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主　論　文　の　要　旨

論文題目 Study of magnetospheric ELF/VLF waves at subauroral latitudes using ground-based and spacecraft observations
(地上・衛星観測を用いたサブオーロラ帯における磁気圏 ELF/VLF 波動の研究)

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論　文　内　容　の　要　旨

Natural radio waves in the extremely low (ELF) and very low (VLF) frequencies range, are believed to be one of the major contributors to acceleration and loss of electrons in the radiation belts. During the VLF-CHAIN campaign (Feb. 17 to 25, 2012) and afterwards (from Sept. 25, 2012), continuous measurements of ELF/VLF emissions, have been carried out using a 100-kHz sampling loop antenna at Athabasca (ATH), Canada (54.60N, 246.36E, L=4.3). To date, there has not been any comprehensive study of the physical properties of such emissions at subauroral latitudes. We explore the properties of magnetospheric ELF/VLF waves using three different approaches.

First, we investigated spectral and polarization characteristics of the waves during the VLF-CHAIN campaign. We found that the polarization angle varied depending on both frequency and time. The 'frequency-dependent' events might be the consequence of the broadening of the ray path that the waves follow from their generation region to the ground. 'Time-dependent' events, have a polarization angle changing from negative to positive values (or vice versa) every few minutes and could be due to variations of the wave duct, either near the generation region or along the propagation path. Using another ground station in Fort Vermillion, ~450 km northwest of ATH, we followed the movements of the ionospheric exit point of three chorus emissions simultaneously observed at both stations. We found that the movement of the exit point does not follow a general direction, but it is subject to a 'hovering' motion suggesting it can be affected by small scale plasma processes.

We then made the first statistical analysis of all ELF/VLF emissions observed on the ground at subauroral latitudes that includes their features, occurrences and association with solar wind and geomagnetic variations. At ATH, we monitored chorus, quasi-periodic (QP) emissions, hiss, and the recently discovered bursty patches from Nov. 2012 to Oct. 2013. We found a maximum occurrence in the morning (06-07 MLT) and a minimum at night (~18 to 02 MLT), in agreement with previous satellite measurements in the inner magnetosphere. We found positive correlation between ongoing substorm and storm activity and the increase of occurrence. The central frequency of the waves was ~1-3 kHz lower than the half gyro-frequency at the conjugate equatorial plane, indicating a wave source at higher latitudes. Superposed epoch analysis showed that the starting time of the emissions is preceded by an increase of the AE index on short (hours) and long (days) term. Solar wind speed also slowly increased, while density and dynamic pressure decreased shortly afterwards, suggesting high-speed solar wind conditions may contribute to the generation of the waves detected at ATH.

Finally, we used this database to compare emissions observed at ATH with observations made by the Van Allen Probes (RBSP) in the magnetosphere, to understand more precisely the processes that affect wave propagation. Out of the total 347 cases we found 77 in which the footprints of RBSP-A and/or B were located within 1000 km from ATH. However, a single case showed the same spectral and frequency features: Feb. 25, 2013 from 12:46 UT to 13:39 UT, we observed a clear QP, centered at 4 kHz, and an accompanying short pulse (SP) lasting less than a second at 4.8 kHz, in the dawn sector (04-06 MLT). Using RBSP-A wave data we found that both emissions had their Poynting vector earthward from the equatorial plane along the field line. We made the first time-delay study of such a conjugate ELF/VLF event and found a time delay of ~+2 to +4 s for the QP (first observed by ATH) and ~ -3 s for the SP (first observed by RBSP-A). Using backward ray tracing from ATH to the geomagnetic equator and forward tracing from the equator to RBSP-A, based on plasmaspheric density observed by the spacecraft, we validate a propagation scenario for the QP emission.

This work provides new and crucial information on the physical characteristics and propagation of several types of ELF/VLF waves, giving an ensemble view of these types of waves at subauroral latitudes. We provide a solid groundwork for further studies of ELF/VLF waves that might include an exhaustive study of plasma wave propagation using a larger dataset of conjugate events between ground and satellites, as well as the possibility of including data from multi-point ground stations.