A new real-time ZTD grid product over China and applications in PPP

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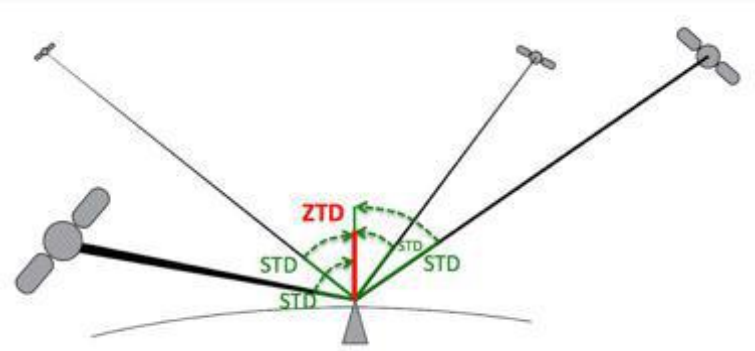
Outline

- Introduction
- Data and processing strategy
- Real-time ZTD grid product
- Summary and Conclusions

Introduction

- ZTD (Zenith Tropospheric Delay)



precisely modeled

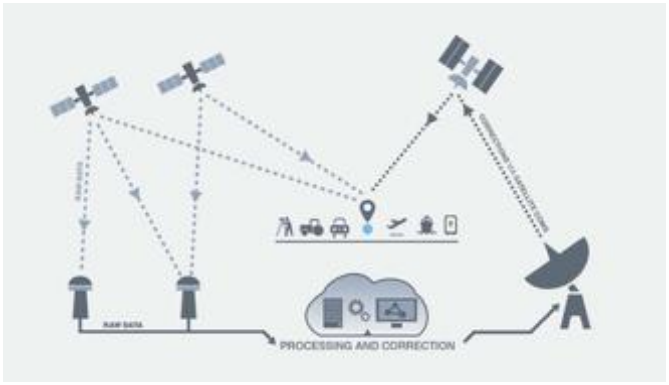
$$ZTD = ZHD + ZWD$$

complex variations of water vapor

- Why we need ZTD in real-time?

Nowcasting

Navigation



PPP

Introduction

- PPP

- Performances of current real-time ZTD models/products

✓ Saastamoinen, Hopfield, ect. → decimeter/sub-decimeter
✓ UNB models, EGNOS → sub-decimeter
✓ SHAO models, GPT2, TropGrid, IGGtrop, ITG → > 4 cm

