Australian Government
Department of Defence
Defence Science and Technology Group

Detection and characterisation of travelling ionospheric disturbances in support of HF sky-wave radar

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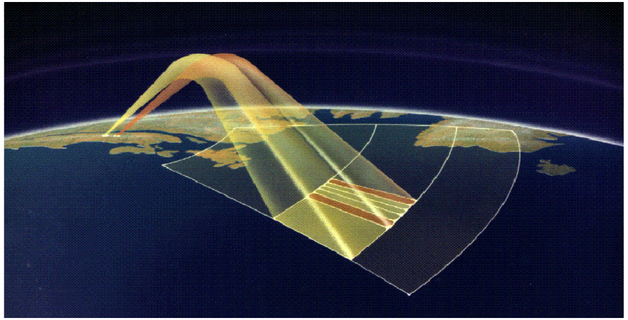
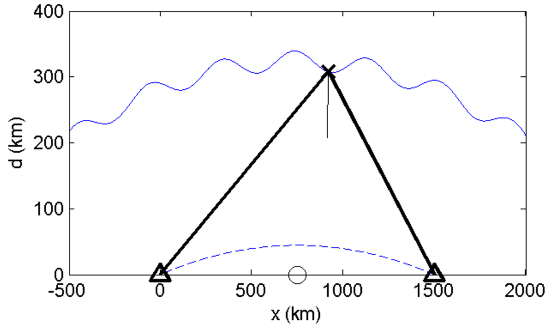
Introduction

- HF sky-wave radars rely on accurate real-time knowledge of the ionosphere for frequency selection and geo-registration of targets.
- The Jindalee Operational Radar Network (JORN) is supported by a data-assimilative regional electron density model known as the RTIM (real-time ionospheric model).
- While this captures the bulk of the medium- to large-scale variability in the ionosphere, certain classes of disturbance remain more difficult to characterise.
  - Travelling ionospheric disturbances (TIDs)
  - Spread-F/micro-multipath structure
  - Storm-related F2 collapse
  - Patchy/complex sporadic-E

