Earth, Planets and Space

VLF/ELF Remote Sensing of Ionospheres and Magnetospheres

Society of Geomagnetism and Earth, Planetary and Space Sciences (SGEPSS)
The Seismological Society of Japan
The Volcanological Society of Japan
The Geodetic Society of Japan
The Japanese Society for Planetary Sciences

Japan Geoscience Union

SpringerOpen

Editorial Board (July 2024)

Editor-in-Chief
Takeshi Sagiya, Nagoya University, Japan

Vice Editors-in-Chief
Masahito Nosé, Nagoya City University, Japan
Aitaro Kato, University of Tokyo, Japan

Editors
Koki Aizawa
Hideo Aochi
Elvira Astafyeva
Pascal Audet
Kiyoshi Baba
Toshitaka Baba
Joseph B.H. Baker
Maxwell C. Brown
Stephan Christoph Buchert
Sonia Calvari
Xiaowei Chen
Peter Chi
Kuo-En Ching
Phil Cummins
Hao Dong
Guangyu Fu
Hidenori Genda
Alexander Grayver
Aditya Gusman
Takeshi Hasegawa
Stuart Henrys
Yuji Himematsu
Hauke Hussmann
Mie Ichihara
Hidekatsu Jin
Art Jolly
Nobuki Kame
Katsuya Kaneko
Ikuo Katayama
Yoko Kebukawa
Kunihiro Keika
Kostas Konstantinou
Juanjo Ledo
Koji Matsuo
Masaki Matsushima
Yasunobu Miyoshi
Hiroshi Nagaoka
Norihiro Nakamura
Atsuko Namiki
Yasuhito Narita
Kazunari Nawa
Kiwamu Nishida
Hiroyo Ohya
Duggirala Pallamraju
Severine Rosat
Susumu Saito
David Shelly
Wataru Suzuki
Youichiro Takada
Sunny Tam
Naoki Uchida
Yanbin Wang
Yih-Min Wu
Yusuke Yokota
Yohei Yukutake
Seiji Zenitani

Advisory Board
Benjamin Fong Chao
Bernard Chouet
Yoshimori Honkura
Toshihiko Iyemori
Hiroo Kanamori
Jun'ichiro Kawaguchi
Hitoshi Mizutani
Yasuo Ogawa
Toshitaka Tsuda
Zhongliang Wu
Kiyoshi Yomogida

Journal Scope

Earth, Planets and Space (EPS) is the official journal of Society of Geomagnetism and Earth, Planetary and Space Sciences, The Seismological Society of Japan, The Volcanological Society of Japan, The Geodetic Society of Japan, and The Japanese Society for Planetary Sciences.
EPS is a peer-reviewed, open-access journal published under SpringerOpen. It is an international journal covering scientific articles in the entire field of earth and planetary sciences, particularly geomagnetism, aeronomy, space science, seismology, volcanology, geodesy, and planetary science. EPS also welcomes articles in new and interdisciplinary subjects, and technical reports on instrumentation and software.

The journal was launched in 1998 and has since published over 4400 articles. All of them are available for free on SpringerLink:

https://link.springer.com/journal/40623/volumes-and-issues

More information about the journal, its article collections, and the submission process is available on the journal homepage:

https://earth-planets-space.springeropen.com

Submit your next research article to Earth, Planets and Space via:

https://www.editorialmanager.com/epsp

Yours sincerely,

Prof. Takeshi Sagiya
Editor-in-Chief, *Earth, Planets and Space*
eic@earth-planets-space.org

Omura *et al. Earth, Planets and Space* (2024) 76:53
https://doi.org/10.1186/s40623-024-02000-z

PREFACE **Open Access**

Special issue "VLF/ELF remote sensing of ionospheres and magnetospheres"

Yoshiharu Omura[1*], Jacob Bortnik[2], Mark Clilverd[3], Andrei Demekhov[4] and Yohei Miyake[5]

Graphical Abstract

The present collection of papers is the result of collaborations and discussions fostered in the 9th VLF/ELF Remote Sensing of Ionospheres and Magnetospheres (VERSIM) Workshop, which was held successfully as a virtual meeting during the week of 16–20 November 2020. The VERSIM working group is an international group of scientists interested in studying the behavior of the magnetosphere and ionosphere by means of Extremely Low Frequency (ELF: 300–3 kHz) and Very Low Frequency (VLF: 3–30 kHz) radio waves, both naturally and artificially generated. We had 59 invited oral papers and 83 poster papers presented during 10 sessions consisting of morning sessions (9–12 am JST) and evening sessions (9–12 pm JST) with 174 registered participants from 20 countries. Two years after the 9th VERSIM meeting the 10th VERSIM Workshop was held as a hybrid meeting, online and in-person at Sodankylä, Finland in November 2022.

We solicited papers for the special issue of the 9th VERSIM Workshop, and currently have 13 papers in it. Among them, we asked Daniel Baker to write a review paper (Baker 2021) summarizing the achievements by the NASA Radiation Belt Storm Probes program (renamed the "Van Allen Probes" mission in November 2012). We received 5 other papers (Foster et al.

*Correspondence:
Yoshiharu Omura
omura@rish.kyoto-u.ac.jp
[1] Kyoto University, Kyoto, Japan
[2] UCLA, Los Angeles, USA
[3] British Antarctic Survey, Cambridge, UK
[4] Institute of Applied Physics of the Russian Academy of Sciences, Nizhny Novgorod, Russia
[5] Kobe University, Kobe, Japan

© The Author(s) 2024. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

2021; Martinez-Calderon et al. 2021; Parrot et al. 2022; Bezděková et al. 2022; Briand et al. 2022; Redoplado et al. 2022) related to spacecraft and grand-based observations of VLF/ELF waves. We also asked David Nunn to write a paper (Nunn 2021) describing the detailed technical issues surrounding the Vlasov Hybrid Simulation code which he has been developing for more than 30 years to reproduce whistler-mode chorus emissions. We also received 4 other papers (Grach et al. 2021; Liu et al. 2021; Fujiwara et al. 2022; Katoh et al. 2023) on particle simulations describing wave-particle interactions and related particle dynamics taking place in the background dipole magnetic field. We also have a paper by Kikukawa et al. (2022) on developing compact plasma particle detectors for use on board future satellite missions.

