Centre of Space Techniques

Space Geodesy Department

Cts

Ionospheric models comparison of single-frequency GPS positioning in Algeria

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Outline

- Introduction and Objectives
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- Data used
- Results analysis
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  - Klobuchar (GPS)
  - Kbds (Beidou)
  - NeQuick (Galileo)
  - EGNOS
- Summary and Conclusions

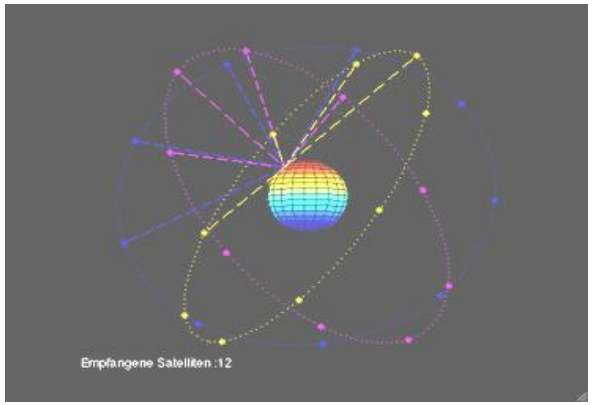
Introduction (GNSS)

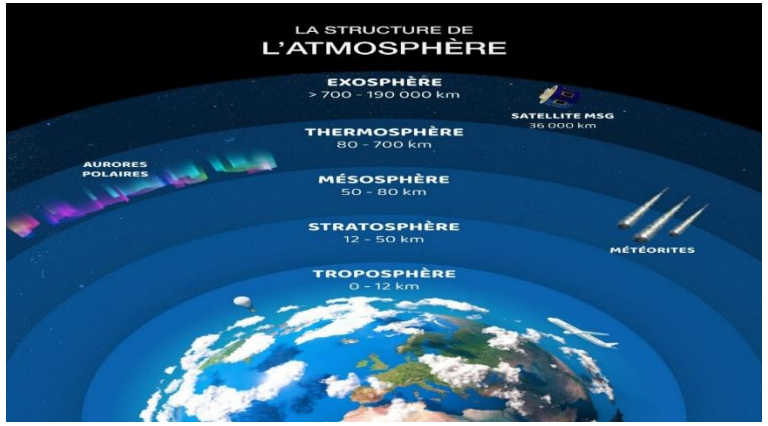
GNSS (GPS, GLONASS, GALILEO, BDS) :

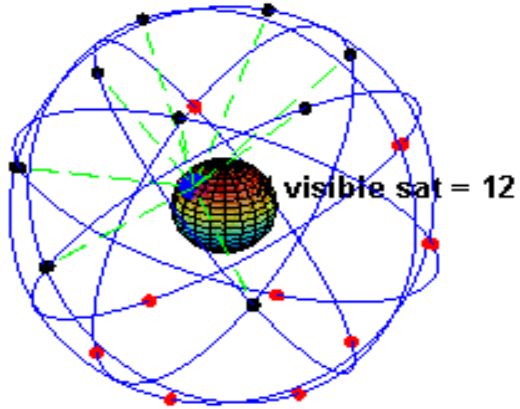
Positioning (position, velocity, acceleration) in a general terrestrial reference system.

GNSS applications

- Geodesy : *National network, Cadastral Network, Urban Networks, ...*
- Industrial Risks : *Auscultation of Dams, Bridge, Tanks Storage of GNL…..*
- Public Works : *Roads, Rail Infrastructure. ...*
- Scientific applications : *Crustal Deformations, Tectonic Movements, Atmospheric Modelling , Climate Change*
- Positioning and navigation in real time (Position, Velocity, ..) : *Terrestrial, Maritime, Aviation,….*
- **Space *weather* : *Ionospheric disturbances,…….***



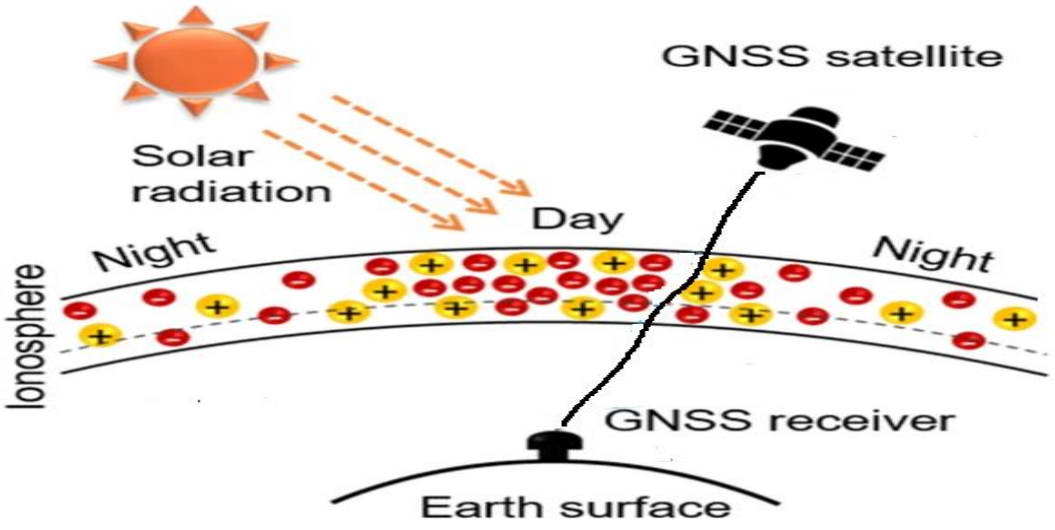




Introduction (GNSS)

- Single Point Positioning (SPP) provides an autonomous position of a receiver using code data from Global Navigation Satellite Systems (GNSS).
- The main problem in SPP (RT : real time) comes from various errors degrading the global positioning system (GPS) signal.

$$l_{mes} = \rho + c(dt_r - dt_s) + Ion + Trop + Rel + RDCB_L + SDCB_L + \varepsilon$$



→ Ionospheric delay contributes to the general GPS error budget in the range of 40–60 m during daytime and 6–12 m at night.

→ To calculate and reduce this effect on the GPS code measurements, different models are used **in RT**.

