SIGNALS GENERATED BY REGIONAL LIGHTNING OBSERVED BY THE GLOBAL WHISTLER DETECTOR NETWORK

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We studied data from the global AWDANet plasmasphere monitoring network for whistlers detected locally, distorting the general statistics of whistlers. Our preliminary results show that apart from the geomagnetically conjugate hemisphere as a potential source region, local lightning generated in the vicinity of the whistler detector stations should also be considered. Our results can improve on the daily and seasonal statistics of whistler occurrence, and locally generated whistlers can contribute to a more complete monitoring of the plasmasphere.

1. Introduction

The global Automatic Whistler Detector and Analyser Network (AWDANet) [1], coordinated by the Space Research Group at Eotvos University, Budapest, plays an important role in the near real time monitoring of Earth's plasmasphere. The system, operating continuously in wide-band very low frequency (VLF), automatically detects and analyses whistlers generated by lightning discharges. Through propagating in the dispersive medium of the magnetosphere, these wide-band electromagnetic signals take on a specific time-frequency shape. It has long been shown that the analysis of the whistlers can yield plasmaspheric electron densities [2]. This task, however, proved to be very difficult to automate, and was first achieved in the AWDANet. The data processing algorithm of the system is currently optimalized for single-hop whistlers, which originate from lightning in the conjugate hemisphere, follow the geomagnetic field lines, and eventually return to the Earth-ionosphere waveguide, where they become detectable on the ground. The source region of these signals have been demonstrated to be around the conjugate point in earlier studies [3,4]. Through the analysis of ground-based data and low Earth orbit satellite data from the ICE wave experiment onboard the DEMETER microsatellite [5], a suspicion arose that the automatic whistler detector may also record signals generated in the broad vicinity of the detector location and reflected from the conjugate ionosphere. Such a mode of wave propagation is known in the literature [2], however, no systematic study of such signals have been carried out before. Signals that trace the geomagnetic field lines twice provide the same kind of information as those originating at the conjugate region with regards to the ionised upper atmosphere. However, they should be treated separately in the automated mass data processing. Based on initial results, the algorithm of the global whistler detector network can be modified such that it takes the possibility of these kind of signals into account, after which the obtained plasmaspheric parameters and whistler statistics will be more accurate.

2. History and motivation

One factor that makes whistlers intrinsically important is that they have been shown affect the total VLF wave intensity in the magnetosphere and play a role in controlling the particle population in the radiation belts through wave-particle interactions [6]. Their mass scale utilization as a remote sensing tool for plasmaspheric monitoring provides another motivation to better understand their source and propagation.

The AWDANet started real-time operation with fifteen stations in 2014. However, the station at Dunedin, New Zealand was set up much

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earlier, among the first stations. Early analysis of the output from the automatic mass processing of measurements showed that whistler occurrence rates at this location show anomalous diurnal distribution with respect to other stations, having a peak during the day. In addition, lightning activity in the geomagnetic conjugate region of Dunedin, lying in Southwest Alaska, can in itself not explain the large number of detected whistlers, [7]. These two problems are illustrated on Figures 1 and 2.

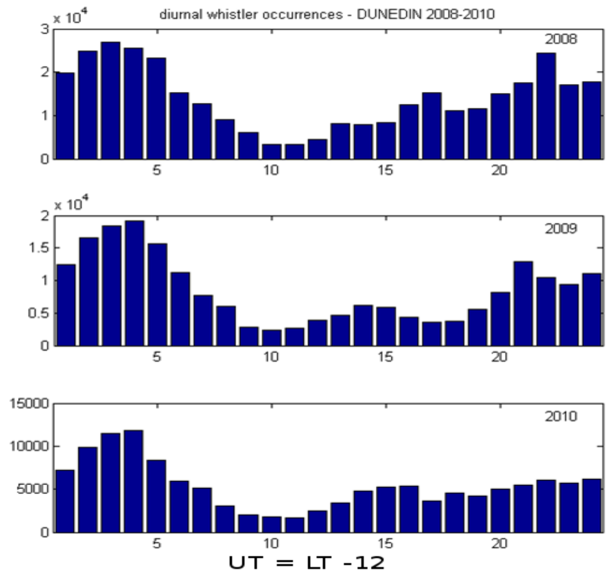

Figure 1. Distribution of whistlers recorded at Dunedin, according to local time. As opposed to other stations, this station shows high daytime activity with a peak at 3 PM local time. The general shape of this curve is persistent over several years.

