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Bureau of Meteorology

The logo for the CRC for SPATIAL INFORMATION, featuring a collage of images including a map of Australia, a satellite view of a city, a high-speed train, and a satellite in space. The text 'CRC for SPATIAL INFORMATION' is written in green and yellow on a dark grey background.

CRC for SPATIAL INFORMATION

The logo for CRC-si, featuring the text 'CRC-si' in a stylized purple font with a curved line above it.

CRC-si

Monitoring and mitigating space weather effects for GNSS applications

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¹ Space Weather Services – Australian Bureau of Meteorology

²Spire Global Inc



Overview

- Introduction to the Space Weather Services provided at the Bureau of Meteorology
- Space weather impact on precise positioning
- Introduction to PPP-RTK / National Positioning Infrastructure (NPI)
- 3D Tomographic Ionospheric Model
- Model performance / Validation (quiet conditions)
- September 2017 storm
- Comparative PPP-RTK performance through storm conditions
- Summary



Australian Bureau of Meteorology Space Weather Services

www.sws.bom.gov.au

- Originally Ionospheric Prediction Service (IPS) 1947-2008.
- 2008 Renamed "Space Weather Services" (SWS) section within Bureau of Meteorology Hazards Prediction Branch.
- Contact details changed `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.

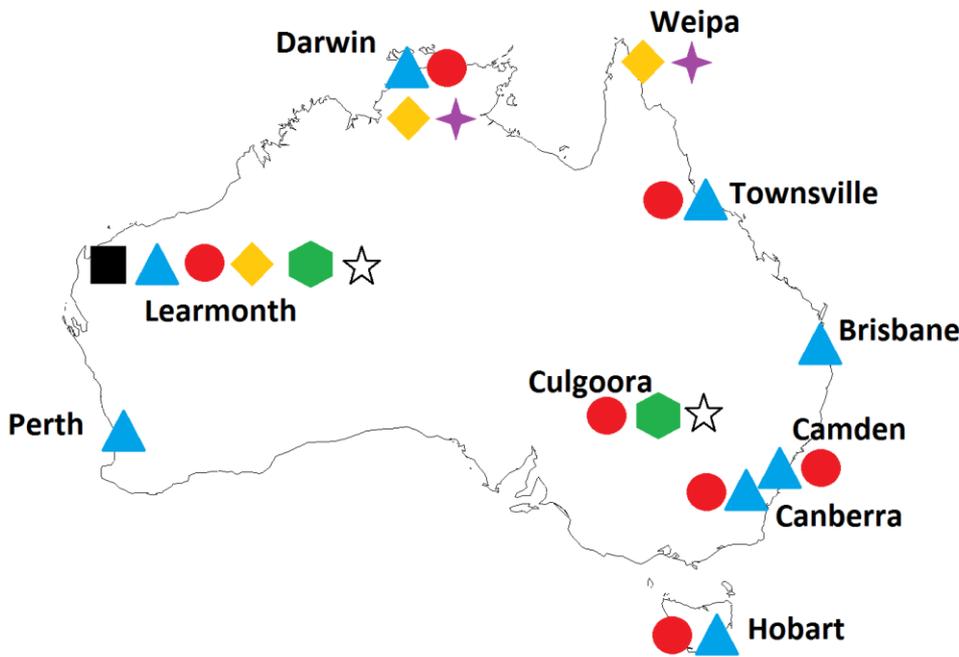




1. SWS Overview: Space Weather Network Sensors and Locations

● ▲ Cocos Is.

✦ ◆ ▲ Niue Is.



- ▲ Ionosonde
- Magnetometer
- ◆ TEC
- ✦ Scintillation
- ◆ Spectrograph
- ☆ Solar Observatory
- GONG
- Riometer
- Neutron

Mawson
▲ ○ ■

Davis
▲ ● ○

Casey
▲ ● ○

Macquarie Is.
● ◆ ○

Scott Base
▲



1. SWS overview: Online Products and Services

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Space Weather Services

Home | Space Weather | Satellite | Geophysical | Solar | HF Systems | Products and Services | Educational | World Data Centre
Looking for something?

Space Weather

FORECAST SOL: Moderate ⚠️ MAG: Normal 🟢 ION: Moderate ⚠️
Wednesday, Apr 20 2016 05:21 UT

You can subscribe to SWS reports & alerts delivered by [email](#). Some alerts can also be delivered by [SMS](#).

Solar Conditions

Solar Wind Speed 	X-Ray Flux B2.8	X-Ray Flares 	Latest Culgoora Spectrograph 	Latest Culgoora H-Alpha Image
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Geophysical Conditions

Geomagnetic Warning Warning	GEOSTAT Alert No Alert	Geomagnetic Alert No Alert	Aurora Alert No Alert	K-Index 1	pc3-Index 5	AusDst-Index > -20	GIC-Index
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HF Propagation Conditions

HF Comms Warning Warning	Current HF Fadeout No Event	HF Fadeout Warning No Event	Polar Cap Absorption 0.1dB <small>AT 05:17 UT</small>
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Ionospheric Conditions

Australasia 	World
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TEC Conditions

Australasia 	World
------------------------	------------------

Note: Information on this page is updated frequently. 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.

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Space Weather Services Review Report and Management Response

disclaimer privacy accessibility



Precise positioning and space weather

Space weather impacts vary by system:

Single-frequency positioning: Impacted by absolute ionospheric delay

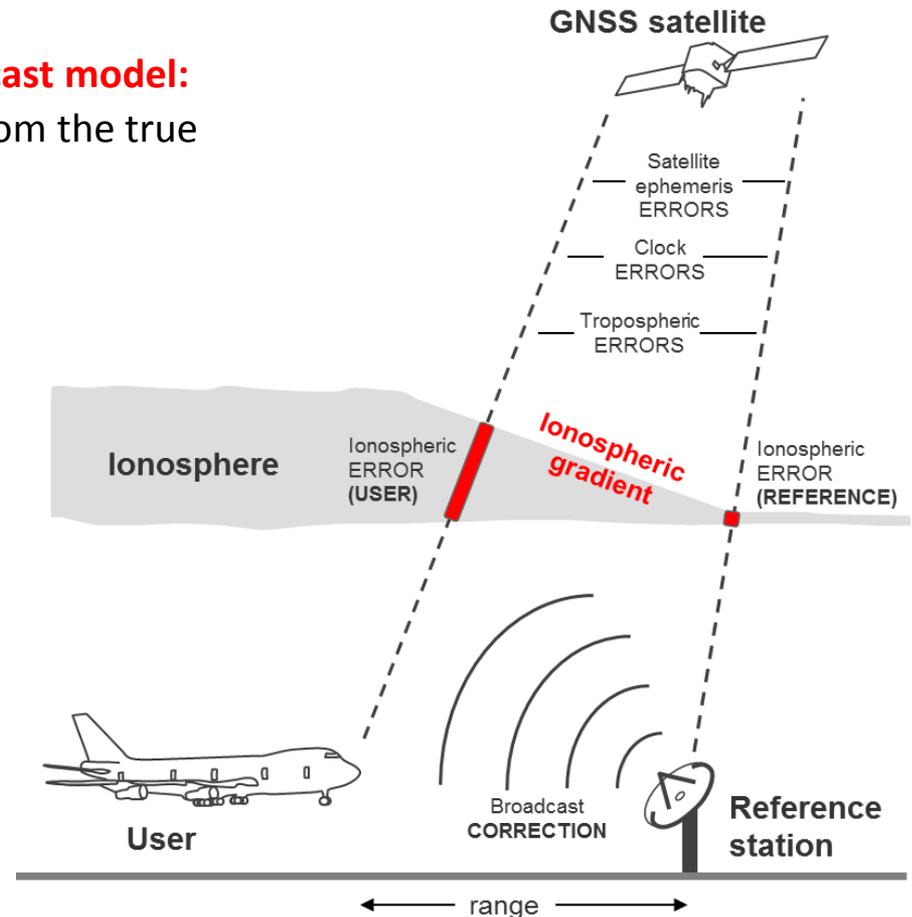
Single frequency positioning utilising broadcast model: impacted by deviation of Klobuchar model from the true ionosphere.