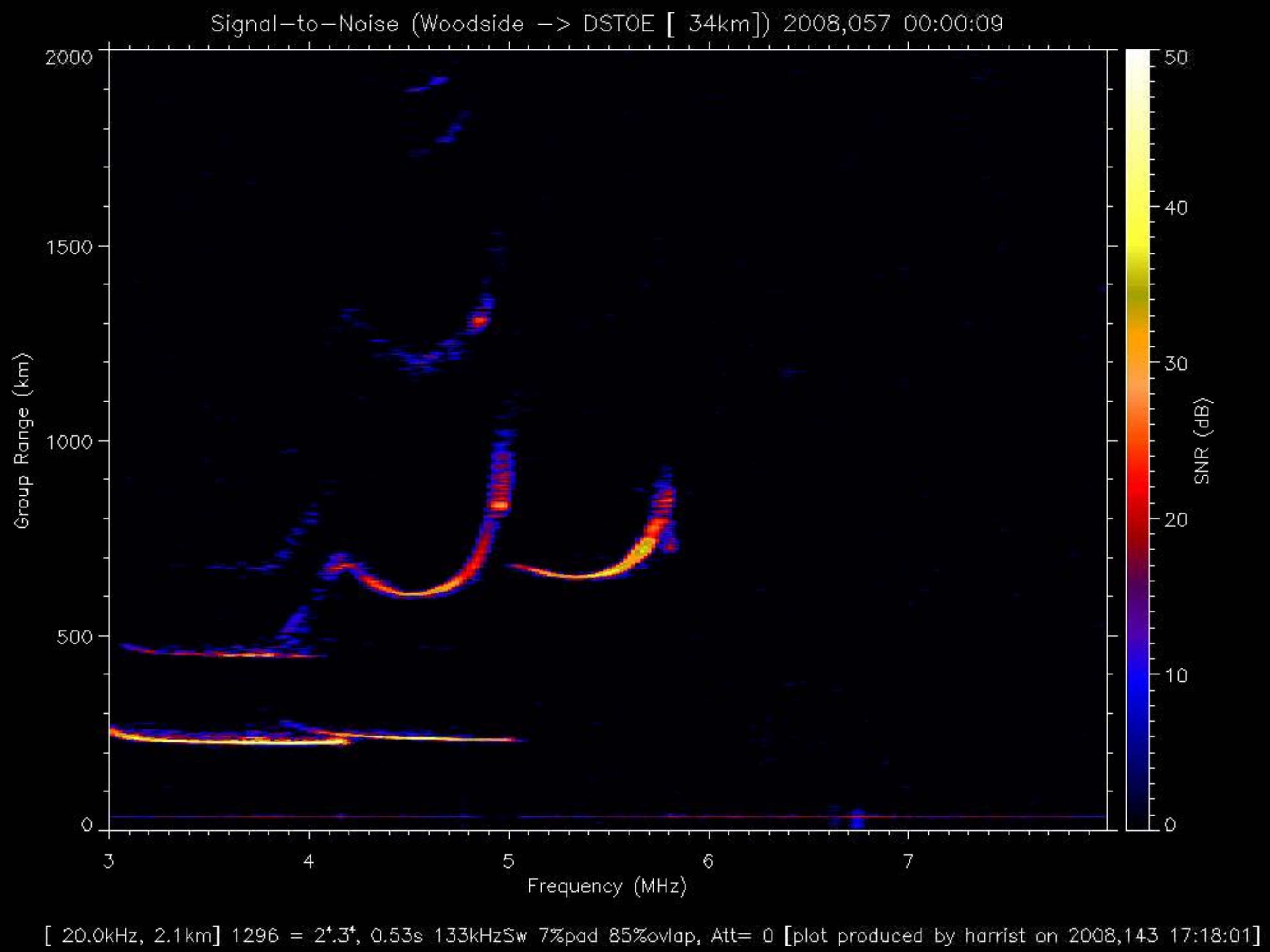


Travelling ionospheric disturbances (TIDs)

- TIDs are wave-like, spatially propagating disturbances, driven by wind perturbations in the thermosphere (atmospheric gravity waves).
  - Medium-scale TIDs (~15–60 minute periods) often associated with regional tropospheric sources (within 1000–2000 km).
  - Large-scale TIDs (~30–180 minute periods) often associated with distant auroral sources at E region heights (primarily geomagnetic storms).

