Generation and Validation of the Second IGS Combined Real-Time Global Ionospheric Maps

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IGS 2022 Virtual Workshop

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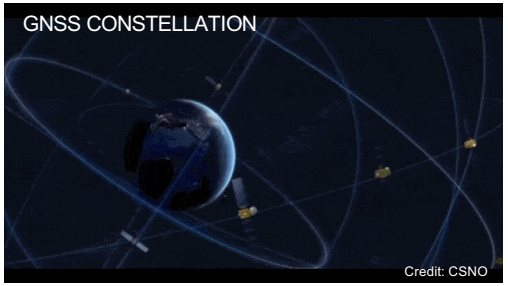
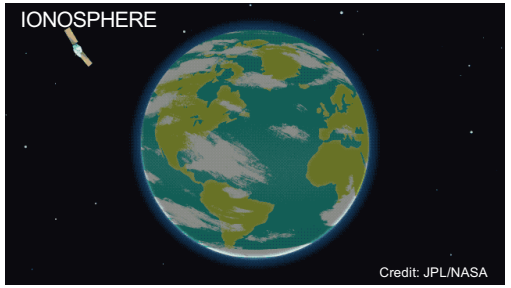
  Validation -> TEC domain (IGS-GIM, GNSS, Jason-3, DORIS)

  Validation -> Positioning domain (SPP, SF-PPP)
- Summary and conclusions





Motivation for RT-GIM combination

Overview of RT-GIMs provided by different ACs

AC	Caster	Mountpoint	Interval
CAS*	products.igs-ip.net:2101	SSRA00CAS0, SSRC00CAS0 (RTCM-SSR)	60s
		SSRA00CAS1, SSRC00CAS1 (IGS-SSR)	
CNES	products.igs-ip.net:2101	SSRA00CNE0, SSRC00CNE0 (RTCM-SSR)	60s
		SSRA00CNE1, SSRC00CNE1 (IGS-SSR)	
UPC	products.igs-ip.net:2101	IONO00UPC1 (IGS-SSR)	15s
WHU	58.49.94.212:2101	IONO00WHU0 (RTCM-SSR)	60s
NRCan**	rt.cacsa.nrcan.gc.ca:12107	IONO00NRC0 (RTCM-SSR)	30s

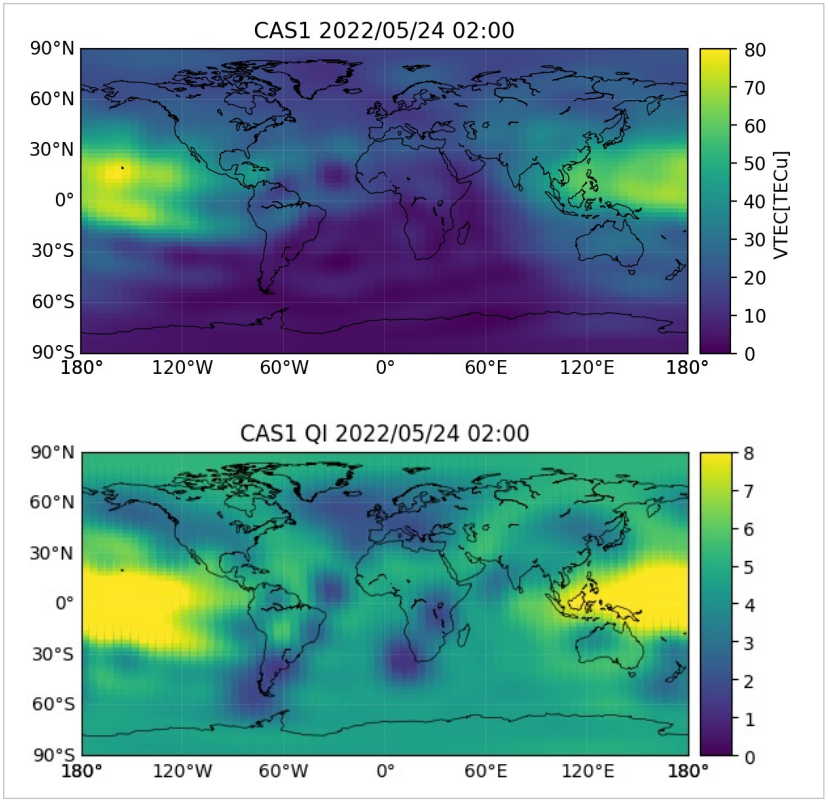
* CAS RT-iono streams with quality indicators are also accessible from cas-ip.gipp.org.cn:2101 (IONO*)

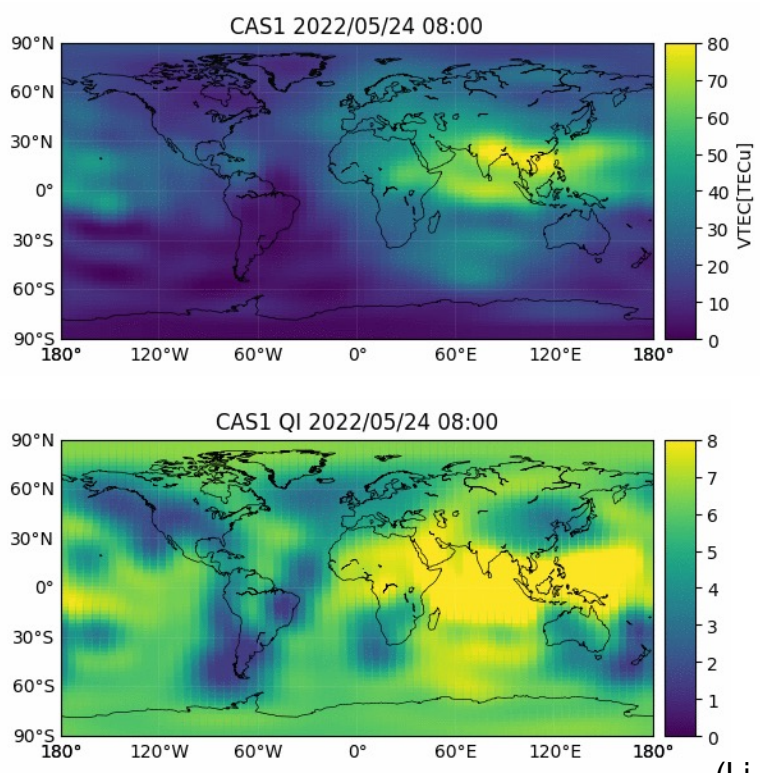
** NRCan RT-iono streams are NOT openly accessible to public by now

Motivation for RT-GIM combination

CAS RT-GIM generation started in mid-2017 using 4-GNSS constellation data

- CAS real-time global TEC maps and associated Quality Indicator (QI) maps





(Li et al. 2020)

