The Combined Real-Time Global Ionospheric Maps for Precise GNSS Applications

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GNSS CONSTELLATION
Credit: CSNO

IONOSPHERE
Credit: JPL/NASA

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

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
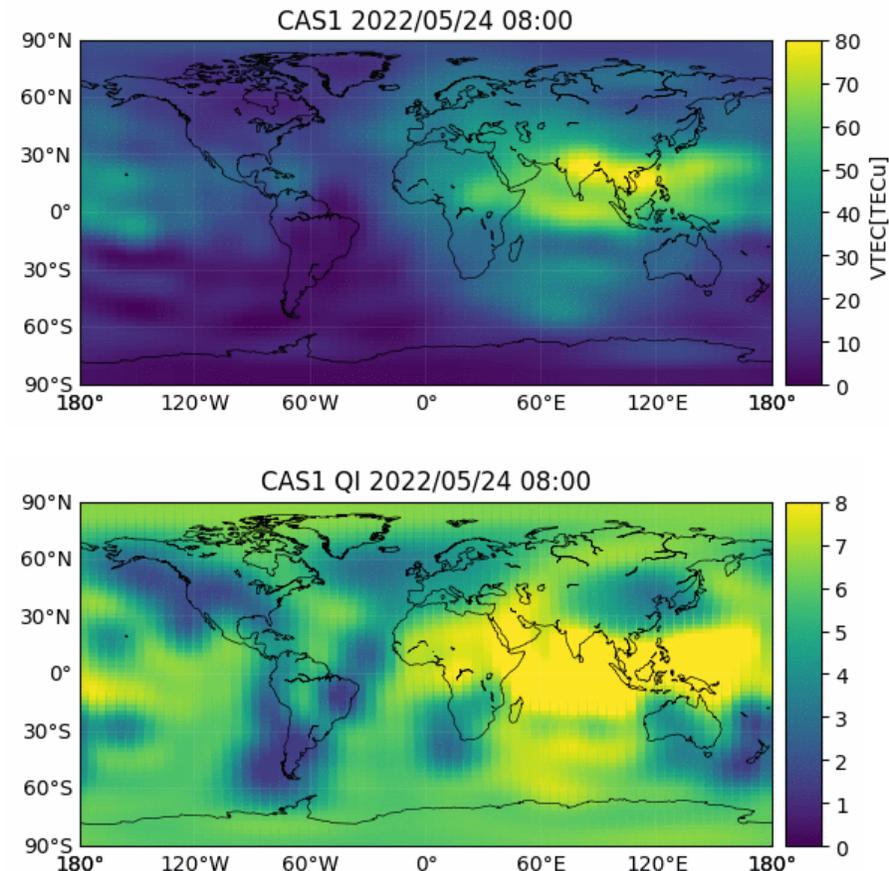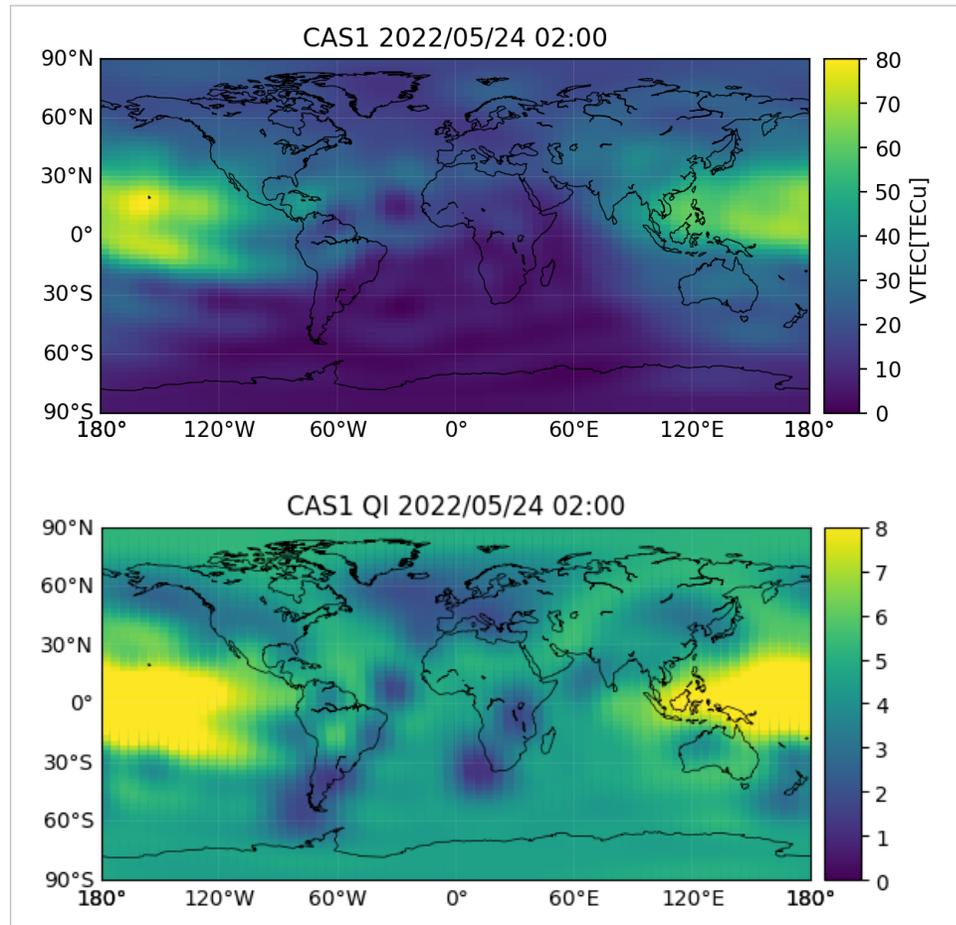
(Li et al. 2020)

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** **UPC**

0.05 **0.32** **0.17**

RT-GIM STD (TECU)

CAS **CNES** **UPC**

4.42 **4.40** **4.42**
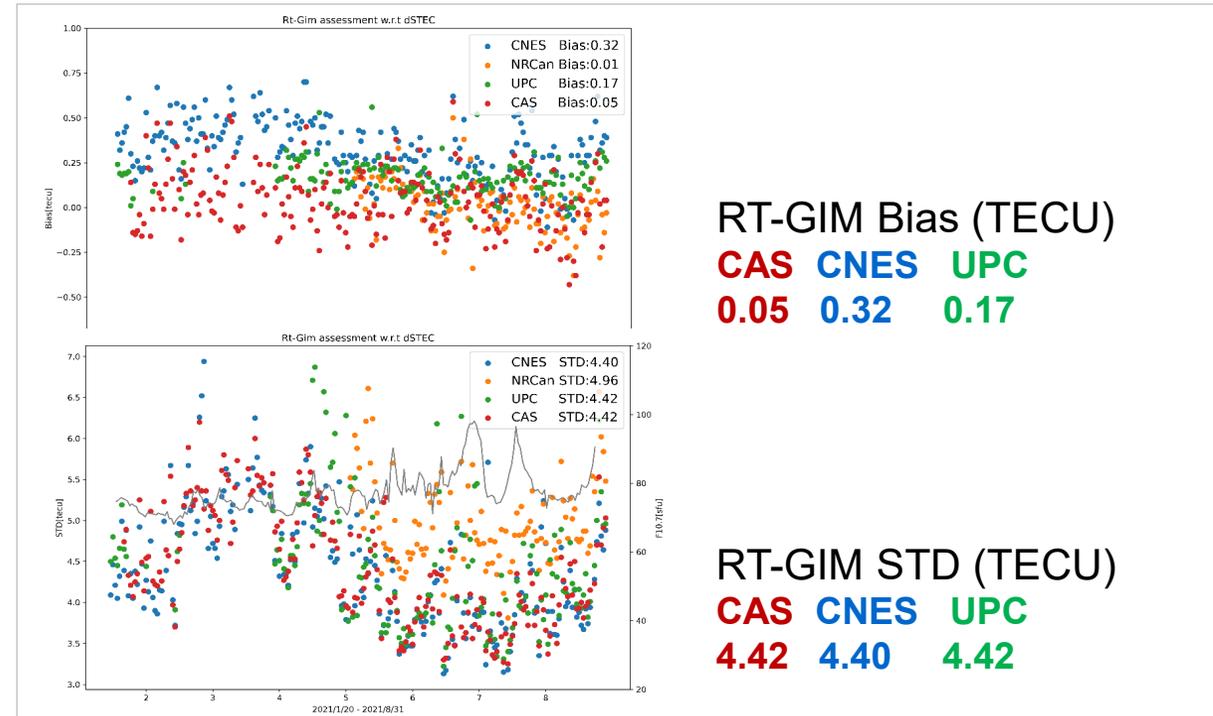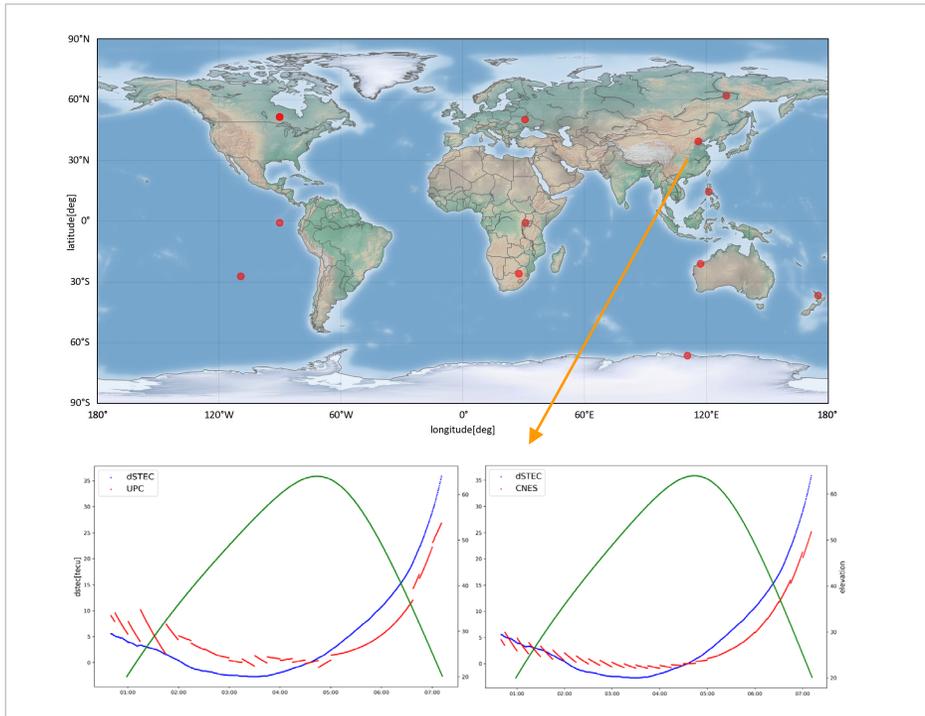
* Accessed from CAS IONO AC

