



# Benefits of IGS RTS for real time ionospheric space weather monitoring

Ningbo WANG<sup>1,2</sup>, Zishen LI<sup>1</sup>

<sup>1</sup>Academy of Opto-Electronics, Chinese Academy of Sciences, Beijing

<sup>2</sup>IAPG, Technical University of Munich, Munich

E-mail: wangningbo@aoe.ac.cn

# Outlines

---

- Background and motivation
- Computation of RT-GIMs at CAS (vTEC modeling)
- Validation of RT-GIMs w.r.t different TEC sources
- Conclusions and future work



## Motivation (1/2)

---

- The rapid and final GIMs provided by IGS since 1998 (~20 years)
- The availability of the IGS global and other regional **RT data streams**, containing **multi-frequency** and **multi-constellation** GNSS measurements, is being crucial for real-time ionospheric modeling and monitoring
  - RT code biases (GPS) SSR format standardized in 2011
  - Ionosphere vTEC SSR format proposed since 2013
  - Real-time IONO activities running within IGS/IAG frames
  - Several research groups working on the computation of RT-GIMs

-> Our targets

- Real-time 2D ionospheric modeling (vTECs) using IGS Real Time Services (RTS)
- Providing reliable RT ionospheric information for ionospheric space weather monitoring and precise GNSS applications



## Motivation (2/2)

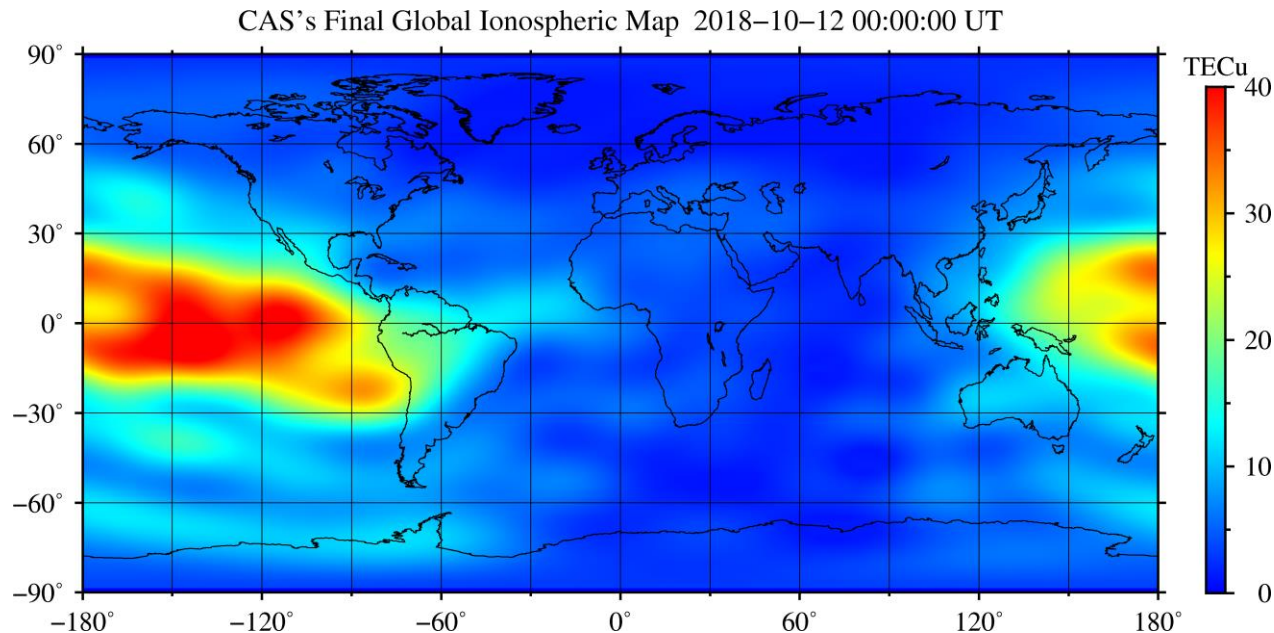
State of the art on RT or NRT ionospheric TEC modeling (as of March, 2018)

Institutions	Methodology	Format	Latency
UPC-IonSAT	4D iono. model + interpolation	RTCM IONO SSR	RT
CNES	SH (7*7)	RTCM IONO SSR (CLK93)	RT
CAS	SH (15*15) + prediction model	RTCM IONO SSR (CAS05)	RT
DLR-NZ	Neustrelitz TEC model (NTCM)	IONEX	RT
DGFI-TUM	B-splines + Kalman filter	IONEX	NRT, 2-3 hours
ROB	ROB-IONO SW	IONEX ( <i>European Region</i> )	RT



# RT-GIM generation at CAS (1/6)

- CAS Ionosphere Analysis Center of the IGS
  - Routine generation of rapid (carg) and final (casg) GIMs since 2014
  - New Ionosphere AC (1/7) of the IGS since 02/2016
  - GIM files routinely delivered to CDDIS since 01/2017 (data: 1998-now)
  - Routine RT-GIM generation since 3<sup>rd</sup> quarter of 2017

