



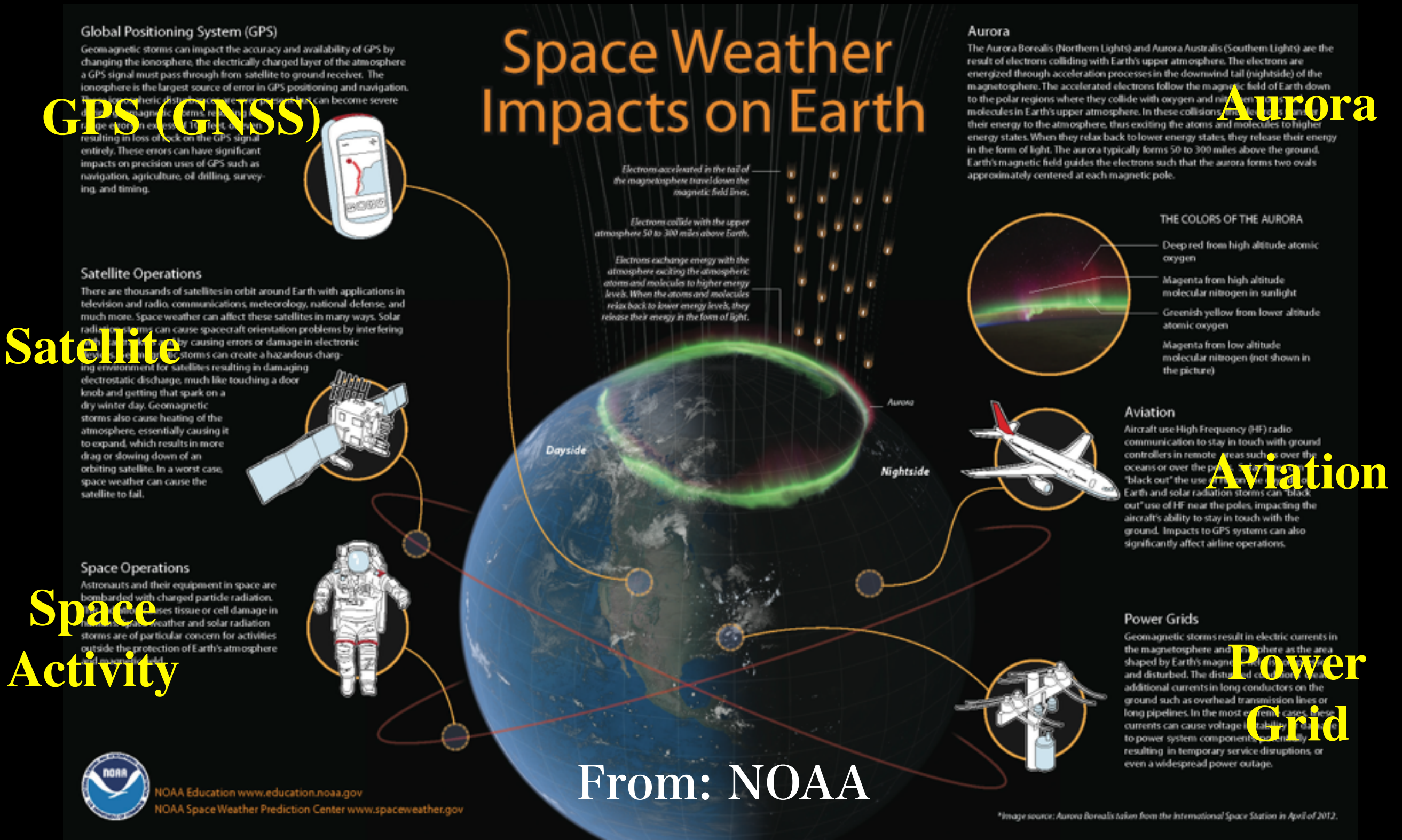
Global Navigation Satellite Systems and Space Weather in the Ionosphere

Keisuke Hosokawa

keisuke.hosokawa@uec.ac.jp

Space Weather

Overview - Summary by NOAA



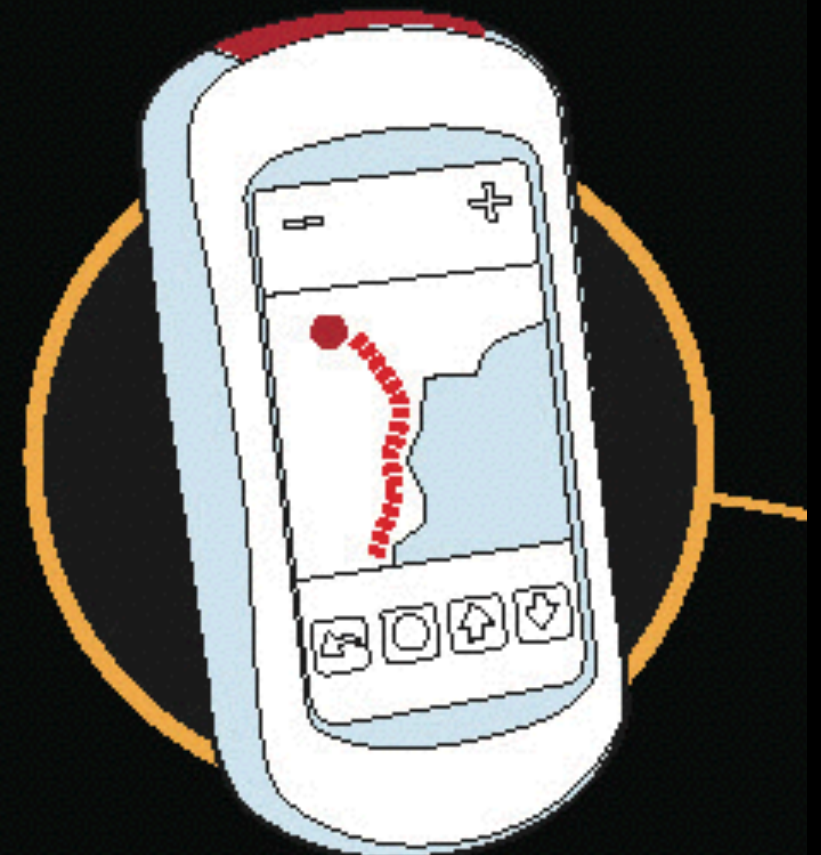
Space Weather

Space Weather Effects on the Global Positioning System

Global Positioning System (GPS)

Geomagnetic storms can impact the accuracy and availability of GPS by changing the ionosphere, the electrically charged layer of the atmosphere a GPS signal must pass through from satellite to ground receiver. The ionosphere is the largest source of error in GPS positioning and navigation. These ionospheric disturbances are ever-present but can become severe during geomagnetic storms, resulting in range errors in excess of 100 feet, or even resulting in loss of lock on the GPS signal entirely. These errors can have significant impacts on precision uses of GPS such as navigation, agriculture, oil drilling, surveying, and timing.

1 foot ~ 30 cm



Outline

- Ionosphere

Quick exercise: Browsing radar data from Norway

- Key ideas of GNSS

- Mechanism of ionospheric effects on GNSS

- Two major ionospheric impacts on GNSS

1. Positioning error

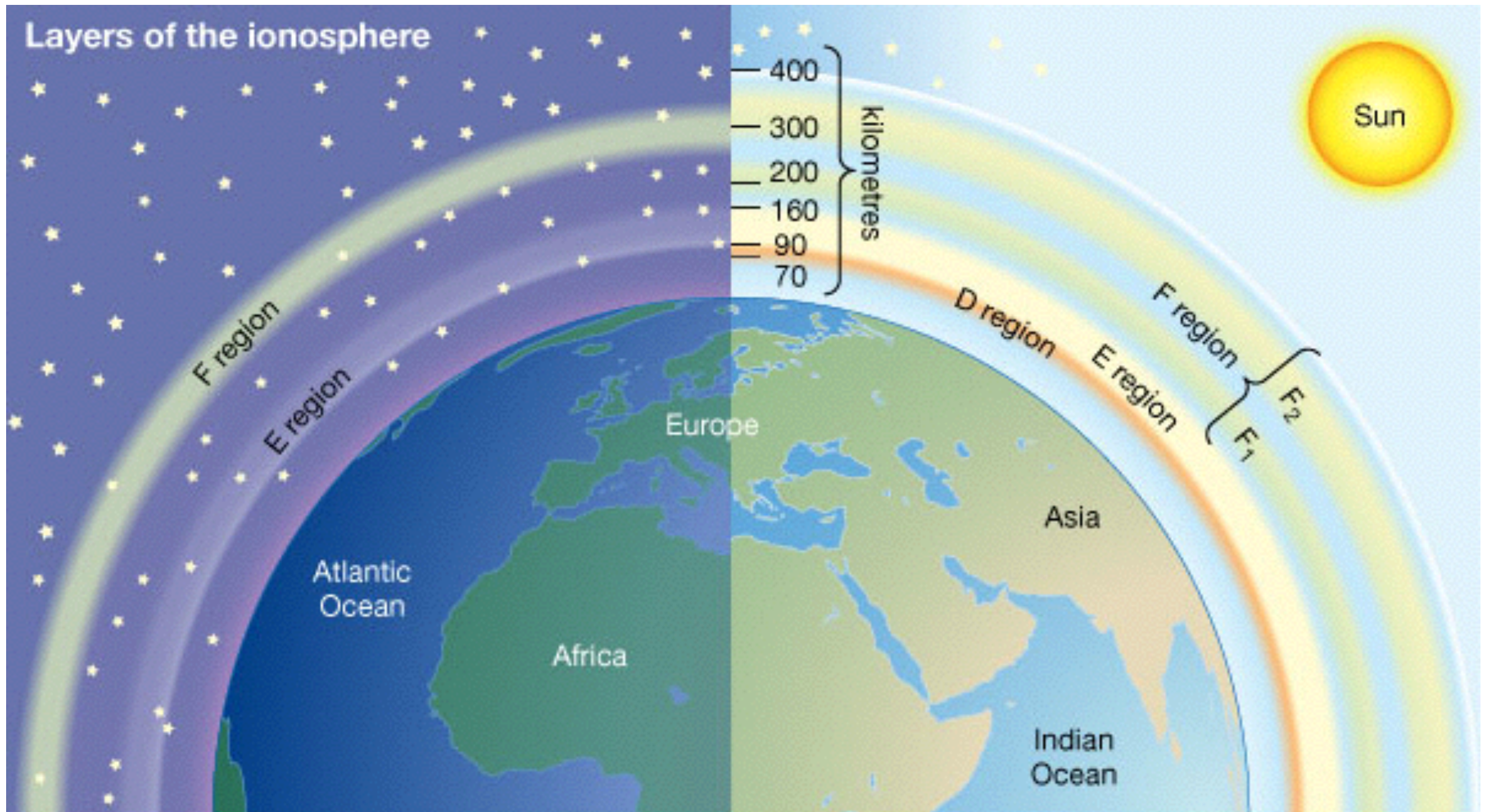
Quick exercise: Browsing GPS TEC data in US

2. Scintillation effect

Quick exercise: Browsing GPS scintillation data

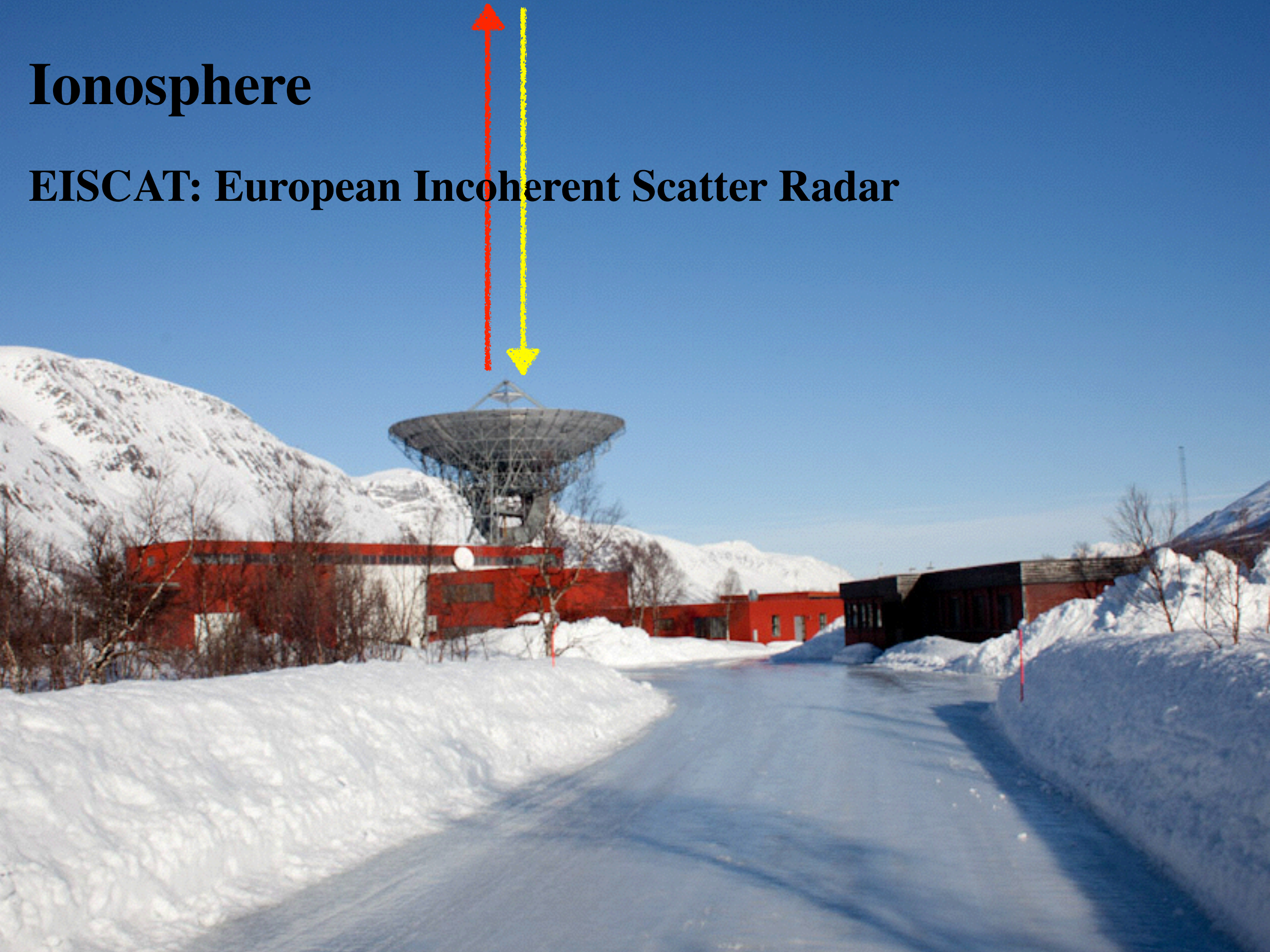
Ionosphere

Region of Ionized Particles in the Earth's Upper Atmosphere



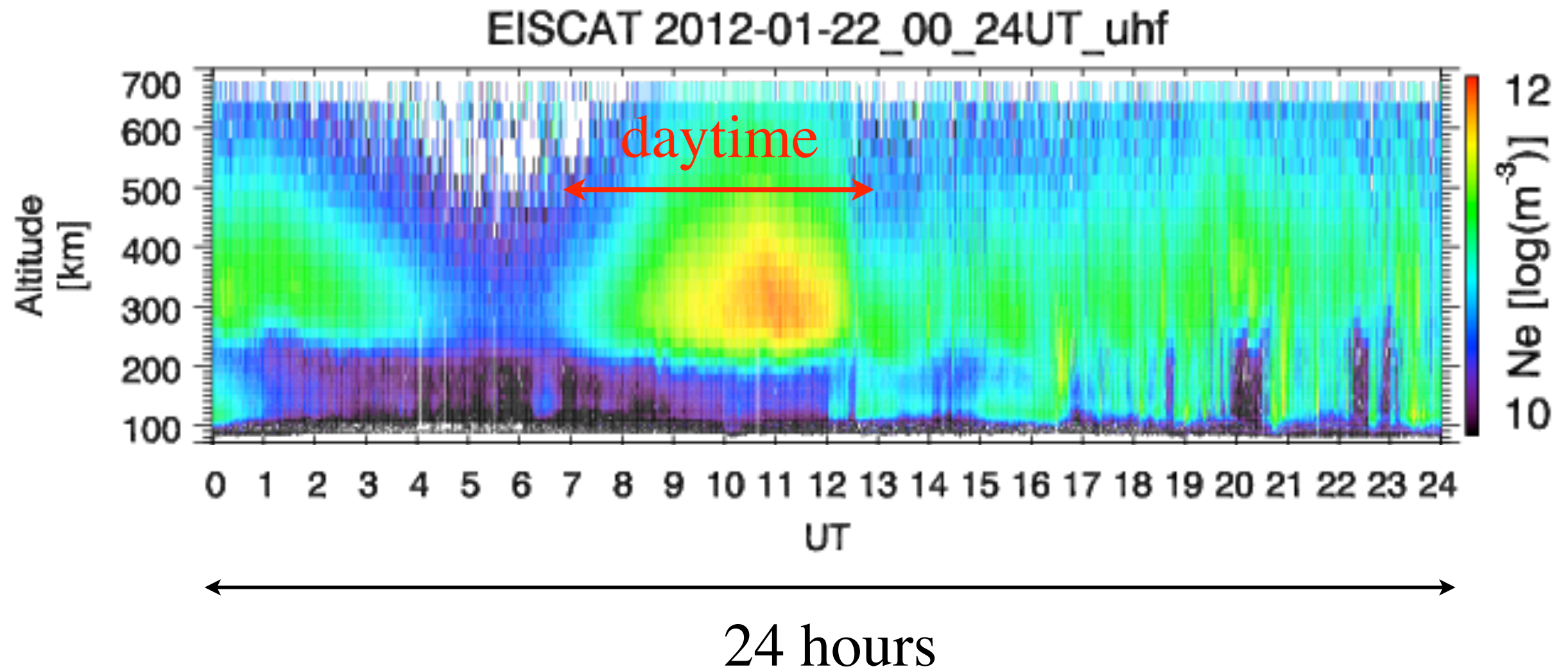
Ionosphere

EISCAT: European Incoherent Scatter Radar



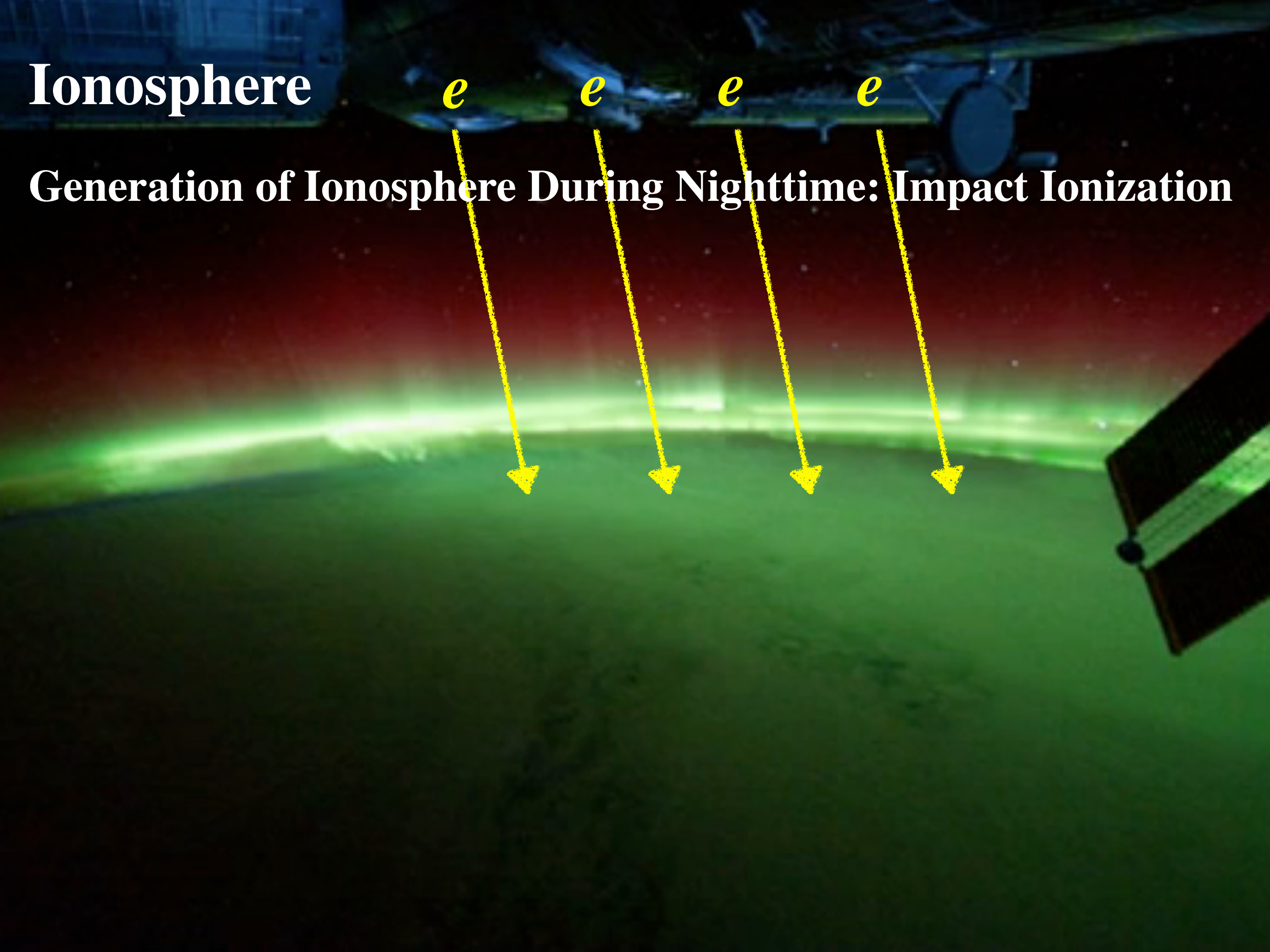
Ionosphere

Generation of Ionosphere During Daytime: Photo Ionization



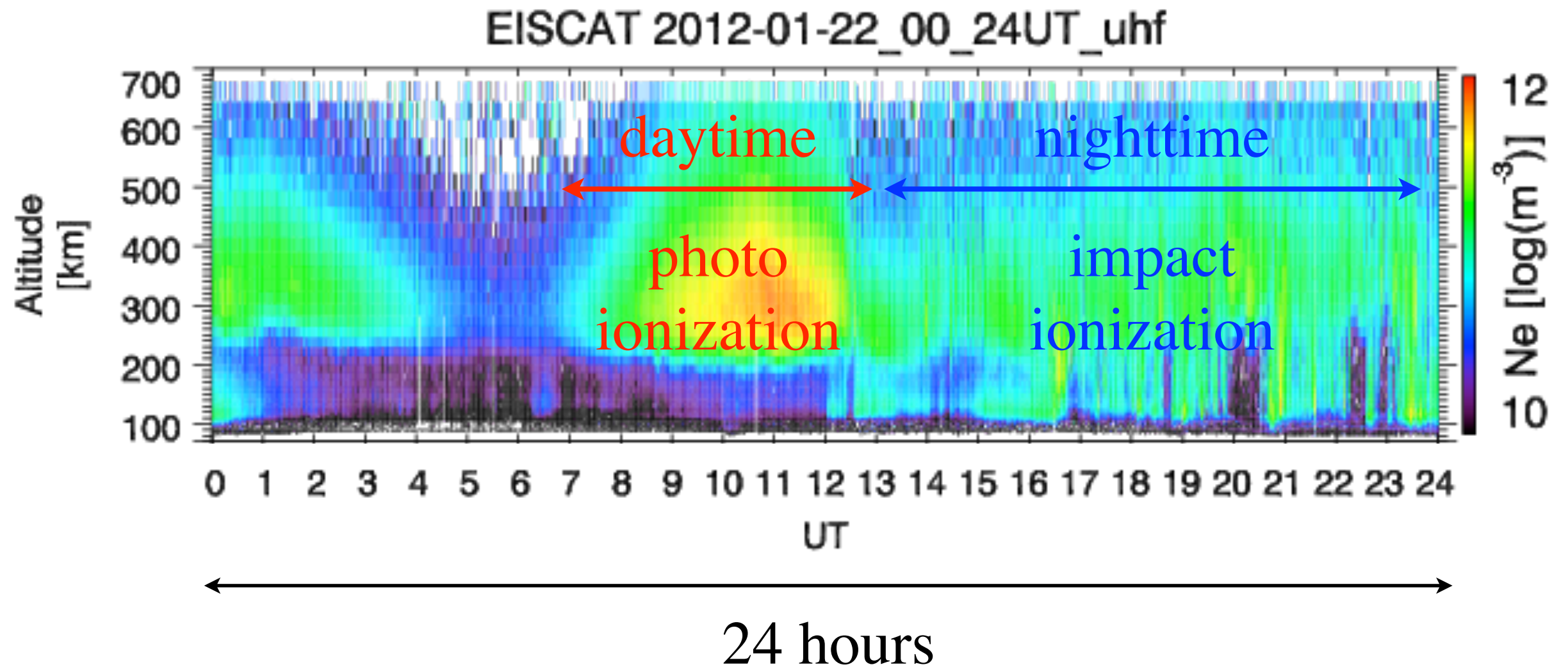
Ionosphere

Generation of Ionosphere During Nighttime: Impact Ionization



Ionosphere

Generation of Ionosphere During Nighttime: Impact Ionization



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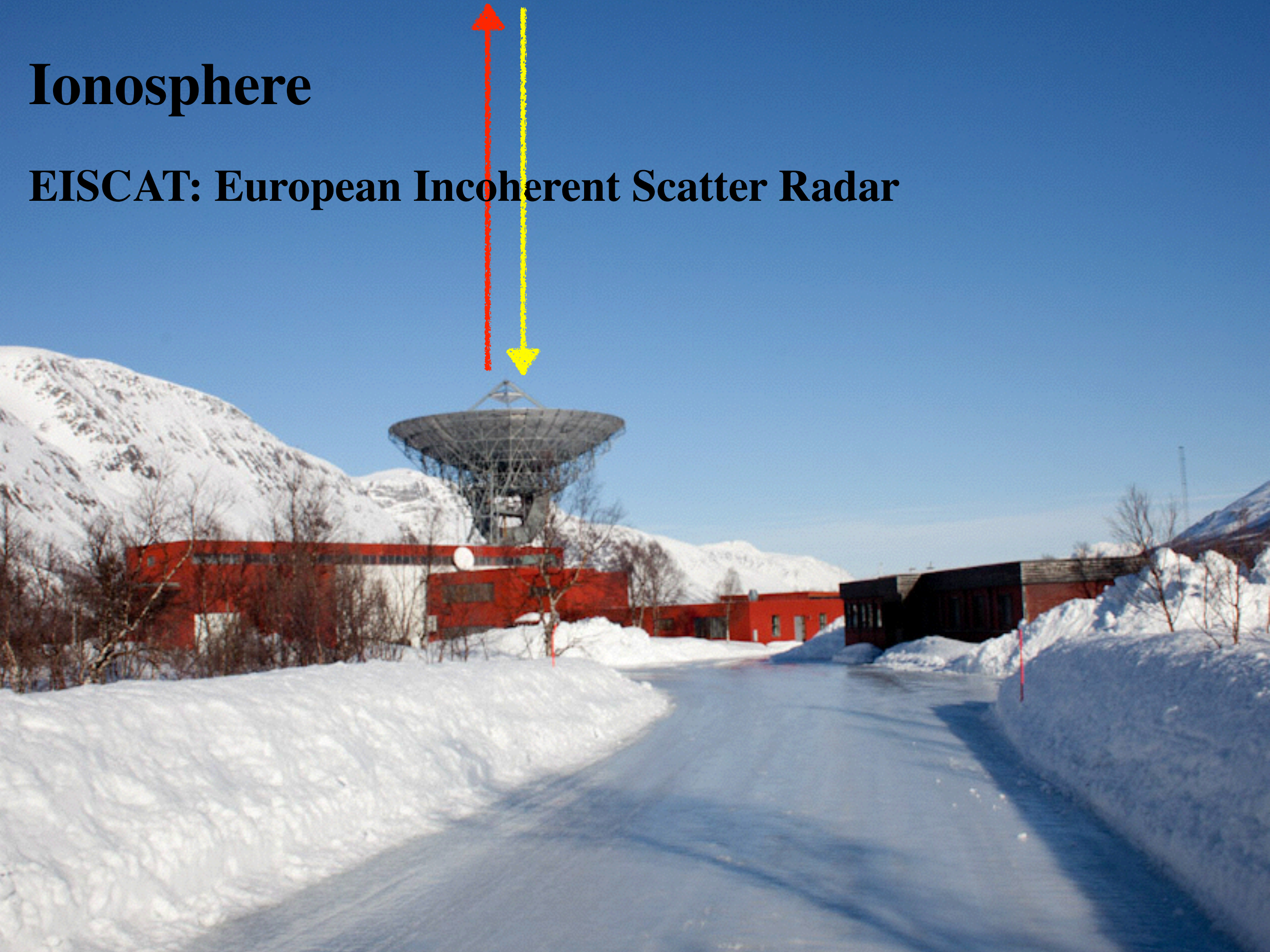
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Ionosphere

EISCAT: European Incoherent Scatter Radar



Quick exercise: browsing radar data from Norway

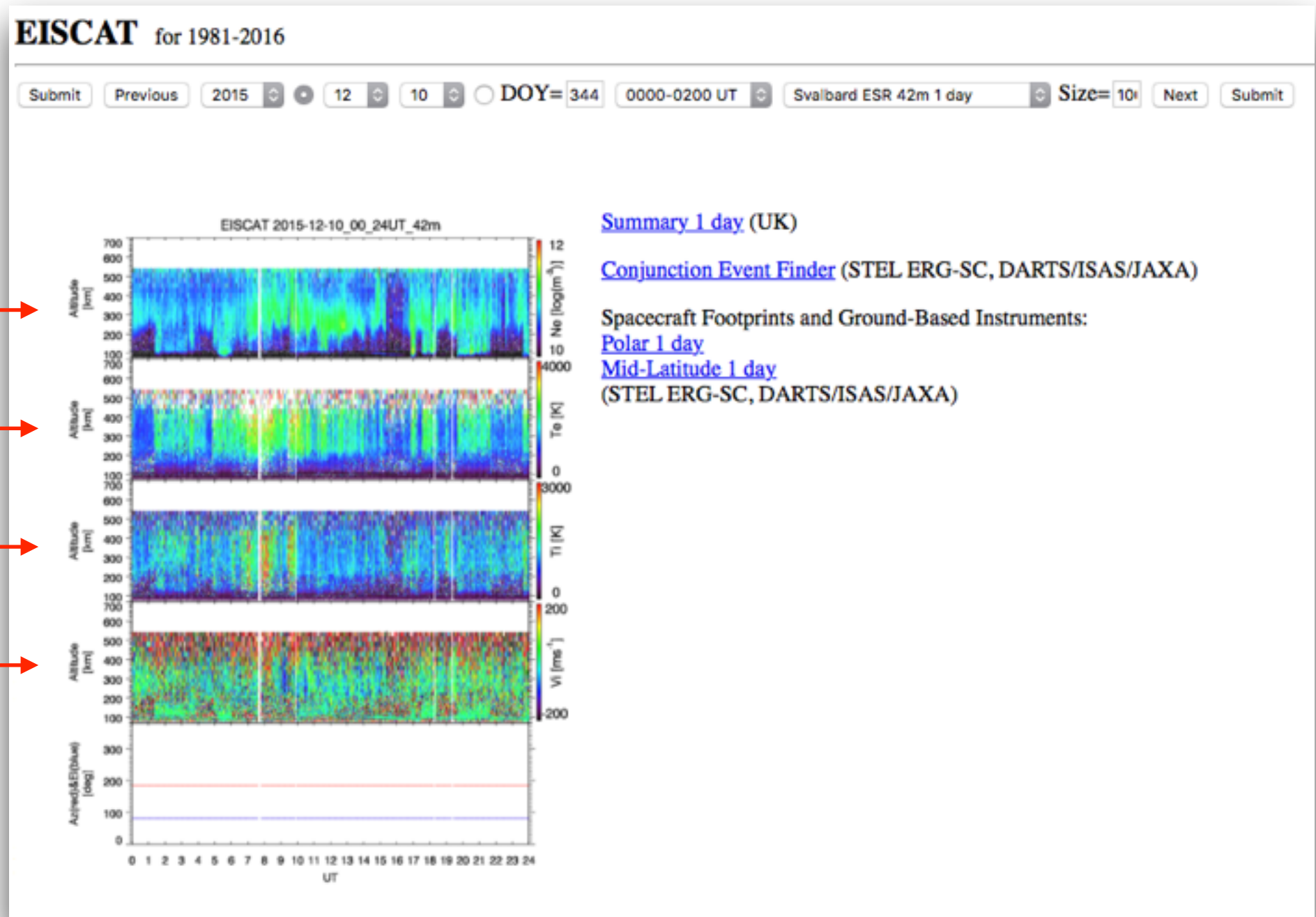
- Visit <http://133.57.20.115/www/cgi-bin/eiscat.cgi>

**Electron
Density** →

**Electron
Temperature** →

**Ion
Temperature** →

**Ion
Velocity** →



Change radar to "Tromso UHF radar"

2. Press Submit

EISCAT for 1981-2016

Submit Previous 2015 12 10 DOY= 344 0000-0200 UT Svalbard ESR 42m 1 day Size= 10 Next Submit

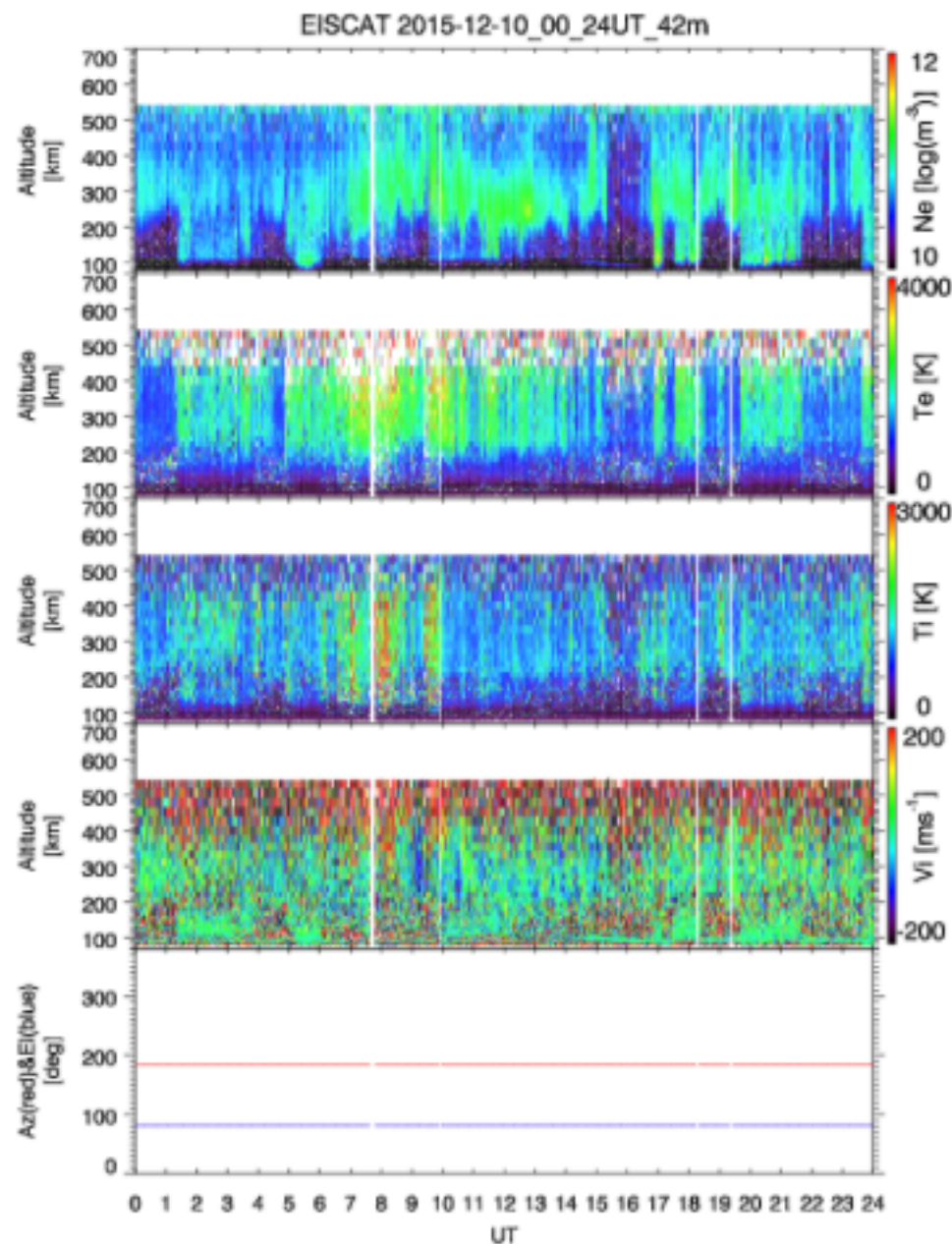
1. Select Tromso UHF radar 1 day

Ne

Te

Ti

Vi



[Summary 1 day \(UK\)](#)

