The FengYun-3 radio occultation sounder GNOS: a review of the missions and results

Weihua Bai[1,2], Yueqiang Sun[1,2], Congliang Liu[1,2], Lijun Liu[1,2], Qifei Du[1,2] , Xianyi Wang[1,2], Danyang Zhao[1,2], Guanglin Yang[3], Mi Liao[3], Zhongdong Yang[3], Xiuqing Hu[3], Xiangguang Meng[1,2],, , Junming Xia[1,2], Yuerong Cai[1,2]

1 Laboratory of Space Environment Exploration (LSEE)
2 Joint Laboratory on Occultations for Atmosphere and Climate (JLOAC)
3 China Meteorological Administration (CMA)

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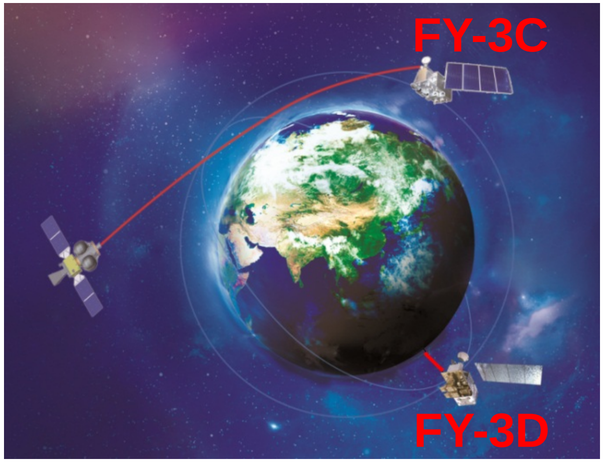
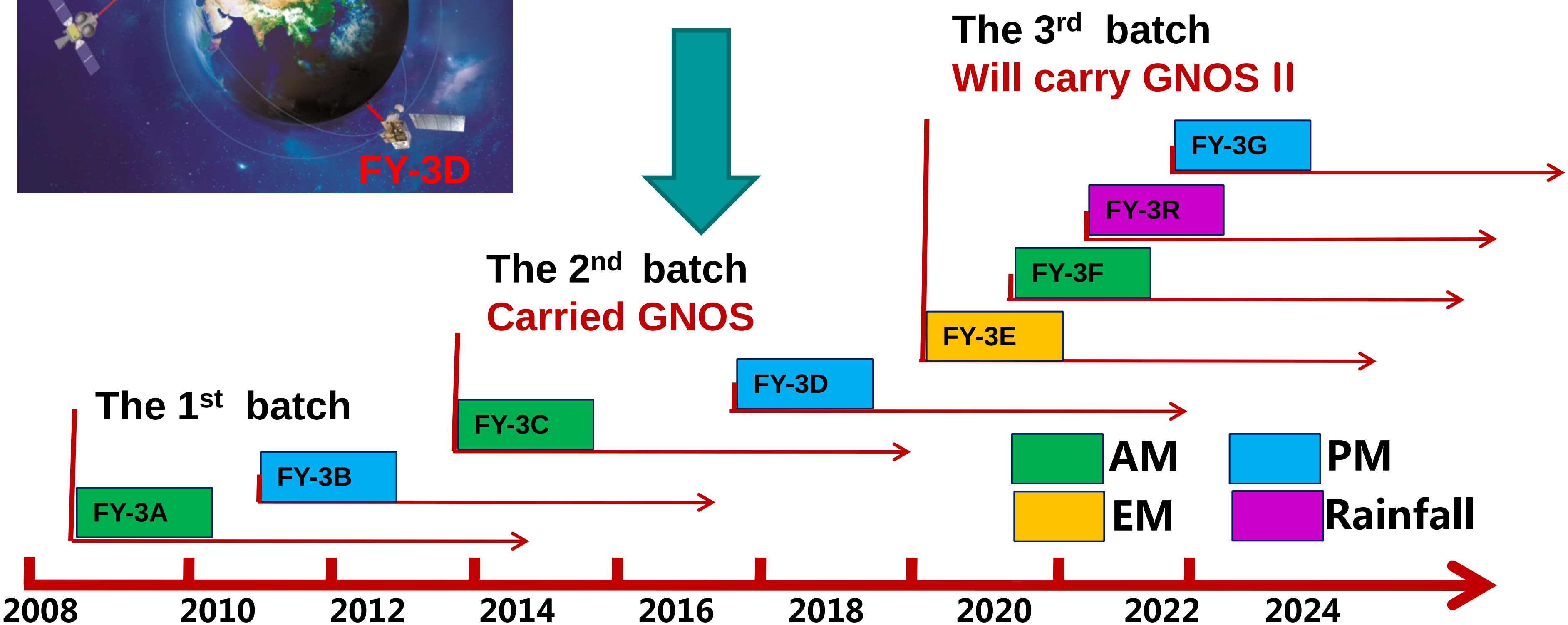
Outline

- ◆1、Overview of the FY-3 GNOS missions
- ◆2、FY-3C/-3D GNOS missions
- ◆3、GNOS II and following missions
- ◆4、Conclusions

Overview of the FY-3 series Satellites

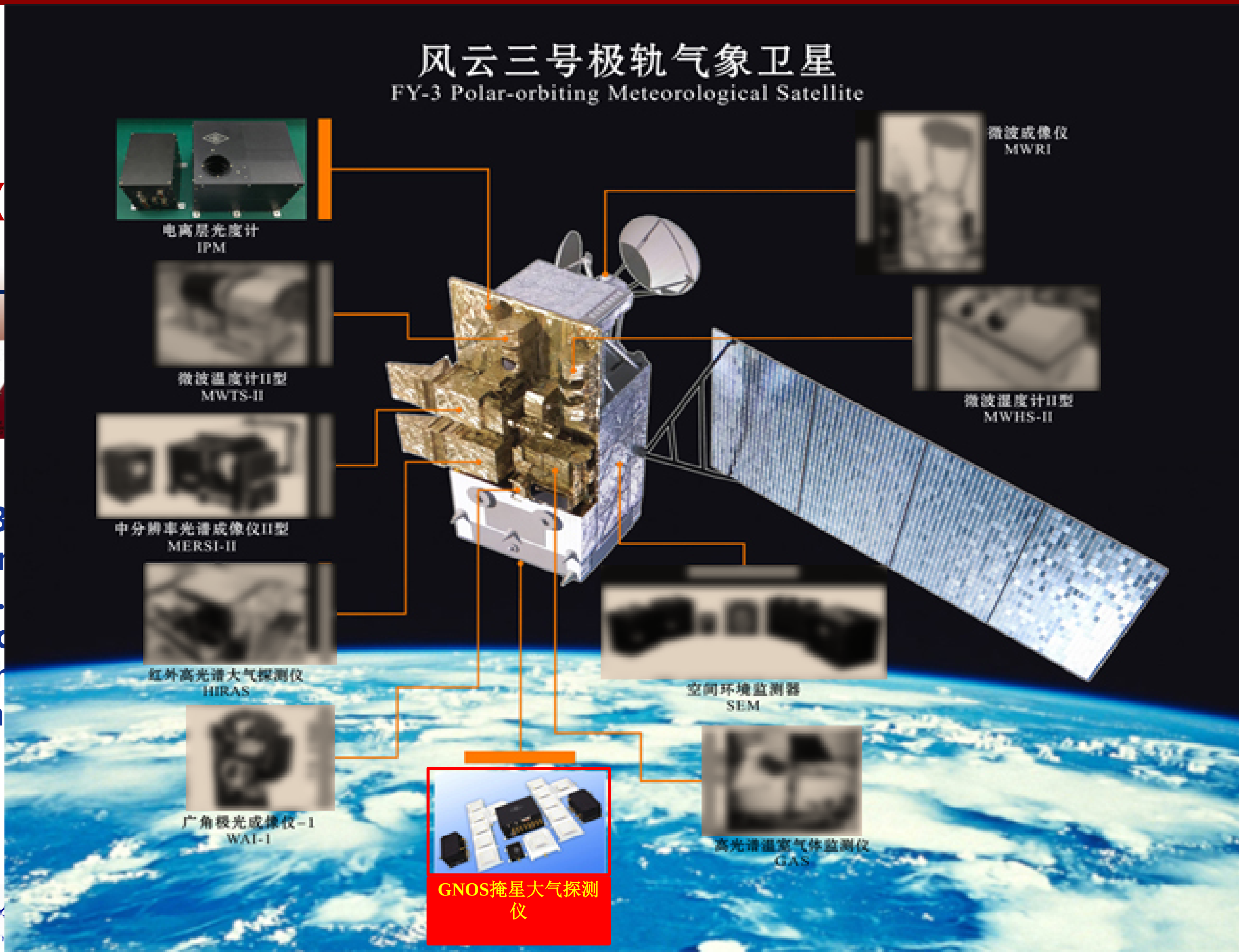


GNOS (GNss Occultation Sounder)



Operational and future missions of FY-3 series satellites

Overview of the GNOS instruments



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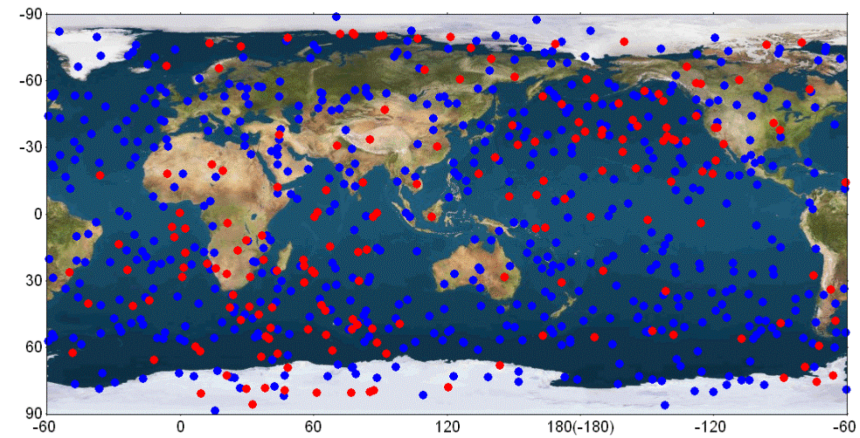
Overview of the GNOS instruments

FY-3C GNOS parameters

Parameters	Content
Instrument mass	7.5kg
Constellation	GPS L1、L2 Beidou B1、B2
Channel number	Positioning: 8 Occultation: GPS 6 Beidou 4
Sampling rate	Positioning & Ionosphere occultation: 1Hz Atmosphere occultation: CL 50Hz OL 100Hz
Clock stability	1×10^{-12}（1secAllan）
Antenna specification	Atmosphere occultation antenna: Gain: >10dBi Antenna field of view: El ±7.5° Az ±35° Positioning & Ionosphere occultation antenna: Gain: -1dBi Antenna field of view: ±60°
Pseudorange precision	≤30cm
Carrier phase precision	≤2mm

Improvements of FY-3D GNOS

Main parameters	FY-3C GNOS	FY-3D GNOS
Number of occultation channels	GPS: 6 BDS: 4	GPS: 8 BDS: 6
Occultation antenna beamwidth (BW)	±35°	±40°



GPS/GNOS RO:
~ 500 events/day/LEO (blue)
BDS/GNOS RO:
~ 200 events/day/LEO (red)

FY-3C/-3D GNOS mission

Product validation (Precise Orbit Determination)

Signal from the up-looking antenna are used for POD of the FY-3C satellite.

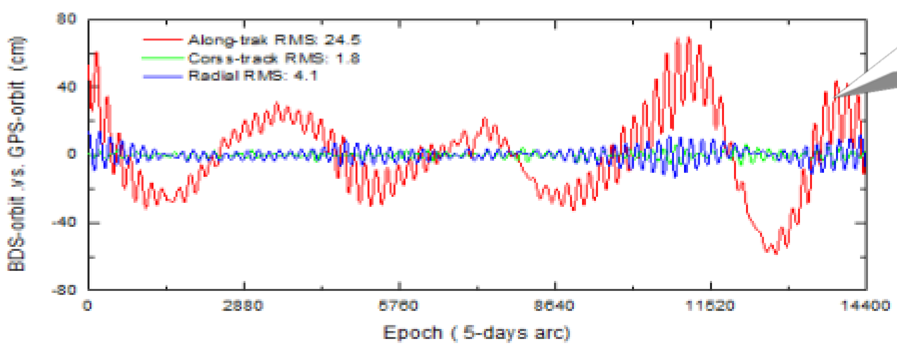
Tab.1 POD Precision Statistics of Position

	Radial RMS(cm)	Along RMS(cm)	Cross RMS(cm)	3D RMS(cm)
MEAN	0.919	1.460	2.232	2.868
MEDIAN	0.925	1.460	2.330	2.911

Tab.2 POD Precision Statistics of Velocity

	Radial RMS (mm/s)	Along RMS (mm/s)	Cross RMS (mm/s)	3D RMS (mm/s)
MEAN	0.018	0.014	0.009	0.025
MEDIAN	0.018	0.014	0.009	0.024

GPS POD:
3D RMS position error is 2.868 cm
3D RMS velocity error is 0.025 mm/s

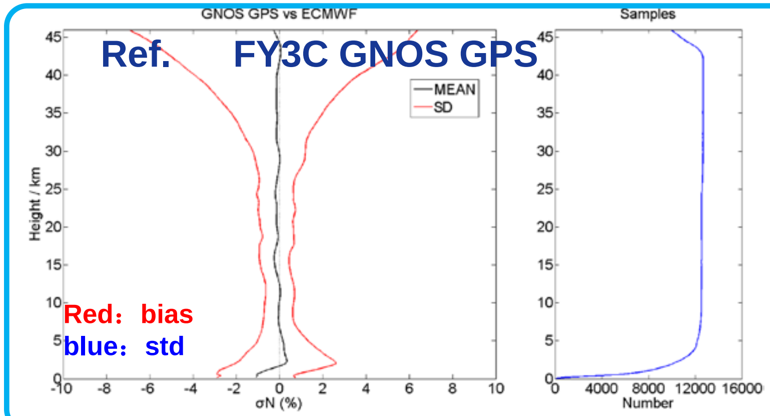


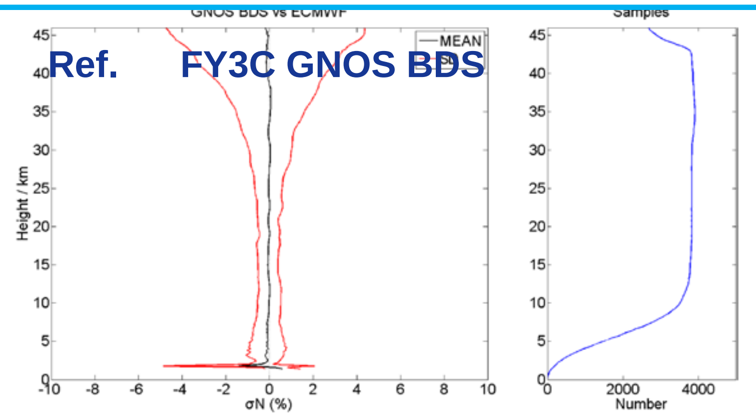
POD error using BDS (5 days)

BDS POD :
3D RMS position error is 30 cm
Error Sources:
Regional coverage,
BDS channel umber,
POD algorithm…

FY-3C/-3D GNOS mission

Product validation (Atmospheric products)

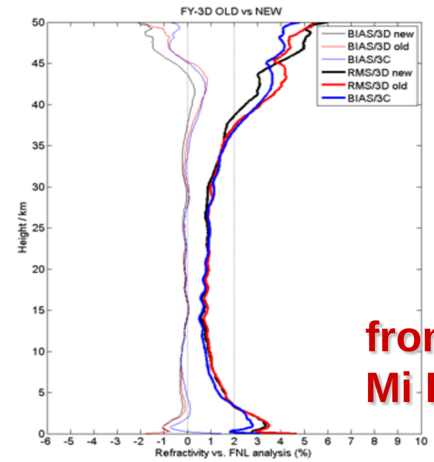




within 200km，±1 h(time)

5-25km	Ref（%）	
	Bias	std
GNOS-GPS vs ECMWF	-0.09	0.75
GNOS-BDS vs ECMWF	-0.04	0.53
COSMIC vs ECMWF	-0.12	0.71

Liao Mi,et al. Preliminary validation of the refractivity from the new radio occultation sounder GNOS/FY-3C. Atmos. Meas. Tech, 9,781-792,2016



from
Mi Lao

FY3D preliminary results of in-orbit testing are consistent with those of FY3C

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Mi Lao (CMA), a detailed talk will be on Tuesday

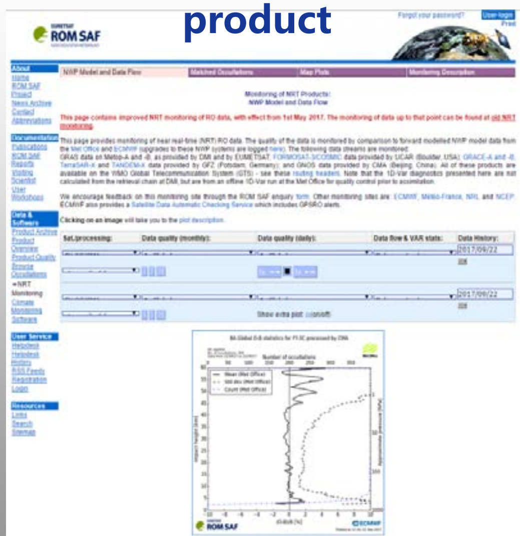
FY-3C/-3D GNOS mission

Product Application (Atmosphere NWP)

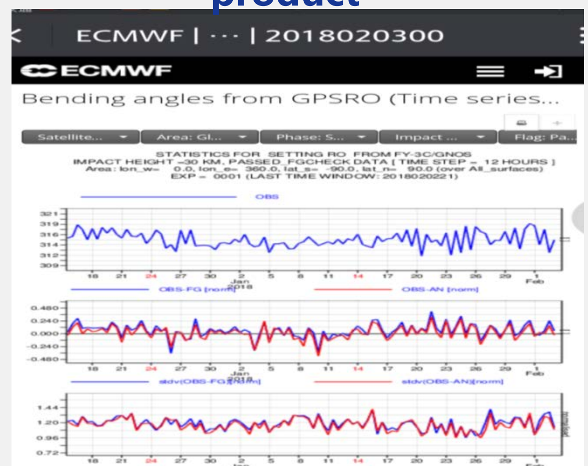
•From June 2017, NSMC has published the products of GNOS via GTS.

