# Ionospheric threat and its mitigation for GNSS implementation in the APAC region

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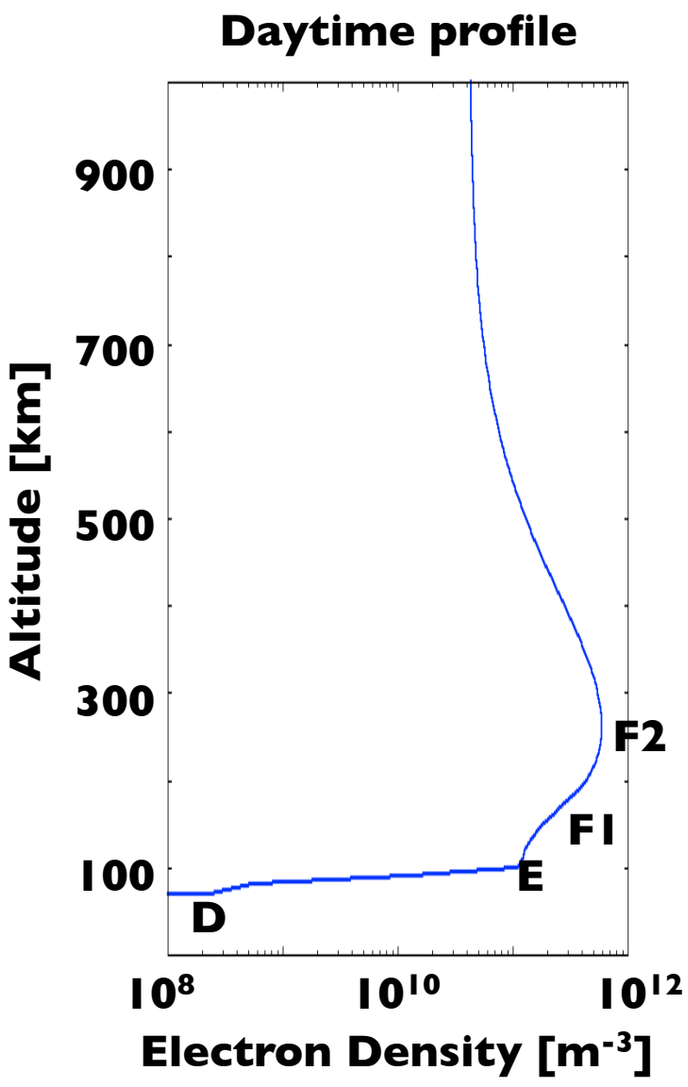
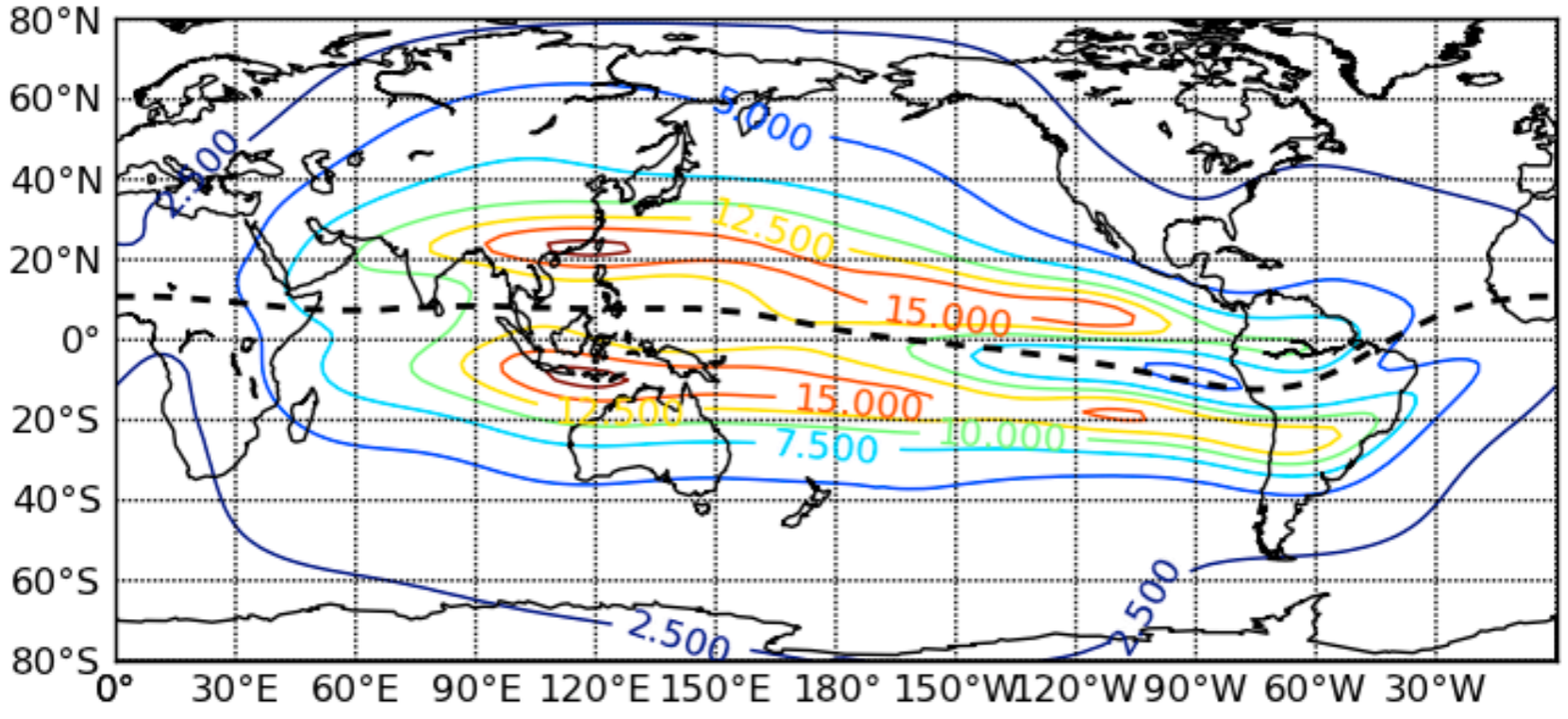
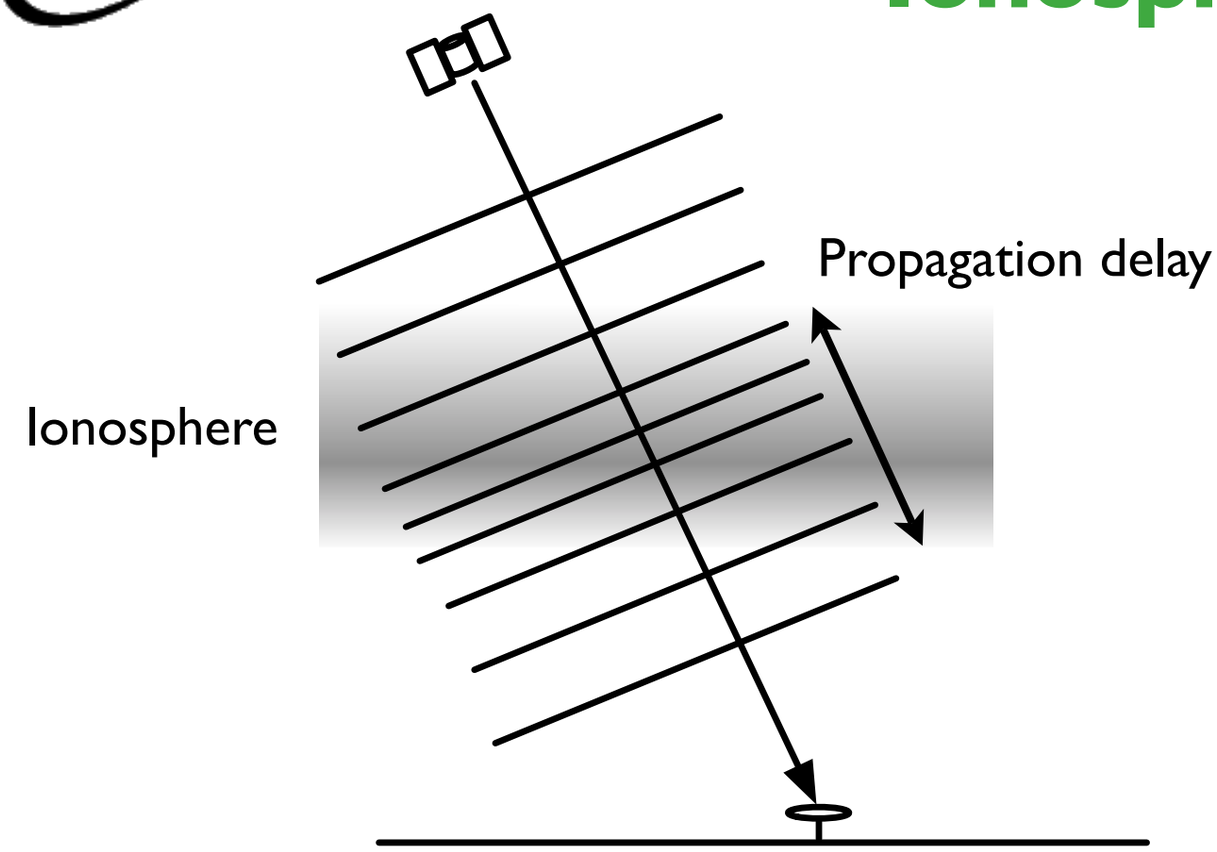
# Ionosphere

