BDS-3 globally broadcast ionospheric time delay correction model(BDGIM) for single-frequency users

13th Meeting of the International Committee on Global Navigation Satellite Systems

Insititute of Geodesy and Geophysics, Chinese Academy of Science

Yunbin Yuan

2018-11-06

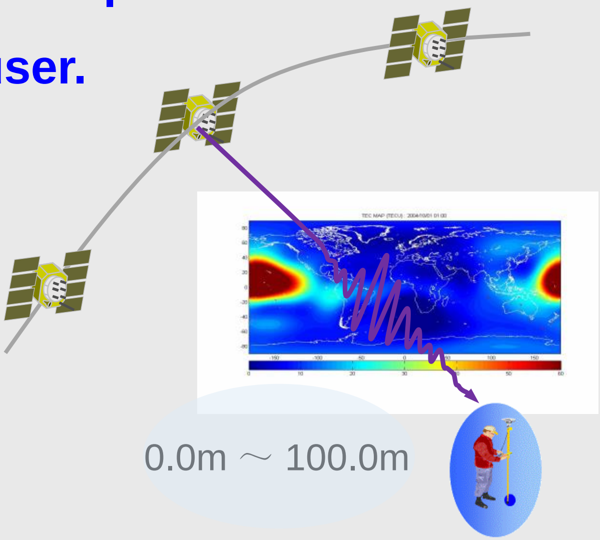
CONTENT

01

Background

Background

Ionosphere is one of the most important error sources for single-frequency GNSS user.



Broadcast ionospheric model is considered as the most convenience and effective approach for ionospheric delay correction of single-frequency users.

- **Different broadcast ionospheric models have been adopted by GPS and Galileo**
- **It is very necessary for BDS3 to develop the global broadcast ionospheric model.**

Background

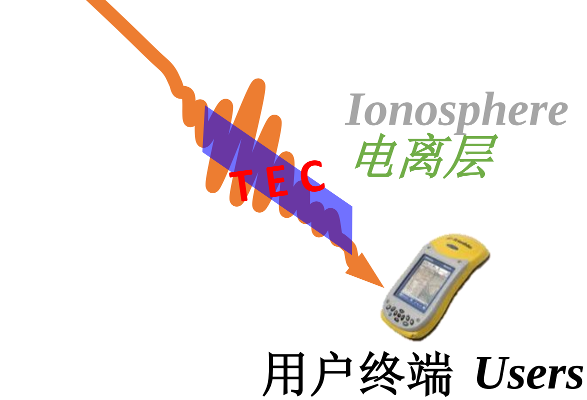
Requirements： a few broadcast parameters and efficient

BDS3： 75%(performance) → **Mathematical model** / **Observation data** / **Estimation method**

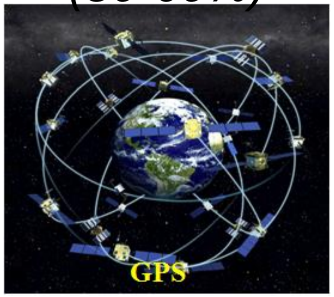
Problems have to be faced

(1) better performance VS. a few broadcast parameters

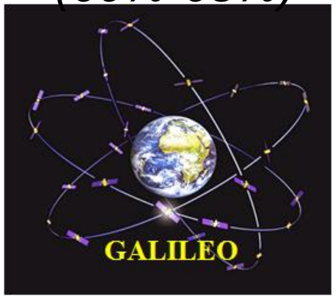
(2) Global service VS. most of monitoring stations distributed in China



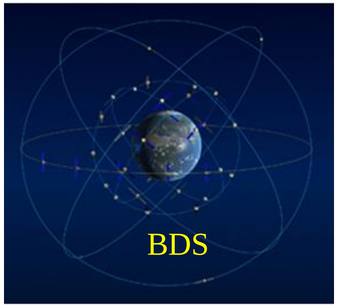
Klobuchar
(50-60%)



NeQuick
(60%-65%)



???

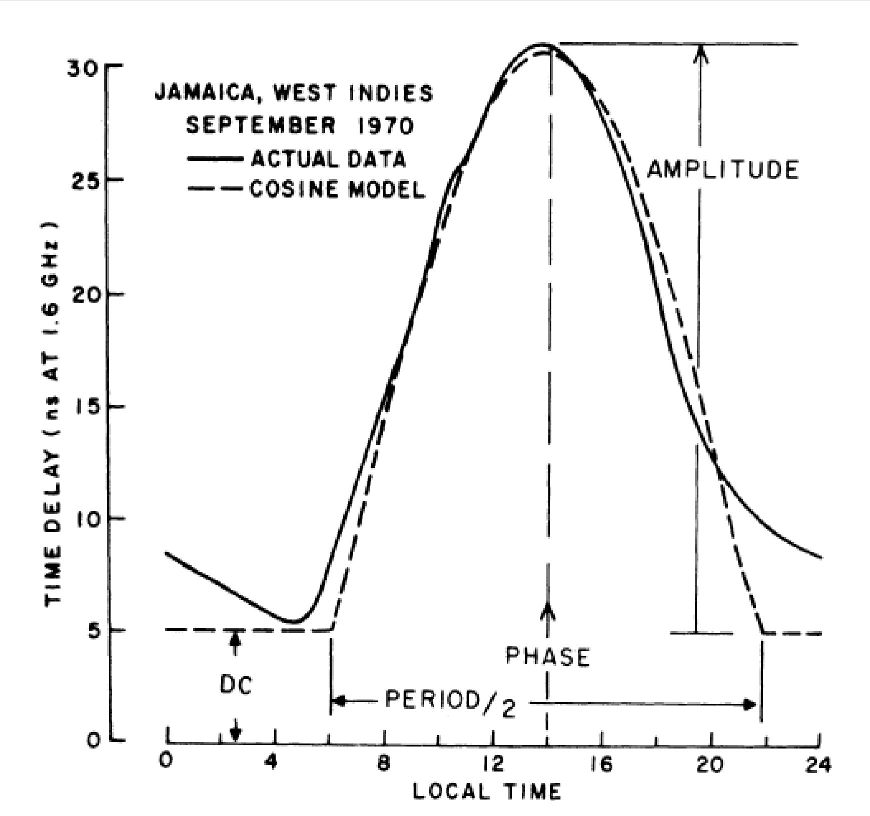


02

Improved and refined Klobuchar (GPS) model

- Basic structure of Klobuchar
- Method for improving and refining Klobuchar model
- Improving and refining Klobuchar model based on real GPS data

