GBAS Ionospheric threat evaluation in the mid-latitude Australian region

Analysis, results and recommendations

Workshop on Ionospheric Data Collection, Analysis and Sharing

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May 2011

Outline

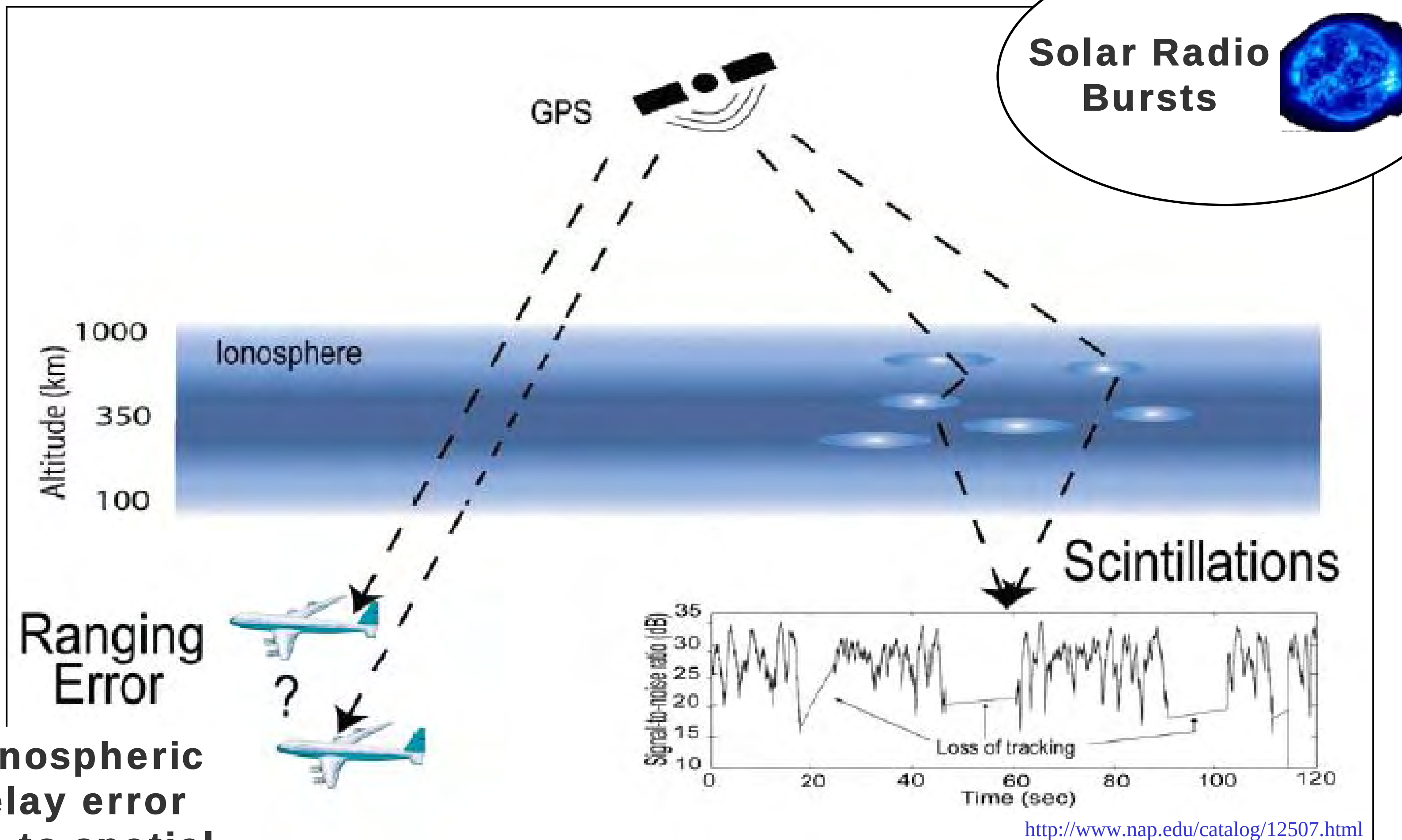
- Ionospheric Prediction Service (IPS)
- Recap: Challenges for GBAS posed by the ionosphere
- GBAS Iono threat model evaluation for Australia
  - Scope of study
  - Results of analysis
  - Assumptions, limitations, recommendations
- Lessons learned from threat model evaluation
- Ionospheric data sources
- Future directions in ionospheric modelling

Ionospheric Prediction Service (IPS)

- Formed in 1949
- Originally concerned mostly with HF communication
- Now within Australian Bureau of Meteorology
- Today, HF customer base still very important but many other ‘space weather’ customers
- Perform consultancies as well as providing general space weather services and products
- Australian Space Forecast Centre (ASFC) and real time website: http://www.ips.gov.au
- Daily S/W bulletin, web and email/SMS alerts

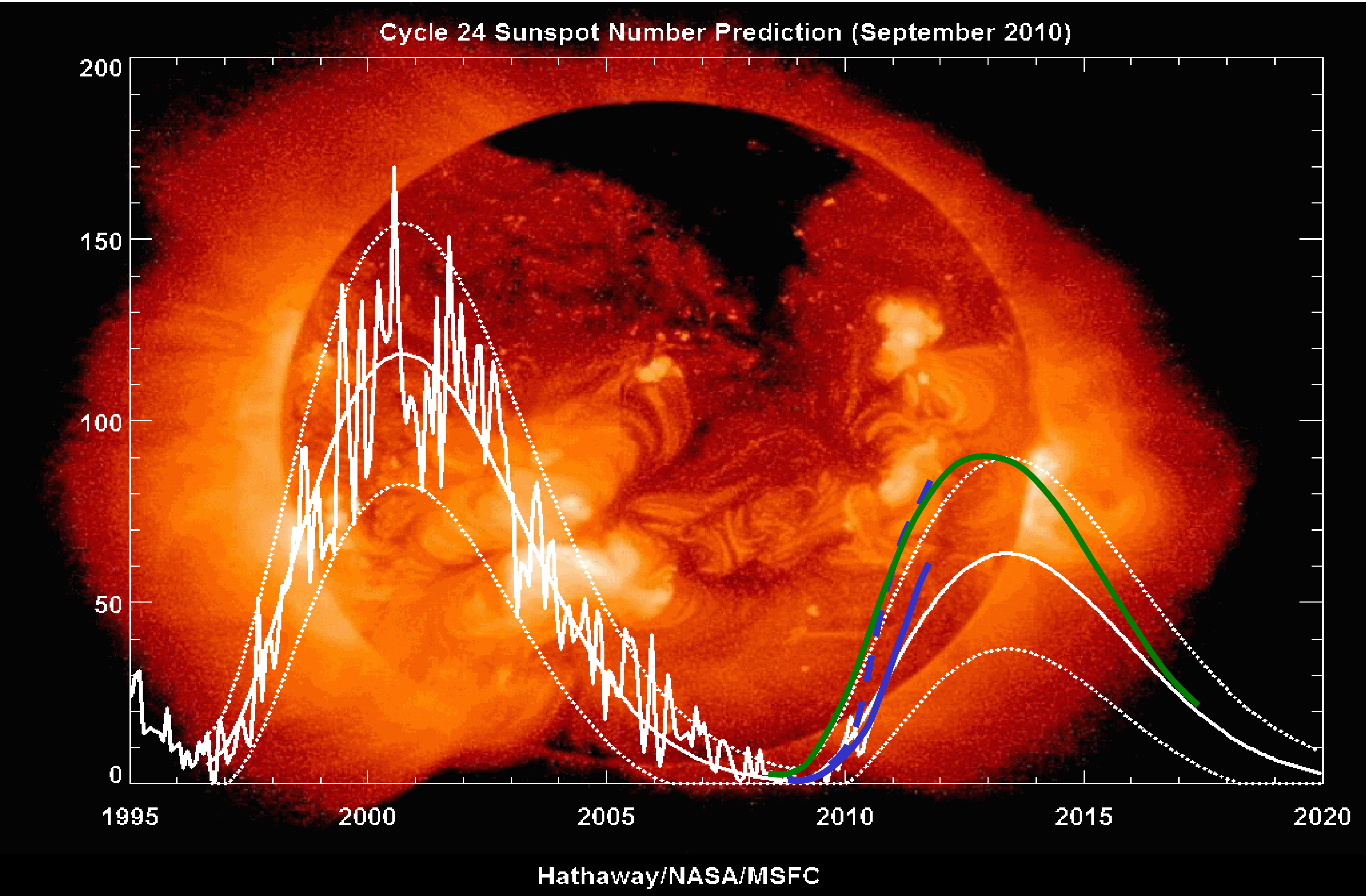
Ionospheric effects on GPS augmentation

Solar Radio Bursts

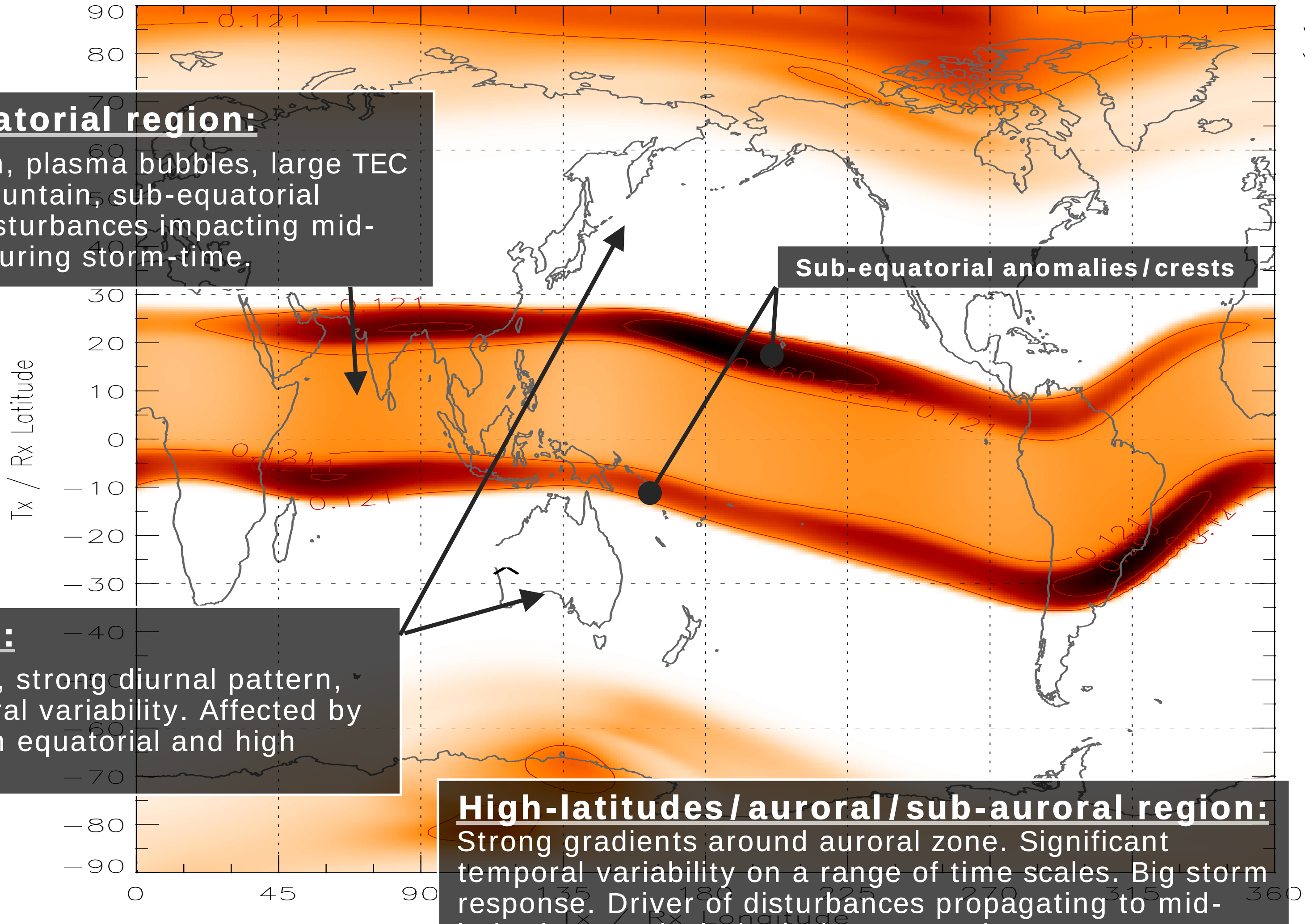


(ionospheric delay error due to spatial gradients)

The solar cycle



Important latitude regimes for GPS effects



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.

Sub-equatorial anomalies / crests

Mid-latitude region:

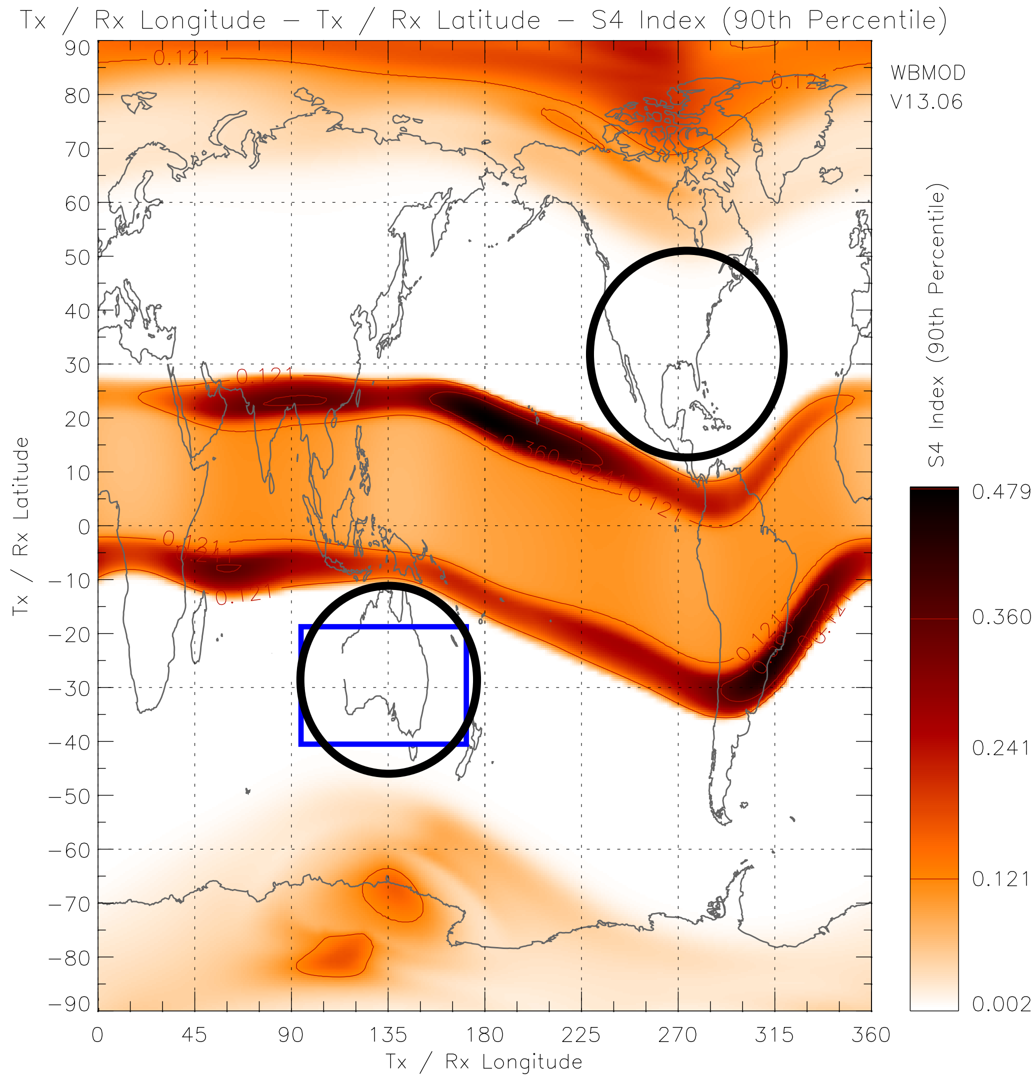
Mostly smaller gradients, strong diurnal pattern, lower spatial and temporal variability. Affected by strong storms, both from equatorial and high latitude regions.