[Conjunction Event Finder](#) (STEL ERG-SC, DARTS/ISAS/JAXA)

Spacecraft Footprints and Ground-Based Instruments:

[Polar 1 day](#)

[Mid-Latitude 1 day](#)

(STEL ERG-SC, DARTS/ISAS/JAXA)

Change date of plot - previous day and next day

EISCAT for 1981-2016

Submit Previous 2015 12 10 DOY= 344 0000-0200 UT Tromso UHF Radar 1 day Size= 10 Next Submit

↑ -1 day

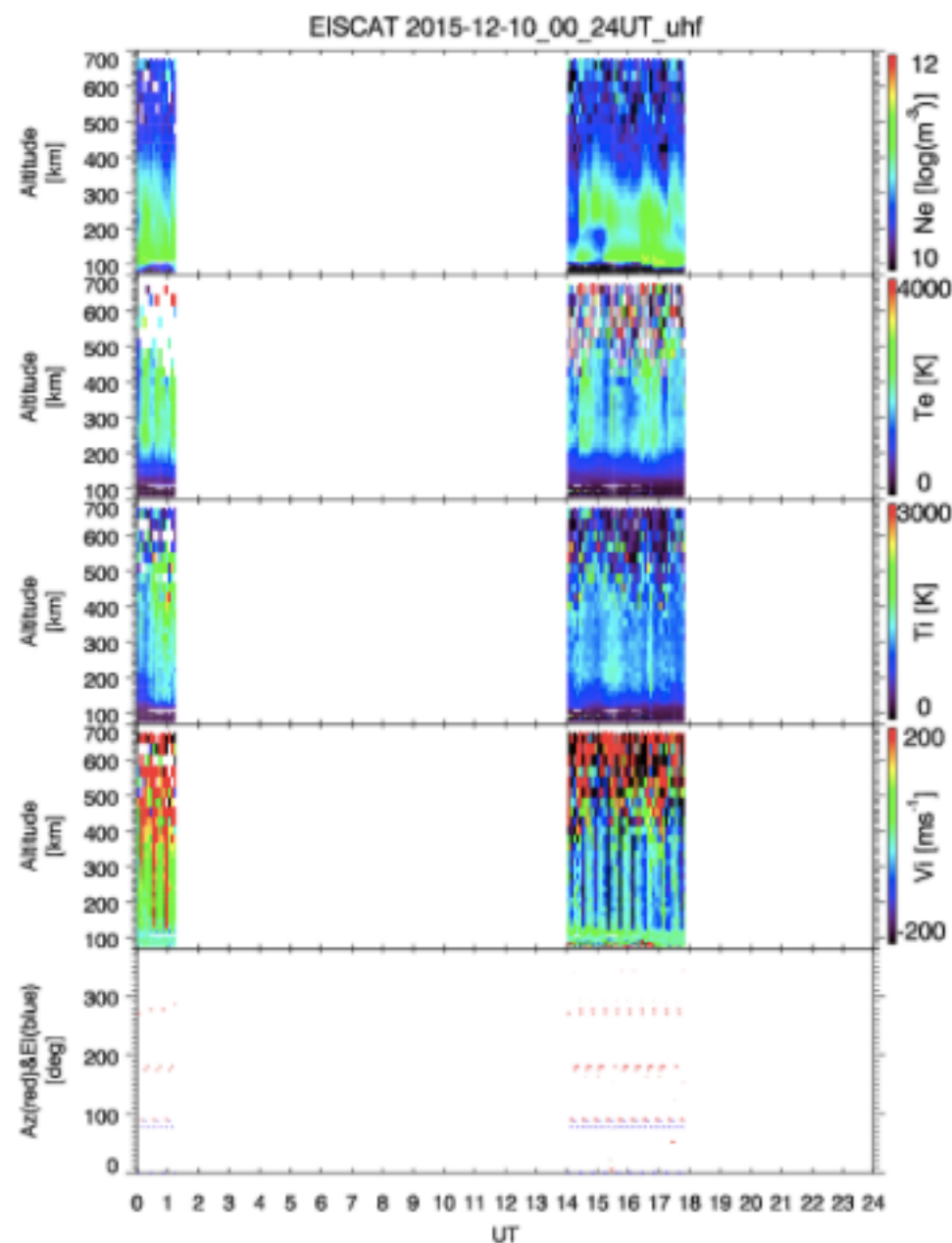
+1 day ↑

Ne

Te

Ti

Vi



[Summary 1 day](#) (UK)

[Conjunction Event Finder](#) (STEL ERG-SC, DARTS/ISAS/JAXA)

Spacecraft Footprints and Ground-Based Instruments:

[Polar 1 day](#)

[Mid-Latitude 1 day](#)

(STEL ERG-SC, DARTS/ISAS/JAXA)

Change date of plot - jump to different day

2. Press Submit

EISCAT for 1981-2016

Submit Previous 2015 12 10 DOY= 344 0000-0200 UT Tromso UHF Radar 1 day Size= 10i Next Submit

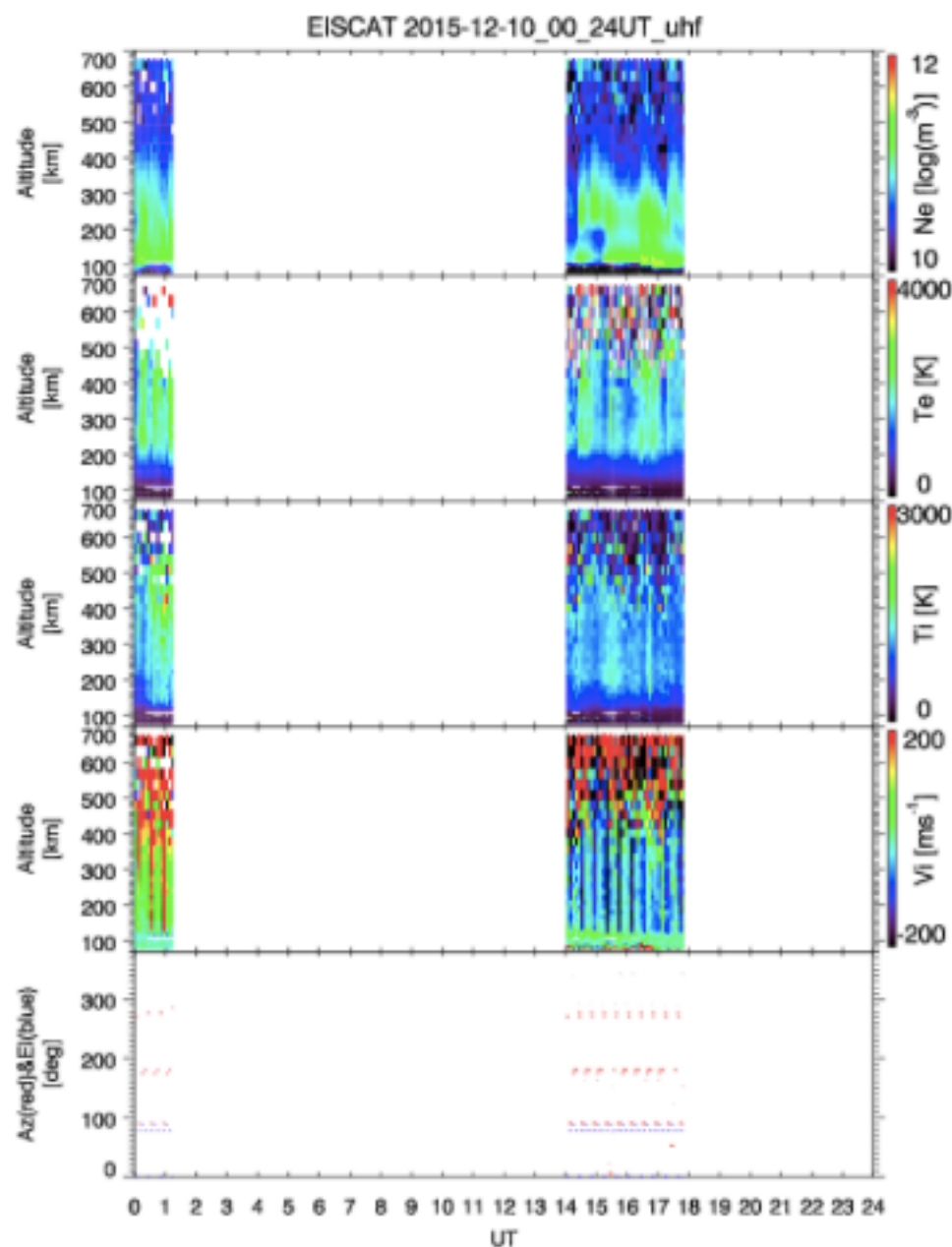
1. Change date (Year, Month, Day)

Ne

Te

Ti

Vi



[Summary 1 day \(UK\)](#)

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Spacecraft Footprints and Ground-Based Instruments:

[Polar 1 day](#)

[Mid-Latitude 1 day](#)

(STEL ERG-SC, DARTS/ISAS/JAXA)

Try the following date:

Jan 13, 2012

10 days continuous measurements in Tromso

EISCAT for 1981-2016

Submit Previous 2012 01 13 DOY= 013 0000-0200 UT Tromso UHF Radar 1 day Size= 10 Next Submit

Photo ionization

Weak impact ionization

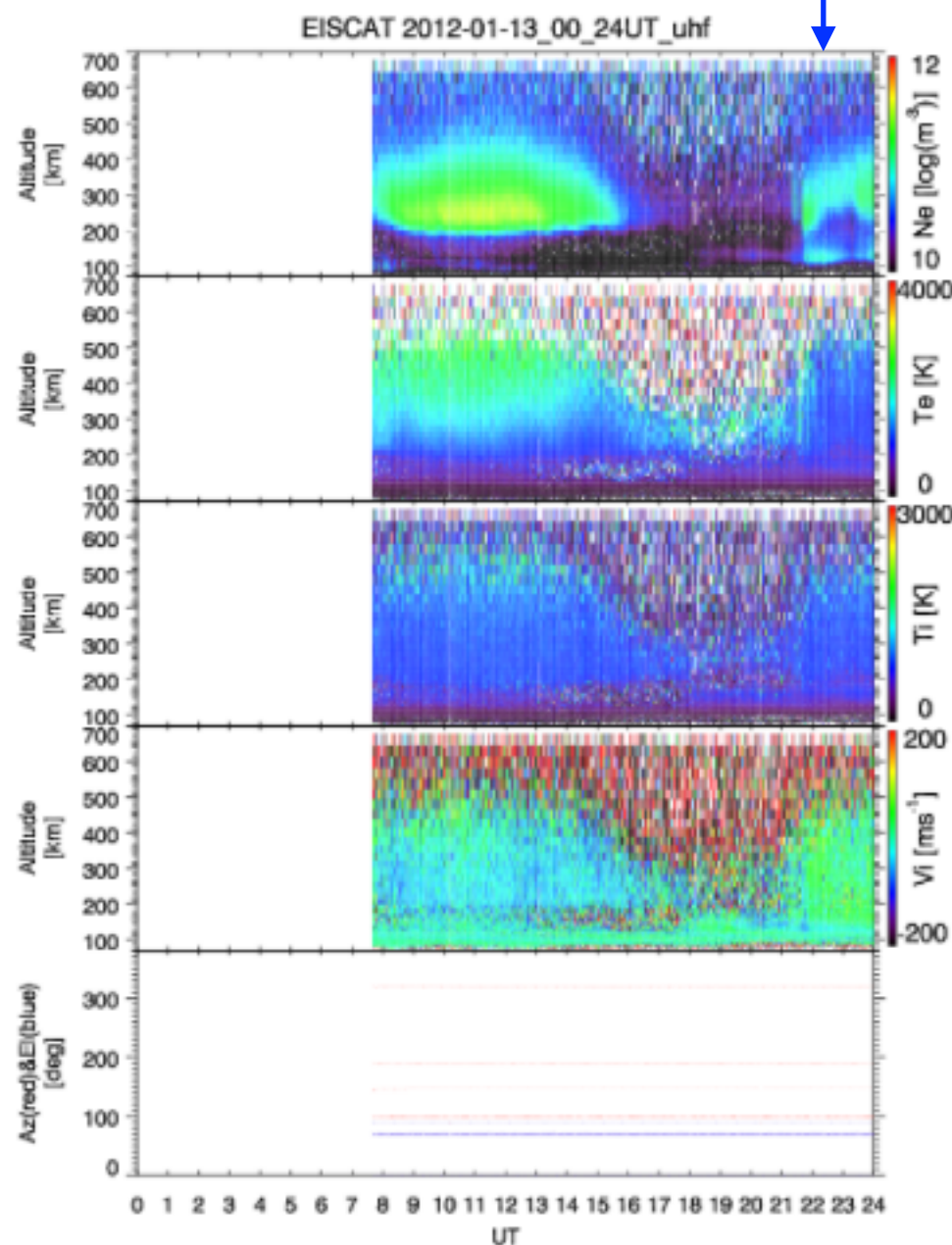
Check next day

Ne

Te

Ti

Vi



[Summary 1 day \(UK\)](#)

[Conjunction Event Finder](#) (STEL ERG-SC, DARTS/ISAS/JAXA)

Spacecraft Footprints and Ground-Based Instruments:

[Polar 1 day](#)

[Mid-Latitude 1 day](#)

(STEL ERG-SC, DARTS/ISAS/JAXA)

10 days continuous measurements in Tromso

EISCAT for 1981-2016

Submit Previous 2012 01 13 DOY= 013 0000-0200 UT Tromso UHF Radar 1 day Size= 10 Next Submit

Photo ionization

Weak impact ionization

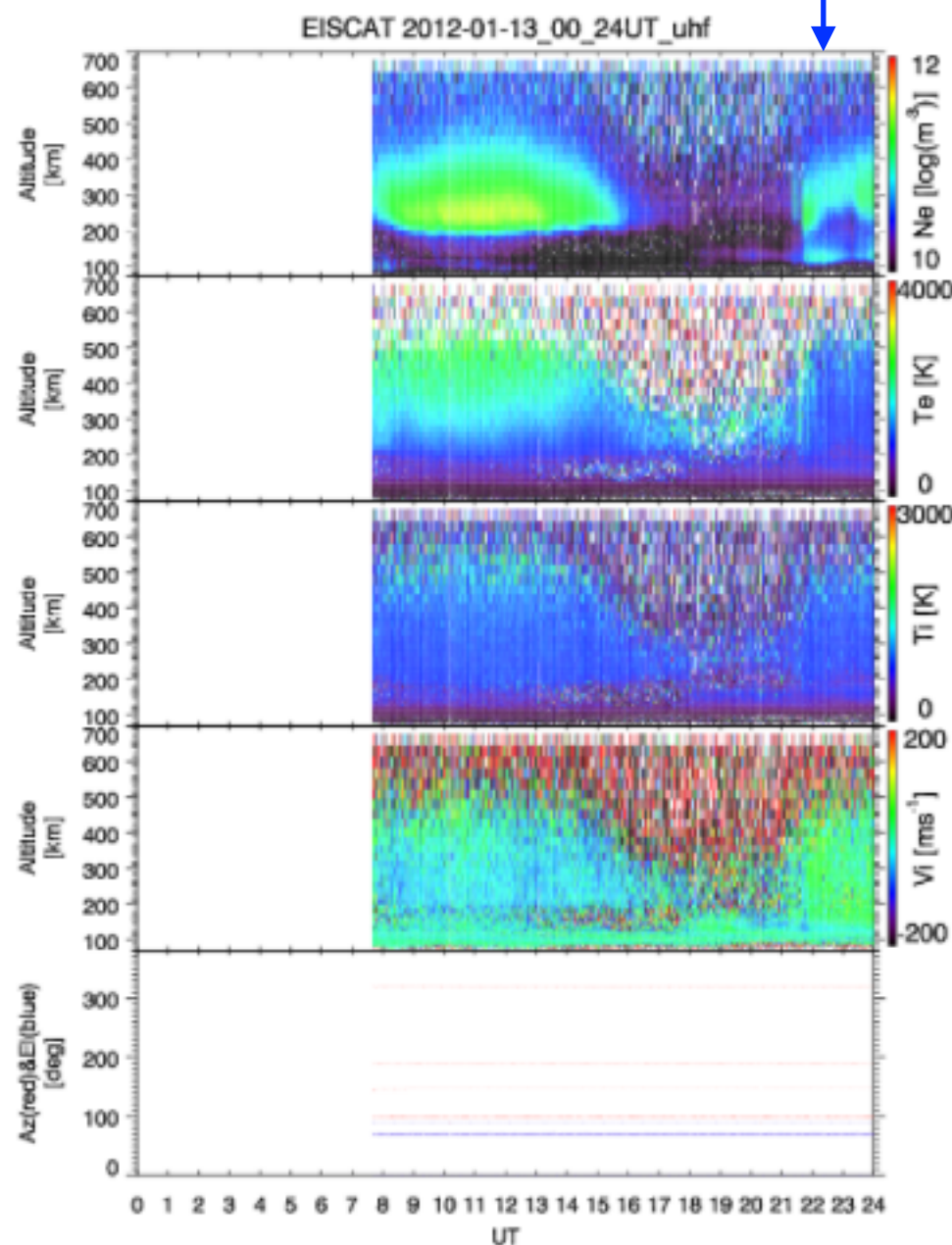
Check next day

Ne

Te

Ti

Vi



[Summary 1 day \(UK\)](#)

[Conjunction Event Finder](#) (STEL ERG-SC, DARTS/ISAS/JAXA)

Spacecraft Footprints and Ground-Based Instruments:

[Polar 1 day](#)

[Mid-Latitude 1 day](#)

(STEL ERG-SC, DARTS/ISAS/JAXA)

The ionosphere never be the same

- Photo ionization: almost similar

- Impact ionization:
large day-to-day variability

10 days later, on Jan 22, 2012

EISCAT for 1981-2016

Submit Previous 2012 01 22 DOY=022 0000-0200 UT Tromso UHF Radar 1 day Size=101 Next Submit

Photo
ionization

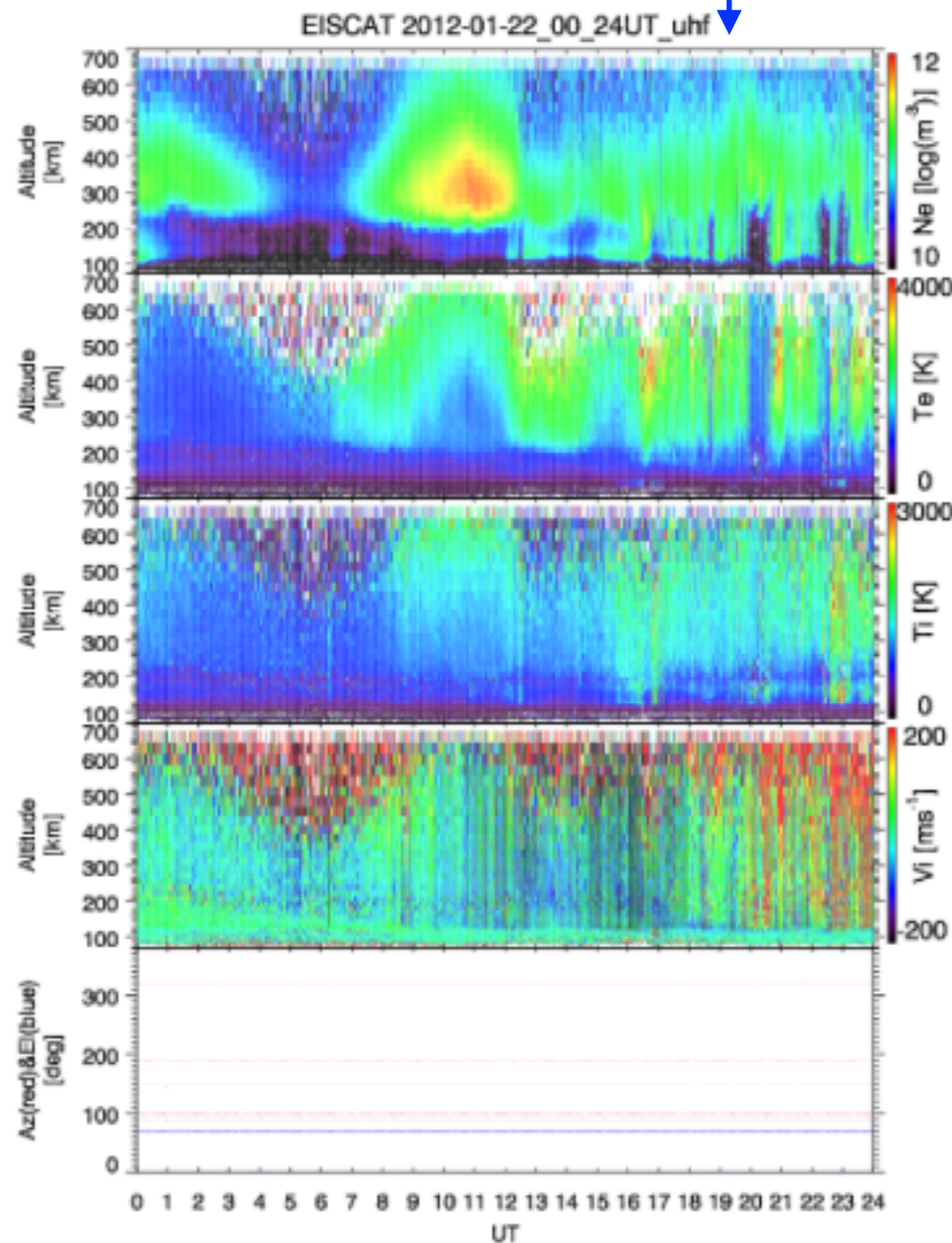
Strong impact ionization

Ne

Te

Ti

Vi



[Summary 1 day](#) (UK)

[Conjunction Event Finder](#) (STEL ERG-SC, DARTS/ISAS/JAXA)

Spacecraft Footprints and Ground-Based Instruments:

[Polar 1 day](#)

[Mid-Latitude 1 day](#)

(STEL ERG-SC, DARTS/ISAS/JAXA)

Jan 22 is a stormy day:



The ionosphere is disturbed during magnetic storms

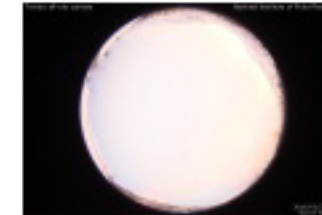
Check aurora data in Tromso on Jan 22, 2012

- <http://nordlys.nipr.ac.jp/acaaurora/Tromso/html/backnumber.html>

Tromso all-sky camera

National Institute of Polar Research
Contact on this page: miyaoka@nipr.ac.jp

[Back Number](#)



latest image

[Toppage](#)

**Find Jan 22, 2012, and
Click the date**

2016/01	2016/02	2016/03				
Su Mo Tu We Th Fr Sa 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31	Su Mo Tu We Th Fr Sa 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29	Su Mo Tu We Th Fr Sa 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31				
2015/09	2015/10	2015/11	2015/12			
Su Mo Tu We Th Fr Sa 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30	Su Mo Tu We Th Fr Sa 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31	Su Mo Tu We Th Fr Sa 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30	Su Mo Tu We Th Fr Sa 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31			
2015/01	2015/02	2015/03	2015/04			
Su Mo Tu We Th Fr Sa 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31	Su Mo Tu We Th Fr Sa 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28	Su Mo Tu We Th Fr Sa 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31	Su Mo Tu We Th Fr Sa 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30			

Check aurora data in Tromso on Jan 22, 2012

Tromso all-sky camera

National Institute of Polar Research

Contact on this page: miyaoka@nipr.ac.jp

[Back Number](#)



latest image

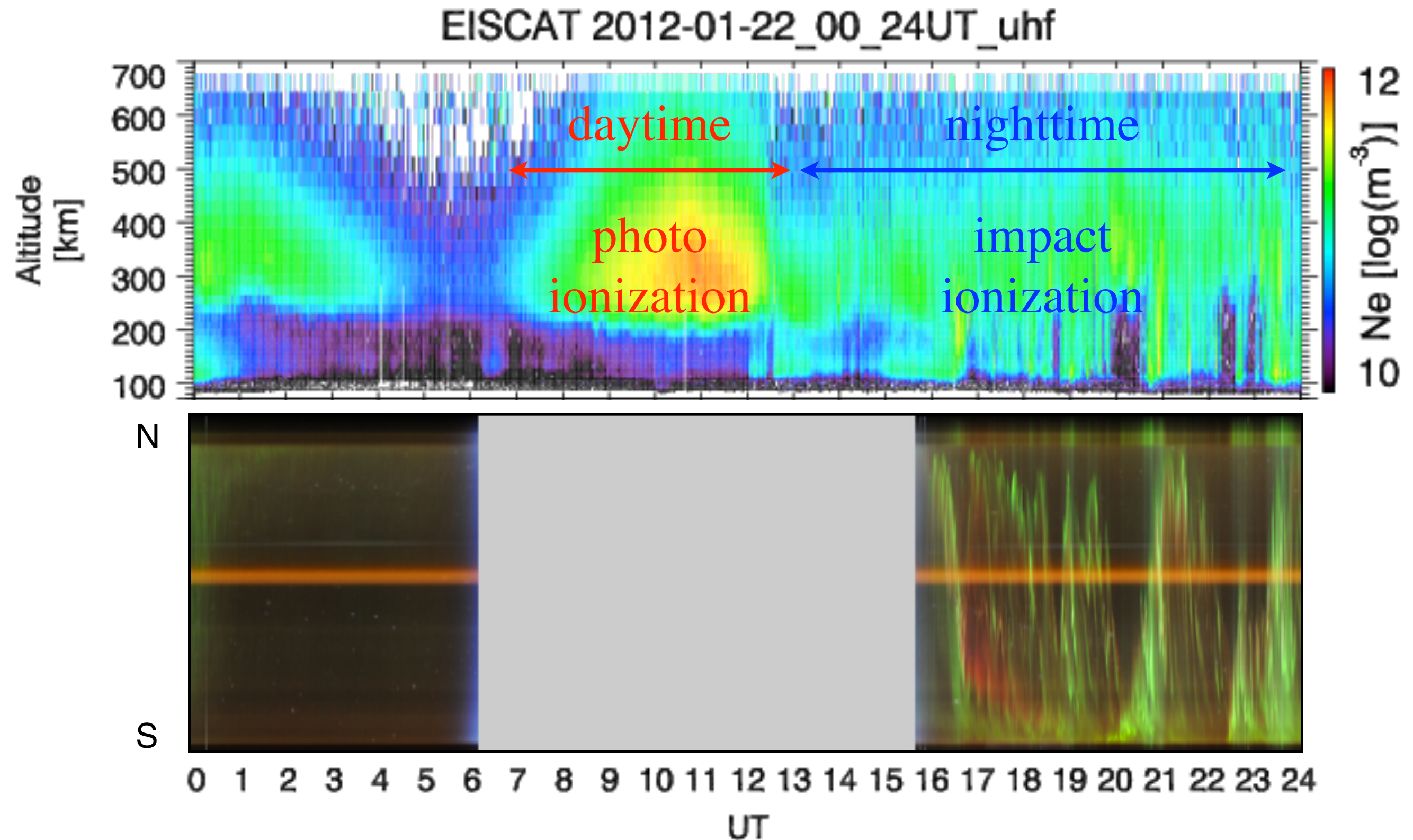
Date: Jan. 22, 2012

[Check movie?](#)

Hourly animation by clicking [the time](#) [Daily animation \(720*480pixel\)](#)

	00'	10'	20'	30'	40'	50'	
0:00							0:00
1:00							1:00
2:00							2:00
3:00							3:00

Check aurora data in Tromso on Jan 22, 2012



Let's play with the EISCAT and Aurora data

- EISCAT:

<http://133.57.20.115/www/cgi-bin/eiscat.cgi>

EISCAT data are available from 1981 to 2015

But, the operation of the radar is not continuous

- All-sky camera in Tromso:

<http://nordlys.nipr.ac.jp/acaaurora/Tromso/html/backnumber.html>

Aurora data in Tromso are available only during winter
Continuous operation of the camera has started in 2009

Outline

- Ionosphere

Quick exercise: Browsing radar data from Norway

- Key ideas of GNSS

- Mechanism of ionospheric effects on GNSS

- Two major ionospheric impacts on GNSS

1. Positioning error

Quick exercise: Browsing GPS TEC data in US

2. Scintillation effect

Quick exercise: Browsing GPS scintillation data

Global Navigation Satellite Systems

GNSS: Global Navigation Satellite System

- ↳ GPS (USA), GLONASS (Russia) in full operation
- ↳ Galileo (EU), BeiDou II (China) will be fully operative

Regional Navigation Satellite System

- ↳ QZSS (Japan), BeiDou I (China), IRNSS (India)

Mission

Provide “precise” position and time not only for navigation of cars, airplanes and ships but also various social activities.

Key idea → Trilateration

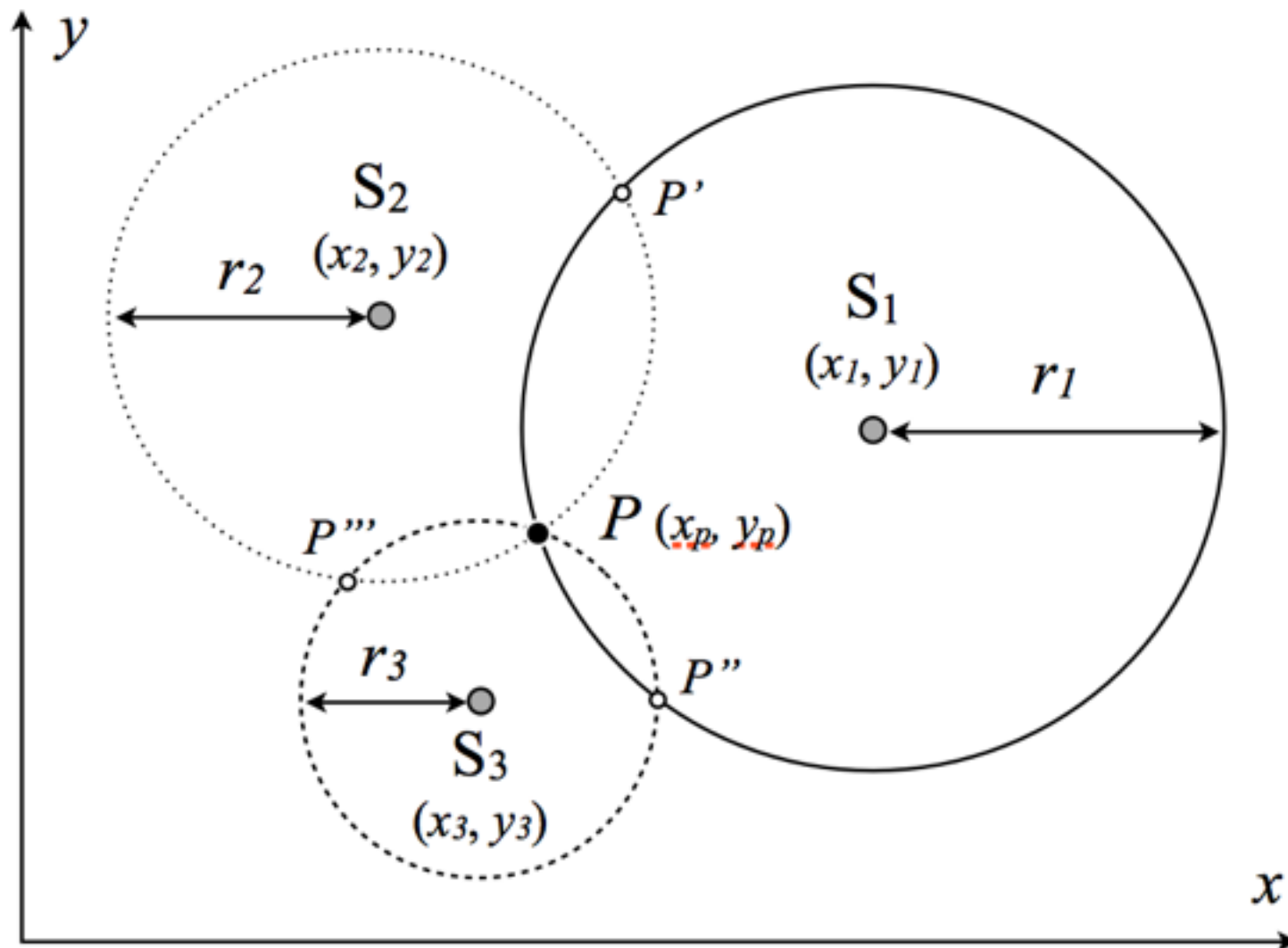
Concept of Satellite Navigation

Trilateration:
2D case

$$r_1^2 = (x_p - x_1)^2 + (y_p - y_1)^2$$

$$r_2^2 = (x_p - x_2)^2 + (y_p - y_2)^2$$

$$r_3^2 = (x_p - x_3)^2 + (y_p - y_3)^2$$



Unknown: x_p , and y_p

↳ equations are solvable.

Concept of Satellite Navigation

Trilateration:

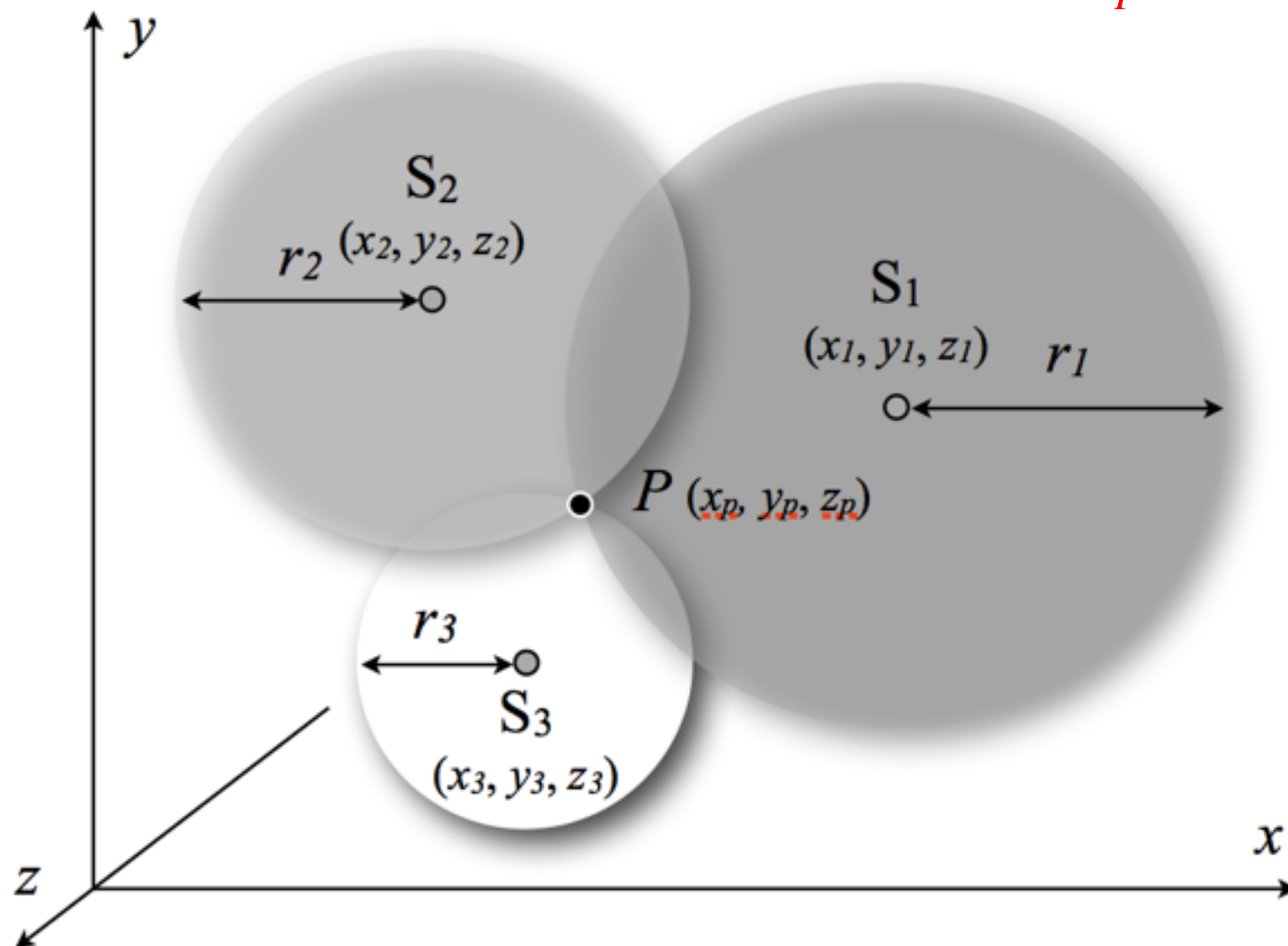
3D case

circles \rightarrow spheres

$$r_1^2 = (x_p - x_1)^2 + (y_p - y_1)^2 + (z_p - z_1)^2$$

$$r_2^2 = (x_p - x_2)^2 + (y_p - y_2)^2 + (z_p - z_2)^2$$

$$r_3^2 = (x_p - x_3)^2 + (y_p - y_3)^2 + (z_p - z_3)^2$$

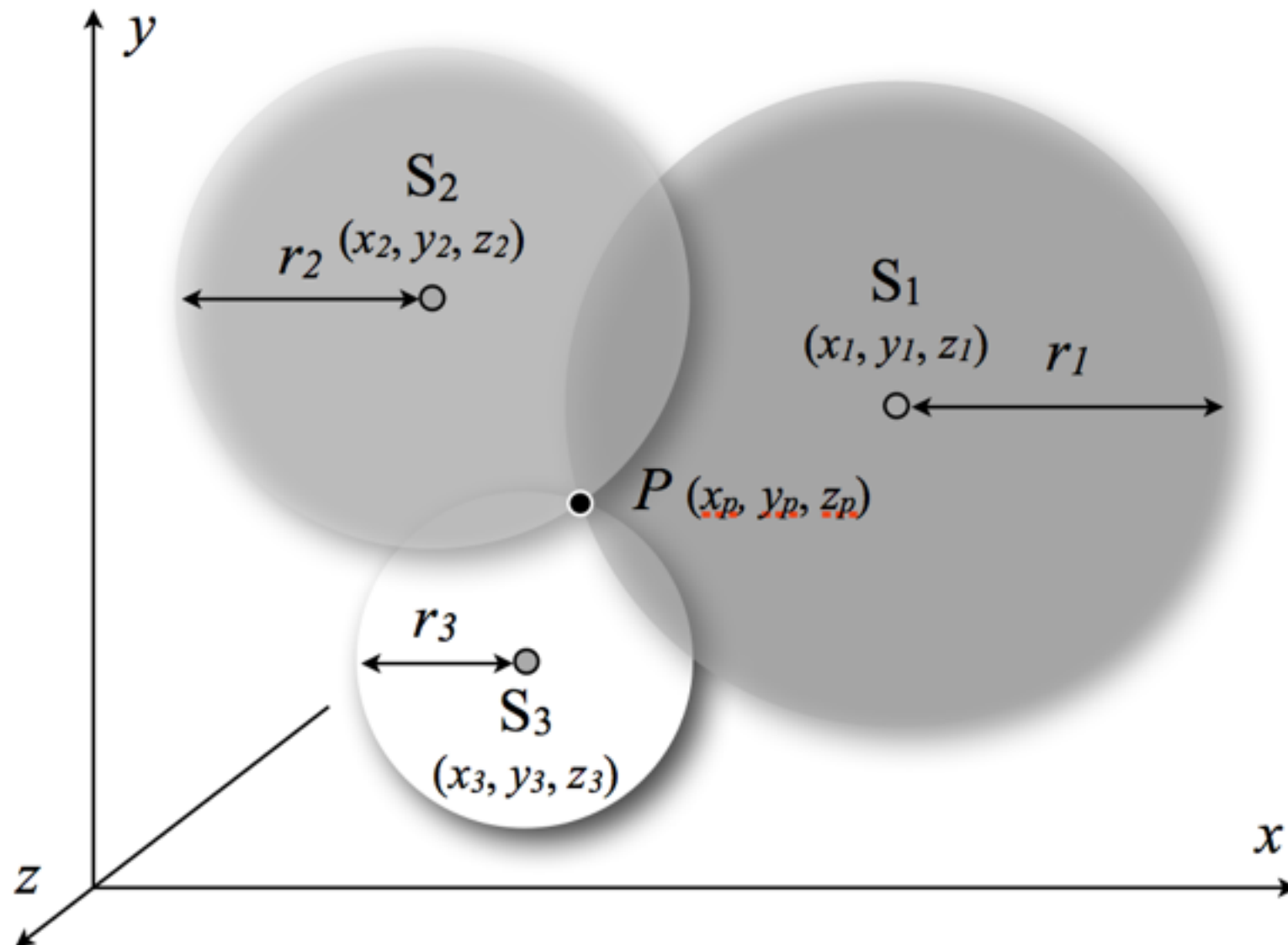


Unknown: x_p, y_p and z_p
 \hookrightarrow equations are solvable.

