WP3 Report - Esteban Martinez

GitHub Repository: GitHub - Minimal88/JSNP7.0 at WP3

Code and Outputs: SERVUS-WP3.rar

Introduction

The main goal of this Work-Package 3 is to implement the POS and PERF Module of SERVUS using an output file information from the LOS module with all the necessary user-satellite Line-Of-Sight information to compute the user XPE and XPL as well as the service performances in terms of availability, integrity, and accuracy across the service volume.

SERVUS is a branch of the SBPT Tool Suite. SERVUS tool provides the following Service Performance over a given service volume over the EGNOS Service Area (ECAC):

- **Accuracy:** Maps represented by the XPE95% (HPE95%, VPE95%)
- **Availability:** Maps represented by the Percentage of time HPL<HAL & VPL<VAL
- **Integrity:** Risk is the probability of Misleading information or Safety Indices HSI=HPE/HPL, VSI=VPE/VPL greater than 1.
- **Continuity Risk:** Maps represented by the Probability to have transitions of PL>AL in seconds sliding windows

The computation of the position errors (XPE) and protection levels (XPL) requires the projection of the range errors and associated sigma bounds through the LSE transference function range-to-position based on the Geometry Matrices in the following way:

1. The Position Errors are estimated from the projection of the range errors through the LSE transfer matrix as follows:
$$[XPE] = ([G]^T[W][G])^{-1}[G]\ [W]\ \{RNGE_{ERROR}\}$$
2. The Protection Levels are obtained from the Covariance Matrices of the LSQ process:

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

$$HPL = K_H\ d_{MAJOR}$$
$$VPL = K_V\ d_{UP}$$

Where:

- [G] is the Geometry Matrix,
- [W] Weighting Matrix composed of the inverse sigmas of the range errors [1/SigmaUERE2]
- $\{RNGE_{ERROR}\}$ is the range error vector.
- KF is the Gaussian factor to reach HPL and VPL to the required confidence levels

$$RangeError = SREU + UISDE + TropoE + AirE$$

$$SigmaUERE^2 = SigmaFLT^2 + SigmaUIRE^2 + SigmaTropo^2 + SigmaAIR^2$$

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

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

 # Horizontal Protection level→ HPL= $K_{HPA}\ d_{MAJOR}$ (K_{HPA}=6.0)
 # Vertical Protection level→ VPL= $K_V\ d_U$ (K_V=5.33)

APV-I → (HPL<HAL and VPL<VAL)

T1 - Implementation

The approach for the implementation is the following:

1. Read the LOS file epoch by epoch.
2. On each EPOCH, Loop over all the users and choose samples with:
   a. Elevation angle > 5 degrees
   b. Flag = 1
3. For each user on the EPOCH, do the following:
   a. Count the number of samples with Flag = 1 (NVSPA)
   b. Compute the Ranging Error
   c. Compute the SigmaUERE2
   d. If (NVAPA > = 4), then:
      i. Build the G matrix
      ii. Compute the PDOP, HDOP, and VDOP
   e. IF PDOP <= 10000, then compute:
      i. Build the W matrix
      ii. Compute XPE, XPL, and XSI.
4. At the end of each EPOCH, do the following::
   a. Write the results into the POS file
   b. Compute the intermediate user Performances
5. At the end of reading the LOS file, do the following::
   a. Compute the final user Performances
   b. Write the results into the PERF file

