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Space Weather Services

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4th AOSWA Workshop

24 - 27 October 2016

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Australian Bureau of Meteorology Space Weather Services

www.sws.bom.gov.au

- Originally **Ionospheric Prediction Service** (IPS) 1947-2014.
- 2014 Renamed "Space Weather Services" (SWS) section within Bureau of Meteorology **Hazards Prediction Branch**.
- office@ips.gov.au → sws_office@bom.gov.au

- **Australian Space Forecast Centre** (ASFC) team consists of
  - 4 Senior Space Weather Forecasters (SSWF's).
  - 7 Space Weather Forecasters (SWF's)
  - Weekly rotation cycle
- Move to 24/7 forecast centre coverage for significant events.

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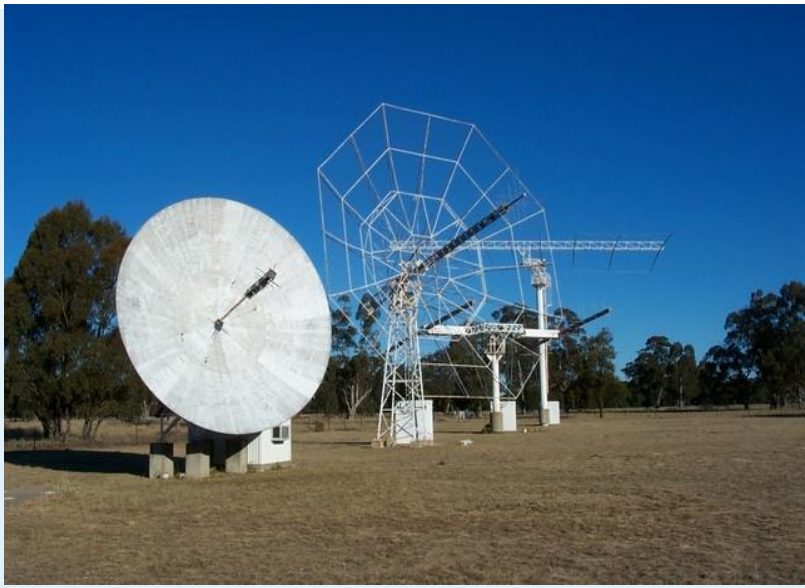
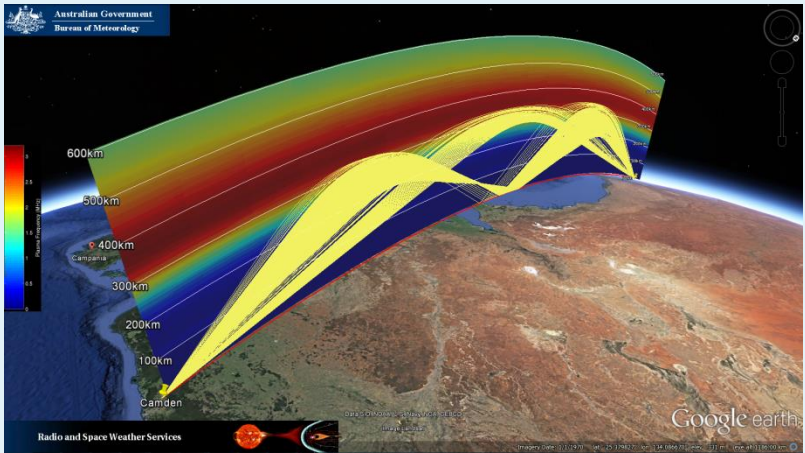
Overview

1. **Overview of Space Weather Services**
   - Space Weather Network
   - Online Services
2. **National Positioning Infrastructure Project**
3. **Ionospheric Modelling and Forecasting**
   - Data Driven Models
4. **Solar and Geophysical Forecasting tools**
   - Solar Forecast Tools
   - Severe Space Weather Model
5. **Recent engagement with …**
   - Critical Infrastructure Groups, Aviation, Industry, Government and General Public.





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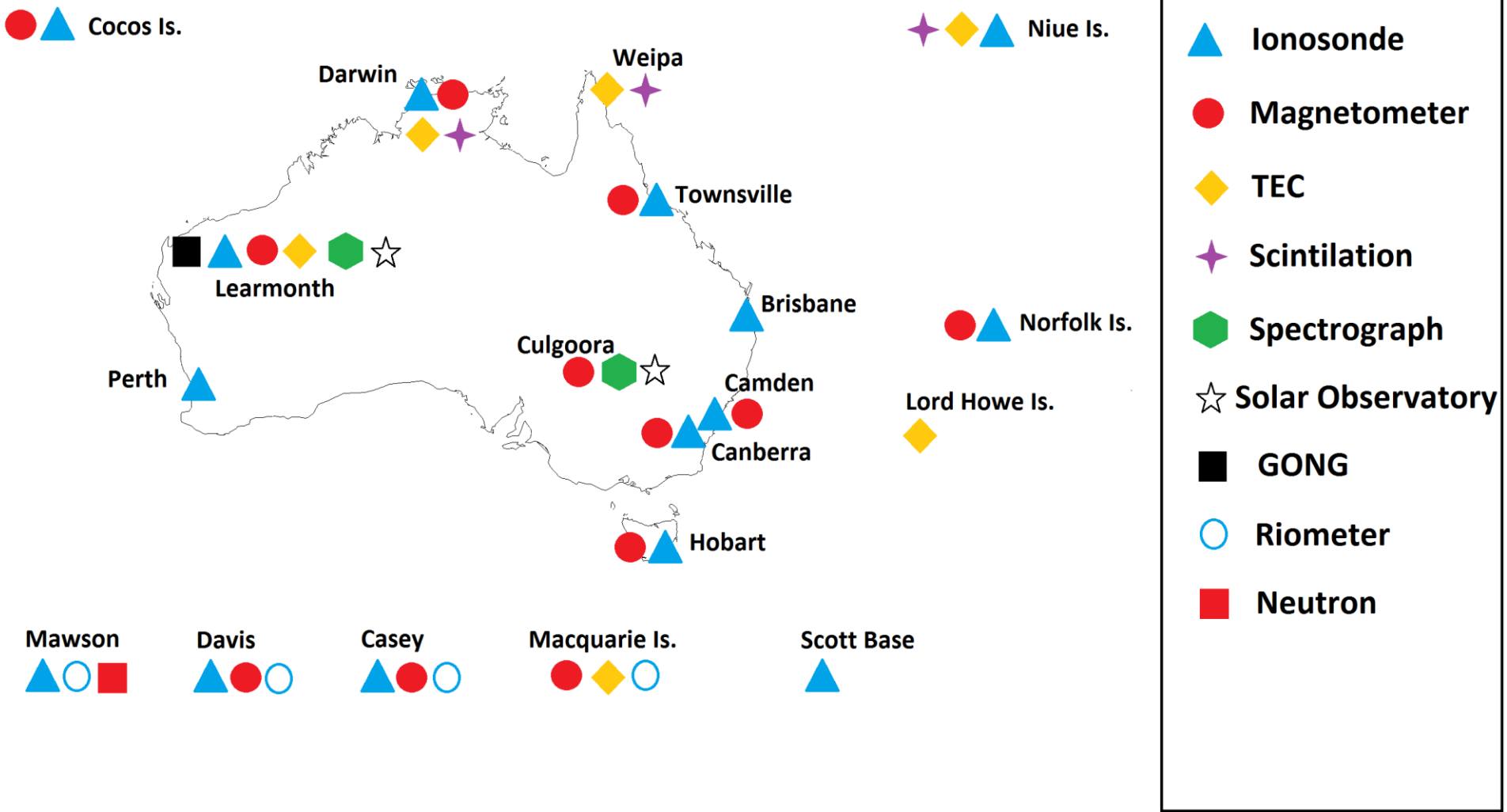
1. Space Weather Sensor Network