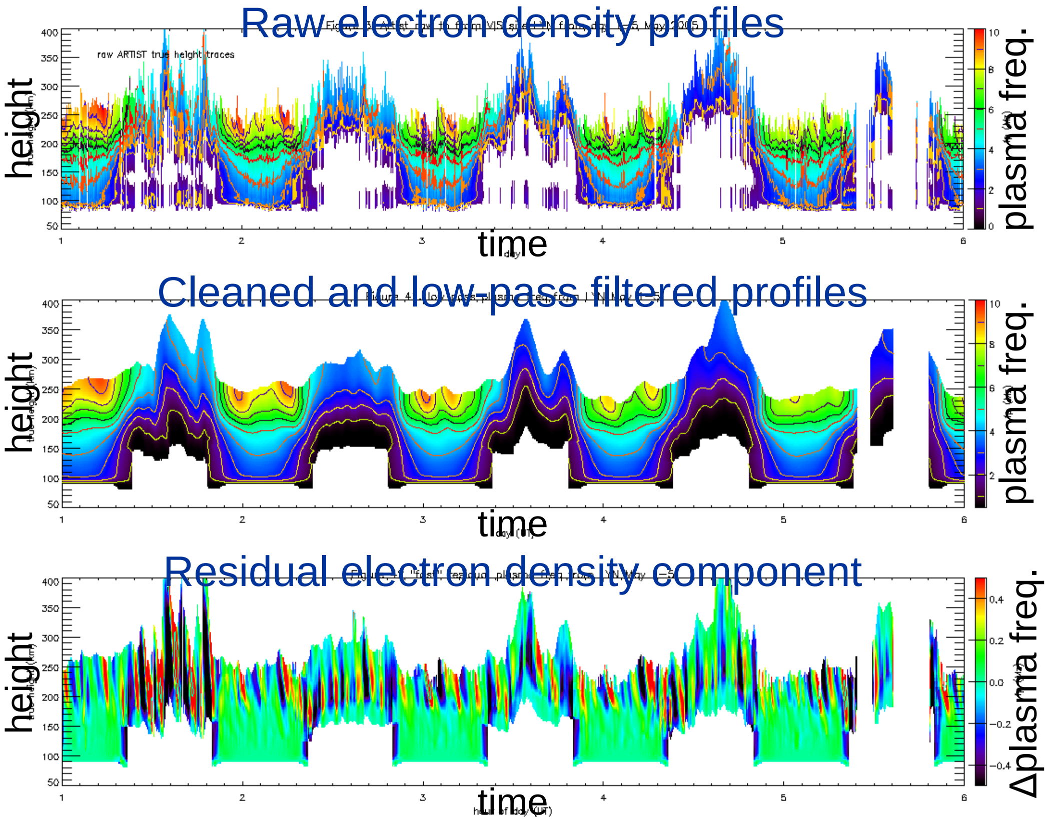


- TIDs result in quasi-periodic disturbance signatures in HF sky-wave observations.
  - Dispersion relation and background winds → characteristic horizontal wavelengths and velocities
  - Forward-tilted phase-front → apparent height-descending signature
- Their effects are also routinely observed by other instruments, including incoherent scatter radars, GNSS total electron content (TEC) and airglow imagers.


Signal-to-Noise (Woodside -> DSTOE [34km]) 2008,057 00:00:09
Group Range (km)
2000
1500
1000
500
0
3
4
5
6
7
Frequency (MHz)
SNR (dB)
50
40
30
20
10
0
[20.0kHz, 2.1km] 1296 = 2⁴.3⁴, 0.53s 133kHzSw 7%pad 85%ovlap, Att= 0 [plot produced by harrist on 2008,143 17:18:01]

HF observations of TIDs

- Example of typical day-to-day and hour-to-hour ionospheric variability as observed by a vertical incidence (VI) sounder.
- Once the lower frequency (diurnal) components are subtracted off, what remains is dominated by the quasi-periodic signatures of TIDs.
- It is these effects that DST Group (and many others) are seeking to better understand.

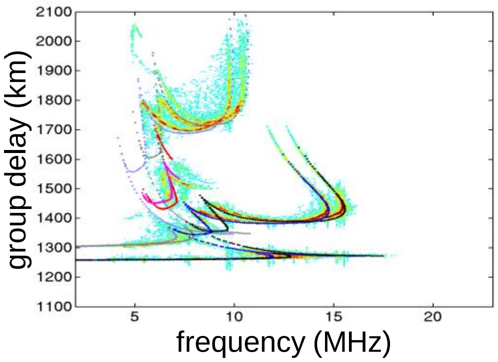


DST Group's TID research program

- Focused on understanding and modelling TID effects on HF propagation, including the use of ionosonde observations at very fine spatial and temporal scales.
- Capturing climatology of TIDs in the Australian region, and their relationship with atmospheric gravity waves in the neutral atmosphere.
- Relating ionogram disturbance signatures to other complementary instruments (e.g. HF radars, airglow imagers and GNSS TEC).
- Underpinning all of this is DST Group's high-fidelity sounder development program (DORS and PRIME).
- The Defence application is to understand performance implications on the current and future JORN, and drive improvements to its real-time ionospheric model.

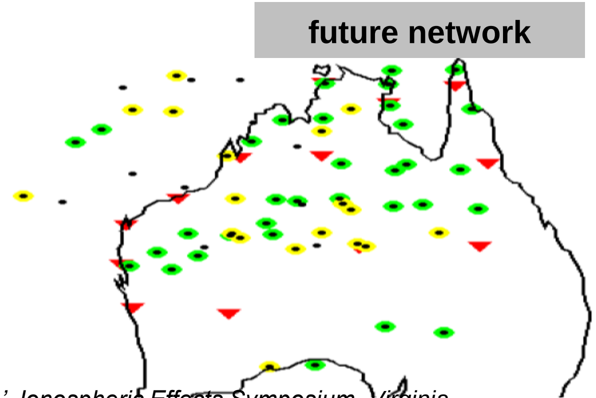
DINIS *(Dense Integrated Network of Ionospheric Sounders)*

- The JORN ionosonde network is progressively being upgraded, including:
  - new high-fidelity DST Group transmitters/receivers
  - more sophisticated on-board signal/image processing
  - faster update rates and finer spatial sampling



- Up to 12 VIS and 27 OIS are currently available to the JORN real-time ionospheric model.