Example of Execution

```
/home/astro/git/JNSP7.0/src/SBPT/SERVUS/USR/UsrPerformances.py /home/astro/git/JNSP7.0/src/SBPT/SERVUS/USR/SCN/EGNOS-SIS-GEO123-JAN19
------------------------------------
--> RUNNING USR-PERFORMANCE ANALYSIS:
------------------------------------

*** Processing Day of Year:  14 ...***
1. Processing file:  /home/astro/git/JNSP7.0/src/SBPT/SERVUS/USR/SCN/EGNOS-SIS-GEO123-JAN19/OUT/USR/LOS/LOS_INFO_Y19D014_G123_150s.dat
2. User POS file created: /home/astro/git/JNSP7.0/src/SBPT/SERVUS/USR/SCN/EGNOS-SIS-GEO123-JAN19/OUT/USR/POS/POS_INFO_Y19D014_G123_150s.dat
3. User PERF file created: /home/astro/git/JNSP7.0/src/SBPT/SERVUS/USR/SCN/EGNOS-SIS-GEO123-JAN19/OUT/USR/PERF/PERF_APVI_Y19D014_G123_150s.dat
4. Generating User Performance Figures...

Ploting: APV-I Availability 0-100% Y19D014 G123 50s
 -> /home/astro/git/JNSP7.0/src/SBPT/SERVUS/USR/SCN/EGNOS-SIS-GEO123-JAN19/OUT/USR/FIGURES/USR_PERF_MAP_APV-I_AVAILABILITY_0_100_Y19D014_G123_50s.png
Ploting: APV-I Availability 70-99% Y19D014 G123 50s
 -> /home/astro/git/JNSP7.0/src/SBPT/SERVUS/USR/SCN/EGNOS-SIS-GEO123-JAN19/OUT/USR/FIGURES/USR_PERF_MAP_APV-I_AVAILABILITY_70_99_Y19D014_G123_50s.png
Ploting: APV-I Availability 0-100% No Interpolation Y19D014 G123 50s
 -> /home/astro/git/JNSP7.0/src/SBPT/SERVUS/USR/SCN/EGNOS-SIS-GEO123-JAN19/OUT/USR/FIGURES/USR_PERF_MAP_APV-I_AVAILABILITY_0_100_NoInterpolation_Y19D014_G123_50s.png
Ploting: HPE 95% Y19D014 G123 50s
 -> /home/astro/git/JNSP7.0/src/SBPT/SERVUS/USR/SCN/EGNOS-SIS-GEO123-JAN19/OUT/USR/FIGURES/USR_PERF_MAP_APV-I_HPE_95_Y19D014_G123_50s.png
Ploting: VPE 95% Y19D014 G123 50s
 -> /home/astro/git/JNSP7.0/src/SBPT/SERVUS/USR/SCN/EGNOS-SIS-GEO123-JAN19/OUT/USR/FIGURES/USR_PERF_MAP_APV-I_VPE_95_Y19D014_G123_50s.png
Ploting: RMS HPE Y19D014 G123 50s
 -> /home/astro/git/JNSP7.0/src/SBPT/SERVUS/USR/SCN/EGNOS-SIS-GEO123-JAN19/OUT/USR/FIGURES/USR_PERF_MAP_APV-I_RMS_HPE_Y19D014_G123_50s.png
Ploting: RMS VPE Y19D014 G123 50s
 -> /home/astro/git/JNSP7.0/src/SBPT/SERVUS/USR/SCN/EGNOS-SIS-GEO123-JAN19/OUT/USR/FIGURES/USR_PERF_MAP_APV-I_RMS_VPE_Y19D014_G123_50s.png
Ploting: MAX HSI Y19D014 G123 50s
 -> /home/astro/git/JNSP7.0/src/SBPT/SERVUS/USR/SCN/EGNOS-SIS-GEO123-JAN19/OUT/USR/FIGURES/USR_PERF_MAP_HSI_MAX_Y19D014_G123_50s.png
Ploting: MAX VSI Y19D014 G123 50s
 -> /home/astro/git/JNSP7.0/src/SBPT/SERVUS/USR/SCN/EGNOS-SIS-GEO123-JAN19/OUT/USR/FIGURES/USR_PERF_MAP_VSI_MAX_Y19D014_G123_50s.png
Ploting: MAX Number of Satellites on Y19D014 G123 50s
 -> /home/astro/git/JNSP7.0/src/SBPT/SERVUS/USR/SCN/EGNOS-SIS-GEO123-JAN19/OUT/USR/FIGURES/USR_PERF_MAP_NSV_MAX_Y19D014_G123_50s.png
Ploting: MIN Number of Satellites on Y19D014 G123 50s
 -> /home/astro/git/JNSP7.0/src/SBPT/SERVUS/USR/SCN/EGNOS-SIS-GEO123-JAN19/OUT/USR/FIGURES/USR_PERF_MAP_NSV_MIN_Y19D014_G123_50s.png
Ploting: MAX HPL Y19D014 G123 50s
```

```
 -> /home/astro/git/JNSP7.0/src/SBPT/SERVUS/USR/SCN/EGNOS-SIS-GEO123-JAN19/OUT/USR/FIGURES/USR_PERF_MAP_HPL_MAX_Y19D014_G123_50s.png
Ploting: MIN HPL Y19D014 G123 50s
 -> /home/astro/git/JNSP7.0/src/SBPT/SERVUS/USR/SCN/EGNOS-SIS-GEO123-JAN19/OUT/USR/FIGURES/USR_PERF_MAP_HPL_MIN_Y19D014_G123_50s.png
Ploting: MAX VPL Y19D014 G123 50s
 -> /home/astro/git/JNSP7.0/src/SBPT/SERVUS/USR/SCN/EGNOS-SIS-GEO123-JAN19/OUT/USR/FIGURES/USR_PERF_MAP_VPL_MAX_Y19D014_G123_50s.png
Ploting: MIN VPL Y19D014 G123 50s
 -> /home/astro/git/JNSP7.0/src/SBPT/SERVUS/USR/SCN/EGNOS-SIS-GEO123-JAN19/OUT/USR/FIGURES/USR_PERF_MAP_VPL_MIN_Y19D014_G123_50s.png
Ploting: MAX HDOP Y19D014 G123 50s
 -> /home/astro/git/JNSP7.0/src/SBPT/SERVUS/USR/SCN/EGNOS-SIS-GEO123-JAN19/OUT/USR/FIGURES/USR_PERF_MAP_HDOP_MAX_Y19D014_G123_50s.png
Ploting: MAX VDOP Y19D014 G123 50s
 -> /home/astro/git/JNSP7.0/src/SBPT/SERVUS/USR/SCN/EGNOS-SIS-GEO123-JAN19/OUT/USR/FIGURES/USR_PERF_MAP_VDOP_MAX_Y19D014_G123_50s.png
Ploting: MAX PDOP Y19D014 G123 50s
 -> /home/astro/git/JNSP7.0/src/SBPT/SERVUS/USR/SCN/EGNOS-SIS-GEO123-JAN19/OUT/USR/FIGURES/USR_PERF_MAP_PDOP_MAX_Y19D014_G123_50s.png
```

T2- POS File

The `POS_INFO_Y19D014_G123_150s.dat` is created by reading and processing epoch by epoch of the `LOS_INFO_Y19D014_G123_150s.dat` file. The following table describes each of the columns of the POS file:

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 Line-Of-Sight 1: Valid for PA and NPA 2: Valid only for NPA
C6	NSV_{VISBLE}	%9d	-	Number of Visible satellites (>5 DEG)
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

T3- PERF File

The `PERF_APVI_Y19D014_G123_150s.dat` is created by reading and processing epoch by epoch of the `LOS_INFO_Y19D014_G123_150s.dat` file. The following table describes each of the columns of the PERF file:

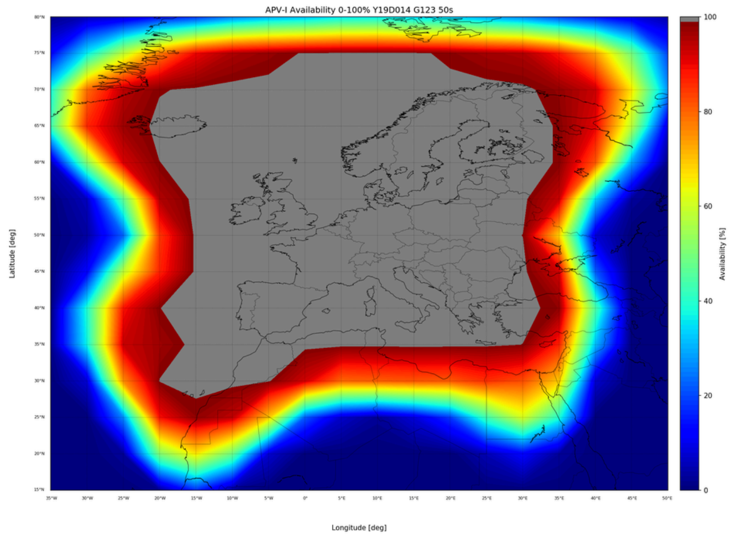
Column	Content	Format	Units	Description
C1	USER ID	%d	-	User ID as a number
C2	ULON	%f	DEG	User Longitude
C3	ULAT	%f	DEG	User Latitude
C4	TOTALSAMP	%d	-	Total Number of samples with Solution (NSVs>4 & PDOP<PDOPmax)
C5	NSVMIN	%d	-	Minimum number satellites used in solution (NSVs>4 & PDOP<PDOPmax)
C6	NSVMAX	%d	-	Maximum number satellites used in Solution (NSVs>4 & PDOP<PDOPmax)
C7	SAMPAVAIL	%d	-	Total Number of available samples (Samples with HPL<HAL and VPL<VAL) APV-I: HAL=40m and VAL=50m
C8	AVAILABILITY	%f	-	Availability of integrity APV-I as the Percentage of time HPL<HAL and VPL<VAL Ratio between the Number of Available Samples and the total samples in the day.
C9	HPERMS	%f	METER	RMS of the Horizontal Position Error (HPE) in APV-I (HPL<HAL and VPL<VAL)
C10	VPERMS	%f	METER	RMS of the Vertical Position Error (VPE) in APV-I(HPL<HAL and VPL<VAL)
C11	HPE95%	%f	METER	95th-Percentile of the Horizontal Position Error in APV-I (HPL<HAL and VPL<VAL)
C12	VPE95%	%f	METER	95th-Percentile of the Vertical Position Error in APV-I (HPL<HAL and VPL<VAL)
C13	HPEMAX	%f	METER	Maximum reached Horizontal Position Error in APV-I (HPL<HAL and VPL<VAL)
C14	VPEMAX	%f	METER	Maximum reached Vertical Position Error in APV-I (HPL<HAL and VPL<VAL)
C15	HSIMAX	%f	-	Maximum reached Horizontal Safety Index (HSI=HPE/HPL) **Not Service level dependent, all samples shall be considered, not only those available APV-I**
C16	VSIMAX	%f	-	Maximum reached Vertical Safety Index (VSI=VPE/VPL) **Not Service level dependent, all samples shall be considered, not only those available APV-I**
C17	HPLMAX	%f	METER	Maximum reached Horizontal Protection Level for APV-I Service level (HPL<HAL and VPL<VAL)
C18	VPLMAX	%f	METER	Maximum reached Vertical Protection Level for APV-I Service level (HPL<HAL and VPL<VAL)
C19	HPLMIN	%f	METER	Minimum reached Horizontal Protection Level or APV-I Service level (HPL<HAL and VPL<VAL)
C20	VPLMIN	%f	METER	Minimum reached Vertical Protection Level or APV-I Service level (HPL<HAL and VPL<VAL)
C21	HDOPMAX	%f	-	Maximum reached Horizontal DOP or APV-I Service level (HPL<HAL and VPL<VAL)
C22	VDOPMAX	%f	-	Maximum reached Vertical DOP for APV-I Service level (HPL<HAL and VPL<VAL)
C23	PDOPMAX	%f	-	Maximum reached Position DOP for APV-I Service level (HPL<HAL and VPL<VAL)

T4 - MAPs PERF Plots

AVAILABILITY APV-1. 0-100%

Map of APV-I Availability with interpolation. Only values from 0 to 100% of availability.

This chart was implemented using the interpolation techniques from Matplot lib [`contourf()`], with NLevles = 100 for smoother transitions. Also, the color mapping was modified to show the availability equal to 100% with gray color. As expected the area around Europe is all gray, and the availability decreases in the areas farther from the center of Europe.