3. Data processing and initial results

We used the time series of whistlers from our detector from three years (2008-2010), and the time series of located lightning strokes from the VLF-based global lightning detector network (World Wide Lightning Location Network, WWLLN [8]). The precision of the time stamps was 1 microsecond. We limited the lightning dataset to the region surrounding the station. The distribution of the time difference between each whistler time stamp and the time stamp of each lightning stroke in the dataset (regionally limited to various distances from Dunedin) should be equivalent to white noise if the two datasets are uncorrelated. Contrary to this, the distribution of the time differences thus obtained show a peak at approximately 3s delay time (see Figure 4). The location of the peak corresponds to the delay of whistlers crossing the plasmasphere twice, or double the typical propagation time. The propagation of signals through the path in the plasmasphere can be modeled using the Appleton-Hartree equation [2]. To account for the propagation path across the ionosphere (before and after propagating in the plasmasphere), we used Park's formula for correction [9]. This correction, in our experience, is generally less than 5% of the total travel time. Thus, we could estimate the total total propagation time. We used values typical for Dunedin (McIlwain parameter L=3.0, the corresponding equatorial electron density neq=1400 1/cm3, critical frequency of the local ionosphere f0F2=6.0 MHz) to calculate the the typical travel time of signals traveling there and back between the two hemisphere. We obtained a value of 2.9 s, which is roughly the double the travel time of signals traveling only a single path. This calculated value shows a good agreement with the statistical results of the lightning-whistler delay histogram (see Figure 4), confirming the presence of whistlers reflected from the conjugate ionosphere.

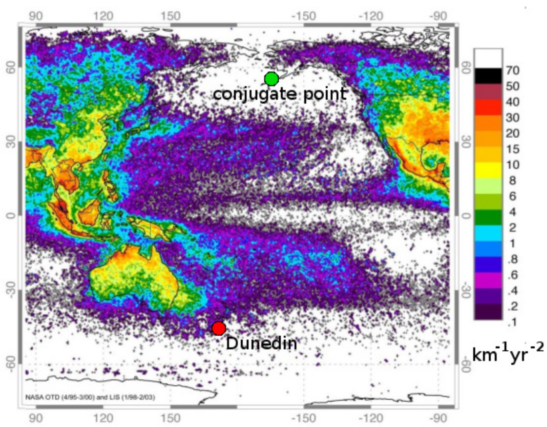

Figure 2. Lightning climatology around Dunedin and around its geomagnetic conjugate point (based on OTD/LIS lightning sensor data). The latter has almost no lightning activity in its vicinity.

A similar conclusion can be drawn based on the distribution of the dispersion of whistler traces. The dispersion of whistlers crossing the plasmasphere twice will show typically double the value of those that traveled only a single path. This can be used to demonstrate their presence. With this goal in mind, we manually determined the dispersion of 700 manually selected whistlers. The obtained dispersion values are plotted in a histogram on Figure 3. The resulting histogram shows a bimodal distribution, supporting the presence of two separate populations. The Eckersley dispersion of a simulated single-hop whistler using the aforementioned plasmaspheric parameters is ~60 $s^{1/2}$. Those whistlers that can be paired up with WWLLN lightning sources local to Dunedin exhibit roughly the double of this value, which corresponds to double hop whistlers, reflected back from the conjugate ionosphere.

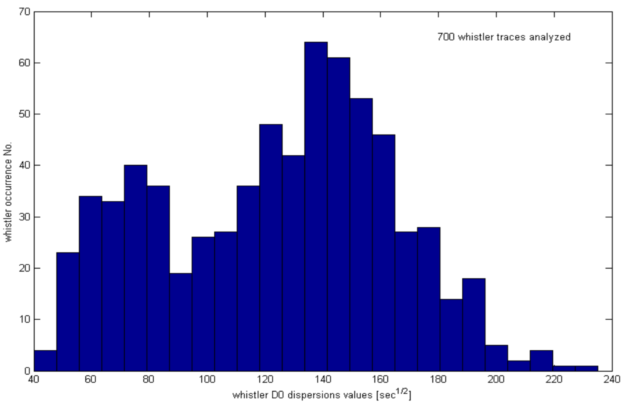

Figure 3. Distribution of the dispersion in a randomly selected subset of whistlers meased in Dunedin. The two peaks can be attributed to whistlers originating in the opposite hemisphere, and to those originating in the same hemisphere and reflected from the ionosphere near the geomagnetic conjugate point, respectively.