Work context

Single frequency receivers

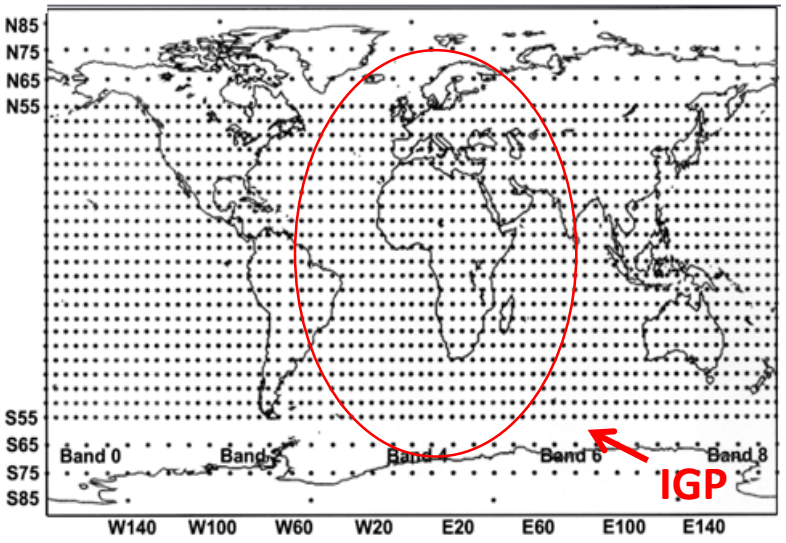
Ionospheric modelling

- **Broadcast model**
- **SBAS**
- **IONEX, GIM…**

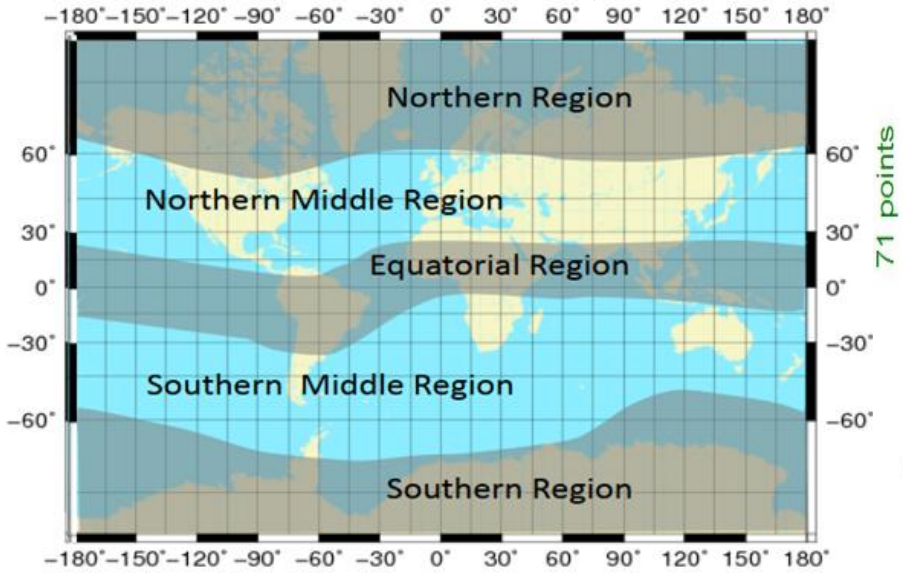
```
     2.11           N: GPS NAV DATA                                 RINEX VERSION / TYPE
teqc  2016Apr1      IGN                        20200304 01:53:03UTCPGM / RUN BY / DATE
    18                                                             LEAP SECONDS
  1.0245D-08   0.0000D+00 -5.9605D-08   0.0000D+00                  ION ALPHA
  9.0112D+04   0.0000D+00 -1.9661D+05   0.0000D+00                  ION BETA
 -3.725290298462D-09-1.332267629550D-14    405504      2095 DELTA-UTC: A0,A1,T,W
                                                                   END OF HEADER
11 20  3  3  0  0  0.0-3.450978547335D-04 1.080024958355D-11 0.000000000000D+00
  2.900000000000D+01-5.459375000000D+01 5.859529787221D-09 2.763949102603D-01
 -2.913177013397D-06 1.588275074027D-02 6.146728992462D-06 5.153715990067D+03
```

GPS Klobuchar
KBDS
NeQuick

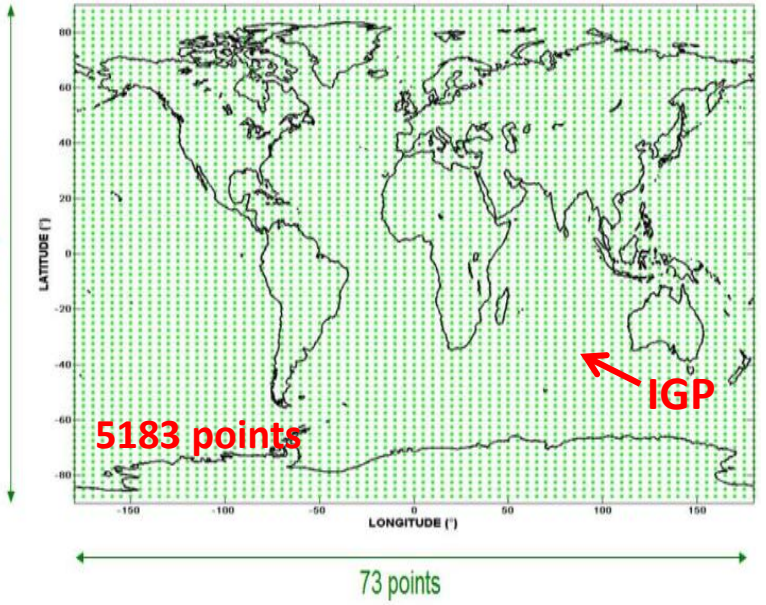
→ On average, 50% correction of the ionospheric error.



(*EGNOS*: *Ionospheric Grid Points 5°x5°*)



Model of the vertical electron profile based on 5 layers.



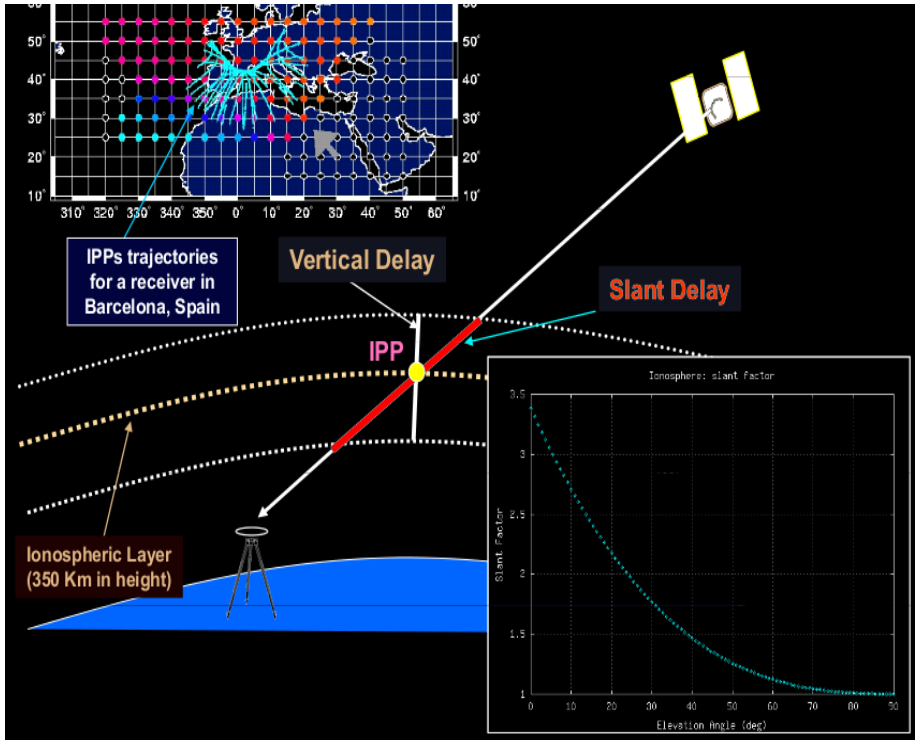
(IONEX: *Ionospheric Grid Points 2,5°x5°*)

Work context

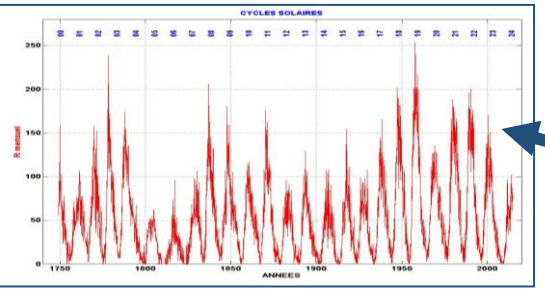
- **Space weather** can cause strong sudden disturbances in the Earth's ionosphere which can degrade the performance and reliability of GNSS ;
- To minimize these degradations, ionospheric effects need to be precisely and timely corrected by providing information of the spatially and temporally variable **Total Electron Content (TEC).**

- TEC is the number of electrons in a column of a cross section per square meter along a trans-ionospheric path :