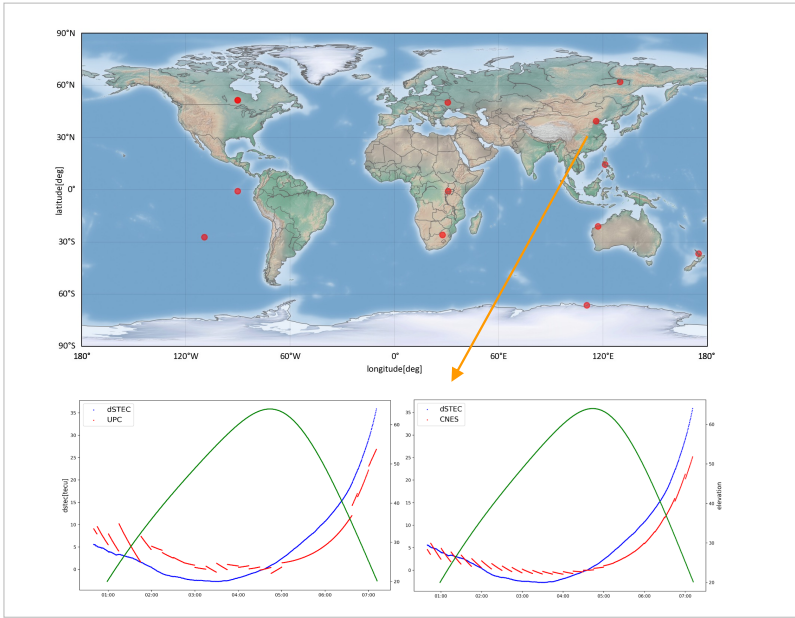
Motivation for RT-GIM combination

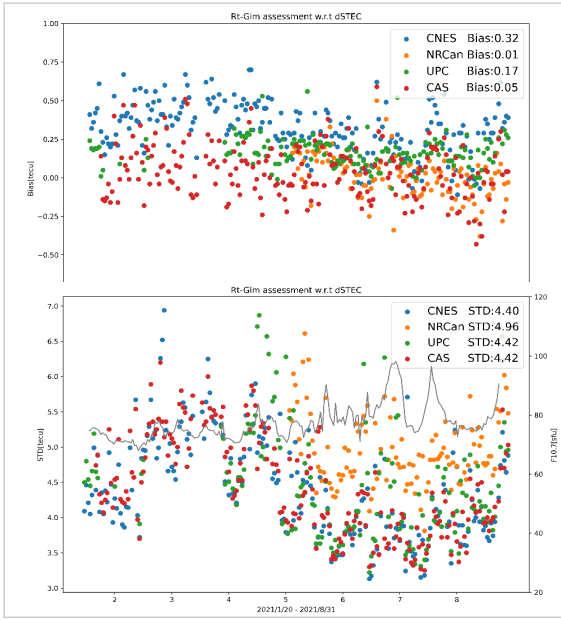
GNSS dSTEC Analysis of different RT-GIMs

- Independent multi-GNSS stations of the IGS-MGEX network (12)
- Differential STEC (dSTEC) analysis using GPS, BDS and Galileo signals
- Time span: January to August 2021 (8 months)

Availability of RT-iono streams*

92% for CNES, **93%** for UPC, **99%** for CAS





RT-GIM Bias (TECU)

CAS	CNES	NRCan	UPC
0.05	0.32	0.01	0.17

RT-GIM STD (TECU)

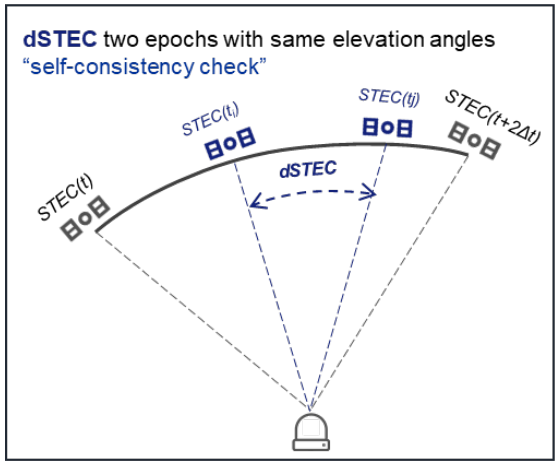
CAS	CNES	NRCan	UPC
4.42	4.40	4.96	4.42

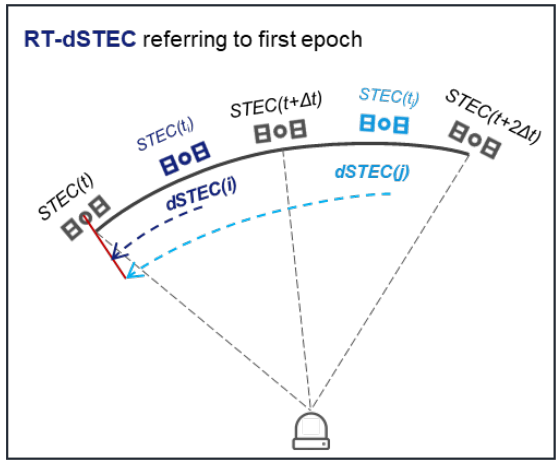
* accessed from CAS IONO AC

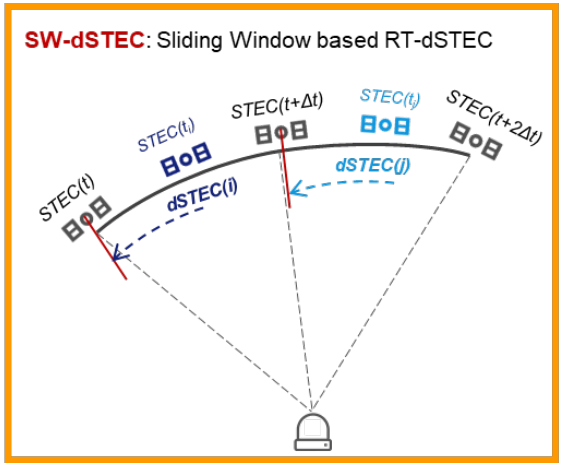
BDSMART

GNSS-dSTEC for GIM combination

- **dSTEC** b.w.t. two epochs with same elevation anlages (self-consistency) -> rapid & final GIM combination
- **RT-dSTEC** referring to the first epoch of individual continuous arcs -> UPC RT-GIM combination
- **SW-dSTEC** a sliding window based RT-dSTEC (SW-dSTEC) -> CAS RT-GIM combination

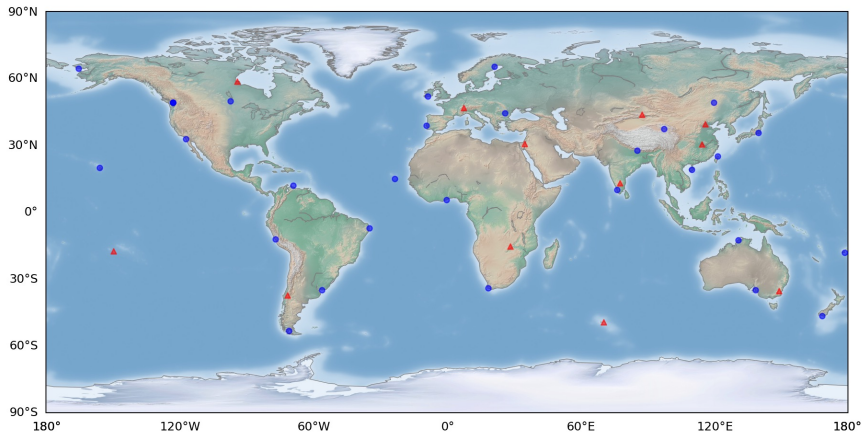




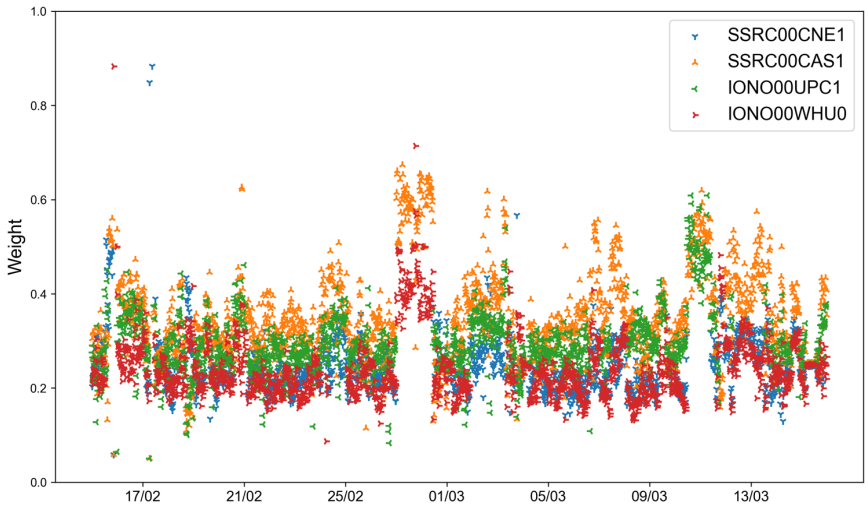


RT-GIM combination

- Input streams: SSRC00CAS1, SSRC00CNE1, IONO00UPC1 and IONO00WHU0
- RT-combination strategy: sliding window based RT-dSTEC (SW-dSTEC) analysis method
- Station network for RT-GIM weighting: 30 stations, G(L1/L2)+E(E1/E5a)+C(B1/B3)
- Generated streams: IONO01IGS0 (RTCM-SSR) + IONO01IGS1 (IGS-SSR)



