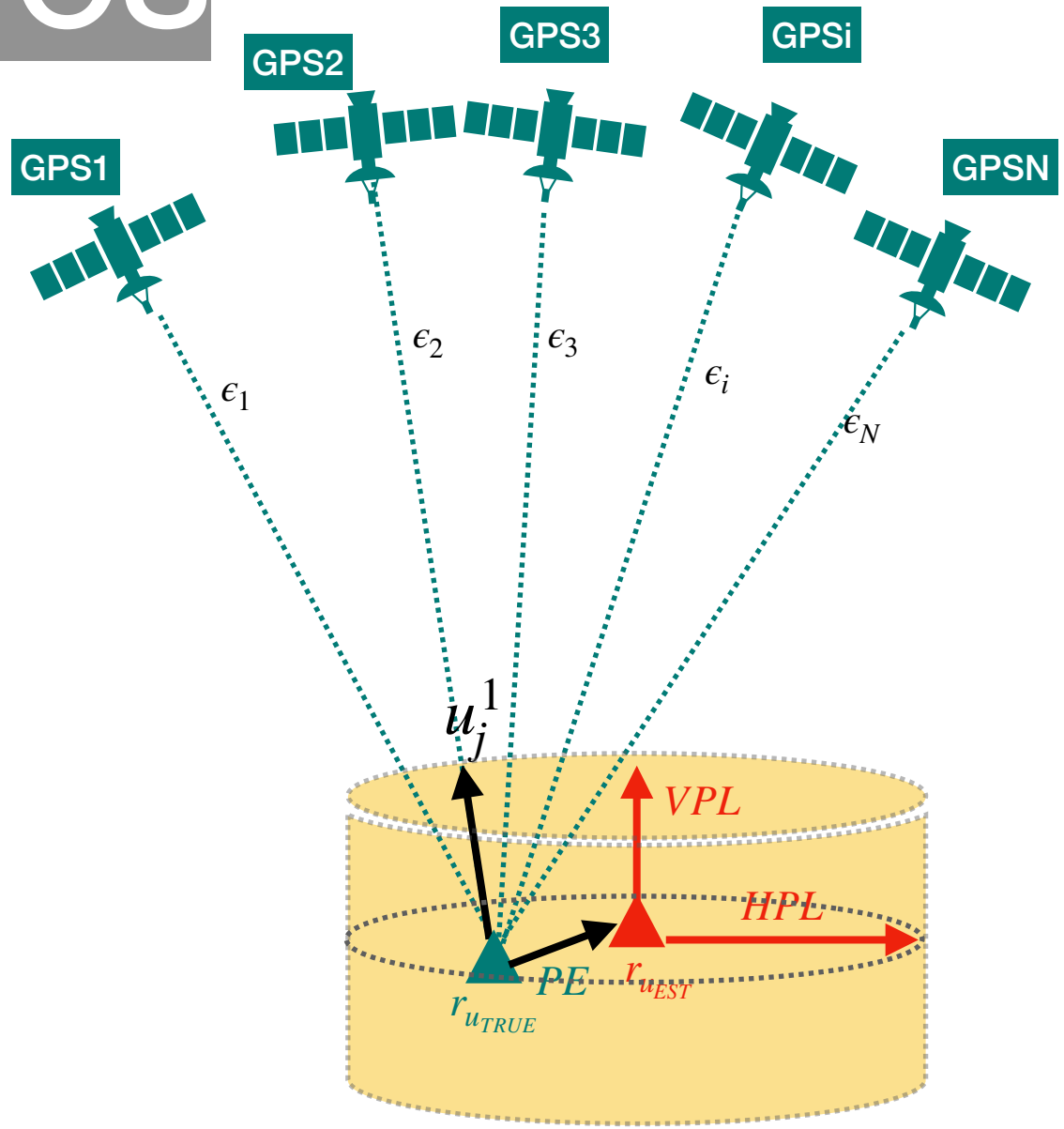
$$VPL_{SBAS} = K_V d_U \qquad K_V = 5.33$$

Horizontal

$$HPL_{SBAS} = \begin{cases} K_{H,NPA} \cdot d_{major} & K_{H,NPA} = 6.18 \\ K_{H,PA} \cdot d_{major} & K_{H,PA} = 6.0 \end{cases}$$

$$d_{major} \equiv \sqrt{\frac{d_{east}^2 + d_{north}^2}{2} + \sqrt{\left(\frac{d_{east}^2 - d_{north}^2}{2}\right)^2 + d_{EN}^2}}$$

POS



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

$$PL = (G^T \mathbf{W} G)^{-1} = \begin{bmatrix} d_{east}^2 & d_{EN} & d_{EU} & d_{ET} \\ d_{EN} & d_{north}^2 & d_{NU} & d_{NT} \\ d_{EU} & d_{NU} & d_U^2 & d_{UT} \\ d_{ET} & d_{NT} & d_{UT} & d_T^2 \end{bmatrix}$$

$$d_{major} \equiv \sqrt{\frac{d_{east}^2 + d_{north}^2}{2} + \sqrt{\left(\frac{d_{east}^2 - d_{north}^2}{2}\right)^2 + d_{EN}^2}}$$

Vertical

$$VPL_{SBAS} = K_V d_U \qquad K_V = 5.33$$

Horizontal

$$HPL_{SBAS} = \begin{cases} K_{H,NPA} \cdot d_{major} & K_{H,NPA} = 6.18 \\ K_{H,PA} \cdot d_{major} & K_{H,PA} = 6.0 \end{cases}$$