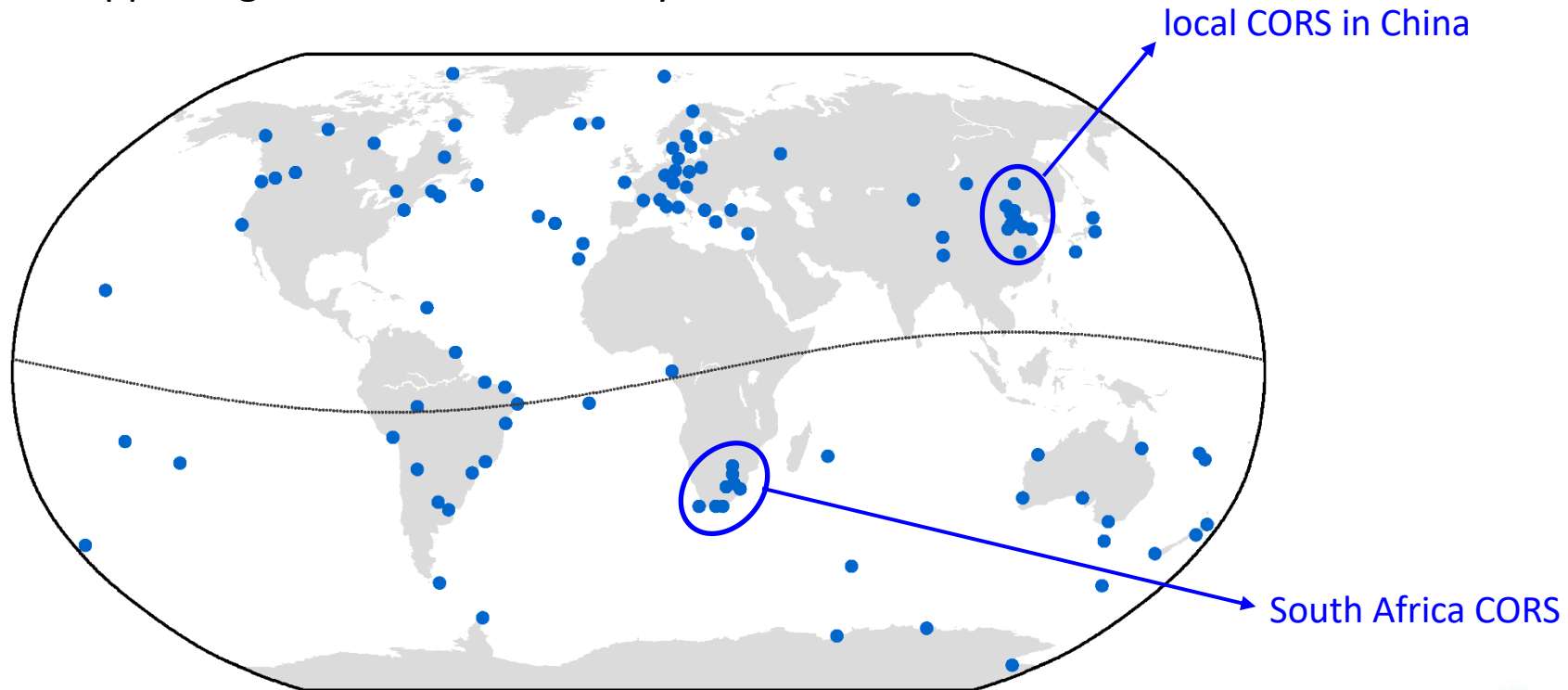


- Tracking networks – IGS +MGEX (> 300 sites)
- Observations – GPS(L1+L2), GLONASS(L1+L2), BeiDou(B1+B2 since 2016)
- Global grids –  $\Delta\text{Lon} \times \Delta\text{Lat}$  (5.0 X 2.5)      Temporal resolution – 1 hour (30 mins since mid-2016)