Not better than 4 cm

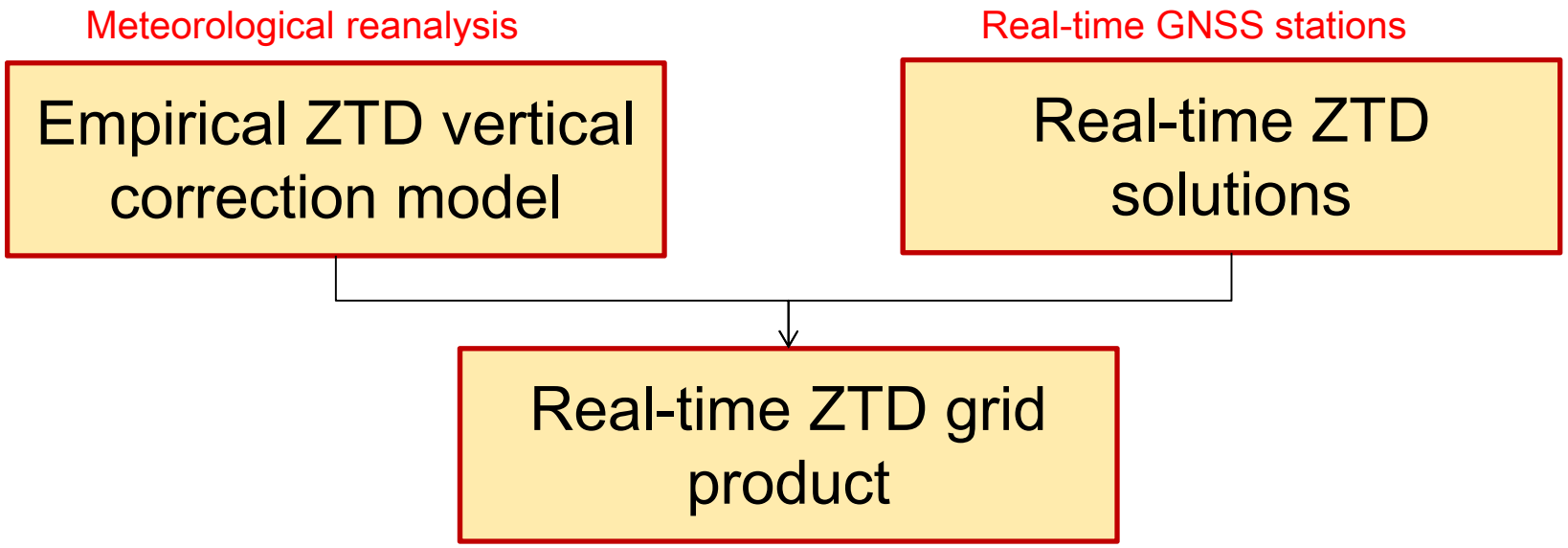
✓ Real-time ZTD product based on CORS → can be better than 2 cm (e.g., Zhang et al., 2013; Yu et al., 2016)

Generally at the scale of several hundreds of km

Introduction

- Objectives
  - ✓ Real-time
  - ✓ High accuracy
  - ✓ At the national scale of China
  - ✓ Easy to use

- Solutions



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Data and processing strategy

- Meteorological reanalysis product

Source	ERA-Interim (ECMWF)
Time resolution	6-hourly
Horizontal resolution	0.75° x 0.75°
Vertical levels	37 (pressure levels)
Period	2011~2014
Fields	geopotential; temperature; specific humidity

- ZTD estimation method

$$ZTD = ZTD_{top} + ZTD_{level}$$

✓ ZTD_{top} : Saastamoinen model
✓ ZTD_{level} : Integration of refractivity

$$N = \frac{k_1(P-e)}{T} + \left(\frac{k_2 e}{T} + \frac{k_3 e}{T^2}\right)$$

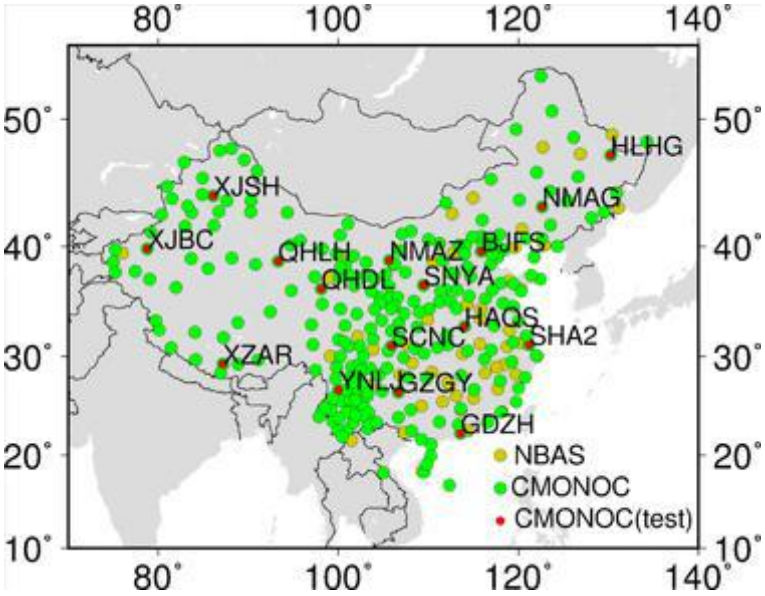
Considering the altitude difference

□ ZTD differences compared to IGS final products (2014)

