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The cooperative Global Ionospheric Map (GIM) using DORIS-dSTEC-based weight

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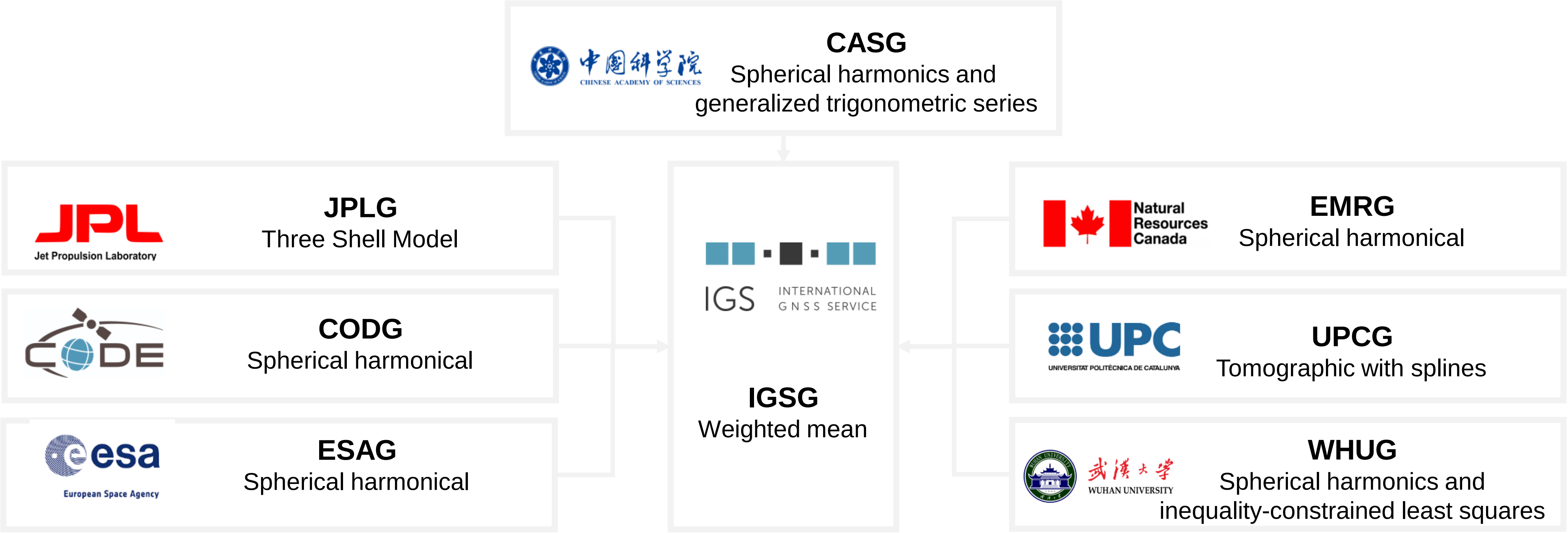
IGS Ionosphere Associated Analysis Centers (IAACs)

- International GNSS Service (IGS) provide freely and openly available GNSS data and products
- IGS Ionosphere Working Group's major task consists of the routine provision of IGS GIMs based on a combination of ionosphere maps.
- IGS Combined GIM has become the most widely used ionospheric TEC map.



IGS Method：Combined GIM based on GNSS EdSTEC

Current Version

- GNSS-based
- Not all GIMs are used (four GIMs used)
- Code is outdated (Fortran, decades ago)
- Comprehensive method is not completely independent (GNSS EdSTEC)

Improvement

- **DORS-based**
- Introduced **all IAAC GIMs** (Seven)
- New Code Version (C/C++ and Python)
- **New Comprehensive method is proposed (DORIS dSTEC)**

Our motivation was to create a more reliable and accurate combined GIM by integrating these diverse data sources, particularly incorporating ***DORIS*** observations to enhance the final product.

