The Bureau of Meteorology

Space weather, a key vulnerability to GNSS

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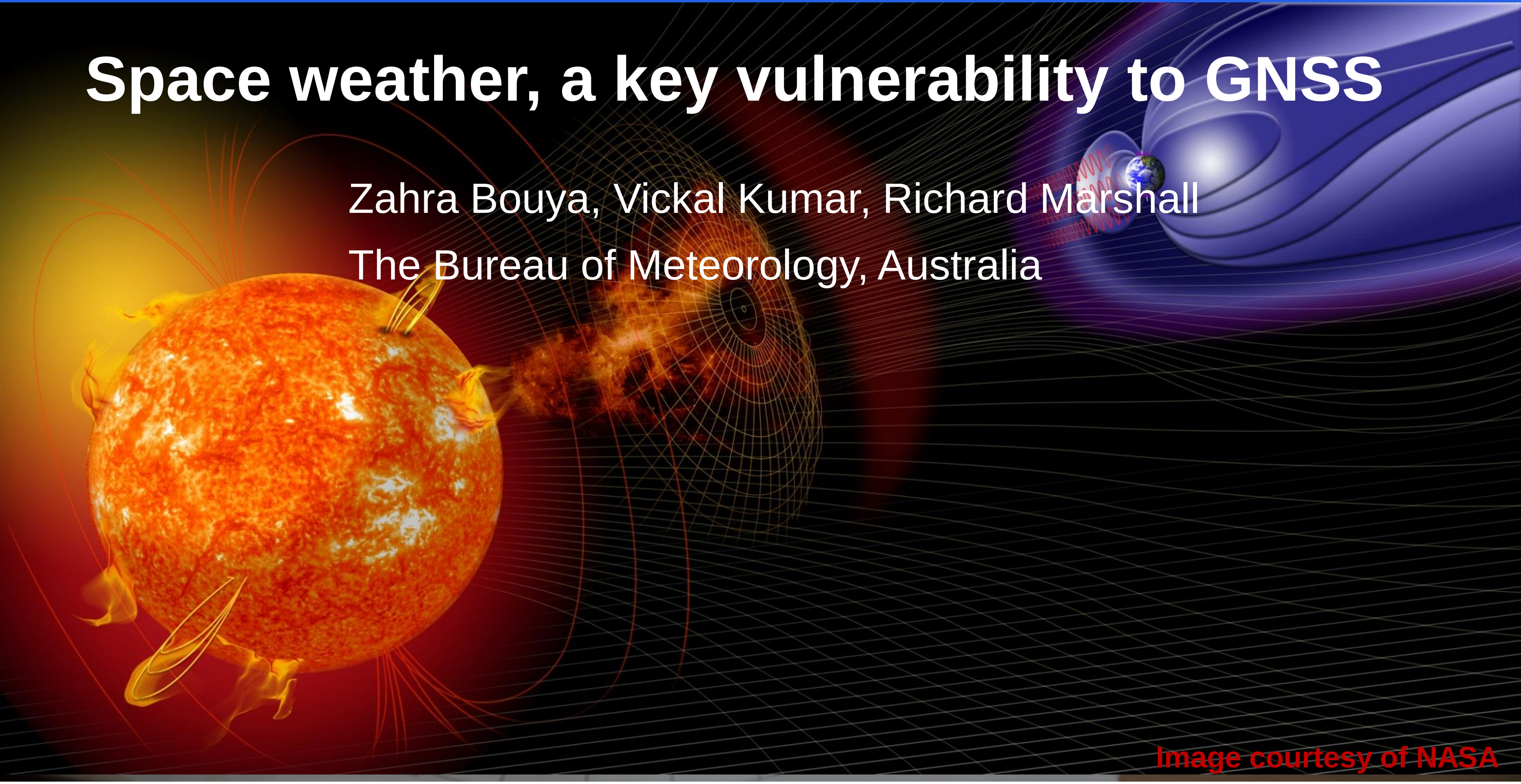


Image courtesy of NASA

Outline

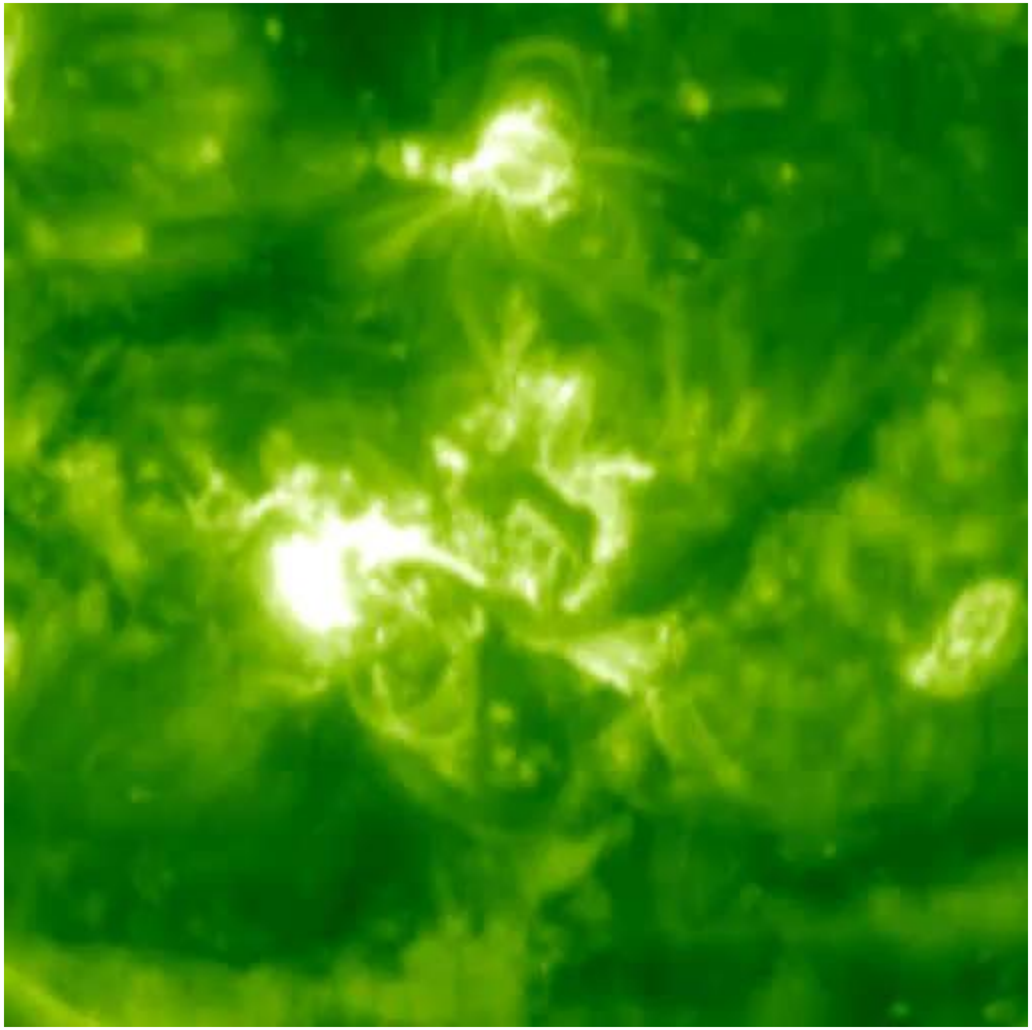
-Introduction: Space Weather effects on GNSS
-Ionospheric ranging error
-Ionospheric Scintillation
-Solar Radio Bursts
-Space Weather Forecasting Centre services
-The Bureau of Meteorology R2O activities

