

Data Services Upgrade: Perfecting the ISIS-1 Topside Digital Ionogram Database

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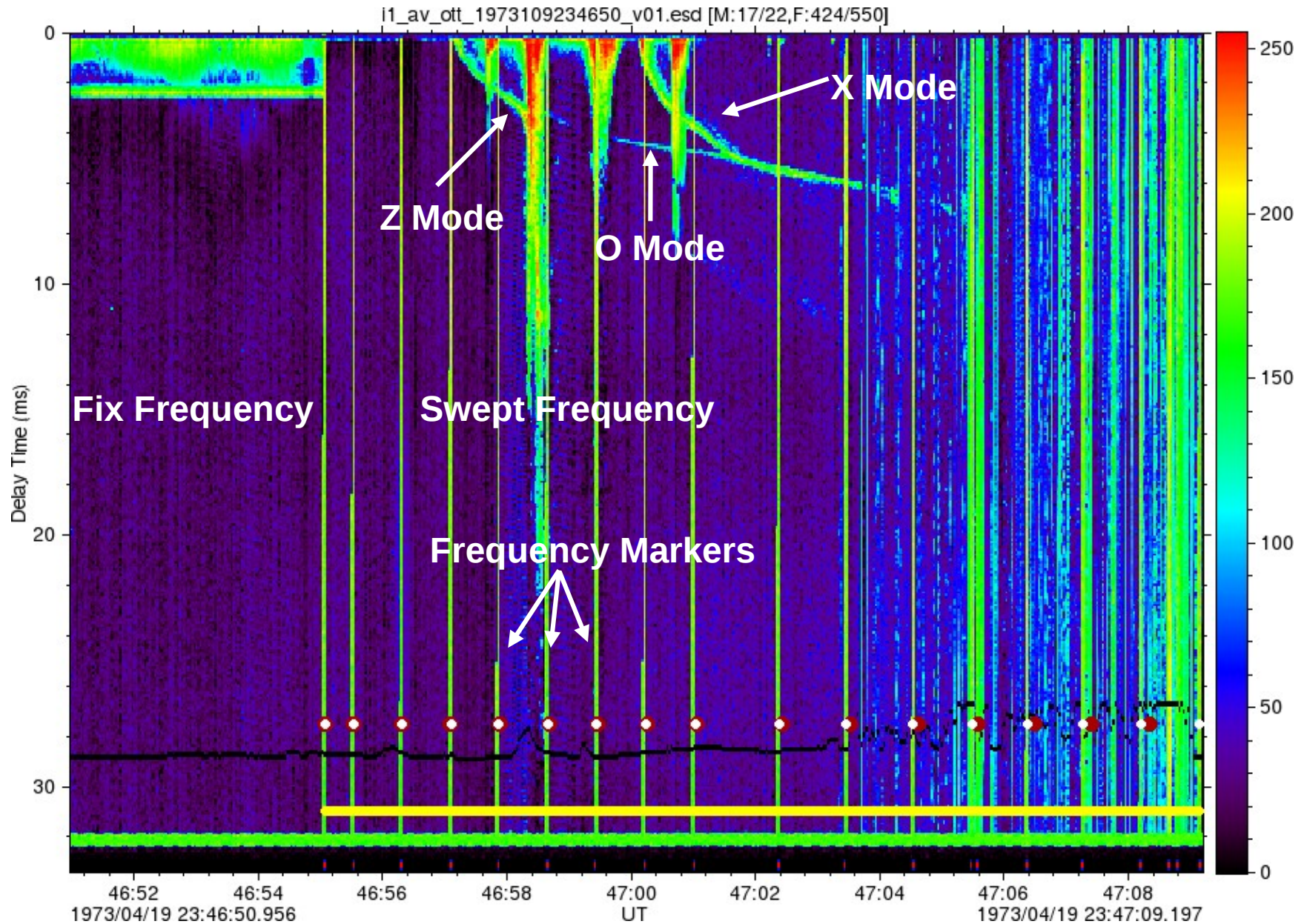
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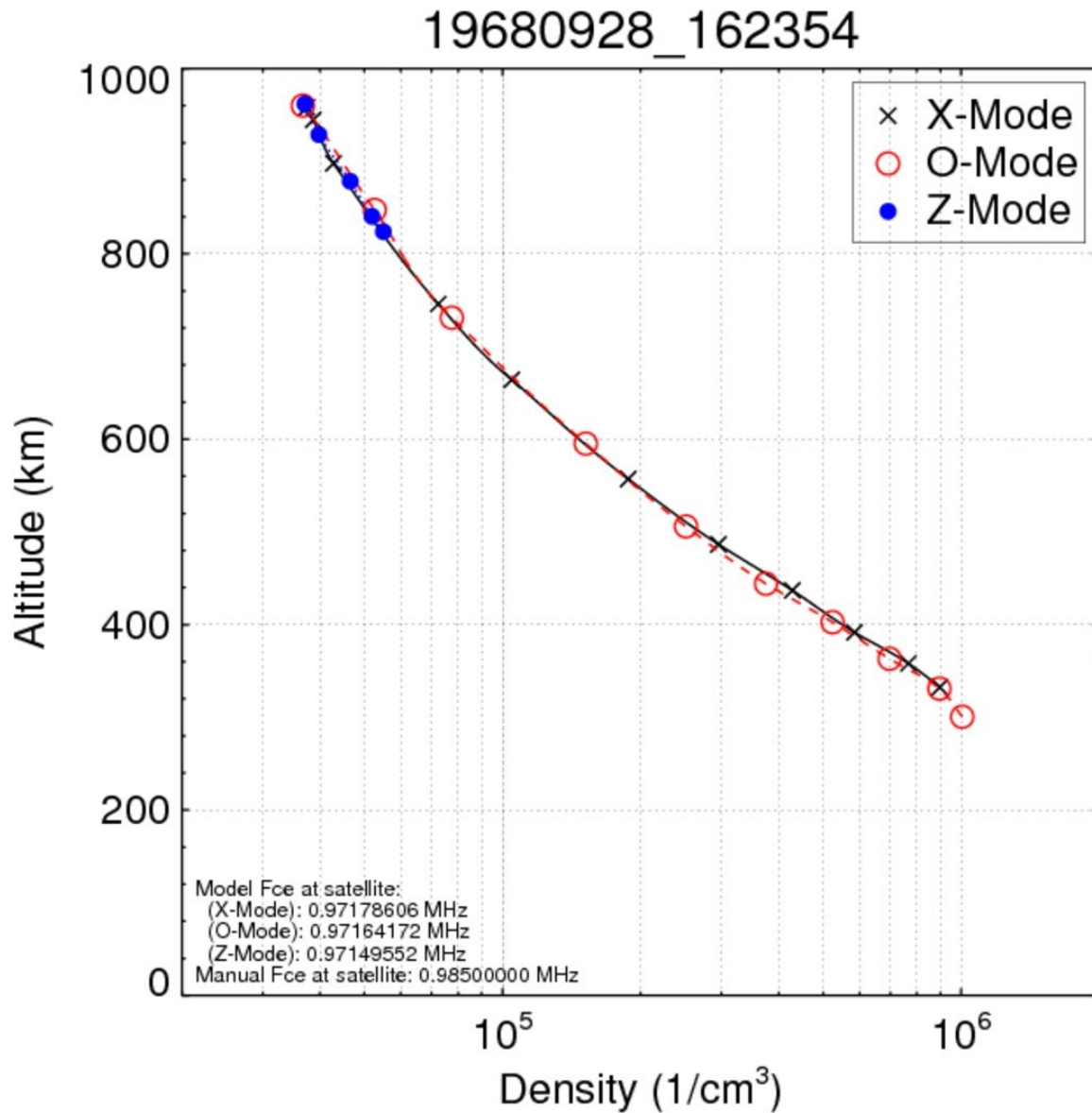
Introduction