Differential / augmented positioning: Most significantly impacted by spatial gradients in the ionosphere

Network RTK: Impacted by non-linear gradients and ionospheric variability with small spatial scales

Positioning using pseudorange → ionospheric error directly impacts positioning algorithm

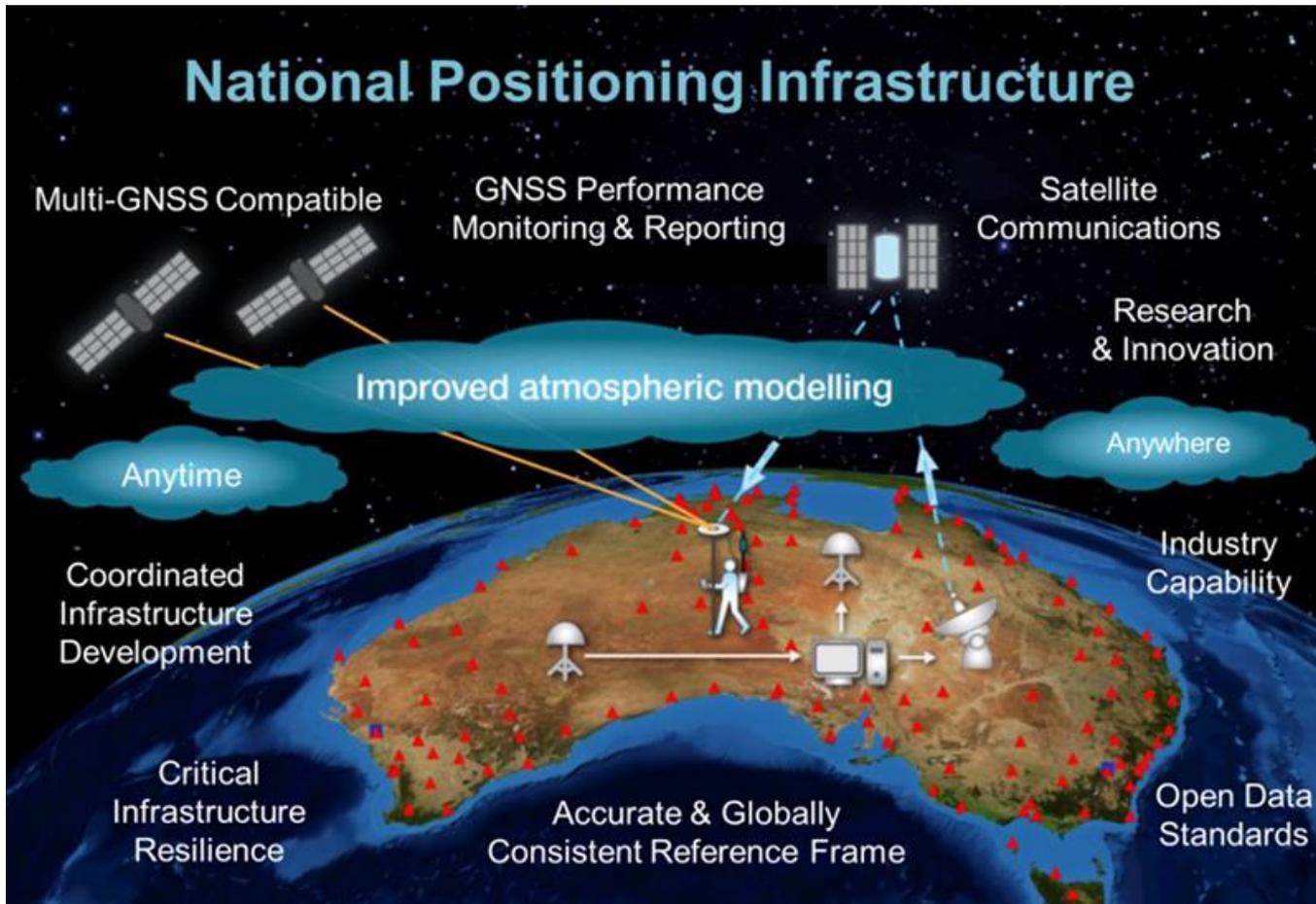
Positioning using carrier phase → ionospheric error impacts ambiguity resolution / positioning





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"





3D Tomographic ionospheric model: 3DB-tomion

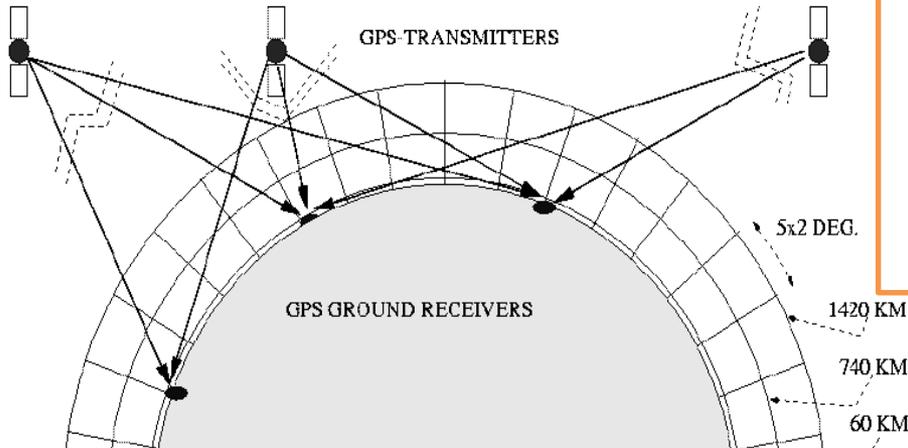


Figure from M. Hernandez-Pajares, J.M. Juan, J. Sanz, O.L. Colombo, Improving the real-time ionospheric determination from GPS sites at very long distances over the equator, J Geo Res, V. 107, No A10, 1296, doi:10.1029/2001JA009203, (2002).