Concept of Satellite Navigation

Trilateration requires

1. To know the precise positions of base stations
2. To observe the distances from at least 3 base stations



Basic Parameters of GNSS Satellite

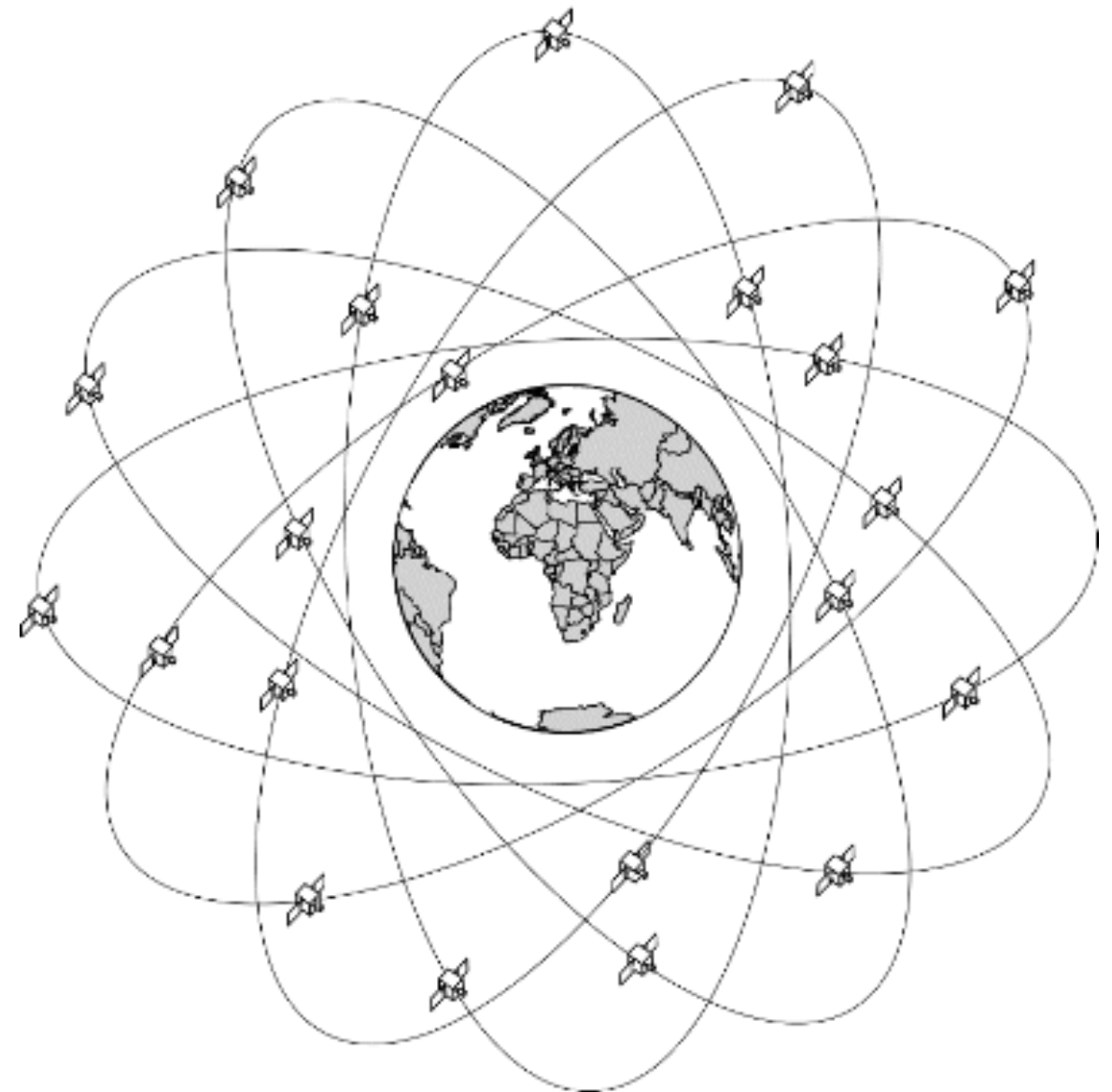
Space System

Summary of the GPS system in space

- Altitude: 20,200 km
- Orbital period: 11 h 58 m
- 6 orbital planes: inclination = 55°
- 4 satellites on each orbital plane

→ the total number of satellites

$$= 4 \times 6 + 8 \text{ (spare)} = 32$$

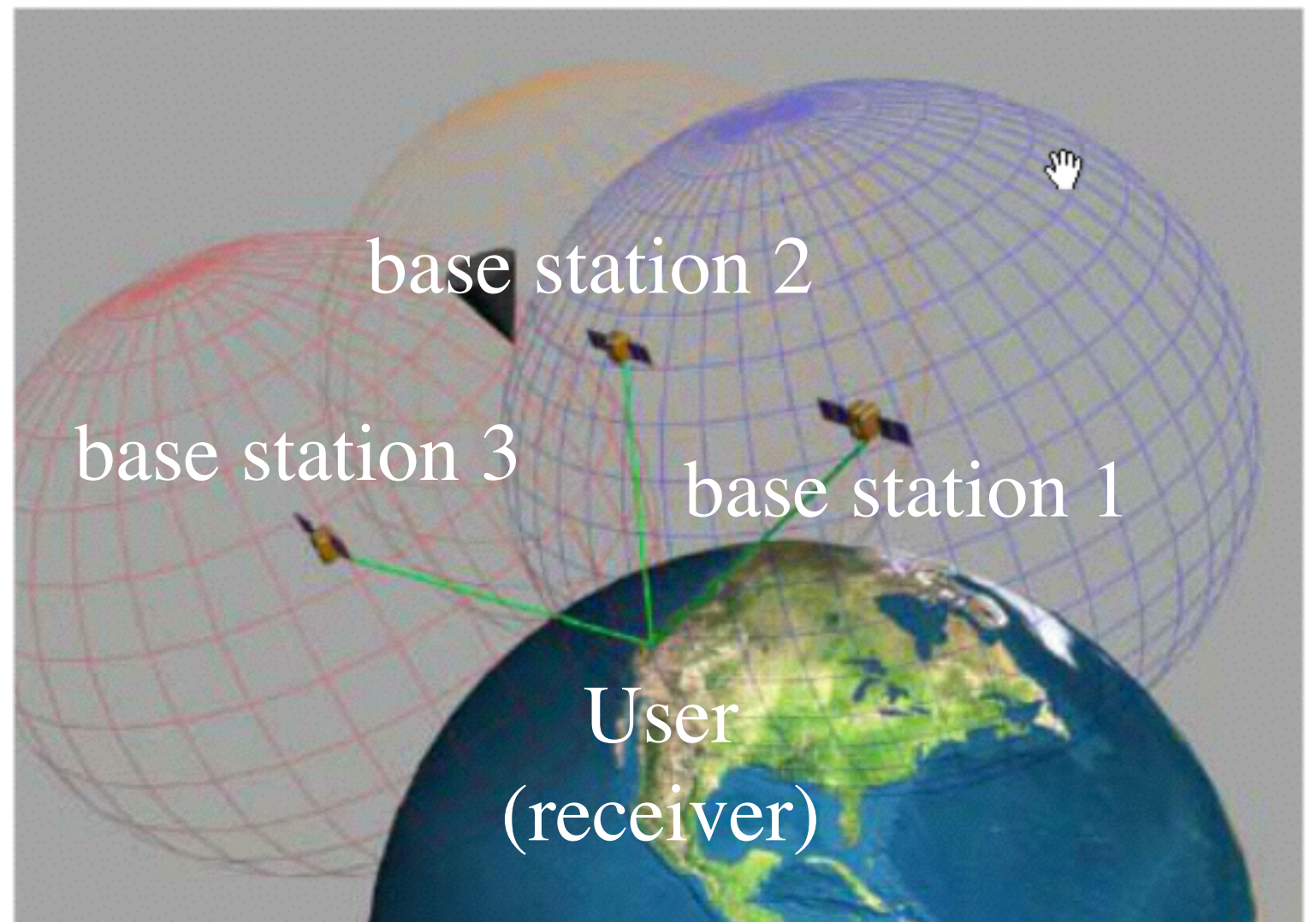


Concept of Satellite Navigation

Satellite-based 3D Trilateration → **Base stations: up in the space**
(exact position is known)

Q: How do we measure the distances to the satellites (base stations)?

A: Use radio waves
always transmitted
from the satellite,
and estimate the
travel time of the
radio waves from the
satellite to the ground.

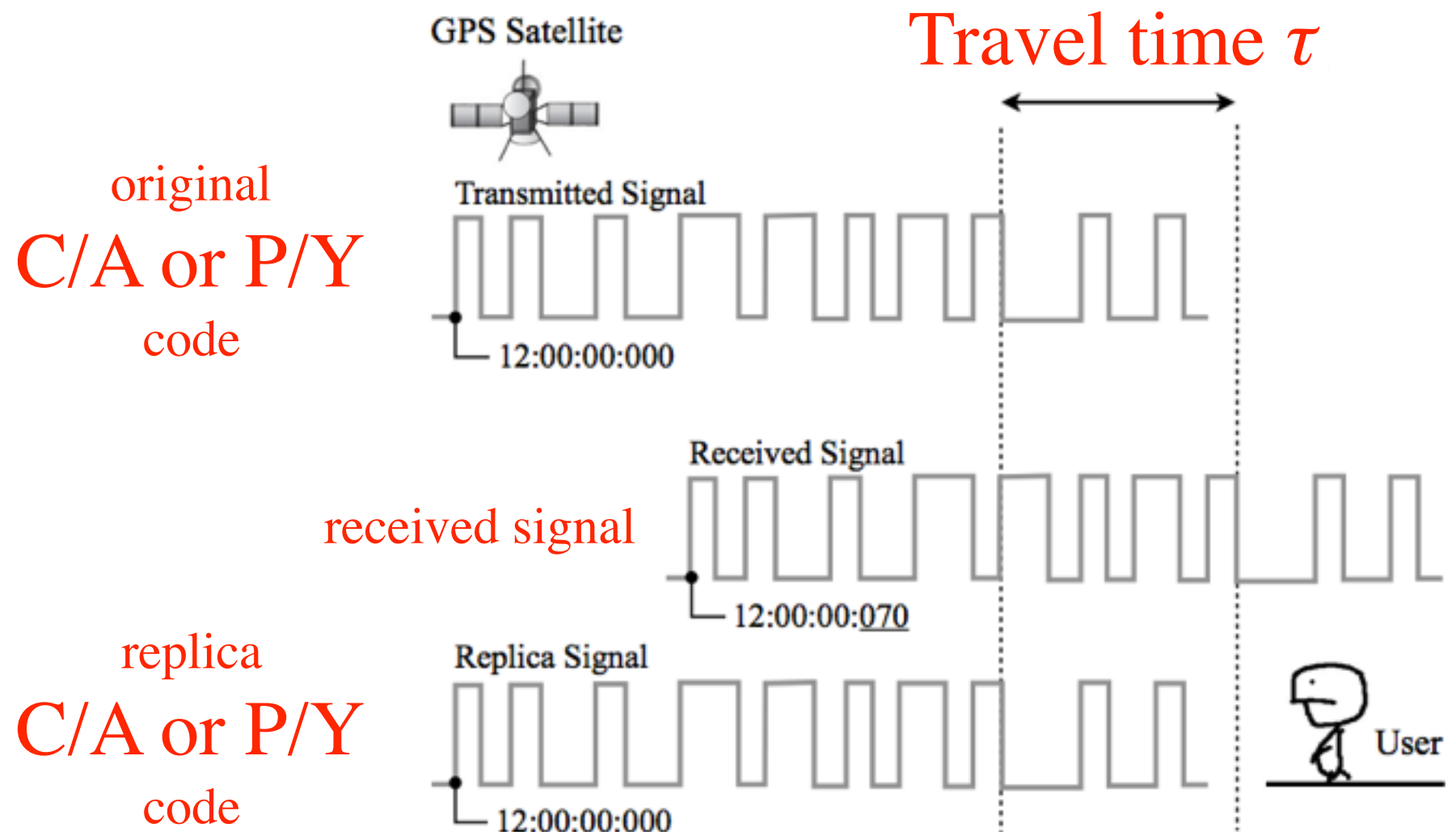


Basic Parameters of GNSS Satellite

Derivation of Transit Time τ

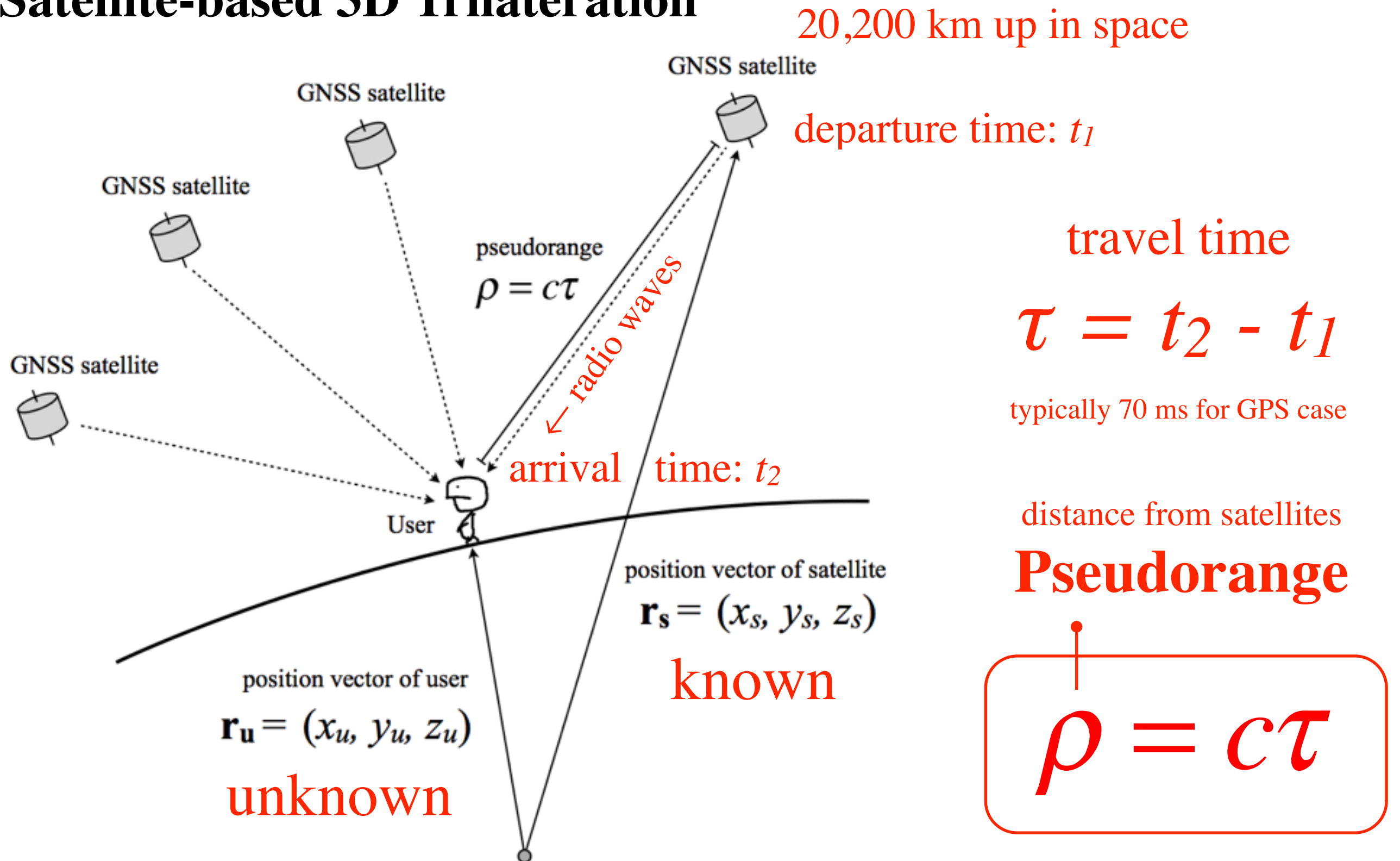
Q. How do we measure the travel time τ ?

A. The travel time τ is derived by calculating a correlation between received coded signal and its replica at the receiver.



Concept of Satellite Navigation

Satellite-based 3D Trilateration



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- Two major ionospheric impacts on GNSS

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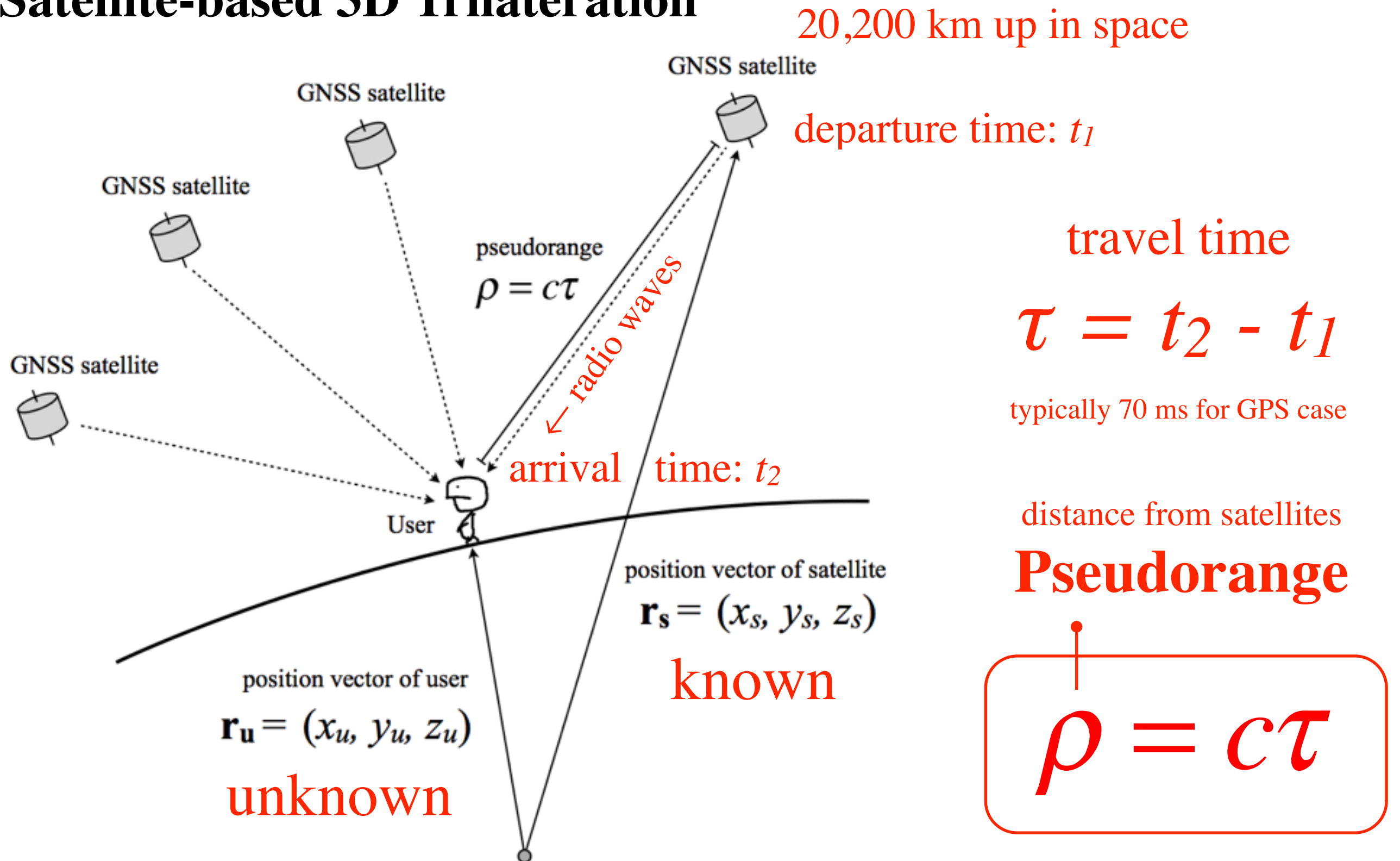
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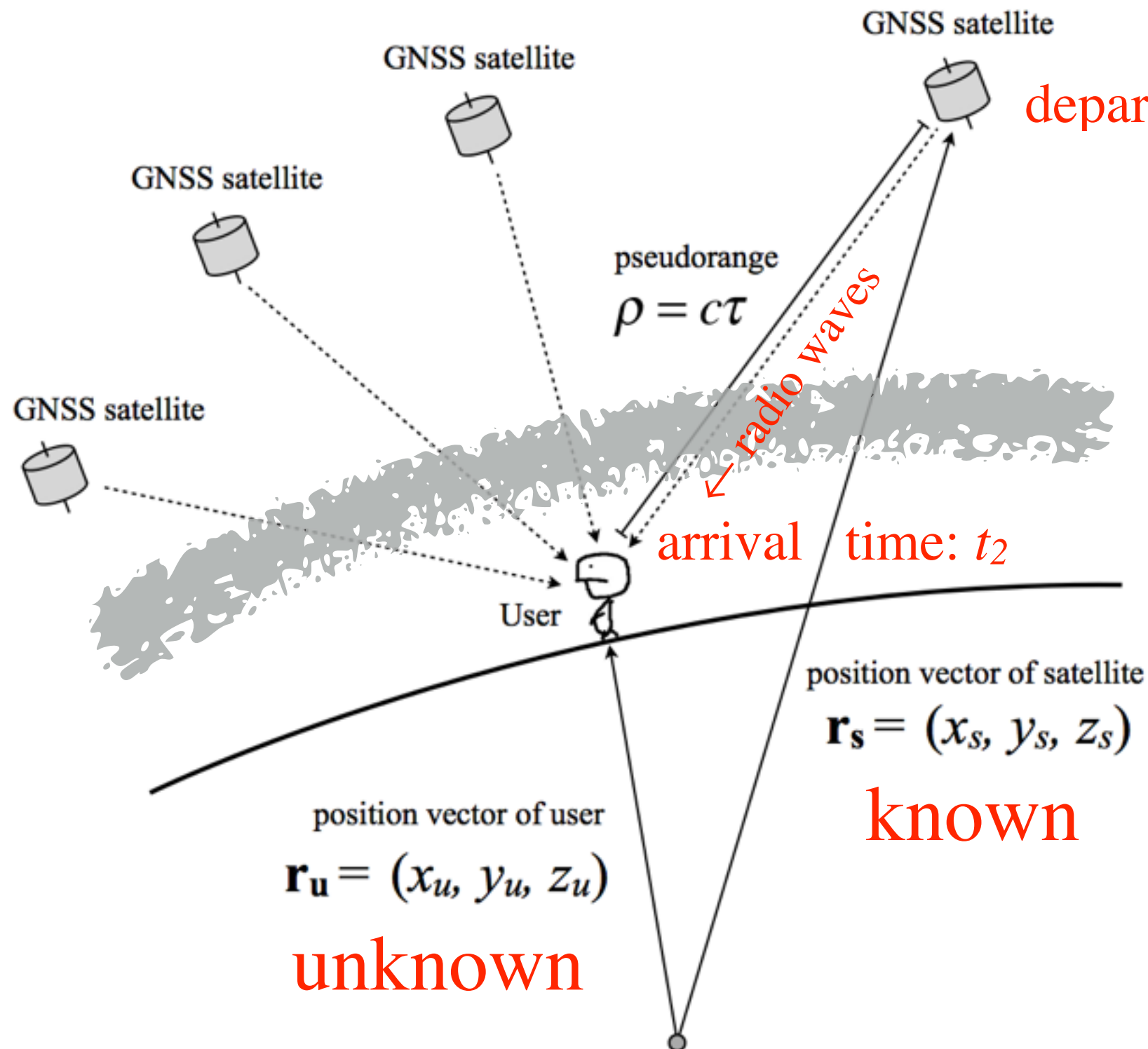
Concept of Satellite Navigation

Satellite-based 3D Trilateration



Concept of Satellite Navigation

Satellite-based 3D Trilateration



20,200 km up in space

departure time: t_1

travel time

$$\tau = t_2 - t_1$$

typically 70 ms for GPS case

distance from satellites

Pseudorange

$$\rho = c\tau$$

Phase Velocity and Group Velocity

Refractive Index:

Propagation of light (i.e., radio waves) in a medium depends on the refractive index n , which is defined as

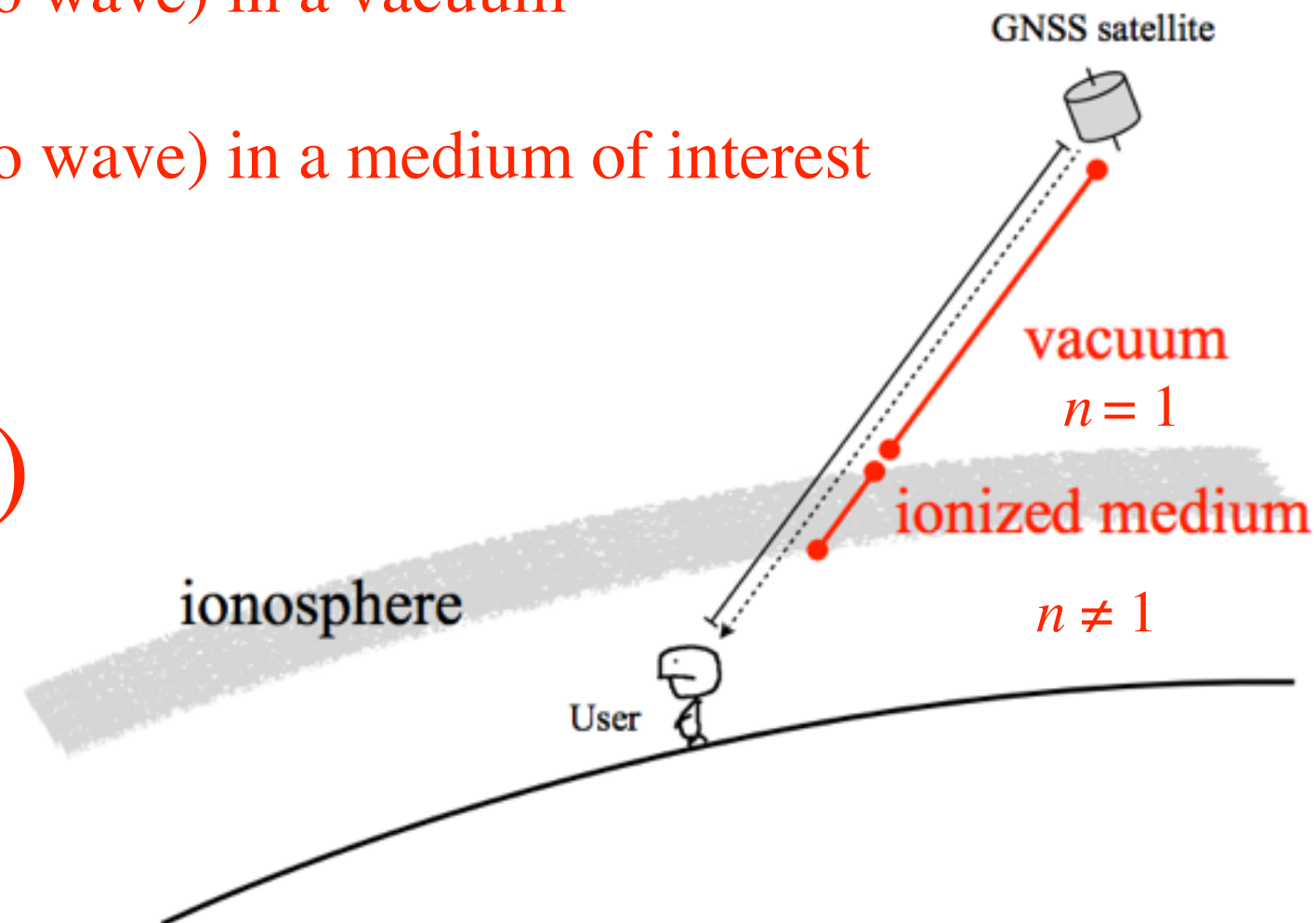
$$n = \frac{c}{v}$$

c —→ speed of light (radio wave) in a vacuum
 v —→ speed of light (radio wave) in a medium of interest

$$n = 1: v = c \text{ (vacuum)}$$

$$n < 1: v > c \text{ (faster)}$$

$$n > 1: v < c \text{ (slower)}$$



Impact of Ionosphere on GNSS

Refractive Index in Ionized Medium

$$n = \frac{c}{v}$$

Refractive index for coded GNSS signal in the ionosphere:

$$n = 1 + \frac{40.3 n_e}{f^2}$$

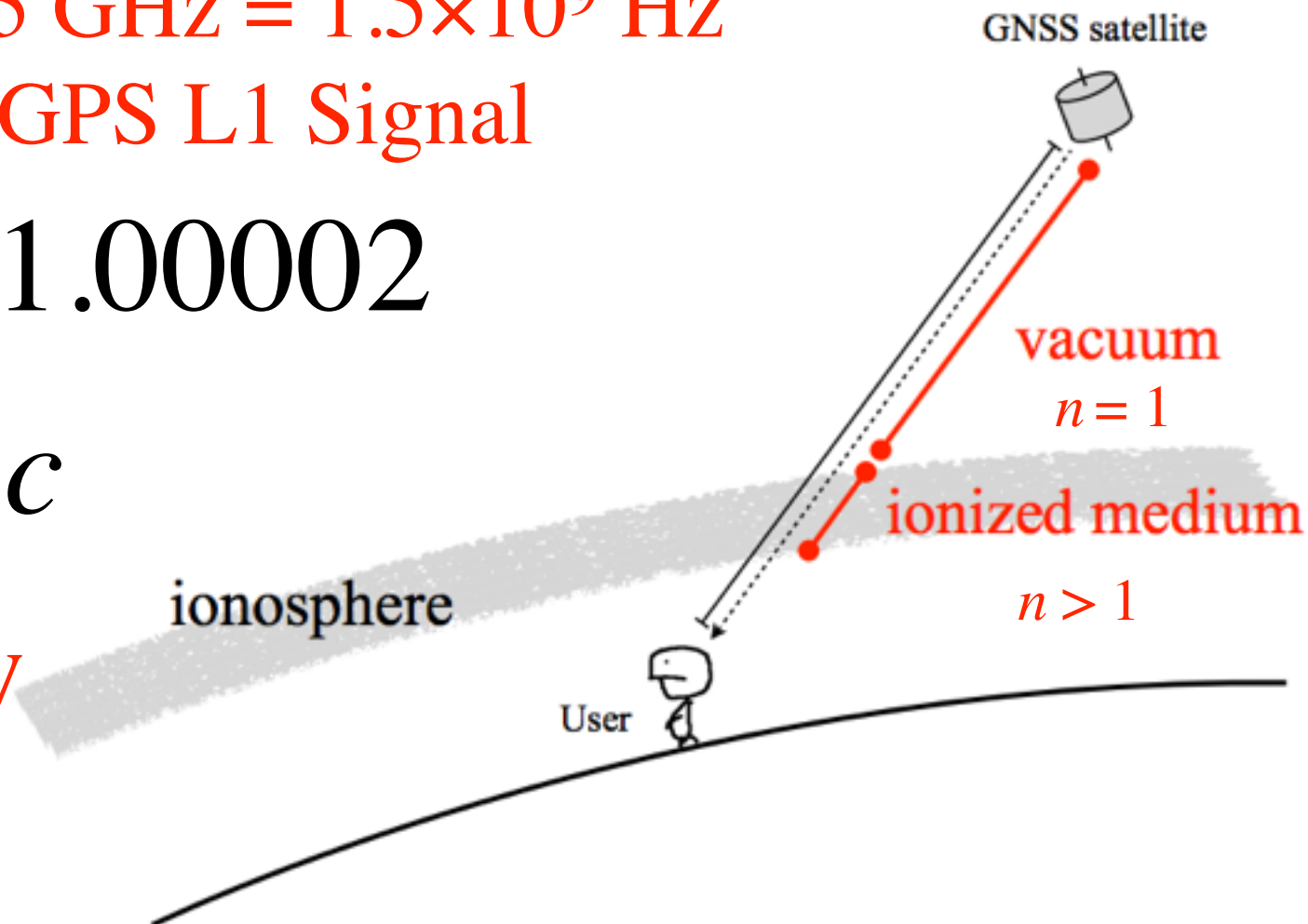
10^{12} m^{-3} in the ionosphere

$\sim 1.5 \text{ GHz} = 1.5 \times 10^9 \text{ Hz}$
for GPS L1 Signal

$$\approx 1 + 2.0 \times 10^{-5} = 1.000002$$

$$\rightarrow v \approx 0.999998 \times c$$

Coded GPS signals slow down in the ionosphere



Impact of Ionosphere on GNSS

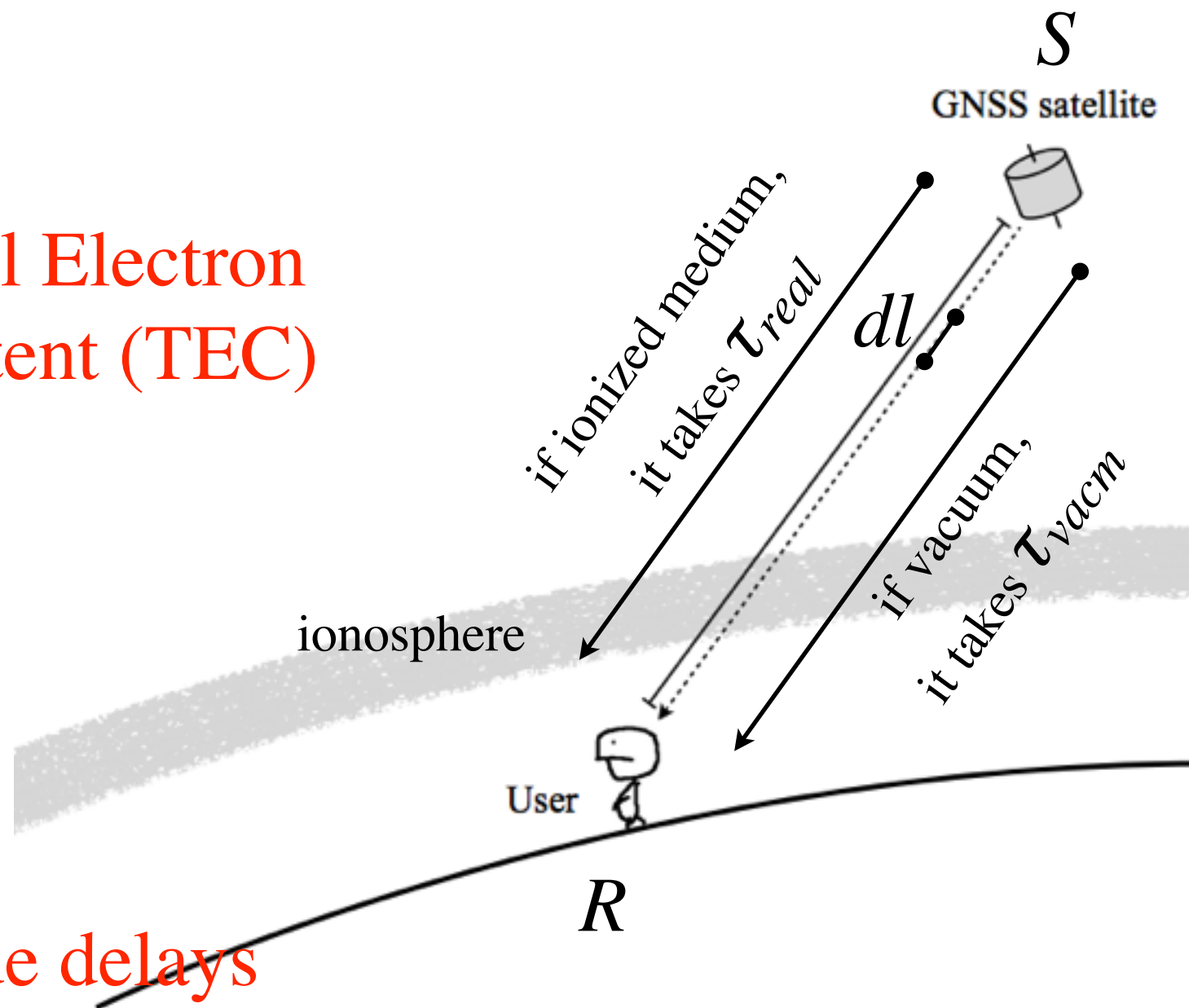
Possible Impact on GNSS

The delay of the coded GNSS signal is ...