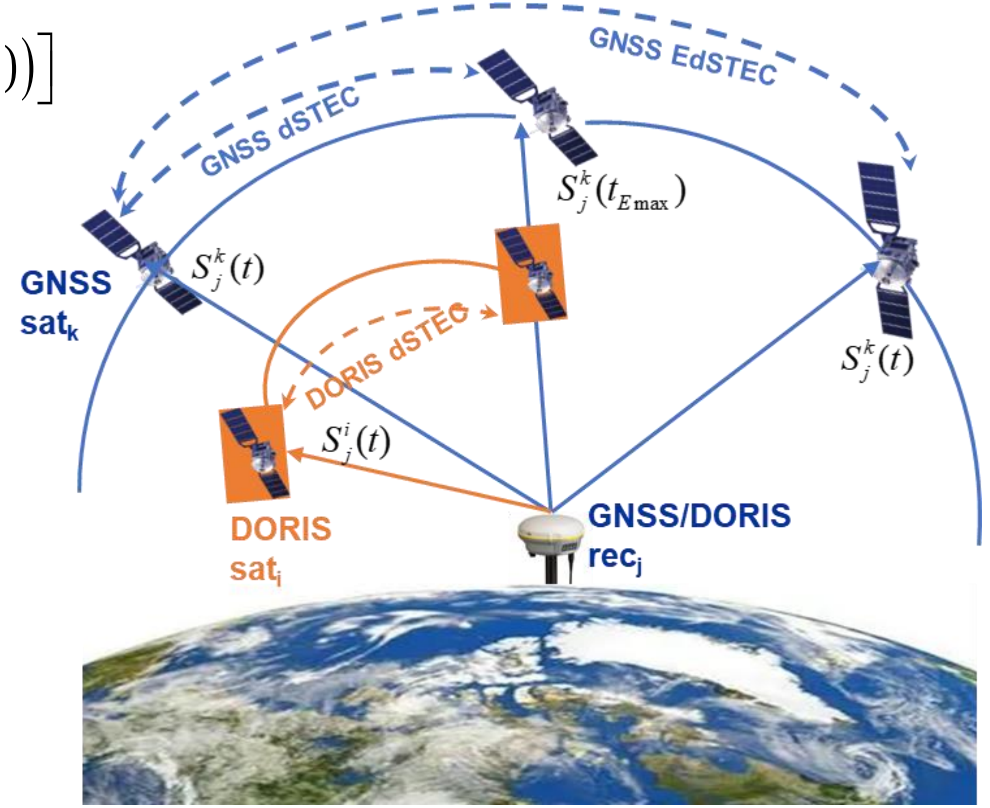
New Method：Combined GIM based on DORIS dSTEC

- Dual-frequency carrier phase measurements form the geometry-free linear combination.

$$dSTEC_{DORIS}(t) = 40.3\times\left(f_1^{-2} - f_2^{-2}\right)\times\left[L_I(t) - L_I(t_{E\max}) - \left(\Delta D(t) - \Delta D(t_{E\max})\right)\right]$$

$$EdSTEC_{GNSS}(t) = 40.3\times\left(f_1^{-2} - f_2^{-2}\right)\times\left[L_I(t) - L_I(t_E)\right]$$

$$dSTEC_{GNSS}(t) = 40.3\times\left(f_1^{-2} - f_2^{-2}\right)\times\left[L_I(t) - L_I(t_{E\max})\right]$$



- Theoretical precision

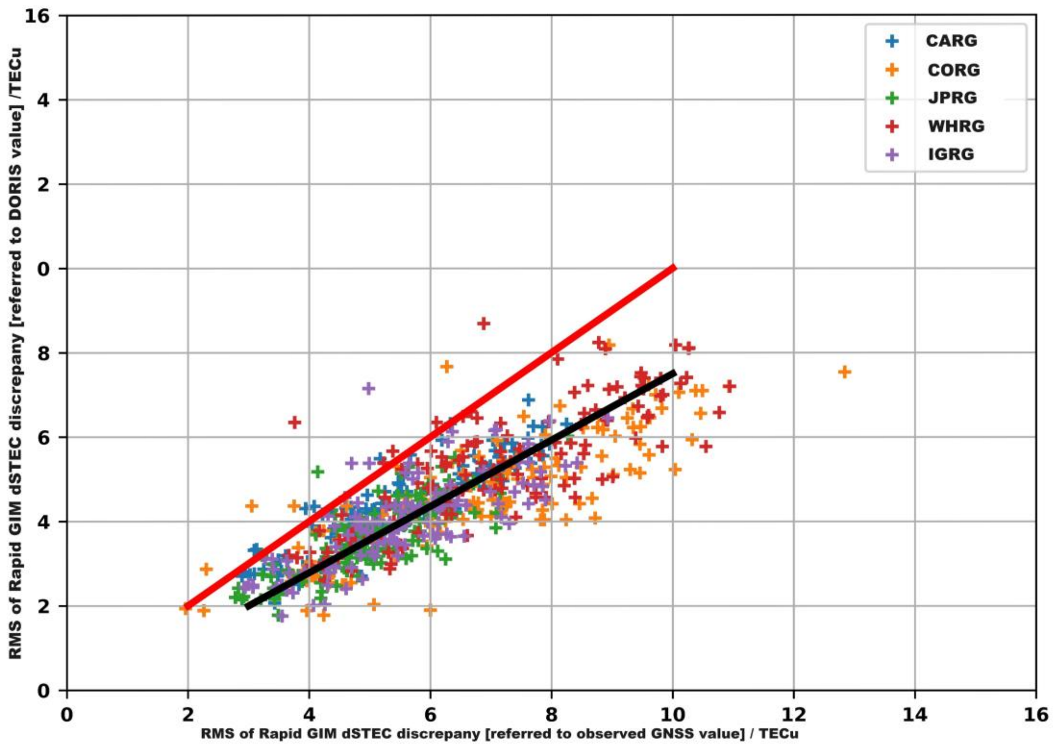
DORIS-dSTEC **0.028 TECu** (σ_{L1}=1.5 mm and σ_{L2}=7.5 mm)