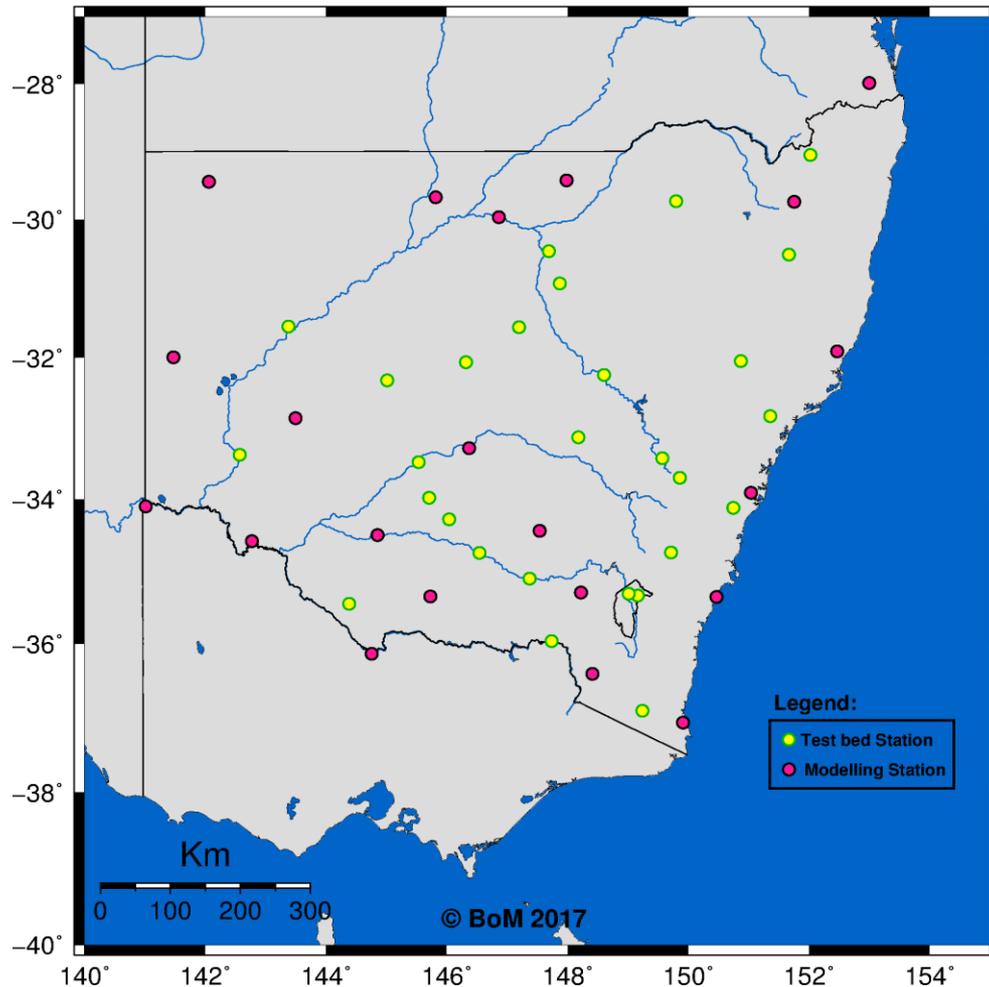
$$\tilde{S}_r^S = \int_{P_r}^{P_s} N_e dl + d_{r,GF} - d_{,GF}^S$$
$$N_e \approx \sum_{ijk}^{IJK} c_{ijk}(t) \cdot \psi_i(\lambda) \cdot \psi_j(\theta) \cdot \psi_k(h)$$

- \tilde{S} : Biased Slant Total Electron Content.
- N_e : Electron Density.
- d : Delay Code Bias.
- ψ_i : Basis function (e.g. splines).
- $c_{ijk}(t)$: Basis function coefficient
- I, J, K : Number of basis functions in each dimension.

- No thin-shell approach, thus reducing miss-modelling.
- TEC is computed by integration of N_e .
- Receiver and satellites DCBs do not depend on geometry, whereas STEC does \rightarrow geometrically decorrelated from STEC.



Ionospheric sounding network



- Reference Network (21 GPS receivers; red dots)
- Test sites (28 receivers; yellow dots).



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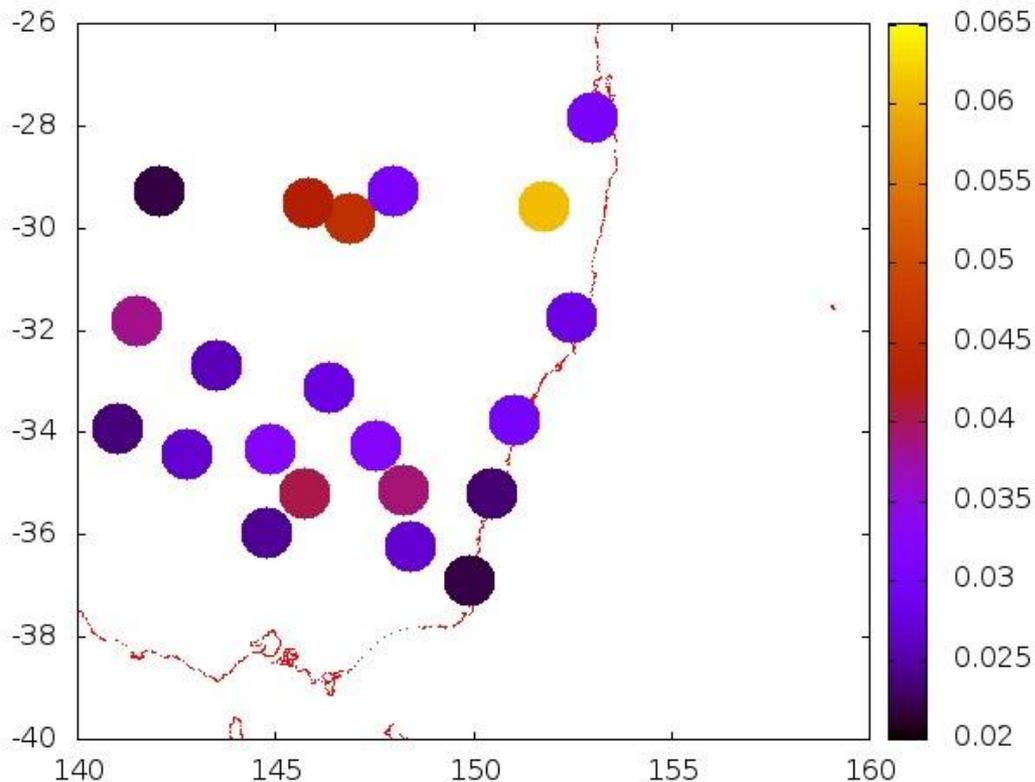
How accurate is the 3D B-splines ionospheric model?



