Space Weather and Critical Infrastructure in the Australian/ New Zealand Region

Richard Marshall

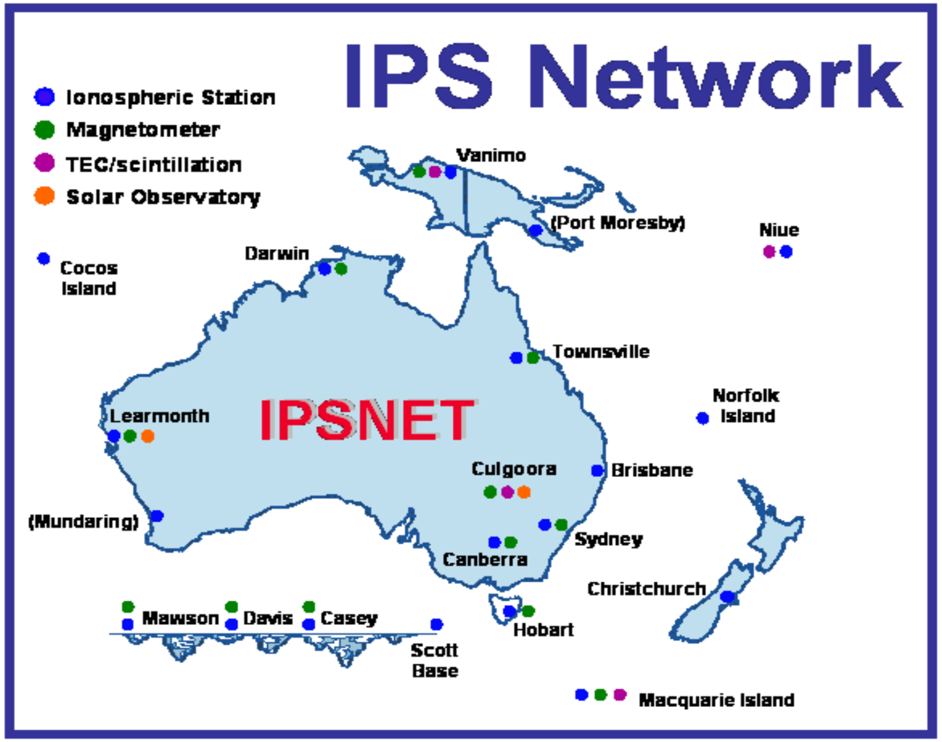
IPS Radio and Space Services
Australian Bureau of Meteorology

The IPS

The Ionospheric Prediction Service - Providing HF Radio services and support since late 1940's

IPS Radio and Space Services

Providing Space Weather services (including HF Radio) and support since late 1990's

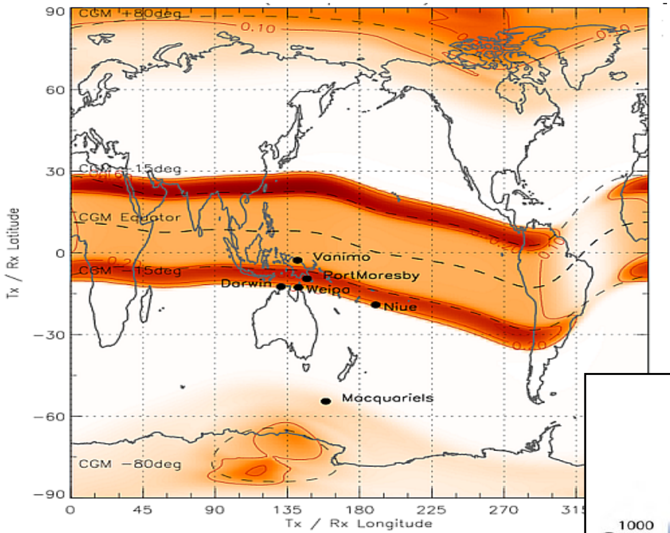


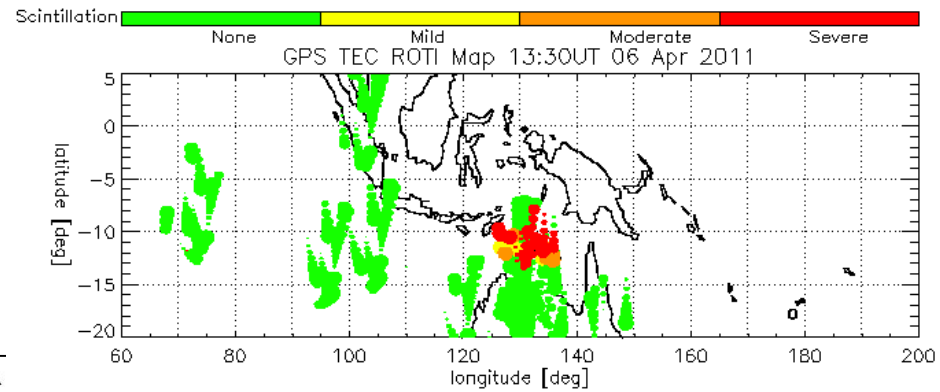
..........Australian BOM's Space Weather Unit since 2007

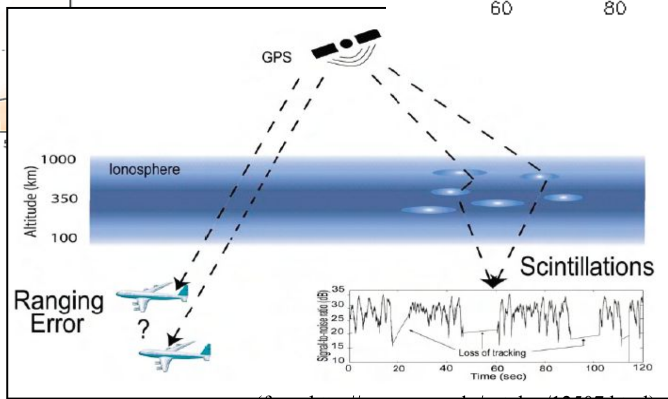
Critical Infrastructure Groups

- The rise of solar cycle 24 and the growing awareness of impacts of space weather has lead to increased interest from critical infrastructure groups within Australia
- Engagement with Australian Government Trusted Information Sharing Network, includes Energy, Communications, and Transport Sector groups
- Communications sector (CSG) includes, Telstra, Optus (satellite operators), UHF/VHF users (major TV broadcasters), HF users (SES)
- Transport sector (TSG) includes major airlines (Qantas, Virgin), Air Services Australia, shipping and rail
- Energy sector (ESG) includes power network asset owners and operators, gas pipeline owners and operators, mining companies
- All groups operate/own/utilise one or more technologies and systems susceptible to space weather

GPS Systems (TSG)