Improved and refined Klobuchar (GPS) model/Basic structure of Klobuchar



$$I_z = \begin{cases} 5E-9 + A_2 \cos \frac{2\pi(t-50400)}{A_4} & A_4/4 > |t-50400| \\ 5E-9 & A_4/4 \le |t-50400| \end{cases}$$

Existing problems:

1. The broadcast parameters are not re-estimated based on the real GPS ionospheric data.

2. The structure is simple relative to the variation of global ionosphere.

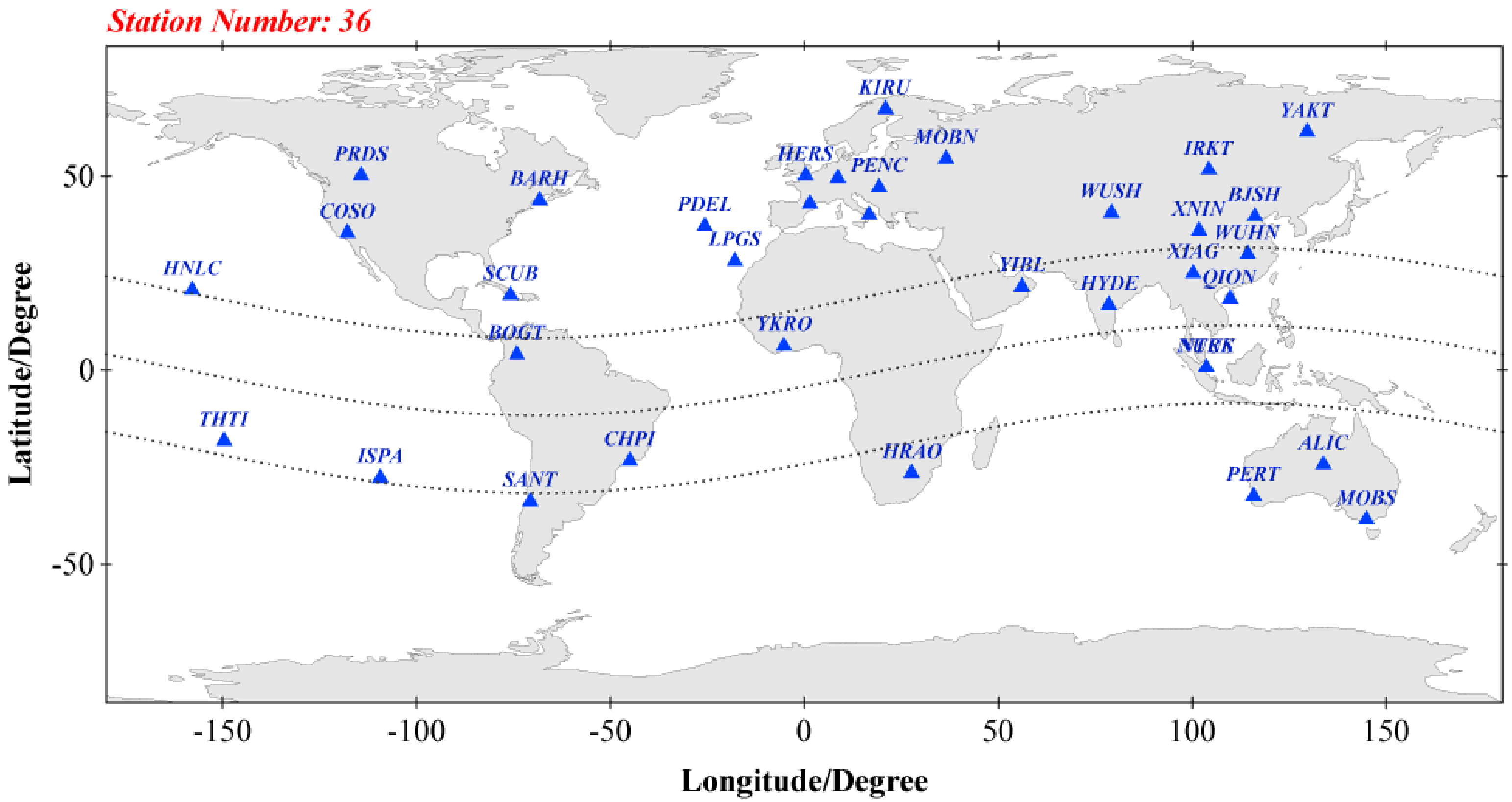
Daily variation of ionospheric TEC based on Klobuchar

(Klobuchar, 1987)

Improved and refined Klobuchar (GPS) model/ Method for improving and refining model structure of Klobuchar