We would like to thank the reviewers of the articles in the special issue. Their names are listed below in alphabetical order: Anton Artemyev, Stas Barabash, Mark A. Clilverd, Morris Cohen, Andrei Demekhov, Philip Erickson, Hitoshi Fujiwara, Essam Ghamry, Miroslav Hanzelka, Liming He, Yasuhide Hobara, Yuto Katoh, Janos Lichtenberger, Lann-Yeng Liu, Jyrki Manninen, Hiroyo Ohya, Michael Rycroft, David Shklyar, S. Sripathi, Danny Summers, Jicheng Sun, Bruce Tsurutani, Shoichiro Yokota.

Author contribution
YO, JB, MC, AD, and YM served as guest editors for this special issue.

Declarations

Competing interests
The authors declare that they have no competing interests.

Received: 15 March 2024 Accepted: 29 March 2024
Published online: 07 April 2024

References
Baker DN (2021) Wave–particle interaction effects in the Van Allen belts. Earth Planets Space 73:189. https://doi.org/10.1186/s40623-021-01508-y
Bezděková B, Němec F, Manninen J (2022) Ground-based VLF wave intensity variations investigated by the principal component analysis. Earth Planets Space 74:30. https://doi.org/10.1186/s40623-022-01588-4
Briand C, Clilverd M, Inturi S et al (2022) Role of hard X-ray emission in ionospheric D-layer disturbances during solar flares. Earth Planets Space 74:41. https://doi.org/10.1186/s40623-022-01598-2
Foster JC, Erickson PJ, Omura Y (2021) Subpacket structure in strong VLF chorus rising tones: characteristics and consequences for relativistic electron acceleration. Earth Planets Space 73:140. https://doi.org/10.1186/s40623-021-01467-4
Fujiwara Y, Nogi T, Omura Y (2022) Nonlinear triggering process of whistler-mode emissions in a homogeneous magnetic field. Earth Planets Space 74:95. https://doi.org/10.1186/s40623-022-01646-x
Grach VS, Demekhov AG, Larchenko AV (2021) Resonant interaction of relativistic electrons with realistic electromagnetic ion–cyclotron wave packets. Earth Planets Space 73:129. https://doi.org/10.1186/s40623-021-01453-w
Katoh Y, Rosendahl PS, Ogawa Y et al (2023) Effect of the mirror force on the collision rate due to energetic electron precipitation: Monte Carlo simulations. Earth Planets Space 75:117. https://doi.org/10.1186/s40623-023-01871-y
Kikukawa M, Asamura K, Zushi T et al (2022) Development of miniaturized pick-up amplification circuit for plasma particle detectors on board satellites. Earth Planets Space 74:188. https://doi.org/10.1186/s40623-022-01746-8
Liu Y, Omura Y, Hikishima M (2021) Simulation study on parametric dependence of whistler-mode hiss generation in the plasmasphere. Earth Planets Space 73:230. https://doi.org/10.1186/s40623-021-01554-6
Martinez-Calderon C, Manninen JK, Manninen JT et al (2021) A review of unusual VLF bursty-patches observed in Northern Finland for Earth. Planets Space Earth Planets Space 73:191. https://doi.org/10.1186/s40623-021-01516-y
Nunn D (2021) The numerical simulation of the generation of lower-band VLF chorus using a quasi-broadband vlasov hybrid simulation code. Earth Planets Space 73:222. https://doi.org/10.1186/s40623-021-01549-3
Parrot M, Němec F, Cohen MB et al (2022) On the use of ELF/VLF emissions triggered by HAARP to simulate PLHR and to study associated MLR events. Earth Planets Space 74:4. https://doi.org/10.1186/s40623-021-01551-9
Redoblado PAAL, Kumar S, Kumar A et al (2022) Lightning evolution and VLF perturbations associated with category 5 TC Yasa in the South Pacific Region. Earth Planets Space 74:65. https://doi.org/10.1186/s40623-022-01632-3

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

FRONTIER LETTER Open Access

Wave–particle interaction effects in the Van Allen belts

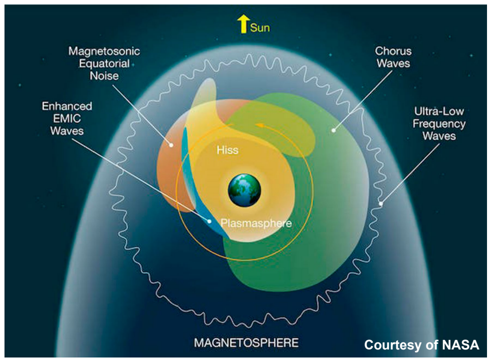
Daniel N. Baker

Earth, Planets and Space 2021, **73**:189 DOI: 10.1186/s40623-021-01508-y
Received: 4 June 2021, Accepted: 24 August 2021, Published: 19 October 2021