$$Ion = \frac{40.3}{f^2}\int N_e dl = \frac{40.3}{f^2} TEC$$

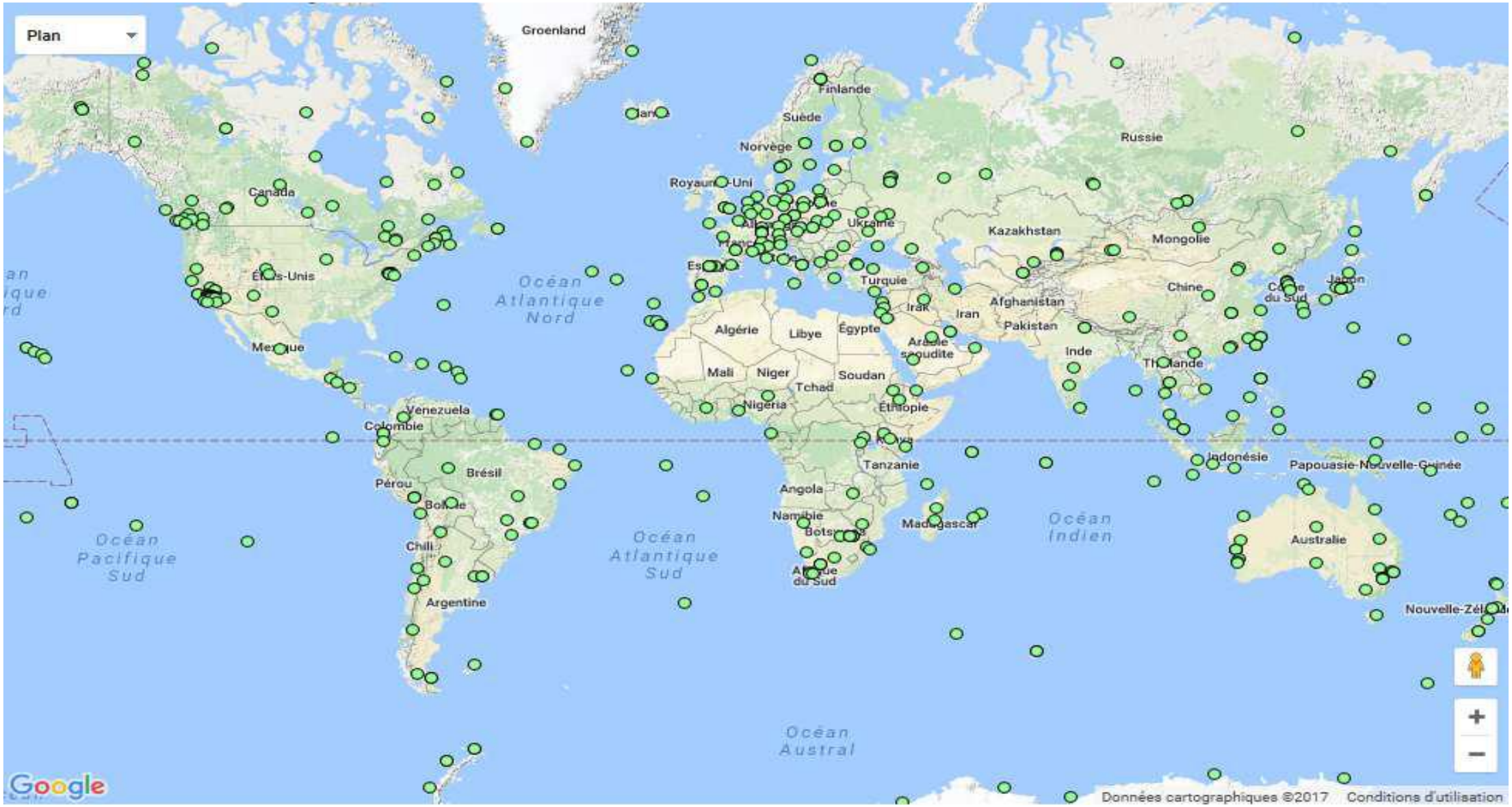


Main characteristics of the Ionosphere:



- Electron density profile
- TEC variability
- Solar Cycle
- Solar storms
- Equatorial anomalies and scintillations

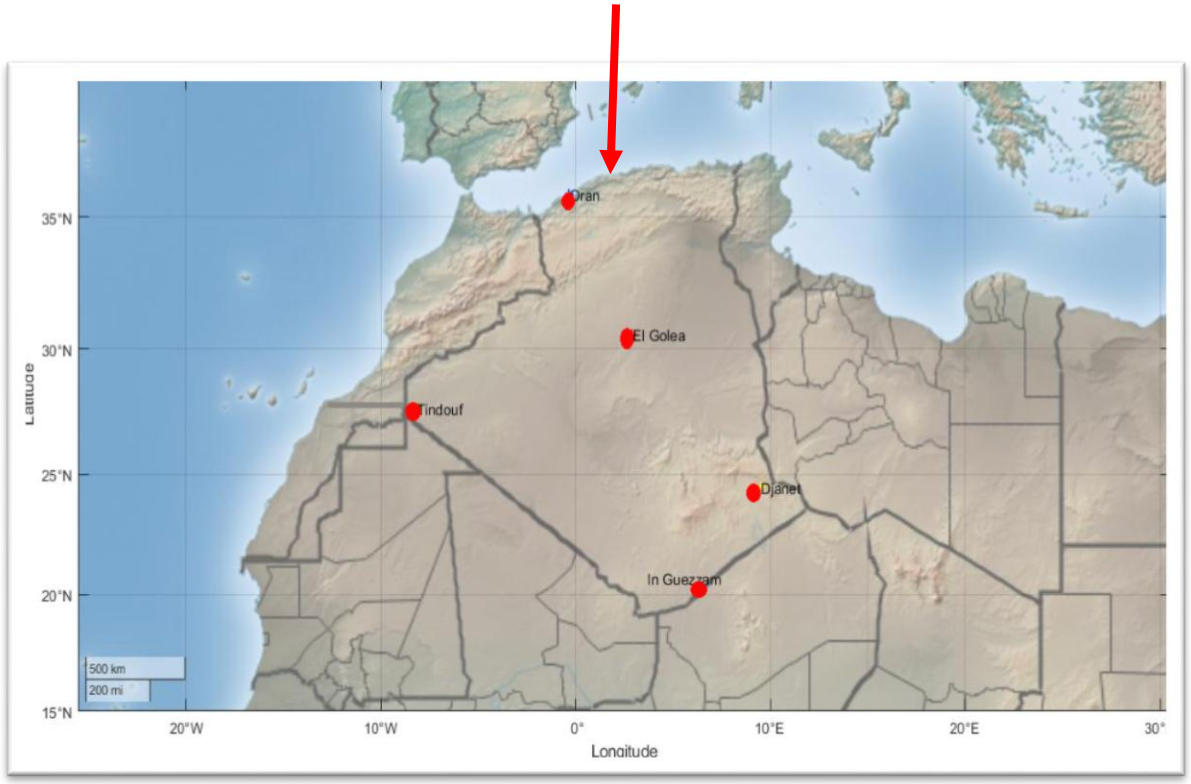
IGS network



IGS network is a global network of 513 permanent and continuously operating stations of geodetic quality

Data used

Real data collected by Trimble NetR9 dual-frequency receivers at five sites in Algeria :

