IGS 2026 WORKSHOP
SANTIAGO DE CHILE
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IGS INTERNATIONAL GNSS SERVICE

RT-FAIRS: Real-Time Factor-Adjusted Ionospheric Residual Statistics approach for generating accuracy information in Global Ionospheric Maps

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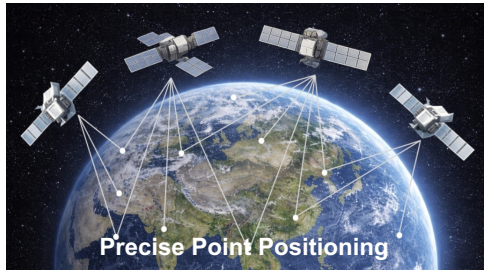
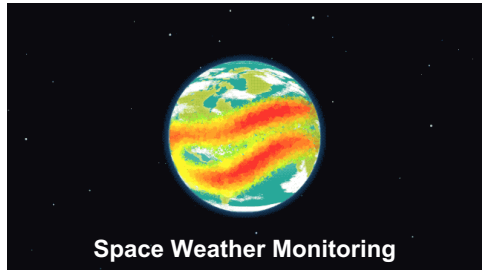
IGS Real-Time Ionosphere Service

- IGS provided real-time global ionospheric maps (RT-GIMs)
  - RTACs generating RT-GIMs increased from 4 to **5** by May 2026: CAS, CNES, UPC, WHU & **NRCan**
  - RT-GIMs available in both RTCM-SSR and IGS-SSR formats
  - UPC provided the first IGS combined RT-GIM in 2019 (RTCM-SSR)
  - UPC and CAS have provided two independent combined RT-GIMs since 2022 (IGS-SSR)





IGS Real-Time Ionosphere Service

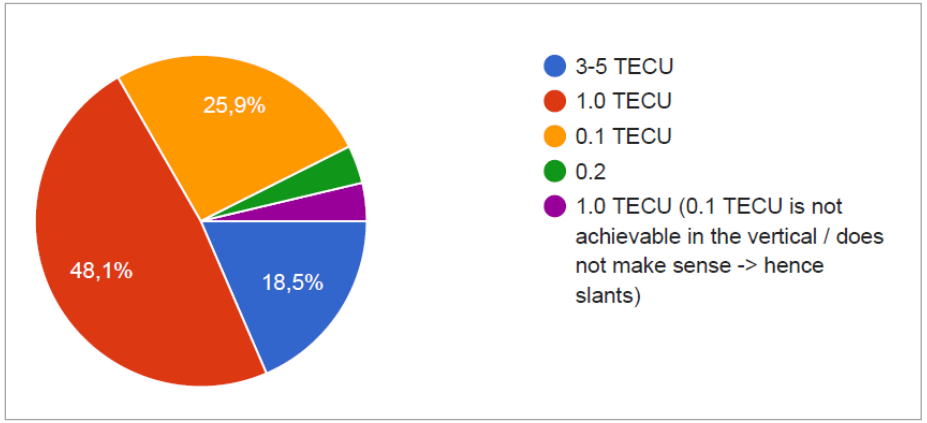
- IGS provided real-time global ionospheric maps (RT-GIMs)

RTACs	Caster	Mountpoint	Interval
CAS*	products.igs-ip.net:2101	SSR?00CAS1	60s
CNES	products.igs-ip.net:2101	SSR?00CNE1	60s
UPC	products.igs-ip.net:2101	IONO00UPC1	15s
WHU	products.igs-ip.net:2101	IONO00WHU1	60s
NRCan	products.igs-ip.net:2101	IONO00NRC1	60s
UPC-combined	products.igs-ip.net:2101	**IONO00IGS1**	15s
CAS-combined*	products.igs-ip.net:2101	**IONO01IGS1**	60s

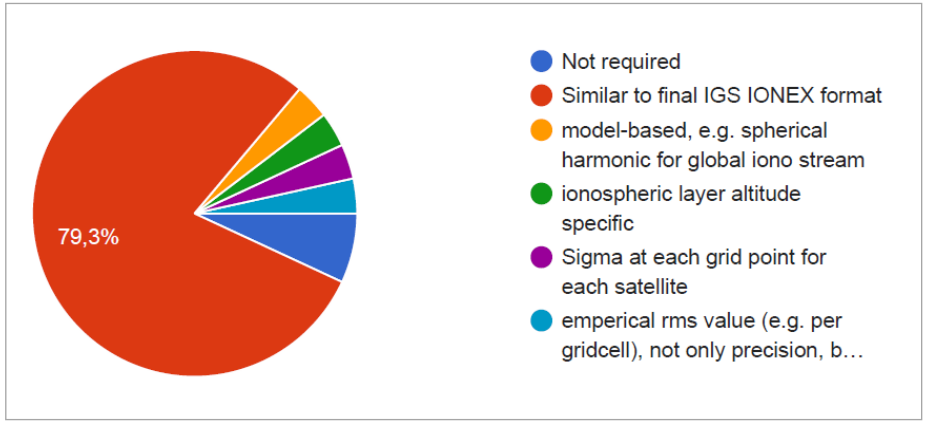
*RT-GIM in IONEX format available from CAS https://data.bdsmart.cn/pub/product/rts/iono/

Motivation

- IGS questionnaire for improved real-time ionosphere correction messages (2022)
  - **Req. 1**: RT VTEC accuracy better than 1.0 TECU (50% of users)
  - **Req. 2**: RT RMS information in IONEX format, in addition to corrections (80% of users)



RT-VTEC accuracy requirement



RT-RMS information requirement

Motivation

- **Roadmap for IGS Real-Time Activities (defined in 2022)**
  - **Phase 1**: extend IGS-SSR format with new messages for attitude, SRP (APC) / CoM offset (draft).
  - **Phase 2**: define an agreed format and to broadcast the RMS map associated to RT VTEC products.
  - **Phase 3**: define an agreed format and to broadcast a satellite-dependent Slant TEC (postprned).
- **IGS Real-Time Ionosphere Task Force**
  - **Task 1**: RT-GIM combination (completed: CAS + UPC)
  - **Task 2**: RT ionospheric RMS message design and product service (ongoing)

RT-FAIRS: algorithms

- **RT-FAIRS**: Real-Time Factor-Adjusted Ionospheric Residual Statistics [Bayesian interpretation]

$$AI = (1-\alpha)\cdot w_{scale}\cdot DI_{SK}\cdot \sigma_{grid} + \alpha \cdot WR$$