High-latitudes / auroral / sub-auroral region:

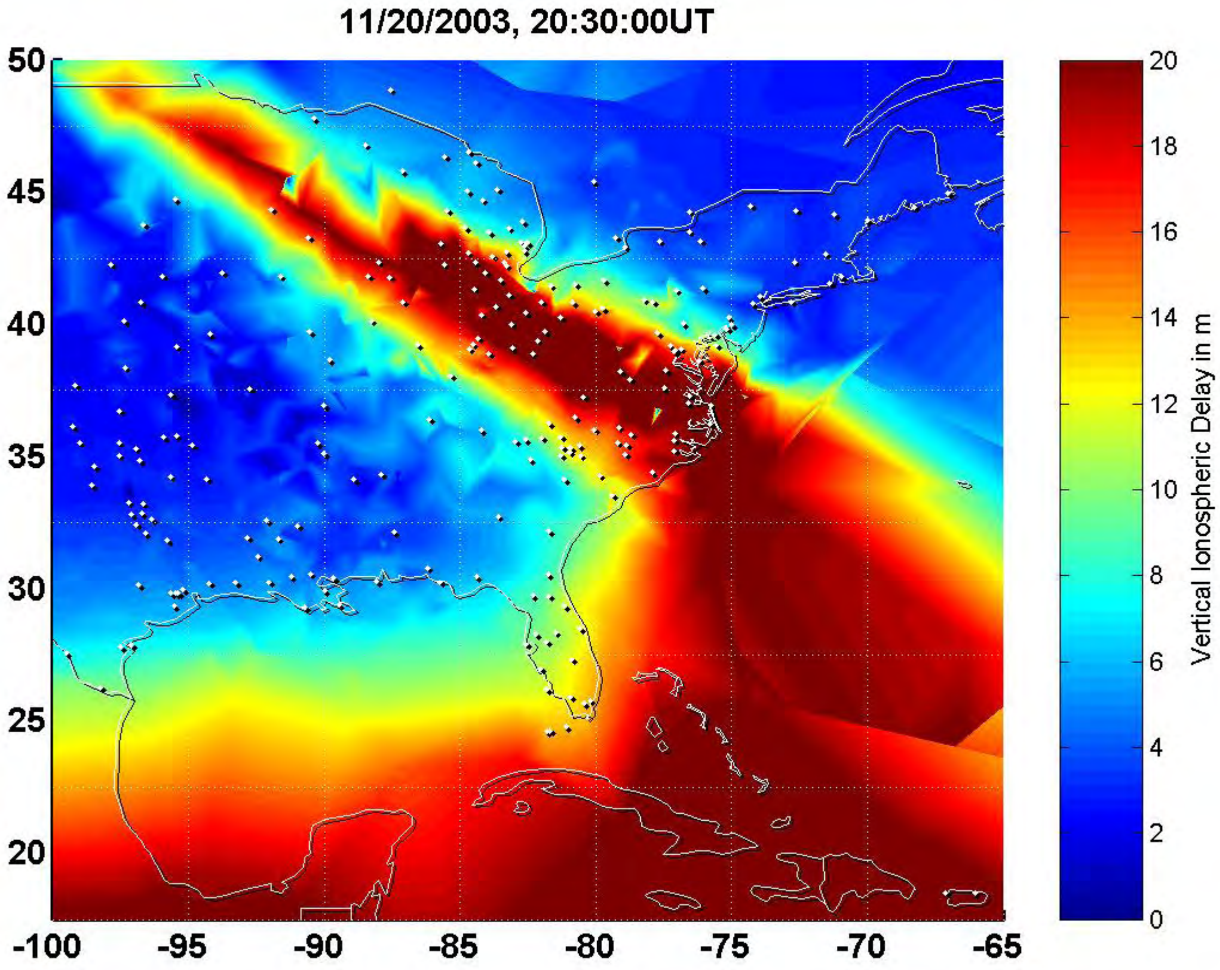
Strong gradients around auroral zone. Significant temporal variability on a range of time scales. Big storm response. Driver of disturbances propagating to mid-latitudes, particularly during storm-time.

The Australian Ionosphere

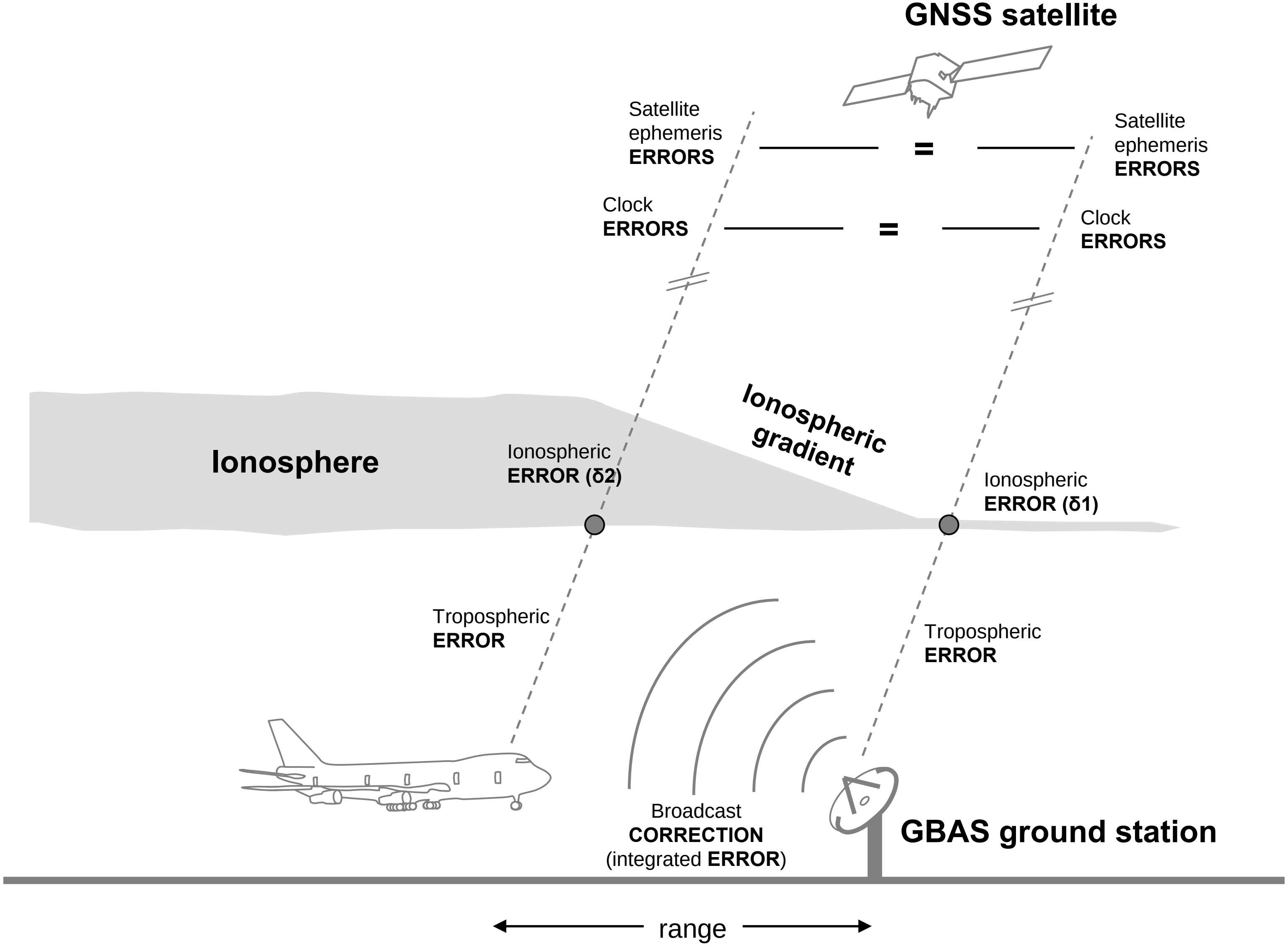
- Predominantly ‘benign’ mid-latitudes
- Under storm conditions, influenced by both equatorial and auroral physics
- Study restricted to latitude range -40° < lat < -20° reflecting both data availability and ionospheric physics



Anomalous Ionospheric gradients in CONUS

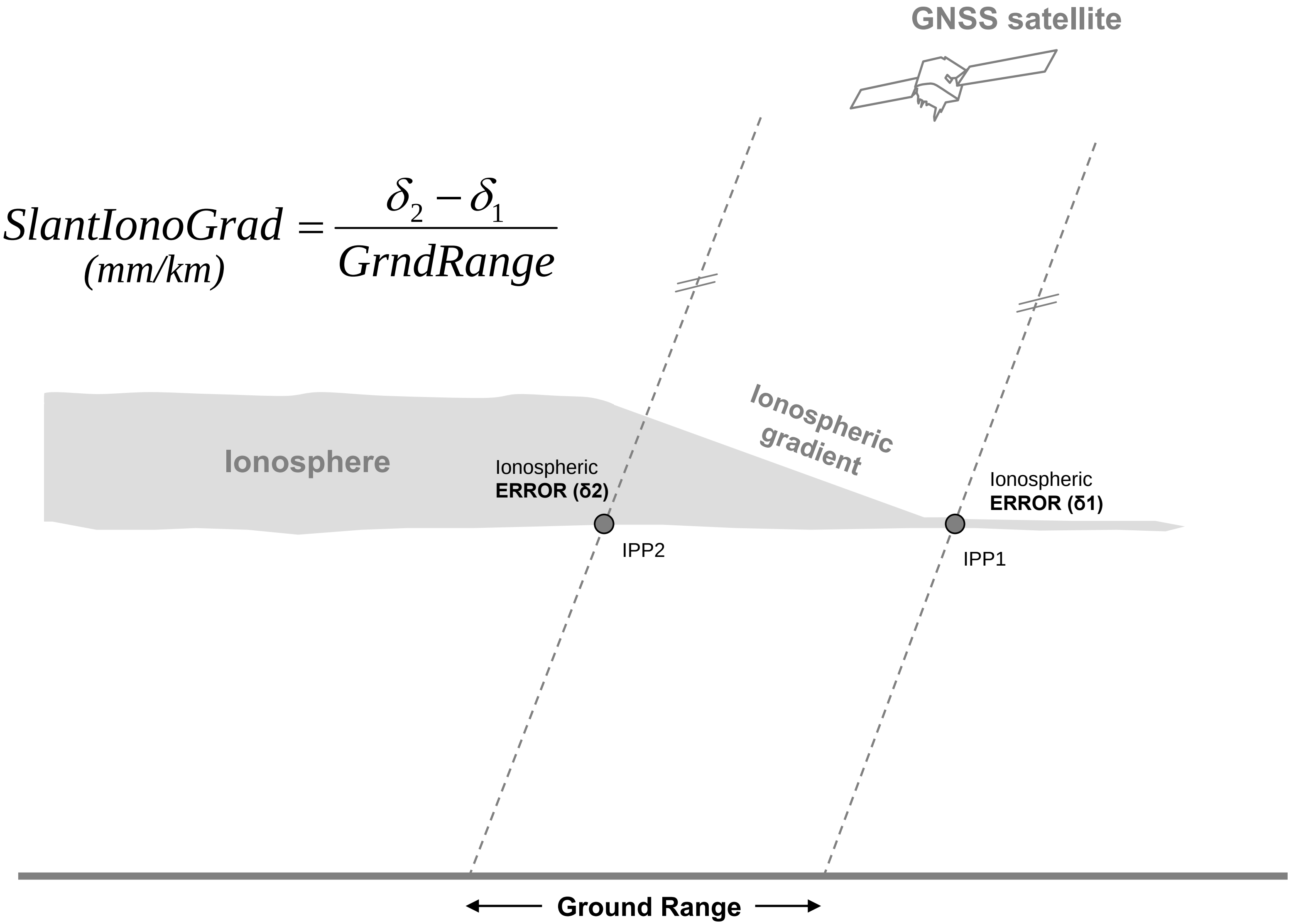


Decorrelation of ionospheric error



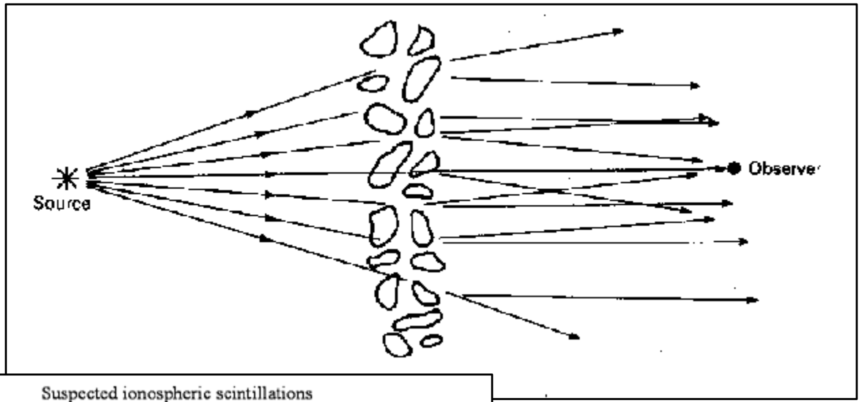
Slant ionospheric gradient

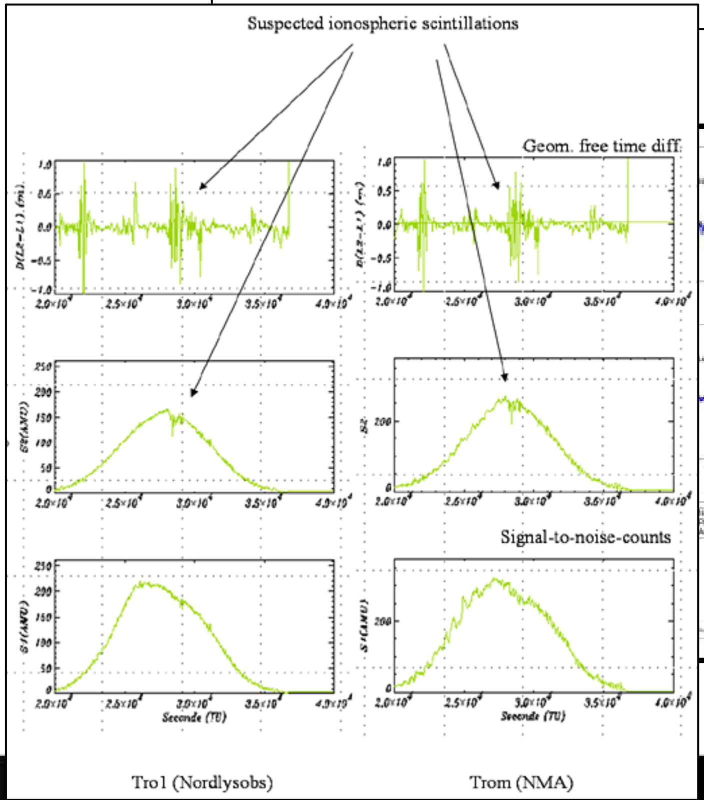
$$\underset{(mm/km)}{SlantIonoGrad} = \frac{\delta_2 - \delta_1}{GrndRange}$$