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** sliding window based RT-dSTEC -> CAS RT-GIM combination
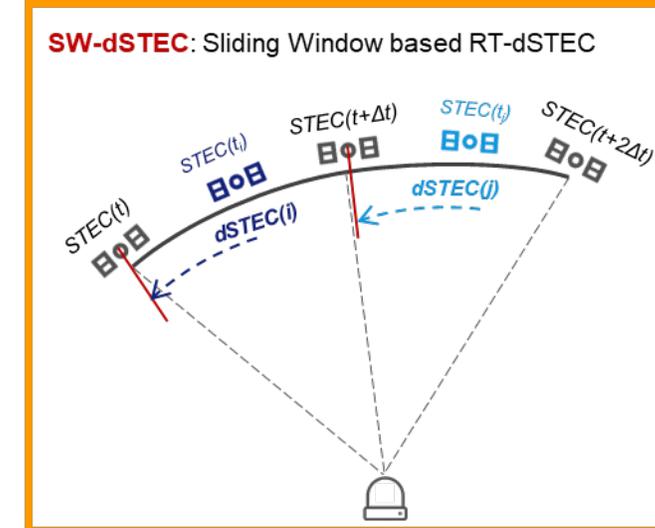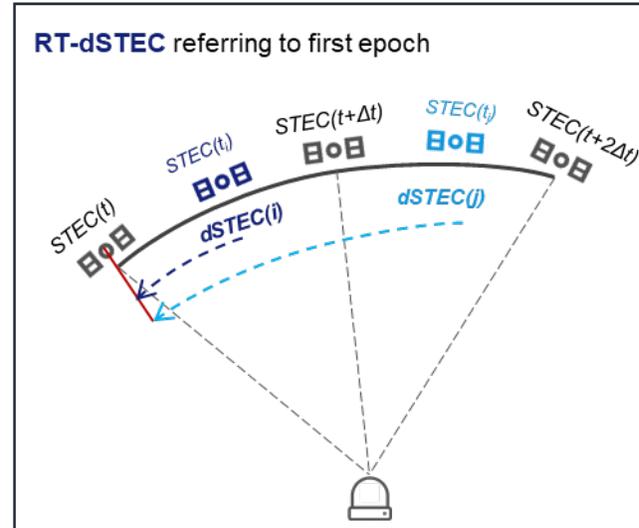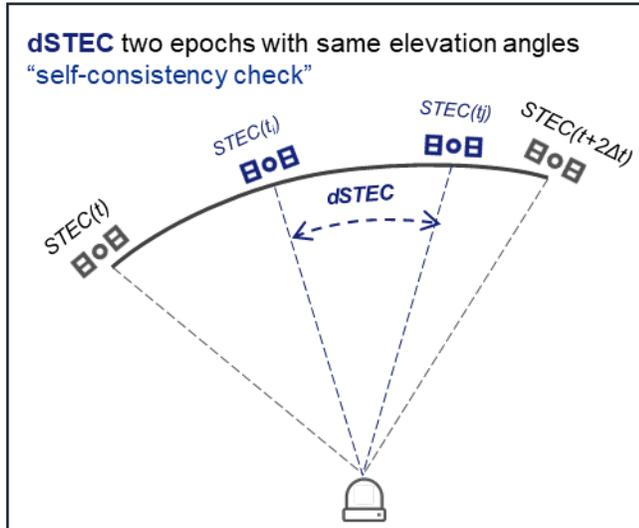
## Overview of RT ionospheric streams used for CAS RT-GIM combination

AC	Caster	Mountpoint	Interval
CAS	products.igs-ip.net:2101	SSRC00CAS1 (IGS-SSR)	60s
CNES	products.igs-ip.net:2101	SSRC00CNE1 (IGS-SSR)	60s
UPC	products.igs-ip.net:2101	IONO00UPC1 (IGS-SSR)	15s
WHU	58.49.94.212:2101	IONO00WHU0 (RTCM-SSR)	60s
UPC-combined	products.igs-ip.net:2101	IONO00IGS0 (IGS-SSR)	15s
CAS-combined*	products.igs-ip.net:2101	IONO01IGS0 (RTCM-SSR) IONO01IGS0 (IGS-SSR)	60s