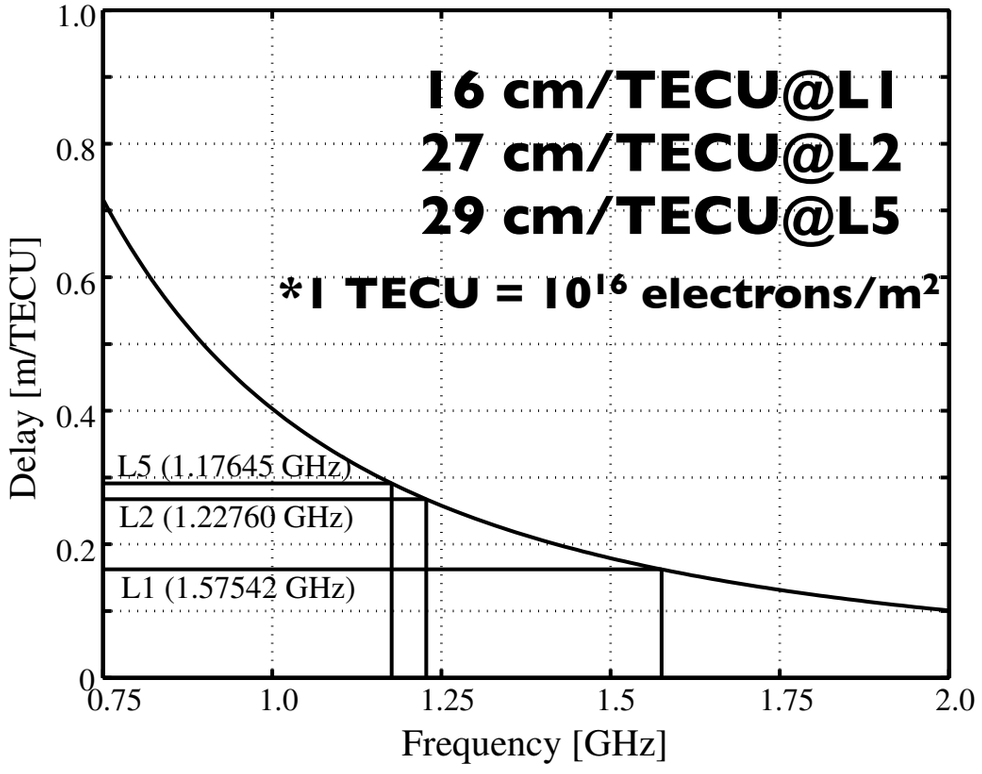



- Ionosphere is the ionized Earth's atmosphere. (i.e. plasma)
  - Altitude: 60 - 1000+ km
- Ionospheric density changes in location, local time, season, solar activity, etc.
- Density peaks around +/- 15° magnetic latitude.
- Characteristics depend strongly on magnetic latitude.

