Near-Real-Time DORIS Data for GNSS-based Ionospheric Maps Validation and Combination

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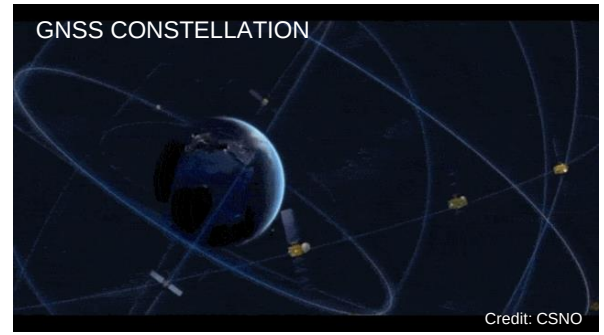
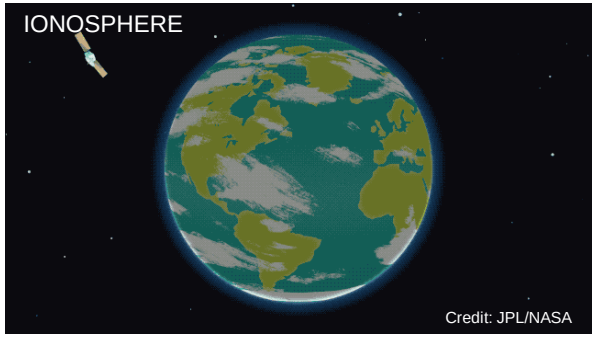
Agenda

- Background and Motivation
- DORIS dSTEC analysis concepts
- Data sets and analysis results

  NRT DORIS data for GIM validation

  NRT DORIS data for GIM combination
- Summary and conclusions

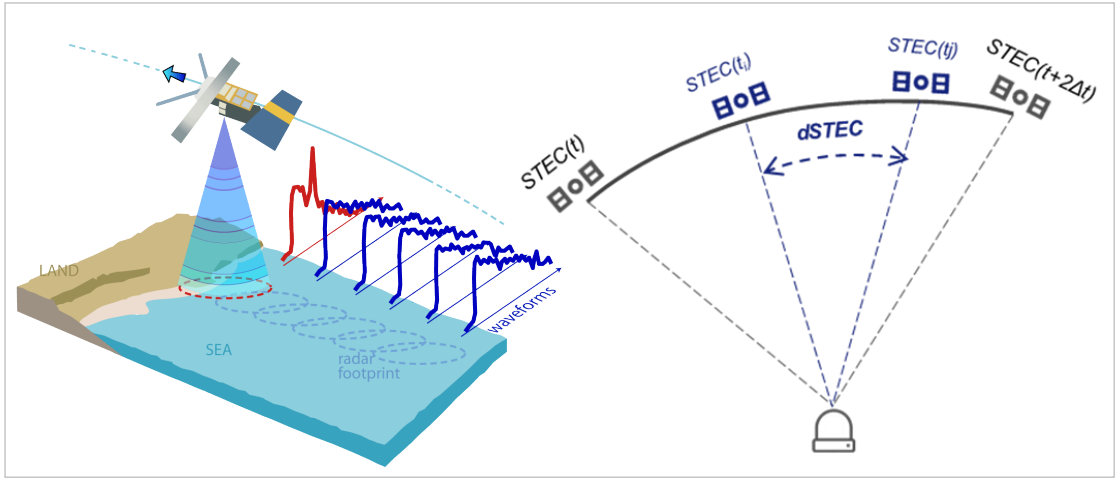




Validation of Real-Time Global Ionospheric Maps (RT-GIMs)

- Self-consistency check
  - *GNSS-derived STEC*: *code smoothing* or *precise point positioning* (PPP) derived, S/R DCB removed.
  - ***GNSS-derived dSTEC***: carrier phase geometry-free combination derived, differential STEC b.w.t. two epochs along individual continuous arcs, low level of observation noises.
  - GNSS derived STEC and dSTEC are available in real-time (few seconds in time latency).