RT data covered region

NO real data covered

- w_{scale} - *scale factor magnifying the model provided precision* (variance–covariance matrix)

$$w_{scale} = \frac{\sum_{i=0}^{N} n_i \cdot scale_i}{\sum_{i=0}^{N} n_i}; \qquad scale = \frac{WR}{\sigma_0 \cdot DI_{SK}}$$

- DI_{SK} - *factor adopted to adjust the residual skewness and kurtosis*

$$DI_{SK} = \frac{1}{2}\left(\frac{|S_K|}{E[|S_K|]} + \frac{|K_E|}{E[|K_E|]}\right)$$

- WR - weighted precision through an improved IDW interpolation algorithm

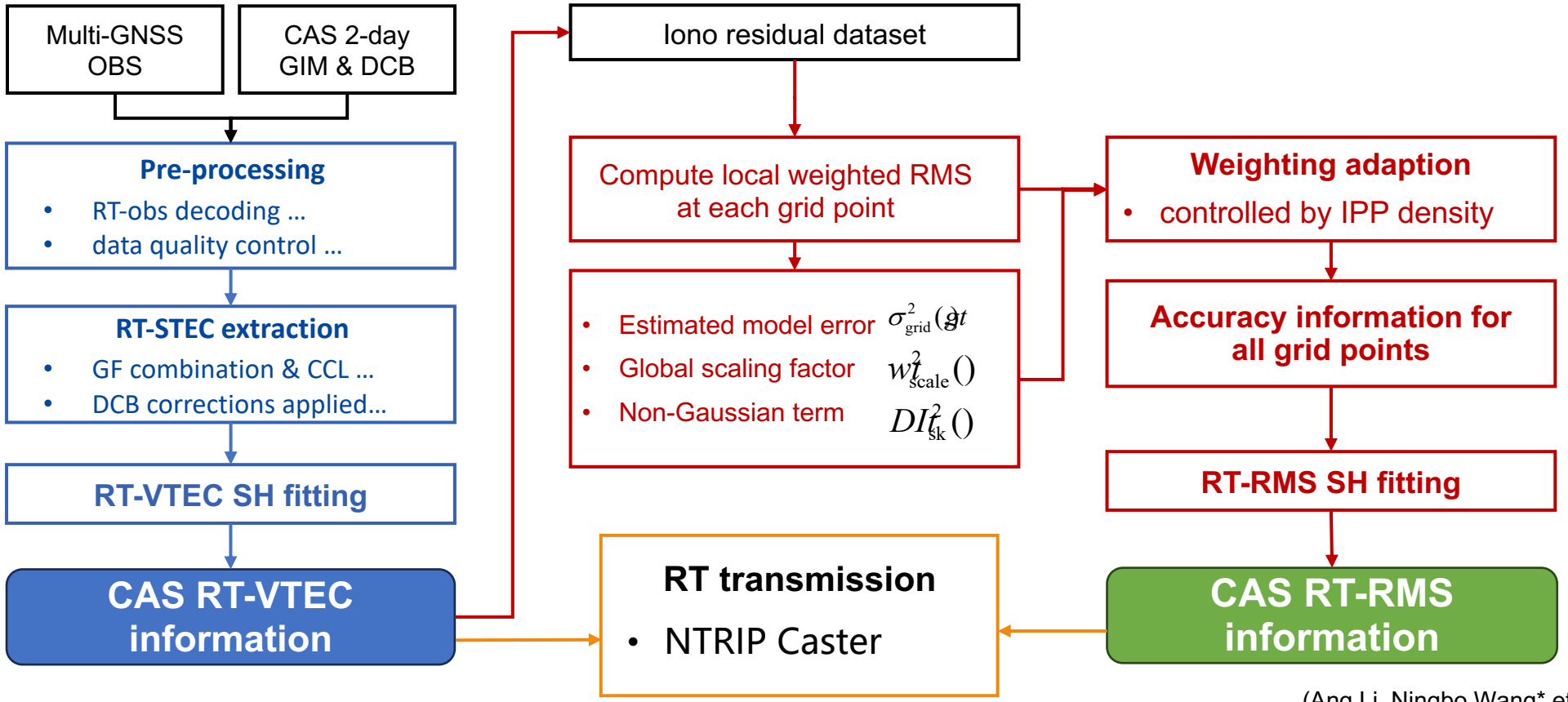
$$WR = \sqrt{\frac{\sum w_i \cdot r_{ipp}^2}{\sum w_i}}$$

$$w_i = \begin{cases} \frac{1}{D_1 \cdot \sigma_r^2}, if \;\; dist_i < D_1 \\ \frac{1}{D_2^2 \cdot \sigma_r^2}, if \;\; D_1 < dist_i < D_2 \\ \frac{1}{D_3^2 \cdot \sigma_r^2}, if \;\; D_2 < dist_i < D_3 \end{cases}$$

(Ang Li, Ningbo Wang* et al., Space Weather, 2026)