POS INFO

FILENAME: POS_INFO_Y19014_GEO123.dat

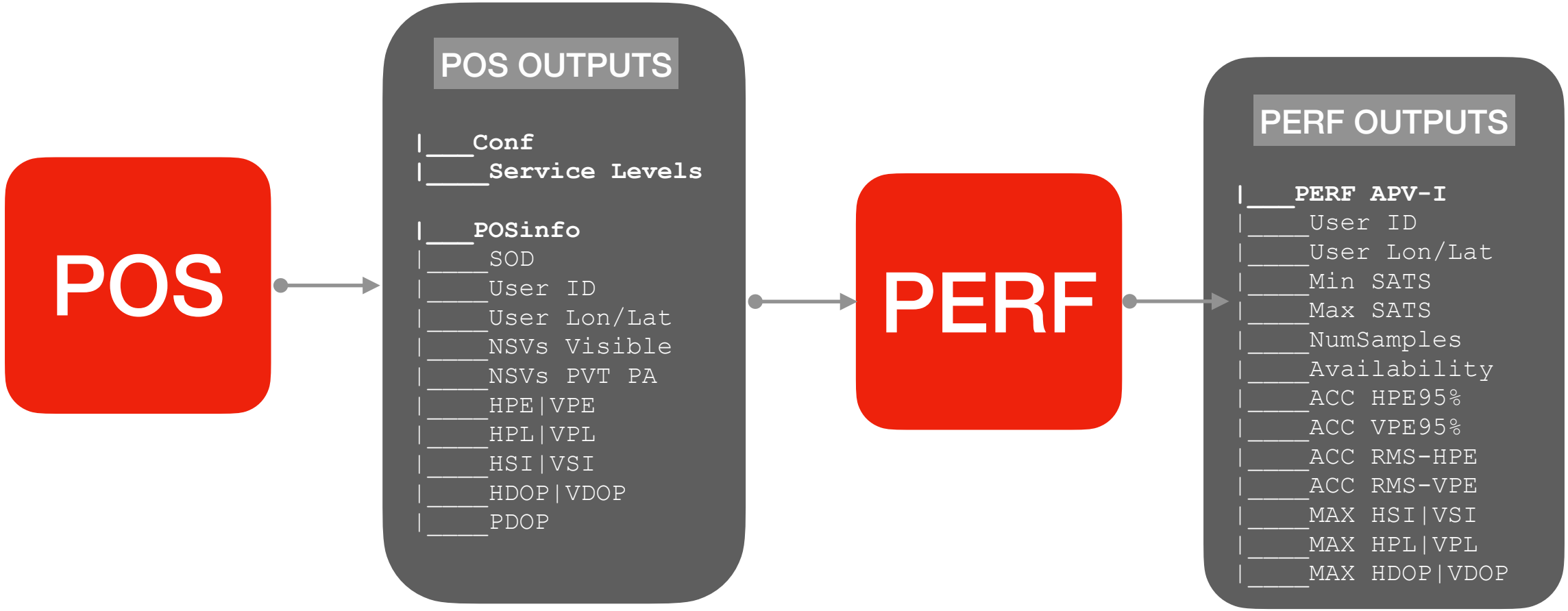
Column	Content	Format	Units	Description
C1	SOD	%7d	SEC	Second of Day
C2	USER ID	%6d	-	User Identifier as a number
C3	ULON	%10.3f	DEG	User Longitude
C4	ULAT	%10.3f	DEG	User Latitude
C5	SOL-FLAG	%7d	-	Solution Flag to indicate if solution is valid or not valid 0: Not Valid 1: Valid for PA
C6	NSVVISBLE	%9d	-	Number of Visible satellites
C7	NSV_{PA}	%10d	-	Number of Satellites used in the PA solution
C8	HPE_{PA}	%10.3f	METER	Horizontal Position Error for PA solution
C9	VPE_{PA}	%10.3f	METER	Vertical Position Error for PA solution
C10	HPL_{PA}	%10.3f	METER	Horizontal Protection Level for PA solution
C11	VPL_{PA}	%10.3f	METER	Vertical Protection Level for PA solution
C12	HSI_{PA}	%10.3f	-	Horizontal Safety Index for PA solution
C13	VSI_{PA}	%10.3f	-	Vertical Safety Index for PA solution
C14	$HDOP_{PA}$	%10.3f	-	Horizontal Dilution Of Precision for PA solution
C15	$VDOP_{PA}$	%10.3f	-	Vertical Dilution Of Precision for PA solution
C16	$PDOP_{PA}$	%10.3f	-	Position Dilution Of Precision for PA solution

