High Variability in HF Radio Frequencies Supported by the Ionospheric F2 Layer during Quiet Geomagnetic Periods

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The ionosphere from 90-500km altitude, is driven by the solar radiation, the geomagnetic field but also the neutral thermosphere atmospheric region, within which the ionosphere comprises a trace component.

Vertical radio sounding in the high-frequency (HF 3-30MHz) range is the traditional method of measuring this ionisation. Oblique HF radio sounding allows measurement of reflection points above oceans and other locations where it is not practical to position vertical sounders.

Oblique sounding paths have been operated between New Zealand and Australia over ~2100km since 2002, covering a range of the solar cycle.

The maximum observed frequency (MOF) on the oblique paths are used to compare with statistical predictions from the standard IPS HF propagation model, which uses monthly median climatological foF2 data.

Variations in MOF may be interpreted in terms of transient upper atmosphere and geomagnetic effects. During solar minimum 2007-09 the relatively quiet geomagnetic conditions reveal a range of atmospheric driven disturbances.

Closely spaced multiple paths and reflection points also allow smaller scale ionospheric structure to be investigated than vertical sounding.
• MOFs are compared with statistical predictions from a climatological HF radio propagation model, [Caruana 1995] which interpolates maximum usable frequencies from a database of monthly median and decile vertical radio sounding frequencies, assumed to implicitly include regular disturbances such as thermospheric tides or equinoctial increases in geomagnetic activity.

• Large variations from predicted median frequency on the propagation path, especially outside the lower and upper decile frequencies, may be interpreted in terms of thermospheric-ionospheric and geomagnetic activity, that is not included in the climatological data.

• Many of the stronger electron density variations appear as wave structures, possibly travelling ionospheric disturbances (TIDs) associated with atmospheric gravity waves (AGWs) [Hines, 1960; Francis 1975; Hocke and Schlegel 1996]. The disturbances may have high latitude sources at thermospheric altitudes [Richmond 1978] or mid-latitude sources at tropospheric-stratospheric altitudes [Gossard, 1962; Boška and Šauli 2001 ; Medeiros et al, 2004].

• The large variations cause problems with short term (daily, hourly) HF communications frequency predictions and the gradients can cause large range errors for HF direction finding (HFDF) or radar (OTHR).
Trans-Tasman Sea oblique sounding using Chirpsounder TCS-5 Tx (NZ Defence) and RCS-5 Rx (IPS) managed by M. Layoun.

Sampling rate is one ionogram per 15 minutes on each path but the two Tx operate at asynchronous times.

1F mode ionospheric reflection points near F2 layer maximum altitude of ~300km in the upper thermosphere.

JionView software by S.Hutchinson autoscales MOFs with high accuracy.
Parameterisation of the level of Ionospheric F2 region support of HF propagation is via the standard T-index [Turner 1968] calculated from regional foF2 values.

Using the predicted or measured monthly or daily T allows MUF estimates on a path in the region but not adjacent to a vertical sounder.

Oblique sounding to test ionospheric propagation models is an active research area [Zolesi et al, 2008]

The model is intended to provide monthly statistical predictions for monthly median (MUF) and decile (UD, OWF) HF frequencies. For many months the observed MOFs compare well with predictions, but individual days can show large variations, sometimes well outside the deciles for extended periods. **What is driving the variability?**

### Model monthly statistical values

**UD** (upper decile) exceeded only 10% of the time,

**MUF** (Maximum Useable Frequency) = median exceeded 50% of the time,

**OWF** (Optimum Working Frequency) = lower decile exceeded 90% of the time.
Observed MOFs often have large excursions with a relatively smooth oscillatory nature and periods over an hour. Sampling rate of 15 mins allows only resolution of wave periods greater than 30 mins.

Examine March 08, which was a fairly active month for this solar minimum, for geomagnetic solar or ionospheric drivers.
Whenuapai-Culgoora March08 MOF vs ASAPS at monthly T=6

Whenuapai-Culgoora MOF vs ASAPS MUF for monthly T

Whenuapai-Culgoora MOFs for 10Mar08 with greatest negative daily Tdifferences (-22) from monthly

Observed MOFs generally larger than predicted MUFs, on this path. This is good for HF predictions as the predicted MUF is supported by the ionosphere.

But the observed MOF can be lower than the lower decile OWF for extended periods.

Examine a day when T-index is low compared with predictions.
Observed MOFs generally larger than predicted MUFs, especially at higher frequencies.

But the observed MOF can be higher than the upper decile UD prediction for extended periods.