RT-FAIRS: algorithms

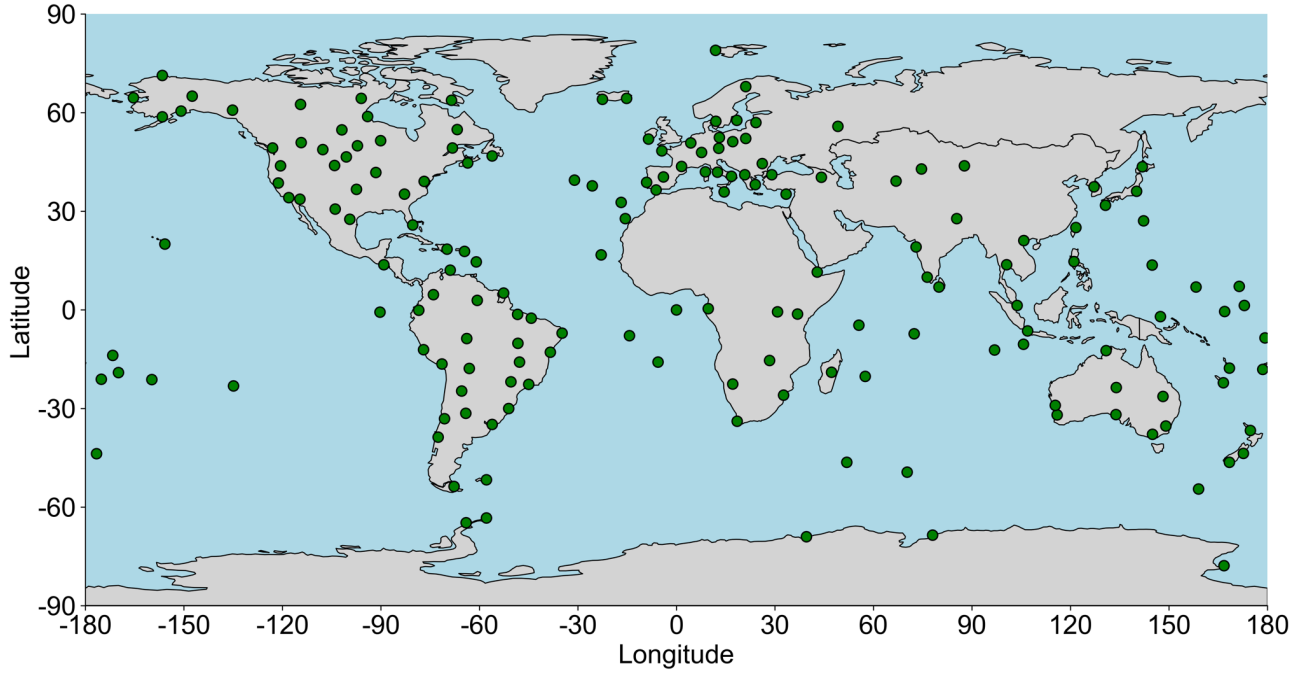
- **RT-FAIRS**: Real-Time Factor-Adjusted Ionospheric Residual Statistics [Bayesian interpretation]



(Ang Li, Ningbo Wang* et al., Space Weather, 2026)

RT-FAIRS: data processing

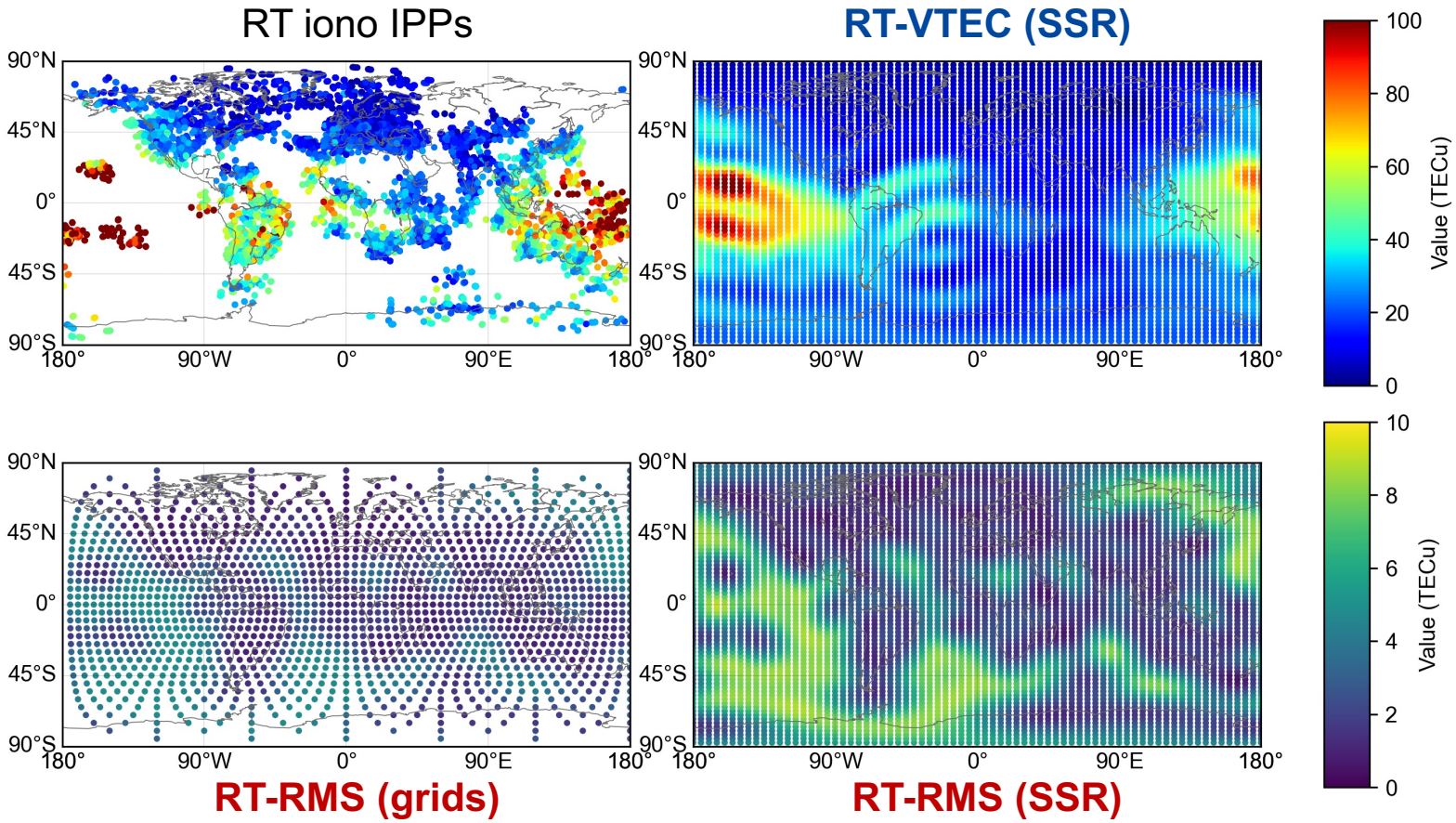
- **RT-FAIRS**: Real-Time Factor-Adjusted Ionospheric Residual Statistics [Bayesian interpretation]
  - Real-time stations: 180 IGS RTS stations
  - GNSS data used: BDS-3(B1/B3), GPS(L1/L2) & Galileo(E1/E5a)



(Ang Li, Ningbo Wang* et al., Space Weather, 2026)