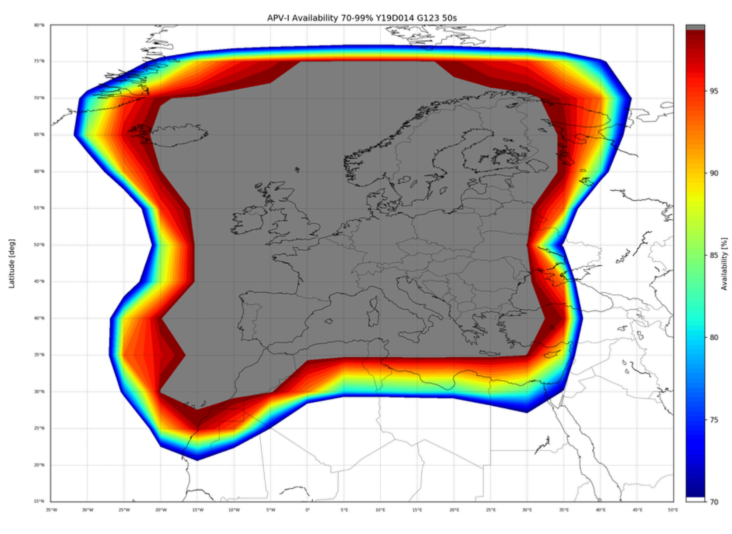
USR_PERF_MAP_APV-I_AVAILABILITY_0_100_Y19D014_G123_50s.png

AVAILABILITY APV-I. 70-99%

Map of APV-I Availability with interpolation. Only values from 70 to 99% of availability.

This chart was implemented with the same interpolation techniques and values. The differences from the previous chart are:

1. The limits go from 70% to 99%.
2. The color mapping is now white for all values lower than 70%.

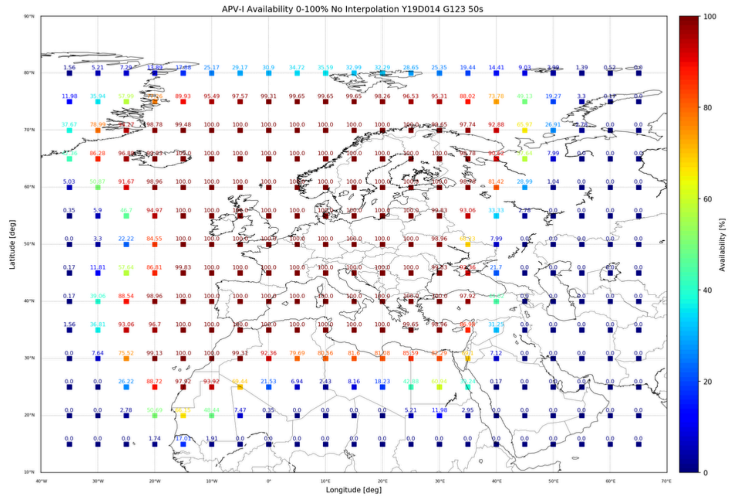


USR_PERF_MAP_APV-I_AVAILABILITY_70_99_Y19D014_G123_50s.png

AVAILABILITY APV-I. No Interpolation

Map of APV-I Availability without interpolation. Only values from 0 to 100% of availability.

This chart represents the original values obtained directly from the PERF file. The availability is computed as the number of valid samples divided by the number of total samples. As expected, it matches with the previous two charts, where 100% availability is reached in the areas around the center of Europe.

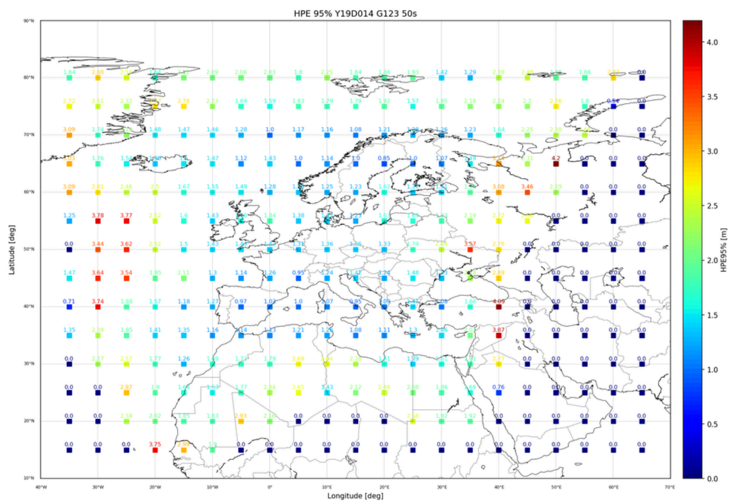


USR_PERF_MAP_APV-I_AVAILABILITY_0_100_NoInterpolation_Y19D014_G123_50s.png

APV-I HPE95%

Map of APV-I Horizontal Position Accuracy (HPE) at 95%.

The values of this chart were computed using the NumPy function called `np.percentile` using as parameters the total HPE values for each user and the 95, which represents the 95th percentile of the HPE.