Large increases in T-index from solar flux increases (active regions) or decreases in T from global geomagnetic activity might be expected to drive the MOF out of limits.
Surprising amount of variation ("% anomaly") from model predictions when the local region is geomagnetically very quiet: Select some days in 2007-08 with Ap=1

Substantial % anomalies approaching 100%, despite low geomagnetic activity. Some is due to dawn and dusk although anomalies high at other times. No correlation with regional 3 hr Kaus index.
Possible disturbance sources

1. Requires a source that will disturb the F2 region ionosphere even when the regional geomagnetic activity remains quiet.
2. Travelling Ionospheric Disturbances (TIDs) caused by Atmospheric Gravity Waves (AGWs) [Hines 1960, Francis 1975; Hocke and Schlegel 1996] are a likely candidate.
3. The travelling nature of the observed disturbances awaits confirmation by comparing multiple radio propagation paths and the possible movement of the disturbance between them.
4. However as tides are assumed to be incorporated into the climatalogical data and medium scale TIDs have been shown to be ubiquitous in the region over the Southern Ocean south of Australia in SuperDARN radar observations [He 2003], it is worth pursuing AGW sources.
5. Possible thermospheric AGW sources are large localised energy inputs from the magnetosphere into the ionosphere via field-aligned-currents (FACs), prevalent at polar latitudes, but often localised enough to not affect the Australasian region geomagnetic index (K aus). The AGW may then propagate horizontally in the thermosphere to the mid-latitude observation point although there are complications with thermospheric winds and the waves may be damped out [Richmond 1978].
6. Sources for the AGWs may also be from below in the troposphere (e.g. cold fronts) or stratosphere (e.g. jet stream) [e.g. Gossard, 1962; Boška and Šauli 2001 ; Medeiros et al, 2004] and these will not affect K aus. There are complications with vertical propagation through wind shear [e.g. Hines and Reddy, 1967] and the waves may be damped out before they reach the upper thermosphere.
Possible disturbance sources

Expect a combination of modes (1), (3) and possibly (4) at the observation radio reflection point.

Propagating AGW modes

**Upper modes** primarily affected by thermosphere
(1) direct wave observed far from thermospheric source
(2) direct wave seen near source

**Lower modes** primarily affected by lower atmosphere (troposphere/stratosphere/mesosphere). Modes occur for thermospheric source and lower atmosphere source such as a tropospheric cold front [T] or stratospheric jet stream.
(3) Wave ducted between surface and large temperature gradient at mesopause observed far from source
(4) Earth reflected wave close to source

Field-aligned-currents (FACs) at E-region (100km) altitudes may be strong thermospheric sources for upper modes,
[C] auroral zone R1 FAC near 14MLT, close to the dayside polar cusp, enhanced during merging of the geomagnetic field and IMF.
[S] Substorm current wedge FAC on the nightside auroral oval.
[P] FACs along the plasmapause
Examine an equinoctial month, as they are when MOF variations from the model MUF often appear to be greatest.

April 2008 was chosen to examine localised high latitude geomagnetic activity and the passage of tropospheric cold fronts near the observation point.

Several days were selected where the MOF variations from the MUF or peak-to-peak appear to be largest for the month.

Propagation delay from source to observation

Medium scale TIDs (MTIDs) [Francis 1974] with velocities of 0.1 – 0.25 km/sec may be produced by thermospheric (polar FAC) or tropospheric sources.

MTIDs from the troposphere would be expected to propagate ~300km to the upper thermosphere in 20 – 50 minutes although horizontal propagation of up to possibly 1500km will lengthen this. However MTID periods are 15 mins to just over 1 hour so the 15 min observation cadence will miss those with periods shorter than 30 mins.

Large scale TIDs (LTIDs) [Bowman 1992] with velocities 0.4 – 1.0 km/sec and periods 30 mins to 3 hours should be fully observable by the 15 min radio sounding and are expected to only have Thermospheric sources.

<table>
<thead>
<tr>
<th>thermospheric AGW source</th>
<th>Distance to IRR-SYD observation point</th>
<th>MTID propagation time</th>
<th>LTID propagation time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasmapause - Macquarie Is (MQI)</td>
<td>2000 km</td>
<td>130-330 mins = 2.2 – 5.6 hrs</td>
<td>33-83 mins = 0.5 - 1.4 hrs</td>
</tr>
<tr>
<td>Pol. cusp - Davis (DAV)</td>
<td>6100 km</td>
<td>410-1020 mins = 6.8–16.9 hrs</td>
<td>100-255 mins = 1.7 - 4.2 hrs</td>
</tr>
<tr>
<td>Closest nightside (12UT) auroral oval at Kaus = 2</td>
<td>2500 km</td>
<td>166-417 mins = 2.8 - 6.9 hrs</td>
<td>42–104 mins = 0.7 – 1.7 hrs</td>
</tr>
<tr>
<td>Closest dayside (00UT) auroral oval at Kaus = 2</td>
<td>3500 km</td>
<td>233-583 mins = 3.9 – 9.7 hrs</td>
<td>58 – 146 mins = 1 - 2.4 hrs</td>
</tr>
</tbody>
</table>
Cold front near observation point for whole day. Tropospheric source possible for daytime waves 00-08UT and 20-24UT but lack of nighttime waves is puzzling. No apparent geomagnetic source.
### 3 hour geomagnetic K indices for the day.