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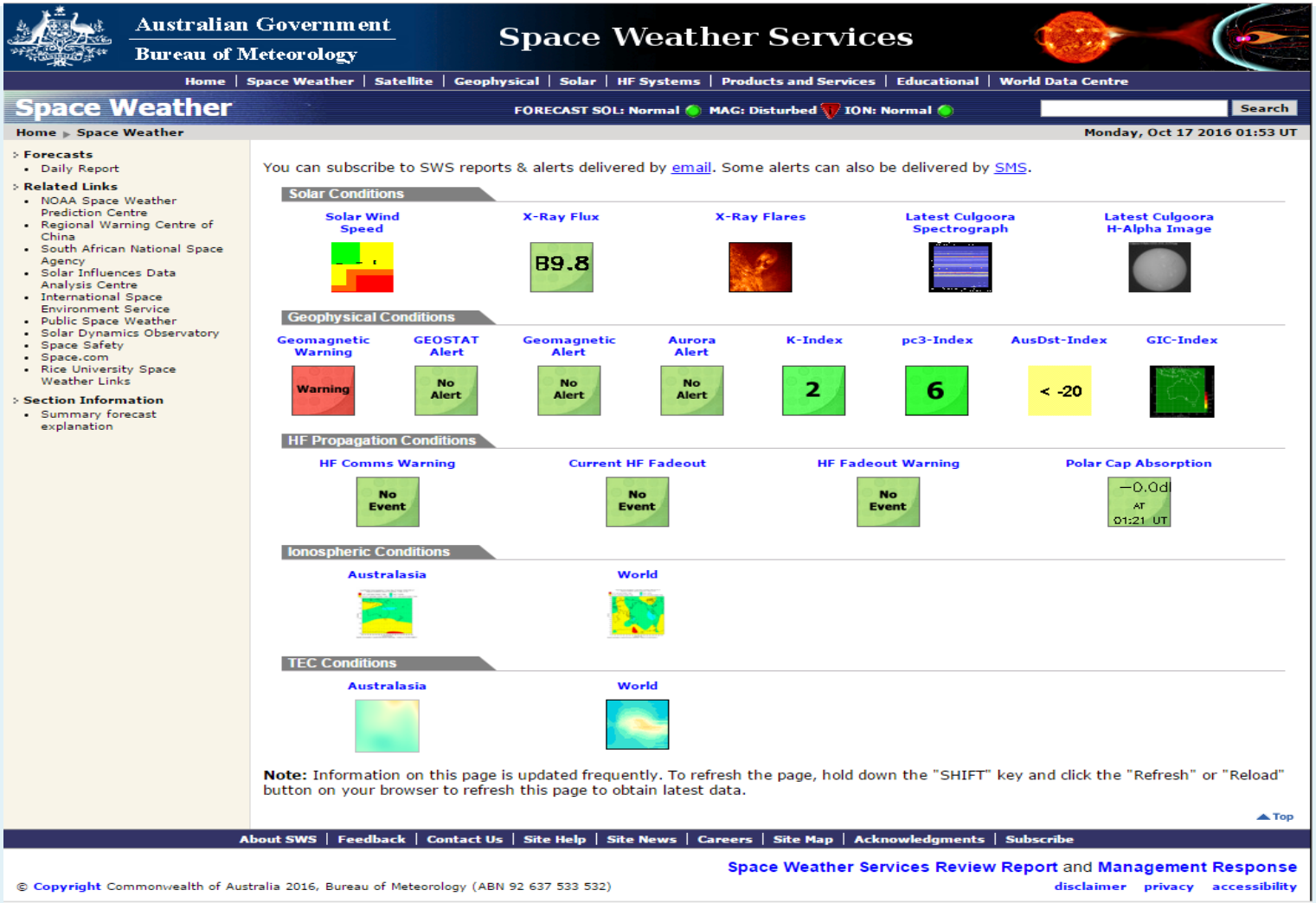
1. Online Products and Services



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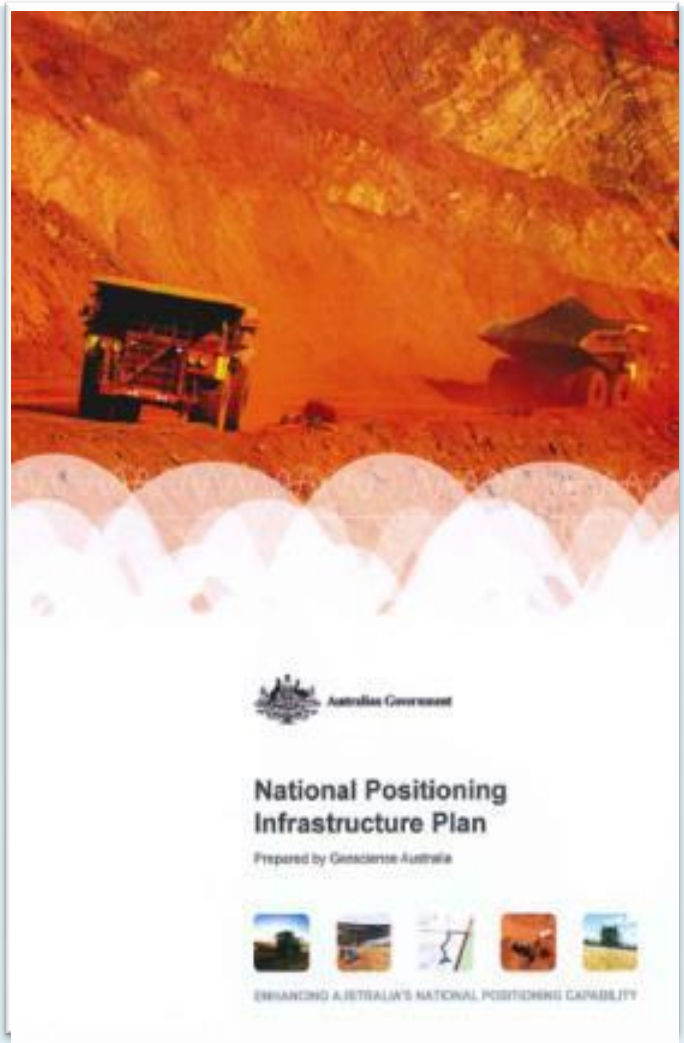
2. National Positioning Infrastructure