• On March 6th 2018, ECMWF started to use GNOS GPS bending angle data in assimilation processing.

EUMESAT real-time quality monitoring of FY-3C GNOS product



ECMWF real-time quality monitoring of FY-3C GNOS product



GNOS/F-3C data has a neutral and positive impacts on GRAPES and ECMWF forecast skill.

Courtesy: EUMESAT, ECWMF and ROM-SAF

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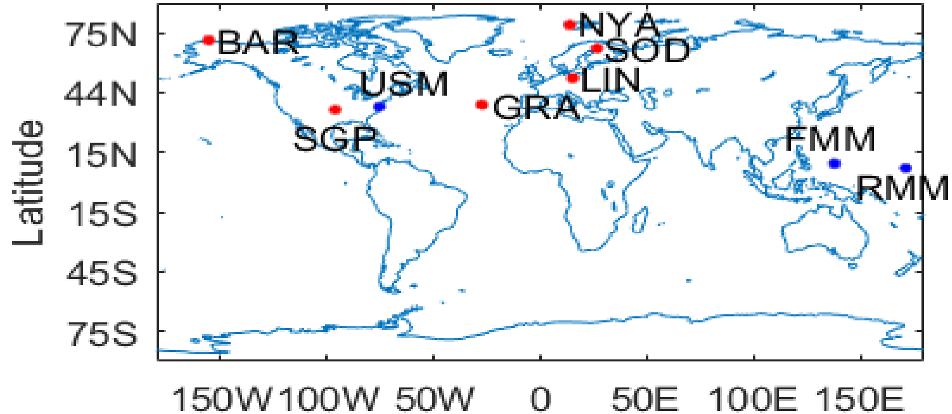
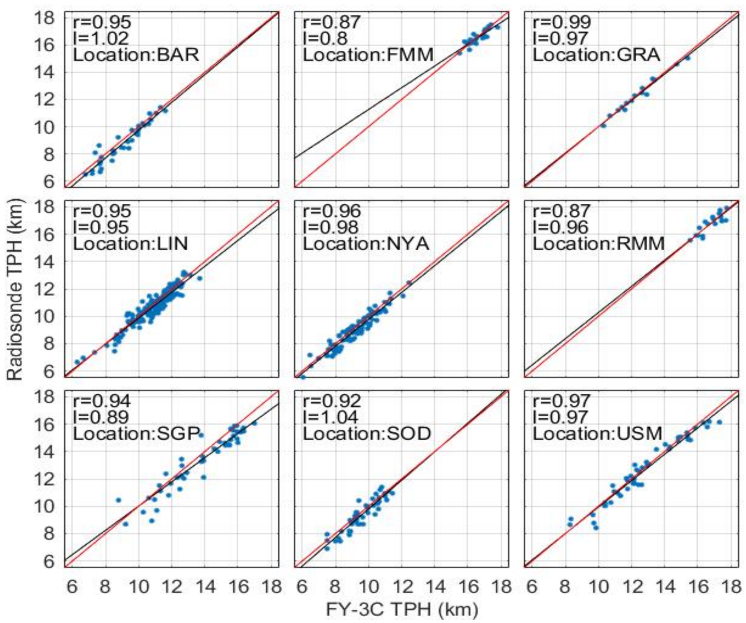
Yan Liu (CMA), a talk about NWP is on Tuesday

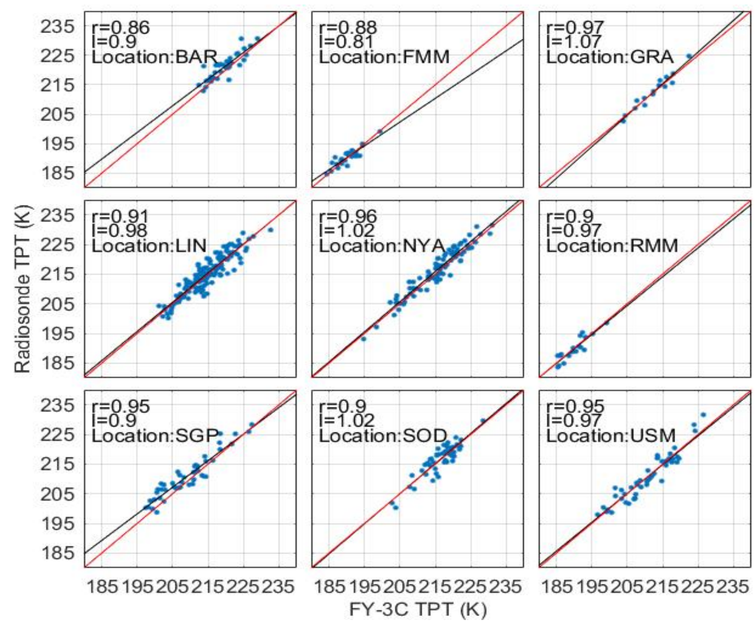
Product Application (Atmosphere Climate)

Tropopause Para.

- Red dot for Global Climate Observing System Reference Upper-Air Network （GRUAN） station(2014.1~2017.12)
- Blue dot for IGRA station (2016.1~2017.12)







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Liu Z.Y. Bai W.H. et al .Validation of Preliminary Results of Thermal Tropopause Derived from FY-3C GNOS Data.Remote Sens. 2019, 11, 1139;

FY-3C/-3D GNOS mission

Product Application (Atmosphere Climate)

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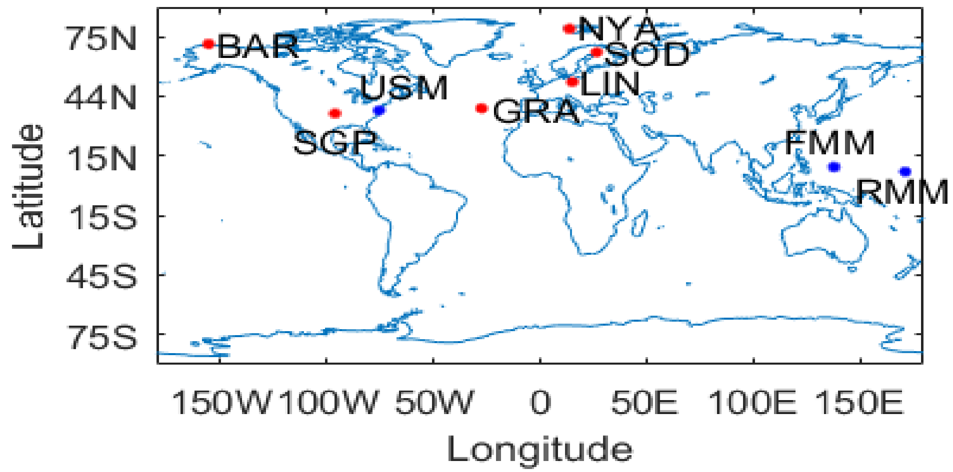


Station	Location	Collocate pairs	TPH Bias	TPT Bias
BAR	71.4N, 155.6W	36	0.27 km	−1.43 K
GRA	39.0N, 27.4W	15	0.05 km	−0.22 K
LIN	52.2N, 15.2E	151	0.07 km	−0.32 K
NYA	78.9N, 13.8E	84	0.21 km	−0.85 K
SGP	36.4N, 96.2W	48	0.40 km	−1.70 K
SOD	67.2N, 26.7E	49	0.20 km	−0.20 K
USM	37.9N, 75.5W	46	0.15 km	0.08 K
FMM	9.5N, 138.1E	27	0.05 km	−0.13 K
RMM	7.1N, 171.4E	18	0.02 km	0.25 K

Liu Z.Y. Bai W.H. et al .Validation of Preliminary Results of Thermal Tropopause Derived from FY-3C GNOS Data.Remote Sens. 2019, 11, 1139;

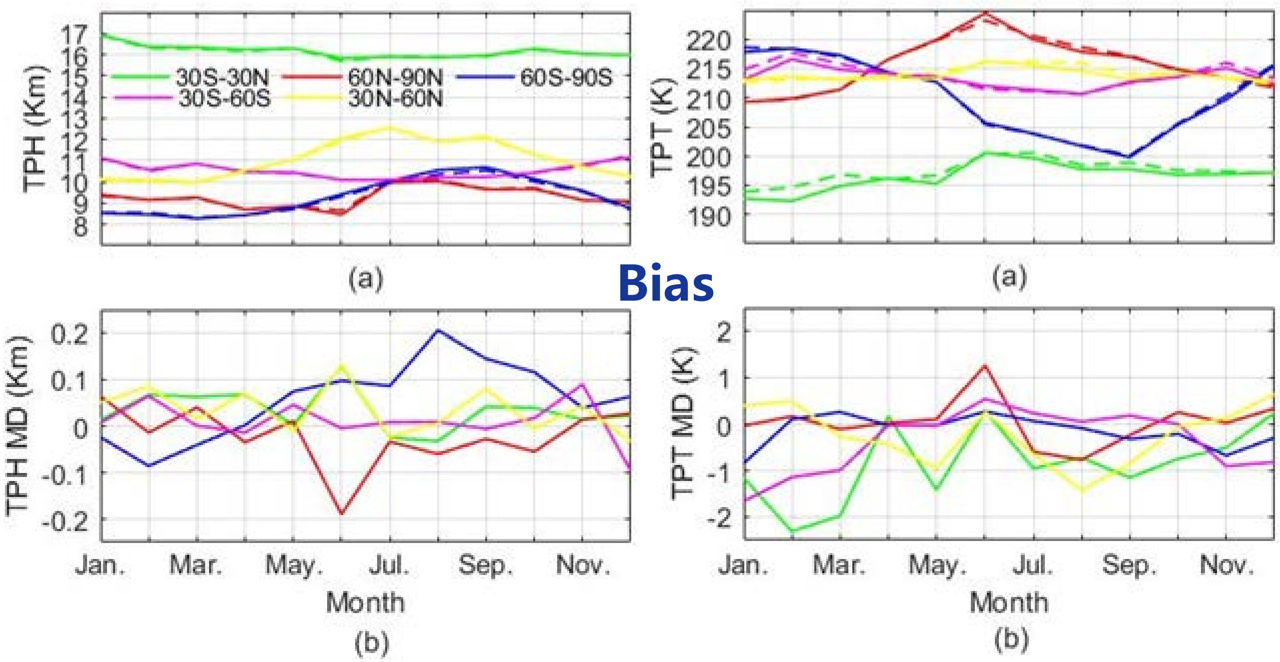
FY-3C/-3D GNOS mission

Product Application (Atmosphere Climate)

Tropopause Para.

- Annual cycle TPH and TPT for different latitude bands derived from collocated 2014-2017 FY3C and COSMIC data.
- Collocated criteria : <3 h and < 300 km.
- **Results from two RO missions show consistency.** The TPH difference is concentrated at Antarctica during Jul to Nov, where FY3C show positive bias compared with COSMIC. This bias may be because the TPH over Antarctica raises during summer and autumn.
  For the TPT, the major bias occurs over tropics and 30S-60S during Jan. to Apr.

FY-3C GNOS(Solid line) vs COSMIC(Dashed line)



Liu Z.Y. Bai W.H. et al .Validation of Preliminary Results of Thermal Tropopause Derived from FY-3C GNOS Data.Remote Sens. 2019, 11, 1139;

FY-3C/-3D GNOS mission

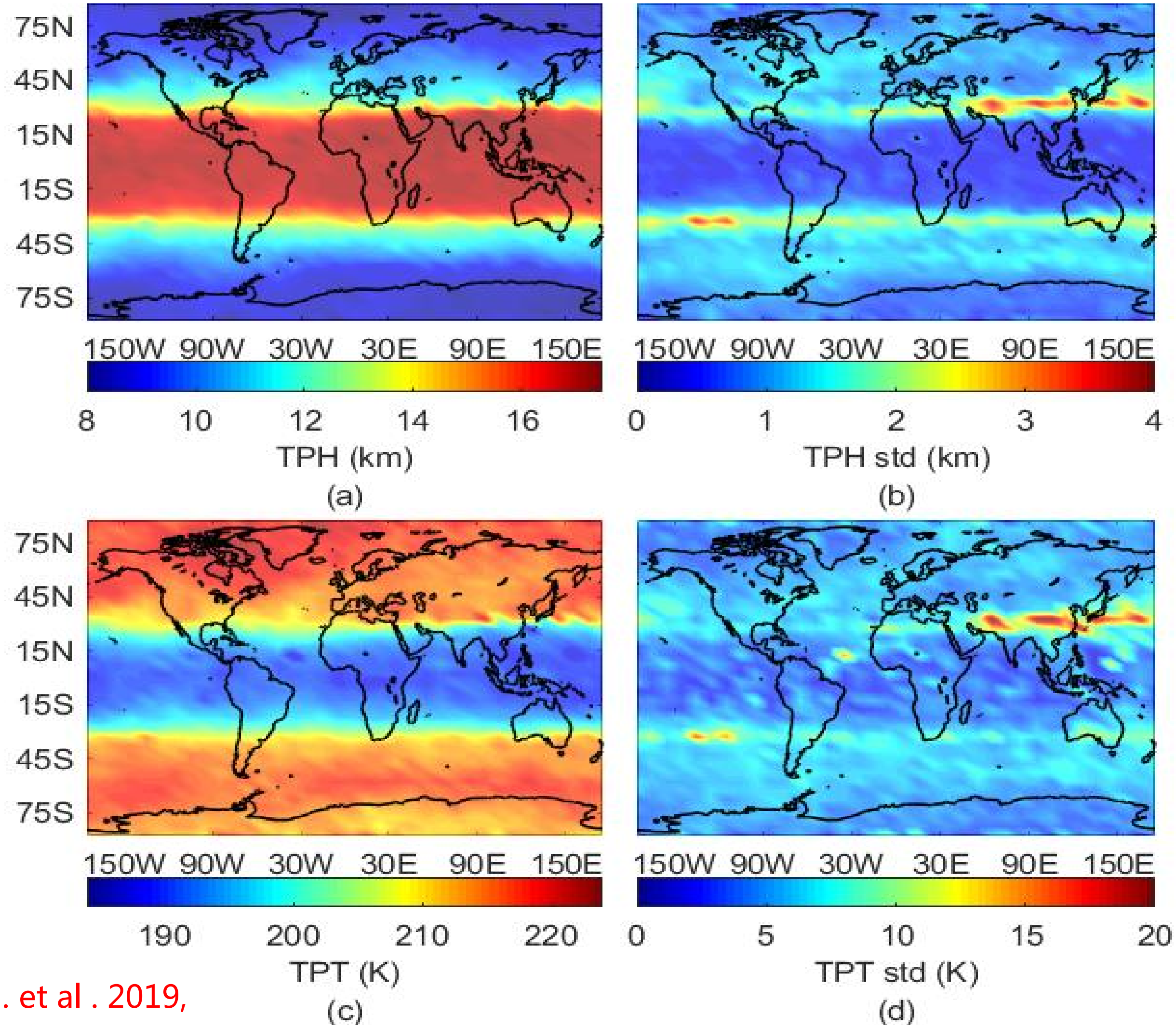
Product Application (Atmosphere Climate)

Tropopause Para.

GNOS global Tropopause Height and Temp.

Mar.~May.

In spring (MAM), the global tropopause parameters presented a good symmetry between Southern and Northern hemispheres.