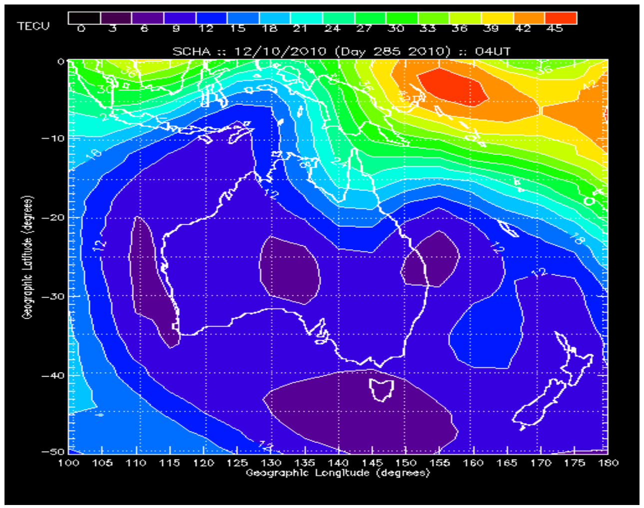


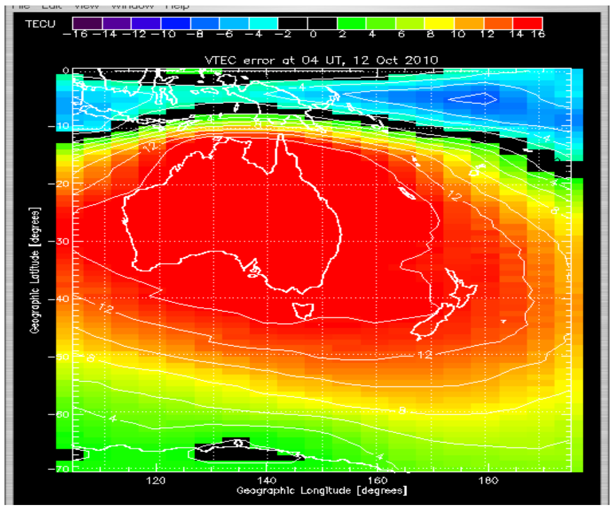


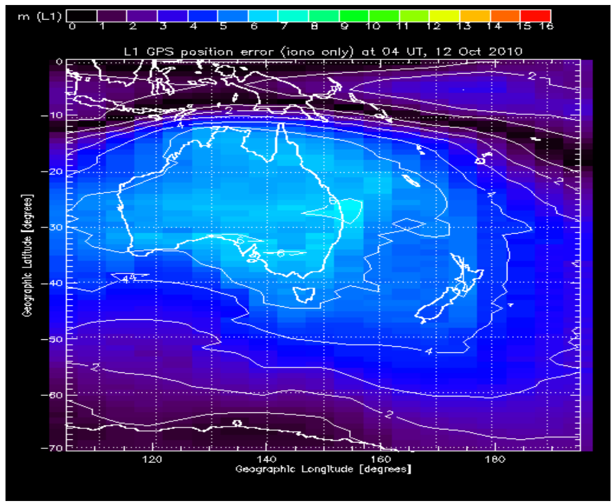
(from http://www.nap.edu/catalog/12507.html)

GNSS Group at IPS:

Mike Terkildsen, Matt Francis, Zahra Bouya







High-End GPS Systems

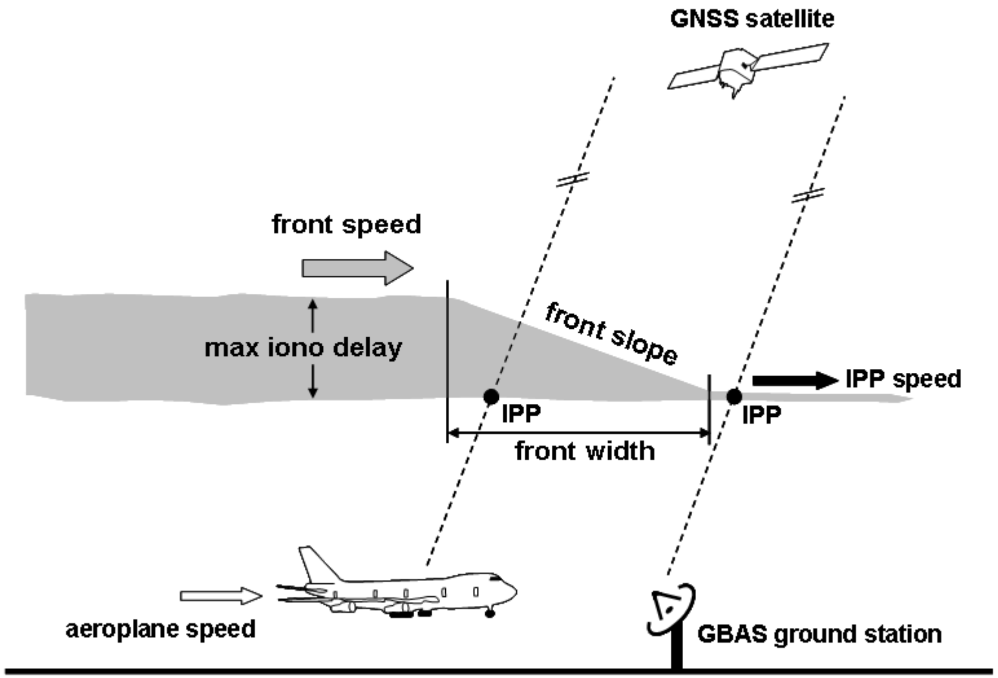
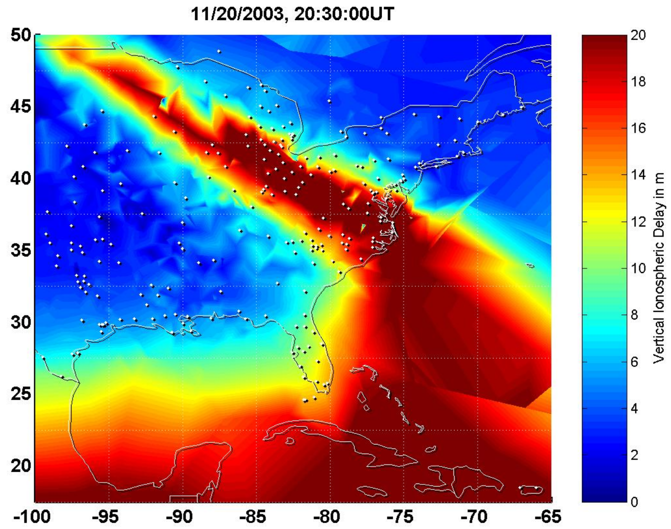
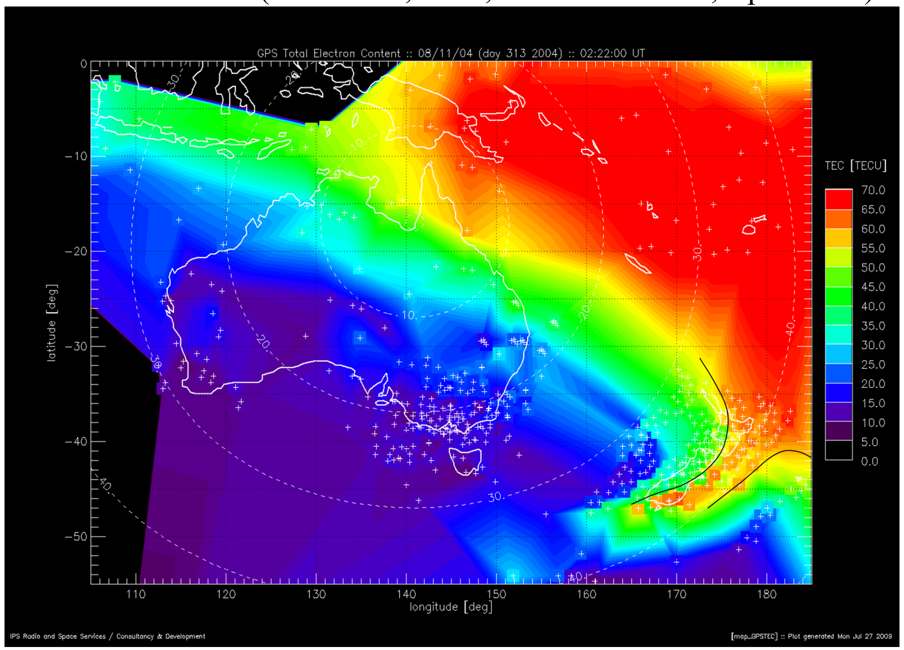


Figure adapted from: Pullen et al, 5th International GBAS Working Group Meeting (GWG/5), Nov 2006

[from Ene et al (2005), Proceedings of ION 2005 National Technical Meeting]