- External-consistency check
  - Altimetry-derived VTECs, available over the oceanic regions.
  - Fully independent to GNSS measurements.
  - Near-real-time altimetry VTECs provided by **Jason-3** (~3 hours in latency)



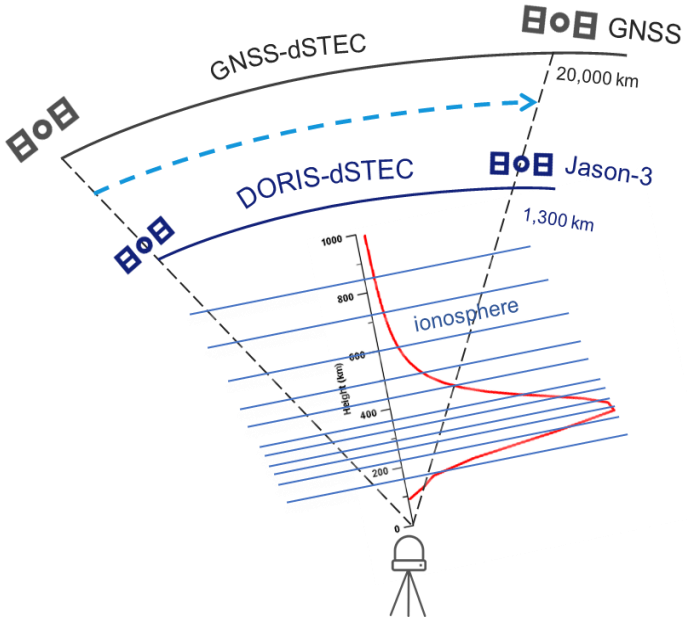
Using DORIS Data to Validate and Combine GNSS generated Ionospheric Maps

- DORIS data: valuable and external data sources to examine the Earth's ionosphere.
- Homogeneous distribution of DORIS ground beacons, covering continental and oceanic regions.
- DORIS data are available from 8 satellite missions: CRYOSAT-2, HY-2C, HY-2D, Jason-3, SARAL, Sentinel-3A, Sentinel-3B and Sentinel-6A
- The large relative frequency ratio (~5) between two frequencies of DORIS: more sensitive to detect the ionospheric information and less prone to measurement noises.
- The standardization of DORIS data formats, i.e., RINEX DORIS 3.0, similar to the existing GNSS RINEX format.
- The decreasing time latency in obtaining DORIS data (~3 hours for Jason-3 DORIS data).

GNSS-dSTEC analysis concept

- **GNSS-dSTEC**: the differential phase STEC along a continuous arc referring to the highest satellite elevation (Hernández-Pajares et al. 2017).
- Only dual-frequency carrier phase measurements used (geometry-free linear combination).
- Avoiding the negative effects of amplified pseudorange noises as well as the intra-day variation of receiver biases in *code-smoothing technique* derived STEC/VTEC.
- GNSS-dSTEC used for the IGS rapid/final TEC maps combination for more than 20 years

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

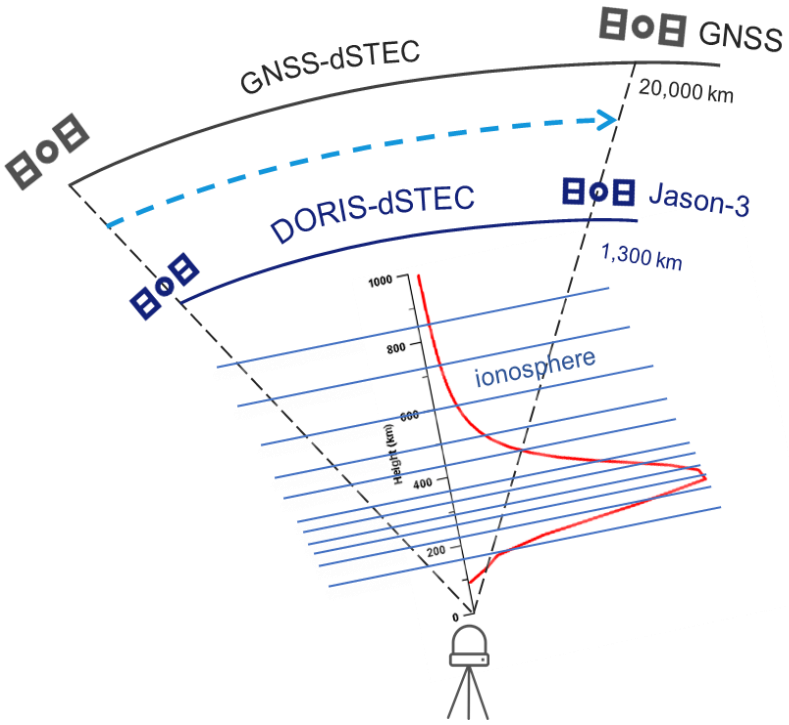


DORIS-dSTEC analysis concept

- The calculation of DORIS-dSTEC is very similar to that of GNSS-dSTEC, generated based on dual-frequency DORIS carrier phase measurements.
- Containing dSTEC information to the height of LEO satellites, e.g. ~1,300 km for Jason-3.