Abstract

Discovering such structures as the third radiation belt (or "storage ring") has been a major observational achievement of the NASA Radiation Belt Storm Probes program (renamed the "Van Allen Probes" mission in November 2012). A goal of that program was to understand more thoroughly how high-energy electrons are accelerated deep inside the radiation belts—and ultimately lost—due to various wave–particle interactions. Van Allen Probes studies have demonstrated that electrons ranging up to 10 megaelectron volts (MeV) or more can be produced over broad regions of the outer Van Allen zone on timescales as short as a few minutes. The key to such rapid acceleration is the interaction of "seed" populations of ~ 10–200 keV electrons (and subsequently higher energies) with electromagnetic waves in the lower band (whistler-mode) chorus frequency range. Van Allen Probes data show that "source" electrons (in a typical energy range of one to a few tens of keV energy) produced by magnetospheric substorms play a crucial role in feeding free energy into the chorus waves in the outer zone. These chorus waves then, in turn, rapidly heat and accelerate the tens to hundreds of keV seed electrons injected by substorms to much higher energies. Hence, we often see that geomagnetic activity driven by strong solar storms (coronal mass ejections, or CMEs) commonly leads to ultra-relativistic electron production through the intermediary step of waves produced during intense magnetospheric substorms. More generally, wave–particle interactions are of fundamental importance over a broad range of energies and in virtually all regions of the magnetosphere. We provide a summary of many of the wave modes and particle interactions that have been studied in recent times.

Keywords: Plasma waves, Energetic particles, Radiation belts, Acceleration



Graphical abstract

Corresponding author: Daniel N. Baker, daniel.baker@lasp.colorado.edu

FULL PAPER Open Access

Resonant interaction of relativistic electrons with realistic electromagnetic ion–cyclotron wave packets

Veronika S. Grach*, Andrei G. Demekhov and Alexey V. Larchenko

Earth, Planets and Space 2021, **73**:129 DOI: 10.1186/s40623-021-01453-w
Received: 25 March 2021, Accepted: 5 June 2021, Published: 21 June 2021

Abstract

We study the influence of real structure of electromagnetic ion-cyclotron wave packets in the Earth's radiation belts on precipitation of relativistic electrons. Automatic algorithm is used to distinguish isolated elements (wave packets) and obtain their amplitude and frequency profiles from satellite observations by Van Allen Probe B. We focus on rising-tone EMIC wave packets in the proton band, with a maximum amplitude of 1.2–1.6 nT. The resonant interaction of the considered wave packets with relativistic electrons 1.5–9 MeV is studied by numerical simulations. The precipitating fluxes are formed as a result of both linear and nonlinear interaction; for energies 2–5 MeV precipitating fluxes are close to the strong diffusion limit. The evolution of precipitating fluxes is influenced by generation of higher-frequency waves at the packet trailing edge near the equator and dissipation of lower-frequency waves in the H^+ cyclotron resonance region at the leading edge. The wave packet amplitude modulation leads to a significant change of precipitated particles energy spectrum during short intervals of less than 1 minute. For short time intervals about 10–15 s, the approximation of each local amplitude maximum of the wave packet by a Gaussian amplitude profile and a linear frequency drift gives a satisfactory description of the resonant interaction.

Keywords: Resonant interaction, Radiation belts, Precipitation, Relativistic electrons, EMIC waves

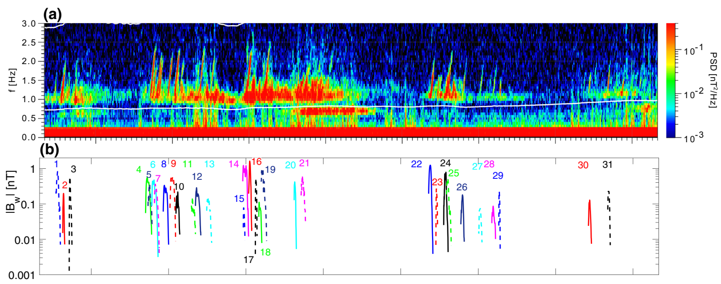


Fig. 1

*Corresponding author: Veronika S. Grach, vsgrach@ipfran.ru

FULL PAPER **Open Access**

Subpacket structure in strong VLF chorus rising tones: characteristics and consequences for relativistic electron acceleration

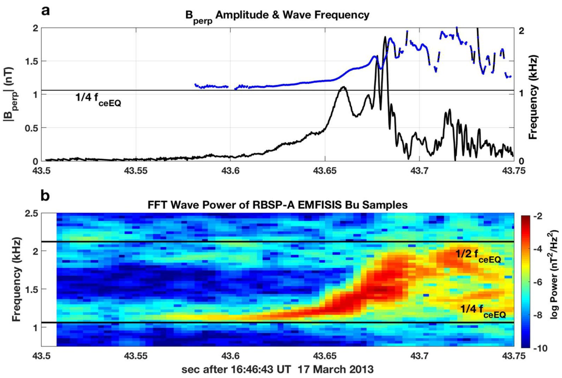
John C. Foster*, Philip J. Erickson and Yoshiharu Omura

Earth, Planets and Space 2021, **73**:140 DOI: 10.1186/s40623-021-01467-4
Received: 16 February 2021, Accepted: 21 June 2021, Published: 7 July 2021

Abstract

Van Allen Probes in situ observations are used to examine detailed subpacket structure observed in strong VLF (very low frequency) rising-tone chorus elements observed at the time of a rapid MeV electron energization in the inner magnetosphere. Analysis of the frequency gap between lower and upper chorus-band waves identifies f_{ceEQ}, the electron gyrofrequency in the equatorial wave generation region. Initial subpackets in these strong chorus rising-tone elements begin at a frequency near 1/4 f_{ceEQ} and exhibit smooth gradual frequency increase across their > 10 ms temporal duration. A second much stronger subpacket is seen at frequencies around the local value of 1/4 f_{ce} with small wave normal angle (< 10°) and steeply rising df/dt. Smooth frequency and phase variation across and between the initial subpackets support continuous phase trapping of resonant electrons and increased potential for MeV electron acceleration. The total energy gain for individual seed electrons with energies between 100 keV and 3 MeV ranges between 2 and 15%, in their nonlinear interaction with a single chorus element.