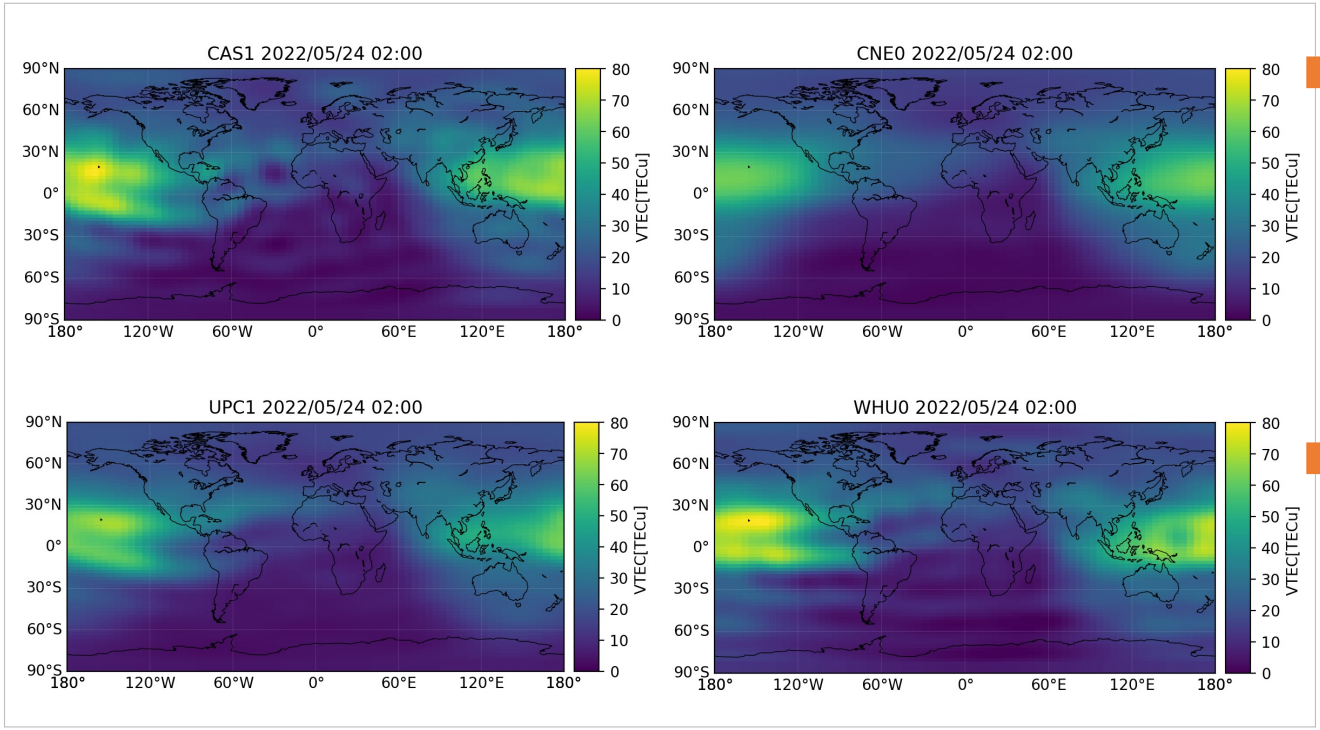
blue circles for combination
red reangles for validation