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

ΔD denotes the geometry correction (i.e., the PCO correction)



Precision analysis of DORIS/GNSS derived dSTEC information

- Ignoring the correlation b.w.t. L1/L2 carrier phase measurements, the theoretical precision of DORIS or GNSS dSTEC can be estimated by

$$\begin{cases} \sigma_{dSTEC}^2 = 2\mu^2\sigma_{LI}^2 \\ \sigma_{LI}^2 \approx \sigma_{L_1}^2 + \sigma_{L_2}^2 \end{cases}$$

σ_{LI} denotes the precision of geometry-free linear combination of dual-frequency DORIS/GNSS phase measurements

- Precision of DORIS-dSTEC reaches 0.028 TECu (σ_{L1}=1.5 mm and σ_{L2}=7.5 mm)
- Precision of GNSS-dSTEC is about 0.25 TECu (σ_{L1}= σ_{L2}=2.0 mm)
- The precision of those derived dSTEC benefits from the large frequency difference (i.e., f_1- f_2)
- Overall, the theoretical precision of DORIS-dSTEC is about 10 times better than GNSS-dSTEC

(Liu, Wang et al. 2023)

Overview of RT-GIMs provided by different analysis centers (ACs)

AC	Caster	Mountpoint	Interval
CAS	products.igs-ip.net:2101	SSRC00CAS1 (*IGS-SSR*[1])	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*[2])	60s
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*)	

* Combined RT-GIMs using *ground based* RT-GNSS data streams

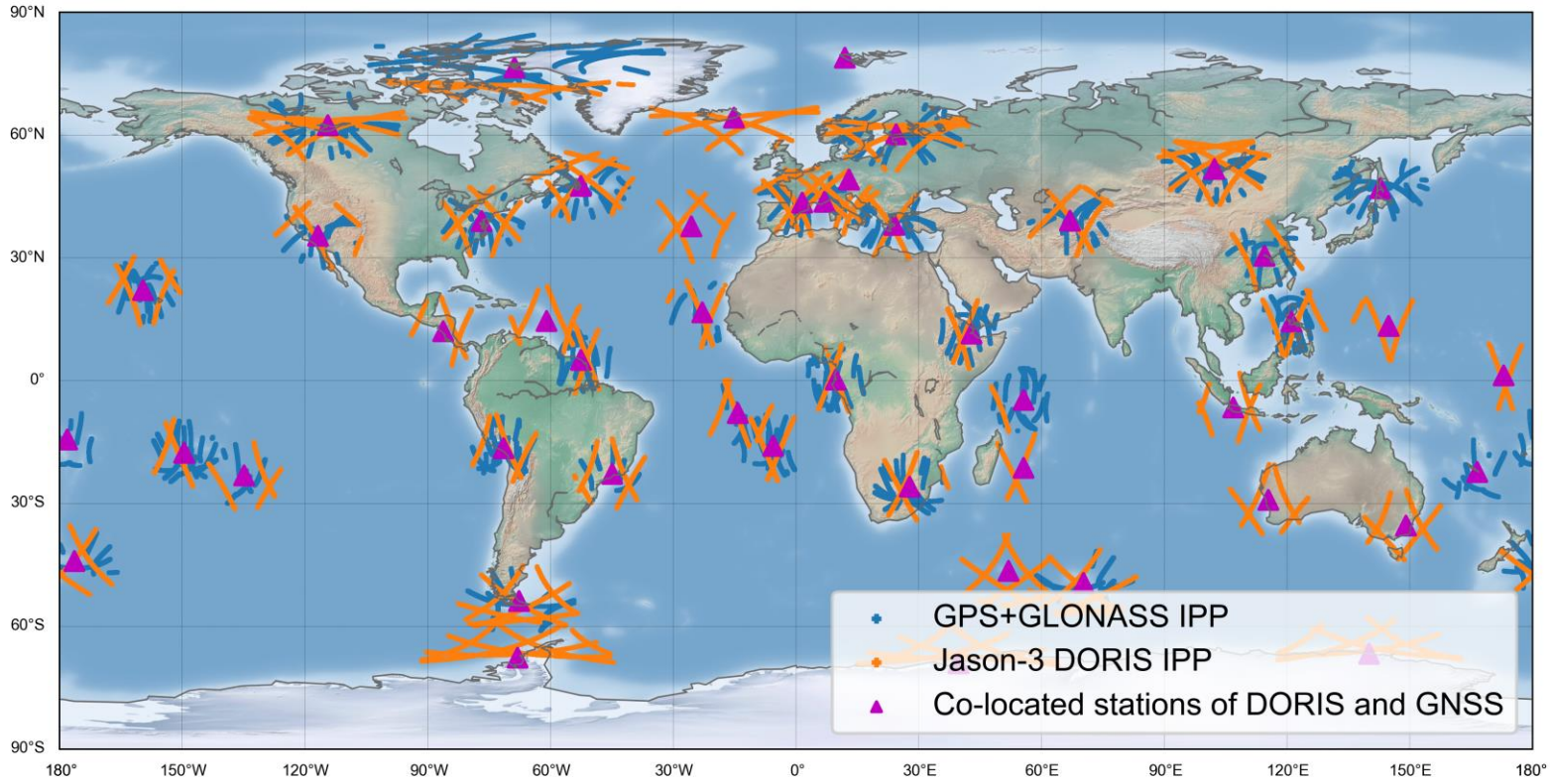
[1] IGS-SSR: IGS State Space Representation (SSR) Format

