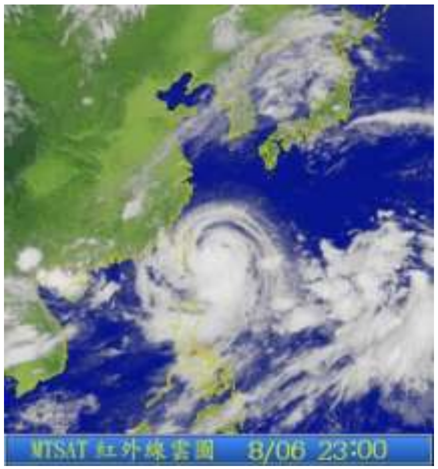
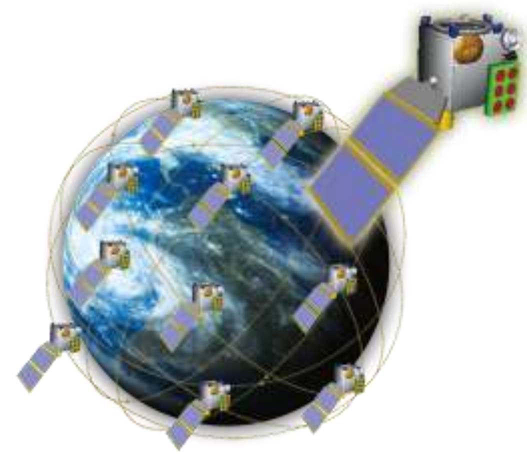
Taiwan's Past, Present, and Future Space Science Program





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jyliu@jupiter.ss.ncu.edu.tw

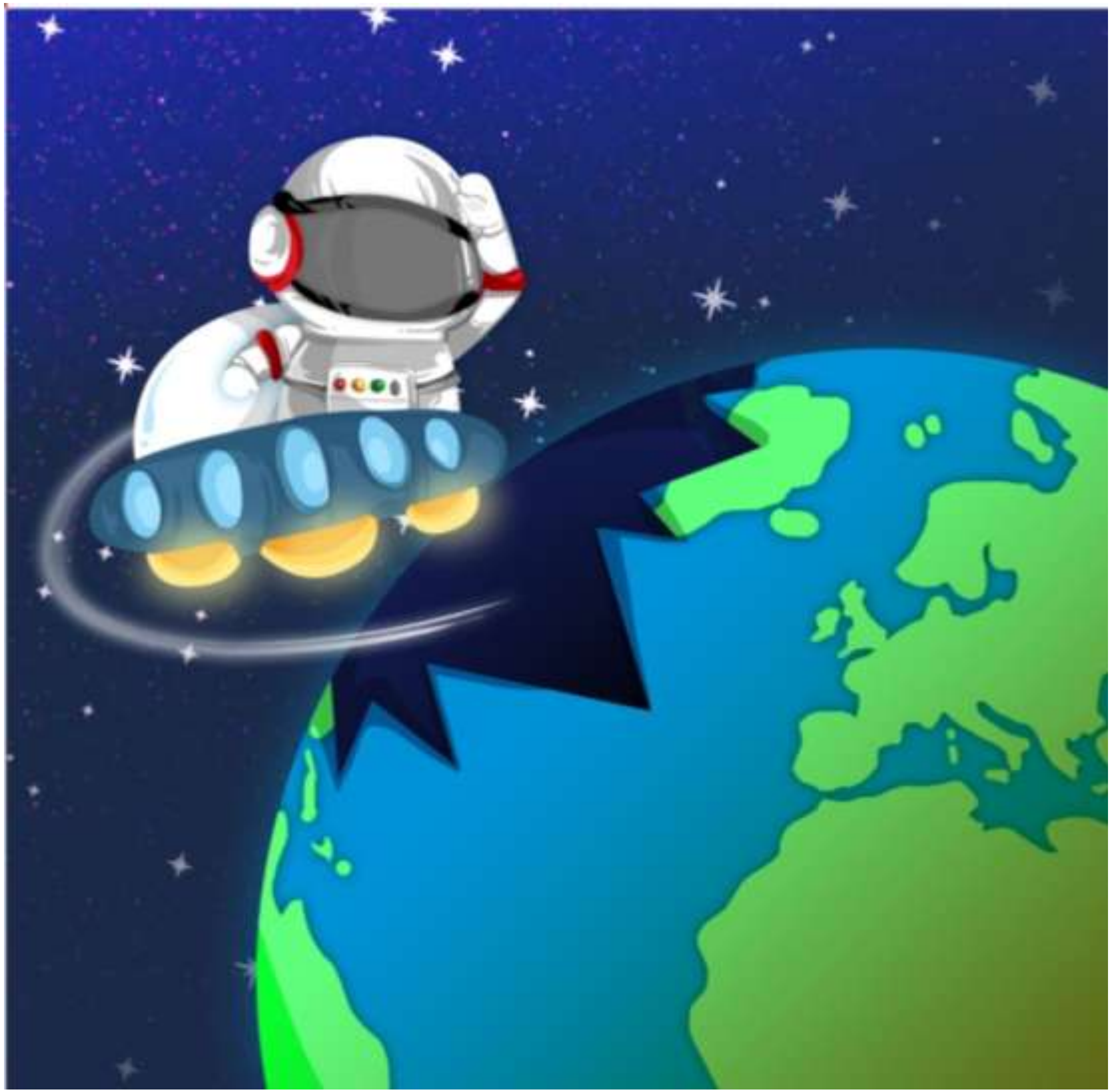
TIGER (Taiwan Ionospheric Group for Education and Research)

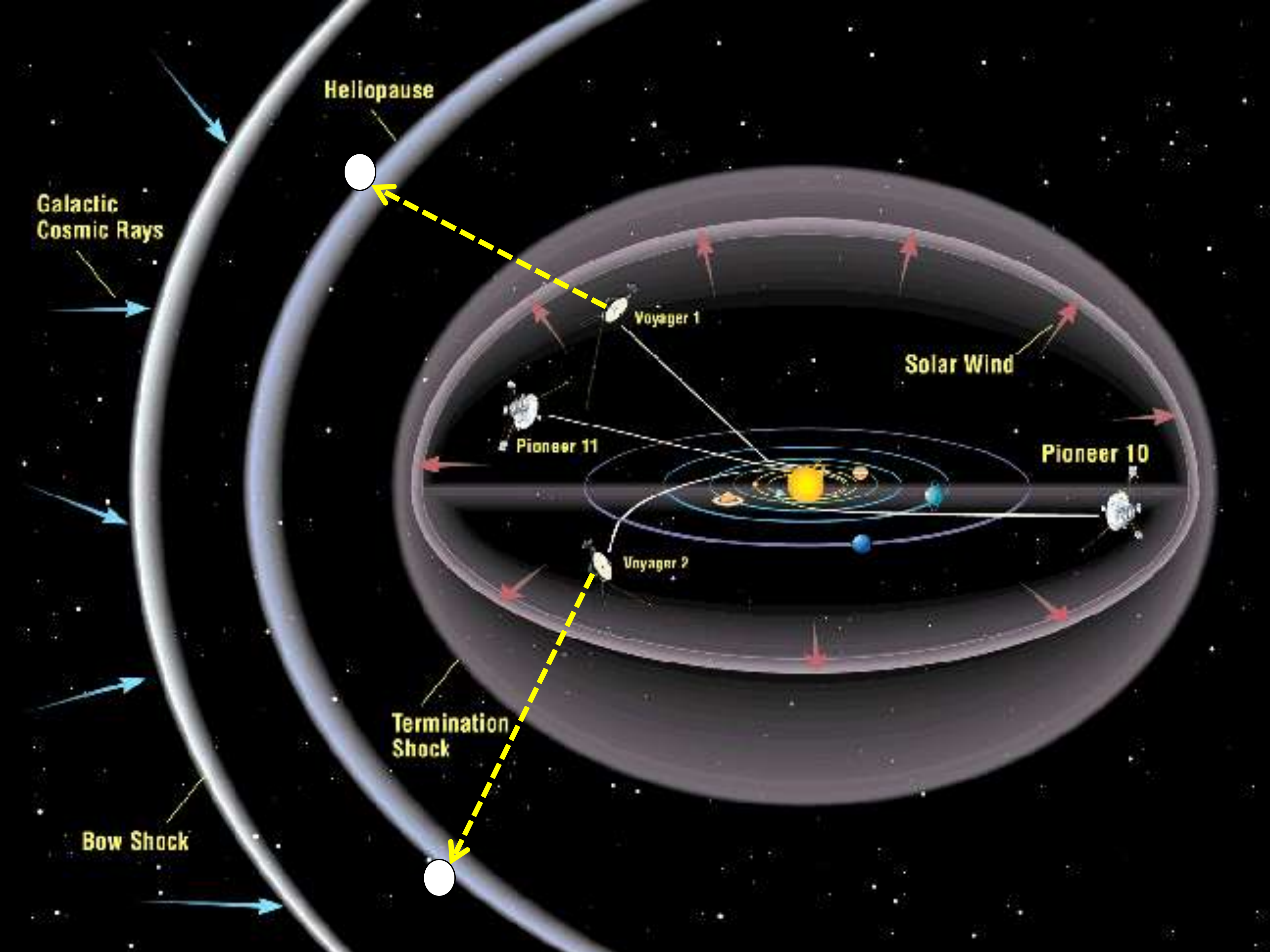
Content

- Space
- Taiwan’s Space Science in past and present
- Weather Forecast
- Ionospheric Weather
- FORMOSAT-5 worldwide Nature Disaster Relief
- FORMOSAT-7/COSMIC-2
- Conclusion
- International collaboration

Space？

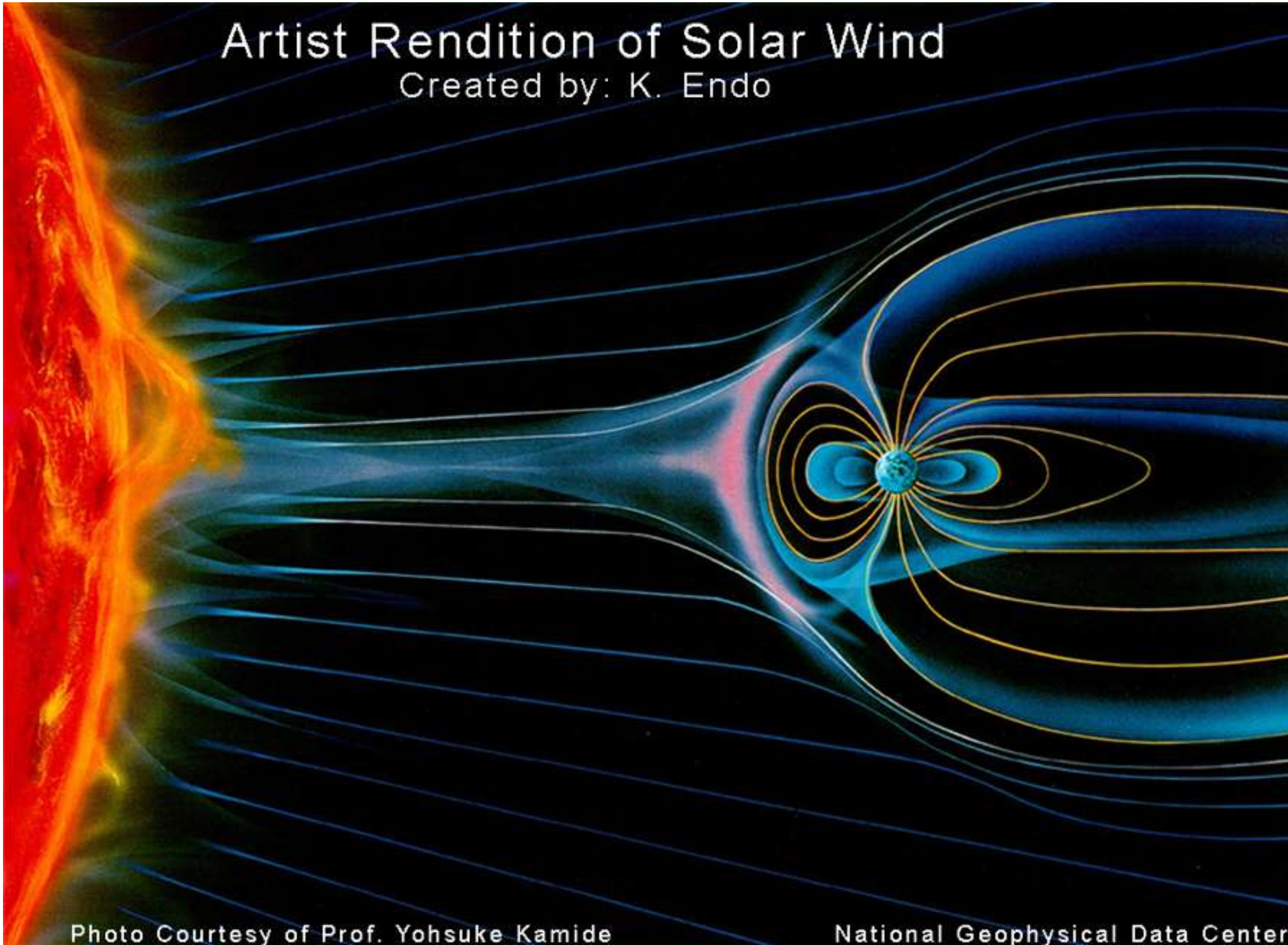
The region can be reached by space crafts!

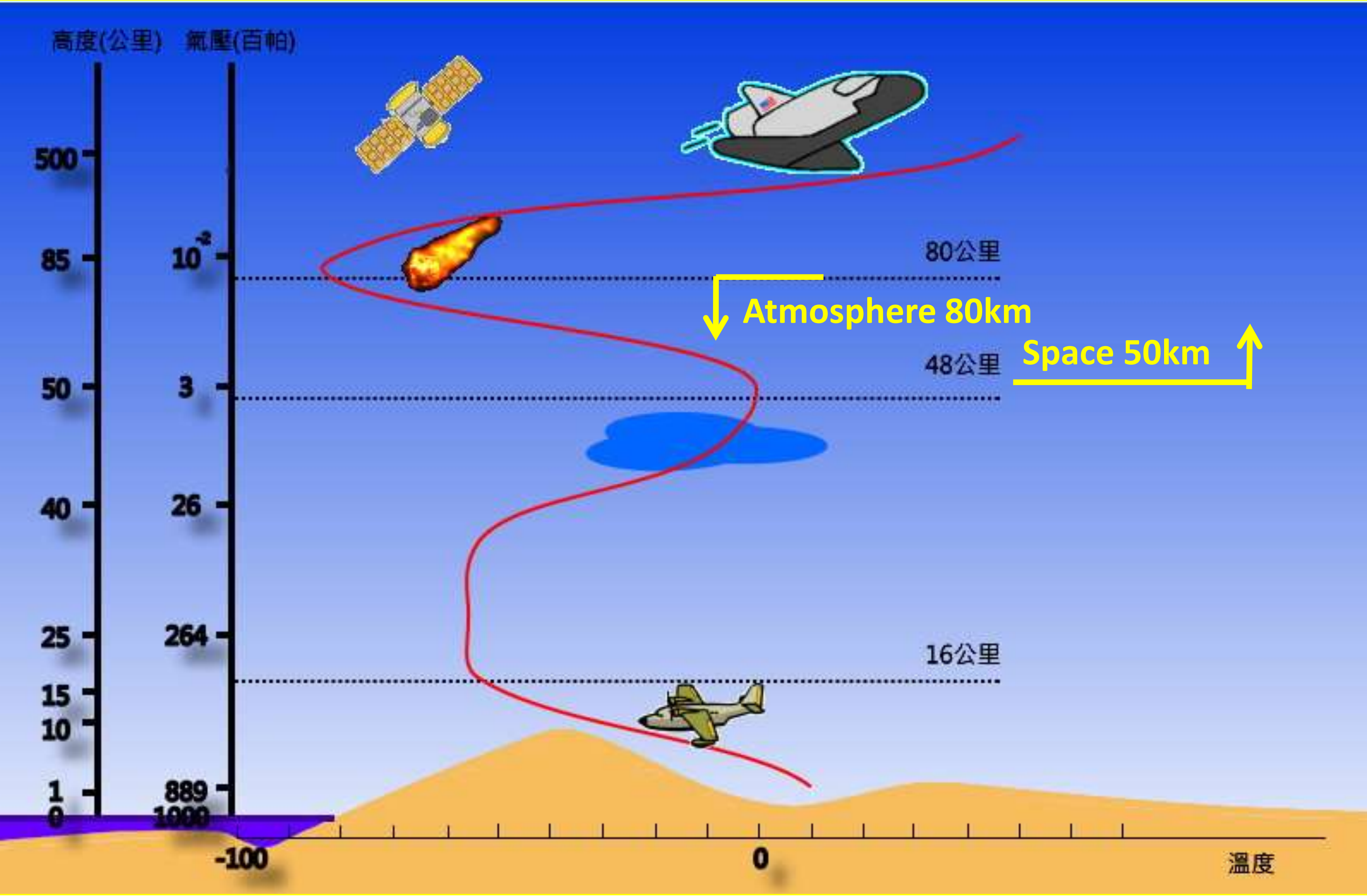



Heliopause
Galactic Cosmic Rays
Voyager 1
Solar Wind
Pioneer 11
Pioneer 10
Voyager 2
Termination Shock
Bow Shock


solarsystem.nasa.gov

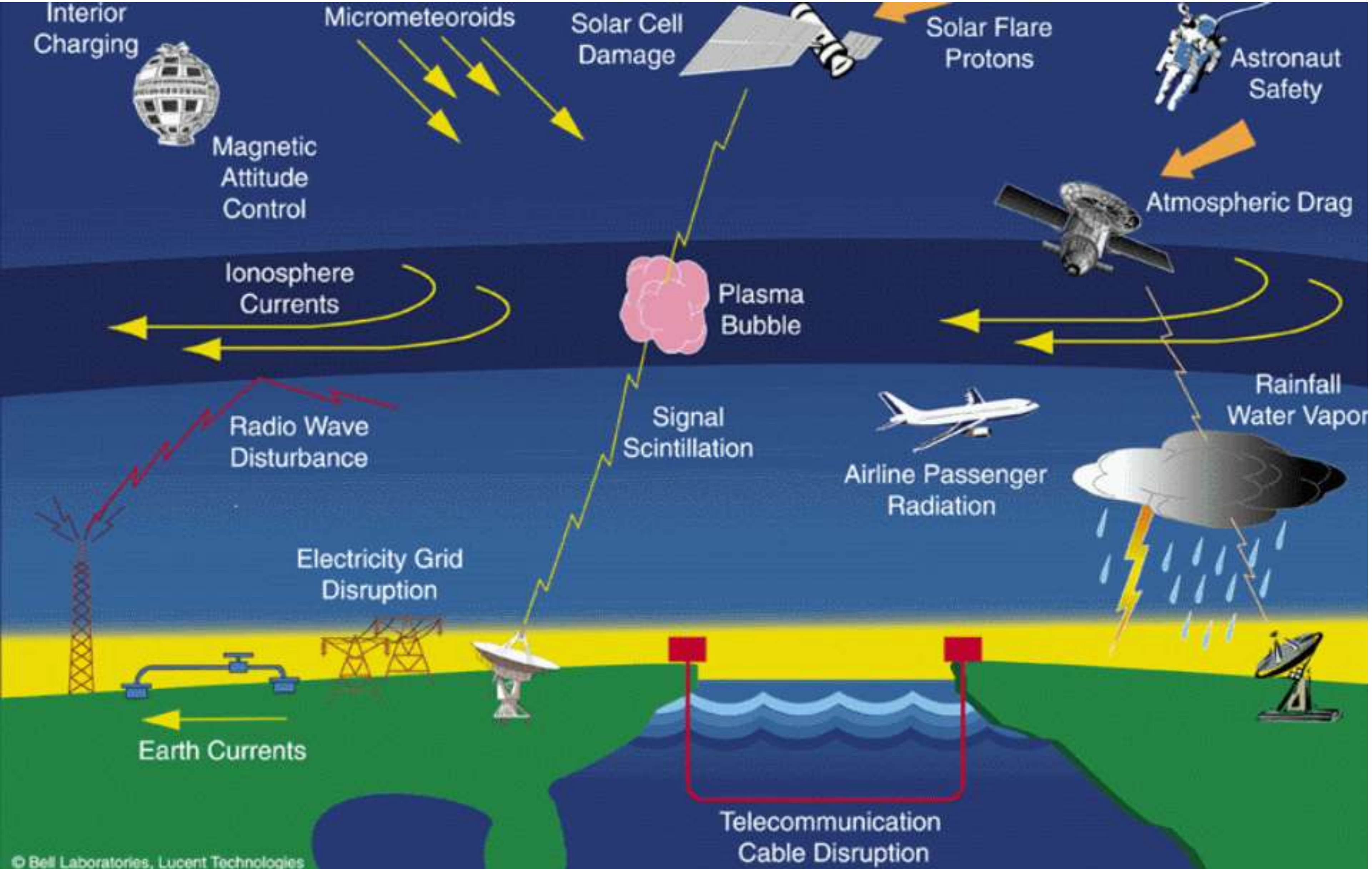
Solar Terrestrial Environment





高度(公里)
氣壓(百帕)
500
85
50
40
25
15
10
1
0
10^-2
3
26
264
889
1000
80公里
48公里
16公里
Atmosphere 80km
Space 50km
-100
0
溫度

Weather and Space Weather



Education and Research of Space Science in past and present

- Space Science Education (1958 -): Under 50, MS 25, and PhD 10 student/year.

(National Central University, ISS 25 professor),
NCKU, other universities/institutes, 10+ professor

- Space Science Research: Solar, Solar Wind, Interplanetary Space, Magnetosphere, Ionosphere, Upper Atmosphere, SMIAL coupling, Space payload, etc.

- Space Science Observation (1950 -): Ionosonde, magnetometer, sunspot, HF Doppler sounding system, total electron content.

(Communication Bureau)

Space Science Education

- Ionospheric Physics
- Magnetospheric Physics
- Radar Science (Chung-Li VHF radar)
- Heliospheric Physics
- Satellite Payload
- MI, AI, LAI, MLT coupling processes
- http://www.ss.ncu.edu.tw/~ssoffice/
- NCKU

Space Science Observations

(The Past, Present, and Future)

- Magnetometer observation: 1965 -
- HF Doppler observation: 1989 -
- GPS TEC observation software (500+): 1994 -
- All Sky Imager: 1997-
- Sounding Rocket
- ROCSAT-1 (FORMOSAT-1): 1999-2004
- FORMOSAT-2/ISUAL: 2004-2016
- FORMOSAT-3/COSMIC: 2006-
- Ionospheric Weather (Data Assimilation): 2012-
- FORMOSAT-5/AIP: 2017
- FORMOSAT-7/TGRO: 2018/2020

Space Science education

IGY 1957-1958

Institute of Geophysics, College of Science
National Central University

Mai-Li Taiwan

Bird's Eye View of Institute of Geophysics, National Central University

Ionosonde observation

NBS C2/C4觀測儀(1966)

Ionosonde observation since 1950

Advanced ionospheric Sounder:
Digisonde Portable Souder and Dynasonde


觀測站全景


觀測天線


觀測站


觀測資料分析

Chung-Li VHF radar

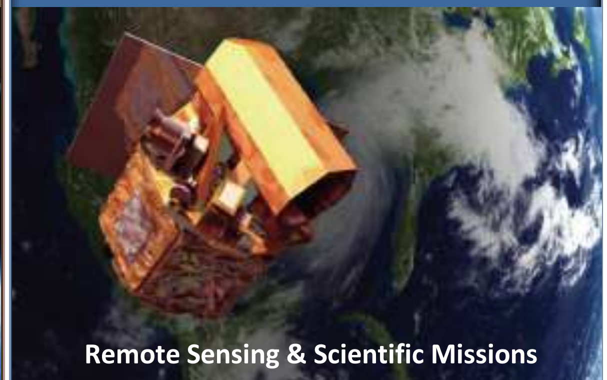
The antenna arrays for the Chung-Li VHF radar on the NCU campus. The radar is operated on 52 MHz with three phase-coherent transmitters, each with a peak power of 40 kW. Each of these modules consists of 64 Yagi antennas, for the atmospheric sounding and titled 32 Yagi antennas, for the ionospheric sounding.

NSPO Satellite Mission Achievements

FORMOSAT-1

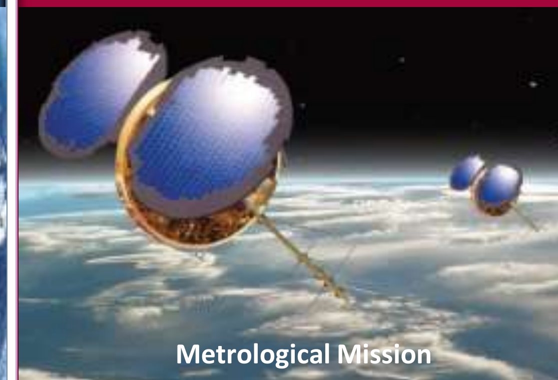
Jan 1999~ June 2004

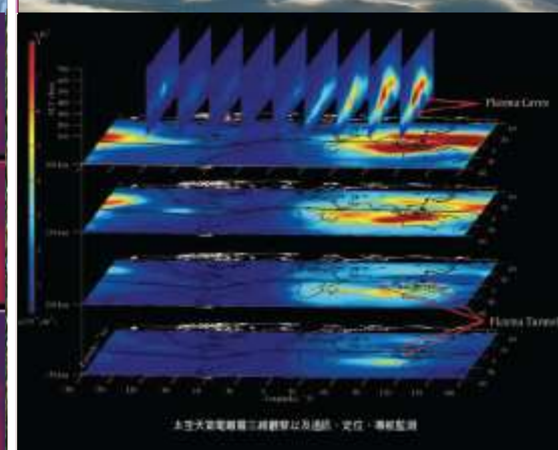
FORMOSAT-2



May 2004 ~ July 2016

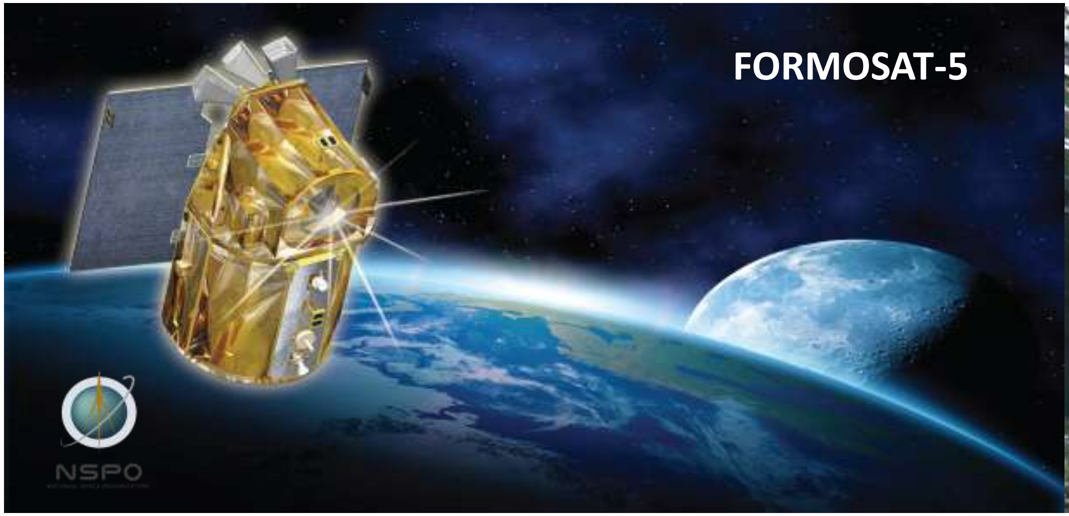
FORMOSAT-3

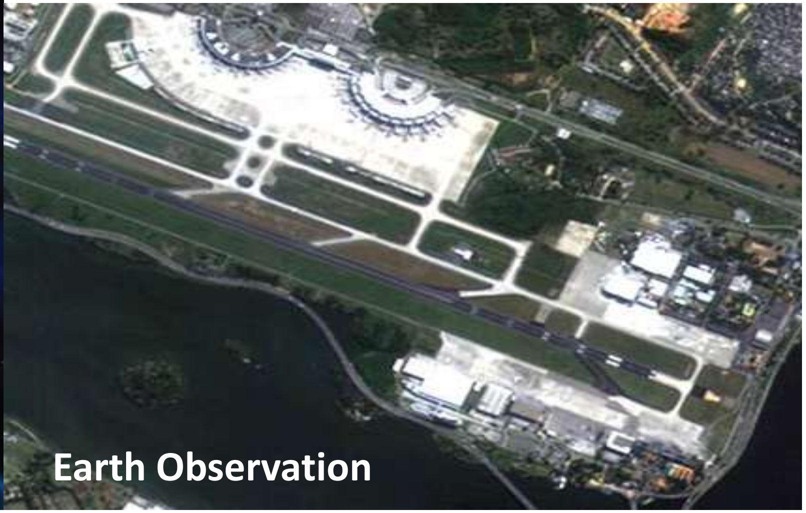


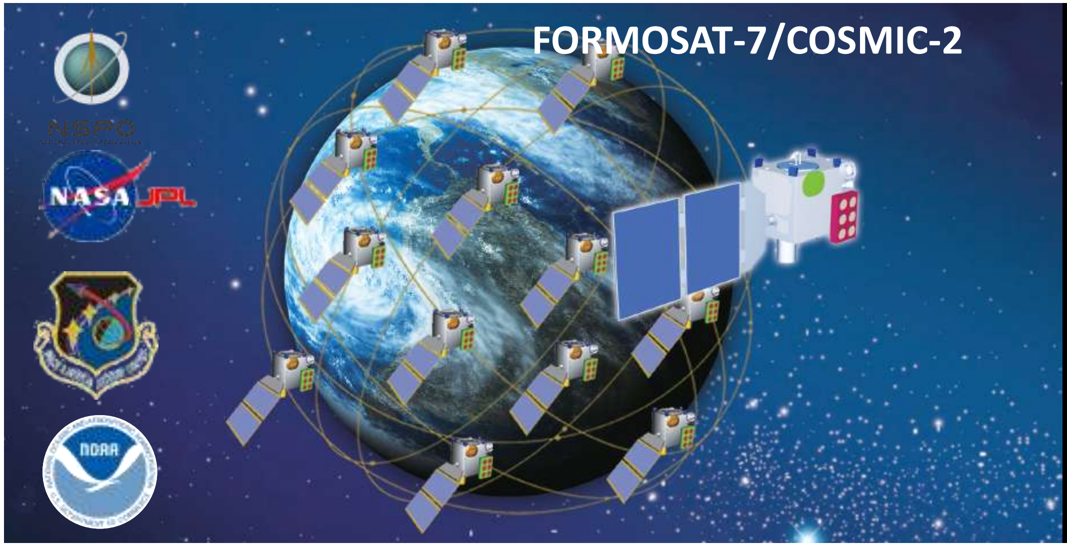


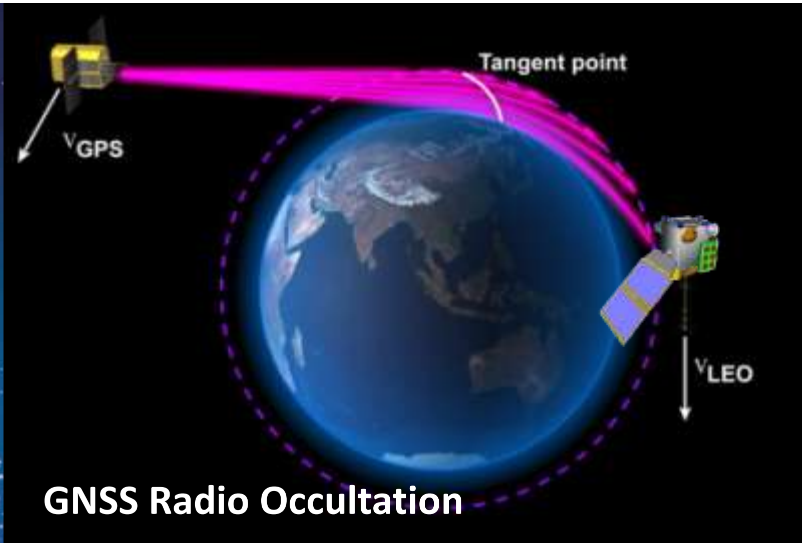
April 2006 ~ Present

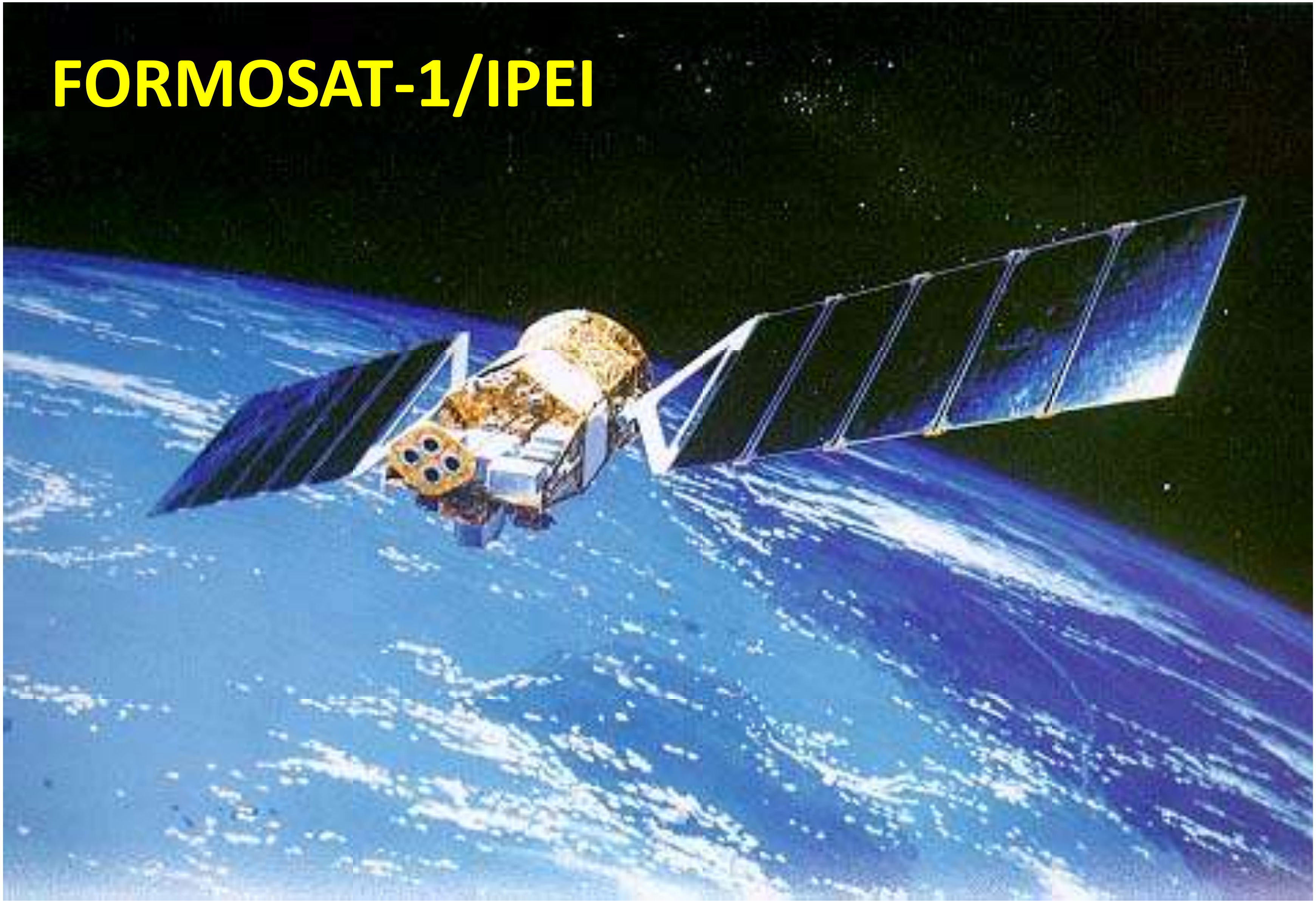
NSPO On-going Programs





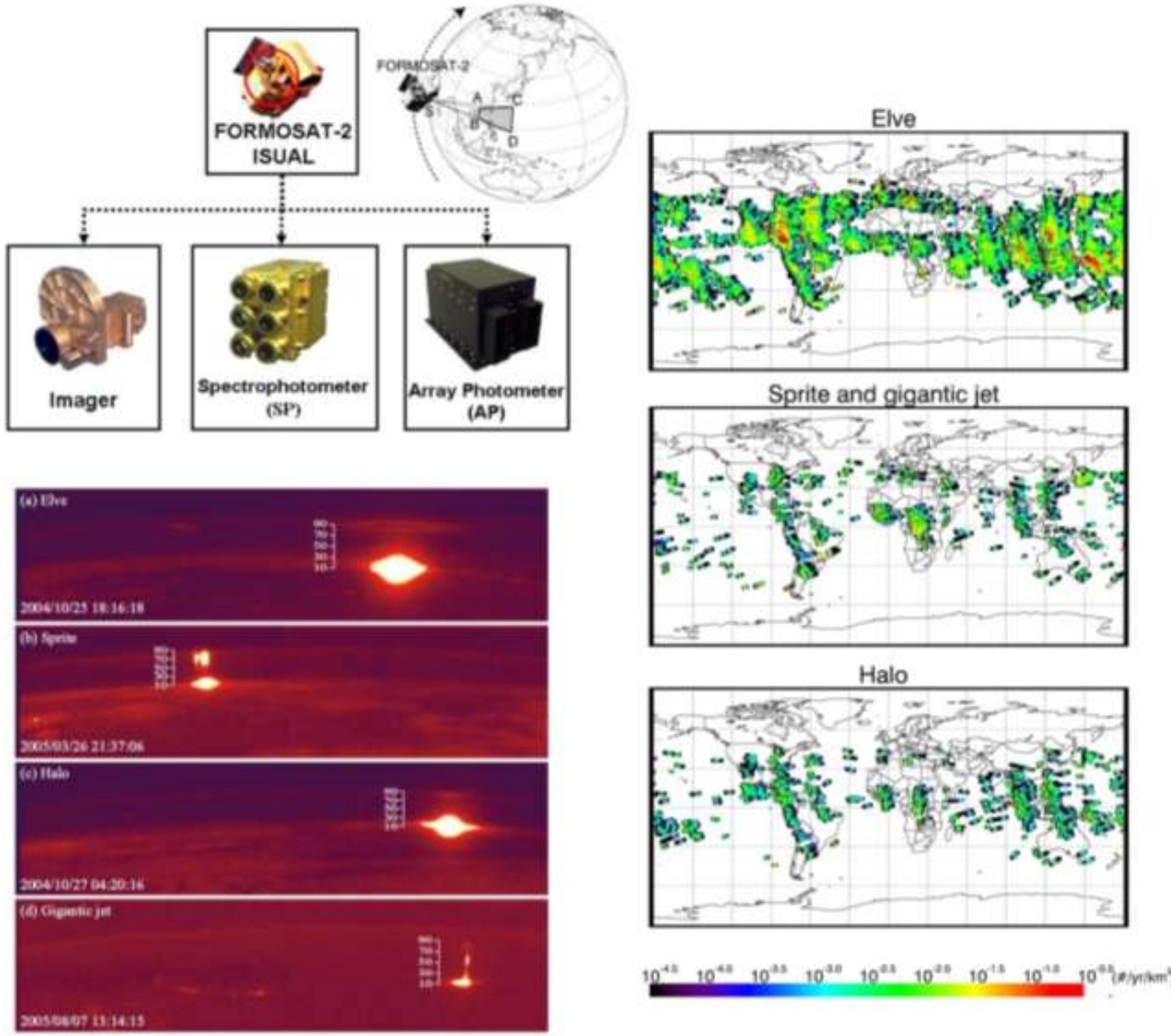






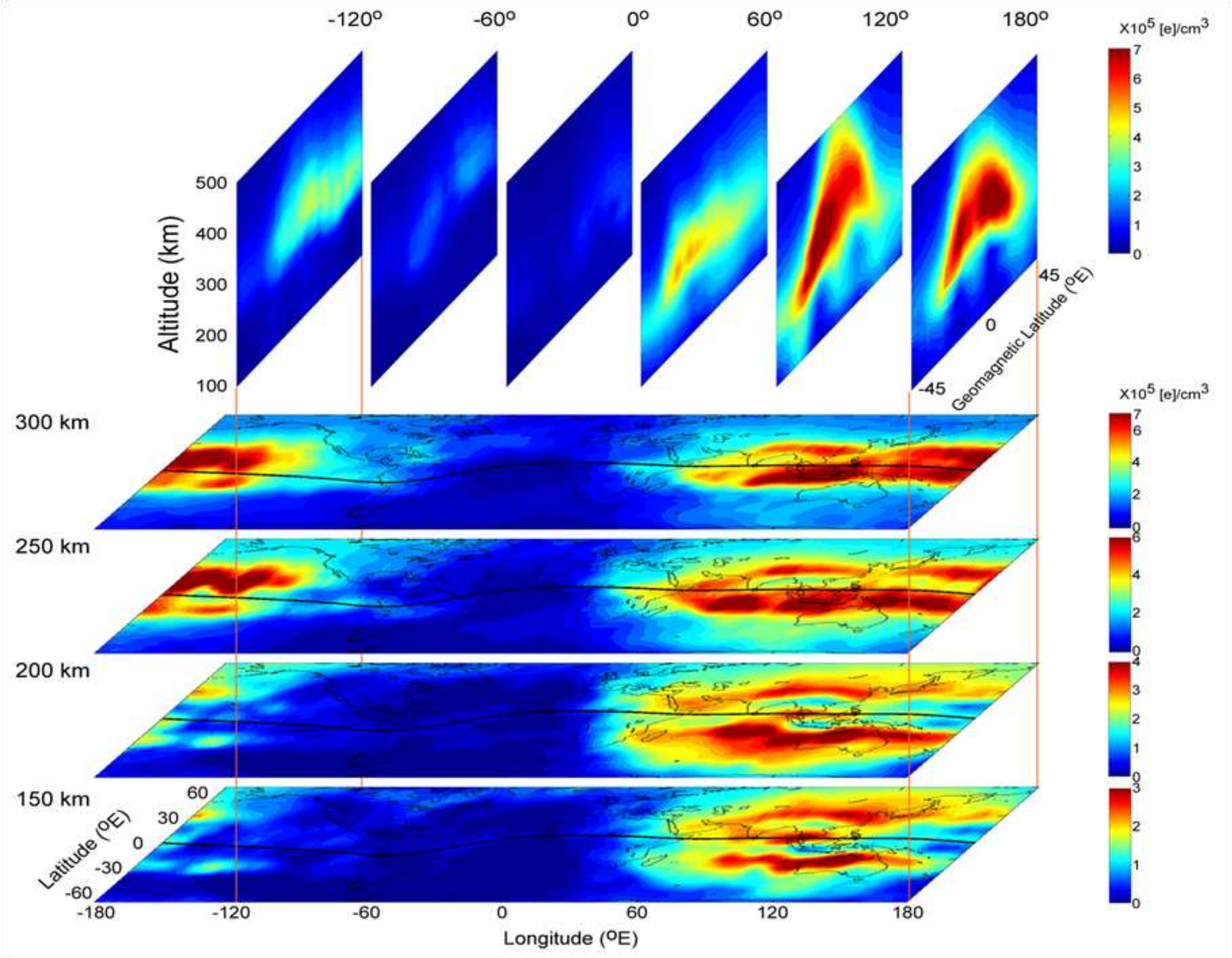
The image of a flying simulation of FORMOSAT-1 and IPEI. IPEI is located at the front panel with a shape of 4 cups on the diamond. 1999/1-2004/4.