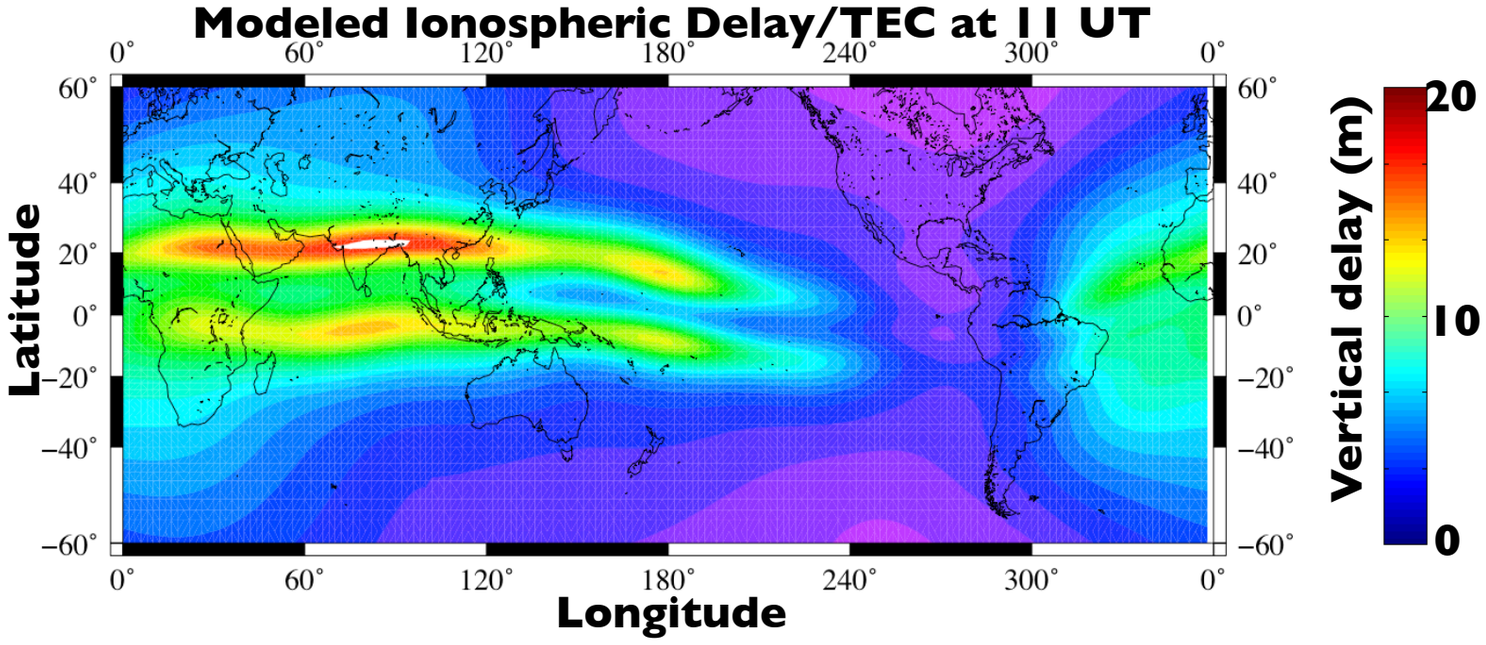


# GNSS and the ionosphere - Ionospheric Delay

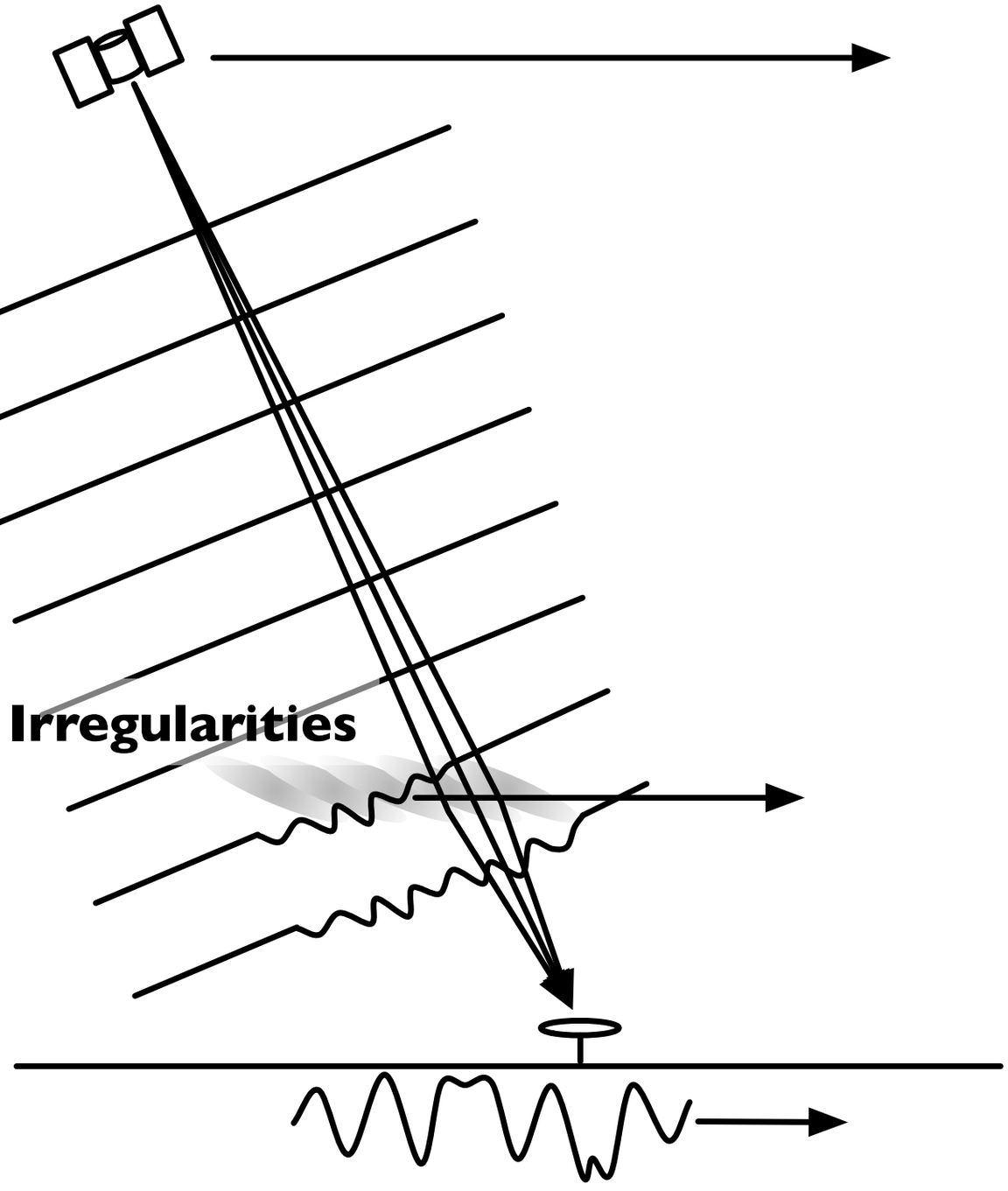



- Ionospheric plasma slows the radio wave propagation velocity
  - Satellite-receiver path appears to be longer than the true length
  - ➡ Ionospheric delay
- Vertical ionospheric delay can be as large as 20-30 m
  - 2-3 times more in slant (along the path) delay