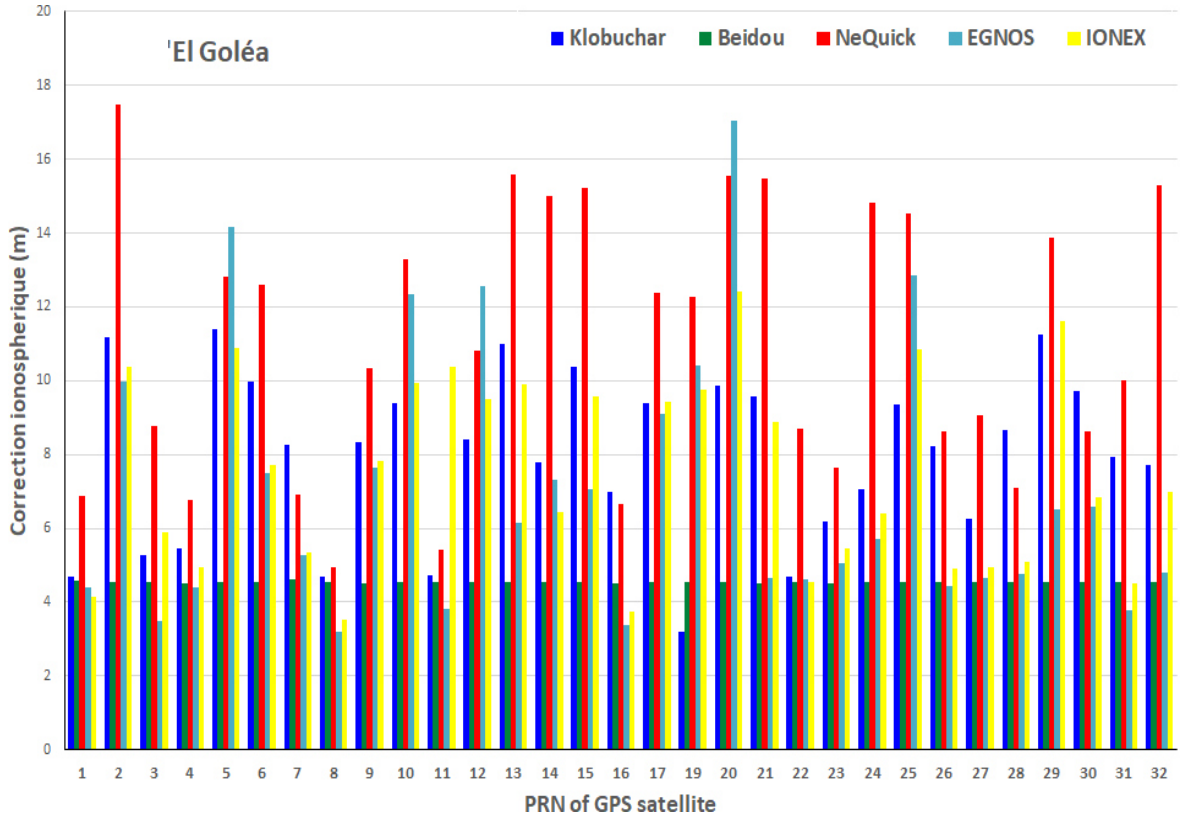


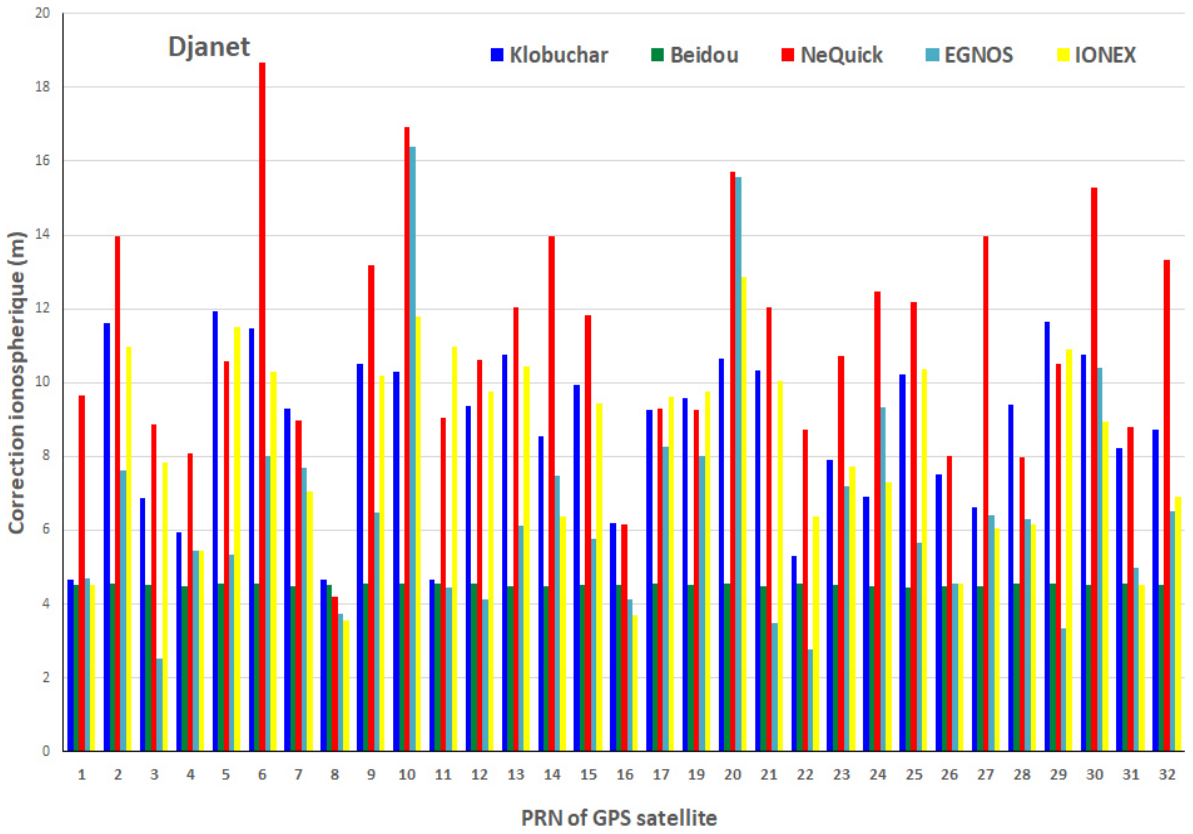
Sites	Latitude (φ)	Longitude (λ)
Oran	35.85°	-0.32°
El Goléa	30.57	2.91
Tindouf	27.66°	-8.14°
Djanet	24.48°	9.52°
In Guezzam	20.31°	6.52°

Effects of the ionospheric models on SPP accuracy in RT

The SPP positions are performed using different ionospheric models (Klobuchar, KBDS, NeQuick, SBAS and IONEX).