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

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
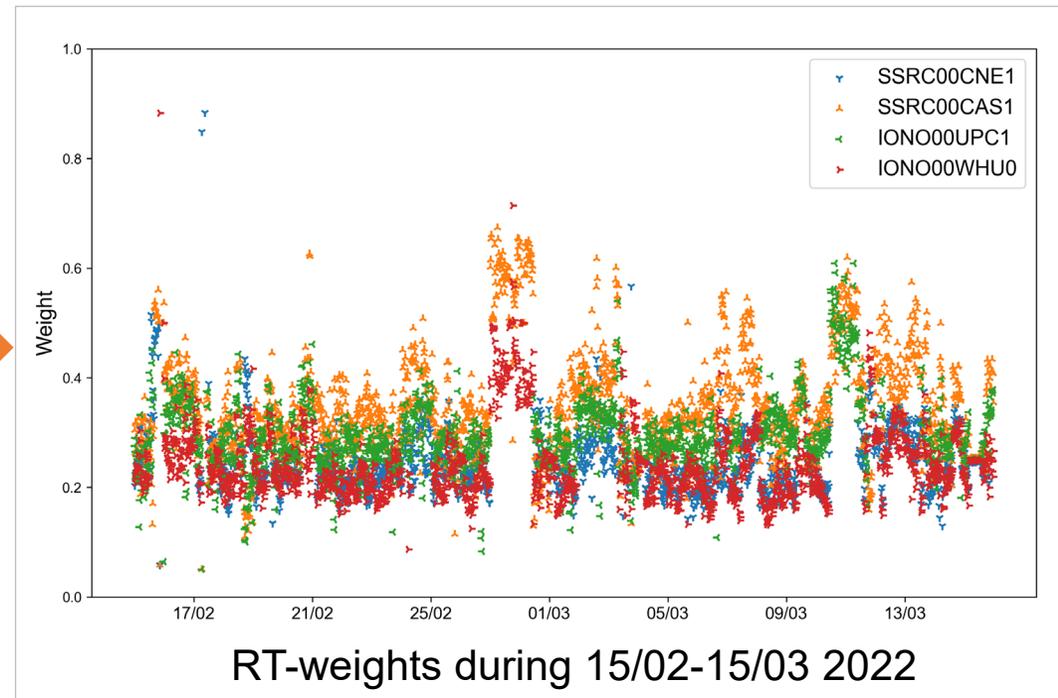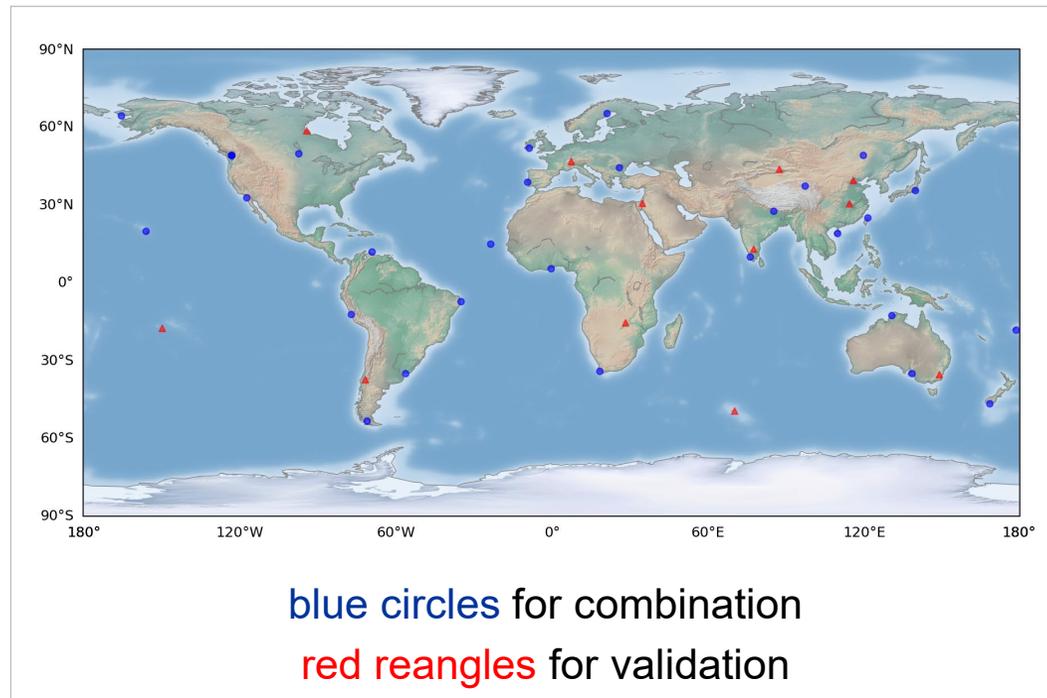
CAS and UPC combined RT-GIM

CAS combined RT-GIM

CASM 2022/05/24 02:00

UPC combined RT-GIM

IGS1 2022/05/24 02:00

CAS1 2022/05/24 02:00

CNE0 2022/05/24 02:00

UPC1 2022/05/24 02:00

WHU0 2022/05/24 02:00
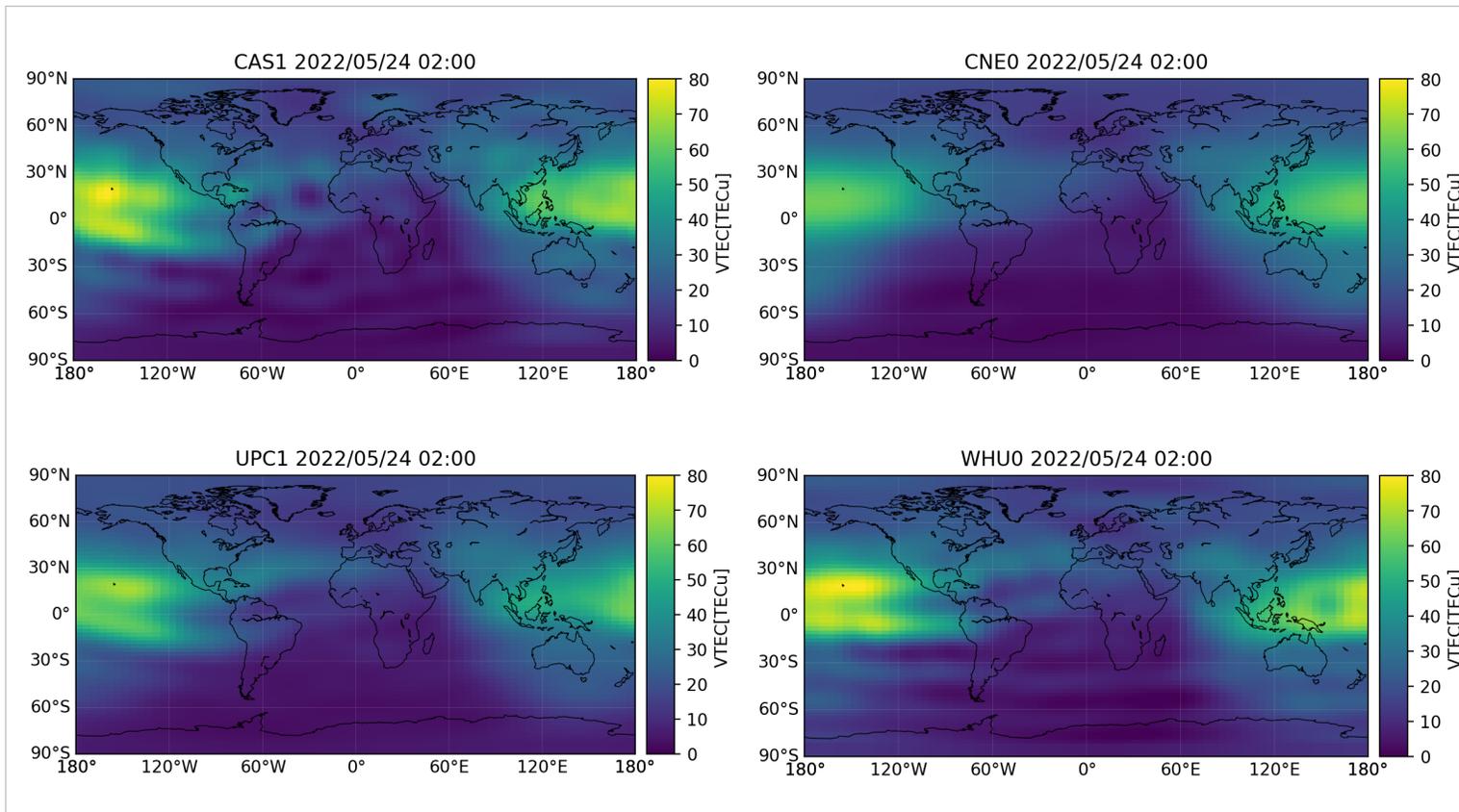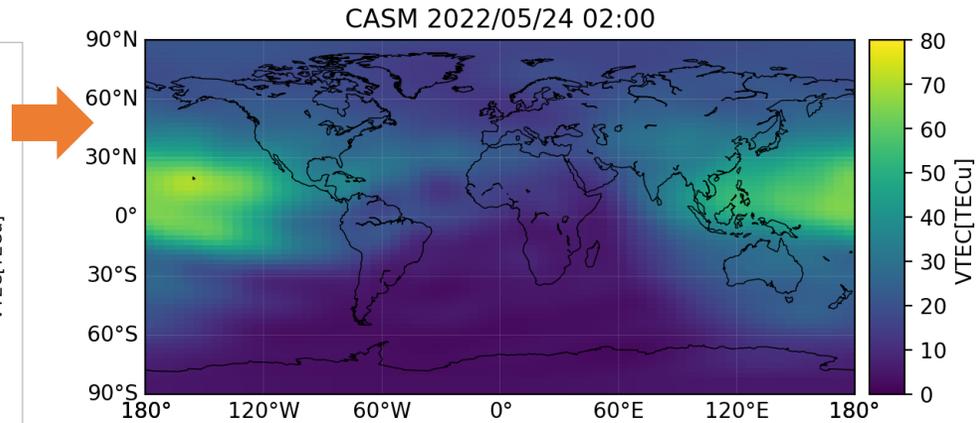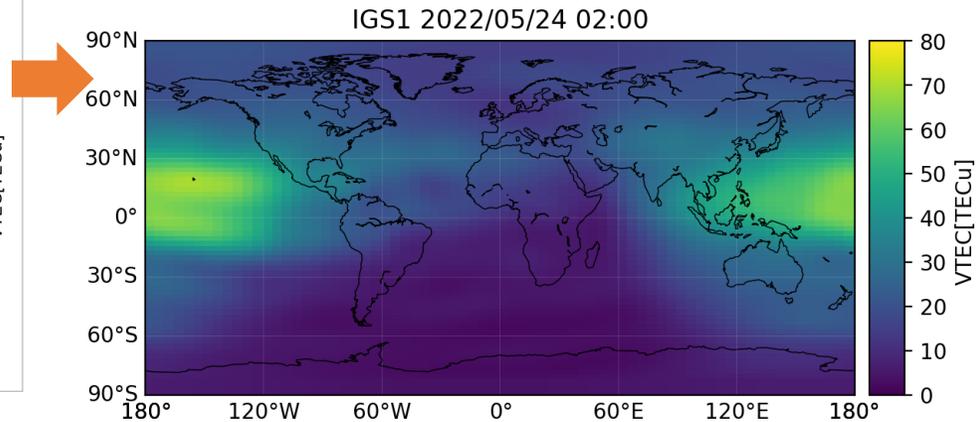
## RT-GIM validation in TEC domain