Keywords: VLF chorus, Subpackets, Radiation belt, Nonlinear interaction, Electron acceleration



Graphical abstract

*Corresponding author: John C. Foster, jcfoster@mit.edu

FULL PAPER **Open Access**

A review of unusual VLF bursty-patches observed in Northern Finland for Earth, Planets and Space

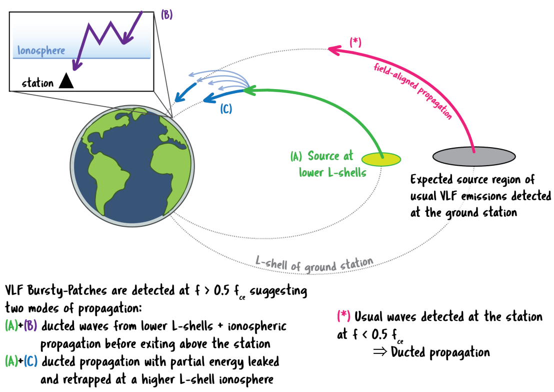
Claudia Martinez-Calderon*, Jyrki K. Manninen, Jemina T. Manninen and Tauno Turunen

Earth, Planets and Space 2021, **73**:191 DOI: 10.1186/s40623-021-01516-y
Received: 1 June 2021, Accepted: 7 September 2021, Published: 19 October 2021

Abstract

Using numerical filtering techniques allowing us to reduce noise from sferics, we are able to clearly study a new type of differently structured very low frequency (VLF) radio waves above f = 4 kHz at the ground station of Kannuslehto in northern Finland (KAN, MLAT = 64.4°N, L = 5.5). These emissions are intriguing, since they are detected at frequencies above half the electron gyrofrequency in the equatorial plane (f_{ce}) for the L-shell of Kannuslehto (f_{ce} ~ 5–6 kHz). They are commonly observed at Kannuslehto, but have also been infrequently reported at other stations, sometimes under different names. Their possible common origin and manner of propagation is still under investigation. This paper unifies the nomenclature by regrouping all these waves detected at frequencies higher than the local equatorial 0.5 f_{ce} at the L-shell of observation under the name of VLF bursty-patches. While these waves have different spectral features, they appeared mostly composed of hiss bursts with durations of a few seconds to several minutes. They also show periodic features with varying periodicity and shape. They are sometimes characterized by single bursts covering very large frequency ranges of several kHz. We also give a review of the different characteristics of VLF bursty-patches observed at Kannuslehto, which at the moment, is the station with the highest observation rate. We present recent observations between 2019 and 2021.

Keywords: VLF waves, Magnetospheric waves, ELF/VLF, VLF bursty-patches



Graphical abstract

*Corresponding author: Claudia Martinez-Calderon, claudia@isee.nagoya-u.ac.jp

FULL PAPER Open Access

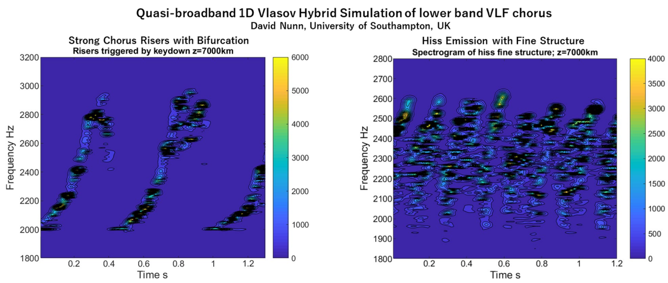
The numerical simulation of the generation of lower-band VLF chorus using a quasi-broadband Vlasov Hybrid Simulation code

David Nunn

Earth, Planets and Space 2021, **73**:222 DOI: 10.1186/s40623-021-01549-3
Received: 7 August 2021, Accepted: 19 November 2021, Published: 11 December 2021

Abstract

In this paper, we perform the numerical modelling of lower-band VLF chorus in the earth's magnetosphere. Assuming parallel propagation the 1d3v code has one spatial dimension z along the ambient magnetic field, which has a parabolic z dependence about the equator. The method used is Vlasov Hybrid Simulation (VHS) also known in the literature as the method of Kinetic Phase Point Trajectories (Nunn in Computer Physics Comms 60:1–25, 1990, J Computational Phys 108(1):180–196, 1993; Kazeminezhad et al. in Phys Rev E67:026704, 2003). The method is straightforward and easy to program, and robust against distribution function filamentation. Importantly, VHS does not invoke unphysical smoothing of the distribution function. Previous versions of the VLF/VHS code had a narrow bandwidth ~ 100 Hz, which enabled simulation of a wide variety of discrete triggered emissions. The present quasi-broadband VHS code has a bandwidth of ~ 3000 Hz, which is far more realistic for the simulation of chorus in its entirety. Further, the quasi-broadband code does not require artificial saturation, and does not need to employ matched filtering to accommodate large spatial frequency gradients. The aim of this paper which has been achieved is to produce VLF chorus Vlasov simulations employing a systematic variety of triggering input signals, namely key down, single pulse, PLHR, and broadband hiss.