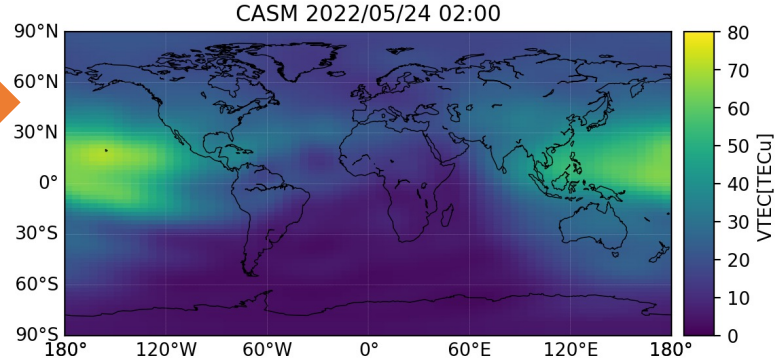
RT-weights during 15/02-15/03 2022

RT-GIM combination

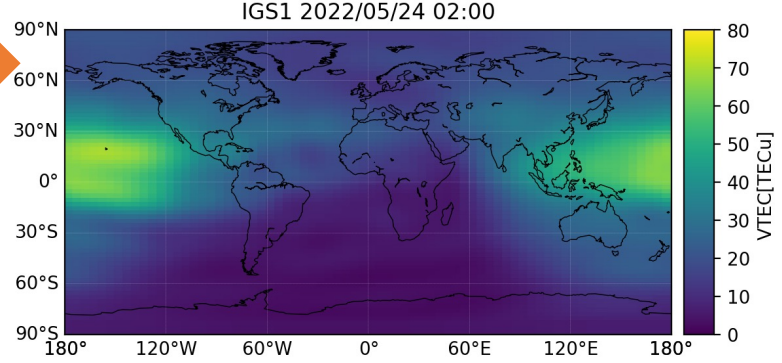
CAS and UPC-IonSAT combined RT-GIM



CAS combined RT-GIM

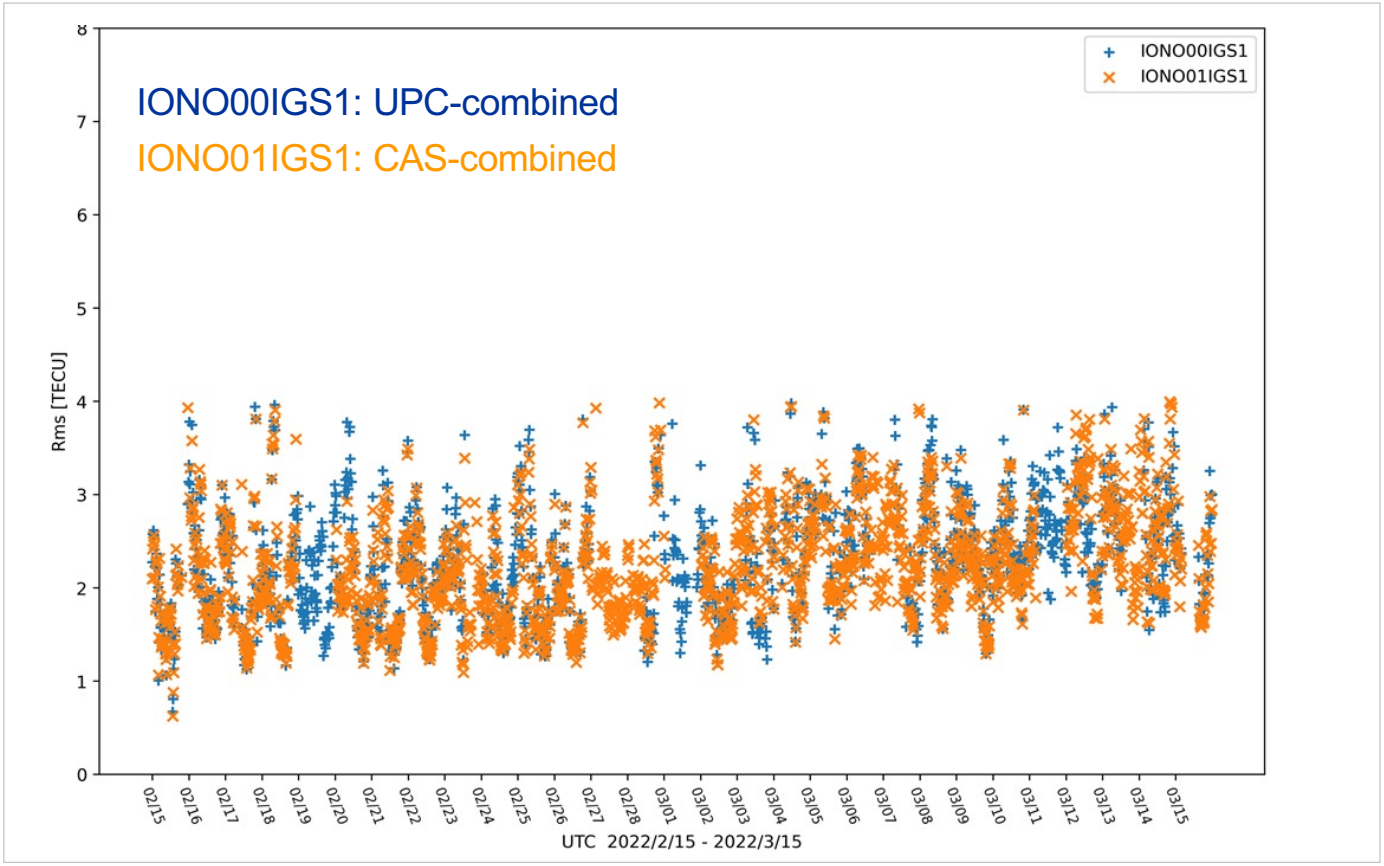


UPC combined RT-GIM



RT-GIM combination

Compared to GNSS RT-dSTEC



Overview of the IGS combined RT-GIMs

AC	Caster	Mountpoint	Interval
UPC-combined	products.igs-ip.net:2101	IONO00IGS0 (IGS-SSR)	15s
CAS-combined*	products.igs-ip.net:2101	IONO01IGS0 (RTCM-SSR)	60s
		IONO01IGS0 (IGS-SSR)	

The 1st combined RT-GIM is generated by UPC-IonSAT and accessible from IGS caster since 01/2021

The 2nd combined RT-GIM is generated by CAS and accessible from IGS caster since 01/2022

* CAS combined RT-GIMs are also accessible from CAS caster cas-ip.gipp.org.cn:2101

RT-GIM validation – method

RT-GIM validation in TEC domain

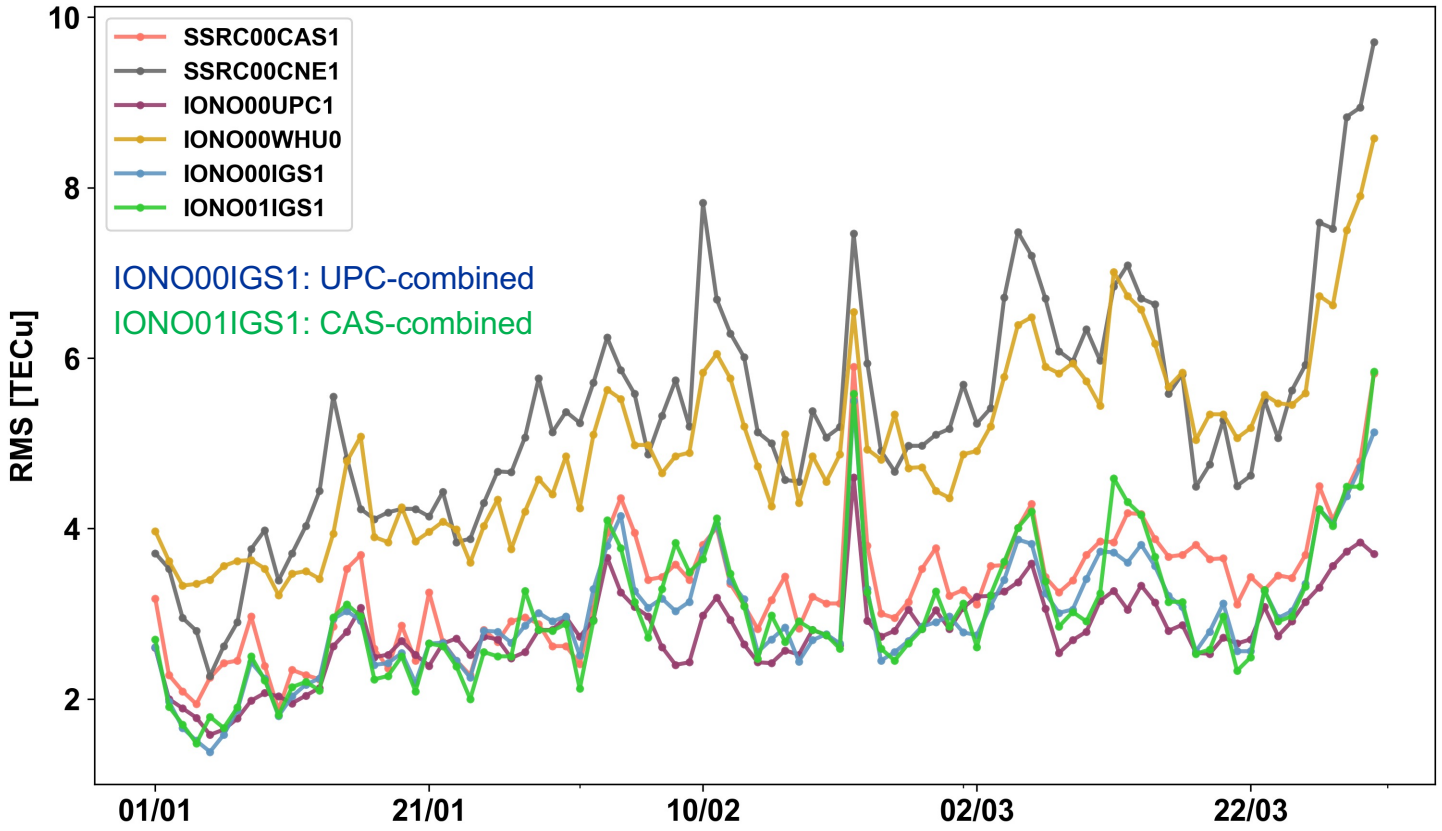
- **IGS-GIM VTEC:** consistency between RT and final combined IGS GIM
- **Jason-3 VTEC:** independent to GNSS data, VTEC analysis over the oceanic regions
- **GNSS dSTEC:** high-quality differential STEC, dSTEC analysis over the continental regions
- **DORIS dSTEC:** independent to GNSS data, high-quality differential STEC, global coverage (60 beacons)

RT-GIM validation in positioning domain

- **GPS L1 SPP:** performance of RT-GIM corrected standard positioning
- **GPS L1 SF-PPP:** performance of RT-GIM constricted single-frequency precise point positioning