FORMOSAT-2/ISUAL



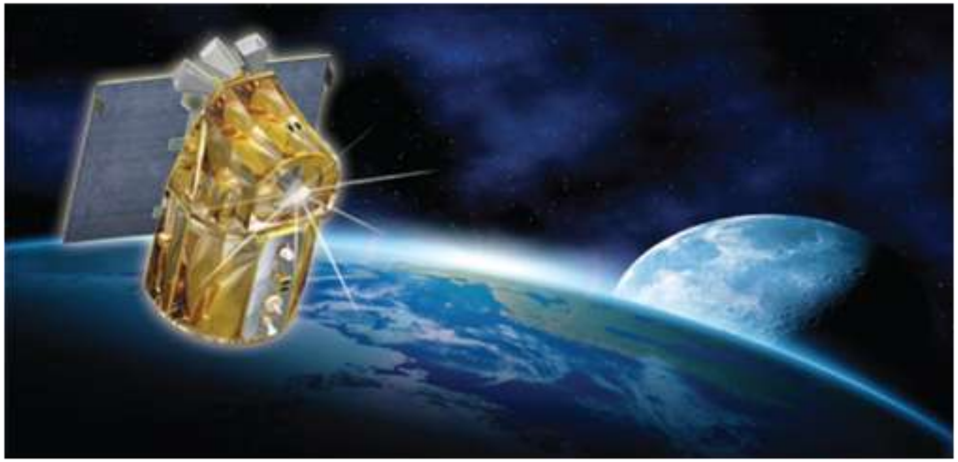
The scientific payload ISUAL onboard FORMOSAT-2 satellite. The observed images and global distributions of Elve, Sprite, Halo, and Gigantic jet. 2004/1-2016/8

FORMOSAT-3/RO



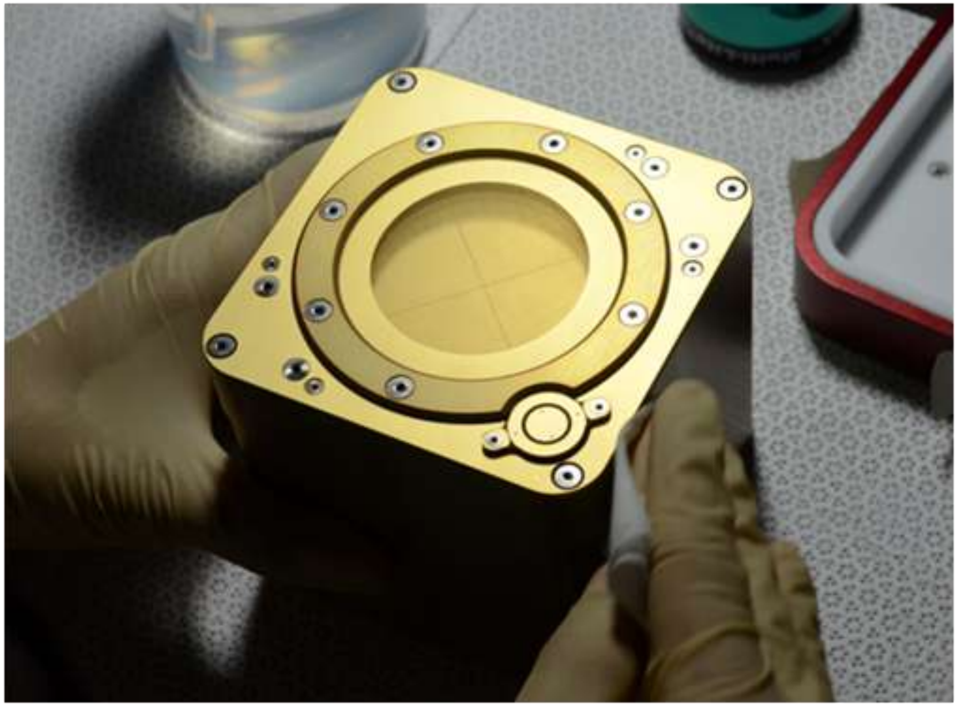
Three-dimensional electron density structure observed by the F3/C at 0600 UT during April-June 2008.
The plasma caves locate right under the EIA crests. 2006/4-

FORMOSAT-5/AIP

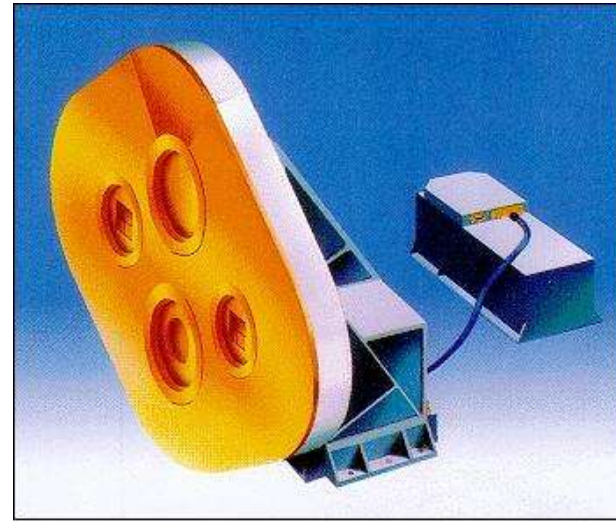


Ionospheric Space Weather

Ionospheric Earthquake Precursor Monitoring



The image of a flying simulation of FORMOSAT-5 and AIP. FORMOSAT-5 (upper panel) and AIP (lower panel).



Ion density: Ni

Ion Temperature: Ti

Perpendicular velocity: V_M

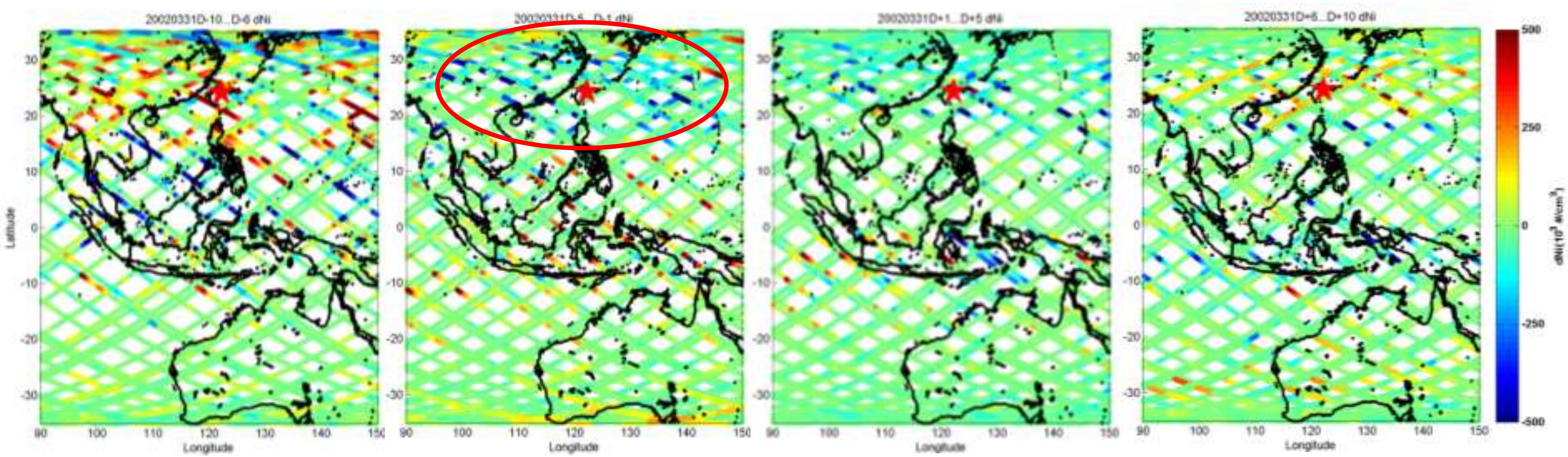
Parallel velocity: $V_{||}$

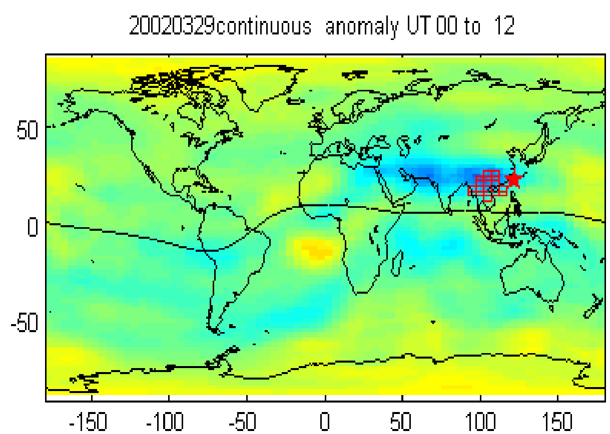
Ram direction velocity: V_Z

FORMOSAT-1 is a low-earth-orbit scientific experimental satellite during 1999/01/27-2004/06/17. After launched into an altitude of 600 km with 35 degree inclination, it circulates around the Earth every 97 minutes, transmitting collected data to Taiwan's receiving stations approximately six times a day. The major mission of FORMOSAT-1 is to measure the ion temperature (Ti), total ion concentration (Ni), and ionospheric ram/transverse velocity by IPEI (ionospheric Plasma and Electrodynamics Instrument).

ROCSAT/IPEI detects the ion density decreases 1-5 days before the 31 March 2002 M6.8 earthquake.

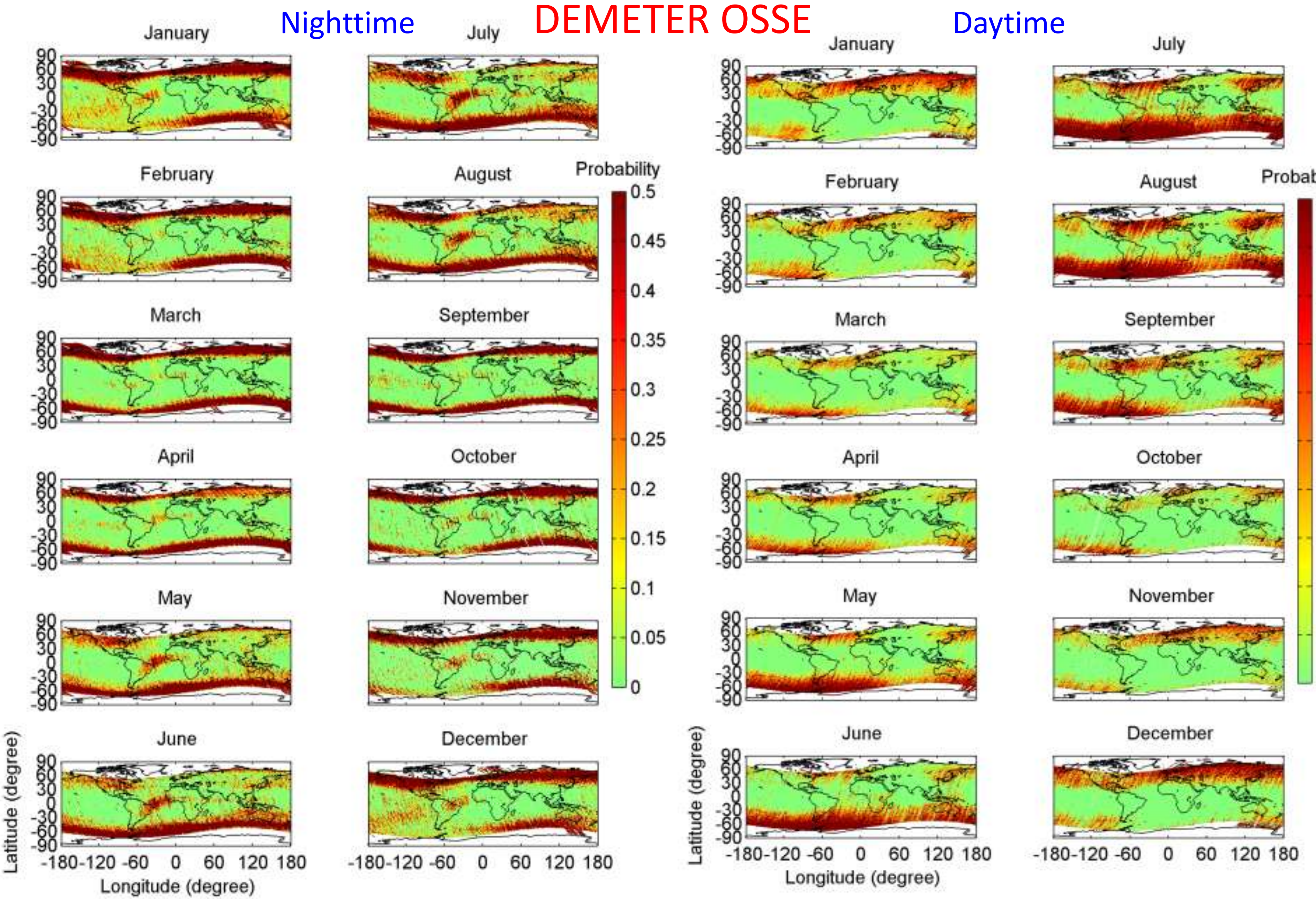
D-10…D-6 D-5…D-1 D+1…D+5 D+6…D+10

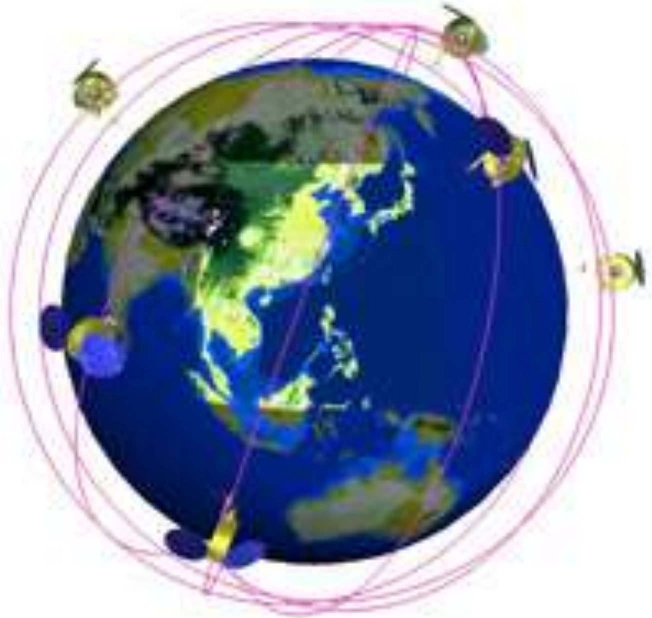




GIM TEC significantly decrease day 2 before the 331 earthquake.

Space weather of the ionospheric irregularity





FORMOSAT-3/COSMIC

Global Real-time
Weather (Meteorology)
Space Weather (Ionosphere)
Observation and Prediction

The FORMOSAT-3/COSMIC program is an international collaboration between Taiwan and the United States that will use a constellation of six remote sensing microsatellites to collect atmospheric data for weather prediction and for ionosphere, climate and gravity research. Data from the satellites will be made freely available to the international scientific community in near real-time.

FORMOSAT-3/COSMIC

- *FORMOSAT-3/COSMIC Constellation was launch at 01:40 UTC, April 14, 2006 (Taiwan Time: April 15 2006) at Vandenberg Air Force Base, CA.* Minotaur Launch

- *Maneuvered into six different orbital planes (inclination ~72°) for optimal global coverage (at ~800 km altitude).*

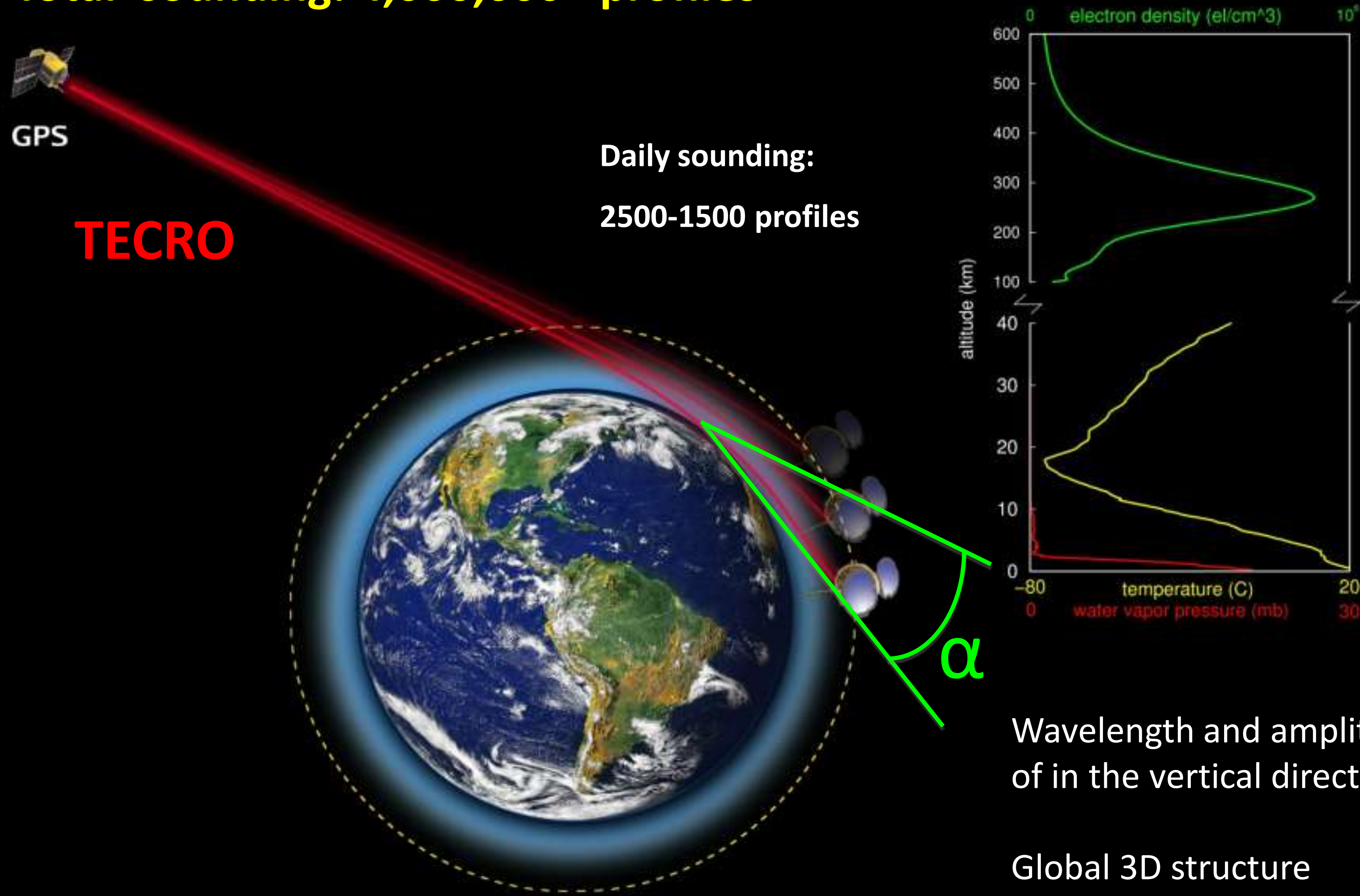
- *Five out of Six satellites are in good health and providing science data.*

GPS Radio Occultation

Total sounding: 4,000,000+ profiles

Daily sounding:

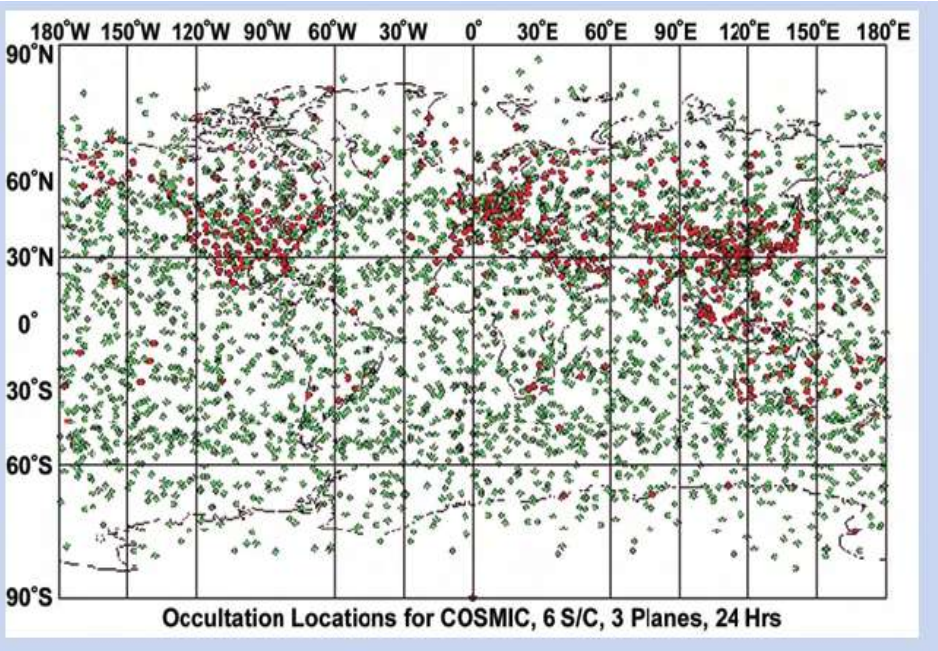
2500-1500 profiles



Wavelength and amplitude of in the vertical direction

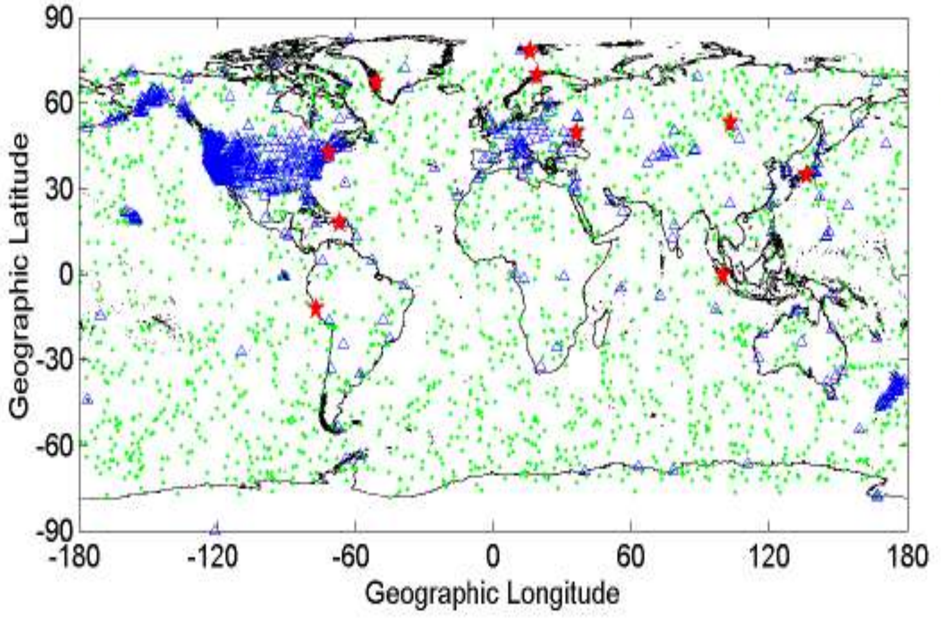
Global 3D structure

Atmospheric and Ionospheric F3/C RO Sounding

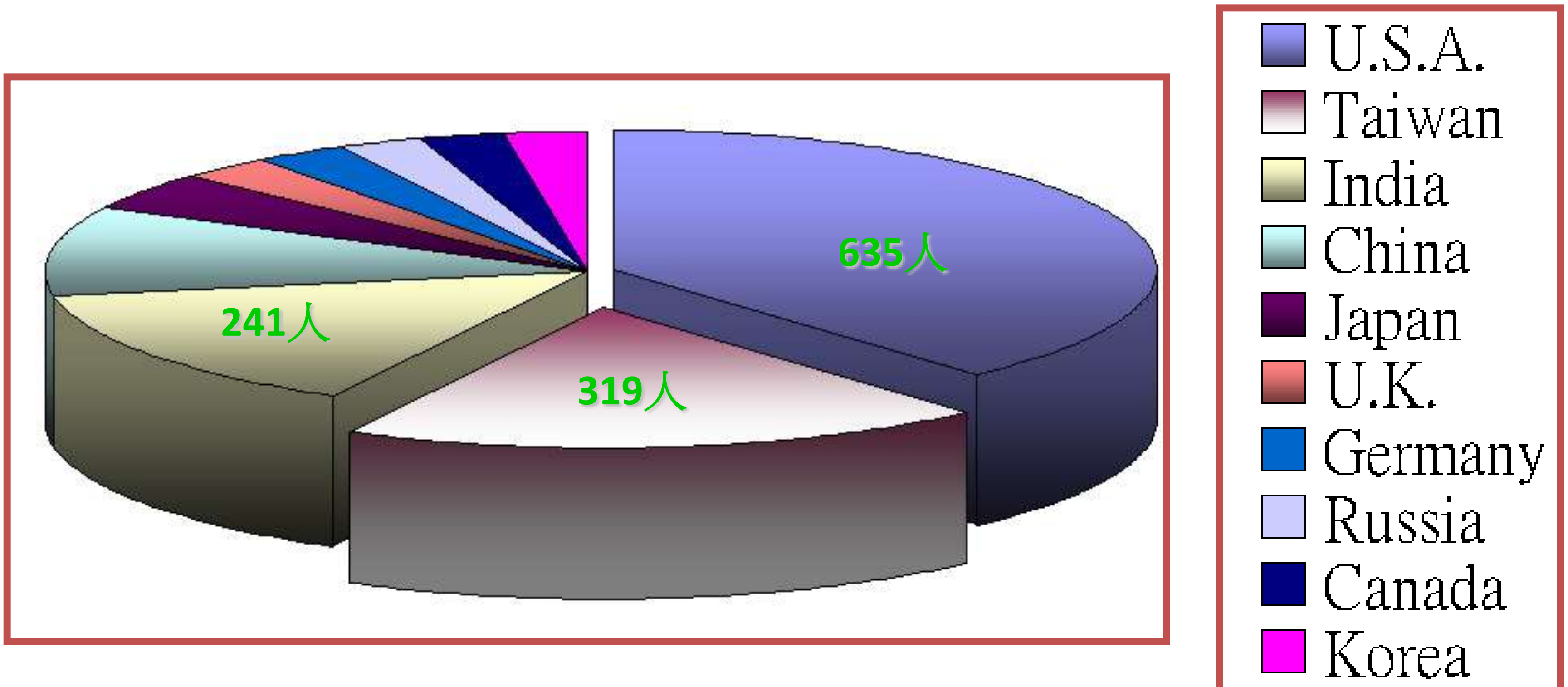


Atmospheric Sounding

Ionospheric Sounding



FORMOSAT-3/COSMIC Users and Nations

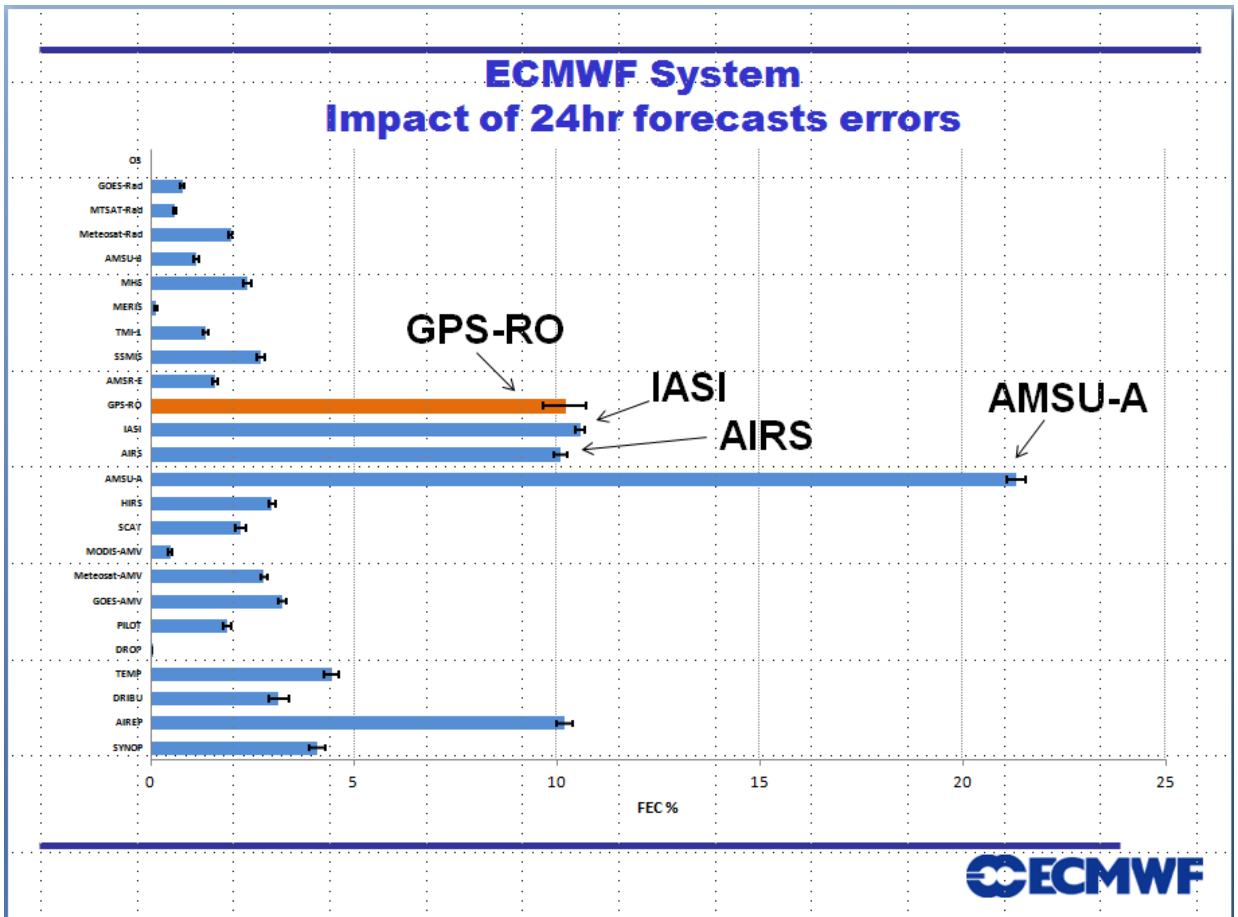


Worldwide users: 2079

Nation: USA, Taiwan, India, China, Japan, UK, Germany, Russia, Canada, Korea, (more than 67 countries).

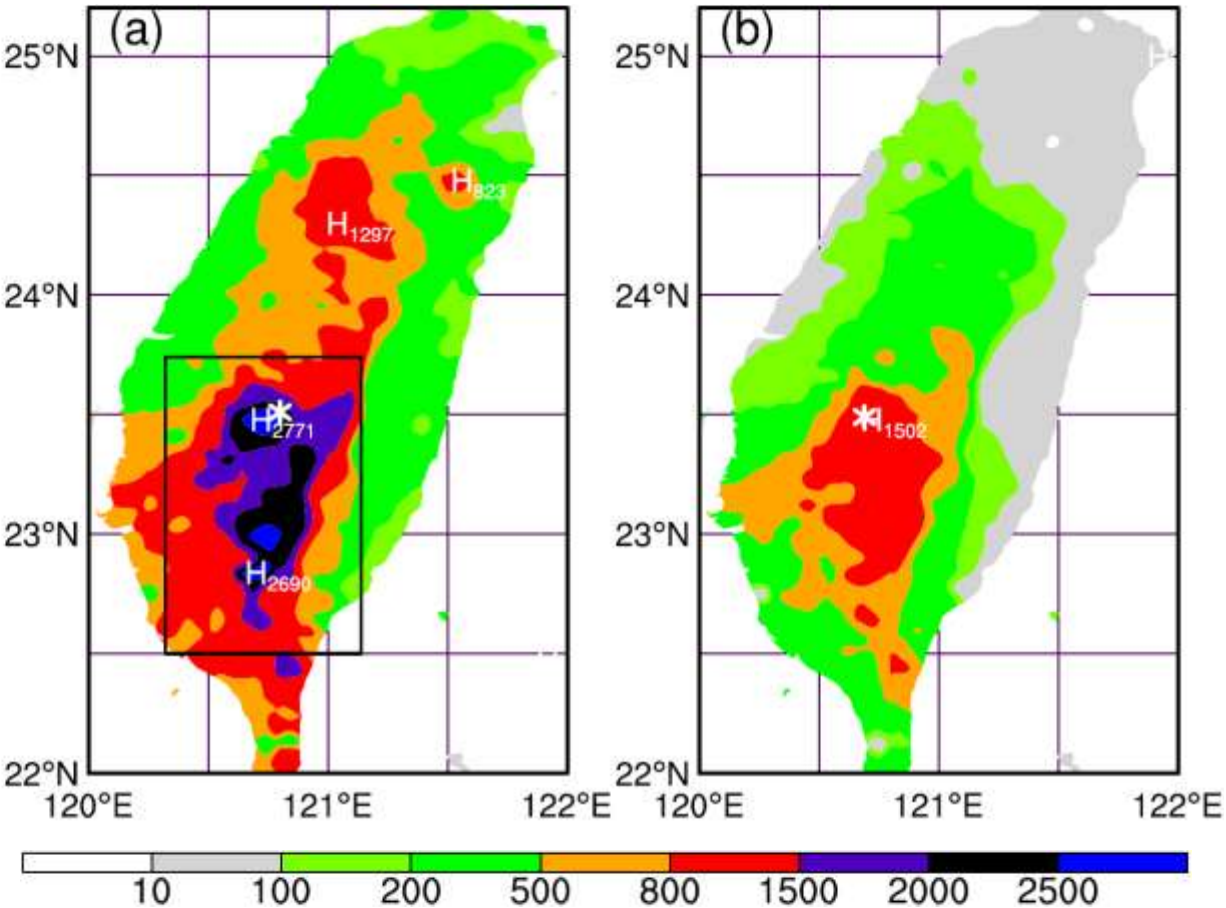
Effectiveness of GPS RO Data

ECMWF Report, according to forecasts in 2012, ranked GPS RO data as the 3rd place in all atmospheric observation data collected by space- and air-borne sensors in which GPS RO contributed 2~3% data that improved 10~20% of weather prediction error.



Observed Rainfall of Typhoon Morakot (2009)

From August 6 to 10, 2009, extraordinary rainfall was brought over Taiwan by Typhoon Morakot, breaking 50 year's precipitation record, causing a loss of more than 700 people and estimated property damage exceeding US$5.5 billion



* Objective analysis
~450 automatic stations

Accumulated rainfall:
(a) 96-h on August 6-10
(b) 24-h on August 8-9

Typhoon Morakot (2009)
Max. 24-h gauge **1504 mm**
Max. 96-h gauge **2874mm**
at Chiayi County
(windward slope of CMR)

24-h rain world record
1825 mm

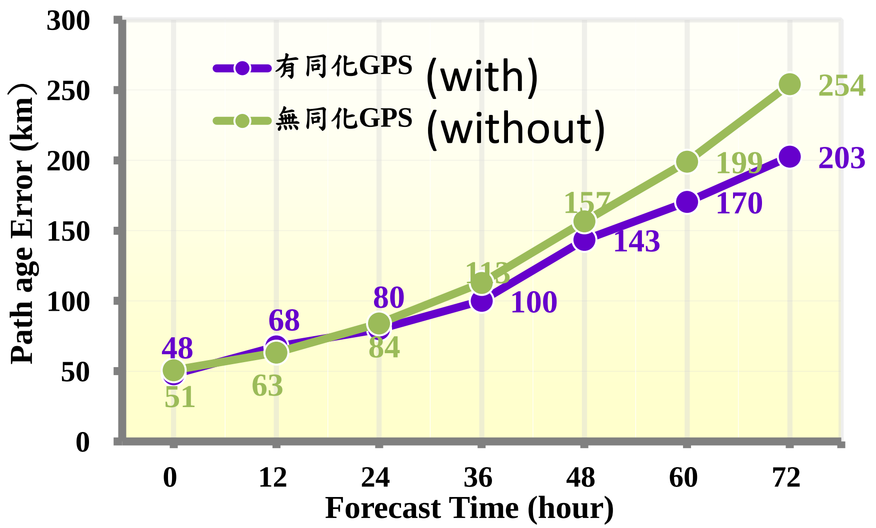
Typhoon Morakot (2009)

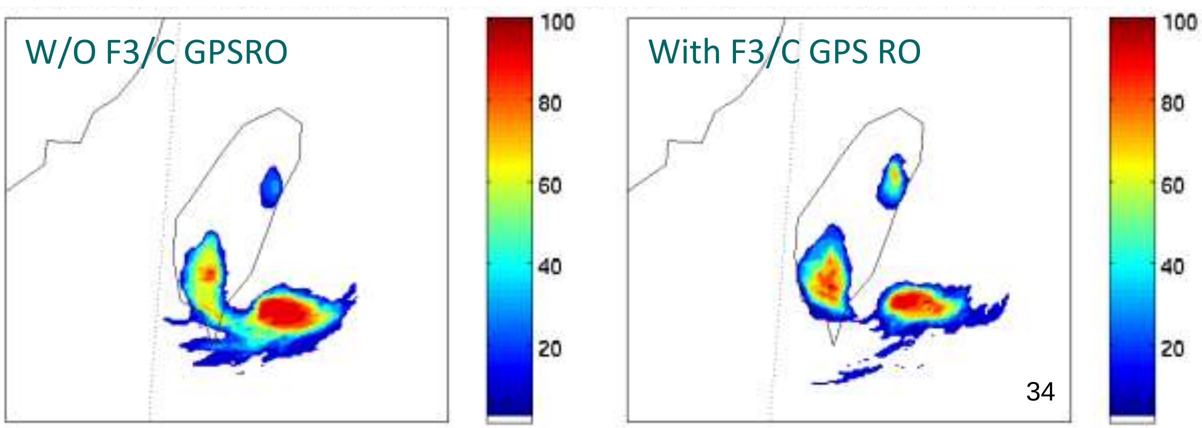
Main concern of typhoon prediction in Taiwan is flooding.

Typhoon Morakot (2009)

Center Weather Bureau Weather Forecast

- Typhoon Morakot pathage and rainfall

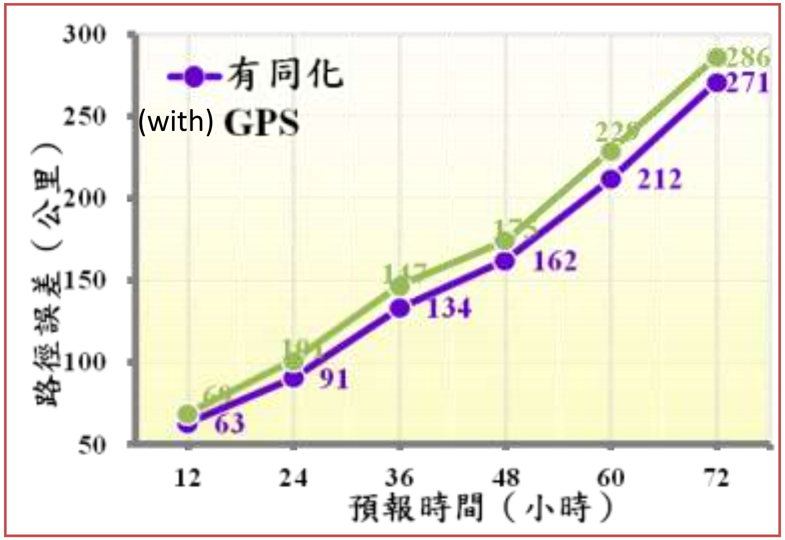




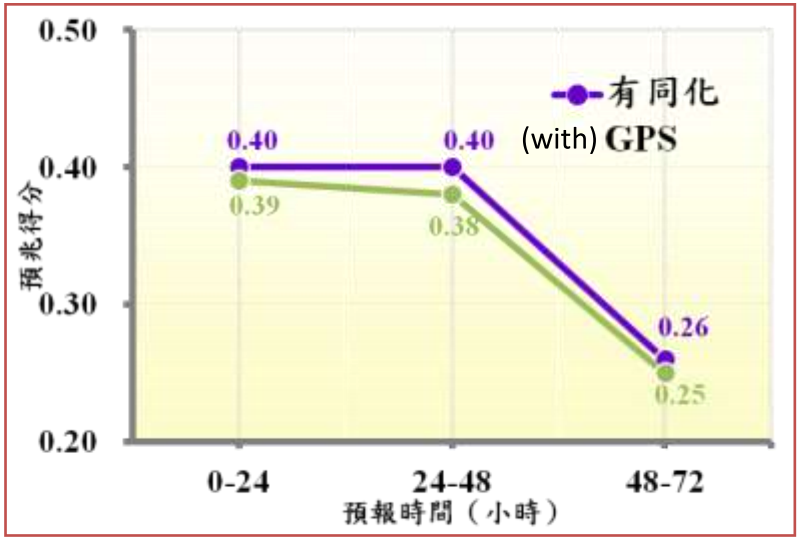
Weather Forecast
Typhoon pathage error and rainfall score

- A statistical study on the forecast of 23 typhoons approaching Taiwan in 2012 shows that F3/C GPS RO data could reduce the pathage error in 24-hour about 10%.

Pathage



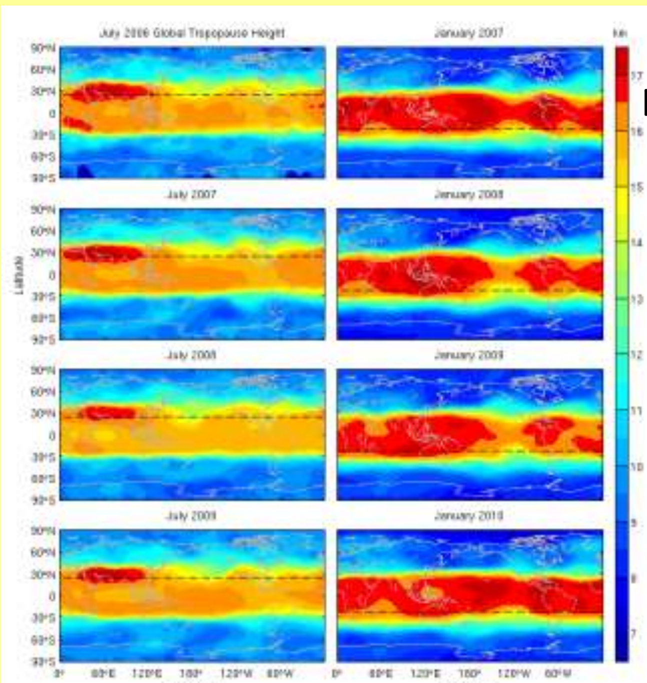
Rainfall (SCORE)



Provided by TTFRI

Global Climate Change

ENSO Warn/Cold vs Tropopause Height



ENSO Warm

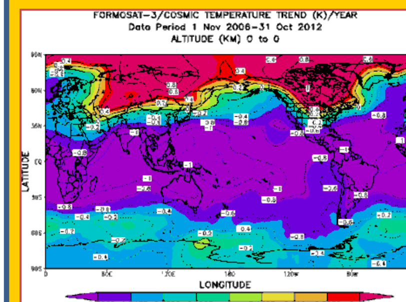
ENSO Cold

Normal

ENSO Warm

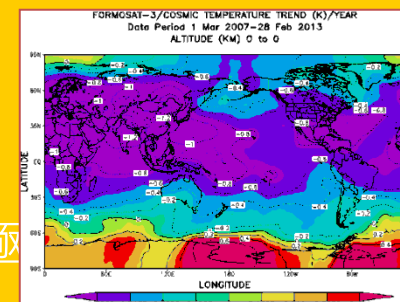
Arctic and Antarctic Winter Warming

Sea Surface Temperature (SST)

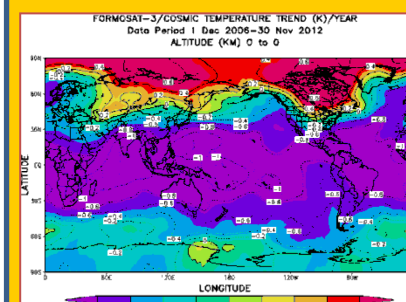


SST in November

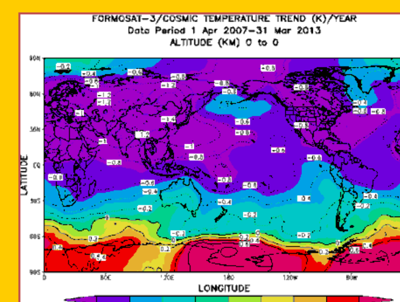
南極



SST in March



SST in December

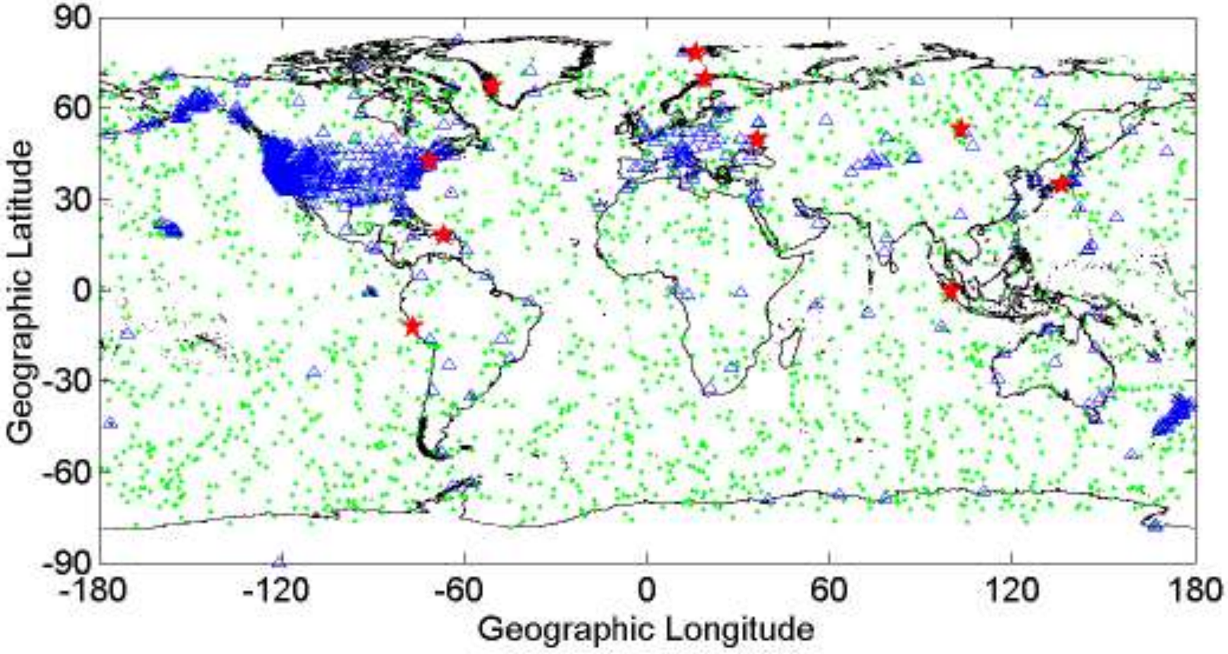


SST in April

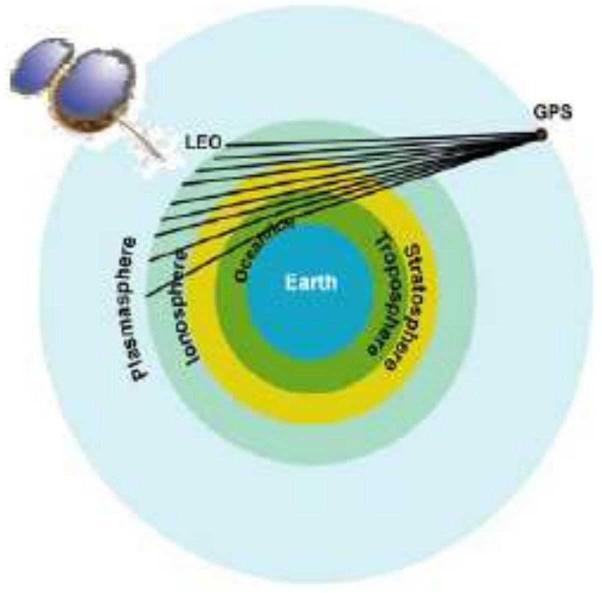
Remark

- It is essential to have F3/C RO atmospheric sounding data for global weather forecasts.
- F3/C RO atmospheric sounding is a powerful tool for weather forecasts, especially sever one such as the typhoon pathage and rainfall.
- F3/C RO atmospheric sounding has been applied to monitor dust storms, volcano eruptions, sudden stratosphere warming.