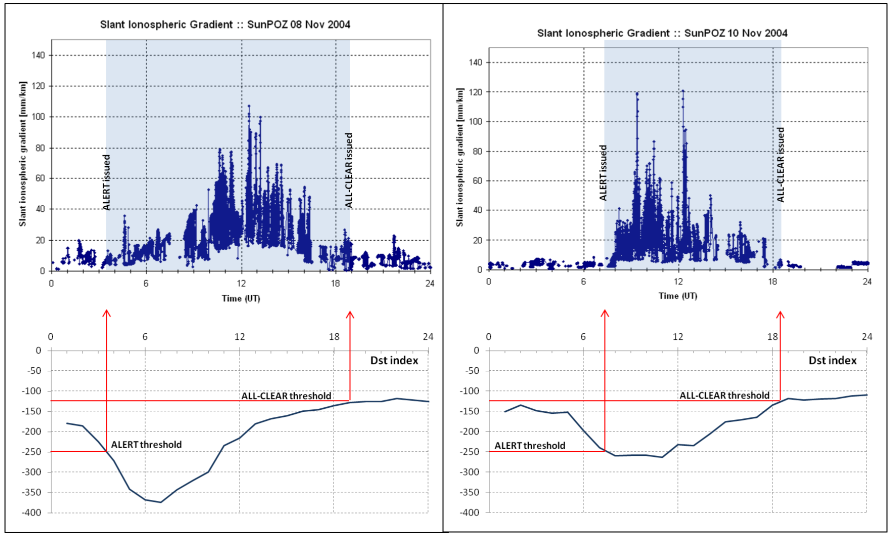


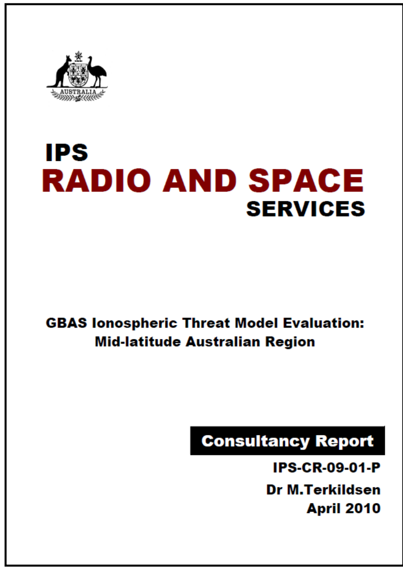
(Terkildsen, 2010, IPS-CR-09-01-P, April 2010)



High-End GPS (TSG – Aviation)

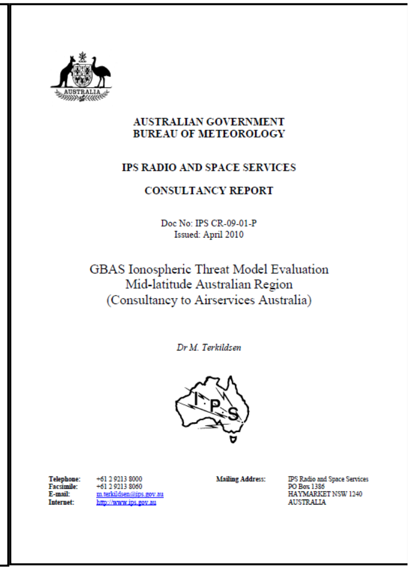
- **April 2010 -** Consultancy to Airservices Australia for GBAS Ionospheric Threat Model Evaluation: Mid-latitude Australian Region




IPS
RADIO AND SPACE
SERVICES

GBAS Ionospheric Threat Model Evaluation:
Mid-latitude Australian Region

Consultancy Report
IPS-CR-09-01-P
Dr M.Terkildsen
April 2010


AUSTRALIAN GOVERNMENT
BUREAU OF METEOROLOGY

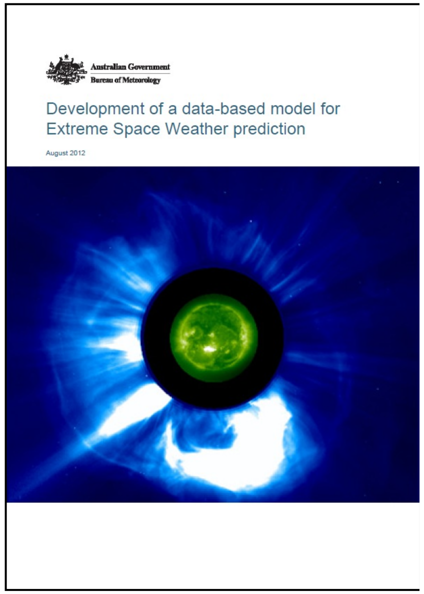
IPS RADIO AND SPACE SERVICES
CONSULTANCY REPORT

Doc No: IPS CR-09-01-P
Issued: April 2010

GBAS Ionospheric Threat Model Evaluation
Mid-latitude Australian Region
(Consultancy to Airservices Australia)

Dr M. Terkildsen

- **May 2012** - Proposed Dst-based alerts for anomalous ionospheric gradient conditions at mid-latitudes

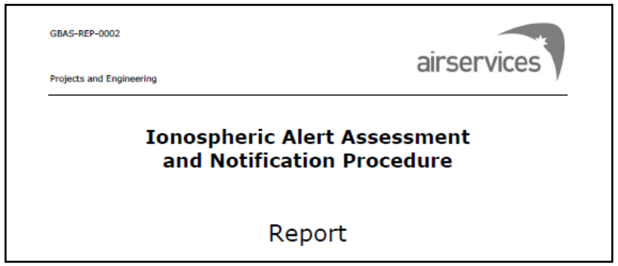

Australian Government
Bureau of Meteorology

Development of a data-based model for Extreme Space Weather prediction

August 2012

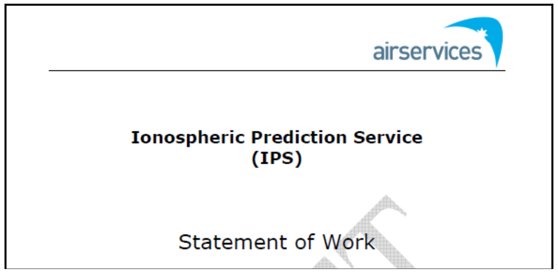
- **Jan-Aug 2012** – Development of a data-based model for Extreme Space Weather prediction; Internal report published August 2012; Scientific journal paper in draft

- **July 2012** – Ionospheric Alert Assessment and Notification Procedure, ASA Protocols