- The ionospheric topside sounders of the International Satellites for Ionospheric Studies (ISIS) program were designed as analog systems. More than 16,000 of the original telemetry tapes from three satellites were used to produce topside digital ionograms, via an analog-to-digital (A/D) conversion process, suitable for modern analysis techniques.
- Unfortunately, many of the resulting digital topside ionogram files could not be manual- or auto-processed to produce topside $N_e(h)$ profiles because of problems encountered during the A/D process.
- Software has been written and procedures have been established to resolve these problems.
- Here we report on (1) the first application of the software and procedures to a significant portion of the ISIS-1 digital topside-ionogram database, (2) software improvements motivated by this activity, (3) $N_e(h)$ profiles automatically produced from these corrected ISIS-1 digital ionogram files, and (4) the availability via the Virtual Wave Observatory (VWO) of the corrected ISIS-1 digital topside ionogram files for research.
- We will also demonstrate the potential of these $N_e(h)$ profiles for making refinements in the International Reference Ionosphere (IRI) and in the determination of transition heights from O^+ to H^+ .
- This work was supported by the NASA Data Services Upgrade Program Grant NNX14AJ78G and Grant 1507281J of the Grant Agency of the Czech Republic.

Example of A "Good" Ionogram



What Can We Do With A “Good” Ionogram



- Inversion of X-, O-, and Z-Mode traces of “good” ionograms to get electron density profiles [e.g., **Jackson, Proc. IEEE, 1969;** **Huang et al., Ann. Geophys., 2002;** **Wang et al., Proc. IES, 2011**].
- Using electron density profiles to study the configuration, dynamics and control of ionosphere environment [e.g., **Benson et al., IES2015, paper #56, Session 8B**].

Problems with the Current ISIS-1 Ionograms

Several problems were encountered during the A/D conversion of the ionogram data contained on the original 7-track analog telemetry tapes:

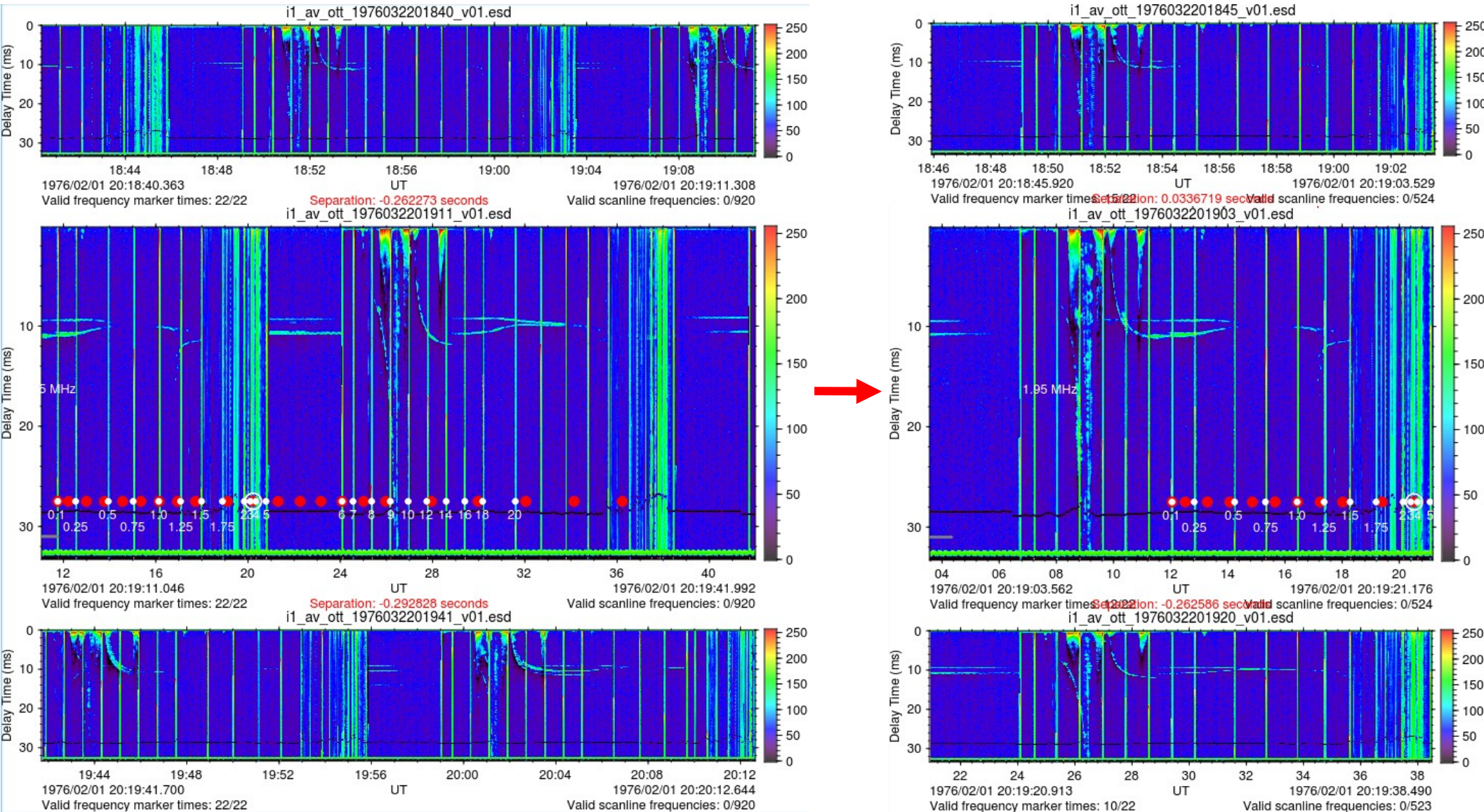
- **Timing problem:** Some timing errors were caused by bit-code errors in reading the time code during the A/D process resulting in incorrect spacecraft position and magnetic field information. Some of these erroneous values could easily be detected as described at spdf.gsfc.nasa.gov/isis/isis-status.html. Some timing errors were caused by variations in the speeds of the tape drives used in the recording and play back of the telemetry data. Some timing errors were caused by duplicate processing of the same data, thus causing overlapped data segments.
- **Ionogram frame-sync pulse detection problem:** When the ionogram frame sync pulse was not properly detected then, in most cases, the frequency marks were also not properly detected and programs such as TOPIST could not automatically process the ionospheric reflection traces into topside $N_e(h)$ profiles.
- **Frequency marker detection problem:** Proper frequency-marker identification was not always guaranteed because of interference signals and strong plasma resonances that could be falsely identified as frequency markers during the A/D process.