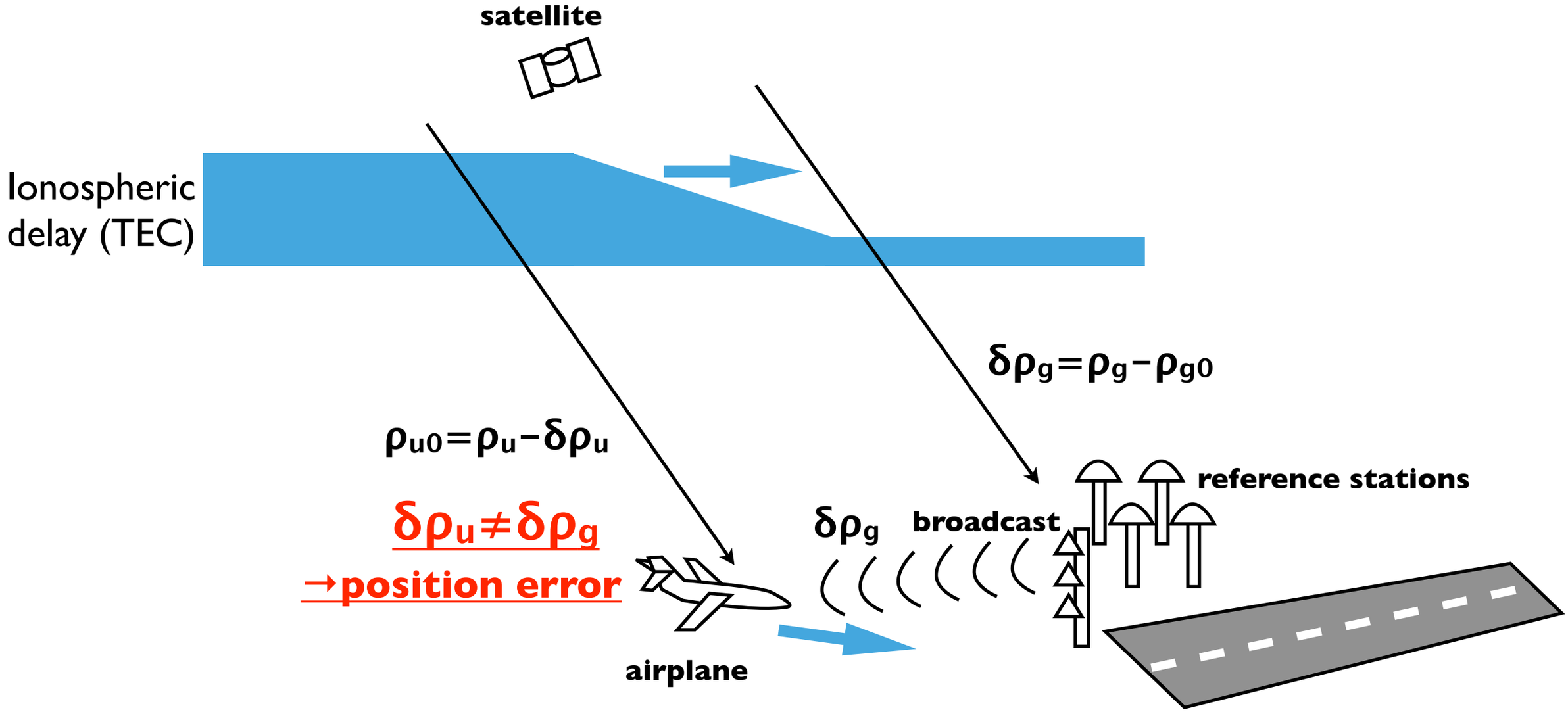


# GNSS and the ionosphere
# - Ionospheric Scintillation



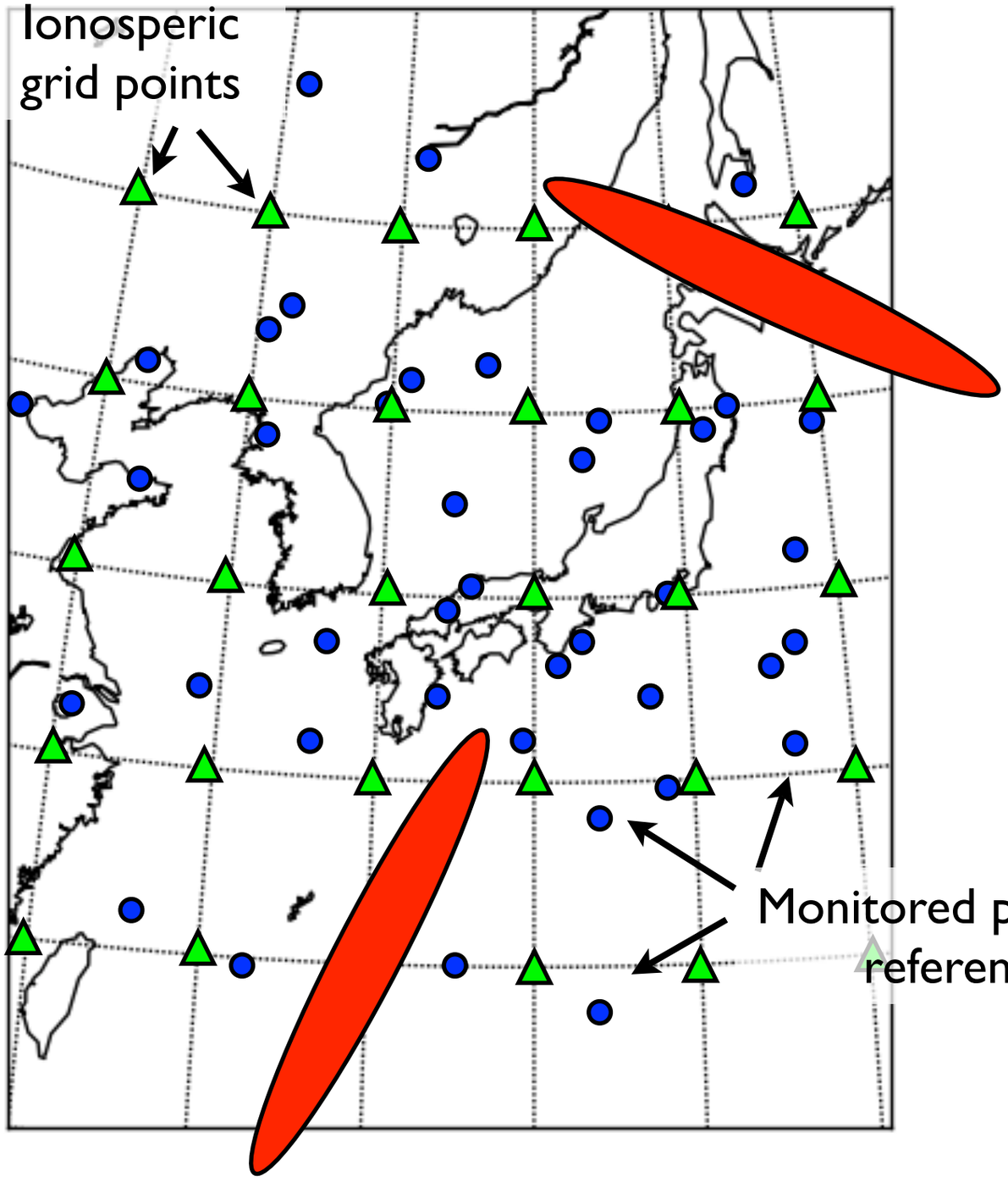

* Ionosphere is not always uniform
  - Irregularities (small scale structures of the ionosphere) diffract radio wave
  - Amplitude and phase of radio waves randomly fluctuates
  - ➡ Ionospheric scintillation
* Scintillation effects
  - Degradation of ranging accuarcy
  - Signal loss-of-lock

# Ionospheric impacts on GNSS-based air navigation system - GBAS




* Different errors between ground reference stations and airplanes result in differential correction error.
* Local spatial gradient in ionospheric delay can be an important error source.