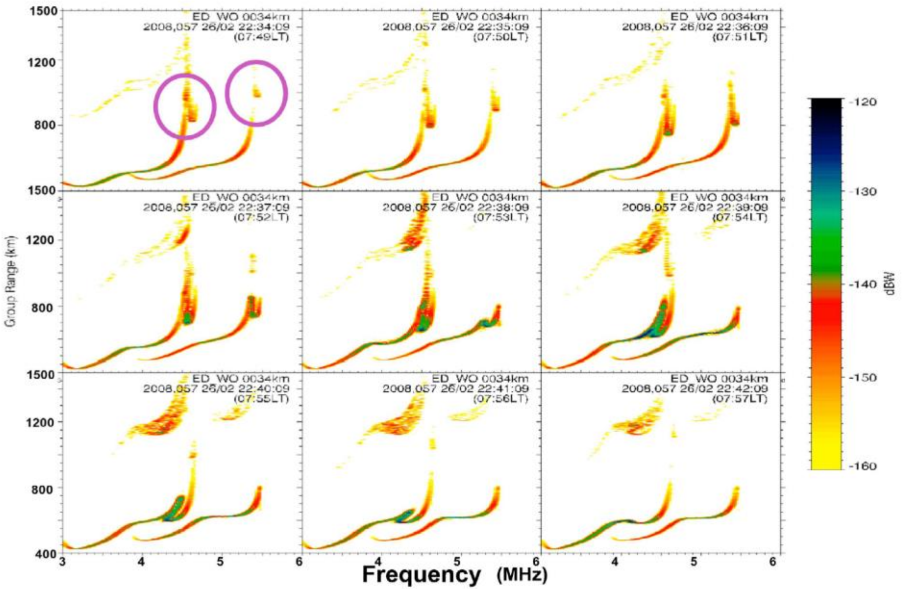
- A greater proportion of disturbances are now routinely captured, including large-scale TIDs.

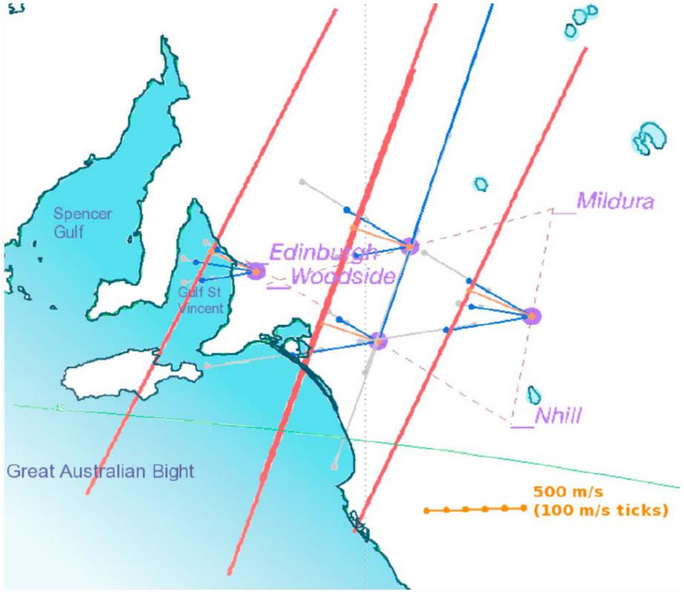


Gardiner-Garden et al. (2011), 'Variability observed in a high-fidelity model of the ionosphere…', Ionospheric Effects Symposium, Virginia.
Heitmann & Gardiner-Garden (2012), 'Ionospheric modelling with a dense network of oblique incidence sounders…', Australian Space Science Conference, Melbourne.