Liu Z.Y. Bai W.H. et al . 2019,

FY-3C/-3D GNOS mission

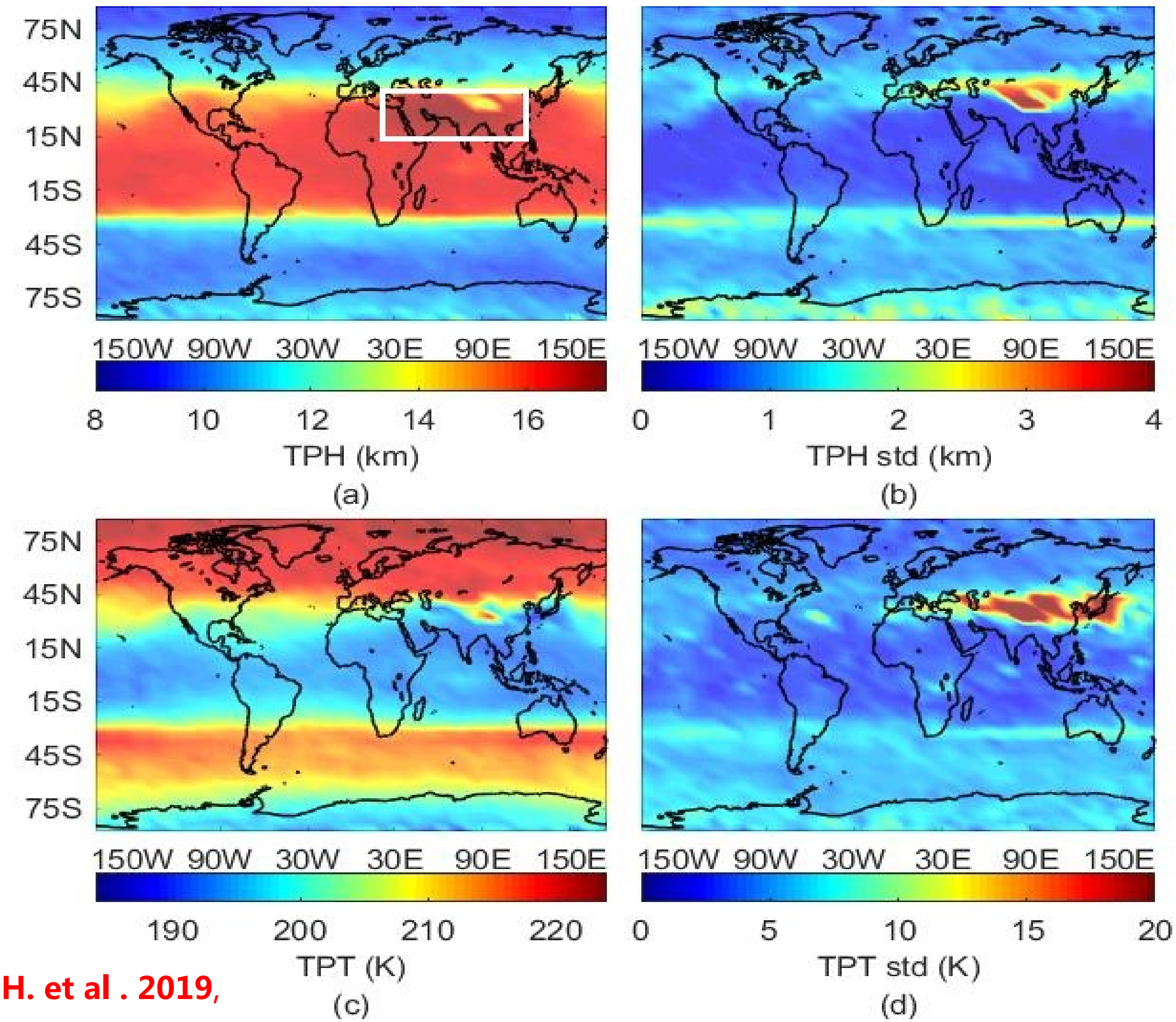
Product Application (Atmosphere Climate)

Tropopause Para.

Jun.~Aug.

The tropical tropopause widened toward the north pole and the southern boundary of tropical tropopause narrowed.
In South Asia, the extremely high tropopause caused by deep convective activity was found , also leads to the considerable variability .
The phenomena confirm with Rieckh,T. et. al.2014
and Li W. et al. 2017

GNOS global Tropopause Height and Temp.



Liu Z.Y. Bai W.H. et al . 2019,

FY-3C/-3D GNOS mission

NSSC

Product Application (Atmosphere Climate)

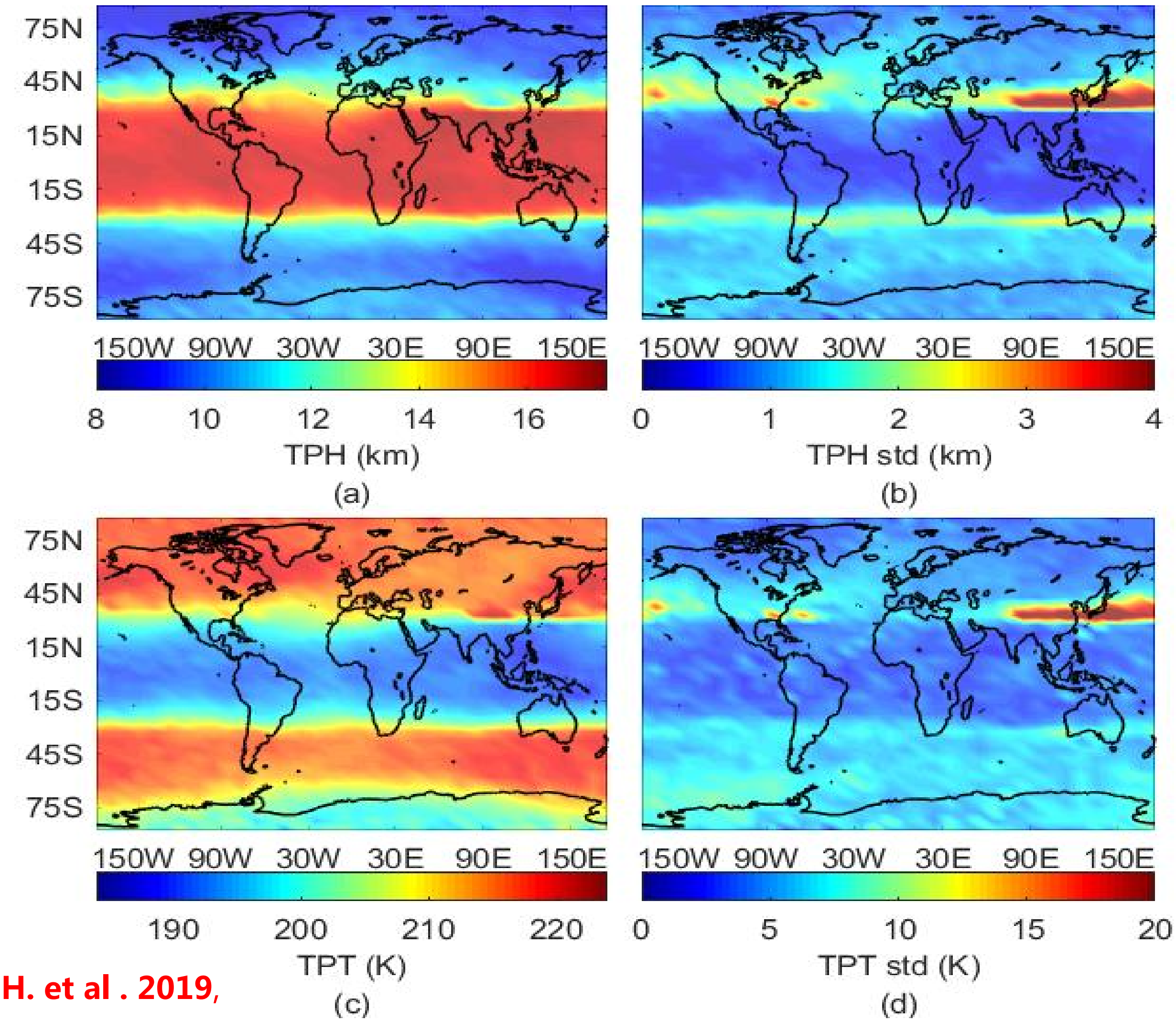
Tropopause Para.

GNOS global Tropopause Height and Temp.

Sept.~Nov.

During summer and autumn (SON), **TPH** above Antarctica rises obviously, about 2 km higher than it in spring, while TPH above the Arctic increased less than 1 km, agrees with Tomikawa et al 2009.

TPT above Antarctica reached its minima in the annual cycle while TPT above the Arctic reached its maxima, which was caused by the differences in dynamical heating of the stratosphere[Zängl,et. al. 2001].



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Liu Z.Y. Bai W.H. et al . 2019,

FY-3C/-3D GNOS mission

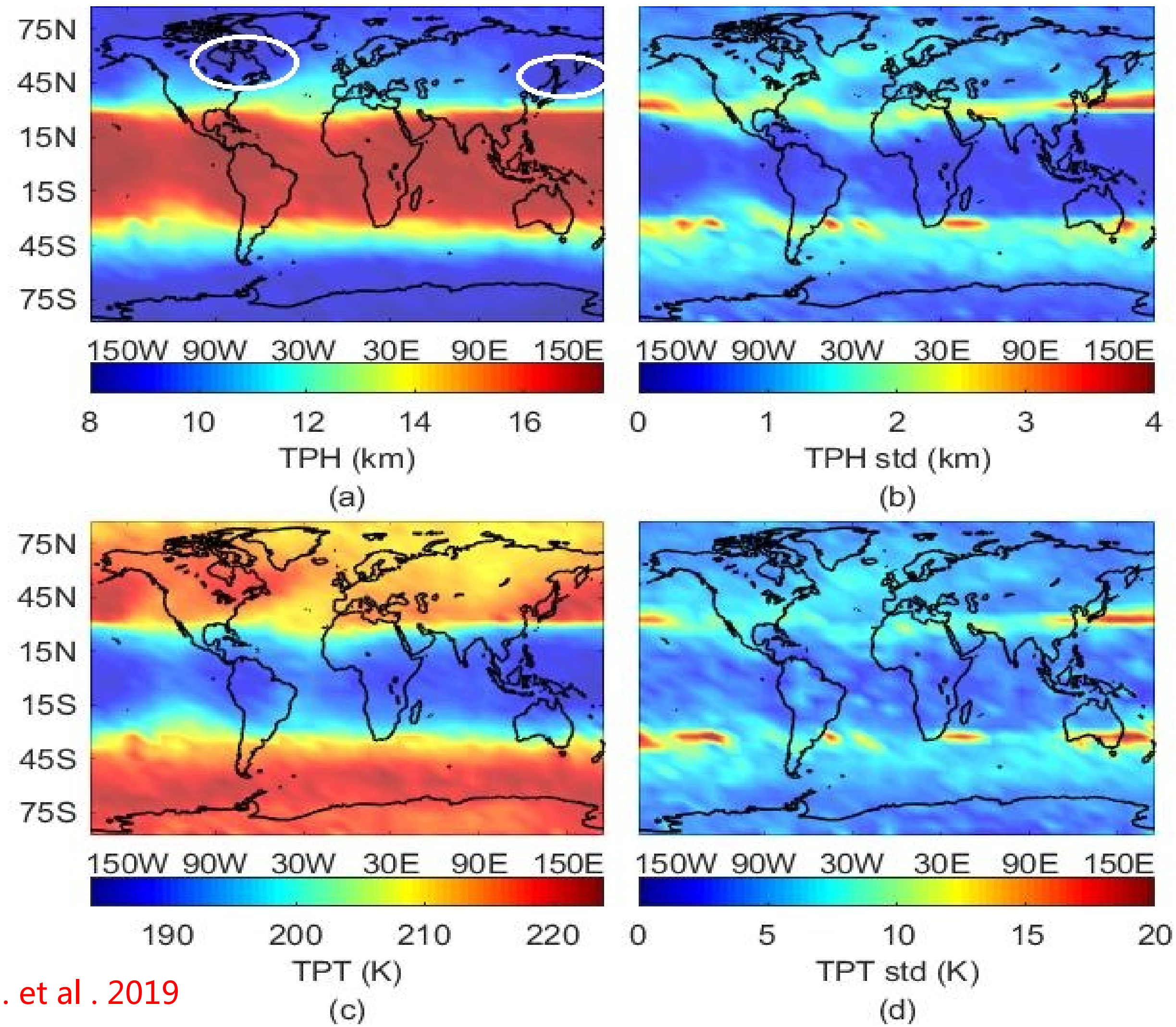
Product Application (Atmosphere Climate)

Tropopause Para.

GNOS global Tropopause Height and Temp.

Dec.~Jan.

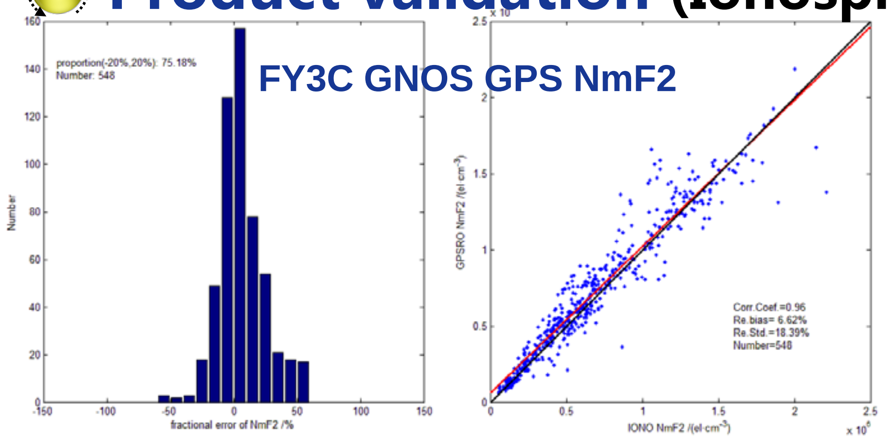
In winter (DJF), strong zonal asymmetry can be seen in the Northern hemisphere. TPH above the tropics increased to its maxima, and the corresponding TPT decreased to around 196 K. Two regions with extremely low TPH occurred at Eastern Canada and Eastern Russia, which are similar with
Rieckh,T. et. al.2014
and Li W. et al. 2017

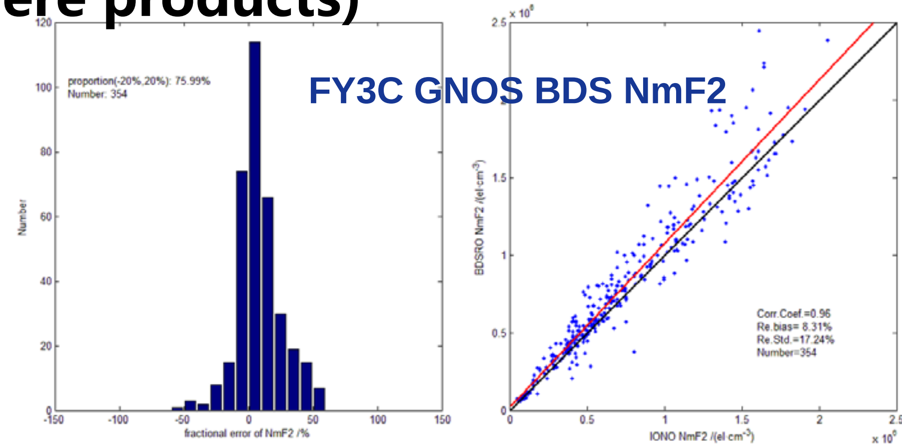


Liu Z.Y. Bai W.H. et al . 2019

FY-3C/-3D GNOS mission

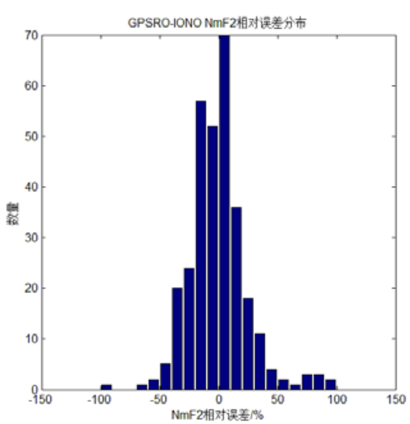
Product validation (Ionosphere products)

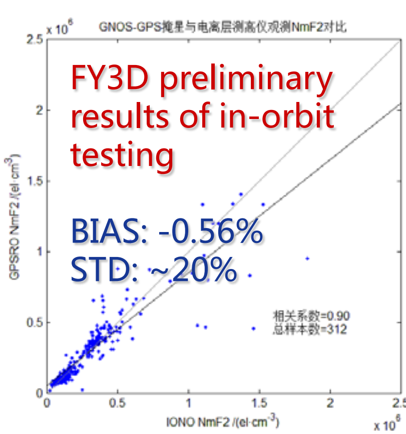


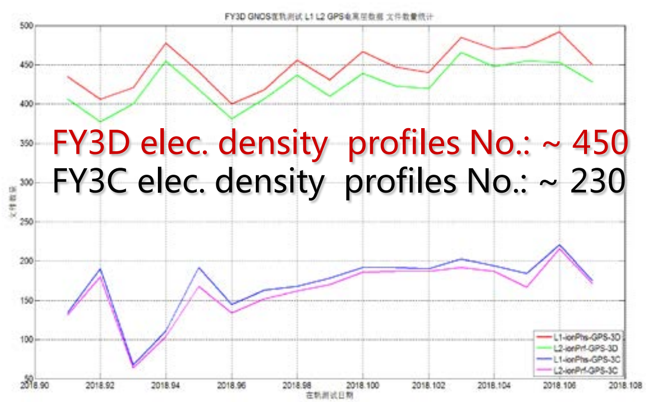


Elec. Density peak	Bias	Std	correlation	Sample No.
NmF2(GPS)	6.62%	18.39%	0.96	548
NmF2(BDS)	8.31%	17.24%	0.96	354

Yang G L, Sun Y Q, Bai W H, et al. Validation results of NmF2 and hmF2 derived from ionospheric density profiles of GNOS on FY-3C satellite[J]. Science China Technological Sciences, 2018:1-12.