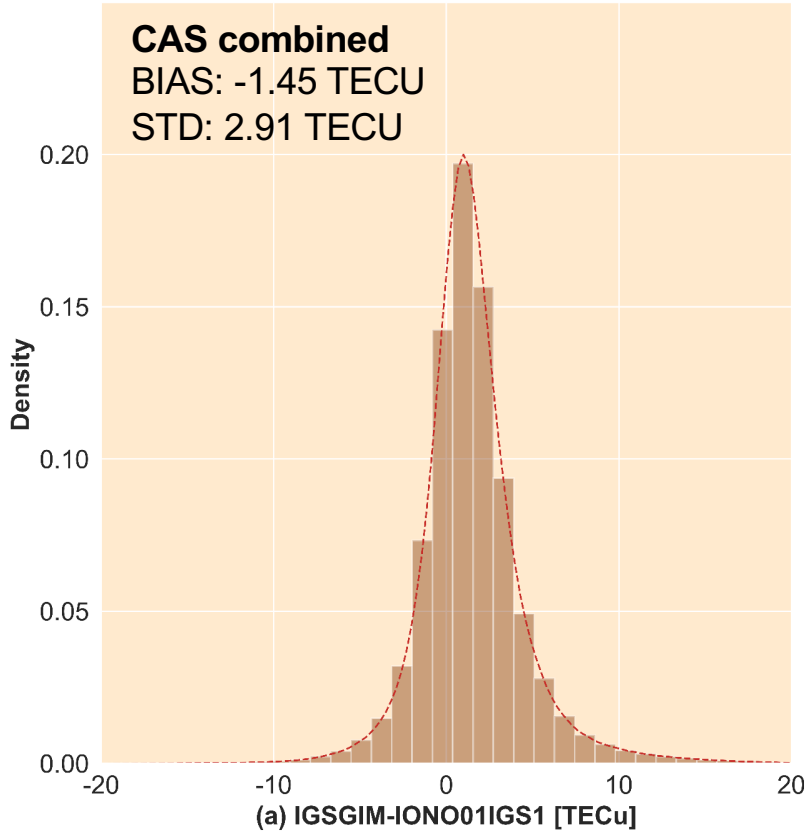
RT-GIM validation – TEC domain

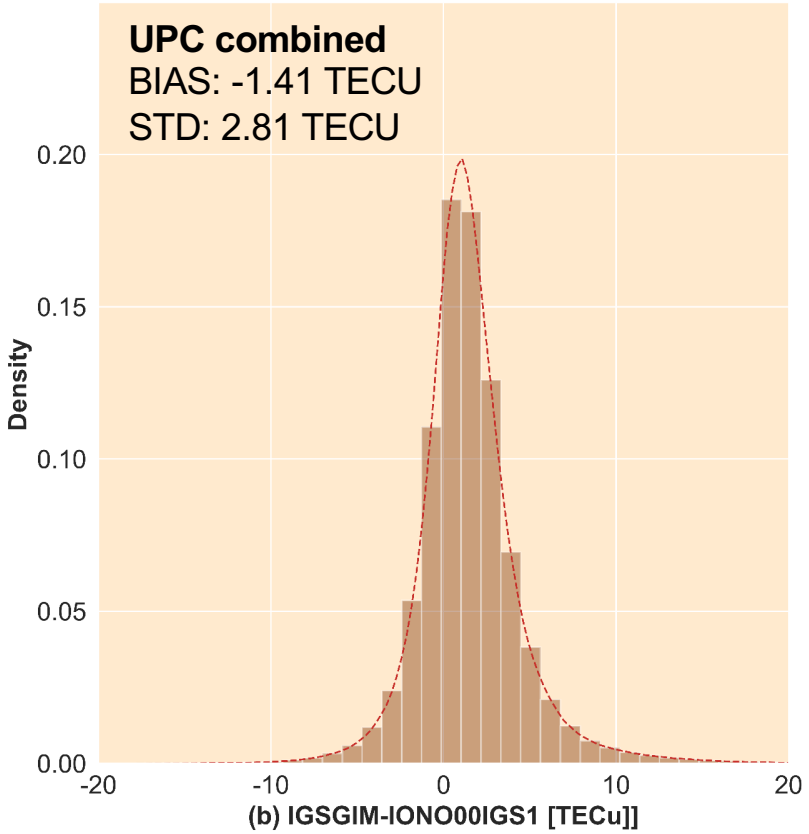
Compared to **IGS-GIM VTEC** – 01/01-31/03, 2022



RT-GIM validation – TEC domain

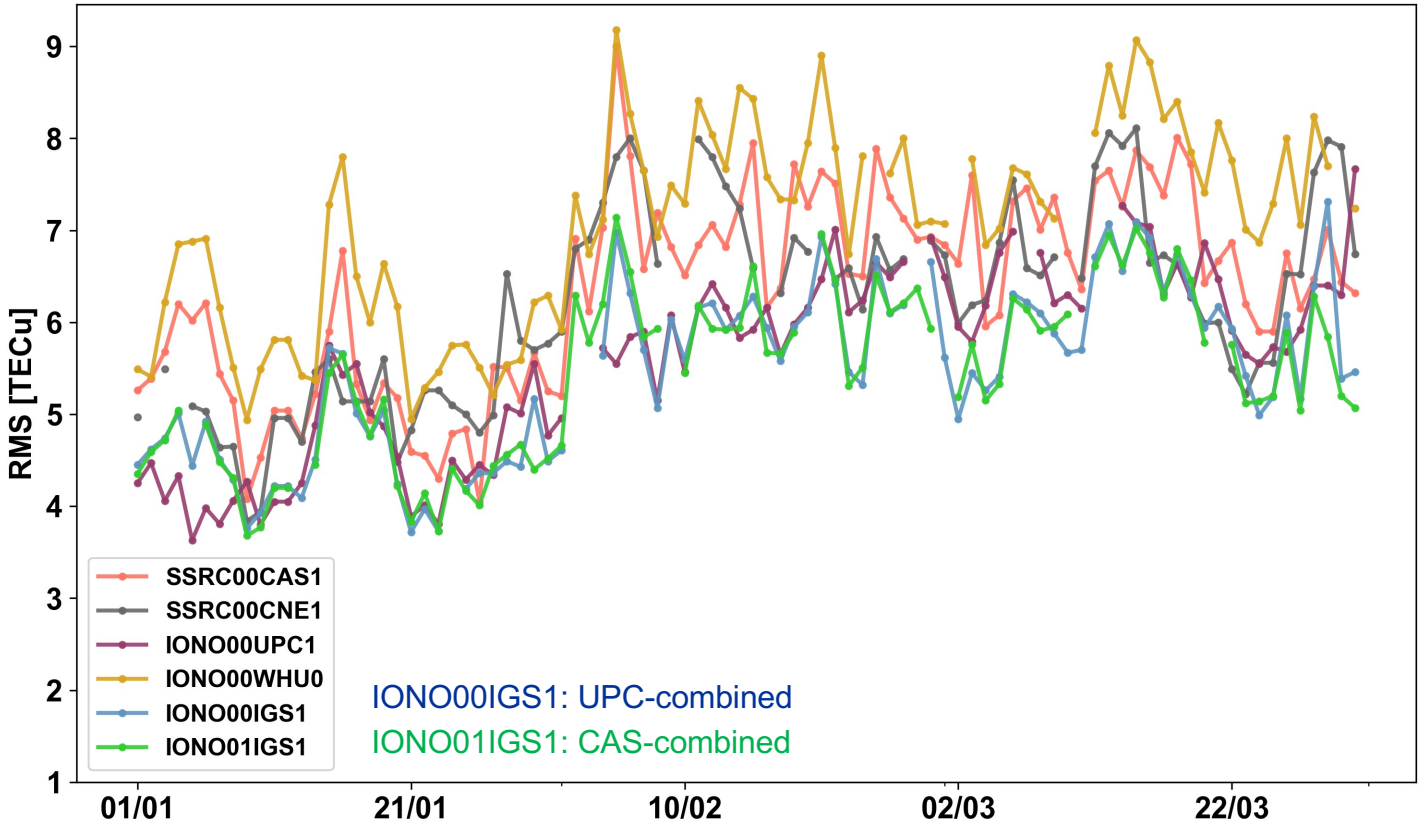
Compared to **IGS-GIM VTEC** – 01/01-31/03, 2022