Introduction: GNSS users

Partial list:

- Aviation
- Maritime
- Agriculture
- Defence
- Mining
- Surveying, construction
- Land and mineral surveys, geophysics
- Science (ionospheric, timing, engineering)
- Natural resource management
- Managing the local environment
- Asset management
- Technology for motorists
- Recreation
- +++

Introduction: Space Weather effects on GNSS



Drivers of space weather

Electromagnetic Radiation
minutes

Particle Radiation
0.5 – several hours

Coronal Mass Ejections (CME)s
hours – days

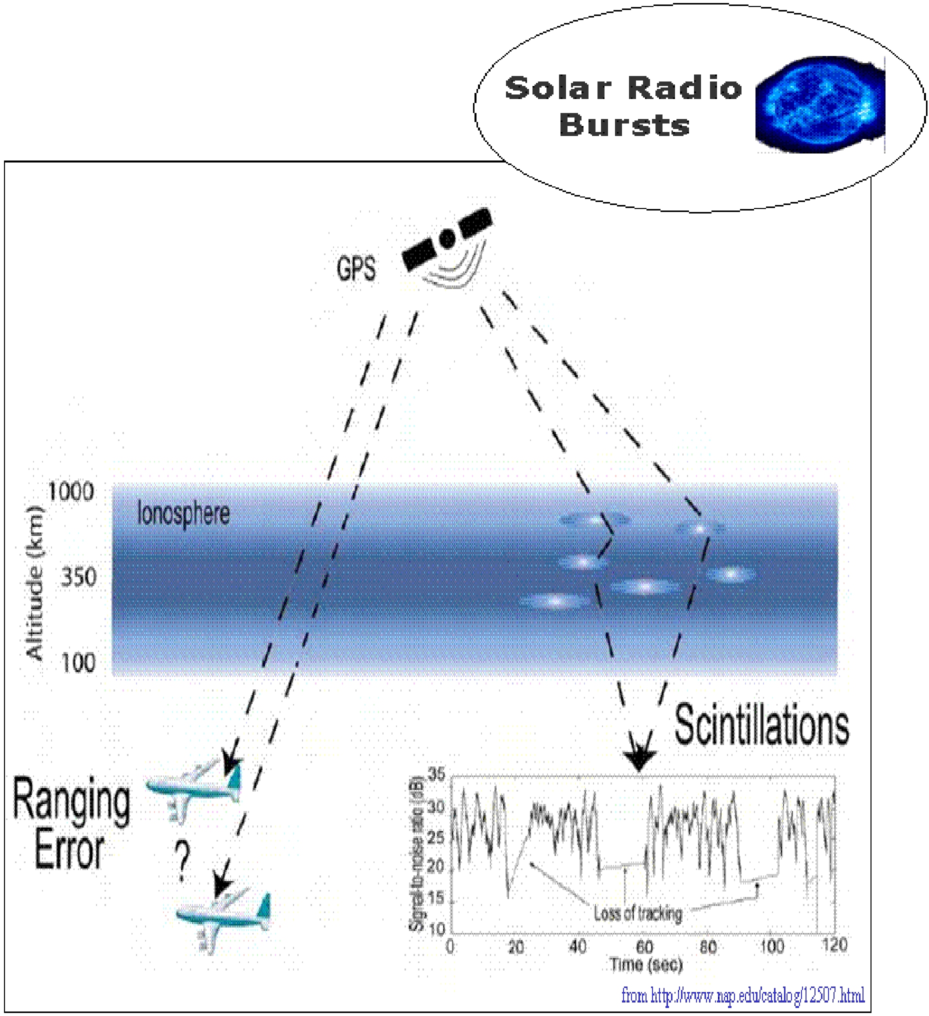
Introduction: Space Weather effects on GNSS

Three major space weather effects:

-Ionospheric ranging error / ionospheric delay

-Ionospheric scintillation

-Solar radio bursts



The ionosphere

Vertical structure:
D, E, F1 and F2 layers (F2 layer is the densest , ~ 350 km).

-Spatial variation:
~3 geographical regions / different behaviors.
(Equatorial/ low latitude, Mid-latitude ,Polar/high latitude)

-Temporal variations:
Closely connected to the solar activity
Short-scale disturbances:
(Ionospheric storms, Traveling ionospheric disturbances (TIDs)) .