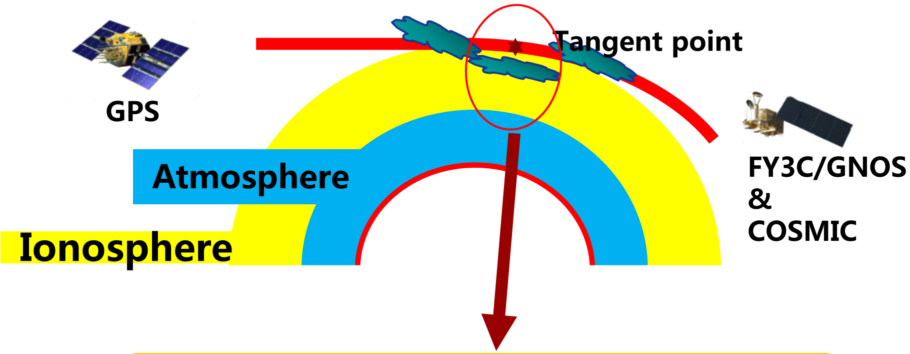


from Guanglin Yang(CMA)

FY-3C/-3D GNOS mission

Product validation (Ionosphere)

Validation of S4max in F2 layer derived from FY-3C GNOS.



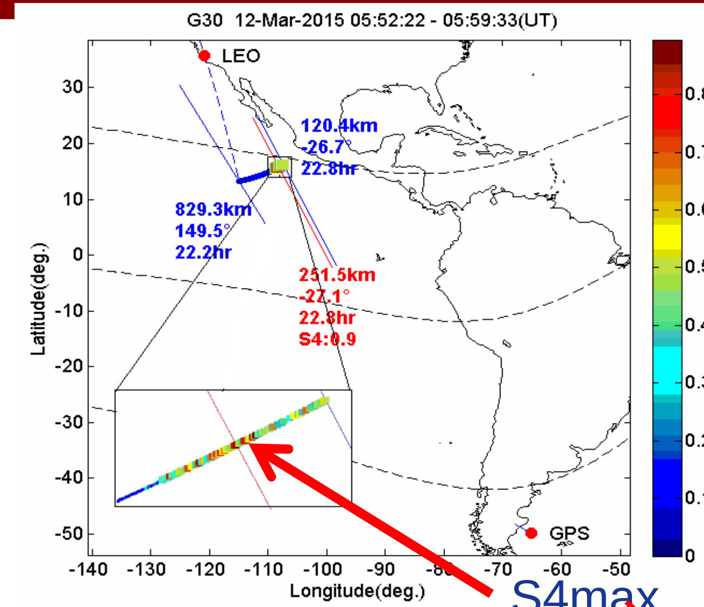
S4max in F layer during January 10, 2014 and January 9, 2015

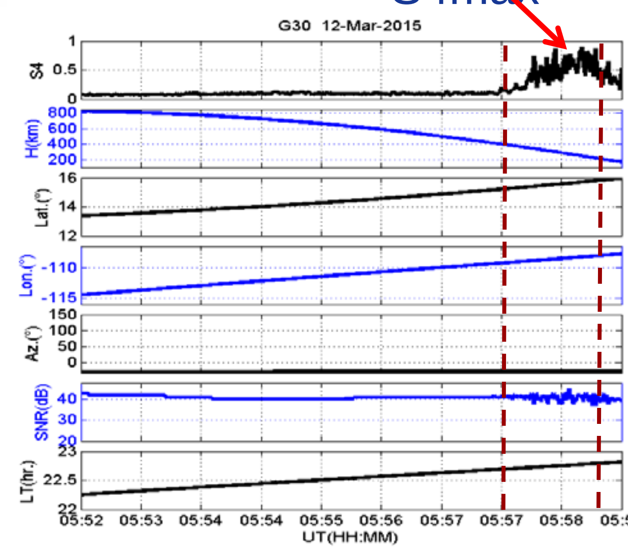
COSMIC	FY3C/GNOS

Matching principles:

- Occultation data quality control (eliminate incomplete and negative EDPs)
- Temporal matching principle (observed within ± 1 hour in time)
- Spatial matching principle(observed within ±2º in space)
- Direction consistency(azimuth angle difference less than 15º)

➢ Selection conditions enable S4max data observed by FY3C/GNOS and COSMIC to match into data pairs and comparable





Bai Weihua, et al. Validation results of maximum S4 index in F layer derived from GNOS on FY3C satellite[J]. GPS SOLUTION,2019,23(1):UNSP 19

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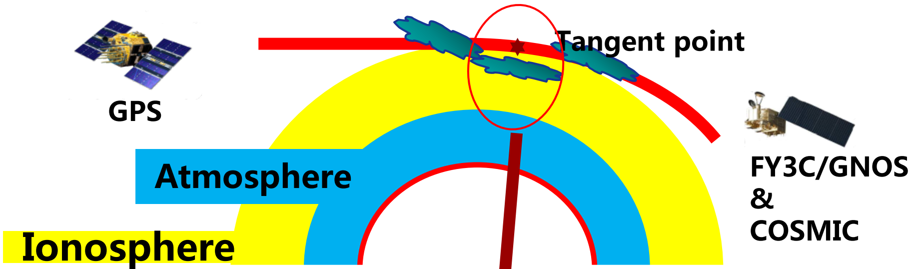
FY-3C/-3D GNOS mission

Product validation (Ionosphere)

Validation of S4max in F2 layer derived from FY-3C GNOS.



S4max in F layer during January 10, 2014 and January 9, 2015

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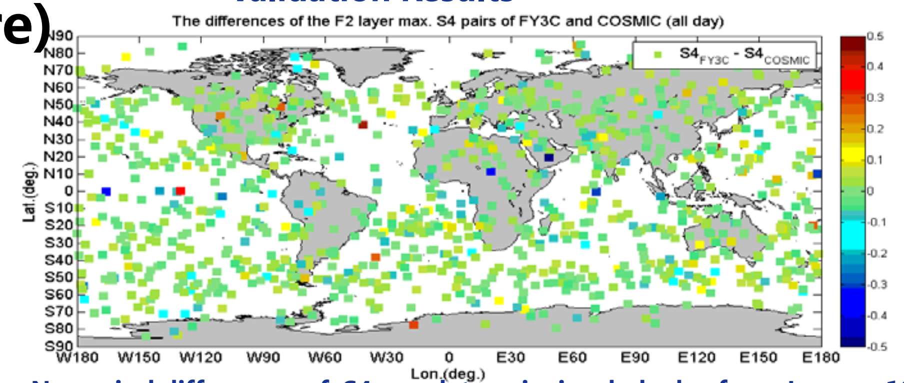
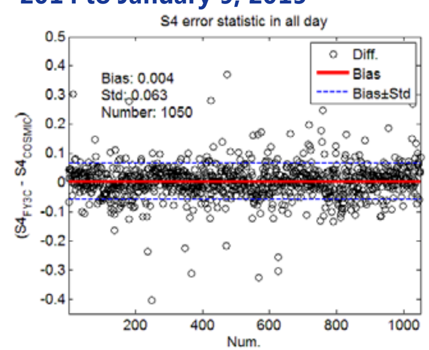
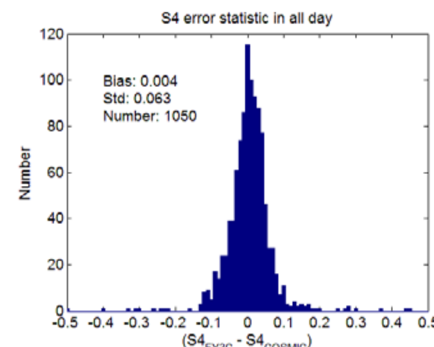
Validation Results



Numerical differences of S4max data pairs in whole day from January 10, 2014 to January 9, 2015





Statistical errors distribution of numerical differences of S4max data pair in whole day from January 10, 2014 to January 9, 2015

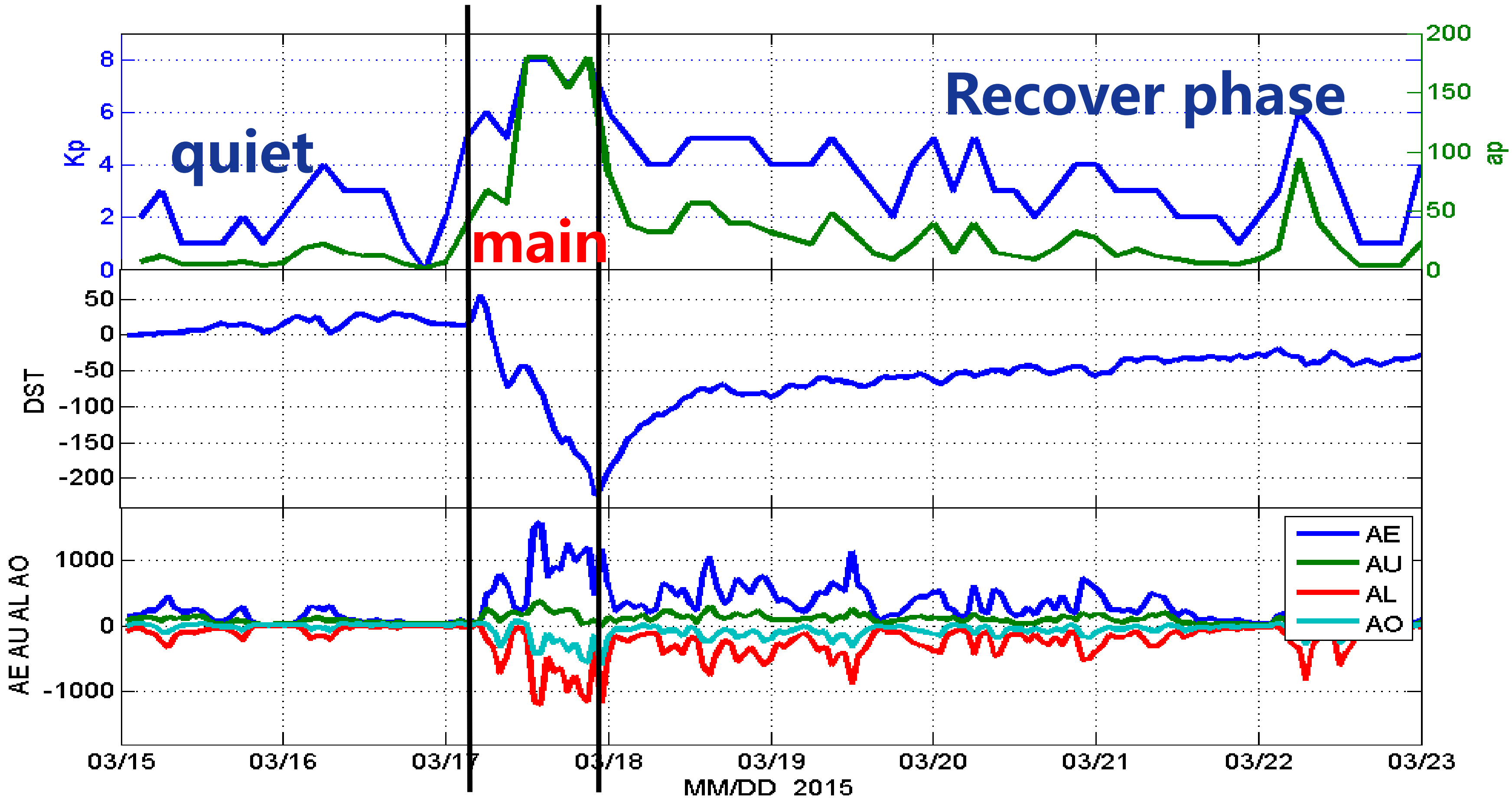
FY3C-COSMIC	Bias	STD
Whole day	0.004	0.063
nighttime	0.007	0.080
daytime	0.001	0.046

Bai Weihua, et al. Validation results of maximum S4 index in F layer derived from GNOS on FY3C satellite[J]. GPS SOLUTION,2019,23(1):UNSP 19

FY-3C/-3D GNOS mission

Product Application (Space Weather)

Magnetic Storm Event study



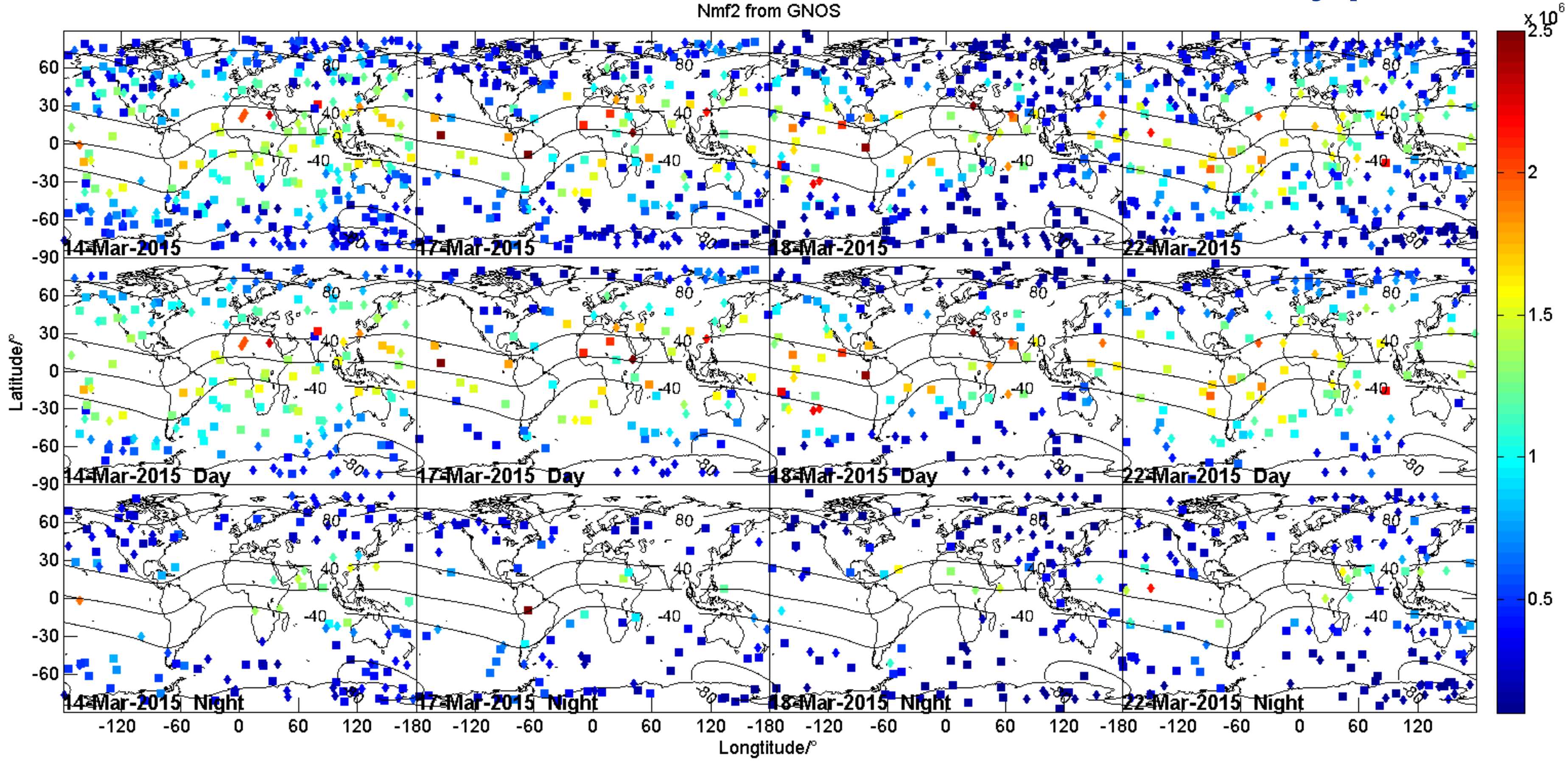
Mar. 2015 Mag. index (data from ISGI)