▶ **IGS-GIM VTEC:** consistency between RT and final combined IGS GIM

▶ **GNSS dSTEC:** high-quality differential STEC, dSTEC analysis over the continental regions

▶ **Jason-3 VTEC:** independent to GNSS data, VTEC analysis over the oceanic regions

▶ **DORIS dSTEC:** independent to GNSS data, high-quality differential STEC, global coverage (60 beacons)
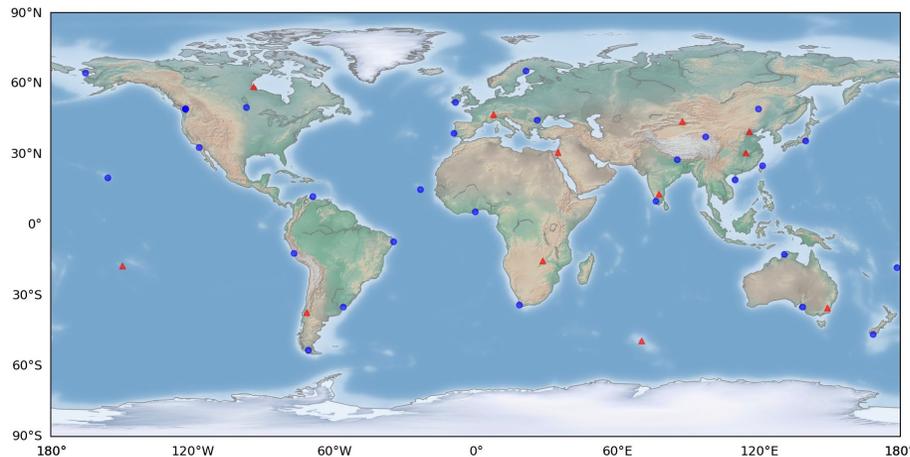
selected GNSS stations (blue circles)
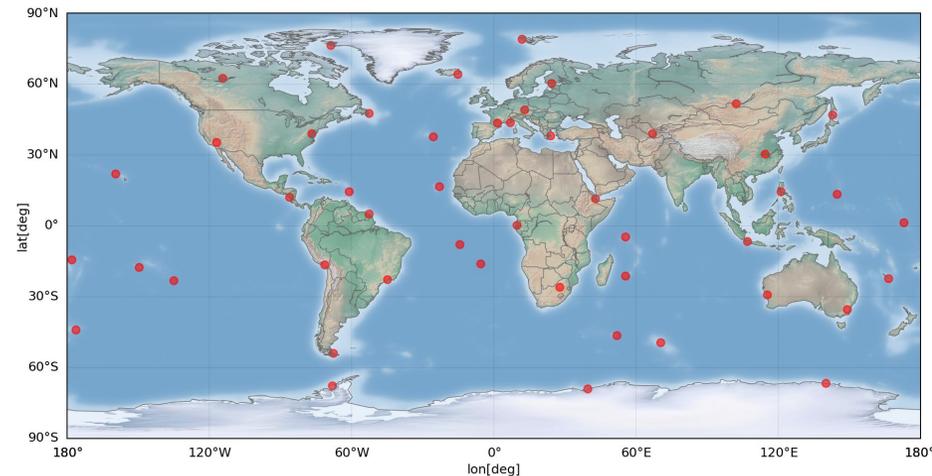
selected DORIS beacons (red circles)
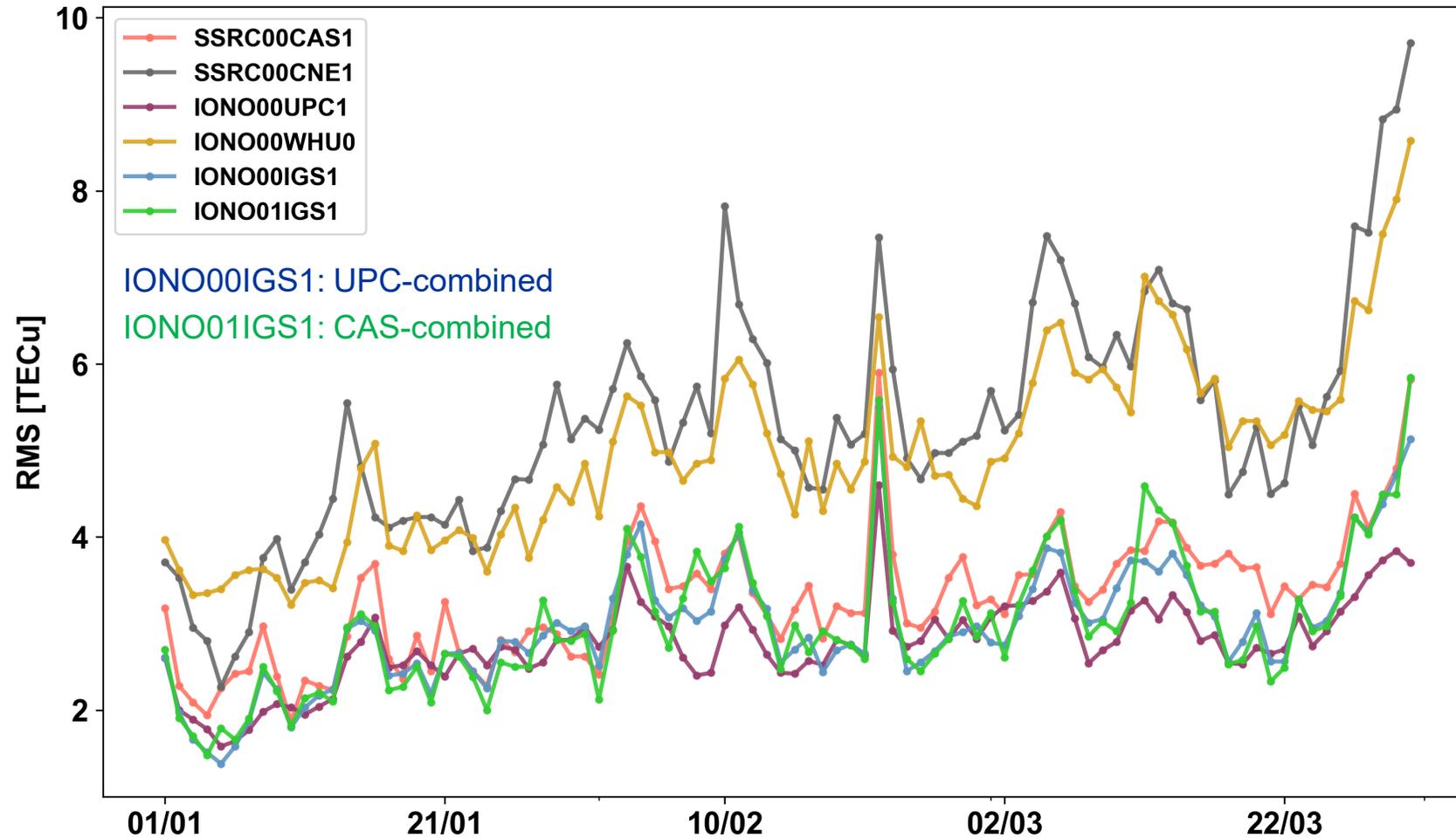
Compared to **IGS-GIM VTEC** – 01/01-31/03, 2022