GNSS-dSTEC 0.250 TECu (σ_{L1}= σ_{L2}=2.0 mm)

GNSS-EdSTEC 0.250 TECu (σ_{L1}= σ_{L2}=2.0 mm)

New Method：Combined GIM based on DORIS dSTEC

- The result confirms that DORIS dSTEC assessment can be used as **an independent way** to validate the quality of those ground GPS/GNSS generated ionospheric models.



- 48 co-located stations
- DOY 001-110, 2022
- Rapid GIM validation

Correlation coefficient (CC) = **0.81**

New Method：Combined GIM based on DORIS dSTEC

- Residual extraction

$$\delta_{GIM}(j) = dSTEC_{\mathrm{GIM-SH}}(\varphi_j, \lambda_j) - \boldsymbol{dSTEC_{\mathrm{ref}}(\varphi_j, \lambda_j)}$$

- Original weights

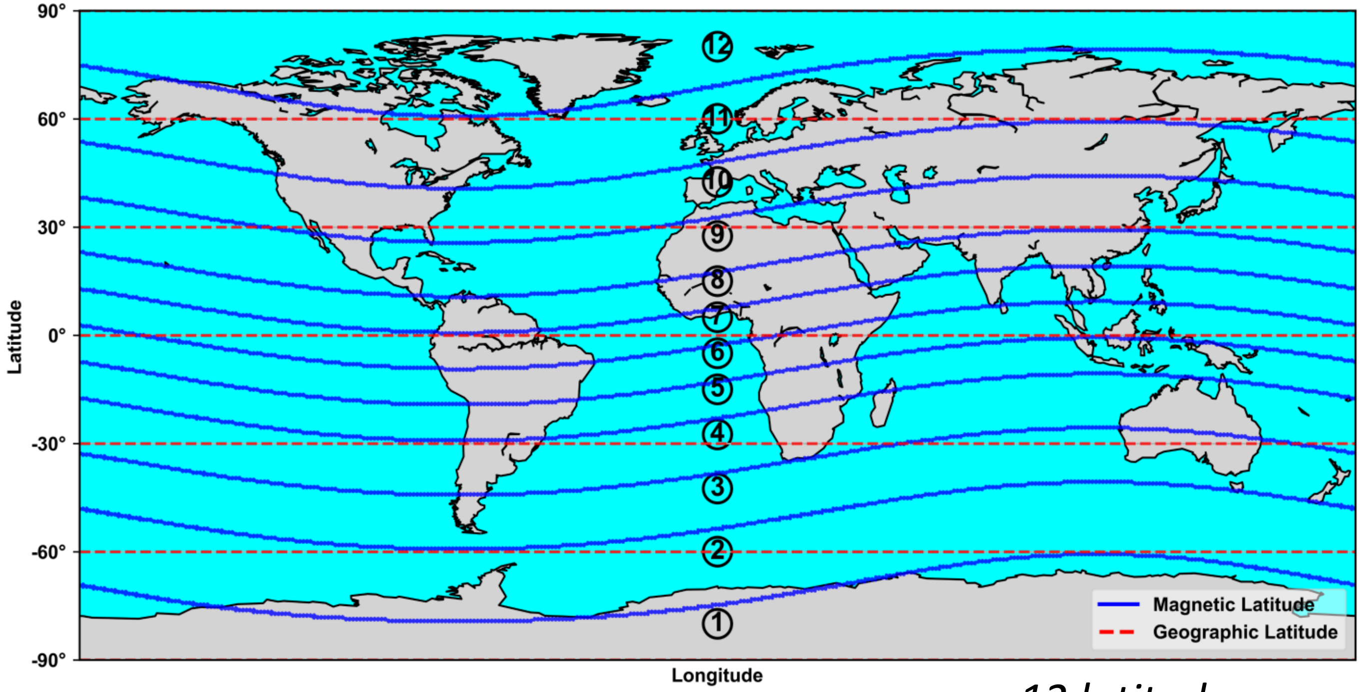
$$W_0 = \left[\frac{\sum(\cos(lat)\cdot \delta_{GIM}(j)^2)}{\sum \cos(lat)}\right]^{-1}$$