Ionospheric corrections comparison of different models

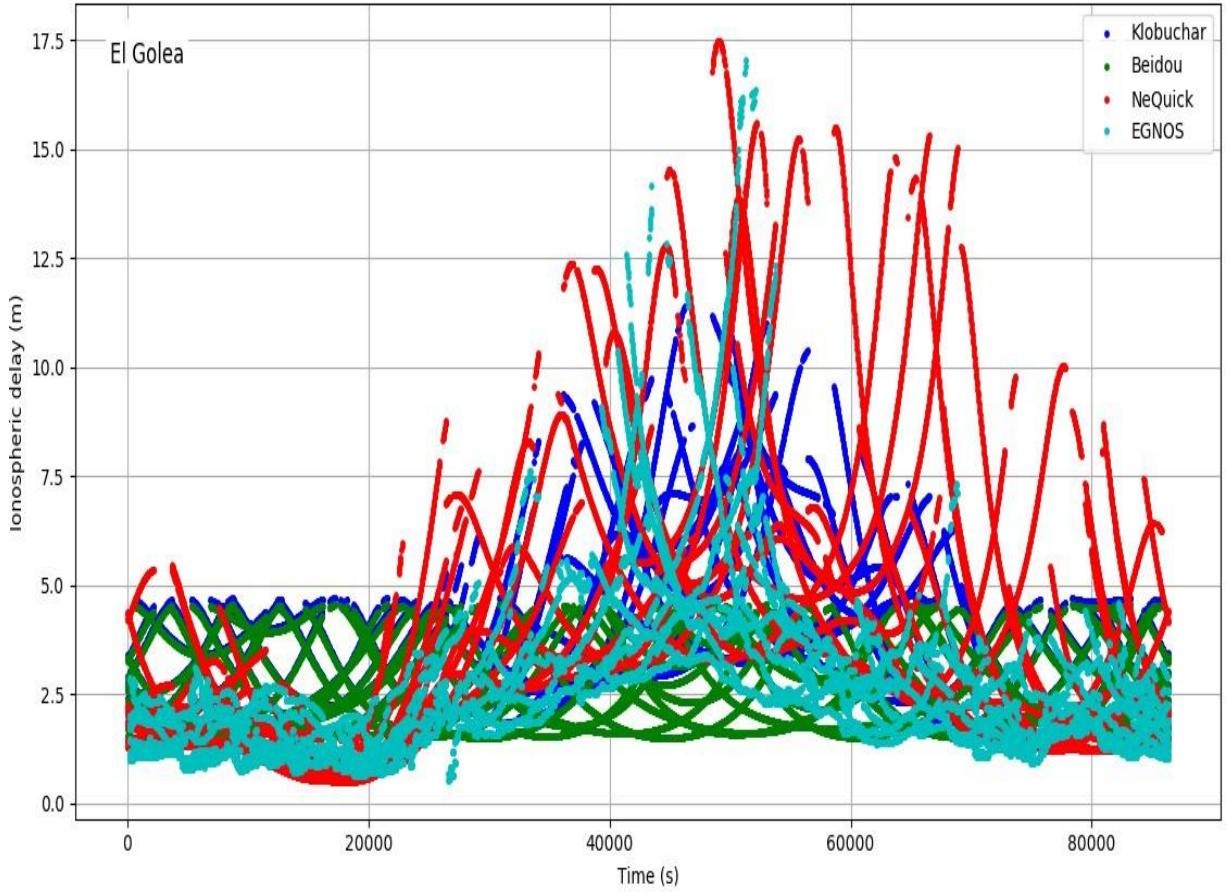


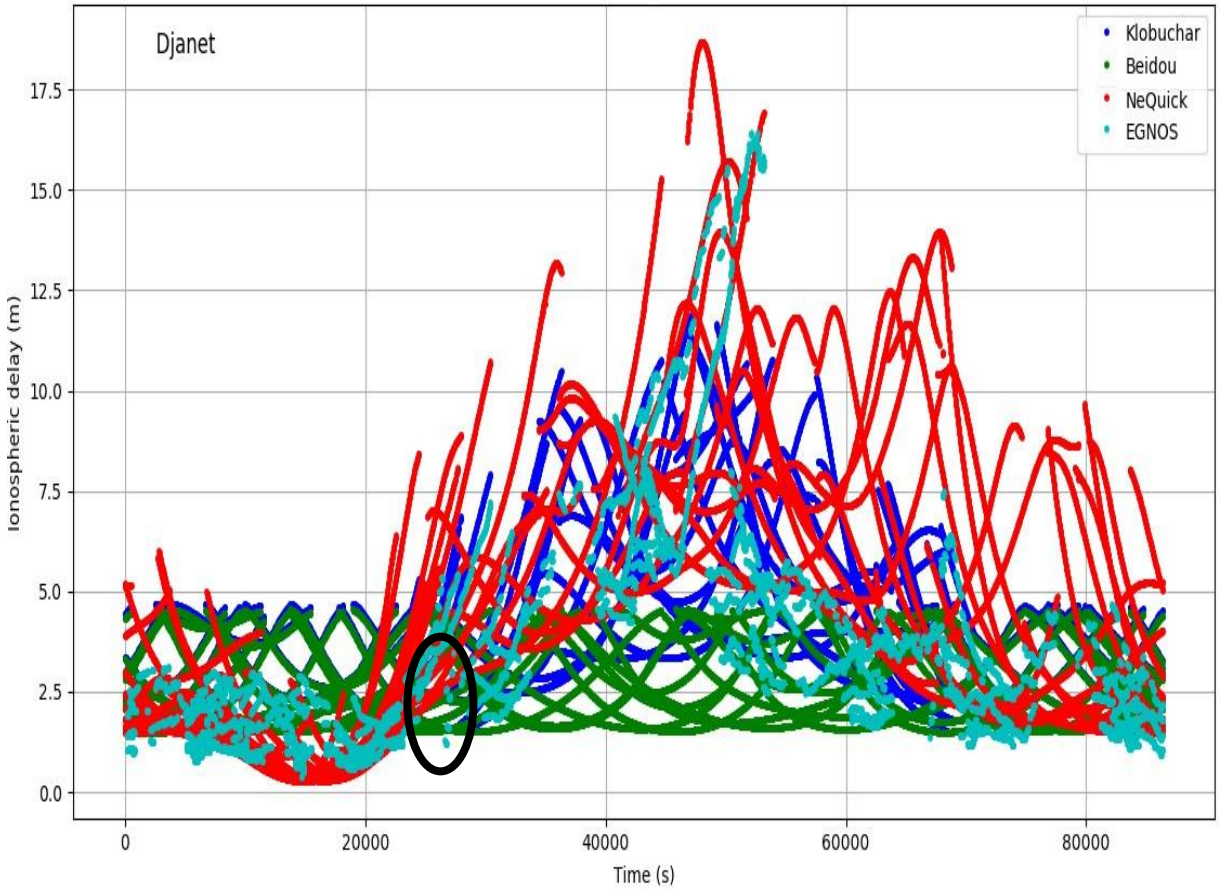


- Corrections based on VTEC values from IONEX files range from **3.5 to 12.5 m**.
- KBDS ionospheric delays are about **4.0 m**,
- Klobuchar are between **2.5 m and 11 m,**
- The ionospheric correction with NeQuick varies between **3.5 and 18.5 m**

Evaluation of ionospheric corrections

Ionospheric corrections for all GPS satellites obtained from the Klobuchar, KBDS, NeQuick models and the grid ionospheric corrections broadcast by EGNOS.

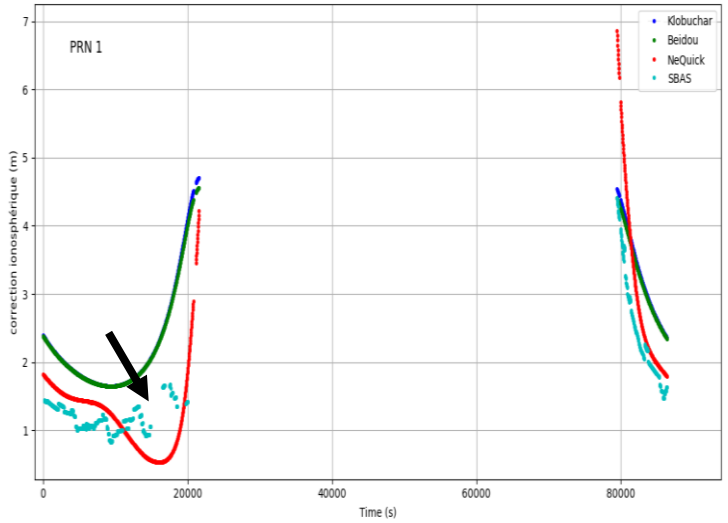


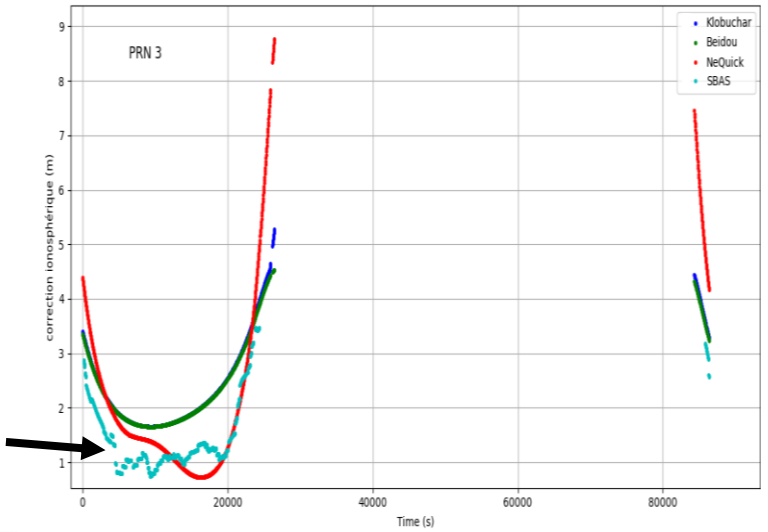


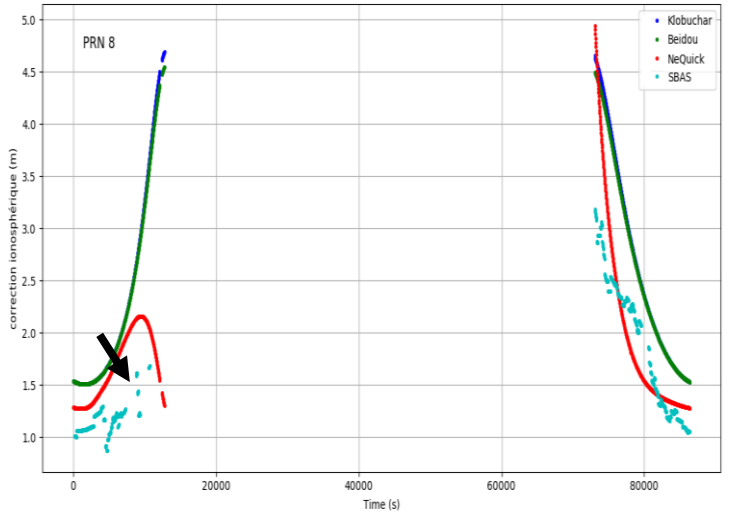
❑ **El Goléa → Klobuchar, NeQuick and EGNOS→ ionospheric correction values are between 2 m to 5 m, and can reach 18 m (for satellites close to the horizon),**

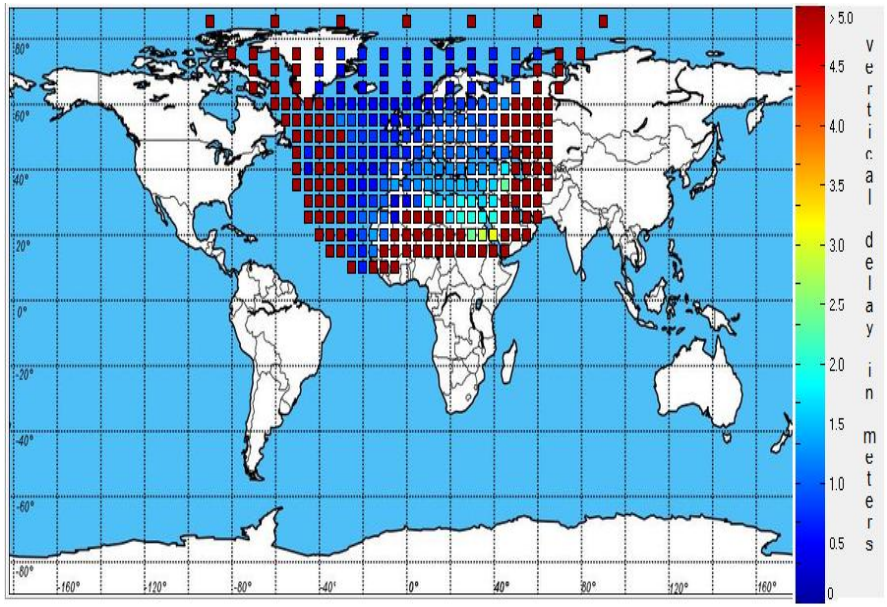
❑ Djanet (EGNOS) → Ionospheric correction values are not continuous.