## RT-GIM generation at CAS (2/6)

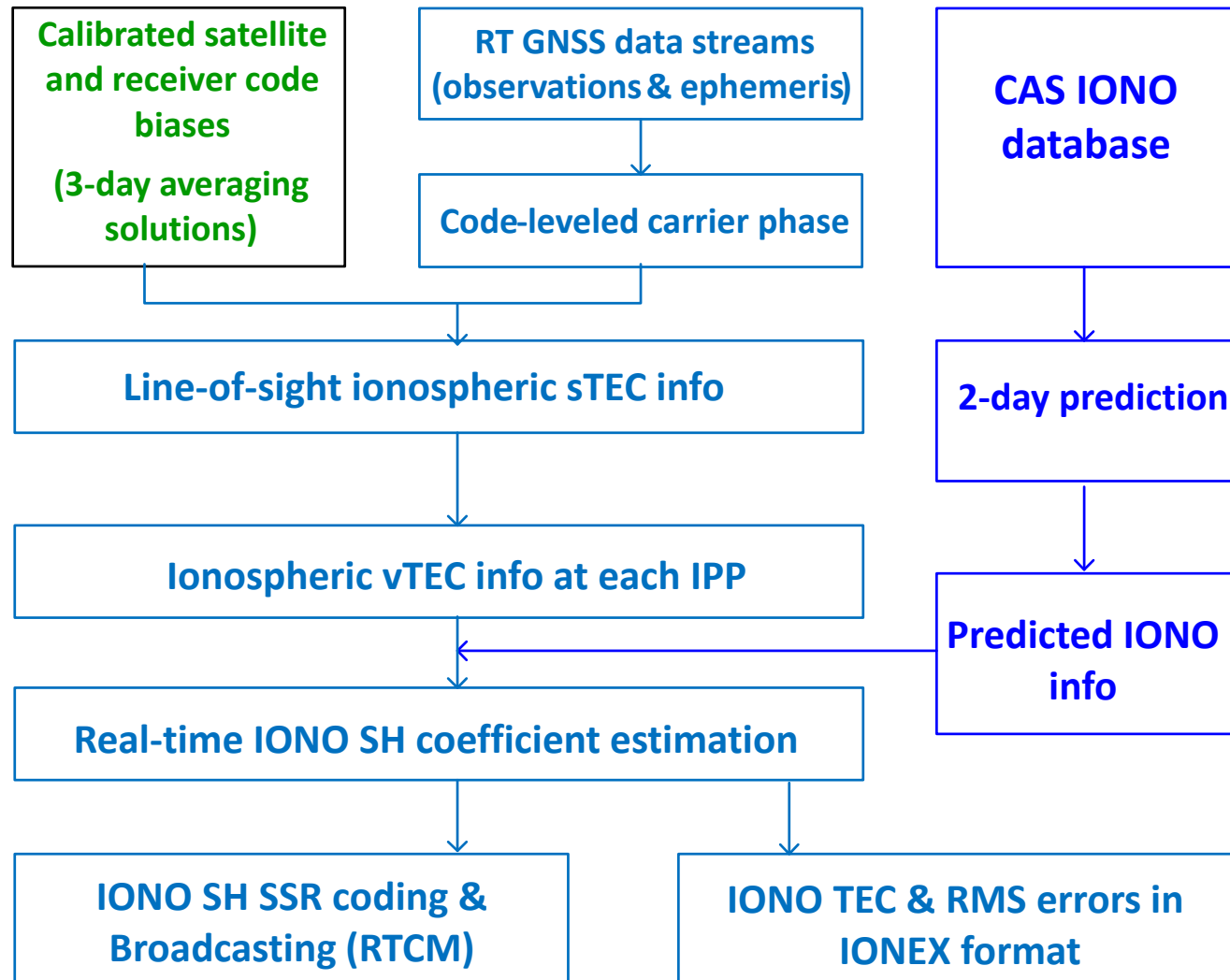
- Routine RT GNSS data processing at CAS
  - IGS+MGEX RT data streams (mainly)
  - Local CORS networks in China and South Africa
  - ~110 global sites
  - Supporting GPS+GLO+GAL+BDS systems



Distribution of RT GNSS sites processed at CAS (UT 13:05, 30/10/2017)

# RT-GIM generation at CAS (3/6)

- Generation of RT-GIMs at CAS



### Details on global RT IONO vTEC modeling

- RT GNSS measurements (~110 routine sites)
  - GPS (L1+L2), GLO (L1+L2), GAL (E1+E5a), BDS-2 (B1+B2)
  - Code-levelled carrier phase (CLC)
  - Pre-determined satellite & receiver code biases (3-day solution)
- IONO information prediction
  - 2-day SH coefficient prediction using harmonic expansion (Fourier series function)
  - Weighting function designed for IONO information prediction
- Estimation of RT SH coefficient
  - SH function:  $15 \times 15$
  - Data sliding window: 15 mins
  - Time resolution: 5 mins