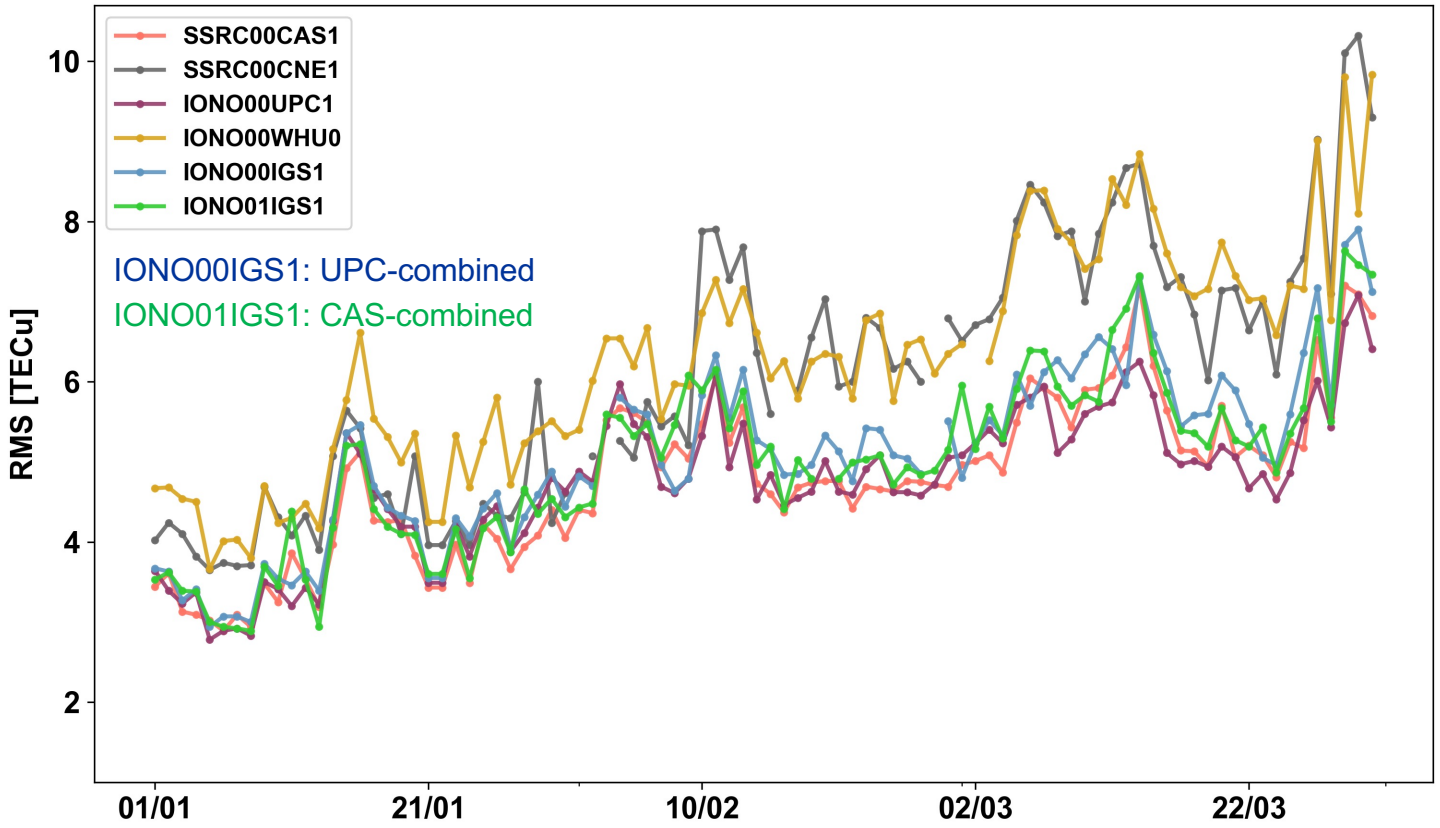
RT-GIM validation – TEC domain

Compared to **Jason-3 VTEC** – 01/01-31/03, 2022



RT-GIM validation – TEC domain

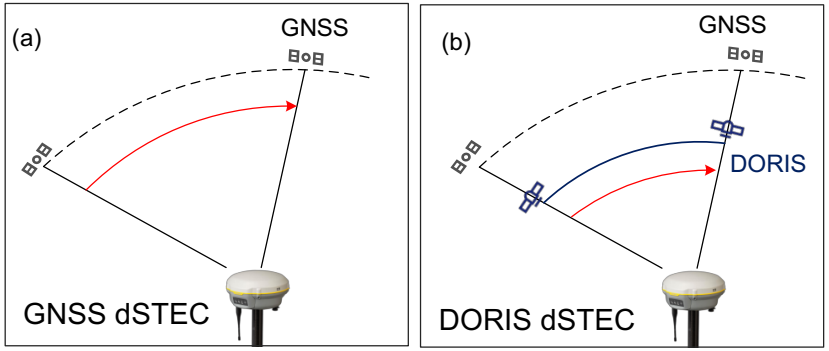
Compared to **GNSS dSTEC** – 01/01-31/03, 2022

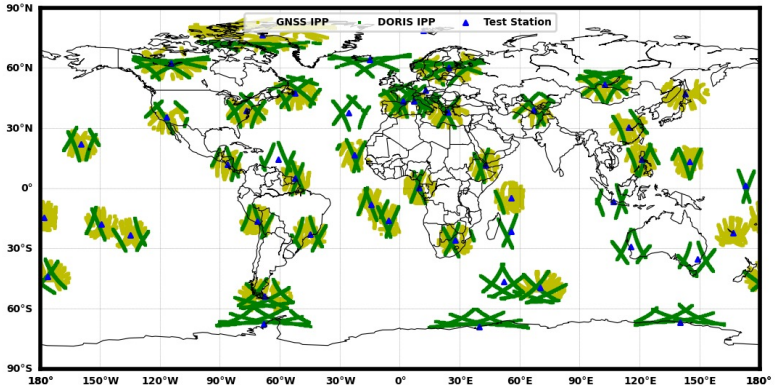


RT-GIM validation – TEC domain

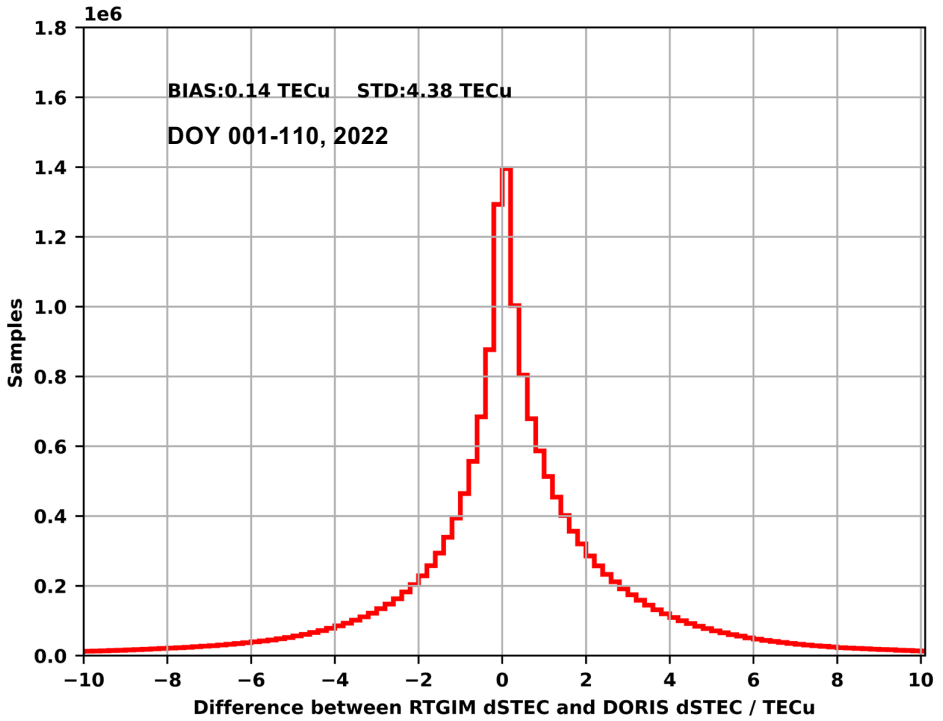
DORIS dSTEC analysis

$$dSTEC_{DORIS}(t) = \mu\left[L_I(t) - L_I(t_{E\max}) - \left(\Delta D(t) - \Delta D(t_{E\max})\right)\right]$$