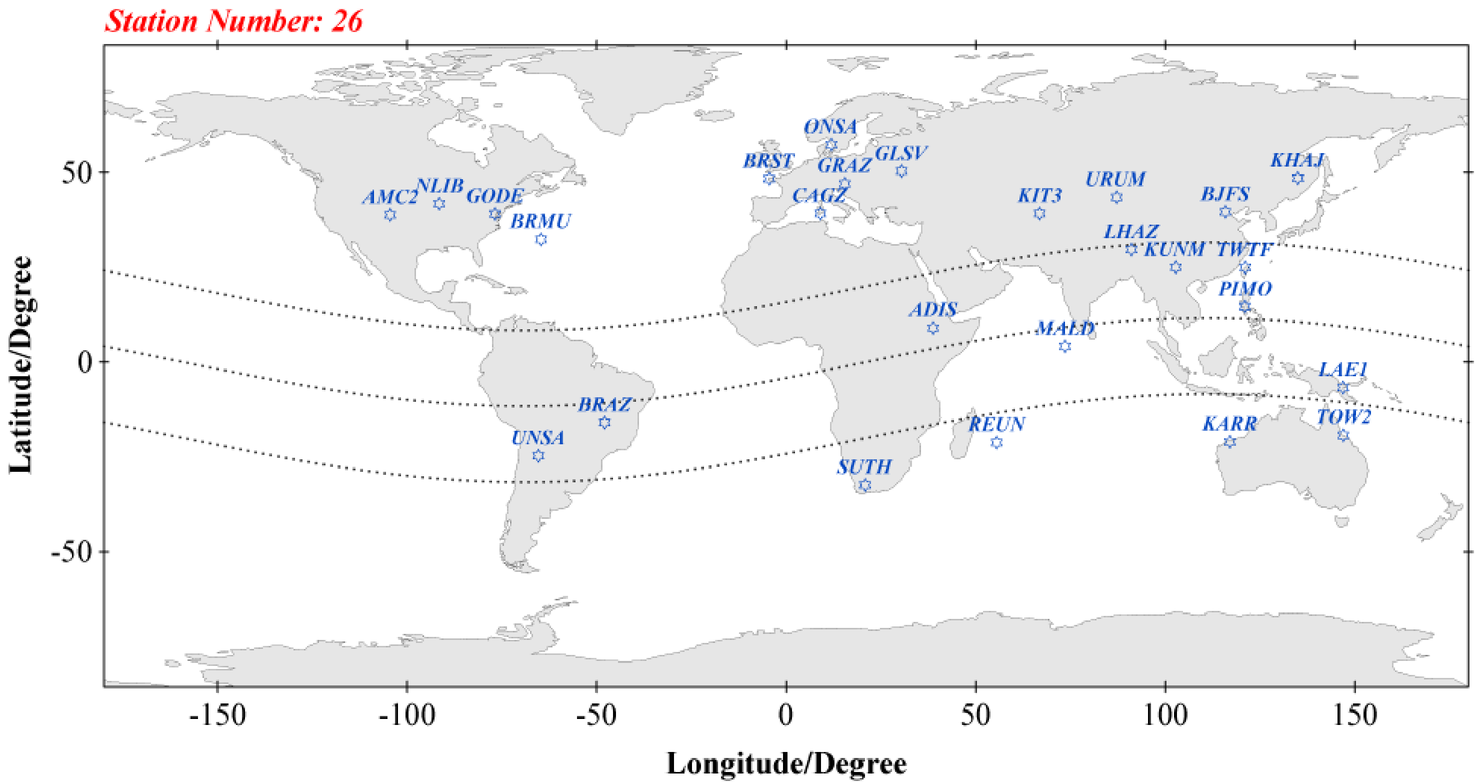
	8Klob	9-14Klob
Equation	$I_z = \begin{cases} 5E-9 + A_2 \cos\dfrac{2\pi(t-50400)}{A_4} & A_4/4 > \lvert t-50400 \rvert \\ 5E-9 & A_4/4 \le \lvert t-50400 \rvert \end{cases}$	$I_z = \begin{cases} A - B\phi_m + A_2 \cos\dfrac{2\pi(t-A_3)}{A_4} & A_4/4 > \lvert t-A_3 \rvert \\ A - B\phi_m & A_4/4 \le \lvert t-A_3 \rvert \end{cases}$
No. of Parameters	8 (alpha, beta)	9 (alpha, beta, A)
		10 (alpha, beta, A and B)
		14 (alpha, beta, gama, A and B)
Estimation strategy	Taylor series expansion + LSQ	
Initial values	8Klob	9Klob, 10Klob, 14Klob
Terminative condition	<1.0E-4 || times>5	

Improved and refined Klobuchar (GPS) model/ Improving and refining Klobuchar model based on real GPS data



Distribution of stations used for estimating the parameters of improved and refined Klobuchar mode

Improved and refined Klobuchar (GPS) model/ Improving and refining Klobuchar model based on real GPS data



Distribution of stations used for validating the performance of improved and refined Klobuchar model

Improved and refined Klobuchar (GPS) model/ Improving and refining Klobuchar model based on real GPS data

Yearly statistical result for different Klobuchar models

Year	Statics	GPS8Klob	RefKlob	IGG8Klob	9Klob	10Klob	14Klob
2002	Per(100%)	65.4	64.0	70.9	68.2	67.2	67.2
	RMS(TECu)	15.1	13.1	11.7	10.8	11.0	11.0
2006	Per(100%)	52.9	58.2	60.0	69.2	69.3	69.3
	RMS(TECu)	5.4	4.3	4.1	4.1	4.1	4.1

The improved and refined Klobuchar based on global real data is also difficult to meet the demand(75%) of BDS in term of the ionospheric delay correction for single-frequency users.

03

A new ionospheric time delay model for BDS3 (BDGIM)

- Mathematical model of BDGIM
- Estimation of BDGIM broadcast parameters
- Performance validation of BDGIM
- Performance of BDGIM validated by SPP

A new ionospheric time delay model for BDS3 (BDGIM)/
Mathematical model of BDGIM

Aims： Solve the contradiction between the high precise description of global ionospheric TEC and limited number of broadcast parameters.

Result shows that： Spherical harmonic (SH) function has been proved as one of most precise approach of representing the variation of global TEC.

$$VTEC(\phi,\lambda)=\sum_{n=0}^{n_{d\max}}\sum_{m=0}^{n}\tilde{P}_{nm}(\sin\varphi)\cdot\left(\tilde{A}_{nm}\cos(m\lambda)+\tilde{B}_{nm}\sin(m\lambda)\right)$$

Existing problem： Too many broadcast, 15×15 → 256

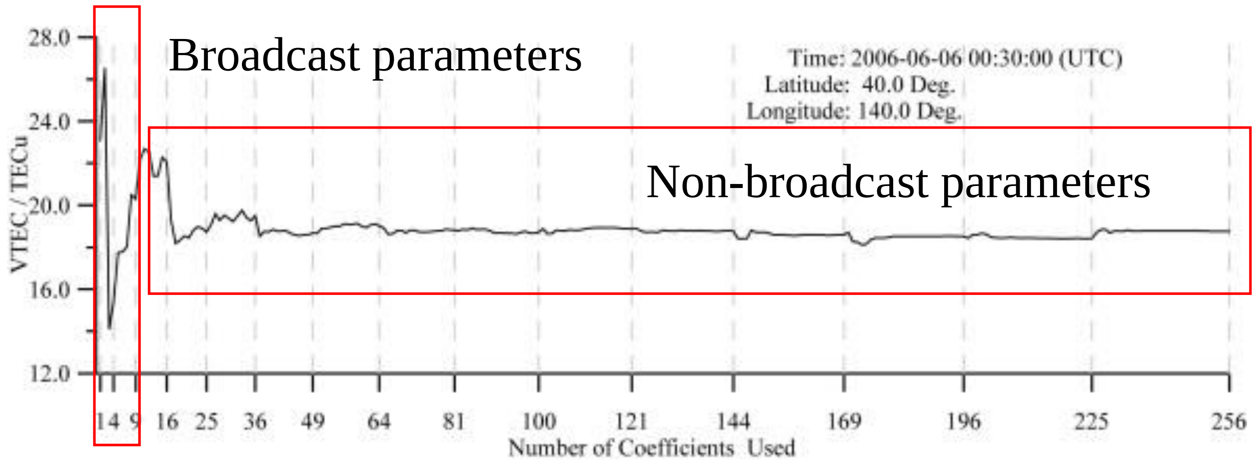
Two approaches may be applied to reduce the number of broadcast parameters:

- ☛ **Reduce the order and degree of SH**
- ☛ **Some coefficients are updated not by the way of broadcast**