Graphical abstract

Corresponding author: David Nunn, dave@djn14.plus.com

FULL PAPER Open Access

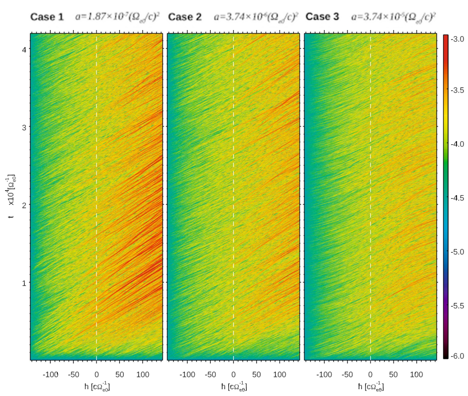
Simulation study on parametric dependence of whistler-mode hiss generation in the plasmasphere

Yin Liu*, Yoshiharu Omura and Mitsuru Hikishima

Earth, Planets and Space 2021, **73**:230 DOI: 10.1186/s40623-021-01554-6
Received: 13 July 2021, Accepted: 3 December 2021, Published: 16 December 2021

Abstract

We conduct electromagnetic particle simulations to examine the applicability of nonlinear wave growth theory to the generation process of plasmaspheric hiss. We firstly vary the gradient of the background magnetic field from a realistic model to a rather steep gradient model. Under such variation, the threshold amplitude in the nonlinear theory increases quickly and the overlap between threshold and optimum amplitude disappears correspondingly, the nonlinear process is suppressed. In the simulations, as we enlarge the gradient coefficient of the background magnetic field, waves generated near the equator do not grow through propagation. By examining the range of suitable values of inhomogeneity factor S (i.e., $|S| < 2$), we find the generation of wave packets is limited to the equatorial region when the background field is steep, showing a good agreement with what is indicated by critical distance in the theory. We then check the dependence of generation of hiss emissions on different hot electron densities. Since the overlap between threshold and optimum amplitude vanishes, the nonlinear process is weakened when hot electron density becomes smaller. In the simulation results, we find similar wave structures in all density cases, yet with different magnitudes. The existence of suitable S values implies that the nonlinear process occurs even at a low level of hot electron density. However, by examining J_E that closely relates to the wave growth, we find energy conveyed from particles to waves is much limited in small density cases. Therefore, the nonlinear process is suppressed when hot electron density is small, which agrees with the theoretical analysis.



Graphical abstract

Keywords: Plasmaspheric hiss, Nonlinear, Particle simulation, Gradient coefficient, Electron density

*Corresponding author: Yin Liu, liu.yin.52z@st.kyoto-u.ac.jp

FULL PAPER **Open Access**

On the use of ELF/VLF emissions triggered by HAARP to simulate PLHR and to study associated MLR events

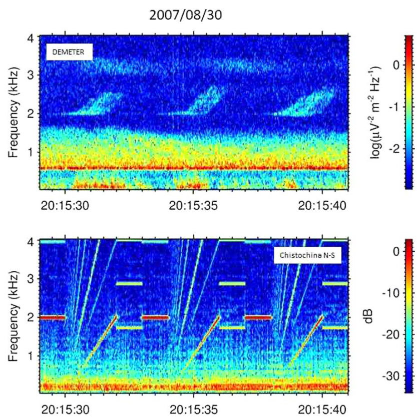
Michel Parrot*, František Němec*, Morris B. Cohen* and Mark Gołkowski*

Earth, Planets and Space 2022, **74**:4 DOI: 10.1186/s40623-021-01551-9
Received: 15 September 2021, Accepted: 25 November 2021, Published: 4 January 2022

Abstract

A spectrogram of Power Line Harmonic Radiation (PLHR) consists of a set of lines with frequency spacing corresponding exactly to 50 or 60 Hz. It is distinct from a spectrogram of Magnetospheric Line Radiation (MLR) where the lines are not equidistant and drift in frequency. PLHR and MLR propagate in the ionosphere and the magnetosphere and are recorded by ground experiments and satellites. If the source of PLHR is evident, the origin of the MLR is still under debate and the purpose of this paper is to understand how MLR lines are formed. The ELF waves triggered by High-frequency Active Auroral Research Program (HAARP) in the ionosphere are used to simulate lines (pulses of different lengths and different frequencies). Several receivers are utilized to survey the propagation of these pulses. The resulting waves are simultaneously recorded by ground-based experiments close to HAARP in Alaska, and by the low-altitude satellite DEMETER either above HAARP or its magnetically conjugate point. Six cases are presented which show that 2-hop echoes (pulses going back and forth in the magnetosphere) are very often observed. The pulses emitted by HAARP return in the Northern hemisphere with a time delay. A detailed spectral analysis shows that sidebands can be triggered and create elements with superposed frequency lines which drift in frequency during the propagation. These elements acting like quasi-periodic emissions are subjected to equatorial amplification and can trigger hooks and falling tones. At the end all these known physical processes lead to the formation of the observed MLR by HAARP pulses. It is shown that there is a tendency for the MLR frequencies of occurrence to be around 2 kHz although the exciting waves have been emitted at lower and higher frequencies.

Keywords: Ionospheric heating, Power Line Harmonic Radiation, Magnetospheric Line Radiation, HAARP, DEMETER



Graphical abstract

*Corresponding author: Michel Parrot, mparrot@cnrs-orleans.fr; František Němec, frantisek.nemec@gmail.com; Morris B. Cohen, mcohen@gatech.edu; Mark Gołkowski, mark.golkowski@ucdenver.edu

FULL PAPER **Open Access**

Ground-based VLF wave intensity variations investigated by the principal component analysis