- 2.5 year research project with collaboration between
  - Bureau of Meteorology's Space Weather Services and…
  - Curtin University (co-lead), Geoscience Australia, LINZ, ThinkSpatial, Position Partners.
- Research challenge is to be able to provide sufficiently accurate ionospheric corrections in order to achieve ***cm*** level PPP-RTK positioning across the full service region at achievable reference network densities, and within an acceptable margin of service availability.
- Commenced: 1st Jan 2016
- Delivery: 30th June 2018



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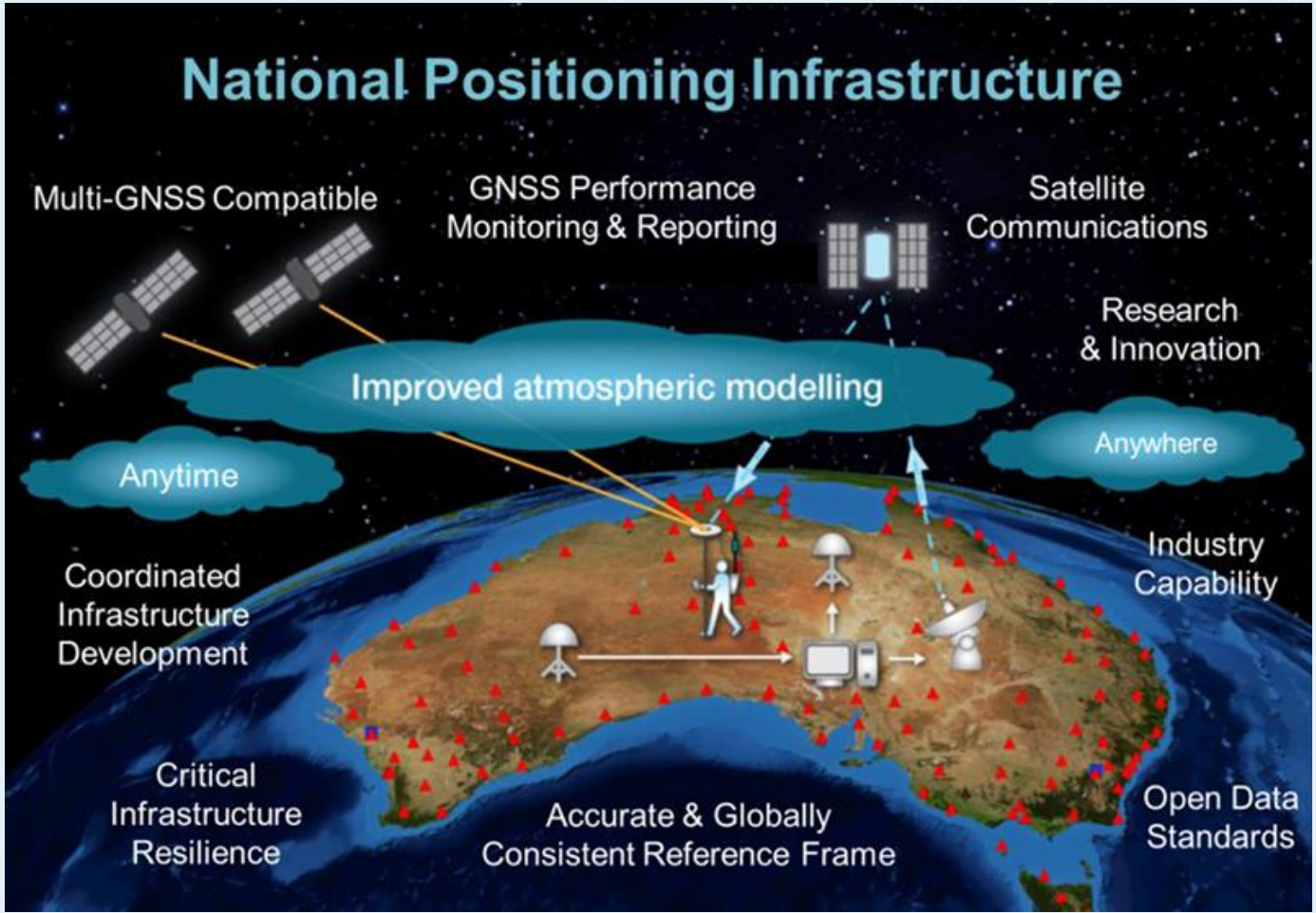
2. National Positioning Infrastructure

"Instantaneous, reliable and fit-for-purpose access to positioning and timing information anytime and anywhere across the Australian landscape and its maritime jurisdictions"