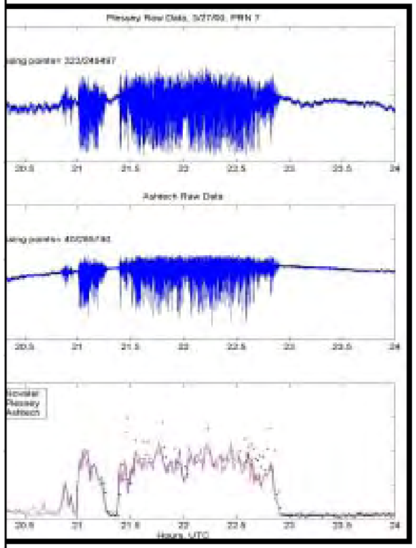
Ionospheric Scintillation

- Rapid fluctuations in phase and/or amplitude on GPS 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 GPS satellites, reducing positioning accuracy
- Clear geographic and diurnal pattern in climatology, closely tied to the occurrence of plasma bubbles





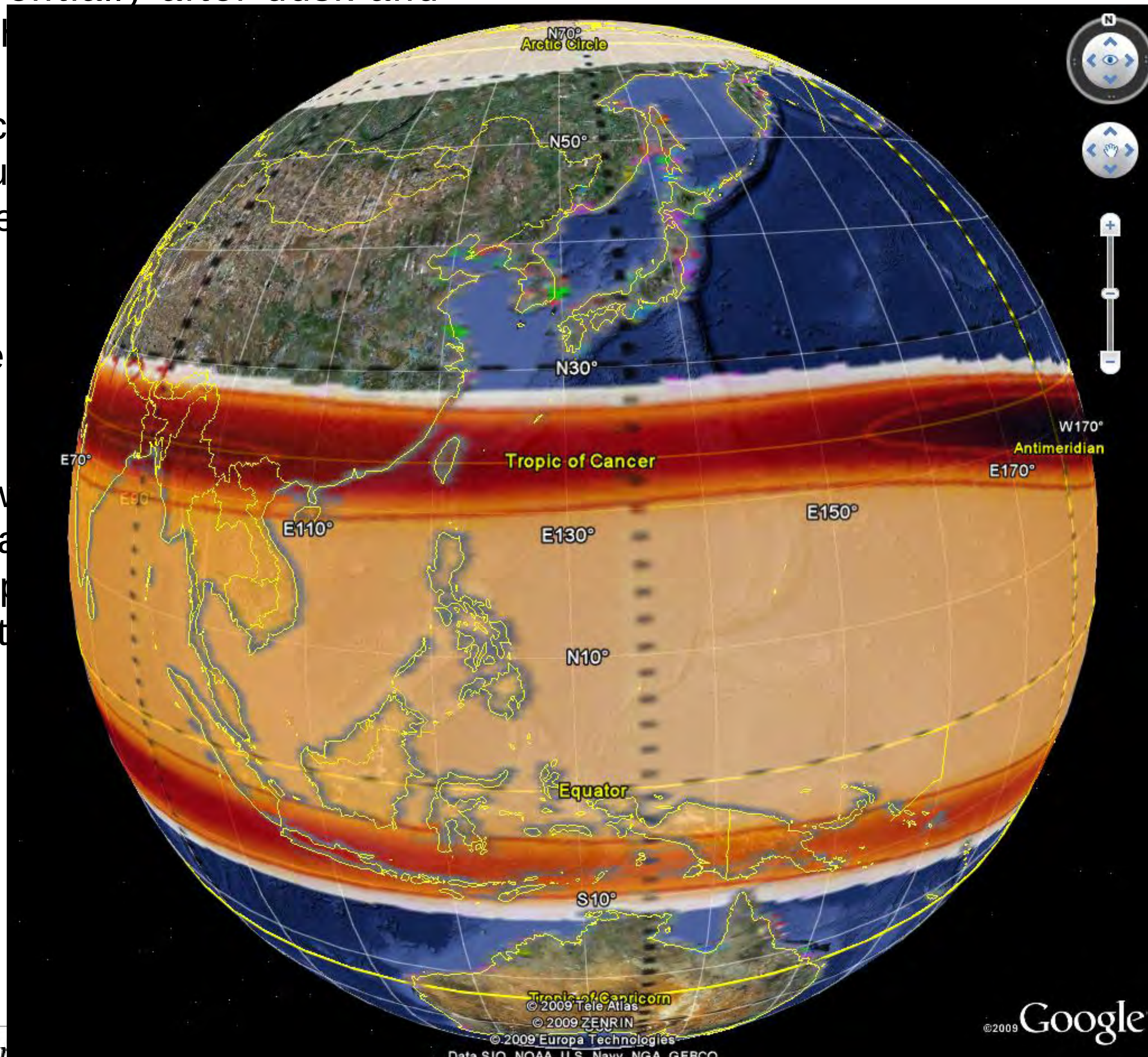
http://scintillations.cls.fr/images/faq/tromsoe.gif

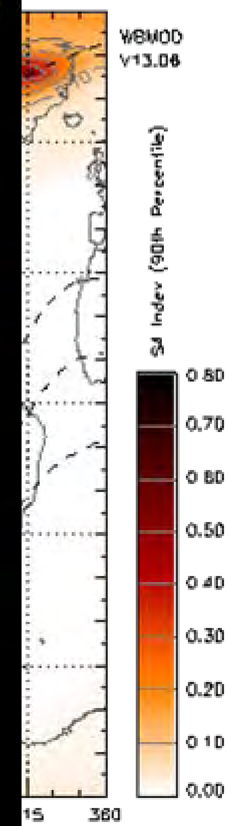


Groves et al (2000)

Ionospheric Scintillation – geographic probability

- Occur preferentially after dusk and before midnigh
- Strongest sc bands of latitu geomagnetic e anomlies)
- Also conside latitudes
- Generally lov mid latitudes a significant, esp sensitivity inst telescopes)





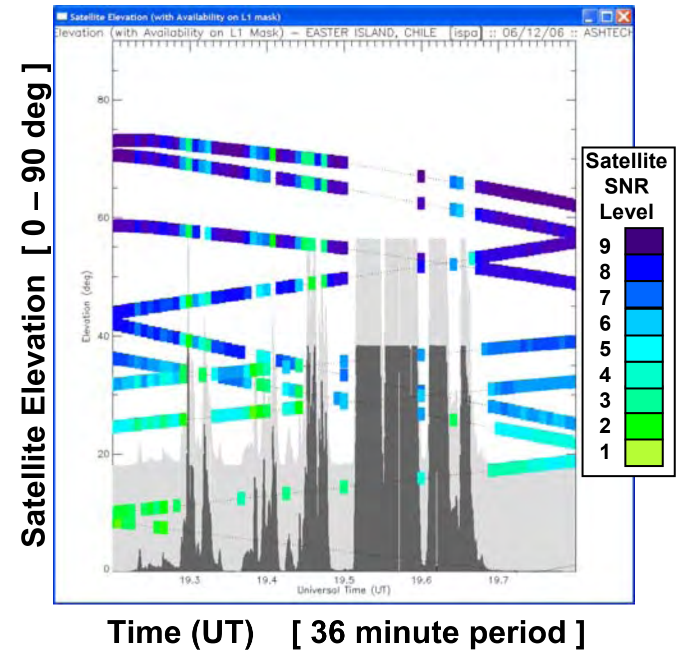
Solar radio bursts

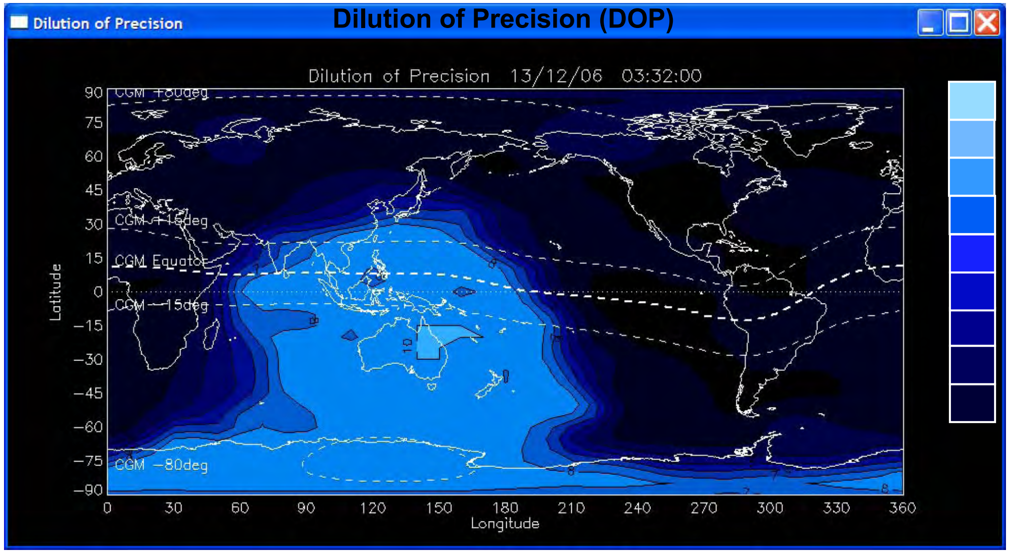
Occur during solar active conditions

Can have strong spectral peaks near the GPS L-band frequencies and thus act as a noise source to GPS receivers in the sunlit hemisphere

Result in reduced SNR for GNSS satellite tracking with potential for loss of lock on one or multiple satellites for affected receivers

Resultant GPS Dilution Of Precision (DOP)

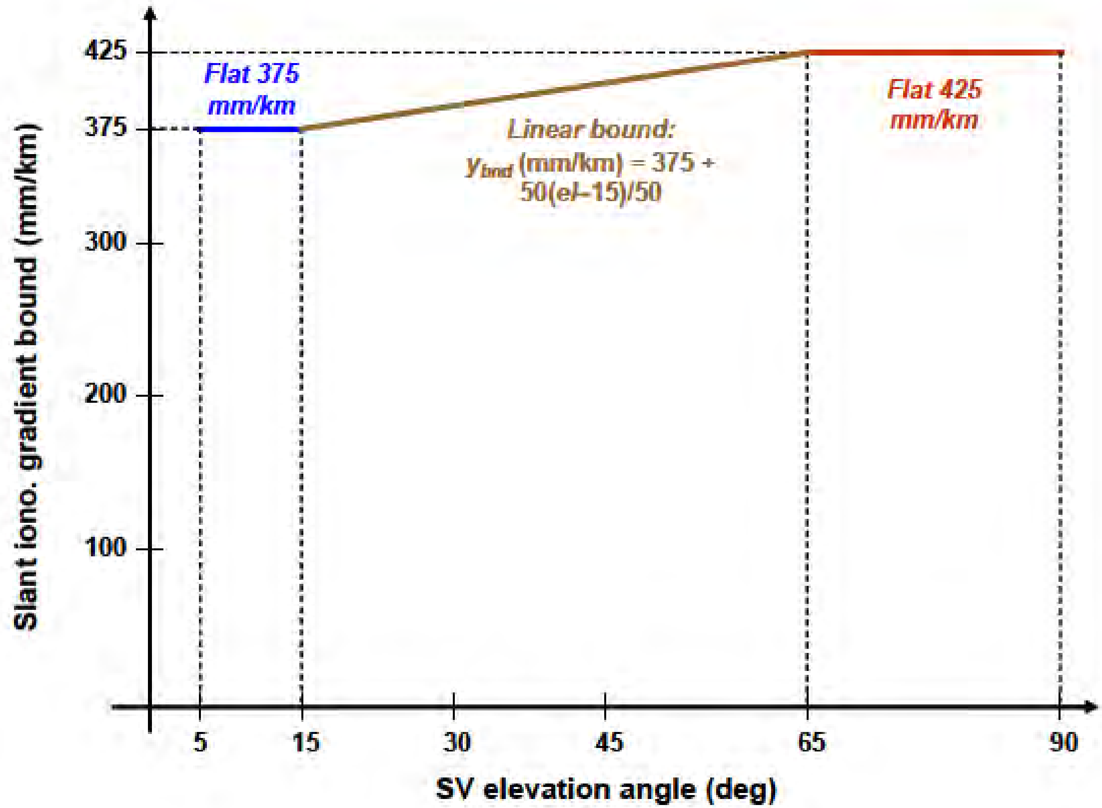




GBAS iono threat model

Simplified ionospheric threat model included in the (CONUS certified) Smartpath design for GBAS (Honewell ECM 10023, 2010)

Specifies threat only in terms of ionospheric spatial gradients



2. Methodology

- Storm identification - positive phase geomagnetic 'superstorms'
- Data sourcing - dual frequency GPS RINEX data from all available short and long baseline regional CORS networks
- Network evaluation - capacity of networks to detect ionospheric gradients based on network geometry
- Data pre-processing - standard GNSS algorithms
- Identification of potential high gradient regions
- Auto-processing for large gradient events
- Manual vetting
- Gradient analysis
- Context of existing ionospheric threat model

Follows original GBAS iono threat analysis

Storm candidate identification

- Major geomagnetic storms list (Kp > 8)
- Restriction to positive phase storms in Aus. longitude sector only (using onset time of storm and independent ionospheric observations)
- Reduced list of 8 storms since 2000