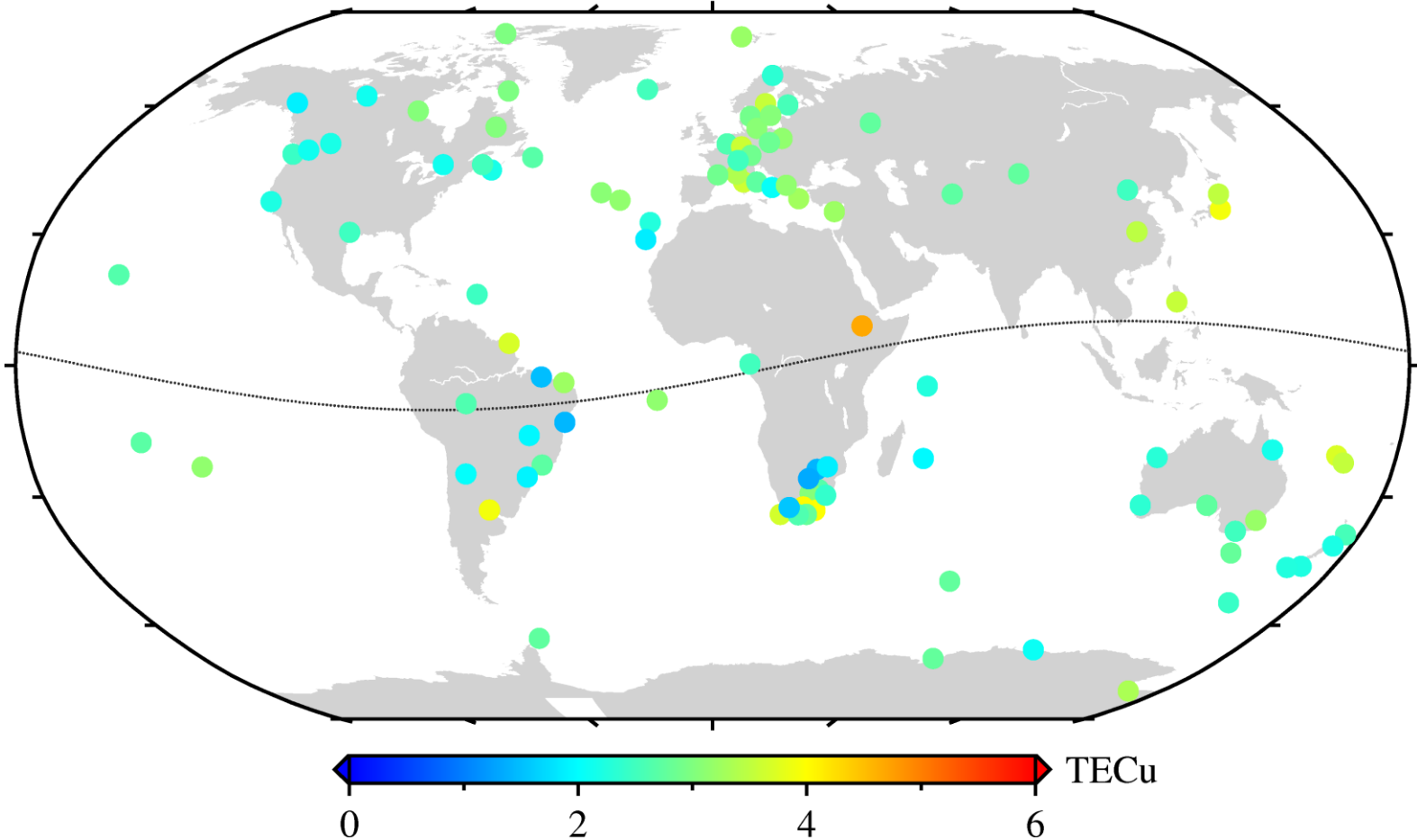




## RT-GIM generation at CAS (5/6)

RMS of CAS's TEC map at each contributing site (Self-consistency)

CAS's Real-time TEC Error Map 2018-10-27 02:30:00 UT



Distribution of RT GNSS sites processed at CAS (UT 13:05, 30/10/2017)

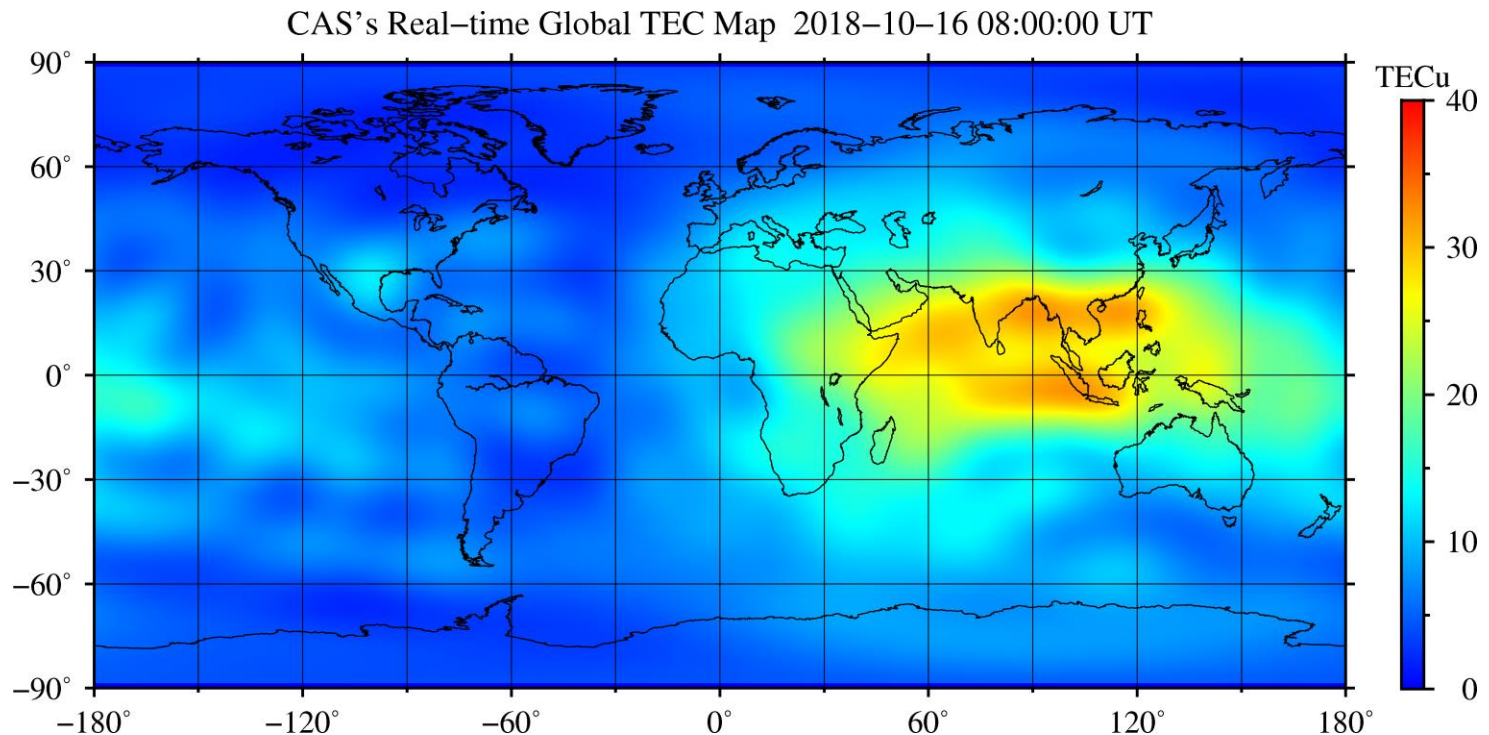
## RT-GIM generation at CAS (6/6)

- RT vTEC SSR broadcasting via Ntrip Caster

Mount point (account required): [products.gipp.org.cn/CAS05](http://products.gipp.org.cn/CAS05)