[2] RTCM-SSR: RTCM State Space Representation (SSR) Format

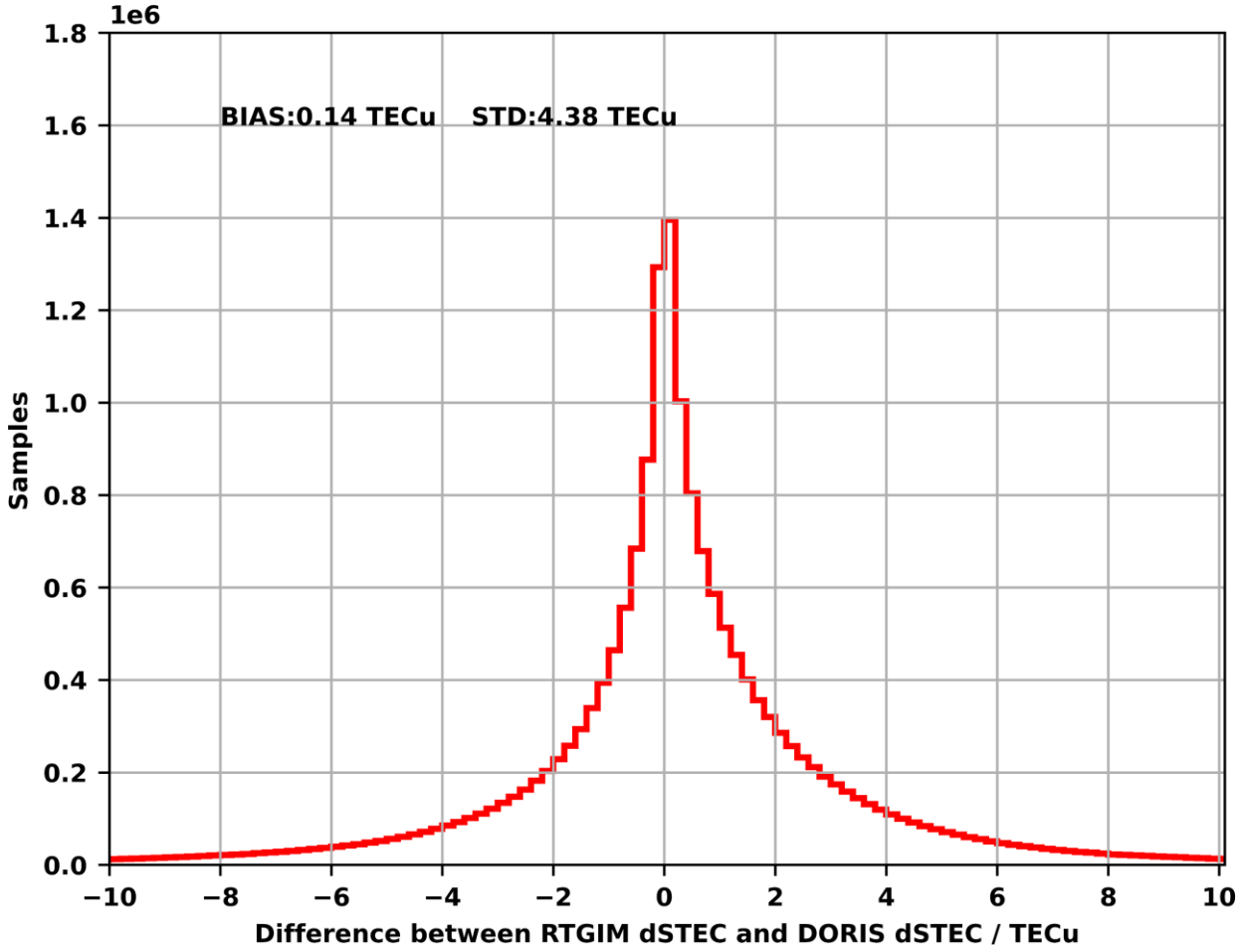
Data sets and results – GIM validation using NRT DORIS data