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

CAS combined
BIAS: -1.45 TECU
STD: 2.91 TECU

UPC combined
BIAS: -1.41 TECU
STD: 2.81 TECU

(a) IGSGIM-IONO01IGS1 [TECu]

(b) IGSGIM-IONO00IGS1 [TECu]]
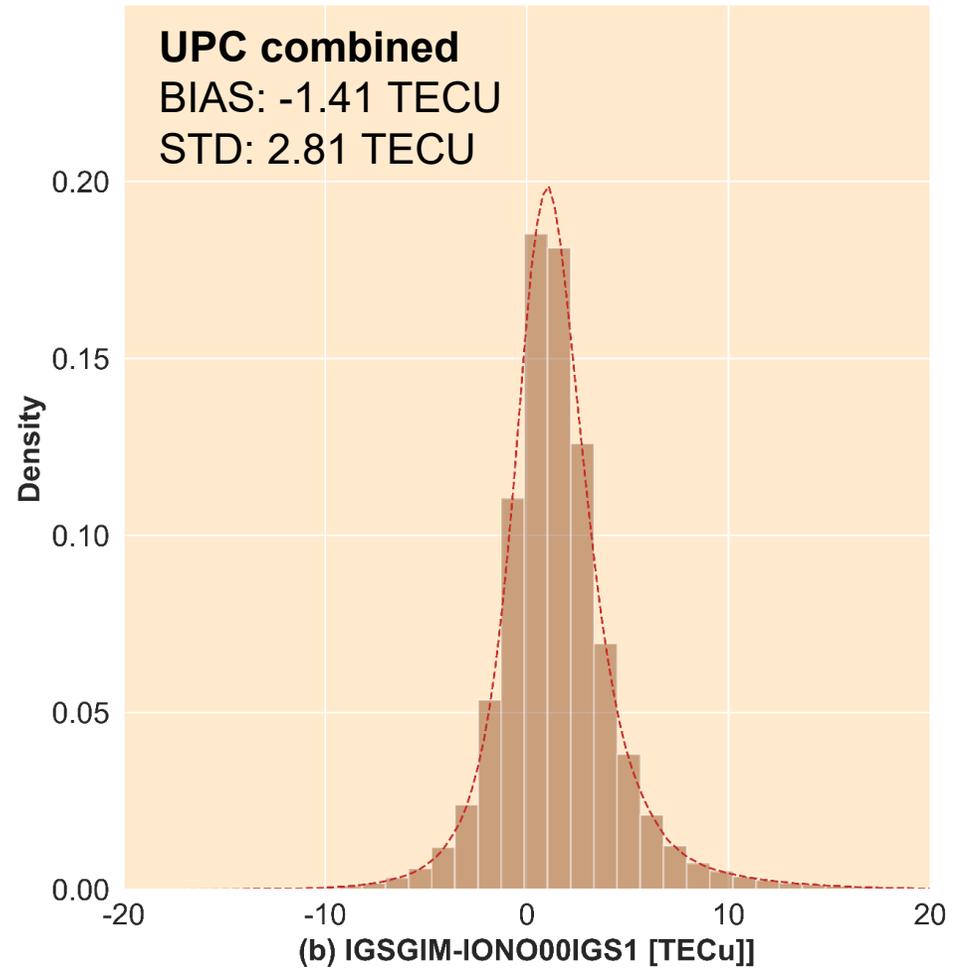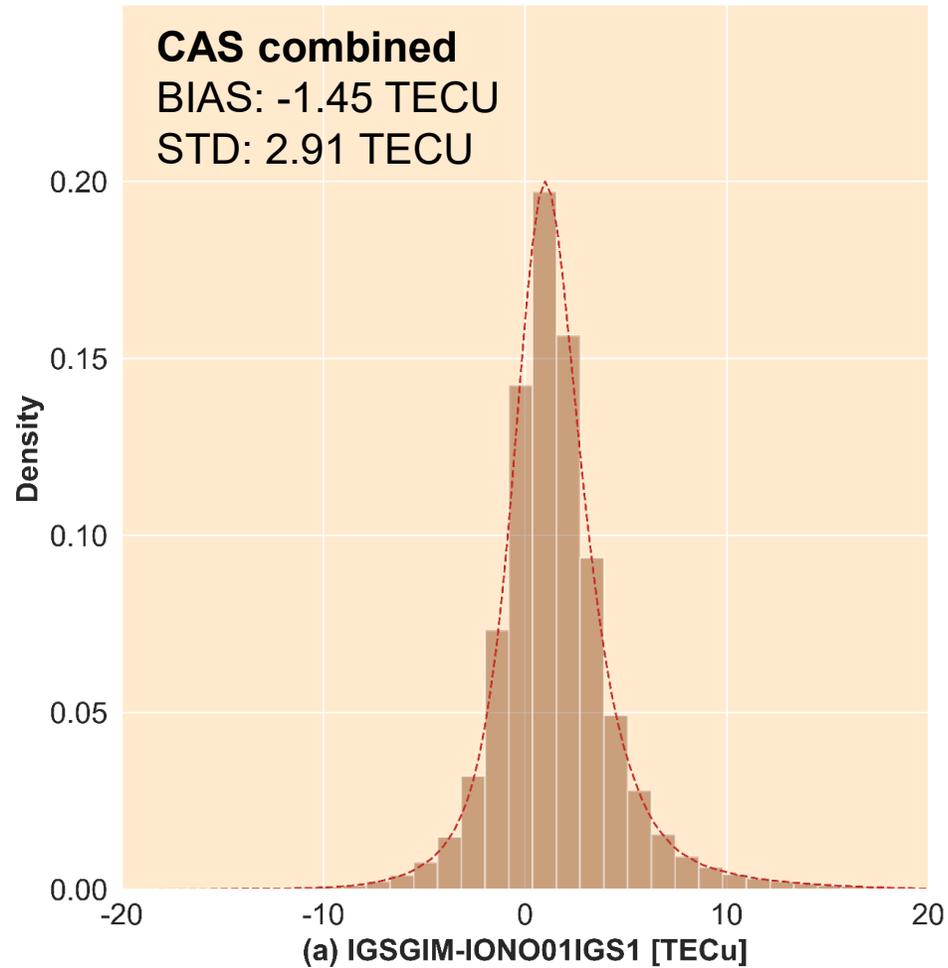
Compared to **Jason-3 VTEC** – 01/01-31/03, 2022