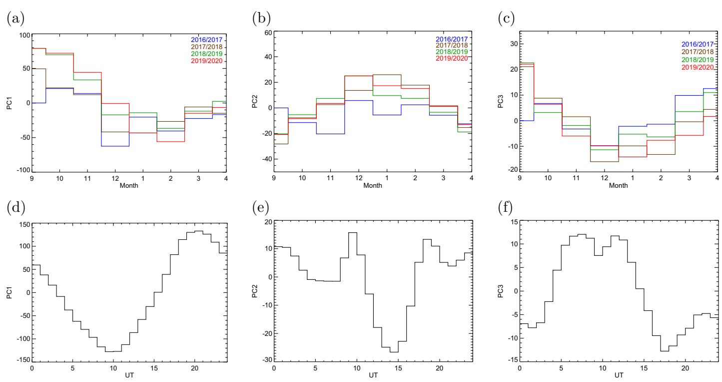
Barbora Bezděková*, František Němec and Jyrki Manninen

Earth, Planets and Space 2022, **74**:30 DOI: 10.1186/s40623-022-01588-4
Received: 28 November 2021, Accepted: 28 January 2022, Published: 14 February 2022

Abstract

Very low frequency wave intensity variations measured by the Kannuslehto station, Finland in the frequency range 0–12 kHz between 2016 and 2020 are analyzed by the principal component analysis (PCA). As the analyzed ground-based measurements are basically continuous, the length of individual basis vectors entering into PCA is fundamentally arbitrary. To better characterize both long- and short-period variations, two PCAs with different lengths of the basis vectors are eventually performed. Specifically, either daily frequency–time spectrograms or individual frequency spectra are chosen as the PCA basis vectors. Analysis of the first three principal components shows substantial variations of the wave intensity due to seasonal and local time effects. Intensity variations related to the geomagnetic activity characterized by Kp and AE indices and standard deviation of the magnetic field magnitude are less significant. Moreover, PCA allows one to distinguish between nighttime and daytime Kannuslehto variations and study them independently. Solar and geomagnetic activity effects on the daytime and nighttime measurements are discussed. Wave intensity variations related to substorm occurrence are also analyzed.

Keywords: ELF/VLF wave intensity, Principal component analysis, Geomagnetic activity, Solar activity, Seasonal variations



Graphical abstract

*Corresponding author: Barbora Bezděková, barbora.bezdekova@mff.cuni.cz

FULL PAPER Open Access

Role of hard X-ray emission in ionospheric D-layer disturbances during solar flares

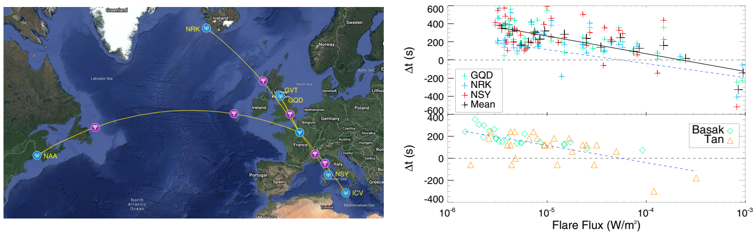
Carine Briand*, Mark Clilverd, Srivani Inturi and Baptiste Cecconi

Earth, Planets and Space 2022, **74**:41 DOI: 10.1186/s40623-022-01598-2
Received: 26 November 2021, Accepted: 23 February 2022, Published: 15 March 2022

Abstract

Any disturbance of the ionosphere may affect operational activities based on HF communication. The electron density is a critical parameter that controls levels of HF-signal absorption. A significant part of the HF absorption takes place in the D-layer. The increase of X radiations during solar flares generates noticeable perturbations of the electron density of the D-layer. However, the ionosphere reacts with some delay to the solar forcing. Several studies have addressed this question of ionospheric sluggishness from the time delay between VLF narrow-band transmissions and soft X-ray emissions during solar flares. Our study initially considers the interpretation of the VLF amplitude time profile. In particular, we show that the maximum of X-ray emission can be associated with a reversal in the VLF amplitude variation with time, i.e. exhibiting a peak or a trough. Then, building on this insight, we perform estimates of the time delay between VLF and soft X-rays during 67 events between 2017 and 2021, thus including the major flares of 2017. We show that the time delay can become negative for flares above X2, proving that soft X-rays are not the initial source of ionization in the case of major flares. From a careful analysis of RHESSI data for some events of September 2017, we demonstrate that radiation above 40 keV (i.e. hard X-rays) is an important forcing source of the ionosphere. This is of crucial interest in the frame of space weather forecasting since the hard X-rays are produced several minutes before the peak of soft X-rays.

Keywords: VLF, Ionosphere, Solar flares, X-ray



Graphical abstract

*Corresponding author: Carine Briand, carine.briand@obspm.fr

FULL PAPER Open Access

Lightning evolution and VLF perturbations associated with category 5 TC Yasa in the South Pacific Region

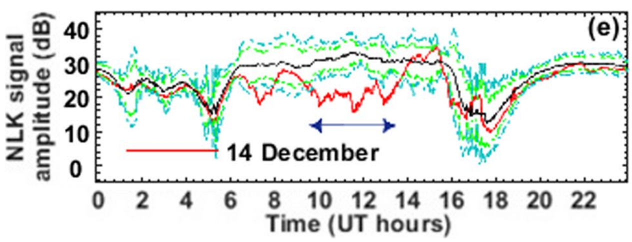
Paolo A. A. L. Redoblado, Sarwan Kumar, Abhikesh Kumar* and Sushil Kumar

Earth, Planets and Space 2022, **74**:65 DOI: 10.1186/s40623-022-01632-3
Received: 12 November 2021, Accepted: 14 April 2022, Published: 28 April 2022