-Ionosphere – forcing from above:

– Variations in solar flux

– Precipitation of particles from magnetosphere

– Electric fields from Solar Wind ←→ magnetosphere interaction

-Ionosphere – forcing from below:

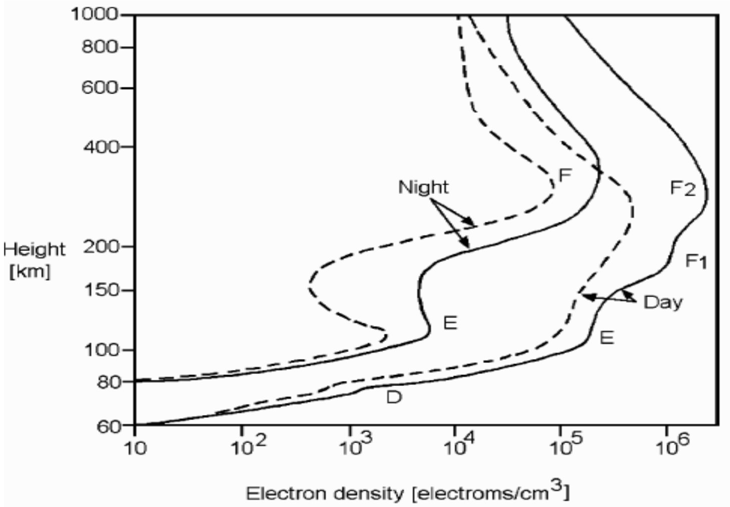
– Neutral atmospheric wave processes

-Effect on radio wave propagation (on various areas)

– Frequency-dependent delay in signal propagation through ionosphere

– Scintillation/frequency spread effects

Vertical profile of the ionosphere

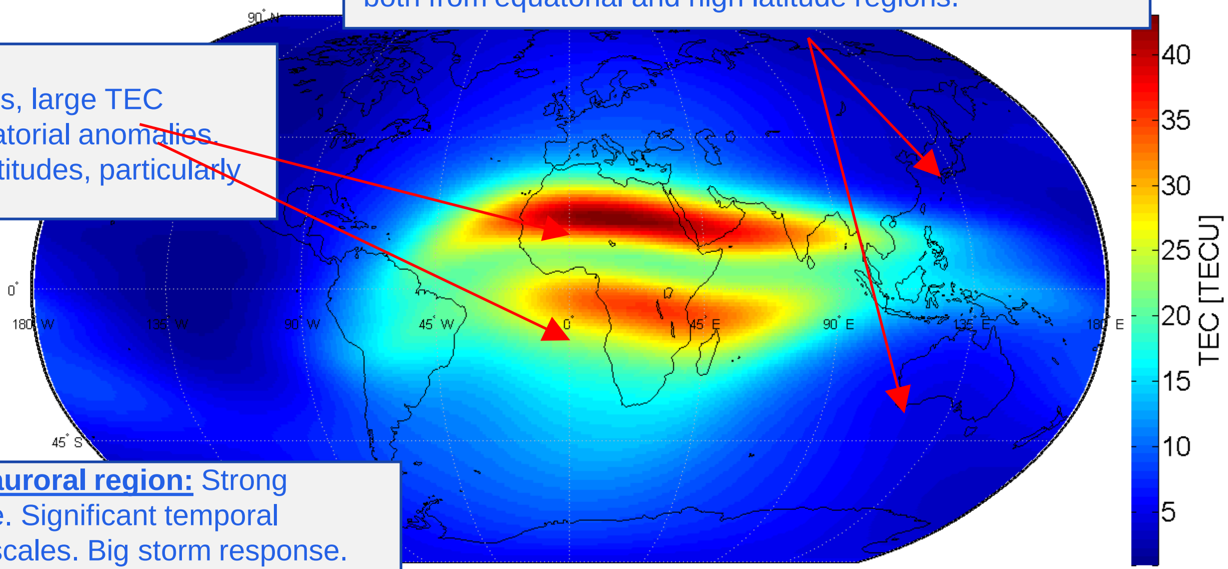


(Hargreaves, 1992)

Important latitude regimes for GNSS effects

Mid-latitude region:
Mostly smaller gradients, strong diurnal pattern, lower spatial and temporal variability. Affected by strong storms, both from equatorial and high latitude regions.

Low latitude/Equatorial region:
Ionospheric scintillation, plasma bubbles, large TEC gradients, equatorial fountain, sub-equatorial anomalies. Driver of disturbances impacting mid-latitudes, particularly during storm-time.



High-latitudes/auroral/sub-auroral region: Strong gradients around auroral zone. Significant temporal variability on a range of time scales. Big storm response. Driver of disturbances propagating to mid-latitudes, particularly during storm-time.

(Najman et al., 2014)

Ionospheric ranging error

Ionospheric delay error

-Ionosphere slows propagation. Additional delay ~ Total Electron Content (TEC) ~ ionospheric density

- Density in F-region ~ 350km altitude

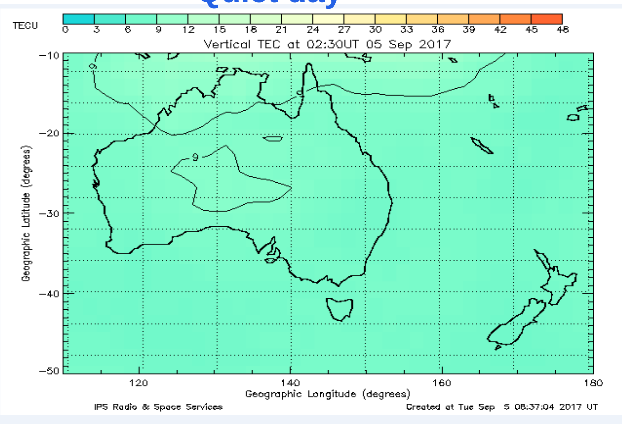
- To measure ionospheric delay unambiguously requires two phase coherent trans-ionospheric signals → dual frequency GPS observing L1 and L2 (1575MHz and 1227MHz resp.)