$$\begin{aligned}\Delta\tau &= \frac{1}{c} \int_S^R \frac{40.3n_e(l)}{f^2} dl \\ &= \frac{40.3}{cf^2} \int_S^R n_e(l) dl \quad \text{Total Electron Content (TEC)} \\ &= + \frac{40.3\text{TEC}}{cf^2} \quad (16)\end{aligned}$$

Coded signals always delay

→ More electrons, larger code delays



Impact of Ionosphere on GNSS

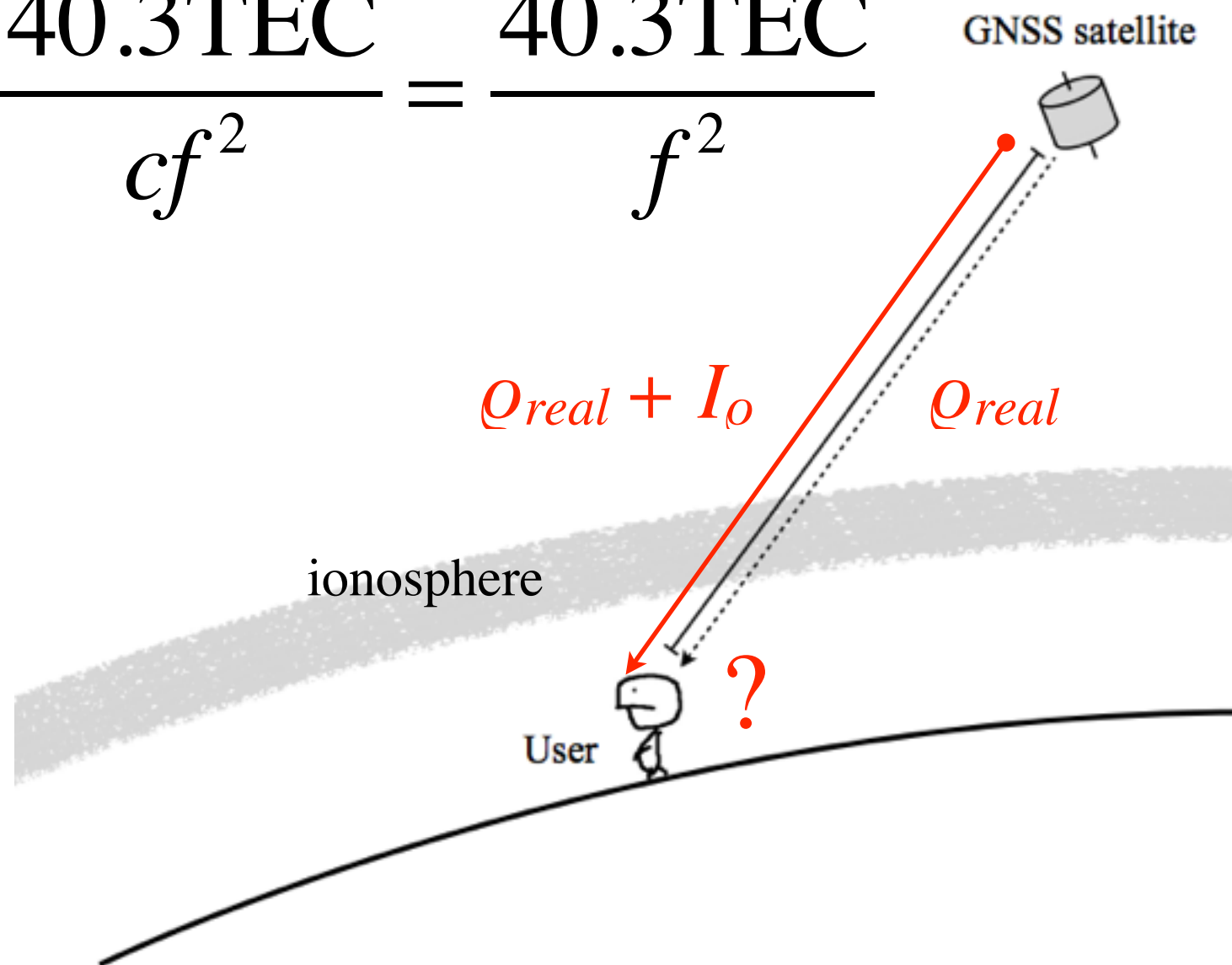
Possible Impact on GNSS

The delay in travel time corresponds to an error in pseudorange:

$$I_{\rho} = c \times \Delta\tau = c \times \frac{40.3\text{TEC}}{cf^2} = \frac{40.3\text{TEC}}{f^2}$$

Error in pseudorange ϱ

When the electron density in the ionosphere increases, that is TEC increases, pseudorange is overestimated.

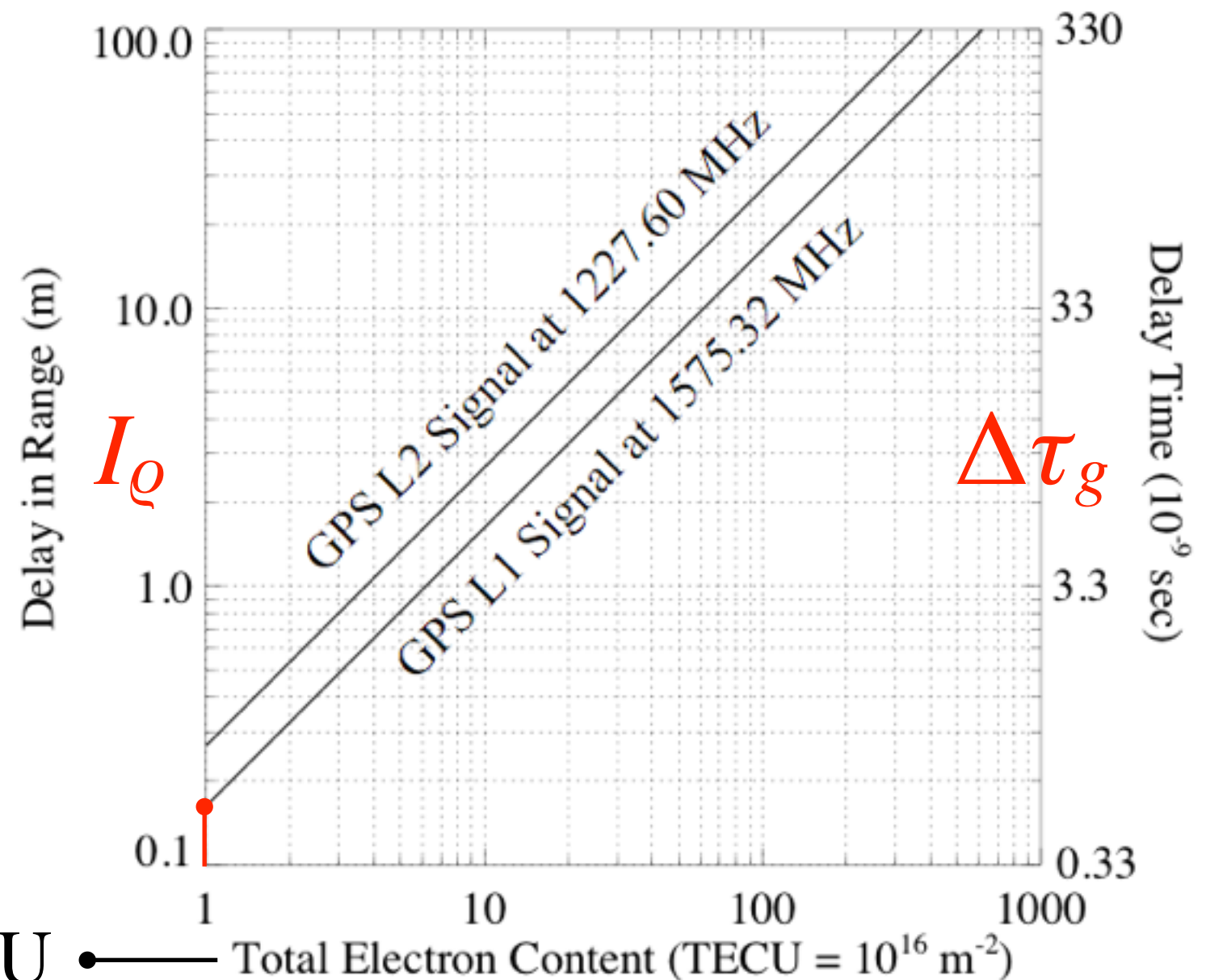


Impact of Ionosphere on GNSS

Possible Impact on GNSS

1 TECU \rightarrow 16 cm error in pseudorange

$$I_{\rho} = \frac{40.3 \text{ TEC}}{f^2}$$

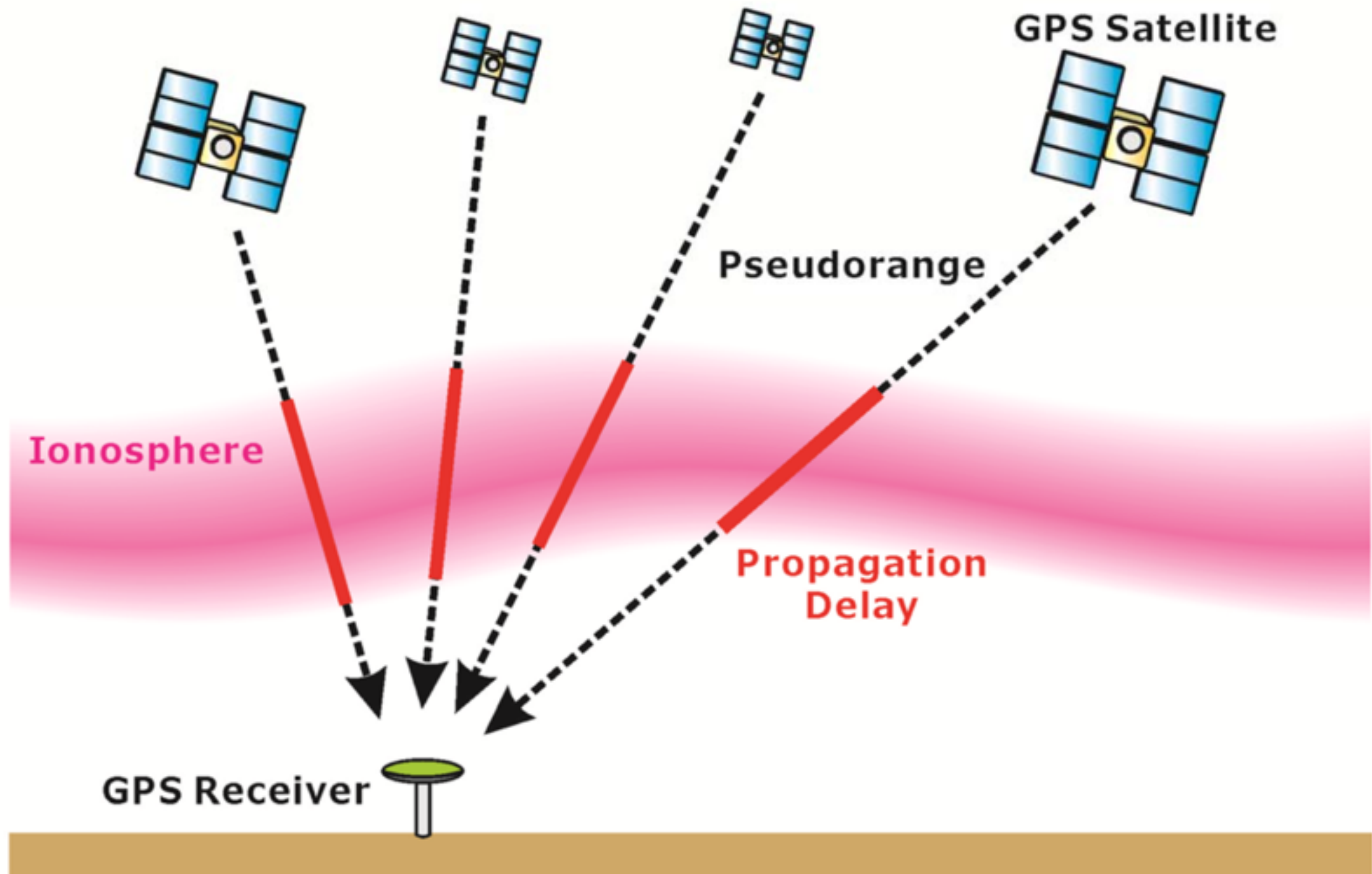


GPS Positioning Error due to Ionosphere

Ionospheric effect on GNSS

1 TECU = 16 cm

$$I_{\rho} = \frac{40.3 \text{ TEC}}{f^2}$$



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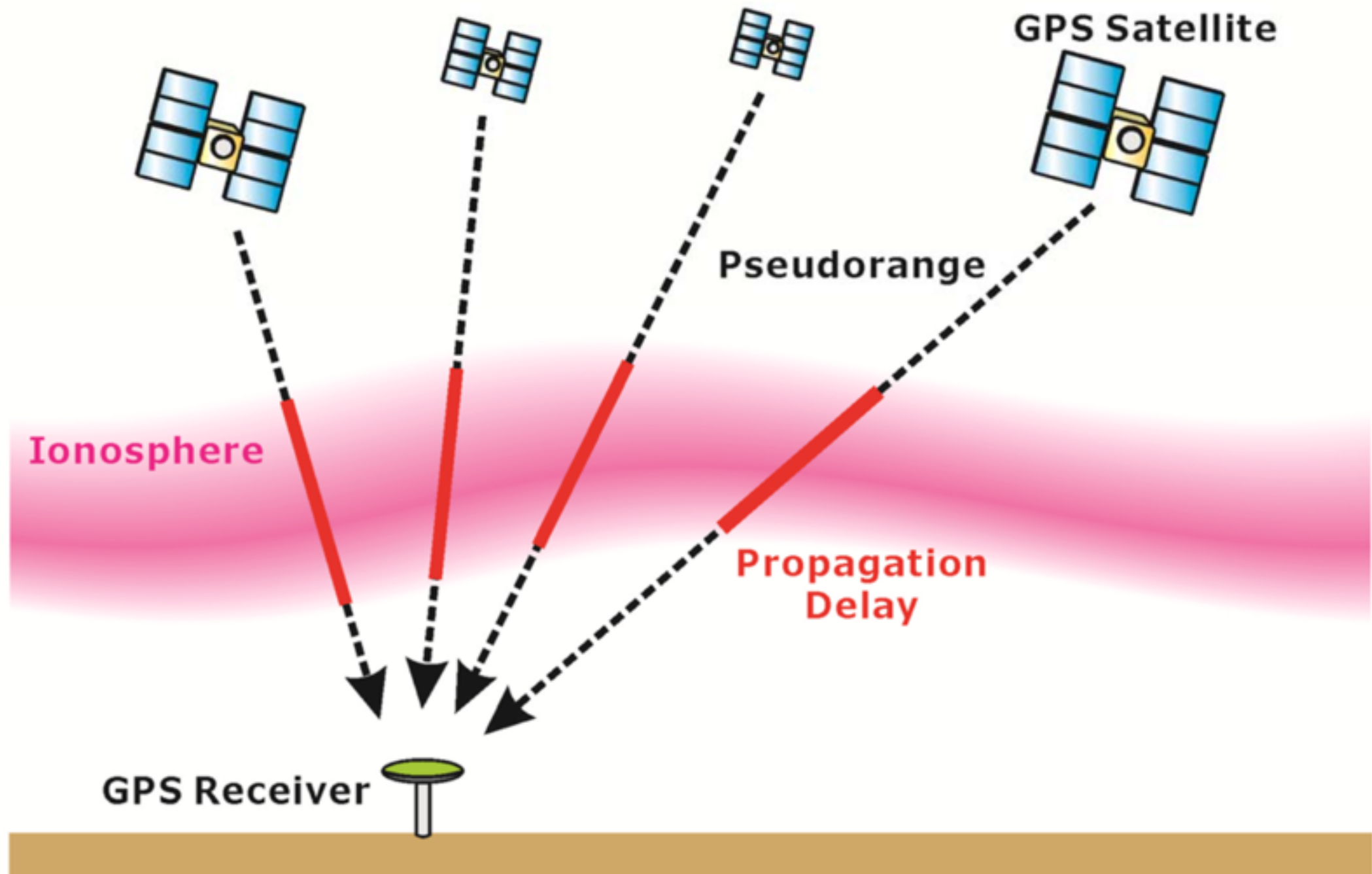
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GPS Positioning Error due to Ionosphere

Ionospheric effect on GNSS – 1

1 TECU = 16 cm

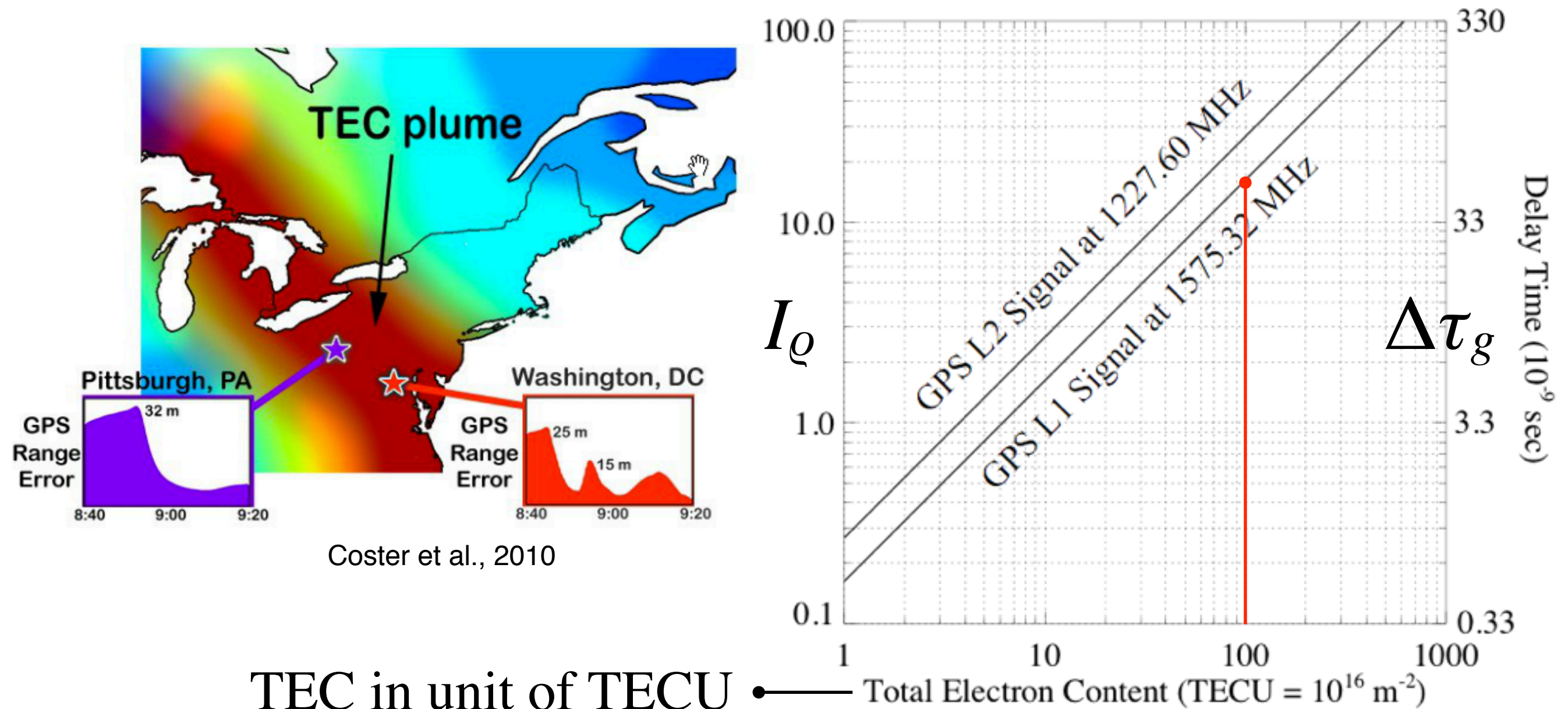
$$I_{\rho} = \frac{40.3 \text{ TEC}}{f^2}$$



Impact of Ionosphere on GNSS

Possible Impact on GNSS

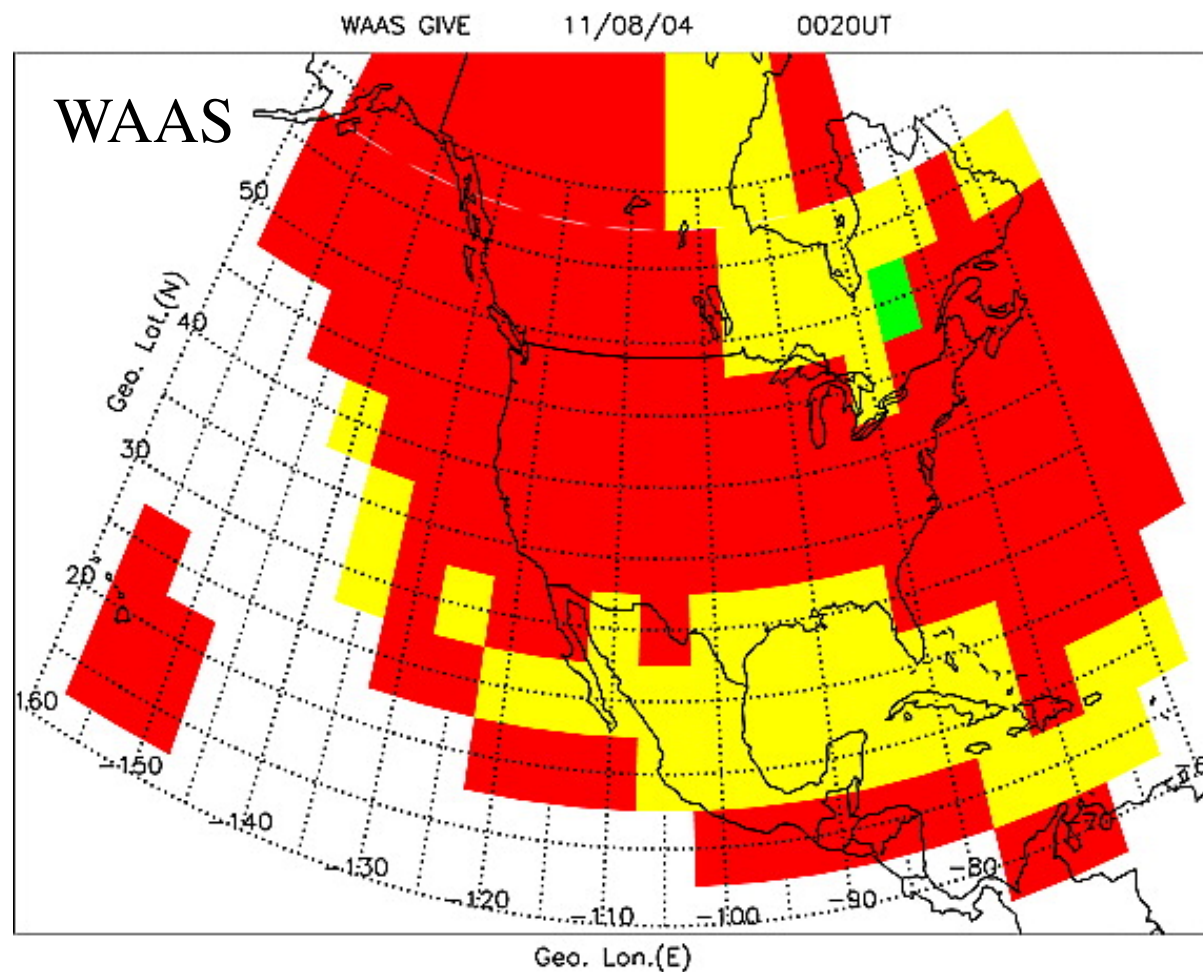
100 TECU \rightarrow over 10 m error in pseudorange!