IONO00IGS1: UPC-combined

IONO01IGS1: CAS-combined
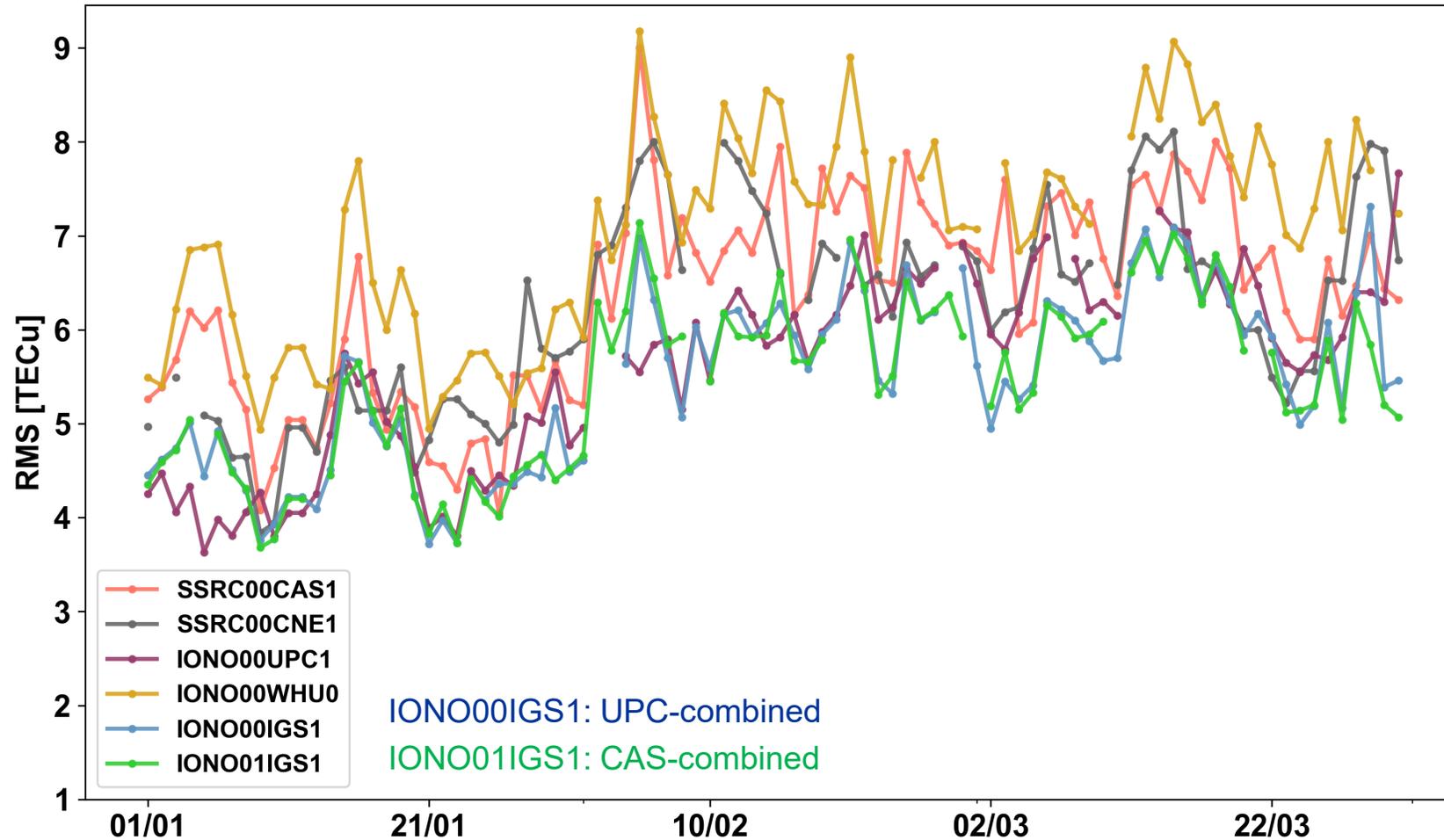
Compared to **GNSS dSTEC** – 01/01-31/03, 2022
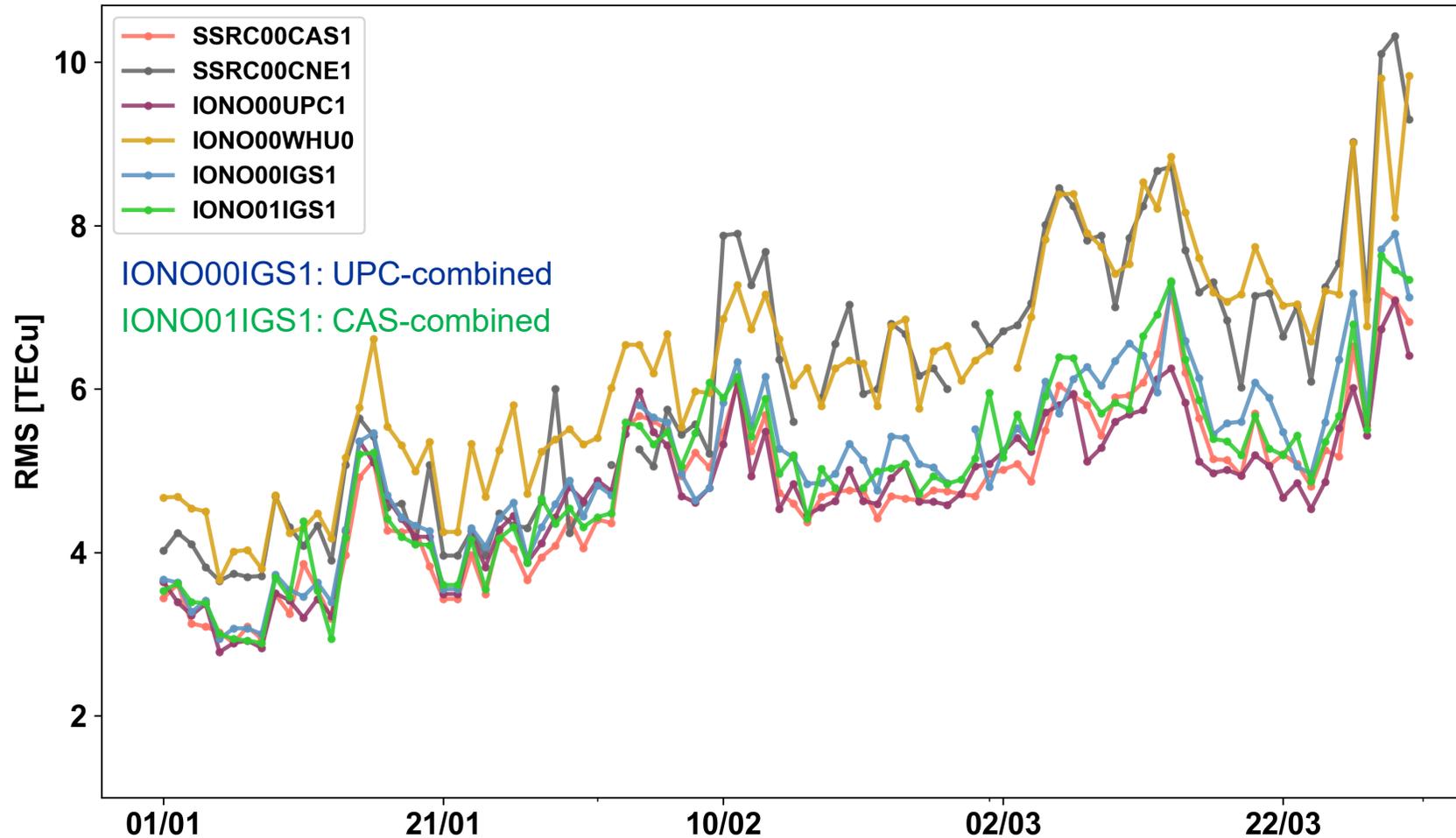
DORIS dSTEC analysis