7. Ionospheric Storm Analysis

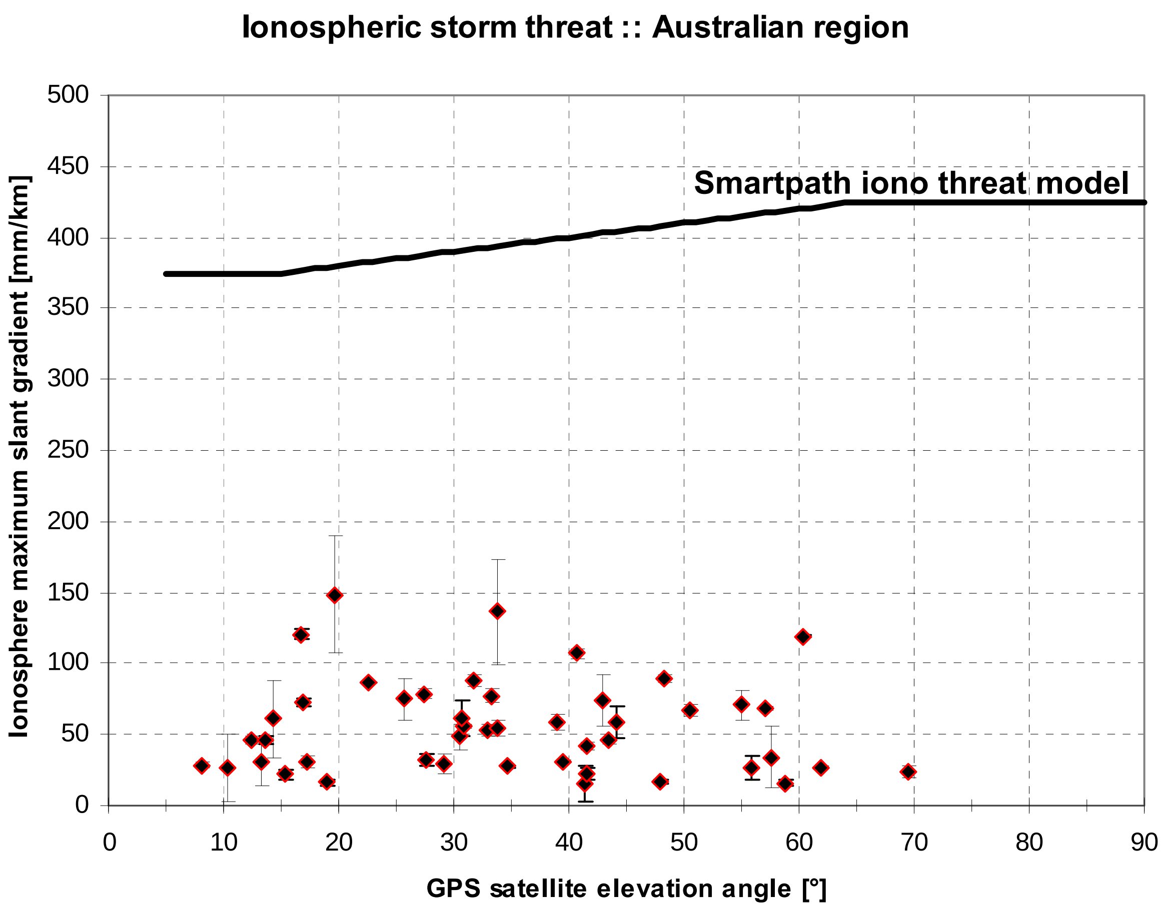


Figure 7-2. Anomalous ionospheric gradient parameters of ionospheric storms in the Australian region in context of the final (Smartpath) GBAS ionospheric threat model. The upper boundary of the threat model is indicated by the solid black line. All observations fall well within the bounds of the threat model

Data for ionospheric characterisation

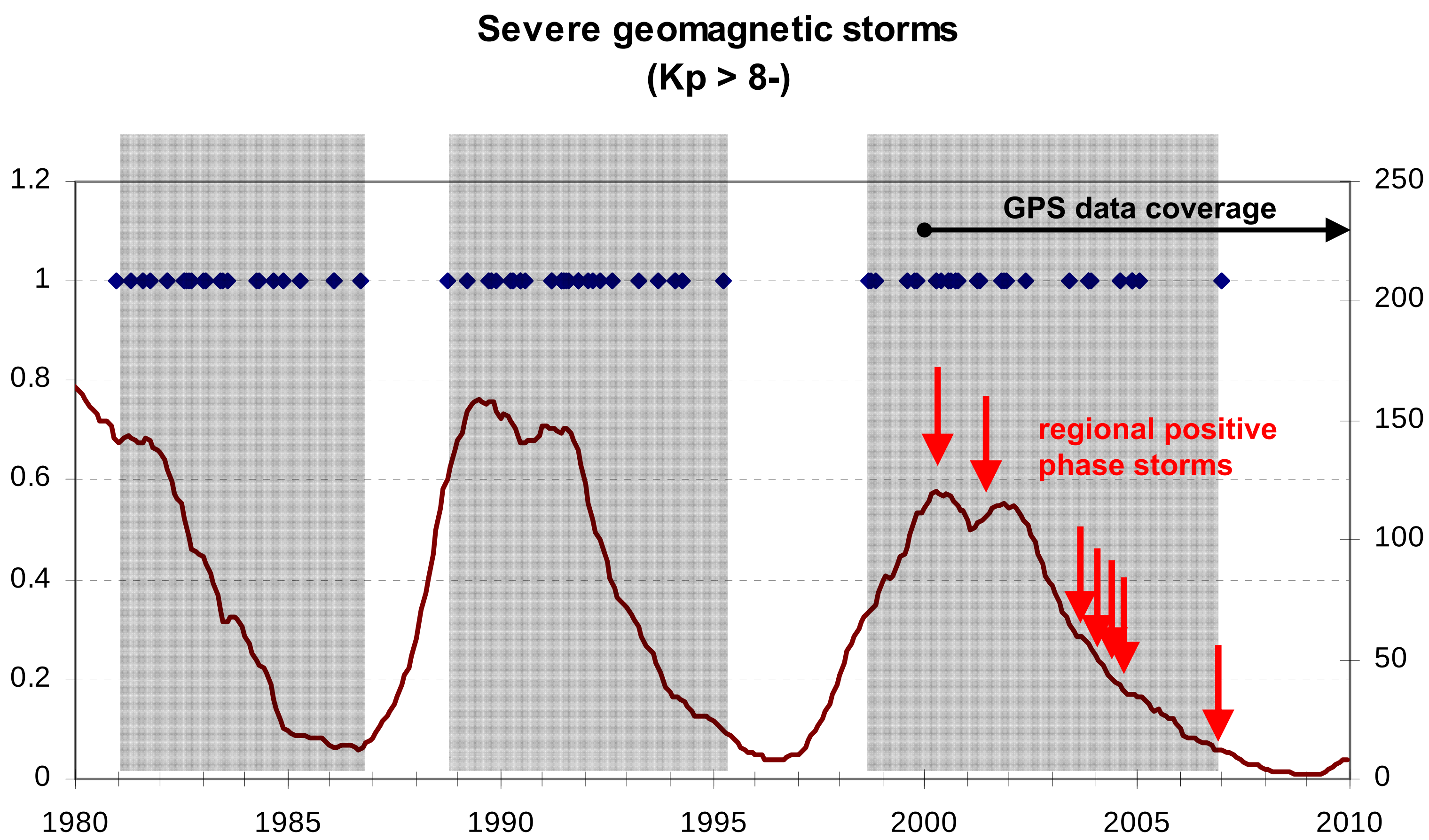
What data is required?

From when?

How much?

Data specifics? (sampling rates, network geometries)

Severe GM storms – looking back



Data for ionospheric characterisation

GNSS data sourcing:

- Requirement for historical data covering the largest ionospheric storms of the previous solar cycle

- Sufficient short baseline GNSS network geometry to enable detection of the full spectrum of ionospheric gradients

- High resolution (1-2s) data

Data for ionospheric characterisation

GNSS data sourcing:

– Standard RINEX data format

– Ionospheric scintillation (ISM or derived from >1Hz GNSS and use of ROTI, DROTI, or comparable parameter)

GNSS Data Sources

- Australia dual frequency GPS (CORS) networks

  - Geoscience Australia (ARGN, SPRGN)
  - Victorian Department of Sustainability and Environment (GPSnet)
  - Queensland Department of Environment and Resource Management (SunPOZ)
  - Landgate, Western Australia
  - National Measurement Institute, Sydney
  - IPS Radio & Space Services, Bureau of Meteorology
  - International GNSS Service (IGS)
  - Land Information New Zealand (PositioNZ)
  - [NSW CORSnet]

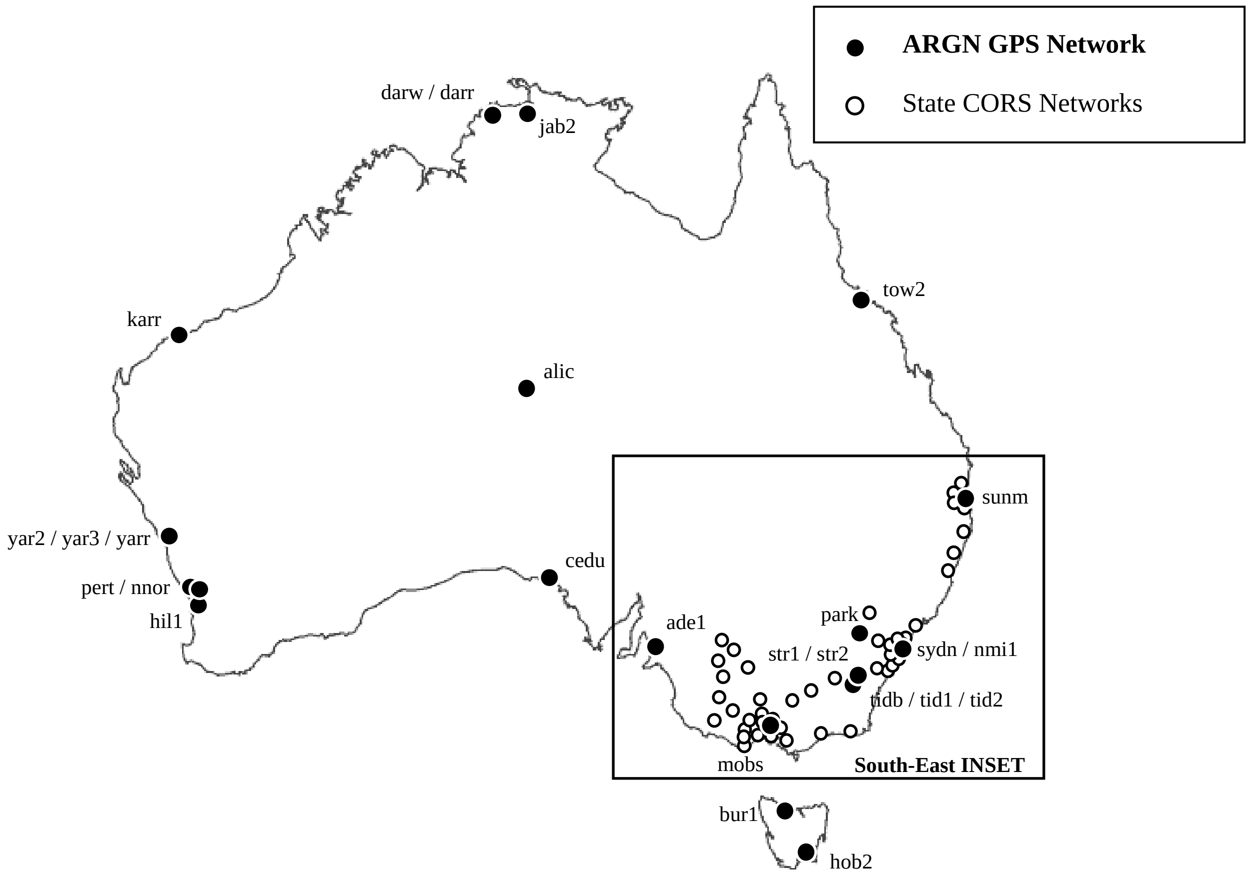
Network Geometry

- GPS data limitations in Australia

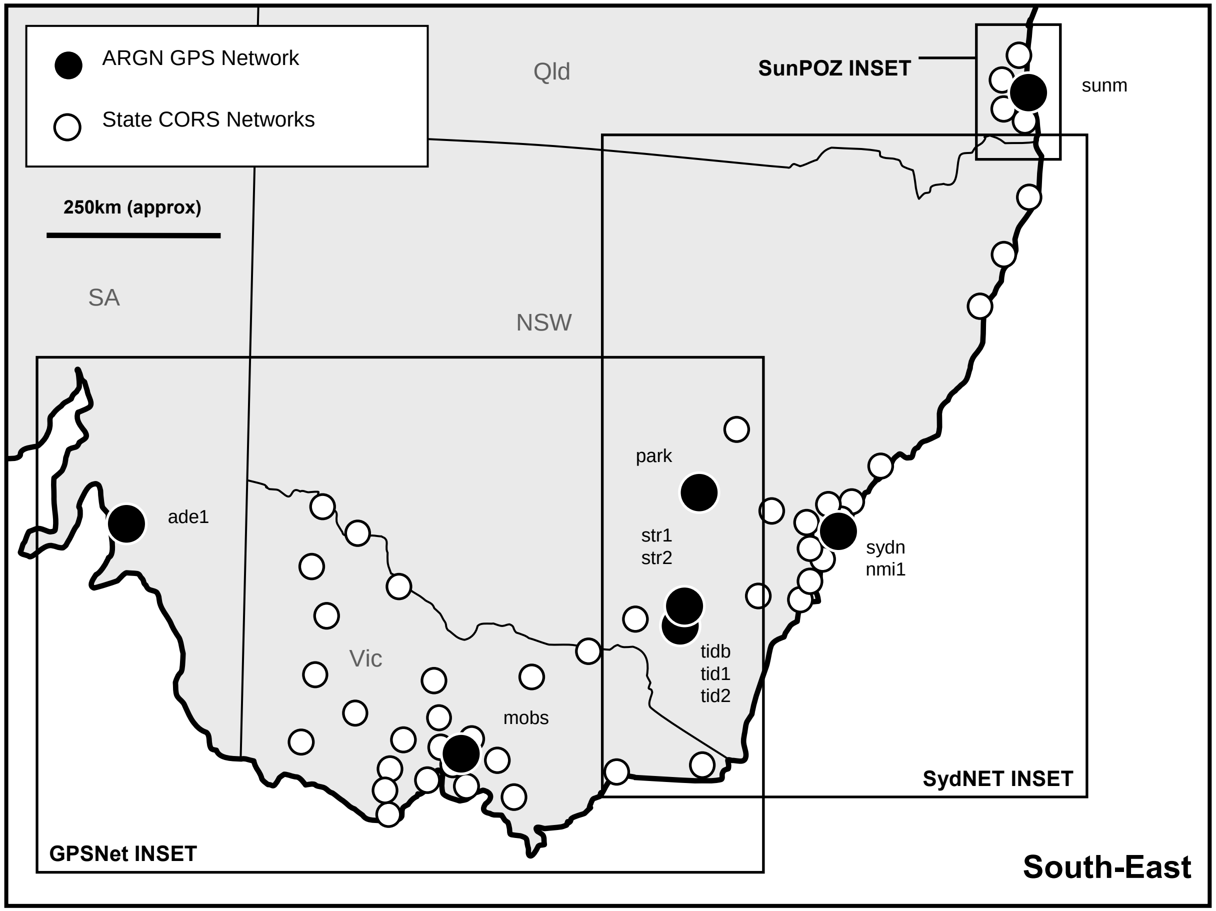
→greater emphasis on evaluating capacity of individual networks and network combinations to detect ionospheric gradients in present study