GBAS-REP-0002
Projects and Engineering
airservices

Ionospheric Alert Assessment and Notification Procedure

Report

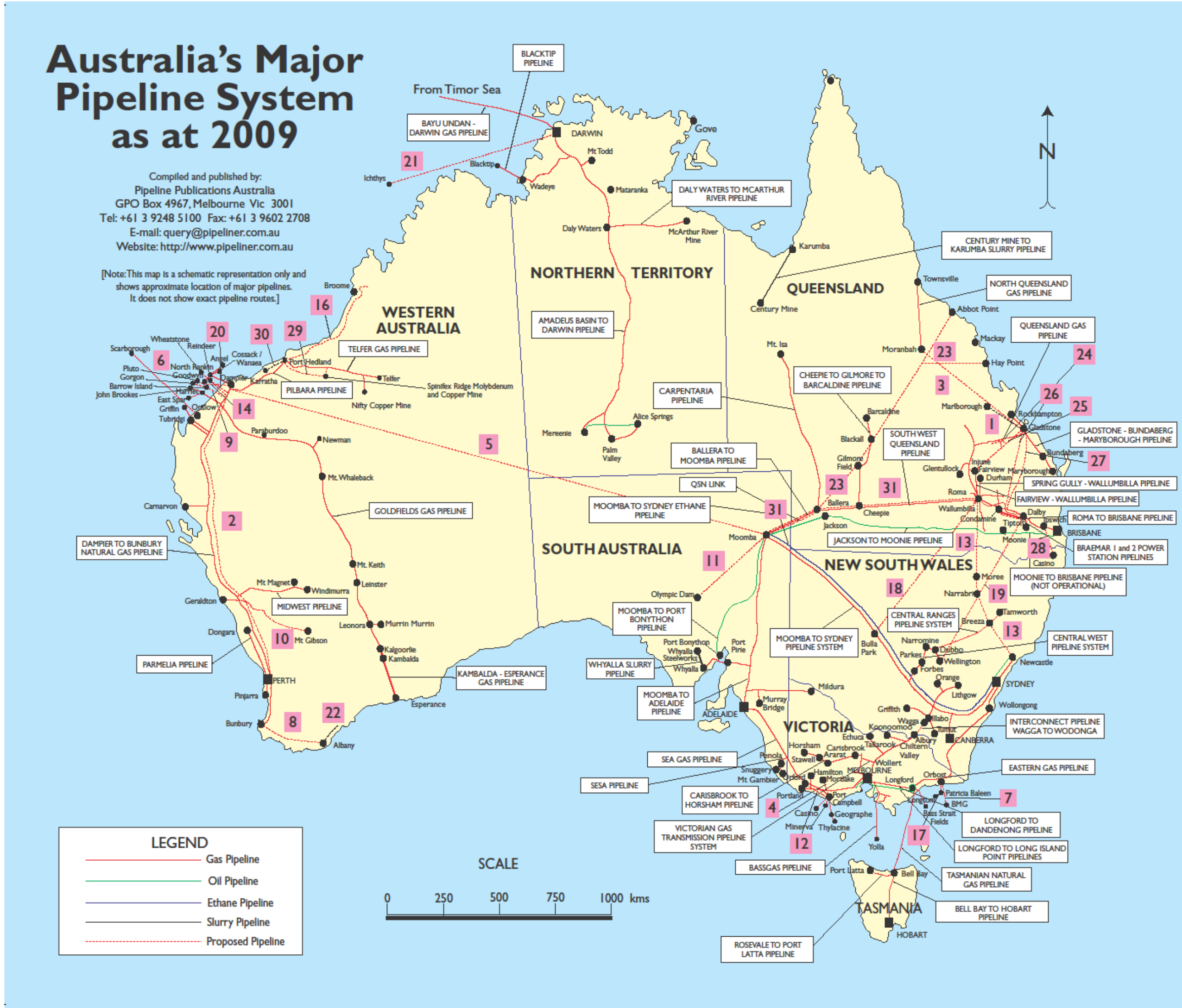

airservices

Ionospheric Prediction Service (IPS)

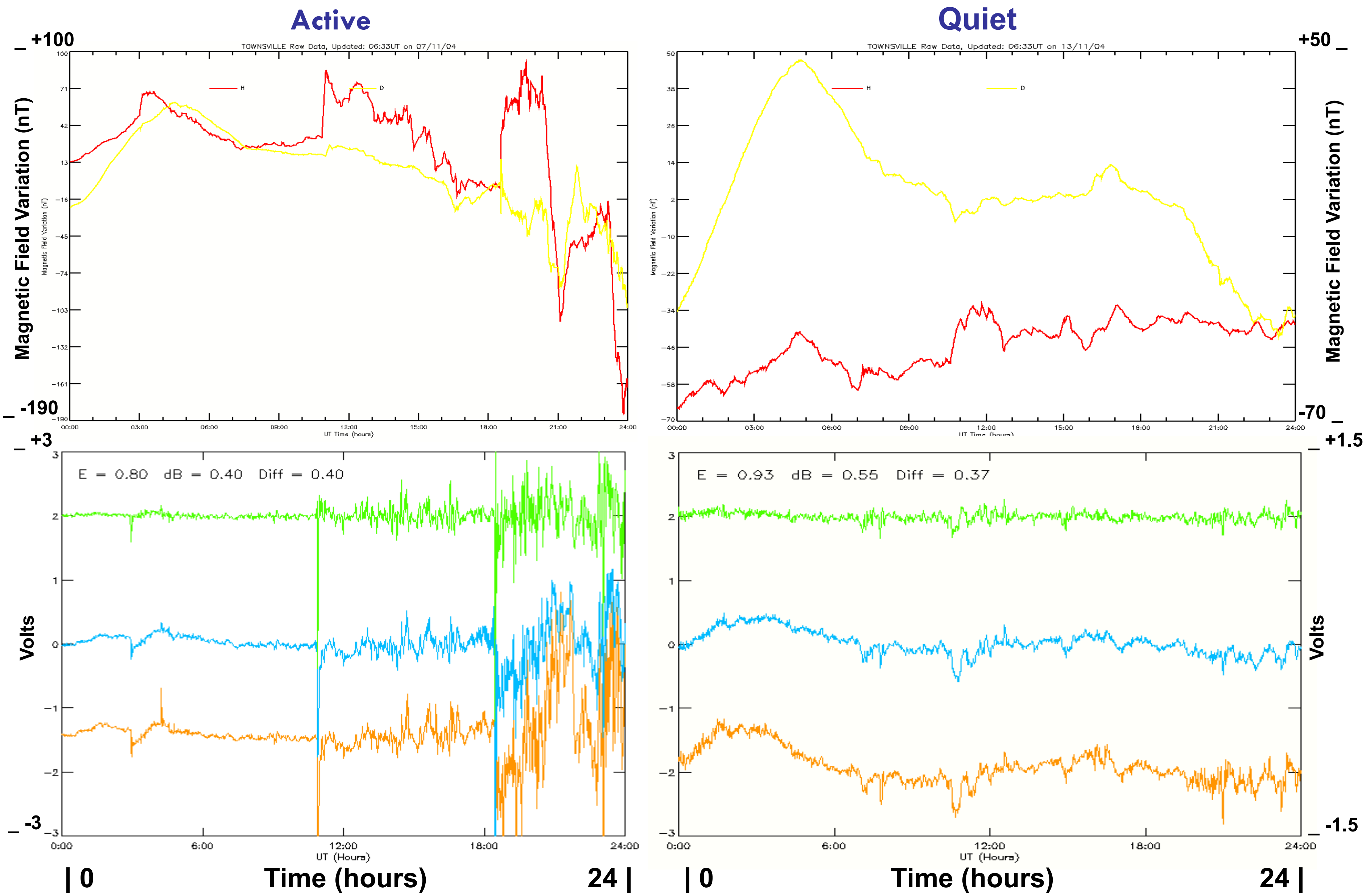
Statement of Work

- **August 2012** – IPS Statement of Work for ionospheric alerts

Australian Pipeline Network (ESG)