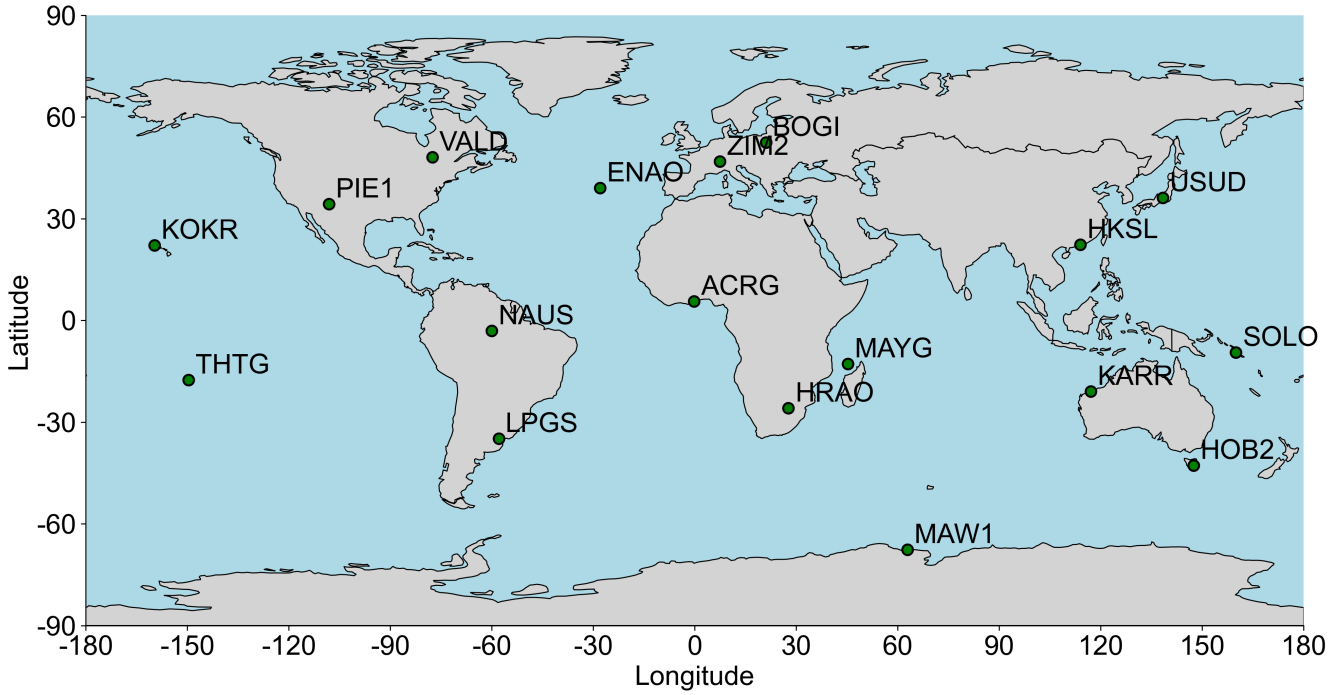
RT-FAIRS: data processing

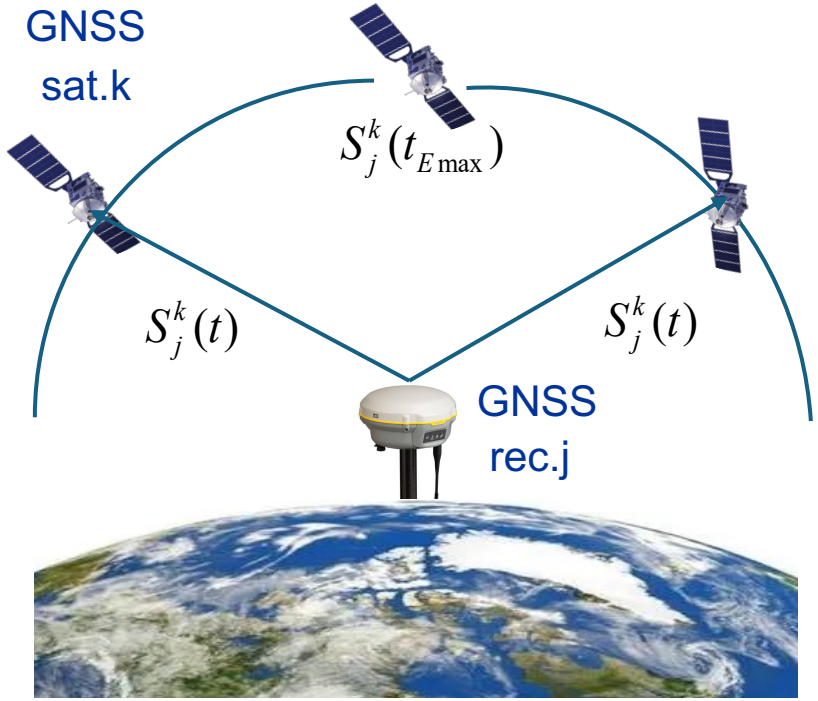
- **RT-FAIRS**: Real-Time Factor-Adjusted Ionospheric Residual Statistics [Bayesian interpretation]



RT-FAIRS: performance validation

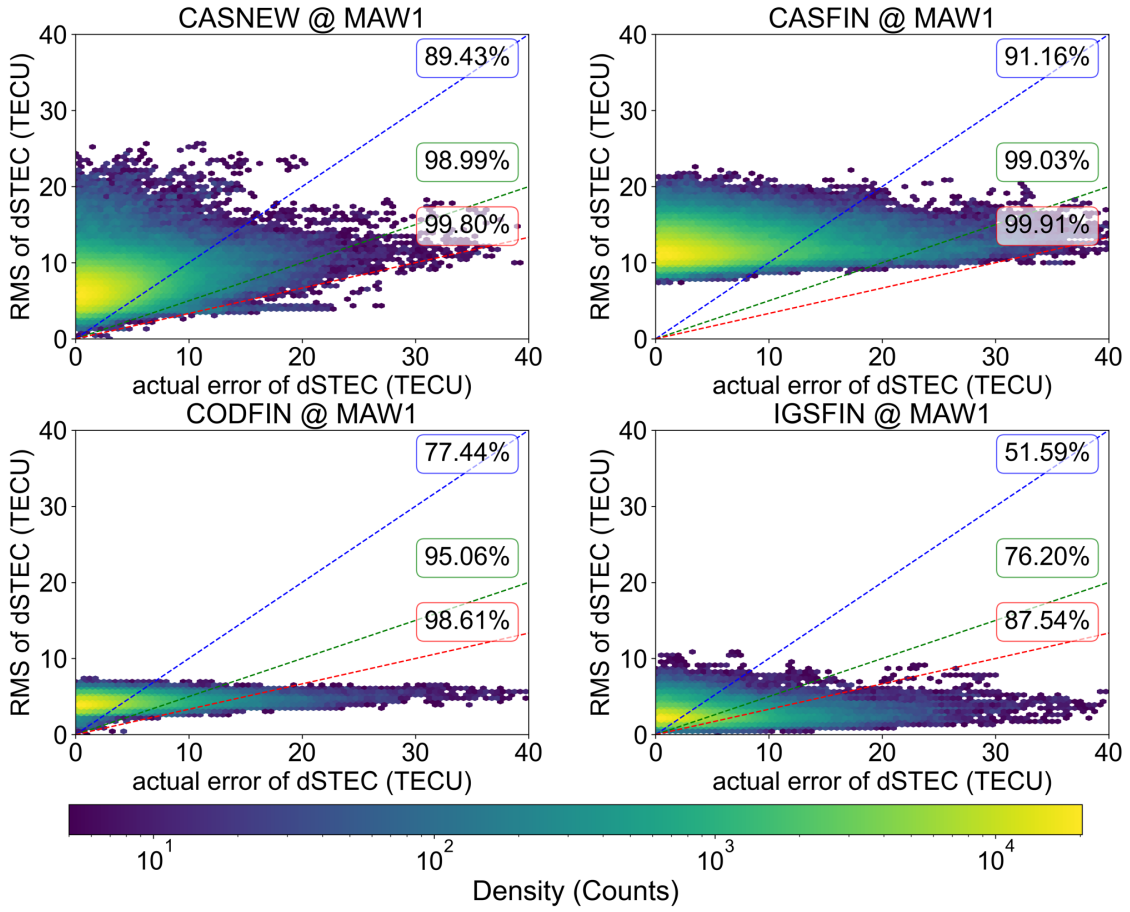
- Validating RT-GIM accuracy information: **Correlation** | **RMSE analysis**
  - Validation stations: 18 independent IGS stations not used in RT-GIM generation
  - GPS dSTEC derived at individual stations is used for RT-RMS assessment