The selected 48 DORIS beacons and co-located GNSS stations

- NRT DORIS data from Jason-3 altimetry used for DORIS dSTEC analysis
- GPS and GLONASS observations of the IGS network used for GNSS dSTEC analysis



Consistency b.w.t. RT-GIM derived and DORIS observed dSTECs

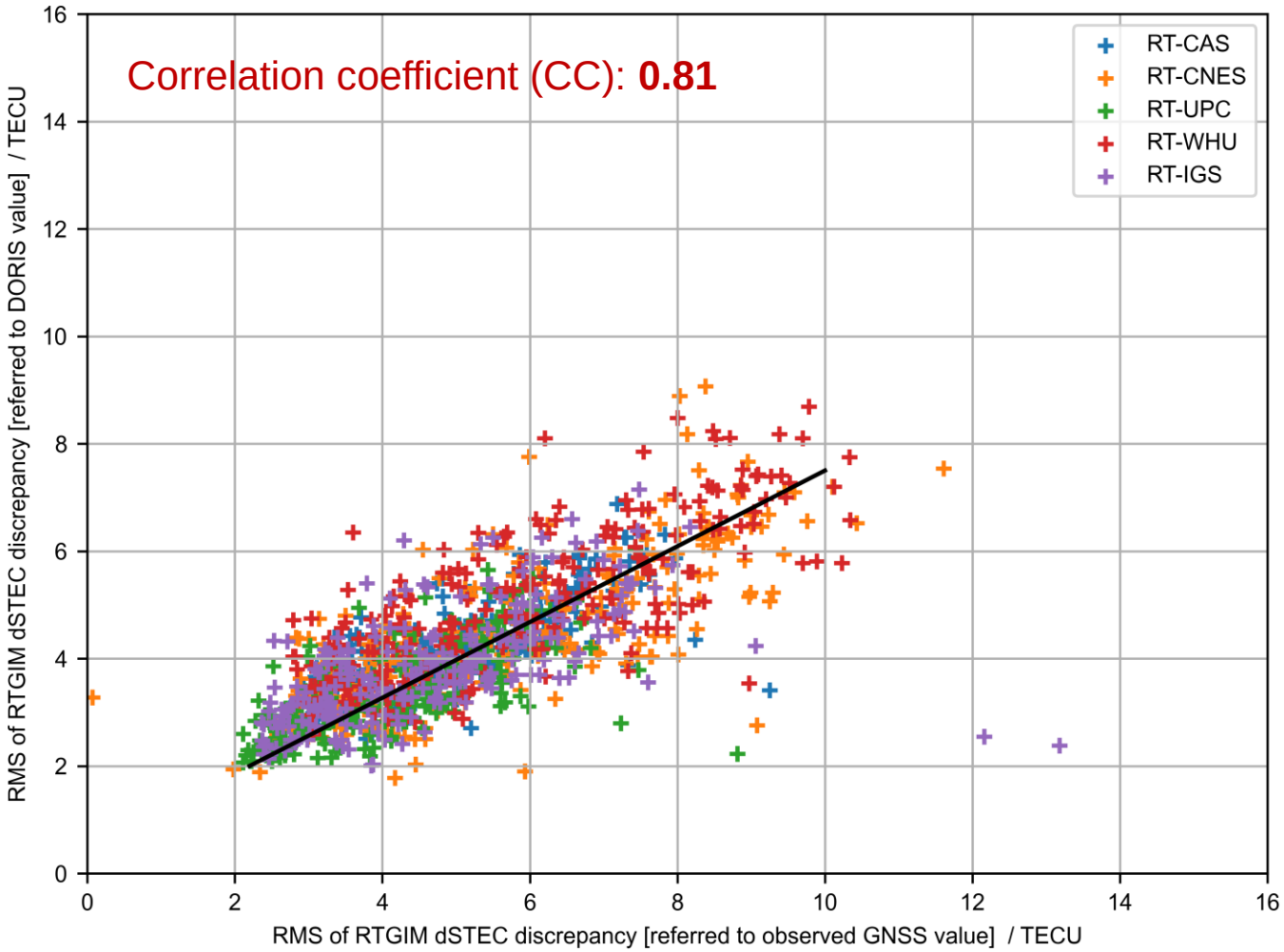


- more than 18,000,000 DORIS dSTEC observables used for the analysis.
- around 77.1% of the dSTEC differences is below +/- 3.0 TECu.
- no systematic bias found b.w.t. Jason-3 DORIS dSTEC and RT-GIM derived dSTEC.