FY-3C/-3D GNOS mission

Product Application (Space Weather)

Magnetic Storm Event study

NmF2 from Level 2 electron density profile



Bai W. H., Wang G. J et al. Application of Fengyun 3-C GNSS occulation sounder for assessing global ionospheric response to magnetic storm event, A.M.T, 12, 1483–1493, 2019

FY-3C/-3D GNOS mission

Product Application (Space Weather)

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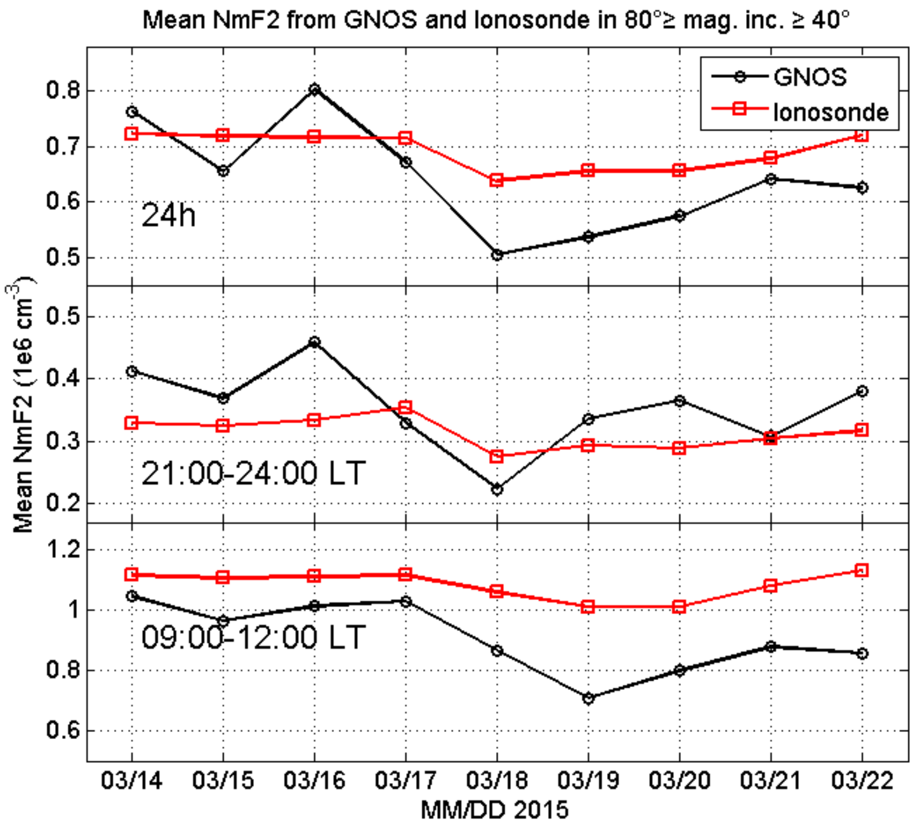

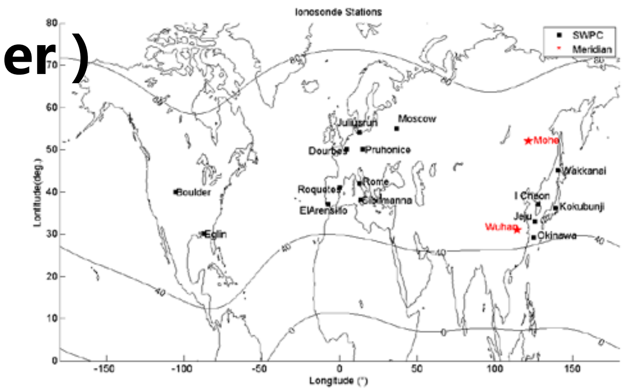

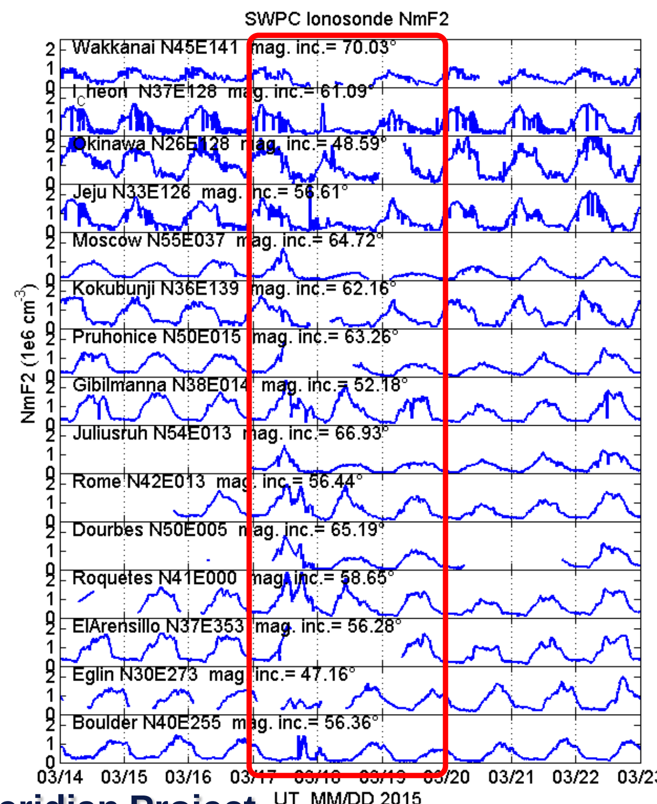

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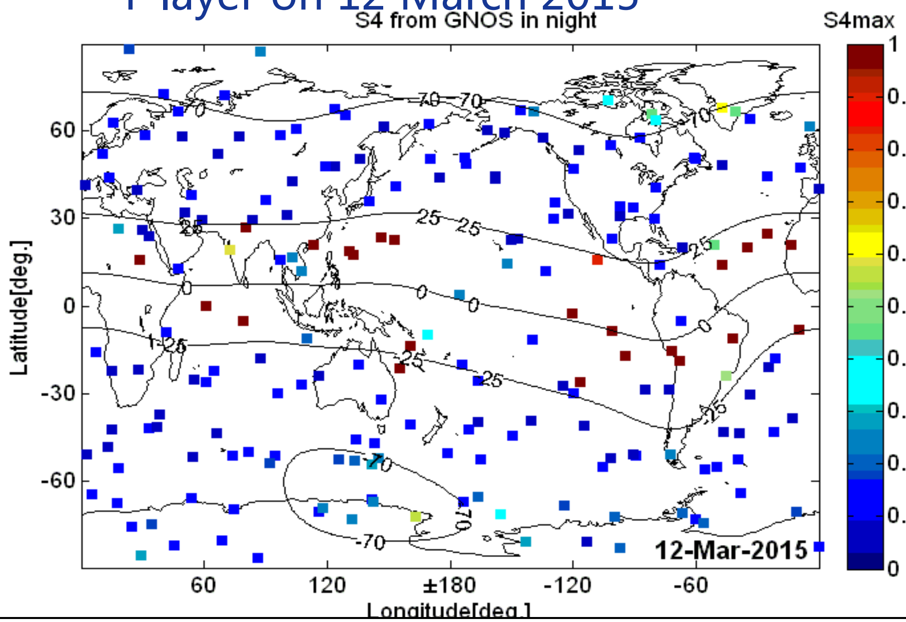
Courtesy: UML GIRO, SWPC & Chinese Meridian Project

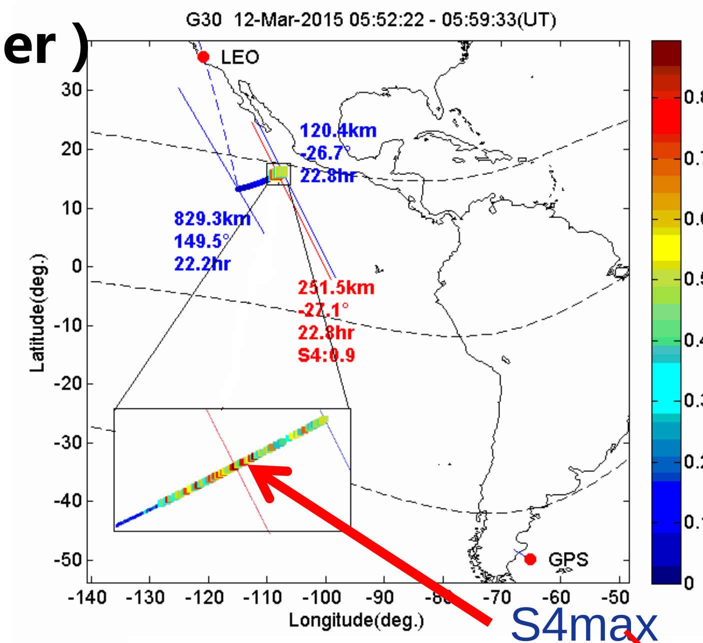
FY-3C/-3D GNOS mission

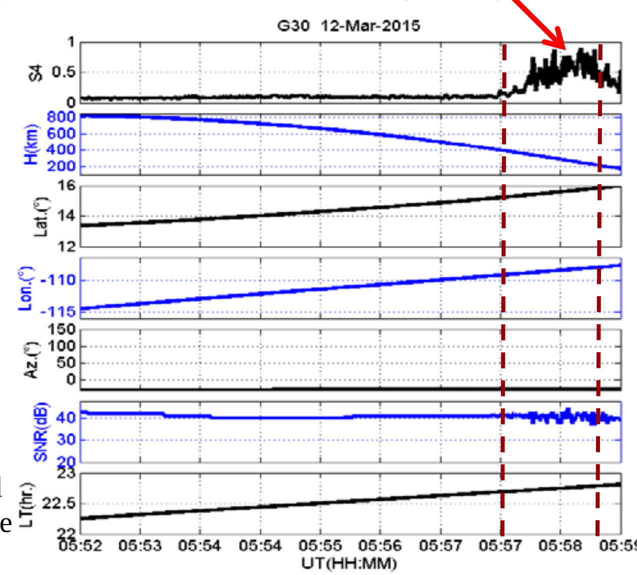
Product Application (Space Weather)

Magnetic Storm Event study

Nighttime distribution of S4max in F layer on 12 March 2015







- GNOS can obtain about 220 events in nighttime.
- The number distribution of GNOS S4 profiles v.s. LT during 12-23 March.
- 75% of S4 profiles locate in the morning and in the evening.

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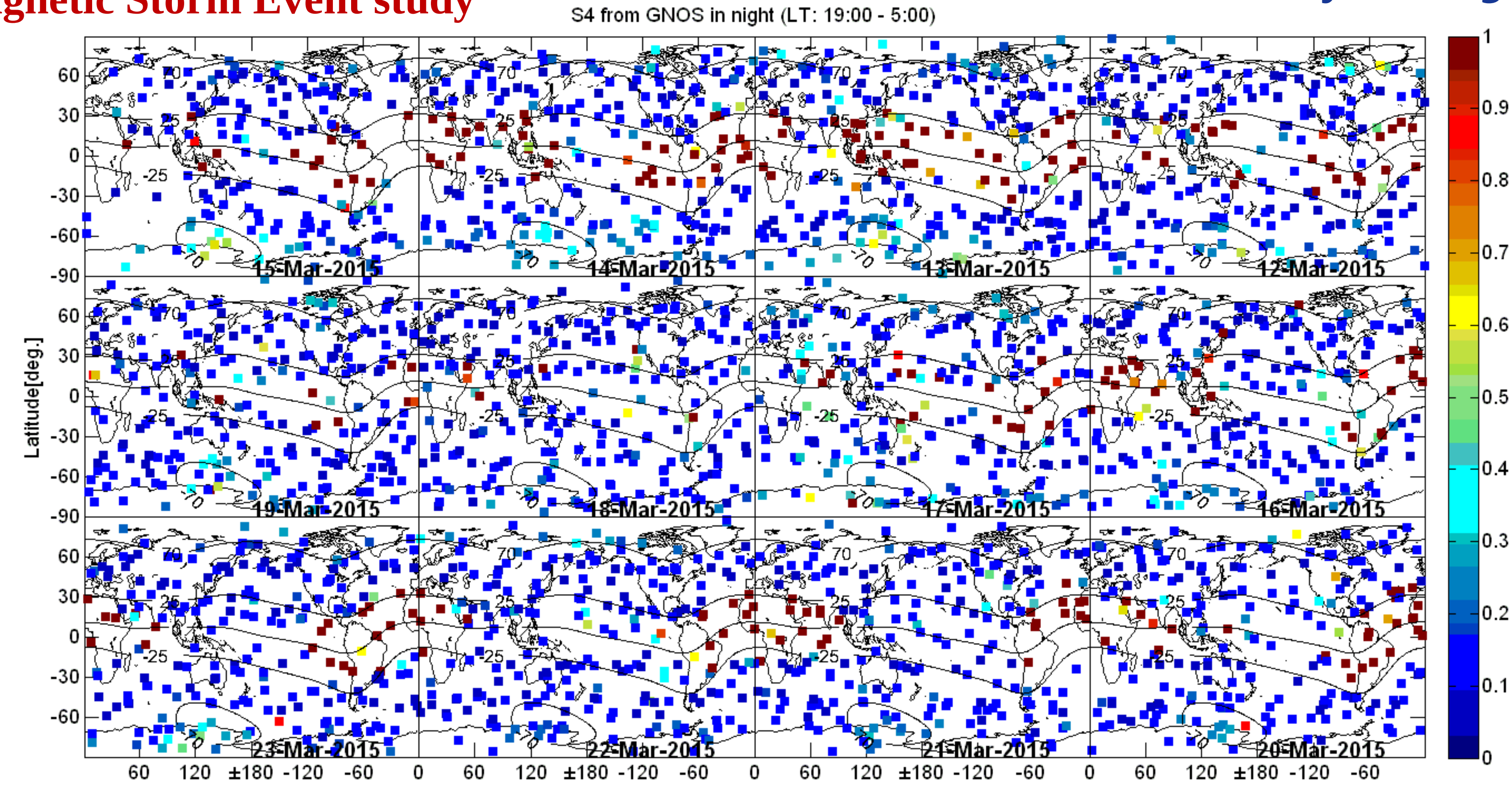
Wang, Guojun, Bai Weihua*,et al. Global ionospheric scintillations revealed by GPS radio occultation data with FY3C satellite before midnight during the March 2015 storm.Advances in Space Research 63.10 (2019): 3119-3130

FY-3C/-3D GNOS mission

Product Application (Space Weather)

Magnetic Storm Event study

Distribution of max S4 in F layer in night



- S4max mainly locate between -25° and 25° Dip Latitude.
- Scintillation enhancement in India and around 160 E sectors during MP, decrease at all longitudes during initial recovery phase of storm.