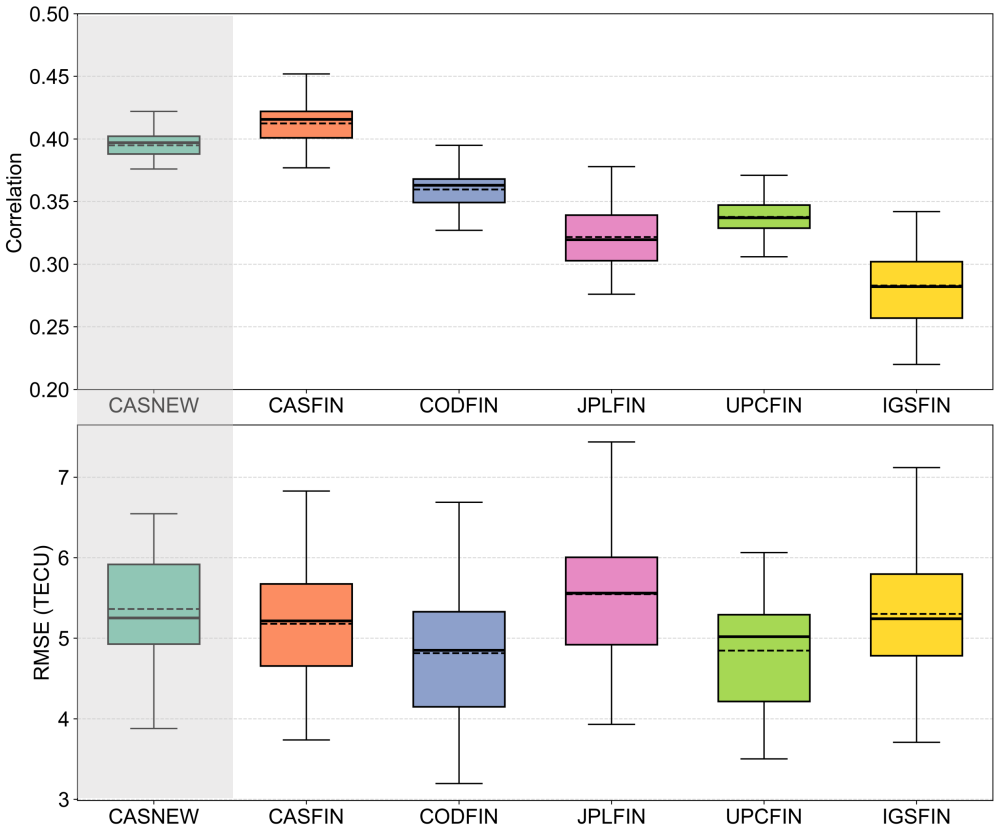




RT-FAIRS: performance validation

- Validating RT-GIM accuracy information: **Correlation** | **RMSE analysis**





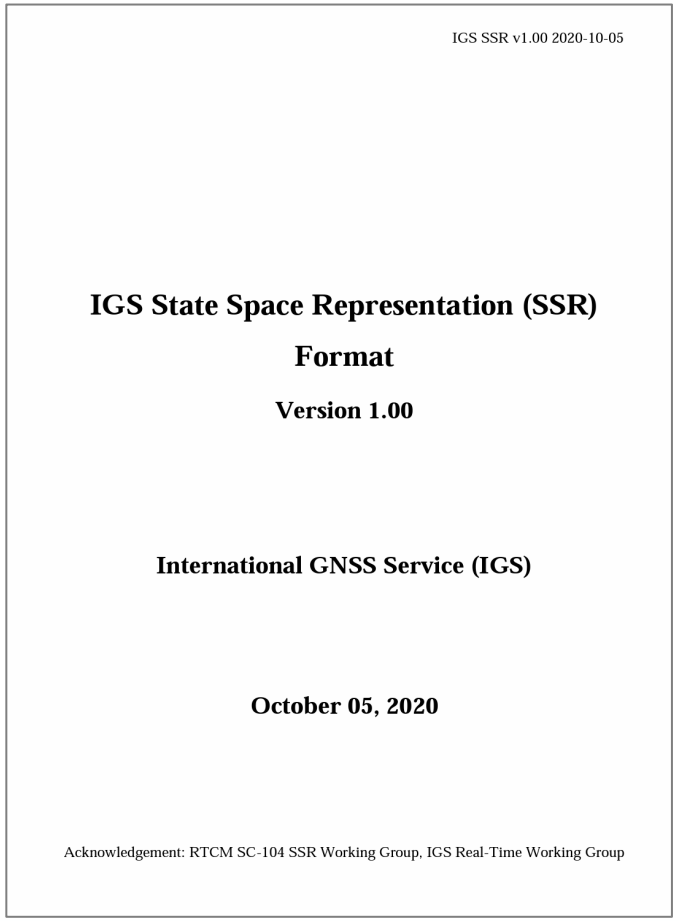
RT-FAIRS: performance validation

- Ionospheric RMS information accelerates PPP convergence during initialization phase