Histogram of differences b.w.t. RT-GIM derived and DORIS observed dSTECs during DOY 001–110, 2022

Data sets and results – GIM validation using NRT DORIS data

Consistency b.w.t. DORIS (Jason-3) and GNSS (G/R) dSTEC assessments



RMS of RT-GIM dSTEC discrepancy referring to DORIS data versus that referring to GPS/GLONASS data during DOY 001-110, 2022.

Data sets and results – GIM combination using DORIS data

RT GNSS data for GIM combination – CAS *OPERATIONAL computation line*

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

NRT DORIS data for GIM combination – CAS new computation line

- Input RT-GIMs: SSRC00CAS1, SSRC00CNE1, IONO00UPC1 and IONO00WHU0
- NRT-combination strategy: DORIS-dSTEC analysis
- Station network for RT-GIM weighting: selected 48 DORIS beacons
- Generated NRT combined GIM: IONEX files

Experimental NRT-GIM combination using Jason-3 NRT DORIS Data

- Input RT-GIMs: SSRC00CAS1, SSRC00CNE1, IONO00UPC1 and IONO00WHU0
- Input DORIS data: Jason-3 NRT DORIS observation data (*ONE* satellite)

GNSS and DORIS dSTEC derived weights of different RT-GIMs

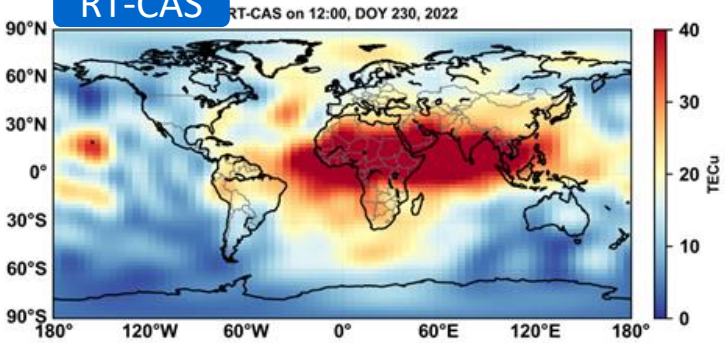
RT-GIMs	GNSS-dSTEC derived weights	DORIS-dSTEC derived weights
RT-CAS	0.29	0.24
RT-CNES	0.19	0.21
RT-UPC	0.35	0.35
RT-WHU	0.17	0.20

DOYs 001-270, 2022

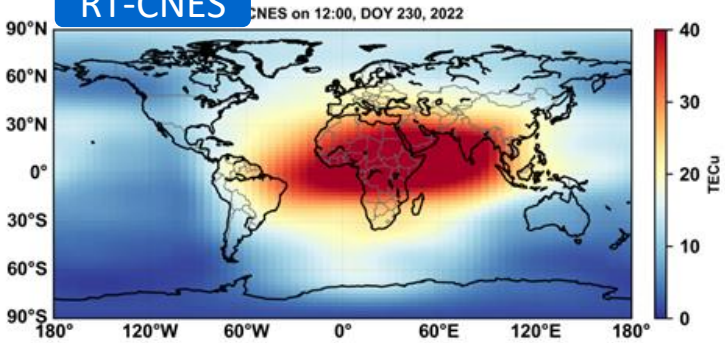
Data sets and results – GIM combination using DORIS data