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Wang, Guojun, Bai Weihua*,et al. Global ionospheric scintillations revealed by GPS radio occultation data with FY3C satellite before midnight during the March 2015 storm.Advances in Space Research 63.10 (2019): 3119-3130

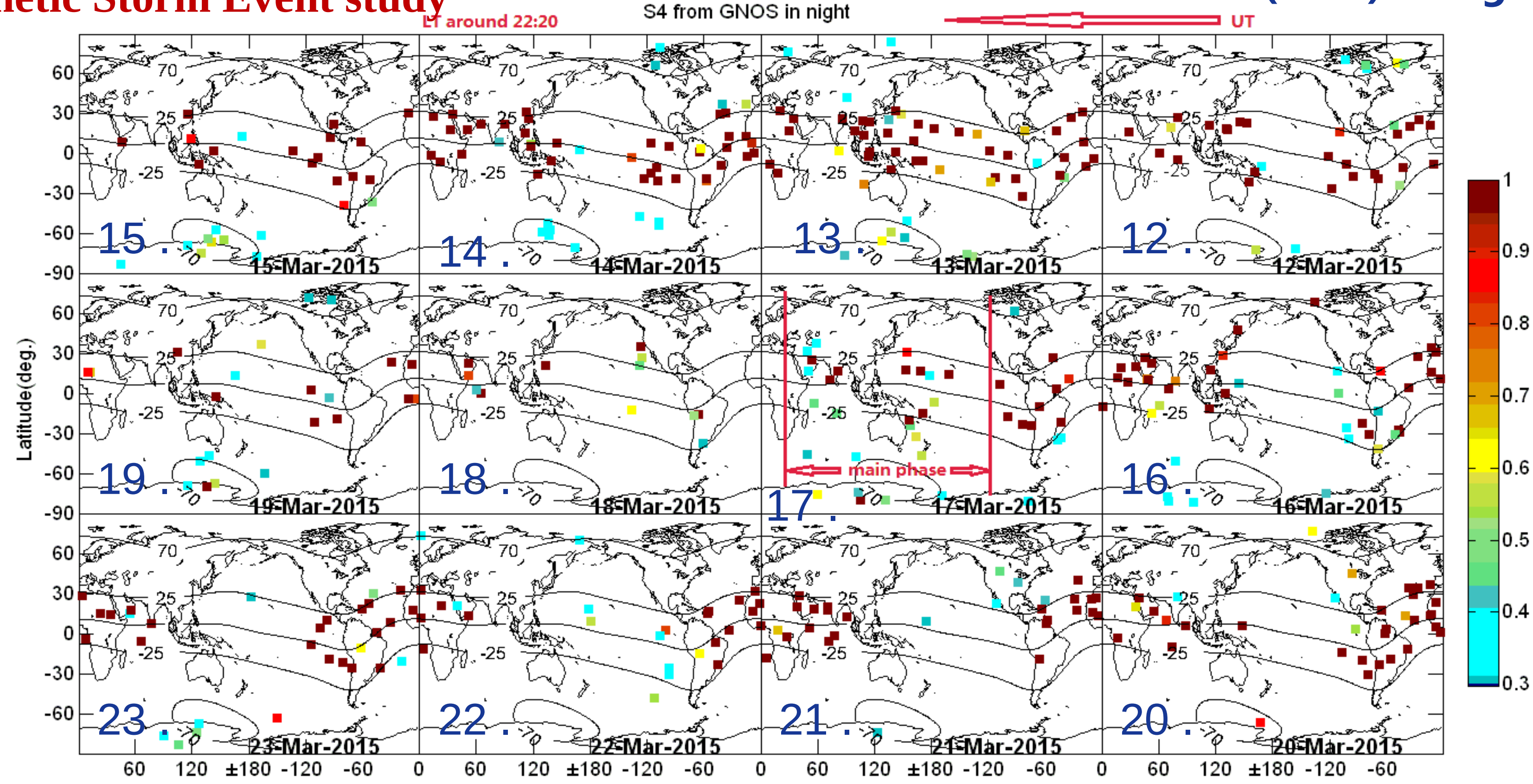
FY-3C/-3D GNOS mission

NSSC

Product Application (Space Weather)

Magnetic Storm Event study

Distribution of maxS4 (>0.3) in night



- S4max mainly locate between -25° and 25° Dip Latitude.
- Scintillation enhancement in India and around 160 E sectors during MP, decrease at all longitudes during initial recovery phase of storm.

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FY-3C/-3D GNOS mission

NSSC

Product Application (Space Weather)

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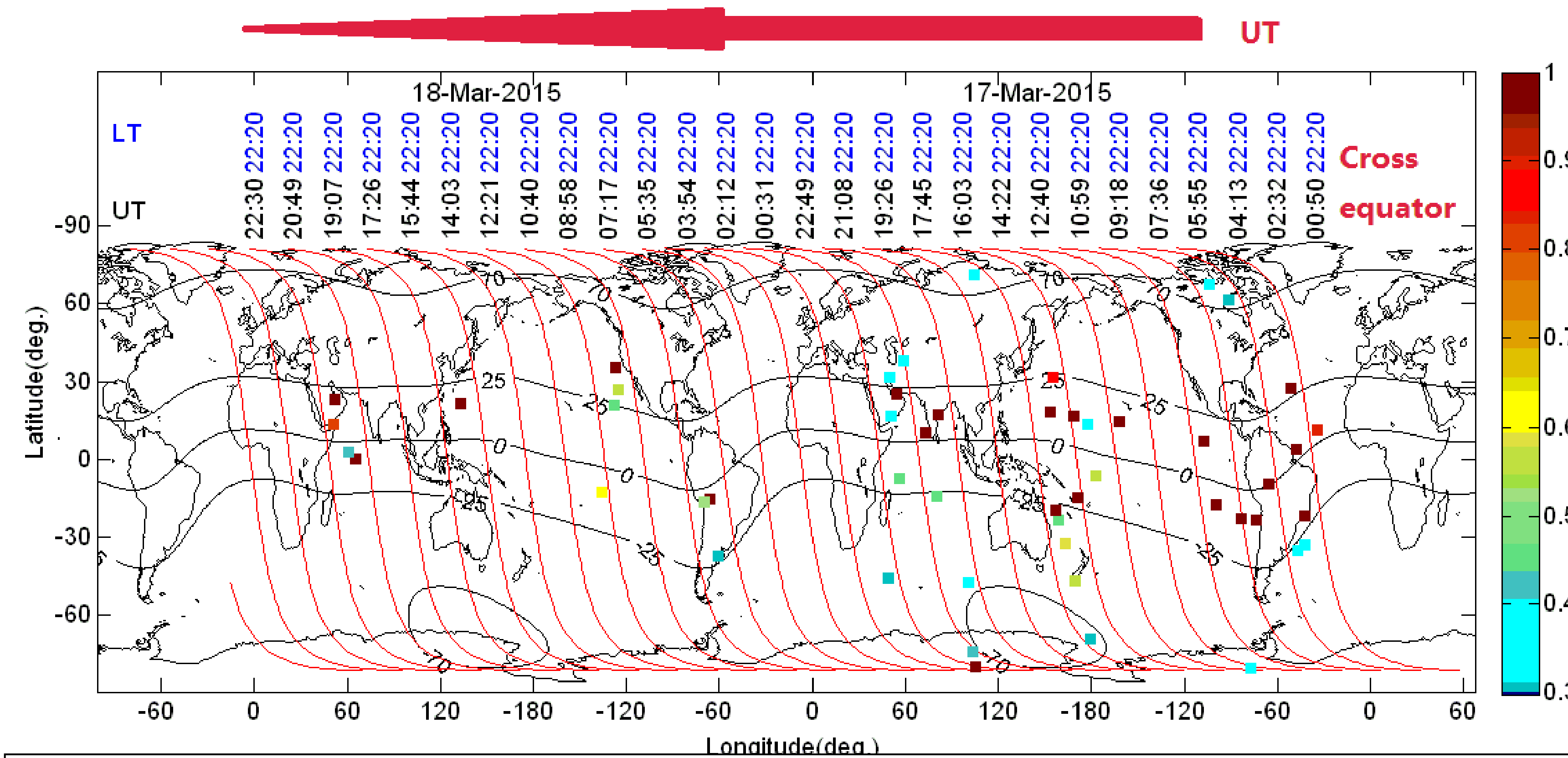

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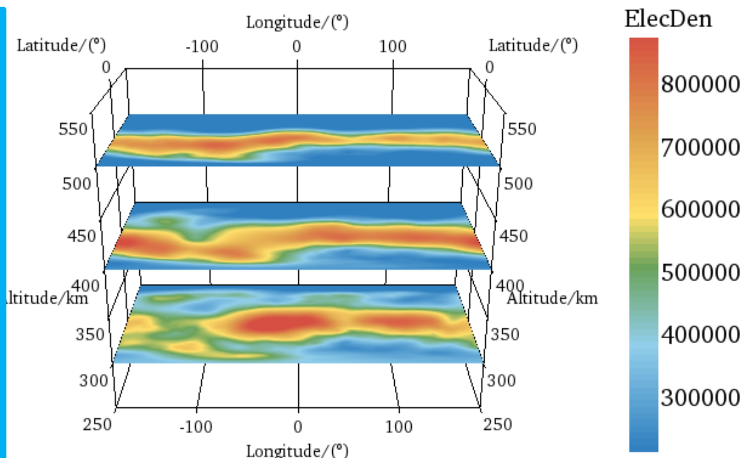
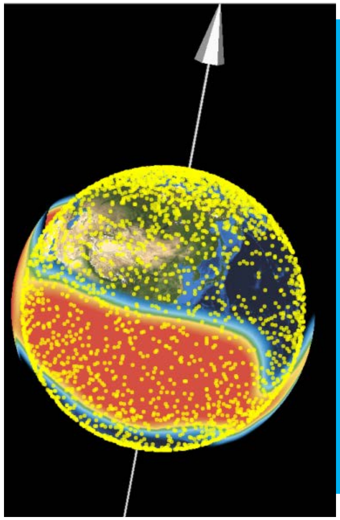
FY-3C/-3D GNOS mission

Product Application (Climate Monitoring)

Level 3 Product and Climate Monitoring

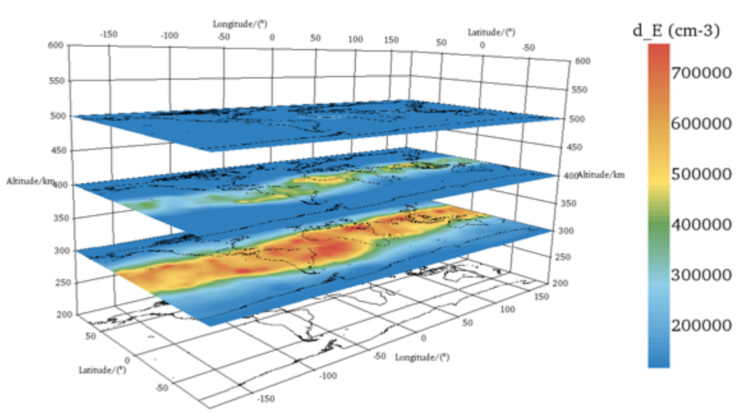
Three-dimensional slice of electron density data (FY3C GNOS 2014.12.01-12.31)



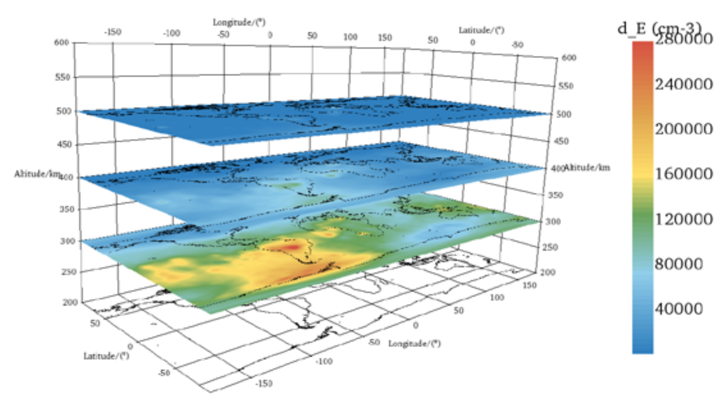


Three-dimensional distribution of electron density data (FY3C GNOS 2014.12.01-12.31)

FY3D GNOS 2018年10月 电离层电子密度数据切片（白天）



FY3D GNOS 2018年10月 电离层电子密度数据切片（夜晚）



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FY-3C/-3D GNOS mission

Product Application (Ionospheric Climatology)

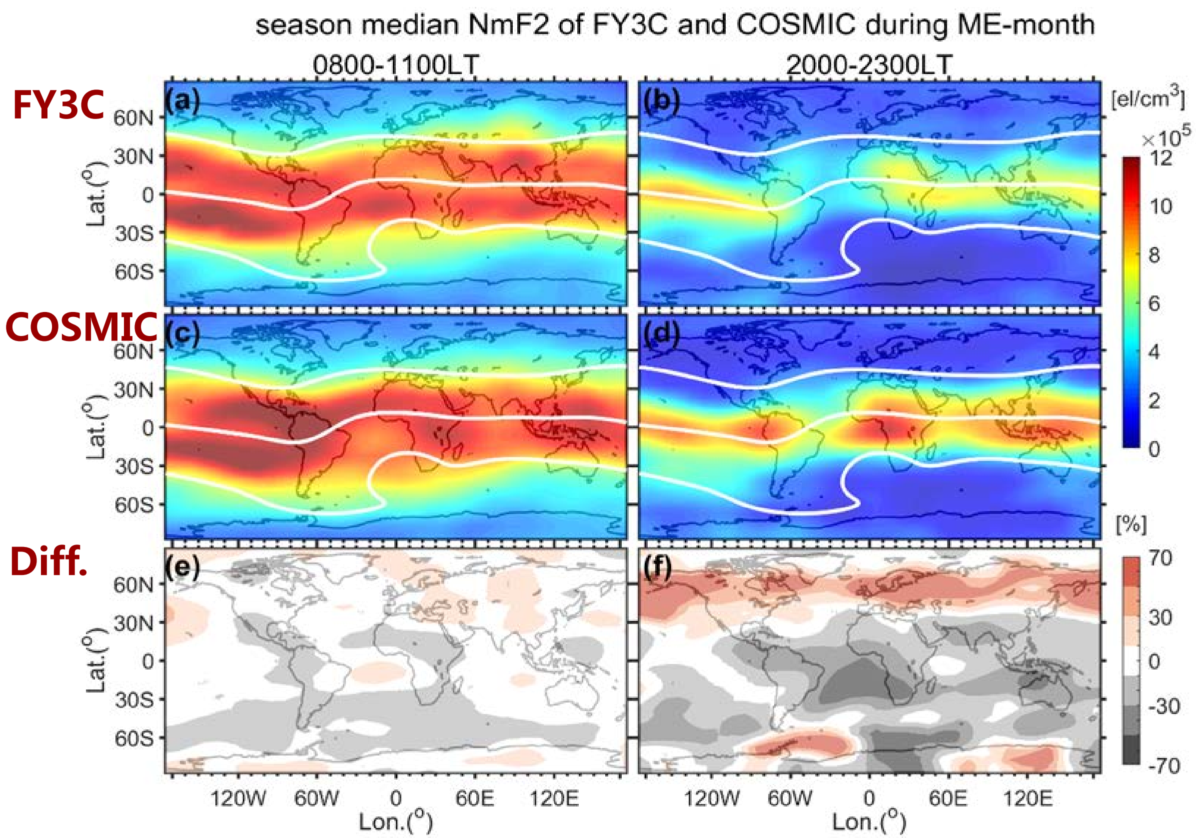
NmF2

ME-month
(±45 days to March equinox)

In ME-month, FY3C/GNOS and COSMIC both show Equatorial Ionospere Anomaly (EIA) (Berkner et al., 1936) and peak longitude structures (Potula et al., 2011), and the peak structures of COSMIC NmF2 are more noticeable than that of FY3C/GNOS.

The discrepancies increase at nighttime, NmF2 of FY3C/GNOS are higher than those of COSMIC in mid-high latitudes but lower in low latitudes.

NmF2 morphology observed by FY3C/GNOS and COSMIC



Bai W.H., Tan G.Y., Sun Y.Q., et al., Comparison and validation of the ionospheric climatological morphology of FY3C/GNOS with COSMIC. Remote Sensing, 2019(under review)

FY-3C/-3D GNOS mission

Product Application (Ionospheric Climatology)

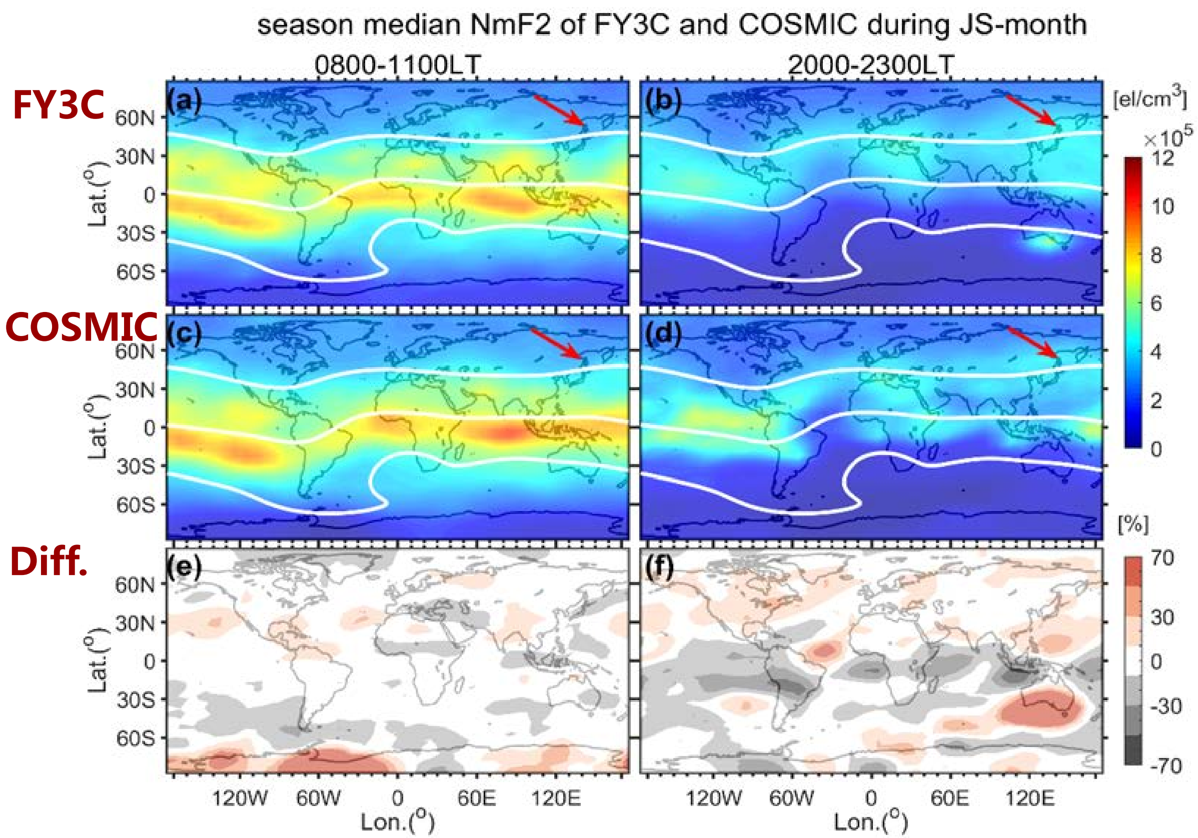
NmF2

JS-month
(±45 days to June solstice)

Daytime NmF2 measured by FY3C/GNOS and COSMIC in winter are higher than those in summer , this behavior of the ionosphere is the winter anomaly(Duncan 1969).