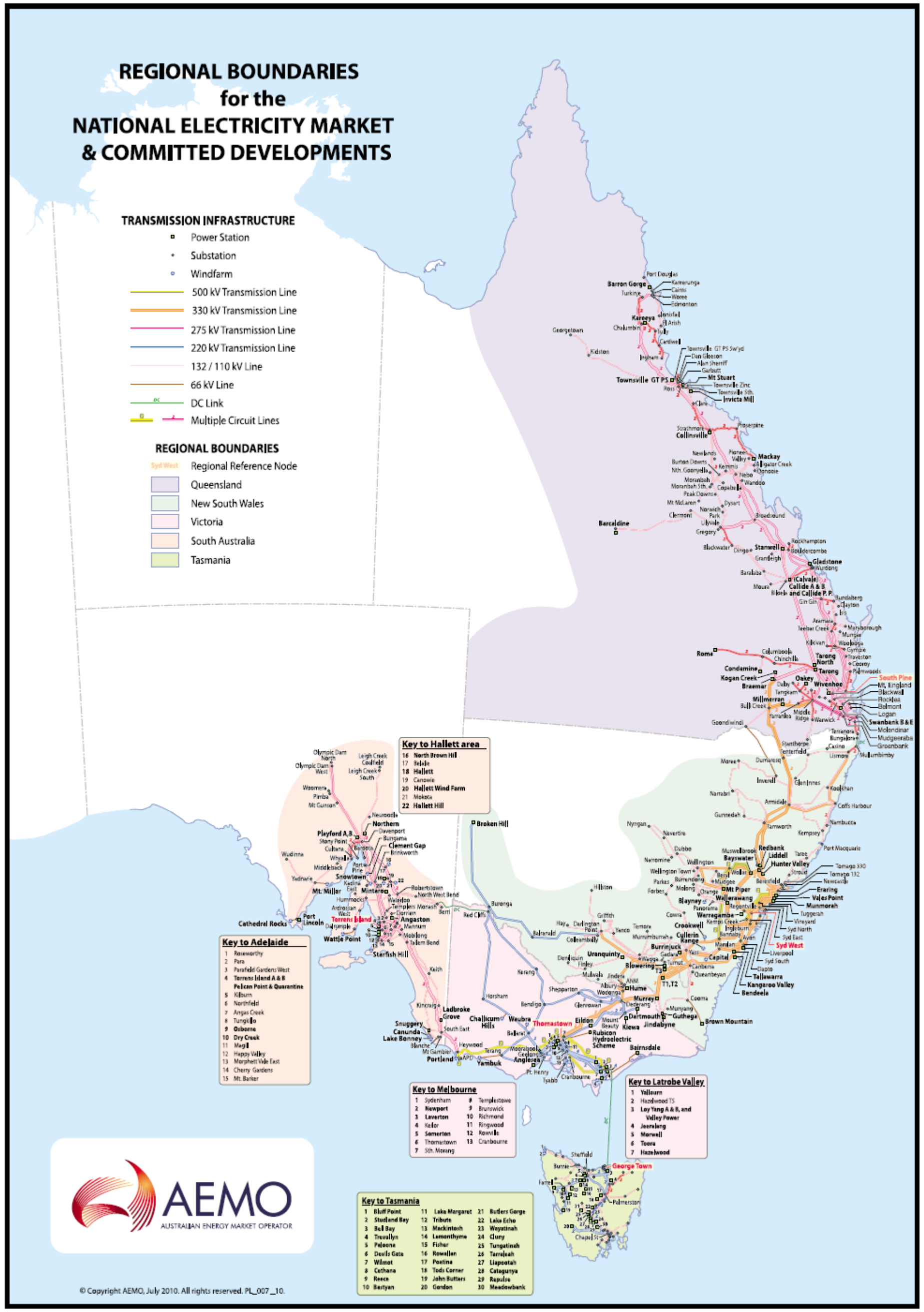


Australian Pipeline Network



(Marshall et al., Space Weather, 2009SW000553)

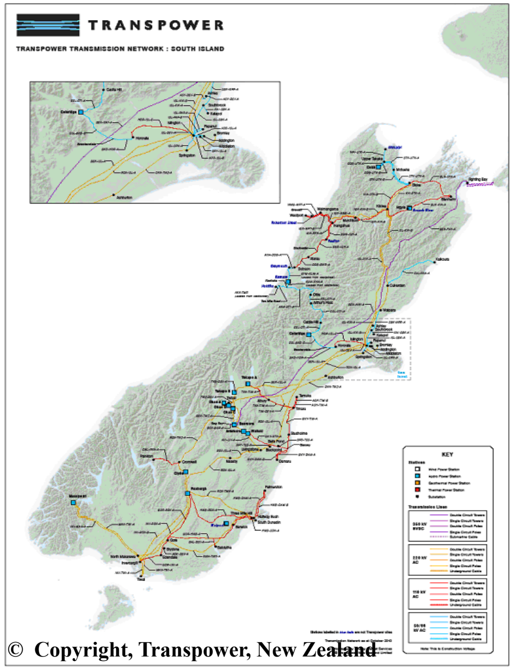
Australian Power Network (ESG)

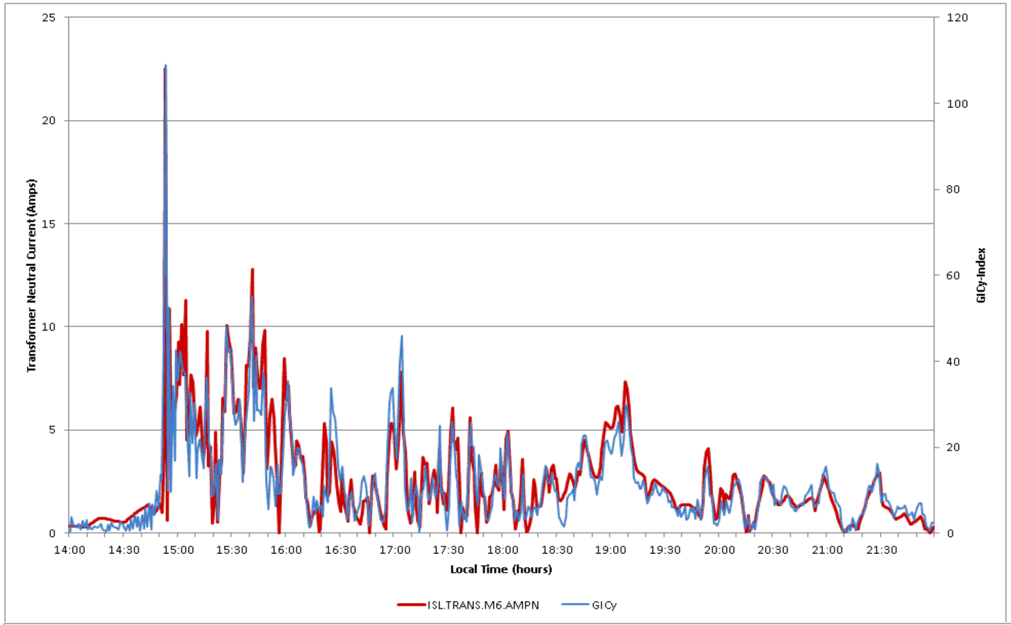


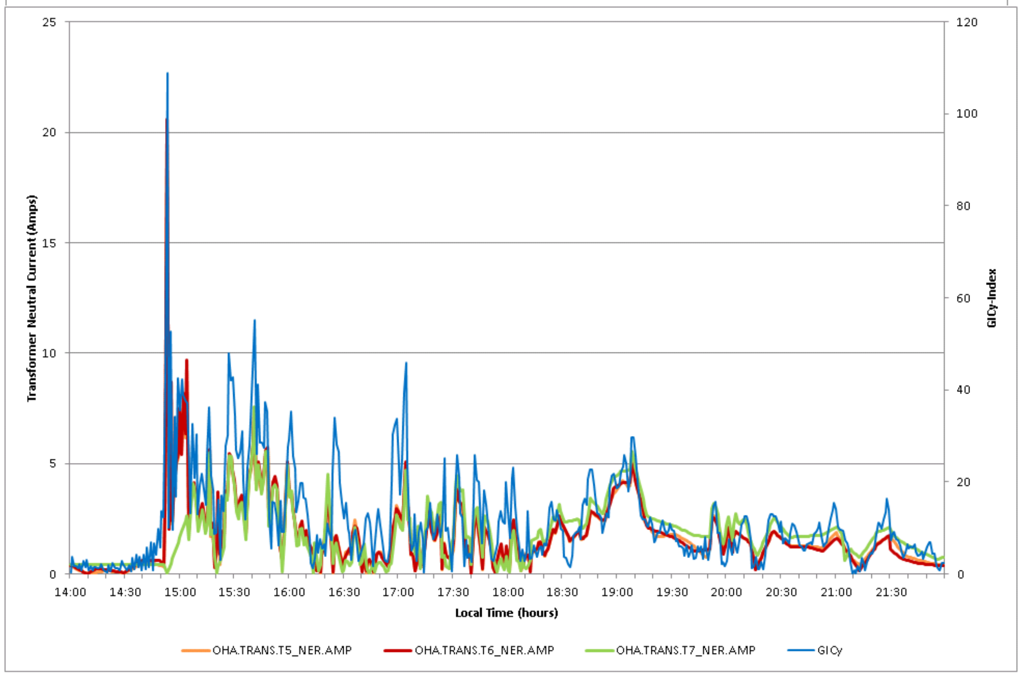
Increased connectivity over recent years