WP3.2: USR-PERF

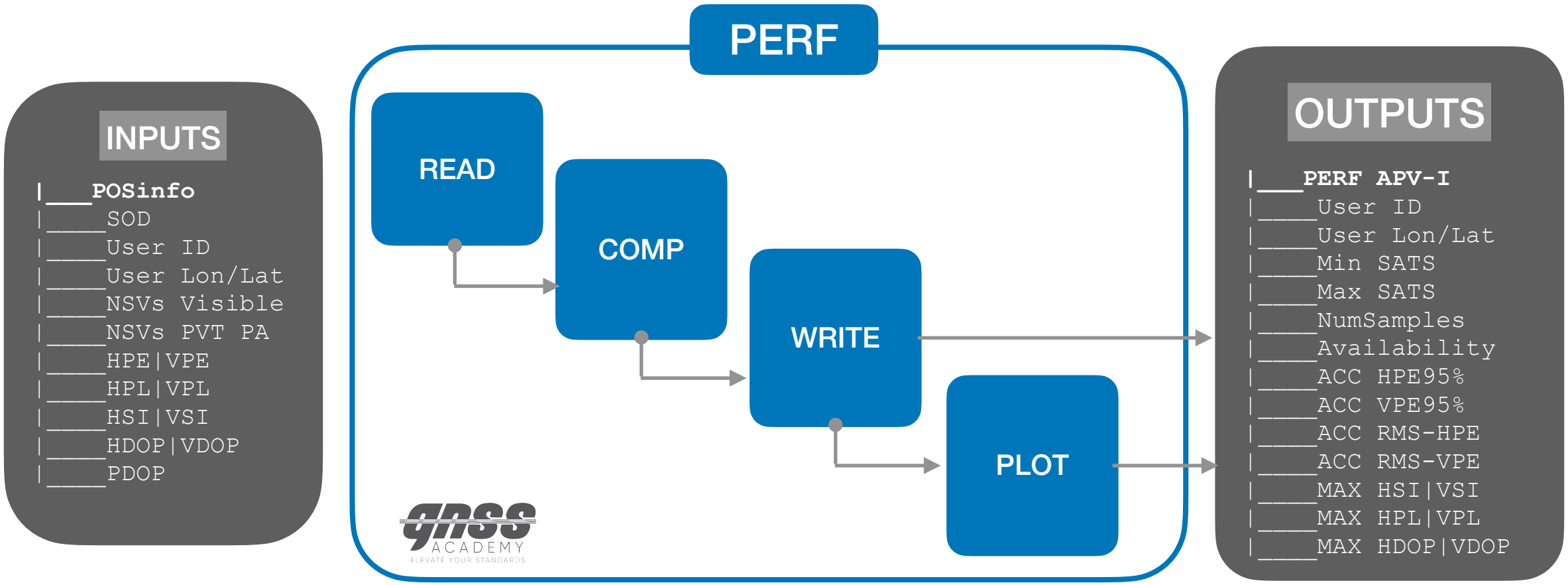
WP3.2: Develop USR-PERF Sub-Module

- **READ** POS_INFO file with instantaneous information
- **COMPUTE** User Service Performances as daily statistics for APV-I Service level:
  - **Availability** APV-I (Req. > 99%) (HAL=40m, VAL=50m)
  - **Accuracy** HPE95%, VPE95% (only avail samps: HPE<16m VPE<20m)
  - **Integrity Risk**: HSI, VSI (req. P(XSI<1)<1E-7/150s)
  - **Continuity Risk** (Req<8E-6/15s) **Not requested**
- **WRITE** a PERF daily file with APV-I Performances per user.
- **PLOT** the daily Service Performance Figures

PERF


POS
POS OUTPUTS
|___Conf
|____Service Levels
|___POSinfo
|____SOD
|____User ID
|____User Lon/Lat
|____NSVs Visible
|____NSVs PVT PA
|____HPE|VPE
|____HPL|VPL
|____HSI|VSI
|____HDOP|VDOP
|____PDOP
PERF
PERF OUTPUTS
|___PERF APV-I
|____User ID
|____User Lon/Lat
|____Min SATS
|____Max SATS
|____NumSamples
|____Availability
|____ACC HPE95%
|____ACC VPE95%
|____ACC RMS-HPE
|____ACC RMS-VPE
|____MAX HSI|VSI
|____MAX HPL|VPL
|____MAX HDOP|VDOP

USR-PERF


INPUTS
|___POSinfo
|____SOD
|____User ID
|____User Lon/Lat
|____NSVs Visible
|____NSVs PVT PA
|____HPE|VPE
|____HPL|VPL
|____HSI|VSI
|____HDOP|VDOP
|____PDOP
PERF
READ
COMP
WRITE
PLOT
gnss ACADEMY ELEVATE YOUR STANDARDS
OUTPUTS
|___PERF APV-I
|____User ID
|____User Lon/Lat
|____Min SATS
|____Max SATS
|____NumSamples
|____Availability
|____ACC HPE95%
|____ACC VPE95%
|____ACC RMS-HPE
|____ACC RMS-VPE
|____MAX HSI|VSI
|____MAX HPL|VPL
|____MAX HDOP|VDOP

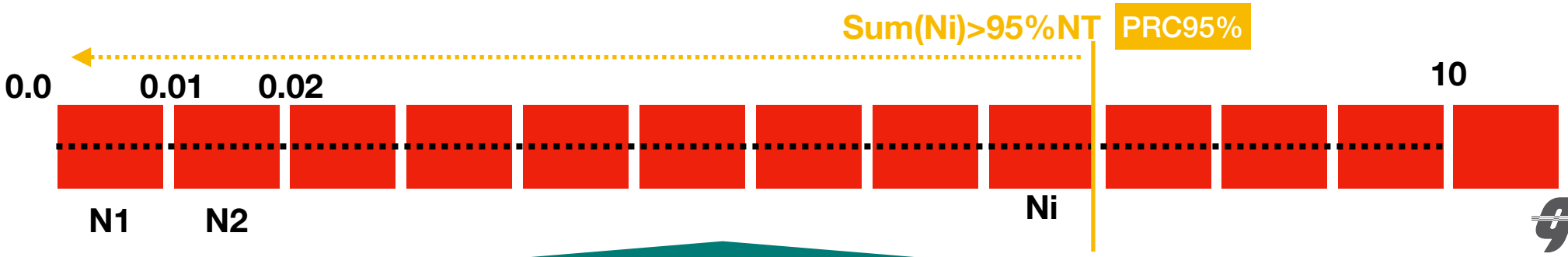
PERF APV-I

FILENAME: PERF_APVI_Y19014_GEO123.dat

Column	Content	Format	Units	Description
C1	USER ID	%d	-	User ID as a number
C2	ULON	%f	DEG	User Longitude
C3	ULAT	%f	DEG	User Latitude
C4	SOLSAMP	%d	-	Total Number of samples with Solution
C5	NSVMIN	%d	-	Minimum number satellites used in
C6	NSVMAX	%d	-	Maximum number satellites used in
C7	SAMPAVAIL	%d	-	Total Number of available samples
C8	AVAILABILITY	%f	-	Availability of integrity APV-I as the
C9	HPERMS	%f	METER	RMS of the Horizontal Position Error
C10	VPERMS	%f	METER	RMS of the Vertical Position Error
C11	HPE95%	%f	METER	95th-Percentile of the Horizontal
C12	VPE95%	%f	METER	95th-Percentile of the Vertical
C13	HPEMAX	%f	METER	Maximum reached Horizontal Position
C14	VPEMAX	%f	METER	Maximum reached Vertical Position Error
C15	HSIMAX	%f	-	Maximum reached Horizontal Safety Index
C16	VSIMAX	%f	-	Maximum reached Vertical Safety Index
C17	HPLMAX	%f	METER	Maximum reached Horizontal Protection
C18	VPLMAX	%f	METER	Maximum reached Vertical Protection
C19	HPLMIN	%f	METER	Maximum reached Horizontal Protection
C20	VPLMIN	%f	METER	Maximum reached Vertical Protection
C21	HDOPMAX	%f	-	Maximum reached Horizontal DOP
C22	VDOPMAX	%f	-	Maximum reached Vertical DOP
C23	PDOPMAX	%f	-	Maximum reached Position DOP

How to Compute PERCENTILE 95%

1. Fix a bin resolution step for the Percentile computation (e.g: 0.001)
2. Count the number of samples in each statistical bin (Ni)
3. Count the total number of samples
4. Compute the cumulated probability associated to each bin. (number of cumulated samples divided by the total number of samples)
5. Keep the bin where the probability is higher than 0.95