The majority of the current version ISIS-1 digital ionograms have the above problems.

Timing Correction

- Ionograms falling out of valid data spans are removed with software. They are caused by bit-code errors in reading the time code during the A/D process.
- Ionograms overlapping in time are removed if it is determined that they are the result of time-code errors or duplicate processing of the same satellite pass.
- When joining two ionograms, time gap/overlap is usually not the scan line separation time. This is caused by variations in the speeds of the tape drives used in the recording and play back of the telemetry data. We shift the data to have only normal scan line separation time between them.
- Even after the above timing corrections an ionogram can have a start time that is slightly earlier or later than the end of the preceding ionogram due to the variations in the speeds of the tape drives.

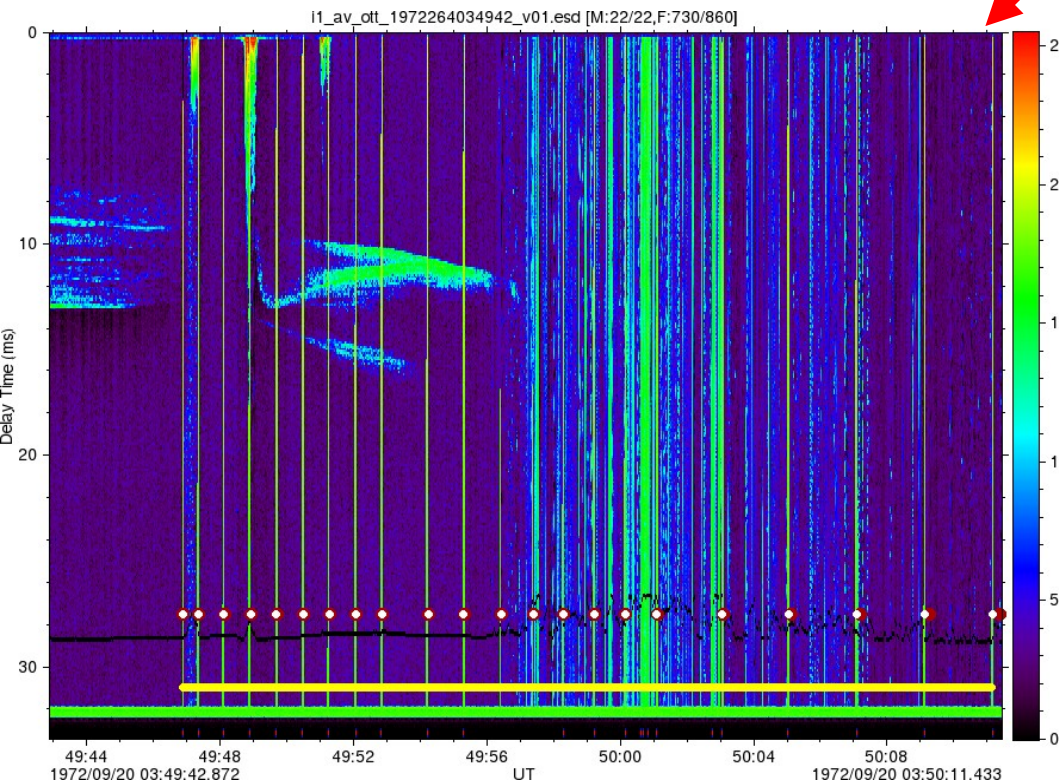
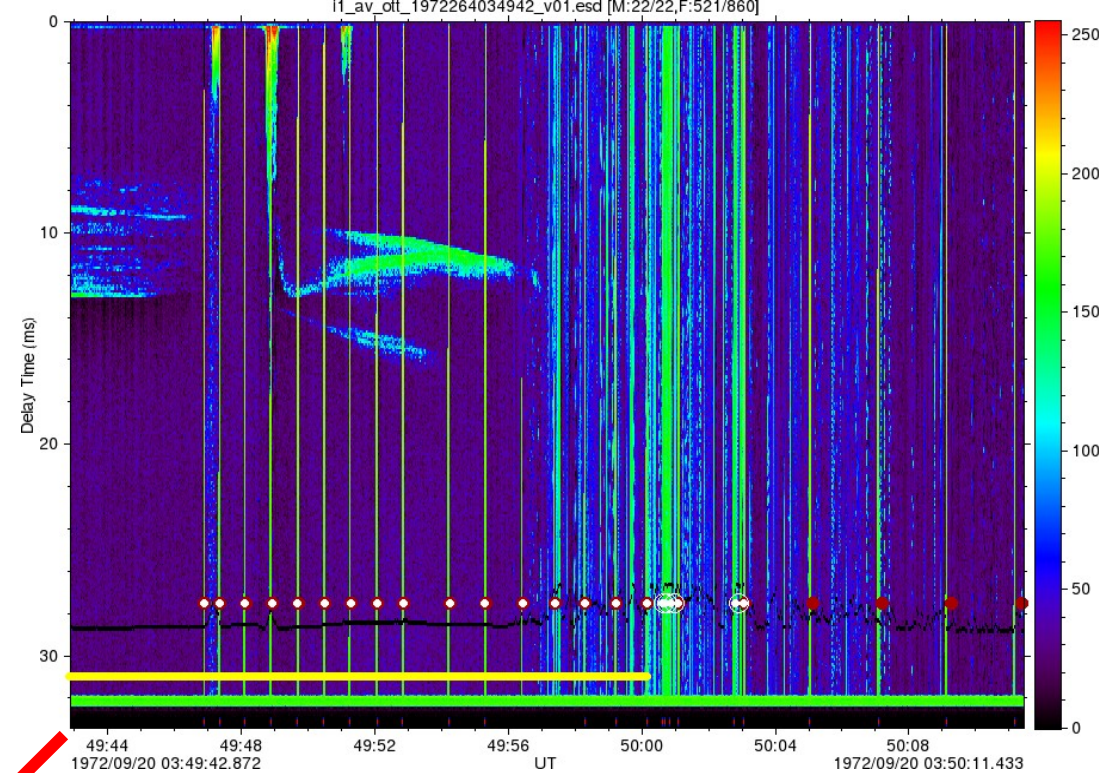
Segmentation Correction



- Segmentation errors were caused by improper identification of the ionogram frame sync pulse
- Software was developed to facilitate efficient ionogram manual segmentation

Frequency Marker Correction

- Missing/Wrongly placed frequency markers prevent the correct determination of frequency values for scan lines.
- Software was developed for the efficient manual correction of frequency markers.
- Automatic pattern matching of frequency markers and standard markers is conducted for scan line frequency interpolation.
- Special adjustment needed between 2-3 MHz and 5-6 MHz is included, so users do not need to include such treatment as they do for version-1 ISIS-1 ionograms.