- **Market Competition**
- **Robustness to demand**
- **Increased susceptibility to Space weather**
- **AEMO operates the energy markets and systems in eastern Australia, including PSSWG**
- **Historically been considered relatively immune to space weather due to mid-latitude location**
- **Several studies over past few years**

New Zealand Power Networks







Date/Time Description

06-Nov-01, 14:52:00 HWB T4 and ISL SVC tripped. Many South Island transformer NER alarms. HVDC running OK

in balanced mode. HVDC load 216MW with Pole 2 and a half pole in service

06-Nov-01, 14:52:00 Buchholz trip

06-Nov-01, 14:53:00 Red phase caused the tripping. D2 protection flag. Maintenance contractor advised

06-Nov-01, 14:53:00 Buchholz trip. SC advised. HBC to call out contractors

06-Nov-01, 15:08:00 Trip. Alstom called out. SC advised

06-Nov-01, 15:25:00 SI NER alarms reset

06-Nov-01, 15:26:00 T4 tripped at HWB. Ohau unit transformers NER saturation. ISL SVC tripped. Unknown cause.

Requested CLU max VArs at ROX 110 kV, Extra machine started. Third cap switched in at BDE.

Requested extra machines on OHA, OHB, OHC running on TWD to alleviate NER

transformer saturation

06-Nov-01, 15:27:00 TKB, CYD, OHA, OHB NER alarms

06-Nov-01, 15:34:00 TOC (Internal transformer fault, explosion vents blown)

06-Nov-01, 15:34:00 HBC advise Red phase unit indicates internal fault. SC told

(Marshall et al., Space Weather, 2012SW000806)

Power Networks - Australian Region

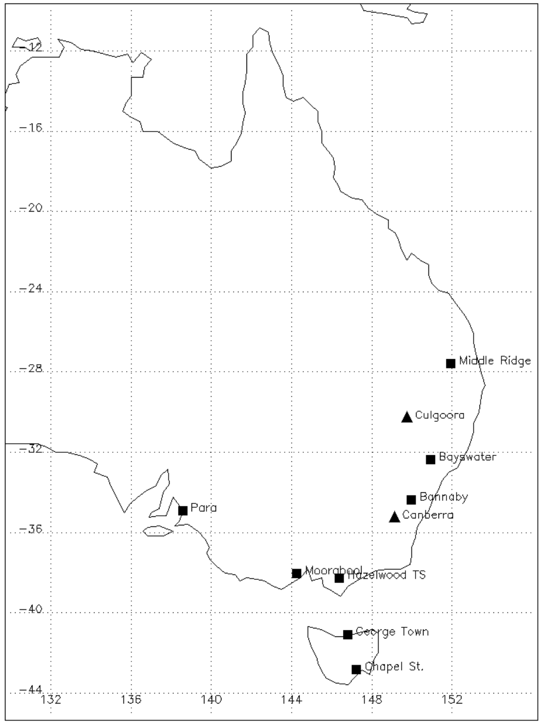
UPDATE ON ASSESSMENT OF POTENTIAL IMPACT OF CORONAL MASS EJECTION, SOLAR FLARES, GEOMAGNETIC STORMS ON THE NEM POWER SYSTEM

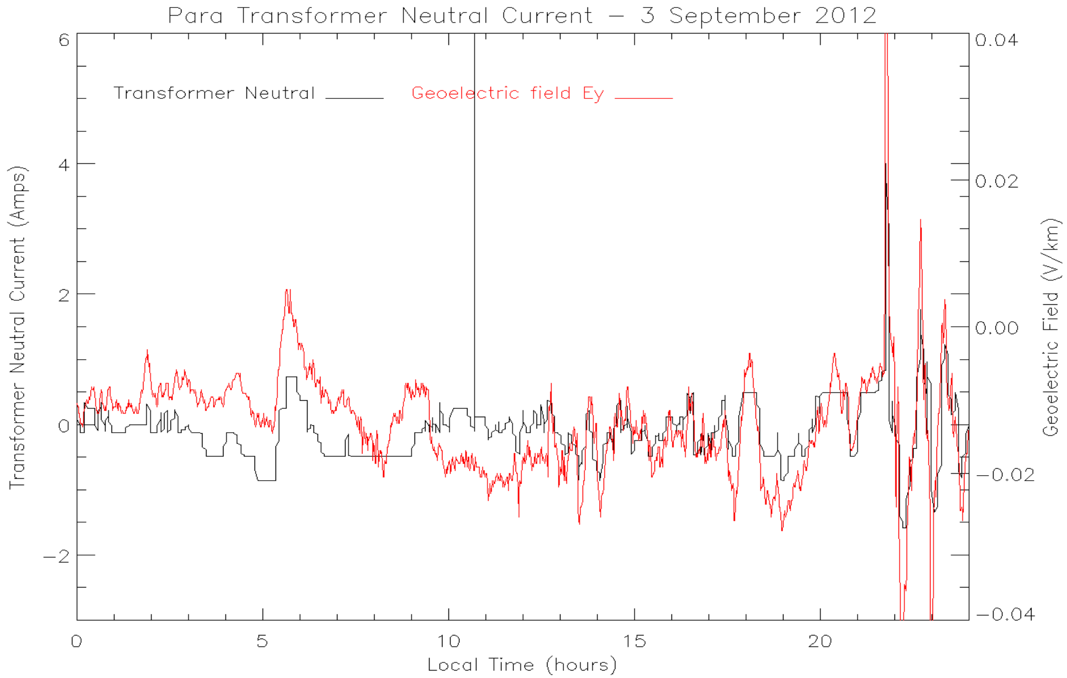
PREPARED BY: AEMO – Power System Security Working Group

VERSION: 1

DATE: 30 December 2011

FINAL





(Marshall et al., submitted to Space Weather)

Power Networks - Australian Region

TISN
FOR CRITICAL INFRASTRUCTURE
RESILIENCE

ESGBULLETIN

August 2012

MESSAGE FROM THE ESG CHAIRS

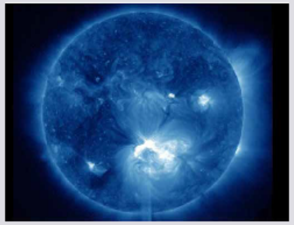
Dear ESG Members

The core value of the TISN has always been information sharing between critical infrastructure owners and operators. The information improves our understanding of both vulnerabilities and mitigation strategies and provides us with a greater appreciation of one's interdependencies.

The ESG is continually sharing information within the energy sector and with other critical infrastructure sectors through a number of projects and communication avenues. An important project that the ESG is currently working on for the benefit of both ESG and other TISN members is the guide to electricity disruptions that aims to bridge the knowledge gap on how electricity shortages are managed. We hope to distribute this product to other sector groups prior to this summer's storm season and will hopefully have a final draft for members to endorse at the next ESG meeting.

...is issue...

- AEMO update on solar storm activity
- APPEA 2012 conference summary
- Industry access to Australian Government classified information
- Energy Networks 2012



SOLAR FLARES BEING MONITORED

A large solar flare in mid-July has highlighted the importance of monitoring the impact of space storms on the NEM transmission network.

As previously reported in AEMO Energy Update, it was thought solar flares only affected infrastructure in the northern hemisphere but recent studies in New Zealand and South Africa raised the possibility that Australian power infrastructure may be affected by storms on the surface of the sun.