PERFORMANCES for PA APV-I

Civil Aviation Requirements

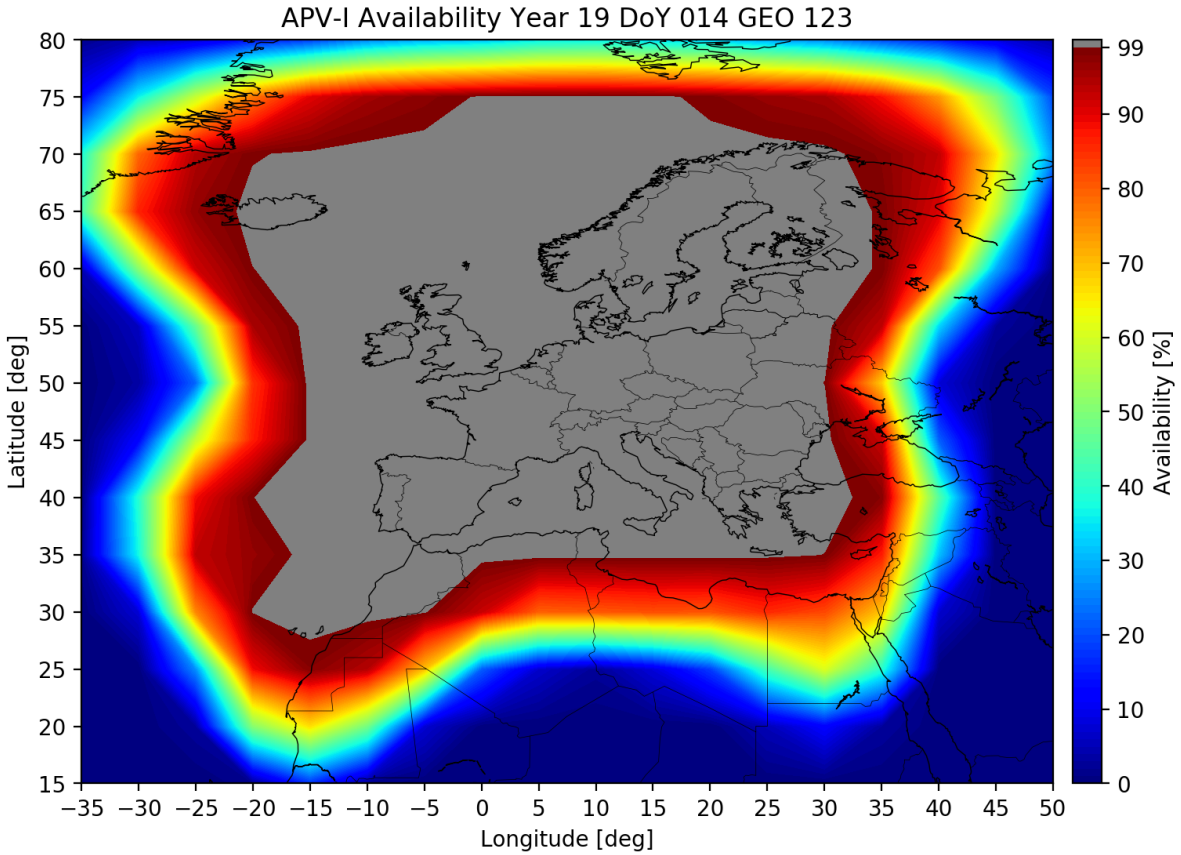
GNSS Signal - In - Space performance requirements (S.A.R.P.S Annex 10, Vol 1)

Typical operation	HORIZONTAL		VERTICAL		Integrity risk	Time To Alert (TTA)	Continuity	Availability
	HNSE Accuracy (@ 95%)	HAL Horizontal Alert limit	VNSE Accuracy (@ 95%)	VAL Vertical Alert limit				
En-route (oceanic/continental low density)	3.7 km (2 NM)	7.4 km (4 NM)	N/A	N/A	1 – 1 × 10–7/h	5 min	1 – 1 × 10–4/h to 1 – 1 × 10–8/h	0,99 to 0,9999
En-route (continental)	3.7 km (2 NM)	3.7 km (2 NM)	N/A	N/A	1 – 1 × 10–7/h	5 min	1 – 1 × 10–4/h to 1 – 1 × 10–8/h	0,99 to 0,9999
En-route, Terminal	0.74 km (0.4 NM)	1.85 km (1 NM)	N/A	N/A	1 – 1 × 10–7/h	15 s	1 – 1 × 10–4/h to 1 – 1 × 10–8/h	0,99 to 0,9999
Initial approach, Intermediate approach, Non-precision approach (NPA), Departure	220 m (720 ft)	556 m (0.3 NM)	N/A	N/A	1 – 1 × 10–7/h	10 s	1 – 1 × 10–4/h to 1 – 1 × 10–8/h	0,99 to 0,9999
EGNOS service Level 2 (SL 2)	*100m*	556 m (0.3 NM)	N/A	N/A	1 – 1 × 10–7/h	8 s	1 – 1 × 10–5/h	*0,999*
Approach operations with vertical guidance (APV-I)	16.0 m (52 ft)	40 m (130 ft)	20 m (66 ft)	50 m (164 ft)	1 – 2 × 10–7 per approach	10 s	1 – 8 × 10–6 in any 15 s	0,99 to 0,9999
EGNOS service Level 3A (SL3A/APV-I)	*16.0 m (52 ft)*	*40 m (130 ft)*	*20 m (66 ft)*	*50 m (164 ft)*	*1 – 2 × 10–7 per approach (150s)*	6 s	*1 – 8 × 10–6 in any 15 s*	*0.99*
EGNOS service Level 3A (SL3A/Open Service)	*3 m*	*40 m (130 ft)*	*4 m*	*50 m (164 ft)*	*1 – 2 × 10–7 per approach (150s)*	6 s	*1 – 8 × 10–6 in any 15 s*	*0.99*
LPV 200	16.0 m (52 ft)	40 m (130 ft)	4.0 m	35 m	xx	xx	xx	xx
APV- II	16.0 m (52 ft)	40 m (130 ft)	8.0 m (26 ft)	20.0 m (66 ft)	1 – 2 × 10–7 per approach	6 s	1 – 8 × 10–6 in any 15 s	0,99 to 0,9999
Category I precision approach (CAT 1)	16.0 m (52 ft)	40 m (130 ft)	6.0 m to 4.0 m (20 ft to 13 ft)	15.0 m to 10.0 m (50 ft to 33 ft)	1 – 2 × 10–7 per approach	6 s	1 – 8 × 10–6 in any 15 s	0,99 to 0,9999

