WARS 2006 Conference in Leura Poster paper
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Title: Ionospheric variability in sounding data from JORN.

Abstract: JORN supports a network of Lowell vertical incident sounders (VIS's) around western and northern Australia. These sounders sample the ionosphere regularly and automatically every 3'45" (since 2002). They provide a unique opportunity to quantitatively describe the variability in the ionosphere in the Australian region, particularly, “fast” variations with periods of 10-90 minutes that are inherently missed or under-sampled in hourly data as well as variation near the bottom of the F layer that is hard to observe in TEC data.

This poster shows samples of JORN VIS data and describes techniques used to clean and process the raw VIS trace data in order to extract a quantitative description of the “mesoscale” ionospheric disturbances observed (with periods of 10-90 minutes). This poster also shows how the data can be displayed in order to focus on this variability. Disturbances are frequently found to have spatial and temporally correlated structures consistent with models of medium scale travelling ionospheric disturbances (mTID’s).

Introduction:

The accompanying plots will show raw and processed data from the JORN network of Lowell DSP VI sounders (running Artist N 4.2.1) in many different forms.

Figure 1 shows the sounder locations and names (acronyms).

A direct way of displaying the time history of the virtual height at a single sounder site is to show the Artist scaled traces (extracted from each individual sounder image) as a two dimensional function of both vertical incident frequency (MHz) and time.

Figure 2 shows an example of such an accumulated virtual height image over 5 days from Lynd River in May 2005.

From this image the value of (and variability in) the E and F layer critical frequencies (foE & foF2) can be observed as well as temporal changes in the pattern of virtual height.

Associated with these vertical incident delay traces are the Artist inverted true height profiles of plasma frequency. This is directly related to the electron density. The plasma frequency can also be displayed as a two dimensional function of both (true) height (km) and time.
Figure 3 shows an image of plasma frequency versus height and time associated with figure 2.

From this image the value of (and variability in) in the true height parameter hmF2 can be observed (and ymF2 to a keen observer). Noise in the inversion also produces significant noise in the image.

It is difficult to observe the presence of the F1 cusp in either of these displays. To draw this parameter into stark relief, the curvature of the Artist virtual height trace (w.r.t. freq) is computed at each time.

Figure 4 shows the image of virtual height trace curvature associated with figure 2.

From this image the value of (and variability in) the frequency of the F1 cusp (fbF1) can be observed. This parameter is where the trace curvature is highly negative (black).

"Cleaning" and validating the raw data:

Common problems apparent in this raw data are discussed at length in **Appendix A**. This presentation focuses on variability in the observed F layer of the ionosphere. To separate variability produced by miss-scaled and missing data and real physical processes, an automatic process to detect and exclude miss-scaled trace data (and smooth the result) is applied. This "cleaning" algorithm is discussed in **Appendix B** (i.e., how the lower frequency part of the virtual height trace is extensively filled and smoothed in order to remove the impact of bad and missing data from the true height inversion process at F layer heights). POLAN is then used to reproduce the inverted true height ionospheric data from these "cleaned" Artist traces. Even though this data is "cleaned" there is still the potential for spurious variability in the scaled parameters caused by missing data and uncertainty in the inversion process. **Appendix C** describes how this poorly scaled parameter data is identified.

Figures 5, 6 & 7 show examples of the virtual height, true height (plasma frequency) and trace curvature data analogous to figures 2, 3 & 4 but based on the “cleaned” data and the POLAN inverted profiles.

The following parts of this presentation ultimately seek to examine the “fast” variation present in the F region of the ionosphere (with periods 10-90 minutes) based on this “cleaned” data. To identify the “fast” variation the original data is “low pass” filtered (with a centred box car filter of 2 hrs) and the residual component is referred to as the “fast” component (i.e., original – low pass result). To validate using the Artist scaled traces in this way it needs to be shown that the pattern of variability in the scaled traces is also present in **the original sounder images**. To create a “truth” dataset for reference the Artist trace extraction software is “second guessed” and an independent virtual height trace versus freq estimate from each sounder image is produced. This is based on the height (delay) of the highest power returned at each frequency (windowed near the Artist trace). This algorithm is described in **Appendix D** and the derived virtual height trace is referred to as the “reduced sounder image” trace. It is assured that virtual height in these traces at a given frequency is the height of the peak of the returned power in the sounder image.

While not entirely independent of the Artist trace this “reduced sounder image” data can never the less be used to validate the raw Artist trace data.

Figures 8 & 9 show examples of the reduced sounder image virtual height trace and the trace curvature data analogous to figures 2, 4, 5 & 7.

Figure 9 shows the F1 cusp variations observed in figures 4 & 7 are also found in the original image power data.