	PPP model	Ionospheric constraint	First 30 epoch (m)		Convergence time (mins)		
			Horizontal	Vertical	100cm	50cm	20cm
Quiet pepiod	PPP	/	**2.85**	**3.06**	**22.6**	**38.9**	**77.4**
	PPP-IC	0.25m	1.20	1.48	19.7	41.3	83.1
	PPP-IC	0.09m	1.21	1.50	24.9	51.7	92.6
	PPP-IC	**RT-FAIRS**	**1.16**	**1.44**	**17.3**	**35.5**	**76.5**
Storm period	PPP	/	**2.56**	**2.75**	**20.9**	**36.4**	**76.6**
	PPP-IC	0.25m	2.33	2.65	17.4	33.7	74.9
	PPP-IC	0.09m	2.33	2.68	19.1	36.5	78.0
	PPP-IC	**RT-FAIRS**	**2.32**	**2.62**	**17.2**	**32.7**	**73.3**

RT-FAIRS: product service

- Proposal for a New IGS-SSR Ionospheric RMS Message (message type 202)



IGS SSR v1.00 2020-10-05

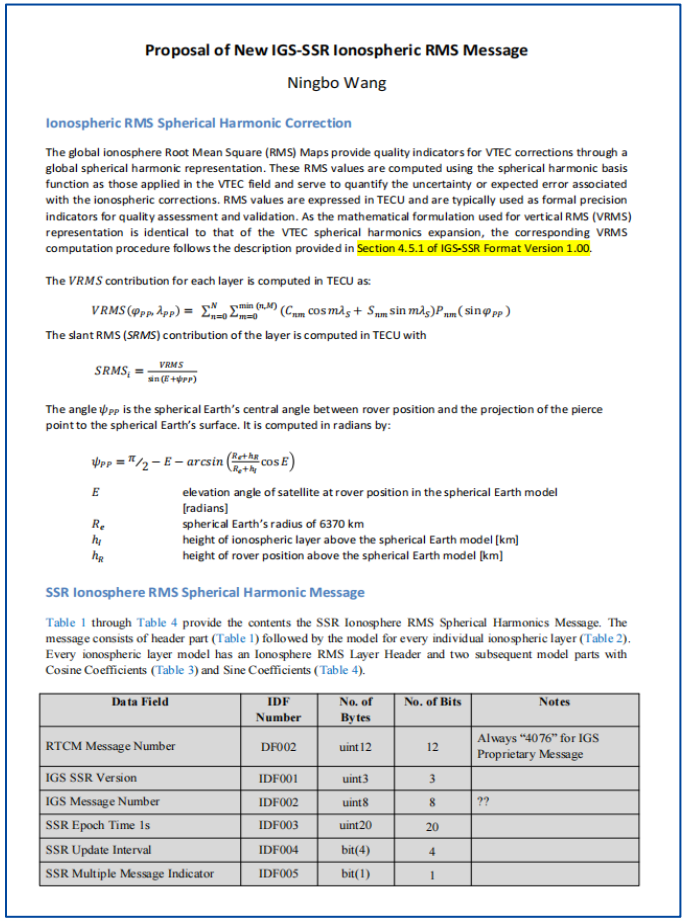
IGS State Space Representation (SSR) Format

Version 1.00

International GNSS Service (IGS)

October 05, 2020

Acknowledgement: RTCM SC-104 SSR Working Group, IGS Real-Time Working Group



Proposal of New IGS-SSR Ionospheric RMS Message

Ningbo Wang

Ionospheric RMS Spherical Harmonic Correction

The global ionosphere Root Mean Square (RMS) Maps provide quality indicators for VTEC corrections through a global spherical harmonic representation. These RMS values are computed using the spherical harmonic basis function as those applied in the VTEC field and serve to quantify the uncertainty or expected error associated with the ionospheric corrections. RMS values are expressed in TECU and are typically used as formal precision indicators for quality assessment and validation. As the mathematical formulation used for vertical RMS (VRMS) representation is identical to that of the VTEC spherical harmonics expansion, the corresponding VRMS computation procedure follows the description provided in Section 4.5.1 of IGS-SSR Format Version 1.00.

The $VRMS$ contribution for each layer is computed in TECU as:

$$VRMS(\varphi_{PP}, \lambda_{PP}) = \sum_{n=0}^{N} \sum_{m=0}^{\min(n,M)} (C_{nm} \cos m\lambda_S + S_{nm} \sin m\lambda_S) P_{nm}(\sin \varphi_{PP})$$

The slant RMS ($SRMS$) contribution of the layer is computed in TECU with

$$SRMS_i = \frac{VRMS}{\sin(E + \psi_{PP})}$$

The angle ψ_{PP} is the spherical Earth's central angle between rover position and the projection of the pierce point to the spherical Earth's surface. It is computed in radians by:

$$\psi_{PP} = \pi/2 - E - arcsin\left(\frac{R_e + h_R}{R_e + h_I} \cos E\right)$$

E	elevation angle of satellite at rover position in the spherical Earth model [radians]
R_e	spherical Earth's radius of 6370 km
h_I	height of ionospheric layer above the spherical Earth model [km]
h_R	height of rover position above the spherical Earth model [km]