- RT-GIM files (CRTG) in IONEX format available at CAS's ftp archive

Data/snapshot archives: <ftp://ftp.gipp.org.cn/product/ionex/>



# RT-GIM validation at CAS (1/7)

## Comparison of diff. TEC sources for IONO model performance validation

	GNSS TEC	GNSS dsTEC	Altimetry vTEC	DORIS dsTEC
Obs.	GF comb.+ CLC	<b>GF Comb.+ Phase</b>	GF Comb.	<b>GF Comb.+ Phase</b>
TEC types	Absolute (V/S)	<b>Relative</b>	Absolute (V)	<b>Relative</b>
Data coverage	Mainly over continents		Only over oceans	Globally uniform distribution
Assessment types	Self- or external consistency		External consistency	External consistency

- GNSS dsTEC assessment: GPS sites of the IGS (60-70, globally arbitrary selected)
- GNSS TEC assessment: IGS final GIMs
- Altimetry vTEC assessment: Jason-3 vTECs
- DORIS dsTEC assessment: DORIS sites of the IDS (14, globally, Jason-3 Phase Meas.)

RT-GIM validation using IONEX files, but NOT RT SH data stream!



## RT-GIM validation at CAS (2/7)

- GNSS and DORIS dsTEC assessment
  - Input data: dual-frequency phase obs.
  - Retrieval of IONO info: geometry-free combination (L4)
  - $L_I(t_k)$  denotes phase derived TEC at epoch  $t_k$
  - $L_I(t_{ref})$  denotes phase derived TEC with highest satellite elevation of the arc
- dsTEC is calculated by forming

$$dsTEC(t_k) = L_I(t_k) - L_I(t_{ref})$$

- Accuracy of dsTEC is much higher than that of the TECs derived from code leveled carrier phase technique

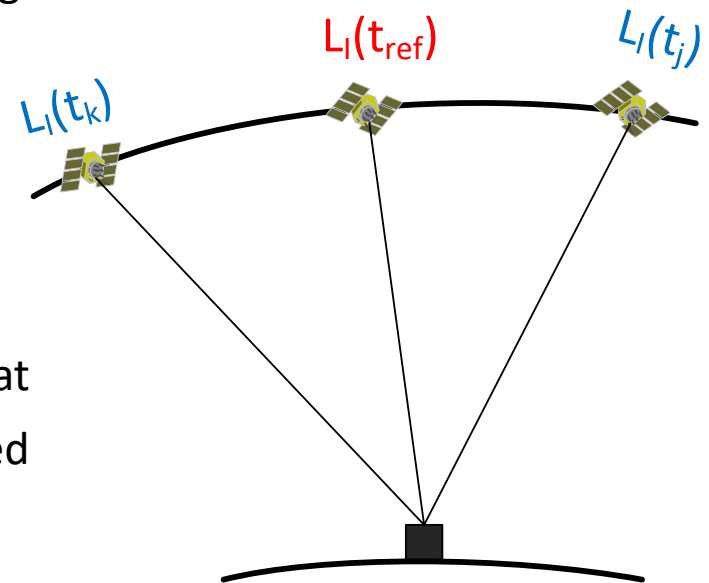
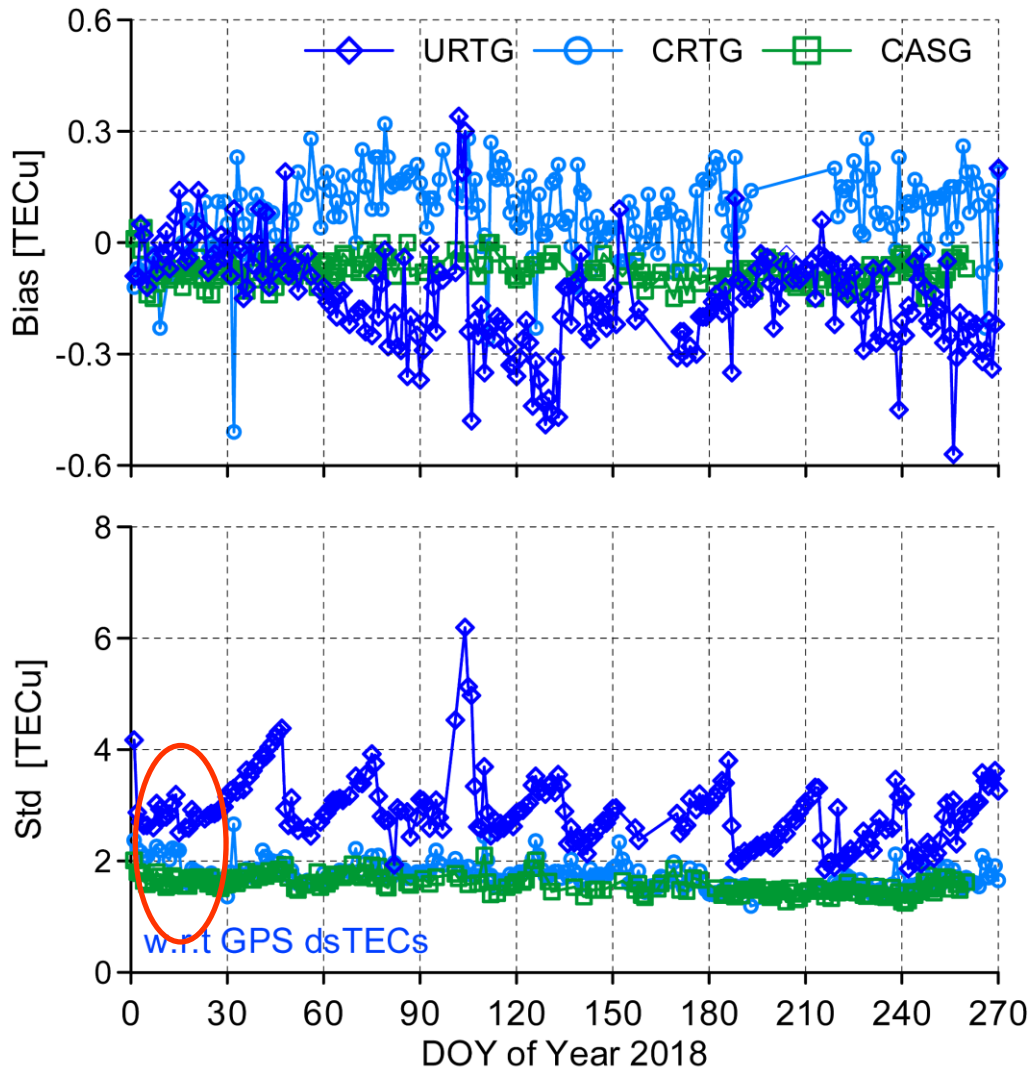