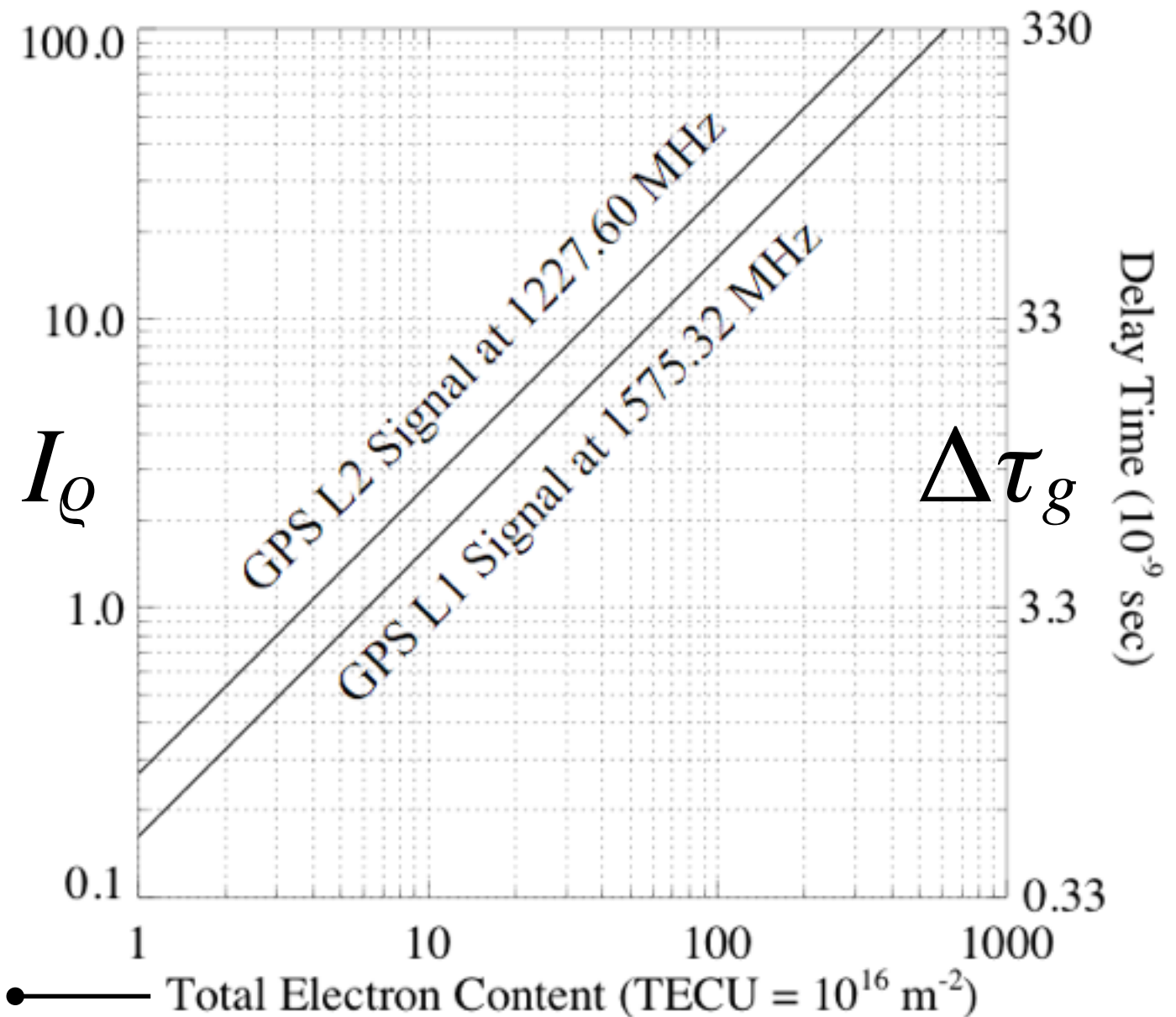
Impact of Ionosphere on GNSS

Possible Impact on GNSS

100 TECU \rightarrow over 10 m error in pseudorange!

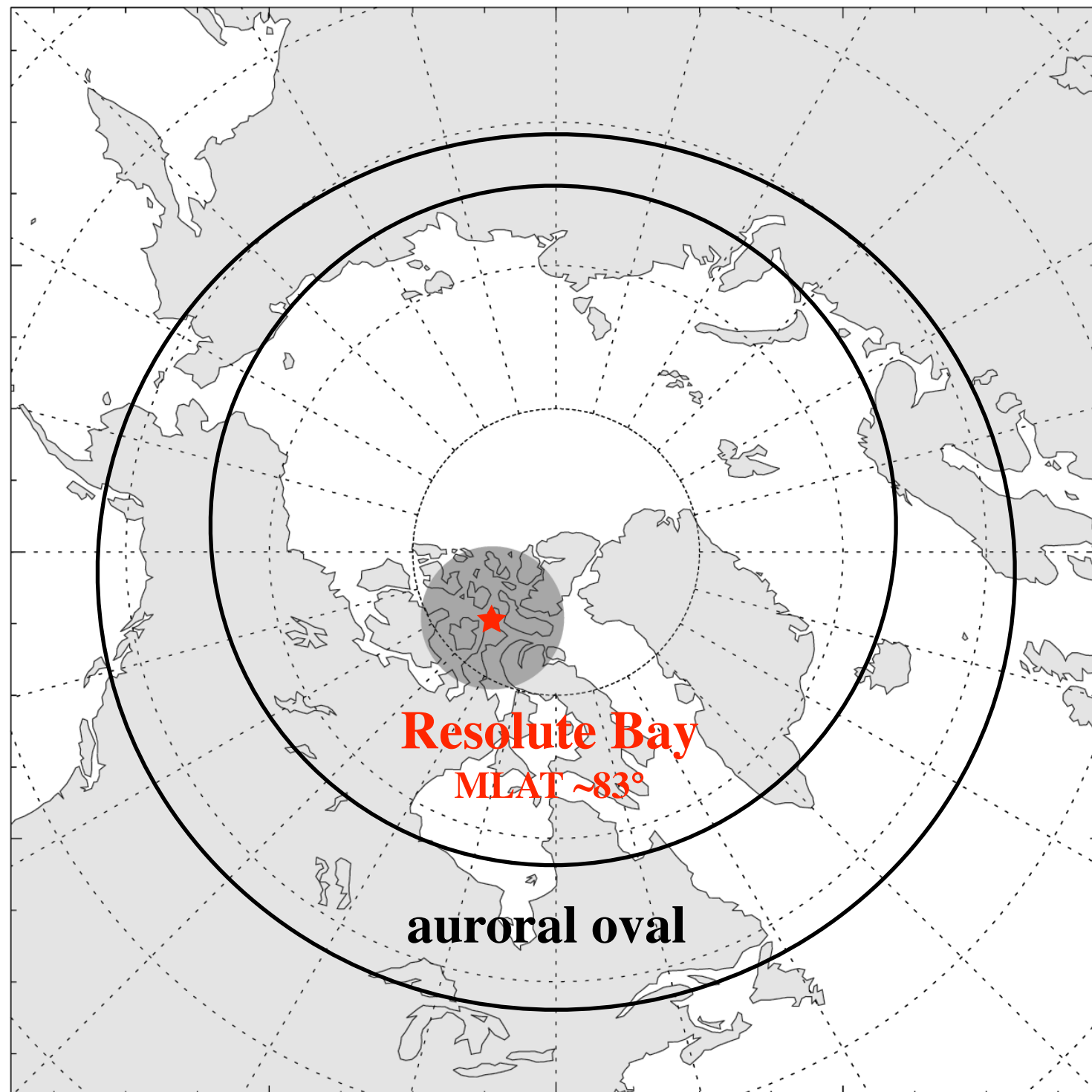


Basu et al., 2008

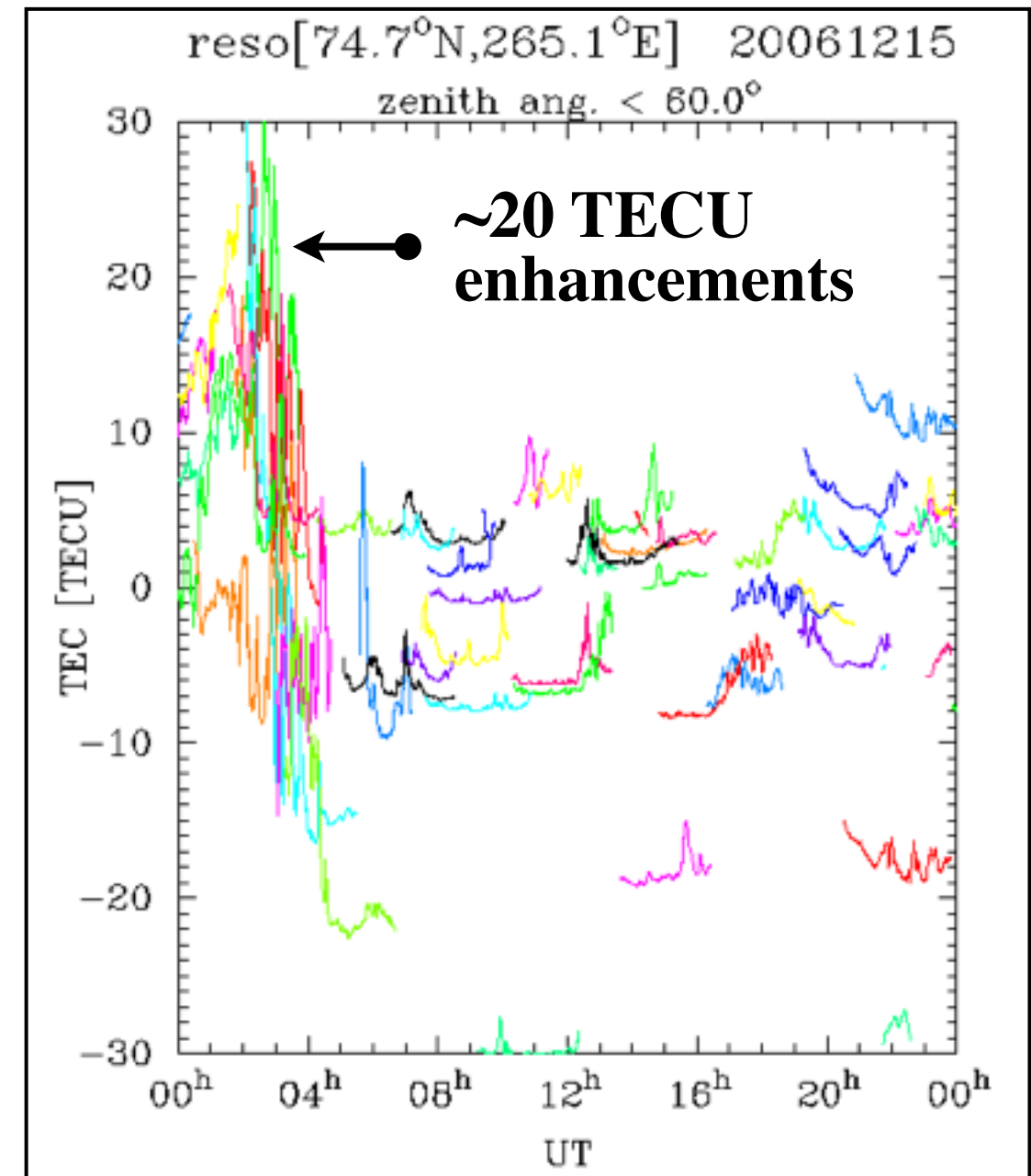


TEC Enhancement in the Polar Region

A magnetic storm in 2006



TEC data from Resolute Bay

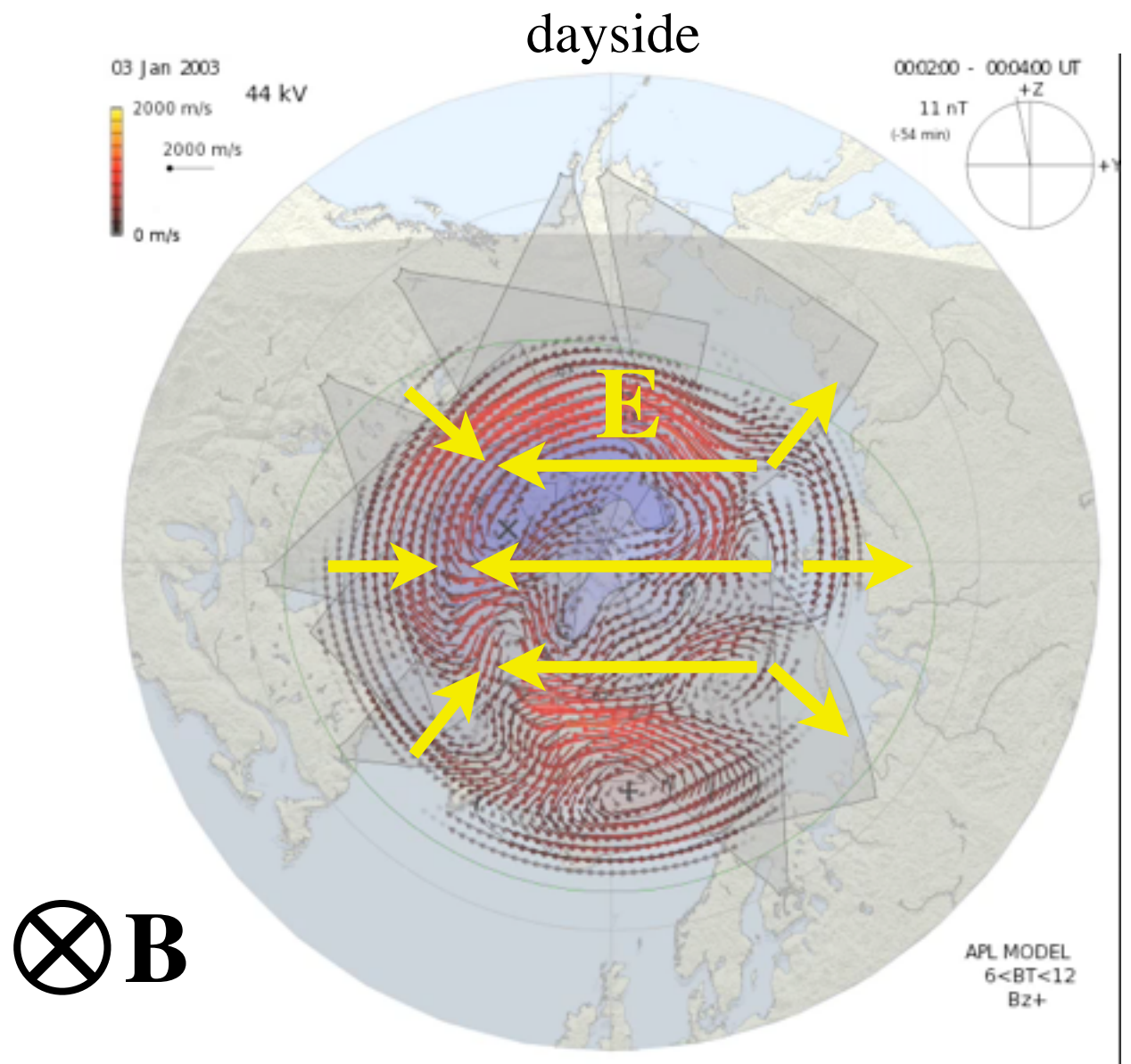
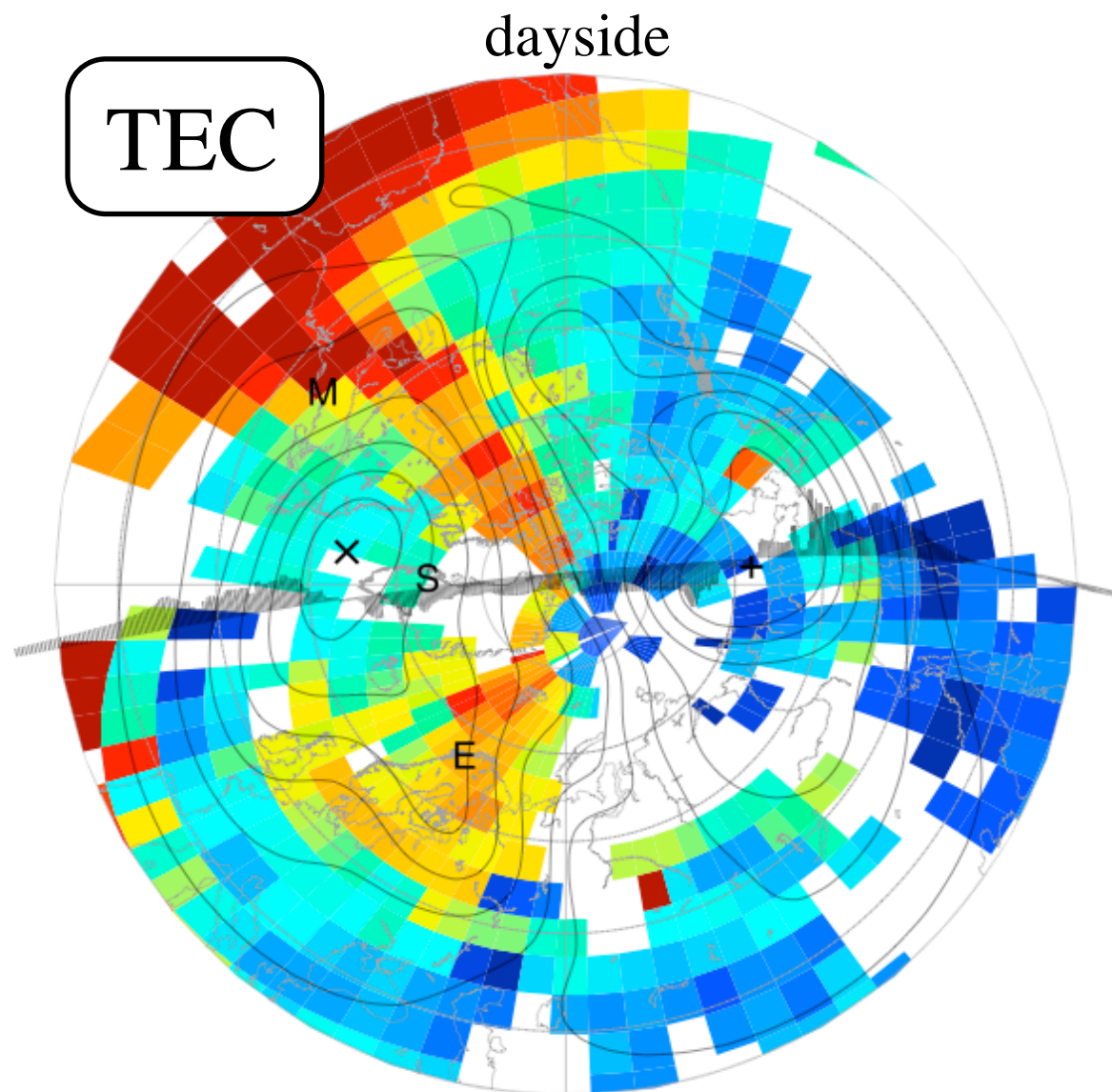


December 15, 2006

TEC Enhancement in the Polar Region

Plasma motion in the high-latitude ionosphere - F region:

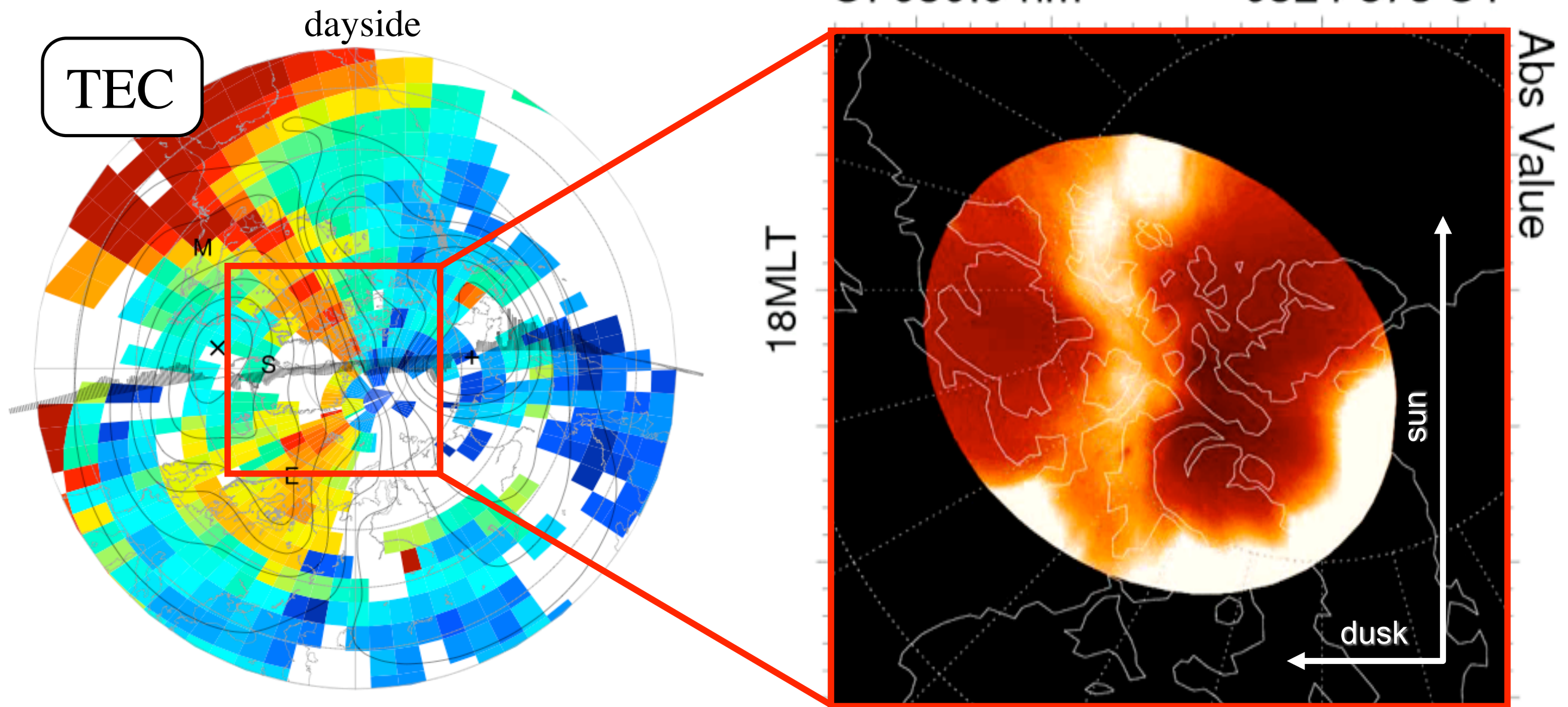
$\mathbf{E} \times \mathbf{B}$ drift: $\mathbf{v} = \frac{\mathbf{E} \times \mathbf{B}}{B^2}$



TEC Enhancement in the Polar Region

Plasma motion in the high-latitude ionosphere - F region:

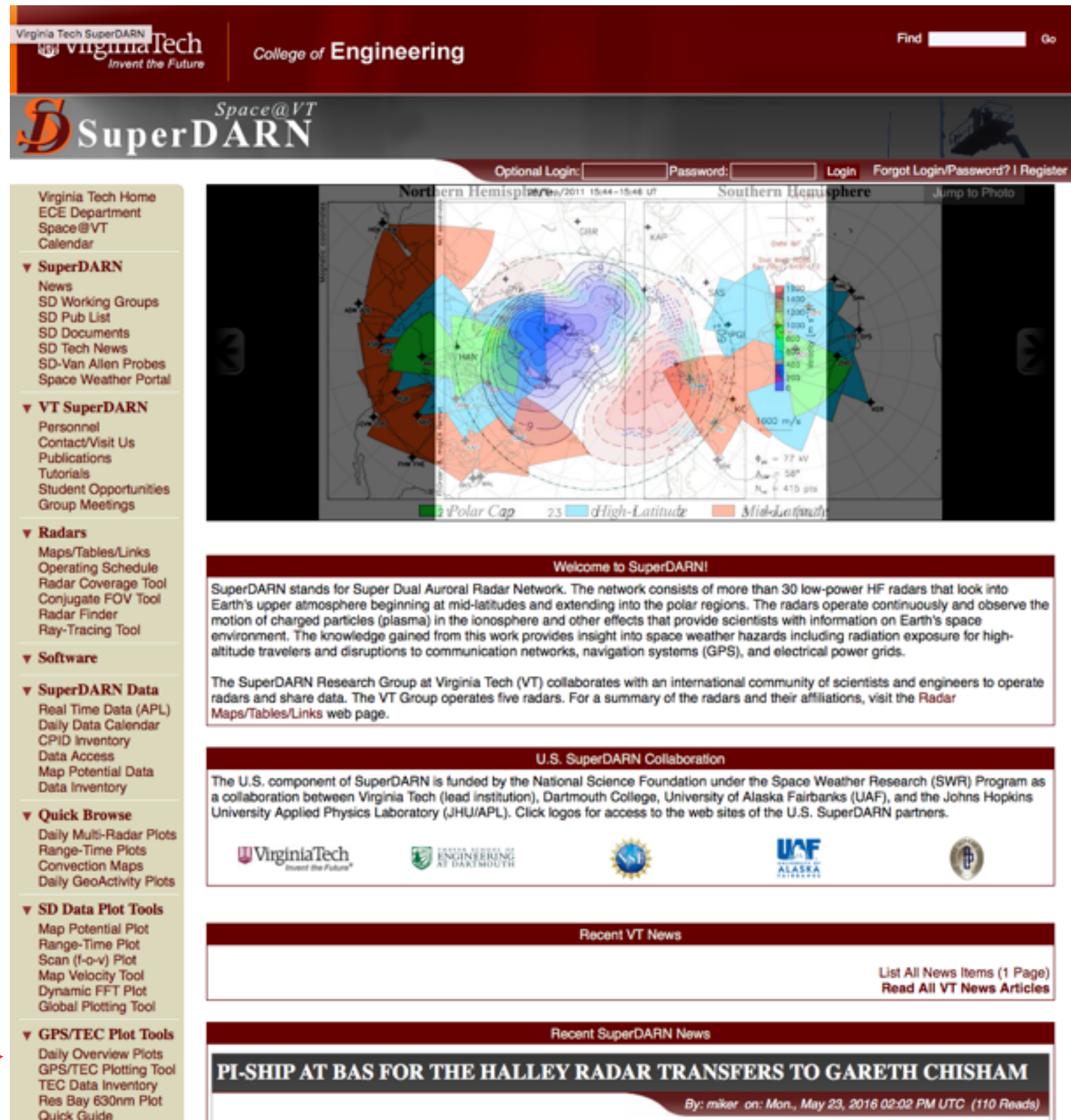
$\mathbf{E} \times \mathbf{B}$ drift: $\mathbf{v} = \frac{\mathbf{E} \times \mathbf{B}}{B^2}$



Quick exercise: Browsing GPS-TEC data in US

Visit VT website:
<http://vt.superdarn.org>

Click
Daily Overview Plots
in the GPS/TEC Plot Tools section



The screenshot displays the Virginia Tech SuperDARN website. The header includes the Virginia Tech logo, "College of Engineering", and a search bar. The main navigation bar features the "SuperDARN" logo and "Space@VT". Below this, there are login fields for "Optional Login:" and "Password:", along with "Login", "Forgot Login/Password?", and "Register" links. The left sidebar contains a list of links under various categories: "Virginia Tech Home", "ECE Department", "Space@VT", "Calendar", "SuperDARN" (News, SD Working Groups, SD Pub List, SD Documents, SD Tech News, SD-Van Allen Probes, Space Weather Portal), "VT SuperDARN" (Personnel, Contact/Visit Us, Publications, Tutorials, Student Opportunities, Group Meetings), "Radars" (Maps/Tables/Links, Operating Schedule, Radar Coverage Tool, Conjugate FOV Tool, Radar Finder, Ray-Tracing Tool), "Software", "SuperDARN Data" (Real Time Data (APL), Daily Data Calendar, CPID Inventory, Data Access, Map Potential Data, Data Inventory), "Quick Browse" (Daily Multi-Radar Plots, Range-Time Plots, Convection Maps, Daily GeoActivity Plots), "SD Data Plot Tools" (Map Potential Plot, Range-Time Plot, Scan (f-o-v) Plot, Map Velocity Tool, Dynamic FFT Plot, Global Plotting Tool), and "GPS/TEC Plot Tools" (Daily Overview Plots, GPS/TEC Plotting Tool, TEC Data Inventory, Res Bay 630nm Plot, Quick Guide). The main content area shows a global map of the Northern Hemisphere with radar coverage. A legend at the bottom of the map indicates "Polar Cap", "High-Latitude", and "Mid-Latitude" regions. Below the map, there is a "Welcome to SuperDARN!" section, a "U.S. SuperDARN Collaboration" section, and a "Recent VT News" section. The "Recent VT News" section lists "List All News Items (1 Page)" and "Read All VT News Articles". The "Recent SuperDARN News" section features a headline "PI-SHIP AT BAS FOR THE HALLEY RADAR TRANSFERS TO GARETH CHISHAM" by miker on Mon., May 23, 2016 02:02 PM UTC (110 Reads).

Dec 31, 2012

00 UT ~ 15 LT in US

03 UT ~ 18 LT in US

06 UT ~ 21 LT in US

09 UT ~ 00 LT in US

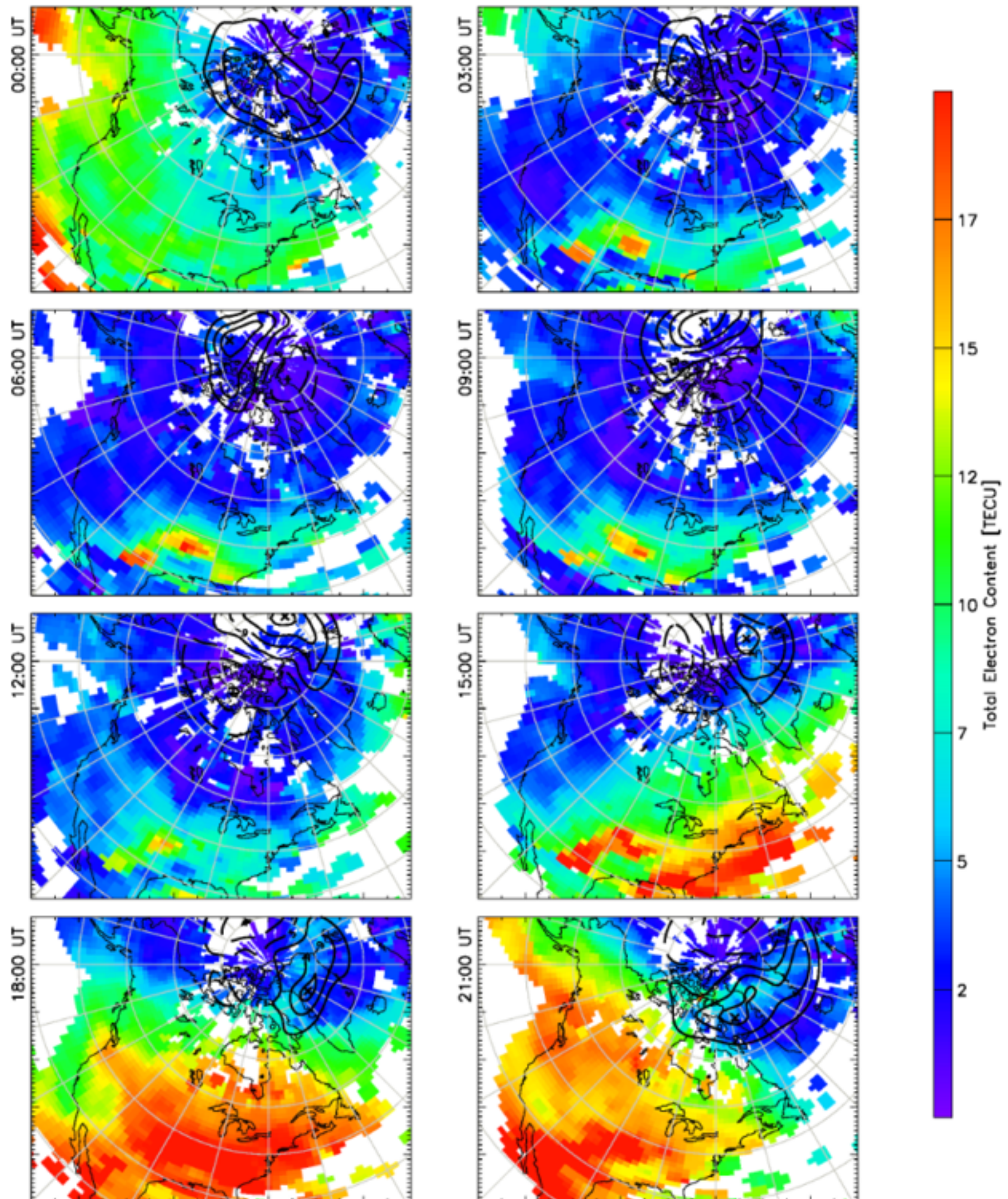
12 UT ~ 03 LT in US

15 UT ~ 06 LT in US

18 UT ~ 09 LT in US

21 UT ~ 12 LT in US

Photo ionization



Jump to Jan 13, 2012, and check the following 10 days

GPS/TEC OVERVIEW PLOTS

- [Click here for interactive GPS/TEC plotting tools](#)

2012/12/31

Change date: 20120113

20121231

Jump

Overlay Radar Data

◀ -10 Days

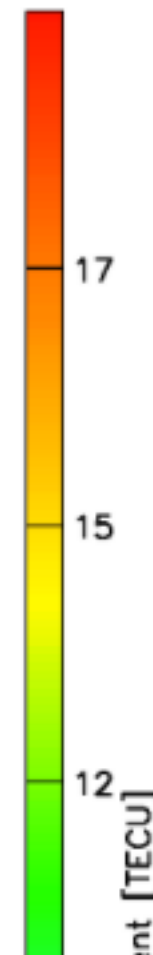
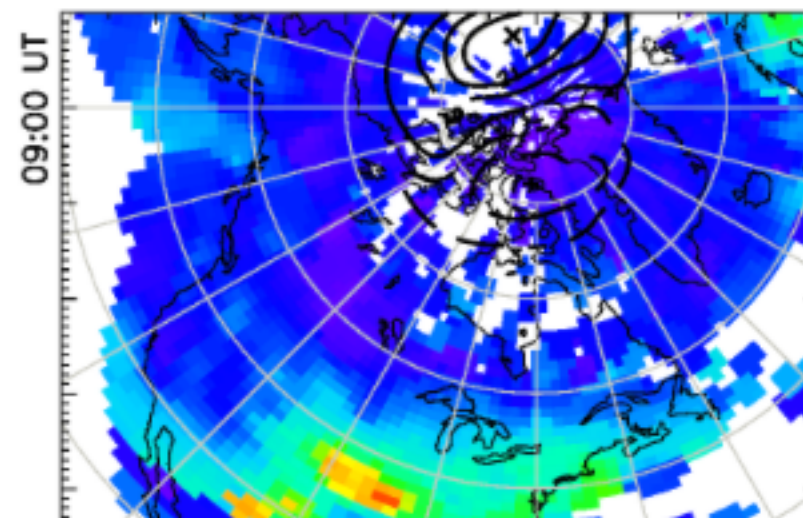
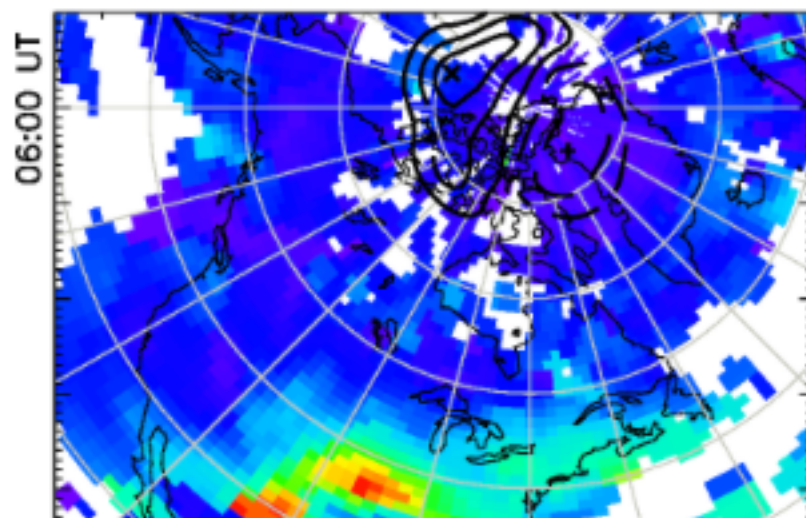
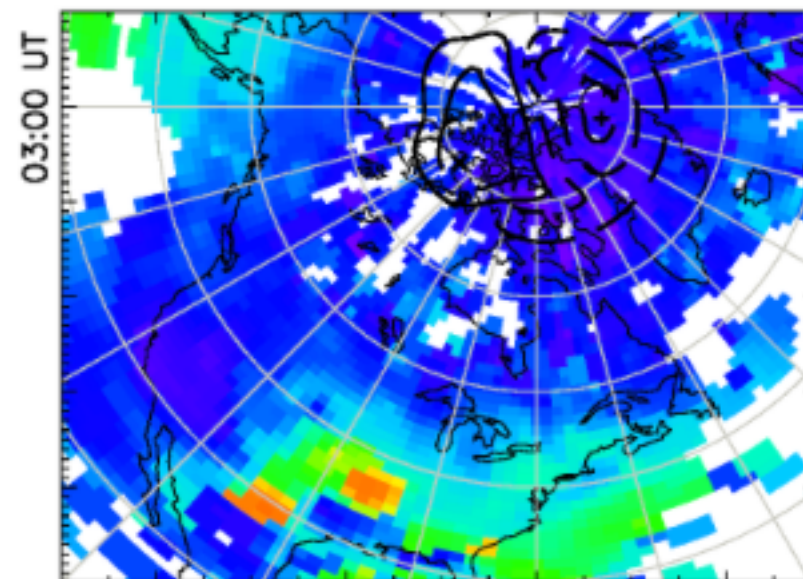
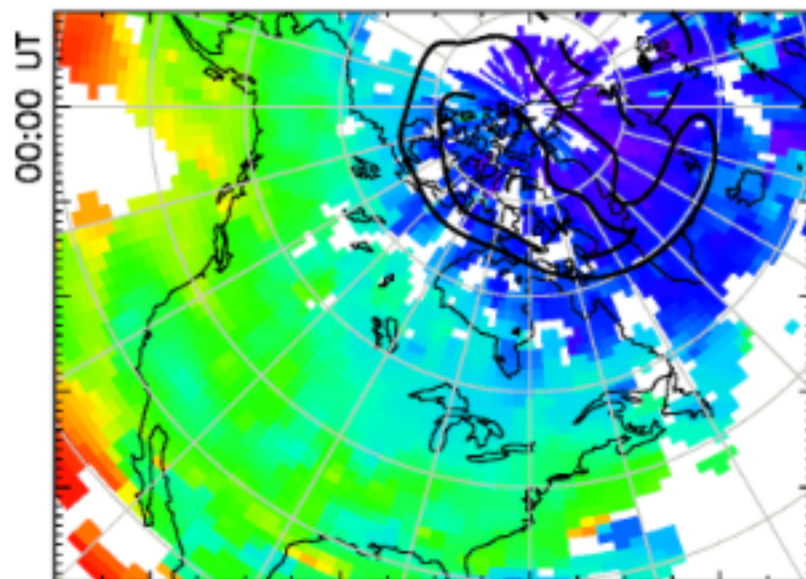
◀ -1 Day

+1 Day ▶

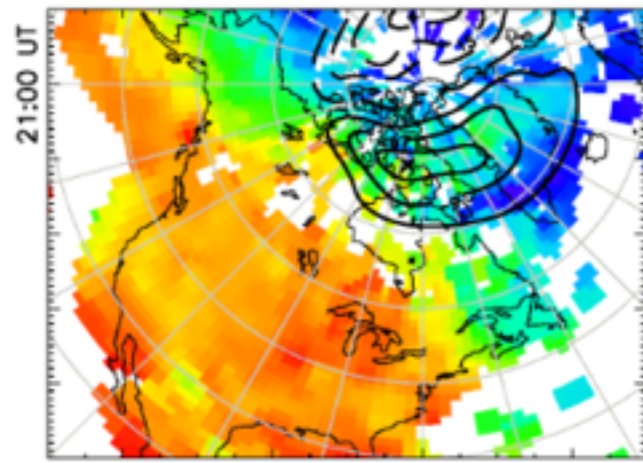
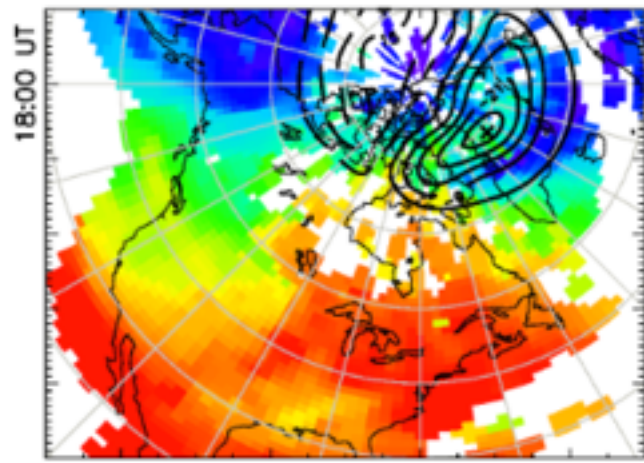
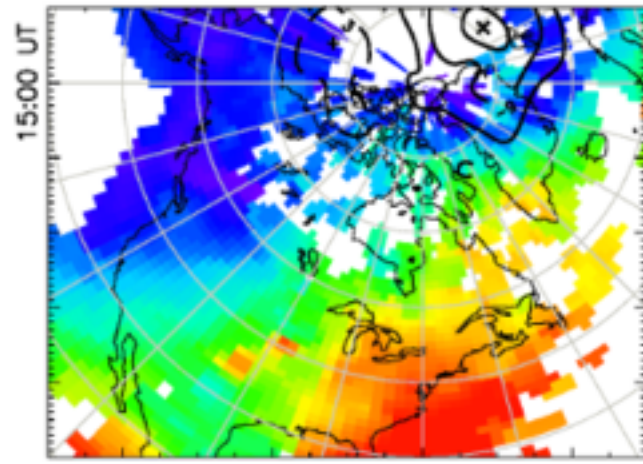
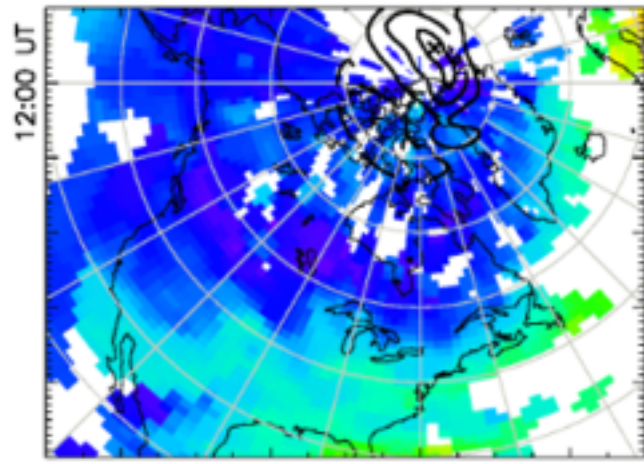
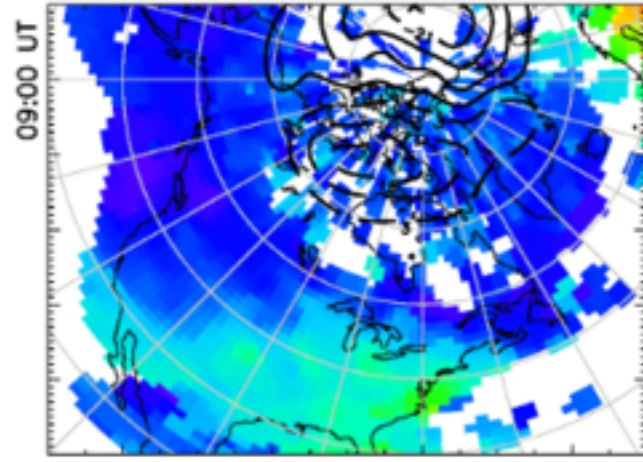
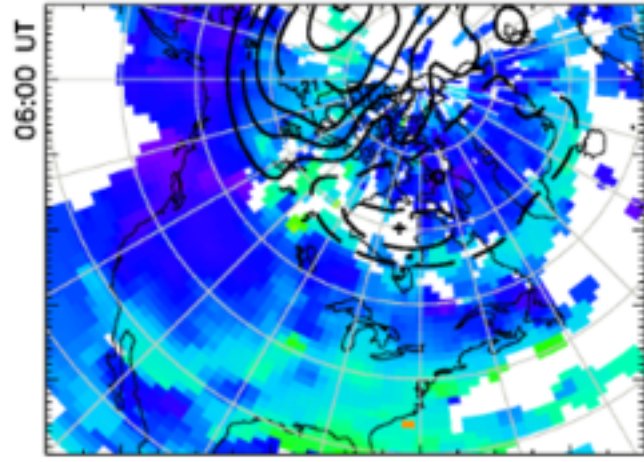
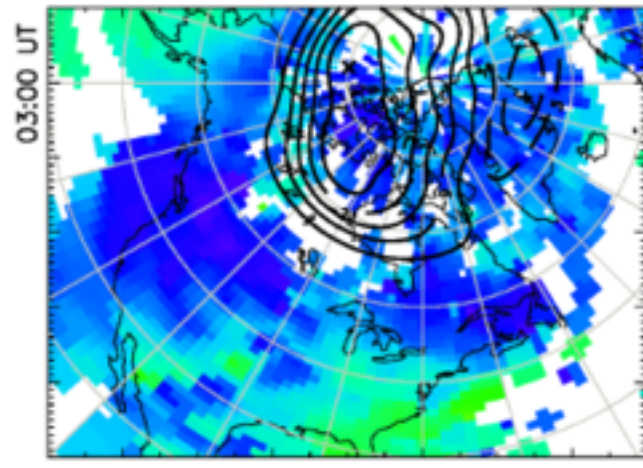
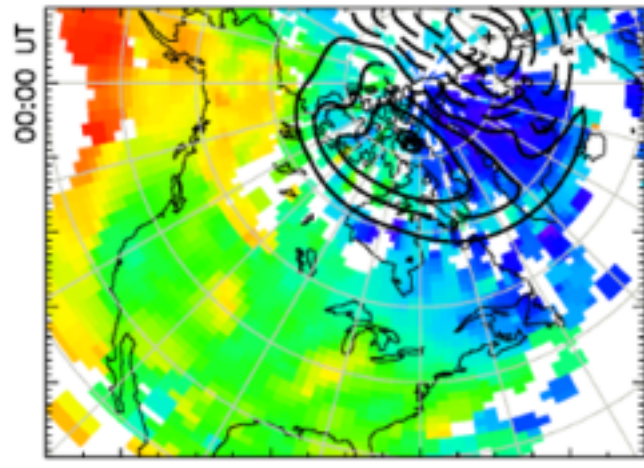
+10 Days ▶