Distribution of occultation events observed by FORMOSAT-3



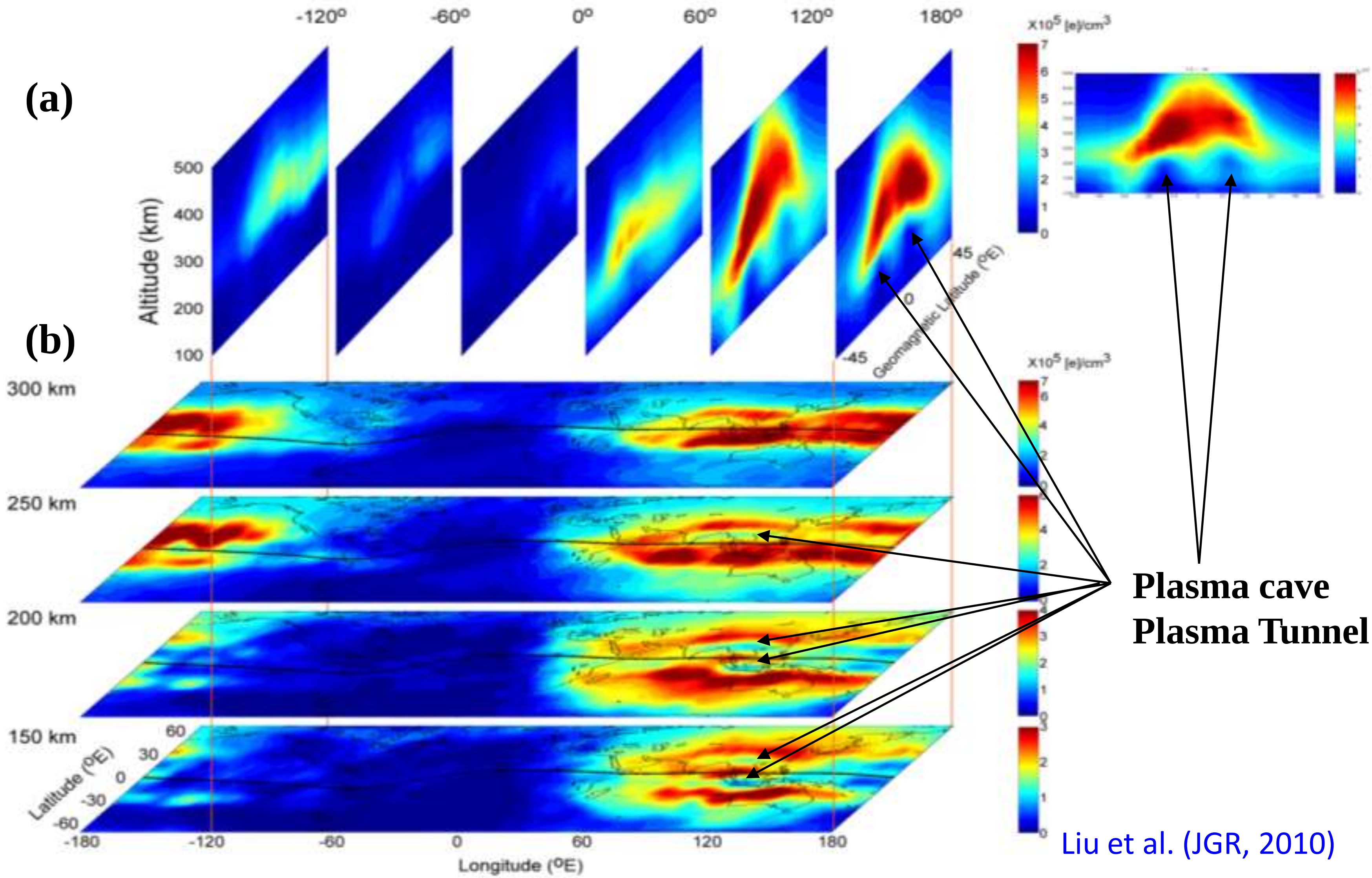
GOX



Ionospheric 3D electron density structure

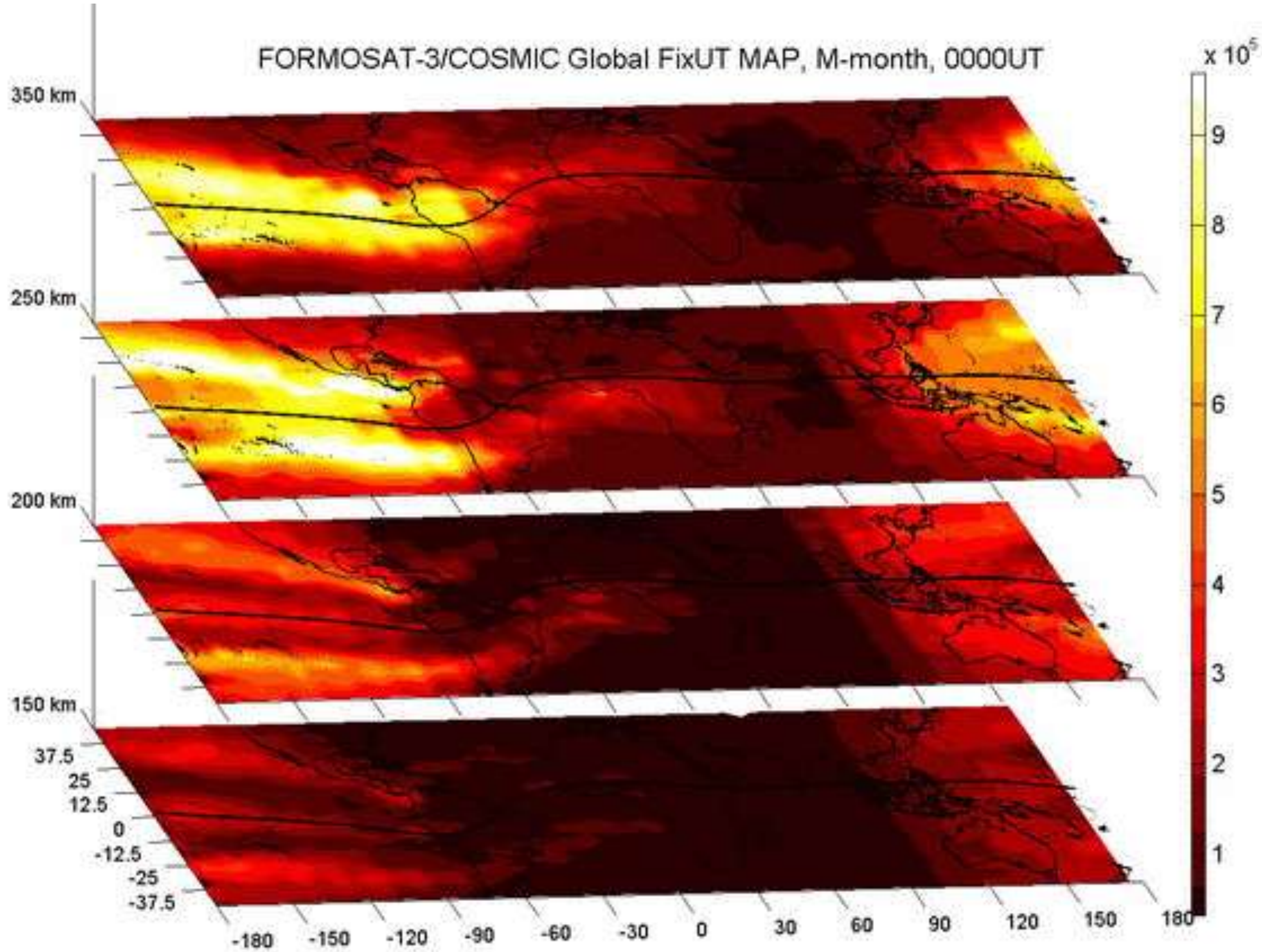
Ionospheric Climate

Ionospheric Plasma Structure

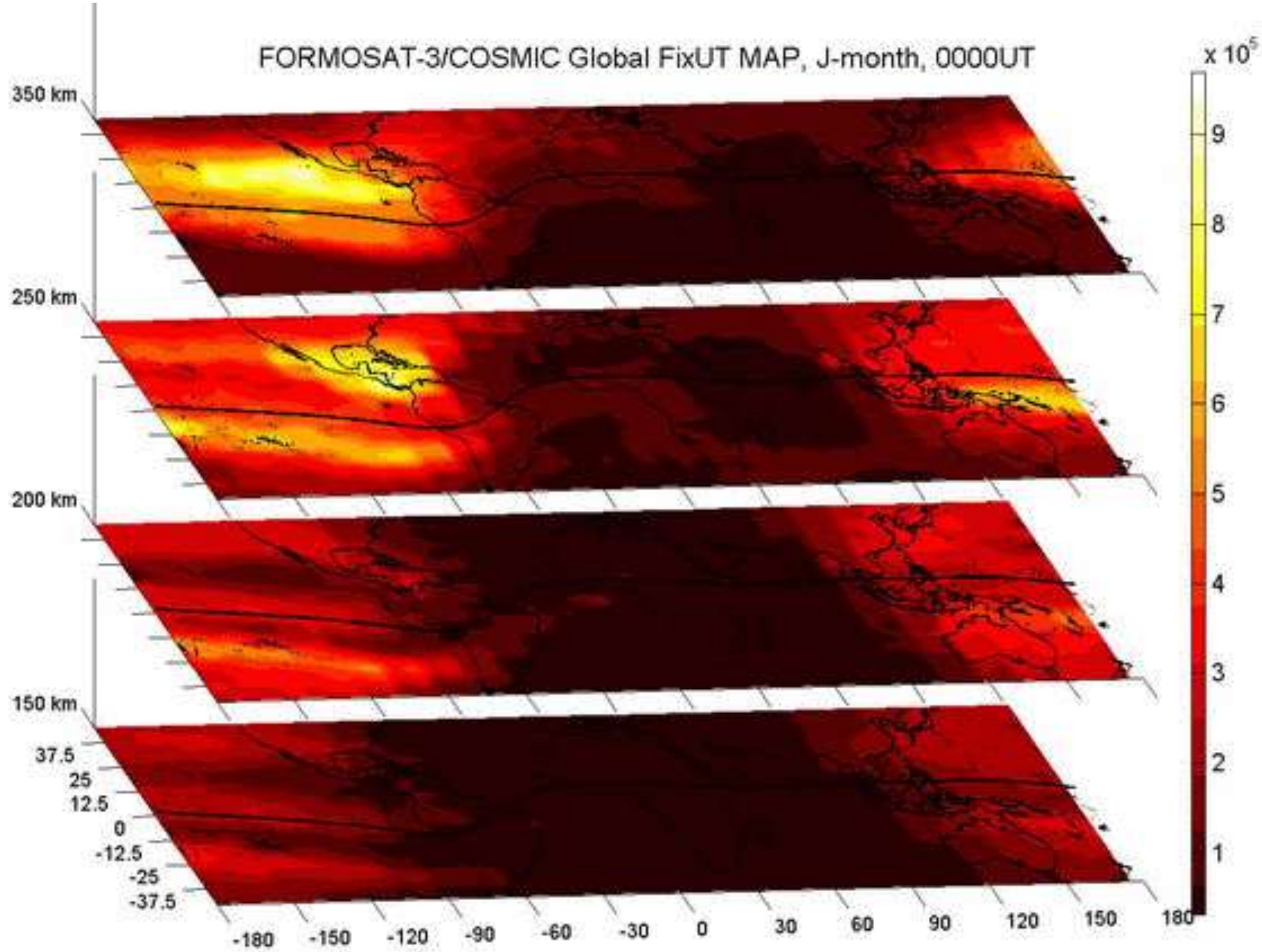


Liu et al. (JGR, 2010)

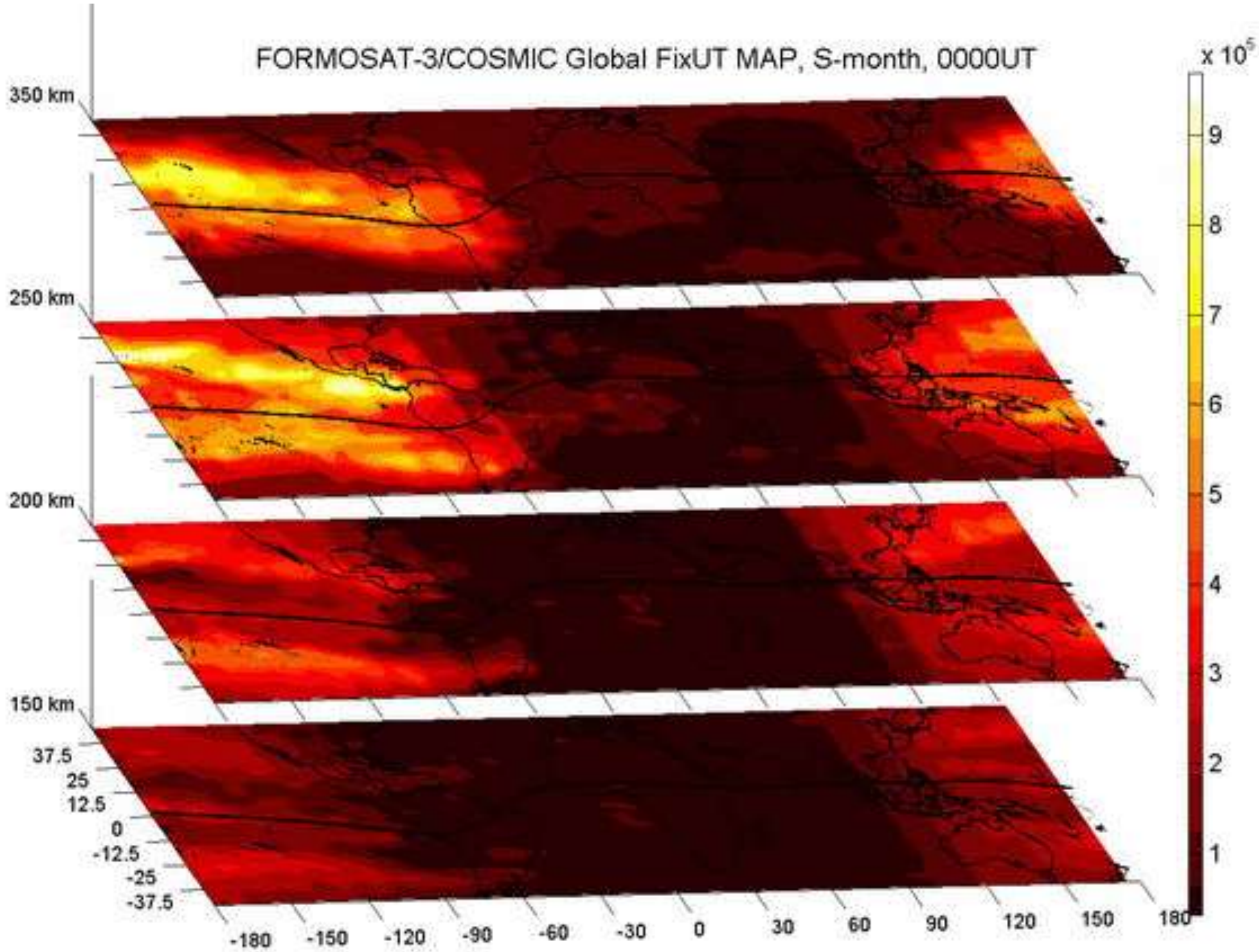
EIA in M-month



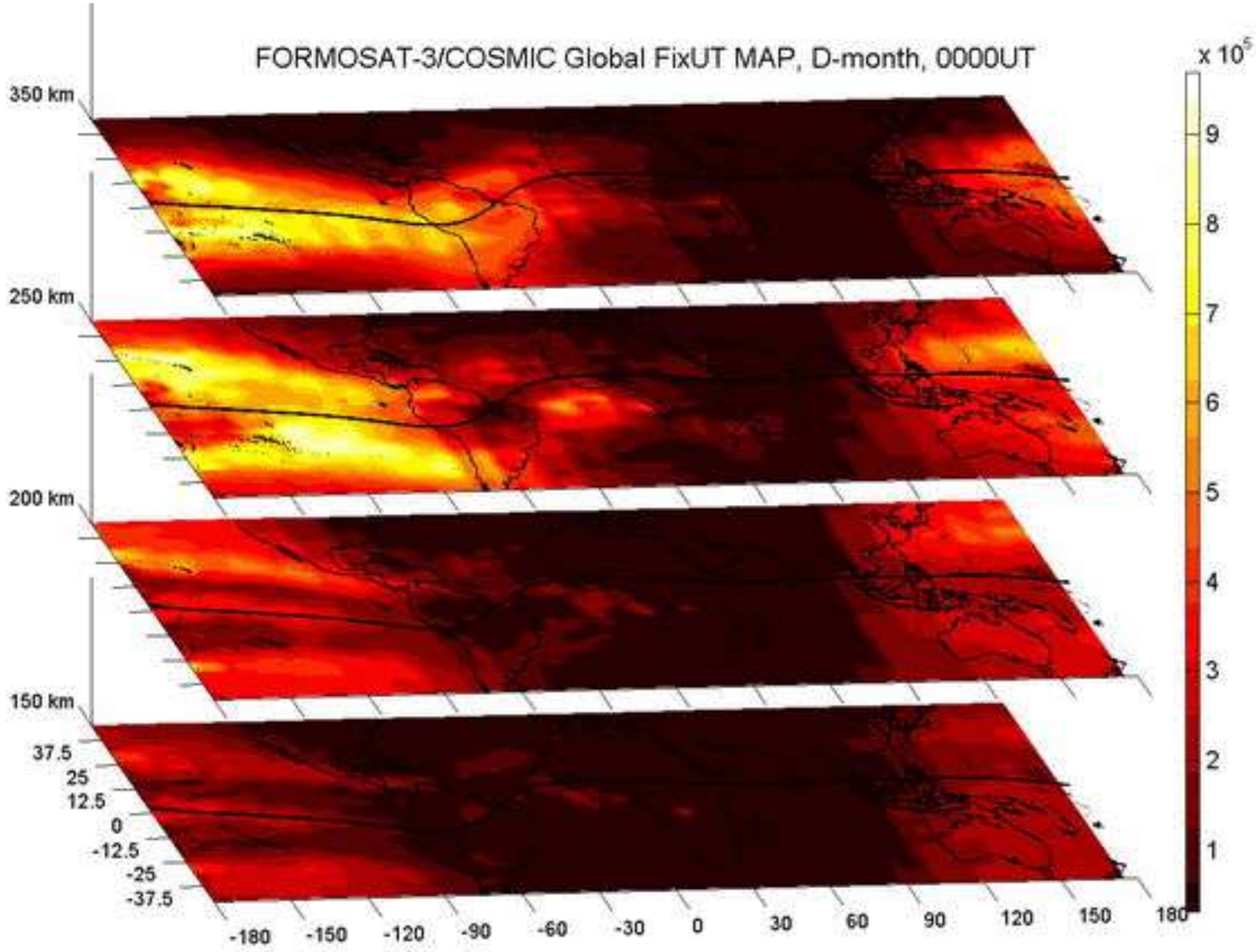
EIA in J-month



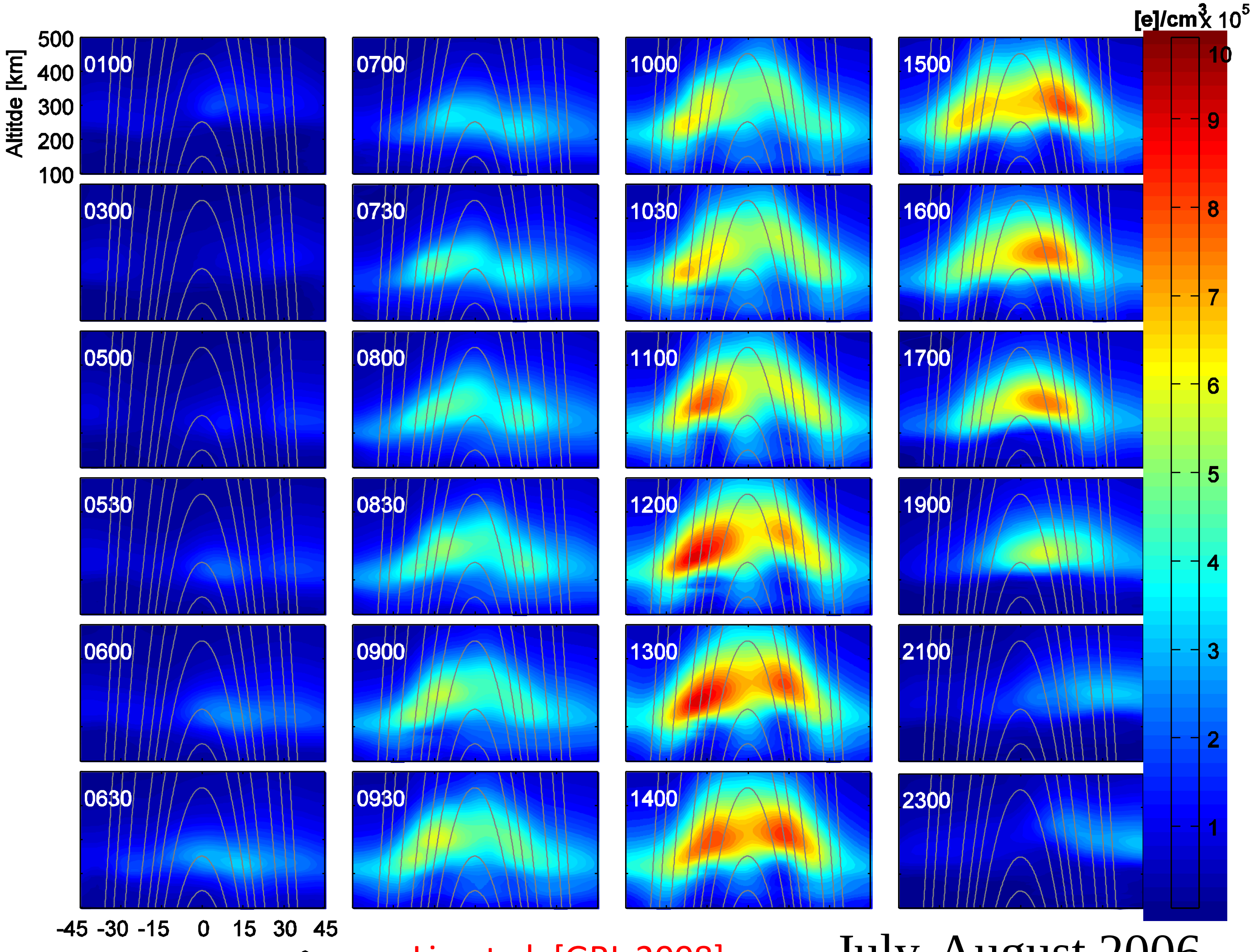
EIA in S-month



EIA in D-month



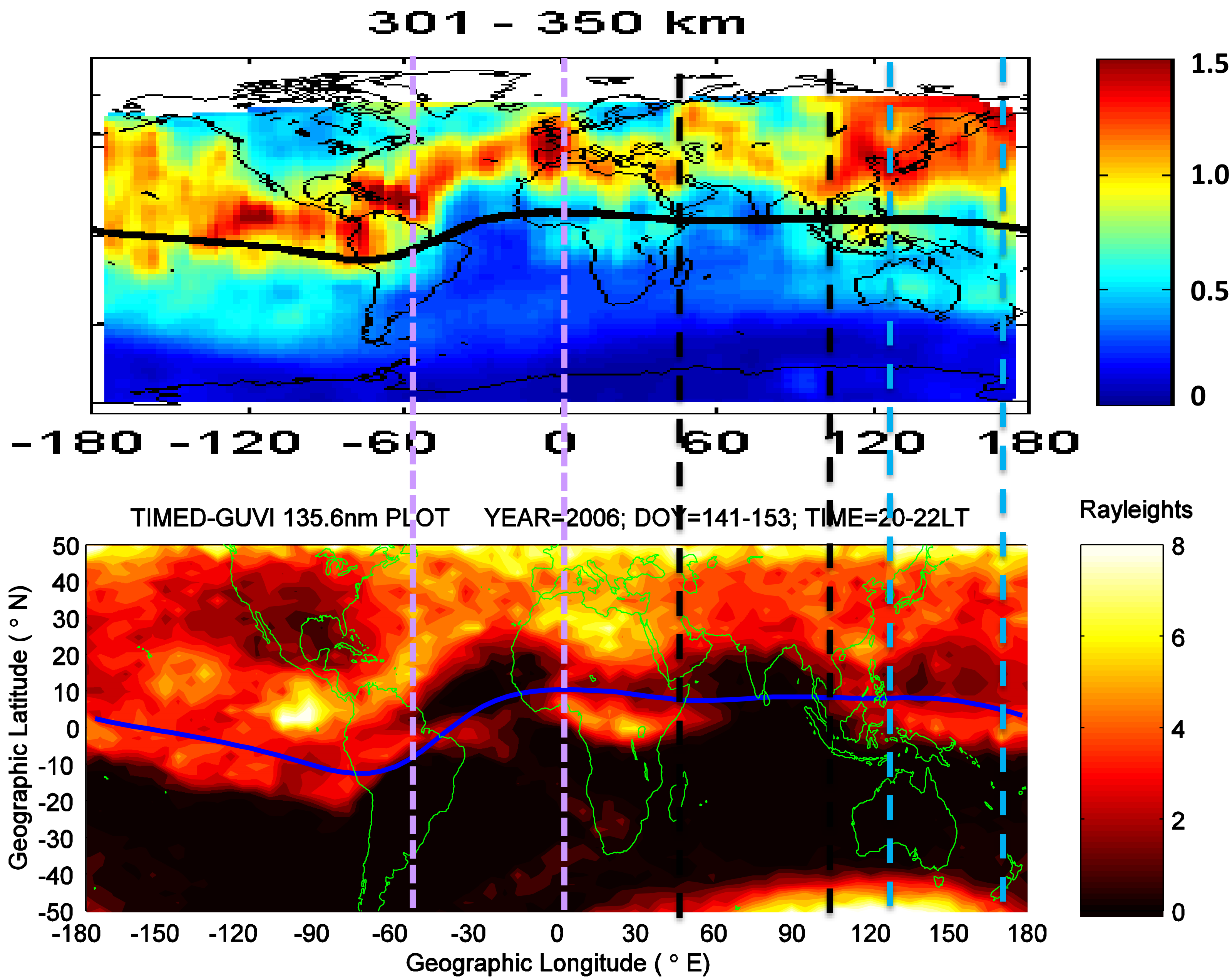
Equatorial Ionization Anomaly



Lin et al. [GRL 2008]

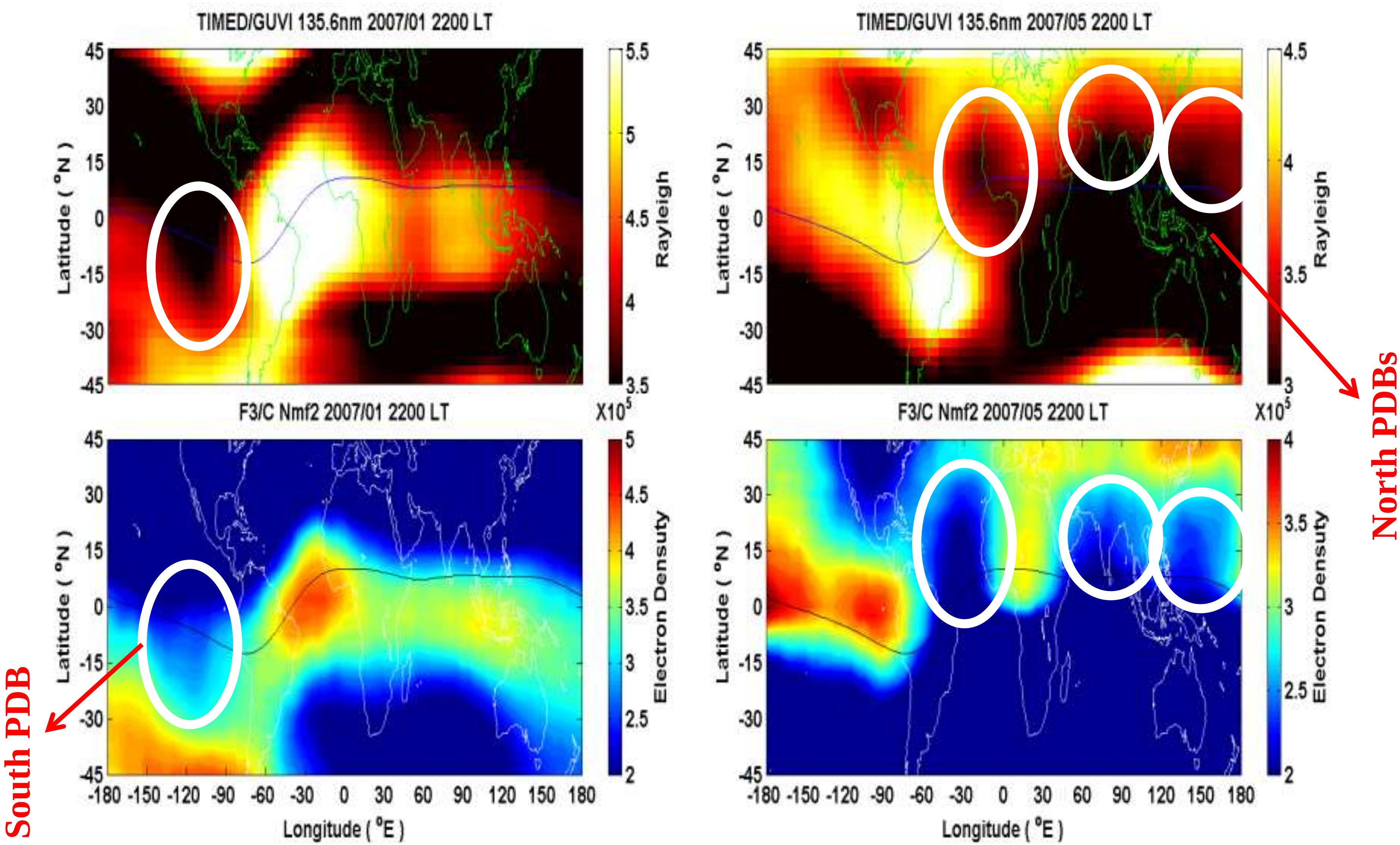
July-August 2006

Plasma Depletion Bay

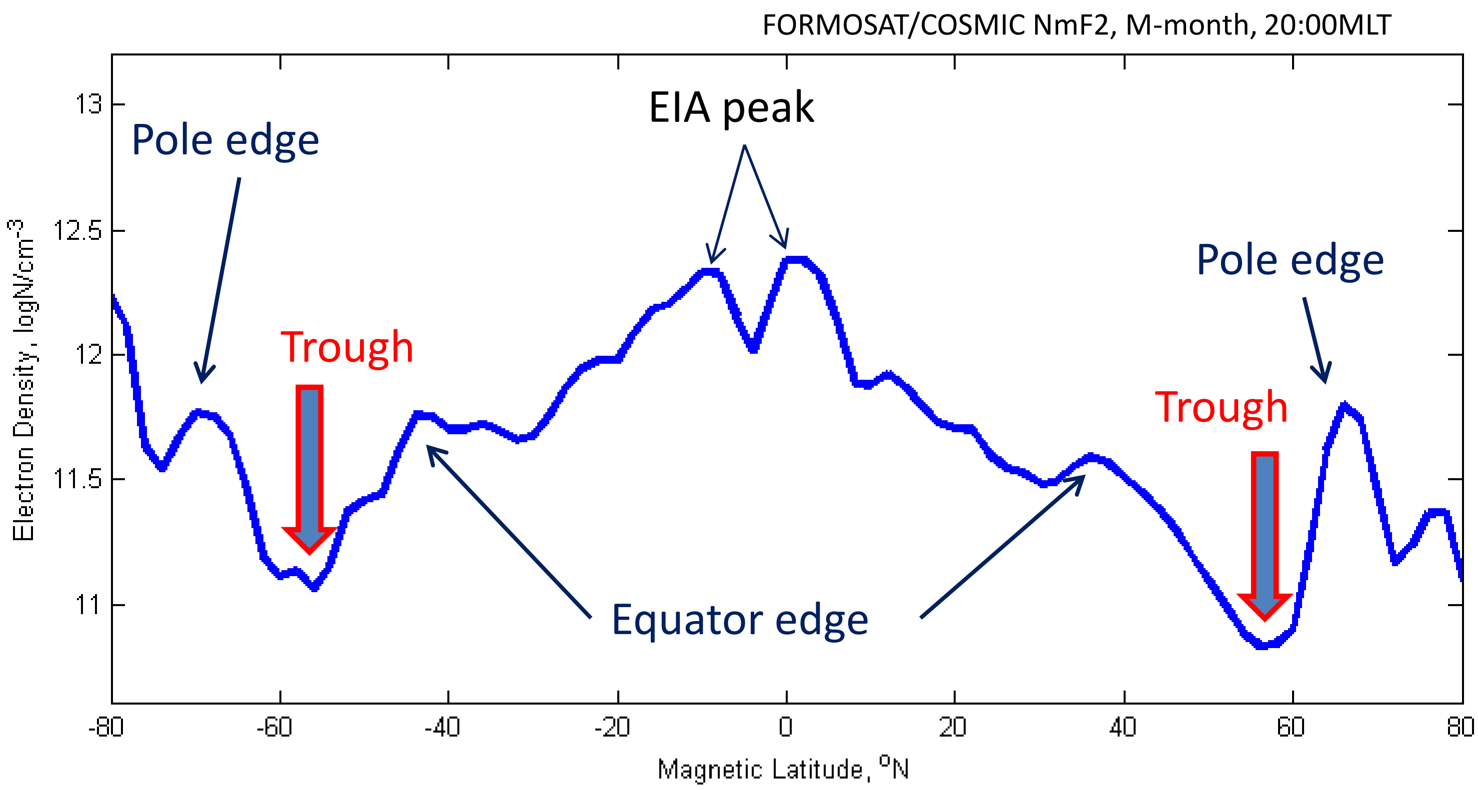


Plasma Depletion Bays (PDBs) observed by F3/C and TIMED GUVI

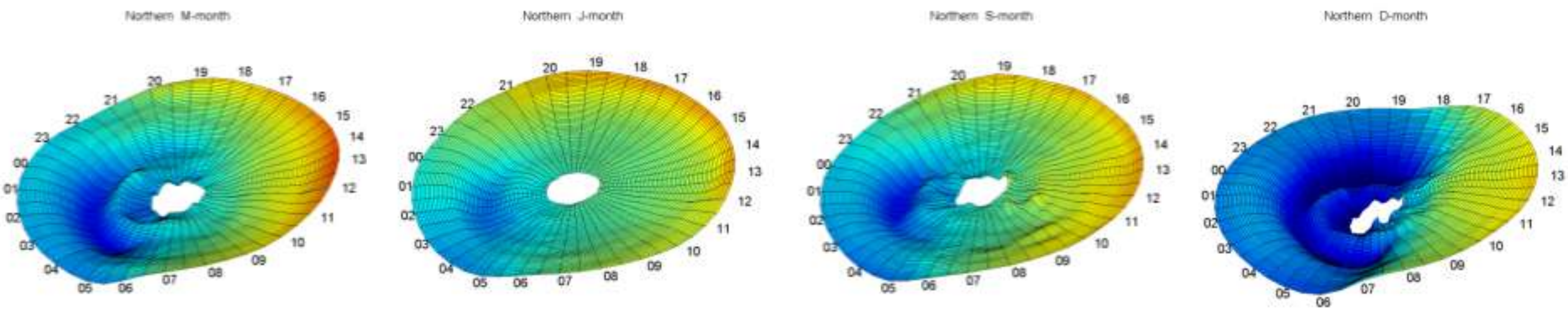
Nighttime ionospheric structures, 2200 LT, 2007 (global fixed local time)



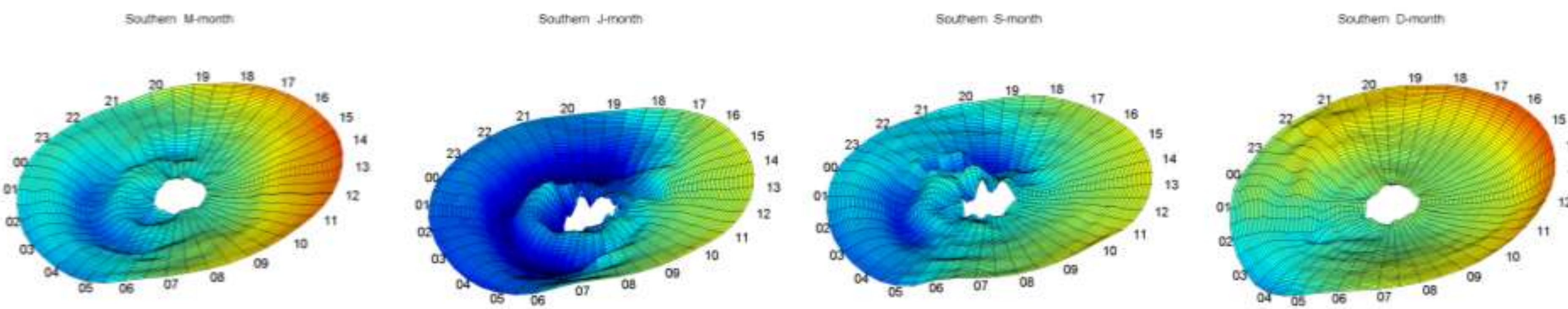
Mid-latitude Trough



Seasonal Variation

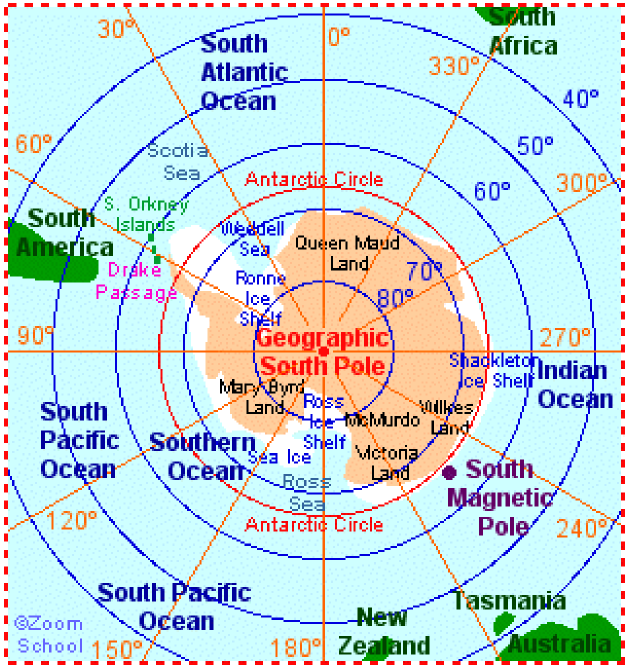


Northern hemisphere



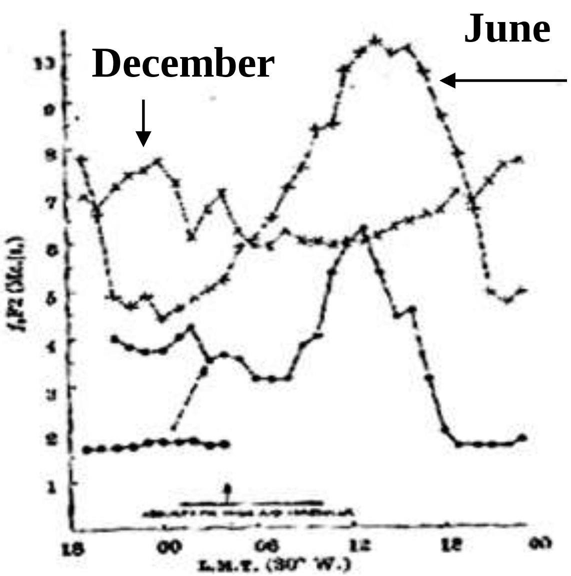
Southern hemisphere

Weddell Sea/Yakutsk Anomaly



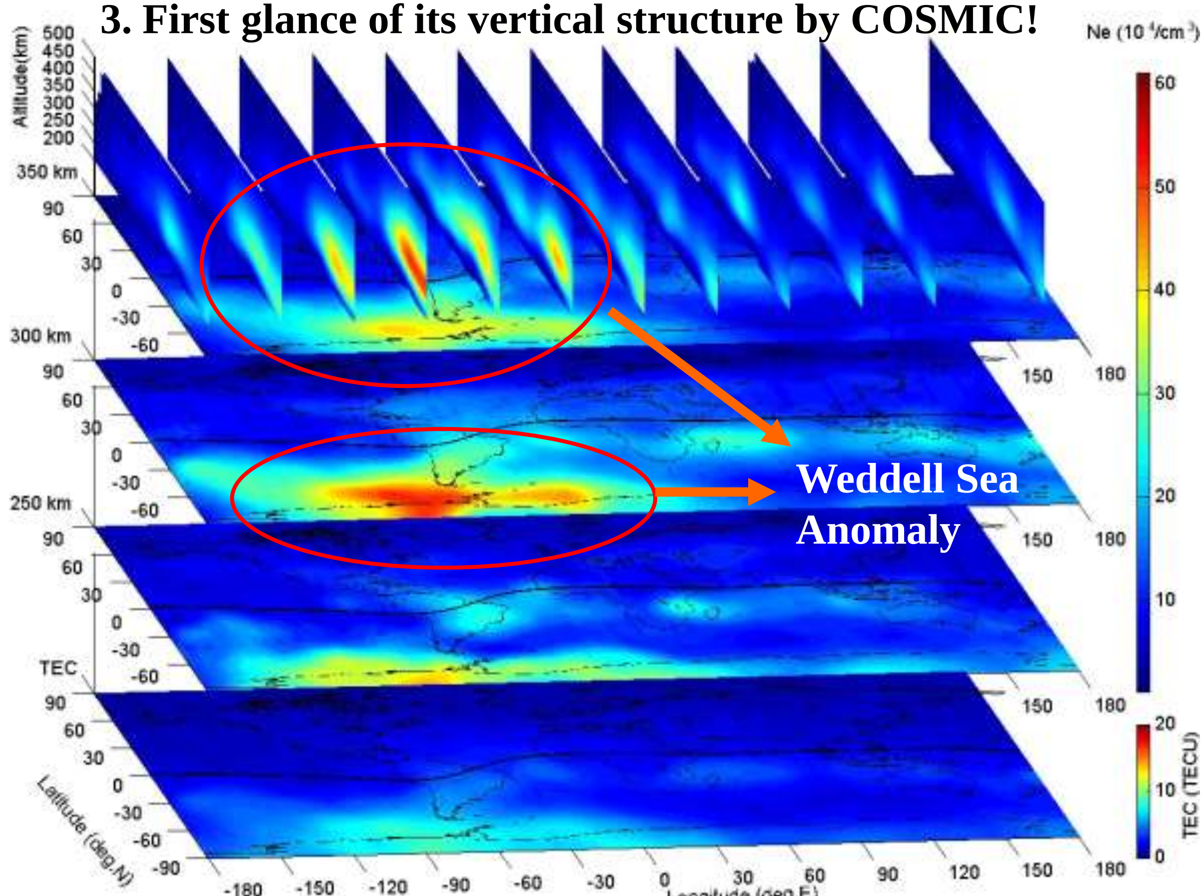
The Ionospheric Weddell Sea Anomaly

1. Stronger nighttime Ne than that during daytime
2. Discovered 50 years ahead of renewed observation by COSMIC
3. First glance of its vertical structure by COSMIC!