Station name	Bias (cm)	RMS (cm)
BJFS	0.29	1.25
CHAN	-0.19	1.09
LHAZ	0.76	1.43
SHAO	-0.53	0.94
URUM	1.94	2.30
WUHN	-0.14	1.38
Mean	0.36	1.40

Data and processing strategy

- GNSS data



GNSS station distribution

CMONOC (~253): product generation

CMONOC (test) (16): product evaluation

NBAS (~95): PPP test

GNSS data processing strategy

Variables	Configuration
Interval	30 sec
Software	PANDA
Mode	Simulated real-time PPP
Orbits & Clocks	IGS archived real-time products
Station Coordinate	Fixed
a-priori ZHD & ZWD	Saastamoinen + GPT
Mapping function	GMF
Cutoff angle	7°
ZWD correction	Constants every 5 min
Horizontal gradient	NS & EW every 12 h

Bias and RMS of real-time ZTD errors at all CMONOC stations (2015)

	Jan.	Apr.	Jul.	Oct.	Mean
Bias (cm)	0.05	0.26	0.28	0.41	0.25
RMS (cm)	1.07	1.22	1.21	1.23	1.18

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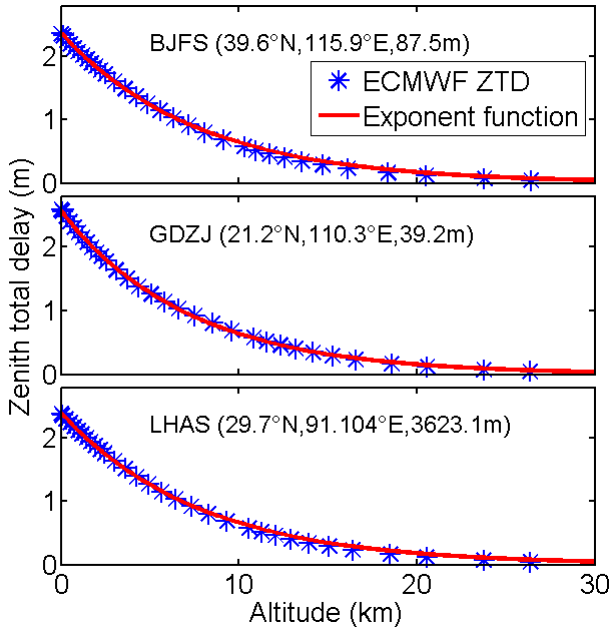
Real-time ZTD grid product

- ZTD vertical correction model



$$ZTD(h) = ZTD_0 \cdot \exp(\beta h)$$

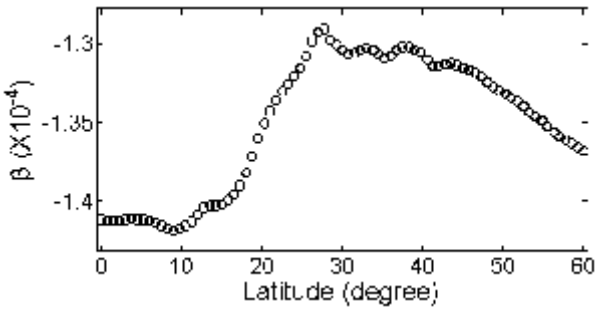
- ZTD fitting residuals

Fitting layer	Bias (cm)	STD (cm)	Max (cm)	Min (cm)
All	-0.39	1.69	2.48	-3.26
Suffer ± 3km	-0.001	0.42	0.59	-0.55