- Ionospheric delay estimated → can correct GPS satellite ranging data and improve positioning

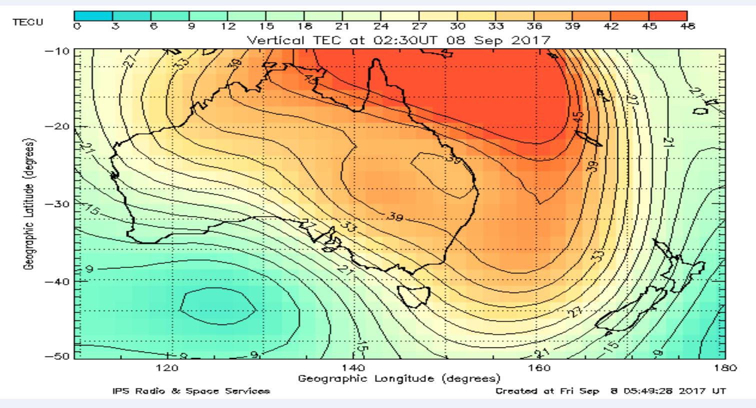
- Multiple techniques for estimating, mapping and applying ionospheric corrections

Morphology during a geomagnetic storm: September 2017

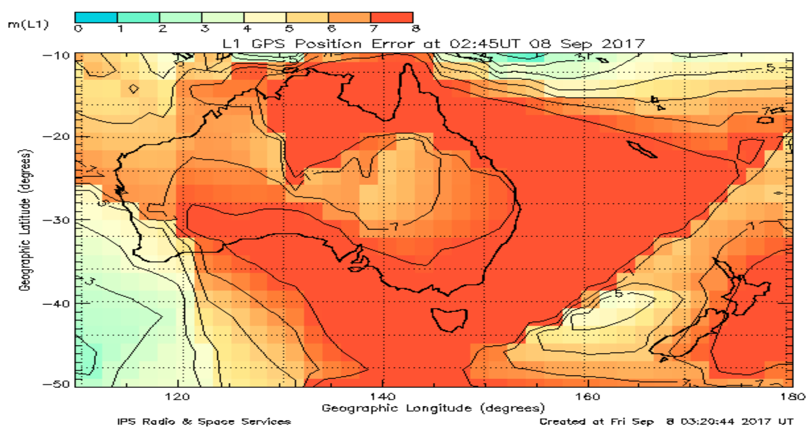
Quiet day



Storm day: Enhancement of excess of 30 TECU



GPS L1 Error plot shows errors up to 8 meters



Ionospheric ranging error

Spatial gradients

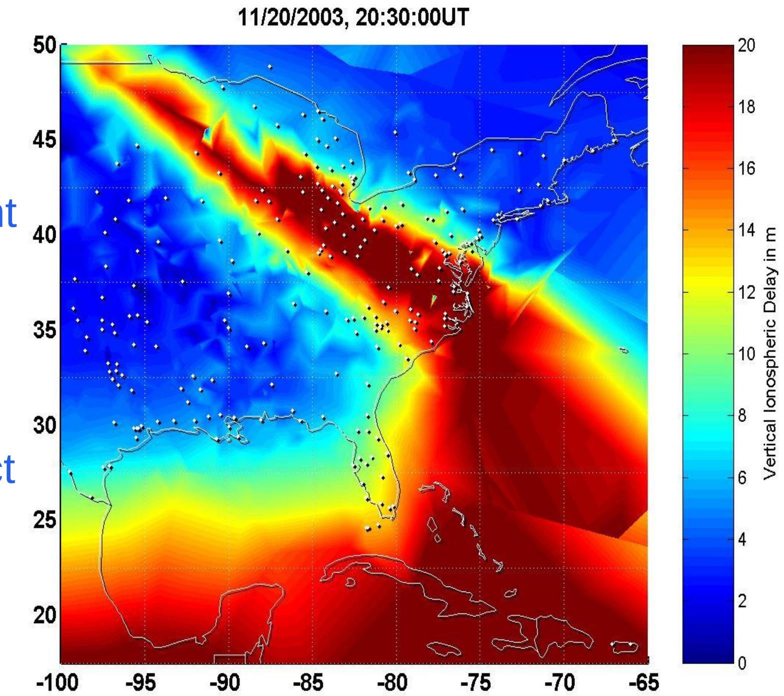
-Spatial gradients significant, especially near the equatorial regions, reducing the positioning accuracy

-Spatial de-correlation of ionospheric error component

-Reduces accuracy/availability of differential/augmentation systems

-Extreme space weather event, with significant impact on GNSS at mid latitudes

Extreme TEC gradients observed over the US during a major storm



(Ene et al., 2005, https://web.stanford.edu)

-The large gradients on the edge of the plume caused large errors in GPS augmentation systems, causing them to cease broadcasting corrections.