<table>
<thead>
<tr>
<th>Time (UT)</th>
<th>Aus</th>
<th>DAV</th>
<th>MQI</th>
<th>CAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>3</td>
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<tr>
<td>06</td>
<td>2</td>
<td>3</td>
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<td>3</td>
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<td>12</td>
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<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>18</td>
<td>5</td>
<td>6</td>
<td>3</td>
<td>6</td>
</tr>
</tbody>
</table>

Regional Aus and high latitude individual stations:
- **DAV** = Davis (cusp)
- **MQI** = Maqaurie Is (plasmapause)
- **CAS** = Casey (polar cap)

A cold front passes ~500km south of the ionospheric reflection point.

Tropospheric source is possible for the afternoon waves 00-06UT but only the edge of the front is close and possibly does not explain the large excursion at 01UT. DAV K is 5 for 20UT and 24UT the day before but this is only moderate activity. The widespread polar geomagnetic activity near 16UT may be responsible for excursions 20-24UT but the response is muted.
Continuous day and night disturbances. Tropospheric sources unlikely. Possible plasmapause (MQI) source for night series at (A). The K at all high latitude stations was 8 at 16UT the day before which may account for (B) at 02UT although propagation time would be 8 hours and should not be more than 6 hours from MQI.

Cold fronts in the Southern Ocean are at least ~1500km south of the ionospheric reflection point.
6 hour mean sea level charts (AMSL) [Bureau of Meteorology]

Cold fronts in the Southern Ocean are more than ~1500km from the ionospheric reflection point.

Large disturbances (A,B) in the local afternoon 01-07UT. Tropospheric sources unlikely. Possible polar cusp/auroral oval source as K for Aus and DAV at 20UT were both 6. Small night waves (C) possibly launched by K=5 at DAV.

<table>
<thead>
<tr>
<th></th>
<th>Aus</th>
<th>DAV</th>
<th>MQI</th>
<th>CAS</th>
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</thead>
<tbody>
<tr>
<td>00UT</td>
<td>3</td>
<td>2</td>
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<tr>
<td>06UT</td>
<td>3</td>
<td>4</td>
<td>5</td>
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</tr>
<tr>
<td>12UT</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>3</td>
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3 hour geomagnetic K indices for the day.
Regional Aus and high latitude individual stations
DAV = Davis (cusp), MQI = Macquarie Is (plasmapause)
CAS = Casey (polar cap).
Cold fronts in the Southern Ocean are more than ~1500km from the ionospheric reflection point.

3 hour geomagnetic K indices for the day.
Regional Aus and high latitude individual stations
DAV = Davis (cusp), MQI = Macquarie Is (plasmapause)
CAS = Casey (polar cap).

Possible global geomagnetic source, with focus near plasmapause for waves in the early night 08-14UT. Tropospheric sources unlikely. No apparent source for 01-06UT waves.
Preliminary conclusions

1. The climatological model from vertical soundings performs well in predicting useable HF frequencies across long term (monthly) periods.

2. Apparent lack of dependence of the MOF anomaly from model MUF values on high levels of regional geomagnetic activity.

3. Variations in anomaly of observed MOF from predicted MUF (median) for the monthly T-index are different from month to month.

4. Greatest monthly anomaly for equinox which could suggest either driving by thermospheric (seasonal turnover) or geomagnetic (better coupling to solar wind / IMF) influences.

5. Substantial MOF anomalies from model MUF values still evident at low geomagnetic activity, suggesting geomagnetic sources for atmospheric disturbances in the thermosphere (e.g. field aligned currents) distant from the region or atmospheric sources below such as cold fronts.

6. Large short term (hours) variations are evident in MOF and often display oscillatory nature, suggestive of TIDs and AGWs but perhaps also the normally varying neutral atmospheric winds.

7. The large number of possible wave sources, wave types and speeds, combined with the possible filtering by neutral winds during propagation, makes associating particular ionospheric disturbances with source regions very complex.

Acknowledgements: NZ Defence Force for transmitters, University of Newcastle for Antarctic magnetometer data.
References


He L., Investigation of medium scale TIDs in the southern hemisphere using the Tasman International Geospace environment radar (TIGER), *Ph.D. thesis La Trobe University, Melbourne, Australia*, 2003.