The NmF2 nighttime enhancement can be seen in mid-latitude(around 60° dip) longitude section in northern summer ionosphere, where the magnetic equator shifts farthest toward the geographic pole, this is the general WSA(Weddell Sea Anomaly), which is consistent with work of Lin et al(2009).

NmF2 morphology observed by FY3C/GNOS and COSMIC



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FY-3C/-3D GNOS mission

Product Application (Ionospheric Climatology)

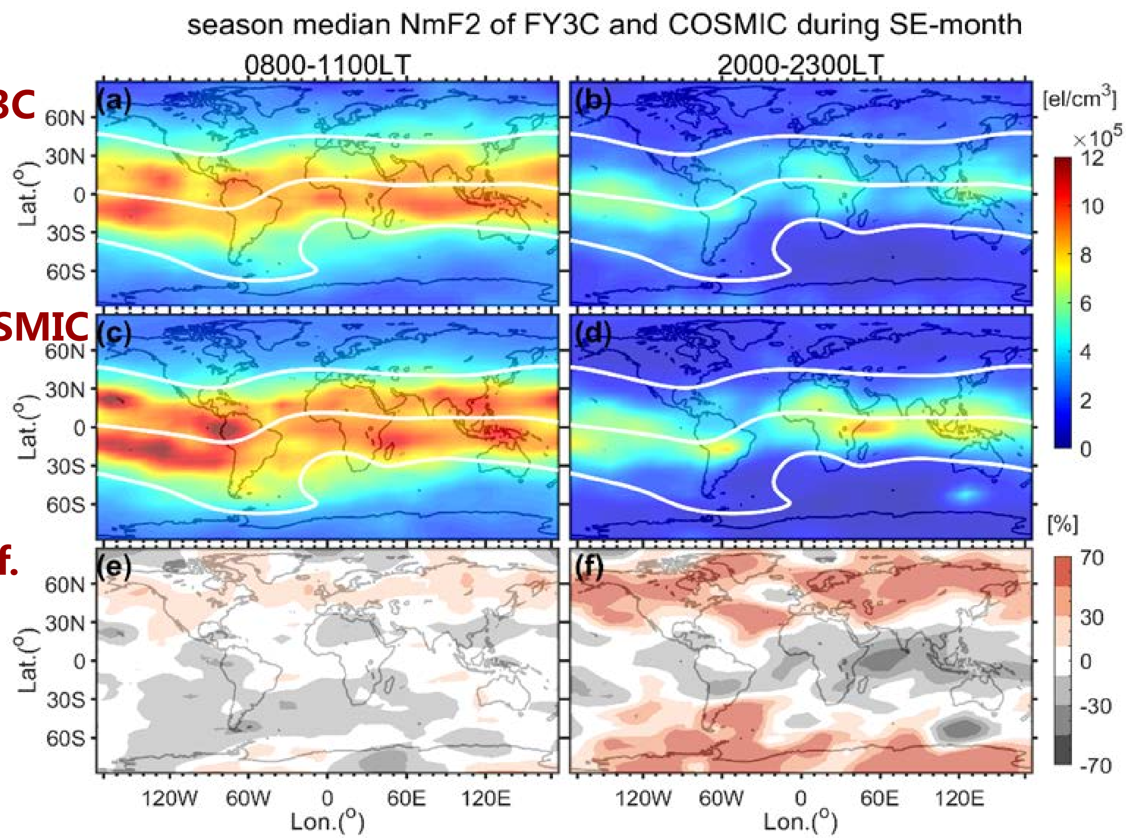
NmF2

SE-month
(±45 days to Sept. equinox)

The season pattern of NmF2 in SE-month are largely close to ME-month, but in lower magnitude.

At daytime, NmF2 observed by FY3C/GNOS and COSMIC during ME-month have a more continuous EIA than that in SE-month, at nighttime, NmF2 during ME-month have more evident peak structures, the stronger NmF2 in ME-month than in SE-month is known as equinoctial asymmetry(Balan et al., 2000).

NmF2 morphology observed by FY3C/GNOS and COSMIC



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FY-3C/-3D GNOS mission

Product Application (Ionospheric Climatology)

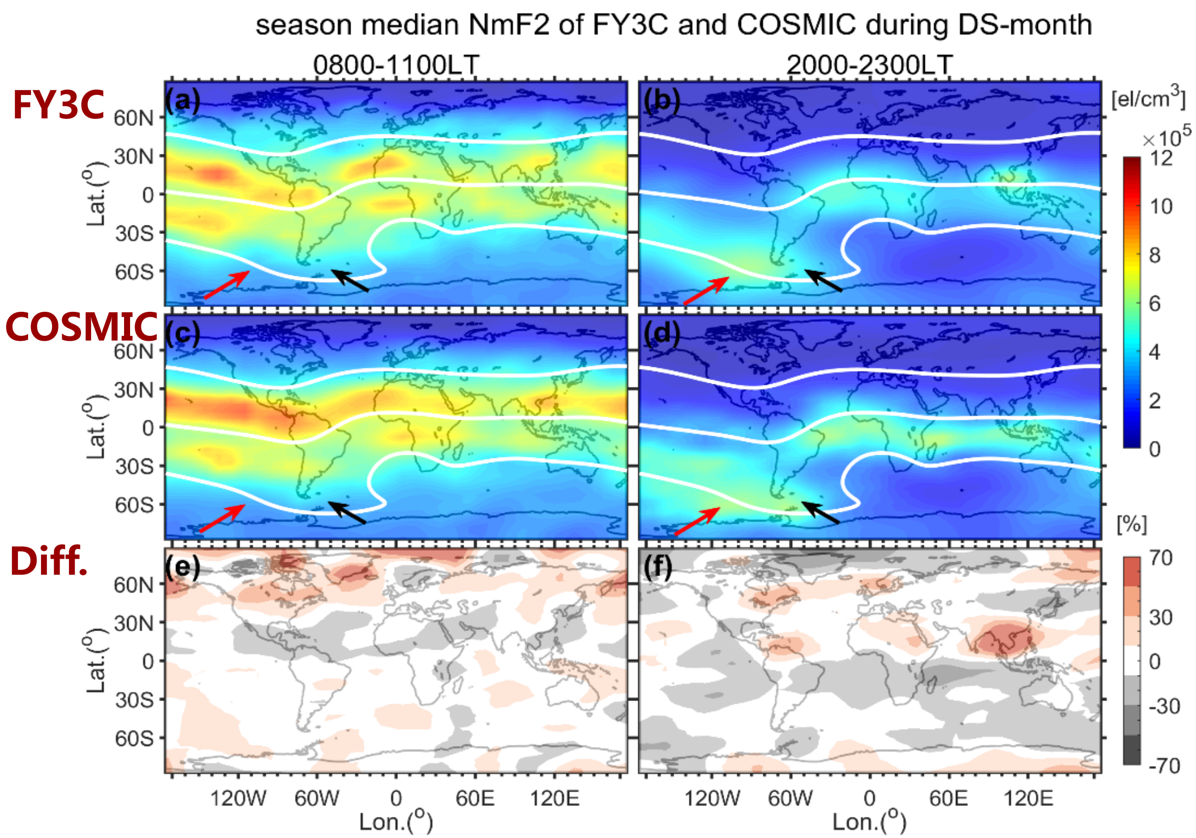
NmF2

DS-month
(±45 days to Dec. solstice)

In DS-month, winter anomaly is also presented, which means that the daytime NmF2 measured by FY3C/GNOS and COSMIC in winter(north hemisphere) are higher than those in summer (south hemisphere) .

FY3C/GNOS and COSMIC both show general WSA (NmF2 nighttime enhancement in about -60º dip) and special WSA (NmF2 nighttime enhancement in Weddell sea area) (Penndorf, 1965), Horvath(2003,2006) also observed the TEC enhancement in southeast Pacific Ocean during 22LT to 24 LT.

NmF2 morphology observed by FY3C/GNOS and COSMIC



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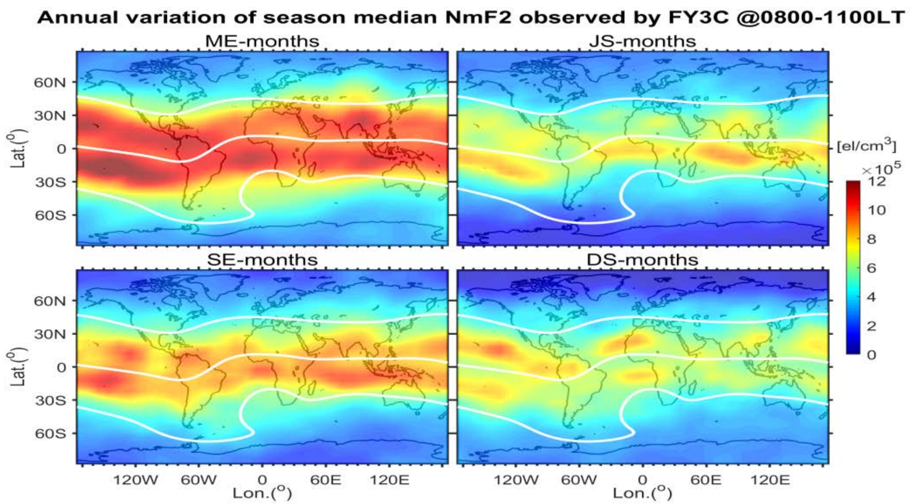
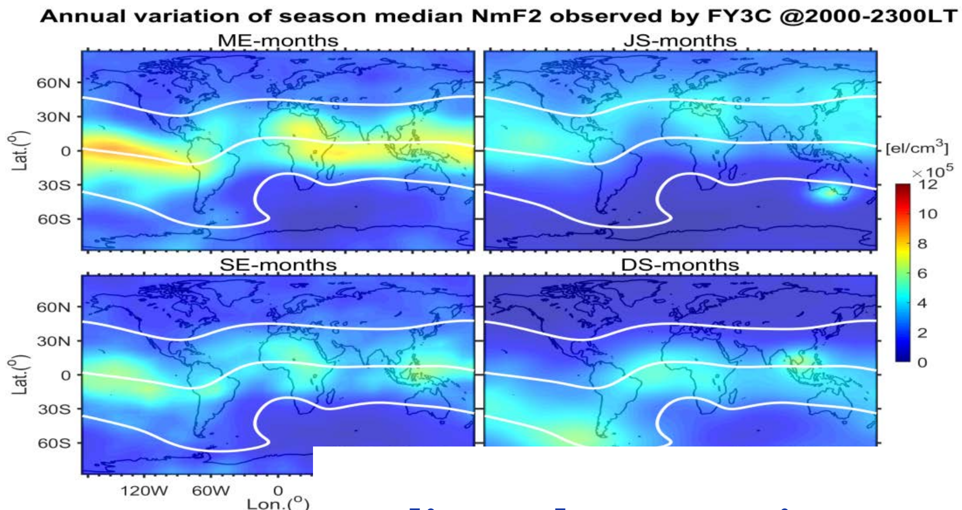
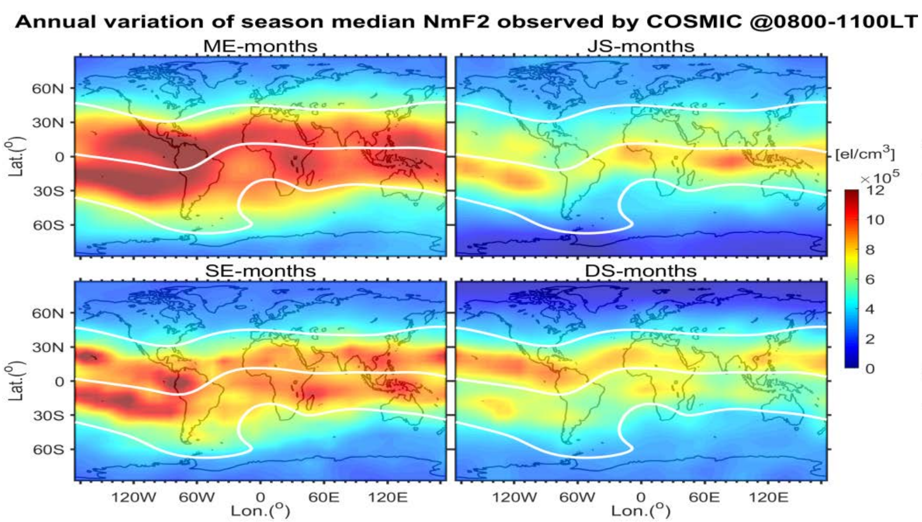
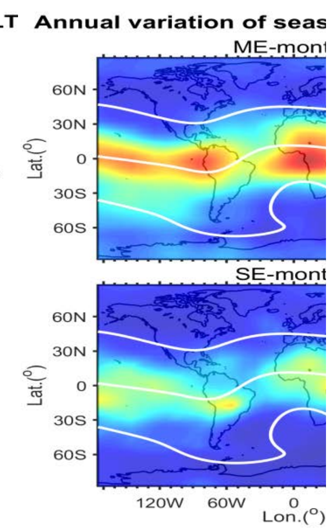
FY-3C/-3D GNOS mission

Product Application (Ionospheric Climatology)









Climatology Consistency

- ✓ Equatorial ionosphere Anomaly(EIA)
- ✓ Semiannual anomaly
- ✓ Winter anomaly
- ✓ Weddell Sea anomaly (WSA)
- ✓ Equinoctial asymmetry

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GNOS II and following missions

GNOS Ⅱ is the upgraded version of FY3 C satellite and D satellite’s GNOS Ⅰ, and possesses both GNSS occultation and reflection functions, and can be used to monitor the ionosphere, atmosphere and Earth surface .It will be firstly launched into space by FY3 E satellite in 2020 as scheduled. After FY3 E satellite, FY3 F/G/R satellite will carry GNOS Ⅱ into space as scheduled.

Primary GNSS-R product:

Ocean surface wind speed.

Main characters:

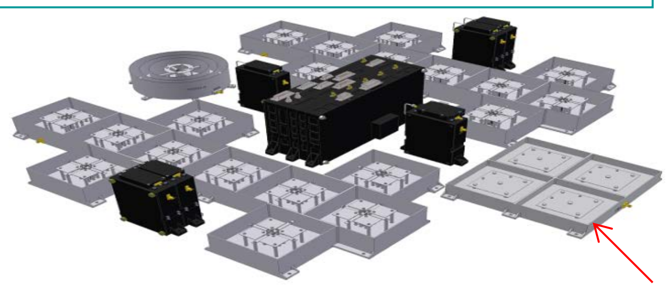
✓Provide both BDS-R and GPS-R products

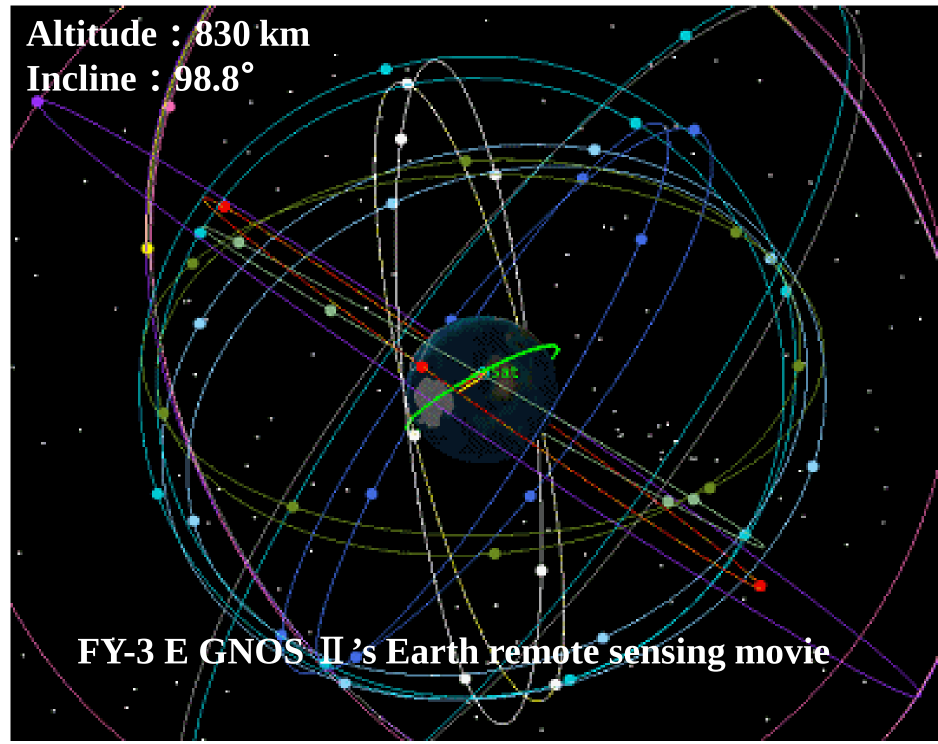
✓Cooperate with a microwave scatterometer fitted on the same satellite.