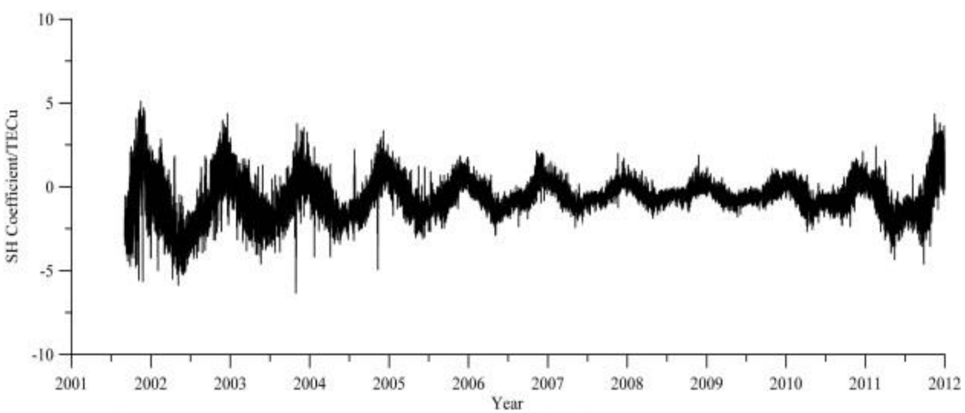
A new ionospheric time delay model for BDS3 (BDGIM)/

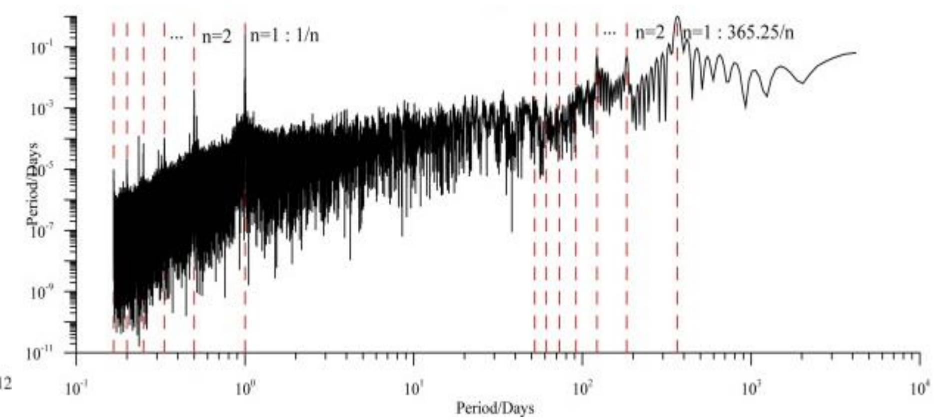
Mathematical model of BDGIM

Approach 1: Predict some coefficients of SH



The contribution of different terms of SH to the calculation of ionospheric TEC





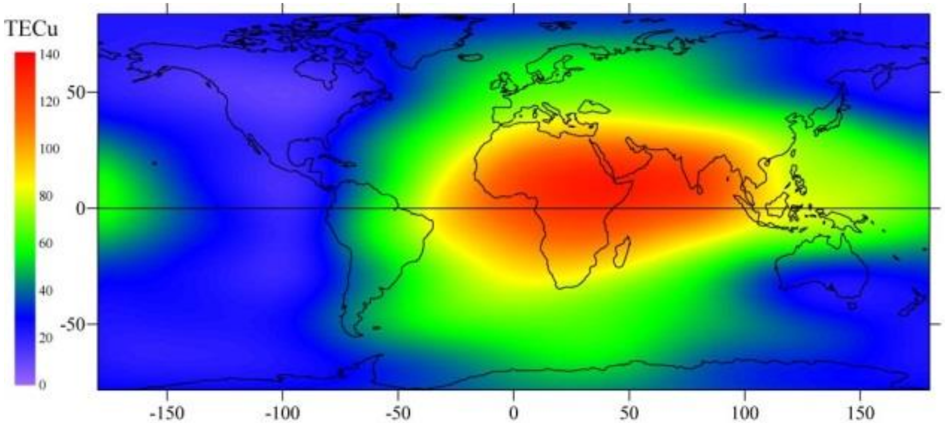
A new ionospheric time delay model for BDS3 (BDGIM)/

Mathematical model of BDGIM

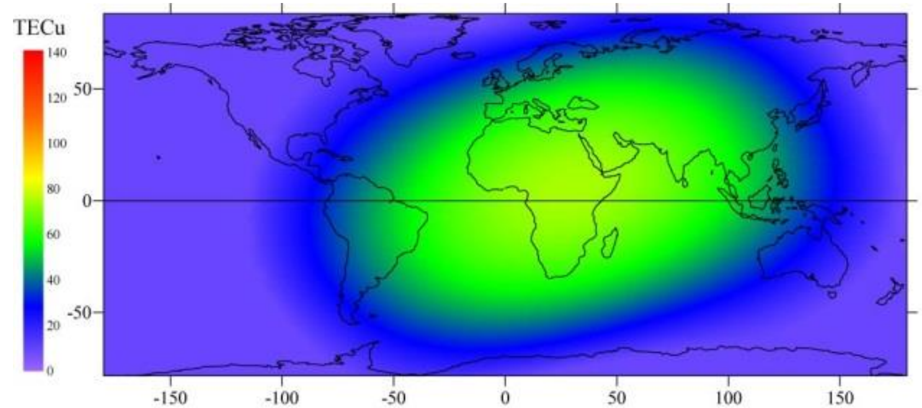
$$T_{vtec} = \underbrace{A_0}_{1} + \underbrace{\sum_{i=1}^{9} \alpha_i A_i}_{2}$$

1: Terms calculated base on coefficients predicted at the local receivers;

2: Terms calculated based on coefficients broadcast by BDS navigation.



BDGIM(Number of broadcast parameters: 9)