# Ionospheric impacts on GNSS-based air navigation system - SBAS

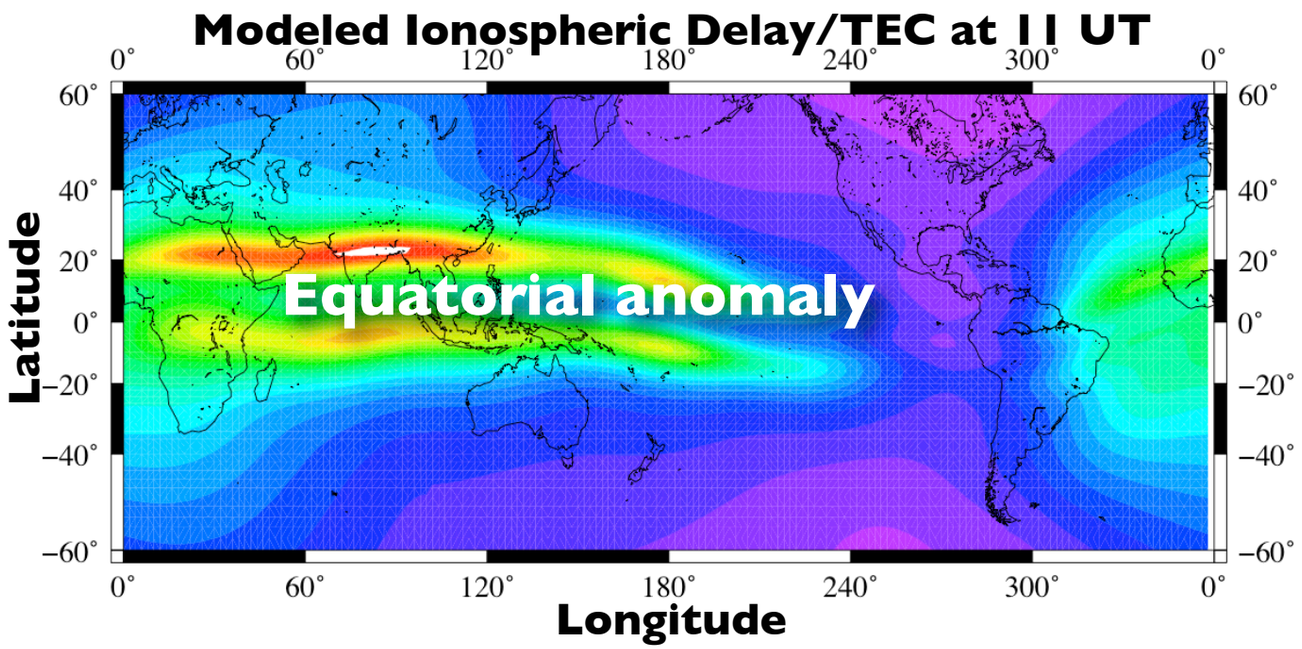


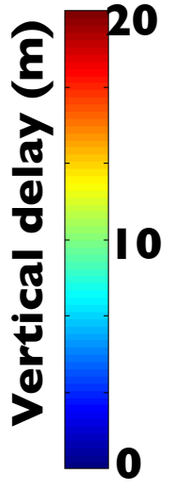

* SBAS monitors the ionosphere by ground stations
* Ionospheric anomalies with scale sizes smaller than the distances between reference stations may be misdetected

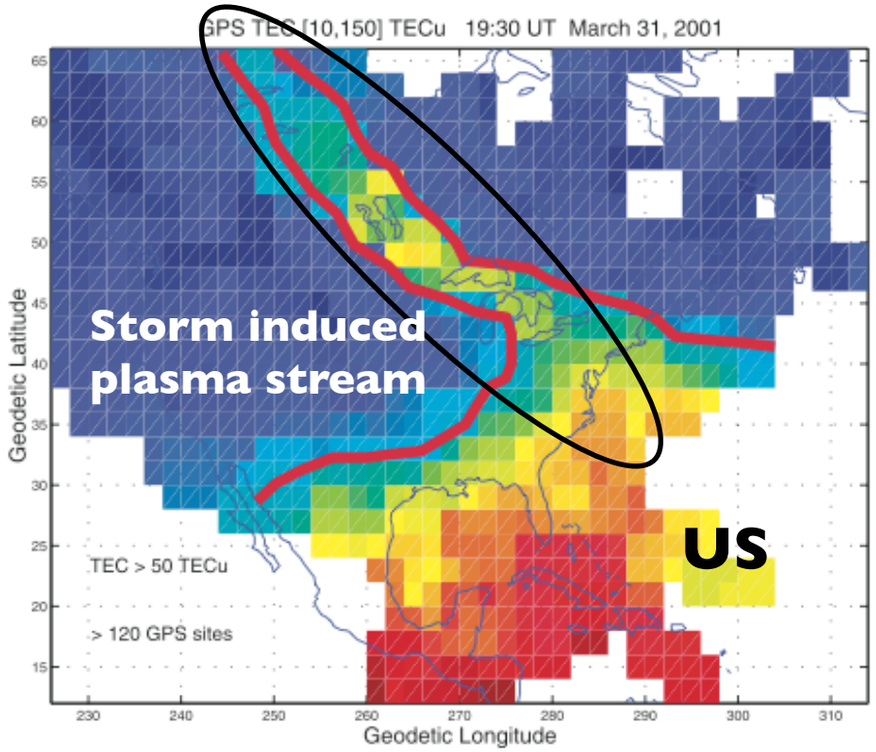
# Mitigation Strategy

* Two different cases
  - Nominal ionosphere
    - Background ionospheric fluctuations, always exists
    - Bound errors with protection level (with confidence of $10^{-7}$ level)
  - Anomalous ionosphere
    - Disturbed ionosphere, not always exists but potentially dangerous
    - Detected or prescreened, and excluded so that the aircraft will not use the misleading information
* Important to know how the ionosphere behaves
  - Ionospheric characterization
* Necessary parameters depends on the system
  - Different characterization for GBAS and SBAS