Illustration of dsTEC concept in a continuous arc of carrier phase observations

# RT-GIM validation at CAS (3/7)

- Performance analysis of RT-GIM (w.r.t **GPS dsTECs**)

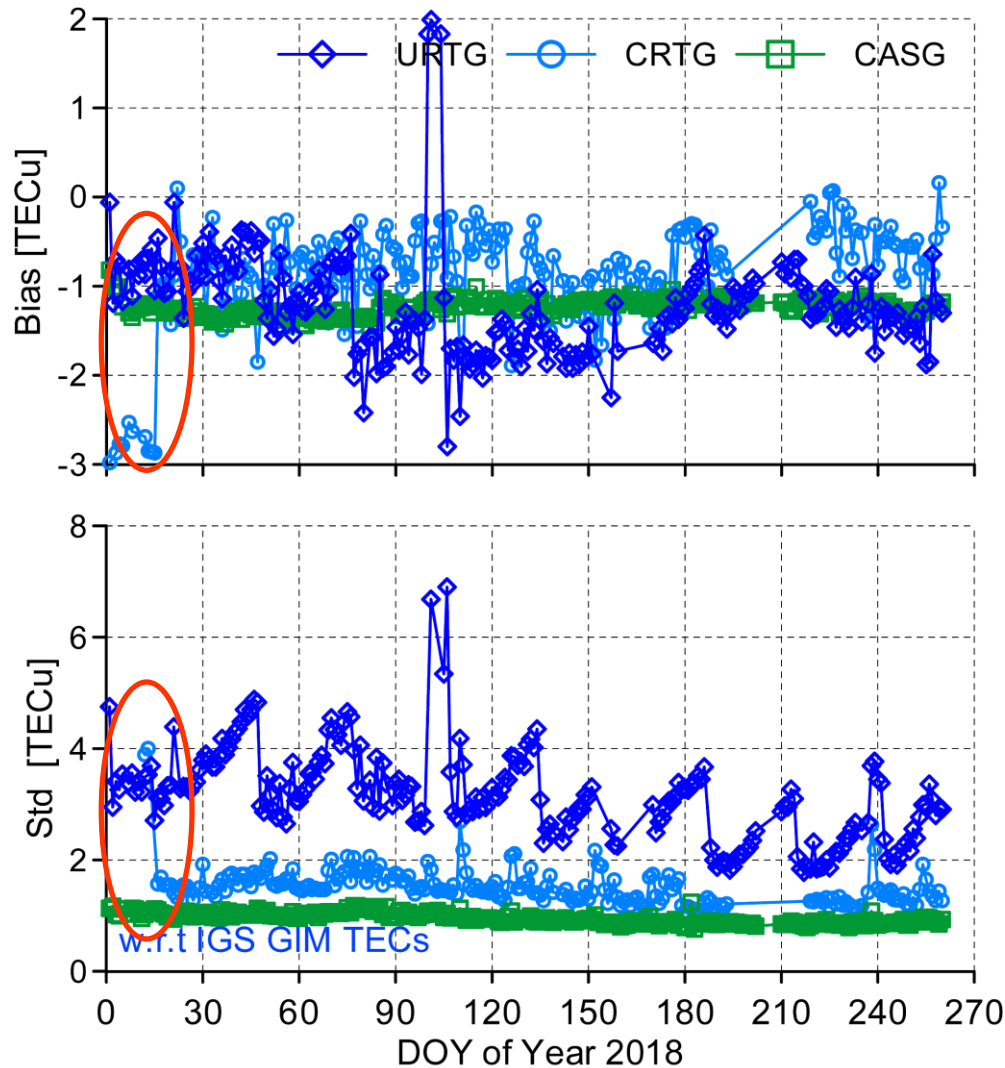


- URTG: RT-GIM of UPC (15 mins)
- CRTG: RT-GIM of CAS (5 mins)
- CASG: final GIM of CAS (30 mins)
- Time period:  
(to the end of September, 2018)
- Performance improvement of CRTG since early 2018
- Slight worse performance of CRTG compared to the final one
- Std errors of URTG show some periodicities