Switch Filter off

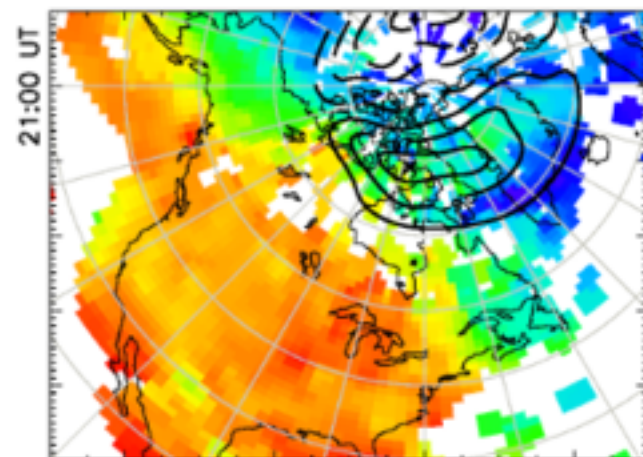
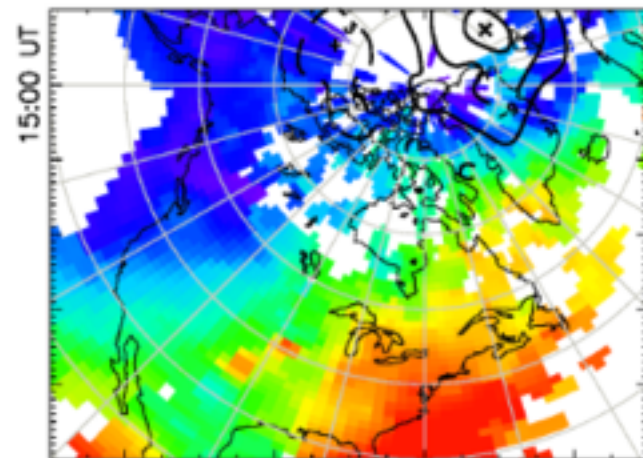
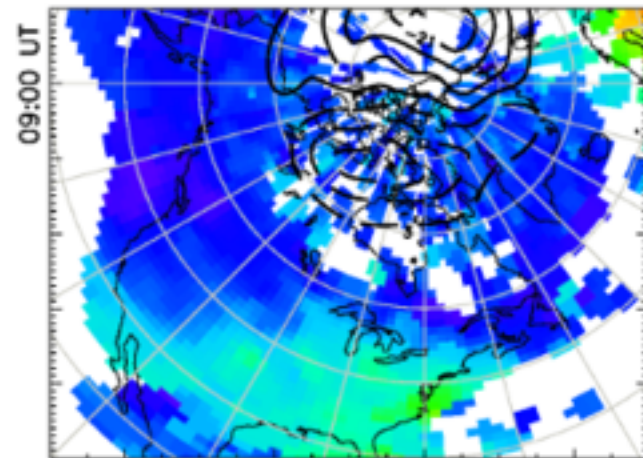
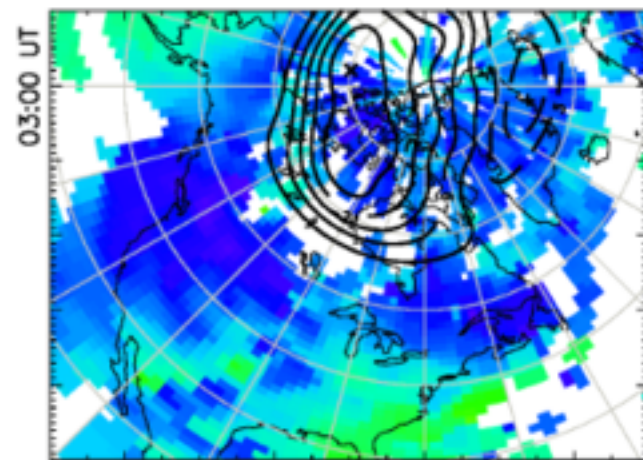
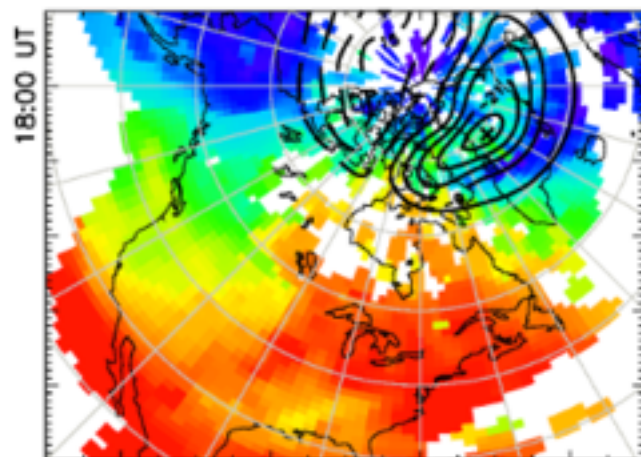
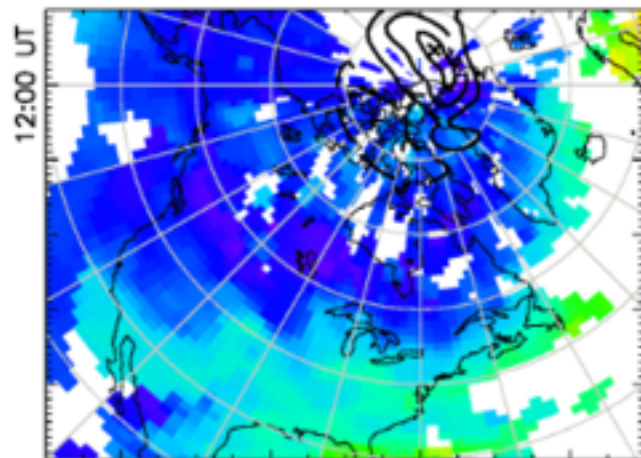
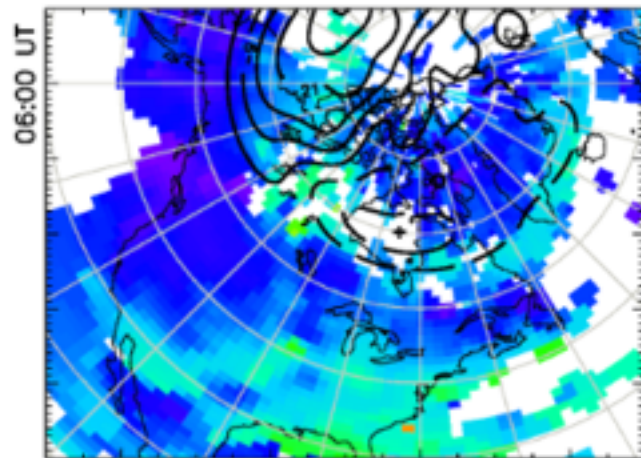
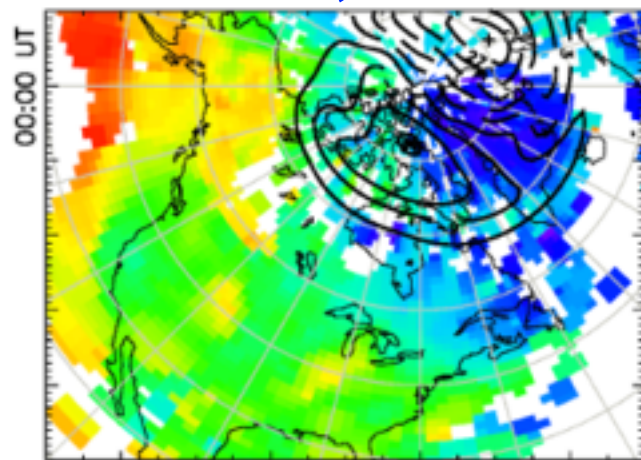
GPS/TEC Overview – 31/Dec/2012



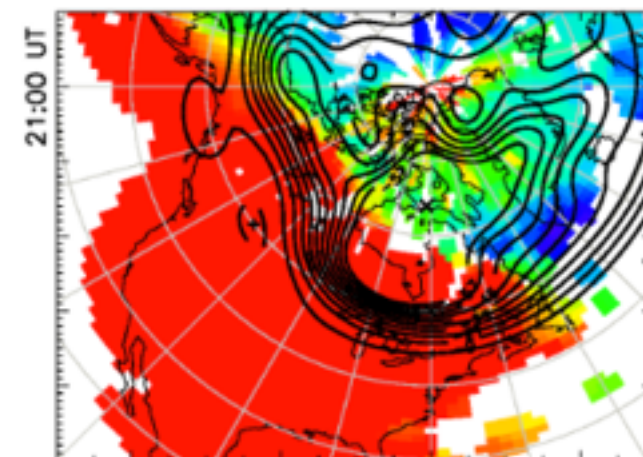
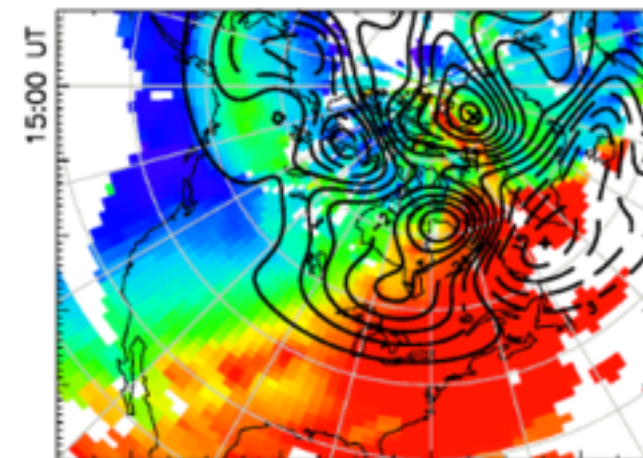
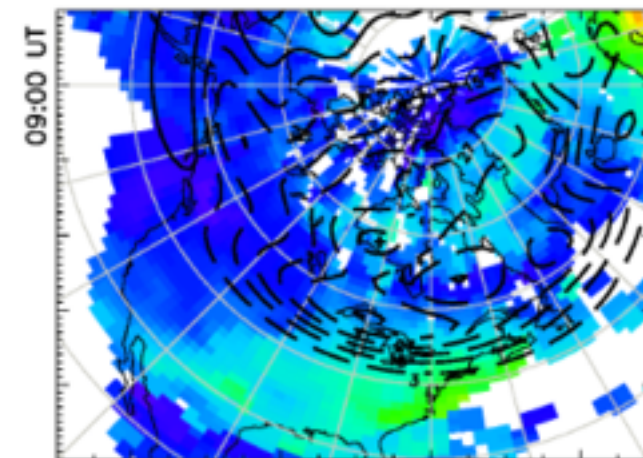
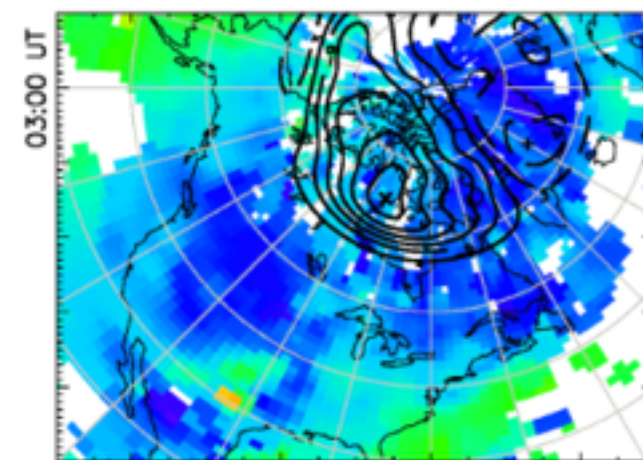
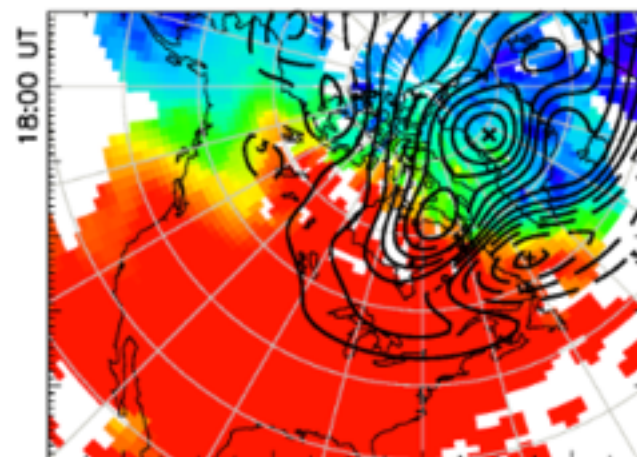
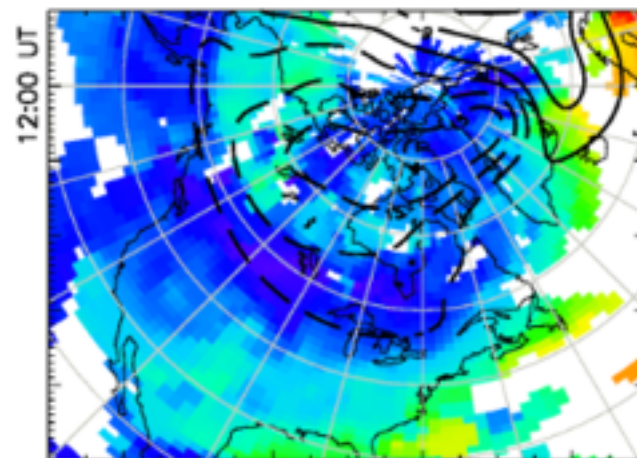
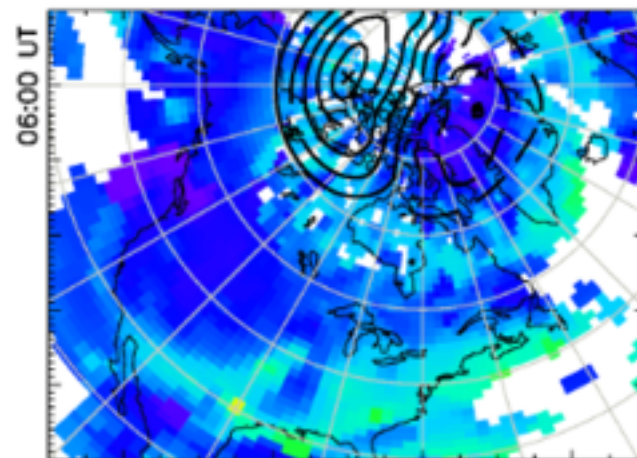
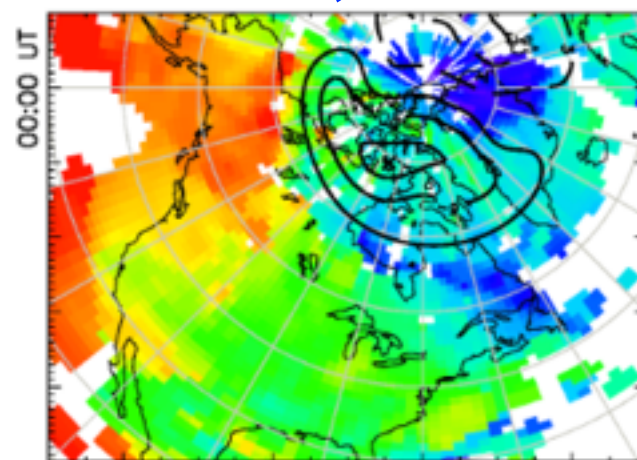
Jan 13, 2012



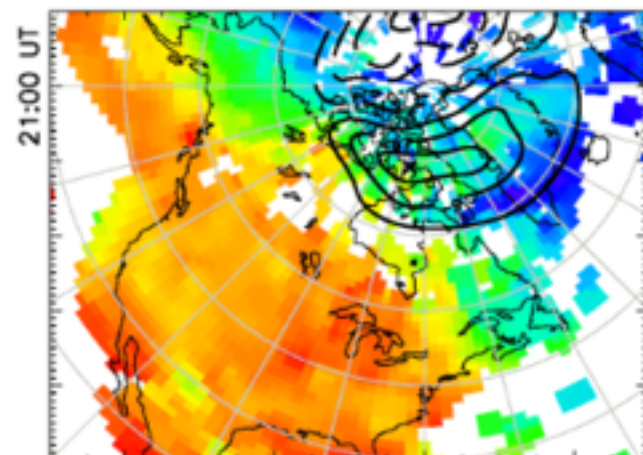
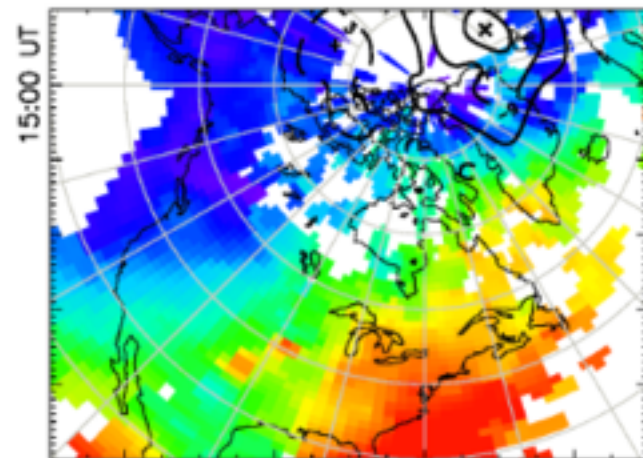
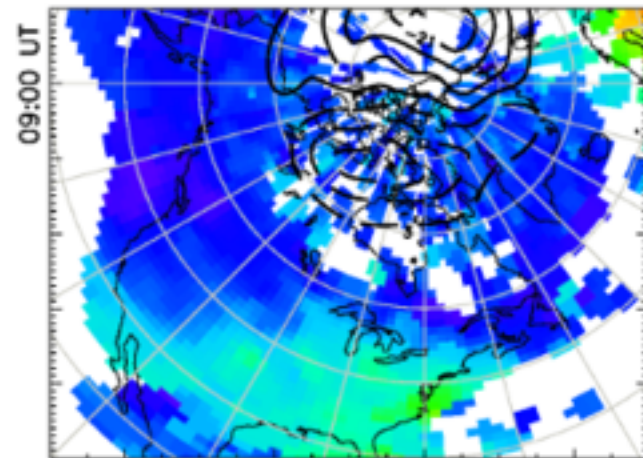
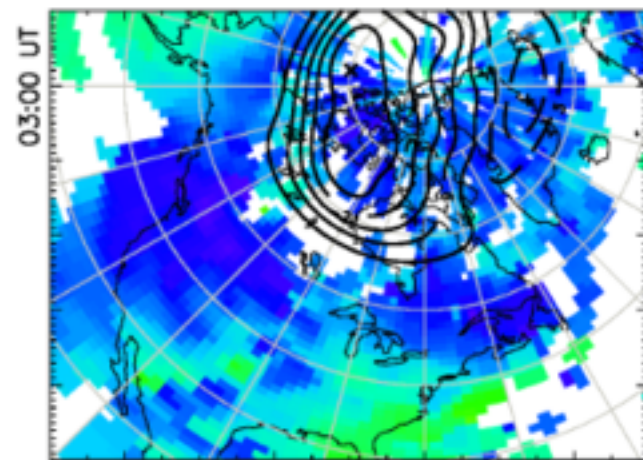
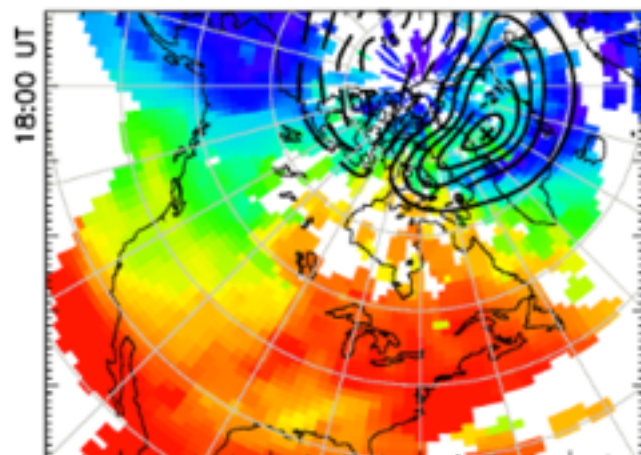
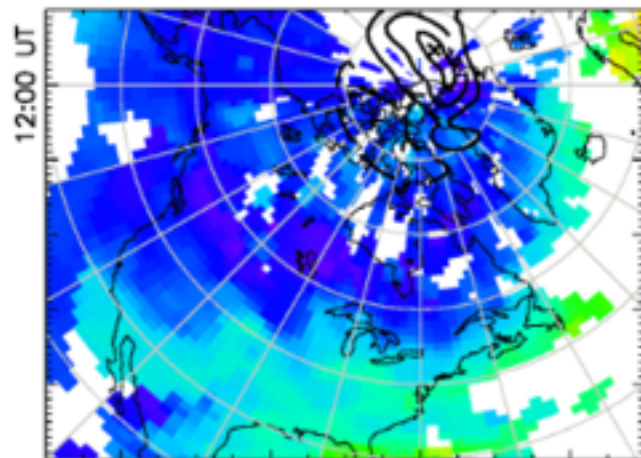
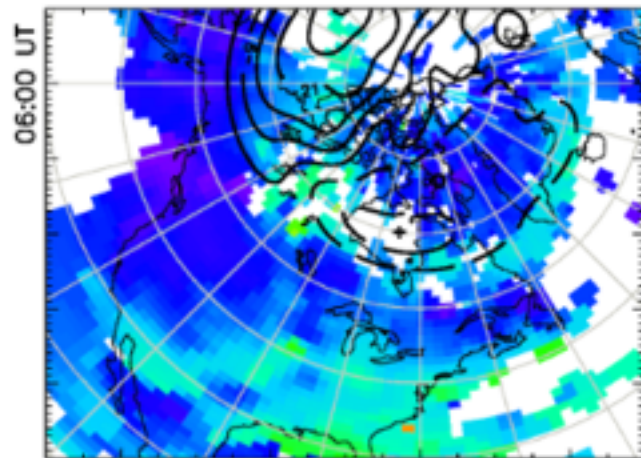
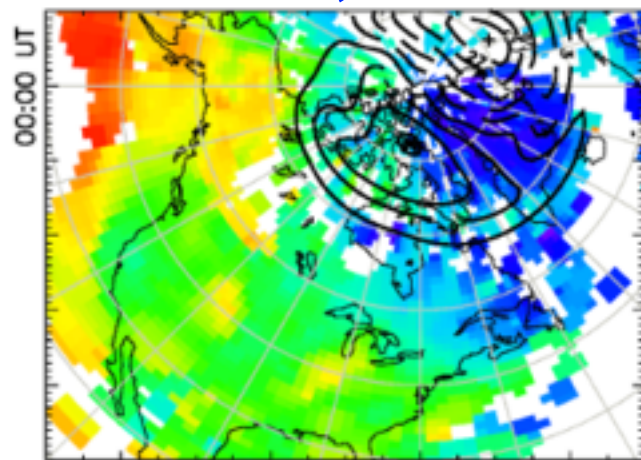
Jan 13, 2012



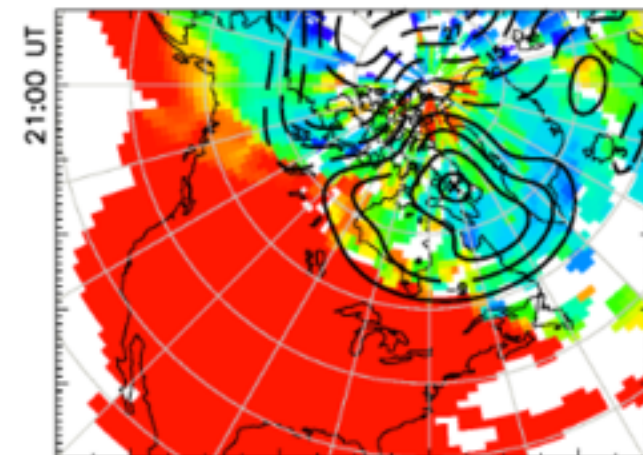
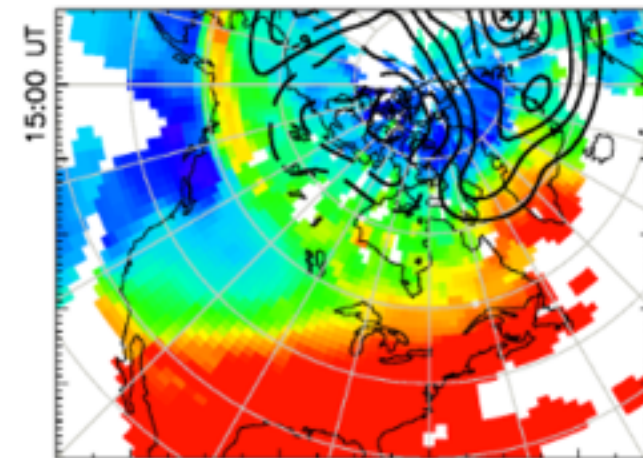
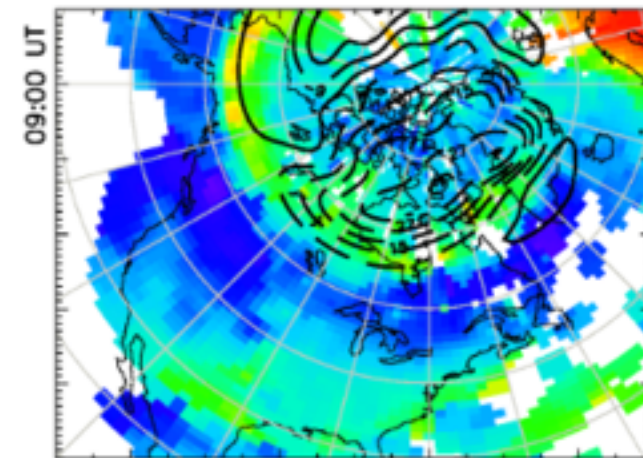
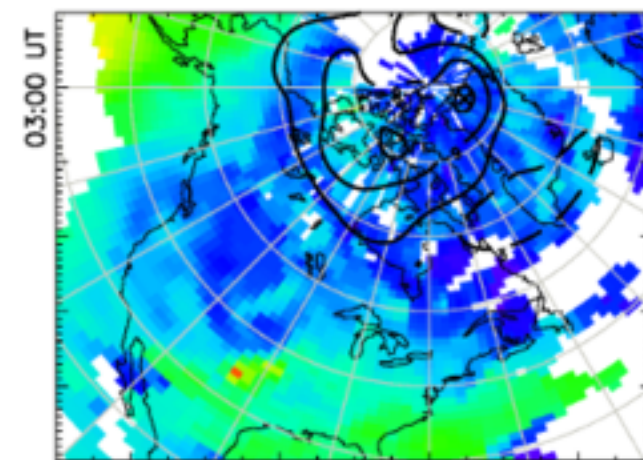
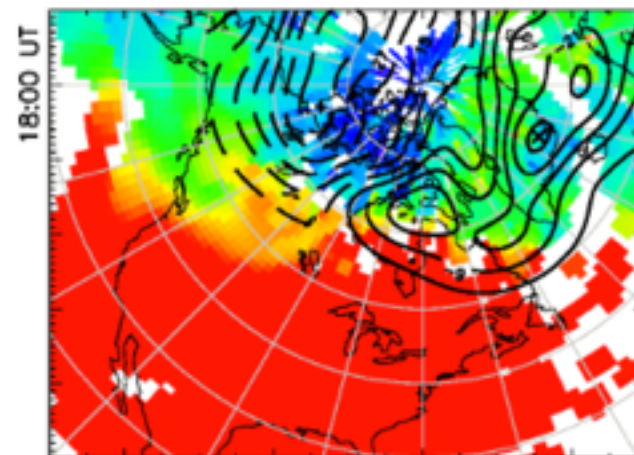
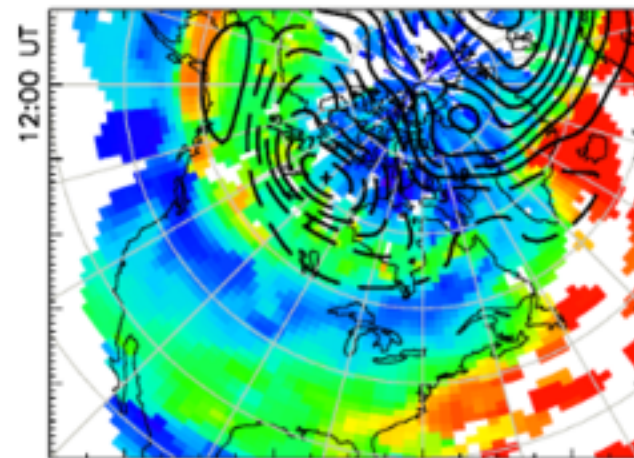
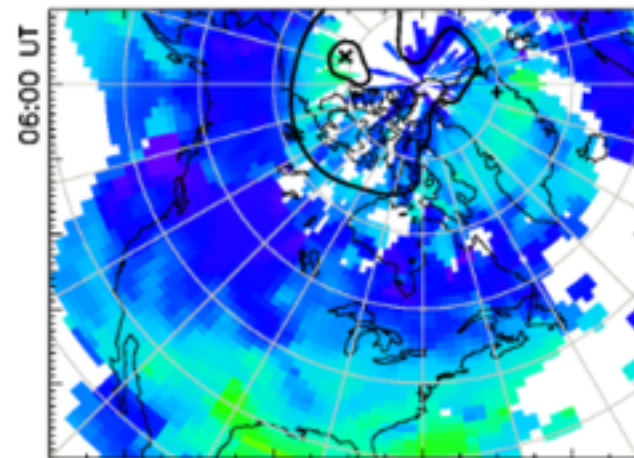
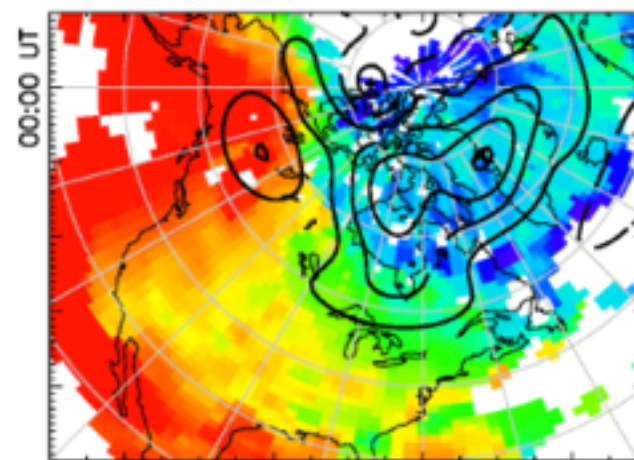
Jan 16, 2012



Jan 13, 2012



Jan 22, 2012



Plot the data on Jan 22 in a different format

GPS/TEC OVERVIEW PLOTS

- Click here for interactive GPS/TEC plotting tools ← Click

2012/12/31

20121231

Jump

Overlay Radar Data

◀ -10 Days

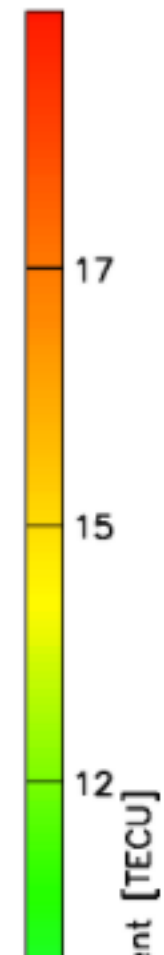
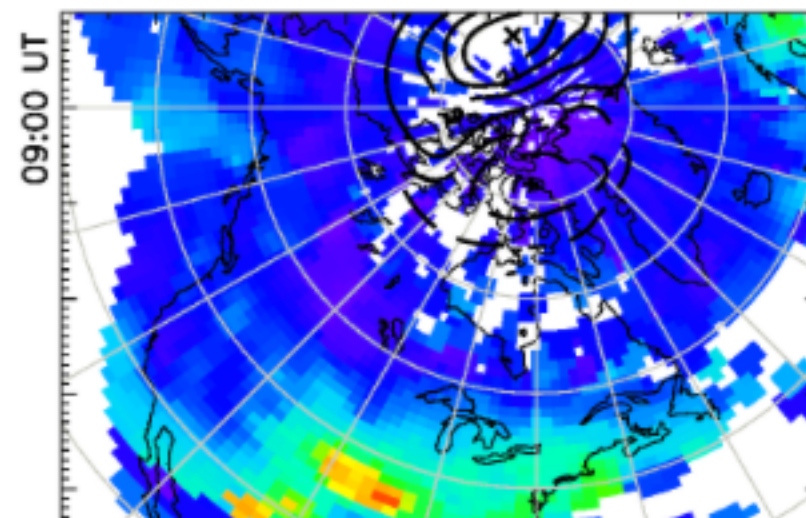
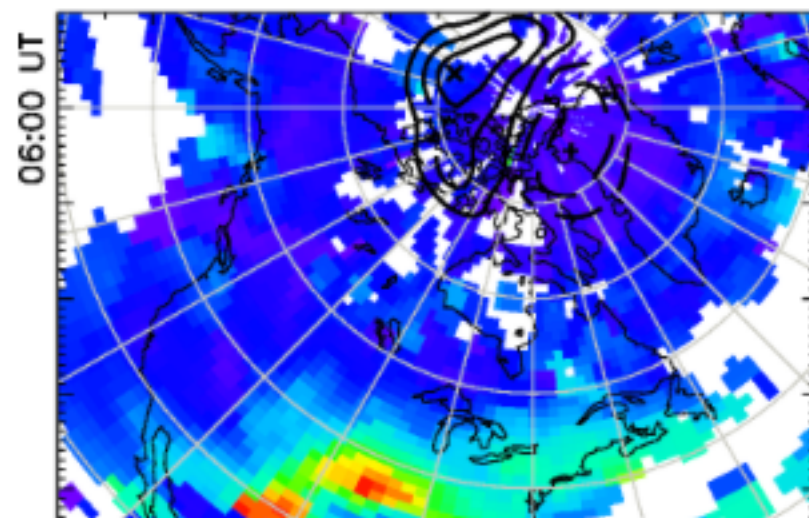
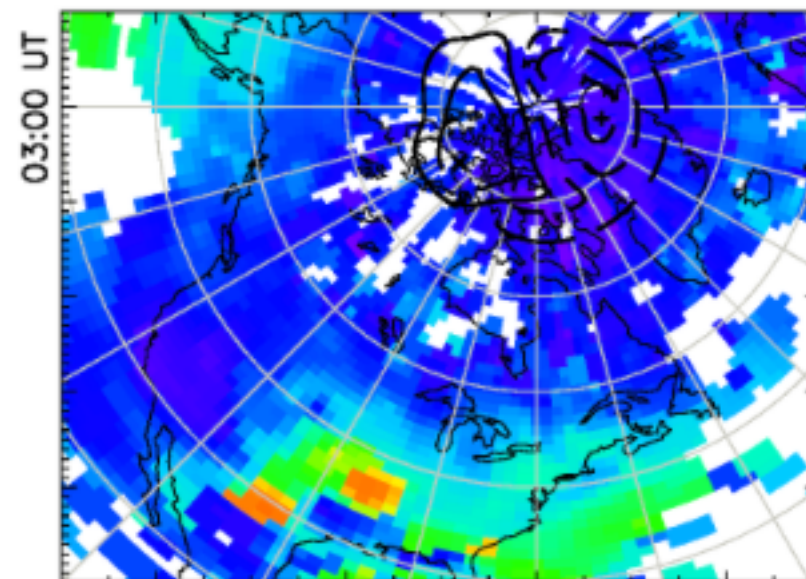
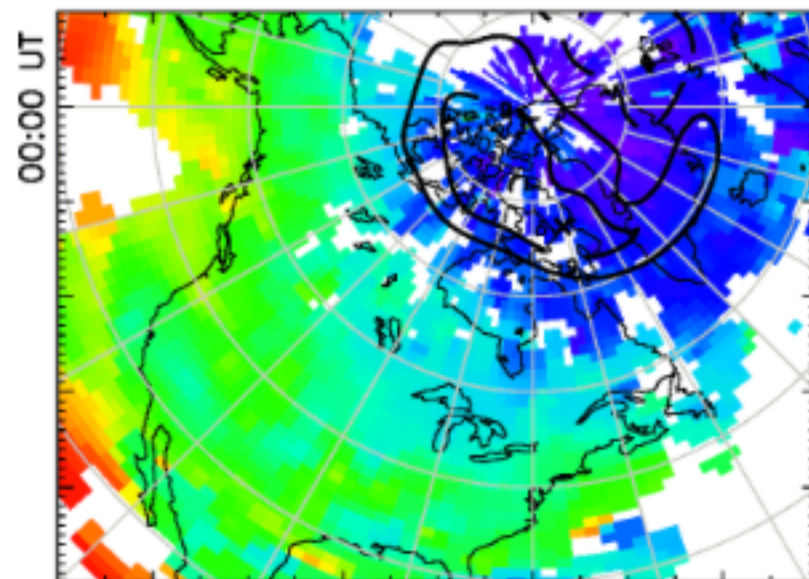
◀ -1 Day

+1 Day ▶

+10 Days ▶

Switch Filter off

GPS/TEC Overview – 31/Dec/2012



Plot the data on Jan 22 in a different format

INTERACTIVE GPS/TEC PLOTTING - FOUR PLOT

- [Click here to create single plots](#) ← Click
- [Click here to create animated movies](#)

Plot

Hemisphere

North

Year

2016

Month

Jun

Day

10

Hour

0

Minute

01

TEC Parameter

Scale (TECU)