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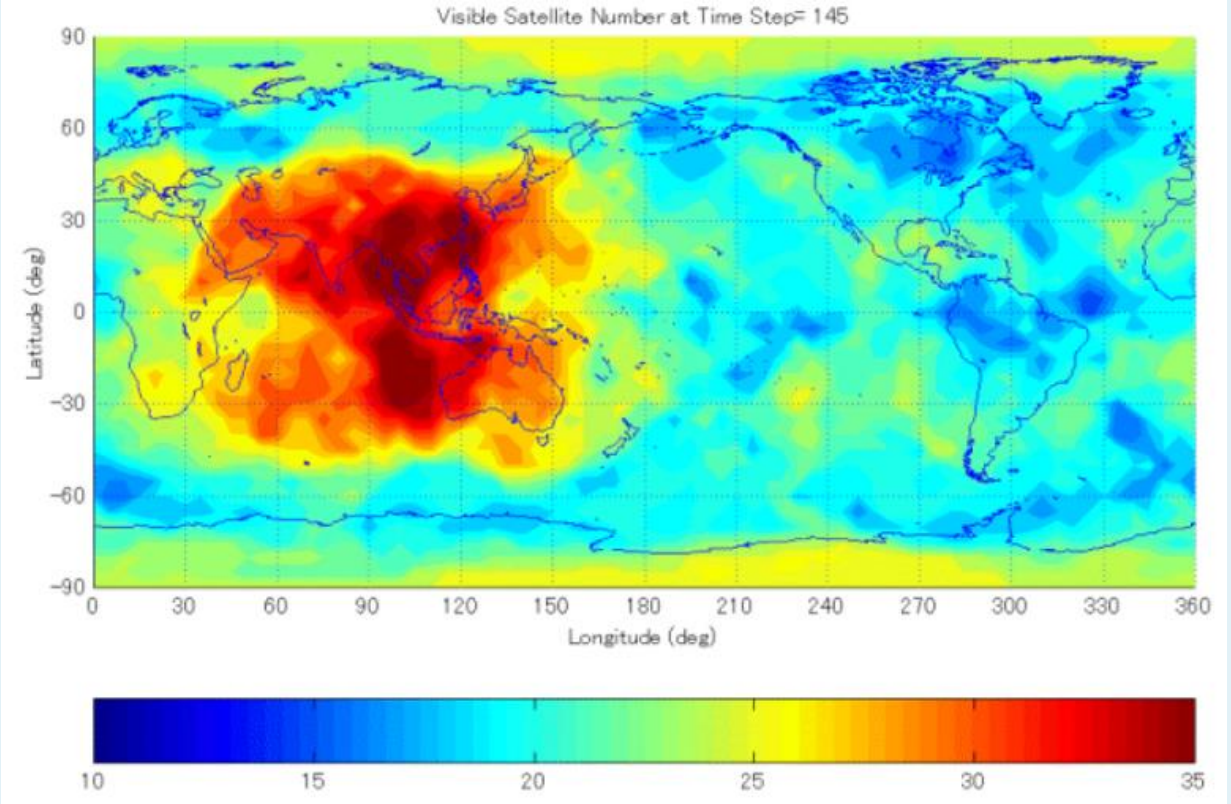
2. Multi-GNSS compatible.

- Australia is fortunately one of few countries that will receive positioning signals from six systems.
  - GPS - USA
  - QZSS - Japan
  - Beidou - China
  - Galileo - Europe
  - IRNSS - India
  - GLONASS – Russia
- Multi GNSS = Faster PPP convergence.



Visible GNSS satellites across the globe by 2020.
Copyright (c) 2009 Japan Aerospace Exploration Agency

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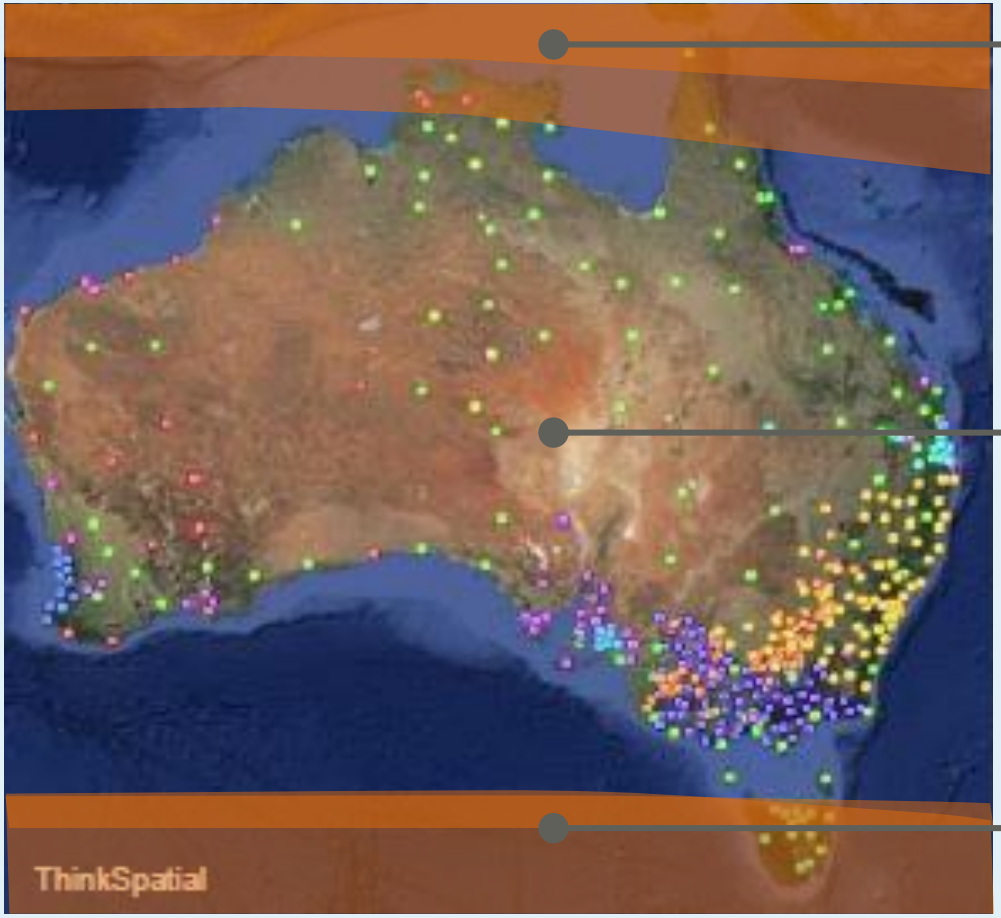
2. Ionospheric Modelling challenges



Low latitudes

Equatorial Plasma Bubbles (EPB)

Large spatial gradients

Ionospheric Scintillation

Mid latitudes

Storm-Enhanced Density (SED)

Medium Scale Travelling Ionospheric Disturbances (MSTID)

High latitudes

Storm-Enhanced (Sub-Auroral) gradients

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2. NPI project challenges

- CORS (Continuously Operating Reference Station) networks operated independently on an ad-hoc basis by state governments and industry
  - However, an Australia wide CORS network (@70km spacing) would be very expensive.
  - NPI planning will investigate ground and space-based delivery systems.
- PPP-RTK provides standard PPP users with additional information (ionosphere, ephemeris data, clock offset) derived from a reference network, enabling high accuracy & low convergence times.
  - Bottleneck is with the accuracy with which ionospheric corrections must be provided to the user.
- Success of the PPP-RTK implementation for the NPI requires a significant improvement in ionospheric modelling accuracy over existing capability.
  - precise sub-TECU ionospheric corrections required to enable ubiquitous rapid positioning at the level of a few cm.

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3. Data Driven Ionospheric Modelling

- **Model types**
  - Regressions
  - Neural networks
  - Decision trees
- **Data requirements**.
  - Training / test data covers long time period (> 1 solar Cycle).
  - All model parameters required at each time point (all or none).
  - Operational data consistent with training data.
- **Benefits**
  - Simpler to develop & implement.
  - Exploits considerable archive of space weather data.
- **Limitations**
  - Availability of relevant and suitable data for training / real time operation.
  - Trend towards climatology in poorly specified models.