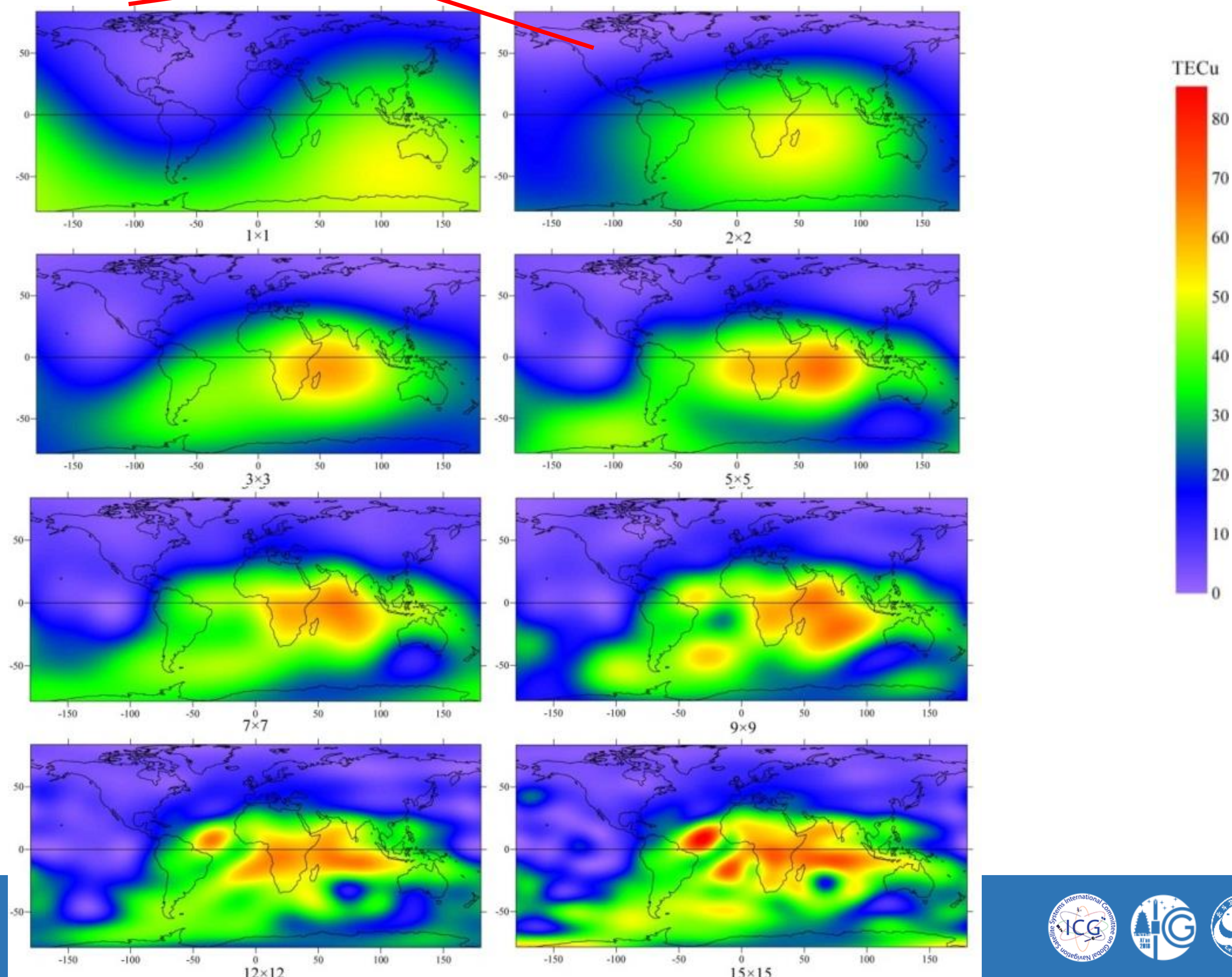
Klobuchar(Number of broadcast parameters: 8)

Comparison of ionospheric TEC map produced by BDGIM and Klobuchar on the 80th day of 2002 respectively

A new ionospheric time delay model for BDS3 (BDGIM)/

Mathematical model of BDGIM

Approach 2: directly ~~reduce the order~~ and degree **Impossible**



A new ionospheric time delay model for BDS3 (BDGIM)/
Estimation of BDGIM broadcast parameters

$$\begin{cases} \mathbf{VTEC} = \begin{bmatrix} \mathbf{B_{ion}} & \mathbf{B_{fix}} \end{bmatrix} \cdot \begin{bmatrix} \mathbf{X_{ion}} \\ \mathbf{X_{fix}} \end{bmatrix} \\ \mathbf{\hat{X}_{u,fix}} = \mathbf{X_{fix}} \end{cases}$$

Broadcast parameters ($\mathbf{X_{ion}}$)

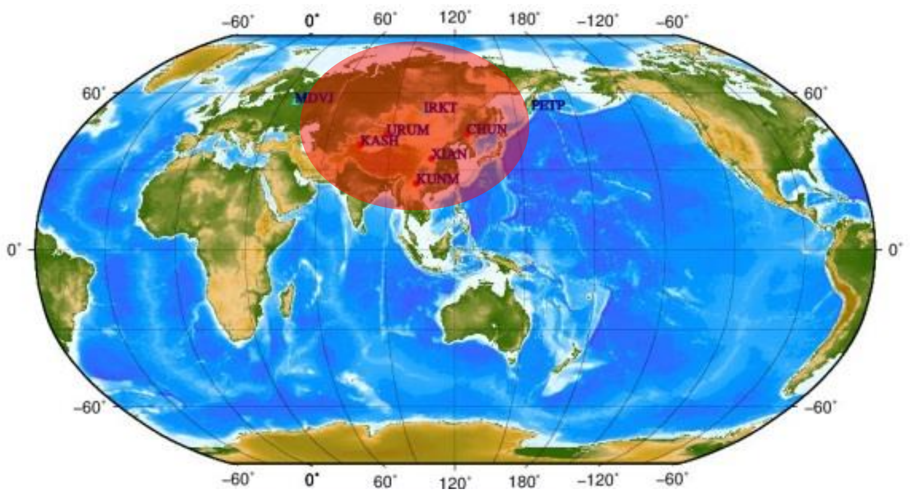
Non-broadcast parameters ($\mathbf{X_{fix}}$)

Where:

$$\mathbf{VTEC} = \begin{bmatrix} \mathbf{VTEC_1} \\ \mathbf{VTEC_2} \end{bmatrix}$$

$\mathbf{VTEC_1}$ → Real

$\mathbf{VTEC_2}$ → Designed



Solution

$$\begin{cases} \mathbf{\hat{X}_{ion}} = \mathbf{N_{BB}^{-1} B_{ion}^{T} PL} \\ \mathbf{D_{\hat{X}_{ion}}} = \hat{\sigma}_0 \mathbf{N_{BB}^{-1}} \\ \mathbf{N_{BB}} = \mathbf{B_{ion}^{T} P B_{ion}} \end{cases}$$