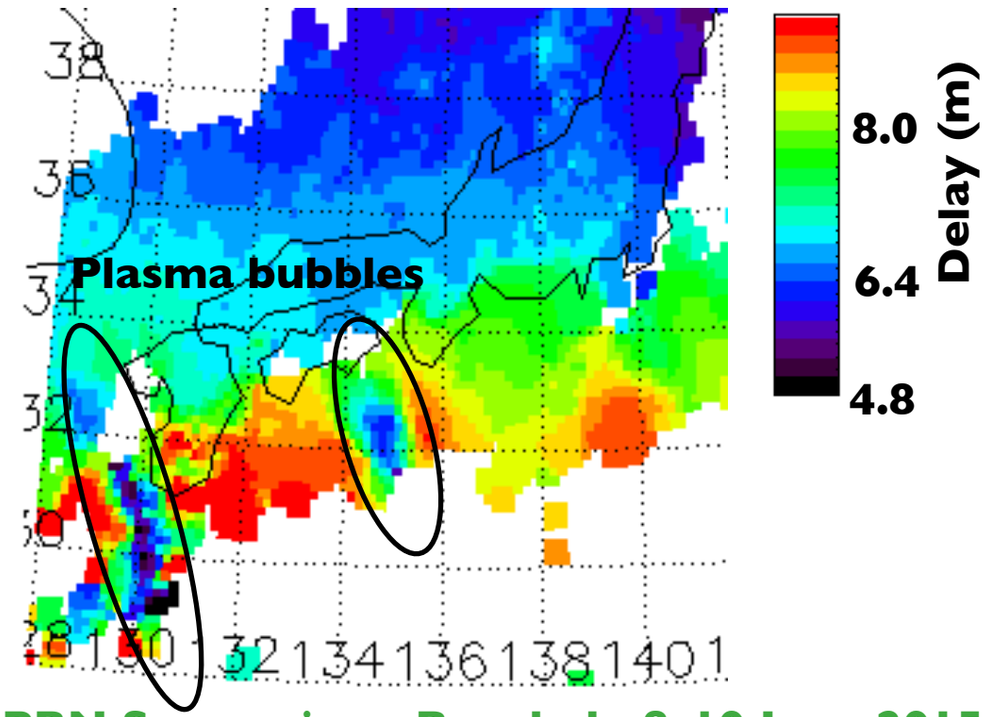
# Low latitude ionosphere - How it is different from mid- and high latitudes




**[Foster et al., 2002]**

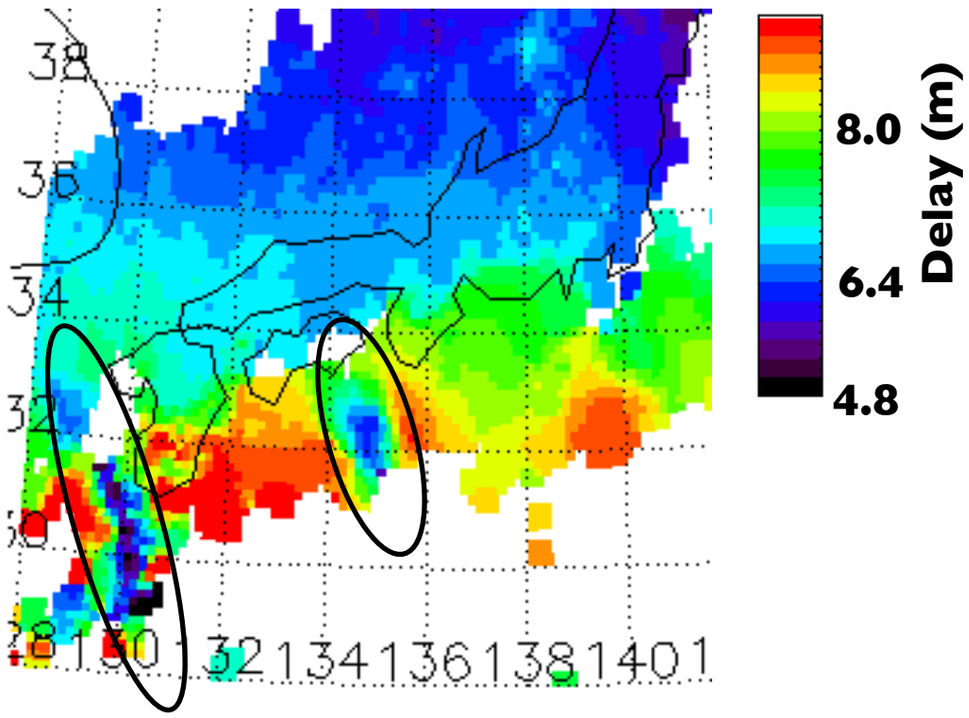



* Ionospheric characteristics strongly depend on magnetic latitude.
  - More delays in low latitude
  - Different phenomena of ionospheric disturbances
    - Different characteristics (gradients, scale size, occurrence rate, etc.)