- **Normalized weights**

$$w_i = W_0^i \Big/ \sum_{k=1}^{n} W_0^k$$

- Combined GIM

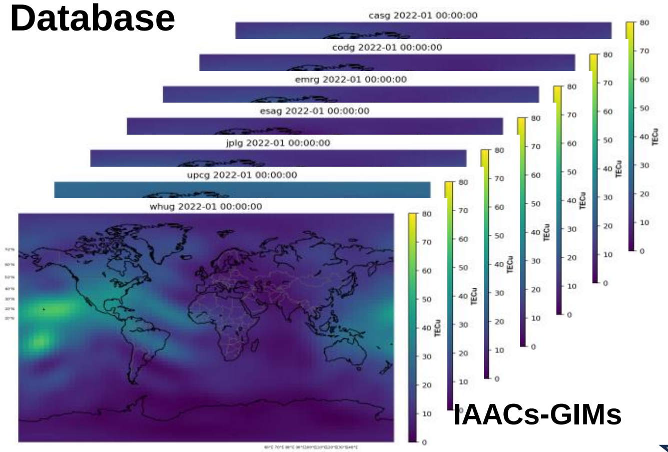
$$VTEC(\beta,\lambda,t) = \sum_{m=1}^{n} w_m * VTEC_{GIM}^{m}(\beta,\lambda,t)$$



