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Performance Assessment of TEC Maps for Correcting Ionospheric Bias in LEO Radar Measurements

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Outline

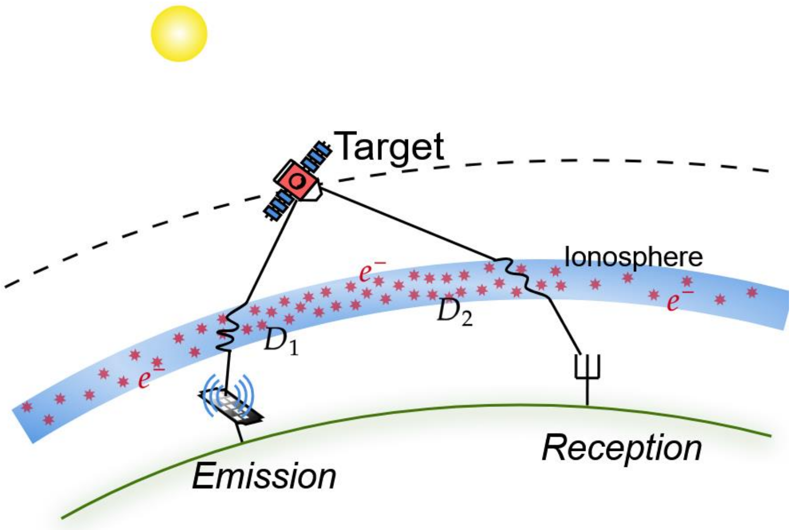
- Introduction
- Chosen TEC maps
- Correction method
- Validation method
- Results
- Conclusion

Introduction

- Unpredictable fluctuations in the ionosphere degrade RF wave propagation
  - ⇒ reducing the reliability of measurements,
  - ⇒ deteriorating orbit restitution,
  - ⇒ association anomalies.

- Directly linked to the integrated electronic content along the ray-path:

$$v_b^{iono} = v_b^{geom} + \frac{40.3}{f_E^2} \frac{d\, STEC_1 + STEC_2}{dt}$$



➔ How to compensate for ionospheric Doppler in radar measurements using public TEC maps?

TEC maps

	IMPC	UQRG	JPL-g
Provider	Ionosphere Monitoring and Prediction Center (IMPC), DLR, Germany	UPC-IonSAT, Universitat Politècnica de Catalunya, Spain	Jet Propulsion Laboratory (JPL), USA
Temporal resolution	5 min	15 min	2 hours
Spatial resolution	1° x 1°	2.5° x 5°	2.5° x 5°
Latency	Real-time	Few days	Few days
Error	Few TECu (w. VTEC)	~1 to 4 TECu	~6 TECu
Extraction method	Single-shell (400 km), assimilation NTCM, LS and recursive filter.	Two-layer voxel (3d model), kriging.	GNSS measurements assimilated on an extended 1-layer iono.

Method : the ionospheric mapping function

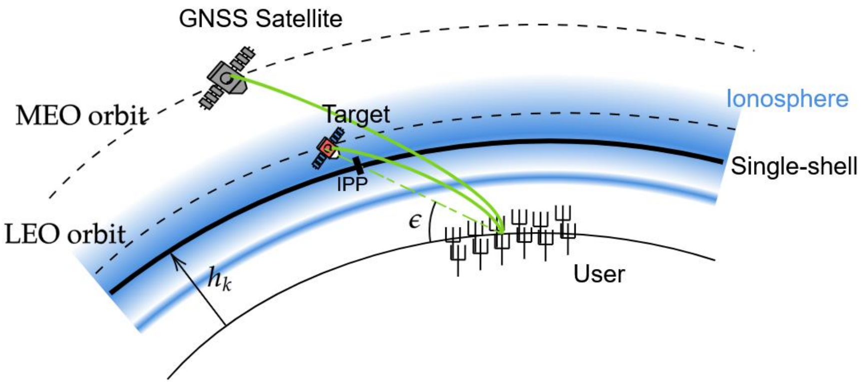
$$\mathrm{sTEC}_{\mathrm{ground}\to\mathrm{LEO}} = \beta\, m(\varepsilon, h_k)\, \mathrm{vTEC}_{\mathrm{ground}\to\mathrm{MEO}}$$

- Single layer models

  ⇒ MSLM (Modified Single Layer Model)

$$m(\varepsilon, h_k) = \frac{\mathrm{sTEC}}{\mathrm{vTEC}} = \left[1 - \left(\frac{R_T \sin\alpha\,(\frac{\pi}{2} - \varepsilon)}{R_T + h_k}\right)^2\right]^{-1/2}$$

$$\alpha = 0{,}9782 \text{ et } h_k = 506{,}7 \text{ km}$$



Geometry used in the single-shell assumption.