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


(a) GNSS dSTEC

(b) DORIS dSTEC

GNSS (yellow) vs DORIS (green) iono observables

BIAS:0.14 TECu   STD:4.38 TECu

DOY 001-110, 2022

Differences bwt RT-GIM modeled and DORIS observed dSTEC
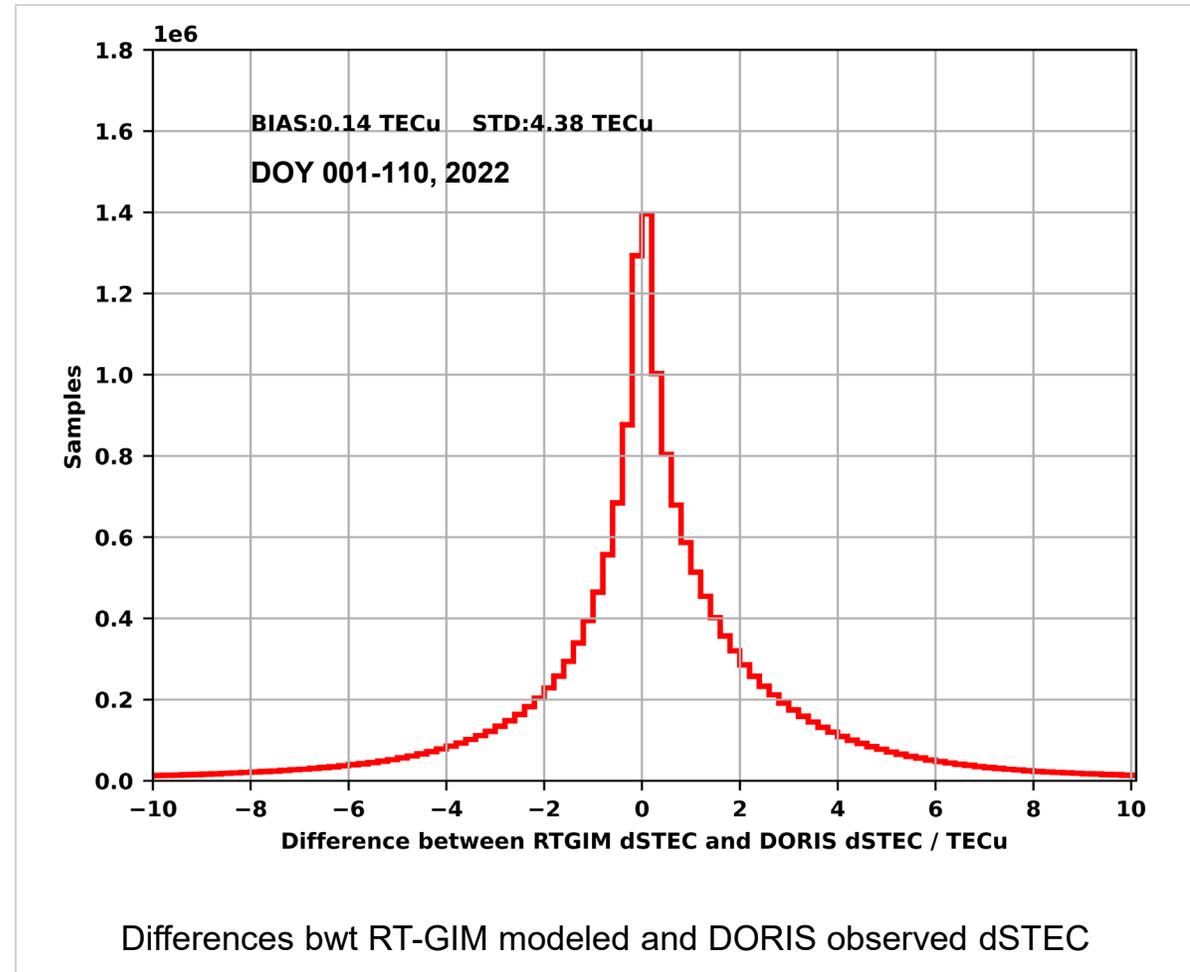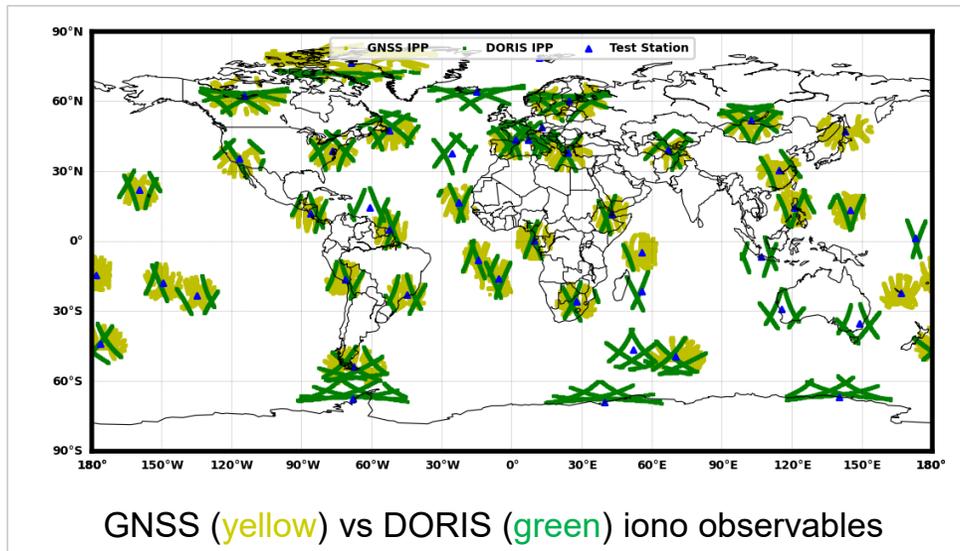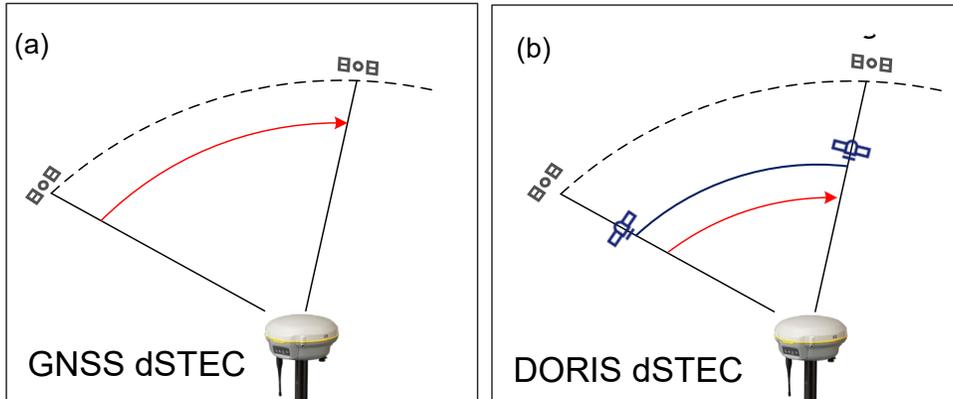
Compared to **Jason-3 DORIS dSTEC** – 01/01-31/03, 2022
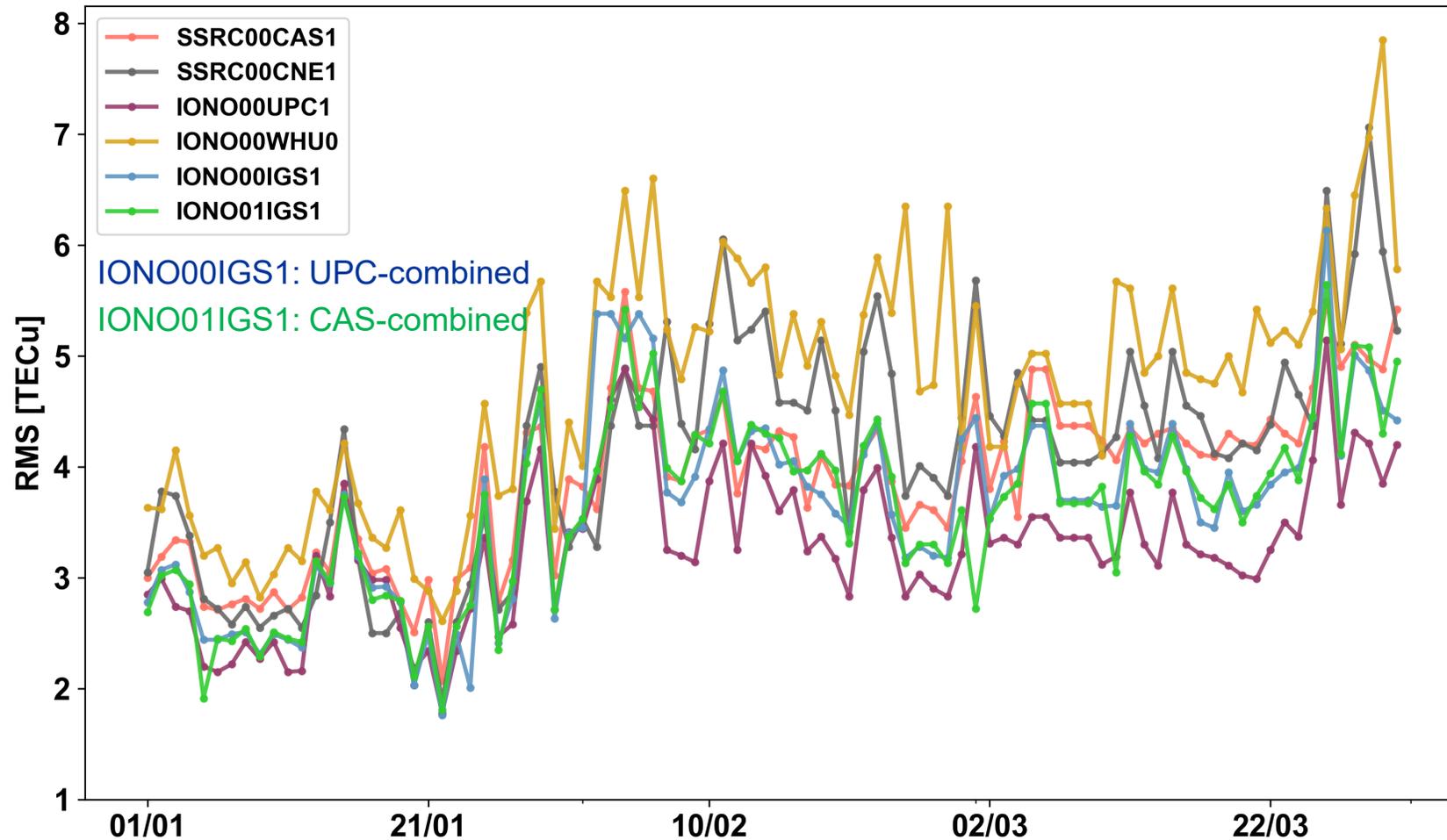
TEC references	Statistics	CAS IONO00CAS1	UPC IONO00UPC1	UPC-combined IONO00IGS1	CAS-combined IONO01IGS1
IGS-GIM VTEC	Bias	-0.54	-0.79	-1.34	-1.29
	STD	3.19	2.63	2.56	2.69
	RMS	3.30	2.75	2.93	3.02
	Rel. error	18.6%	15.7%	16.6%	16.9%
Jason-3 VTEC	Bias	3.51	3.52	2.71	2.72
	STD	5.24	4.28	4.7	4.68
	RMS	6.37	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%