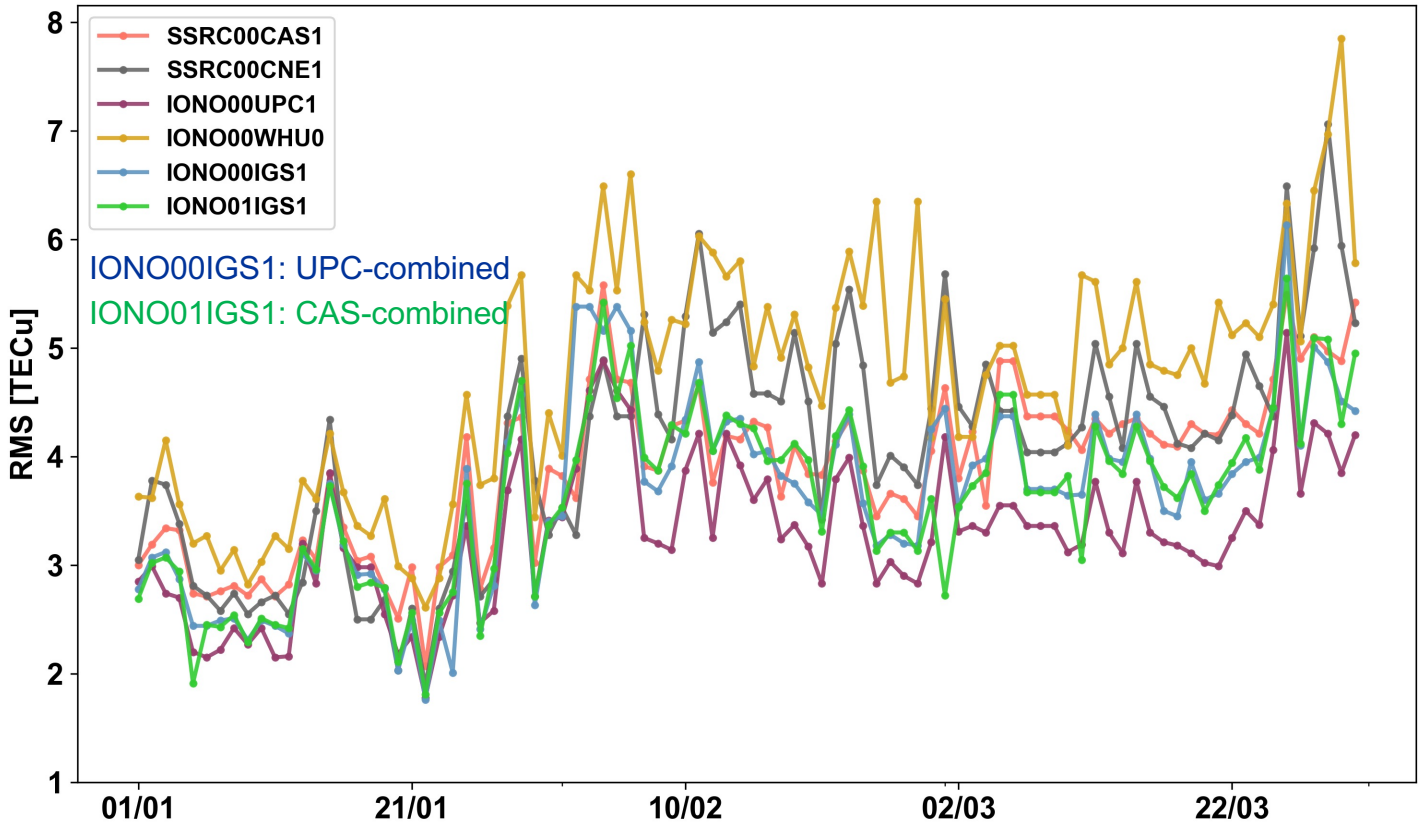
GNSS (yellow) vs DORIS (green) iono observables



Differences bwt RT-GIM modeled and DORIS observed dSTEC

RT-GIM validation – TEC domain

Compared to **Jason-3 DORIS dSTEC** – 01/01-31/03, 2022



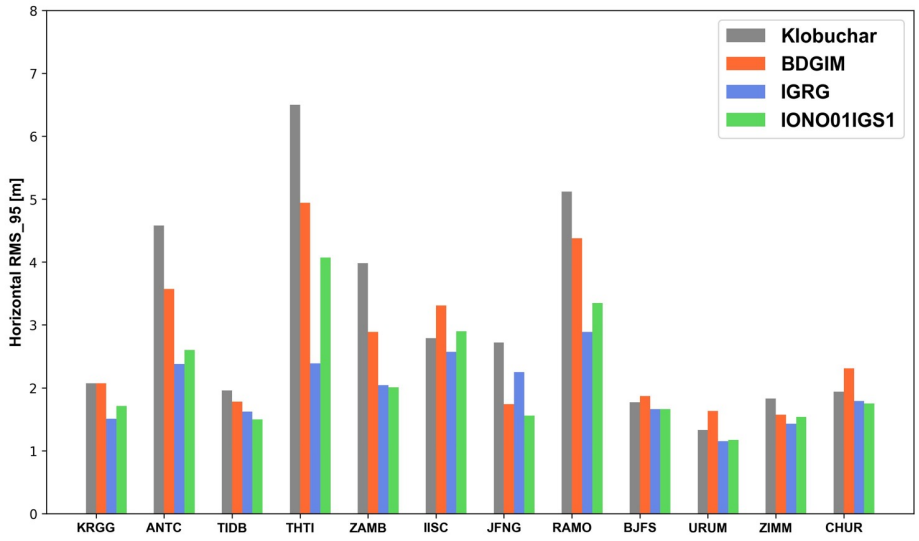
RT-GIM validation – TEC domain

(01/01-31/03, 2022)

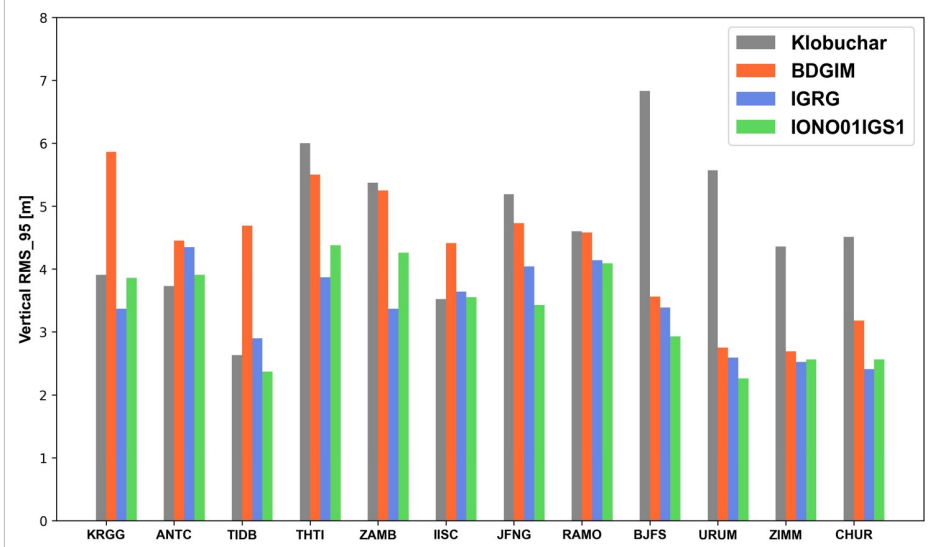
		CAS IONO00CAS1	UPC IONO00UPC1	UPC IONO00IGS1	CAS IONO01IGS1
IGS-GIM VTEC	Bias	-0.54	-0.79	-1.34	-1.29
	STD	3.19	2.63	2.56	2.69
	RMS	3.30	2.75	2.93	3.02
	Rel. error	18.6%	15.7%	16.6%	16.9%
Jason-3 VTEC	Bias	3.51	3.52	2.71	2.72
	STD	5.24	4.28	4.7	4.68
	RMS	6.37	5.58	5.49	5.49
	Rel. error	34.9%	30.86%	30.2%	30.0%
GNSS dSTEC	Bias	0.3	0.01	0.04	0.05
	STD	4.74	4.71	4.99	4.95
	RMS	4.75	4.72	5.03	4.93
	Rel. error	36.7%	36.5%	38.9%	38.5%
DORIS dSTEC	Bias	0.36	0.16	0.15	0.18
	STD	3.85	2.28	3.65	3.65
	RMS	3.86	3.26	3.65	3.63
	Rel. error	43.6%	38.0%	41.7%	42.3%