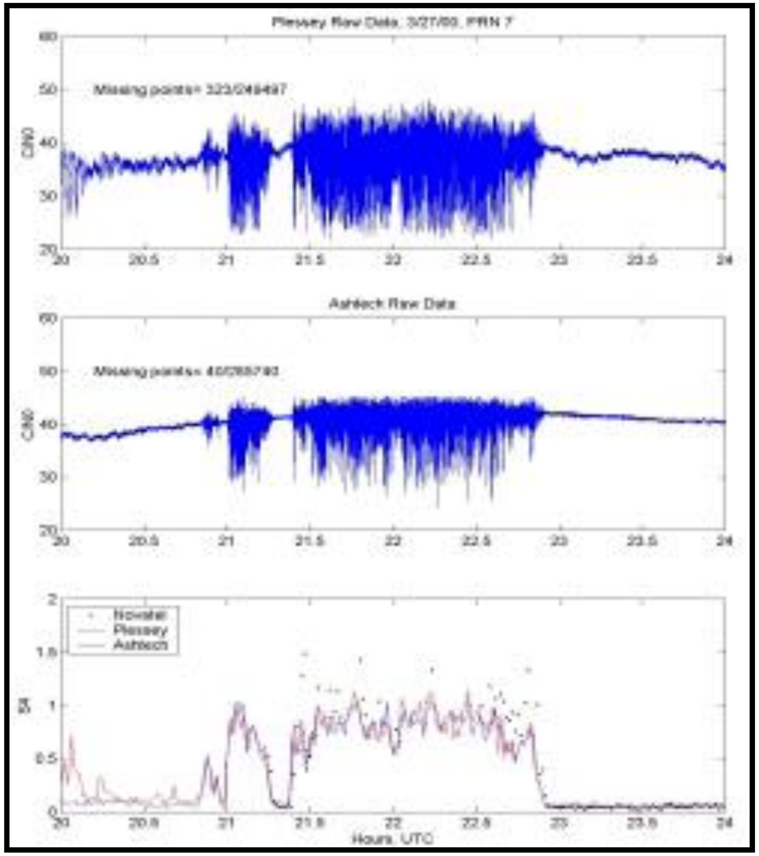
Ionospheric Scintillation

-Rapid fluctuations in phase and/or amplitude on GNSS signals

- Caused by small scale inhomogeneities in the ionosphere → diffraction screen effect

- Can be severe enough to cause loss of lock on one or more satellites, reducing positioning accuracy

- Clear geographic and diurnal pattern in climatology



(Groves et al., 2000)

Ionospheric Scintillation