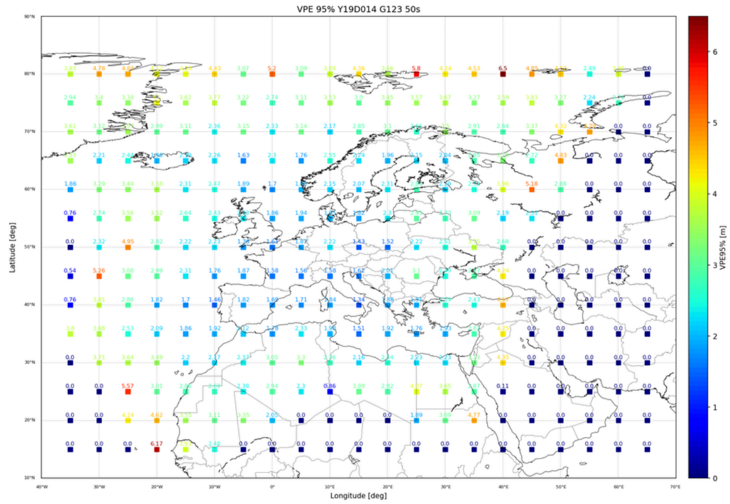


USR_PERF_MAP_APV-I_HPE_95_Y19D014_G123_50s.png

APV-I VPE95%

Map of APV-I Vertical Position Accuracy (VPE) at 95%.

The values of this chart were computed using the NumPy function called `np.percentile` using as parameters the total VPE values for each user and the 95, which represents the 95th percentile of the VPE.

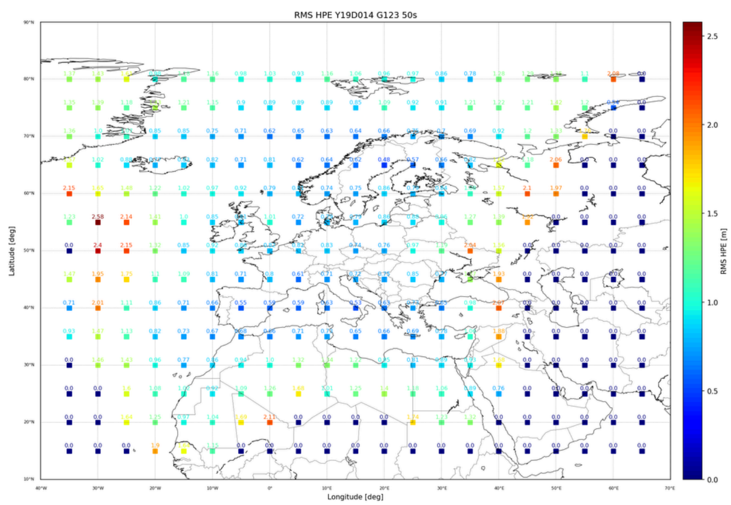


USR_PERF_MAP_APV-I_VPE_95_Y19D014_G123_50s.png

APV-I RMS HPE

Map of RMS APV-I Horizontal Position Accuracy.

The values of this chart were generated by simply computing the Root Mean Square of all the HPE values for each user. As expected the areas at the center of Europe have better accuracy than the areas at the outer borders of Europe. The farther areas with values of 0.0 don't represent a better accuracy. This means there were not enough samples to compute the HPE.

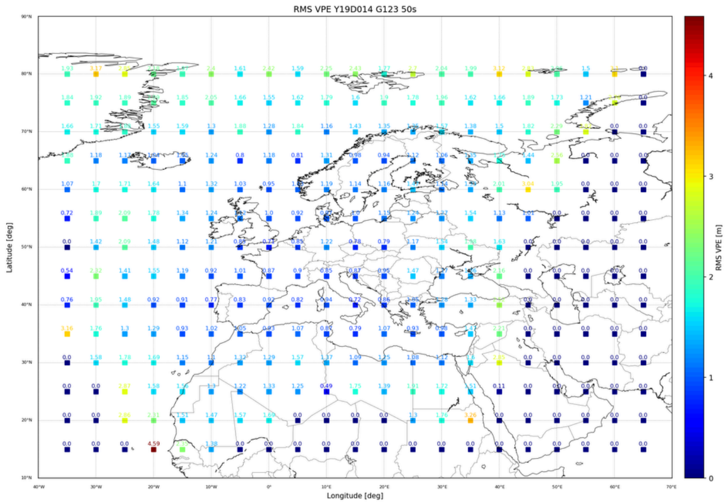


USR_PERF_MAP_APV-I_RMS_HPE_Y19D014_G123_50s.png

APV-I RMS VPE

Map of RMS APV-I Vertical Position Accuracy.

The values of this chart were generated by simply computing the Root Mean Square of all the VPE values for each user. As expected the areas at the center of Europe have better accuracy than the areas at the outer borders of Europe. The farther areas with values of 0.0 don't represent a better accuracy. This means there were not enough samples to compute the VPE.