Group Manager Real Time Operations Mark Miller said minor solar storms aren't likely to have an effect on Australia's power infrastructure but large Coronal Mass Ejections (CMEs) have the potential to cause damage.

"Coronal Mass Ejections cause geomagnetic storms on earth, which can cause geomagnetically induced current (GIC) on transmission lines. These DC currents create harmonics on the AC network and over-heating on transformers or reactors. This can lead to transformer and reactor failures and disruption to the network," Mark said.

In recent months AEMO and the Power System Security Work Group (PSSWG), which consists of representatives from Transmission Network Service Providers (TNSPs) together with the Bureau of Meteorology, IPS Radio and Space Services, have been assessing the potential impact of solar storms which tend to peak every 11 years, with the next level of heightened activity occurring over 2012-13.

Fortunately the recent solar flare did not impact the power system.

AEMO has been working with TNSPs to assess the potential effects of solar storms by installing monitoring equipment on the transmission network. Data is already being collected through the SCADA system in South Australia via Electranet and Queensland via Powerlink. Over the next few months data will become available from other TNSPs.

AEMO also receives warning emails from IPS Radio and Space Services if there is a possibility of a solar flare occurring in the coming days. These warnings are like a weather forecast for solar activity.

The damage caused by solar flares is not to be underestimated. A period of solar storm activity in March 1989 saw virtually the entire Canadian province of Quebec plunged into darkness. In total 21,500 MW of load and generation was lost and it took more than nine hours to fully restore supply.

"The monitoring and mitigation measures we are implementing or considering are prudent and the cost is relatively small when compared to the damage that could be caused by solar storms," Mark said.

For more information about solar storm monitoring see:

ACE spacecraft – the red trace in the top box is the north-south magnetic field – if it goes below -20nT for an hour, a significant storm will probably result.

http://www.swpc.noaa.gov/ace/MAG_SWEPAM_24h.html

Magnetic storm index –
http://www.ips.gov.au/Geophysical/1/2/4

Australian Energy Market Operator Stakeholder Newsletter 7

Ongoing development of SOP's for Space Weather

- Further monitoring results
- More extensive modelling to identify vulnerable components
- Feedback of findings to SOP's

Extreme Space Weather (ESW) Model

- Most space weather impacts "of concern" in Australian/NZ region associated with extreme events

- Develop model to forecast extreme events to assist critical infrastructure

- Generalised Linear Model (GLM) techniques – not resource intensive

- Event-based analysis (M.Terkildsen)

- Requirements:

  LATENCY
  - 'Long range' warning (> 12 hours) ◊ Based on solar data only (in ASFC)
  - 'Short range' alert (~ 1 hour) ◊ Based on solar data + ACE

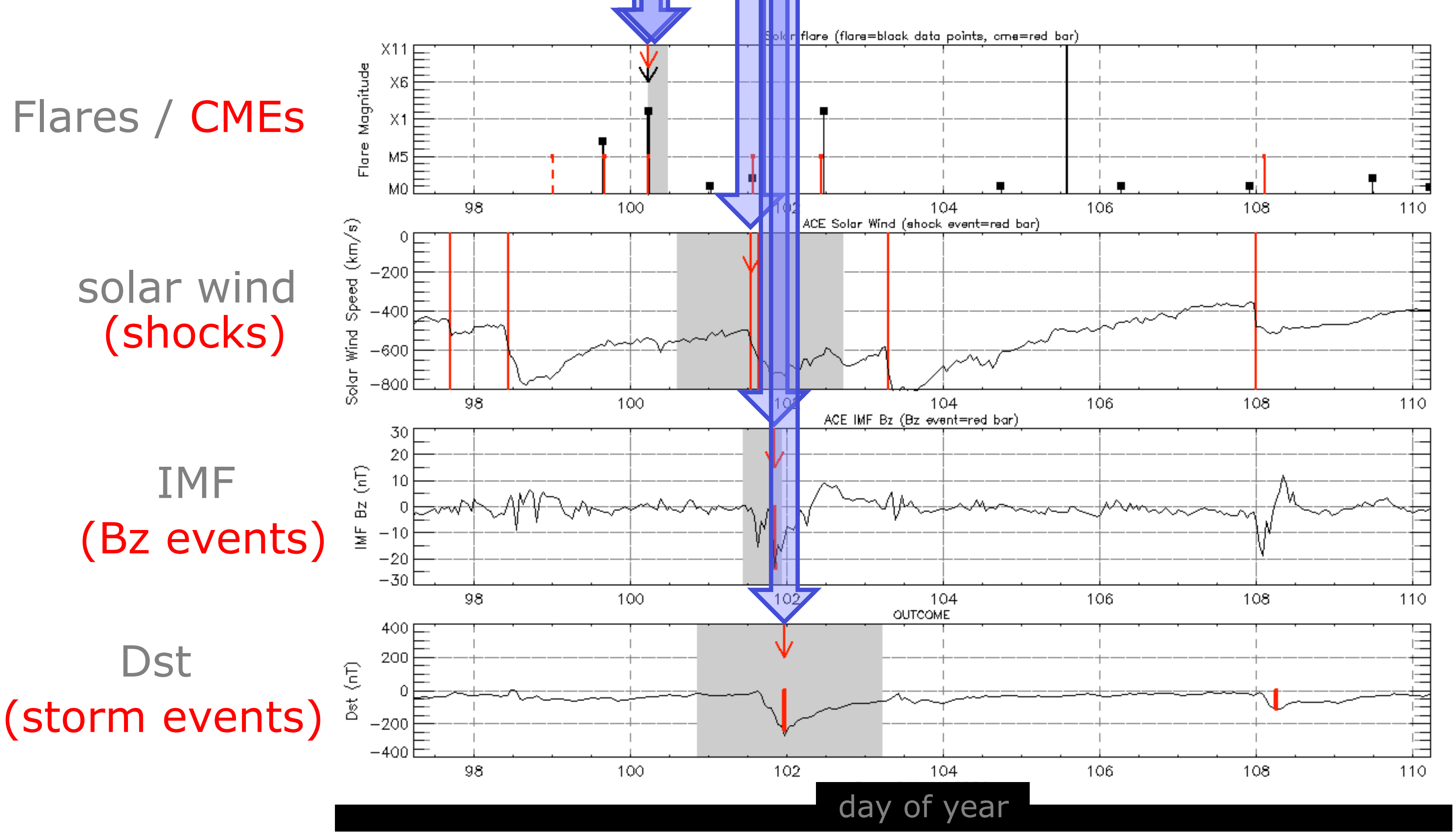
  ACCURACY
  - Long range: Optimise to minimise missed events
  - Short range: Optimise for forecast accuracy

  SIMPLICITY
  - Design for active use in space weather forecast environment

ESW Model Events

Event- based analysis

solar disturbance event



ESW Model Parameters

Model covariates (the 'input data')

X-RAY FLARE

- Solar flare magnitude
- Solar flare duration

LOCATION OF SOLAR ACTIVE REGION

- Latitude of solar active region
- Longitude of solar active region

CME CHARACTERISTICS

- Presence of Halo CME (CME width)
- CME speed

SOLAR CYCLE

- Solar Cycle Phase

[SOLAR WIND / IMF

- IMF Bz
- Solar wind shock]

ESW Model GLM

Generalised Linear Model

Response variable (what is being modelled)

$$dstN = \begin{cases} 0 & Dst \geq -50 \\ |Dst + 49| & else \end{cases}$$

Model (a GLM)

$$\ln(\mu_i) = \alpha_0 + \alpha_1 x_{i1} + \alpha_2 x_{i2} + \cdots + \alpha_m x_{im}$$

Training data (for fitting model coefficients)

15 years data (1996 – 2010)

Prediction (a binary output)

$$y_i = \begin{cases} 0, & p_i(y \mid \mu) < p_{thresh} \\ 1, & p_i(y \mid \mu) \geq p_{thresh} \end{cases}$$

$x_{i1} \ldots x_{im}$ → Input variables

$a_0 \ldots a_m$ → Coefficients (to fit)

$p_i(y \mid \mu)$ → Response distribution

p_{thresh} → Threshold on event probability used to produce binary prediction (ESW event/no-event). Optimised for required model performance.