Ionosonde Observation

(Bellchambers and Piggott, 1958)



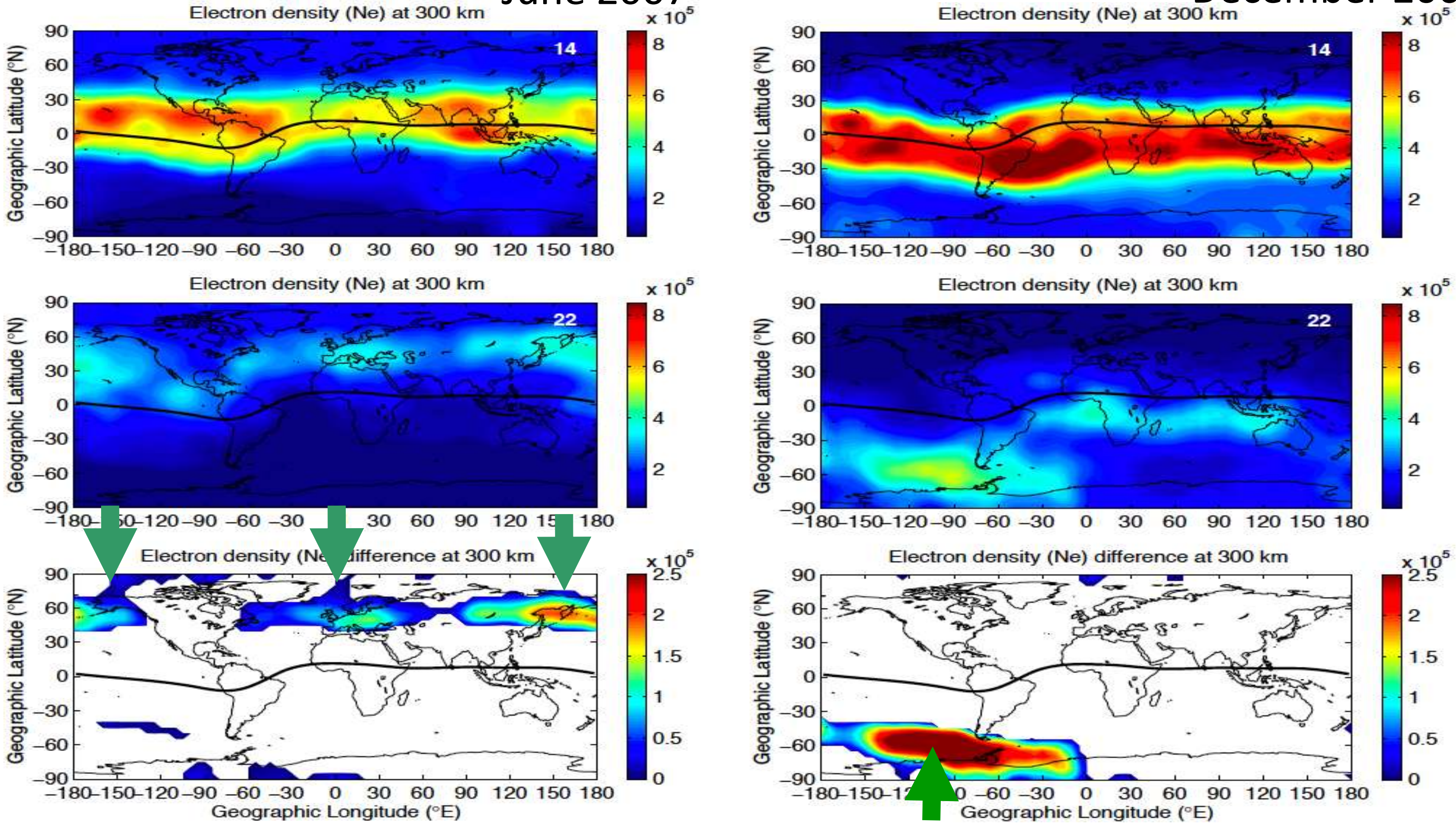
Lin et al., 2009

Weddell Sea anomaly in the Southern hemisphere and Yakutsk Anomaly in the North hemisphere

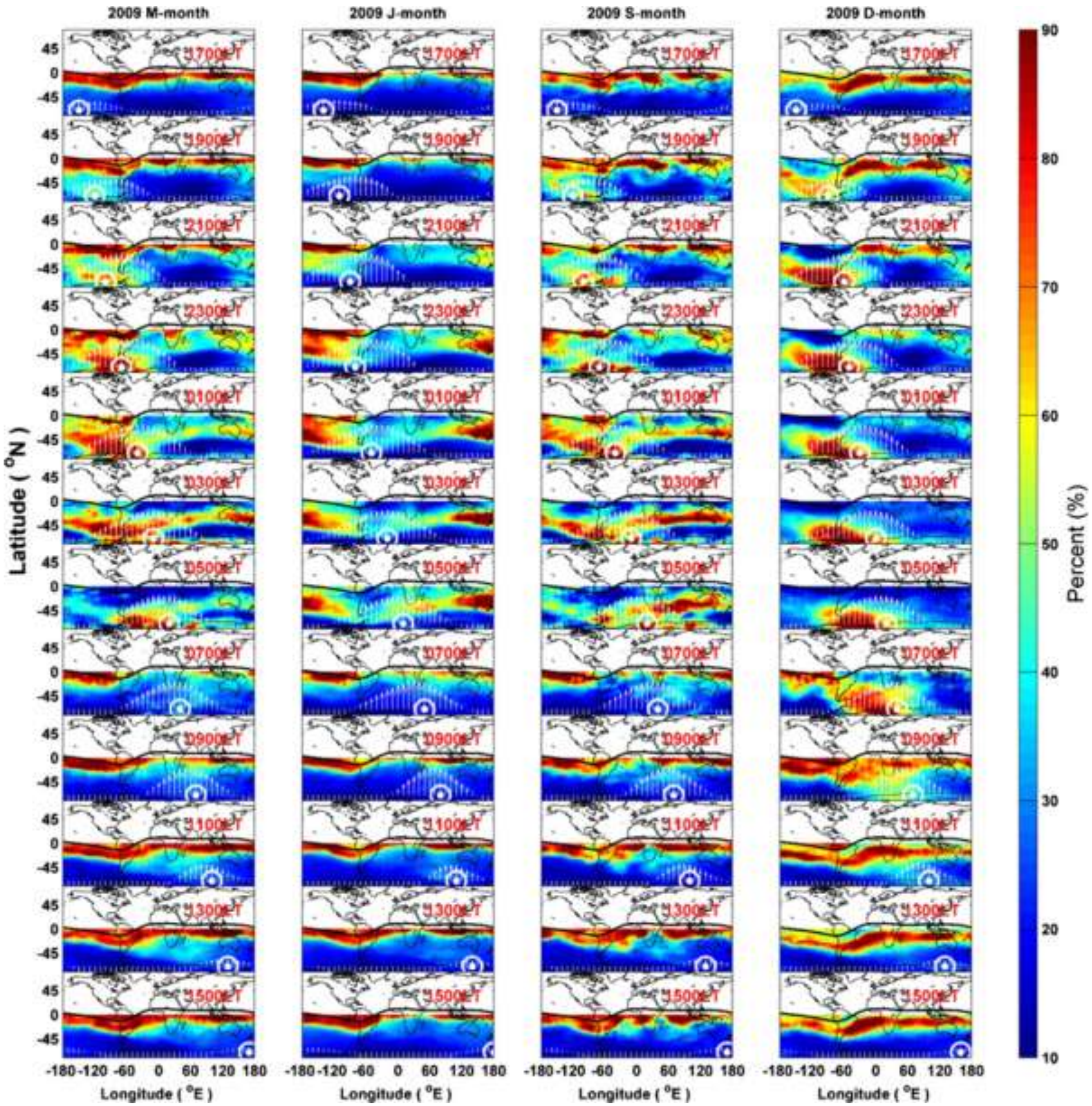
Ne(2200LT) > Ne(1400LT)

- driven by equatorward meridional neutral wind

June 2007 December 2007

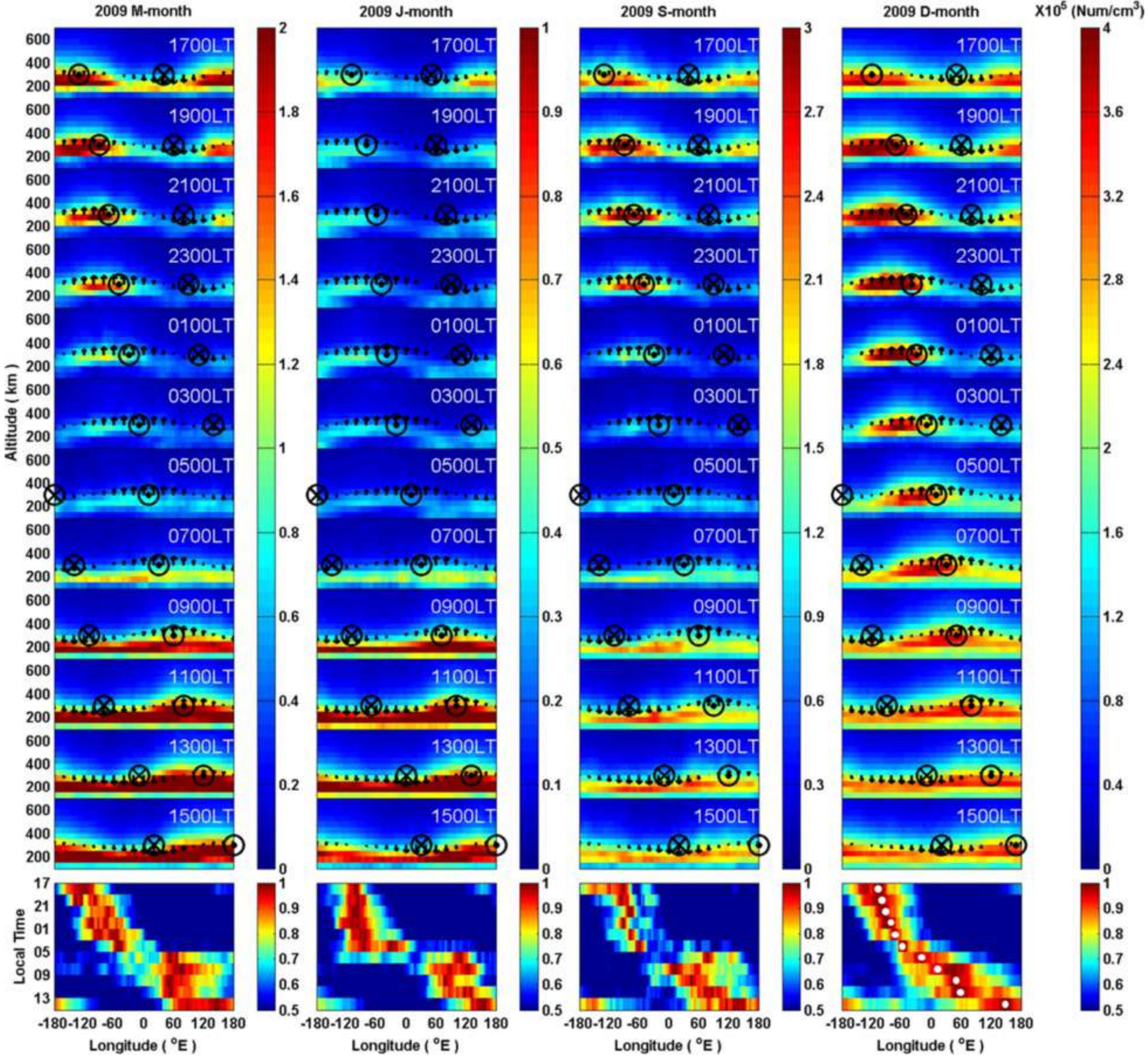


Lin et al. [2010]



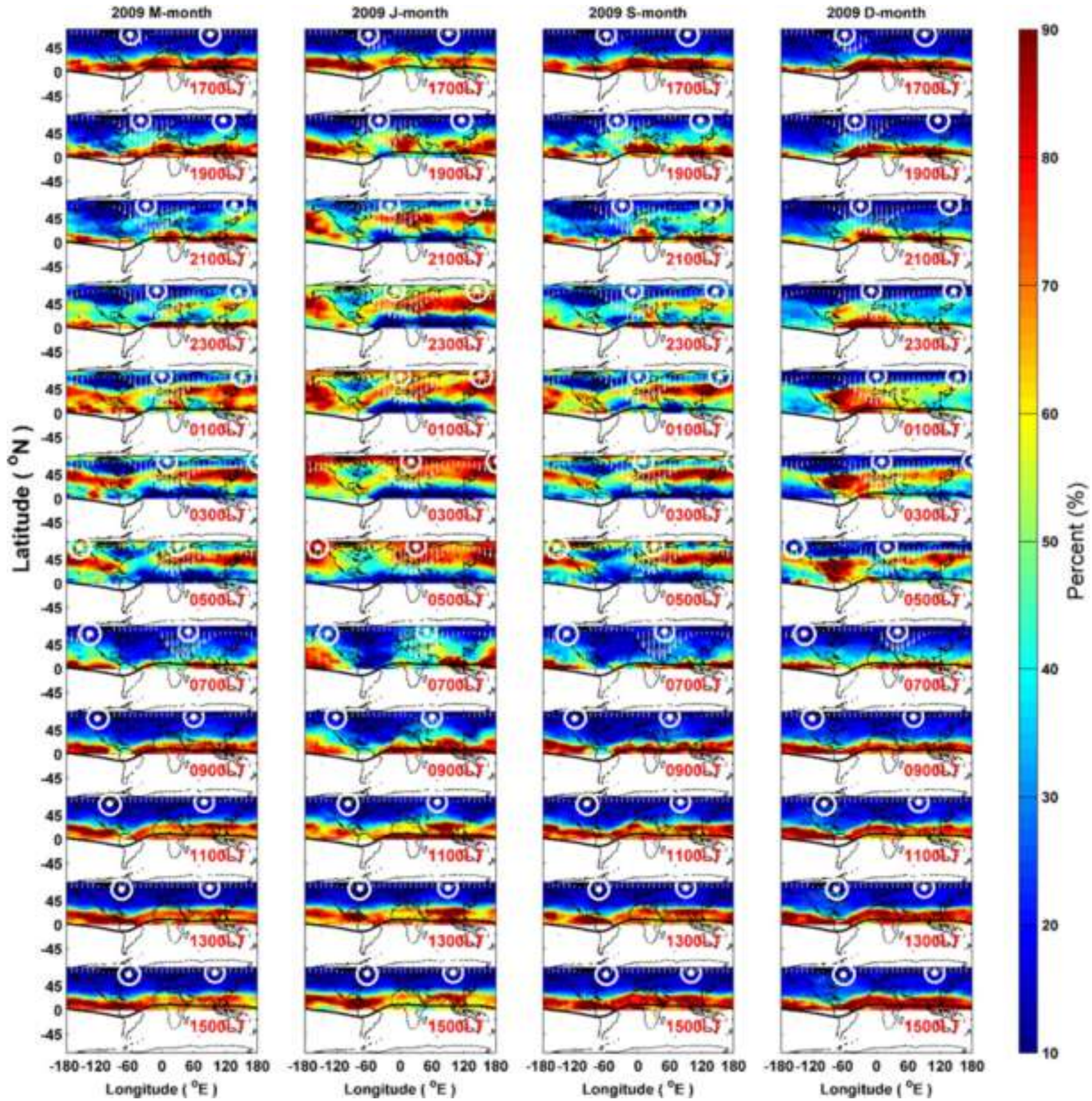
Diurnal variations of F3/C N maps at 300-km altitude at various global fixed local times in the 4 months in the Southern Hemisphere. The electron density is standardized and the colorbar range from 10 to 90 % of the electron density at each time-point plot individually. White arrows are the magnetic meridional effect U and white circle-dots are the longitudinal maximum upward effect WM at 75° S geographic, respectively.

Chang et al. [EPS 2015]



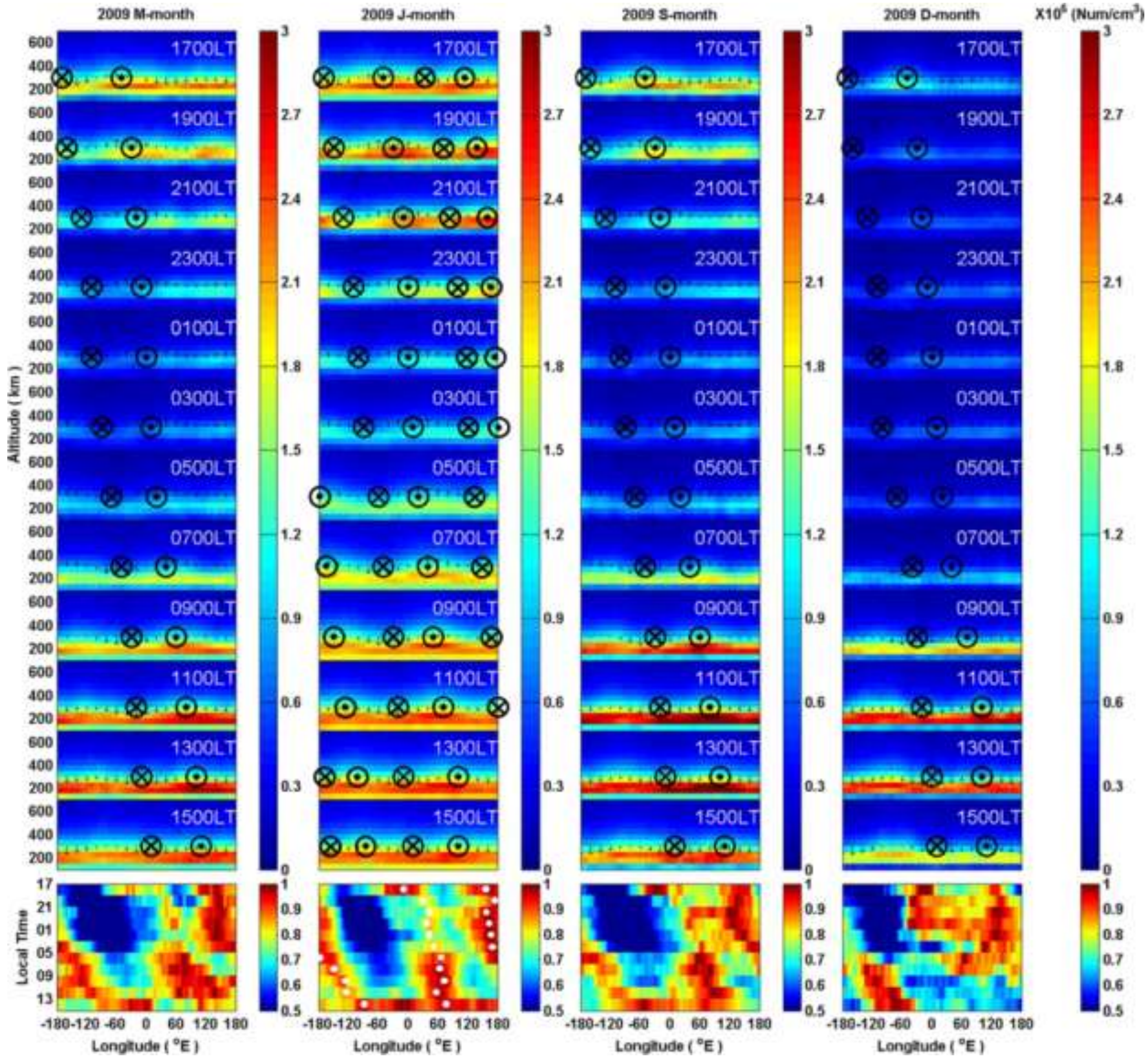
Upper panels are the altitude variations of the F3/C N within 40–80° S geographic at various global fixed local times in the 4 months. Bottom panels are extracted from the 300-km altitude N at 60° S geographic. Black circle-dots and circle-crosses and arrows denote the longitudinal equatorward and poleward maximum effect U and vertical effect W at 75° S geographic, respectively. White dots are the longitudinal maxima NM at 300-km altitude in the D-month. The two segmented eastward phase shifts 167 and 296 m/s are computed by averaging three-time-point fitting shift by 1 point over the period of 1700–0300 LT and 0300–1700 LT, respectively.

Chang et al. [EPS 2015]



Similar to Fig. 1 but for the Northern Hemisphere. White arrows are the magnetic equatorward effect U and white circle-dots are the longitudinal maximum upward effect WM at 55° N geographic, respectively.

Chang et al. [EPS 2015]



Upper panels are the altitude variations of the F3/C N within 30–60° N geographic at various global fixed local times in the 4 months. Bottom panels are extracted the 250-km altitude N at 45° N geographic. Black circle-dots and circle-crosses and arrows denote the longitudinal equatorward and poleward maximum effect and vertical effect W at 55° N geographic at 250-km altitude, respectively. White dots are the longitudinal maximum NM at 250-km altitude in the J-month. The two eastward phase shifts 91 and 121 m/s are computed by averaging three-time-point fitting shift by 1 point in 135° E–115° W and 50° W–100° E latitudinal zone, respectively.

Chang et al. [EPS 2015]

Remark

- It is found that the multiple-speeds in the eastward phase shift are about of 167 and 296m/s for WSA feature in the southern hemisphere, while the peaked double MSNAs (YKAs) with speeds yield 91 and 121m/s in the northern hemisphere.
- The WSA/YKA features in fact yield eastward phase shift and appear all year round.

Ionospheric Scintillation

S. Basu et al. / Journal of Atmospheric and Solar-Terrestrial Physics 64 (2002) 1745–1754 1747

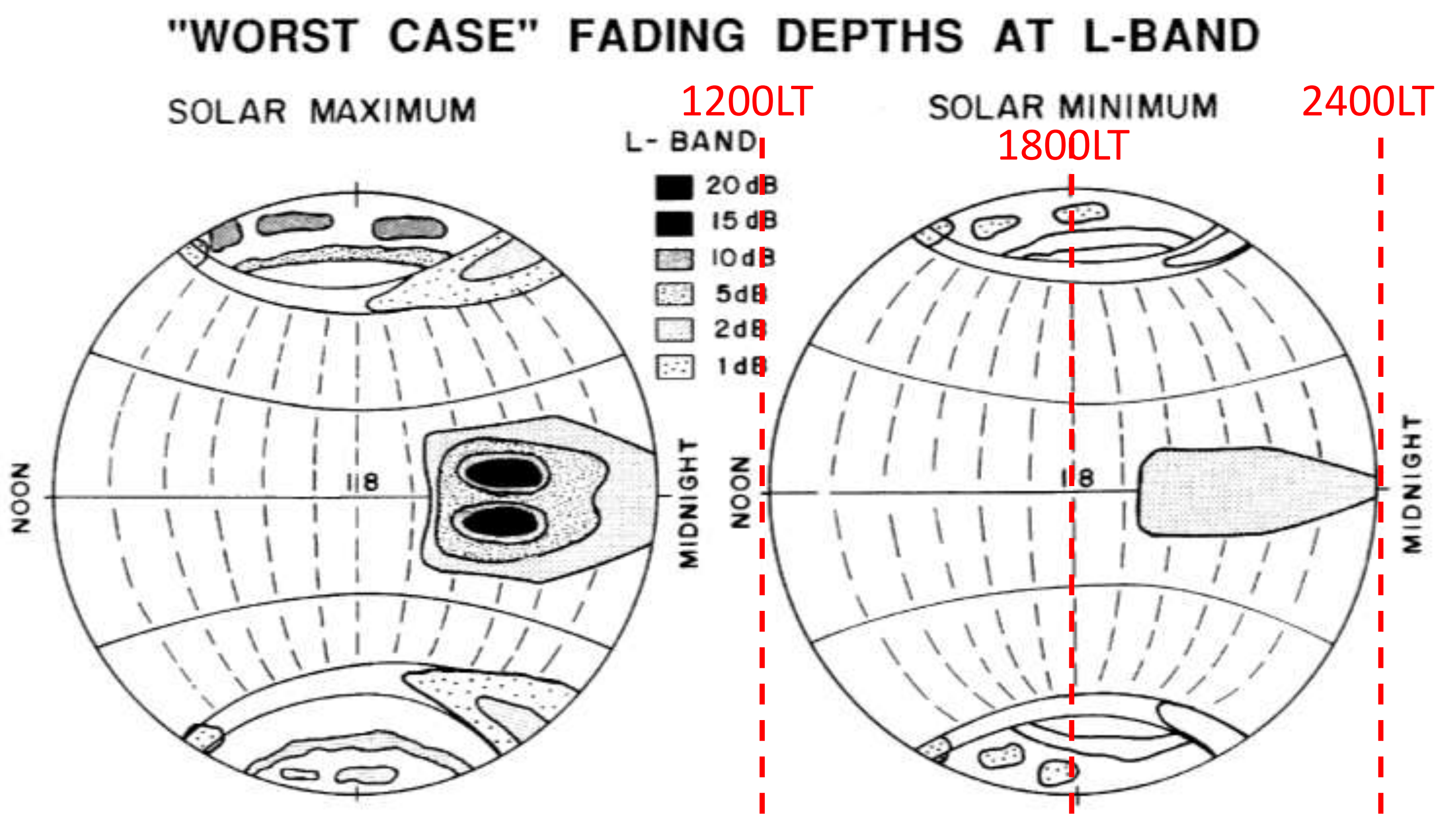


Fig. 1. Schematic of the global morphology of scintillations at L-band frequencies during the solar maximum (left panel) and solar minimum (right panel) conditions. Reproduced from S. Basu and K.M. Groves, Specification and forecasting of outages on satellite communication and navigation systems, Space Weather, Geophysical Monograph 125, 424–430, 2001. Published 2001 by the American Geophysical Union. Reproduced/modified by permission of American Geophysical Union.

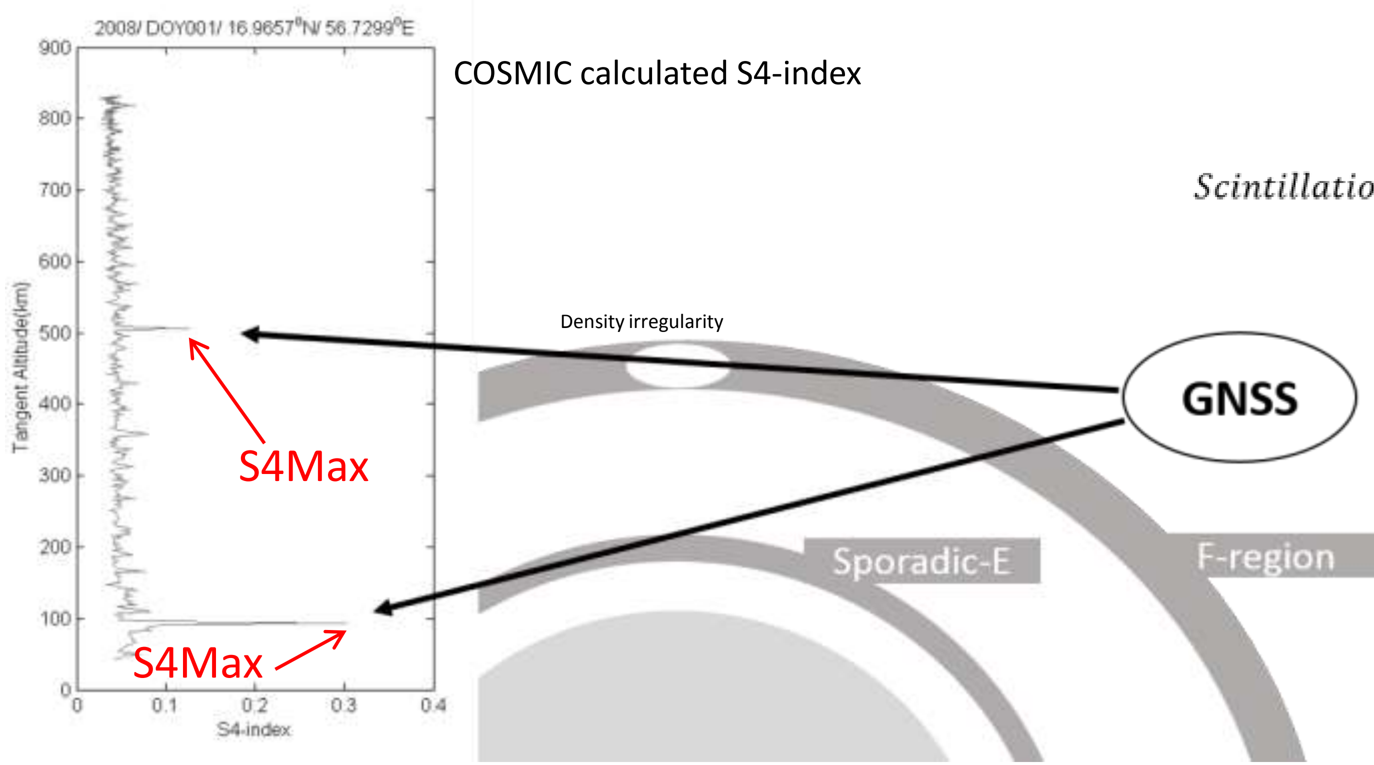
Basu et al. [JASTP 2002]

FORMOSAT-3/COSMIC S4-index measures signal-to-noise intensity fluctuations from the raw 50-Hz L1 amplitude measurements and these intensity measurements and recorded in a 1-Hz data stream.

$$S_4 = \frac{\sqrt{\left\langle \left(I - \overline{\langle I \rangle}\right)^2 \right\rangle}}{\overline{\langle I \rangle}}$$

$\langle I \rangle$: mean RMS intensity within 1 sec (mean value of 50 data)

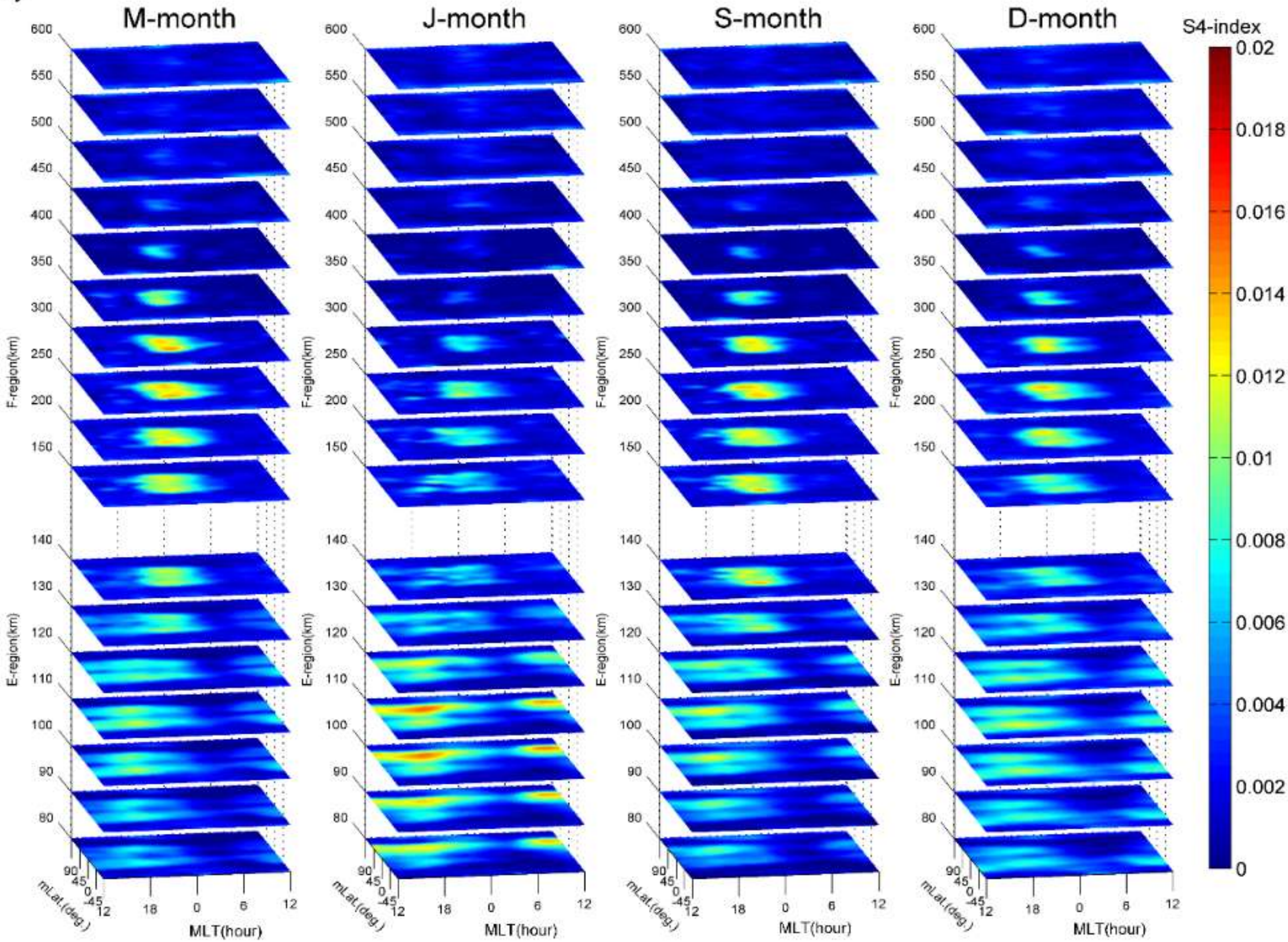
$\overline{\langle I \rangle}$: a low-pass filtered 1 sec mean RMS intensity (Low-pass filtered $\langle I \rangle$, to be short.)



$$Scintillation \propto \frac{\Delta N}{N}$$

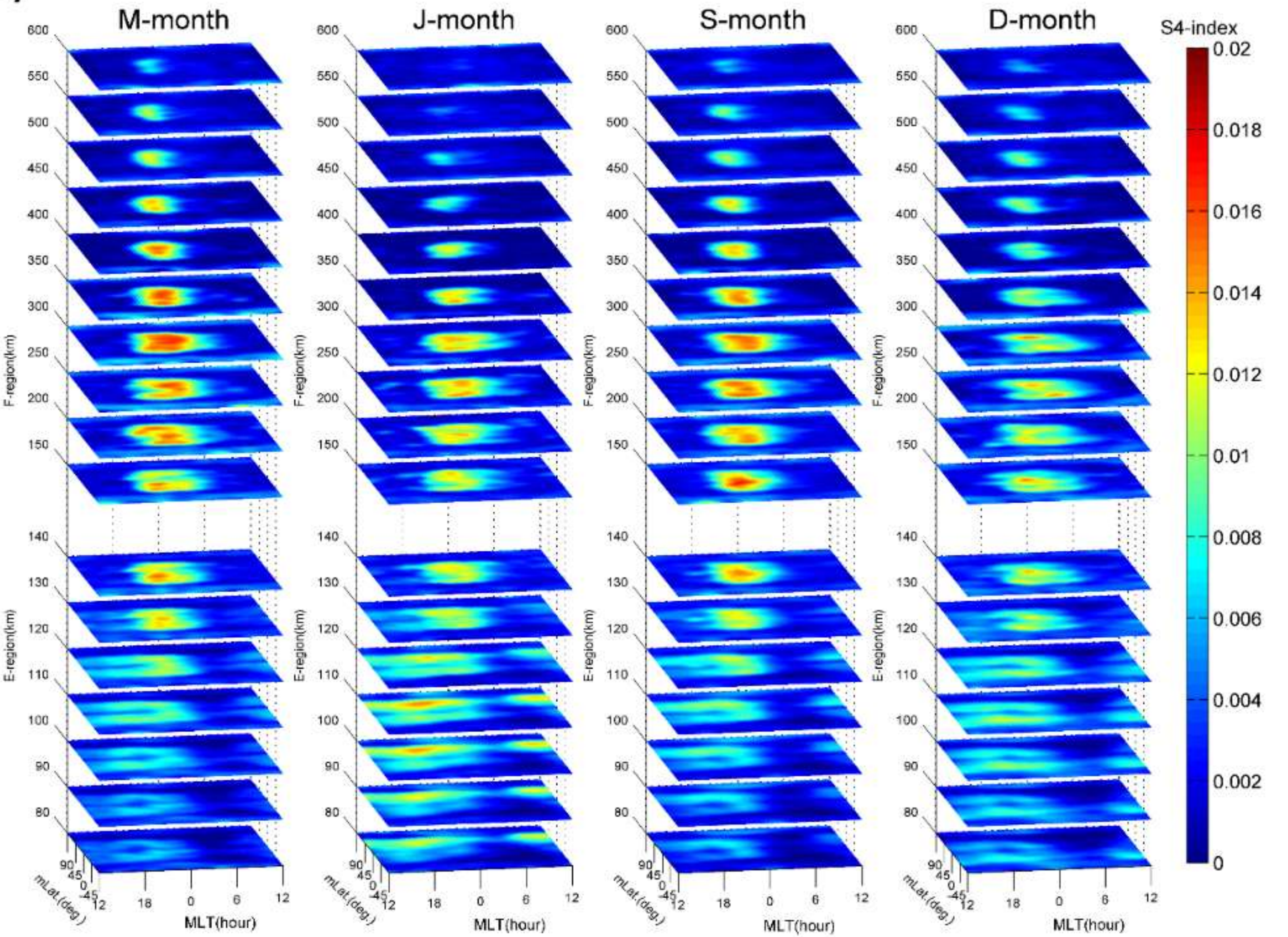
(a) the solar minimum

Liu et al. [SGP 2015]

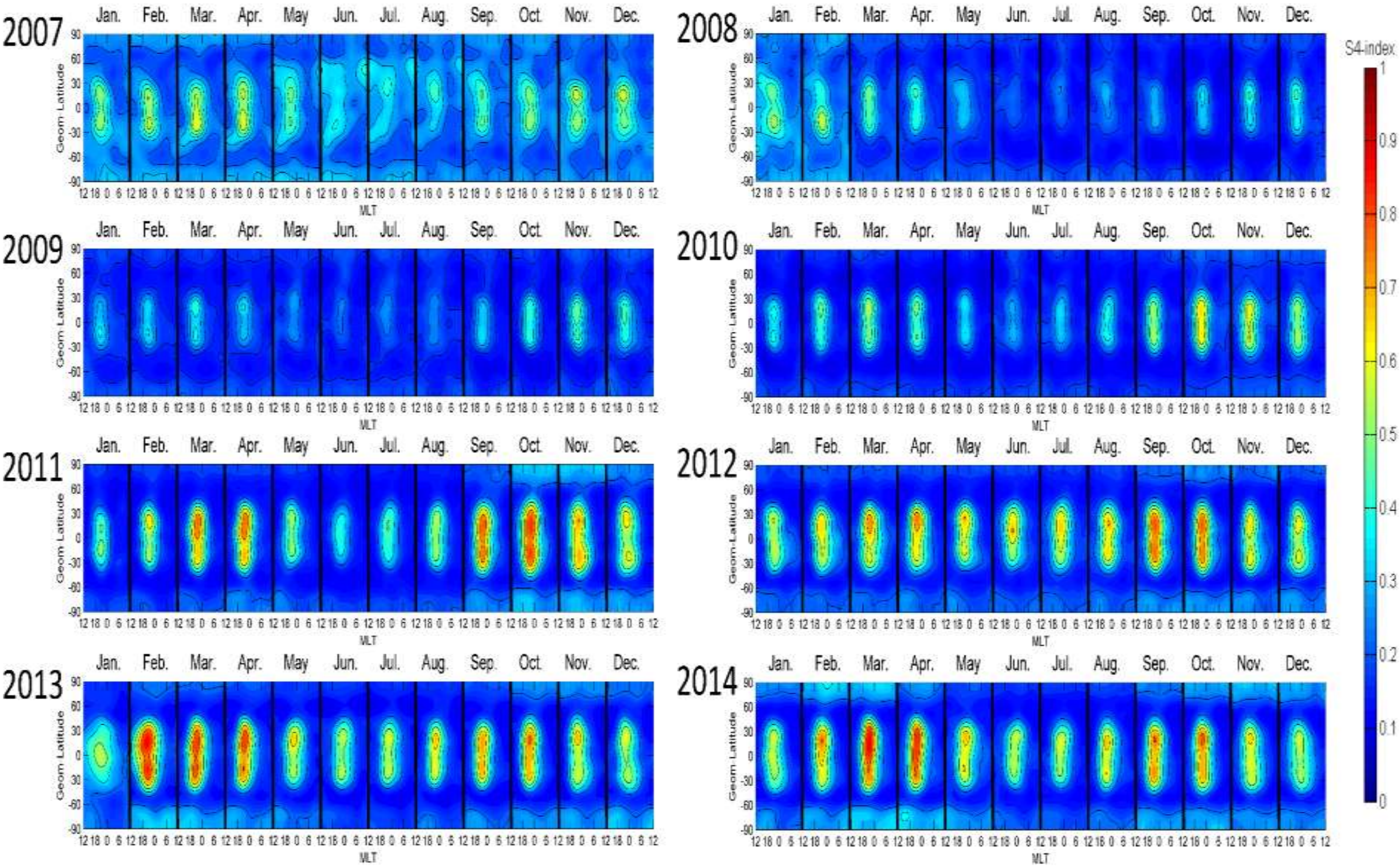


(b) the solar maximum

Liu et al. [SGP 2015]

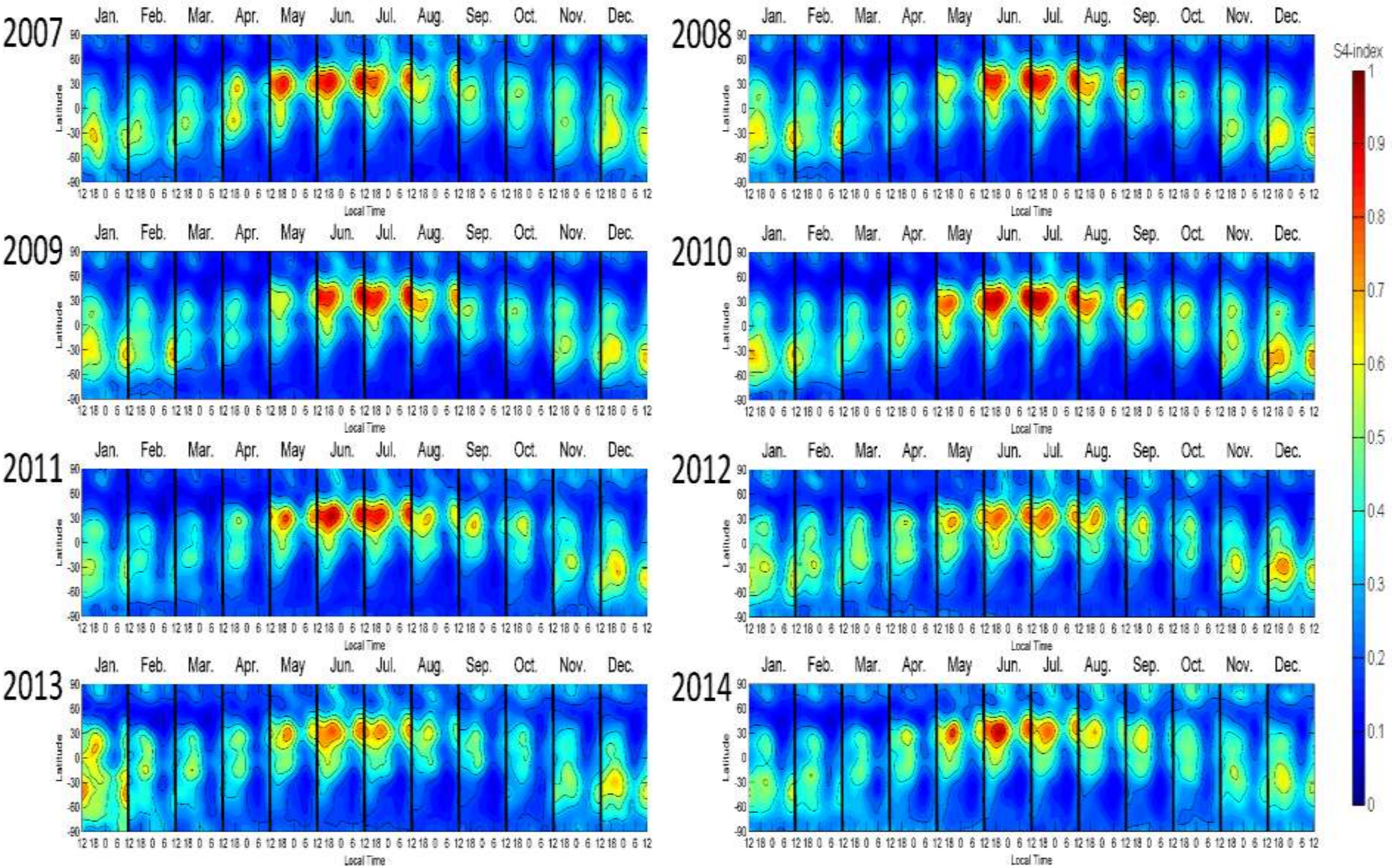


The F-region (i.e. 150-450km) S4max in 2007-2014.