Ionospheric model performance

Post-fit residuals

- Compares the raw input data with the modelled output



Highly accurate model

- RMS ranges from **0.02 to 0.07 TECu**.
- No geographical trend due to the local-support feature of B-splines.



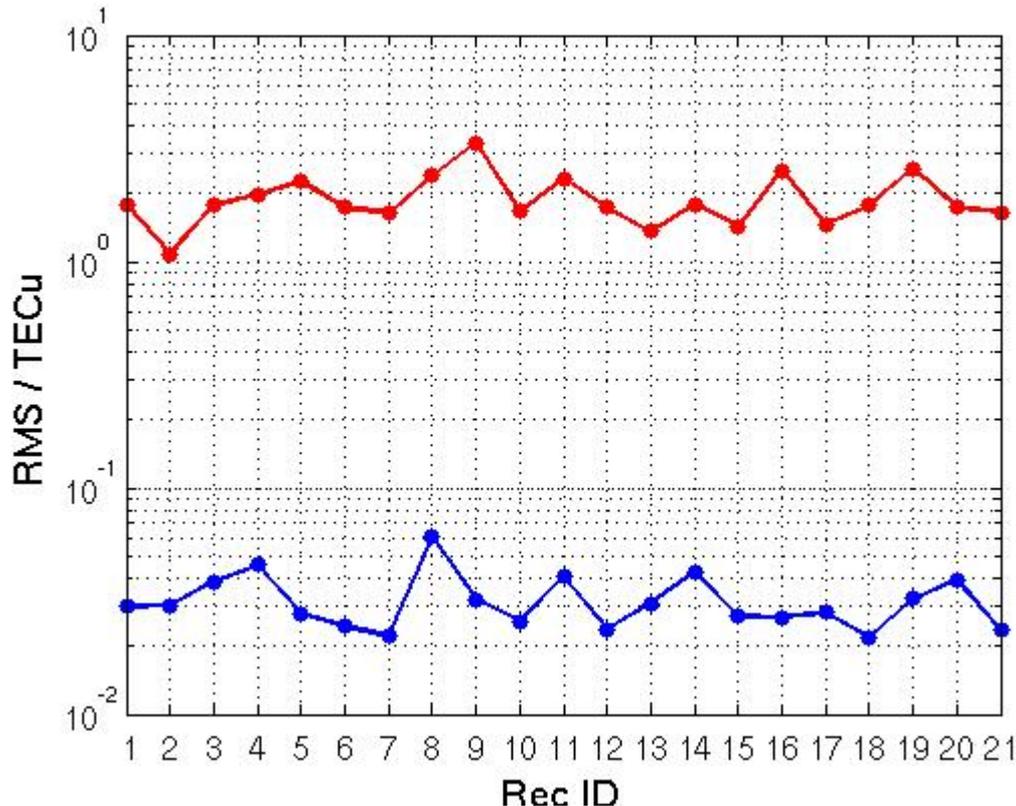
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Ionospheric model performance

3D ionospheric model? Why bother?



- RMS for 2D model is ~ 100 times higher than for 3D models.
- **2D residual RMS** is at TECu level (1 TECu ~ 0.1 m) \rightarrow Cannot support positioning techniques to achieve RMS at cm level in real-time.
- **3D residual RMS** is at 10^{-2} TECu level (i.e \sim mm) \rightarrow It might support positioning techniques to achieve RMS at cm level in real-time.



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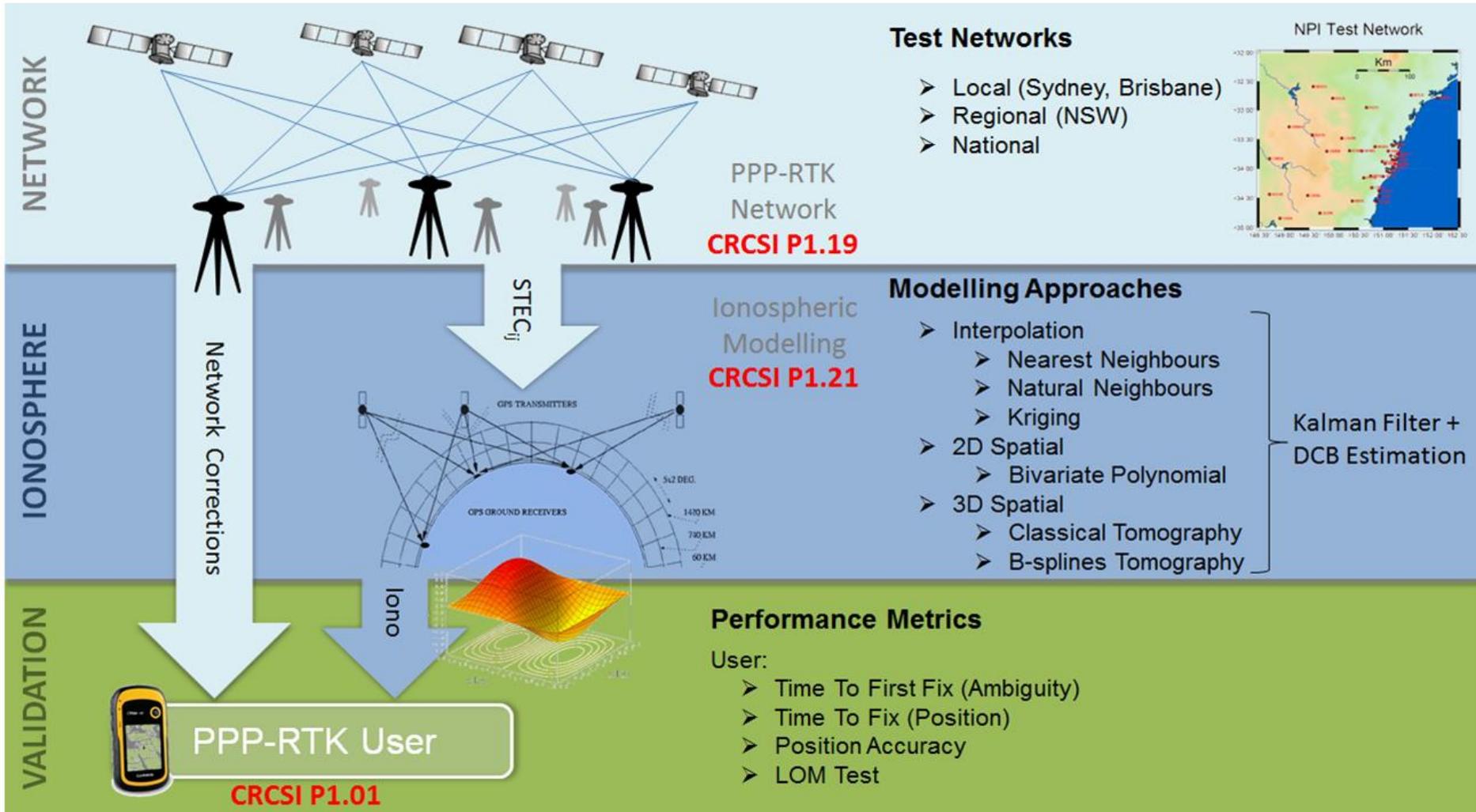
By how much does the model improve
positioning performance?