4. Conclusion

Our investigation demonstrated that the detections by the AWDANet include a significant number of locally generated whistlers. These may contribute to the unexpectedly large number of whistlers registered at Dunedin, and to the understanding of their anomalous diurnal distribution. By modifying the algorithm of the AWDANet, such signals can be monitored continuously. This enables a comprehensive analysis of such whistlers and makes possible their statistical study, leading to more detailed understanding of the signal propagation in the plasmasphere. Their practical significance is that the opposite seasons of the two hemisphere show strong and weak lightning activity at opposite times of the year, while their diurnal cycle is also offset from each other, therefore we expect that they can complement each other, leading to a more uniform monitoring of the plasmasphere. This is a fortunate scenario given the considerably difficulty in setting up additional stations at conjugate locations, often completely precluded by the lack of any landmass in the given region.

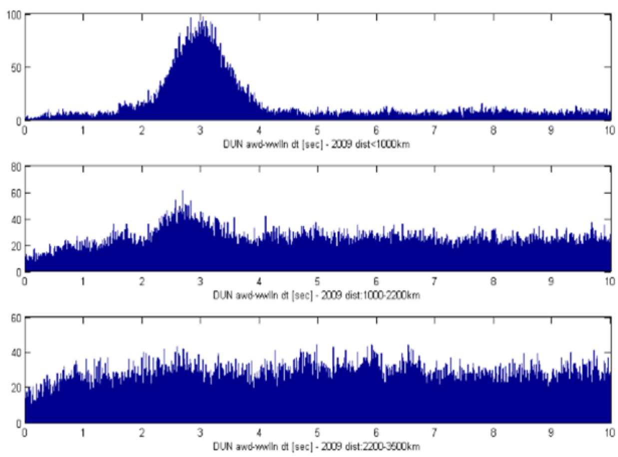

Figure 4. Distribution of the lightning-whistler delay time for whistlers detected in Dunedin and lightning strokes located at various ranges of distance measured from Dunedin. The peak near dt=3s points to the connection between the lightning strokes and the whistlers. According to the figure, the sources of whistlers are lightning located predominantly within 1000 km of Dunedin.

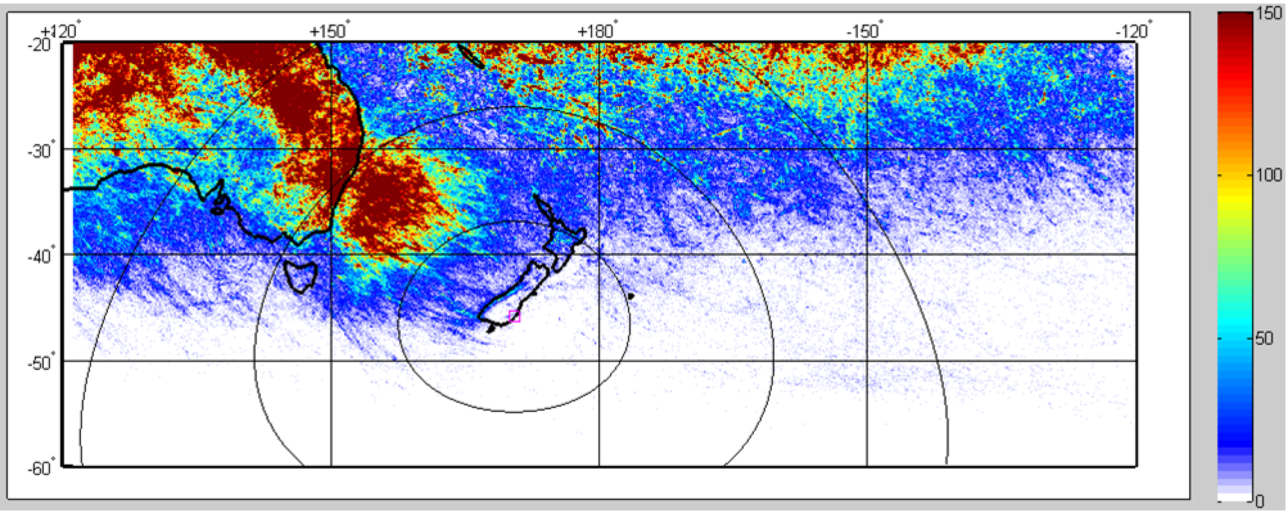

Figure 5. The long-term geographic distribution of lightning activity around New Zealand, based on data from WWLLN. Circles show 1000 km, 2200 km and 3500 km distance from Dunedin. Although lightning activity is much higher outside of the 1000 km circle, near Australia, the number of source lightning is much lower in this range. This highlights the importance of the geographic location of the lightning to become whistler sources, and supports the conclusion that the studied whistlers originated close to the station.

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