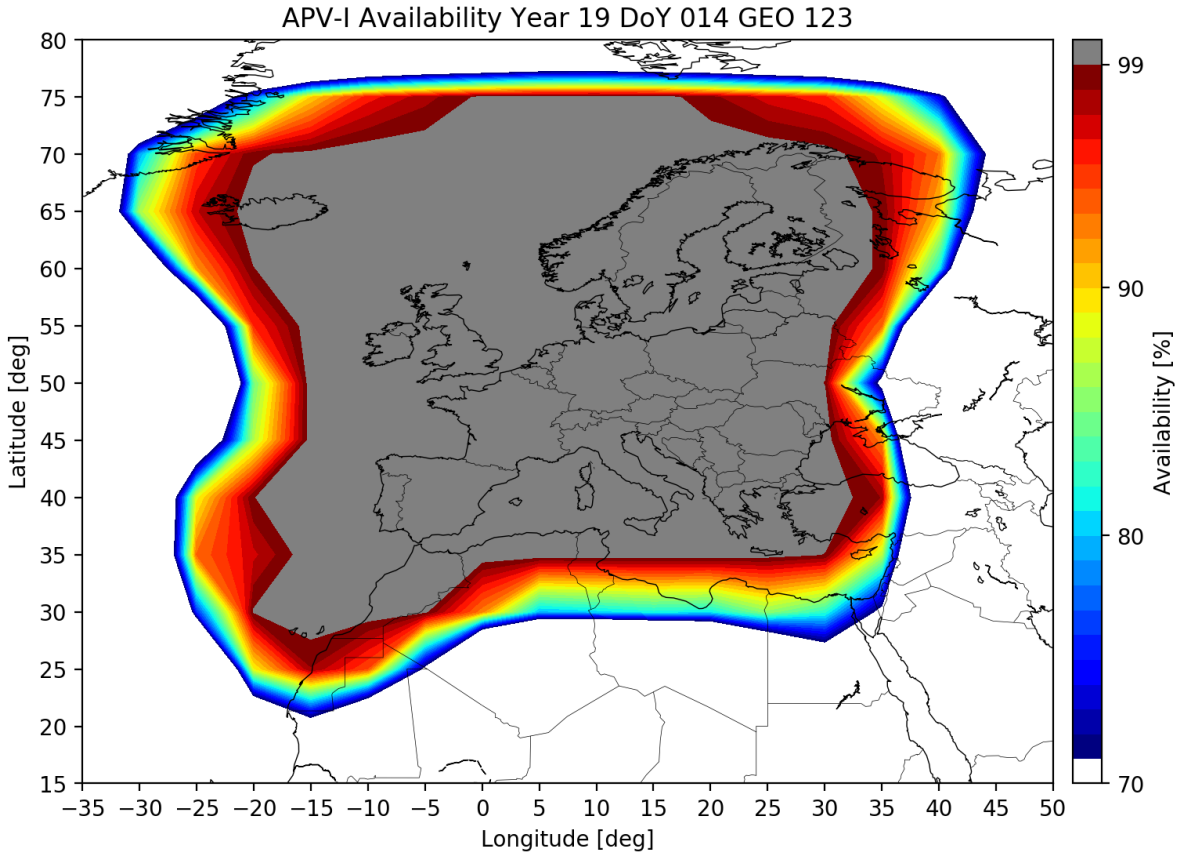
APV-I

AVAILABILITY

0-100%



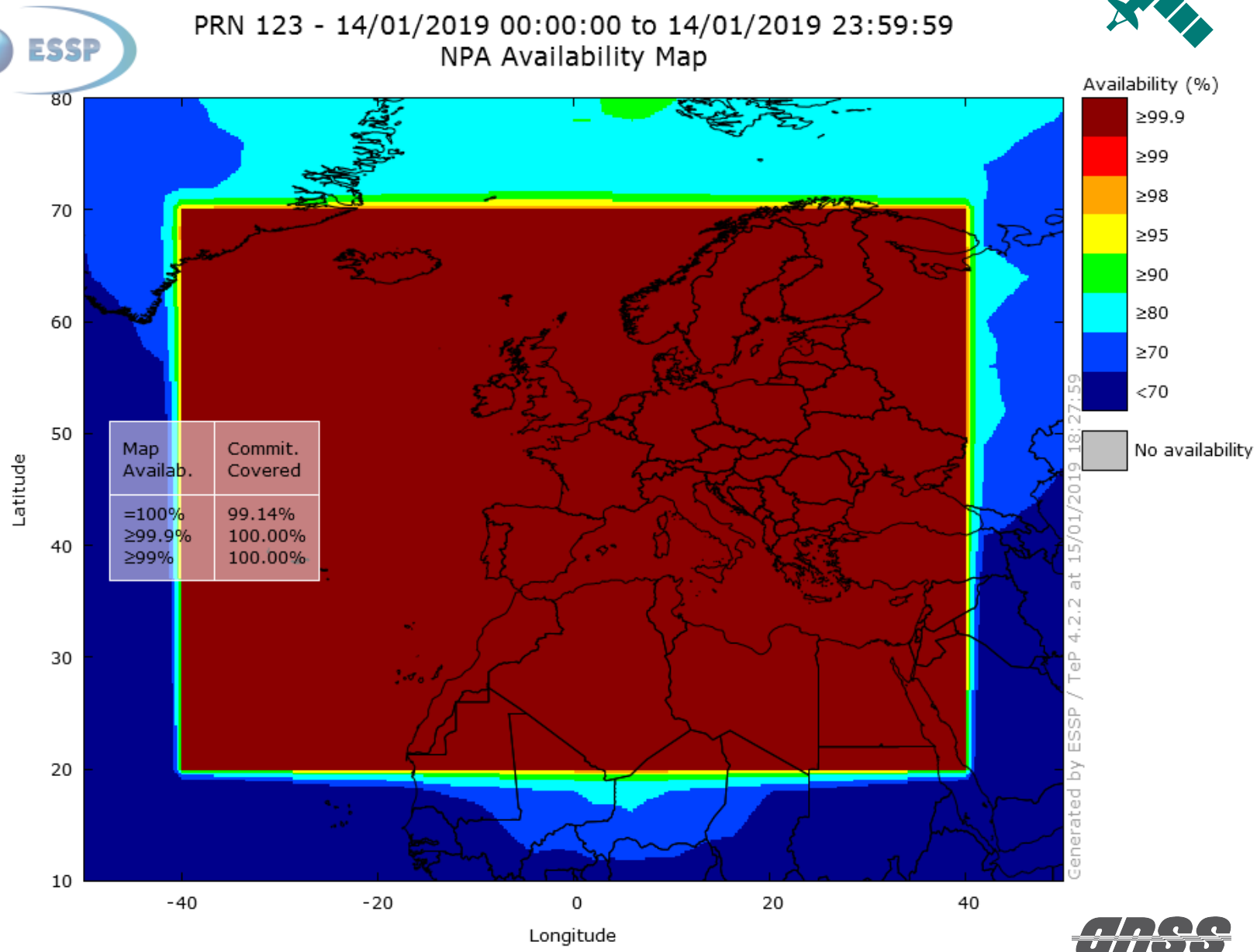
70-99%



AVAILABILITY