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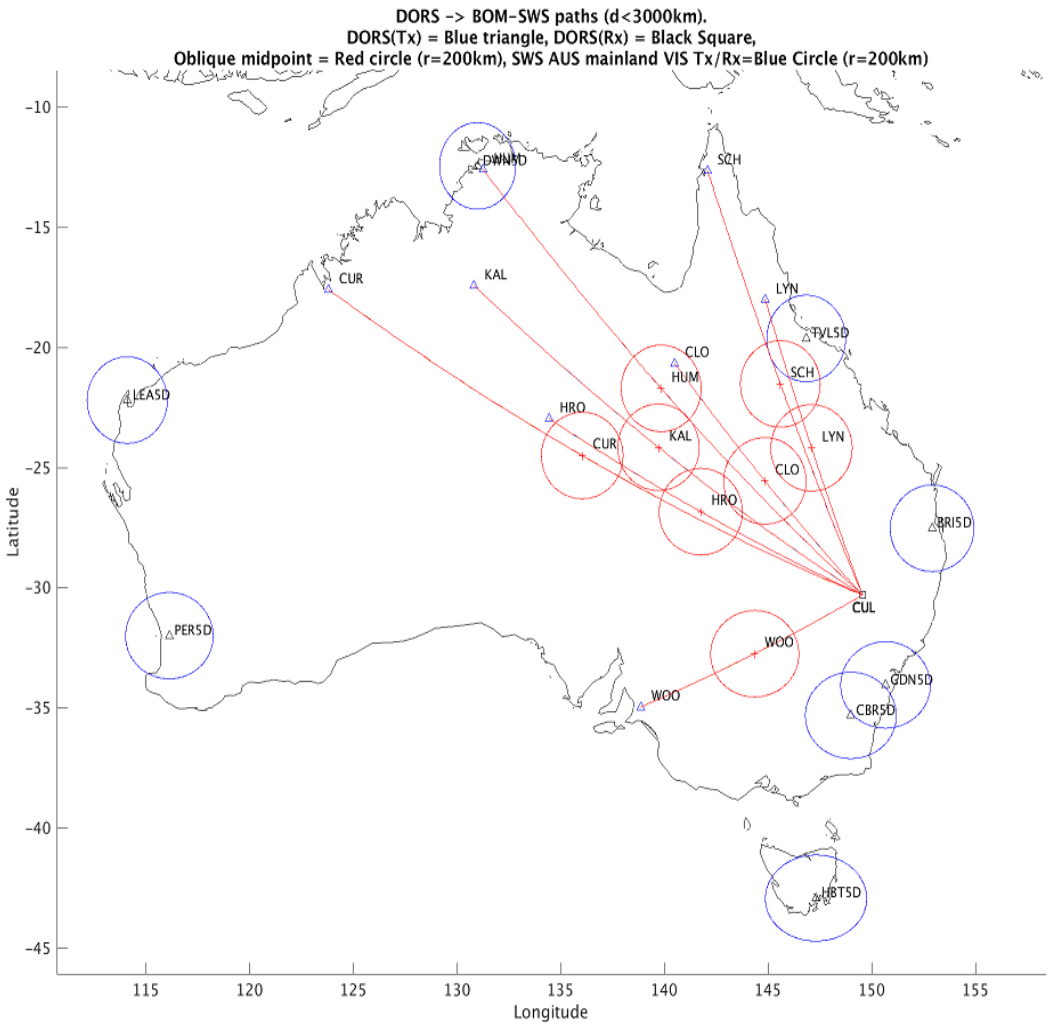
3. Vertical + Oblique sounder network

- Trialing use of both Vertical and Oblique ionograms.
- 8 VIS (Vertical Incidence Sounders) on the Australian mainland and Tasmania, plus Niue, Norfolk and Cocos Islands.
- 7 oblique paths via a DORS (Digital Oblique Receiver System) on loan from DST Group (formerly DSTO).
- Data fed into ionospheric data assimilation model
  - Increased spatial resolution of real time ionospheric maps.
  - Study/Observation of Medium Scale TID's.



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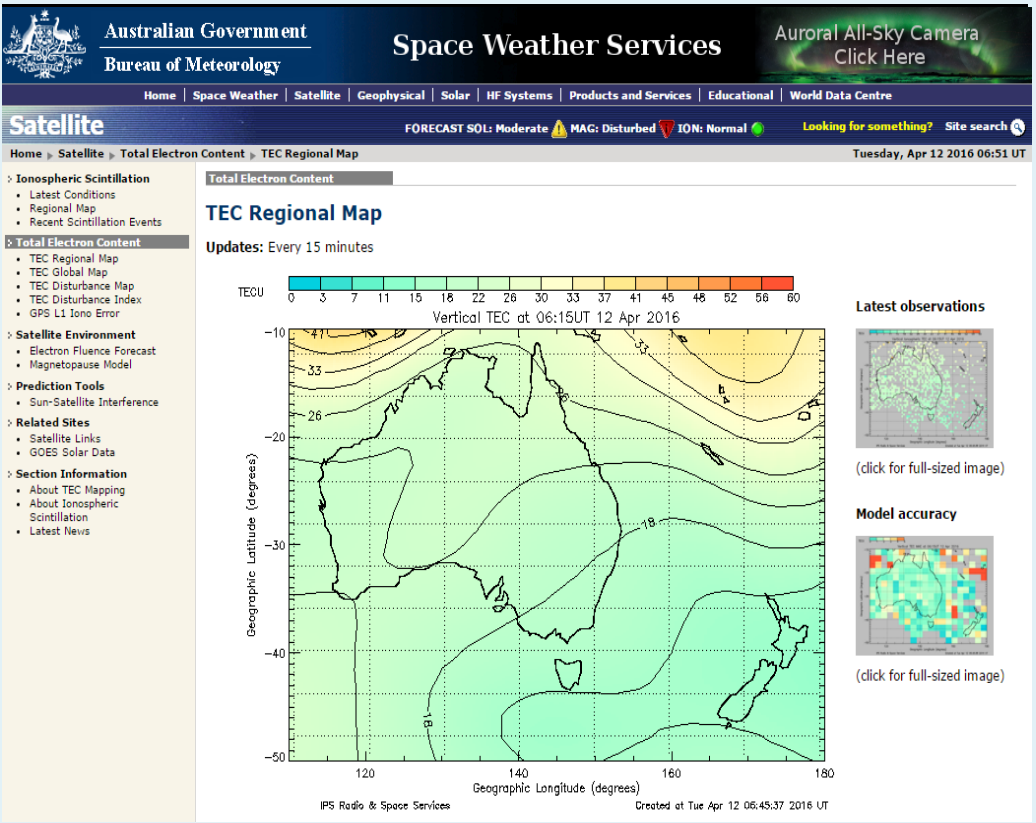
3. Regional Specific Forecasting and TEC/f_0F2

Modeling the Australian region



- **Spherical Cap Harmonic Analysis (SCHA) for TEC mapping**

- **TEC/foF2 forecast model**
  - Combined use of the Principal Component Analysis (PCA) and artificial Neural Network (NN) for topside ionospheric model.
  - Utilise Neural networks due to the non-linearity of the ionosphere.

