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Overview of properties of lightning whistlers detected close to Jupiter during the first half of the Juno mission

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Abstract

By the 16th science Juno spacecraft flyby, the global coverage of Jupiter was completed, with polar passes separated by 22.5 degrees of longitude. During the close approaches to Jupiter the Waves instrument [1] onboard Juno detected numerous whistlers, dispersed electromagnetic waves generated by Jovian lightning which propagated to the spacecraft through the ionospheric and magnetospheric plasma. A high sampling frequency of 50 kHz allows us to distinguish individual whistler traces even if they are separated by only several milliseconds. In this study, we present the distribution of lightning whistlers detected below radial distances of 6 Jovian radii. We also discuss the latitudinal, longitudinal and altitudinal variations in the occurrence rates of whistlers with different rates of their frequency drift and different upper cutoffs.

1. Introduction

Lightning currents generate impulsive radio waves in a broad range of frequencies, which get dispersed by their passage through the plasma environment of the planet. The measurements of such dispersed waves by the Voyager 1 spacecraft (known from terrestrial observations to be generated by lightning) were the first evidence of lightning at Jupiter [2]. These whistlers had dispersions on the timescale of several seconds at frequencies of several kHz due to their propagation through the high-density magnetized plasma in the Io plasma torus. Thanks to the unique orbit of the Juno spacecraft a new type Jovian low dispersed whistlers was discovered in the measurements of the Waves instrument [3]. As their path through the dense Jovian ionospheric plasma is short, the accumulated dispersion is low, and the time scales of these whistlers decrease down to scales from several milliseconds to tens of milliseconds. These whistlers may propagate below ionosphere in the range of one to several thousand kilometers but with a possibility of no sub-ionospheric propagation [4].

2. Statistics of observations

Our dataset consisting of more than three and half thousand whistlers shows that lightning discharges occur predominantly at mid-latitudes, although cases of polar lightning are also observed. The lack of detections in the tropics might be a consequence of propagation of Jovian whistlers in field-aligned ducts, which would not allow them to reach Juno's altitude. However, the prevailing mid-latitude occurrence of Jovian lightning was also seen by the microwave radiometer (MWR) instrument [5]. Observed peak occurrence rates of more than 4 whistlers/second in short orbital segments and an average rate of 1 whistler/second in midlatitudes are similar to thunderstorms at Earth [6]. These rates are larger by one order of magnitude than those from the MWR observations. The observed peak rates exceed six times the peak rates from the Voyager 1 observations [7].

3. Spectral forms of observed whistlers

Besides expected spectral forms of electron whistlers with a downward frequency drift typical for terrestrial observations, we also found in our dataset spectral forms with upward frequency drift, as well as events at frequencies above 10 kHz that are probably also related to lightning. These unusual spectral forms can be explained by the peculiar properties of the mode structure and group velocity for extremely low plasma densities. Unusual spectral forms are not discussed in this study.

For our study we have selected only whistlers with a downward frequency drift. Similarly, as in our previous study [3] we have categorized them into two dispersion classes according to the difference of propagation delays at 2 and 5 kHz, whenever this was possible. Class 1 events had a difference less than 5 ms (Fig. 1), events with larger dispersions fell into class 2. Most of the Jovian whistlers are also frequency limited by upper cutoffs. The observed spectral shapes of Jovian whistlers provide us with a valuable source of information about the integral properties of the Jovian ionosphere (and inner magnetosphere). Low-dispersion class 1 events indicate the presence of regions with very low ionospheric density: we needed to decrease the overall density profile estimated by Voyager [8] by a factor of 10 in order to fit the steep Class 1 whistler trace in Fig. 1.

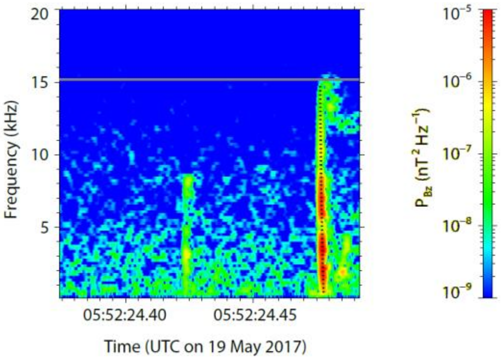

Figure 1: Example of frequency–time power spectrogram of the magnetic field fluctuations of Jovian whistlers (Class 1). The horizontal grey line shows the local proton cyclotron frequency calculated from measurements of the vector magnetometer (MAG) instrument [9]. The black dotted line was calculated from a field-aligned propagation model of electromagnetic waves in a cold plasma.

4. Summary

We have collected more than three and half thousand lightning whistlers detected by the Waves instrument close to Jupiter during the first half of the Juno mission. We have found that Jovian lightning discharges occur predominantly at mid-latitudes. We have found an asymmetry in the whistler occurrence in both hemispheres: the average lightning stroke rate in the northern hemisphere is approximately twice higher than in the southern hemisphere. Comparison of whistler spectral shapes with calculations of their frequency dependent group delay allows us to estimate parameters of the topside ionosphere of Jupiter. Low-dispersion class 1 events indicate the presence of regions with very low ionospheric density.

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