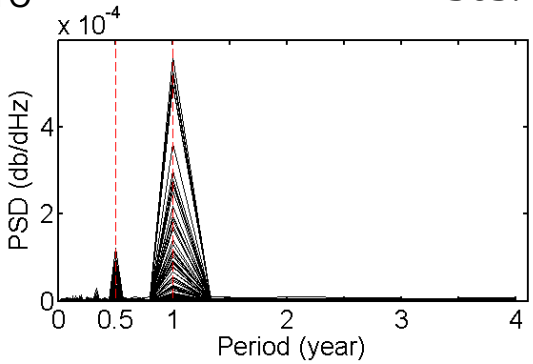
- ✓ Modeling of β

$$\beta = a_0 + a_1 \cos(2\pi \frac{doy}{365.25}) + a_2 \sin(2\pi \frac{doy}{365.25})$$
$$+ a_3 \cos(4\pi \frac{doy}{365.25}) + a_4 \sin(4\pi \frac{doy}{365.25})$$

- Profiles of ZTD at 2014/04/01 00UTC



Spatial



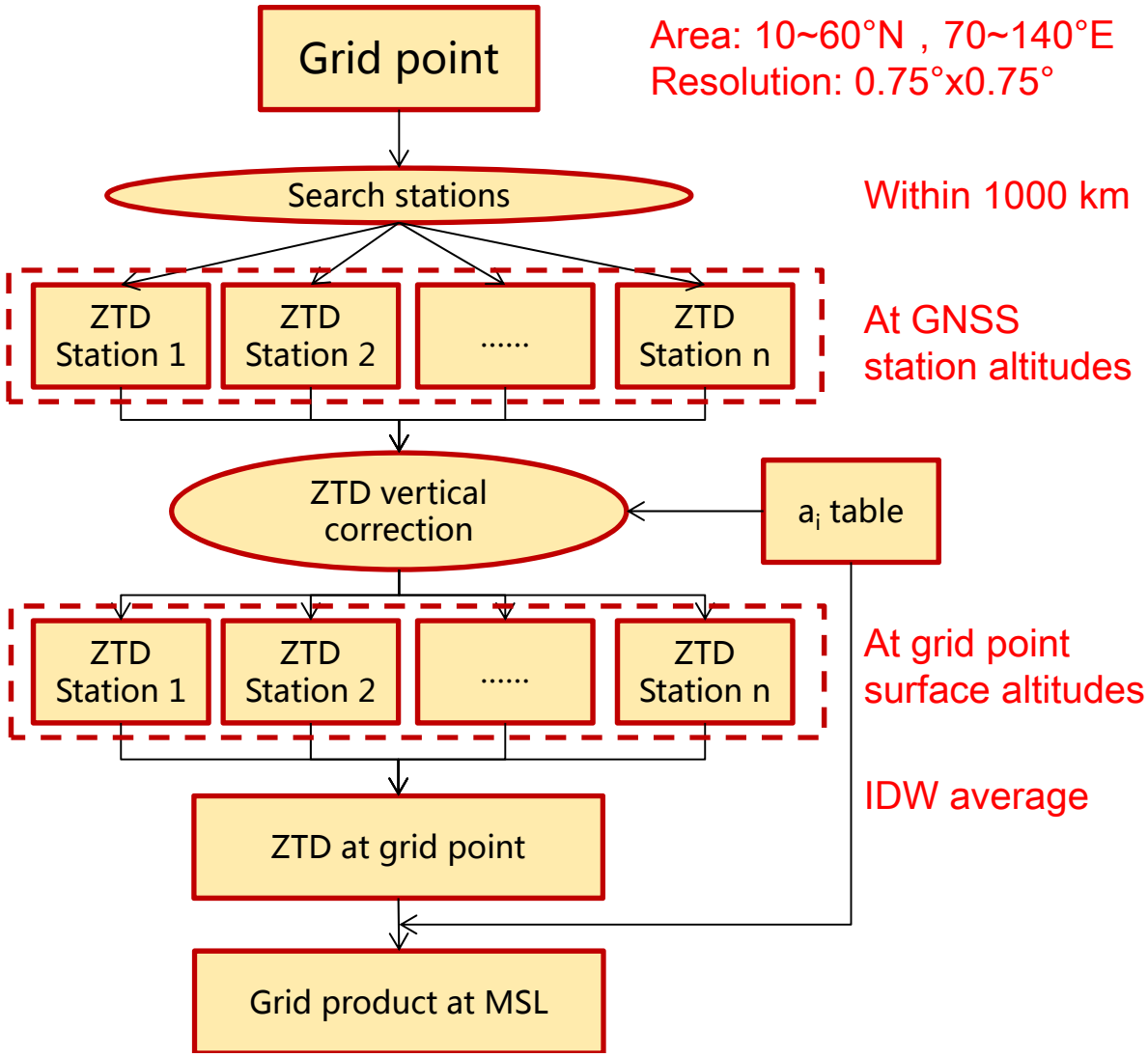
Temporal

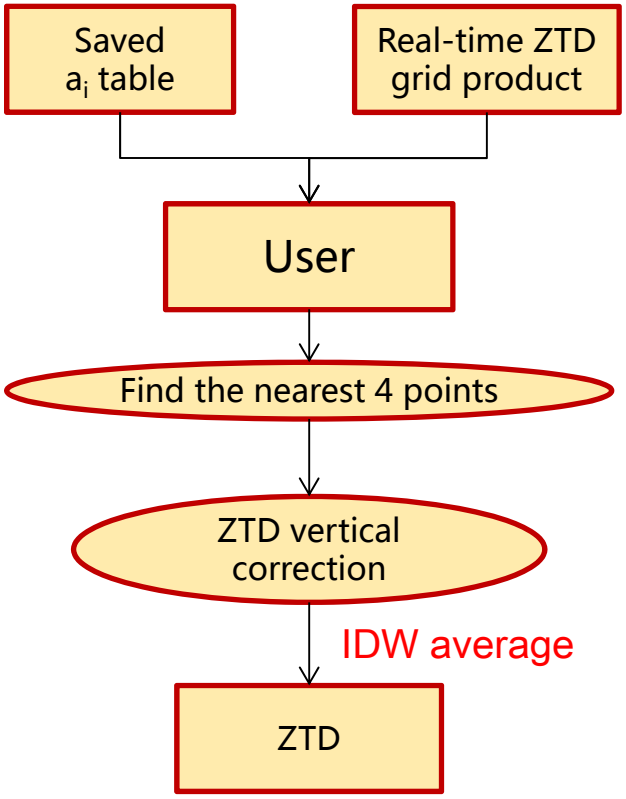