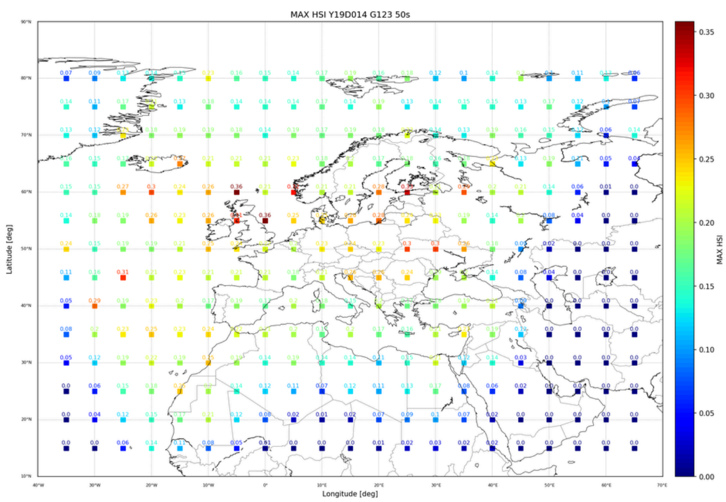
USR_PERF_MAP_APV-I_RMS_VPE_Y19D014_G123_50s.png

MAX-HSI

Map of the Maximum Horizontal Safety Index (HSI) reached during the day. This plot does not depend on APV-I.

HSI = HPE / HPL

The maximum HSI value of all the users is around 0.35, which is a good value for non-precision approaches in aviation.



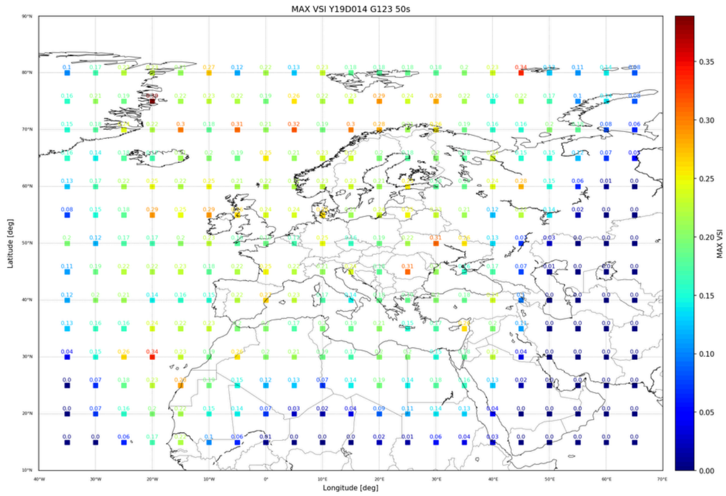
USR_PERF_MAP_HSI_MAX_Y19D014_G123_50s.png

MAX-VSI

Map of the Maximum Safety Index (VSI) reached during the day. This plot does not depend on APV-I.

VSI = VPE / VPL

The maximum VSI value of all the users is around 0.35, which is a good value for non-precision approaches in aviation.

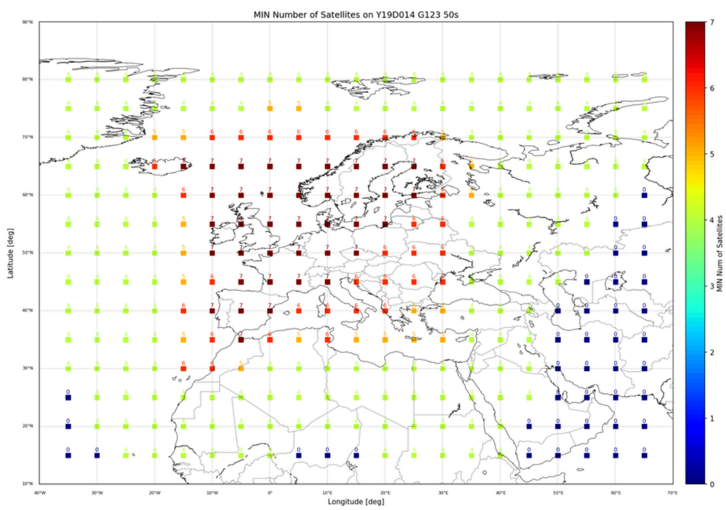


USR_PERF_MAP_VSI_MAX_Y19D014_G123_50s.png

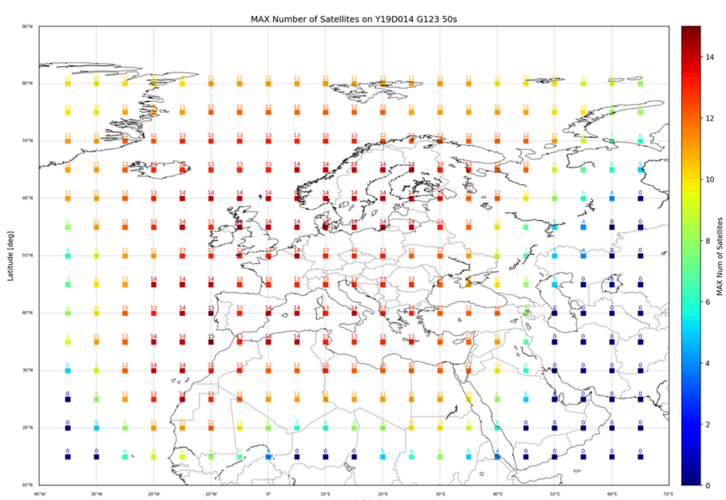
MIN/MAX-SATS

Map of the Minimum and Maximum Number of Satellites in View (NSV).

The values of these 2 charts are generated by counting the satellites in view for each user with an elevation of 5 degrees and the FLAG equals to 1. In the bottom-right corner, both the maximum and minimum number of satellites is 0, which matches the previous charts where no PA solution can be computed at that area.



