Automatic retrieval of plasmaspheric electron densities: first results form Automatic Whistler Detector and Analyzer Network

***János Lichtenberger*[1], *Csaba Ferencz*[1], *Dániel Hamar*[1], *Péter Steinbach*[2], *Craig Rodger*[3], *Mark Clilverd*[4] and *Andrew Collier*[5],**

[1]Space Research Group, Department of Geophysics and Space Sciences,
Eötvös University, Budapest, Pázmány Péter sétány 1/A, H-1117 Hungary,
spacerg@sas.elte.hu

[2]Research Group for Geology, Geophysics and Space Sciences,
Hungarian Academy of Sciences, Budapest, Pázmány Péter sétány 1/A, H-1117 Hungary,
spacerg@sas.elte.hu

[3]Department of Physics, University of Otago, P.O. Box 56, Dunedin, New Zealand,
crodger@physiscs.oatgo.ac.nz

[4]British Antarctic Survey, High Cross, Madingly Road, Cambridge CB3 0ET,
United Kingdom, macl@bas.ac.uk

[5]Hemanus Magnetic Observatory, P.O. Box 32, Hermanus, 7200, South Africa; School of Physics, University of KwaZulu-Natal, Durban, 4001, South Africa, collierab@gmail.com

Abstract

There is an increasing 'demand' for plasmaspheric electron density data for plasmasphere models in Space Weather related investigations, particularly in modeling charged particle accelerations and losses in Radiation Belts. The global Automatic Whistler Detector and Analyzer (AWDA) system network detects millions of whistlers in a year. But the analysis of the whistlers to extract the plasmaspheric electron density information has thus far proved to be slow and time consuming. A recently developed whistler inversion model opened the way for an automated process of whistler analysis, not only for single whistler events but for complex analysis of multiple-path propagation whistler groups. An automatic analyzer algorithm was also developed and a practical implementation of such a system on a PC cluster is done. The prototype of AWDA runs on the cluster in quasi-realtime mode, the analysis of a whistler group take a few minutes. In this paper we present the first results of test runs processing whistlers from our archive database. We are planning to install this algorithm on AWDANet nodes in the near future to archive the quasi-realtime mode of operation in providing plasmaspheric electron densities.

1. Introduction

All space weather models and forecasting methods are dependent on data for either boundary conditions or the specification of model parameters. At best these data come from in-situ observations or a statistical model parametrized by geomagnetic indices. In the worst case estimates are used to provide some representative values. In-situ satellite observations are able to measure the densities directly and can sample wide and continuous latitudinal and longitudinal ranges, but suffer from a number of inherent weaknesses: very few platforms give simultaneous comprehensive measurements of particles, waves and fields. Data availability is also very often limited in space and time: at best there will be a handful of observations of a given parameter at any given time throughout all of geospace. With very few exceptions (such as GOES data), data are generally not available in real or even near-real time, limiting their use for forecasting. Finally, the high costs of satellite fabrication and launch make it unlikely that these limitations will be overcome any time soon. However, ground based measurements provide a complementary or alternative data source for space weather models. Clearly the combination of ground and space based measurements would provide the best results, but the ground based measurements have several advantages over the space based ones. They are generally inexpensive and can produce continuous temporal and spatial coverage, which may be limited by the occurrence of the phenomena. Most ground-based stations have access to the Internet, thus capable of providing real-time data.

The cold electron density distribution of the plasmasphere is a key parameter for modeling the plasmasphere and radiation belts, but is difficult to measure routinely. Whistlers have been regarded as cheap and effective tools for case

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studies of plasmasphere diagnostics since the early years of whistler research [1], but have not been used as an operational tool since reducing whistler data to equatorial densities is very labour intensive for statistical studies. These equatorial densities were obtained by whistler inversion analysis, which in turn was based on a combination of wave propagation, plasmaspheric electron density distribution and magnetic field models. Such equatorial electron number density measurements based on operator-scaled whistler data led to the discovery of the plasmapause [2]. Broadband VLF recordings extending over a few decades probably contain millions of whistlers that can be used in plasmasphere diagnostic studies. The recently developed Automatic Whistler Detector system setup at various AWDANet nodes [3] collects whistlers in high numbers, e.g. the rate at the Antarctic peninsula is close to 10 million per year. However, the human effort needed to analyze a whistler is rather on the order of an hour than a minute, (this estimate is based on long term experiences of many researchers) thus this huge potential cannot be utilized fully this way. An algorithm [4] that can overcome this bottleneck and can be used to automate the whistler analysis (AWA) procedure [5] was also developed recently.