SpICE *(Spatial Ionospheric Correlation Experiment)*

- A series of campaigns involving very fine-scale quasi-VI sounder networks.
- Deduce TID power spectra and component velocities using cross-correlations.

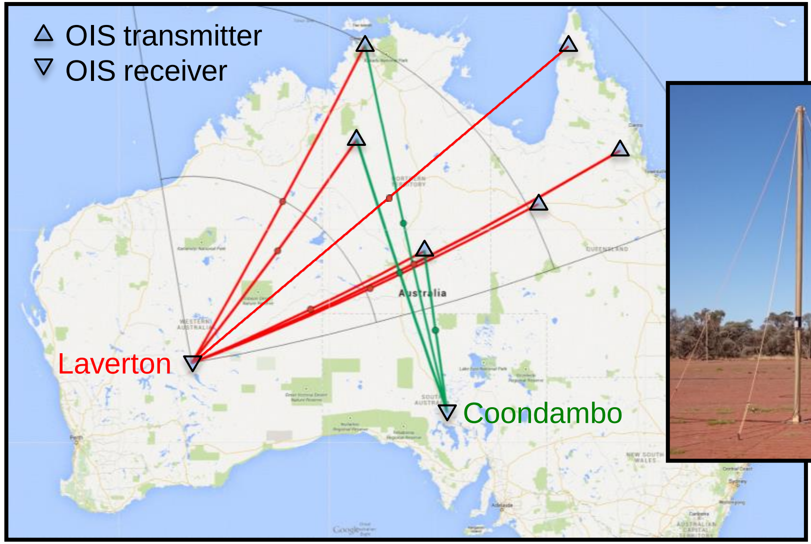


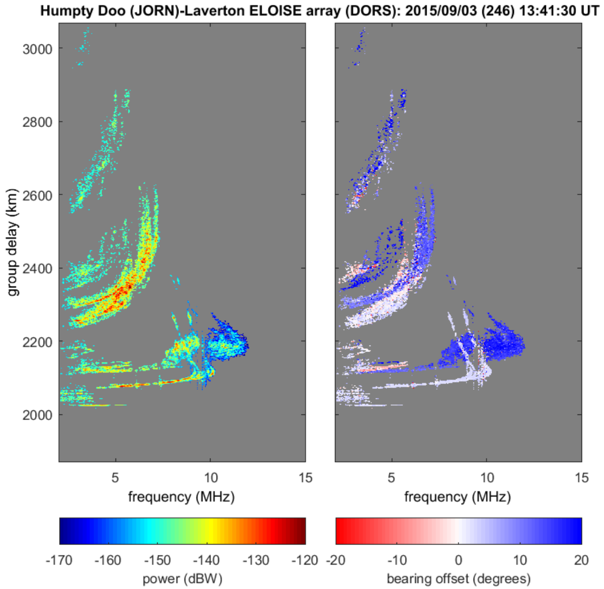


Harris, Cervera & Meehan (2012), 'SpICE: A program to study small-scale disturbances in the ionosphere', JGR, vol. 117, A06321.

ELOISE *(Elevation-scanned Oblique Incidence Sounder Experiment)*

- Angle-of-arrival and Doppler observations on a network of oblique sounder paths.