Experimental NRT-GIM combination using Jason-3 NRT DORIS Data

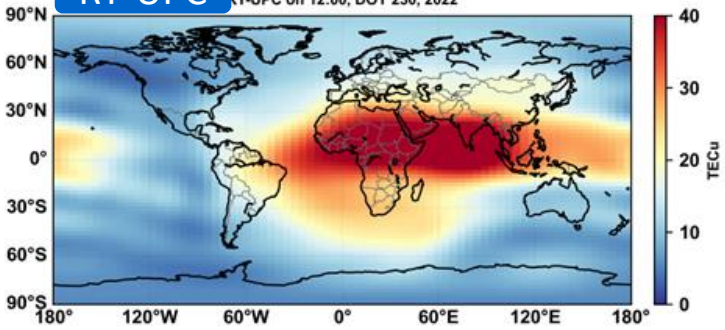
RT-CAS



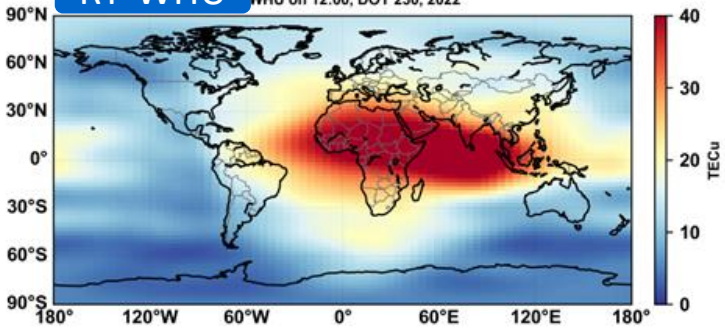
RT-CNES



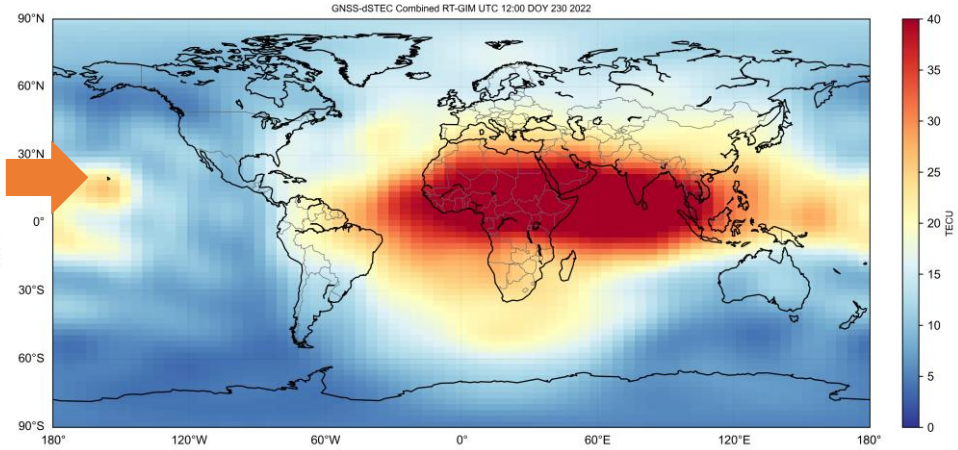
RT-UPC



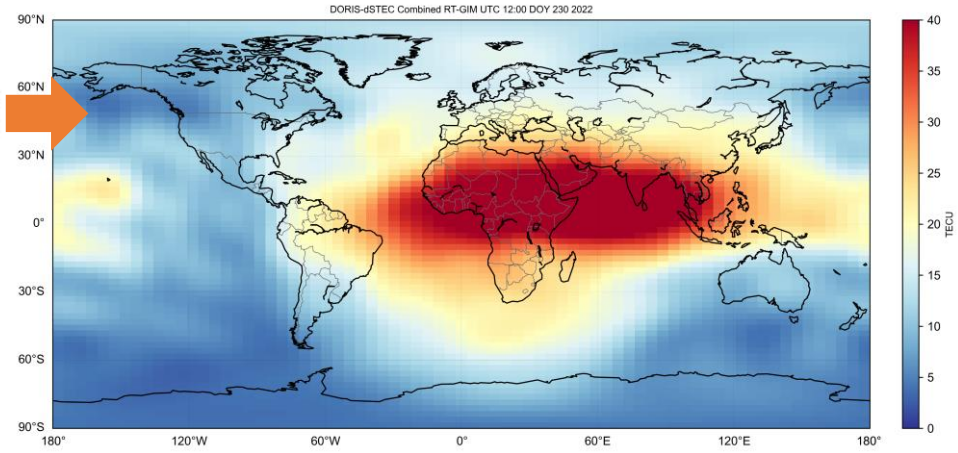
RT-WHU



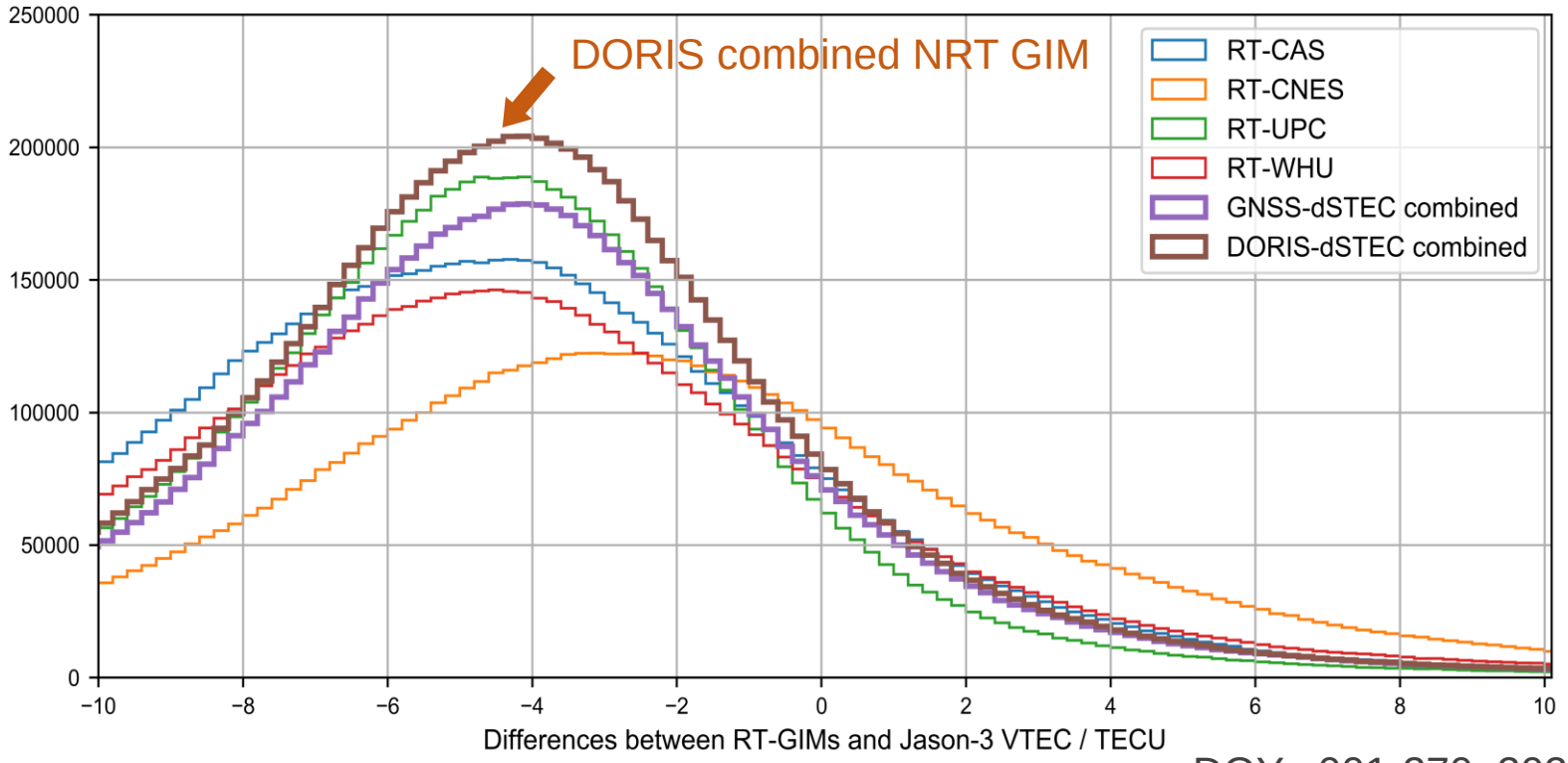
GNSS-dSTEC combined GIM



DORIS-dSTEC combined GIM



Experimental NRT-GIM combination using Jason-3 NRT DORIS Data



DOYs 001-270, 2022

	STD / TECu
RT-CAS	5.46
RT-CNES	6.83
RT-UPC	4.36
RT-WHU	6.11
RT-GNSS*	4.80
RT-DORIS**	**4.71**

* RT-GNSS: GNSS-dSTEC combined RT-GIM

** RT-DORIS: DORIS-dSTEC combined RT-GIM

Summary and conclusions

- The concept of DORIS dSTEC assessment is proposed, which is the extension of the existing GNSS dSTEC validation method.
- No systematical bias is found between RT-GIM derived dSTEC and DORIS observed dSTEC.
- The overall correlation coefficient is 0.81 for the validation result using DORIS and GNSS dSTEC.
- DORIS dSTEC assessment can be used as an independent way to validate the quality of those ground GPS/GNSS generated ionospheric models.
- The NRT & rapid combined GIMs are routinely generated at CAS using DORIS data.
- We have one proposal within the IGS Ionosphere Working Group to provide independent rapid and final IGS combined GIMs.

For mode details, please refer to our ASR DORIS special issue paper

Liu A., Wang N., Dettmering D., Li Z., Schmidt M., Liang W., Yuan H.: Using DORIS Data for Validating Real-Time GNSS Ionosphere Maps. Advances in Space Research, 10.1016/j.asr.2023.01.050, 2023*

Thanks for your attention