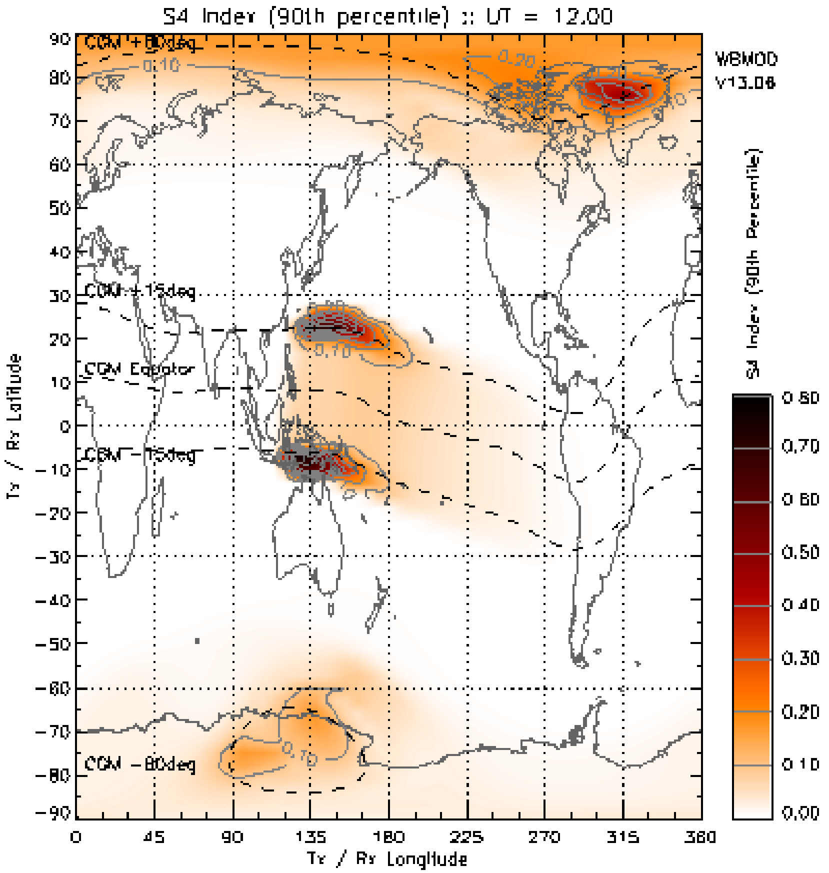
-Occur preferentially after dusk and before midnight

-Strongest scintillation occurs in two bands of latitude 5-15 degrees from the geomagnetic equator (sub-equatorial anomalies)

-Also, considerable scintillation at high latitudes

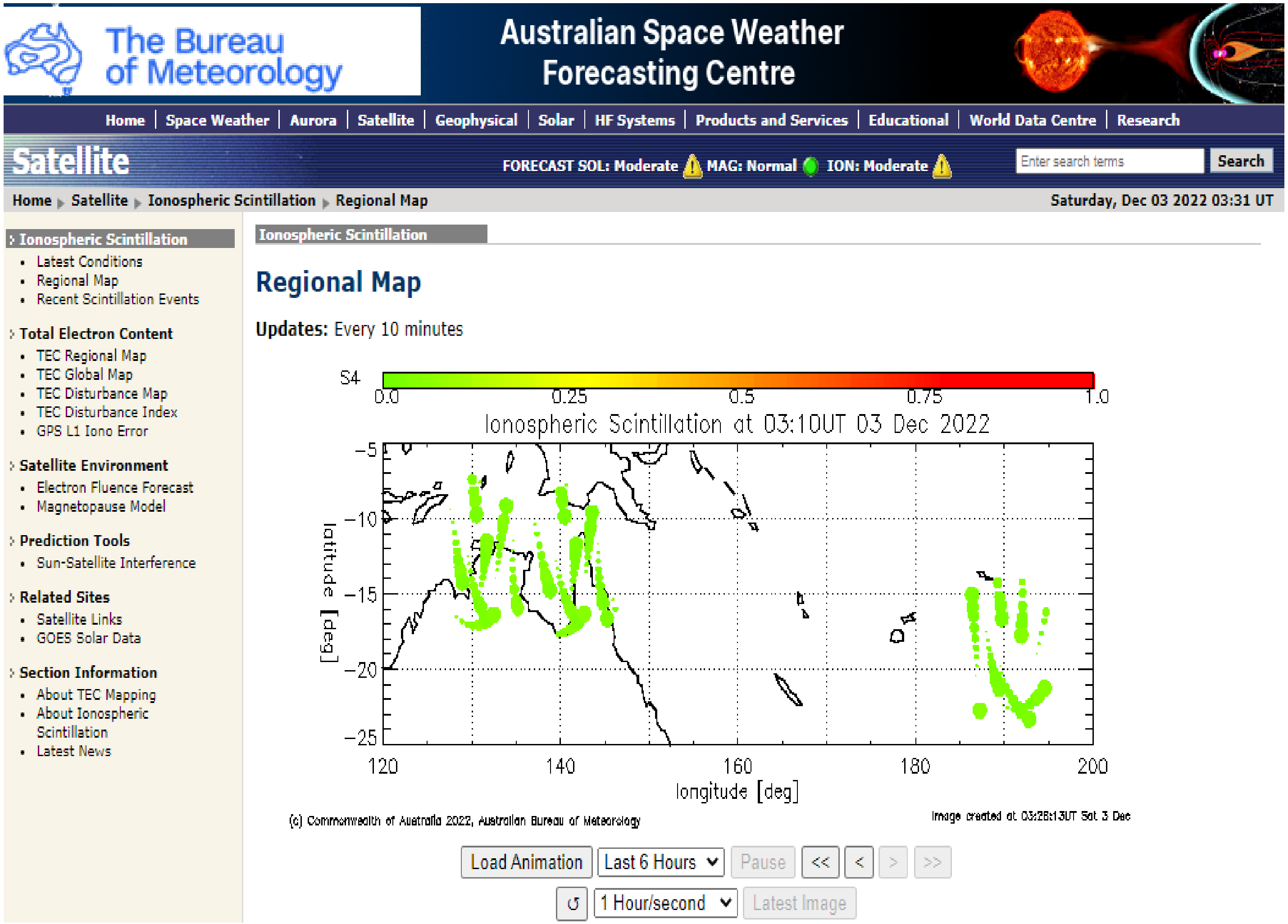
-Generally low levels of scintillation at mid latitudes although can at times be significant, especially for high phase sensitivity instruments