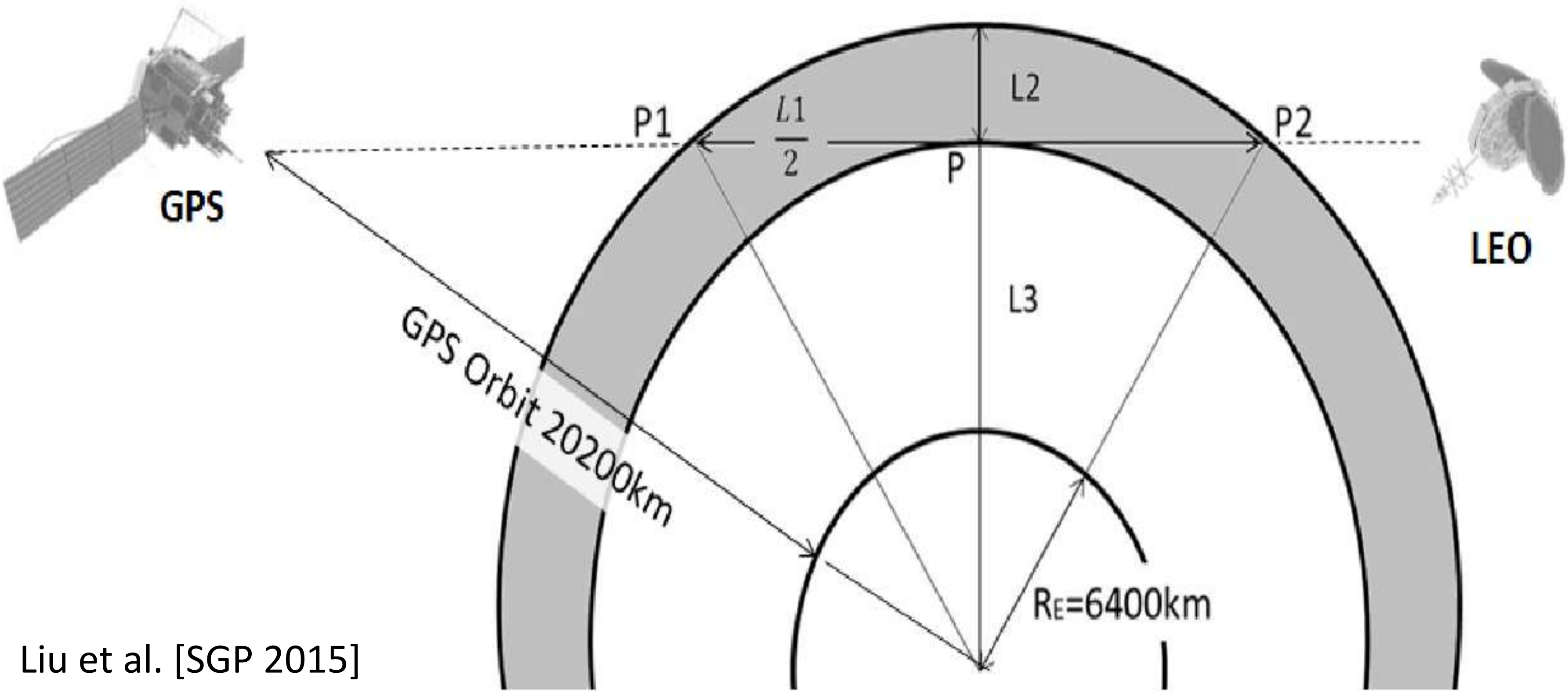
Liu et al. [SGP 2015]

The E-region (i.e. 80-130km) S4max in 2007-2014.



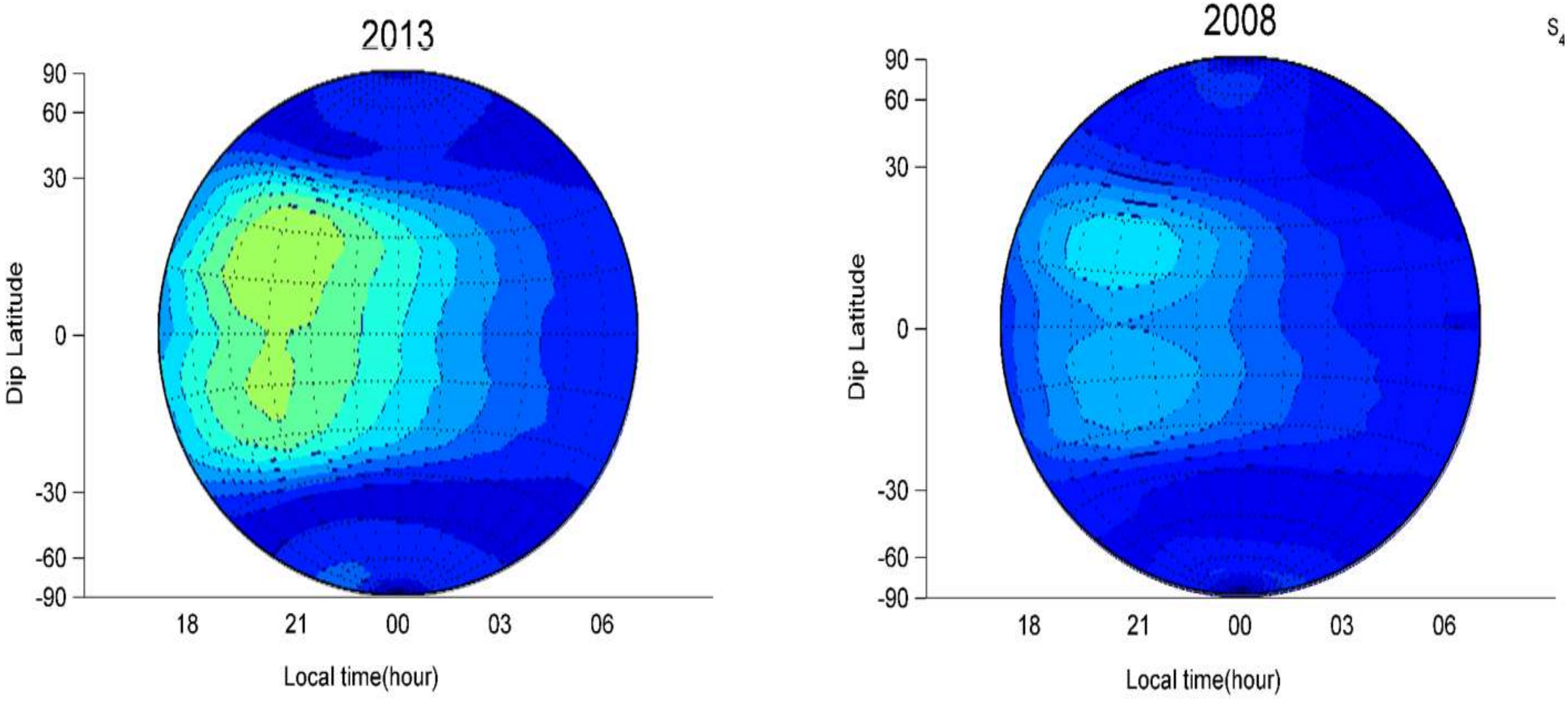
Liu et al. [SGP 2015]

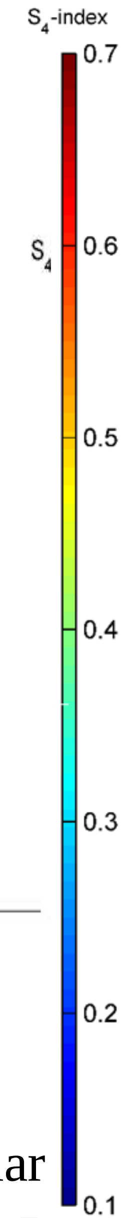
The conversion of the space based F3/C RO scintillation to the ground-based one.



Liu et al. [SGP 2015]

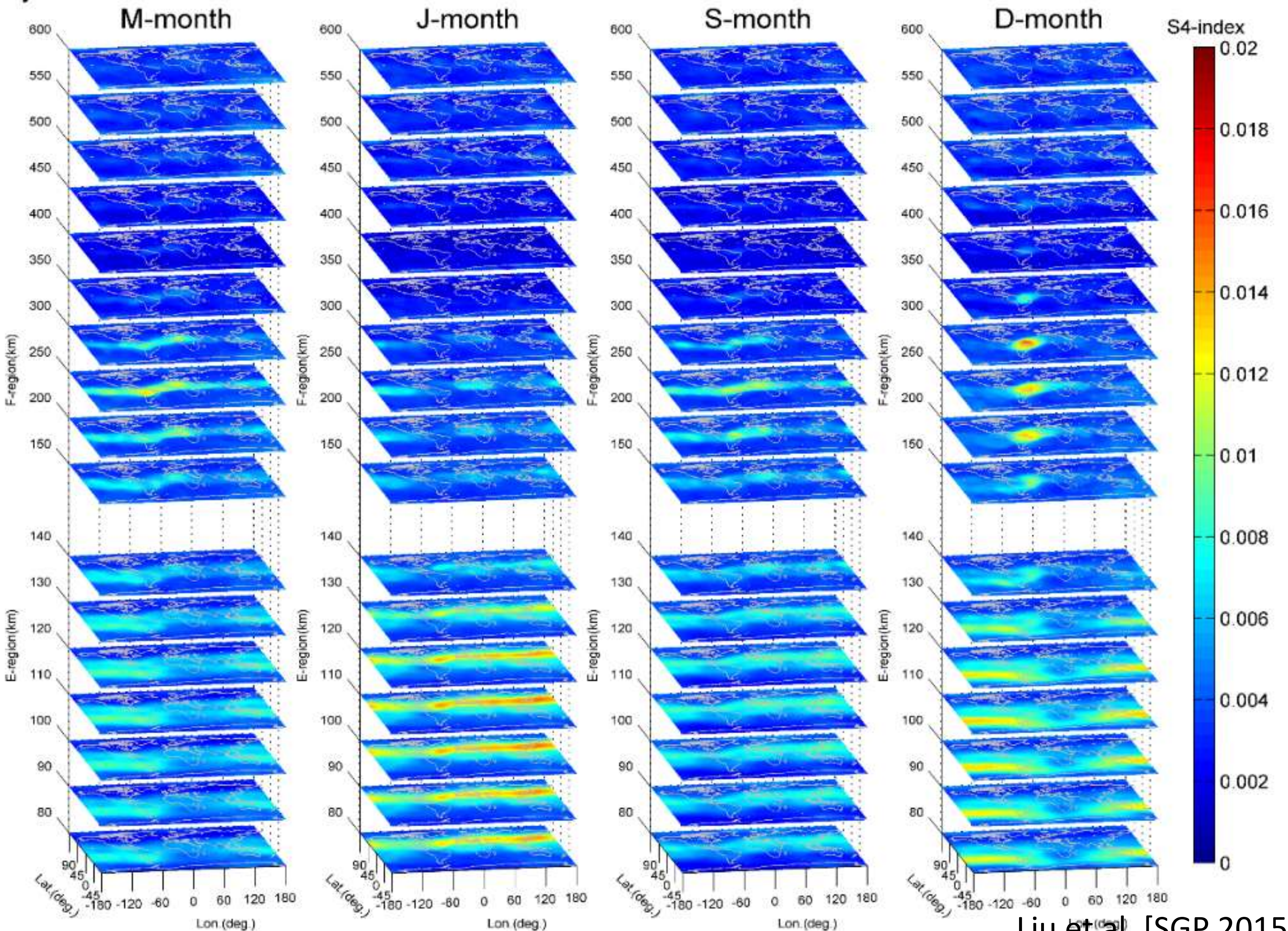
A Gnomonic projection of annual mean diurnal S4max variation





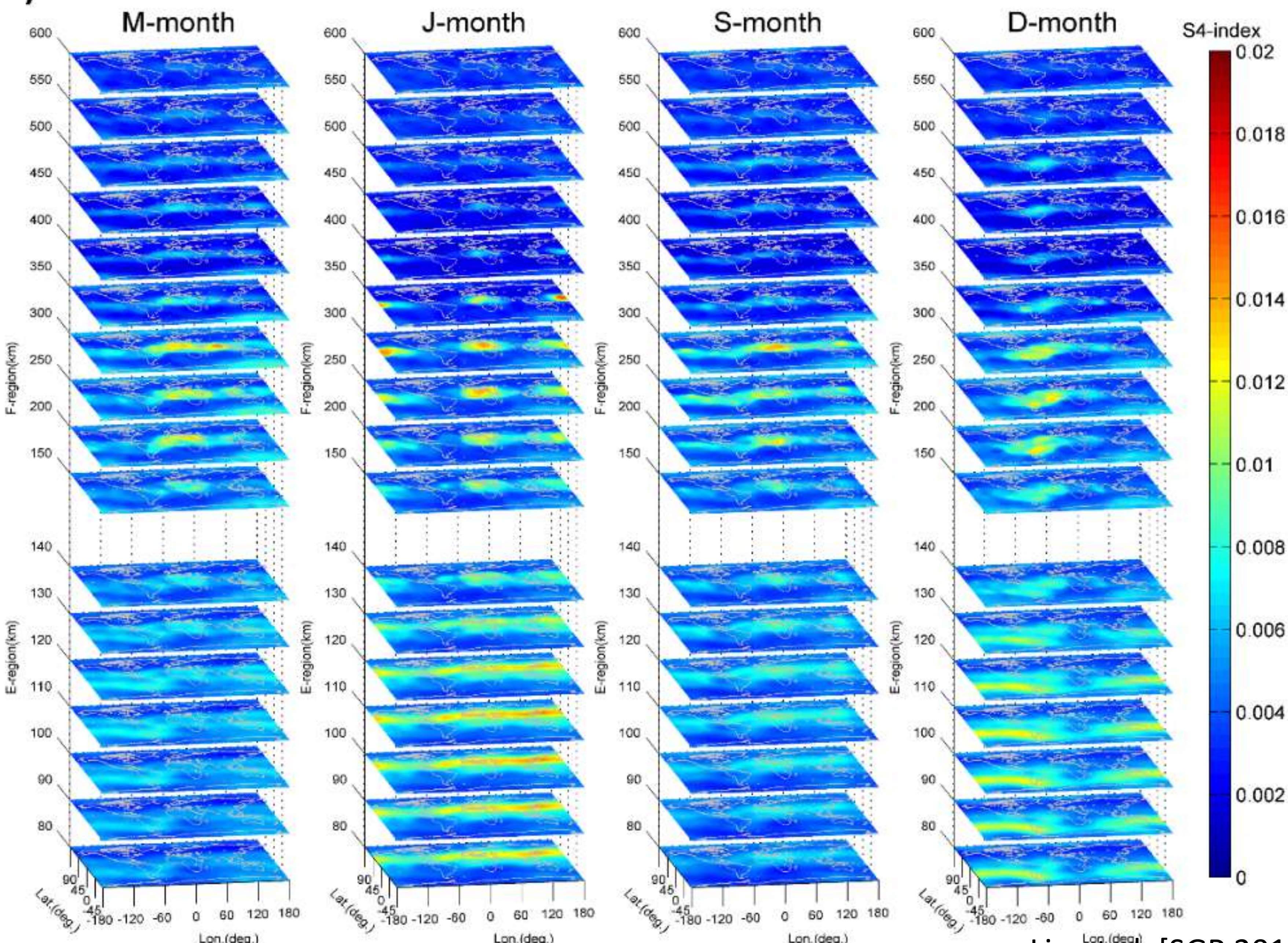
The global S4-index diurnal variation in Gnomonic projection during (a) solar minimum year 2008, and (b) solar maximum year 2013.

(a) The geographic distribution of S4max in solar minimum

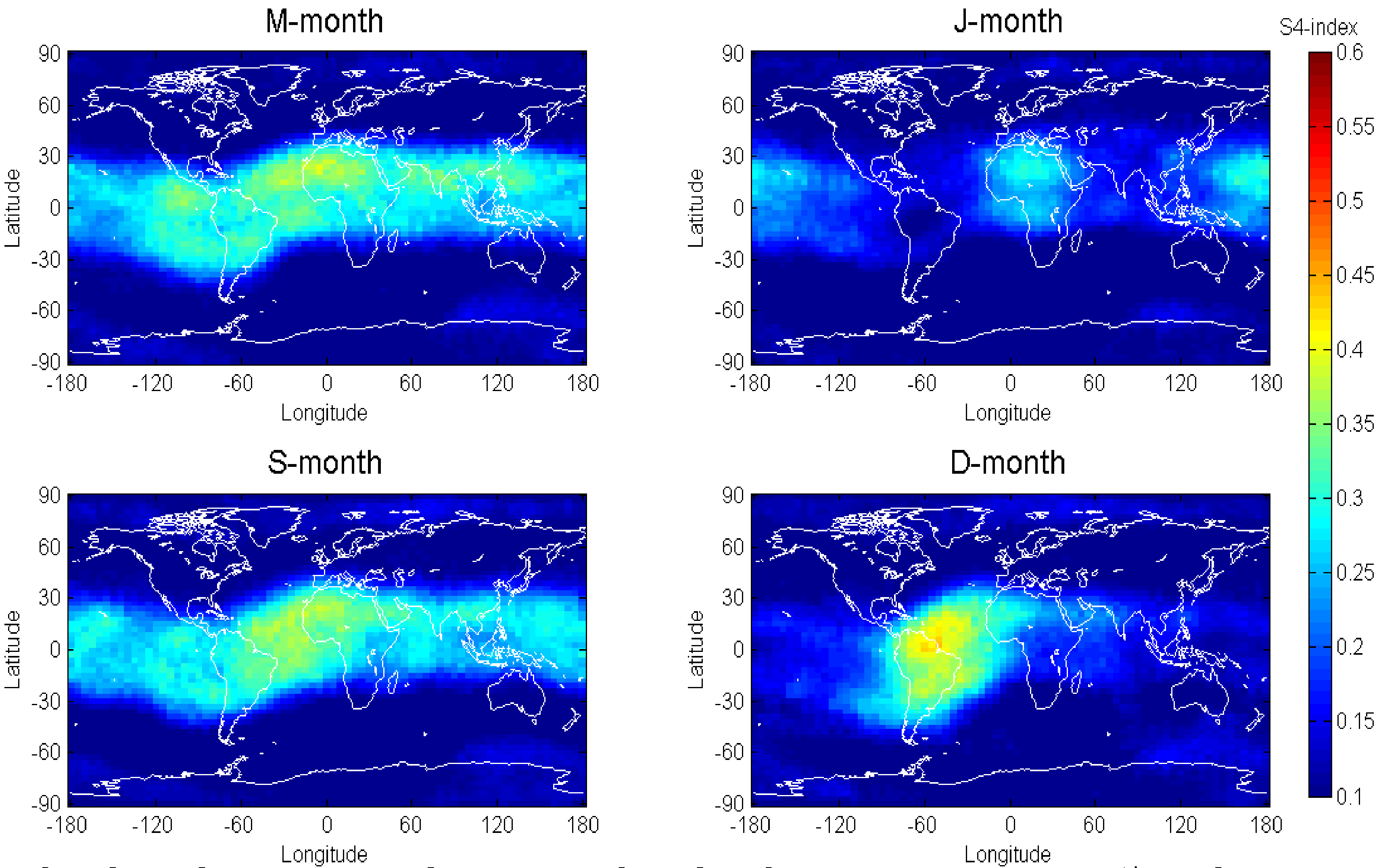


Liu et al. [SGP 2015]

(b) The geographic distribution of S4max in solar maximum



Liu et al. [SGP 2015]



The diurnal mean S4-index geographic distribution in equinoxes (±45 days to March 22th and September 22th) and solstices (±45 days to June 22th and December 22th) during the F3/C operation period 2007-2014.

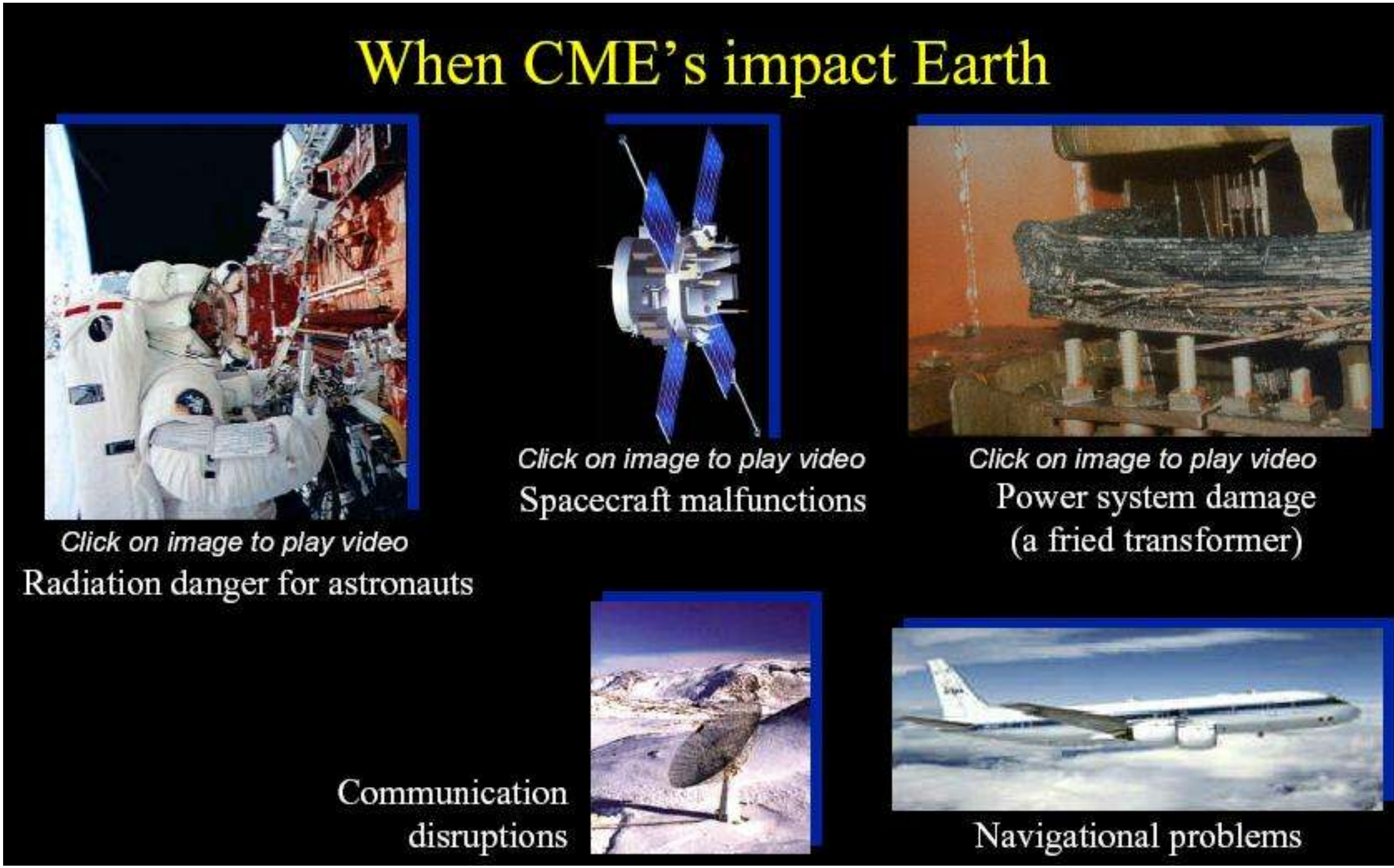
Remark

- The most prominent signatures of the F3/C S4 max in the E- (F-)region are in middle (equatorial-low) latitudes of the Summer J-month (equinox) months.
- The F3/C S4 max in the E-region is mainly contributed by the Es (sporadic-E) layer. Neutral wind is essential!
- The F3/C S4 max in the F-region lies between 20N and 20S and expends to higher latitudes in the equinox and D months. E×B plasma fountain is essential!

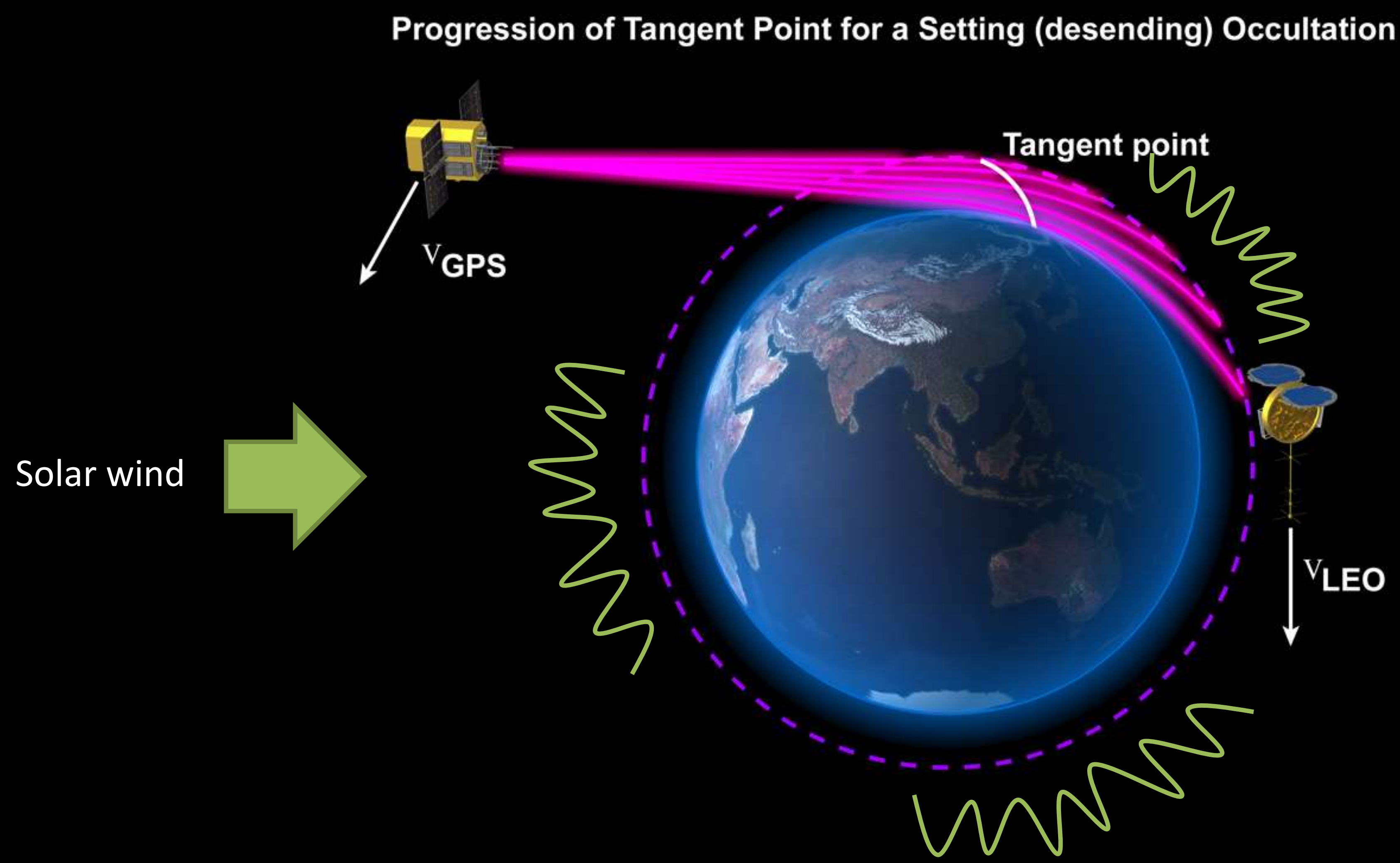
Remark

- The worst case scintillation on the ground appears in the low-latitude of $\pm 30^{\circ}$ peaking around $\pm 20^{\circ}$ mLat from the post-sunset of 1900 MLT till post-midnight of 0200-0300 MLT.
- The place experienced the worst-case scintillation is the low-latitude ionosphere between South America and **Africa**.
- F3/C provides 3D structure and dynamics of the ionospheric scintillation of GPS (GNSS) signals for the positioning, navigation, and communication applications.

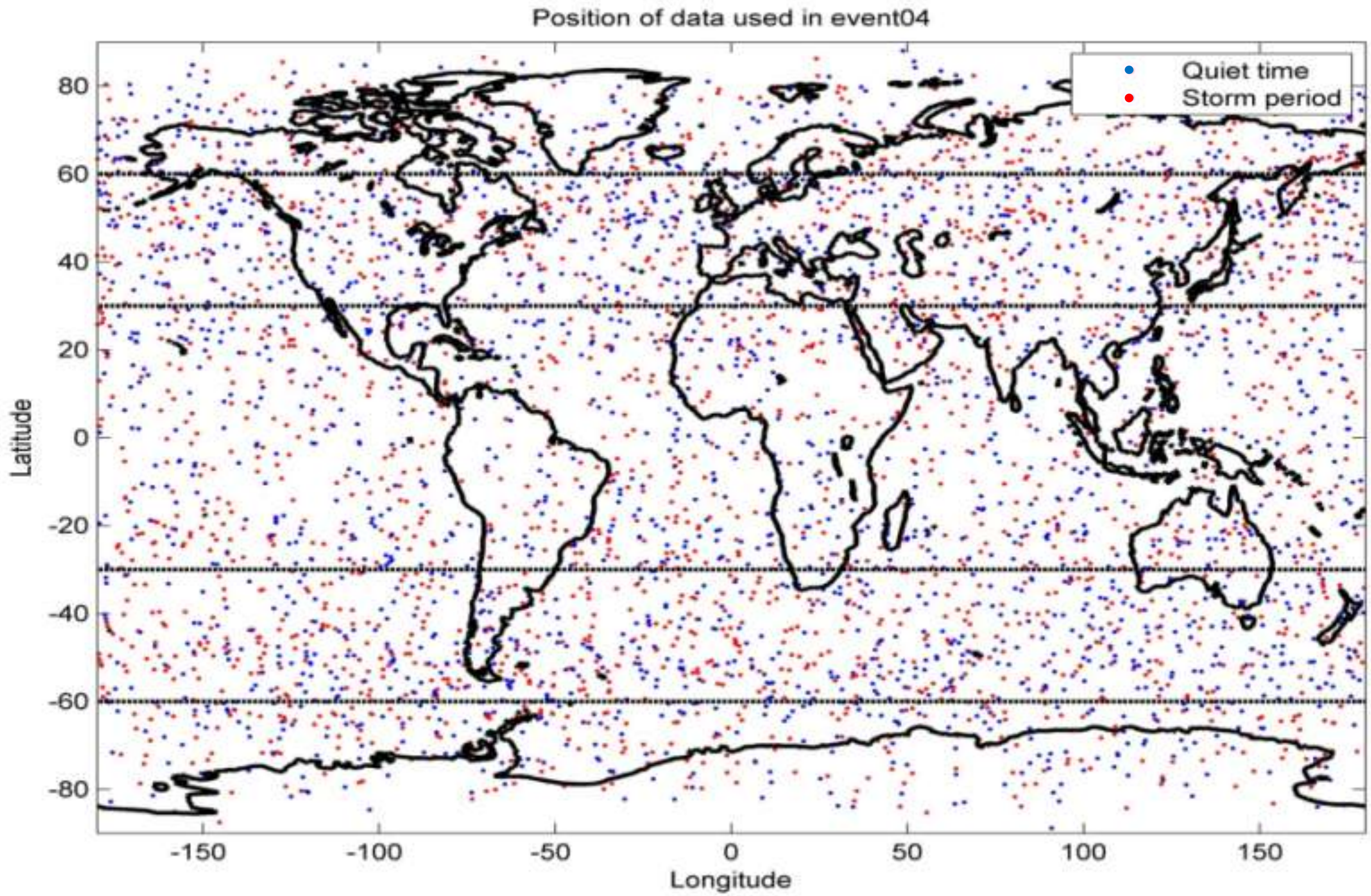
Space Weather: Solar Storm



Storm the Ionosphere

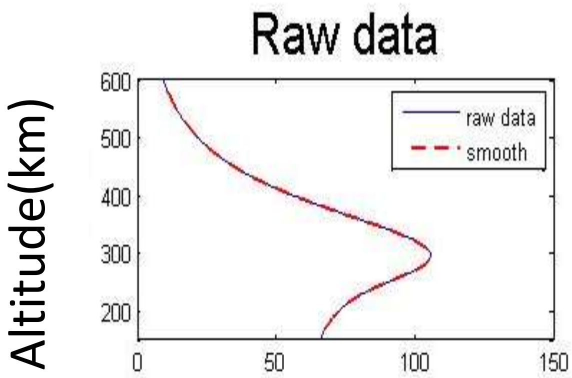


Position of RO profile From 2010/04/30 to 2010/05/04

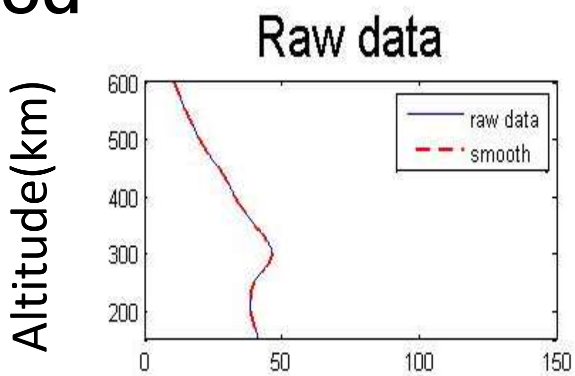


Fluctuations in vertical profiles

Quiet time



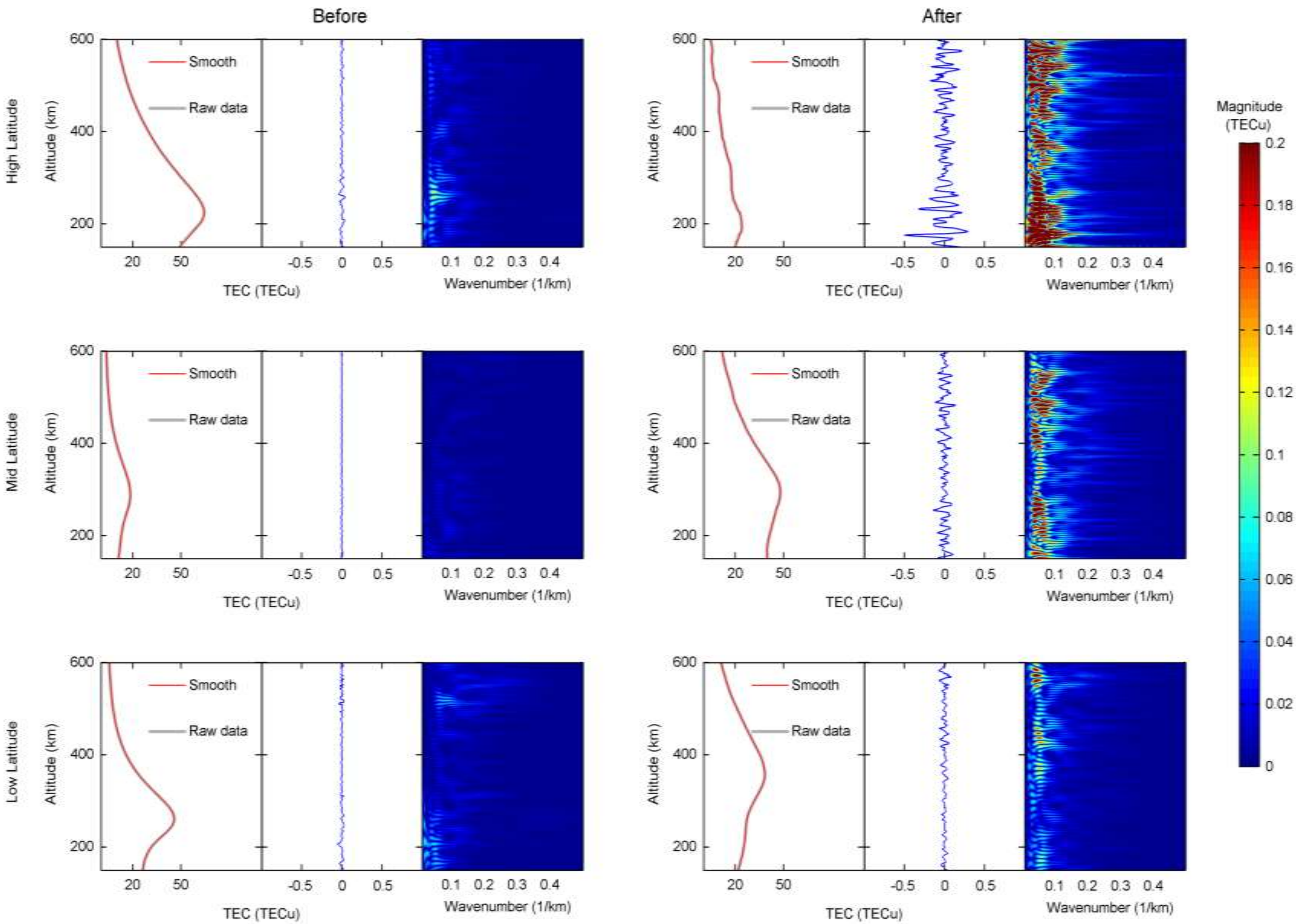
Storm period



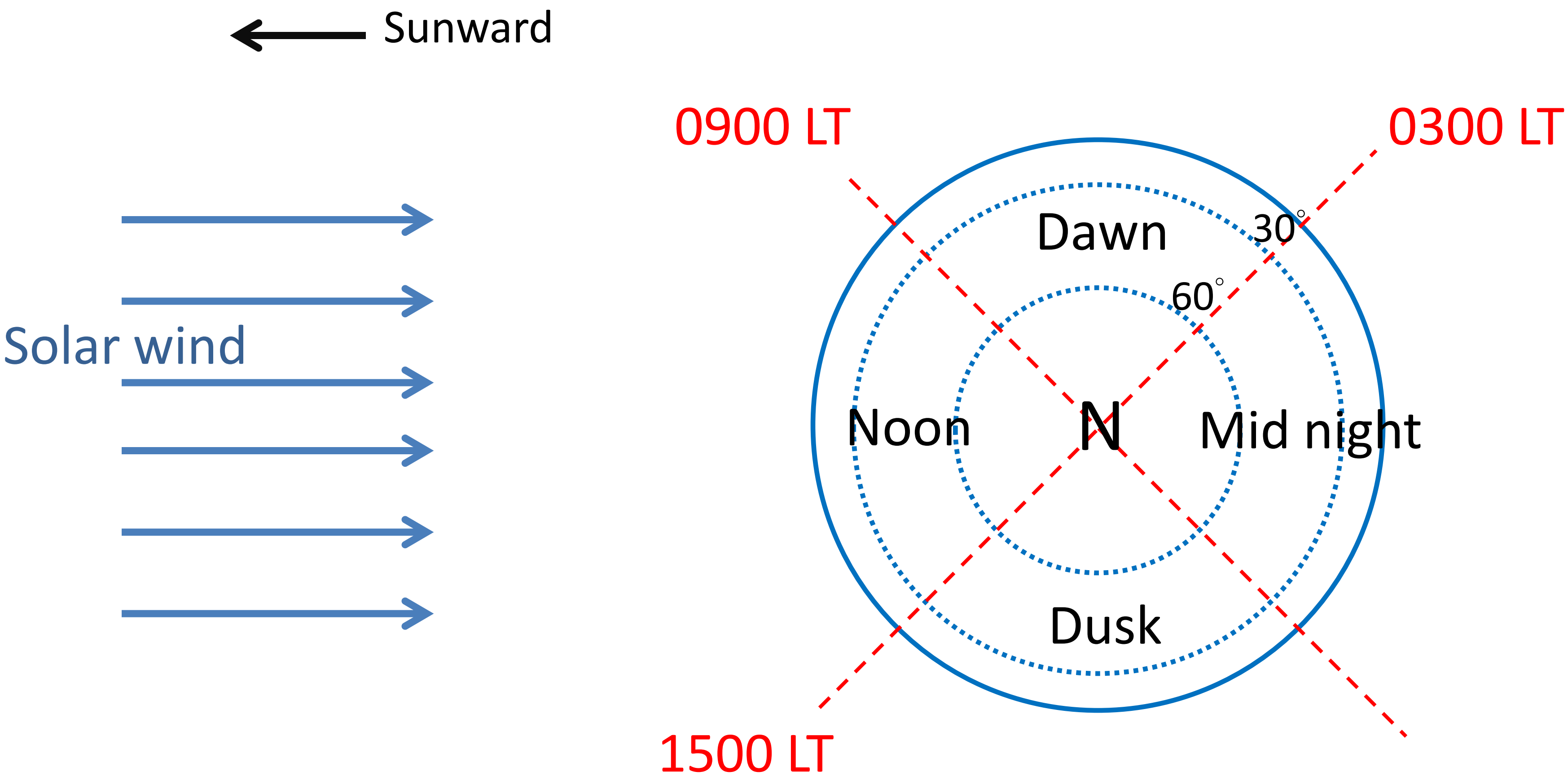
TEC (TECu)