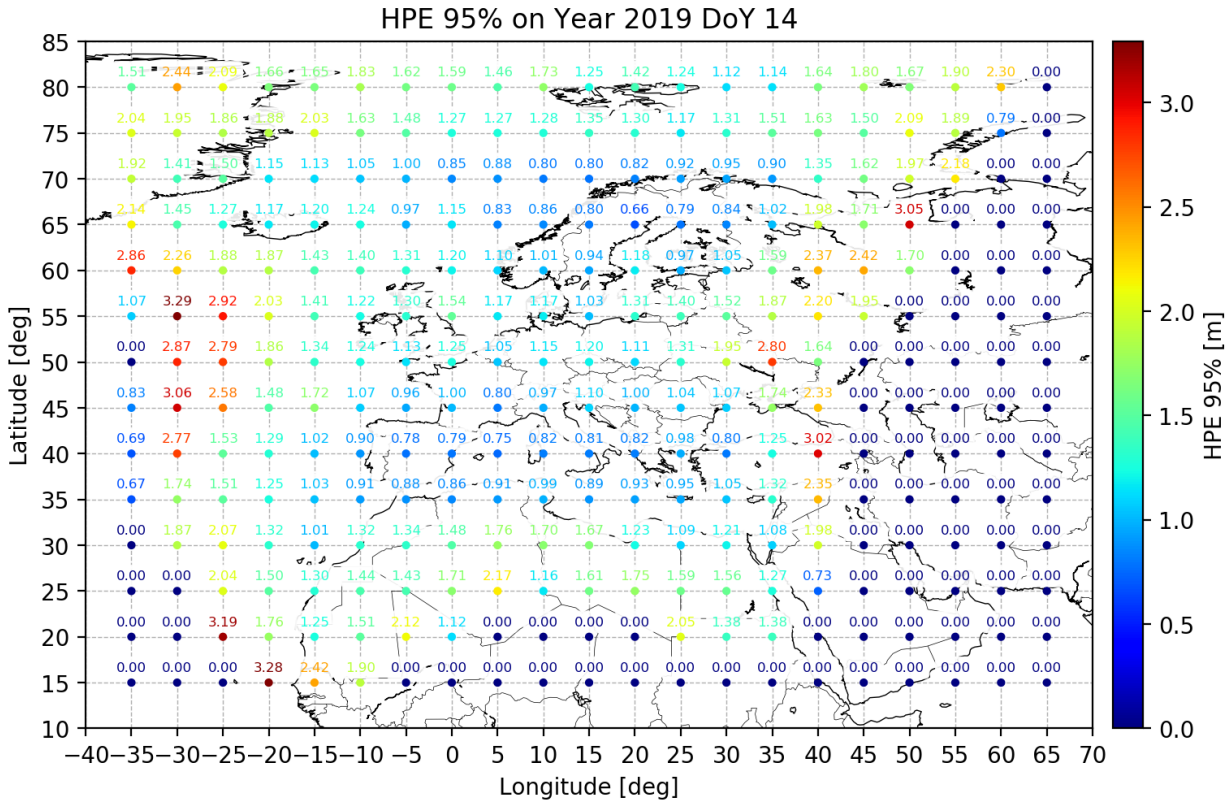
NPA

HAL=556m
VAL=N/A

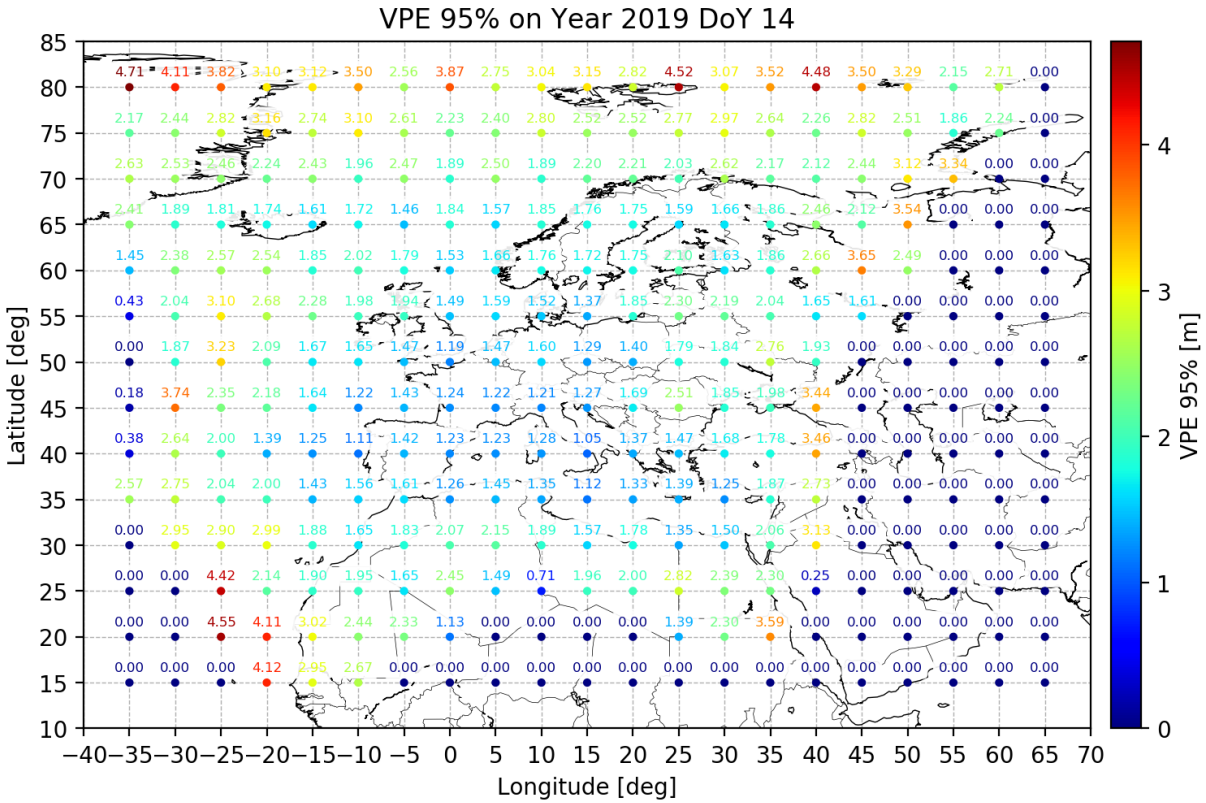


ACCURACY

HPE95%



VPE95%

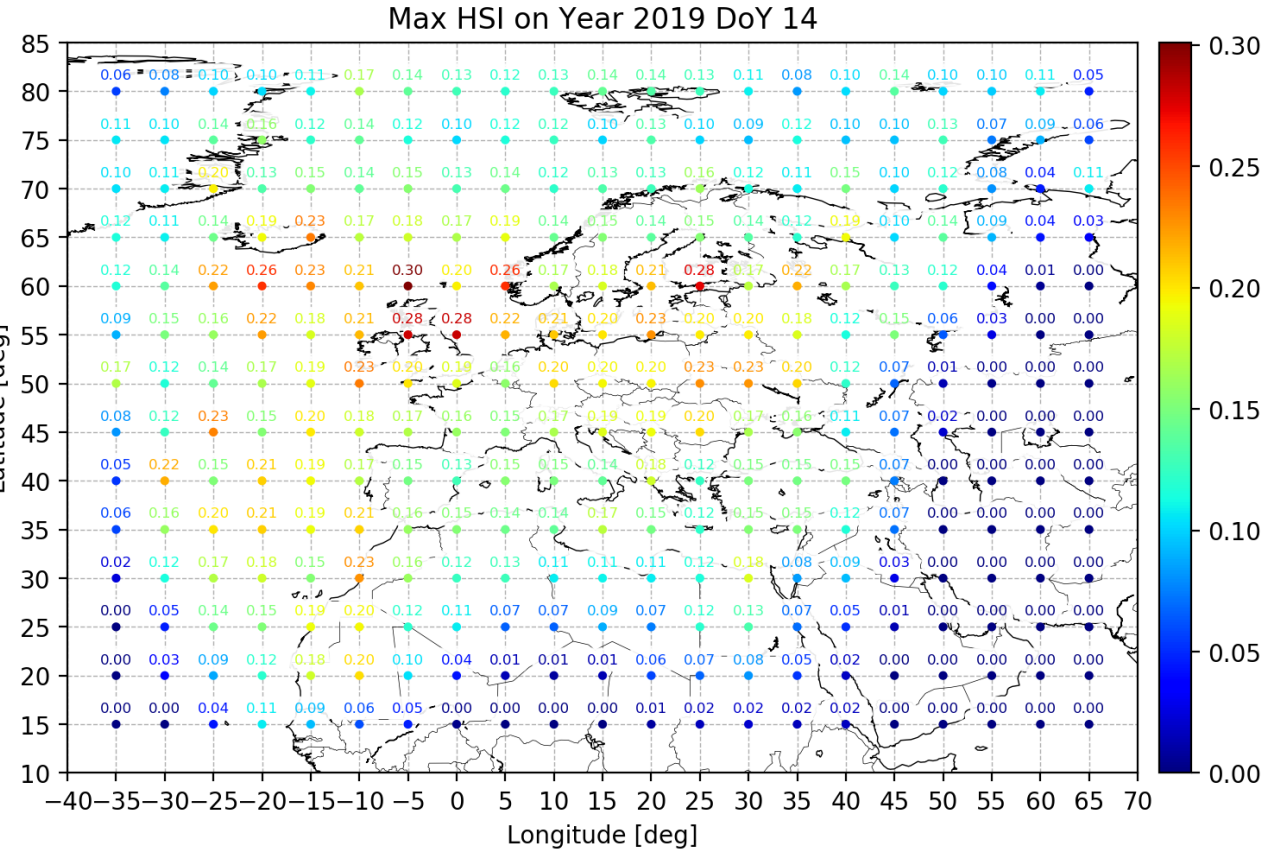