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The “fast” variation parts of 2, 5 & 8 are computed and displayed for each of the raw cleaned and reduced traces in **figures 10, 11 & 12** (by running a temporal box car smoother over the data and producing a residual).

Apart from occasional missing images and bad traces, the numerical difference between each of the image, raw, and cleaned traces shows that the pattern of virtual height variation presented in the cleaned data is similar to both the raw and the reduced original sounder data. Information removed by the cleaning process is found to be, bad traces, very fast geophysical signals (eg kinks with periods < 10 minutes) or instrument sampling noise (< 5 km).

This establishes that an analysis of the variation in the POLAN profiles (produced by inverting the cleaned trace data) and the associated scaled parameter data is likely to represent a true geophysical signal (after periods of bad data have been excluded).

Analysis of variability in the sounder data:

The data from the network of JORN VIS sounders samples the regional ionosphere's electron density eN(X,Y,z, t) (or equivalently the plasma frequency fp) with horizontal scales on the scale of the site separations (600 -1000 km) and vertical scales of 5-10 km and time scales of 5-15 minutes (after some smoothing). To see clearly the structure of the rapidly changing variability the large scale and slowly varying patterns of variability must first be removed (like peeling an onion) in order to reveal the finer detail in starker relief.

In general variability in the ionosphere (like tropospheric weather) can be separately described in terms of

1. The "climatological (daily) cycle" that varies from place to place and month to month. This cycle can be used to describe what a "typical" day looks like at any place and time and is available from empirically based models. This climatological cycle is a result of representing the "normal" or "typical" balance of forces in the ionosphere and is extracted from data by determining the median state of the ionosphere over a number of days. This is the typical "large scale" spatial and temporal structure of the ionosphere.
2. "Synoptic variations" around (or on top of) the climatological cycle represent the hour-to-hour and day-to-day variations in the ionosphere. The typical amplitude (but not the phase) of these disturbances is represented in the upper and lower decile limits often produced by climatological models. This is the ionosphere's response to non-uniformity or anomalies in the large-scale geophysical processes that produce the ionospheric electron density, anomalies like day-to-day (and hour to hour) variations in the strength of electron density transport via the equatorial fountain or the changes in electron density caused by constituent or temperature or recombination changes expanding away from auroral regions during storms. These variations are expected to be large in horizontal scale and have periods typically of greater than 1 hour. These are essentially slow variations that are sampled many times by an update rate of 3'45".
3. "Mesoscale disturbances" in the ionosphere are disturbances that are generally more local (small) in scale and/or fast acting (with periods of less than 90 minutes) than the "synoptic variation". Common examples are medium scale travelling ionospheric disturbances (mTID's). They are referred to as "mesoscale" because they fit between the larger synoptic patterns of variation and the very fast disturbances (on a scale of seconds and not captured within the VIS data).

This separation of variability is logically based on the different major physical (dynamical) processes that combine to determine the electron density at any location and time. In data analysis (as opposed to geophysical modelling) this separation is unattainable and the different scales of variability are often merged and difficult to separate. Never the less this separation is used as guidance for the following discussions and analysis.

While most of the variation in the normal E layer can be represented by the climatological daily cycle and much of the variation in sporadic E is thought to be “mesoscale” in its nature, this poster focuses on extracting the behaviour of the F layer.

This analysis is done using the “cleaned” virtual height trace data and the corresponding true height described earlier (see figure 5 and 6). Associated with these traces (and the inversion process) is the determination of the scaled parameters, foF2, hmF2, ymF2 (or h0F2) and the estimation of iTEC for all sounder locations and times.

Figures 13, 14, 15, 16 and 17 show examples of each of these raw parameters (foF2, hmF2,ymF2 ,h0F2 (= hmF2-ymF2) and iTEC (estimated ionospheric total electron content) over a sample 5 days for all the JORN sites.

Note: Parameter h0F2 is significantly less noisy than either ymF2 or hmF2 that have highly correlated errors.

Figures 18-22 show the corresponding climatological median daily cycle derived from a full months worth of day for May 2005. The different timing of dawn (in UT) at each site and the strong day night differences are clearly present in this median data.

To extract a picture of the synoptic variability in the original data the climatological daily cycle is removed and the result is low pass smoothed to produce an estimate of the low frequency ionospheric anomalies.

Figures 23-27 show the corresponding synoptic “anomaly” fields for each parameter. The sensitivity in the scales for each of these figures has increased by a factor of 2 to 3 compared to the original scale because the climatological daily cycle contains so much of the total variation in the original data.

The last part of the original data (after the removal of the climatological cycle and the slowly varying synoptic variations) is the rapidly varying residual. This part is expected to contain information on any “fast” variations in the ionosphere as well as parameter noise.

Figures 28-32 show the corresponding “fast” or residual fields for each parameter. Again the sensitivity in the scales for each of these figures has increased because the typical magnitude of “fast” residual variability is less than the slower synoptic variations.