SSR Ionosphere RMS Spherical Harmonic Message

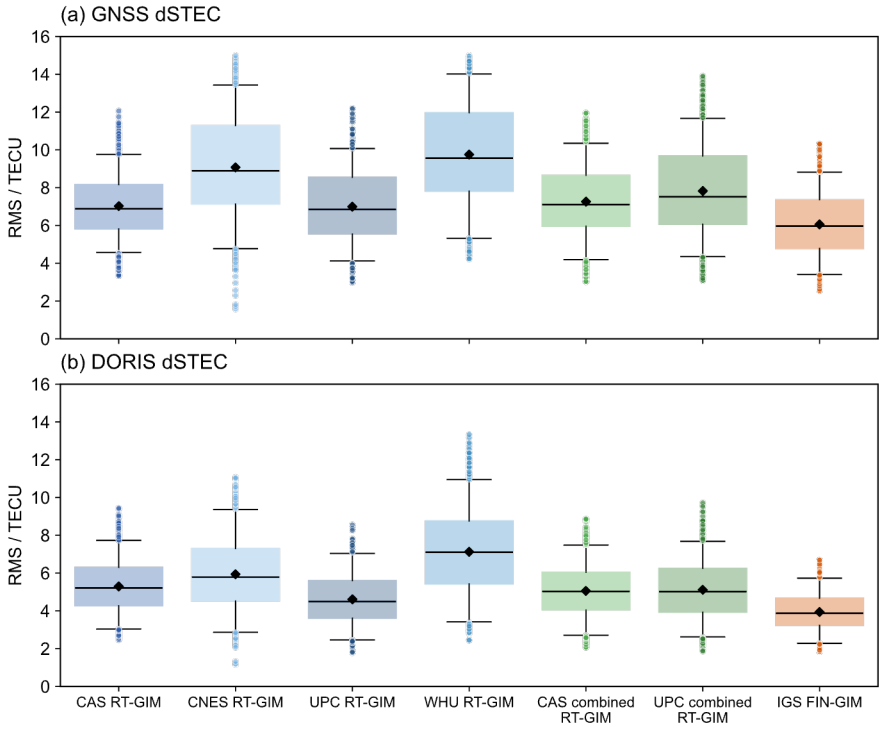
Table 1 through Table 4 provide the contents the SSR Ionosphere RMS Spherical Harmonics Message. The message consists of header part (Table 1) followed by the model for every individual ionospheric layer (Table 2). Every ionospheric layer model has an Ionosphere RMS Layer Header and two subsequent model parts with Cosine Coefficients (Table 3) and Sine Coefficients (Table 4).

Data Field	IDF Number	No. of Bytes	No. of Bits	Notes
RTCM Message Number	DF002	uint12	12	Always "4076" for IGS Proprietary Message
IGS SSR Version	IDF001	uint3	3	
IGS Message Number	IDF002	uint8	8	??
SSR Epoch Time 1s	IDF003	uint20	20	
SSR Update Interval	IDF004	bit(4)	4	
SSR Multiple Message Indicator	IDF005	bit(1)	1	

RT-GIM Applications

- CAS RT-GIMs for space weather monitoring

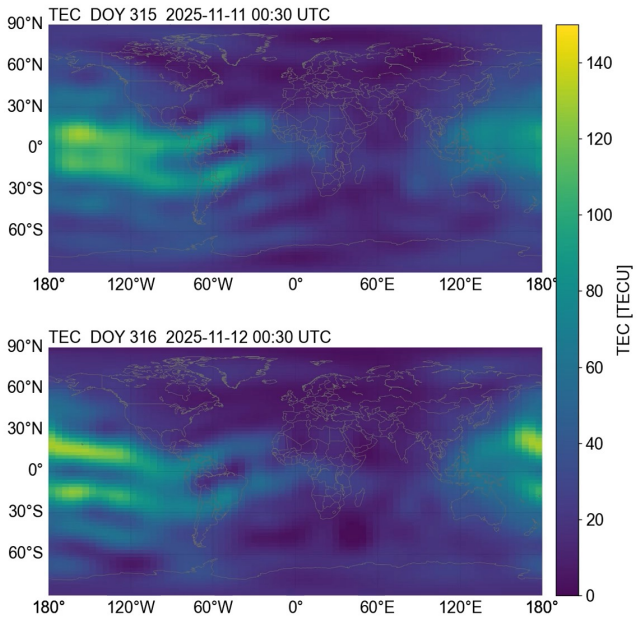
Operational Runs at **CMA**
ICAO Global Space Weather Center



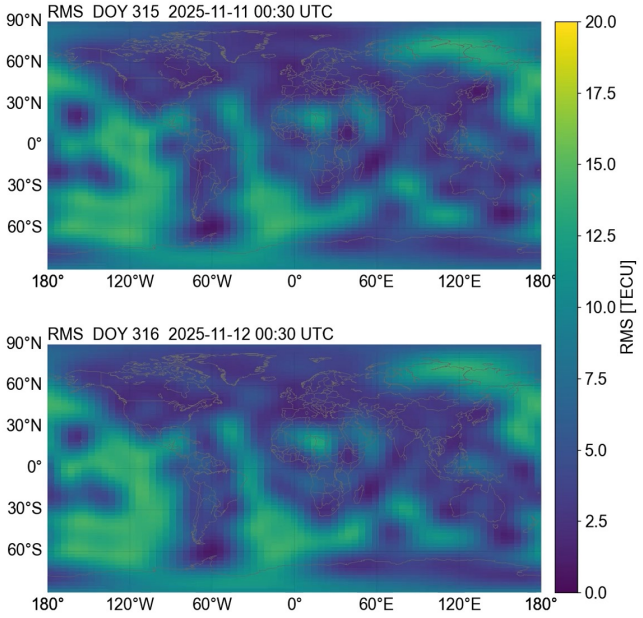
Routine validation using GPSS- and DORIS-dSTEC

RT-GIM Applications

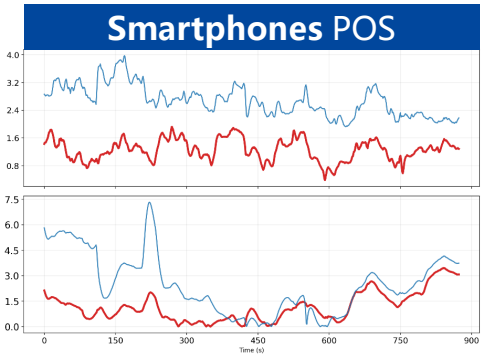
- CAS RT-GIMs for precise positioning of smartphones and smartwatches



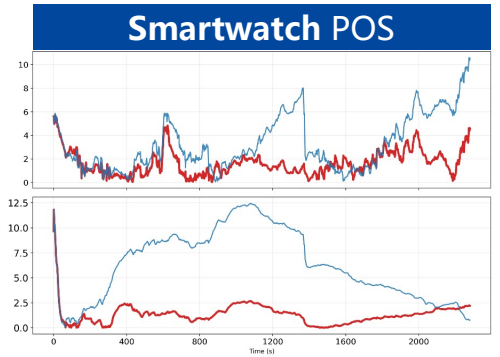
Data source: CAS
GIM: IGS-SSR RT-VTEC



Data source: CAS
GIM: IGS-SSR RT-RMS



Hor. ***52.3%***
Ver. ***51.7%***



Hor. ***51.1%***
Ver. ***76.7%***

Real-Time Service

- CAS Real-Time Ionospheric Service
  - 2018: real-time global VTEC products
  - 2022: real-time combined global VTEC products
  - 2025: real-time global ionospheric RMS products
  - Ionospheric mountpoints (message types 201 for VTEC & 202 for RMS):

    IONO00CAS1 (IGS-SSR, **VTEC & RMS**) | IONO01IGS1 (IGS-SSR, RT-VTEC)
  - SSRC01CAS1: orbit, clock, code/phase biases, global **VTEC & RMS** maps
  - IGS BKG caster: products.igs-ip.net | CAS caster: igs.bdsmart.cn

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1–5 June 2026

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Thank You!