Ionospheric Model Test Bed

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Ultimate validation tool → How well does the model improve GNSS positioning?





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Ionospheric Model Test Bed

Performance Metrics:

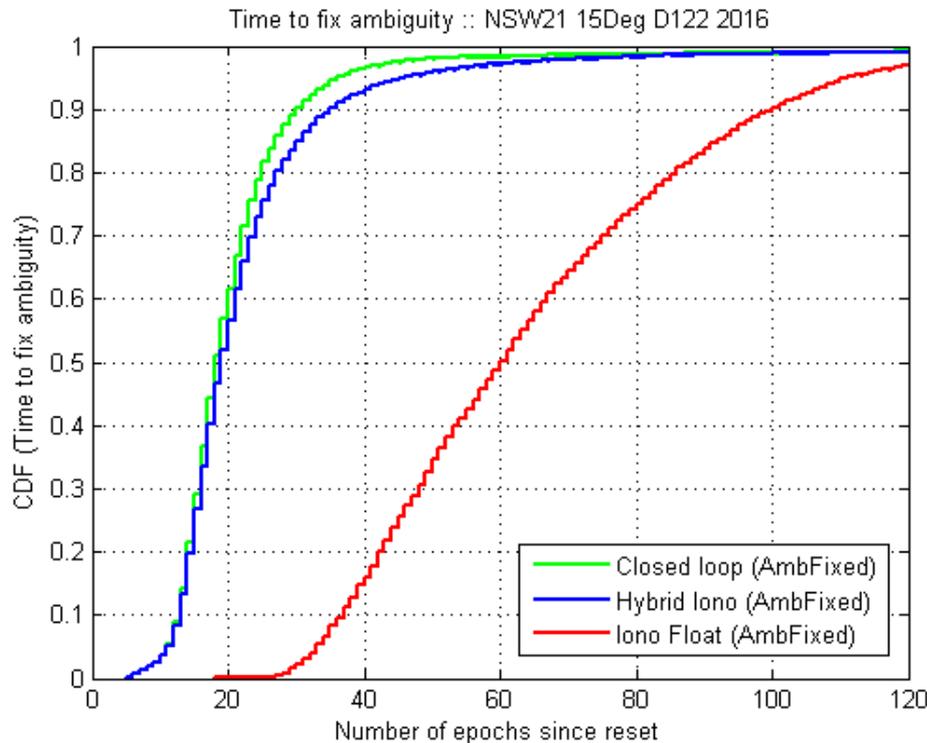
- **Time To Fix Ambiguity (TTFA)**
 - Time required to resolve each ambiguity to integer
 - Impacted significantly by the accuracy of the ionospheric model
- **Time To Fix Position (TTFP)**
 - Time required for a user to reach a positioning accuracy better than 10cm
- TTFA / TTFP analysed across all sites
- Results analysed in terms of Cumulative Distribution Functions (CDFs) of TTFA and TTFP



Results – Quiet Conditions

Time to Fix Ambiguity (TTFA)

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- Baselines range from 50 to 230 km.
- 1 epoch = 30 "
- 15° elevation mask

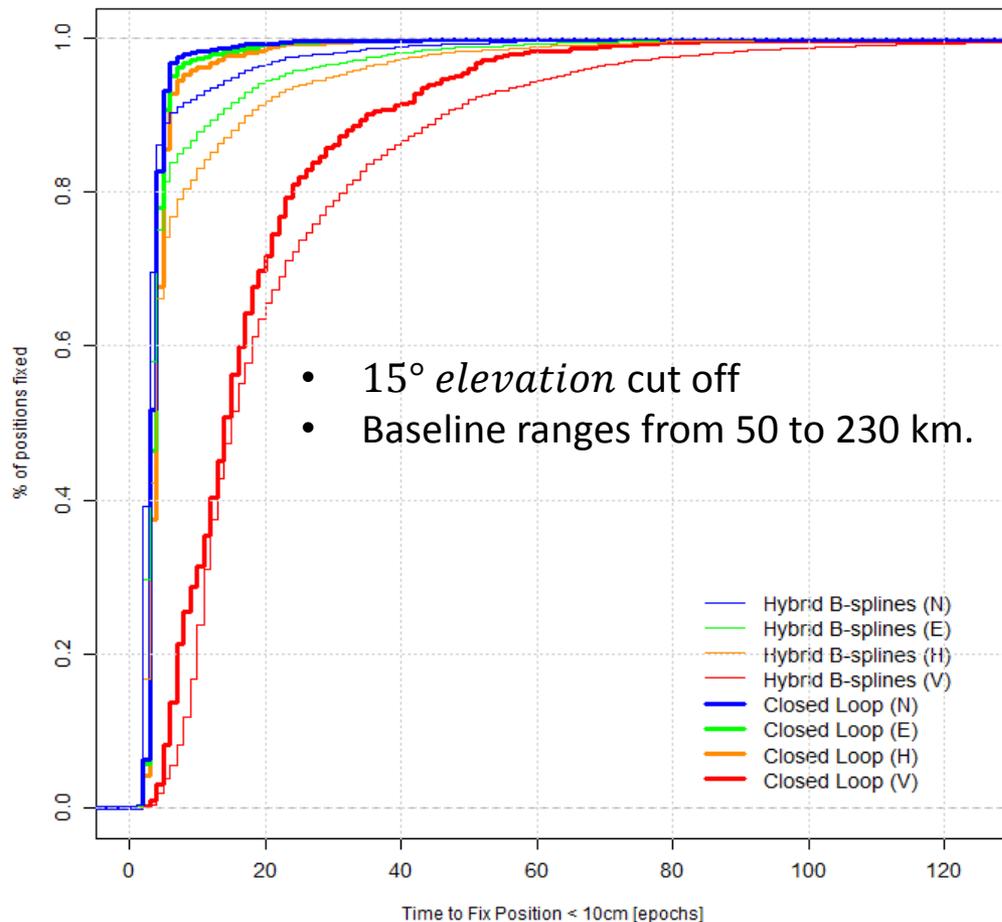
CDF	# epochs / Closed-loop	# epochs / Iono model	# epochs / Float
68%	~22	~22	~74
90%	~30	~34	~100

- **Closed loop**: Observed STEC at reference sites used as ionospheric corrections in fictitious rover located at reference sites → **Baseline network performance**
- **Ionospheric hybrid model**: 3D B-splines ionospheric model with interpolation to rover sites
- **Float solution**: No ionospheric correction provided to rovers.