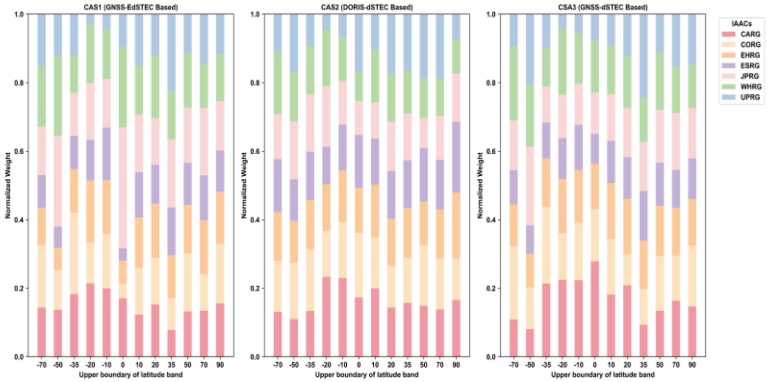
12 latitude zones

New Method：Combined GIM based on DORIS dSTEC

Database



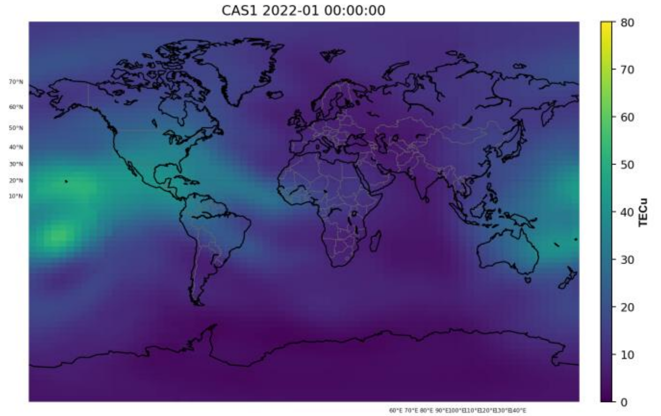
Combined Solution



OUTPUT：Combined GIMs

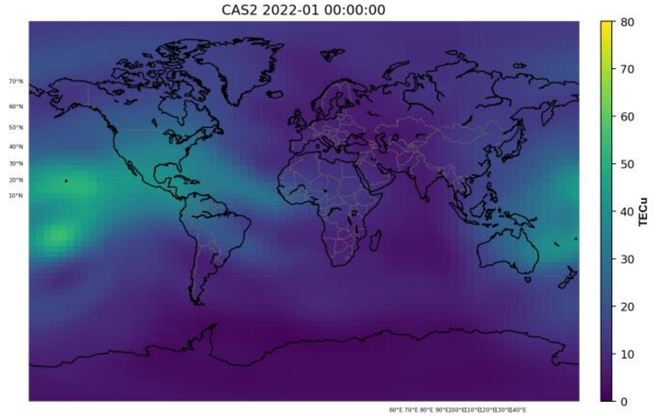
CAS1:

Based on GNSS EdSTEC

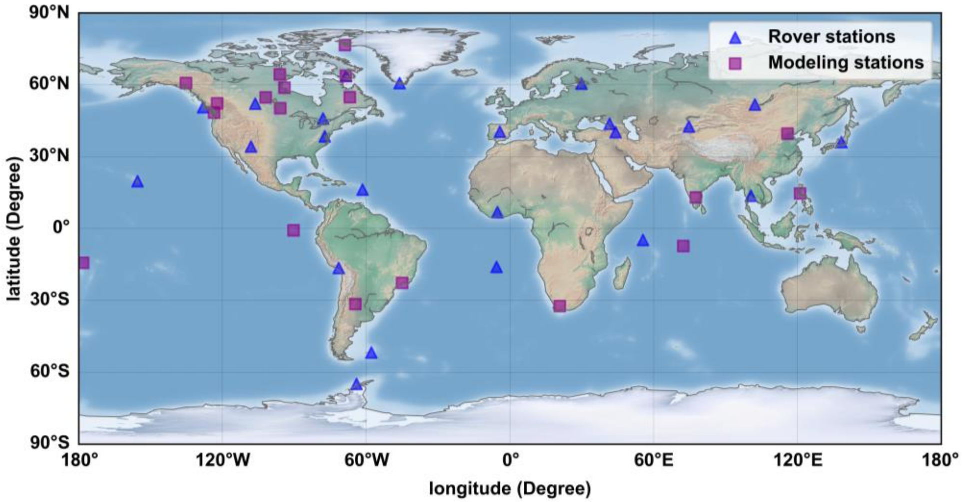


CAS2:

Based on DORIS dSTEC



New Method： Combined GIM based on DORIS dSTEC



GNSS Stations

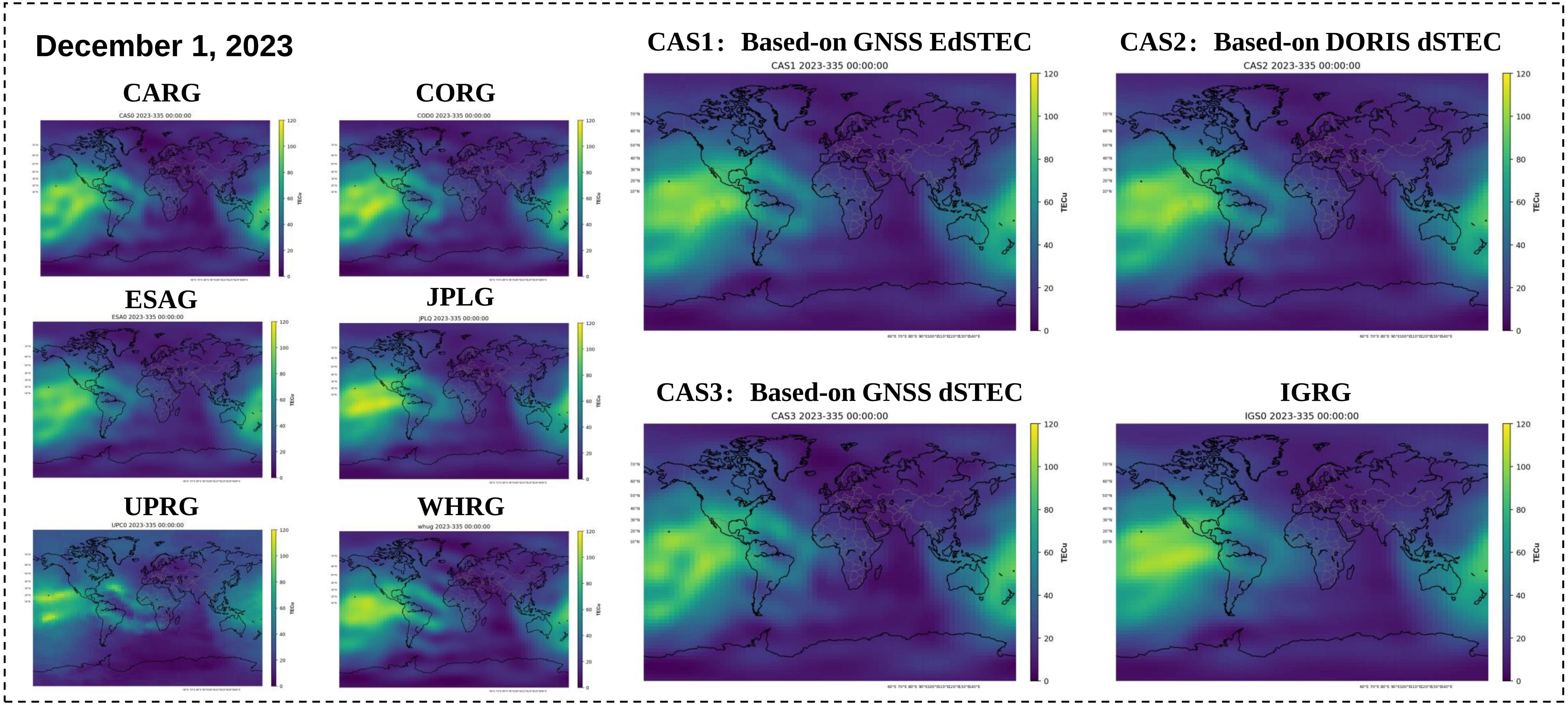
DORIS Beacons

https://ids-doris.org/doris-system/tracking-network/site-logs.html

Products ID	Weighting scheme	PROS	CONS
[A] CAS1	GNSS EdSTEC	• Reduce the impact of mapping errors.	• Data samples are limited. • Correlation with model input
[B] CAS2	DORIS dSTEC	• More independent reference sources • Observation coverage of marine areas.	• Significant delays • Real-time data has a delay of 2-3 hours.
[C] CAS3	GNSS dSTEC	• Reduce the impact of mapping errors.	• Correlation with model input