→Analyse distribution of inter-station spacings and network geometry to confirm gradient detection capacity

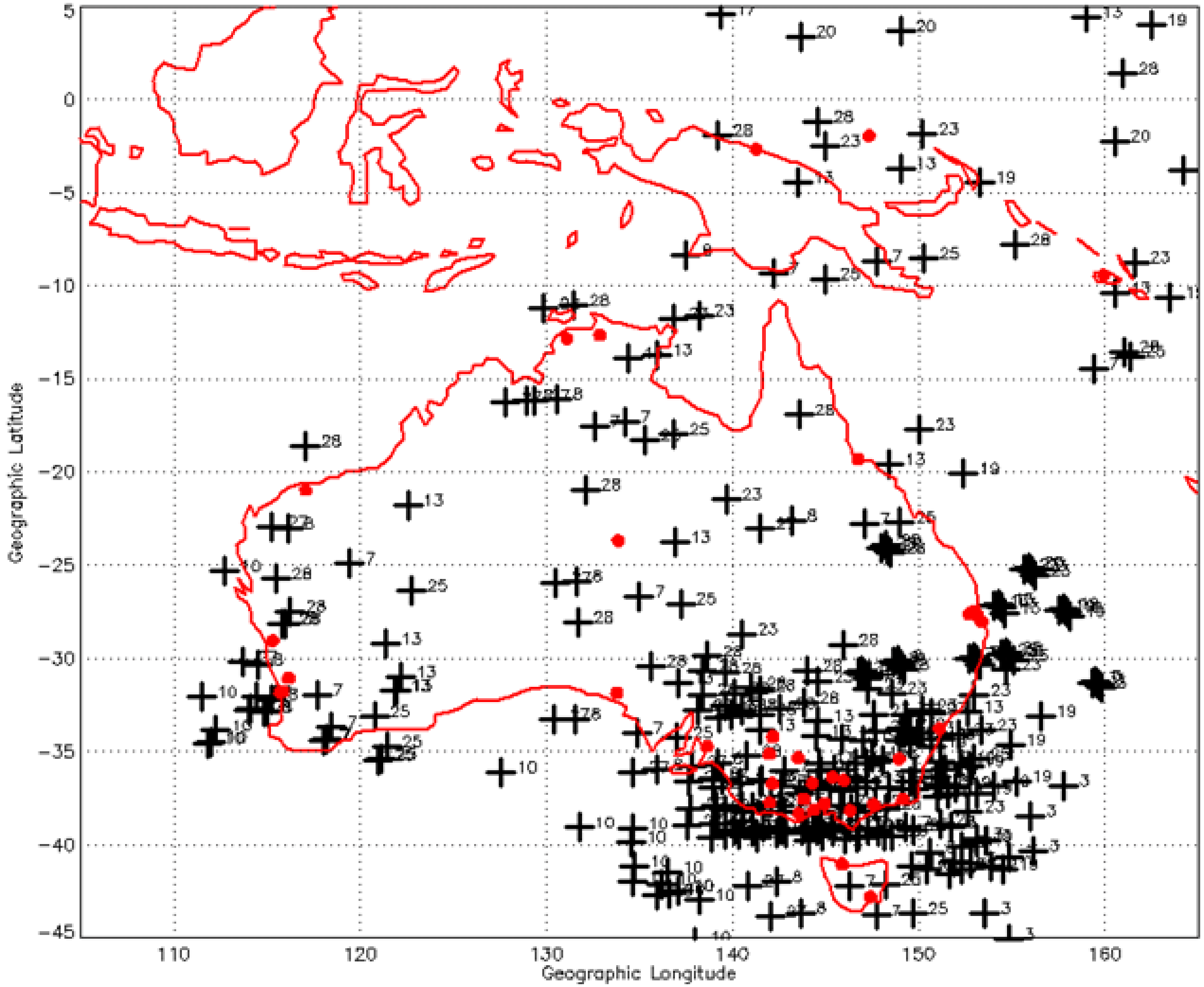
GPS network map (old)

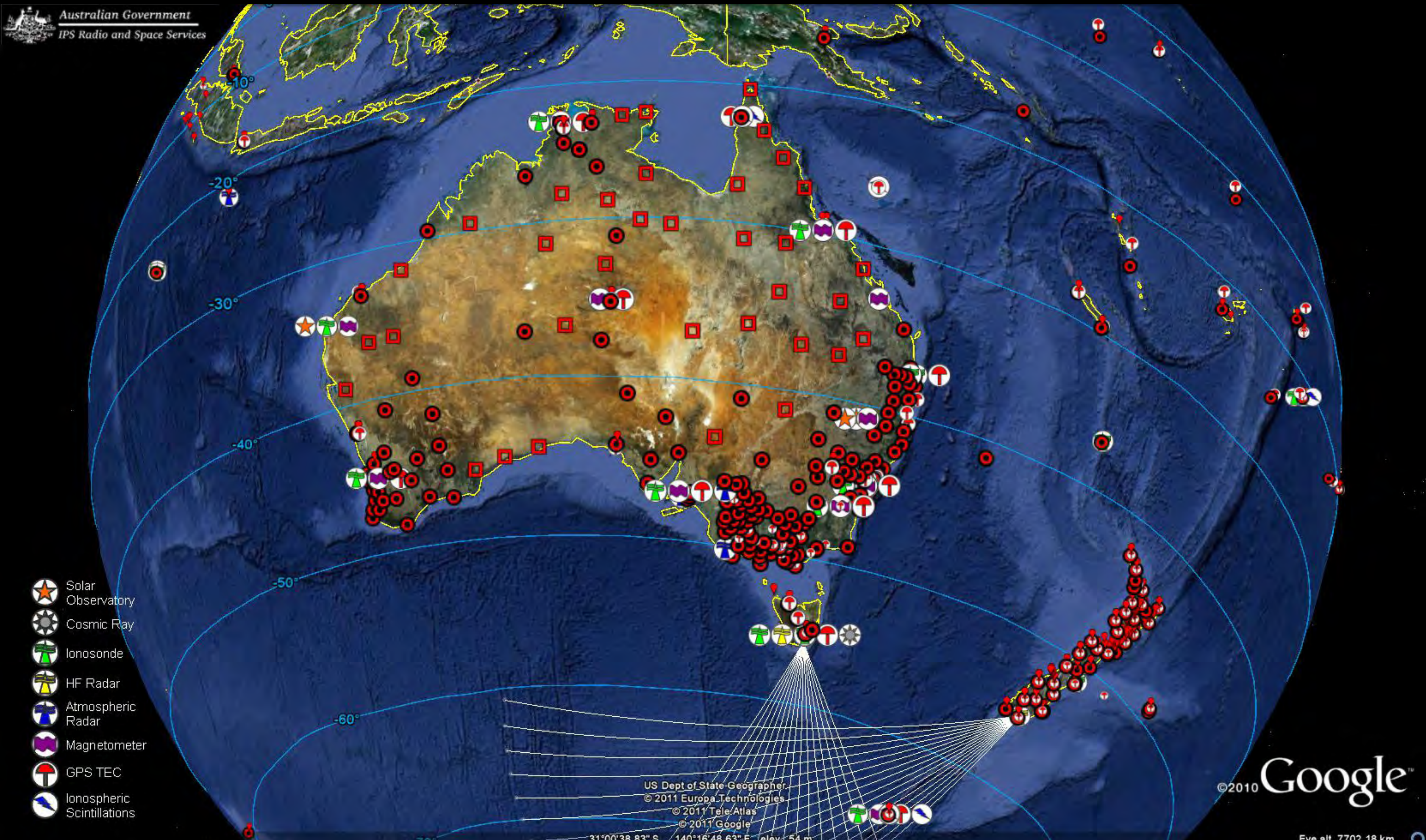


GPS network map (SE detail)



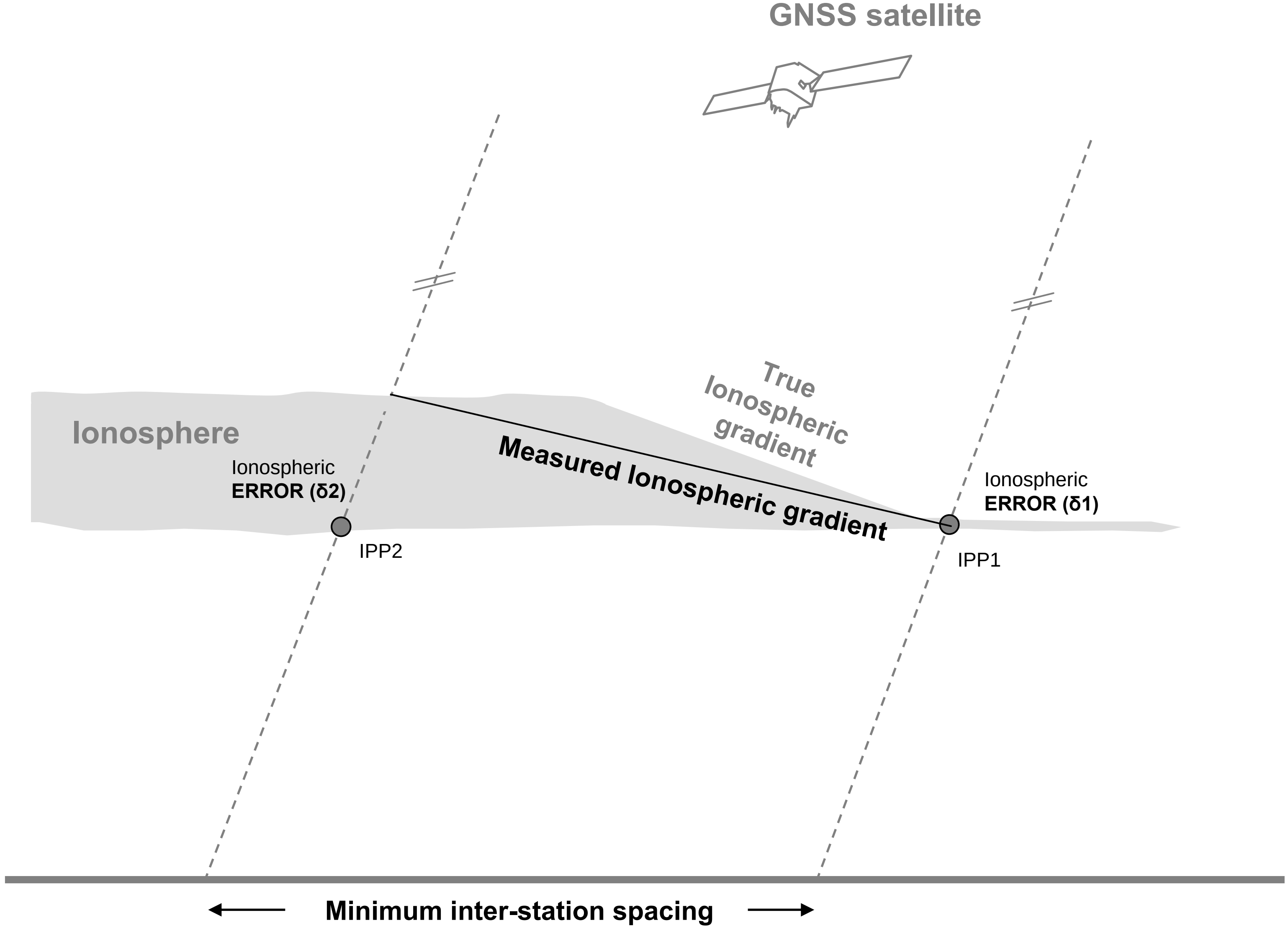
Example of ionospheric coverage



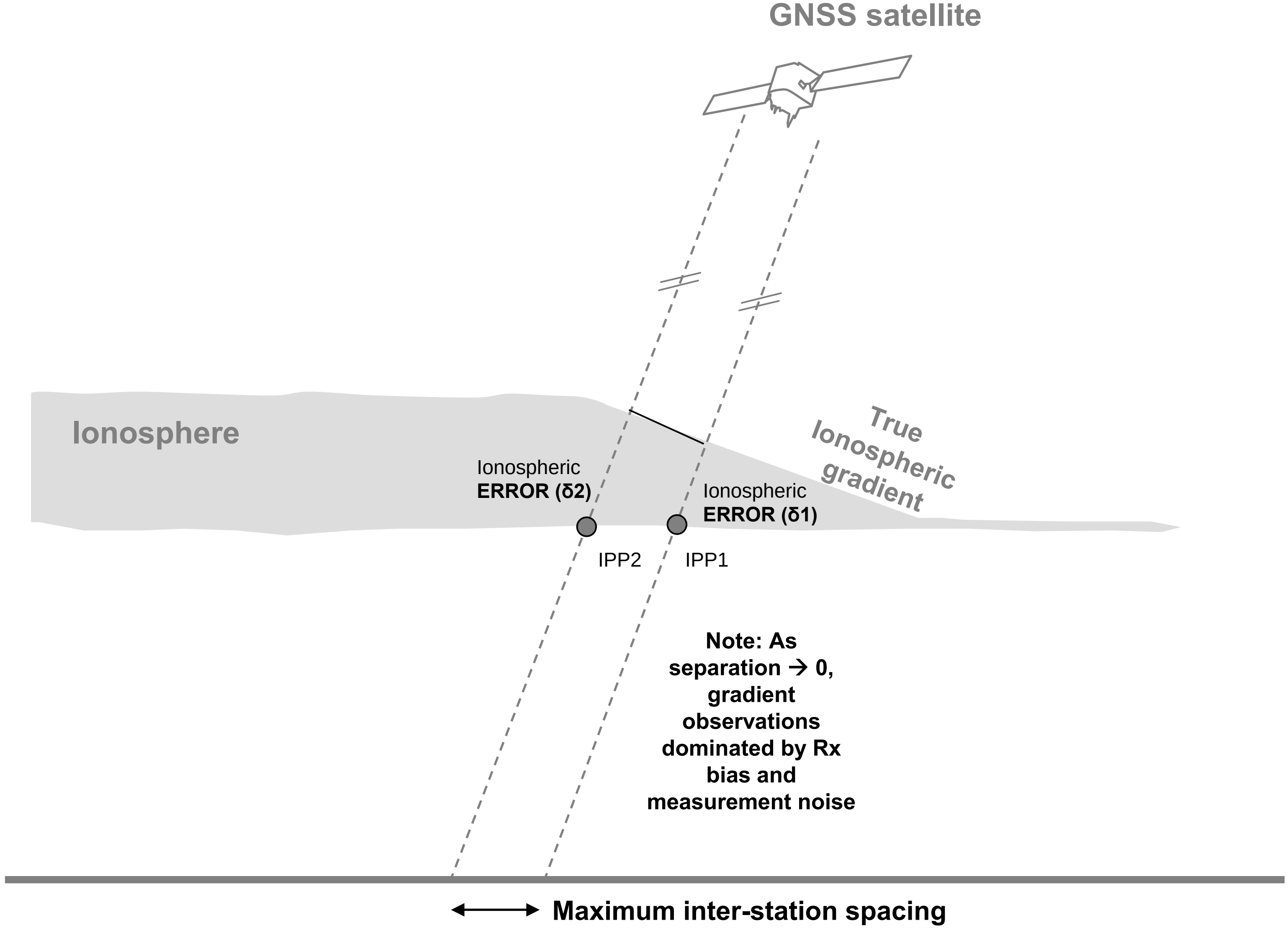


Australian Government
IPS Radio and Space Services
-10°
-20°
-30°
-40°
-50°
-60°
-70°
Solar Observatory
Cosmic Ray
Ionosonde
HF Radar
Atmospheric Radar
Magnetometer
GPS TEC
Ionospheric Scintillations
US Dept of State Geographer
© 2011 Europa Technologies
© 2011 Tele Atlas
© 2011 Google
31°00'38.83" S 140°16'48.63" E elev 54 m
©2010 Google
Eye alt 7702.18 km