USR_PERF_MAP_NSV_MIN_Y19D014_G123_50s.png

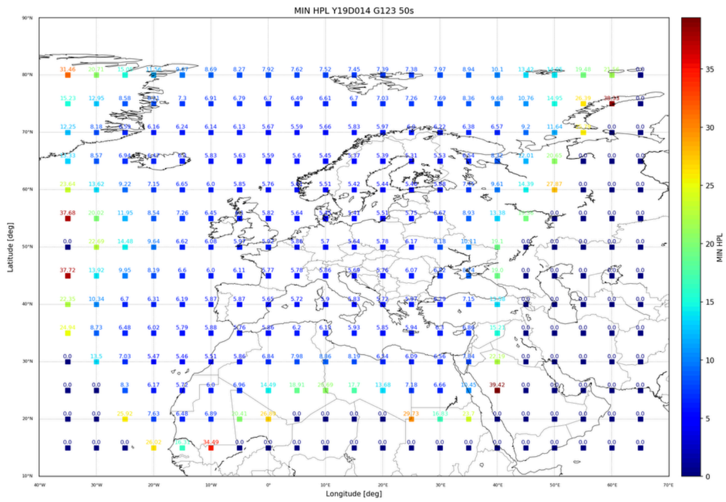


USR_PERF_MAP_NSV_MAX_Y19D014_G123_50s.png

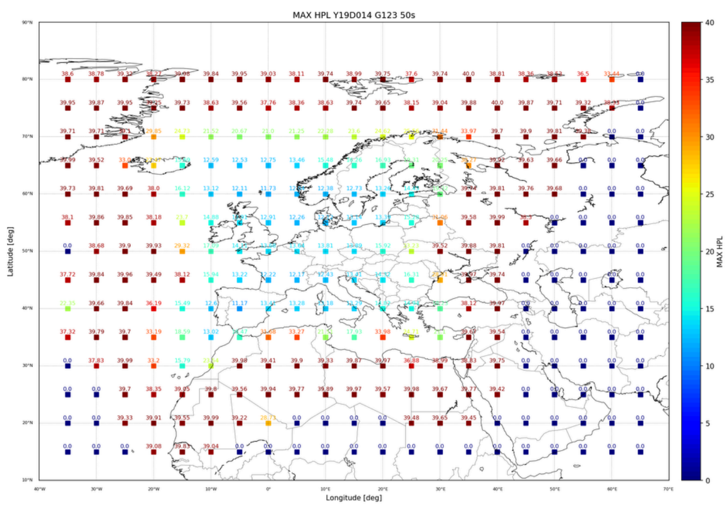
MIN/MAX-HPL

Map of the Minimum and Maximum Horizontal Protection Level (HPL) reached during the day.

In the center of Europe, which is the main important area, the lowest HPL values are around 6m and the highest HPL values are around 13m, which are excellent values for aviation.



USR_PERF_MAP_HPL_MIN_Y19D014_G123_50s.png

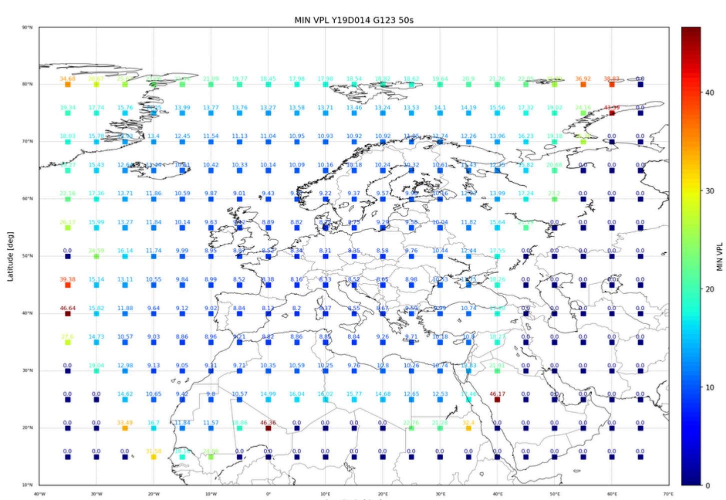


USR_PERF_MAP_HPL_MAX_Y19D014_G123_50s.png

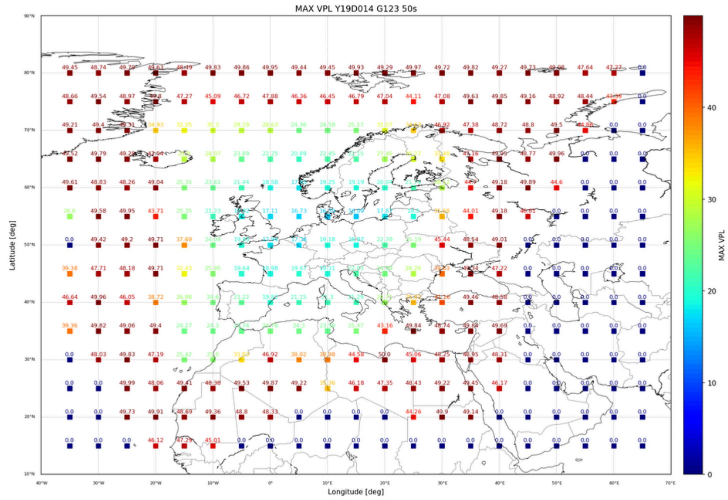
MIN/MAX-VPL

Map of the Minimum and Maximum Vertical Protection Level (VPL) reached during the day.