Second order polynomial

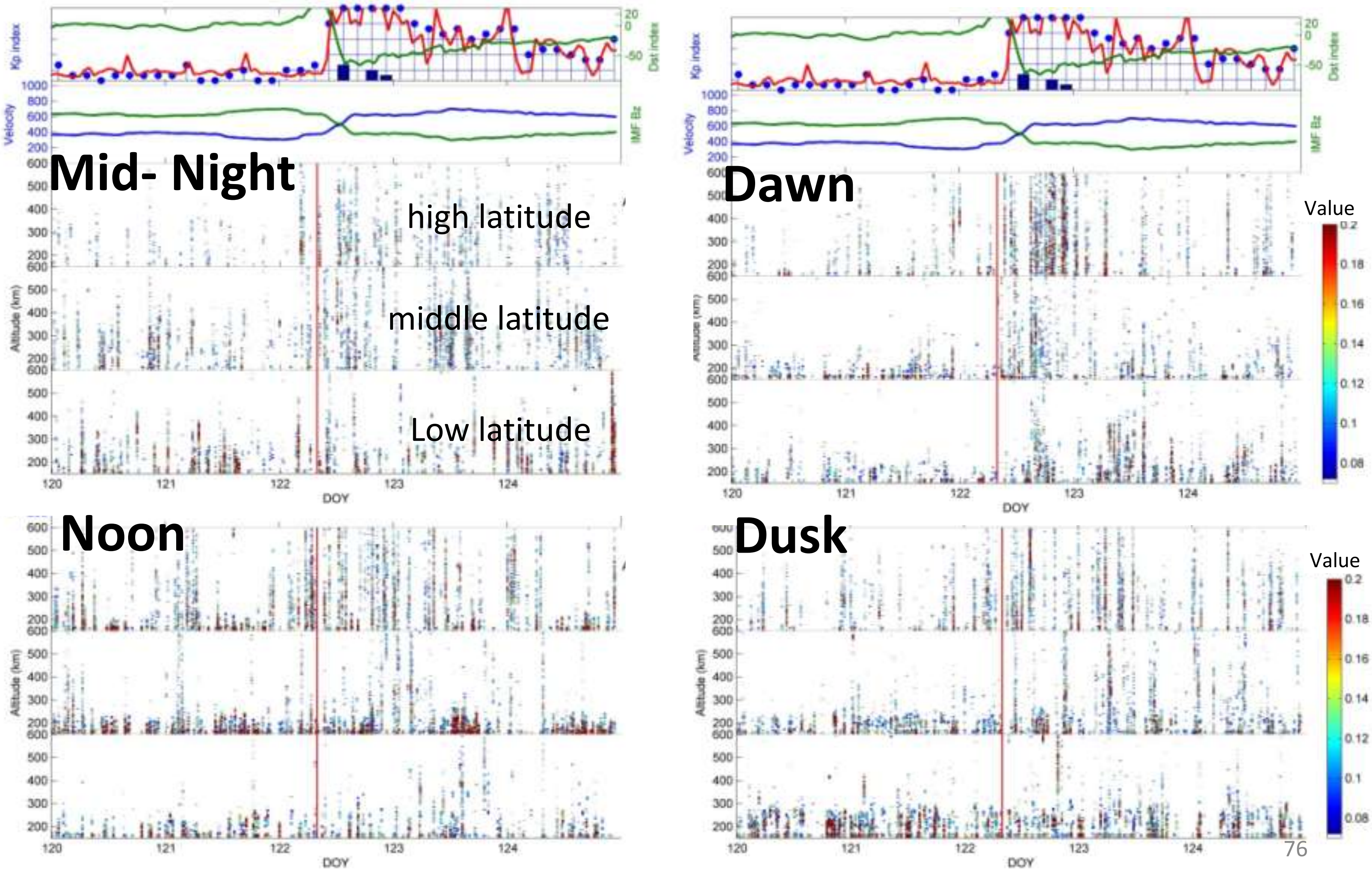
Matlab: smooth



Before
After
High Latitude
Mid Latitude
Low Latitude
Altitude (km)
600
400
200
Smooth
Raw data
20
50
TEC (TECu)
-0.5
0
0.5
0.1
0.2
0.3
0.4
Wavenumber (1/km)
Magnitude (TECu)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0

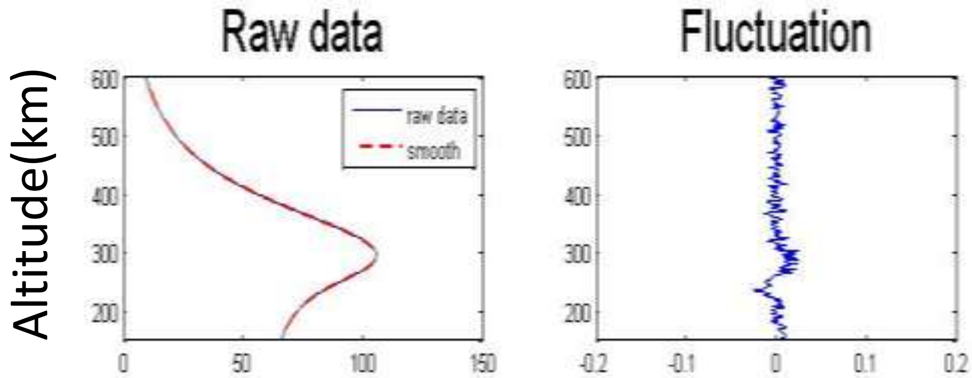

Sunward
Solar wind
0900 LT
0300 LT
Dawn
30°
60°
Noon
N
Mid night
Dusk
1500 LT

TEC vertical fluctuation From 2010/04/30 to 2010/05/04

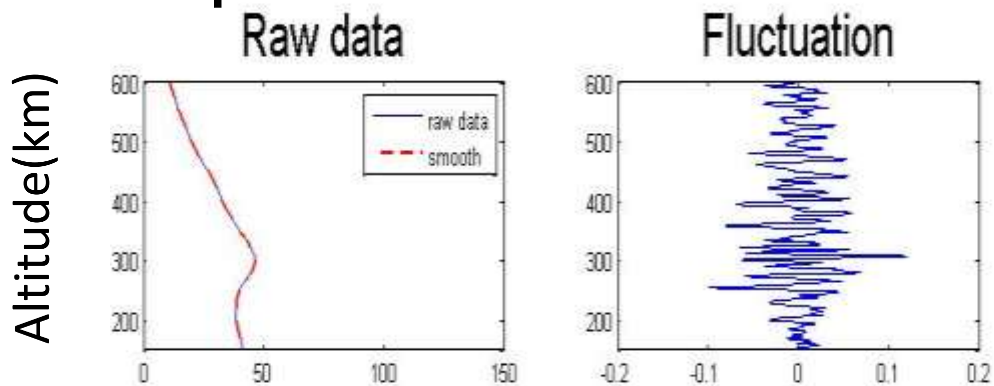


Vertical fluctuation profile

Quiet time

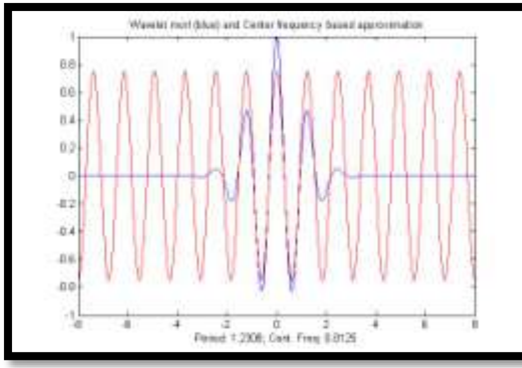


Storm period



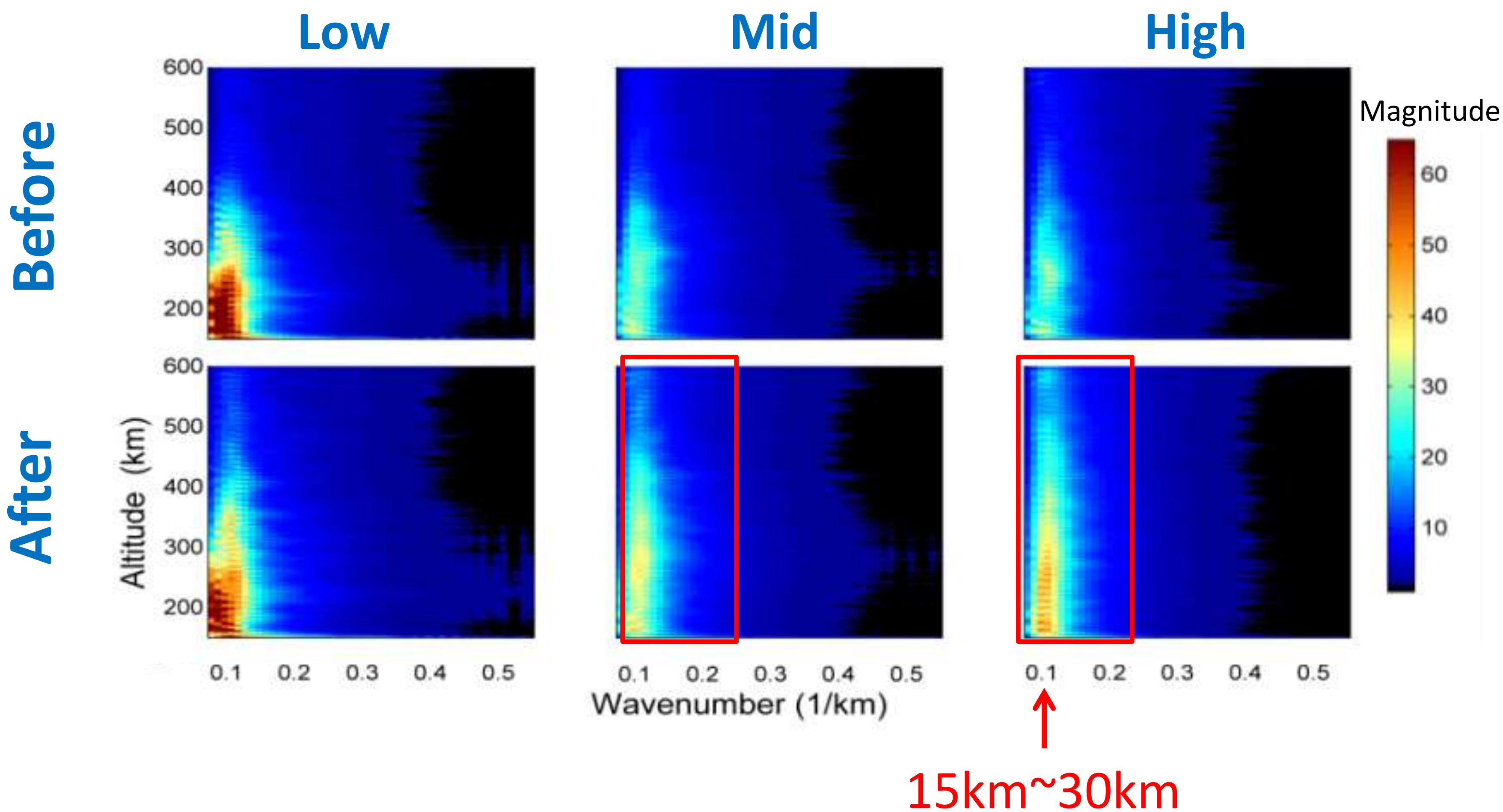
TEC (TECu)

Mother wavelet- Morlet

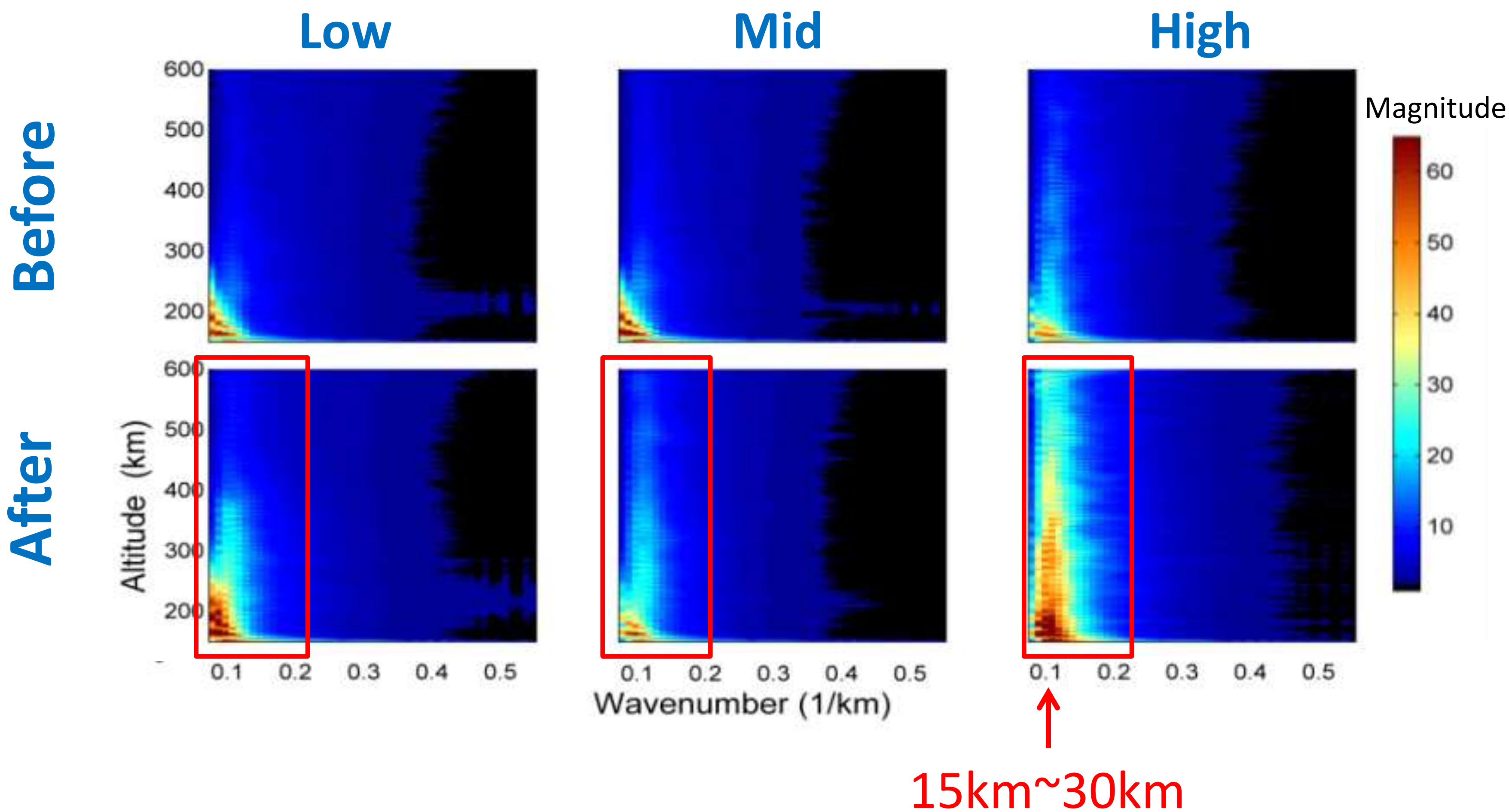


Wavenumber

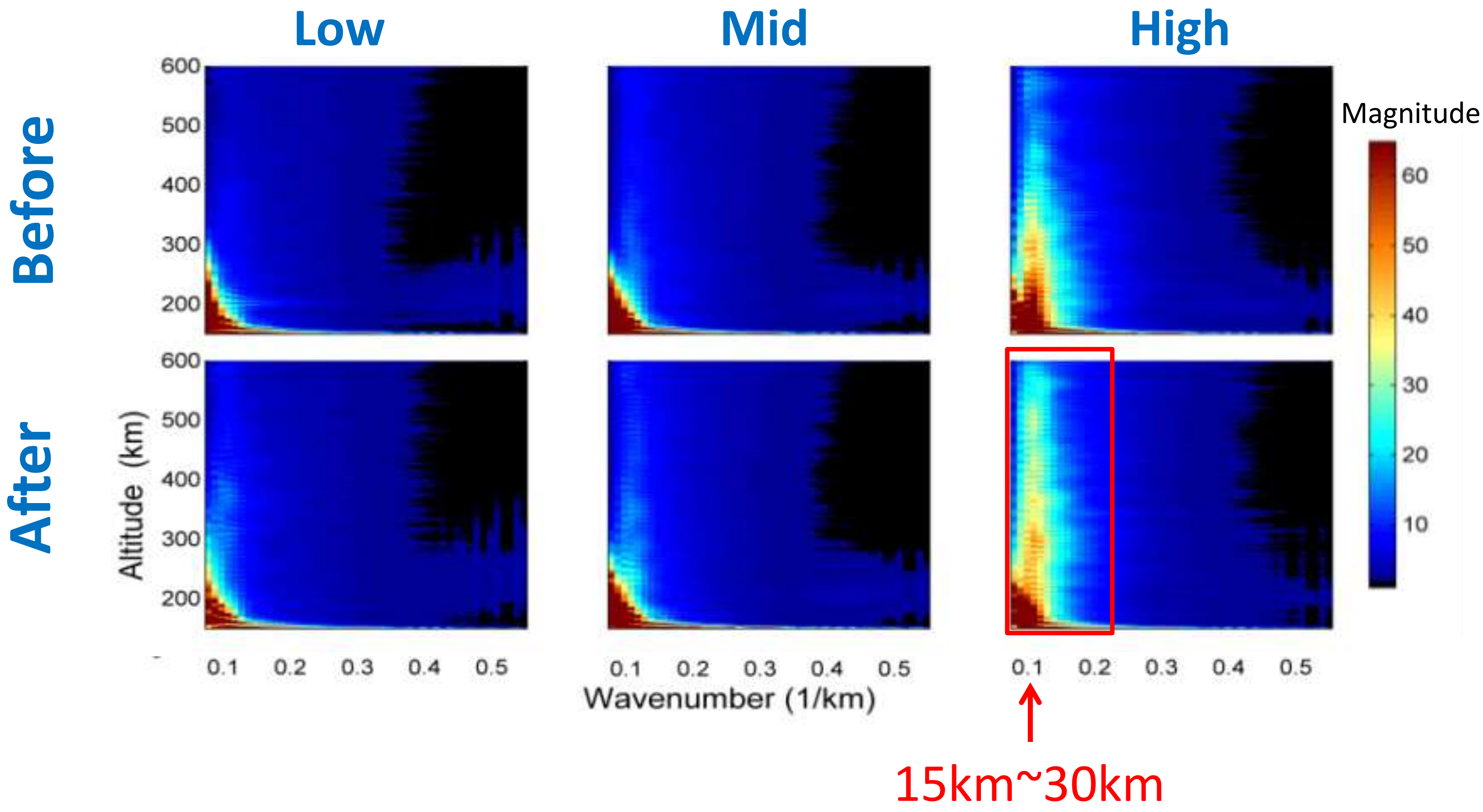
2010/05/02 TEC vertical fluctuation
Mid-night side



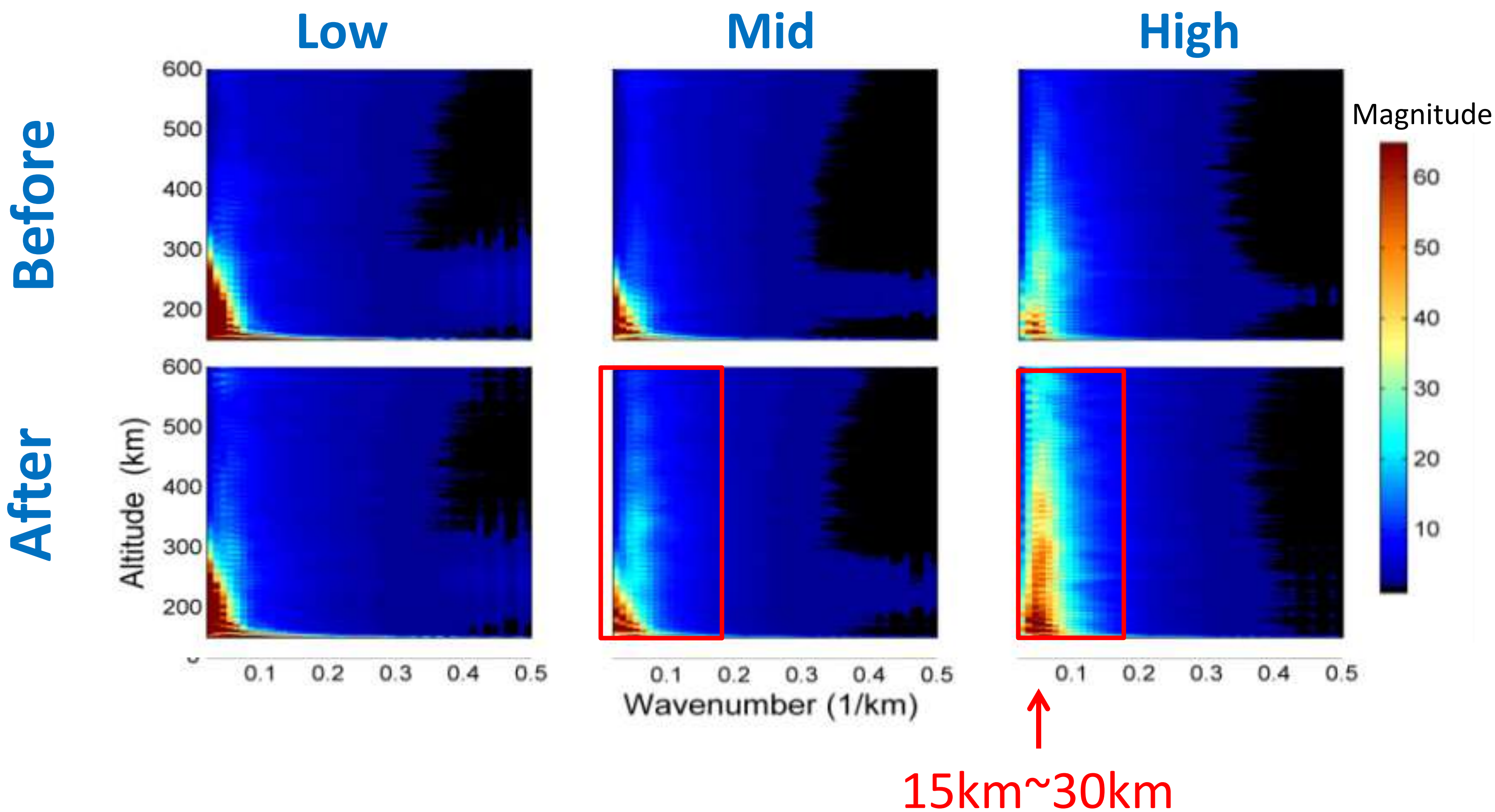
2010/05/02 TEC vertical fluctuation
Dawn side



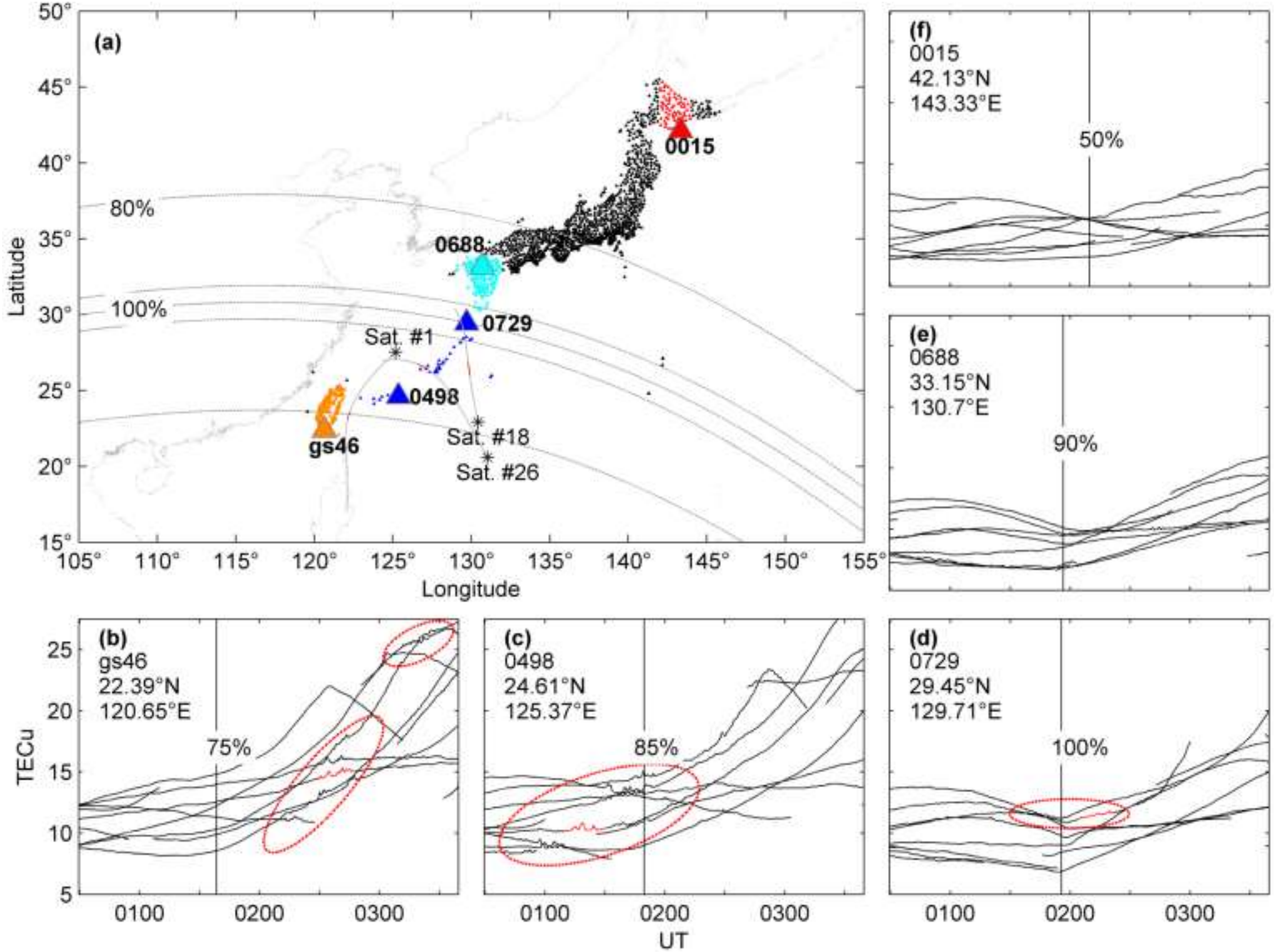
2010/05/02 TEC vertical fluctuation
Noon side



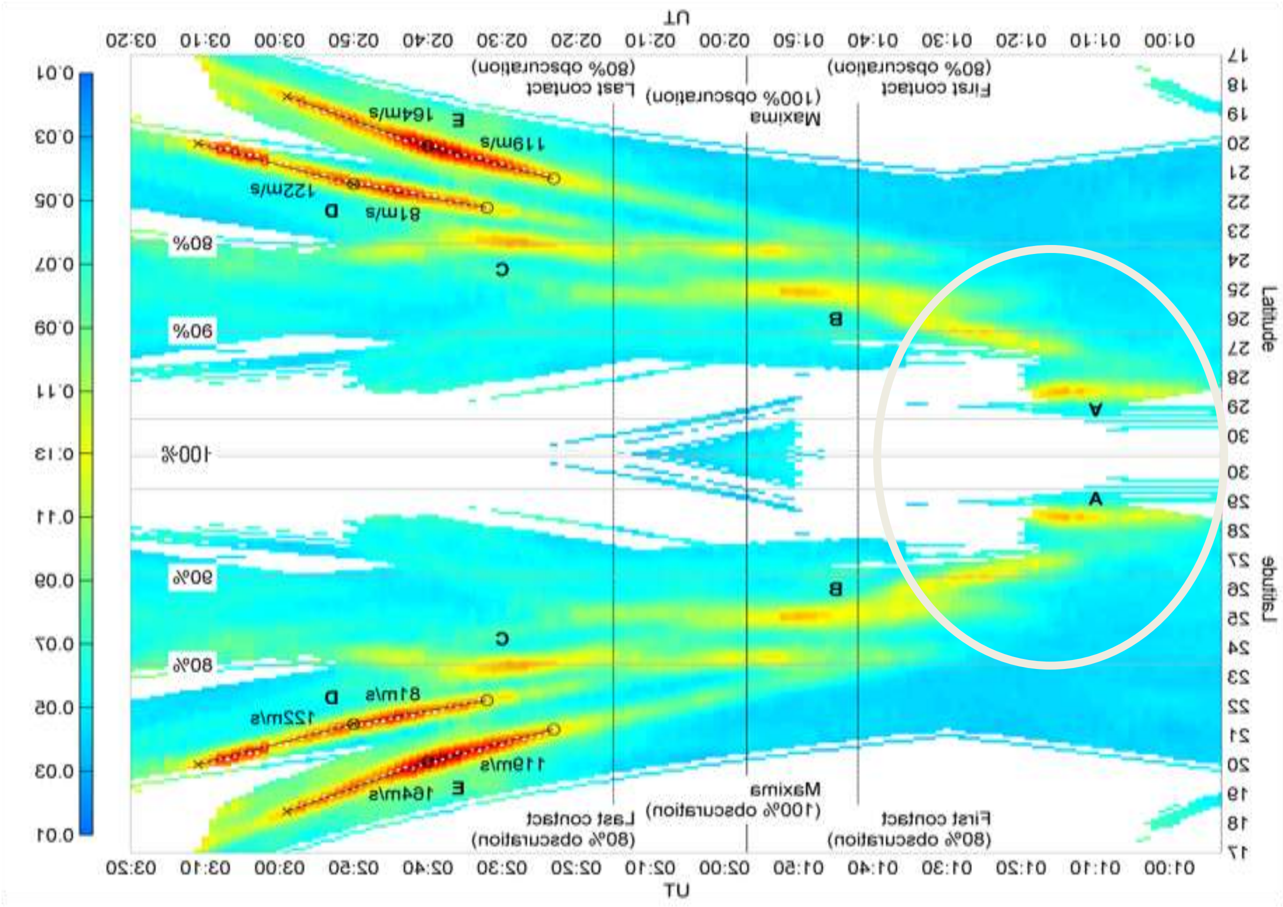
2010/05/02 TEC vertical fluctuation
Dusk side



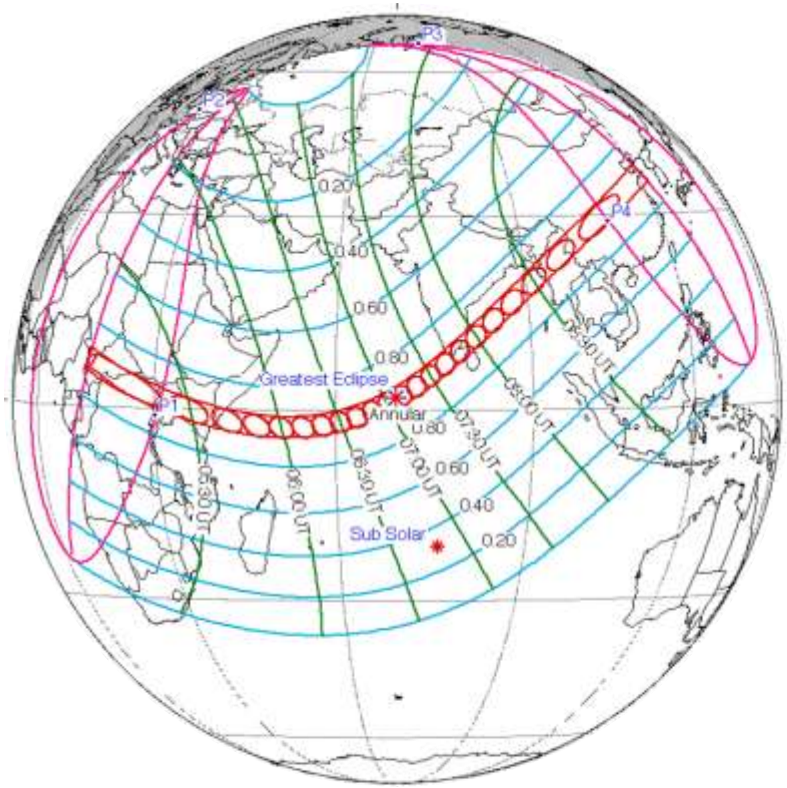
2010/01/15 Annual Solar Eclipse
(Ring of Fire)



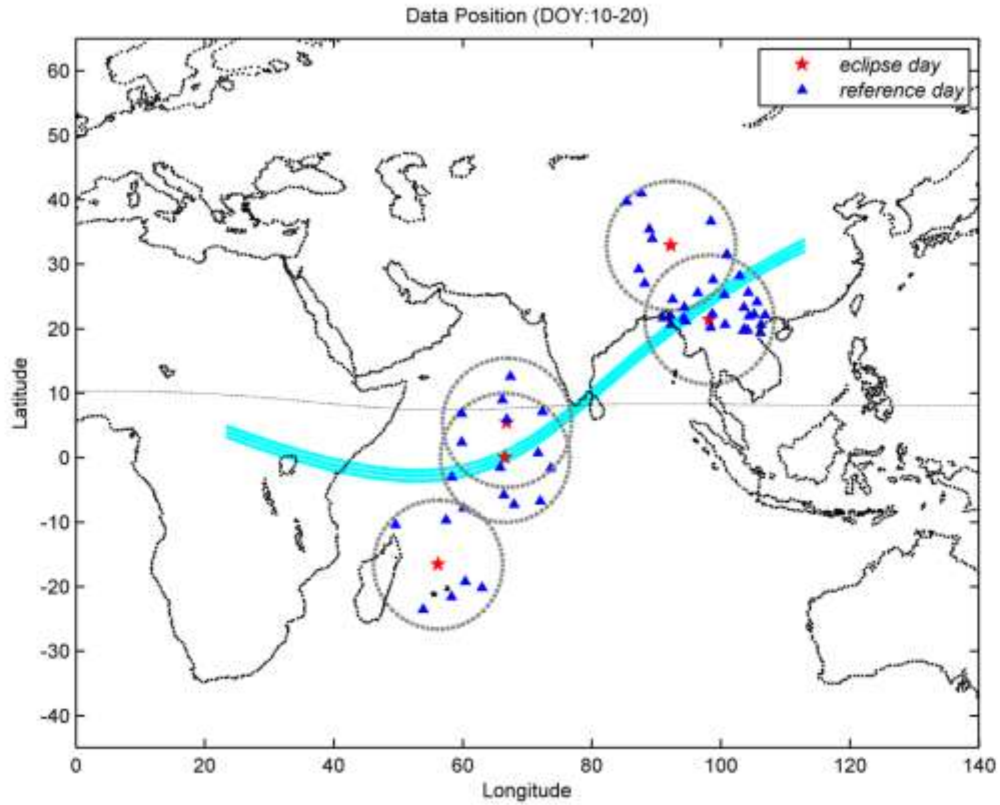
(a)
80%
100%
0015
0688
0729
0498
gs46
Sat. #1
Sat. #18
Sat. #26
Latitude
Longitude
50°
45°
40°
35°
30°
25°
20°
15°
105°
110°
115°
120°
125°
130°
135°
140°
145°
150°
155°
(f)
0015
42.13°N
143.33°E
50%
(e)
0688
33.15°N
130.7°E
90%
(b)
gs46
22.39°N
120.65°E
75%
(c)
0498
24.61°N
125.37°E
85%
(d)
0729
29.45°N
129.71°E
100%
TECu
25
20
15
10
5
0100
0200
0300
UT


UT
Latitude
First contact
(80% obscuration)
Maxima
(100% obscuration)
Last contact
(80% obscuration)
A
B
C
D
E
81m/s
122m/s
119m/s
164m/s
80%
90%
100%

2010/01/15 Annual Solar Eclipse (Ring of Fire)



(http://eclipse.gsfc.nasa.gov/eclipse.html, NASA)

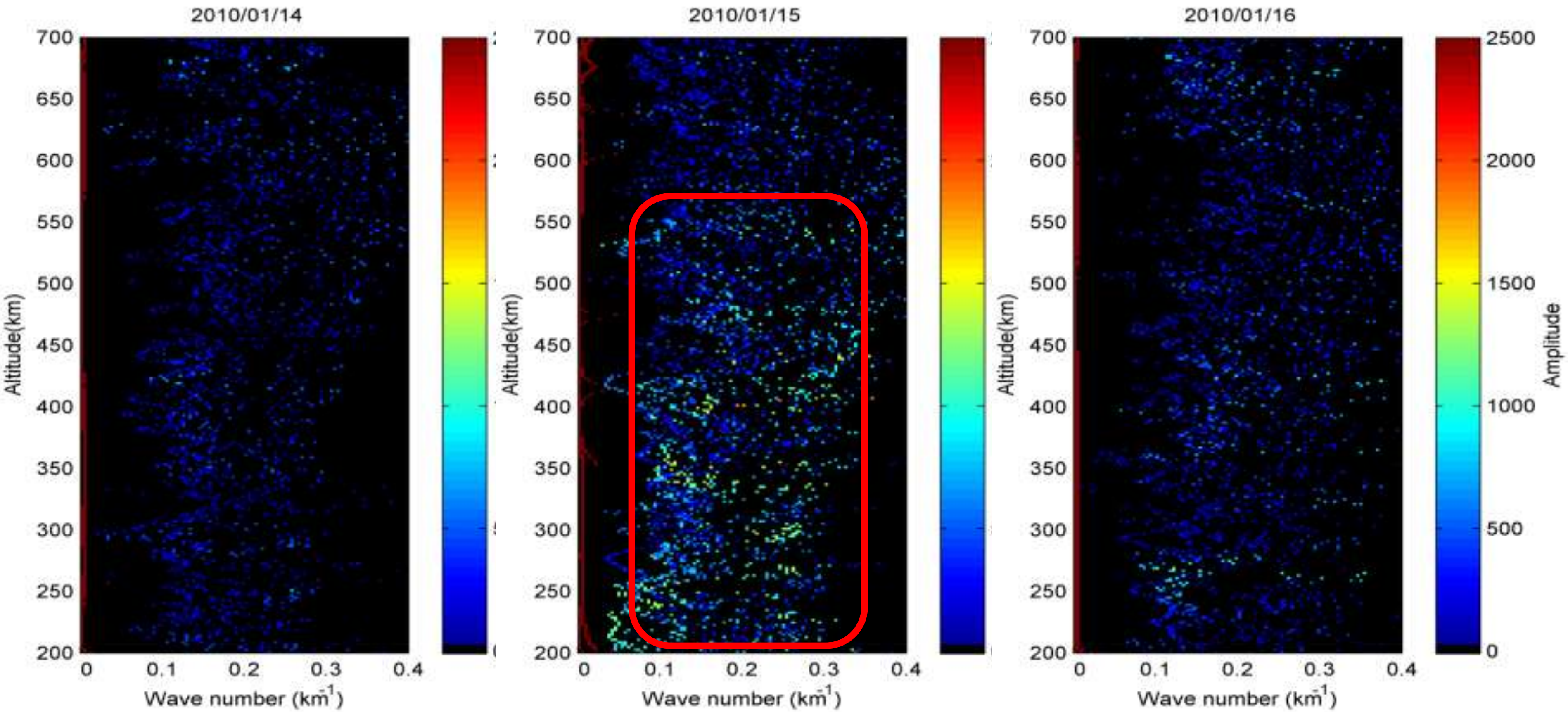


Eclipse period 05:18-08:55 UT

Observation zone: 5

Reference data point in each zone: 7/11/8/12/23

Day 1 Before | Eclipse Day 2010/01/15 | Day 1 After

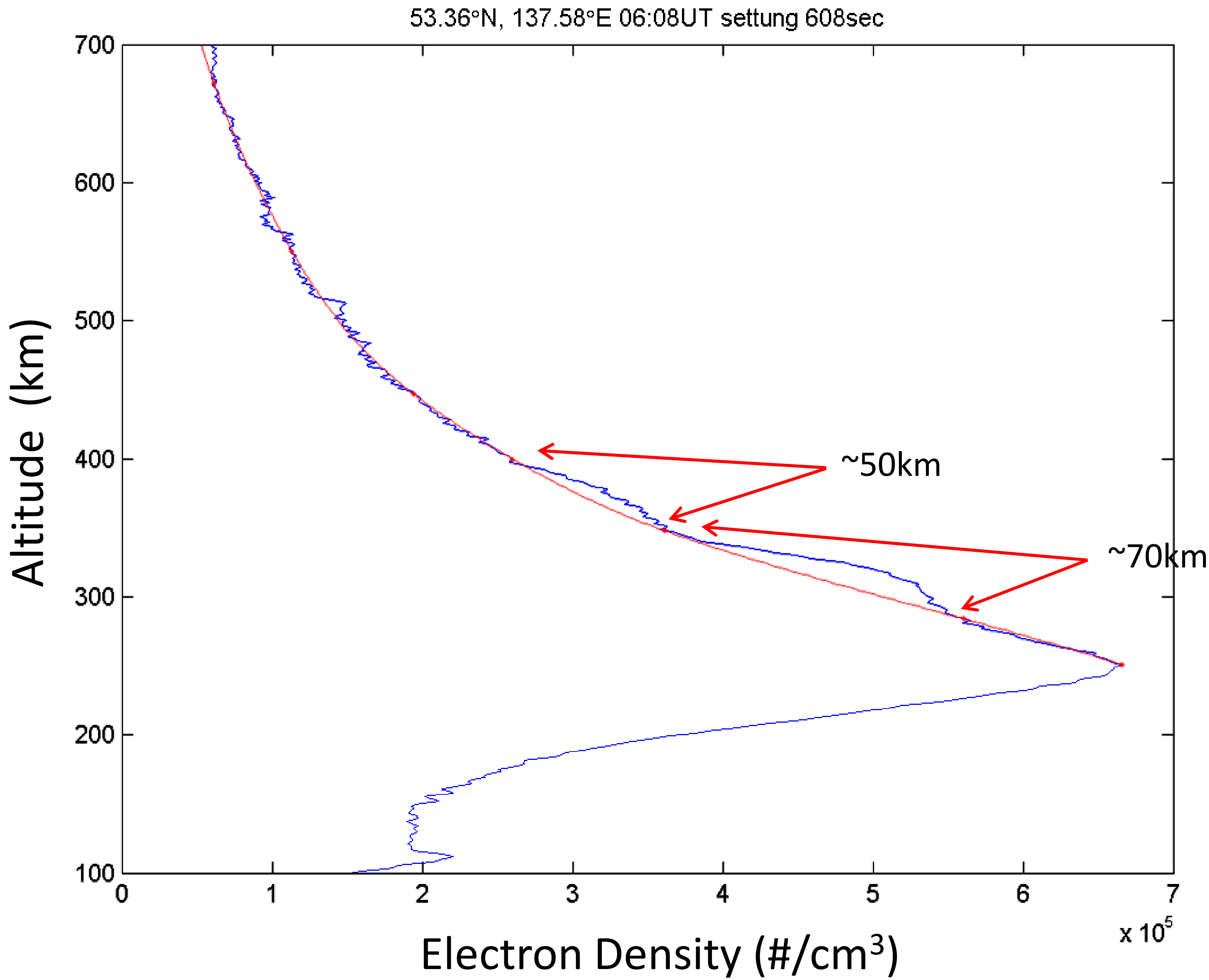


RO Scan the atmosphere and ionosphere

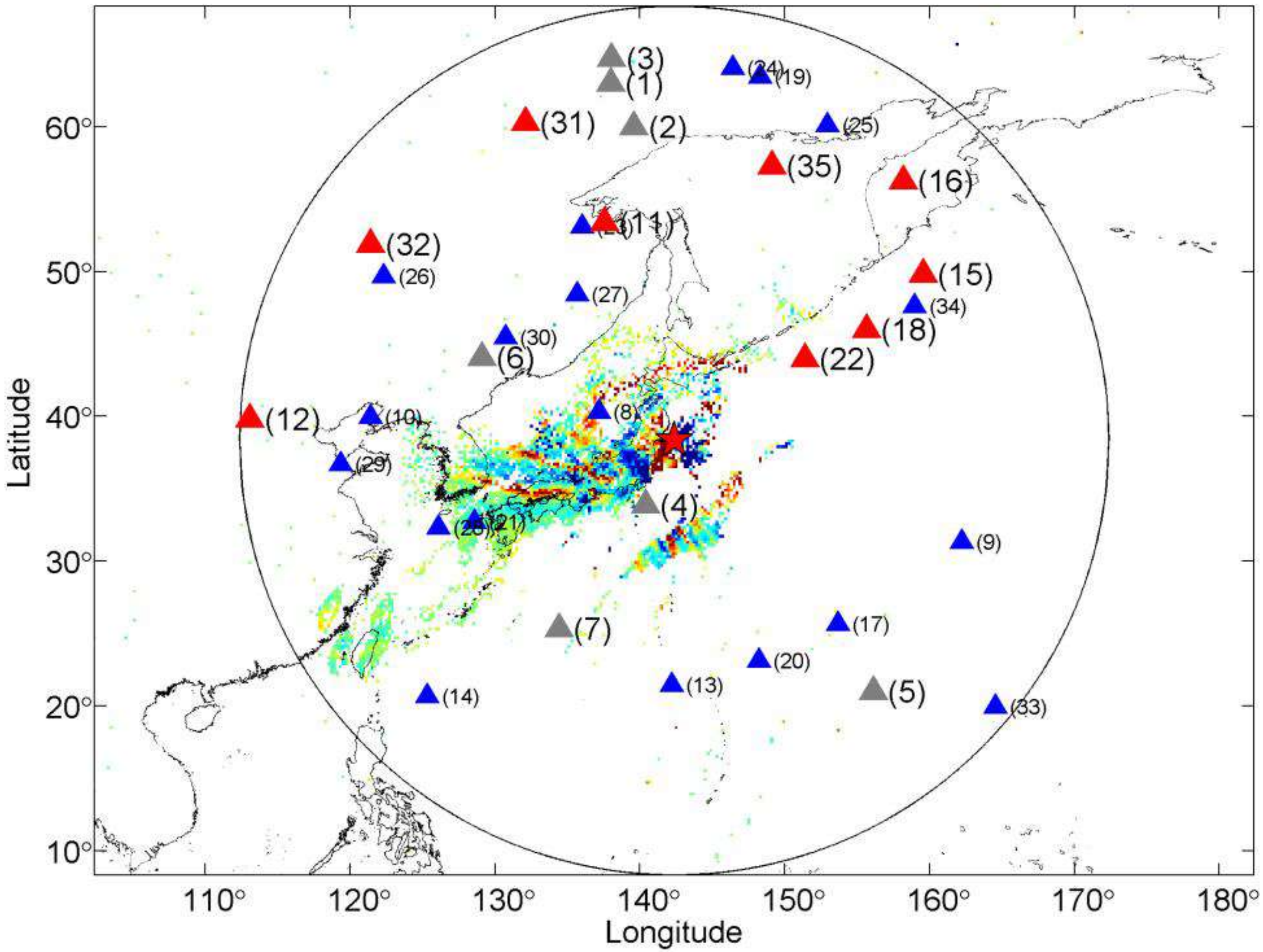
Earthquake Details

This is a computer-generated message -- this event has not yet been reviewed by a seismologist.