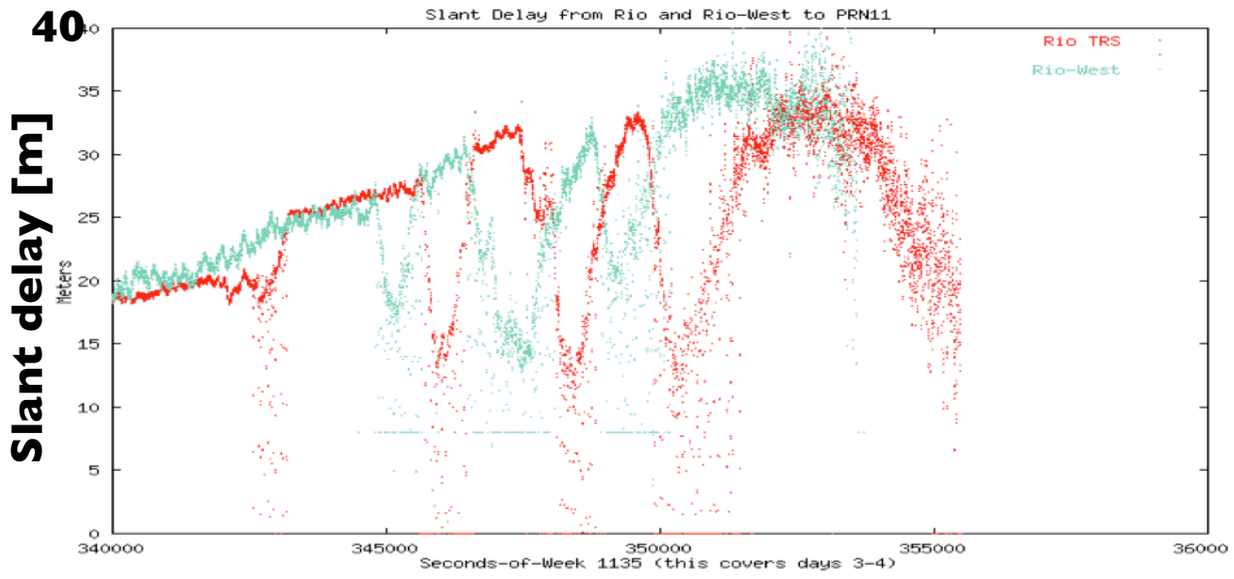
# Low latitude ionospheric disturbance - Plasma bubble

**Vertical TEC variation over Japan**

**21:25:30 JST on 7 April 2002**




**Slant delay at Rio de Janeiro, Brazil**




* Ionospheric density depletion elongated in the north-south direction
* Accompany very steep ionospheric gradient and scintillation
* Frequently occur after sunset in high solar activity periods
* In the Asia-Pacific region, higher occurrences are observed during equinox seasons (March-April and September-October)

**[ICAO NSP Report on Ionospheric effects on GNSS,2006]**

# How to characterize the ionosphere?

* Characterization needs large number of data
  - The number of data that can be obtained in each States/ Administrations are limited
* Coordinated data collection, sharing, and analysis are effective.
  ➡ APANPIRG CNS-SG decided to establish Ionospheric Studies Task Force (ISTF)

# Ionospheric Studies Task Force (ISTF) - History

* September 2010
  ICAO Asia Pacific Air Navigation Planning and Implementation Group (APANPIRG) meeting (Bangkok) identified a need of studying ionospheric effects on GNSS in the low latitude region

* May 2011
  Workshop on Ionospheric data collection, analysis and sharing to support GNSS implementation (Bangkok) recommended a task force to be established.

* July 2011
  Ionospheric Studies Task Force (ISTF) was established under APANPIRG CNS/MET subgroup (currently CNS subgroup).

# Ionospheric Studies Task Force (ISTF)

* Facilitate ionospheric data collection and sharing in the Asia-Pacific (APAC) region
* Study the need for development of regional ionospheric threat models for GBAS and SBAS,
* Develop them if the need is identified.
* Investigate the effects of space weather on CNS systems in the APAC Region

# Ionospheric Studies Task Force (ISTF) - Tasks

| Sequence | Task | Description | Task Lead |
|---|---|---|---|
| 1 | 1. Data Collection | Collection, integration, administration and distribution of data collected from States and Administrations | Dr. Saito (Japan) |
| | 2. Iono Analysis | Formulation of ionosphere analysis methodologies, data analysis and characterization of the ionosphere to generate information required for completion of the IONO MODEL task | Dr. Chun (ROK) |
| 2 | 3. TEC Generation | Generation of regional TEC gradient information for ionospheric study in the Asia/Pacific region | Dr. Terkildsen (Australia) |
| | 4. Scintillation Data | Generation of regional scintillation information for ionospheric study in the Asia/Pacific region | |
| 3 | 5. Iono Model | Review of the information from IONO ANALYSIS/ TEC GENERATION/ SCINTILLATION DATA and development of GBAS and SBAS models for the Asia/Pacific region if needed | SBAS: Dr. Sakai (Japan) |
| | | | GBAS: Dr. Yoshihara (Japan) |
| - | 6. Space Weather | Analyze, based on data shared within ISTF and public information, the effects of space weather and the concept of operations for the provision of space weather information in support of international air navigation. | Dr. Tsugawa (Japan) |

# Ionospheric Studies Task Force (ISTF) - Status and Plan

* Activities
  - Five face-to-face meetings (ISTF/5 in February 2015 in Japan in conjunction with ICAO NSP CSG meeting)
  - 4 webconferences
* Outcomes
  - Data contribution from 8 States/Administrations (Australia, Hong Kong China, India, Japan, Philippines, Thailand, Singapore, and USA)
  - Common data formats: GTEX (delay), SCINTEX (scintillation)
  - Common tool: AATR analysis tool (ENRI), LTIAM tool (developed by FAA)
  - Period of interests for
  - Initial data analysis: Need of threat model for APAC region is identified (US CONUS model cannot bound the ionosphere in APAC region)
* Delivery: APANPIRG CNS-SG in 2015 (July)

# Summary

* Ionosphere has impacts on GNSS based air navigation.
* Ionospheric characterization is the key to effective mitigation of the ionospheric impact.
* Ionospheric Studies Task Force is working on.
  - Low latitude region (including large part of APAC region) needs specific characterization (threat model)
  - Working to deliver threat model by2015