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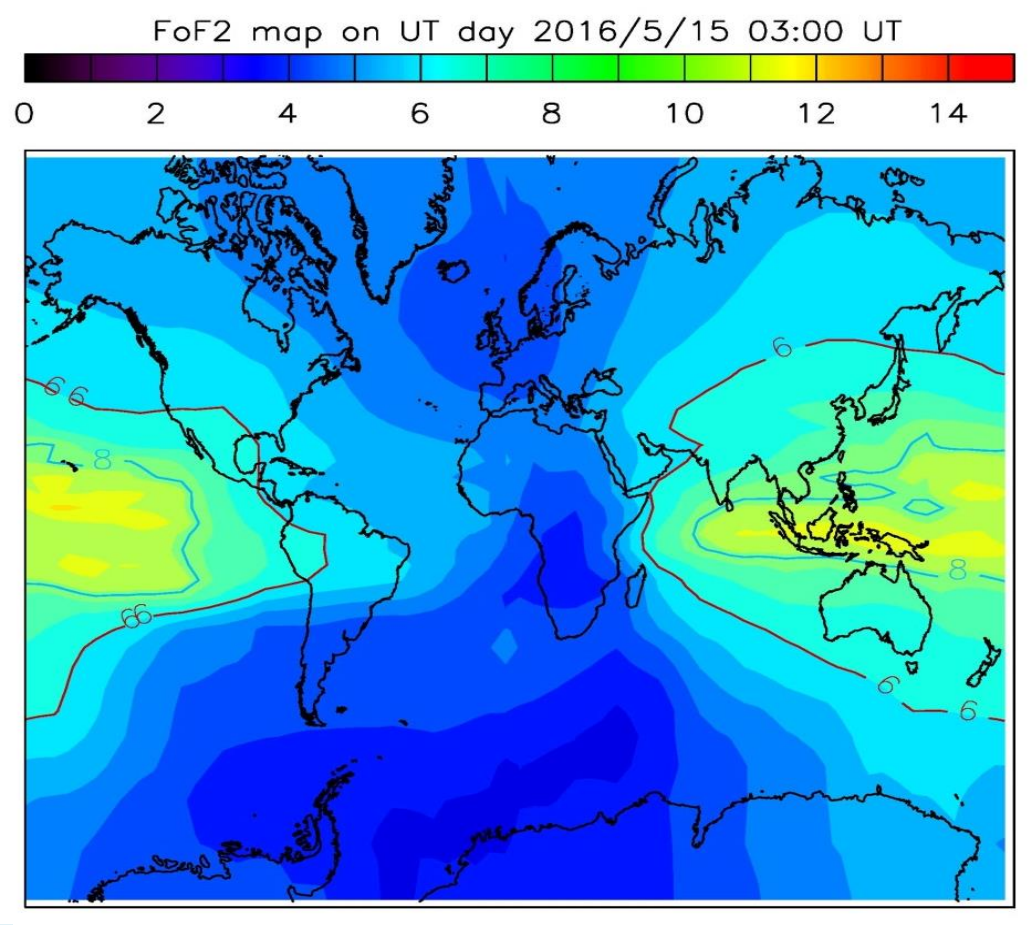
3. Quiet-Time f_0F2 model and Short Range Forecasting

- Motivation: Improvement in short term HF forecasting for the local Australian region.
- Study of data gathered from 50 years of f_0F2 observations.
  - Result: Model of non storm-time ionospheric support.
  - Support daily operations: 3 day T-Index forecast.

Further analysis into…

- Storm time behaviour and underlying trends.
- Cause and trends seen in this variability.



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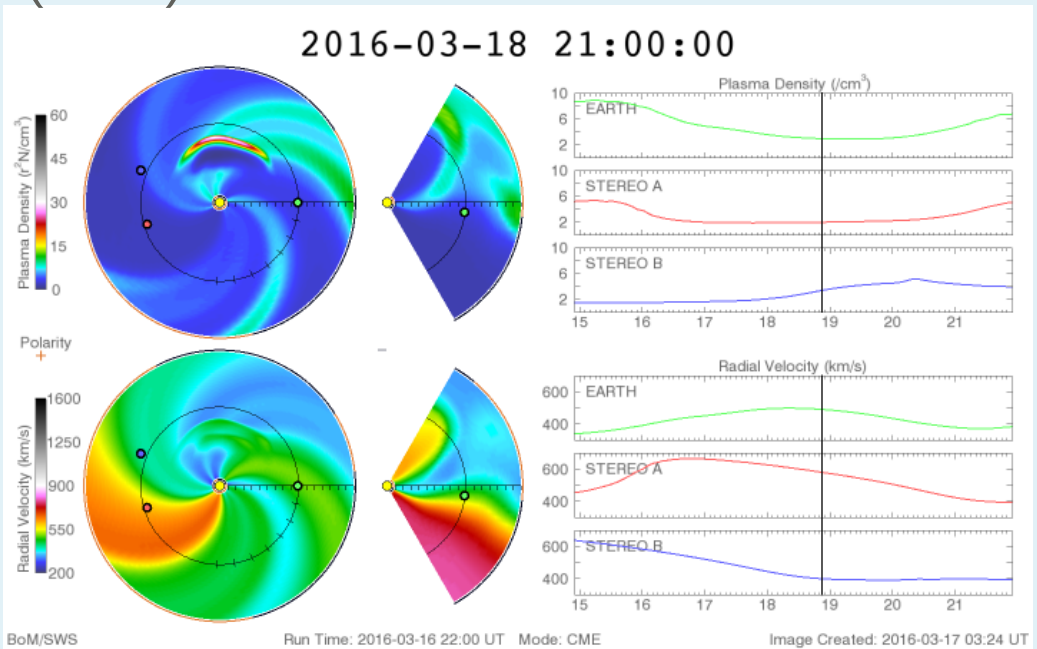
4. Solar + Geophysical Analysis Tools.

- Tools used to assist with daily forecasts and nowcasts in the ASFC…
  - Enlil (SWPC)
  - Flarecast Model (SWS)
  - Flare Probability Model (SWS)
  - Severe Space Weather model (SWS)

- **Enlil**
  - Low resolution simulations of ambient solar wind conditions.
  - CME modelling via parameters obtained from CAT tool.
  - Simulation times ~1hr (8 core Linux workstation).