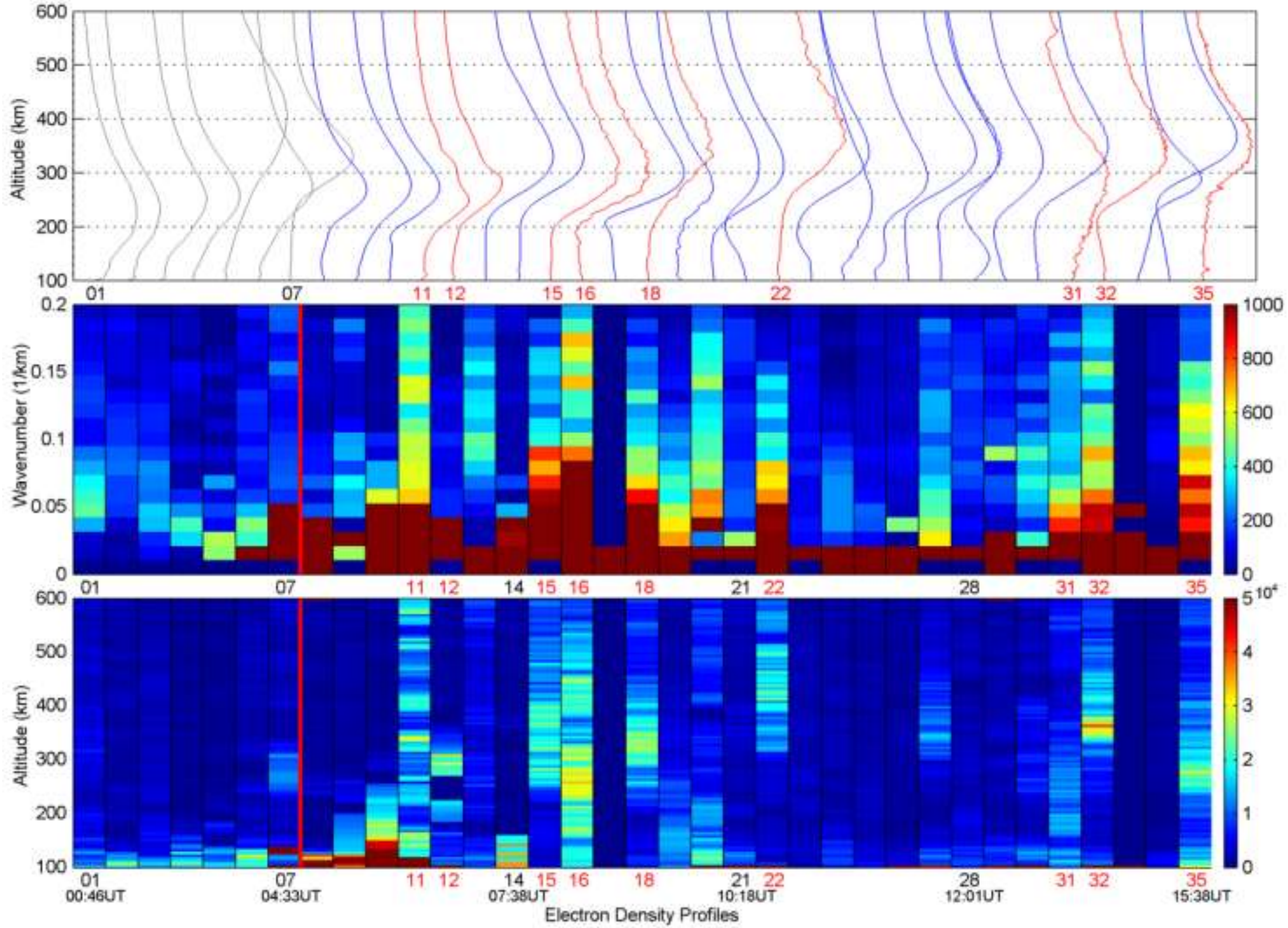
Magnitude	8.9 9.0
Date-Time	**Friday, March 11, 2011 at 05:46:23 UTC** Friday, March 11, 2011 at 02:46:23 PM at epicenter Time of Earthquake in other Time Zones
Location	38.322°N, 142.369°E
Depth	24.4 km (15.2 miles) set by location program
Region	NEAR THE EAST COAST OF HONSHU, JAPAN
Distances	130 km (80 miles) E of **Sendai, Honshu, Japan** 178 km (110 miles) E of **Yamagata, Honshu, Japan** 178 km (110 miles) ENE of **Fukushima, Honshu, Japan** 373 km (231 miles) NE of **TOKYO, Japan**
Location Uncertainty	horizontal +/- 13.5 km (8.4 miles); depth fixed by location program
Parameters	NST=350, Nph=351, Dmin=416.3 km, Rmss=1.46 sec, Gp= 29°, M-type="moment" magnitude from initial P wave (tsuboi method) (Mi/Mwp), Version=A
Source	USGS NEIC (WDCS-D)
Event ID	usc0001xgp



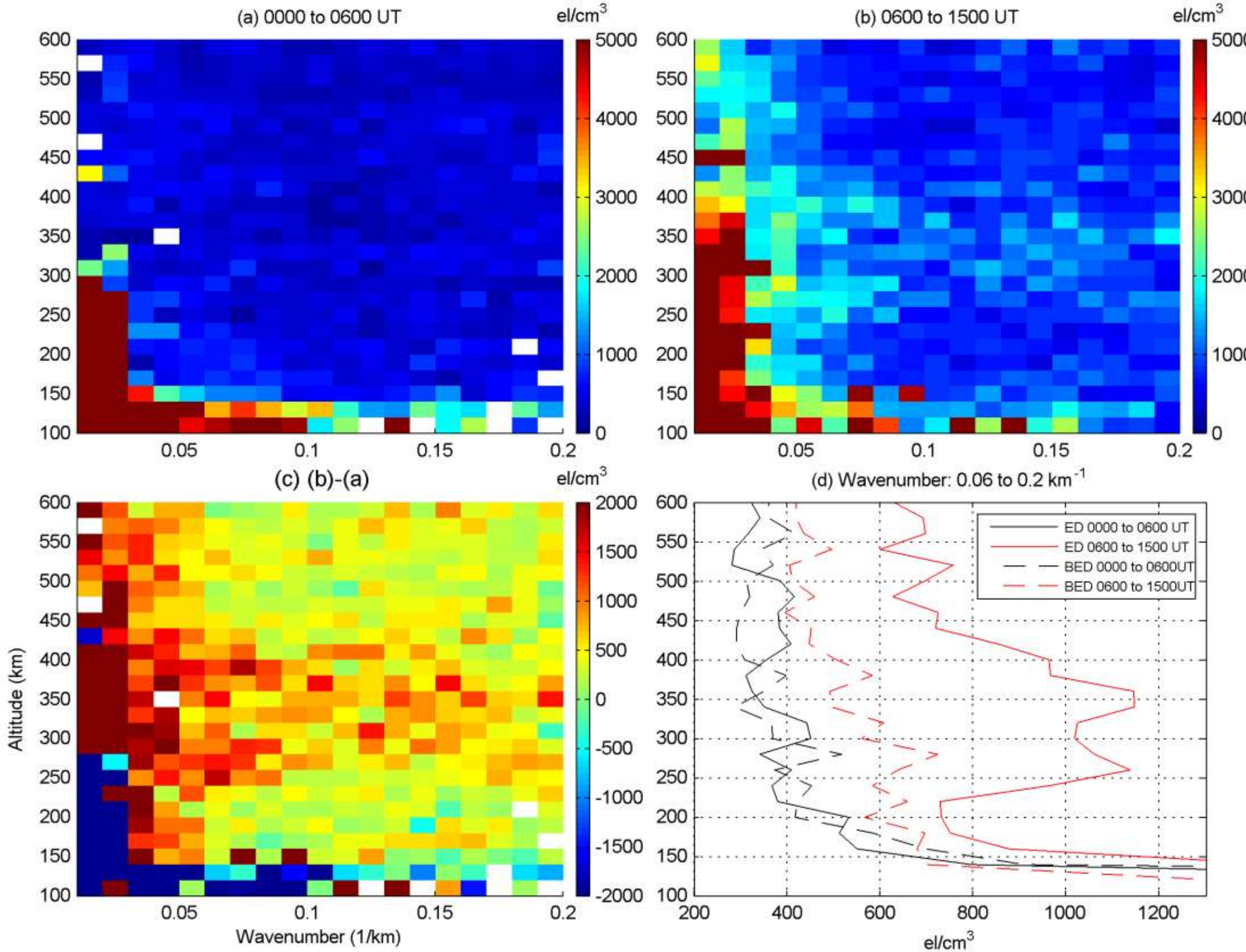
The electron density profile observed 22 minutes after earthquake.



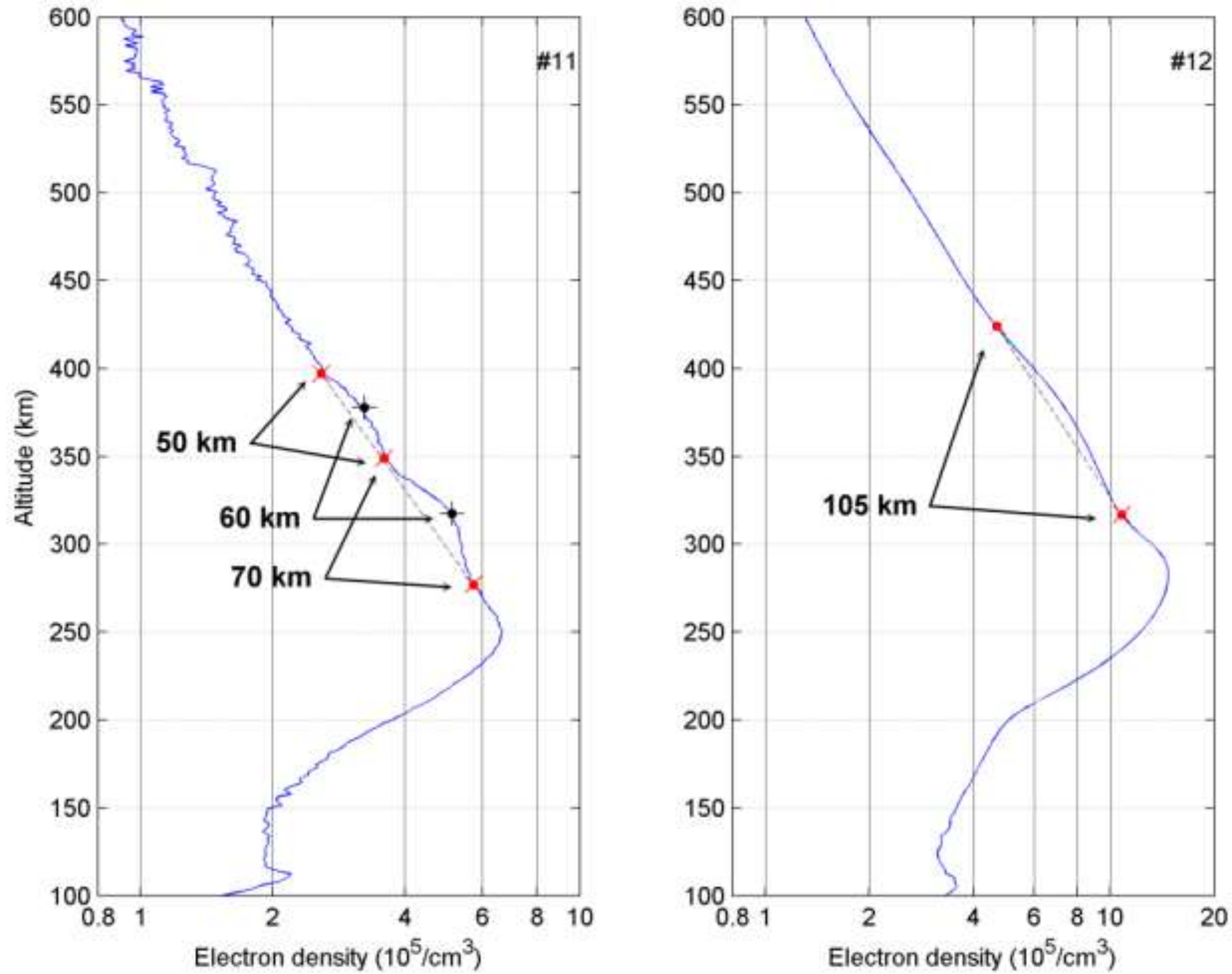
Locations of the electron density profiles observed by F3/C RO during the earthquake.



The electron density profiles and their HHT power spectra within the radius of 3000 km from the epicenter during the Tohoku earthquake.



The HHT spectra before and after the earthquake

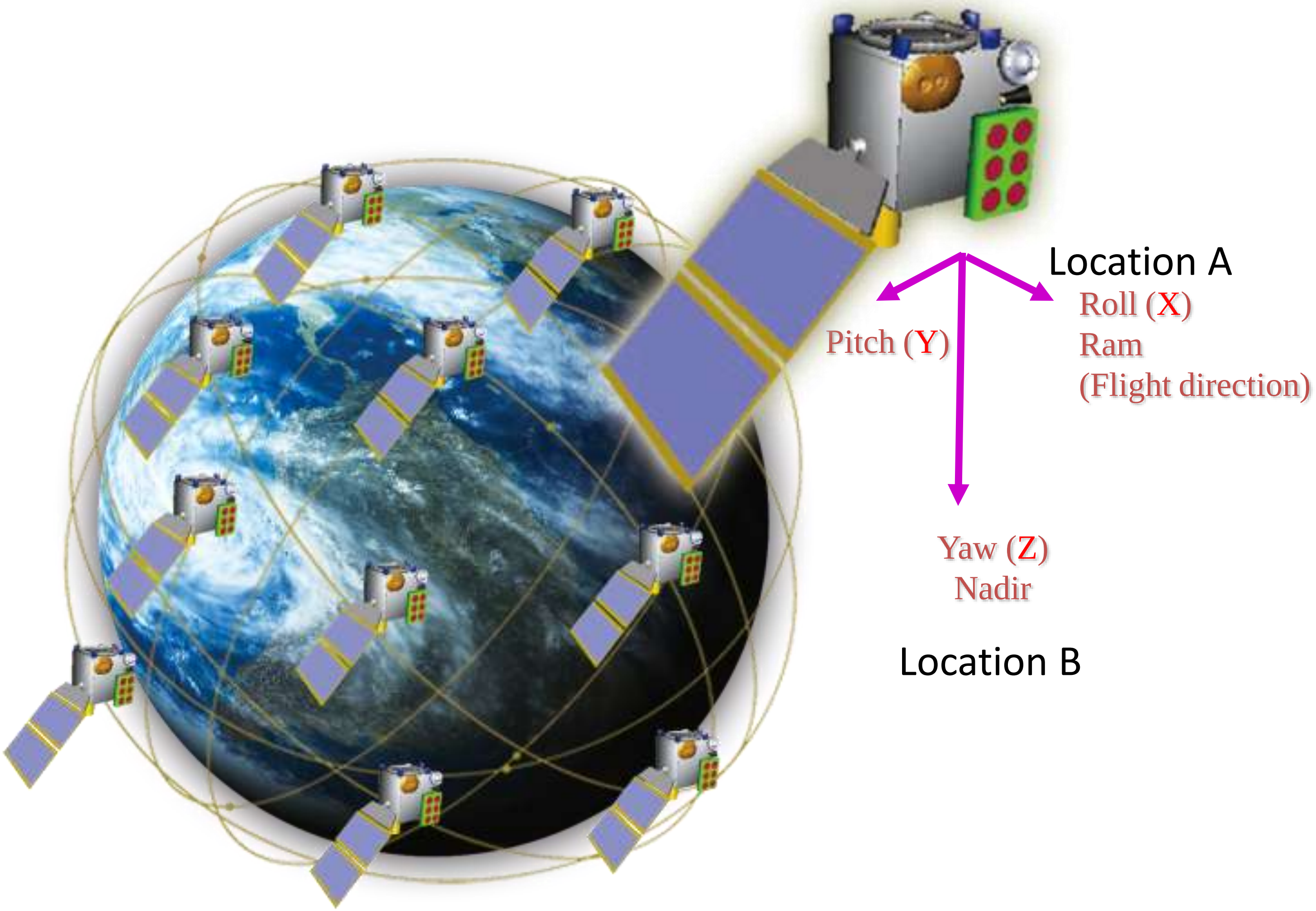


Prominent long wavelength increase-fluctuations in the electron density profiles after the earthquake. Profile#11 (a) and Profile#12 (b) are observed 1712 km 250 North and 2521 km East from the epicenter at 06:08 UT and 06:12 UT, respectively

Remark

- The wavelengths >30 km of the STIDs in TEC, grad TEC, and electron density in the vertical direction are enhanced after the earthquake/tsunami onset.
- The wavelengths of 3-20 km in the electron density variations in the vertical direction become prominent during the solar eclipse period.
- The wavelengths of 15-30 km in the electron density variations in the vertical direction become prominent during the storm period.
- It can be seen that that the disturbances triggered by earthquakes, solar eclipses, and storms can reach above400-600 km altitude.

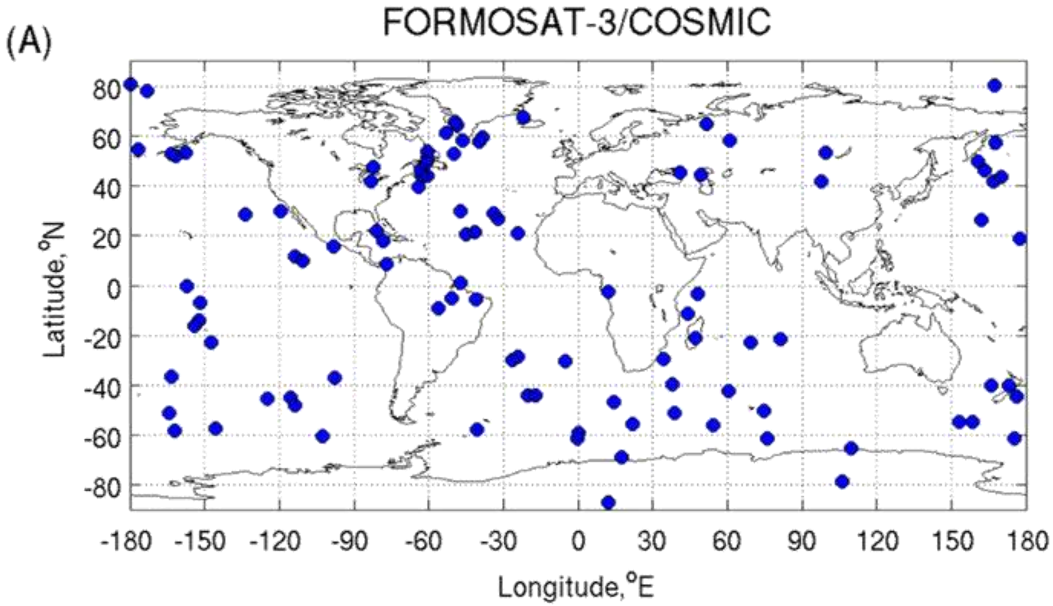
FORMOSAT-7/COSMIC-2



F7/C2 – Major Activities

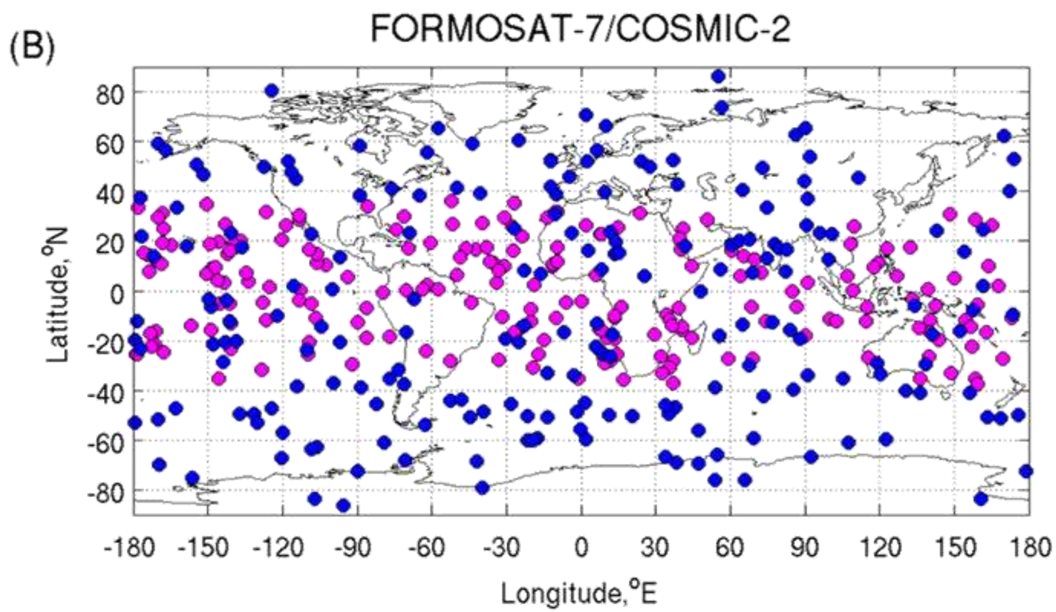
- 1st Launch – 2018
- 2nd Launch - 2020
- Science Payload: IVM and Tri-band Beacon
- First launch funded. Working to get funding for the 2nd launch

F7/C2 vs F3/C



With 6 satellites + GPS, 60 minutes

About 80-100 profiles per hour



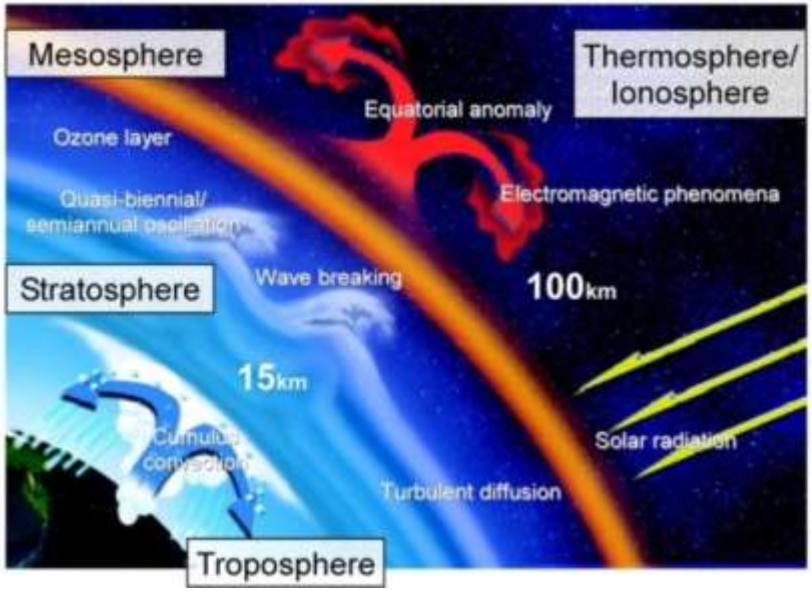
With 12 satellites + GPS, 60 minutes

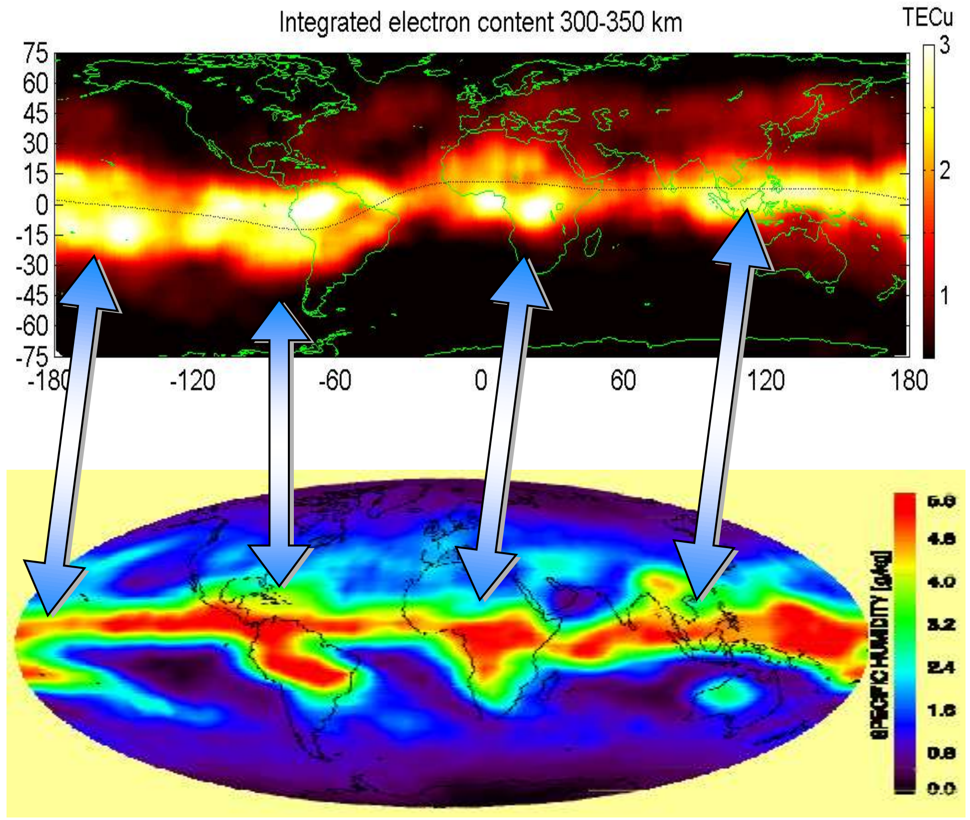
About 400 profiles per hour

What is future impact of F7/C2 on ionospheric research?

Simultaneous Observations

F3/C RO simultaneously profiling the atmosphere and ionosphere can be used to have a better understanding on the AI coupling (energy and wave).

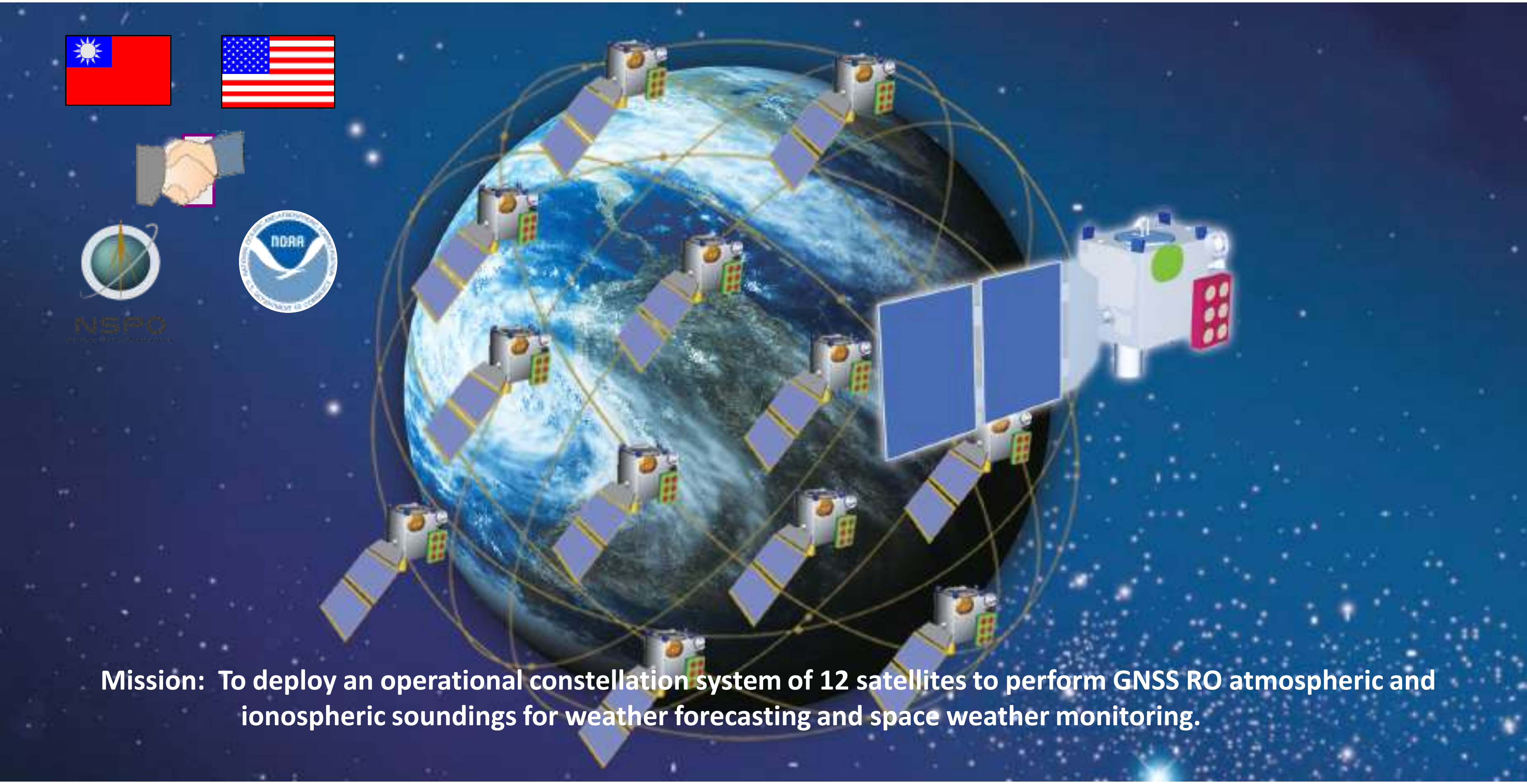




Atmospheric humidity at 5 km altitude

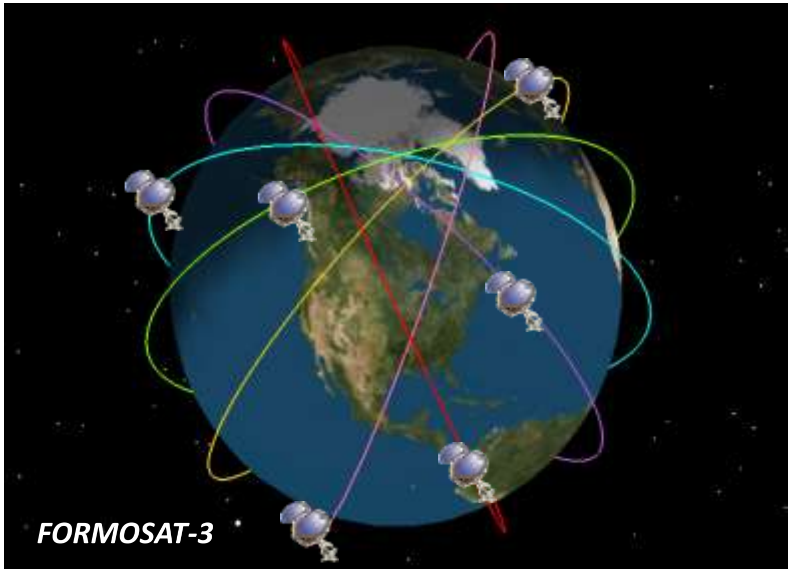
[Courtesy of Dr. Jens. Wickert of the GFZ]

FORMOSAT-7/COSMIC-2

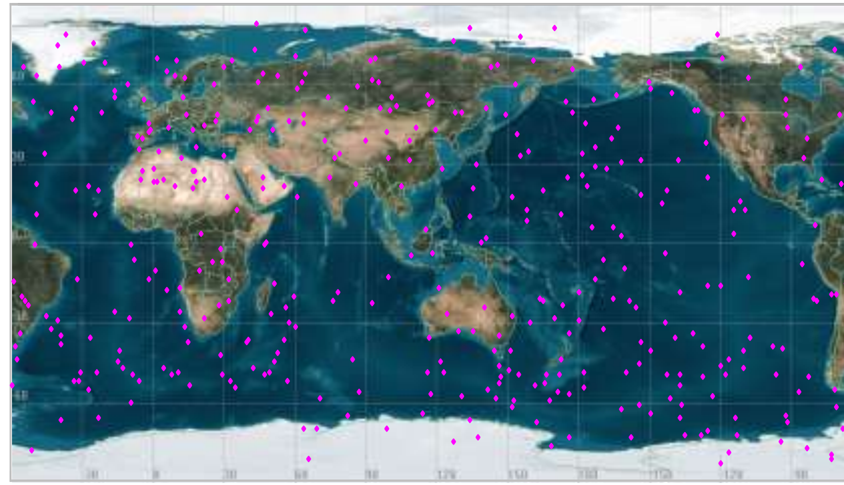


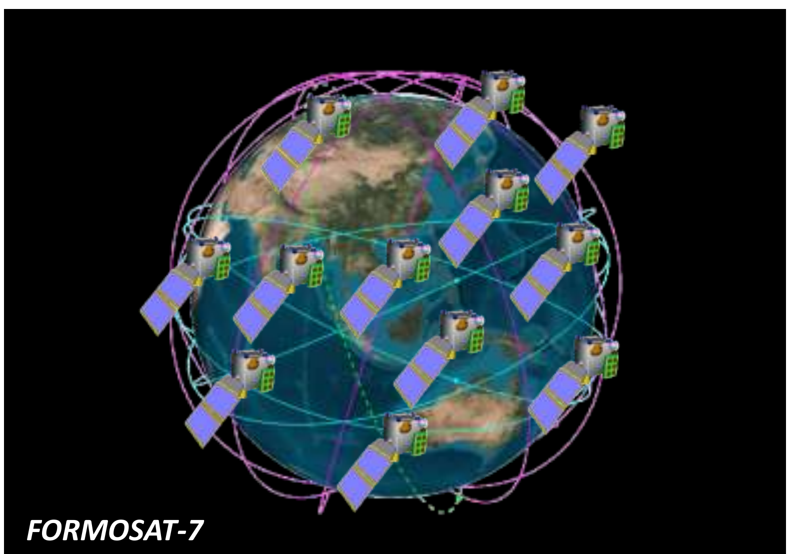
Mission: To deploy an operational constellation system of 12 satellites to perform GNSS RO atmospheric and ionospheric soundings for weather forecasting and space weather monitoring.

Comparison of Data Coverage

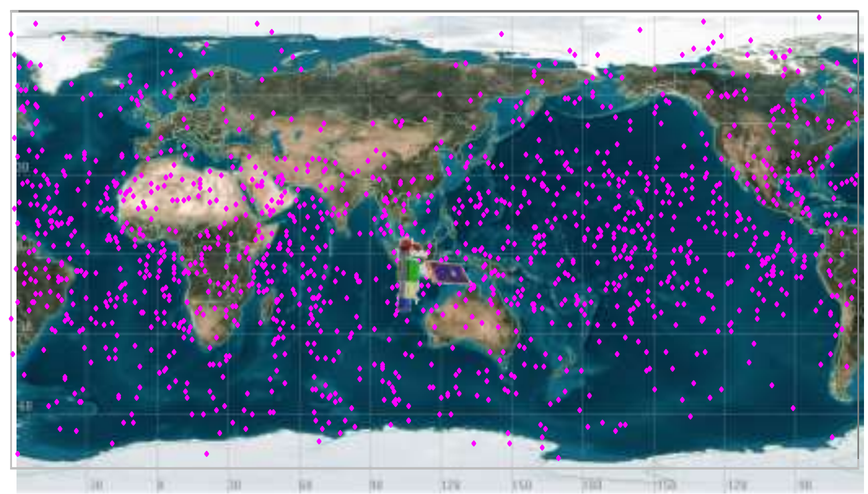


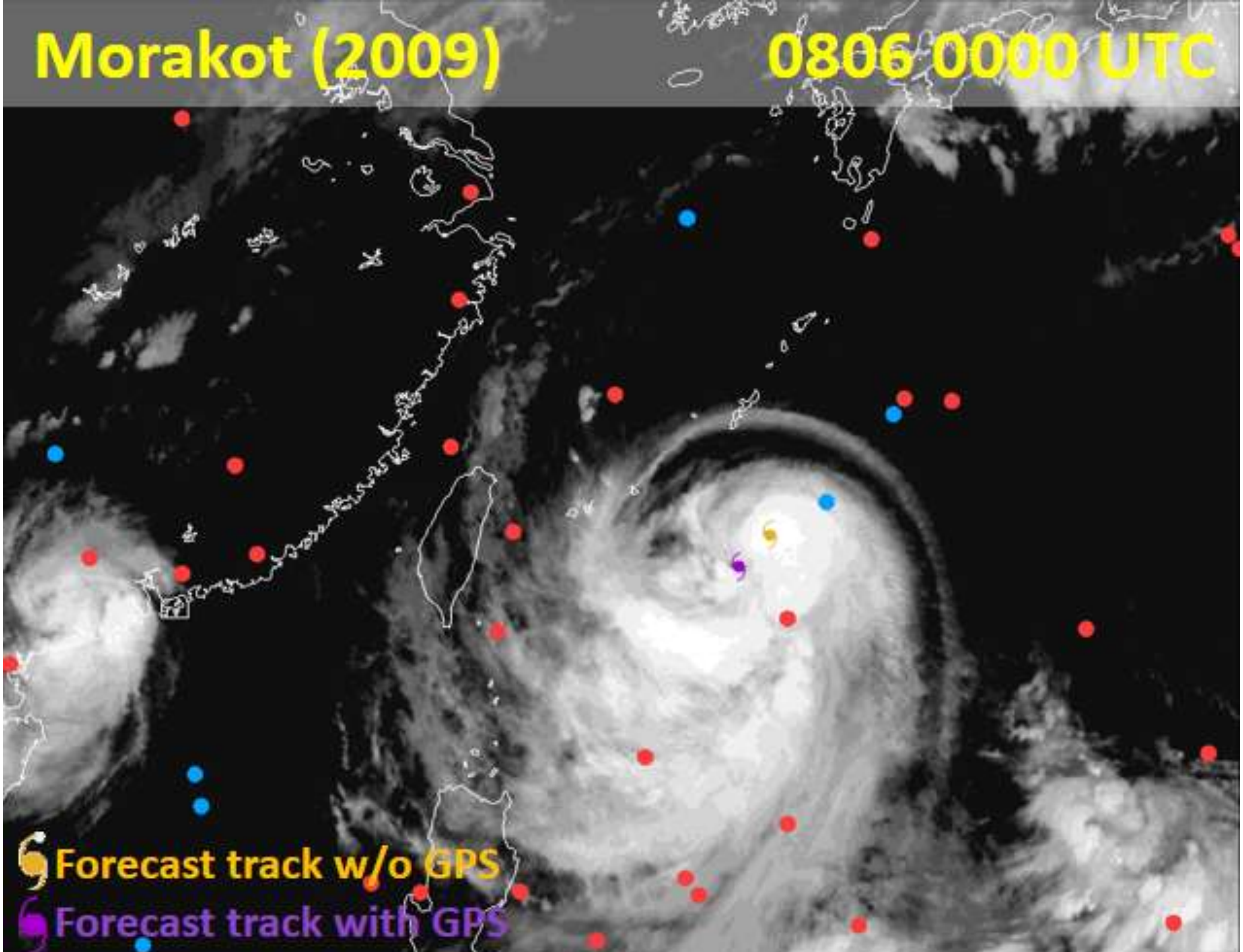
FORMOSAT-3 Occultations – 3 Hrs Coverage





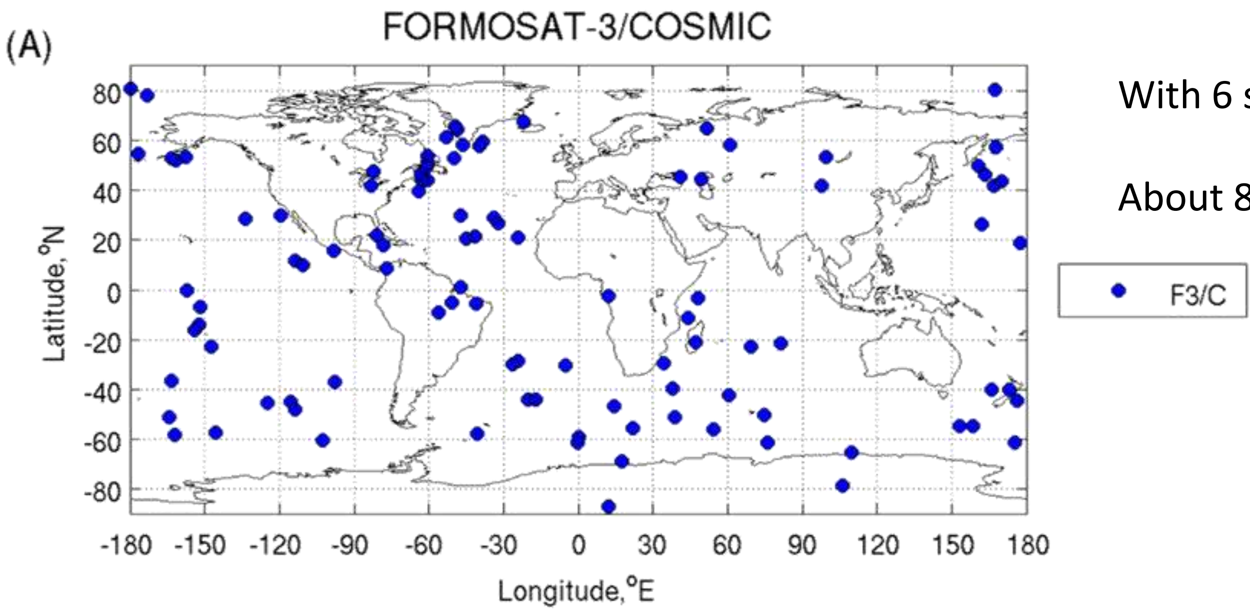
FORMOSAT-7 Occultations – 3 Hrs Coverage





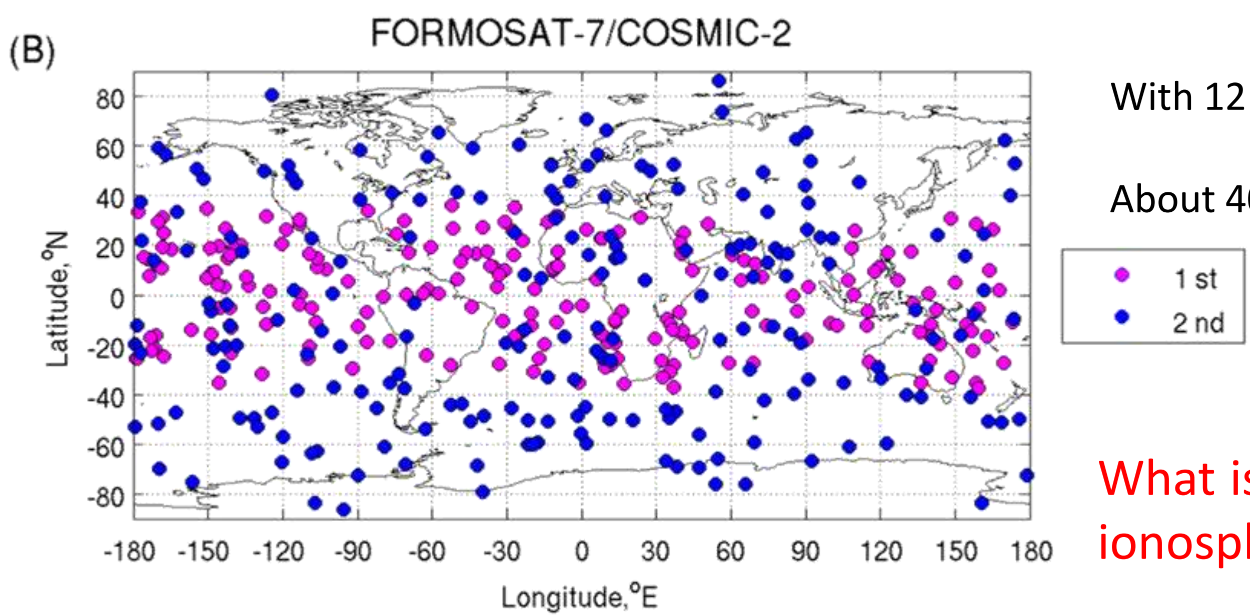
●FORMOSAT-3
●FORMOSAT-7-1
●FORMOSAT-7-2

F7/C2 vs F3/C



With 6 satellites + GPS, 60 minutes

About 80-100 profiles per hour

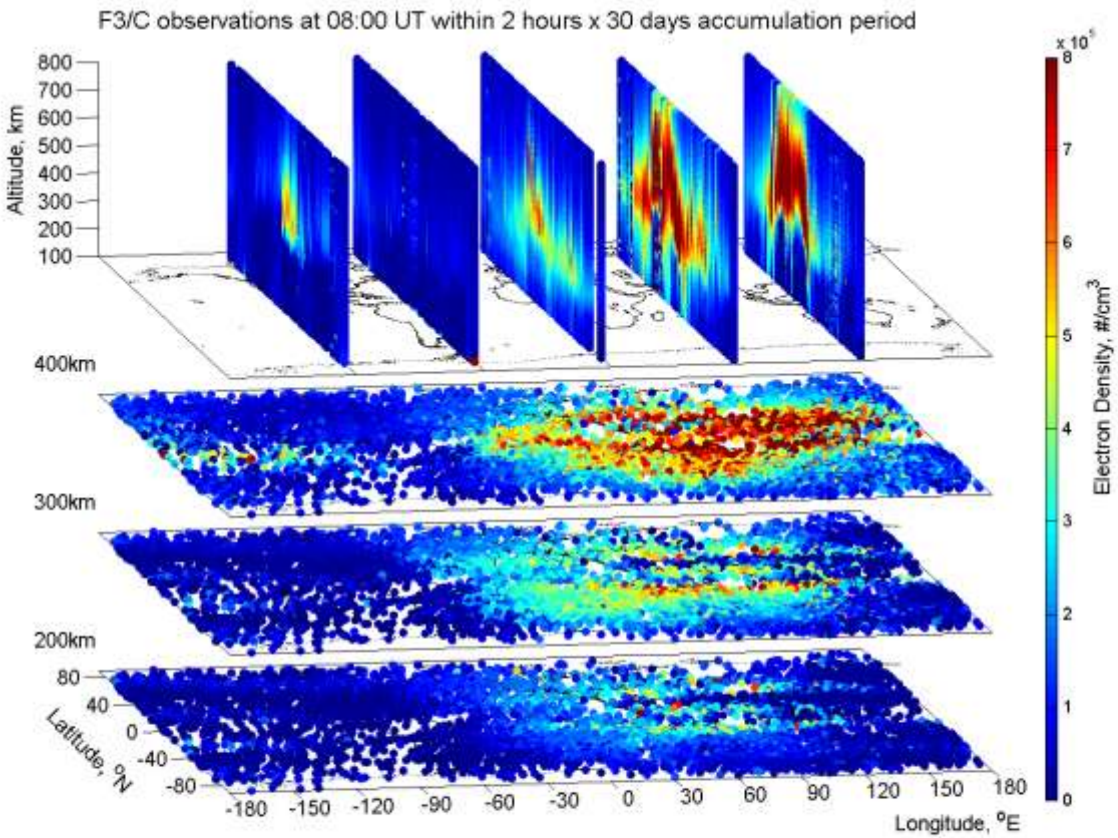


With 12 satellites + GPS, 60 minutes

About 400 profiles per hour

What is future impact of F7/C2 on ionospheric research?