Geographic probability



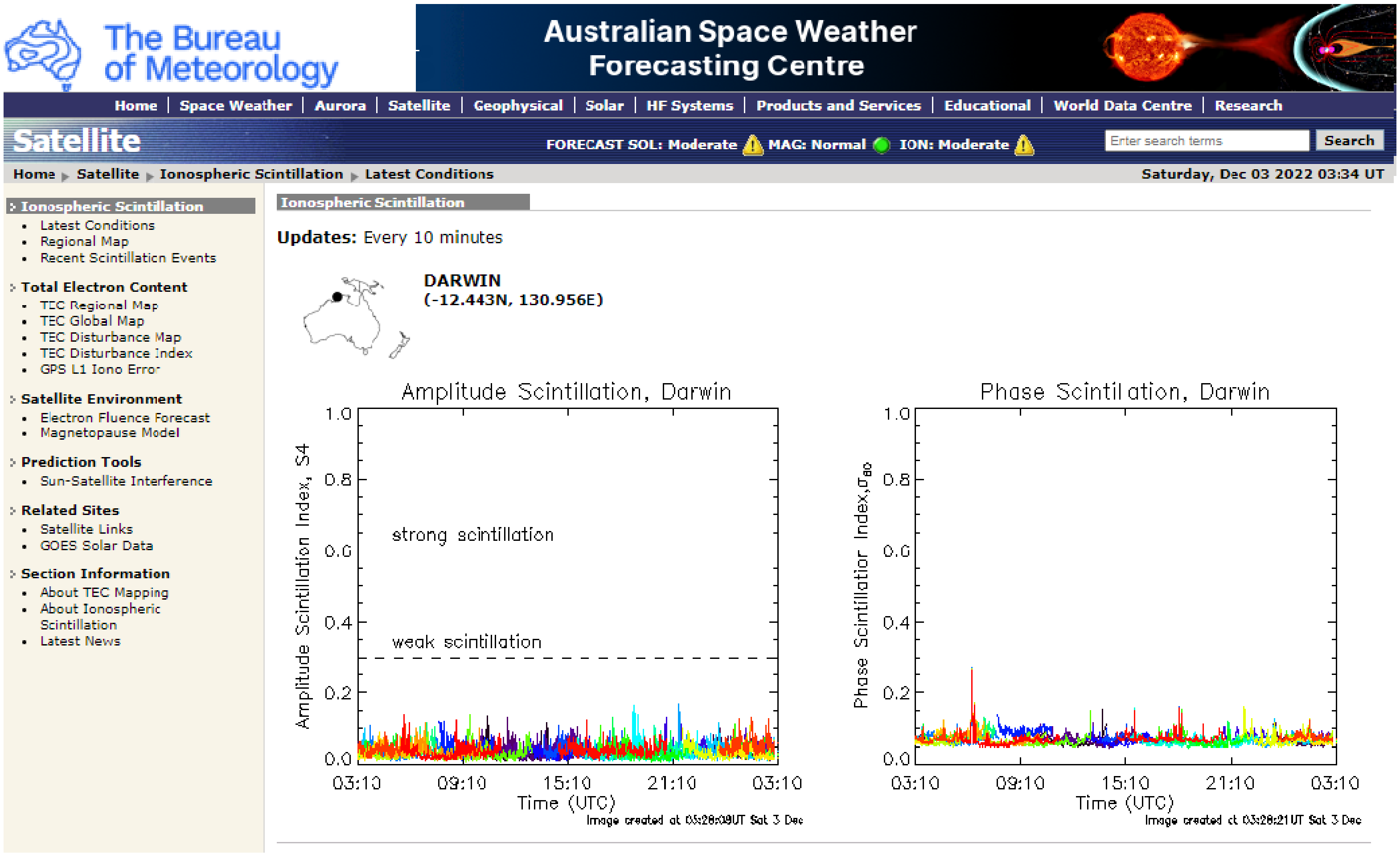
Ionospheric Scintillation

Regional map

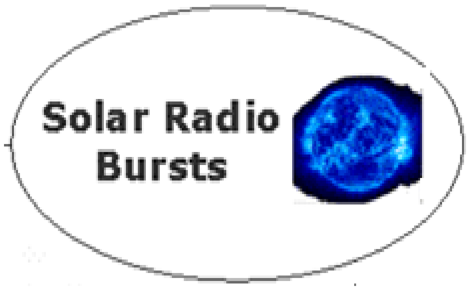


Ionospheric Scintillation

Latest ionospheric conditions



Solar Radio Bursts



-Radio burst from active region on sun, commonly associated with solar flares

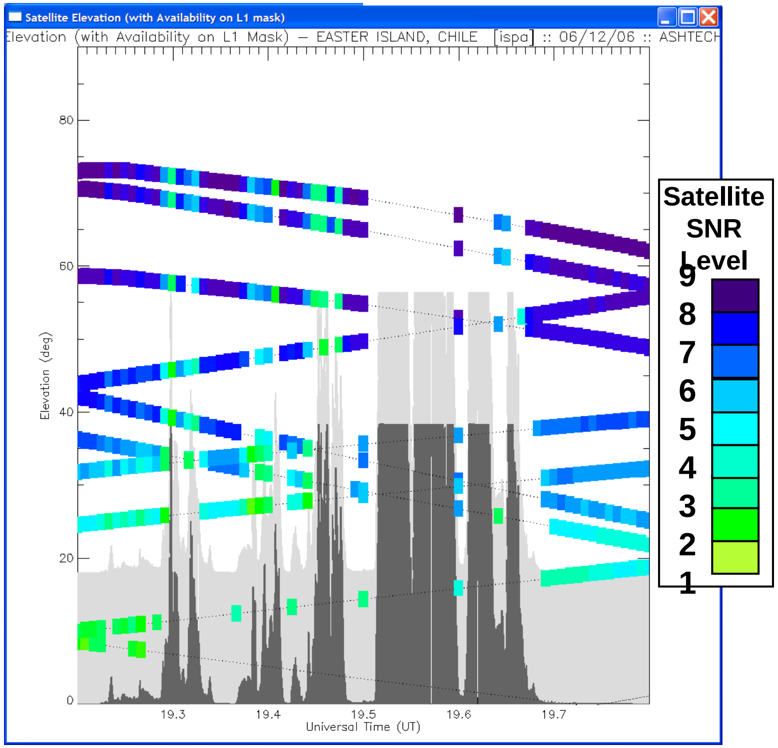
-Particularly bad when they have a spectral peak in the L-band, near GPS frequencies

-Act as interference source to GPS receivers

-Can cause loss of tracking on GPS satellites, particularly those at low elevation angles

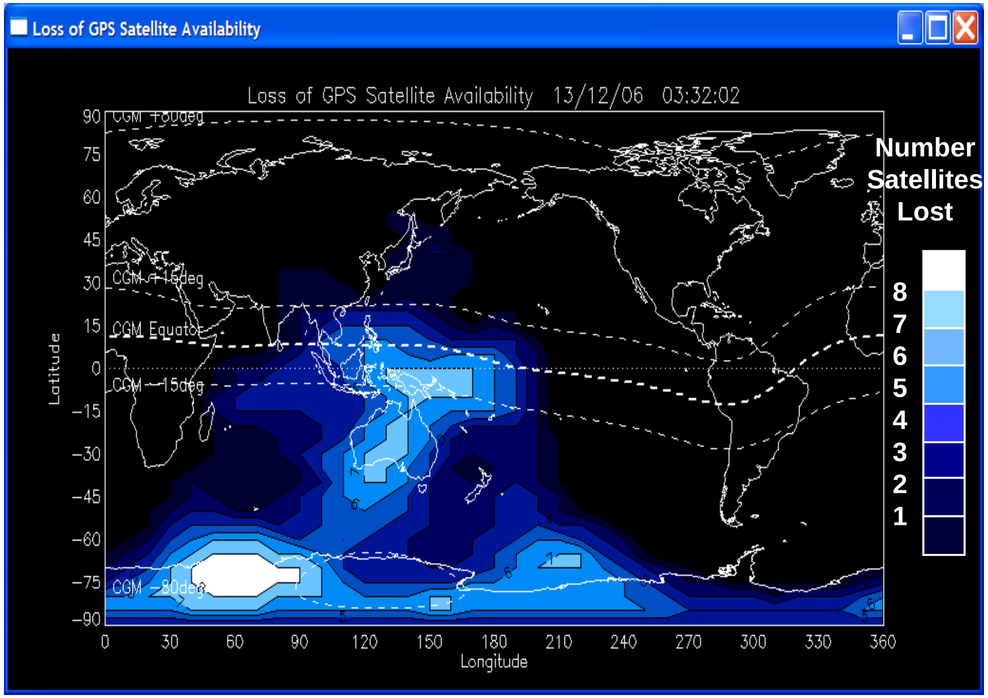
-Loss of navigation solution in extreme events