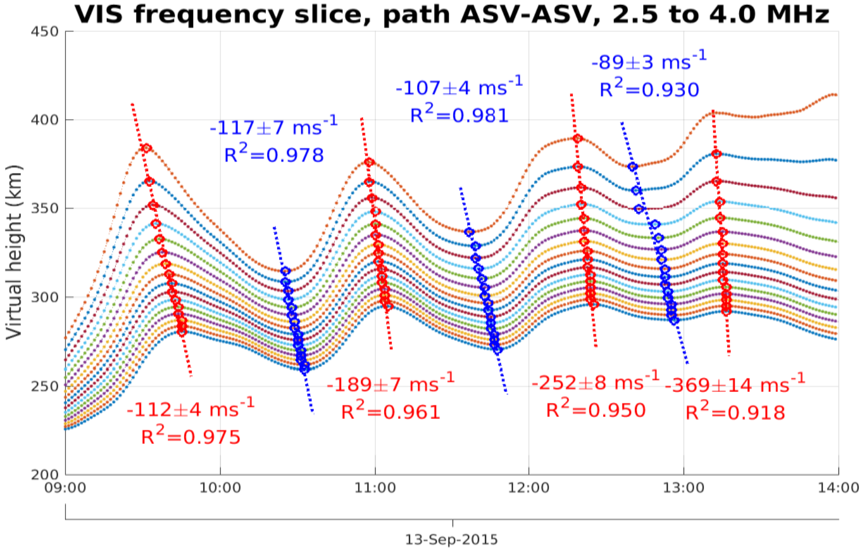


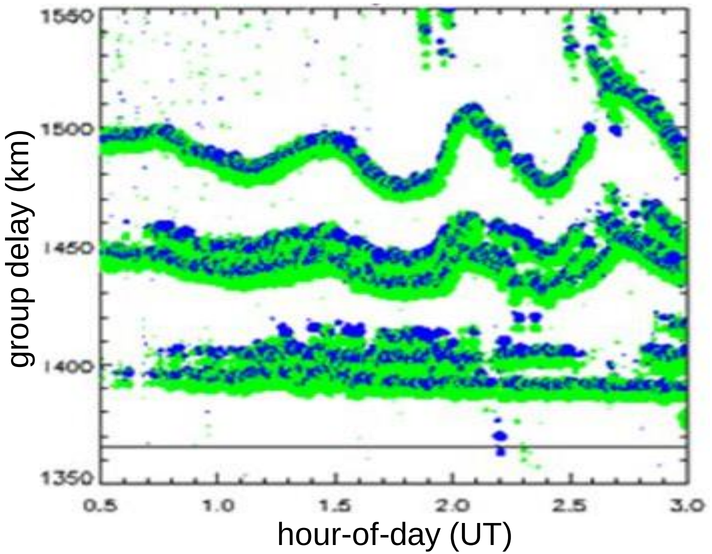


Ward et al. (2015), 'ELOISE – Towards an enhanced understanding of ionospheric variability…', Australian Space Research Conference, Canberra.
Heitmann et al. (2017), 'Observations and modeling of traveling ionospheric disturbance signatures…', URSI General Assembly & Scientific Symposium, Montreal.

ELOISE *(Elevation-scanned Oblique Incidence Sounder Experiment)*

- The angle-of-arrival paths were embedded in a broader network of ionosondes, and collected alongside JORN transponder and target-of-opportunity tracks.