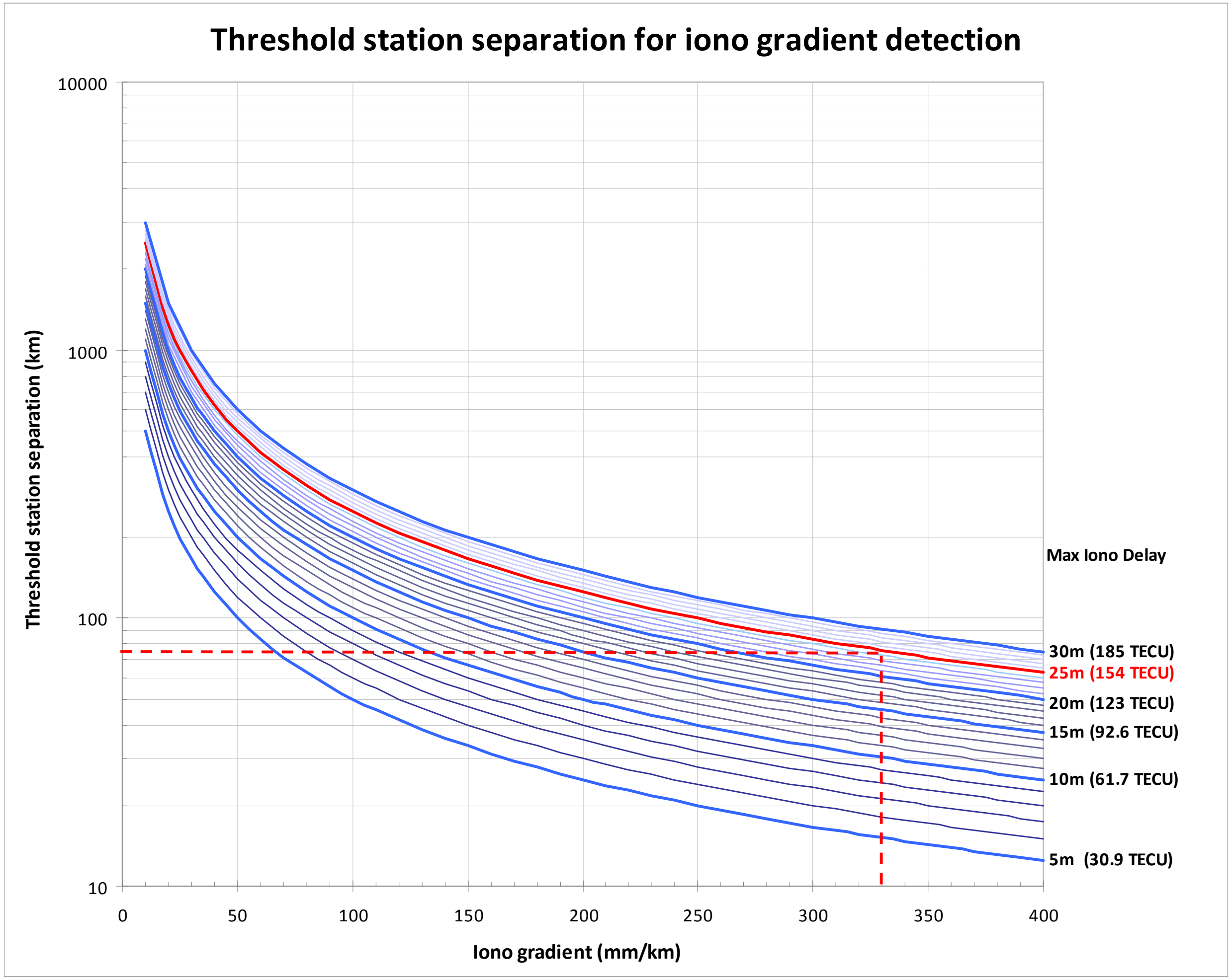
Under-sampled network



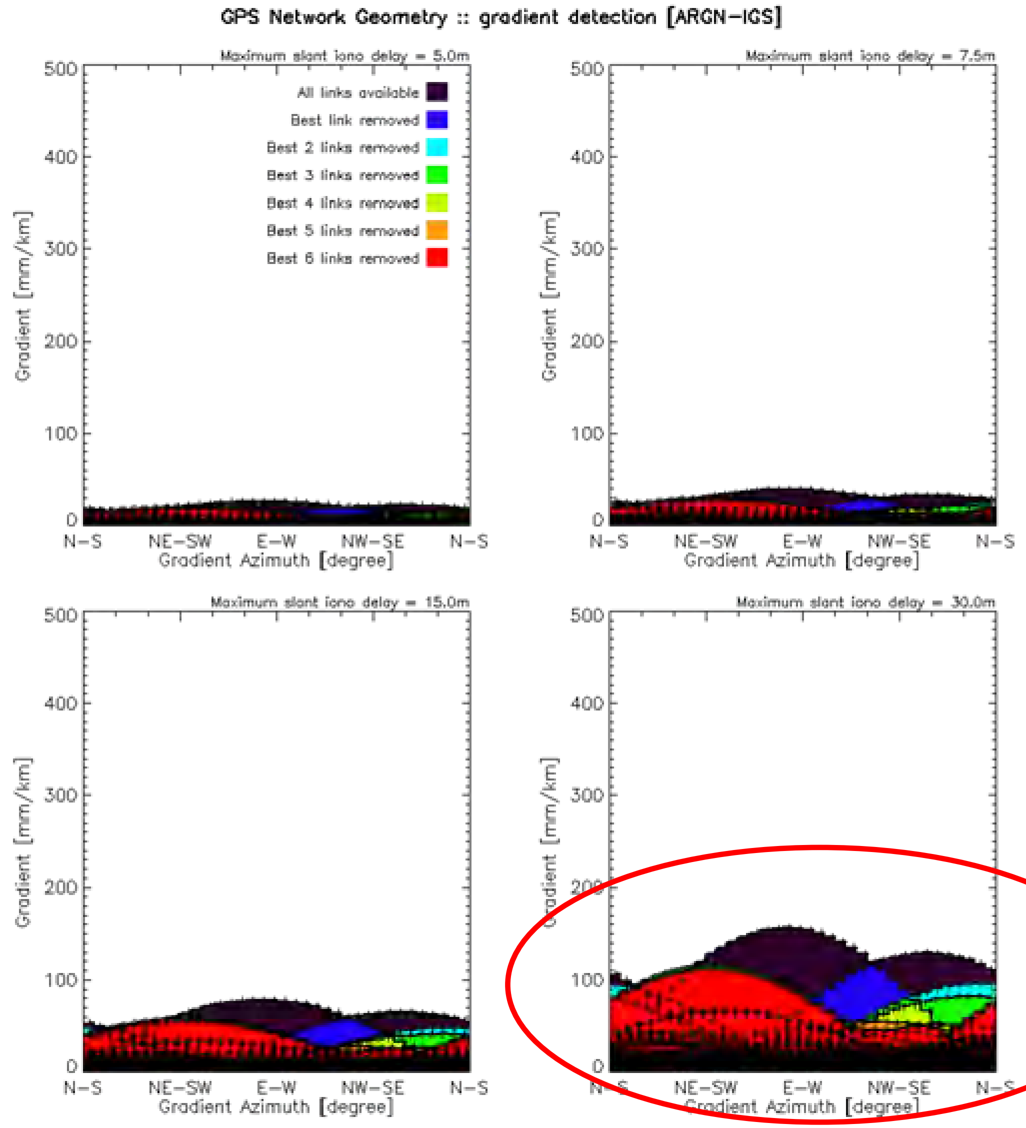
Closely-spaced network



Threshold inter-station spacing for gradient detection

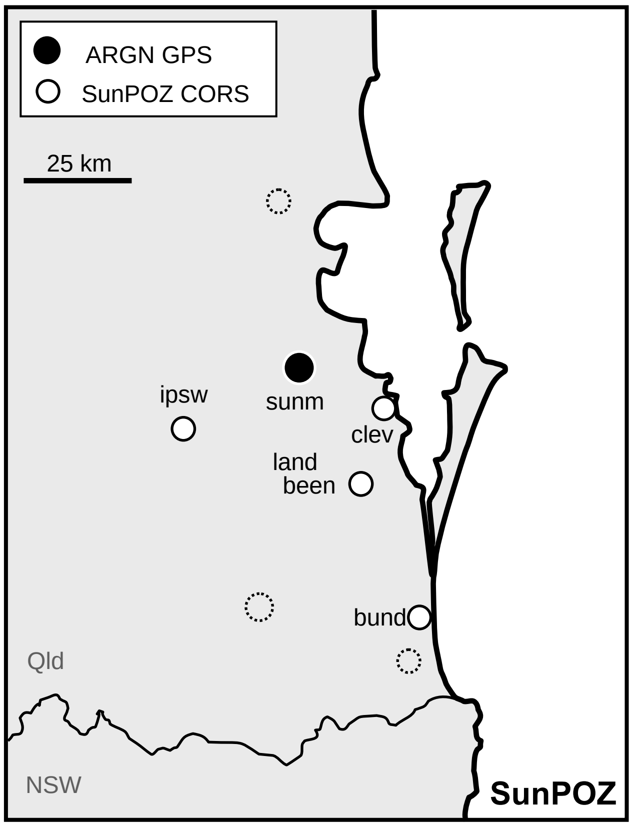


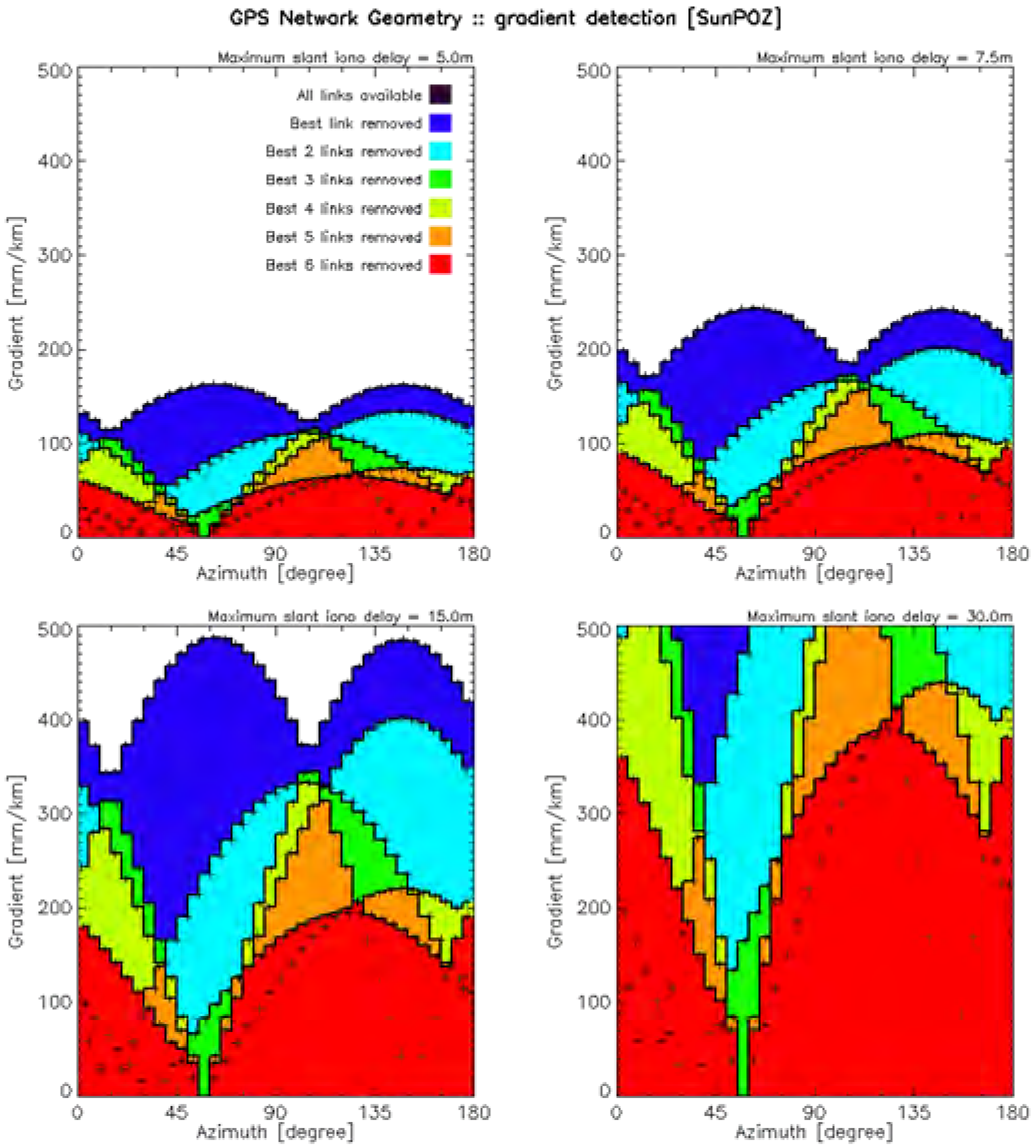
ARGN – national long baseline CORS



Very poor capacity to detect large ionospheric gradients, even for the largest events

SunPOZ - State CORS Queensland





Some assumptions

1) Longitudinal invariance in storm response
2) Anomalous gradient occurrence exclusively during superstorms
3) Study period 2000-2008 representative
4) Restricted region of applicability