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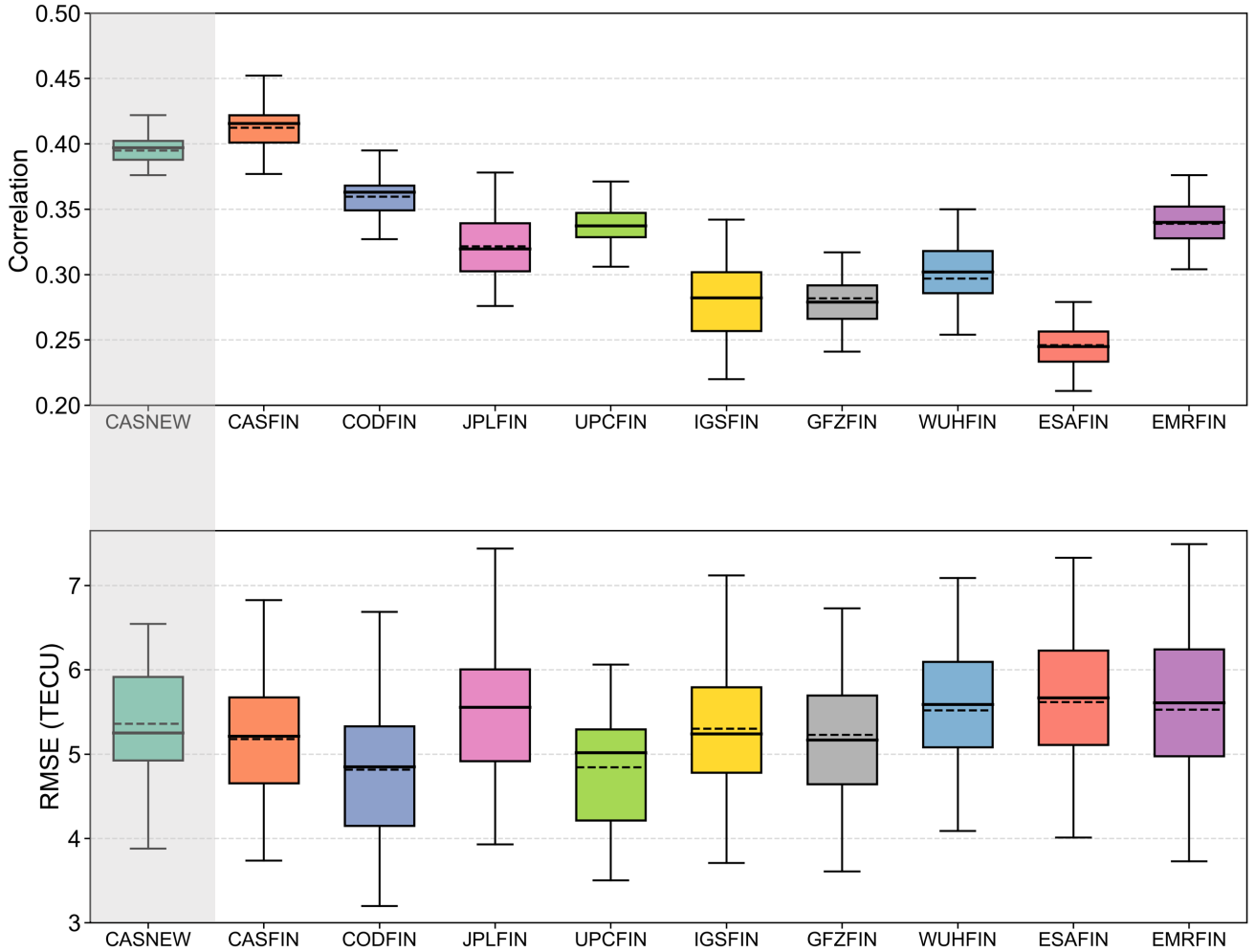
CAS caster: **https://igs.bdsmart.cn**

CAS data center: **https://data.bdsmart.cn**

Real-time versus final RMS



Real-time versus final RMS

Period	GIMs	Correlation coefficients			RMSE (TECU)		
		Mean	Median	STD	Mean	Median	STD
Quiet period	**RT-CAS**	0.395	0.397	0.016	5.35	5.38	0.78
	CASFIN	0.412	0.416	0.017	5.18	5.23	0.71
	CODFIN	0.360	0.363	0.016	4.83	4.85	0.77
	JPLFIN	0.322	0.320	0.022	5.56	5.56	0.80
	UPCFIN	0.338	0.337	0.017	4.85	5.05	0.66
	WUHFIN	0.297	0.302	0.024	5.52	5.59	0.75
	ESAFIN	0.246	0.245	0.017	5.62	5.67	0.83
	EMRFIN	0.339	0.340	0.018	5.53	5.61	0.94
	IGSFIN	**0.283**	**0.282**	**0.035**	**5.32**	**5.24**	**0.76**
	GFZFIN	0.282	0.279	0.019	5.23	5.17	0.78
Storm period	**RT-CAS**	0.379	0.380	0.019	5.47	5.56	0.88
	CASFIN	0.390	0.392	0.021	5.27	5.32	0.77
	CODFIN	0.334	0.337	0.024	5.03	5.14	0.78
	JPLFIN	0.323	0.324	0.024	6.08	6.13	0.81
	UPCFIN	0.331	0.335	0.021	5.32	5.41	0.71
	WUHFIN	0.295	0.280	0.031	5.99	5.94	0.86
	ESAFIN	0.265	0.257	0.027	6.12	6.22	0.92
	EMRFIN	0.327	0.320	0.025	6.23	6.42	0.97
	IGSFIN	**0.277**	**0.298**	**0.026**	**5.43**	**5.46**	**0.77**
	GFZFIN	0.281	0.273	0.028	5.78	5.96	0.93