Sensitivity test:
10^{-6} β → 2.8 mm ZTD

RMS: 3.9×10^{-6} (1.09 cm ZTD)

Real-time ZTD grid product

- Real-time ZTD product generation



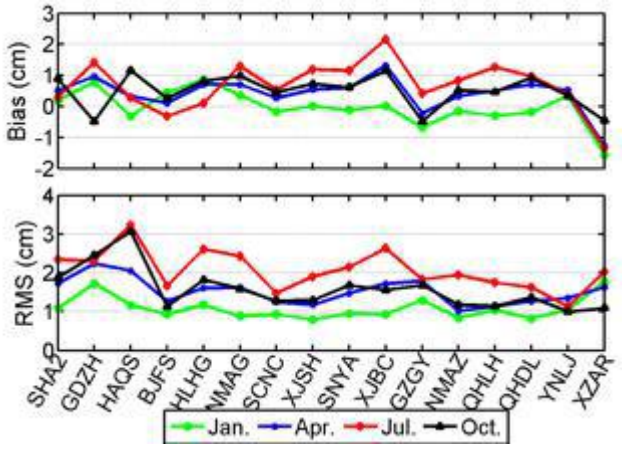


Real-time ZTD grid product

- Real-time ZTD product accuracy assessment
  - ✓ 16 CMONOC stations as test stations
  - ✓ The other CMONOC stations for real-time ZTD product generation