2. Implementation of Automatic Whistler Analyzer algorithm [5]

The implementation of AWA algorithm is based on Virtual Trace Transformation (VTT) [4] that uses a simplified model of equatorial electron density distribution in the plasmasphere. This model coupled to he whistler inversion method in [4] and forms the bases of AWA algorithm. The principle of this algorithm differs basically from the traditional whistler analysis method. The latter required manual scaling of f-t pairs in a whistler spectrogram, trace by trace and then running a whistler propagation model on these input data to obtain plasmaspheric electron densities and propagation L-values. The AWA algorithm applies to the *spectrogram* matrix and produces a transformed spectrogram exhibiting vertical structures. The practical implementation is based on this feature, the automatic algorithm searches for the best plasmaspheric parameters that corresponds to vertical structures on VTT matrix.

3. Prototype of AWA algorithm on a PC cluster

The principal goal of the application AWA is to obtain plasmaspheric electron densities at all possible magnetic latitudes and longitudes, these data can then be used for modeling of the plasmasphere. The AWA algorithm is a very CPU intense process, but our goal is to provide data enough to monitor the variations of the plasmasphere due to changes in MLT and dynamic processes. This is equivalent to 10-15 density data at a location and AWA implemented on a PC cluster can fulfill this goal. We have setup a PC cluster of 52 CPU cores/ 104 CPU threads , AWA runs on this cluster in quasi real-time mode, that is after an initial delay of ~15-20 minutes, it processes 10-15 multiple path whistler groups per hour. The major advantage of AWA over the traditional methods is to provide a true density description over a range of L-values (a range that is covered by the traces of the whistler group) and an estimation of L-dependence of the equatorial density outside this interval, that can be valid between $1.4 < L < L_{pp}$, where L_{pp} is the location of plasmapause.

4. First result of AWDANet on archive data

Our primary goal is to install AWA algorithms on majority of AWDANet nodes (Figure 1) to obtain plasmaspheric densities in quasi real-time. However, this is a long process, requires years and substantial financial investments (there is an ongoing project funded by EU-FP7 entitled 'PLASMON: A new, ground based data-assimilative model of the Earth's Plasmasphere – a critical contribution to Radiation Belt modeling for Space Weather purposes', which includes plans for deployments of AWA systems at AWDANet nodes). Since the installation of the first AWDANet node in 2002 at Tihany, Hungary, the network detected millions of whistlers and these whistler have not been analyzed yet, though the densities obtained from these data can be useful for case studies and plasmasphere model developing, refinement and validation, particularly the data of those stations where multiple path whistler groups occur frequently.
We are now able to perform case studies for different conditions:

- Same time, different magnetic meridional (Figure 2)
- Same day, different magnetic meridional (Figure 3)
- Different days, same magnetic meridional before and after a large magnetic storm (Figure 4)

The prototype cluster is able to process 300-400 events a day.

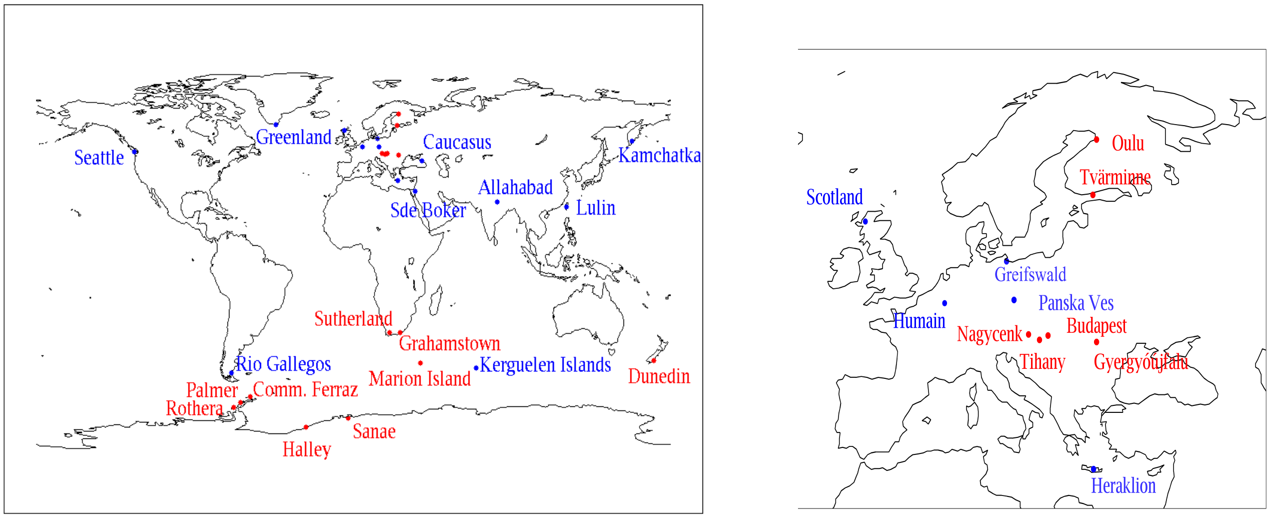

Figure 1. AWDANet stations (*operating*, *planned*)