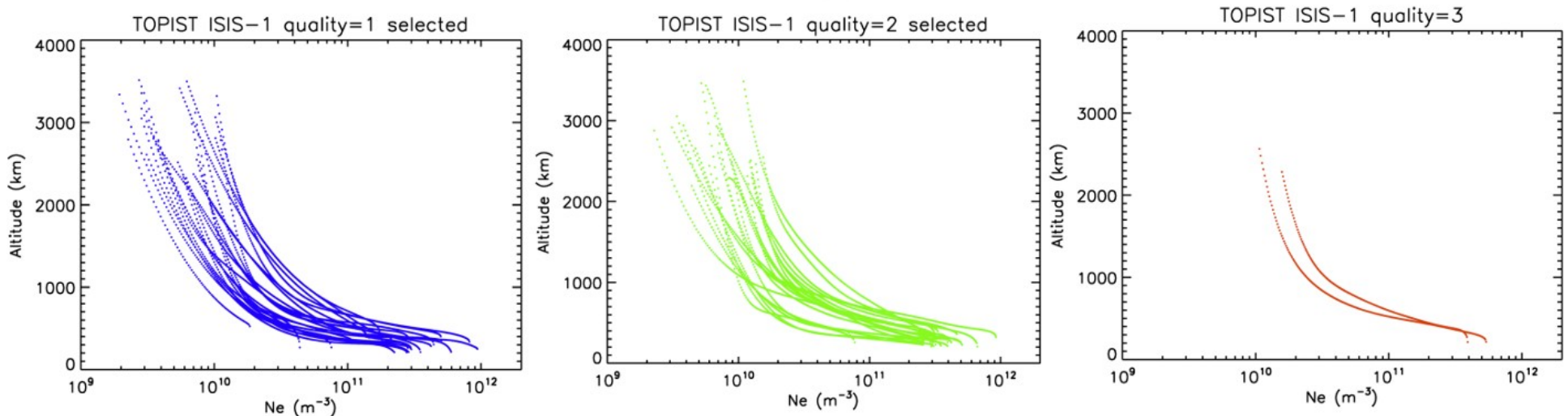
- Large red dots: Standard frequency markers for reference.
- Small white dots: Actual frequency markers for the ionogram.
- Yellow bar: Valid frequency range.

Current Status of Our Data Correction Work

- There are ~80,000 digital ISIS-1 ionograms from Ottawa station from 1969 to 1983.
- It is necessary to have software capable of efficient processing of this large amount of data. A full suite of software was developed to solve the problem.
- Standard data correction procedure:
 - 1) Removal of files with timing error (out-of-bounds and overlap)
 - 2) Fixing segmentation problems
 - 3) Fixing frequency marker problems
 - 4) Frequency interpolation between the correct times for the frequency markers
 - 5) Final checking for quality control
- A significant amount of manual work is needed to accomplish the above tasks to yield a high-quality data, even with the help of very efficient software tools.
- The majority of the ISIS-1 Ottawa station digital data from 1969 to 1983 has been fully processed in the past 8 months. Another 2-3 months will be needed to process the remaining data.
- Final version-2 ISIS-1 Ottawa station data from 1969 to 1983 will be available from spdf.gsfc.nasa.gov/isis/isis-status.html and the Virtual Wave Observatory (VWO) [*Fung, Radio Science Bulletin, 2010*] for public access.

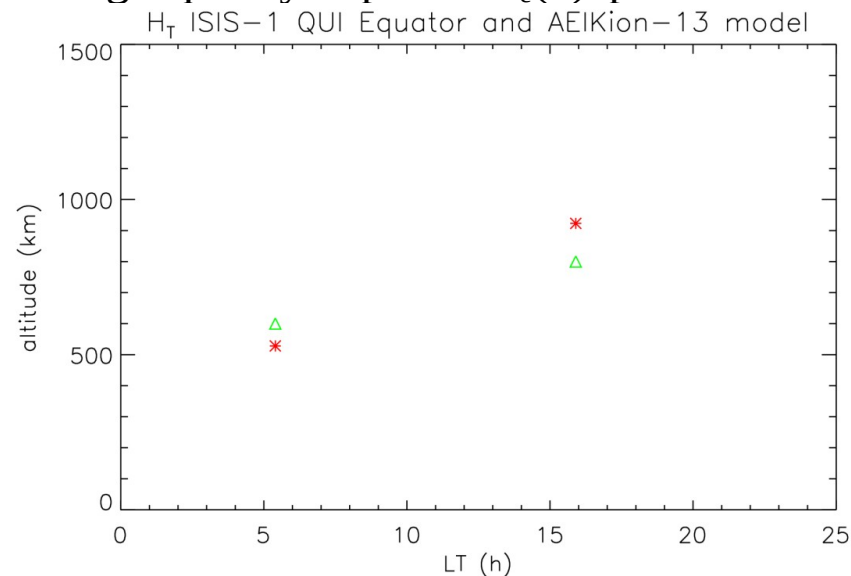
Automatically-Produced $N_e(h)$ Profiles