- Physical models : variable height h_k, multiple-layer ionosphere, azimuth dependent effects.
- Data-driven / Empirical Models, e.g. BIMF. (Lyu et al 2018)

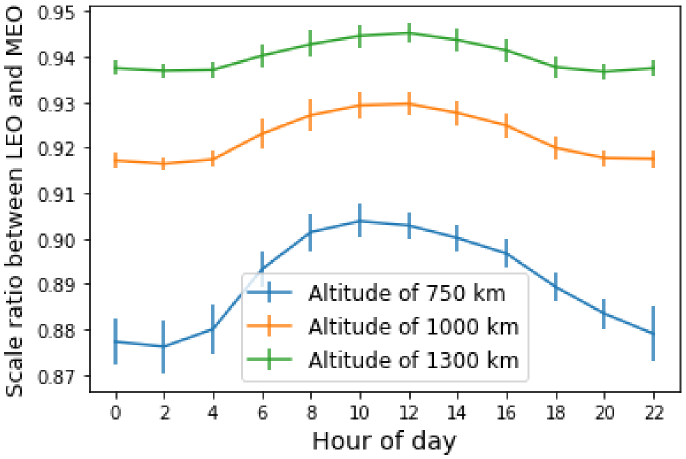
Method : the scale factor

$$\mathrm{sTEC}_{\mathrm{ground}\rightarrow\mathrm{LEO}} = \boldsymbol{\beta}\, m(\varepsilon, h_k)\, \mathrm{vTEC}_{\mathrm{ground}\rightarrow\mathrm{MEO}}$$

- Compensates for the difference in integration altitude between LEO and MEO (infinity).
- Accurate and efficient ⇒ estimated from the integration of vertical ionospheric profiles.
- PyIRTAM : rapid global ionospheric electron density estimates.

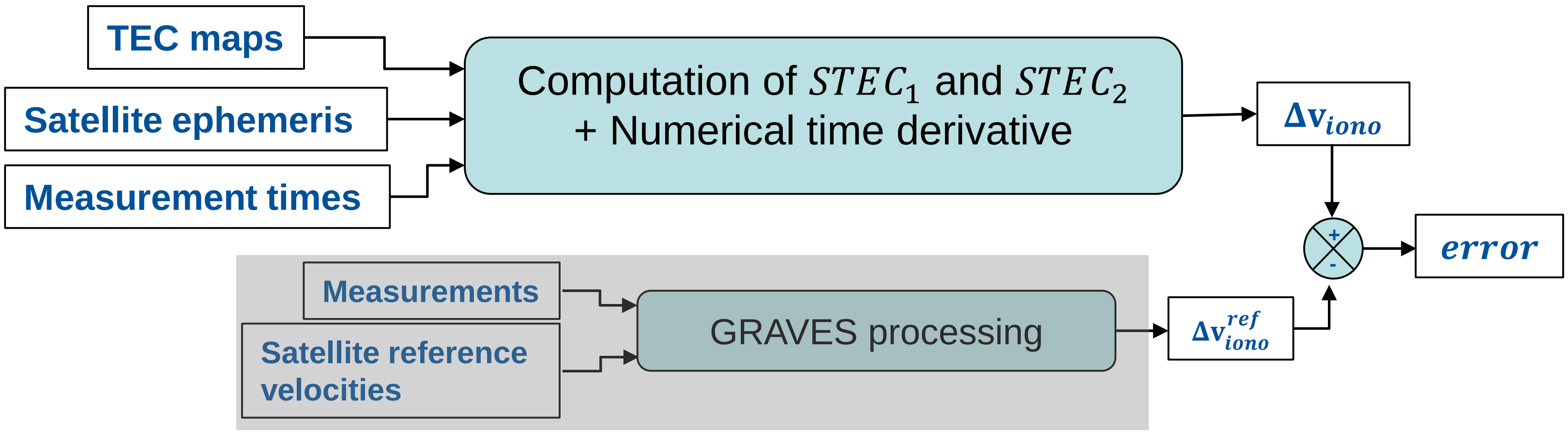
✓ $\boldsymbol{\beta} \approx \mathbf{90}\ \% \pm \mathbf{4}\%$

PyIRTAM global and fast



Diurnal Variation of the LEO–MEO Scale Ratio for Different Altitudes (Four-Month Average at a Single Location).

Results : validation method



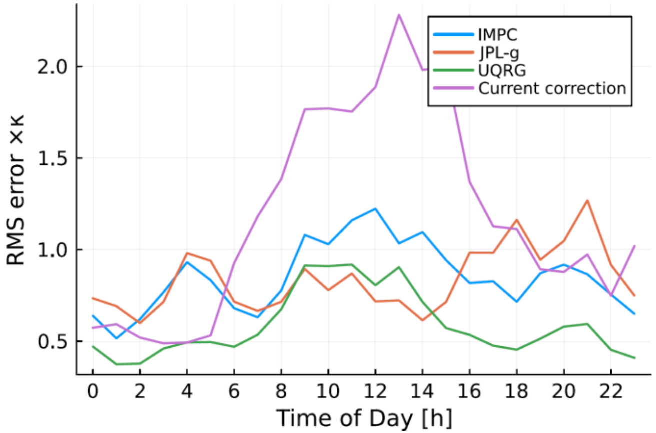
- Satellites with precise ephemeris (DORIS positioning system) :