In the center of Europe, the lowest VPL values are around 9m and the highest VPL values are around 20m, which are good values for aviation.



USR_PERF_MAP_VPL_MIN_Y19D014_G123_50s.png

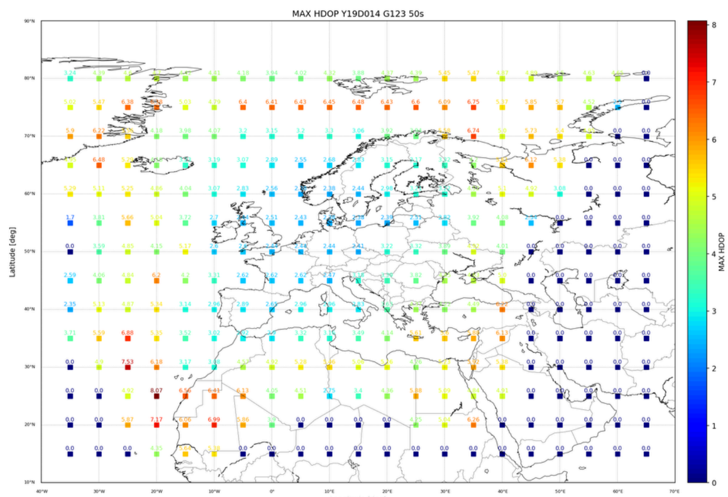


USR_PERF_MAP_VPL_MAX_Y19D014_G123_50s.png

MAX-HDOP

Map of Maximum Horizontal Dilution of Precision (HDOP) reached during the day.

In the center of Europe, the highest HDOP values are around 3m, which is acceptable for most applications, but not for precision approaches in aviation.

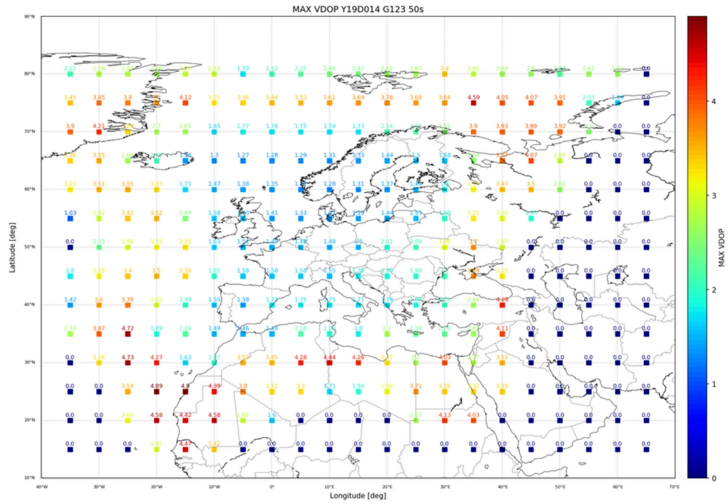


USR_PERF_MAP_HDOP_MAX_Y19D014_G123_50s.png

MAX-VDOP

Map of Maximum Vertical Dilution of Precision (VDOP) reached during the day.

In the center of Europe, the highest VDOP values are around 2m, which is acceptable for most applications, including precision approaches in aviation.

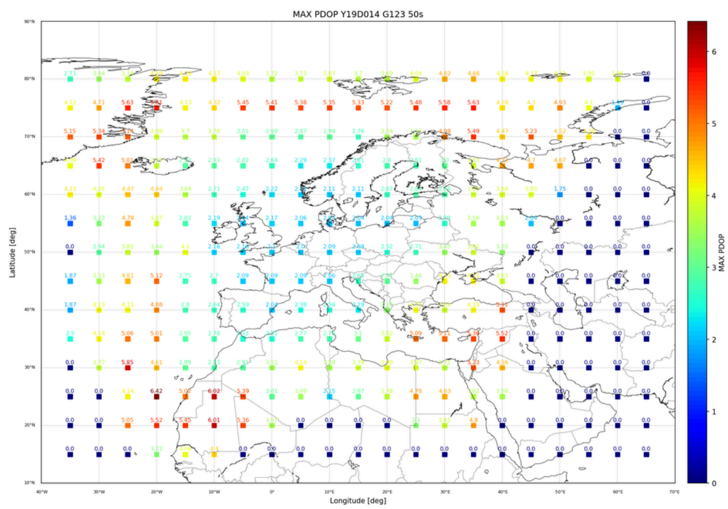


USR_PERF_MAP_VDOP_MAX_Y19D014_G123_50s.png

MAX-PDOP

Map of Maximum Position Dilution of Precision (PDOP) reached during the day.

In the center of Europe, the highest PDOP values are around 2m, which is acceptable for most applications, including precision approaches in aviation.



USR_PERF_MAP_PDOP_MAX_Y19D014_G123_50s.png

Conclusions

- The execution time of the code is highly dependent on the approach implemented by the algorithms.
- Reading the LOS file and computing the POS and PERF outputs on an epoch-by-epoch basis, shows a better performance than:
  - Reading the LOS file line-by-line
  - Creating the POS file and then reading it for computing the PERF outputs
- Performances in the Center of Europe are better than the areas around Europe.
- The geometry of the satellites matches the performances of each user.
  - More satellites in view will generate better performances for the user.
- In general, the user performances computed and shown at the center of Europe are suitable for most of the applications.