Results – Quiet Conditions Time to Fix Position (TTFP)

Cumulative Distribution Function



1. Closed-loop:
 - **H**: Uncertainty for 90% of computed positions is below 10cm in less than **10 epochs**.
 - **V**: Uncertainty for 90% of computed positions are below 10cm in less than **40 epochs**.
2. Hybrid model:
 - **H**: Uncertainty for 90% of computed positions are below 10cm in less than **20 epochs**.
 - **V**: Uncertainty for 90% of computed positions are below 10cm in less than **50 epochs**.



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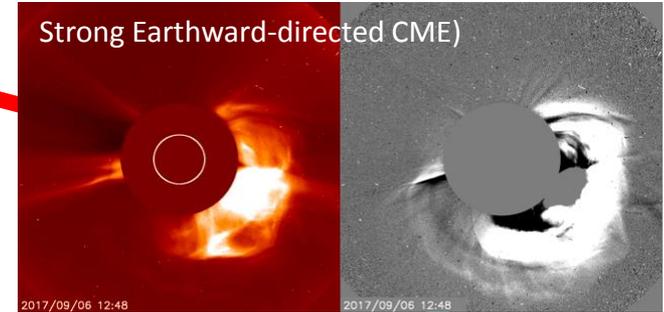
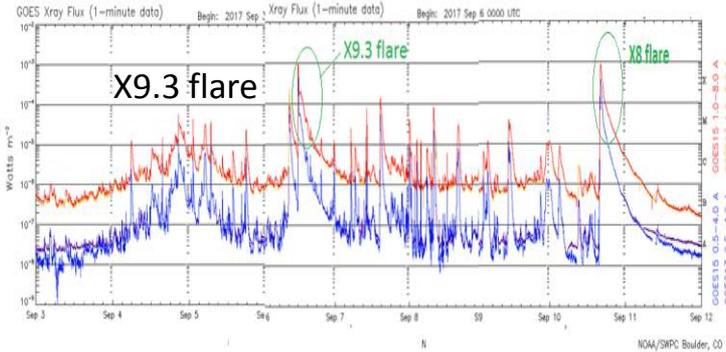
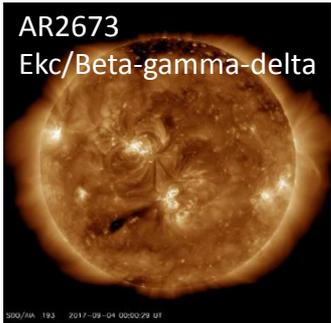
What happens during an ionospheric storm?



September 2017 Space Weather Event



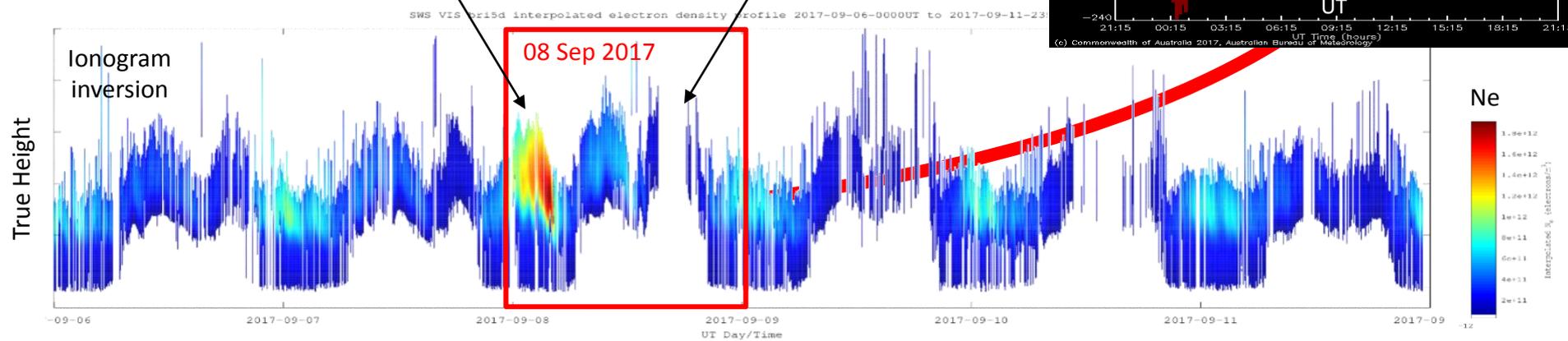
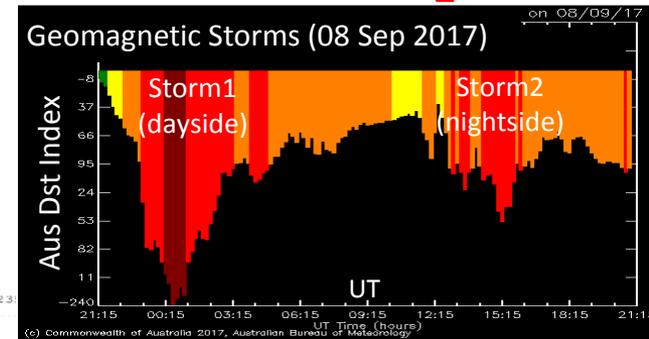
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Impact on Precise GNSS??

Strong positive phase ionospheric storm (dayside)

Weak bottom-side ionospheric signature (nightside)