ESW Model Validation

Model validation: Solar data only

Optimising for no missed events (false negatives = 0)

Leave-One-Out Cross Validation (LOOCV)

true positives	6
false positives	25
false negatives	0
total events	644

Probability threshold
(to determine binary outcome)

ESW event threshold (dst < -250)

ESW Model GLM

Model validation: Solar data + IMF Bz (< -20nT)

Optimised for <u>no missed events</u> (false negatives = 0)

Dichotomisation threshold

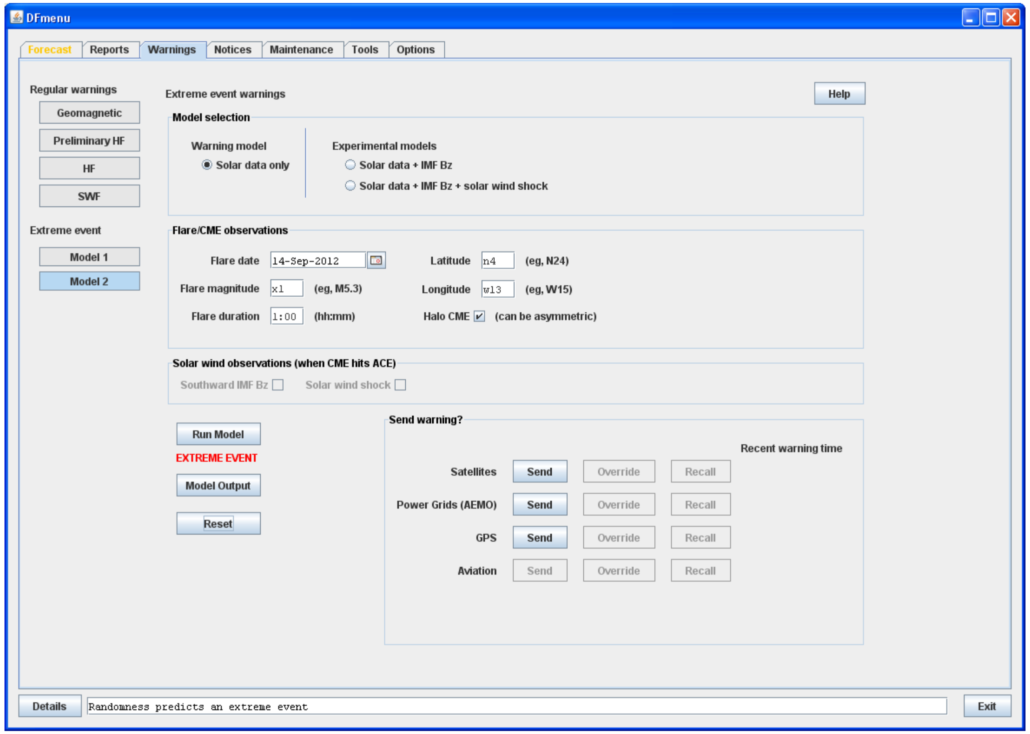
ESW event threshold

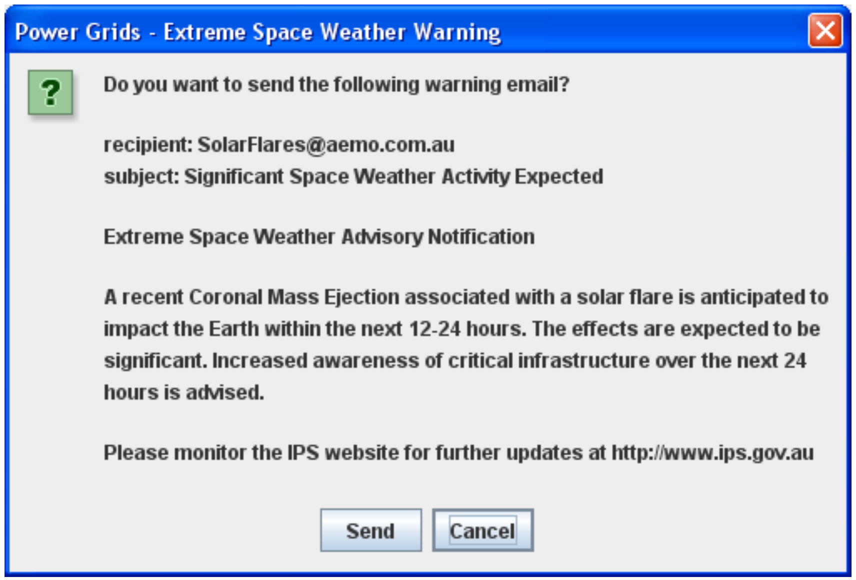
Leave-One-Out Cross Validation (LOOCV)

true positives	6
false positives	7
false negatives	0
total events	644

ESW Model Implementation

- Operational GUI in ASFC
- Uses Dst-based ESW models as a back-end, proving both binary and probabilistic forecasts for ESW
- Accepts a range of covariates for added flexibility
- Simple text warning message

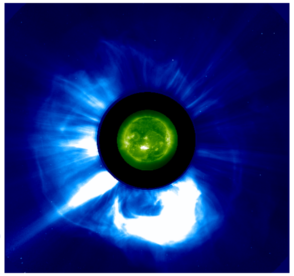


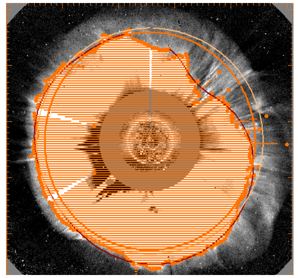


Future Developments

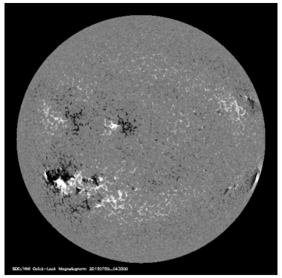
- ACE solar wind parameters
- CME symmetry parameter / CME "mass"

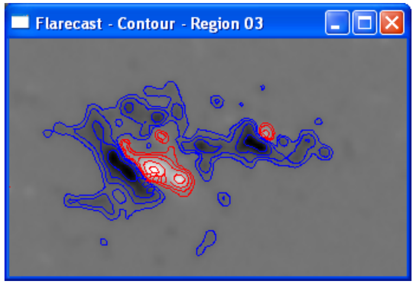
(e.g. Kim et al 2008, 2010)

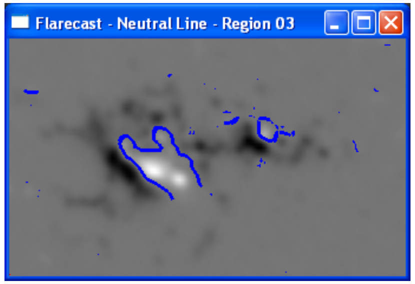


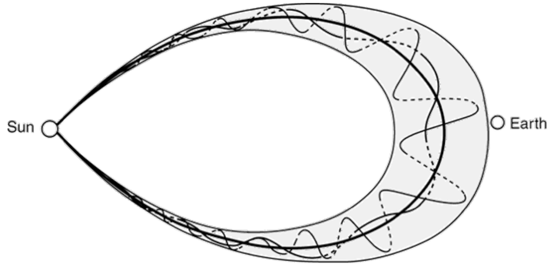


- Active region magnetic characteristics (proxy for IMF Bz events?)









- CME travel time (flare-shock interval) to replace CME plane-of-sky speed (a poor proxy for true CME speed)
- Type II / Type IV radio bursts
- Direct modelling of ESW parameters as response
  - GIC index
  - Ionospheric gradient index