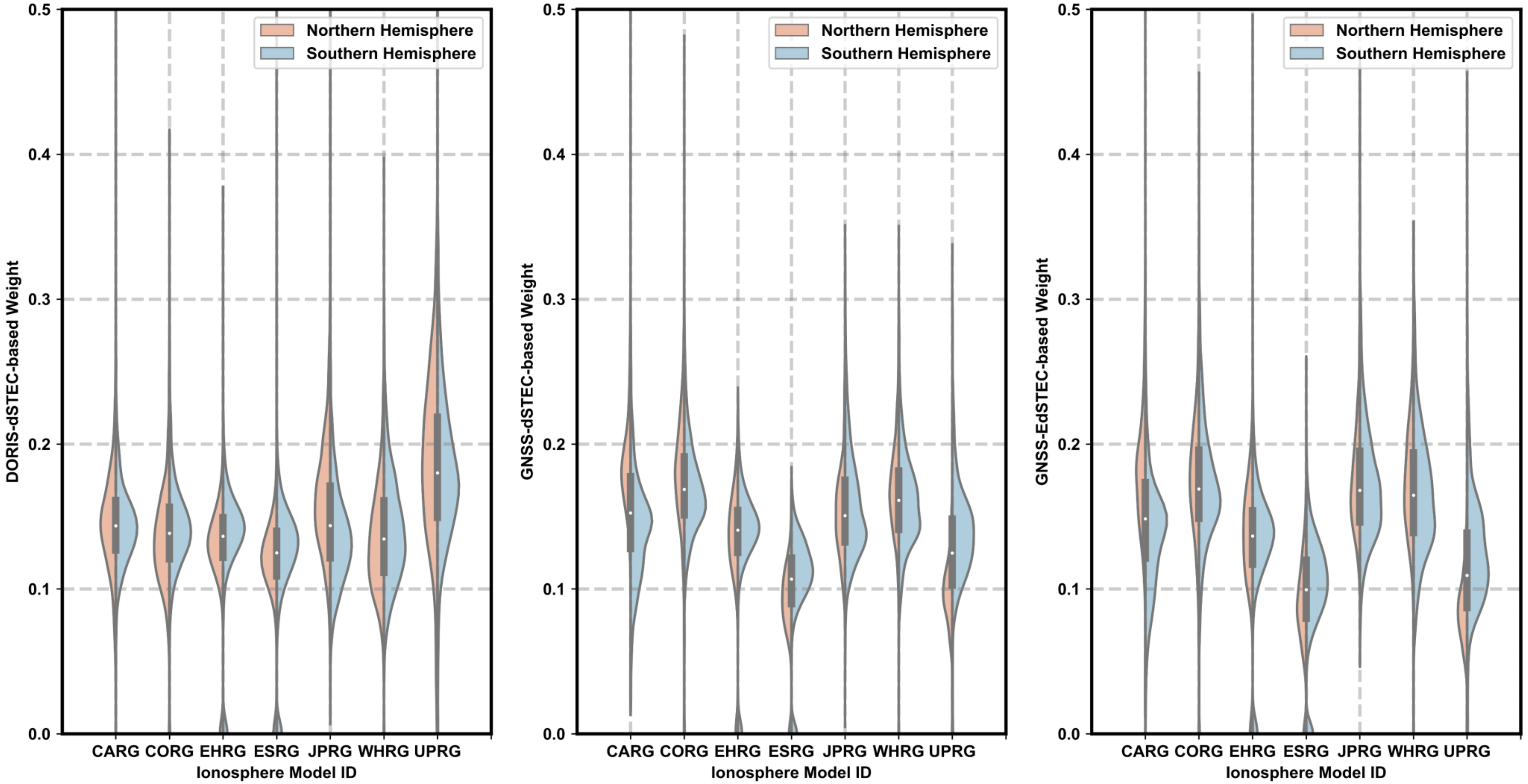
GIM combination and validation

CAS and IGS combined Rapid GIM



GIM combination and validation

Normalized weights in two methods

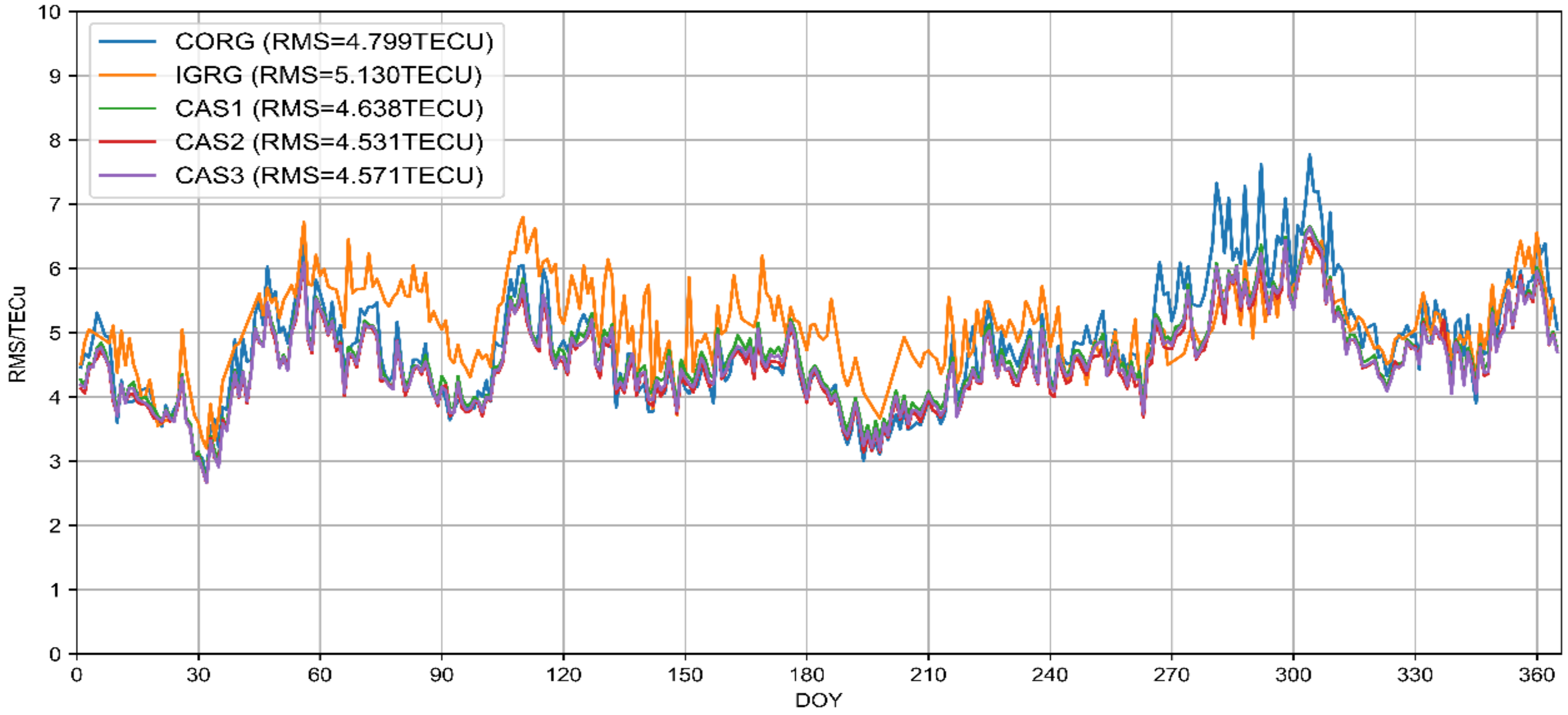


Normalized weights in three methods

ID	2020			2021			2022		
	GNSS dSTEC	GNSS EdSTEC	DORIS dSTEC	GNSS dSTEC	GNSS EdSTEC	DORIS dSTEC	GNSS dSTEC	GNSS EdSTEC	DORIS dSTEC
CARG	0.143	0.139	0.153	0.156	0.149	0.152	0.153	0.148	0.145
CORG	0.155	0.154	0.154	0.172	0.167	0.147	0.171	0.172	0.140
EHRG	0.131	0.132	0.147	0.141	0.137	0.141	0.131	0.129	0.127
ESRG	0.112	0.112	0.144	0.113	0.109	0.137	0.099	0.095	0.117
JPRG	0.146	0.168	0.120	0.141	0.168	0.132	0.156	0.173	0.148
WHRG	0.144	0.145	0.133	0.152	0.155	0.138	0.163	0.167	0.138
UPRG	0.166	0.150	0.148	0.124	0.115	0.150	0.126	0.114	0.184

GIM combination and validation

Accuracy w.r.t JASON-3 VTEC



Year	GIMs RMS [TECU]				
	CORG	IGRG	CAS1	CAS2	CAS3
2021	4.799	5.130	4.638	**4.531**	4.571
2022	6.776	6.857	6.405	**6.305**	6.353

Conclusions and future work

- The concept of DORIS dSTEC assessment is proposed, which is the extension of the existing GNSS dSTEC validation method. DORIS dSTEC assessment can be used as an independent way to validate the quality of those ground GPS/GNSS generated ionospheric models. (CC = 0.82)
- IGS-CAS generated three types Combined GIM, i.e., CAS1, CAS2 and CAS3 (w.r.t JASON VTEC)