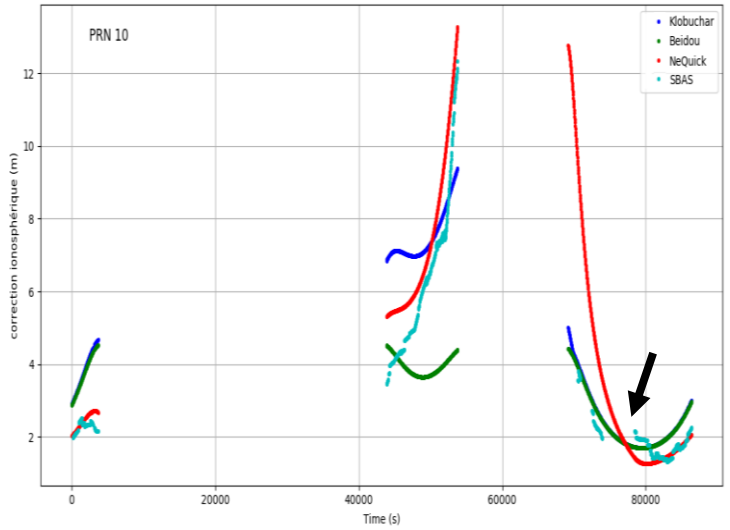
Evaluation of ionospheric corrections (Djanet case)

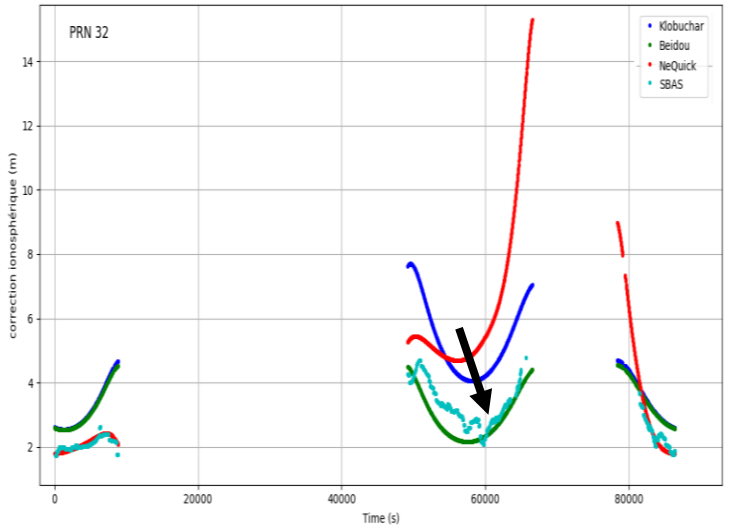












Grid of ionospheric corrections transmitted by EGNOS

Accuracy analysis: Position error (95%), 3D error and RMS (in m)

Klobuchar model

- The electronic content is concentrated in a thin layer at 350 kilometers altitude.

Sites	HPE(95%)	VPE(95%)	Error $3D_{max}$	Error $3D_{mean}$	$\sigma_{3DError}$	3D RMS
Oran	2.21	4.18	9.59	1.43	1.48	3.01
El Goléa	3.62	4.68	15.81	2.24	1.14	2.79
Tindouf	4.46	4.93	6.89	2.99	1.15	3.21
Djanet	3.46	5.30	7.93	2.82	1.11	3.03
In Guezzam	2.41	4.87	7.25	1.35	1.47	3.11

KBDS model

- The layer of maximum electronic density of the ionosphere, fixed at 375km),

Sites	HPE(95%)	VPE(95%)	Error $3D_{max}$	Error $3D_{mean}$	$\sigma_{3DError}$	3D RMS
Oran	2.56	4.07	11.51	1.24	1.42	2.78
El Goléa	4.25	4.58	15.23	3.22	1.48	3.16
Tindouf	4.97	4.11	8.40	3.73	1.37	3.53
Djanet	3.91	4.40	8.19	2.84	1.28	3.12
In Guezzam	2.84	4.65	6.97	1.48	1.59	2.96

NeQuick model

- The model uses five predefined regions,
- The NeQuick model calculates correction using daily solar activity information,

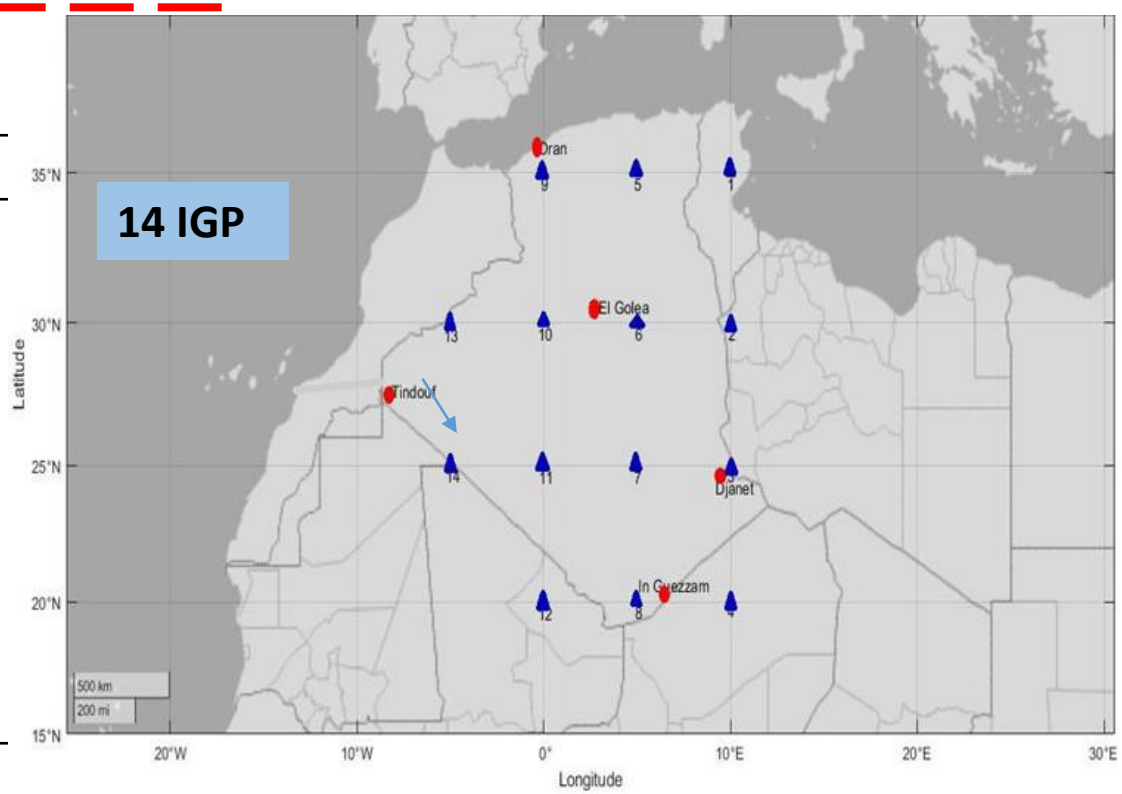
Sites	HPE(95%)	VPE(95%)	Error $3D_{max}$	Error $3D_{mean}$	$\sigma_{3DError}$	3D RMS
Oran	2.09	4.05	10.34	1.21	1.35	2.63
El Golea	2.27	4.35	17.10	2.31	1.22	2.61
Tindouf	2.59	4.29	6.60	2.41	1.16	2.68
Djanet	3.21	4.77	7.14	2.76	1.36	3.09
In Guezzam	3.53	5.05	7.52	1.57	1.75	3.36

Ionospheric delay with EGNOS

Sites	HPE(95%)	VPE(95%)	Error $3D_{max}$	$Error3D_{mean}$	$\sigma_{3DError}$	3D RMS
Oran	1.72	2.68	7.36	1.54	0.76	1.72
El Goléa	3.24	3.15	40.31	1.97	2.14	2.95
Tindouf	2.06	3.48	6.31	1.82	0.94	2.07
Djanet	28.92	9.90	>50	9.35	45.27	48.96
In Guezzam	8.68	106	>50	14.37	34.65	37.67

- For Djanet and In Guezzam sites, the accuracies are higher than **34.65 m**.
- The ionospheric grid transmitted by EGNOS gives more accurate results for latitudes above 27° compared to the three models.