Abstract

In this paper, we present the D-region ionospheric response during the lifespan (10–19 December 2020) of a severe category 5 tropical cyclone (TC) Yasa in the South Pacific by using the very low frequency (VLF, 3–30 kHz) signals from NPM, NLK, and JJI transmitters recorded at Suva, Fiji. Results indicate enhanced lightning and convective activity in all three regions (eyewall, inner rainbands, and outer rainbands) during the TC Yasa that are also linked to the wave-sensitive zones of these transmitter–receiver great circle paths. Of the three regions, the outer rainbands showed the maximum lightning occurrence; hence convective activity. Prominent eyewall lightning was observed just before the TC started to weaken following its peak intensity. Analysis of VLF signals amplitude showed both negative and positive perturbations (amplitudes exceeding $\pm 3\sigma$ mark) lasting for more than 2 h with maximum change in the daytime and nighttime signal amplitudes of − 4.9 dB (NPM) and − 19.8 dB (NLK), respectively. The signal perturbations were wave-like, exhibiting periods of oscillations between ~ 2.2 and 5.5 h as revealed by the Morlet wavelet analysis. Additionally, the LWPC modeling of the signal perturbations indicated a 10 km increase in the daytime D-region reference height, H', and a 12 km decrease in the nighttime D-region H' during TC Yasa. The D-region density gradients (sharpness), β, showed small perturbations of 0.01–0.14 km^{-1} from its normal values. We suggest that the observed changes to the D-region parameters are due to the enhanced convection during TC Yasa which excites atmospheric gravity waves producing traveling ionospheric disturbances to the D-region.

Keywords: VLF perturbations, Lightning, D-region, Tropical cyclones



Graphical abstract

*Corresponding author: Abhikesh Kumar, abhikesh.kumar@usp.ac.fj

FULL PAPER Open Access

Nonlinear triggering process of whistler-mode emissions in a homogeneous magnetic field

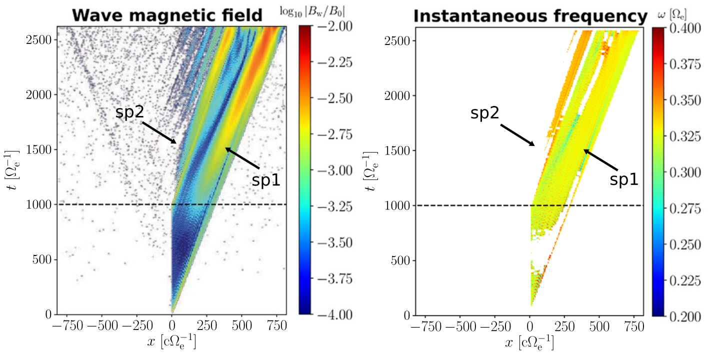
Yuya Fujiwara*, Takeshi Nogi and Yoshiharu Omura

Earth, Planets and Space 2022, **74**:95 DOI: 10.1186/s40623-022-01646-x
Received: 16 July 2021, Accepted: 15 May 2022, Published: 18 June 2022

Abstract

We perform an electromagnetic particle simulation of triggered emissions in a uniform magnetic field for understanding of nonlinear wave–particle interaction in the vicinity of the magnetic equator. A finite length of a whistler-mode triggering wave packet with a constant frequency is injected by oscillating an external current at the equator. We find that the first subpacket of triggered emissions is generated in the homogeneous magnetic field. By analyzing resonant currents and resonant electron dynamics in the simulation, we find that the formation of an electron hole in a velocity phase space results in resonant currents, and the currents cause wave amplification and frequency increase. We obtain the interaction time of counter-streaming resonant electrons in a triggering wave packet with a finite width. By changing the duration time of the triggering pulse, we evaluate the interaction time necessary for formation of an electron hole. We conduct 4 runs with different duration times of the triggering pulse, 980, 230, 105, 40 Ω_e^{-1}, which correspond to cases with interaction times, 370%, 86%, 39%, and 15% of the nonlinear trapping period, respectively. We find generation of triggered emissions in the three cases of 370%, 86%, and 39%, which agrees with the conventional nonlinear model that the nonlinear transition time, which is necessary for formation of resonant currents, is about a quarter of the nonlinear trapping period.

Keywords: Wave–particle interaction, Whistler-mode waves, Triggered emissions, Cyclotron resonance, Phase-bunching, Particle simulation



Graphical abstract

*Corresponding author: Yuya Fujiwara, fujiwara.yuya.53v@kyoto-u.jp

EXPRESS LETTER Open Access

Effect of the mirror force on the collision rate due to energetic electron precipitation: Monte Carlo simulations

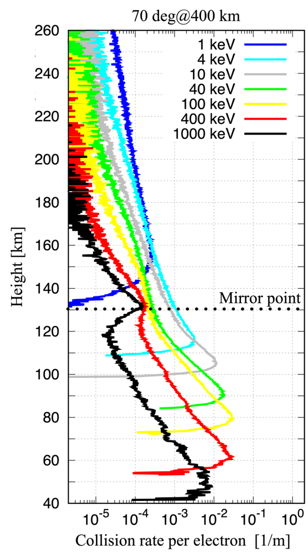
Yuto Katoh*, Paul Simon Rosendahl, Yasunobu Ogawa, Yasutaka Hiraki and Hiroyasu Tadokoro

Earth, Planets and Space 2023, **75**:117 DOI: 10.1186/s40623-023-01871-y
Received: 16 June 2022, Accepted: 10 July 2023, Published: 2 August 2023