INTEGRITY

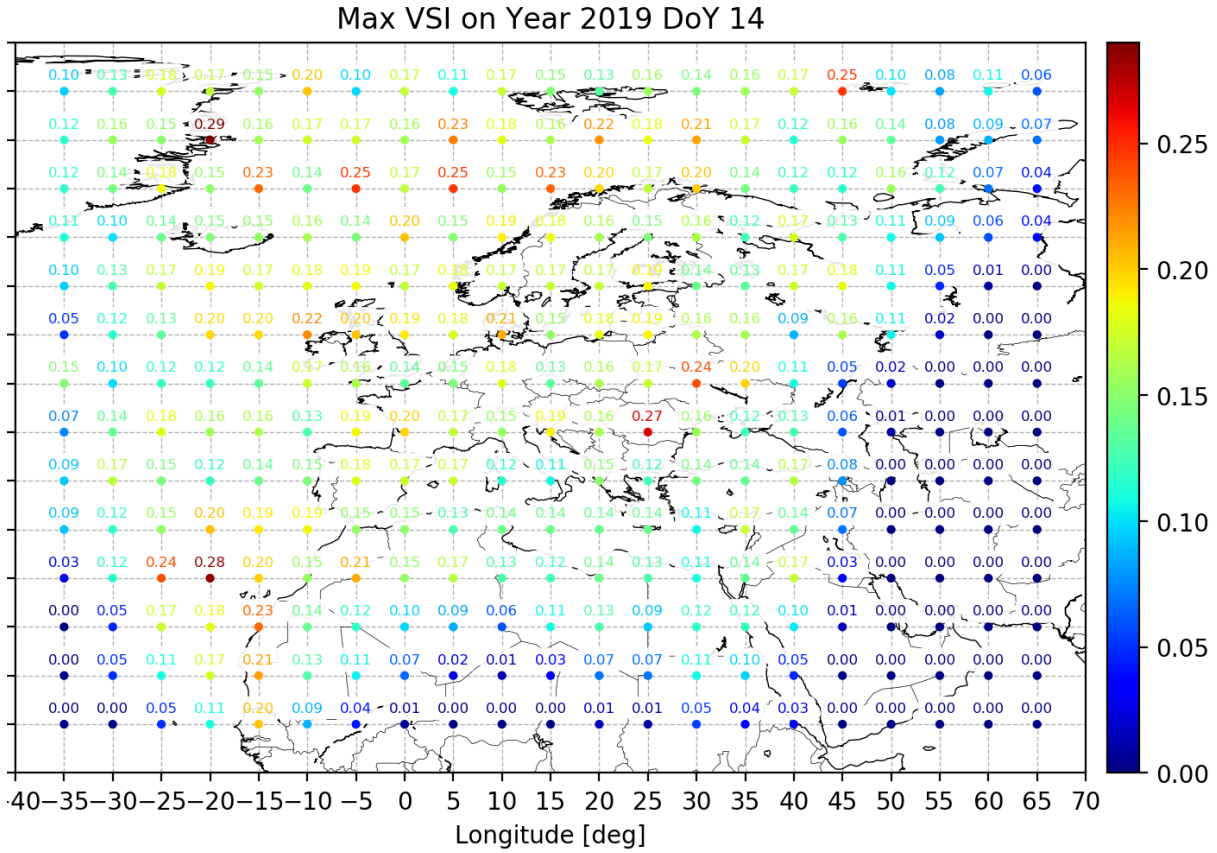
XSI=XPE/XPL

REQ. P(XSI>1)<1E-7/150s

MAX HSI

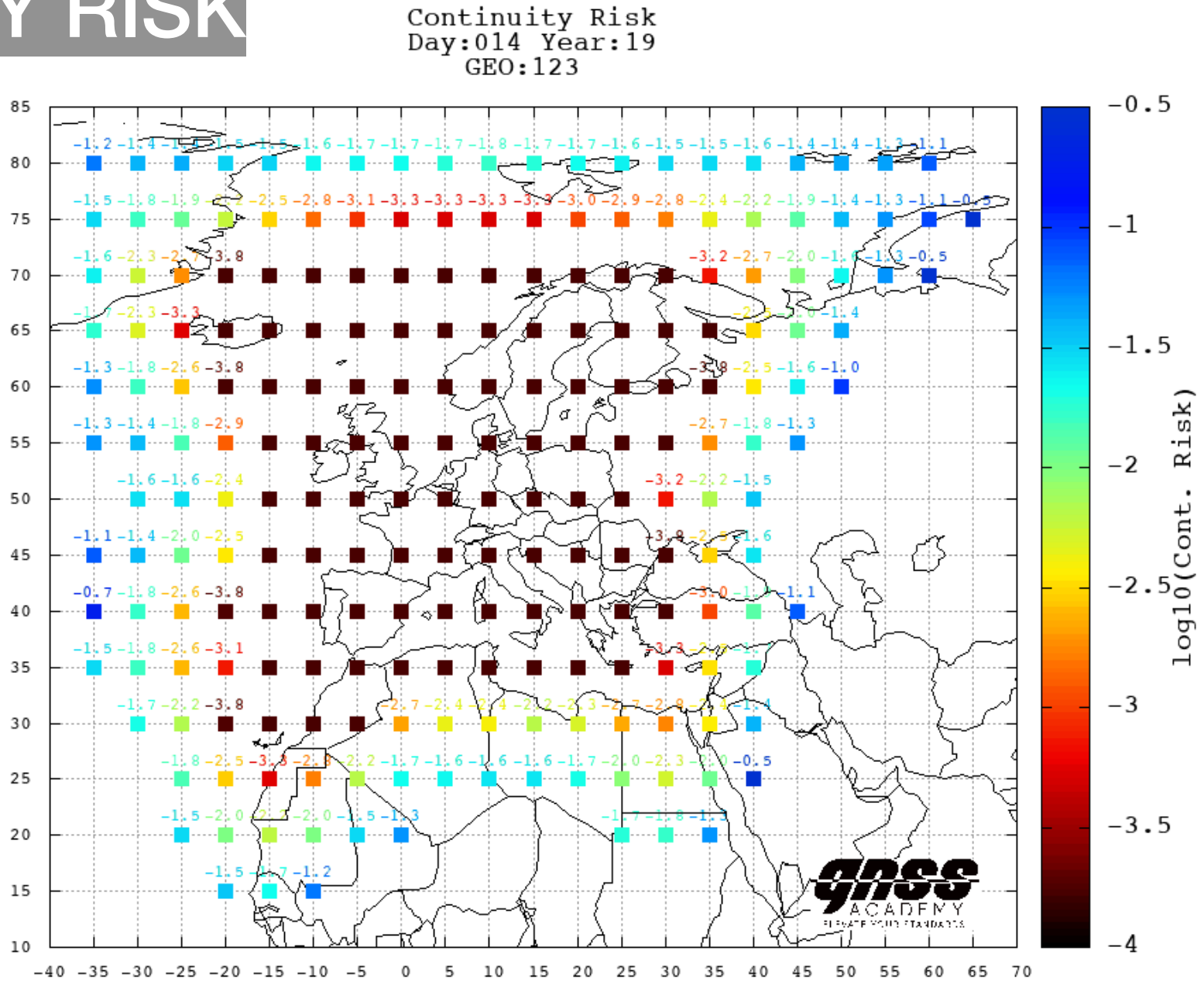


MAX VSI



CONTINUITY RISK

REQ. CR<8E-6 ECAC LandMasses



SEE WORK-PACKAGE DESCRIPTION:

SERVUS-WP3-USR-POS-PERF_Module.pdf


End