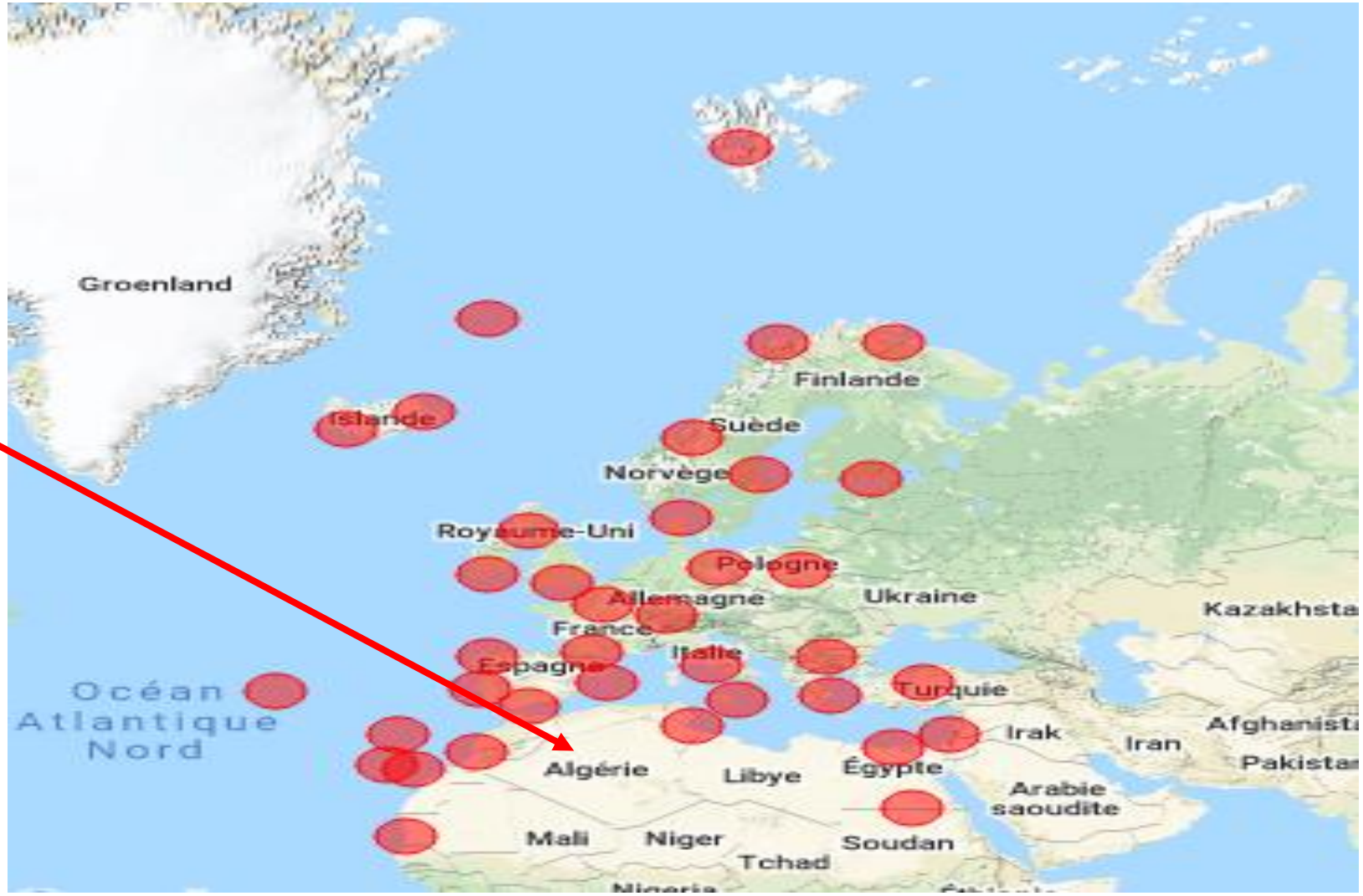
Sites	IGP	Ionospheric delay (m)
Oran	9	**1.22**
El Goléa	10	13.86
	6	1.20
Tindouf	13	**1.53**
	14	5.60
Djanet	3	> 20 m
	7	> 20 m
	4	> 20 m
In Guezzam	8	> 20 m
	4	> 20 m



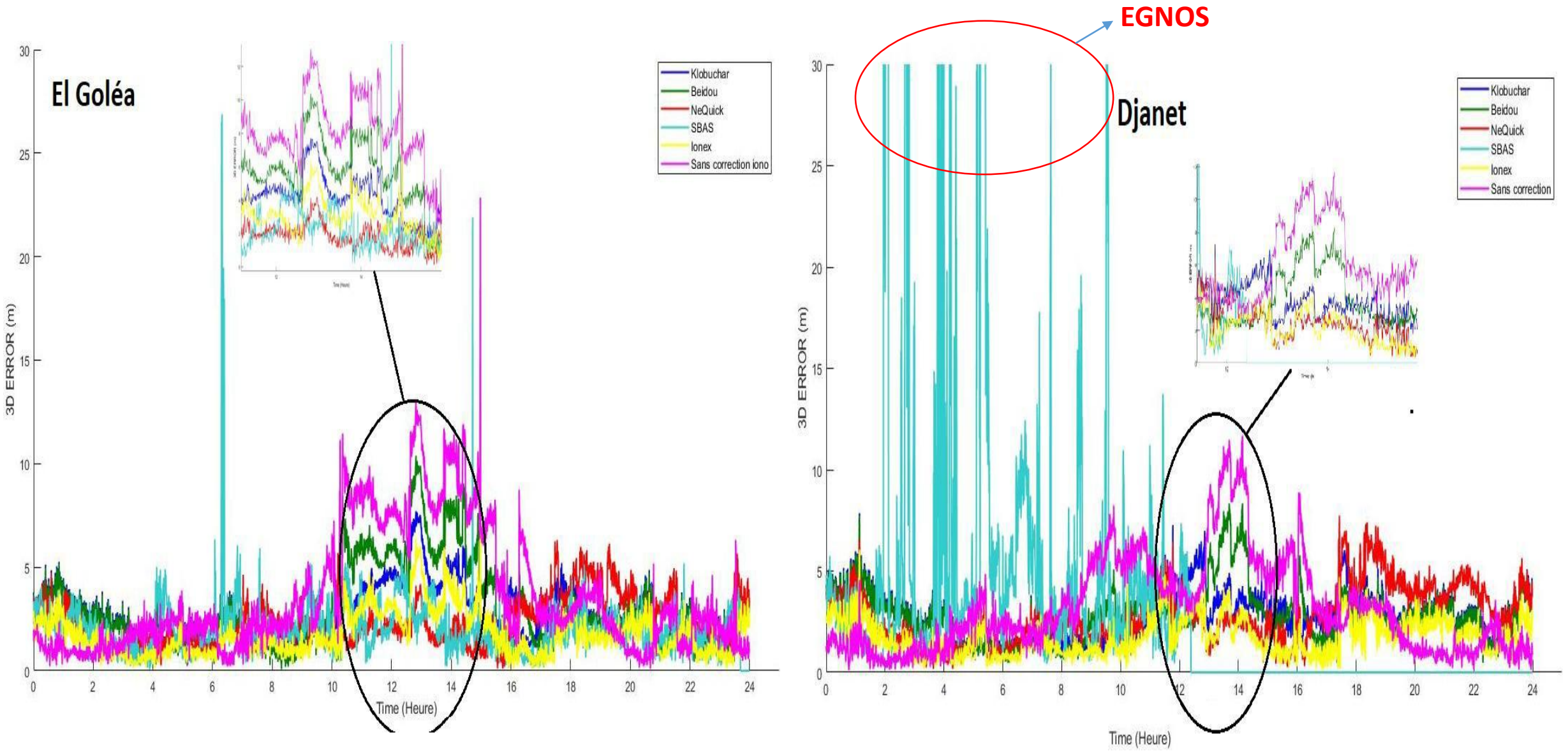
Current EGNOS network of 39 RIMS stations

The ionospheric correction of each IGP is calculated from the current EGNOS network.