Most of the stations are only located in China and a few of them in other area

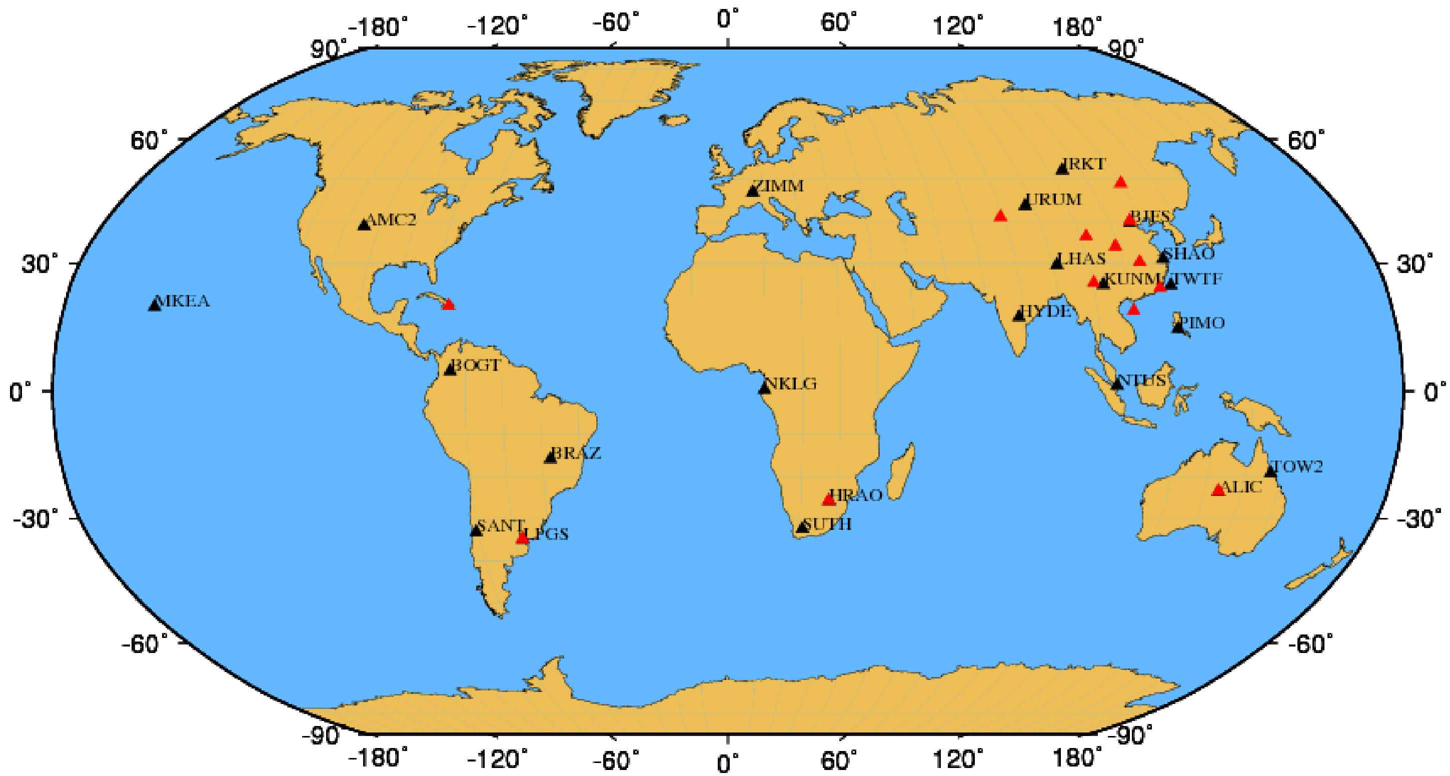
A new ionospheric time delay model for BDS3 (BDGIM)/

Performance validation of BDGIM validated by GPS-TEC

Date：2001-2010, 2012(1-80)

Monitor station(▲)：9(China)+4(other area)

Validation station(▲)：19(global distribution)

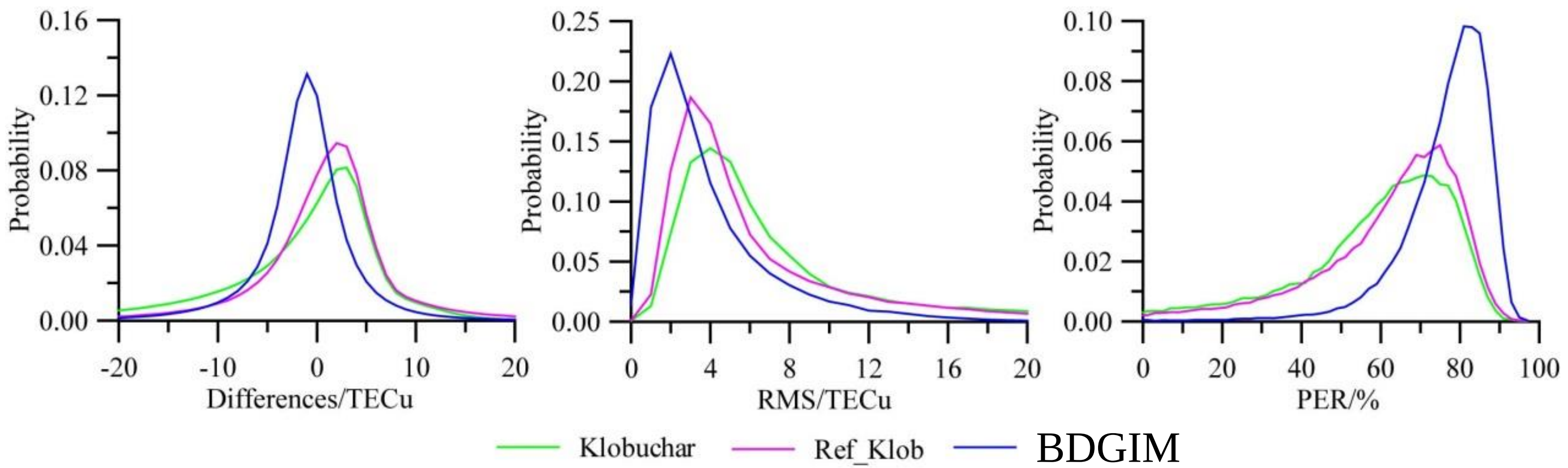


A new ionospheric time delay model for BDS3 (BDGIM)/

Performance validation of BDGIM validated by GPS-TEC

- Compared with the ionospheric TEC from real GPS data
- Validated by the SPP (one epoch and single frequency)
- GPS and CODE Klobuchar models are introduced for comparison