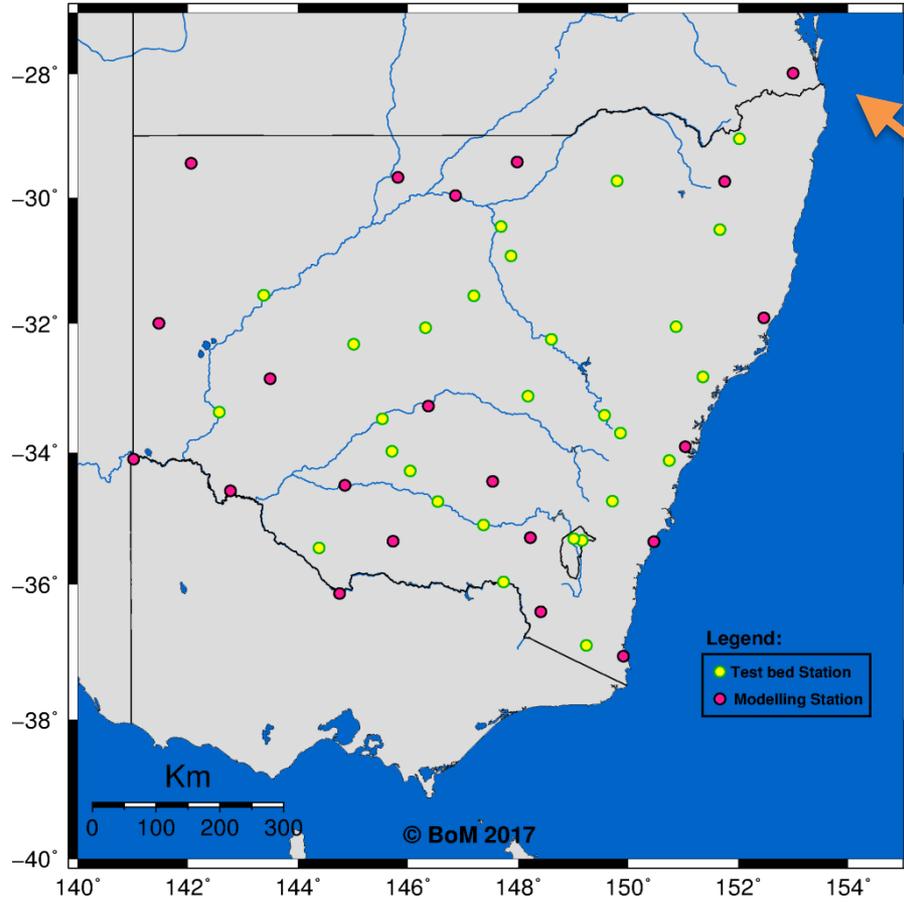


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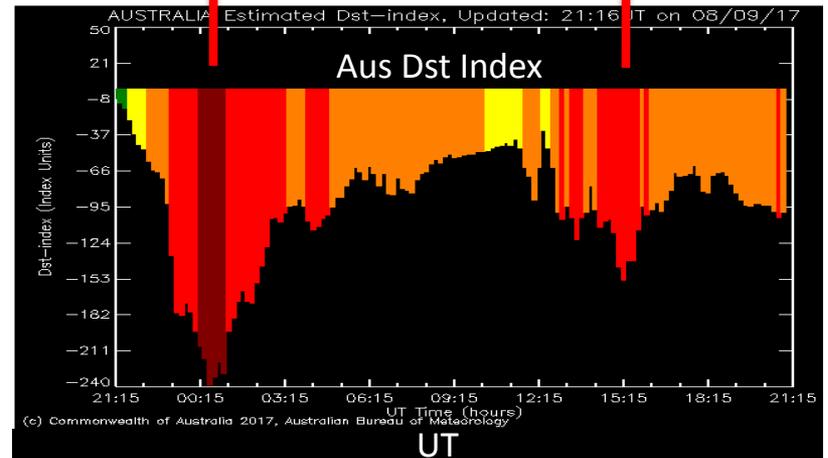
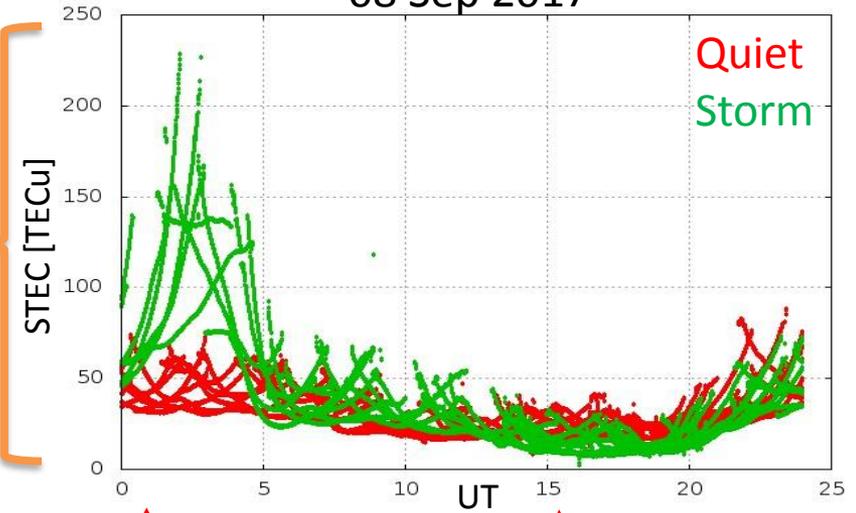
Results