A1. Longitudinal ‘invariance’ of ionospheric response

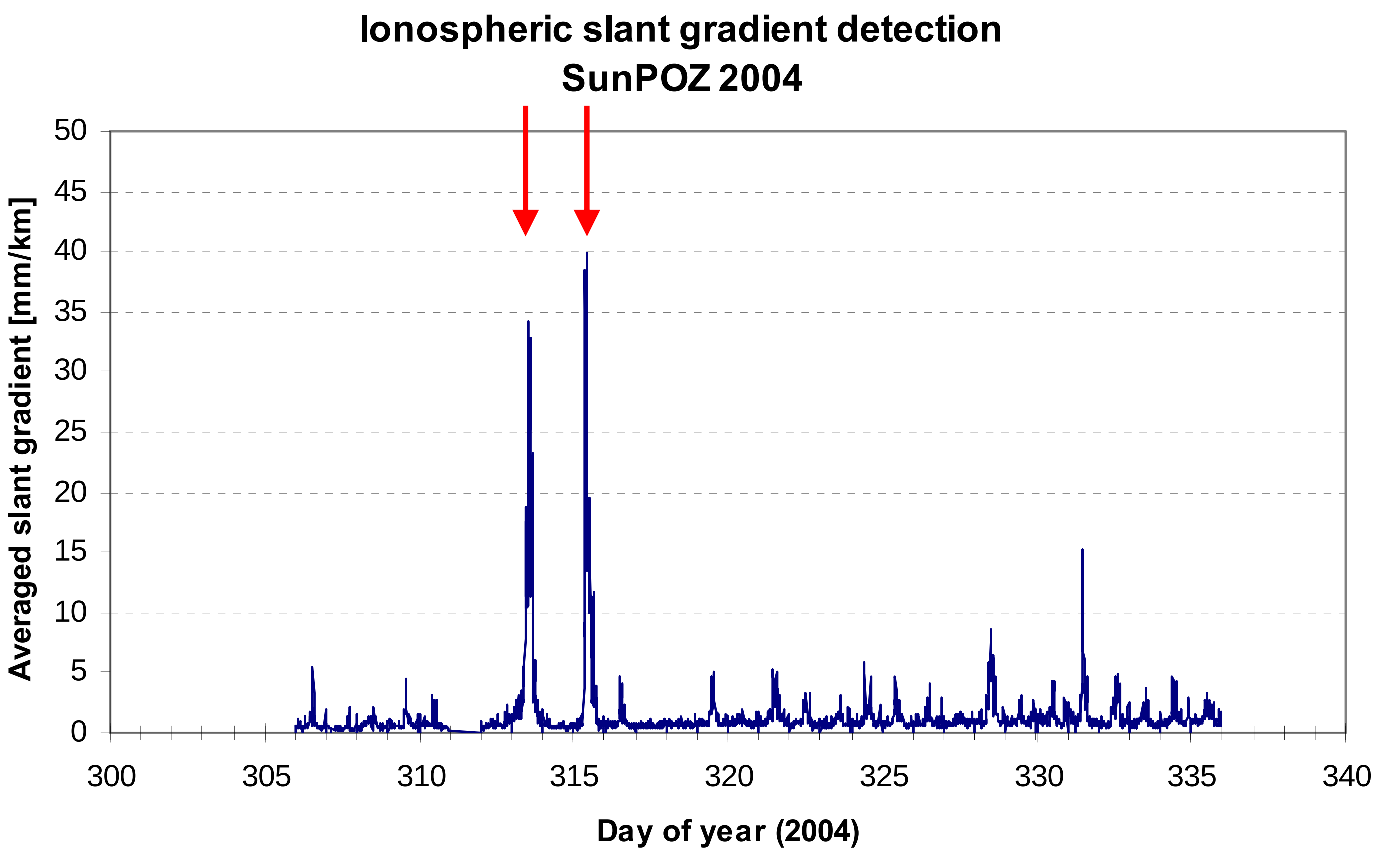
- Ionosphere described more strongly by latitude than longitude.
- Although there are longitude sectors with unique characteristics (eg CONUS) these are very broad local time sectors
- IPS experience does not suggest any major difference in ionospheric characteristics between the East and West coasts of Australia

A2. Validation of storm selection

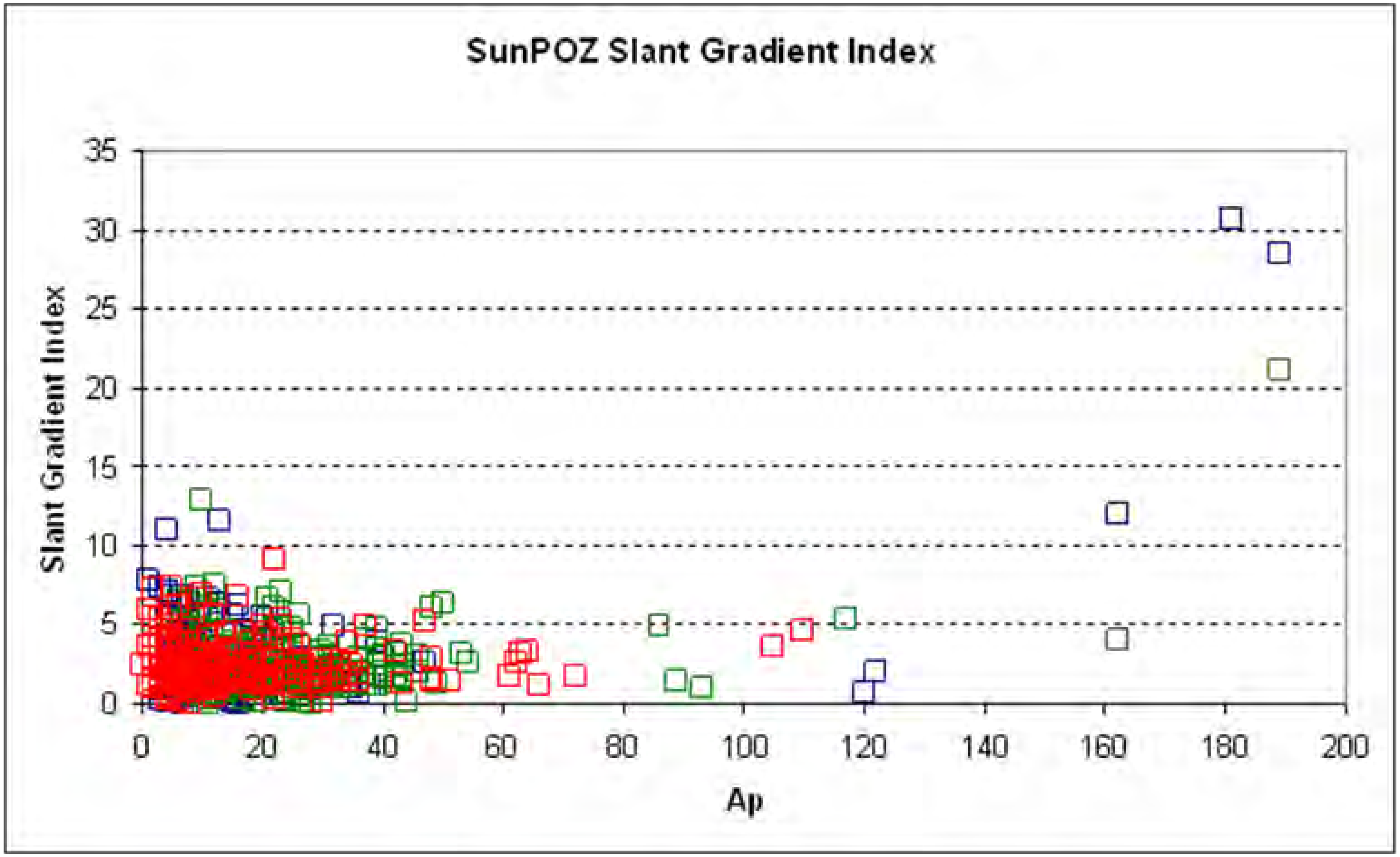
The largest anomalous ionospheric gradients in the Australian mid-latitude region occur during geomagnetic “superstorms” (as identified by threshold level of Kp), more specifically those storms that have a positive phase in the Australian longitude sector.

- Additional work at IPS on validating this assumption
- Ionospheric gradient index derived for this validation, and used to automatically process/analyse four years of short-baseline GPS data to confirm association of anomalous gradients with superstorms

Anomalous gradient event detection using gradient index



Max Ionospheric gradient index during storms (2002-2005)



A3. Representative study period

This study covering the period 2001 – 2008 is representative of the full range of ionospheric gradients that may occur in the Australian region.

- Qualified. Representative of regional anomalous ionospheric gradients over last solar cycle
- Likely representative of anomalous ionospheric gradients in the Australian region
- Recommend ongoing monitoring of anomalous ionospheric conditions for further confidence (eg CONUS experience)

A4. Region of applicability

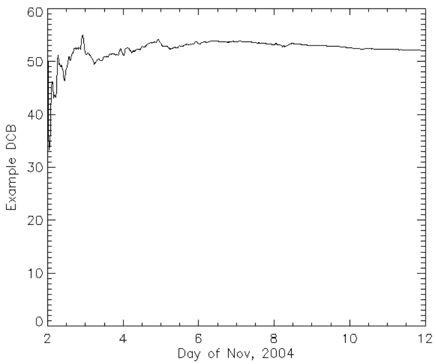
- Results limited to Australian longitude sector, mid-latitudes (-40° < glat < -20°)
- Southern boundary: Dictated by archive data coverage (poor short-baseline coverage in Tas)
- Northern boundary: Dictated by archive data coverage, as well as the unique ionospheric physics of the equatorial zone.
- Studies of the impact of the equatorial ionosphere on GBAS-like systems is ongoing in other states
- Recommend advance iono monitoring for northern Australia for future certification of GBAS

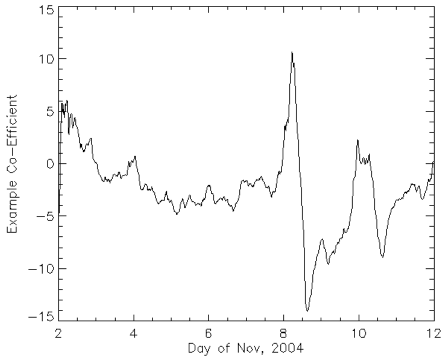
Extra slides

- Extra slides follow

Real-time regional TEC model

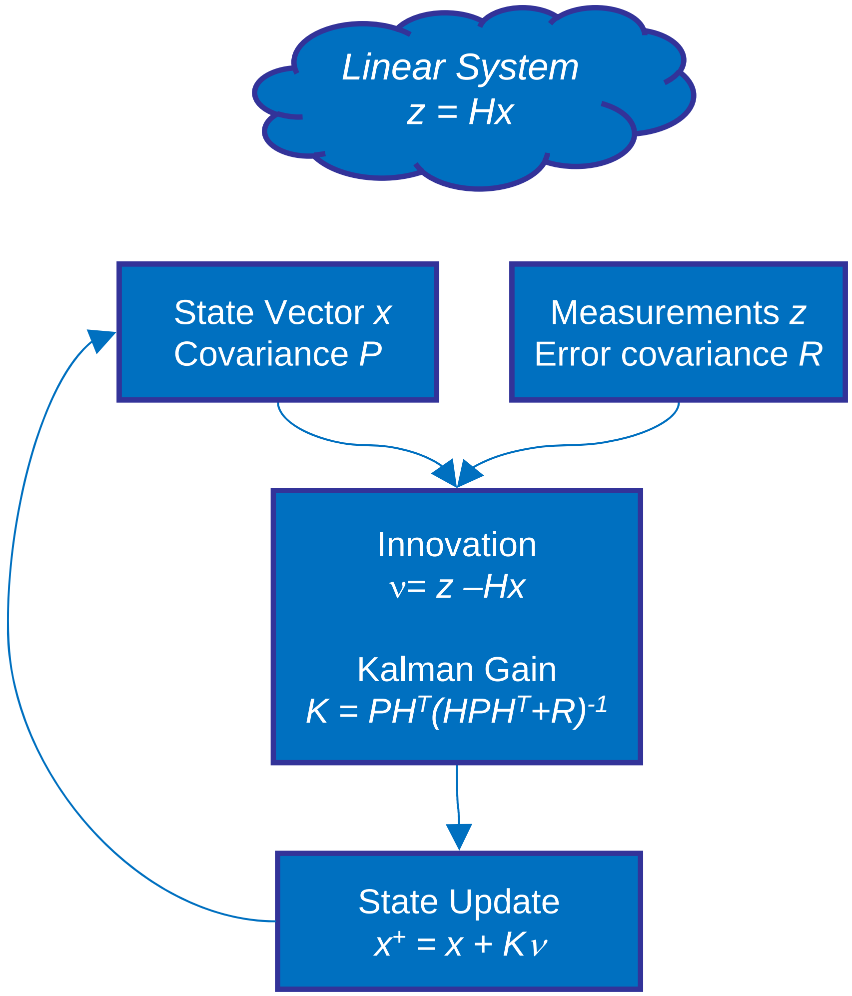
- IPS has developed a Kalman Filter driven real-time TEC modelling capability
- The model uses Spherical Cap Harmonic Analysis (SCHA) for spatial mapping of TEC
- The filter states are the SCH basis co-efficients, the GPS Rx biases and a plasmaspheric TEC scaling factor.
- Utilises data from > 60 GPS sites across the region, along with ~8-10 ionosondes, with capacity to expand further





Kalman Filter

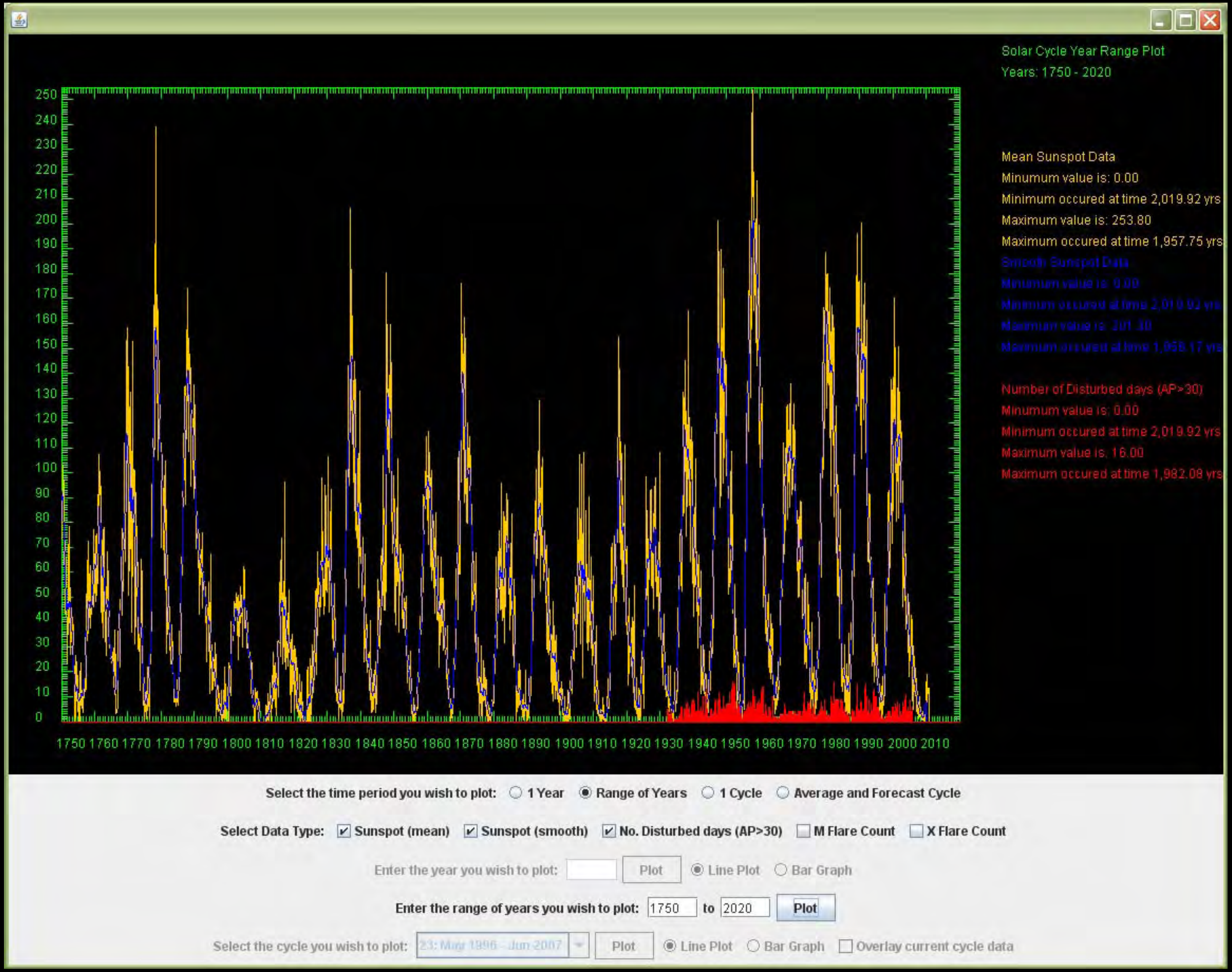
- Optimal solution for the discrete linear state estimation problem
- Widely used in many areas including GNSS trajectory tracking
- Relatively small computational processing overheads