-Difficult to predict. Can "nowcast" only



Solar Radio Bursts

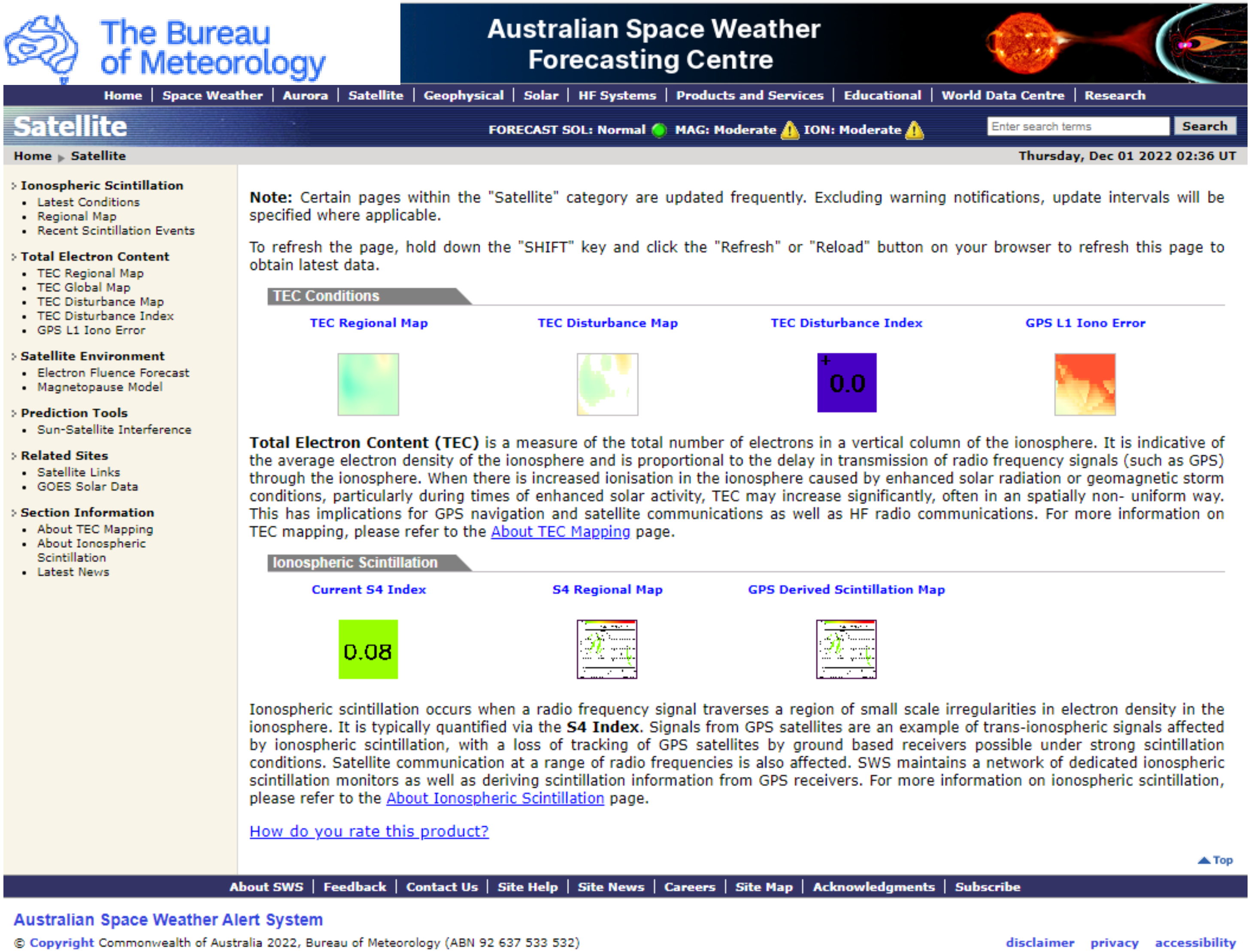
Solar Radio Burst Impact on GPS – 6 Dec 2006 ~10 minutes



Loss of GPS satellite availability

Space Weather Forecasting Centre services

https://www.sws.bom.gov.au


The Bureau of Meteorology

Australian Space Weather Forecasting Centre

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Satellite

FORECAST SOL: Normal MAG: Moderate ION: Moderate

Enter search terms Search

Home ▸ Satellite

Thursday, Dec 01 2022 02:36 UT

Ionospheric Scintillation
- Latest Conditions
- Regional Map
- Recent Scintillation Events

Total Electron Content
- TEC Regional Map
- TEC Global Map
- TEC Disturbance Map
- TEC Disturbance Index
- GPS L1 Iono Error

Satellite Environment
- Electron Fluence Forecast
- Magnetopause Model

Prediction Tools
- Sun-Satellite Interference

Related Sites
- Satellite Links
- GOES Solar Data

Section Information
- About TEC Mapping
- About Ionospheric Scintillation
- Latest News

Note: Certain pages within the "Satellite" category are updated frequently. Excluding warning notifications, update intervals will be specified where applicable.

To refresh the page, hold down the "SHIFT" key and click the "Refresh" or "Reload" button on your browser to refresh this page to obtain latest data.

TEC Conditions

TEC Regional Map | TEC Disturbance Map | TEC Disturbance Index | GPS L1 Iono Error

0.0

Total Electron Content (TEC) is a measure of the total number of electrons in a vertical column of the ionosphere. It is indicative of the average electron density of the ionosphere and is proportional to the delay in transmission of radio frequency signals (such as GPS) through the ionosphere. When there is increased ionisation in the ionosphere caused by enhanced solar radiation or geomagnetic storm conditions, particularly during times of enhanced solar activity, TEC may increase significantly, often in an spatially non- uniform way. This has implications for GPS navigation and satellite communications as well as HF radio communications. For more information on TEC mapping, please refer to the About TEC Mapping page.

Ionospheric Scintillation

Current S4 Index | S4 Regional Map | GPS Derived Scintillation Map

0.08

Ionospheric scintillation occurs when a radio frequency signal traverses a region of small scale irregularities in electron density in the ionosphere. It is typically quantified via the **S4 Index**. Signals from GPS satellites are an example of trans-ionospheric signals affected by ionospheric scintillation, with a loss of tracking of GPS satellites by ground based receivers possible under strong scintillation conditions. Satellite communication at a range of radio frequencies is also affected. SWS maintains a network of dedicated ionospheric scintillation monitors as well as deriving scintillation information from GPS receivers. For more information on ionospheric scintillation, please refer to the About Ionospheric Scintillation page.

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Australian Space Weather Alert System

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The Bureau of Meteorology R2O activities

-Probabilistic solar flare forecast ML model	**Operational**
-Severe Space Weather Watch model supporting decision making in the Space Weather Forecasting Centre	**Operational**
-Regional Total Electron Content model	**Operational**
-Regional scintillation underpinning alerts	**Operational**
-Ionospheric Scintillation forecast model bridging observations gaps and latency issues	**Prototype / under development**
-Global 3D ionospheric and forecast model for global HF Communications and GNSS	**Under development**

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Thank you

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