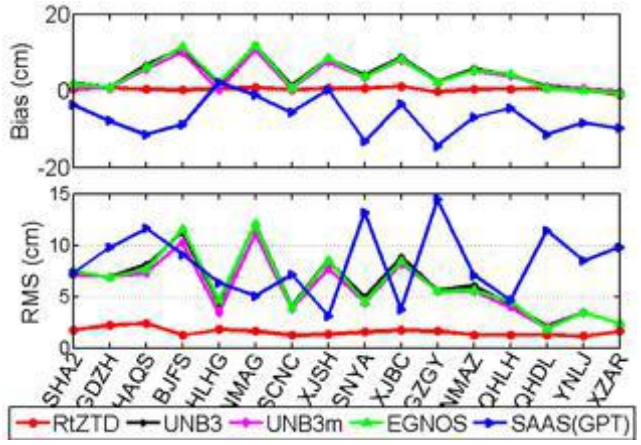
Bias and RMS of real-time ZTD errors

	Jan.	Apr.	Jul.	Oct.	mean
Bias (cm)	-0.03	0.41	0.66	0.49	0.39
RMS (cm)	1.09	1.52	2.07	1.57	1.56



Bias and RMS in each month at each station

No obvious errors in different regions

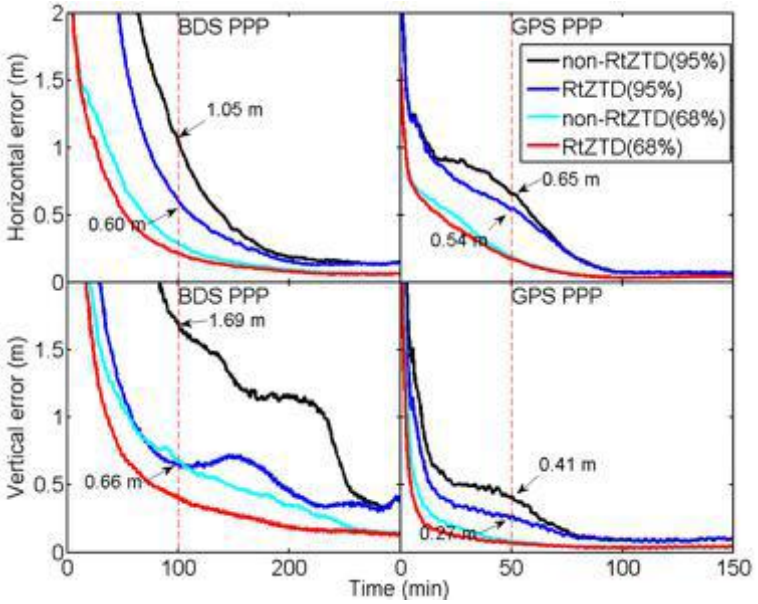


ZTD comparisons

Improvements compared to empirical models

Real-time ZTD grid product

- PPP convergence tests
  - ✓ 95 NBAS stations as PPP test stations
  - ✓ Period: Apr 4-10, 2016
  - ✓ Observations: GPS/BDS



PPP convergence comparisons

Convergence Thresholds: H (0.2m), V (0.5m)

Convergence time (min) comparisons

	H(95%)	V(95%)	H(68%)	V(68%)	
BDS	194.5	252.5	123.0	146.5	w/o
	181.0	192.0	105.0	76.5	with
	6.9%	**24.0%**	**14.6%**	**47.8%**	
GPS	78.0	34.0	48.5	7.5	w/o
	77.0	14.0	47.0	5.0	with
	1.3%	**58.8%**	**3.1%**	**33.3%**	

Significant improvements in vertical component

Summary and Conclusions

- **Real-time ZTD grid product**
  - ✓ Empirical ZTD vertical correction model + real-time GNSS network
  - ✓ High accuracy (< 1.5 cm)
  - ✓ Real-time (5 min interval)
  - ✓ High resolution (0.75° x 0.75°)
  - ✓ At the national scale over China
  - ✓ Easy to use (saved table + real-time ZTD grid products)
  - ✓ Significantly accelerate PPP convergences, especially in the vertical component
  - ✓ Can be easily expanded to the global scale

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Thanks!

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