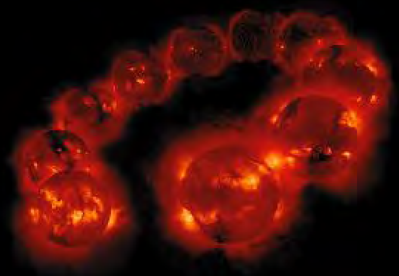


3D Model Development

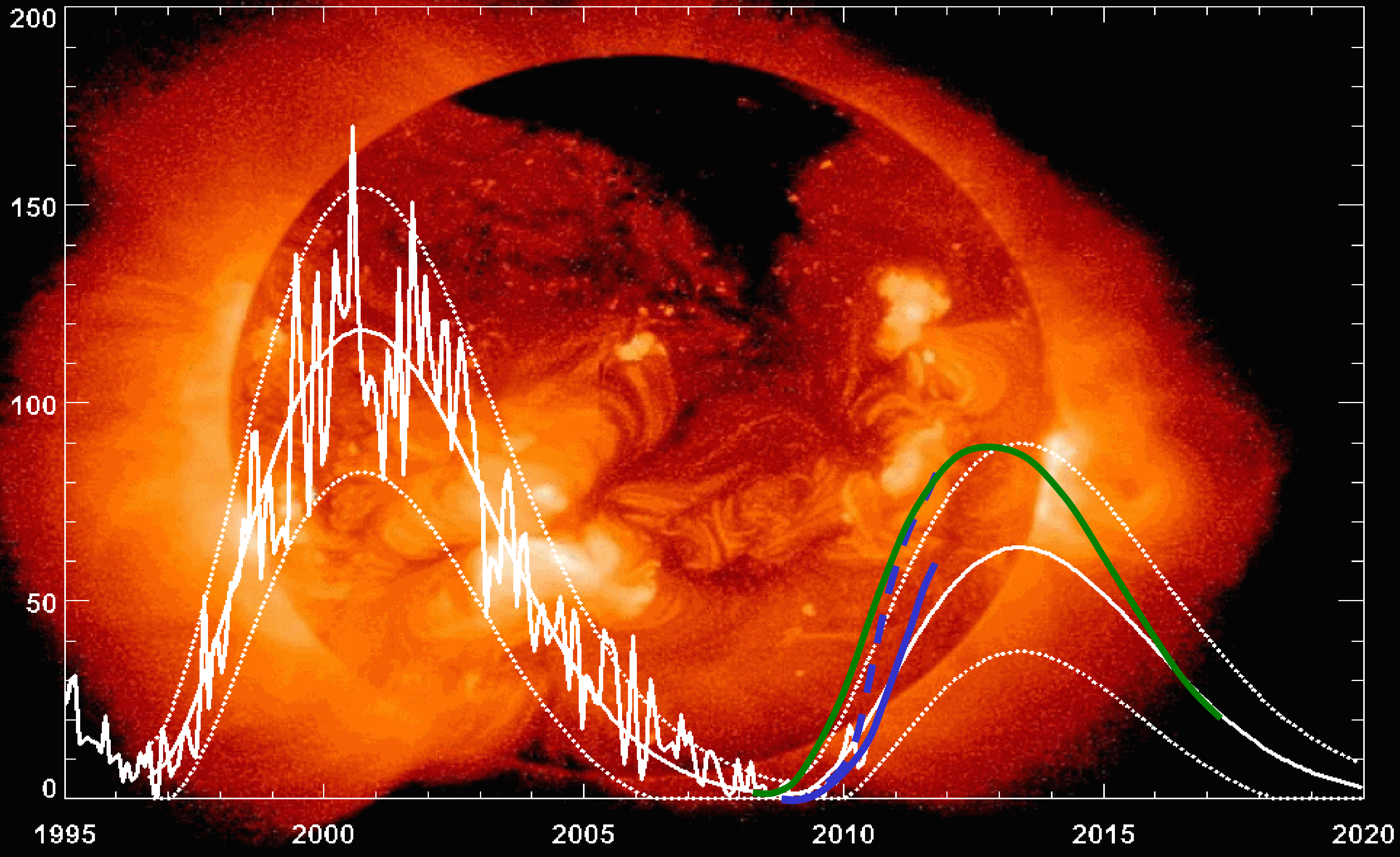
- A full 3D ionosphere + plasmasphere real time model is currently under development.
- Model driven by a range of input data, including:
  - ground based GPS
  - Ionosonde vertical soundings
  - Ionosonde oblique soundings
  - LEO satellite GPS
  - LEO satellite radio occultation (RO) observations
- The current approach uses the NeQuick2 ionospheric profiler as a base vertical model, with free model parameters constrained by the real time input data and mapped in 2D using SCHA.

So what about the next solar activity cycle?





Cycle 24 Sunspot Number Prediction (September 2010)

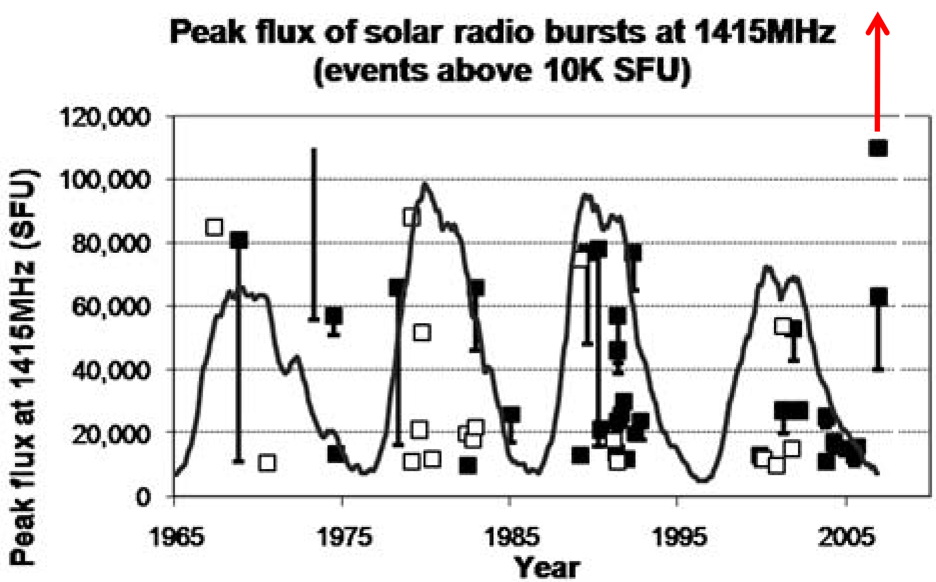


Hathaway/NASA/MSFC

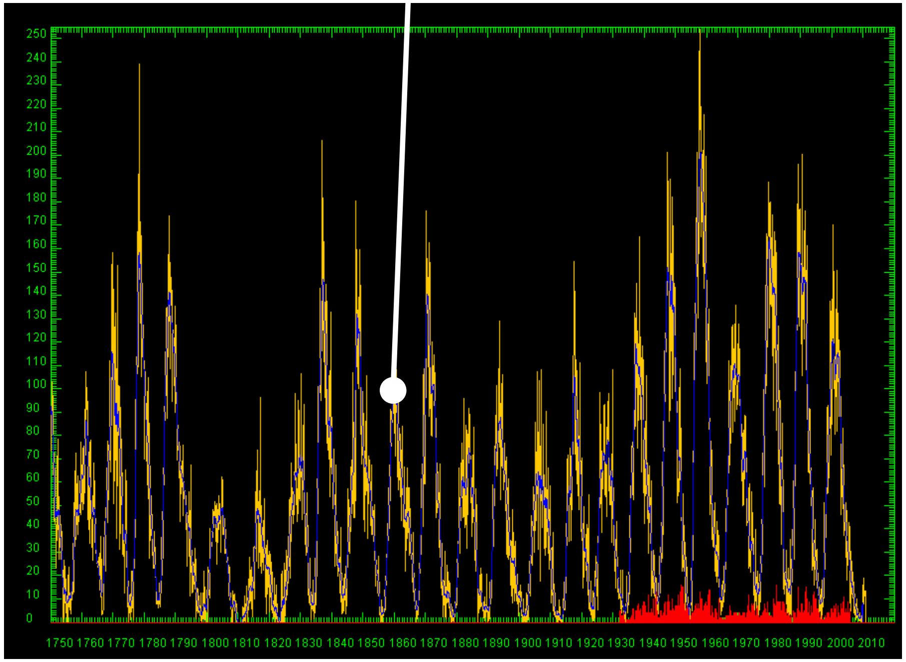
A low solar cycle

- Cycle 24 is forecast to be a relatively low solar cycle (peak SSN ~ 60-90)
- In which case there are likely to be less geomagnetic storms, however the intensity of major storms is not well correlated with the peak of the solar cycle, ie major storms are still likely
- Some examples:

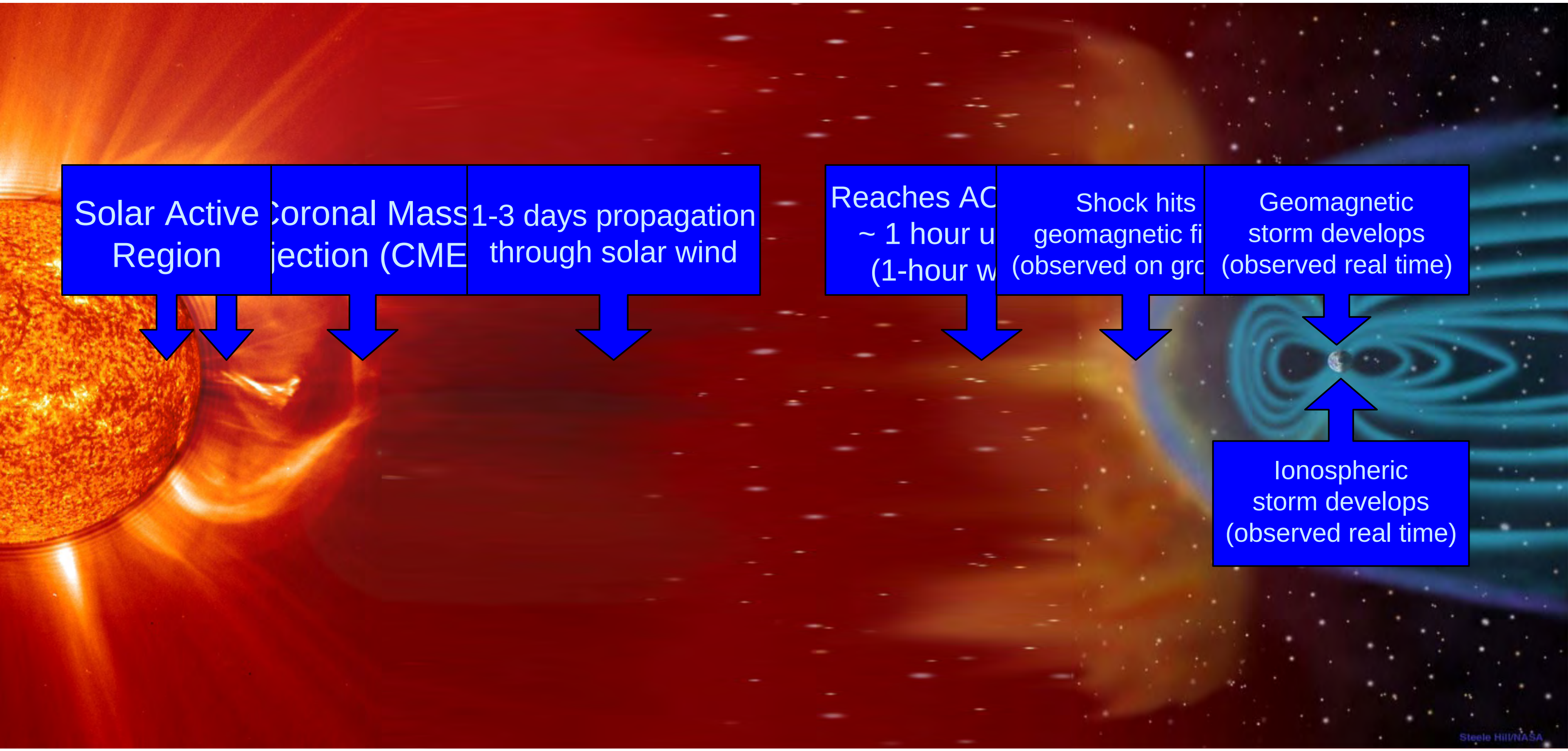
The largest SRB (~1million SFU) occurred near solar minimum



The Carrington event occurred during a rather unremarkable solar cycle



Space Weather



IPS Extreme SpWx Event Alert Service

- Under development at IPS
- Very high alert threshold (minimise false positives)
- Driven by growing demand for advance warning of <u>extreme</u> space weather events from various critical industries (eg power networks, pipelines, SES)
- Implemented as a chain of alerts Sun-Earth during S/W event development, each building on the previous, with increasing probability estimates
- To provide sufficient lead time for industries to build awareness, prepare, and ultimately take action to minimise impact of extreme space weather events
- Output can be tailored to GBAS/aviation requirements such as ionospheric storm-front and gradient monitoring