- Manual ionogram trace identification works for small-scale case studies. For large-scale investigations using large amount of ionograms, this method is very difficult, if not impossible, because it takes a significant amount of time.
- Automatic ionogram trace identification and inversion are a solution for such a problem.
- TOPside Ionogram Scaler with True-height (TOPIST) [*Huang et al., Ann. Geophys., 2002; Bilitza et al., Radio Sci., 2004*] is a tool specially designed for such a purpose.
- Below is an example of selected TOPIST automatically-produced $N_e(h)$ profiles from version-2 ISIS-1 QUI ionograms from 1976 with different quality flags (with 3 being the highest quality).



Upper Transition Height Determination

- One important application of topside $N_e(h)$ profiles is the determination of the upper transition height (Ht); it corresponds to the altitude where the distribution of dominant ions changes from the topside ionosphere (O^+) to the plasmasphere (H^+ and He^+). It is a key parameter since magnetospheric-ionospheric interaction processes are important in this transition region.
- We used a method developed by *Webb et al. [Radio Sci., 2006]* to determine Ht. This procedure assumes diffusive-equilibrium, uses an electron temperature model (IRI) as an input, and employs a least-square fit to N_e profiles to determine ion (O^+ and H^+) profiles and from them Ht.
- A preliminary test using TOPIST ISIS-1 topside $N_e(h)$ profiles from the equatorial telemetry station QUI was performed. Only profiles from $\pm 15^\circ$ diplat are selected and only two local times were populated (5.4 h and 15.9 h) by the data represented in the last figure. The processed data show an average Ht of about 530 km for 5.4 h LT and about 920 km for 15.9 h LT. The AEIKion-13 model [*Truhlik et al., Adv. Space Res., 2015*] produced values of about 600 km and 800 km at these local times, respectively. Thus, there is a reasonable agreement between the data and the model.
- The availability of more high-quality topside $N_e(h)$ profiles will enable improvements to current models of Ht.



Improving the IRI Model

- The International Reference Ionosphere (IRI) [*Bilitza, Adv. Space Res., 2015*] is an international project sponsored by the Committee on Space Research (COSPAR) and the International Union of Radio Science (URSI). These organizations formed a Working Group in the late sixties to produce an empirical standard model of the ionosphere, based on all available data sources. Several steadily improved editions of the model have been released. For given location, time and date, IRI provides monthly averages of the electron density, electron temperature, ion temperature, and ion composition in the altitude range from 50 km to 2000 km.
- The major data sources are the worldwide network of ground-based ionosondes, the powerful incoherent scatter radars (Jicamarca, Arecibo, Millstone Hill, Malvern, St. Santin), the ISIS and Alouette topside sounders, and in situ instruments on several satellites and rockets.
- A significantly improved ISIS-1 ionogram database covering more than a solar cycle with the help of automatic Ne(h) profile tools like TOPIST will help to improve the representation of the topside electron and ion densities in IRI.

Summary

- There are major problems affecting the majority of the current ISIS-1 digital ionogram data
- Special software and procedures have been developed to address these problems
- We are close to finishing the correction of ~80,000 ISIS-1 Ottawa ionograms from 1969 to 1983 with huge quality and usability improvements
- Version-2 ISIS-1 digital ionogram data will be made available via SPDF (<http://spdf.gsfc.nasa.gov>) and VWO (<http://vwo.nasa.gov>) for easy public access
- There are many uses for this improved database, including large-scale automatic processed Ne(h) profiles, improving the IRI, transition height investigations, deducing magnetic-storm-induced changes to high-latitude topside electron-density profiles, etc.