GPS L1 SPP corrected with different ionospheric models

- Klobuchar: GPS broadcast ionospheric model, BDGIM: BDS-3 global broadcast ionospheric model
- igrg: IGS rapid-GIM, IONO01IGS1: CAS-combined RT-GIM



Horizonal accuracy of GPS L1 SPP (95% percentile)

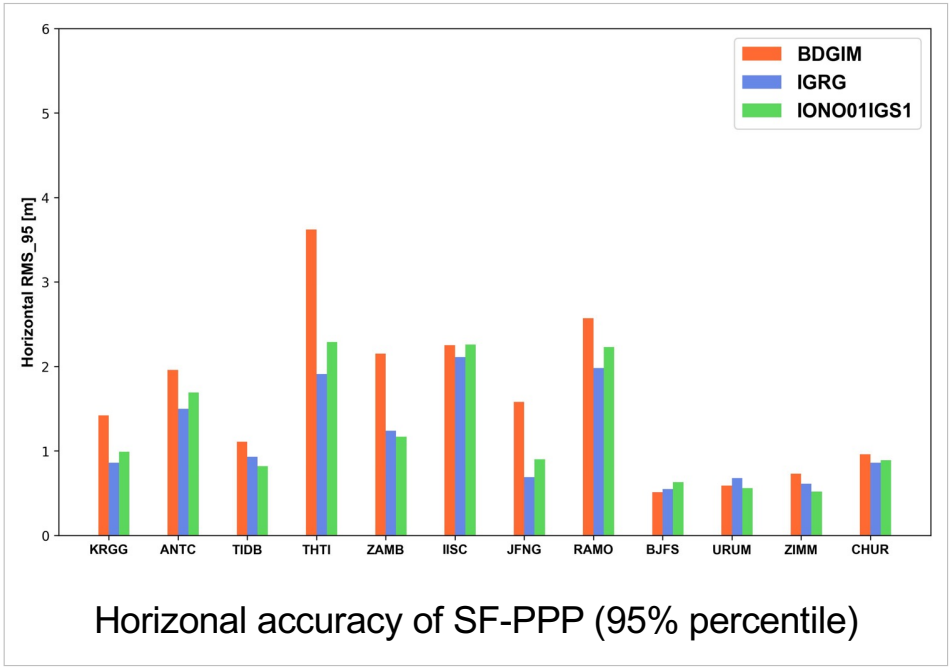


Vertical accuracy of GPS L1 SPP (95% percentile)

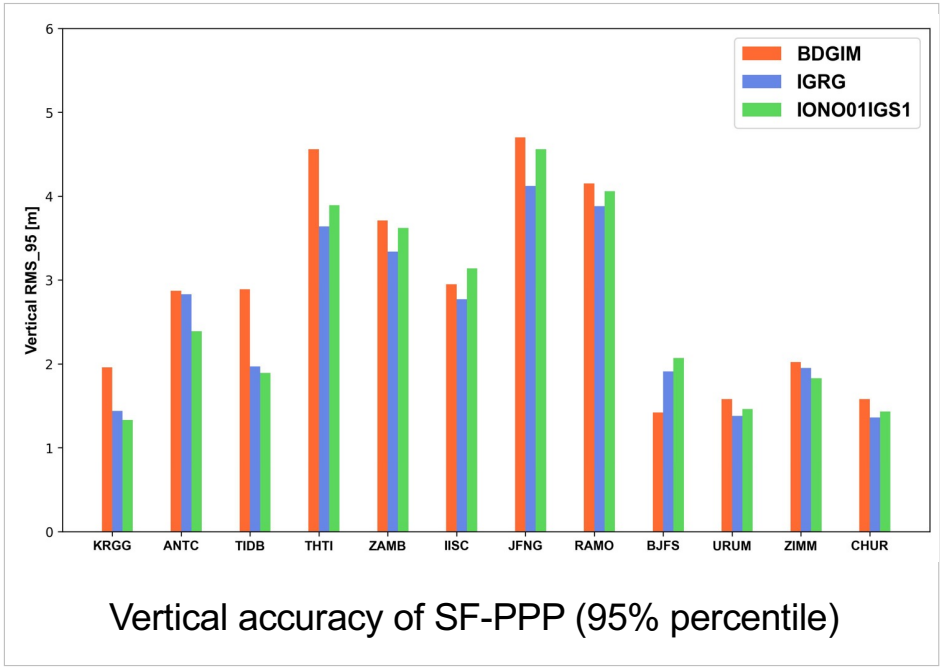
(site locations on slid 7)

GPS L1 SF-PPP constricted with different ionospheric corrections

- BDGIM: BDS-3 global broadcast ionospheric model
- igrg: IGS rapid-GIM, IONO01IGS1: CAS-combined RT-GIM



Horizonal accuracy of SF-PPP (95% percentile)



Vertical accuracy of SF-PPP (95% percentile)

(site locations on slid 7)

GPS L1 SF-PPP constricted with different ionospheric corrections

- BDGIM: BDS-3 global broadcast ionospheric model
- igrg: IGS rapid-GIM, IONO01IGS1: CAS-combined RT-GIM

Horizonal and vertical accuracy of SF-PPP using different ionospheric models (95% percentile)

Items	Ionospheric models	Mean / m	Minimum / m	Maximum / m
Horizonal component	BDGIM	1.74	0.51	5.32
	IONO01IGS1	1.41	0.52	4.19
	IGRG	1.22	0.52	3.04
Vertical component	BDGIM	2.93	0.83	7.89
	IONO01IGS1	2.73	0.84	5.99
	IGRG	2.59	0.66	6.06

Summary and conclusions

- A sliding window based RT-GNSS dSTEC (SW-dSTEC) technique is proposed for RT-GIM combination.
- A second combined RT-GIM is generated and provided to the IGS since January 2022 at CAS (IGS caster: products.igs-ip.net:2101, IONO01IGS0, IONO01IGS1).
- The quality of combined RT-GIM was evaluated in both TEC correction and positioning domains.
- In addition to Jason VTEC and GNSS dSTEC analysis, DORIS differential STEC (dSTEC) is used as an independent reference to validate the quality of RT-GNSS ionospheric maps.
- The positioning analysis indicates that the performance of combined RT-GIM is approaching that of IGS rapid GIM, especially in those regions with dense RT-GNSS receivers.
- The continuity of CAS combined RT-GIM requires further improved, which is the work we are focusing on.

Zukunft denken

Thinking the Future

Thanks for your attention

In case of any questions, please feel free to contact

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