Ionospheric Weather Monitoring



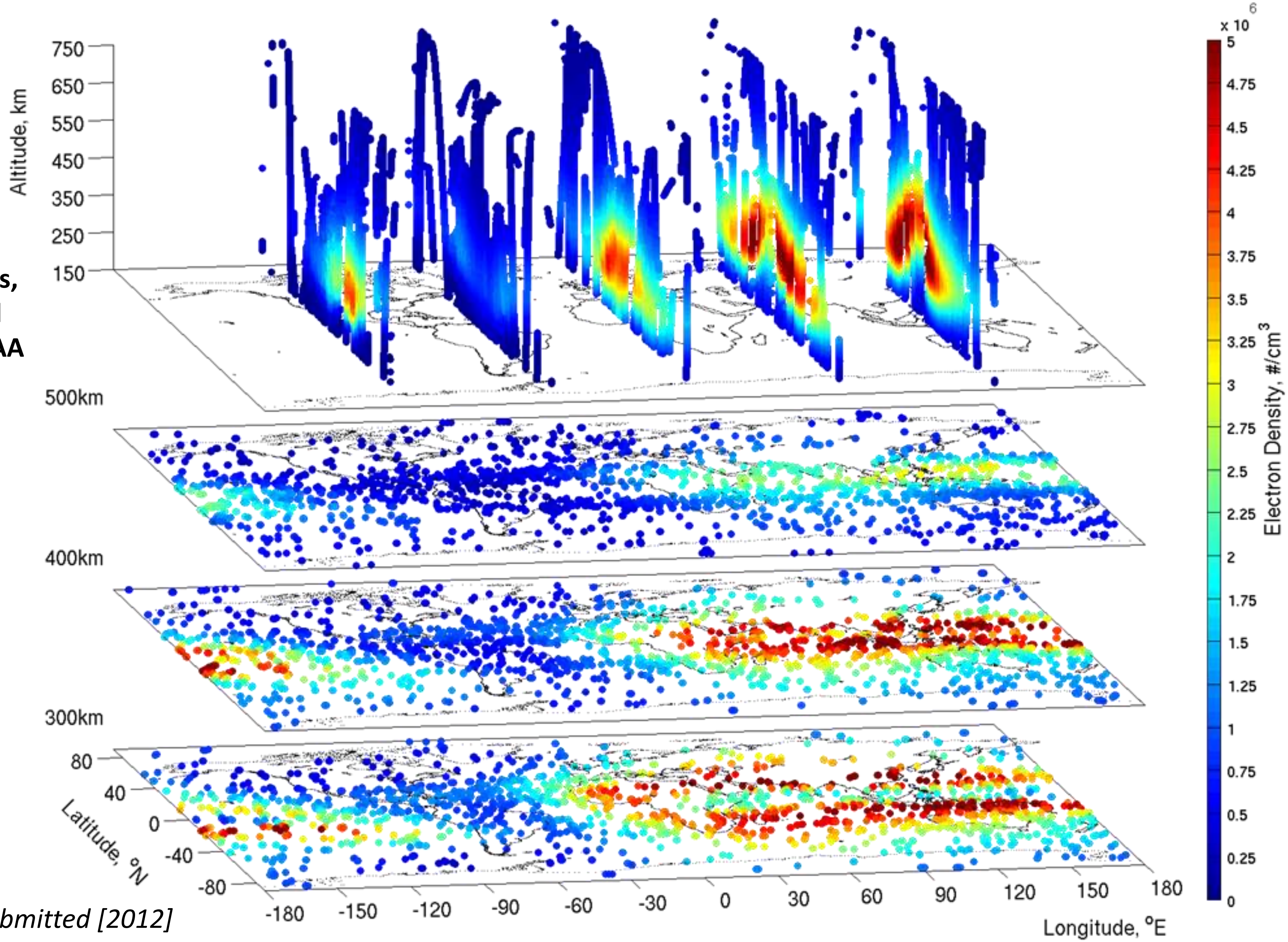
Latitudinal slices are at -120˚, -60˚, 0˚ 60˚ and 120˚ longitude with a interval of ±2.5˚.

- Solar activity variations
- Seasonal variations
- Monthly variations
- Tidal effects
- Diurnal variations
- Semi-diurnal variations
- Disturbed period effects
- Other temporal variations
- Irregularities

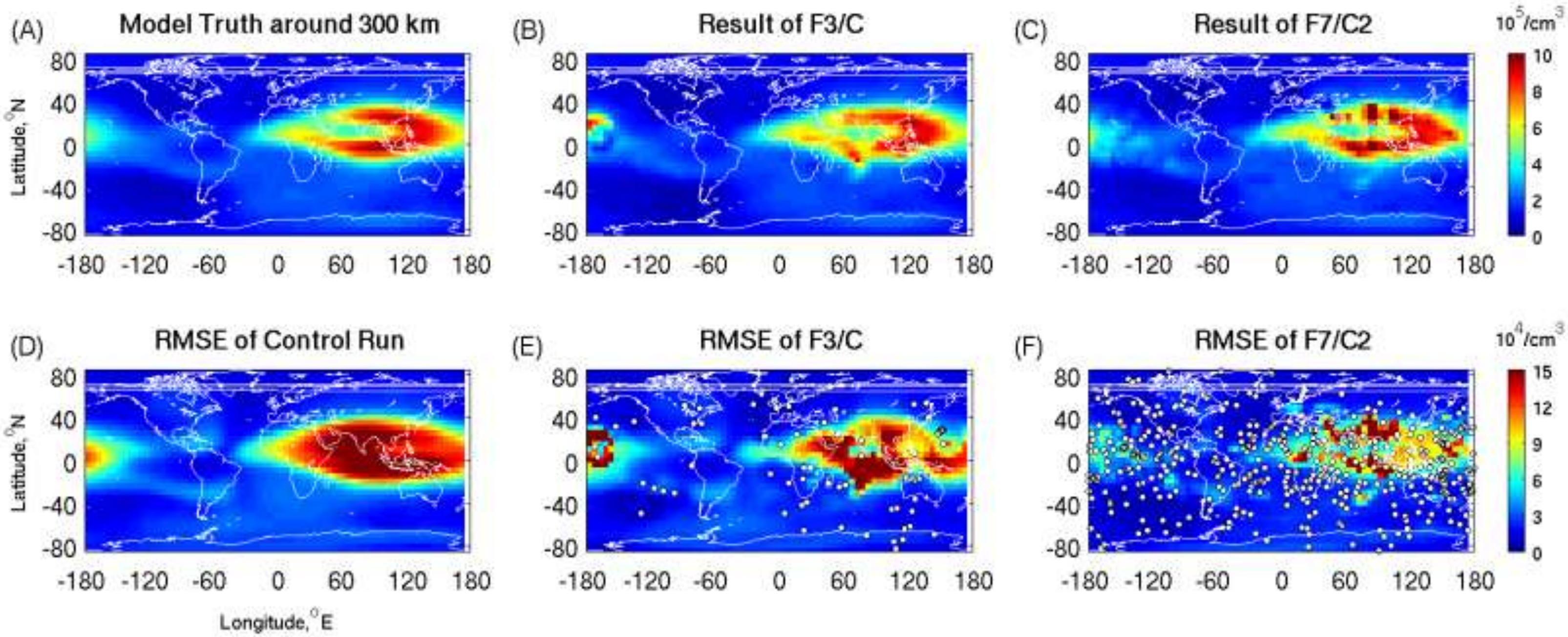
Could it be advanced by F7/C2 ?

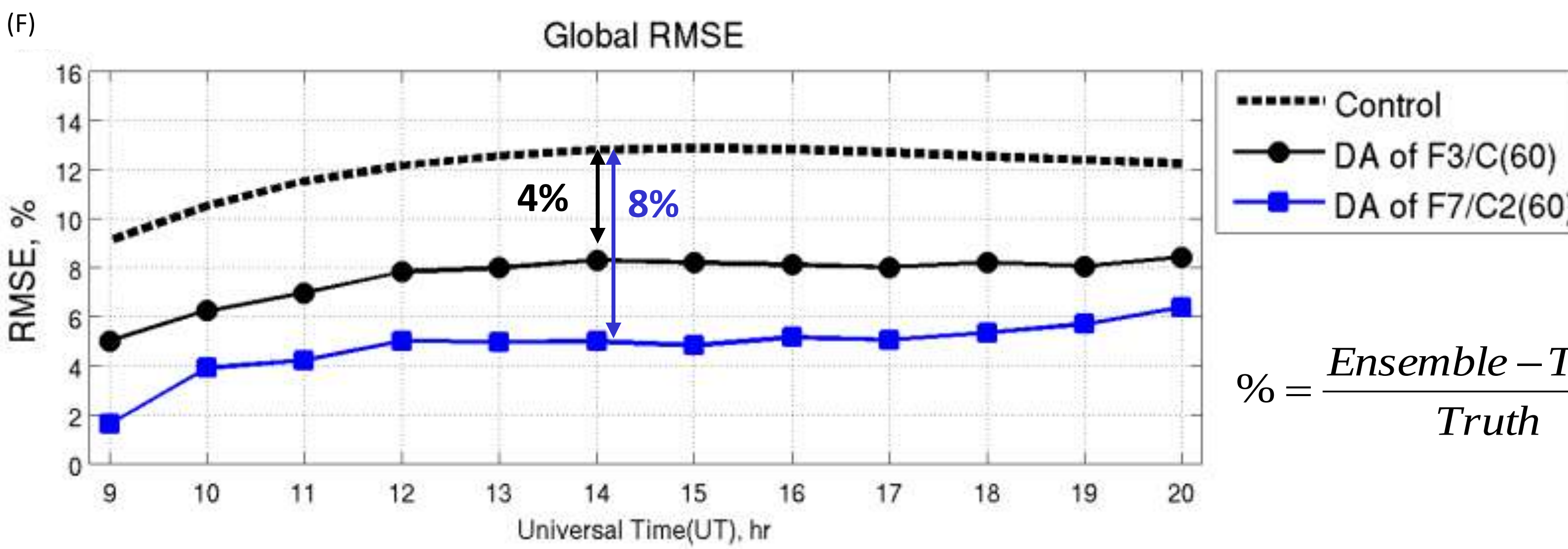
Simulated F7/C2 observations at 08:00 UT within 1 hour x 1 day accumulation period

12 satellites, 28 GPS and 24 GLONAAA



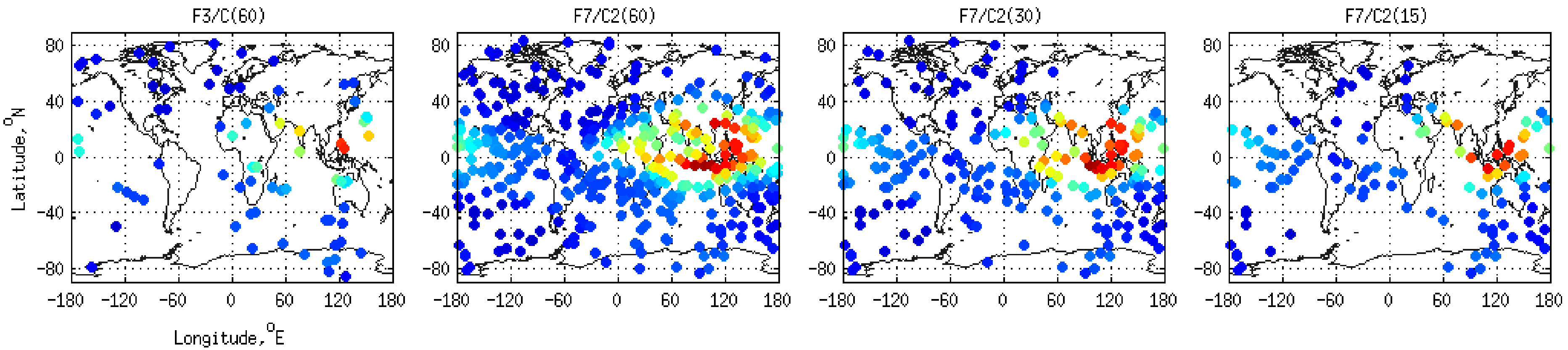
Lee et al. submitted [2012]

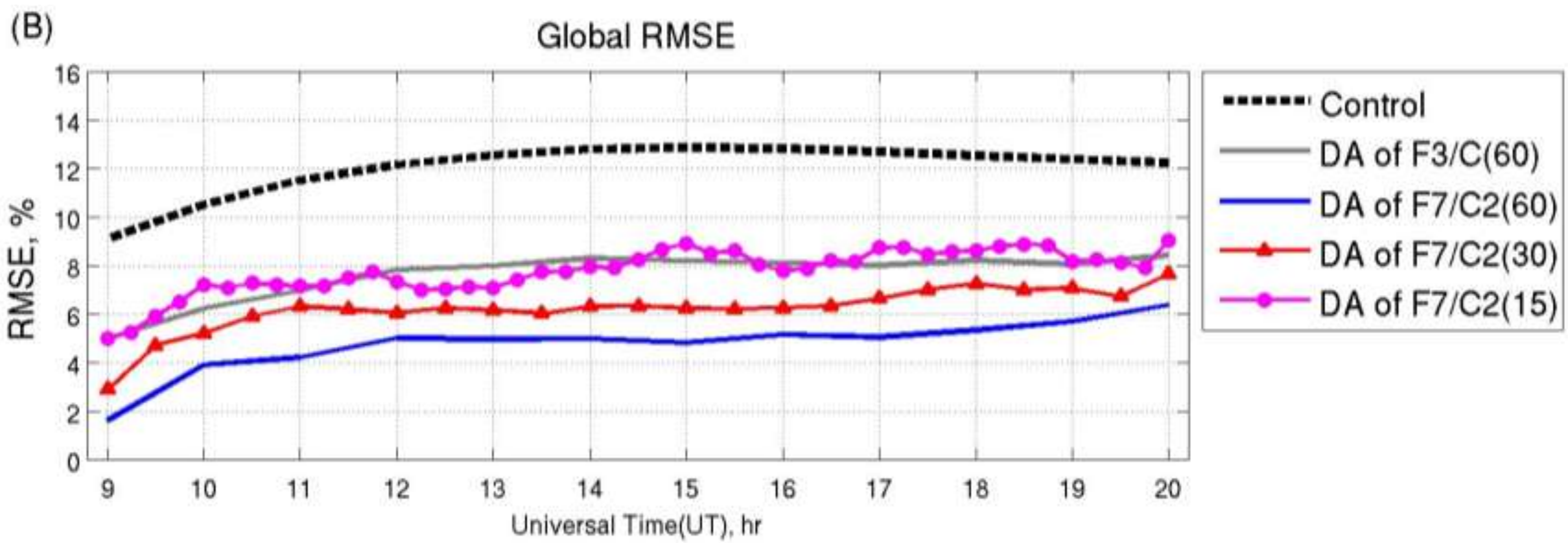




$$\% = \frac{Ensemble - Truth}{Truth} \times 100$$

Shorten assimilation window





Lee et al. [JGR 2013]

The F7/C2 data latency might not be less than 15 minutes for operational assimilation.

Remark

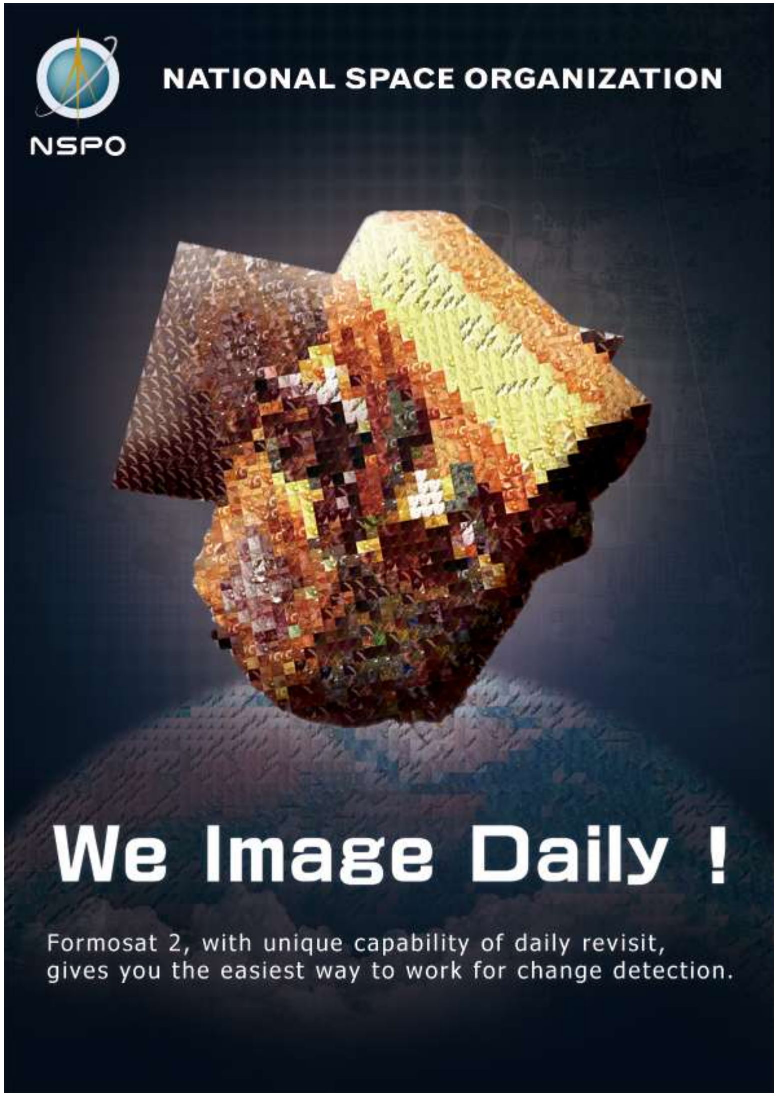
- F7/C2 shall play an extremely essential role for the weather forecast.
- F7/C2 will make that ionospheric monitoring and space weather forecast become reality, especially positioning, navigation, and communication applications.

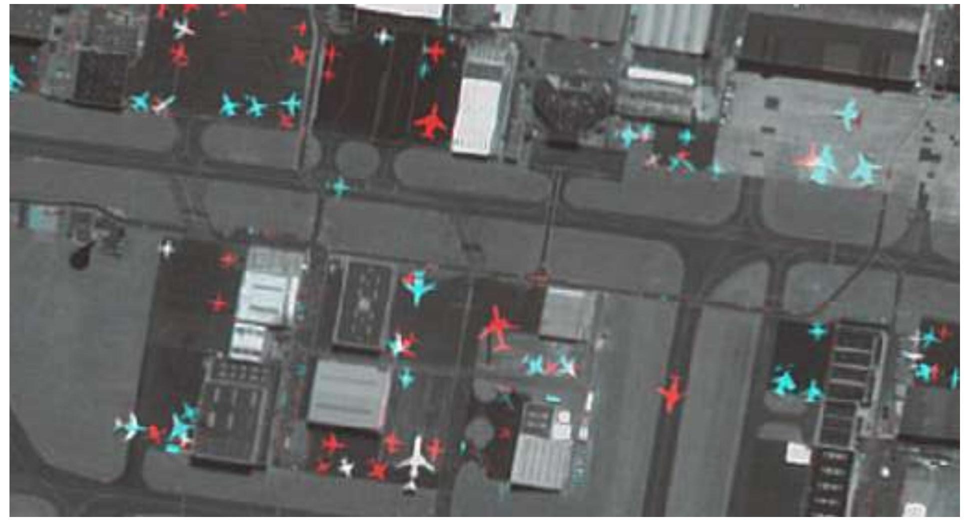
Support to Worldwide Nature Disaster Relief

2004 Southern Asia Tsunami
2008 Wilkins Ice Shelf Corruption
2008 Sichuan Earthquake
2011 Eyjafjallajokull Volcano
Shinmoedake Volcano
2011 Japan Earthquake

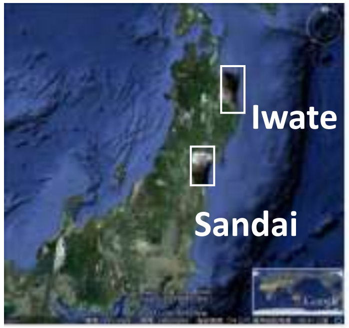
FORMOSAT-2 has supported more than 236 events across 57 countries since its launch.

FORMOSAT-2 – Daily Revisit Capability

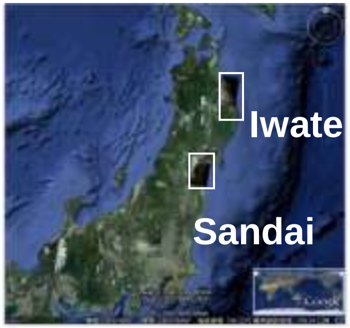




Japan Earthquake and Tsunami (2011.3.11)

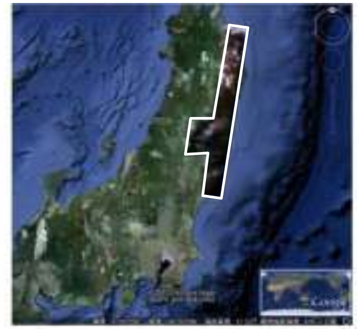


2011/03/10

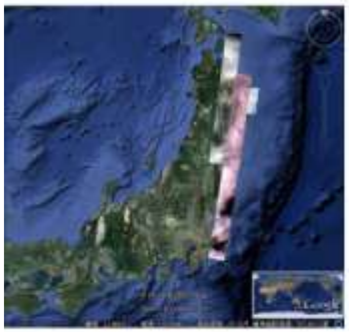


2011/03/11

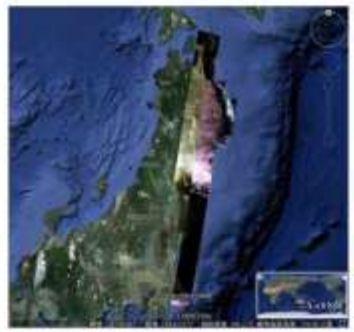
2011/03/12

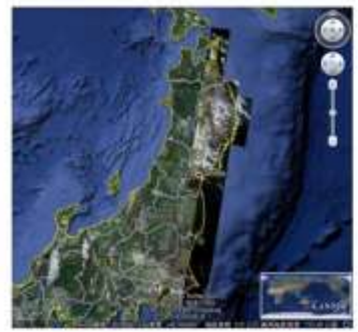

2011/03/13


2011/03/14


2011/03/15

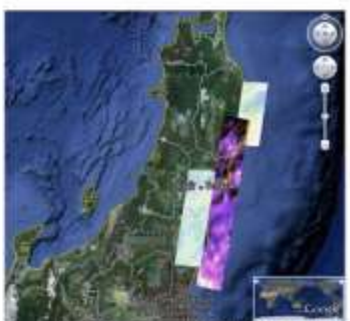

2011/03/16


2011/03/17


2011/03/18


2011/03/19


2011/03/20

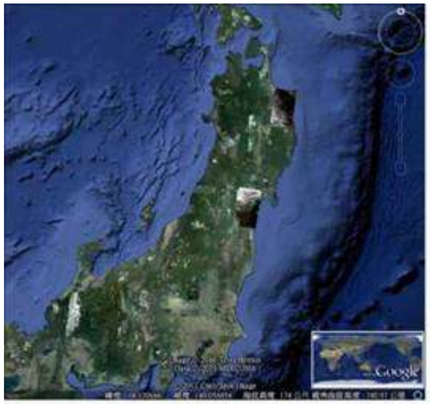

2011/03/21


2011/03/22


2011/03/23


2011/03/24

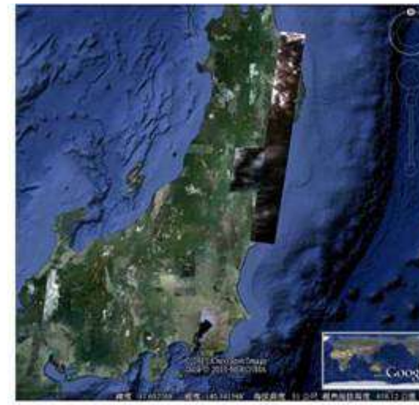
Iwanuma, Miyagi



2011/03/10

2011/03/11

2011/03/12



2011/03/13

Before
(2011/03/11)

After
(2011/03/12)

宮城縣岩沼市

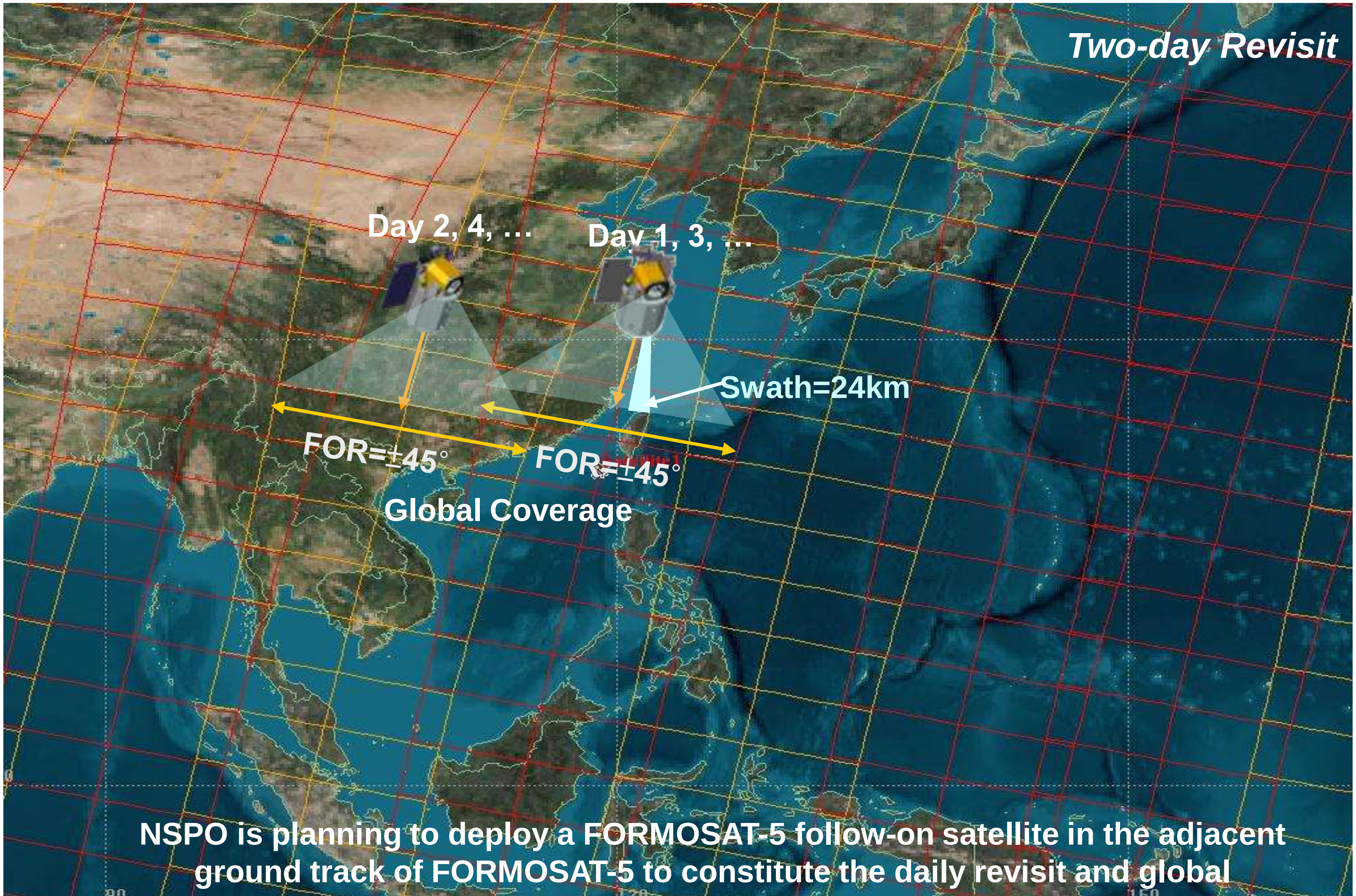
FORMOSAT-5


Mission: To build up Taiwan's self-reliant space technology on the remote sensing satellite system
and to continuously serve the global imagery users' community of FORMOSAT-2.

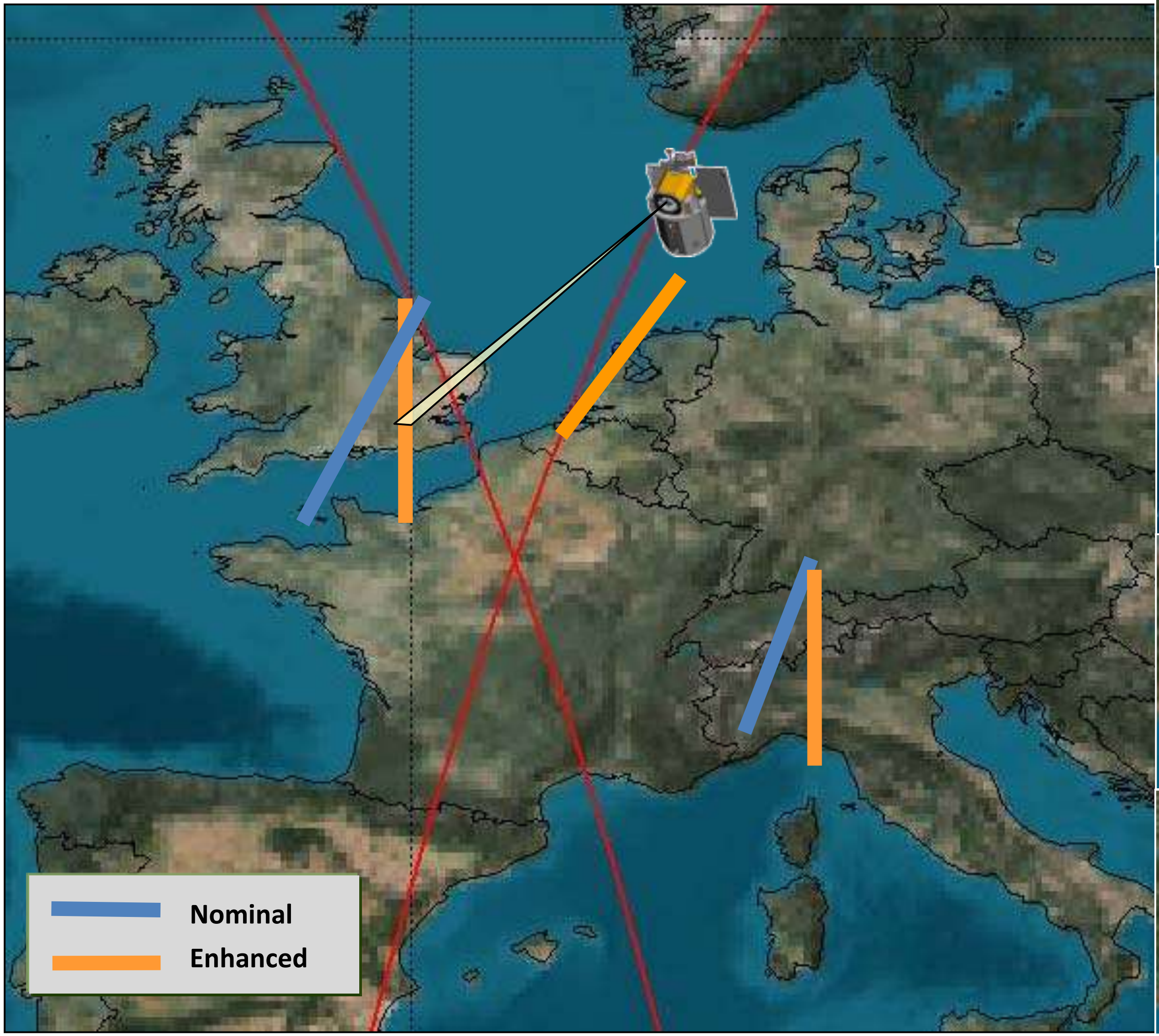
The Key System Specification

Key Parameter	Specification
Orbit	SSO @ 720km/98.28°
Revisit Period	2 days
Mission Life	5 years
GSD	PAN (2m) / MS (4m)
Swath	24 km
Spectral Bands	PAN + 4MS
RSI Image Sensor	CMOS Image Sensor
RSI duty Cycle	8%
Satellite Weight	525 kg

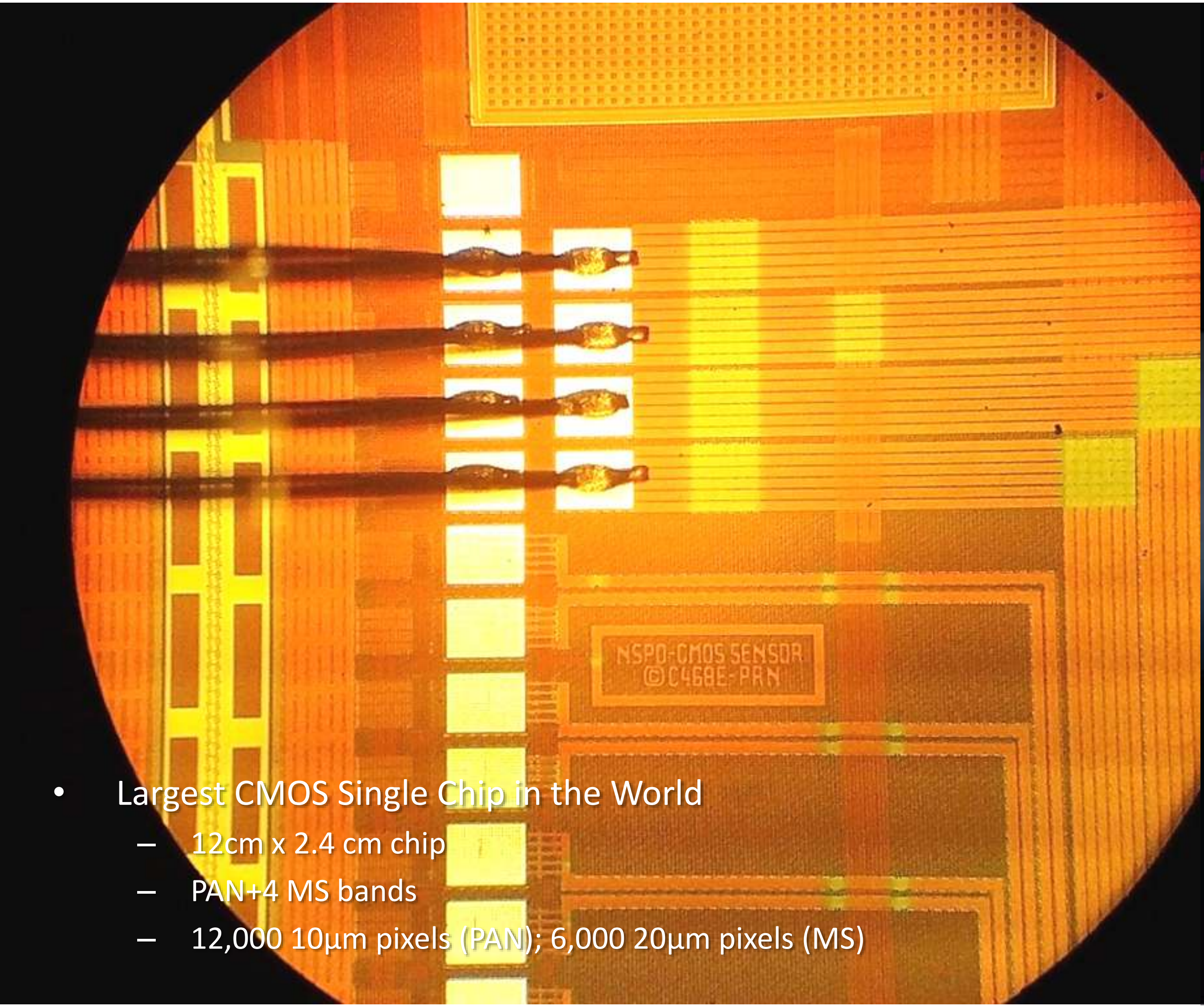
Mission Orbit (SSO@ 720km/98.28°)

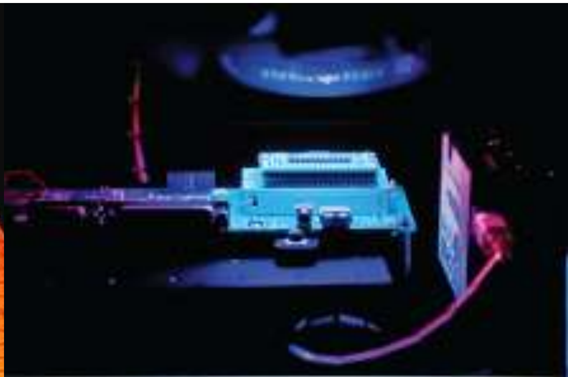


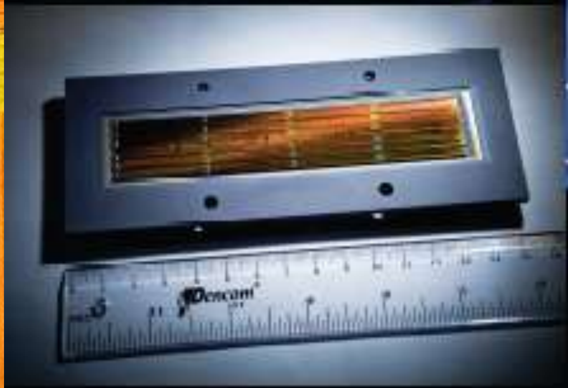
Smart Agility Capability

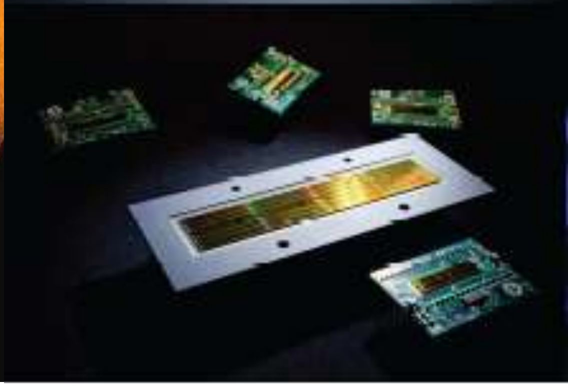


CMOS Image Sensor









- Largest CMOS Single Chip in the World
  - 12cm x 2.4 cm chip
  - PAN+4 MS bands
  - 12,000 10µm pixels (PAN); 6,000 20µm pixels (MS)

Conclusion

- FORMOSAT satellites provide not only helps on global weather forecast and space weather monitoring but also supports on worldwide nature disaster relief.

FORMOSAT-2 Global Watch

Washington DC, USA
FORMOSAT-2 Imagery 20120603

San Francisco Bay, USA
FORMOSAT-2 Imagery 20141102

Venice, Italy
FORMOSAT-2 Imagery 20091209

London, UK
FORMOSAT-2 Imagery 20060719

Amsterdam, Netherland
FORMOSAT-2 Imagery 20130501

Bay of Arcachon, France
FORMOSAT-2 Imagery 20121015

Geesthacht, Germany
FORMOSAT-2 Imagery 20091005

Udachny mine, Russia
FORMOSAT-2 Imagery 20120725

Tokyo, Japan
FORMOSAT-2 Imagery 20120204

Hokkaido Abashiri Drift Ice, Japan
FORMOSAT-2 Imagery 20110219

Thank you for Your Attention