Abstract

We study the effect of the mirror force on the collision rate due to the energetic electron precipitation into the ionosphere. We solve the motion of individual precipitating electrons with the mirror force, where collisions with neutral gas are computed by the Monte Carlo method. By comparing the results with those without the mirror force, we examine the effect of the mirror force on the altitude profile of the ionization rate. First, we carry out simulations of mono-energetic precipitation of 3 keV electrons whose initial pitch angle is 70 degrees at 400 km at $L = 6.45$. We find that the collision rate peaks at around 120 km altitude and that the duration of the collision is scattered in time with a delay of about 5 ms compared with the result without mirror force. Next, we perform mono-energetic precipitation of the different energy and pitch angle ranges. Simulation results demonstrate that larger kinetic energy lowers the altitude profiles of the collision rate, consistent with previous studies. We also find that the upward motion of electrons bounced back from their mirror points results in the upward broadening of the altitude profile of the collision rate. Simulation results for electrons with kinetic energies above 100 keV show that a secondary peak of the collision rate is formed near the mirror point. The formation of the secondary peak can be explained by the stagnation of electrons around the mirror point at 130 km altitude, because the relatively long duration of staying in neutral gas increases the number of collisions. Simulation results show that under the precipitation of electrons in the kinetic energy range larger than tens of keV with the pitch angle close to the loss cone, the maximum collision rate in the altitude range lower than 100 km becomes one order of the magnitude smaller. The results of the present study suggest the importance of the mirror force for the precise modeling of ionospheric response due to the energetic electron precipitation caused by the pitch angle scattering through wave–particle interactions.

Keywords: Energetic electron precipitation, Collision rate, Elastic scattering, Numerical simulation



Graphical abstract

*Corresponding author: Yuto Katoh, yuto.katoh@tohoku.ac.jp

TECHNICAL REPORT **Open Access**

Development of miniaturized pick-up amplification circuit for plasma particle detectors on board satellites

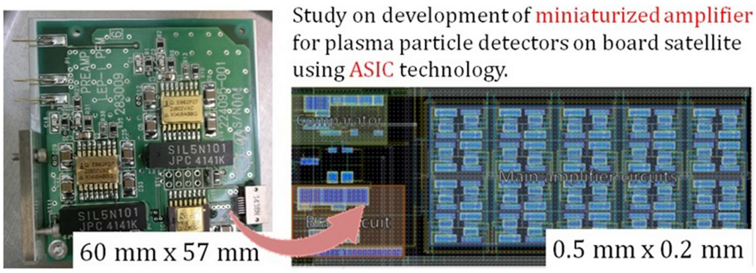
Motoyuki Kikukawa*, Kazushi Asamura, Takahiro Zushi, Satoshi Kurita and Hirotsugu Kojima

Earth, Planets and Space 2022, **74**:188 DOI: 10.1186/s40623-022-01746-8
Received: 27 May 2022, Accepted: 2 December 2022, Published: 23 December 2022

Abstract

Plasma particles and waves are important observation targets in space plasmas for understanding the mechanisms of energy and momentum transfer between waves and particles because space plasmas are essentially collisionless. Multi-point observations are crucial for understanding the spatial–temporal variations of space plasmas. To realize such observations by a large number of satellites, onboard instruments should be miniaturized to reduce their required resources. This paper proposes a small amplifier for plasma particle detectors onboard satellites. This charge-sensitive amplifier converts an electron cloud emitted from the detector, for example a microchannel plate, to a current pulse that can be handled by a time-of-flight measurement circuit to determine the particle velocity and thus mass. The amplifier is realized using application-specific integrated circuit technology to minimize size. Its dimensions are estimated to be 2120 μm $\times$ 1680 μm, which are much smaller than those of a conventional amplifier.
The response time of the proposed amplifier has a variation of less than 1.2 ns over the range of expected input levels. The amplifier can handle up to 2 $\times$ 10^7 signals per second and has a sensitivity of 1.5 V/pC at 20°C.

Keywords: ASIC, Multi-point observation, Amplifier for time-of-flight technique



Graphical abstract

*Corresponding author: Motoyuki Kikukawa, kikukawa.motoyuki.75u@st.kyoto-u.ac.jp

Information for Contributors

General

1. Manuscripts should be submitted through the journal’s Editorial Manager system (https://www.editorialmanager.com/epsp/default.aspx).
2. Only papers not previously published will be accepted, and the emphasis is on the originality of concept or observation.
3. Five varieties of article types are available.
   - 3.1 “Full Paper” without word limit.
   - 3.2 “Express Letter” has a limit of 5000 words including the main text, figure legends and table legends. The sum of the number of figures and tables should be less than or equal to 5.
   - 3.3 “Frontier Letter” can be submitted upon invitation by the Editor-in-Chief.
   - 3.4 “Technical Report” describes the technical development of instrument or software.
   - 3.5 “Comment” is a substantial re-analysis of a previously published article in the journal. ”Comment” should not exceed 1000 words.
4. Authors retain the copyright, and distribution of articles is free under the CC BY license.

Technical

1. Manuscripts should be written in English with double spacing.
2. Each manuscript should be organized in the following order: title, authors’ names, affiliations, abstract, key words, main text, acknowledgement, appendix, references, and supplementary materials. A graphical abstract image must be uploaded during submission which should provide the reader with a visual description of the topic covered in the article.
3. The corresponding author should be clearly indicated.
4. The abstract is limited to 350 words and should be informative and include principal findings and conclusions. Please avoid abbreviations.
5. The main text can have multiple free headings.
6. High-resolution figures should be provided in the following format; PDF (preferred format for diagrams), PNG (preferred format for photos or images), EPS ,TIFF, JPEG, BMP. The graphical abstract should be approximately 920×300 pixels and should be uploaded as a JPEG, PNG or SVG file.
7. References must follow the Springer Basic style.

Correspondence

If you have any questions, please contact info@springeropen.com.

© EPS Steering Committee 2024 All rights reserved.

A Grant-in-Aid for Publication of Scientific Research Results (24HP2006) from Japan Society for the Promotion of Science is used for printing.

Contents

Cover image: Omura, Y. *et al.*, *Earth, Planets and Space* 2024, **76**:53 DOI: 10.1186/s40623-024-02000-z