# RT-GIM validation at CAS (4/7)

- Performance analysis of RT-GIM (w.r.t IGS GIM vTECs)



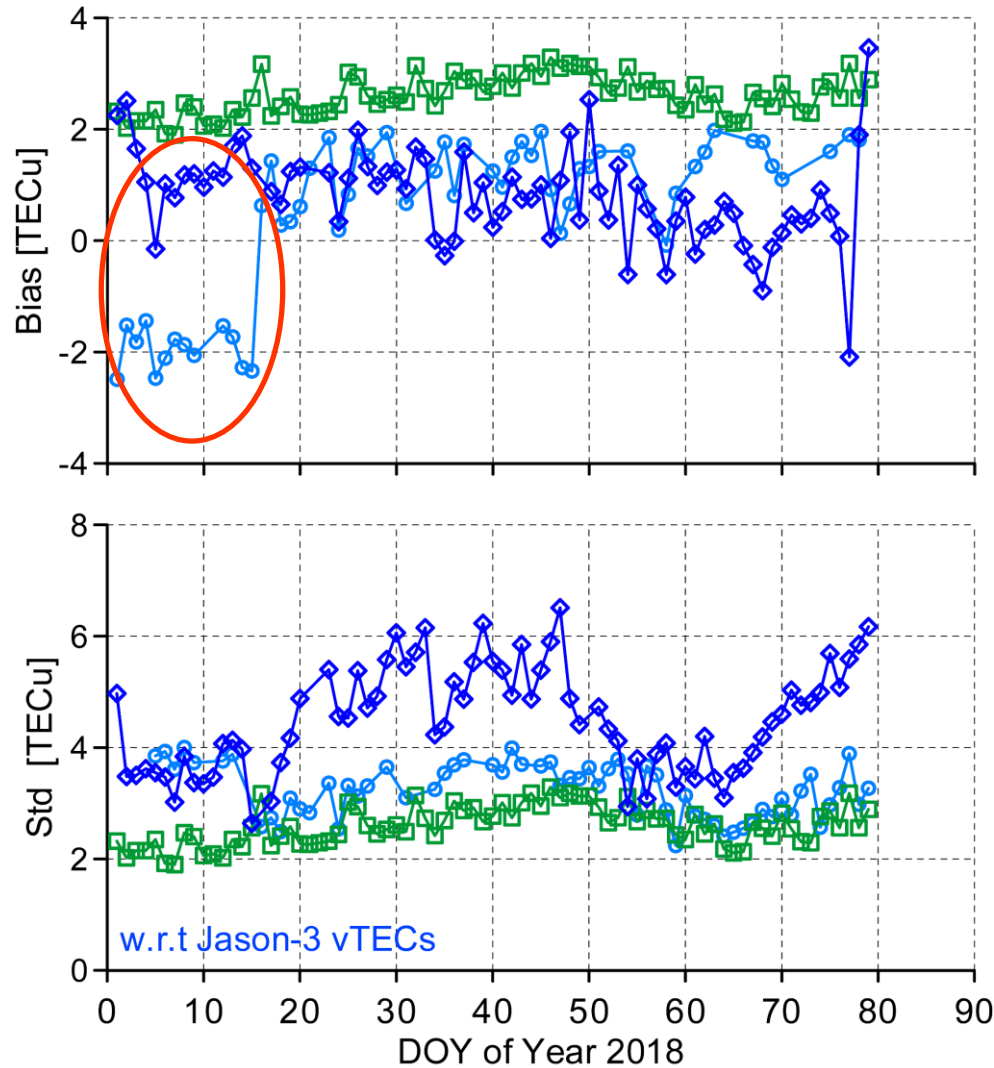
- URTG: RT-GIM of UPC (15 mins)
- CRTG: RT-GIM of CAS (5 mins)
- CASG: final GIM of CAS (30 mins)

- Performance improvement of CRTG since early 2018
- Slight worse performance of CRTG compared to the final one
- Std errors of URTG still show the periodicities



# RT-GIM validation at CAS (5/7)

- Performance analysis of RT-GIM (w.r.t Jason-3 vTECs)