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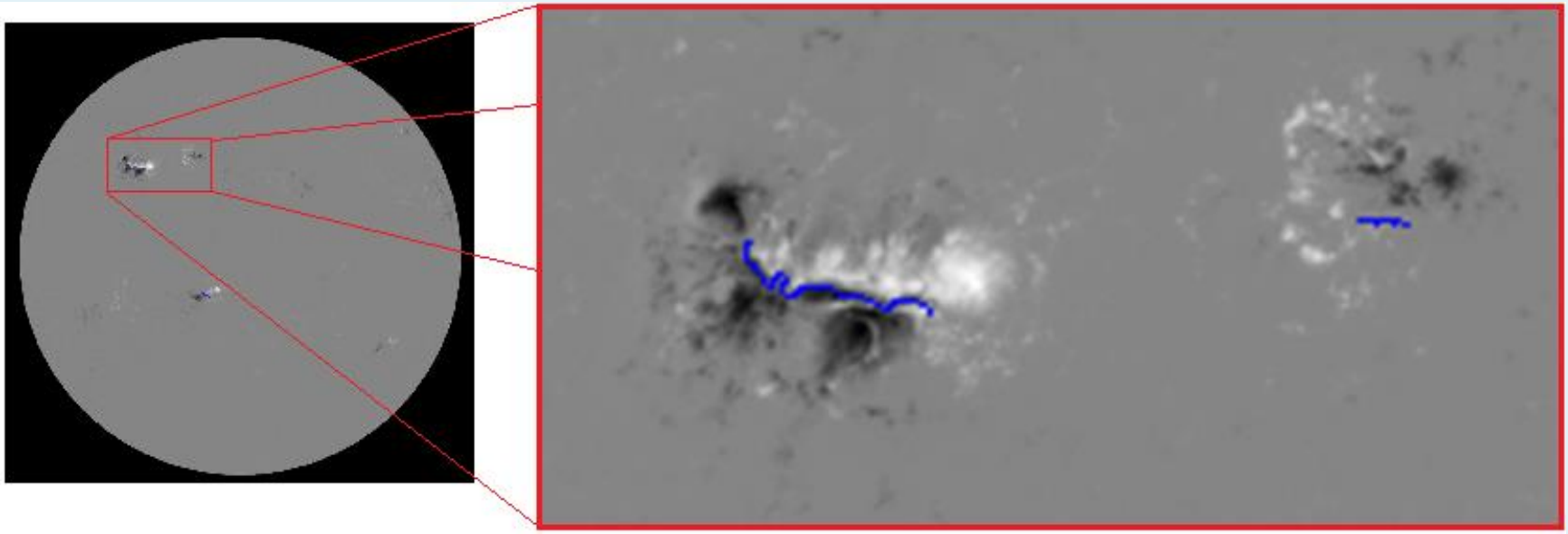
4. Flarecast

- Automated solar flare forecast based on region characteristics
- Deterministic model using
  - Solar Dynamic Observatory (SDO) or
  - GONG HMI solar magnetograms and image processing
- Output is generated in near real-time as new input data becomes available.
- Many different parameters of the active region and the neutral lines are estimated.
- Estimates capability of a region to produce M, M5+ or X-class solar flares.



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4. Flare Probability Model

Statistical Model: estimates the probability over the next 24 hours of an X-ray solar flare ≥ M1(≥ X1) in magnitude (peak flux)

Flare Probability (%)

	M	X	Mag	Zur	Area	Now at...
2389	1	1	β	Dso	50	S10 E06
2390	2	1	β	Dac	190	S16 W24
2391			α	Hsx	50	N06 E60
DISK	3	1				

Model selection is based on data availability, using all or a subset of these region characteristics:

- Location
- Classification
- Area / areal growth rate
- Number of spots
- Magnetic complexity
- Magnetic characteristics (length of neutral line, maximum N-S magnetic gradient, ++)
- Recent flaring history

Solar Conditions

Solar Flare Forecast

Updates: Hourly
Last update: 04:00 UT 10-Oct-2016

M (NOAA R1) **10%**

X (NOAA R3) **<1%**

Latest forecast of solar X-ray flare probability over the next 24 hours.

Solar Flare Probabilities

Region	≥ M1	≥ X1
full disk	10%	<1%
2598	<1%	<1%
2599	5%	<1%
2600	1%	<1%

Solar flare forecasts are also available through the WMO Information System (search for "solar flare"; requires registration).

Explanation of the NOAA Space Weather Scales are available through the NOAA Scales.

For more information on the solar flare forecast please visit the Solar Help Page.

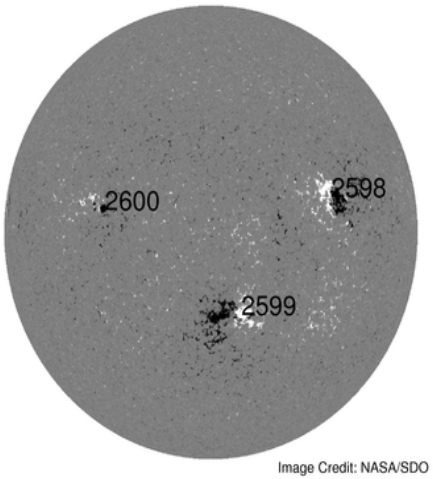

Image Credit: NASA/SDO

Full size image

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4. Severe Space Weather (SSW) Model

- Operational GUI used within the Australia Space Forecast Centre (ASFC).
- General linear statistical model as a back-end, providing both binary and probabilistic forecasts for SSW. Inputs include…
  - Location of active region on solar disk
  - X-ray flare magnitude/duration
  - Presence of halo CME (CME width)
  - CME speed
- Prediction of D_{st} < -250nT
- Short Duration GIC Warning
  - Automated solar wind shock detection (ACE)
- Sustained GIC Activity Warning
  - Sustained Bz southward event (ACE)

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5. Critical Infrastructure Groups

- Australian Energy Market Operator (**AEMO**) manages both wholesale and retail markets in electricity and gas across all of Australia (one of few worldwide).
- In-situ sensors for GICs (observed in both power grids and pipelines).
- SWS has implemented **Severe Space Weather** Warnings as an integral part of mitigating procedures for power networks.
- Development of the **GIC-index**, to quantify periods of GIC activity.
- Modelling the power grid response to space weather storms is intended to form part of the mitigating procedures and is a work in progress.