Total Electron Content

Min Value:

0

Max Value:

20

Median Filtering

Lat/Lon Bin:

1

2

Start Lat:

20

Threshold:

0.20

Coordinates

Magnetic

XRange:

-50

30

YRange:

-50

10

Convection Map

☐ Plot Convection Map

☐ Plot Heppner-Maynard Boundary

North Radars

☐ Inuvik (inv 64)

☐ Rankin (rkn 65)

☐ Clyde River (cly 66)

☐ King Salmon (ksr 16)

☐ Kodiak (kod 7)

☐ Saskatoon (sas 5)

☐ Goose Bay (gbr 1)

☐ Pykkvibaer (pyk 9)

☐ Prince George (pgr 6)

☐ Kapuskasing (kap 3)

☐ Stokkseyri (sto 8)

☐ Hankasalmi (han 10)

☒ Hokkaido (hok 40)

☒ Hokkaido West (hkw 41)

☒ Blackstone (bks 33)

☒ Wallops Island (wal 32)

☒ Fort Hays West (fhw 204)

☒ Fort Hays East (fhe 205)

☒ Christmas Valley West (fhw 206)

☒ Christmas Valley East (fhe 207)

☒ Adak West (adw 208)

☒ Adak East (ade 209)

Plot the data on Jan 22 in a different format

INTERACTIVE GPS/TEC PLOTTING - SINGLE PLOT

- [Click here to create animated movies](#)
- [Click here to create a four plot overview](#)

Change data to Jan 22, 2012 20:00

Plot

Hemisphere	Year	Month	Day	Hour	Minute
North	2016	Jun	10	0	01

TEC Parameter

☒ Total Electron Content
☐ TEC Error
☐ None (map only)

Min Value: 0 Max Value: 20
Min Value: 0 Max Value: 10

Median Filtering

☒ Apply Median Filtering
☐ Plot Latitudinal TEC Gradient

Lat/Lon Bin: 1 2 Start Lat: 20 Threshold: 0.10

Coordinates

Magnetic XRange: -50 30 YRange: -50 10
Rotate map by: 0 deg. (clockwise)

Convection Map

☒ Plot Convection Map
☐ Plot Heppner-Maynard Boundary
☐ Plot Day/Night Terminator

Radar Measurements

☐ Plot Radar Measurements
☐ Select All

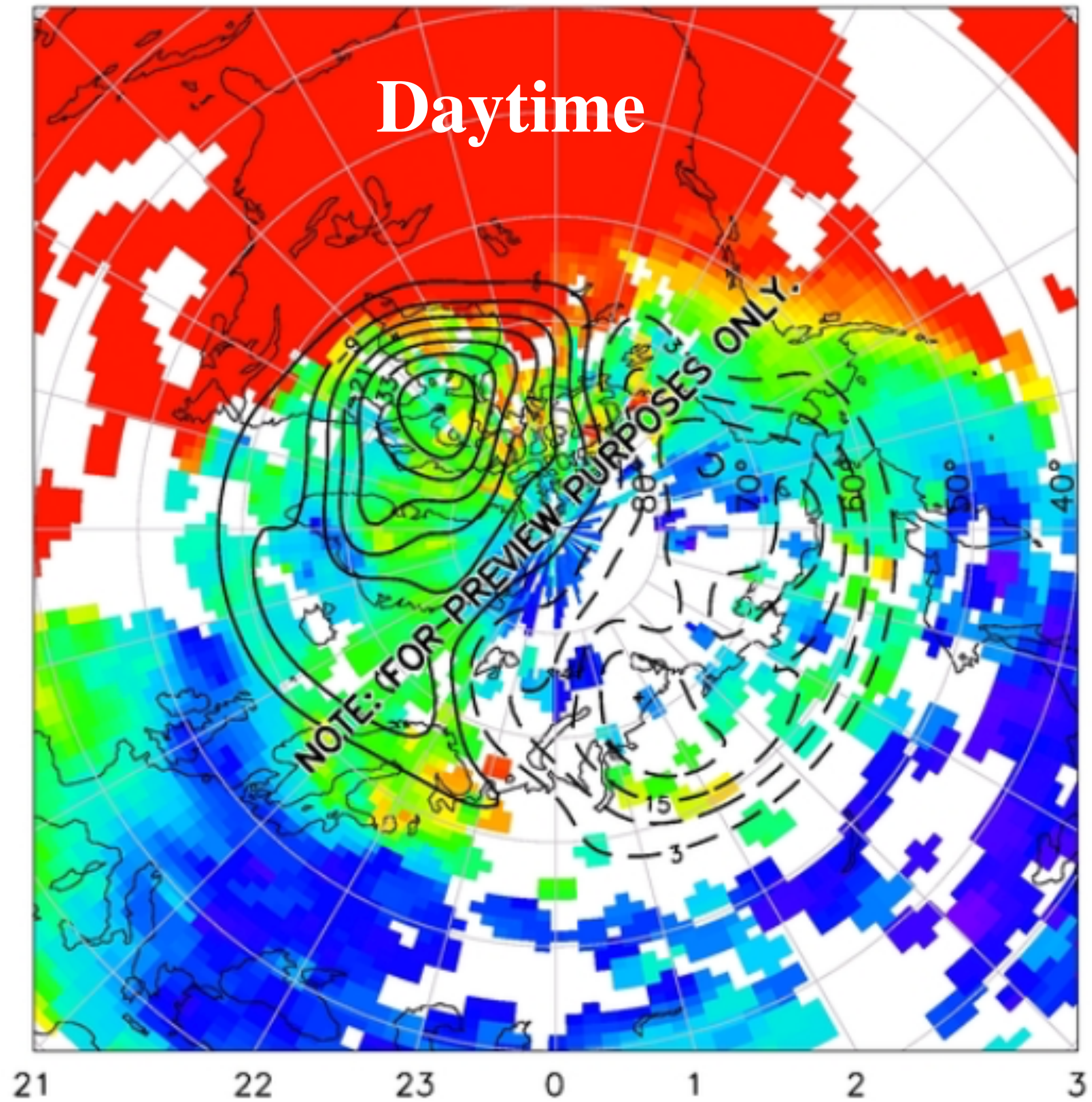
Plot

Select MLT

Press Plot

Debug: ☐

Daytime



Outline

- Ionosphere

Quick exercise: Browsing radar data from Norway

- Key ideas of GNSS

- Mechanism of ionospheric effects on GNSS

- Two major ionospheric impacts on GNSS

1. Positioning error

Quick exercise: Browsing GPS TEC data in US

2. Scintillation effect

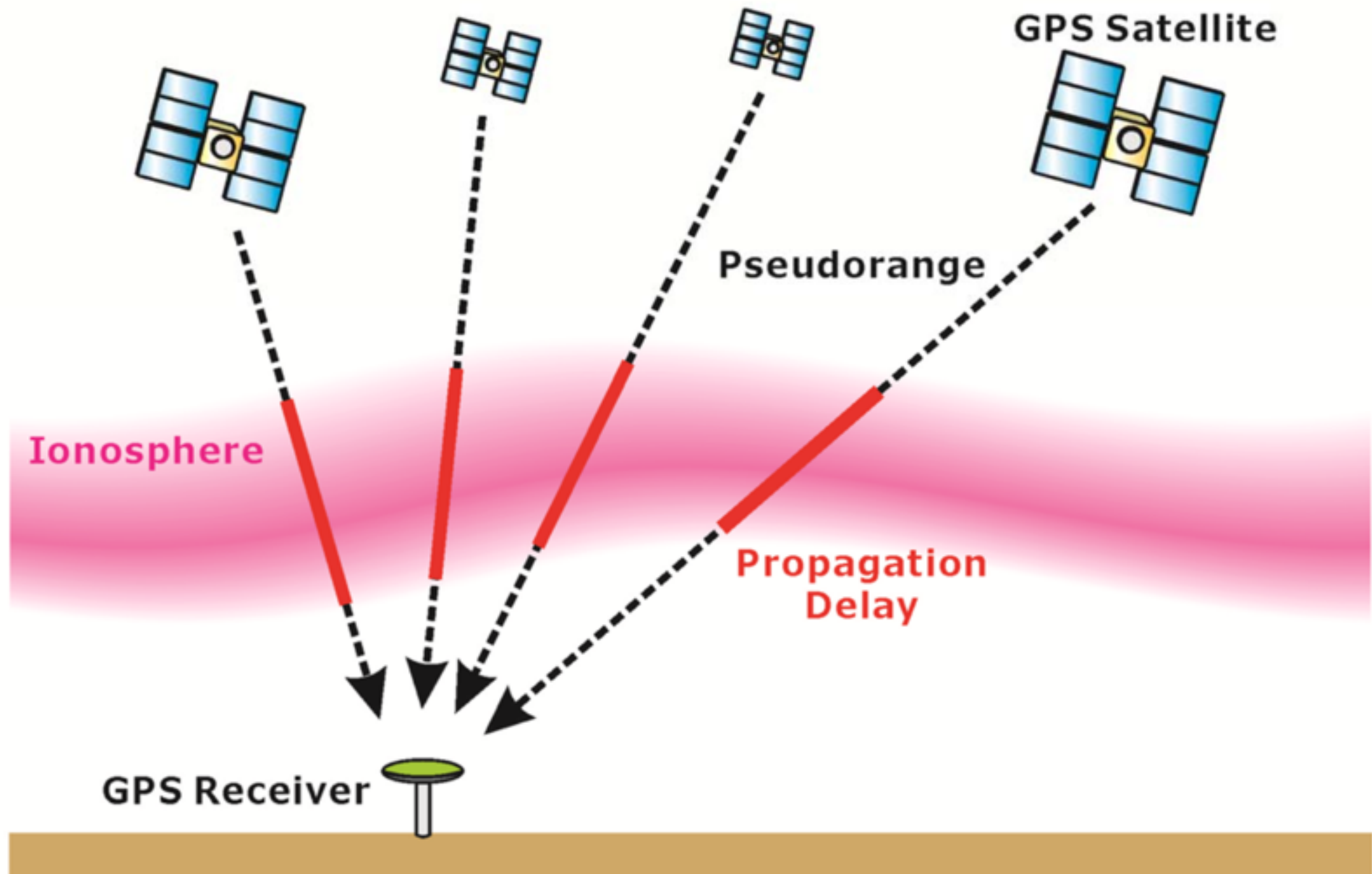
Quick exercise: Browsing GPS scintillation data

GPS Positioning Error due to Ionosphere

Ionospheric effect on GNSS – 1

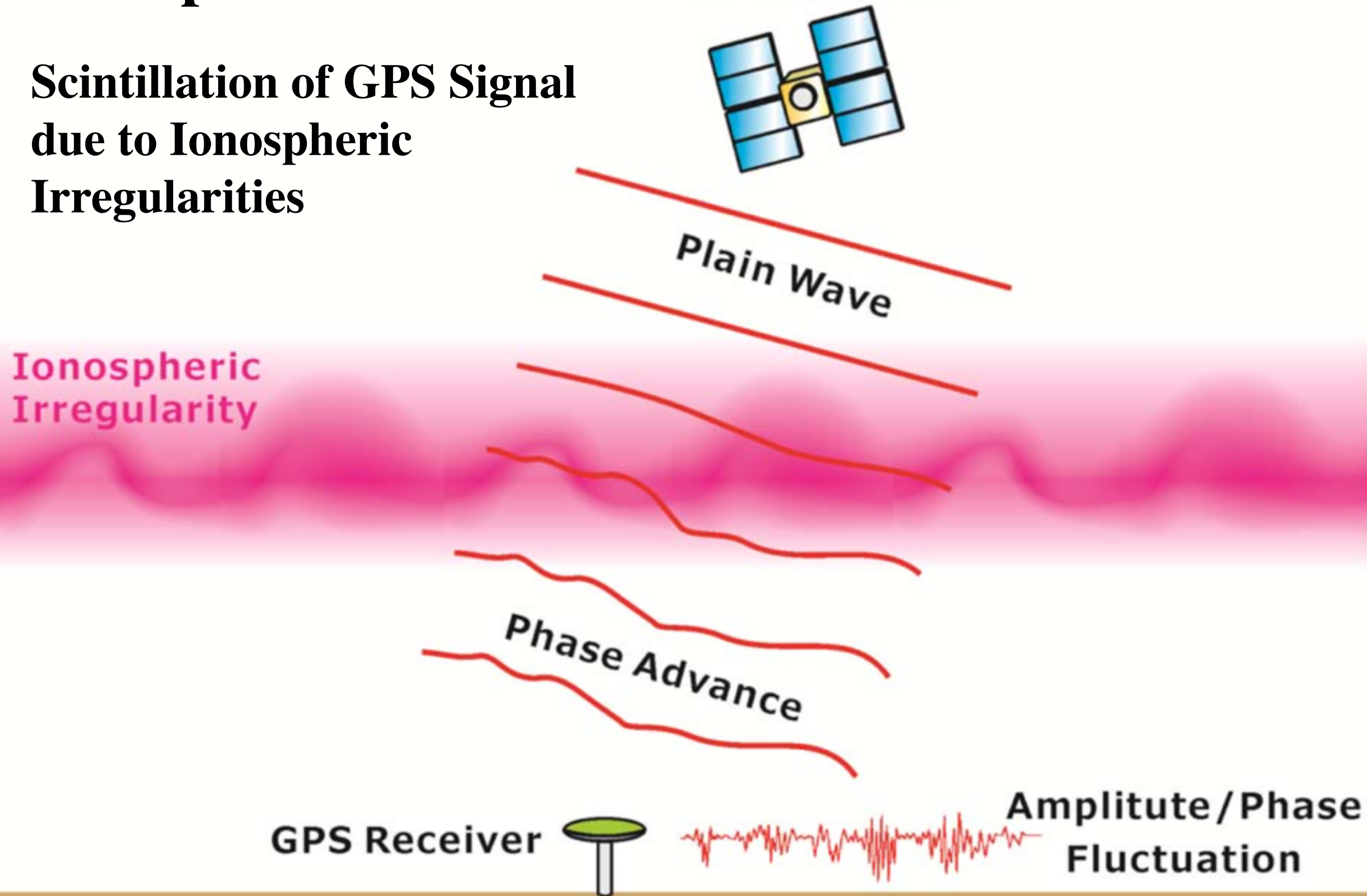
1 TECU = 16 cm

$$I_{\rho} = \frac{40.3 \text{ TEC}}{f^2}$$



Ionospheric Effect on GNSS - 2

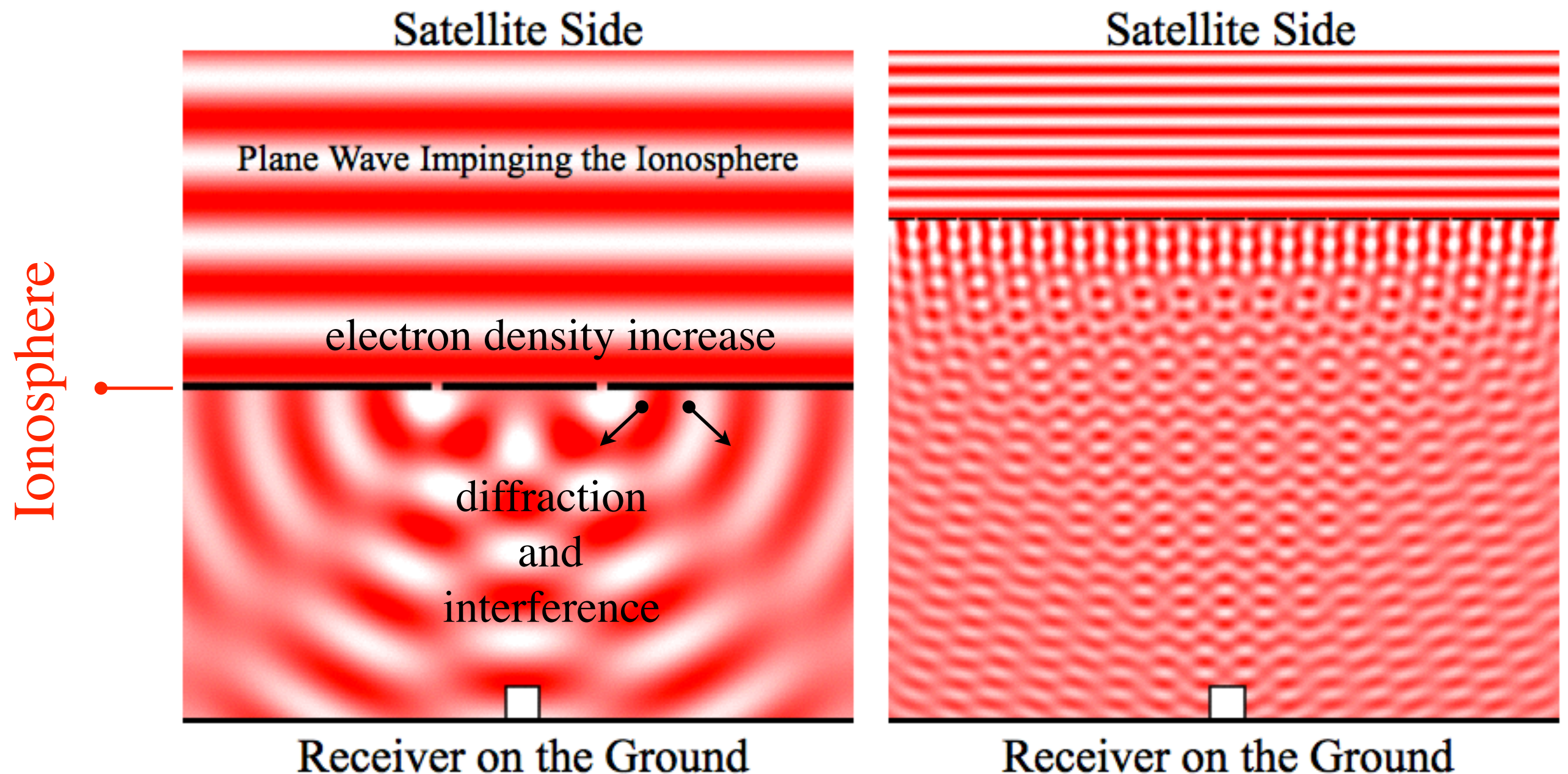
Scintillation of GPS Signal due to Ionospheric Irregularities



Ionospheric Scintillations

Scintillations: Fluctuations in the received signal on the ground

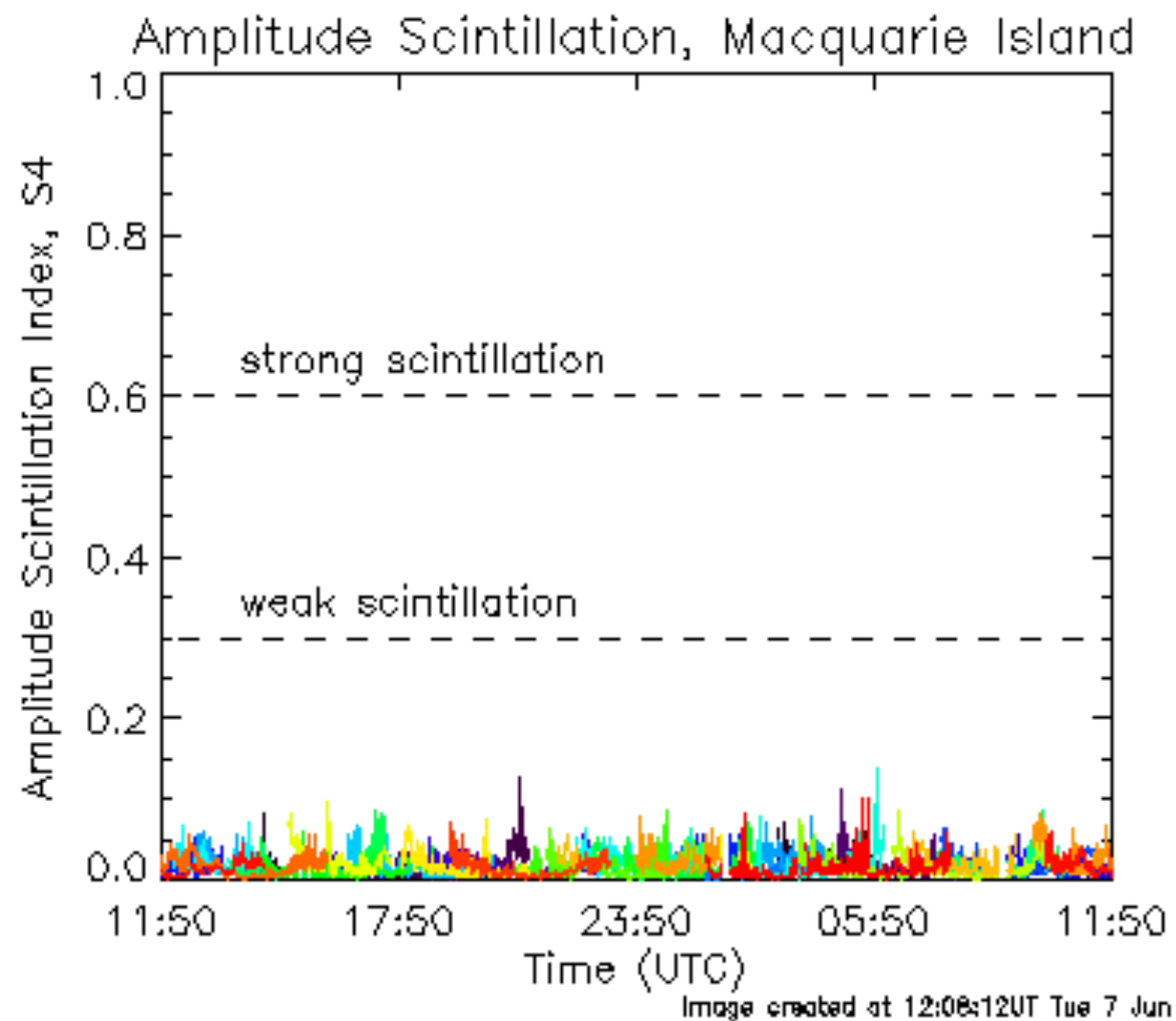
Cause: interference of diffracted signals by the irregular ionosphere



Two Types of Scintillation

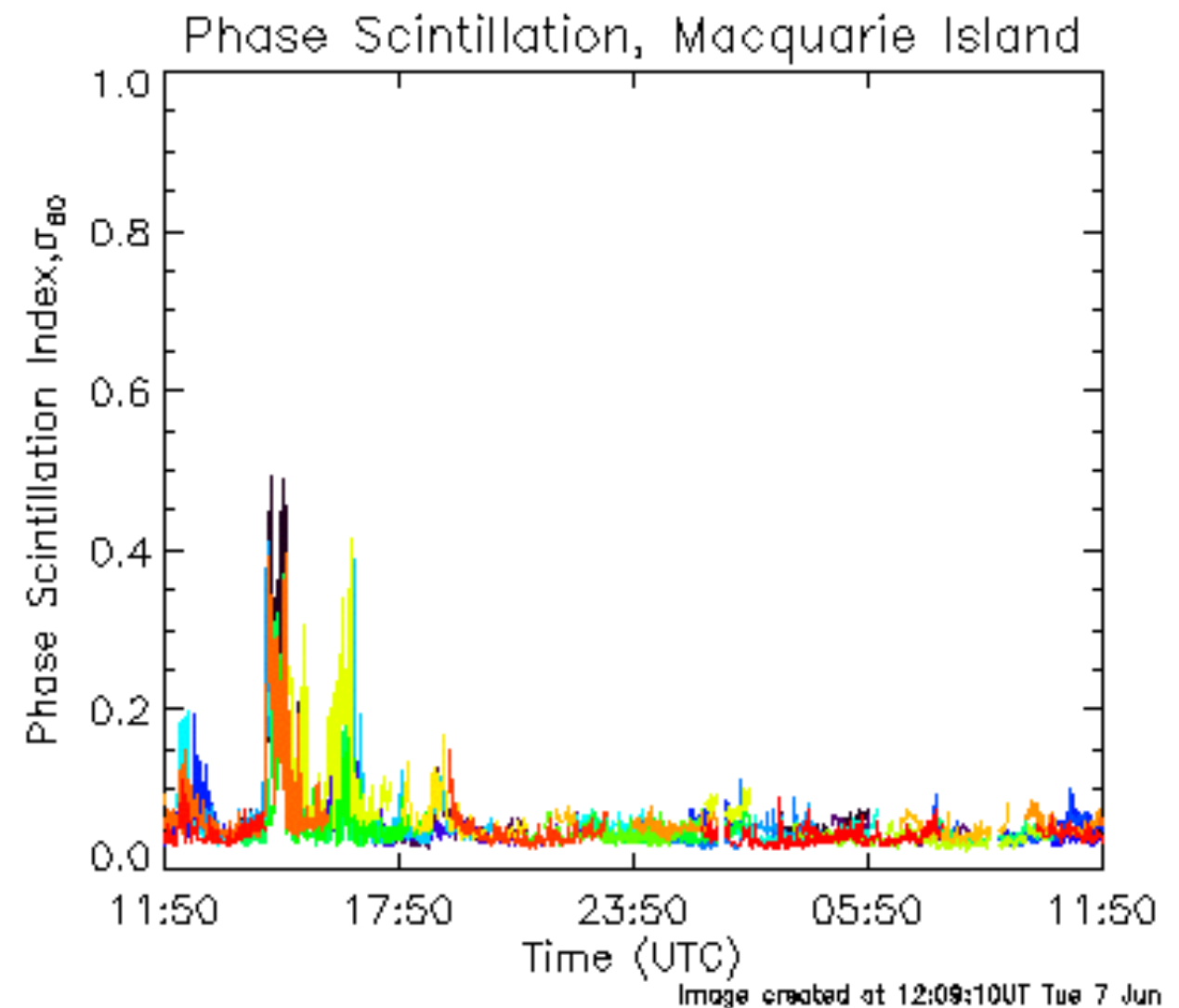
Amplitude scintillation:

$$S_4 = \sqrt{\frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2}}$$



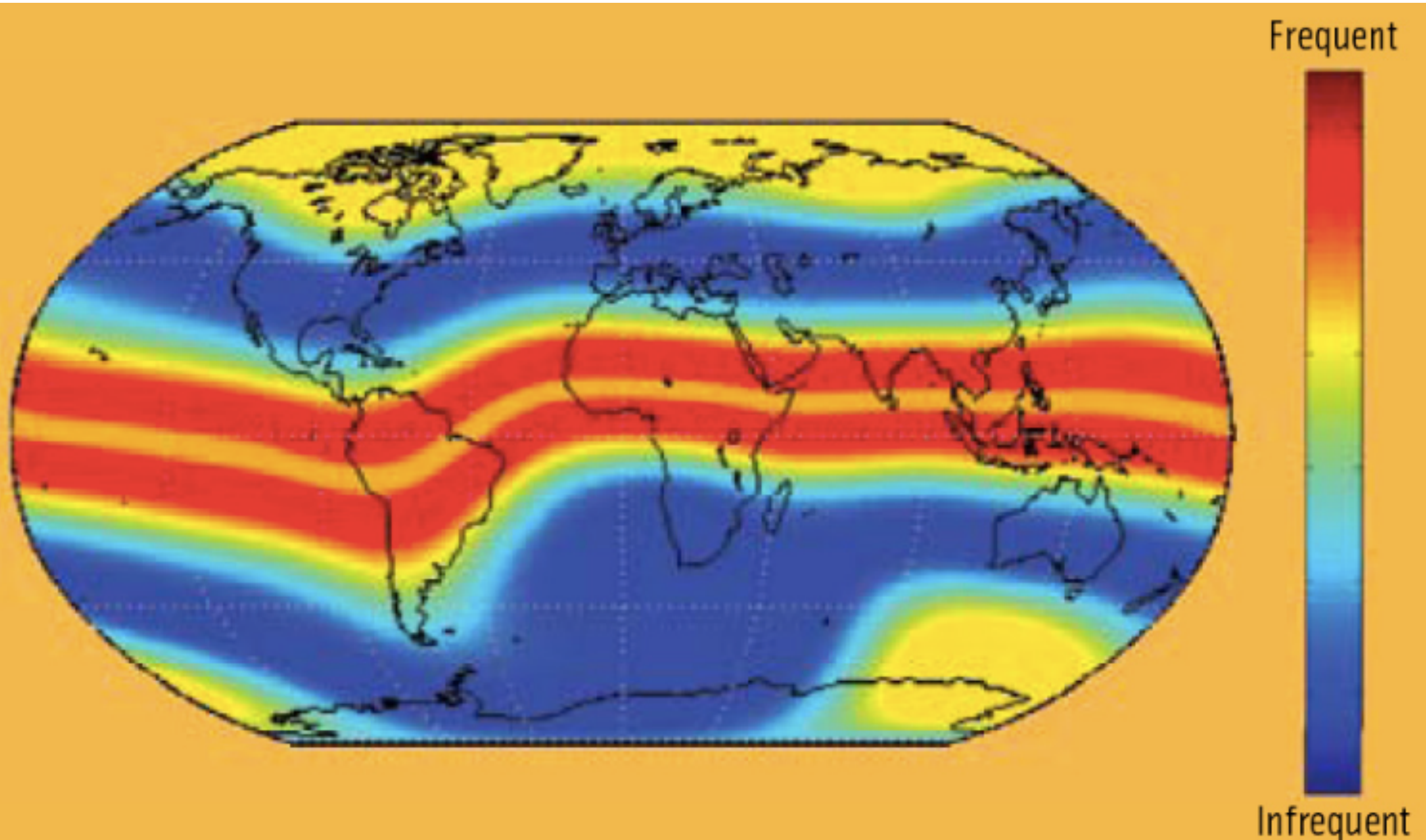
Phase Scintillation:

$$\sigma_\phi = \text{STDB}(\phi)$$



Global Distribution of GPS Scintillations

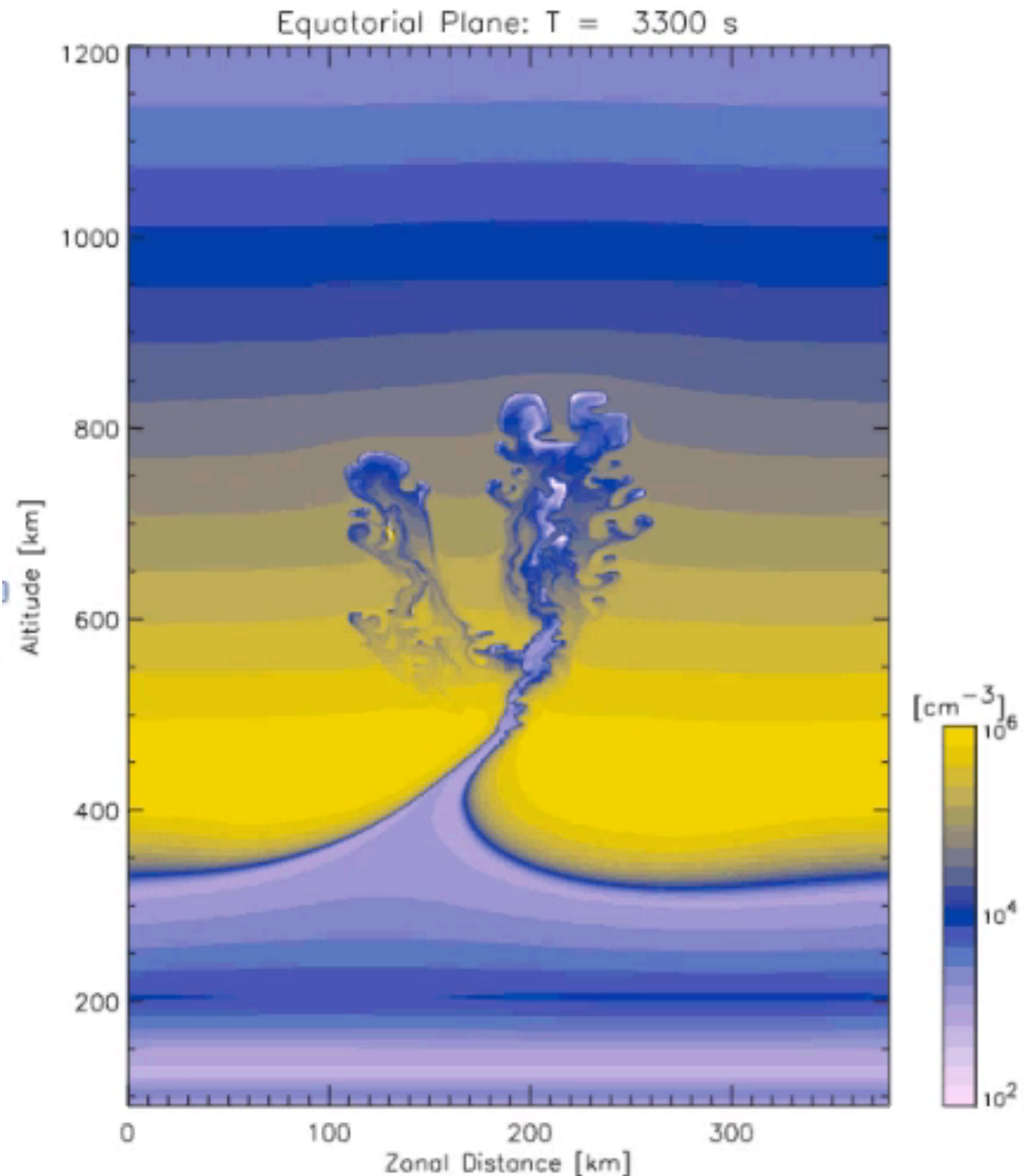
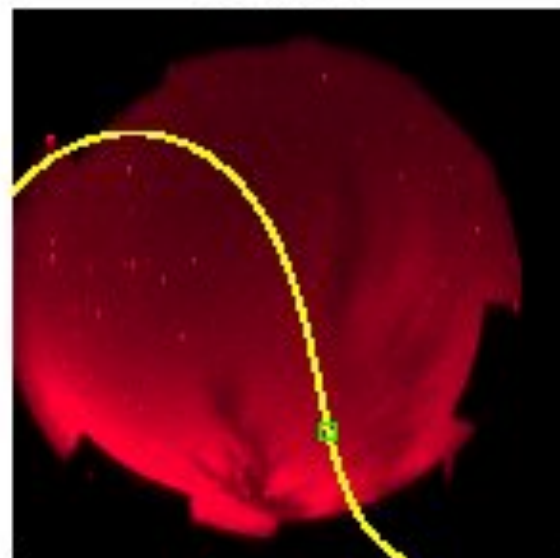
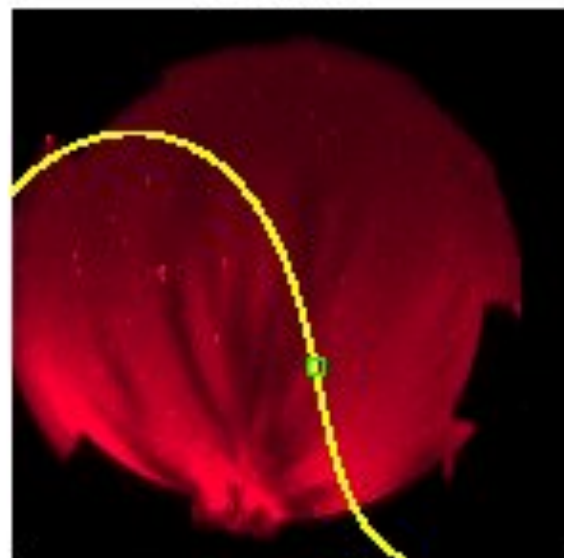
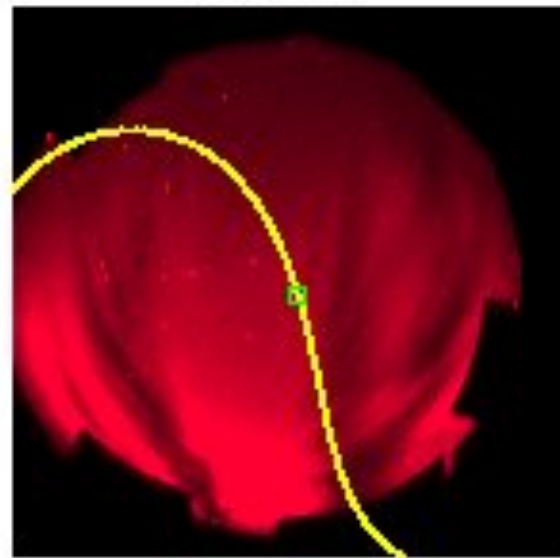
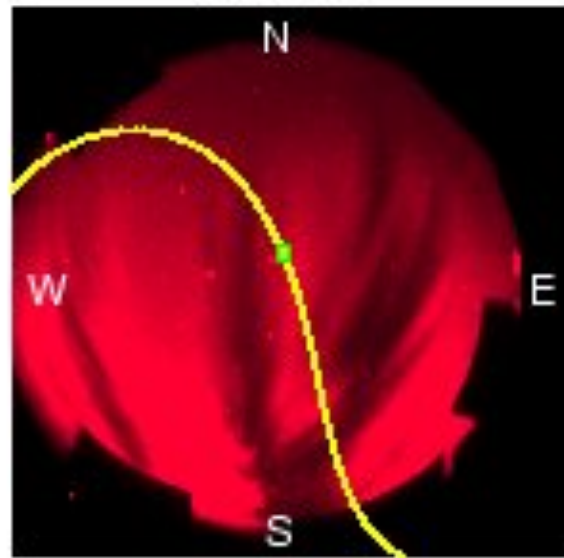
Two Hotspots of Scintillation: Equatorial and Polar Regions



