Electron Density Dataset from IMAGE RPI Magnetospheric Dynamic Spectra

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The primary objective of the NASA New Investigator Project (NIP), Automating Electron Density Determinations from Magnetospheric Dynamic Spectra (NNX06AH07G), was to develop an automatic fitting technique to process a large database of approximately five years of NASA Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) spacecraft Radio Plasma Imager (RPI) passive dynamic spectra observations, with the goal to extract the local electron density. Four major steps are involved in this process: data preparation, automatic fitting, manual correction, and data release.

1. Data Preparation

The data format commonly used by scientists in the analysis of IMAGE/RPI observations is known as the Level Zero, Telemetry or L0 format. Staff from the University of Massachusetts Lowell Center for Atmospheric Research (UMLCAR), the RPI instrument's PI institution, developed several analysis tools using L0 data. These software were bundled together into the RPIAnywhere software suite. Details on the L0 data format, and the analysis tools are available from their website at http://ulcar.uml.edu/rpi.html. For the work on this project the PostPro1 software tool from the RPIAnywhere suite was used in a batch mode to convert the L0 data files into text format files that could be more easily read by our automatic fitting software.

4-min resolution files of IMAGE related parameters were generated by Dr. Scott A. Boardsen as a courtesy to this project. Among these parameters, IMAGE orbit and model electron cyclotron frequency were used directly. The Tsyganenko T96 model was used as a proxy for the background magnetic field. This model requires the solar wind dynamic pressure, IMF Bz, and the DST index as input. If these parameters were not available, default values of solar wind pressure of 2.1 nPa, IMF Bz of 0 nT, and DST of -10 nT were used.

2. Automatic Fitting

The IMAGE spacecraft had a polar orbit from about 1000 km to 7 Earth radii (Re) altitude. The RPI instrument operated from 3 kHz to 3 MHz, which covers plasma resonance frequency characteristic of the Earth's magnetosphere. For our investigation, its passive power spectra observations between 3 and 1000 kHz were used.

The automatic fitting procedure to determine electron plasma frequency, f_{pe}, from RPI dynamic spectra has five key steps in each time step: 1) Search for an enhancement peak in the dynamic spectra; 2) Assume the peak is an upper hybrid band and attempt to determine f_{pe} self consistently using a model electron cyclotron frequency, $f_{ce,model}$, calculated using Tsyganenko T96 magnetic field model; 3) If unsuccessful, assume the peak is related to Z-mode enhancement and repeat 2); 4) If still unsuccessful (or no peak found initially) then attempt to search for a continuum edge and estimate f_{pe} based on edge location; 5) If still no discernable known plasma feature exists, record that no f_{pe} value could be determined for that time step.

More detailed procedures for RPI dynamic spectra automatic fitting for a specific time range are:

1. Read in power spectrum data within this time range.

2. Calculate the L value for each time step.

3. Calculate Carpenter and Anderson model electron plasma frequency, $f_{pe,model}$, based on the L value.

4. Calculate the upper boundary of the search region in frequency space, $upbf$, which is the larger of $2.5 f_{pe,model}$ and 75 kHz. The lower boundary is $f_{ce,model}$.

5. If $f_{ce,model} < 20$ kHz, search for $n + \frac{1}{2}$ emission bands, which is primarily for the purpose of removing them from the search region, but which allows for an estimation of the electron cyclotron frequency, f_{ce}. If an f_{ce} is not found from the $n + \frac{1}{2}$ bands, its neighbors' f_{ce} values, if exist, will be interpolated for it.

6. Try to get f_{pe} from first the upper-hybrid band or, if that does not succeed, the Z-mode band. First, set the search range between $f_{ce,model}$ and $upbf$. If $n + \frac{1}{2}$ bands exist, its last power minimum will replace $f_{ce,model}$ as the lower boundary. Find the peak power, p_{max}, and its related frequency, f_{max}. Further get frequency f_{lo} and f_{up} before and after f_{max} where power drops 8 $dB/Hz^{\frac{1}{2}}$ from p_{max}. Set $f_1 = f_{lo}$, $f_2 = \sqrt{f_{up}^2 - f_{ce,model}^2}$, and $rsmd = |f_2 - f_1|/[(f_1 + f_2)/2]$. If $rsmd < \frac{1}{8}$, we set $f_{pe} = (f_1 + f_2)/2$ from this upper-hybrid band. Or else, set $f_1 = \sqrt{f_{lo}^2 + f_{lo} f_{ce,model}}$, $f_2 = \sqrt{f_{up}^2 - f_{ce,model}^2}$, and $rsmd = |f_2 - f_1|/[(f_1 + f_2)/2]$. If $rsmd < \frac{1}{8}$, we set $f_{pe} = (f_1 + f_2)/2$ from this Z-mode band. Or else, repeat the above checking by decreasing signal strength drop by 8 $dB/Hz^{\frac{1}{2}}$.

7. If still no f_{pe} found, search for a continuum edge between $f_{ce,model}$ (If $n + \frac{1}{2}$ bands exist, its last power minimum will replace $f_{ce,model}$ as the lower boundary) and $upbf$ by fitting with hyperbolic function, the coefficients of which are based on a continuum edge case study done in conjunction with active RPI observations. A total of three iterations can be done to further refine the search region until at least an 8 $dB/Hz^{\frac{1}{2}}$ edge enhancement is found.

8. Finally, correct data dropouts and f_{pe} gradient anomalies by using temporally adjacent fitted values.

The software suite for undertaking the automatic fitting was first developed in the Matlab programming language, and then was converted to the IDL programming language based on Space Science Analysis and Visualization (SSAV) toolkit, for Z-mode integration, final automatic fitting, manual correction, and dataset production.

3. Manual Correction

Generally the automatic fitting routine does a good job to find f_{pe}. However, in some cases manual corrections are needed to correct automatic fitting errors. These incorrect fits appear to be due primarily to data complexity. The following guidelines are followed during the manual corrections:

1. Follow the automatic fitting f_{pe} trend as much as possible, but make proper adjustments if the automatic trend is too far from the actual trend obviously missed by it.

2. Add missing f_{pe} if possible if a clear spectrum power peak or continuum edge is seen close to the neighboring f_{pe} trend.

3. Avoid f_{pe} on erroneous "power stripes" at some discrete frequencies if it is not close to neighboring f_{pe} trend.

4. Remove all those close to noise band unless there are very clear signatures.

5. Remove f_{pe} values too far away from predominant neighboring trend or spreading too much to form a clear trend.

6. Avoid the traces where there can be multiple possibilities and we do not know which ones are true.

All the automatic fitting results have been manually inspected and corrected, if necessary,

4. Data Release

After we got f_{pe}, electron density was obtained using $n_e = 4\pi^2\epsilon_0 f_{pe}^2 m_e/e^2$, where ϵ_0 is electric constant, m_e the electron mass, and e the electron charge. A total of 204845 valid electron density data points were obtained for the period between January 2001 and December 2005. The final IMAGE electron density dataset includes time tags, satellite location in Solar Magnetic (SM) coordinates, magnetic local time, magnetic latitude, L-shell, model electron cyclotron frequency, and electron density. The dataset is planned to be published at CDAWeb (http://cdaweb.gsfc.nasa.gov) and VMO (Virtual Wave Observatory, http://vwo.nasa.gov). for public access.