  - CAS1 (GNSS EdSTEC): RMS = 6.405 TECU
  - **CAS2 (DORIS dSTEC): RMS = 6.305 TECU**
  - CAS3 (GNSS dSTEC) : RMS = 6.353 TECU
  - IGRG (GNSS EdSTEC): RMS = 6.857 TECU
- More validation in positioning domain for the combined global ionospheric TEC,
- As more DORIS near-real-time data becomes available, the timeliness of this comprehensive product will be significantly improved.

Full Name: **CAS2OPSRAP_$YYYY$DOY0000_01D_30M_GIM.INX**

Some Reference.

- *Hernández-Pajares, M., Roma-Dollase, D., Krankowski, A., García-Rigo, A., & Orús-Pérez, R. (2017). Methodology and consistency of slant and vertical assessments for ionospheric electron content models. Journal of Geodesy, 91(12), 1405-1414. doi:10.1007/s00190-017-1032-z*
- *Liu, A., Wang, N., Dettmering, D., Li, Z., Schmidt, M., Wang, L., & Yuan, H. (2023). Using DORIS data for validating real-time GNSS ionosphere maps. Advances in Space Research, 72(1), 115-128. doi:10.1016/j.asr.2023.01.050*
- *Liu, Q., Hernández-Pajares, M., Yang, H., Monte-Moreno, E., Roma-Dollase, D., García-Rigo, A., . . . Ghoddousi-Fard, R. (2021). The cooperative IGS RT-GIMs: a reliable estimation of the global ionospheric electron content distribution in real time. Earth System Science Data, 13(9), 4567-4582. doi:10.5194/essd-13-4567-2021*

Thanks for your attention

In case of any questions, please feel free to contact

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