Ionospheric Storm STECs

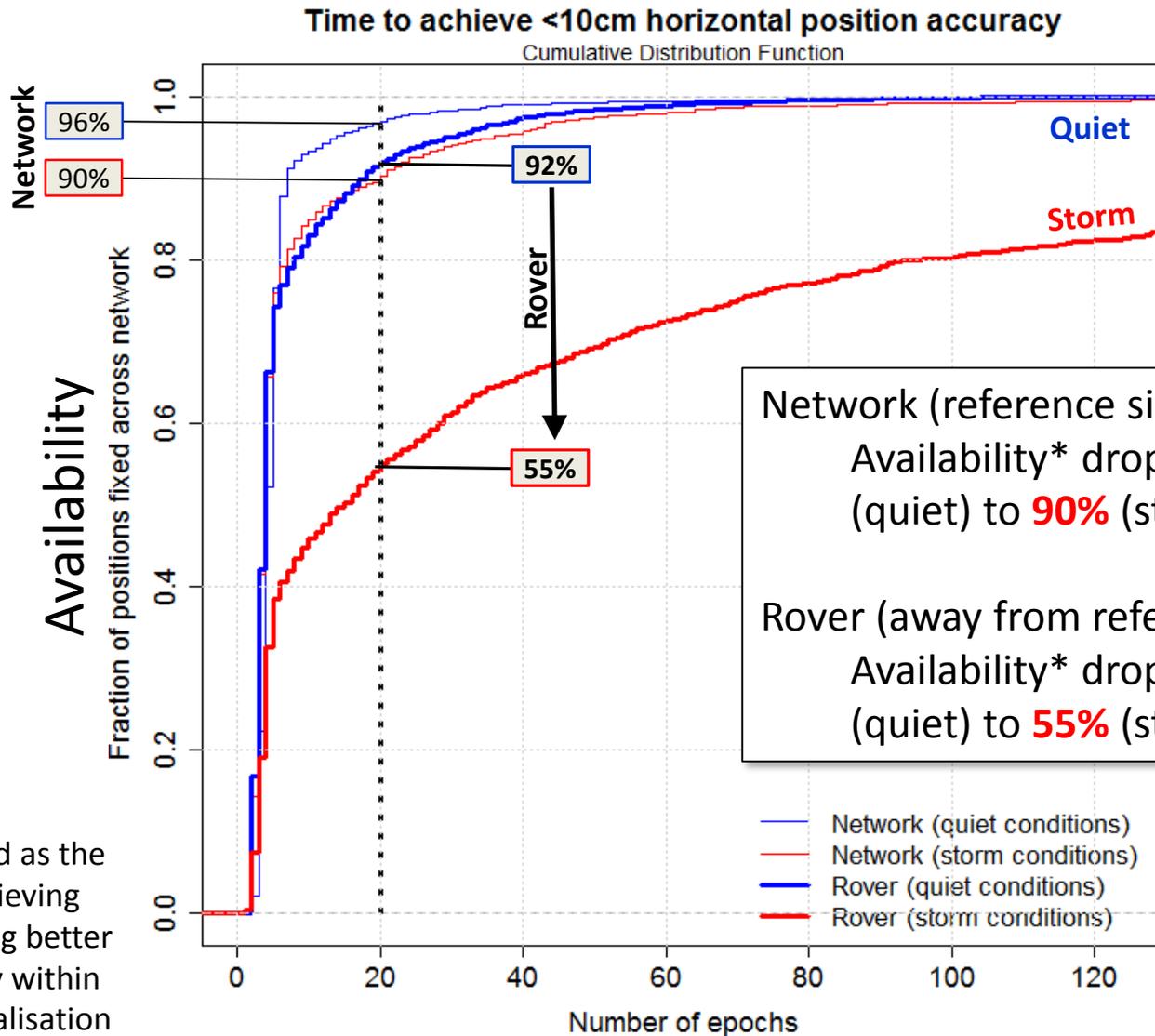


08 Sep 2017





PPP-RTK performance Quiet versus Storm (CDFs)



Network (reference sites):
Availability* dropped from **96%**
(quiet) to **90%** (storm)

Rover (away from reference sites):
Availability* dropped from **92%**
(quiet) to **55%** (storm)

* Availability defined as the % of locations achieving horizontal positioning better than 10cm accuracy within 20 epochs from initialisation



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The previous CDFs showed averaged performance over a day...

How does the time evolution of the storm impact the positioning application?

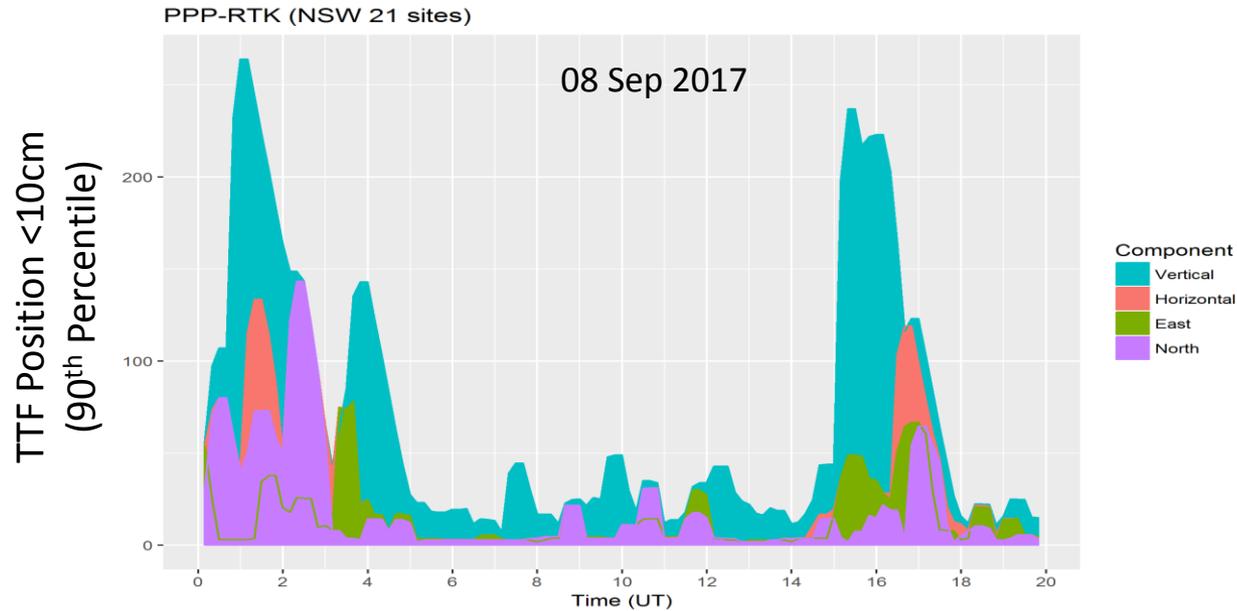
Can the temporal variation in positioning performance help identify an appropriate proxy for space weather impact to GNSS?



Results



Time evolution of CDF summary measure (90th percentile TTFP)

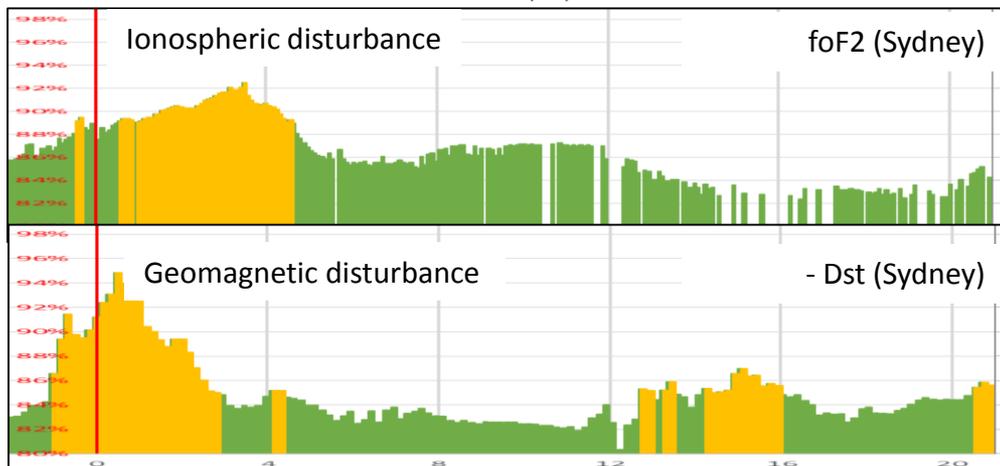


Both storm periods (dayside and nightside) degrade positioning performance

Lagged response to the geomagnetic disturbance by ~2hrs

Well correlated with the large scale ionospheric disturbance during the day (summarised by foF2).

Nightside event appears to be related to a topside disturbance (not seen by ionosonde)





Summary

- **Quiet conditions:** 3D Ionospheric model corrections → TTFA and TTFP similar to closed-loop (baseline/network performance) with >80% availability (of positioning to <10cm within 10 epochs) across the network in the horizontal component.
- **Storm conditions:** 3D Ionospheric model corrections → TTFP increases across the network around 2 hours after the geomagnetic storm at day time (~03:00-04:00 UT).
- Correlation and delay between DsT and Ambiguity Success Rate.
- No clear correlation between DsT and STEC, TTFP.
- Influence of the plasmasphere on the PPP-RTK platform → lower Ambiguity Success Rate at local night time (~16:00-17:00 UT).



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A banner for the CRC for SPATIAL INFORMATION. The banner is dark grey with the text 'CRC for SPATIAL INFORMATION' in green and white. It is overlaid on a collage of images including a map of Australia, a satellite view of a city, a high-speed train, and a satellite image of Earth.

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Thank you!
Questions?

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