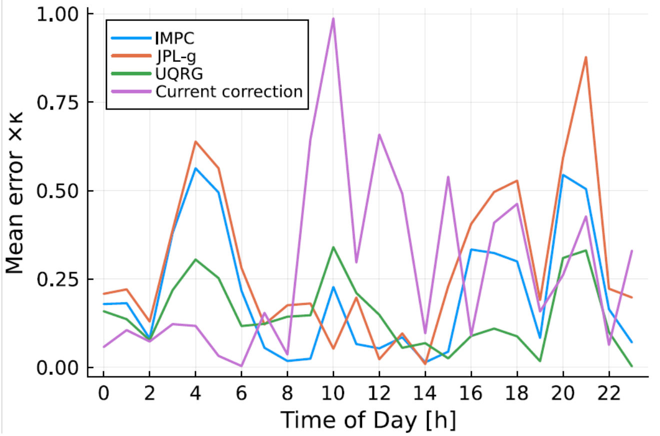
Name	Perigee (km)	Inclination (°)	Name	Perigee (km)	Inclination (°)
Cryosat-2	723	92	Sentinel-3B	809	99
Saral	791	98	Haiyang-2C	953	66
Jason-3	1339	66	Haiyang-2D	950	66
Sentinel-3A	809	99	Swot	900	77

Results on on-sky data

- Results on 4 months of continuous GRAVES measurements : September to December 2024.
- Current correction : empirical, learned on-sky correction.
- Quantified performances :

	Current Corr.	IMPC Corr.	UQRG Corr.	JPL-g Corr
Mean	69 %	63 %	72 %	71 %
RMS	54 %	67 %	78 %	66 %

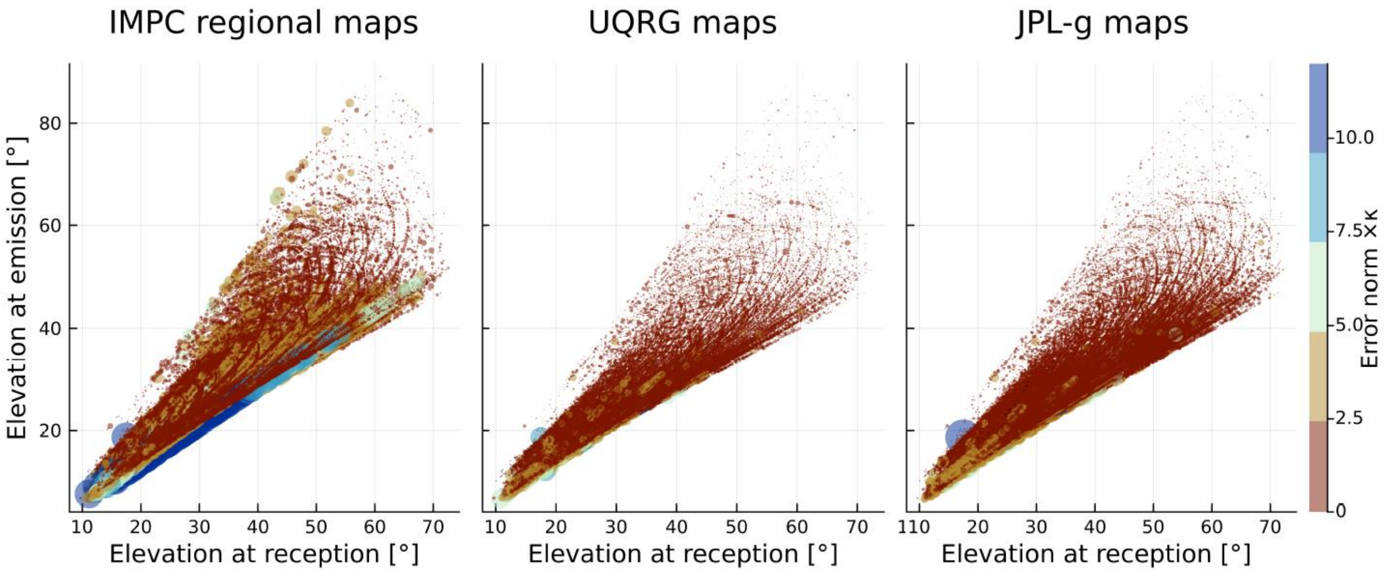




***κ normalization factor**

Results on on-sky data

- Important dependency on the target's elevation :



- Expected, <u>emphasizes the importance of the ionospheric mapping function</u>.

Conclusion and perspectives

- The use of vTEC maps is a credible solution for correcting ionospheric Doppler at NRT or short notice :
  - ✓ Efficiency.
  - ✓ Robustness to high solar activity and sudden solar events.
- UQRG TEC maps from the UPC provided the best performances so far.

➢ Which mapping function is relevant for each TEC map ?

➢ What are the uncertainties associated to each measurement ?

➢ Is there room for improvement through finer spatial sampling ?

⌛ The relevance on the orbit determination process and the effectiveness of the associations have yet to be demonstrated.

Thank you for your attention !
Any questions ?