Orbit:

✓Altitude: 833km

✓Inclination: 98.8°





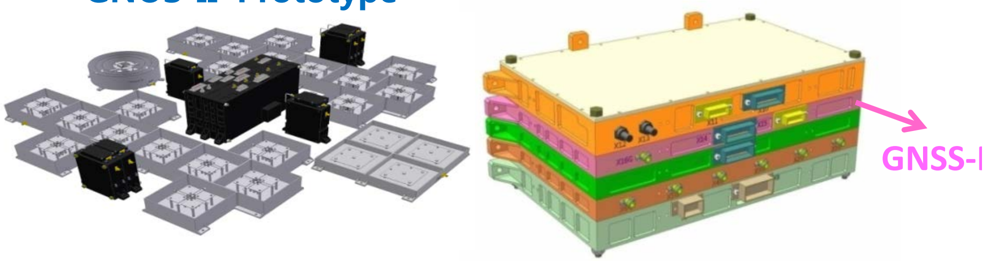
Reflection antenna(Off-pointing to the back ：20°)

GNOS II and following missions

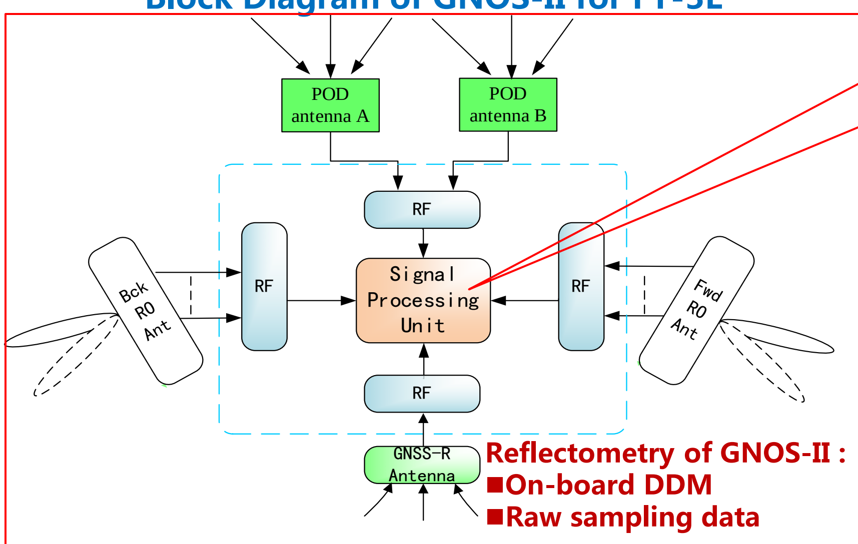
Payload introduction

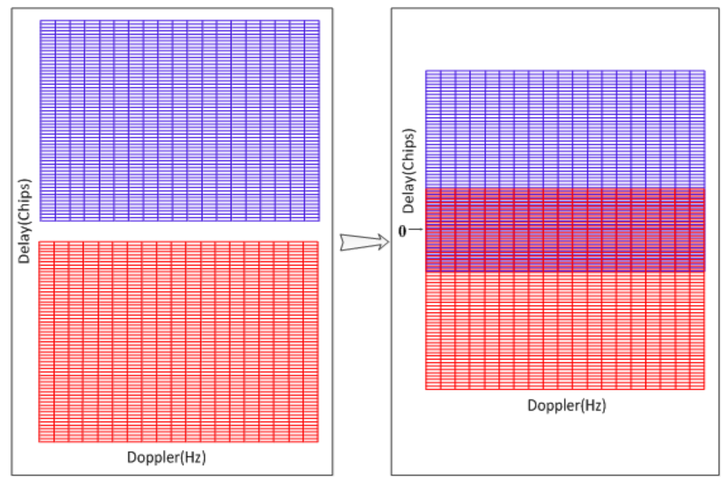
GNOS Ⅱ is the upgraded version of FY-3C /-3D GNOS, and Possesses both GNSS occultation and reflection remote sensing functions.

GNOS-II Prototype



Block Diagram of GNOS-II for FY-3E





GNOS II's Non-uniform DDM Model

Parameters	Values
The length of sampling time	10 s (could be reset)
Operation limit	<50 km 12 hot points (could be reset)

Raw sampling Model

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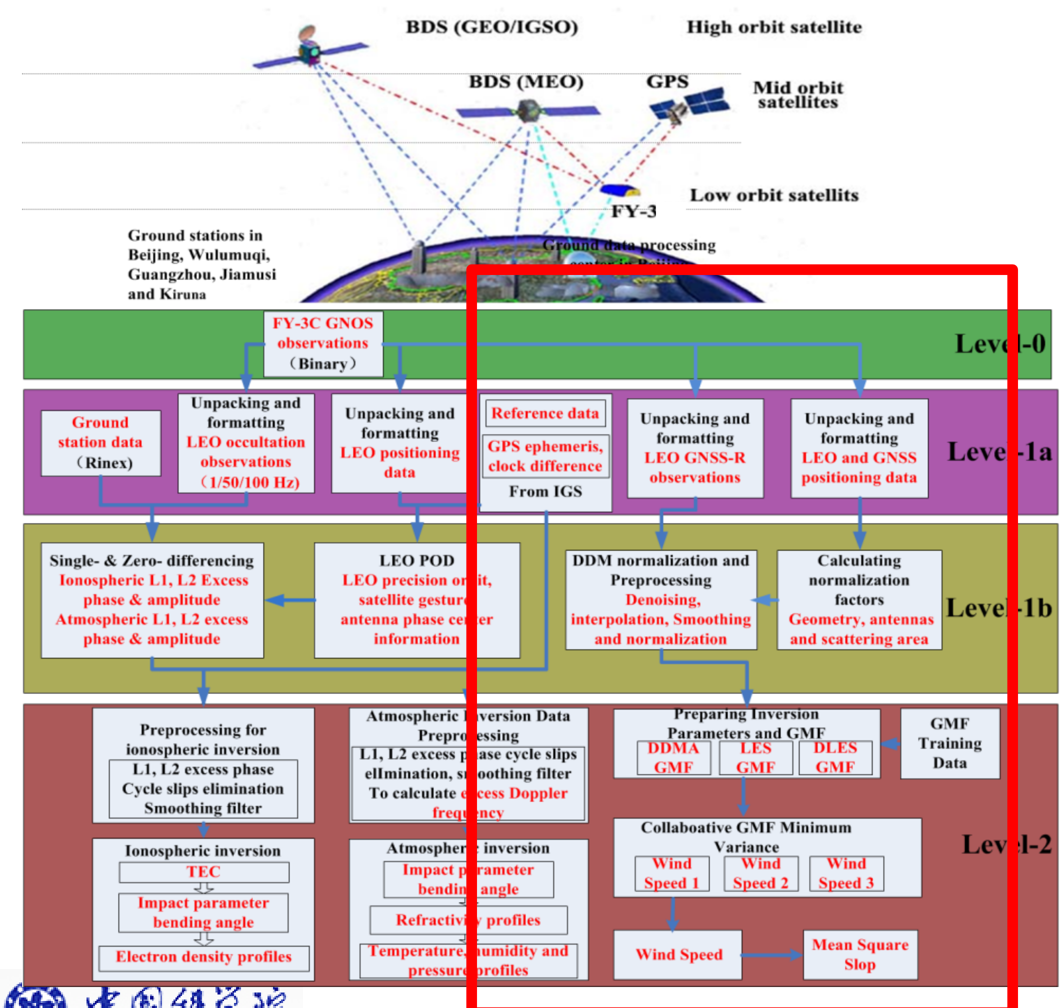
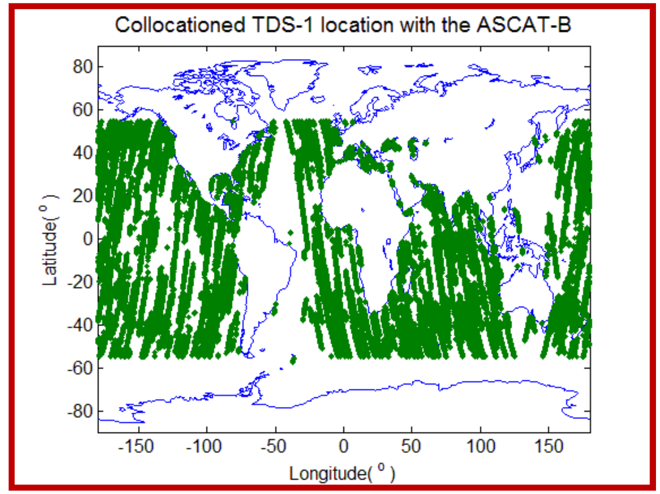
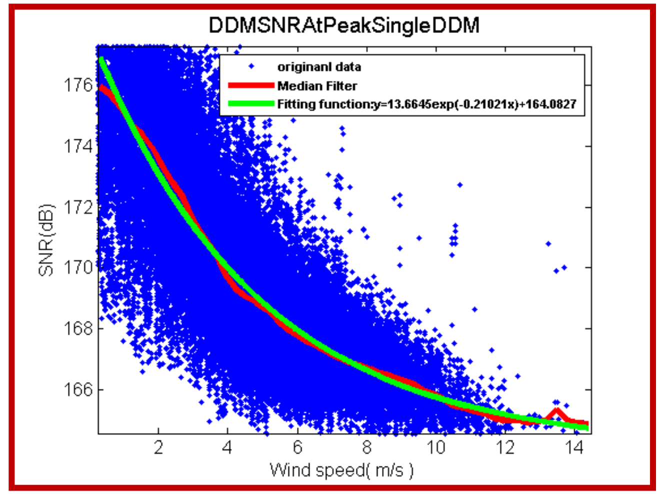
GNOS II and following missions

NSSC

Data processing system







TDS-1 data testing
Wind speed: ~ 2m/s

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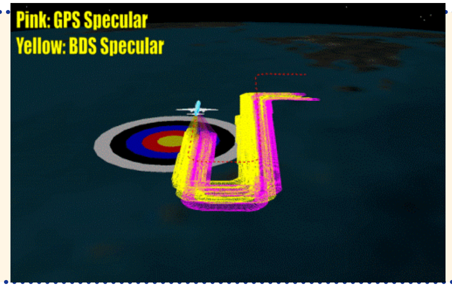
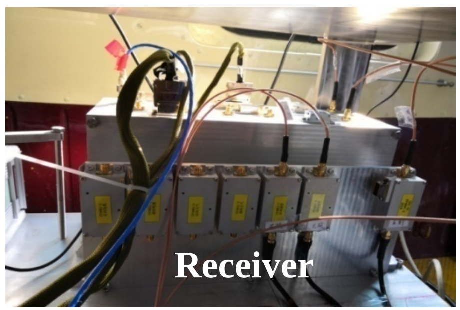
GNOS II and following missions

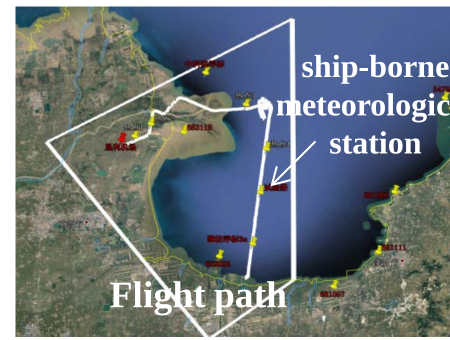
Airborne testing experiment

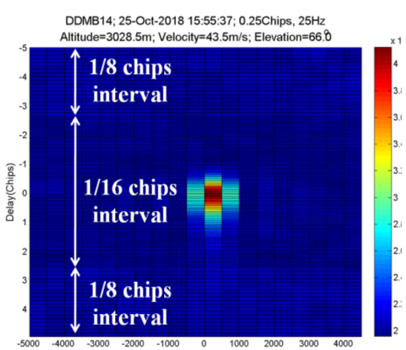
Time: 18- 25 october,2018
Place: Bohai Sea, China
Flight altitude: 3000 m
Flight times: 4



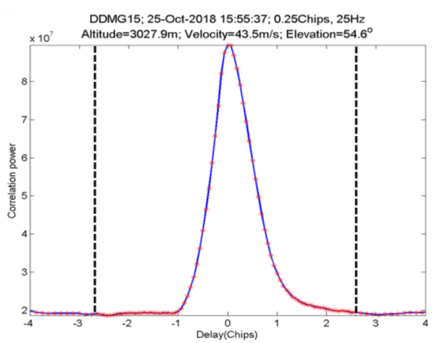
Flight Number	Time	Sea surface wind speed ranges (m/s)
1	Am,18,Oct,2018	5.6～9.3
2	Am,18,Oct,2018	1.9～5.8
3	Am,25,Oct,2018	6.4～9.9
4	Pm,25,Oct,2018	7.1～9.8



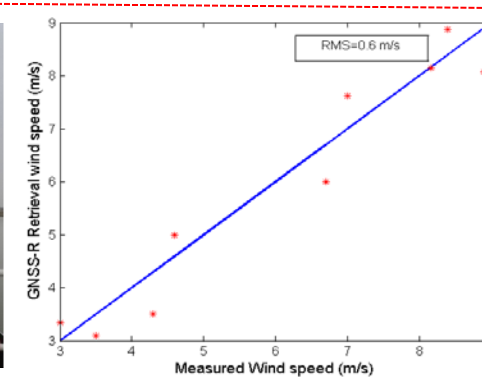




BDS-R DDM



BDS-R DM



Compared with ship-borne meteorological station, Wind speeds' RMS is 0.6 m/s (2m/s ～10m/s)

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Conclusion

- FY-3C GNOS products have been using in weather, climate and space weather fields successfully.
- FY-3D GNOS is at the end of in-orbit testing. The validation results are as well as FY-3C.
- FY-3E with GNOS II is planed to launch in 2020.
- Following FY-3 satellites will carry GNOS II as a key payload…

Look forwards your cooperation…

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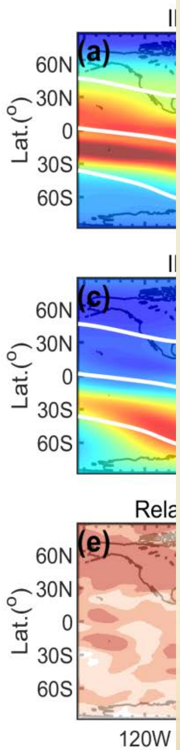
THANKS ALL
Email:bjbwh@163.com
FY-3
COSMIC
Metop

Product Application (Ionospheric Climatology)

season median NmF2 of FY3C&COSMIC and IRI-2016 during DS-month



The global ionospheric climatological characteristics of NmF2 predicted by IRI-2016 are highly consistent with that of NmF2 probed by FY3C&COSMIC like

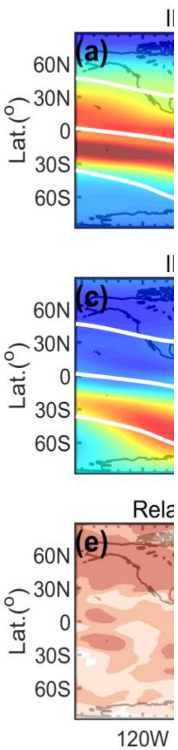
- EIA
- Annual anomaly
- Semiannual anomaly
- WSA

Though exceptions do exist in IRI-2016 like

- absence of the equinoctial asymmetry and the longitude structures of NmF2 in nighttime sector of ME-month.
- large overestimation of NmF2 in SE-month and DS-month.
- Wider and larger WSA in southern summer ionosphere.

Product Application (Ionospheric Climatology)

season median NmF2 of FY3C&COSMIC and IRI-2016 during DS-month



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