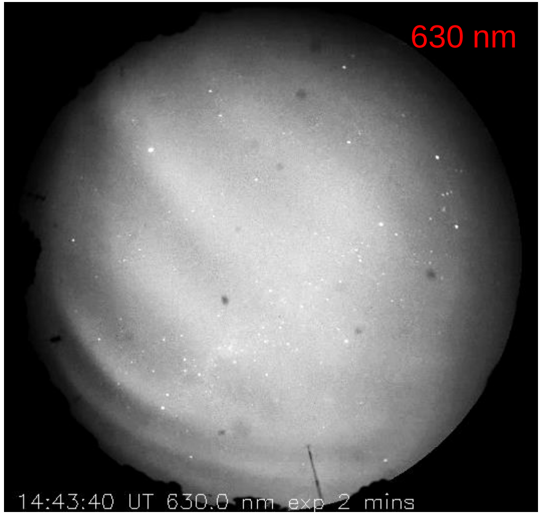


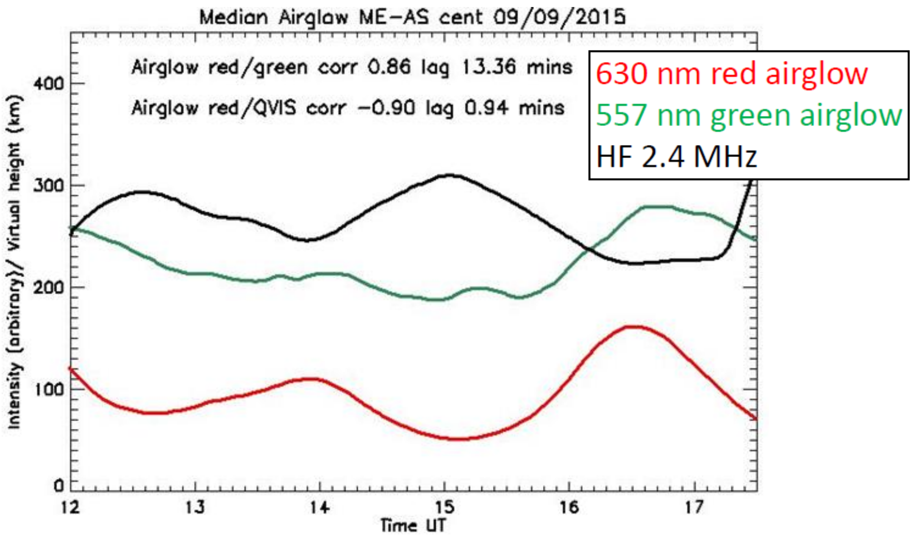


Ward et al. (2015), 'ELOISE – Towards an enhanced understanding of ionospheric variability…', Australian Space Research Conference, Canberra.
Pederick et al. (2017), 'Interpreting Observations of Large-Scale Traveling Ionospheric Disturbances by Ionospheric Sounders', JGR, doi:10.1002/2017JA024337.

TRACE *(Thermospheric Radar Airglow Correlation Experiment)*

- Anti-correlated behaviour observed in ionospheric airglow intensity and HF virtual height of reflection.
  - Time lags between different effective heights consistent with tilted TID phase fronts.