Unavailability of RIMS station in Algeria

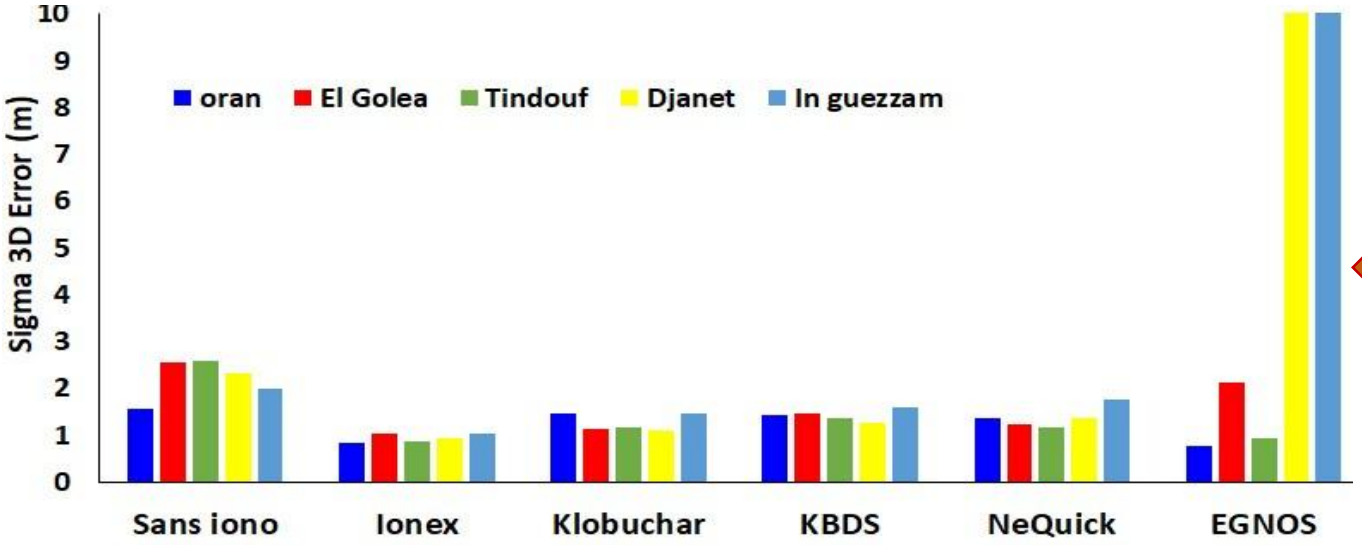


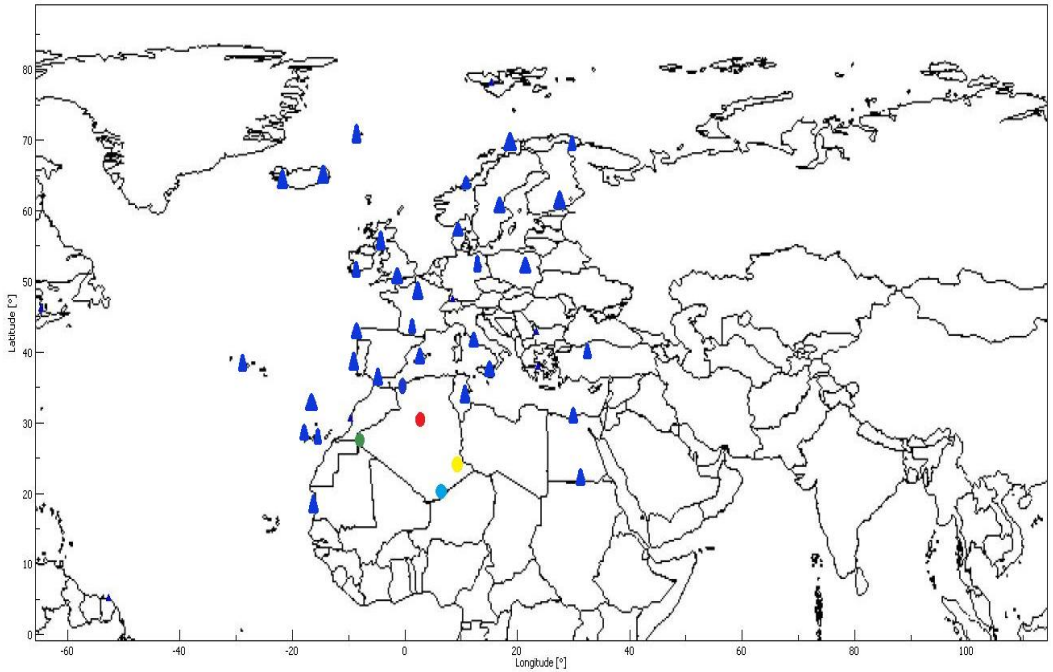
3D error for each models



3D error (with zoom) in position errors from 12:00 to 14:00

Results summary



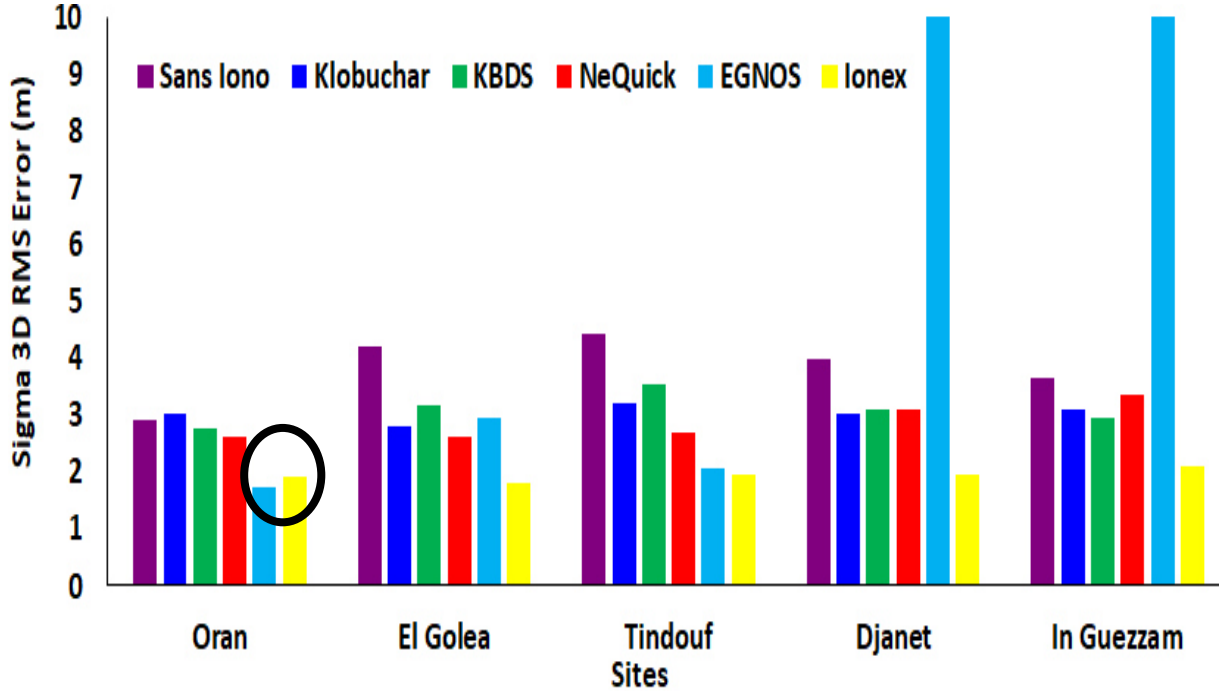


Positioning accuracy results using IONEX are better than the 4 other models :

- Except for Oran (grid transmitted by EGNOS), the improvement is **0,76 m**, although for IONEX this value = to **1.48 m** ;

- While for Djanet and In Guezzam, the **accuracy** using 3 models allows to obtain better results than EGNOS corrections (**σ exceeds 30 m**) ;

- EGNOS corrections depend on geographical location.



Conclusion

- **IONEX** model, in absolute mode, gives better results for the five sites at different latitudes and longitudes. This model is based on data collected from reference stations around the world, whose coordinates are precisely predetermined.
- The results show that accuracy is quasi similar using the 3 other models (**Klobuchar, KBDS and NeQuick**). This accuracy varies between **0.85 m and 1.75 m**.
- Assessment of accuracy, by considering the **ionospheric corrections transmitted by EGNOS**, are interesting in case of single-frequency receivers, **this improvement is limited by the distance from the service area.**
  - The accuracy is less than 0.94 m for Oran and Tindouf.
  - While the maximum deviation reached 45.27 m, for the southern region of Algeria (Djanet and In Guezzam),
  - Ionospheric delay is not perfectly modeled.
  - Both sites are far from the RIMS station network.

Perspectives

The comparison of accuracy was carried out in February 2020; the obtained results are very satisfactory and require other perspectives:

- It would be interesting to apply ionospheric models on different periods of the year by considering the different seasons ;
- in case of data availability (permanent stations), extend this study over several years by taking into account the solar activity.