Clearest in these figures is the higher level of “fast” variability seen in the height parameters during the night compared to daytime.

While some spatially and temporally coherent structures are visible in these figures they also demonstrate the difficulty in using just the parameter data to understand the “fast” or mesoscale disturbances observed within the sounder network.

Another way of looking at and quantifying this same observation is to compute the lagged auto-correlation and the power spectral density at an individual site.

Figure 33 shows an example of the time history of the, raw total foF2, the low pass smoothed value and the climatological median over a 5 of days at Lynd River in May 2005

Figure 34 shows a corresponding plot of the low pass "anomaly" and the fast "residual" (as well as parameter estimation uncertainty) after the climatological cycle has been removed.

To quantify the temporal coherence and periods of variability in this data the lagged autocorrelation and power spectral from all (31 days) data in May 2005 is computed. These are done both before and after the removal of the climatological background as well as for the "fast" residual.

This shows that removing the median diurnal cycle removes most (but not all) of the diurnal cycle and the underlying levels of covariance can be quantifies as 4.5, 0.9 and 0.08 MHz^2 respectively (sigma of approximately 2.2, 1, and 0.3 MHz respectively)

Figures 35 & 36 show the autocorrelation and power spectral density of the original foF2 data at Lynd River for May 2005.

Figures 37 & 38 show the same autocorrelation and power spectral density based on the synoptic anomaly data

Finally **figures 39 & 40** show the autocorrelation and power spectral density of the fast residual.

While figures 39 & 40 shows some geophysical signal in the "fast" residual variation of the F layer parameter data, because the parameters describing the F2 peak are superimposed on the underlying noise in the parameter estimation information is difficult to extract.

To better describe the temporal and vertical structure of these fast variations in electron density the POLAN images of plasma frequency (versus height and time at each single site) like figure 6 are re-examined.

Taking the cleaned true height data presented in figure 6 and applying a low pass smoother to every height produces a picture of the slower synoptic variations in electron density at this site.

F**igure 41** shows the image of slowly varying plasma frequency (versus height and time) over 5 days at Lynd River in May 2005.
The associated residual or fast variation is presented in **figure 42**.
The heights of the top (hmF2) and nominal bottom (h0F2) of theF2 layer are over plotted for reference.

Figure 42 clearly shows the periodic coherent vertical and temporal structure of the "fast" disturbances in the inverted plasma frequency (electron density) field. These are an expression of the variability in electron density that is causing the virtual height variation presented in figure 10.

Some parts of this structure are phase locked to the time of day and can be separately identified by taking a running median of 10 adjacent days. This presents a picture of the very rapid transition produced by the dawn terminator that is smoothed out in the climatological median diurnal cycle.

To see the correlated vertical and temporal of these disturbances in more detail, a zoomed in image of the fast residual variations is displayed for 3 nearby sites, Scherger, Lynd River and Longreach in **Figures 43-45** (for part of 2nd May2005).

Some of these disturbances are associated with larger scale synoptic disturbances but many are also present at times when the background plasma frequency is quiescent.

These periodic disturbances have a temporal and vertical structure that is propagating down in true height over time. The peak amplitude of these disturbances is often below the F2 peak height (particularly at night). During the day the bottom part of these disturbances is associated with the variability in the F1 cusp frequency (fbF1) observed in figures 4,7 & 9.

These periodic disturbances have a temporal and vertical structure very much like medium scale TID’s and appear ubiquitously throughout the VIS sounder network data at a level of signal that is above the background noise.

Conclusions:

The figures in this poster have displayed only a small sample of the data available and have instead focused on showing how the larger amount of data can be presented.

Principle conclusions based on this and wider analyses are,

- The raw Artist electron density profiles are so noisy (due largely to missing and miss-scaled virtual height trace data) that information about the structure of rapid changes in the derived electron density is lost.

- If the original raw traces are “cleaned” then the POLAN inverted electron density profile captures a smoother view of the fast changes in eN and the vertical and temporally coherent structure of fast variations can be observed.

- The fast variations in electron density observed though out the JORN sounder network generally have downward propagating anomalies with peaks often below the F2 peak height.

- Some of these disturbances are associated with large-scale synoptic variations in the ionosphere and some occur when the underlying background state of the ionosphere is slowly varying (quiescent).

- These periodic disturbances have a temporal and vertical structure very much like medium scale TID’s and appear ubiquitously throughout the VIS sounder network data at a level of signal that is above the background noise.

- The F2 scaled parameters generally are adequate to capture and describe the climatological and large scale synoptic variability in the F layer but a great deal of the fast variation is in the F layer ionisation occurs in the bottom side of the F layer below the F2 peak. These F layer ionospheric variations are difficult to identify with the FoF2 and hmF2 parameters.