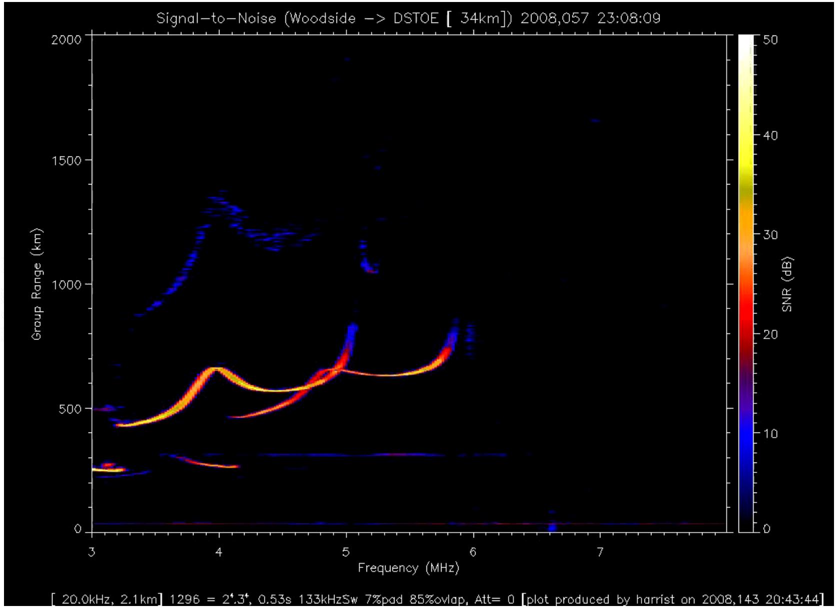


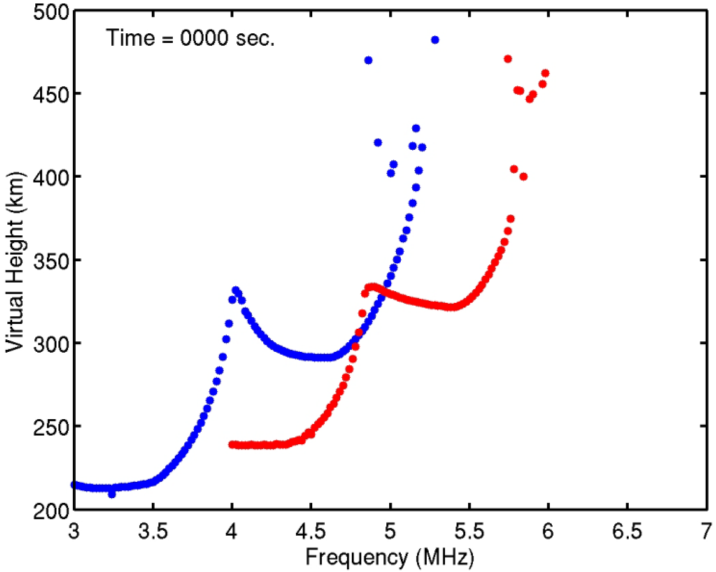


Unewisse et al. (2016), 'Airglow results from ELOISE', Australian Space Research Conference, Melbourne.

Modelling medium-scale TID signatures

- Realistic ionogram TID signatures can be synthesised using a physics-based (Hooke) perturbation model and 3D geomagnetic ray tracing (PHaRLAP).

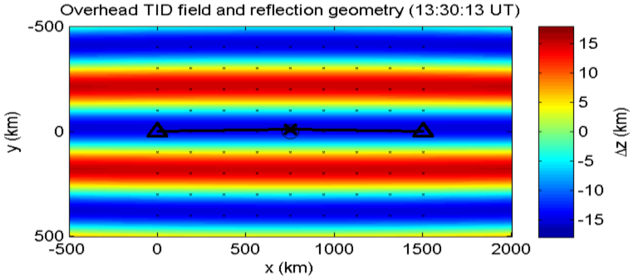


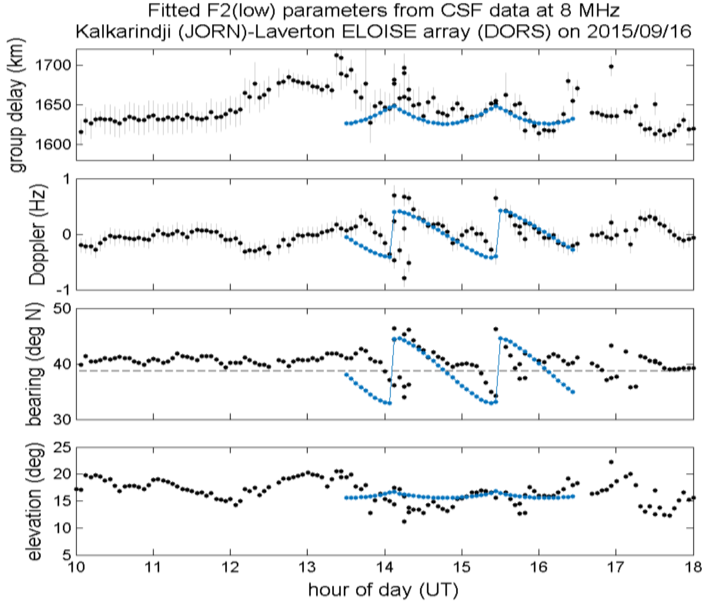


Cervera & Harris (2014), 'Modeling ionospheric disturbance features in quasi-vertically incident ionograms…', JGR, vol. 119, pp. 431–440.

Modelling large-scale TID signatures

- Corrugated mirror models can also be effective in predicting the off-angle propagation modes on oblique paths associated with large-scale TIDs.





layer height: 280 km (untilted)

period: 80 minutes

horizontal wavelength: 400 km

azimuth angle: -90 deg (wrt tx bearing)

amplitude of height perturbation: 15 km

Heitmann et al. (2017), 'Observations and modeling of traveling ionospheric disturbance signatures…', URSI General Assembly & Scientific Symposium, Montreal.

Summary and conclusions

- HF sky-wave radar is one of many technologies sensitive to TIDs.
- DST Group has a long-running research program, with a strong emphasis on experimentation, that aims to improve our understanding of TIDs and their impact on HF propagation.
- Parameterised models can reproduce many of the ionogram signatures routinely observed.
- As such, it appears there is scope to improve operational ionospheric models and geo-registration of targets in future.