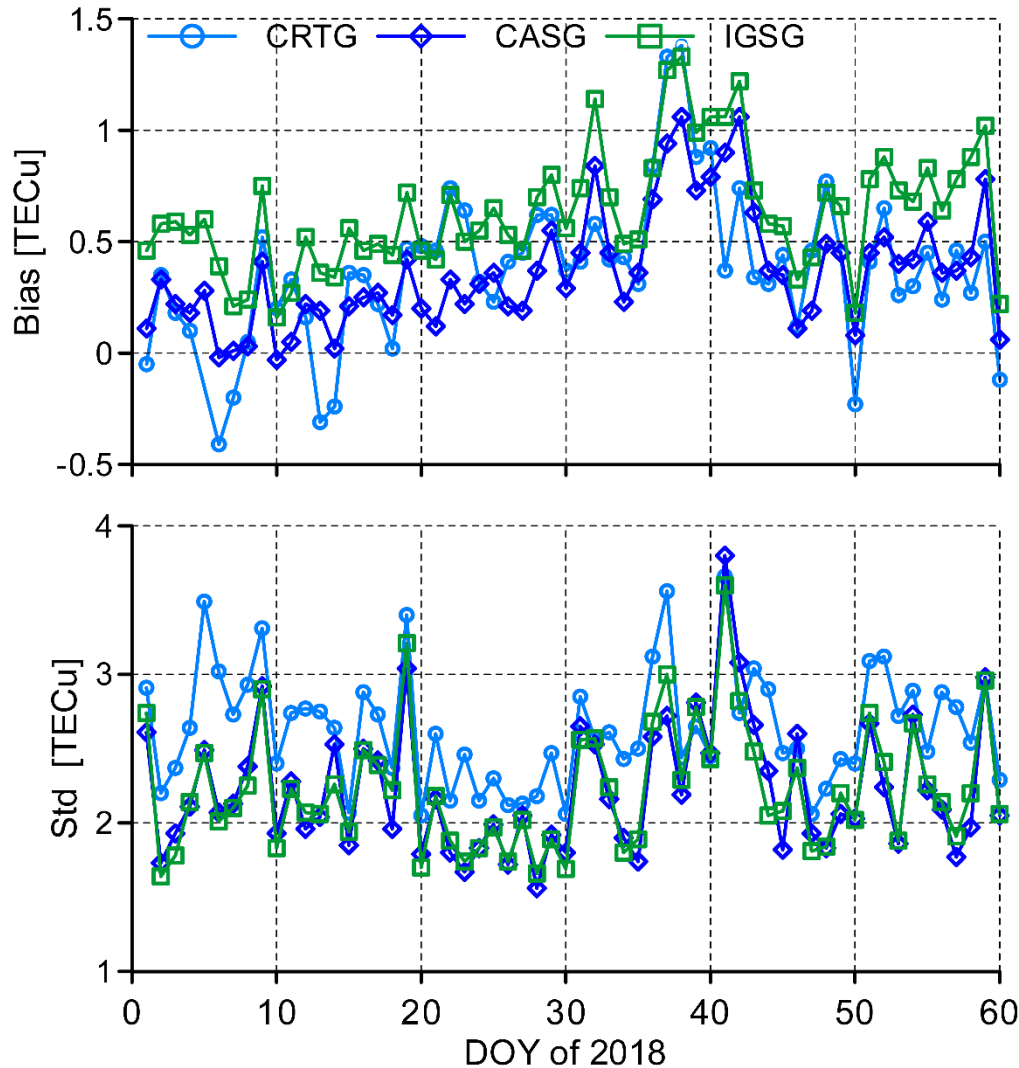
- URTG: RT-GIM of UPC (15 mins)
- CRTG: RT-GIM of CAS (5 mins)
- CASG: final GIM of CAS (30 mins)

- Performance improvement of CRTG since early 2018
- Std errors of URTG still larger than CRTG (consistency with assessments relative to GPS dsTECs and IGS GIM TECs)



# RT-GIM validation at CAS (6/7)

- Performance analysis of RT-GIM (w.r.t Jason-3 DORIS dsTECs )



- CRTG: RT-GIM of CAS (5 mins)
- CASG: final GIM of CAS (30 mins)
- IGSG: IGS final GIM (2 hours)

- Performance improvement of CRTG since early 2018 can NOT be identified (site number, distribution, ONLY Jason-3)
- Consistency between CRTG and the final ones





## RT-GIM validation at CAS (7/7)

Comparison of RT and final GIMs w.r.t diff TEC sources (doy 001-270, 2018)

		URTG**	CRTG	CASG
w.r.t. GPS dsTEC	Bias	-0.14	<b>0.10</b>	<b>-0.07</b>
	Std	2.93	1.76	1.57
	Rms	3.00	1.84	1.64
w.r.t. IGS GIM vTEC	Bias	-1.21	<b>-0.92</b>	<b>-1.23</b>
	Std	3.13	1.62	0.96
	Rms	3.42	1.86	1.56
w.r.t. Jason-3 vTEC*	Bias	0.81	<b>1.00</b>	<b>1.20</b>
	Std	4.49	3.38	2.60
	Rms	4.65	3.84	2.87
w.r.t DORIS dsTEC	Bias	–	<b>0.37</b>	<b>0.34</b>
(Jason-3)	Std	–	2.64	2.20
	Rms	–	2.69	2.26

\* Jason-3 TECs only cover DOY 001-079, 2018

\*\* Time period DOY 102-106 is excluded from the statistic



## Conclusions and future work

---

- Routine RT-GIM generation since 3<sup>rd</sup> quarter of 2017 at CAS
  - CAS's RT vTEC SSR broadcasted via mount point [CAS05](#)
  - Updates ([bugs fixed](#)) of RT vTEC SSR since October 30, 2018  
(many thanks to Manuel from UPC for pointing us the problems)
  - RT-GIM files in IONEX format also available from CAS's ftp archive
- Performance of CRTG routinely assessed w.r.t diff TEC sources (post-processing)
  - Absolute TEC references (2): IGS final GIM + Jason-3 vTECs
  - Relative TEC references (2): GPS dsTEC + [DORIS dsTEC](#)
  - Performance [improvements](#) of CAS's RT-GIM (CRTG) since early 2018
  - Slight worse of RT-GIM than the final one (smaller bias but larger std)
- In the next step
  - Continuously join the combination of RT-GIMs of the IGS
  - Ionospheric irregularity monitoring products (ROTI, RROT...) at CAS:  
[post-processing mode \(finished\)](#) -> real-time mode





**Thanks for your attention**

If any questions, please feel free to contact:  
[wangningbo@aoe.ac.cn](mailto:wangningbo@aoe.ac.cn) / [ningbo.wang@tum.de](mailto:ningbo.wang@tum.de)