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Event Summary 21–25 June 2015

Date/Time (AEST)	Who	Event/Action
1102–1302 21 June	Bureau	A long duration solar flare was observed peaking at 1236
21 June	Bureau	Type IV radio emissions observed
21 June	Bureau	Earth directed plasma cloud or Coronal Mass Ejection (CME) confirmed with satellite imagery from the SOHO satellite
21-22 June	Bureau	Modelling and analysis of event indicate possible severe event—predicted time of arrival estimated to be 0600 23 June
1439 22 June	Bureau	Severe Space Weather WATCH issued
1457 22 June	AEMO	Issued market notice 49199—Severe Space Weather Watch
0359 23 June	Bureau	CME observed by ACE satellite
0407 23 June	Bureau	Issued a Severe Space Weather WARNING for short duration GIC
0435 23 June	Bureau	Peak GIC-index observed across space weather network monitors
0435 23 June	AEMO	Observed peak transformer neutral currents in power network
1425 on 23 June	Bureau	Observed storm peak—estimated Australian Dst-index of -236 nT
23 June	Bureau	Analysis of further Earth directed CME activity with predicted time of arrival of 1000UT on 24 June—severe warning window valid for 72 hours from initial time of issue
1446 25 June	Bureau	Severe space weather threat passed - issued Severe Space Weather warning CANCELLATION notice
1508 25 June	AEMO	Issued market notice 49206 - Severe Space Weather Watch cancellation

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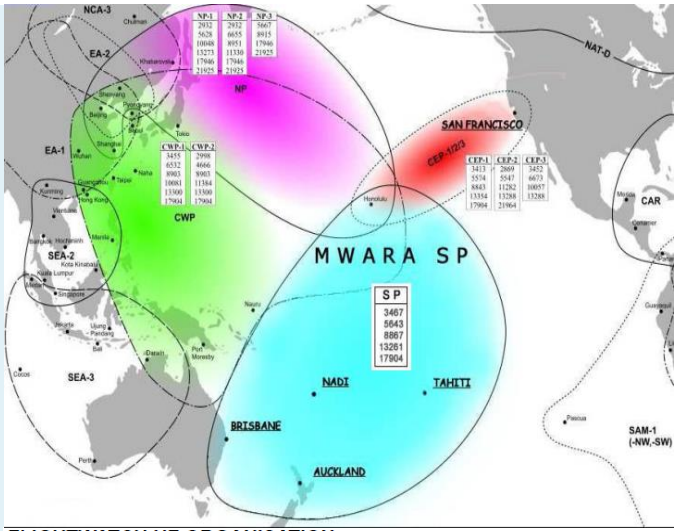
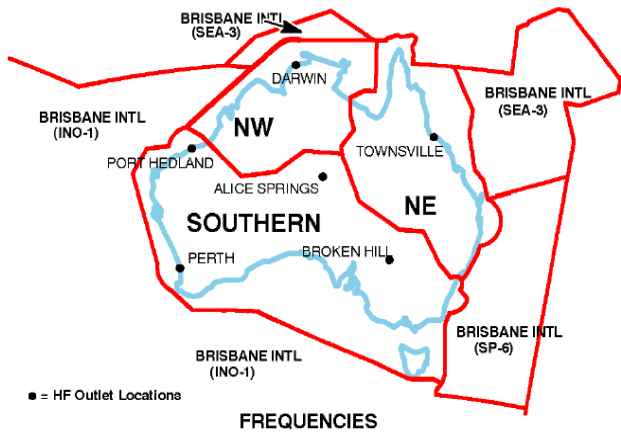
5. Aviation Space Weather strategy

To enable space weather products produced by the Bureau to be more specific and relevant to the aviation industry.

- Engagement with Aviation industry
  - working to tailor current products & services (impact focussed).
  - Identify un-met aviation user needs.
  - Determine need for specific Space Weather products through a common portal within the Bureau's Aviation Weather Services
  - ICAO regional requirements for HF radio, GNSS.
- Short term goals: Space weather training for aviation meteorologists.
- Longer term goals: Develop products & services addressing user requirements from consultations.



FLIGHTWATCH HF ORGANISATION



FREQUENCIES

NORTH WESTERN	3452	6541	8843	SP-6	BRISBANE INTL	3467	5643	8867	13261	17904 (KHZ)
NORTH EASTERN	3452	6610	8831	SEA-3	BRISBANE INTL	3470	6556	11396	13318	17907 (KHZ)
SOUTHERN	3461	6565	8822	INO-1	BRISBANE INTL	3476	5634	8879	13306	17961 (KHZ)

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5. Space Weather Users Workshop

- 2014: Review of Space Weather Services.
- Positive recommendations from reviewers, review committee and small number of key stakeholders.
- Nov 2015: SWS staged its inaugural Space Weather Users Workshop, over 100 stakeholders + members of the general public.

- January 2016: customer survey distributed through via email, feedback was received from over 700 customers.

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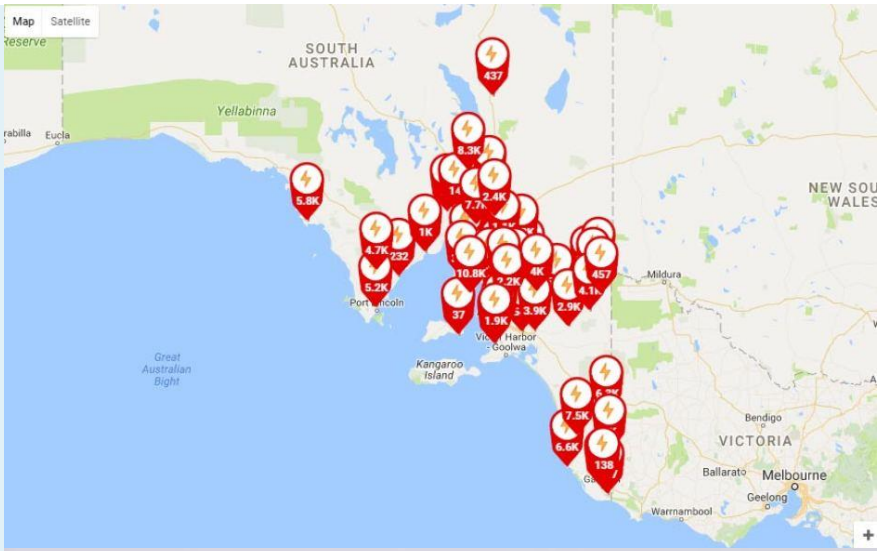
5. Infrastructure Failure Hazard Workshop

- NSW Government Infrastructure Failure Hazard Workshop, Sep 2016.
- Outline risks to critical infrastructure and potential impacts (state-wide) of a severe space weather event (Carrington level CME) in particular GIC's, transformer damage and power system instability.
- Recent severe weather (1 day after the workshop) in South Australia, the loss of 22 towers and 3 major transmission lines and a ***state-wide*** power outage of ~9 hours.
- A Severe Space Weather event has potential to cause long lasting damage to infrastructure with extensive outages on a similar and/or longer time scale.



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Thank you

Dr. Zahra Bouya

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