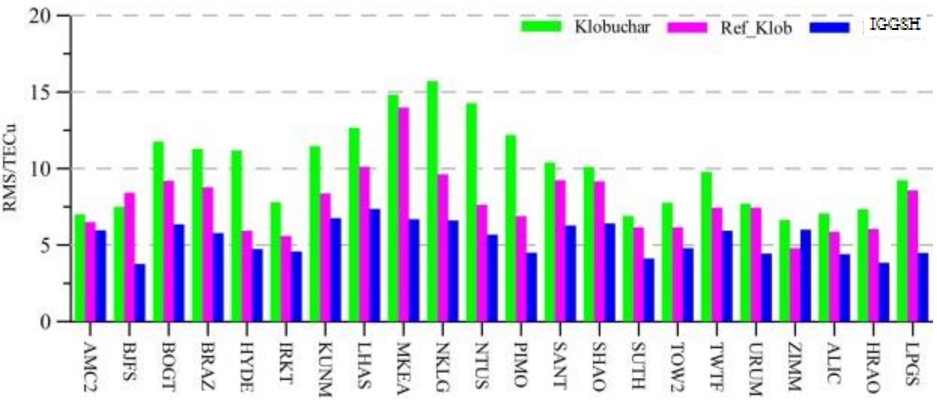
Distribution of accuracy indices for different broadcast ionospheric models w.r.t. the ionospheric TEC from real GPS data

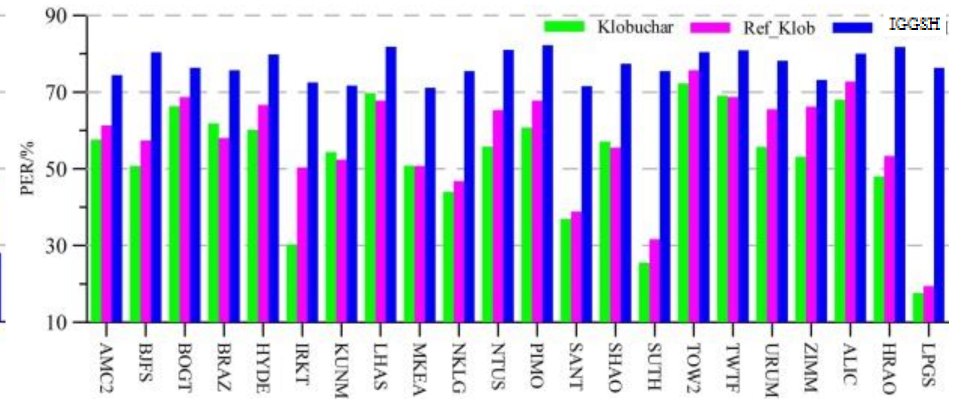


A new ionospheric time delay model for BDS3 (BDGIM)/

Performance validation of BDGIM validated by GPS-TEC

RMS(left) and correction percent(right) of different ionospheric model averaged from 2001-2012 over each station



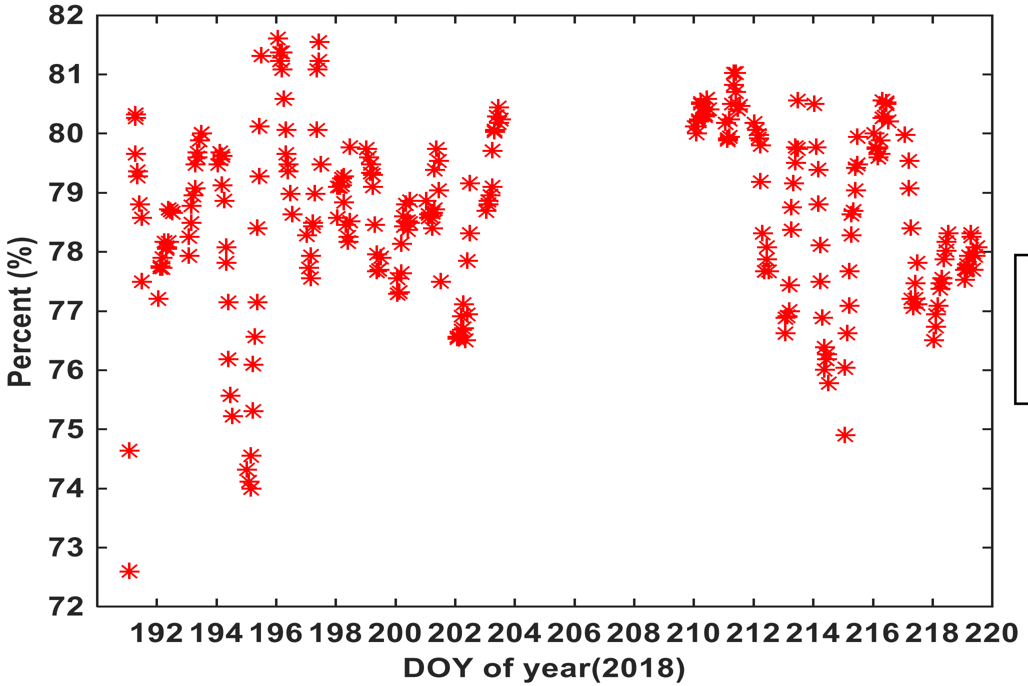


Models	Over the area of China		Other area in global	
	RMS/TECu	Percent	RMS/TECu	Percent
BDGIM	**5.3**	**79.6%**	**6.4**	**74.2%**
Klob	9.5	61.5%	10.1	58.3%
Ref_Klob	8.0	63.8%	8.3	61.6%

A new ionospheric time delay model for BDS3 (BDGIM)/
Performance of BDGIM validated by BDS-TEC

Monitor station：25(China)+0(other area)

Date：2018, 192 to 204 and 211 to 220



Correction Percent: 78.63%;
RMS: 3.55 TECu

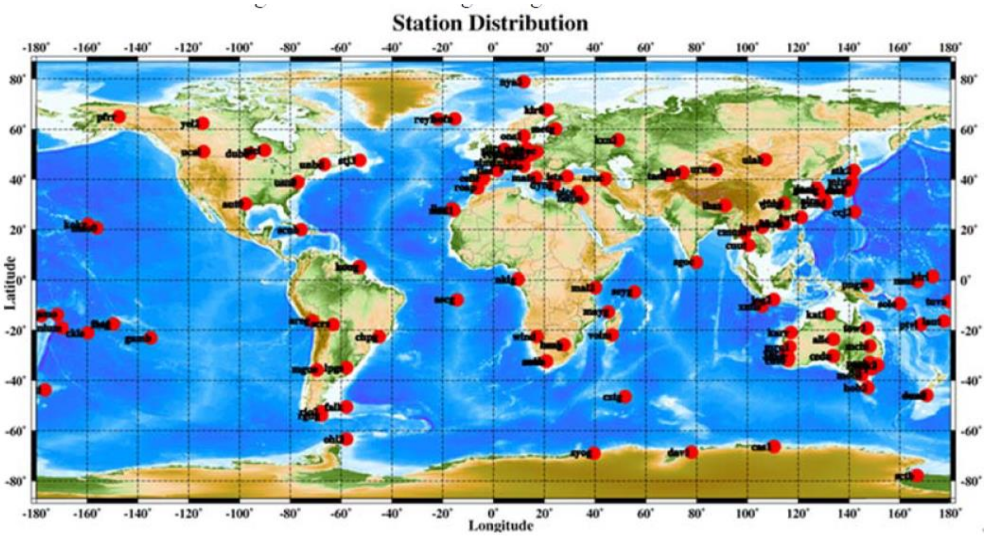
Correction percent and RMS of BDGIM over China