Source of Equatorial Scintillations

Plasma Bubble

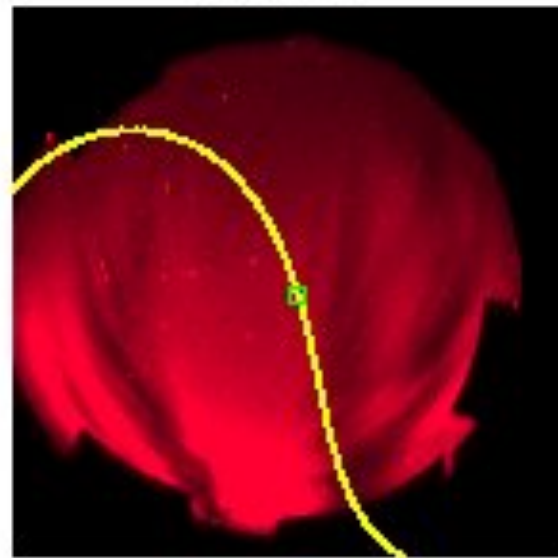
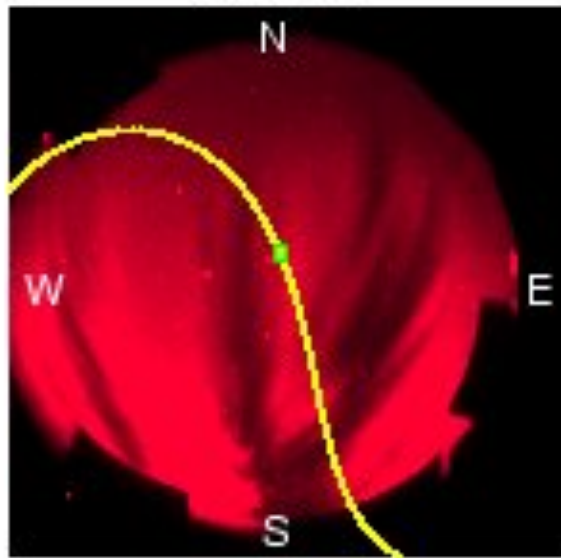
777.4 nm All Sky Images, Feb 16-17, 2002
22:22 LT 22:46 LT



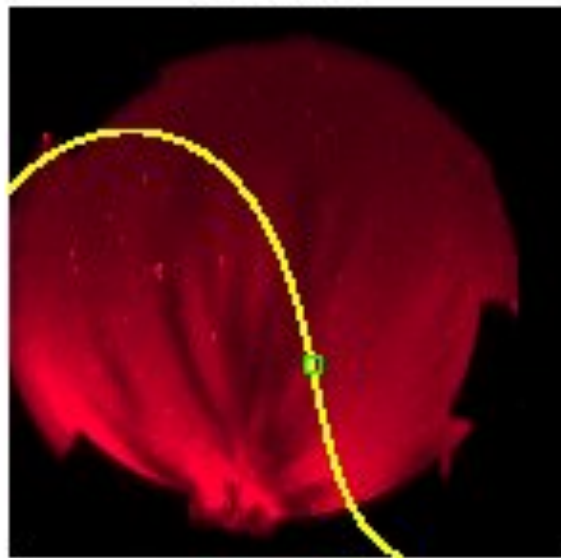
Source of Equatorial Scintillations

Plasma Bubble: Effect on GPS Scintillations

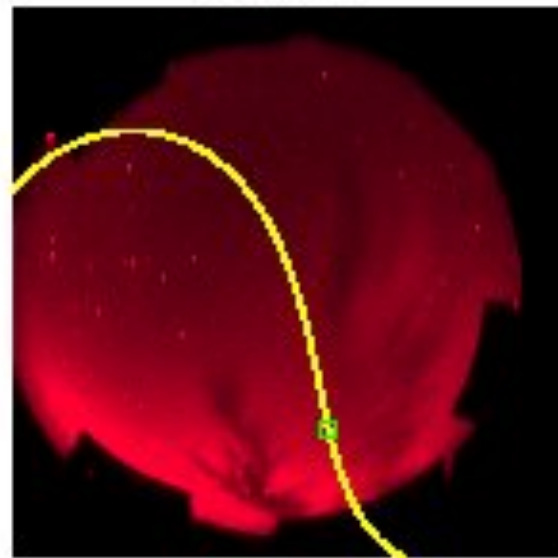
777.4 nm All Sky Images, Feb 16-17, 2002
22:22 LT 22:46 LT



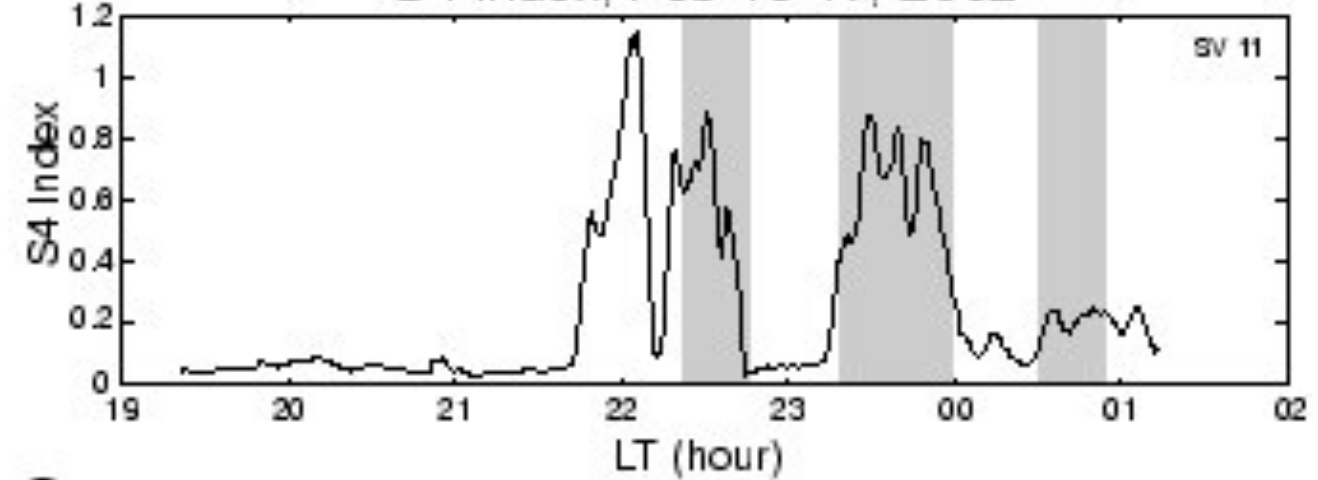
23:26 LT



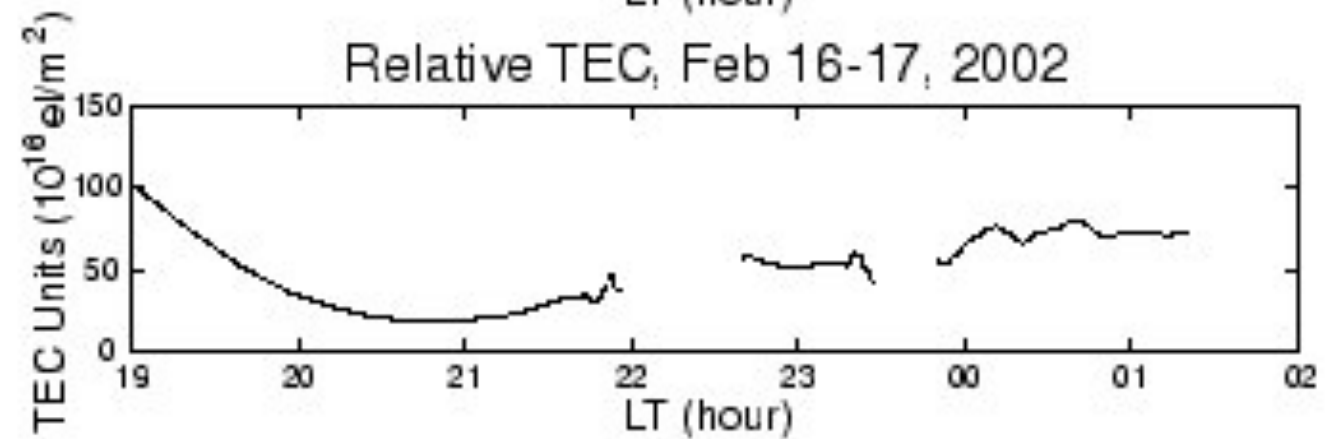
00:06 LT



S4 Index, Feb 16-17, 2002

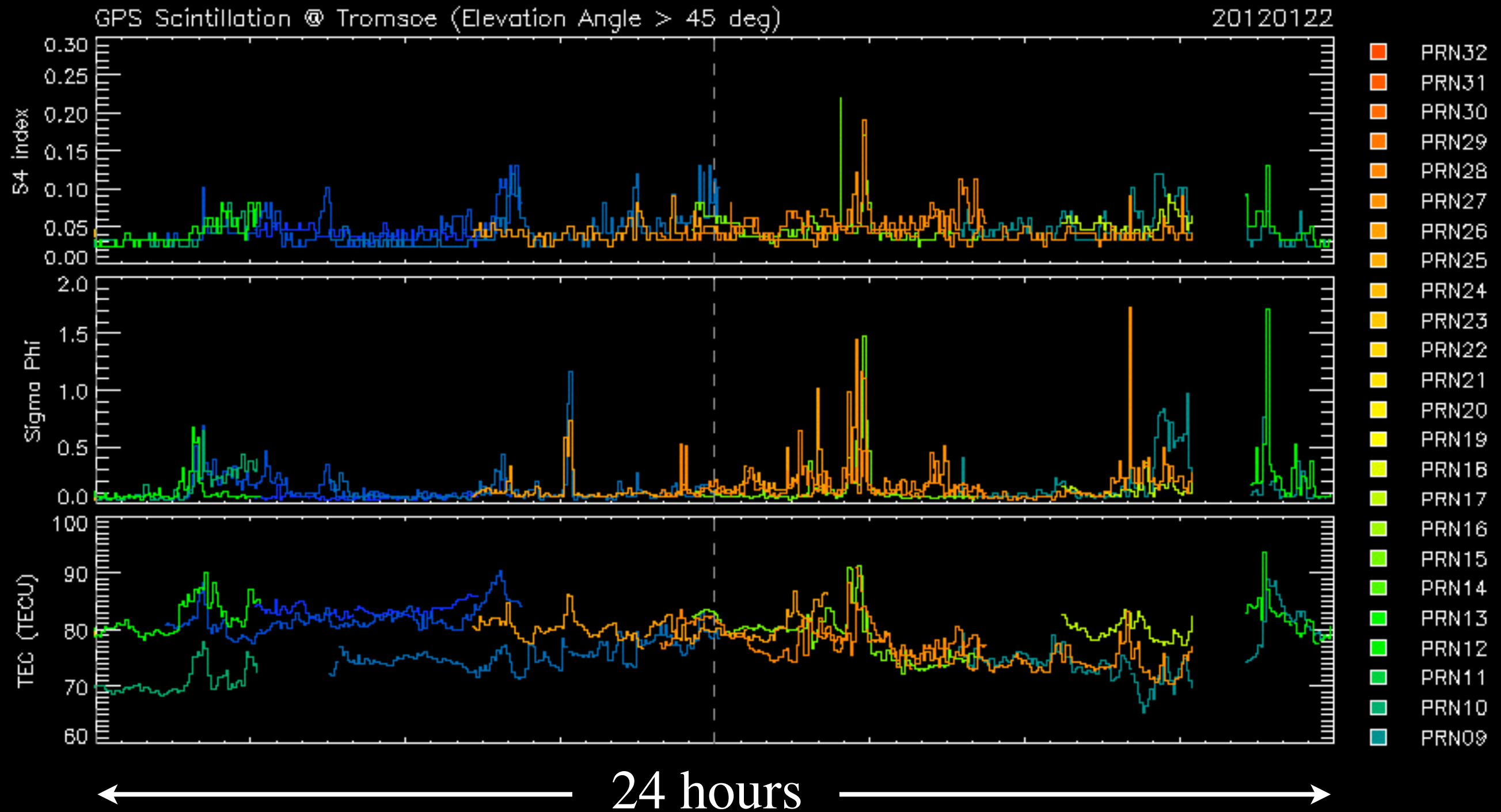


Relative TEC, Feb 16-17, 2002



Source of High-Latitude Scintillations

GPS Scintillation Measurement in Tromso, Norway



Quick exercise: Browsing GPS Scintillation Data

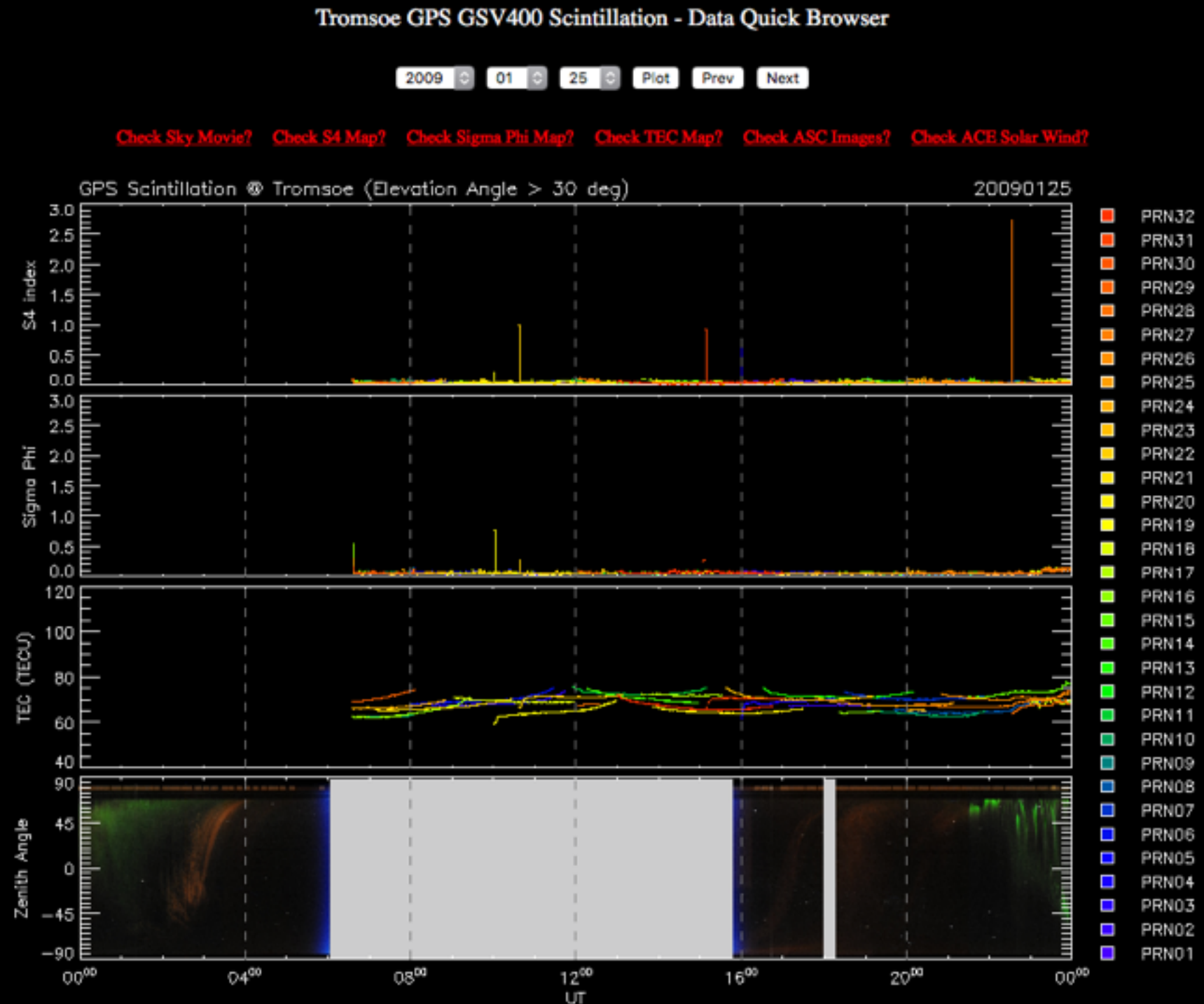
<http://gwave.cei.uec.ac.jp/cgi-bin/hosokawa/tromsoe/tromsoe.cgi>

S4 index
amplitude scintillation →

Sigma phi
phase scintillation →

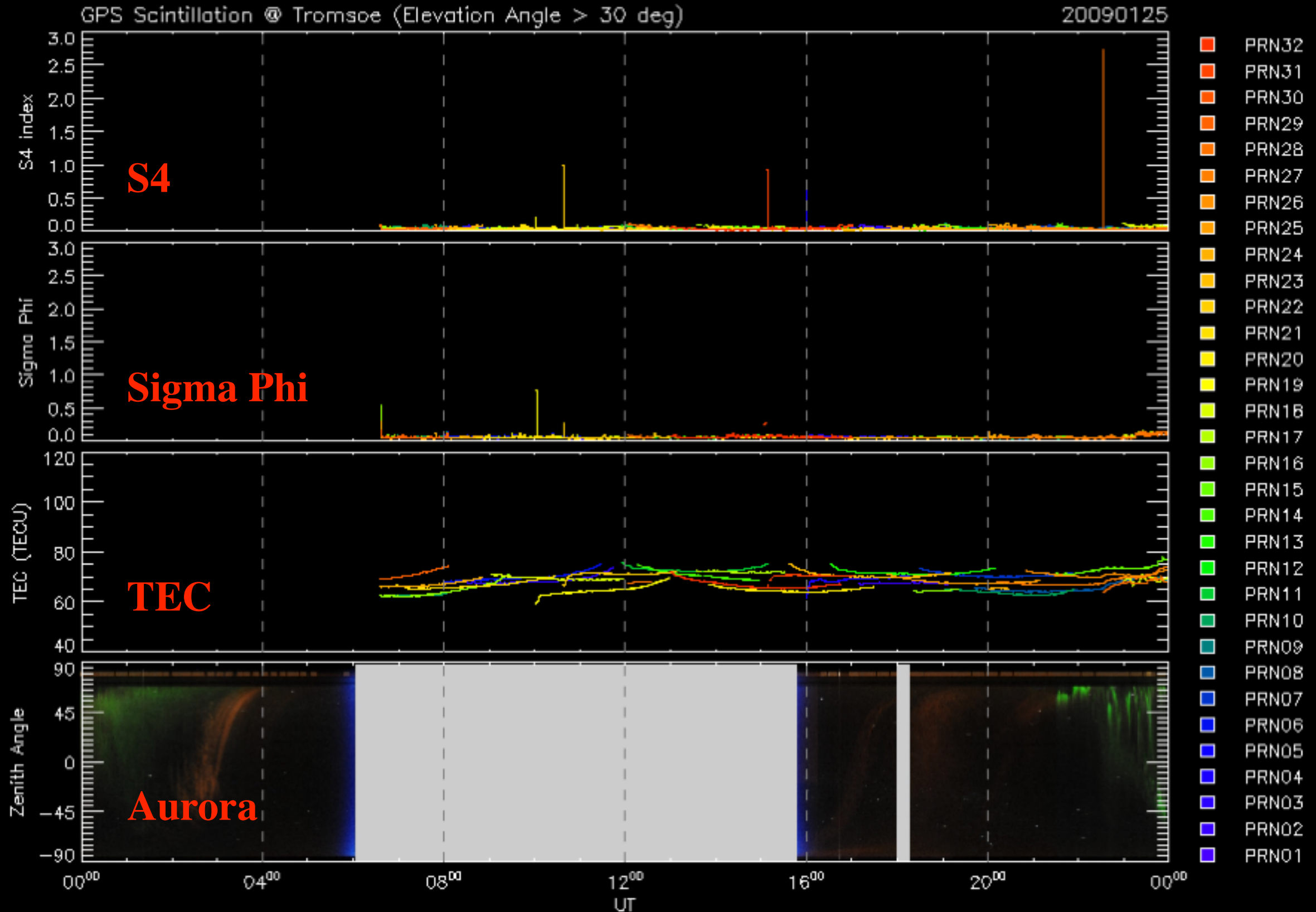
TEC →

Aurora Data →



Change date

2009 01 25 Plot Prev Next

[Check Sky Movie?](#) [Check S4 Map?](#) [Check Sigma Phi Map?](#) [Check TEC Map?](#) [Check ASC Images?](#) [Check ACE Solar Wind?](#)

Jump to Jan 20, 2012, and check the following 10 days

Check various movies (heavy)

Aurora data
in 2D

SW
data

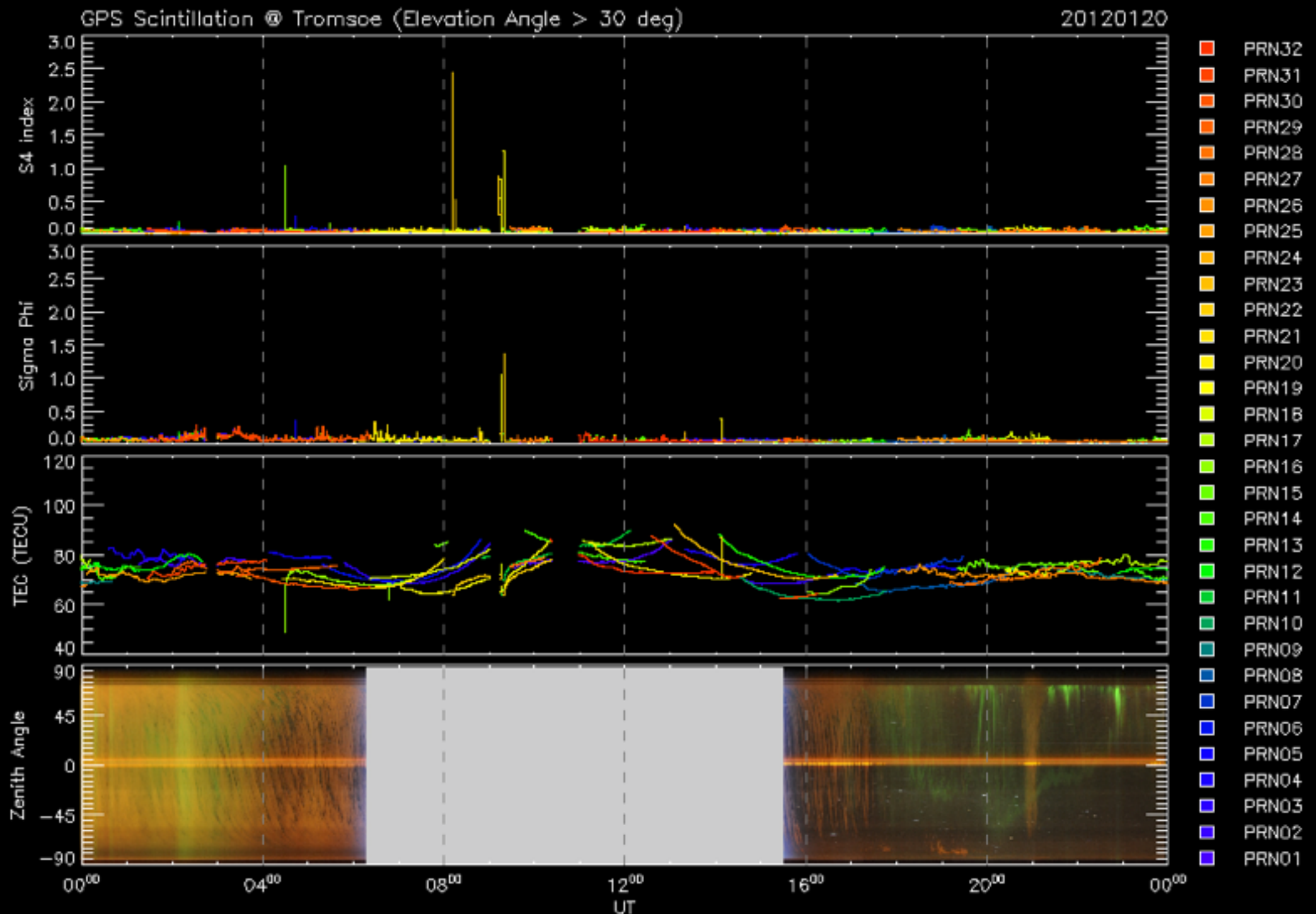
↓ ↓ ↓ ↓
[Check Sky Movie?](#) [Check S4 Map?](#) [Check Sigma Phi Map?](#) [Check TEC Map?](#) [Check ASC Images?](#) [Check ACE Solar Wind?](#)

S4

Sigma Phi

TEC

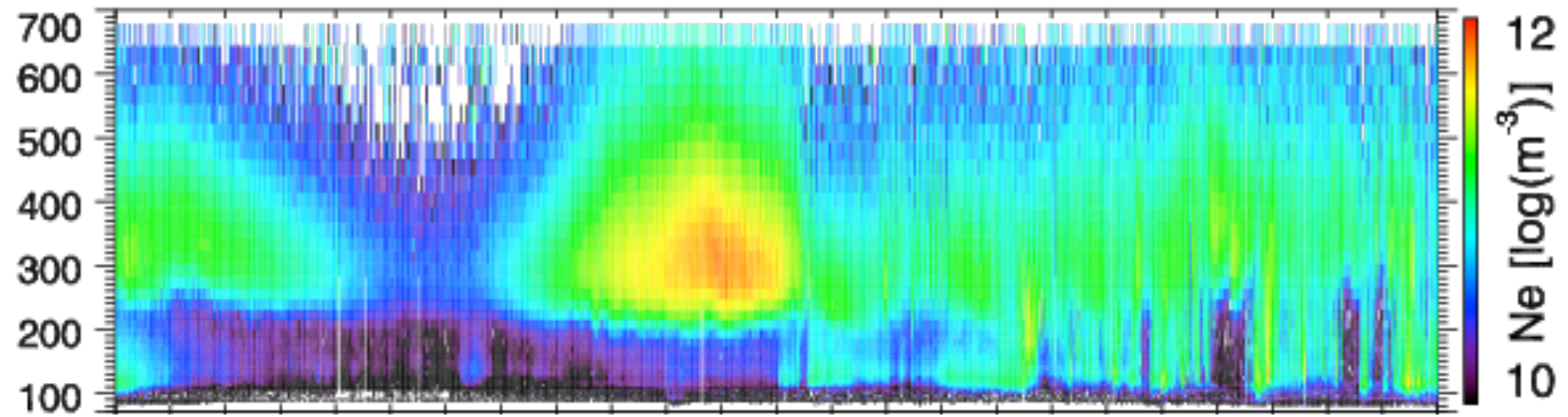
Aurora



EISCAT 2012-01-22_00_24UT_uhf

Ne

Altitude
[km]

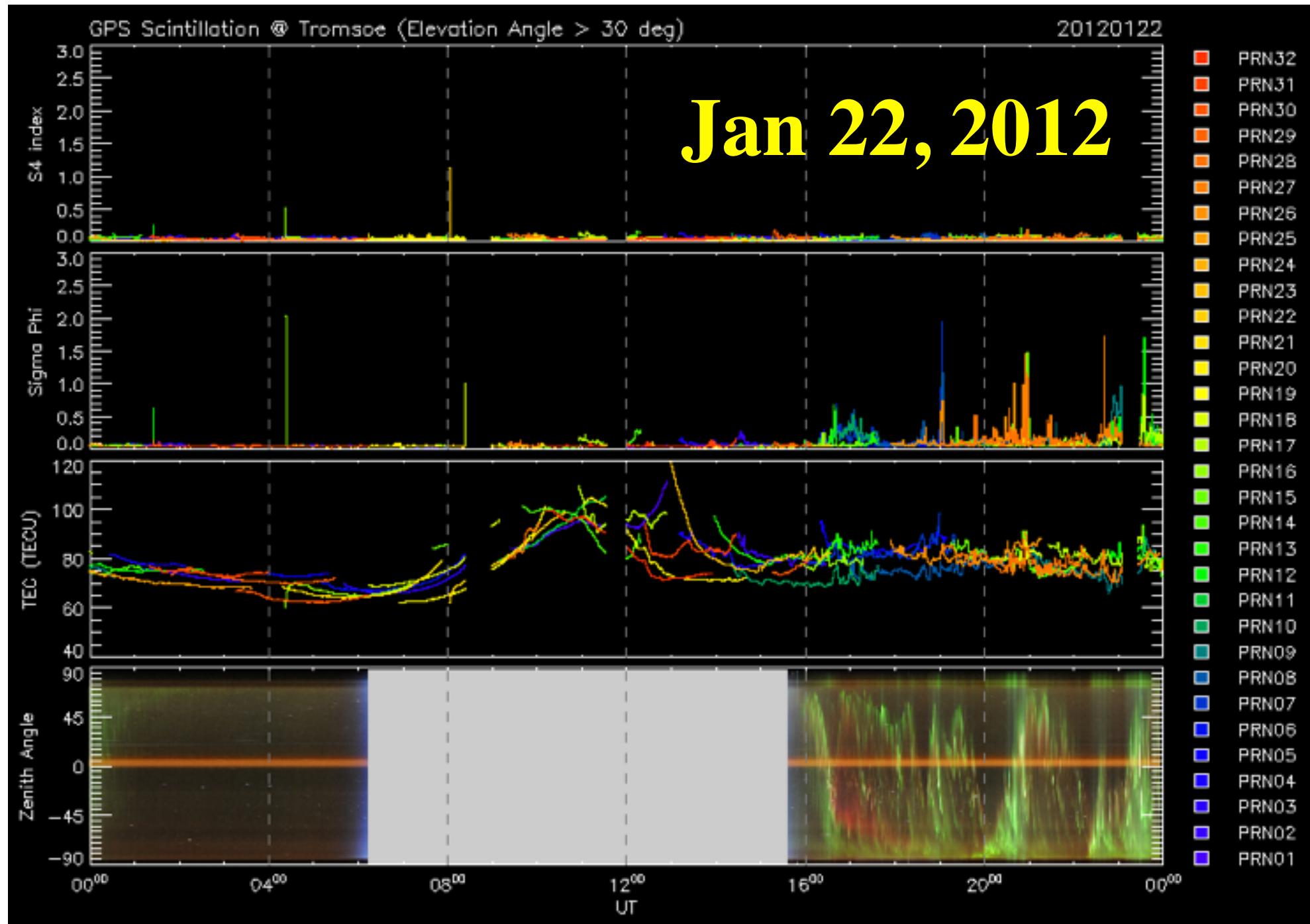


S4 index

Sigma phi

TEC

Aurora
Data



Data on Jan 22, 2012

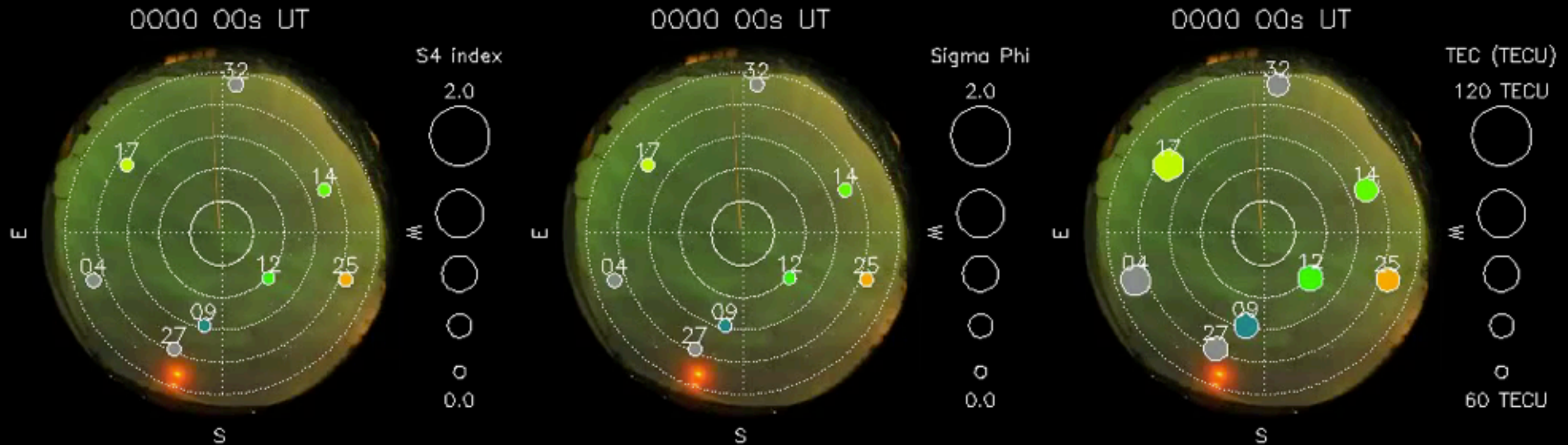
The size of the circles indicates the intensity of the parameters

S4 index
amplitude scintillation

Sigma phi
phase scintillation

TEC

GPS GSV400 Data on Colour ASC @ Tromsøe 20120122

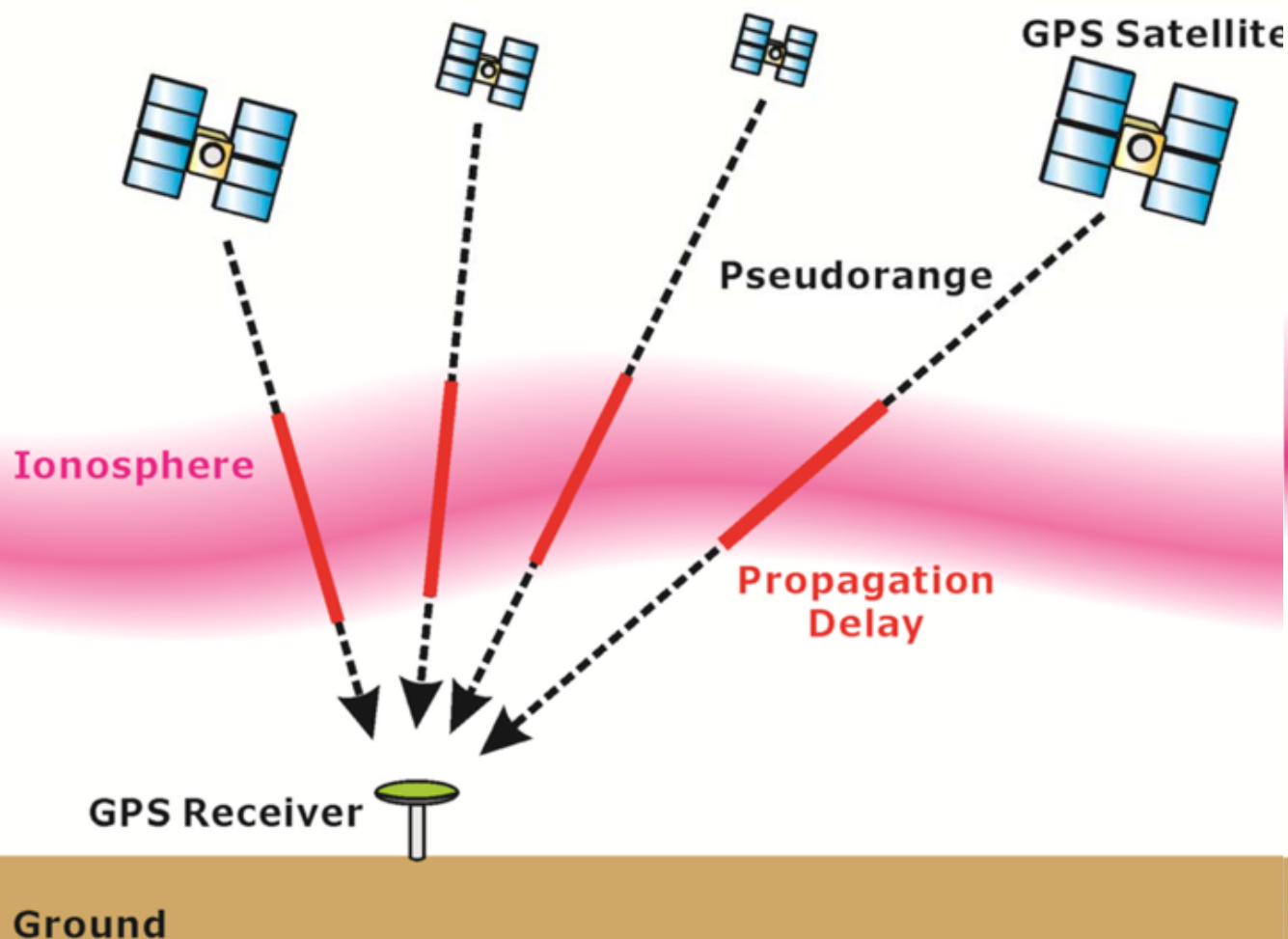


Summary: GNSS + Space Weather

Two major ionospheric space weather impacts on GNSS

Positioning Error due to enhancement of TEC

$$I_{\rho} = \frac{40.3 \text{ TEC}}{f^2}$$



Scintillation effect

1. Phase scintillation
2. Amplitude scintillation