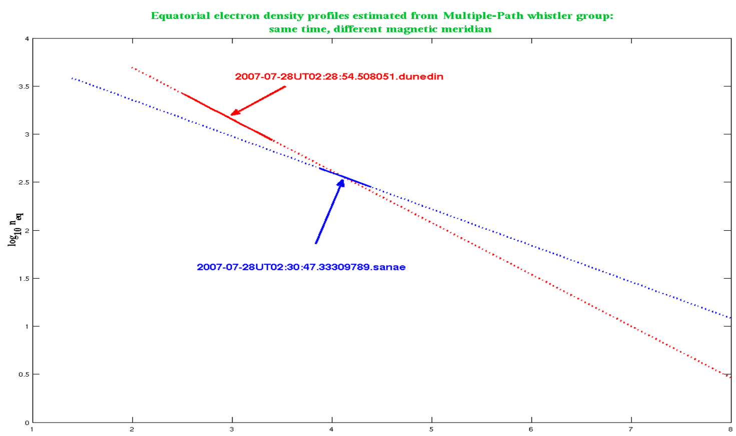

Figure 2. Equatorial electron density profiles obtained from whistler groups recorded at Sanae (Antarctica) and Dunedin (New-Zealand) at the same time. The L-range covered by the group is plotted with solid line, while the estimation outside this region is plotted by dotted line. This estimation is valid till the plasmapause.

5. Conclusion

The global Automatic Whistler Detector and Analyzer Network detected millions of whistlers since 2002, however, until now these data have not been analyzed to obtain plasmaspheric electron densities due to the huge manpower required for the traditional analysis. The recently developed new whistler inversion method allowed to automate the analysis process and led to a system with a practical implementation of AWA algorithm. A PC cluster has been setup to prototype the quasi real-time mode of operation of AWDANet, this prototype is used to process archive whistler data for case studies and plasmasphere model developments.

6. Acknowledgments

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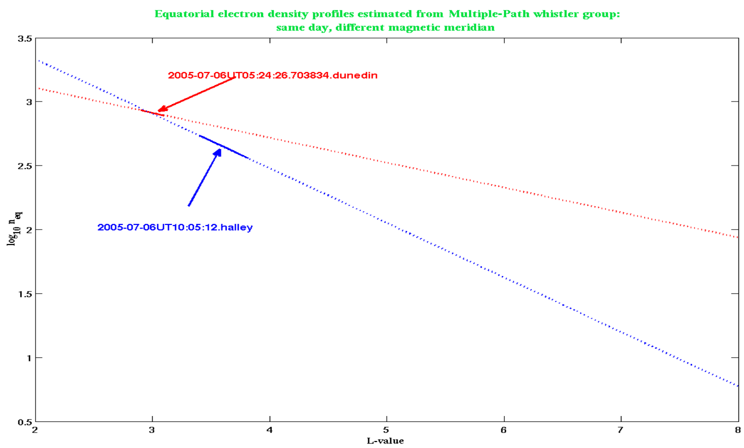

Figure 3. Equatorial electron density profiles obtained from whistler groups recorded at Halley (Antarctica) and Dunedin (New-Zealand) at the same day. The L-range covered by the group is plotted with solid line, while the estimation outside this region is plotted by dotted line. This estimation is valid till the plasmapause.

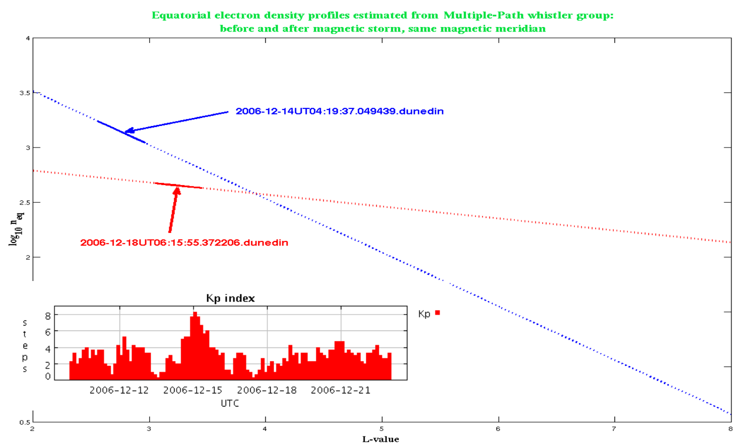

Figure 4. Equatorial electron density profiles obtained from whistler groups recorded at Dunedin (New-Zealand) at the before and after a large geomagnetic storm. The L-range covered by the group is plotted with solid line, while the estimation outside this region is plotted by dotted line. This estimation is valid till the plasmapause.

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