(01/01-31/03, 2022)

Aerospace Information Research Institute (AIR), CAS

GPS L1 SF-SPP corrected by different ionospheric corrections

► BDGIM: BDS-3 Global broadcast Ionospheric Model;   IGRG: IGS rapid-GIM;

► IONO00IGS1: *UPC-combined* RT-GIM;   IONO01IGS1: *CAS-combined* RT-GIM;

Horizonal accuracy of SF-SPP (95% percentile)

Vertical accuracy of SF-SPP (95% percentile)

(location of test sites on slid 8)

GPS L1 SF-PPP constricted with different ionospheric corrections

▶ BDGIM: BDS-3 Global broadcast Ionospheric Model;   IGRG: IGS rapid-GIM;

▶ IONO00IGS1: *UPC-combined* RT-GIM;   IONO01IGS1: *CAS-combined* RT-GIM;

Horizonal accuracy of SF-PPP (95% percentile)

Vertical accuracy of SF-PPP (95% percentile)
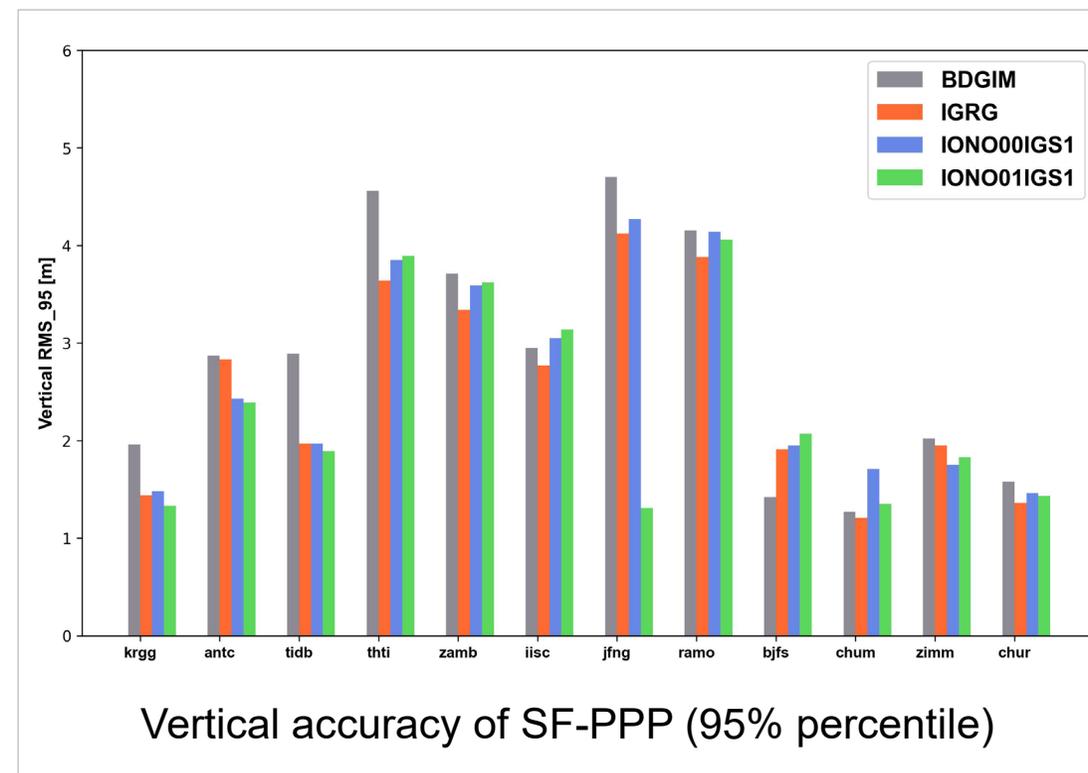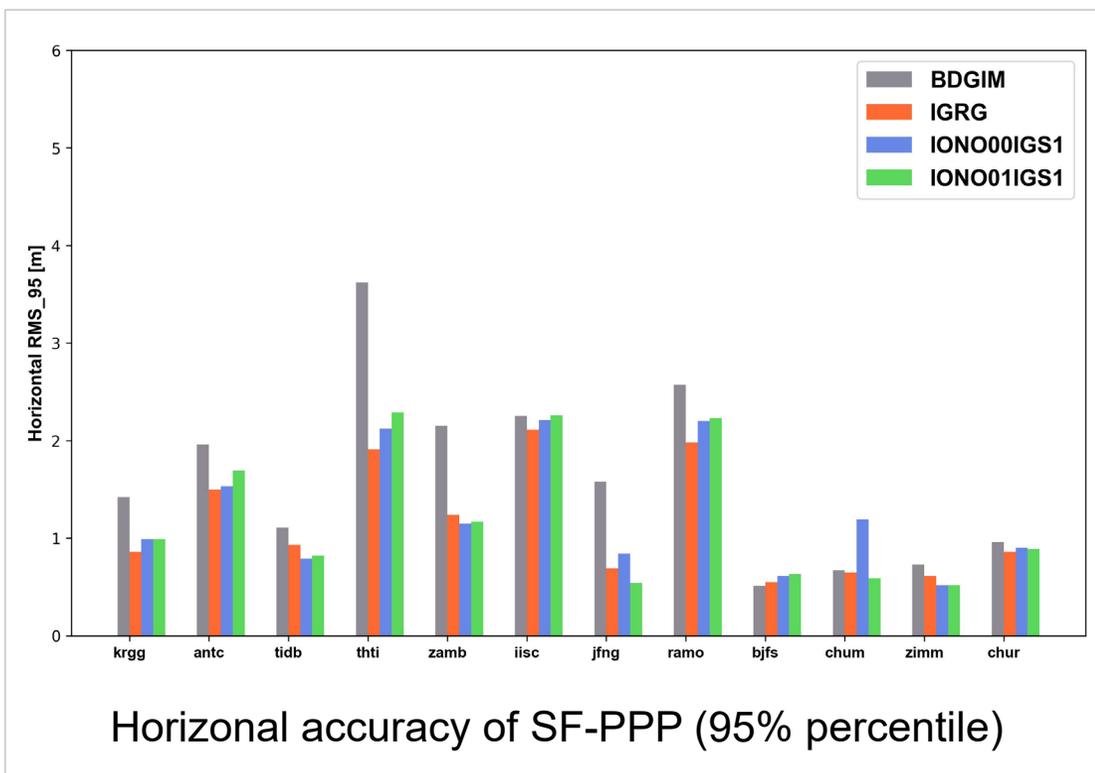
(location of test sites on slid 8)

# GPS L1 SF-PPP constricted with different ionospheric corrections

▶ BDGIM: BDS-3 Global broadcast Ionospheric Model;   IGRG: IGS rapid-GIM;

▶ IONO00IGS1: *UPC-combined* RT-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	1.84	0.51	6.20
	IONO00IGS1	1.48	0.47	5.69
	IONO01IGS1	1.50	0.48	4.97
	IGRG	1.41	0.48	4.70
Vertical component	BDGIM	3.31	1.16	8.68
	IONO00IGS1	3.12	1.03	7.76
	IONO01IGS1	3.08	1.05	8.13
	IGRG	2.94	0.91	7.53

▶ 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.

▶ 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.

To access CAS-combined RT-GIM data streams, try

IGS caster: products.igs-ip.net:2101

Mountpoints: IONO01IGS0, IONO01IGS1

Thanks for your attention

In case of any questions, please feel free to contact

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