A new ionospheric time delay model for BDS3 (BDGIM)/
Performance of BDGIM validated by BDS-TEC

Validation station：

140 (global distribution)

Date： 2017, 002 to 032 and 240 to 272



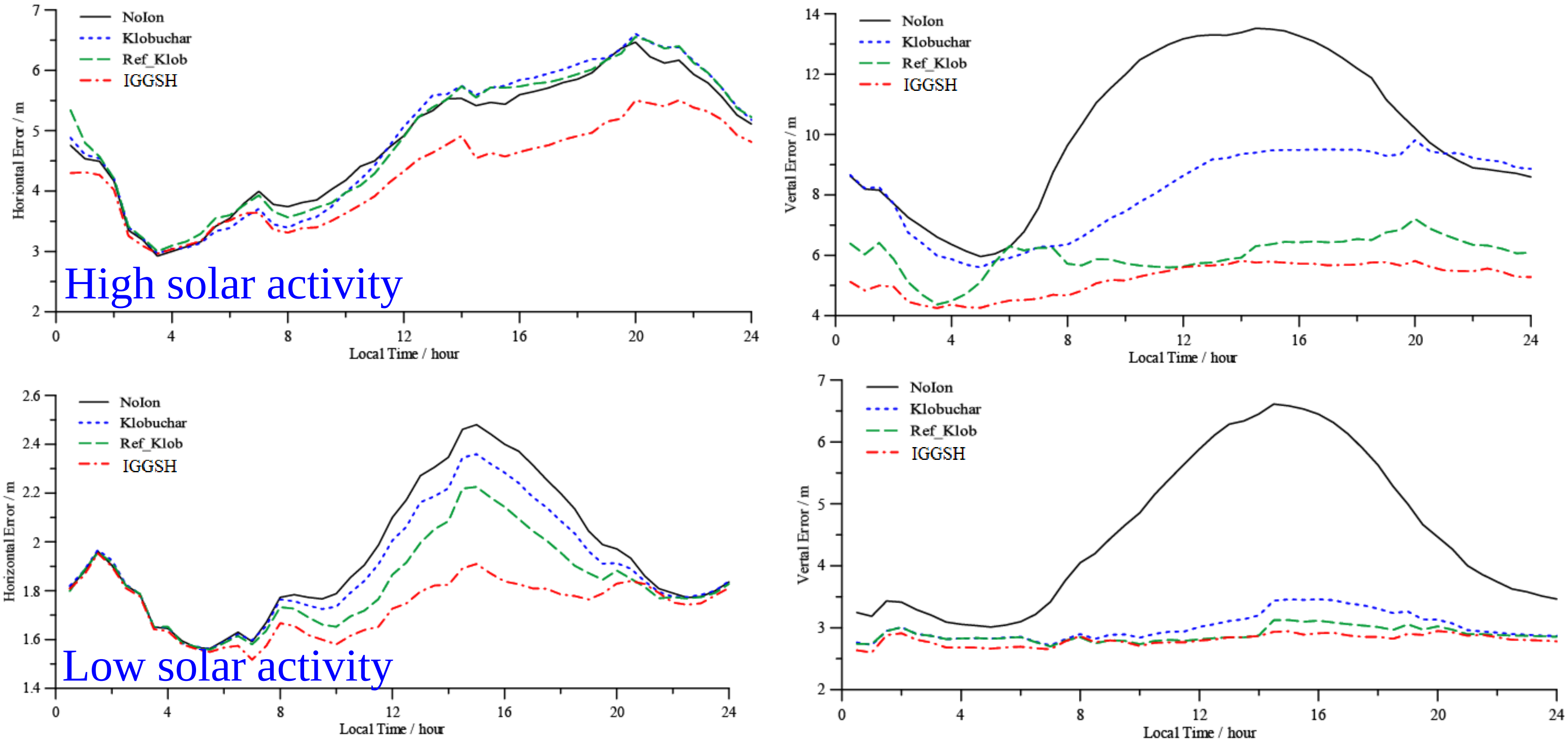
Models	Comparison against GPS-TEC Bias/TECu	RMS/TECu
BDGIM	**-0.24**	**3.56**
Klob	-1.53	5.49
Gal Nequick	1.68	4.66

Models	Comparison against IGS GIM Bias/TECu	RMS/TECu	Percent
BDGIM	**4.00**	**3.58**	**77.2%**
Klob	1.79	5.71	71.3%
Gal Nequick	-1.57	4.44	72.6%

A new ionospheric time delay model for BDS3 (BDGIM)/

Performance of BDGIM validated by SPP

Horizontal and vertical accuracy of SPP based on different ionospheric model



Horizontal accuracy **Vertical accuracy**

A new ionospheric time delay model for BDS3 (BDGIM)/
Comparison between BDGIM and Klobuchar

Items \ Model			BDGIM	Klob	Ref_Klob
Method	Math.	Day	**Improved SH**	Cos function	
		Nigh		Constant(5ns)	
	Estimation of Para.		LSQ	experience	LSQ
Characteristics	No. of Brd. Para.		9	8	8
	Period of update		2 hours	7 days	One days
	No. of Stations		**9(China)+4(other area)**	5-7 (global)	~ 200
Performance	Percent (GPS-TEC)	Local	**79.6%**	58.3%	61.5%
		Global	**77.5%**	59.3%	
	Improvement of accuracy for SPP		**60.1%**	49.7%	52.8%
	Horizontal accuracy		**significant**	No significant	
	Vertical accuracy		Vey significant	significant	

04

Conclusions

Conclusions

- **A broadcast ionospheric model with high precision is needed by BDS and the existing methods and approaches (e.g. Klobuchar) cannot meet the corresponding demand.**
- **A new broadcast ionospheric model, named as BDGIM, has been developed for about 10 years by our group based on the spherical harmonic function and it is especial for BDS3, as well as GPS/Galileo.**
- **BDGIM can be updated with the real GNSS data and only 9 parameters need to be broadcast via the BDS navigation.**
- **The yearly average correction percent is greater than 75% for BDGIM and it is munch better than improved and refined Klobuchar.**
- **The contribution of BDGIM to the improvement of SPP is reflected both on the horizontal and vertical accuracy, while that of Klobuchar model is only on the horizontal accuracy.**

THANK YOU!

13th Meeting of the International Committee on Global Navigation Satellite Systems