# VLF/ELF Remote Sensing of Ionospheres and Magnetospheres (VERSIM)

Annual newsletter of VERSIM: a joint IAGA/URSI working group
Editor: Andrei Demekhov No. 34, December 2019

Dear VERSIM friends and colleagues,

This end of year newsletter is opened by a message from Prof. Jacob Bortnik.

"I would like to thank the VERSIM community for the opportunity of serving as the IAGA co-chair of VERSIM. I assumed my role at the 2013 IAGA meeting in Merida, Mexico, and stepped down this past July, at the 27th General Assembly of IUGG in Montreal, Canada. In the interim, we've held several successful sessions at a number of large meetings, three VERSIM workshops (6th: Dunedin, New Zealand; 7th: Hermanus, South Africa; 8th: Apatity, Russia) and have endured many attempts at semi-humorous April Fool's messages. It has been my pleasure and privilege to serve this important and historic group over the past 6 years alongside my wonderful URSI co-chair Dr. Mark Clilverd, and am delighted to leave the group in the (more than) capable hands of my successor, Dr. Andrei Demekhov. Wishing everyone a happy, healthy, and successful new year ahead, and a great VERSIM meeting in Kyoto in 2020!

Jacob Bortnik"

As for me as a new IAGA co-chair, I have been very much excited by the VERSIM activity since our regular meetings have started in 2004. They of course grew on an excellent basis formed during the "pre-meeting" era. This working group has always been strong due to its regular participants who maintain high level of research and ensure keeping the specific subjects in line with modern trends. On the other hand, the co-chair's role is quite important in circulating current information that is of interest to the group members. I admit that I can never become such a famous co-chair as, e.g., Jacob or Craig, but will try to keep the information flux in the group on an acceptable level. I would like to ask Jacob to continue his 1st-April column in our VERSIM newsletter and also hope on his help with my first and next steps on this route. I am relying on an activity of all existing group members and hopefully new ones coming (also) from the young side. In this respect, the VERSIM journal club seems a very good initiative deserving a support. General scope of our group seems to be OK and not limiting our involvment in modern studies like machine learning applications, advanced techniques of signal analysis, the role of ELF/VLF waves in climate change, etc. You can learn about excellent results on both traditional and newer trends in ELF/VLF research when reading this annual newsletter.

I hope you will read this newsletter with interest, and wish you all both happy and successful 2020!

Andrei Demekhov, IAGA co-chair

Jacob Bortnik, retired IAGA co-chair

Mark Clilverd, URSI co-chair

**BELGIUM**: Report prepared by Dr. Fabien Darrouzet (Fabien.Darrouzet@aeronomie.be), Royal Belgian Institute for Space Aeronomy (BIRA-IASB), 3 Avenue Circulaire - 1180 Brussels - Belgium, http://awda.aeronomie.be/

We continue our project to detect whistler waves with VLF measurements. A VLF antenna has been installed in October 2010 in Humain, Belgium (Lat~50.11°N, Long~5.15°E), in order to detect whistlers and determine electron densities along propagation paths. The VLF antenna is made of two perpendicular magnetic loops, oriented N-S and E-W and with an area of approximately 50 $m^2$ each. We have re-done a statistical analysis of the data from 2010 to 2017 and this allows D. Koronczay from Hungary to study and publish source regions of whistlers from many stations [Koronczay et al., 2019] (see Figure).

We have installed in January-February 2016 another antenna at the Belgian Antarctic station Princess Elisabeth (Lat~71.57°S, Long~23.20°E), with the help of Dr. J. Lichtenberger (Hungary). This antenna is composed of two search coils, without a mast in order to withstand the weather at such latitudes. The instrument was shut down in May 2016, due to power shut down at the station. The instrument was re-started during the season 2017-2018 but many electromagnetic perturbations are now detected in the signal. The origin of the noise has been identified last year and a new team is actually (November 2019 – February 2020) at the station to fix it and make the instrument working.

Those antennas are part of AWDAnet, the Automatic Whistler Detector and Analyzer system's network. This network covers low, mid and high magnetic latitudes including conjugate locations. It has been initiated by Dr. J. Lichtenberger (Hungary).

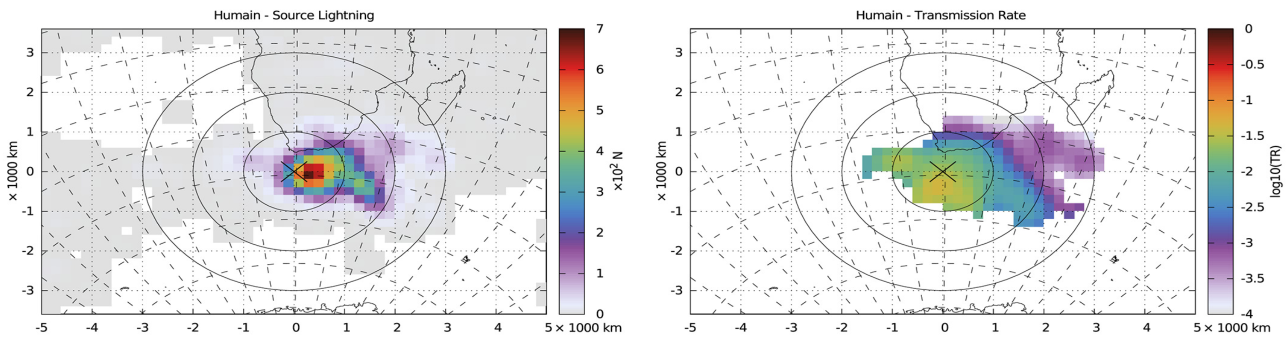
Reference:

Koronczay, D., Lichtenberger, J., Clilverd, M. A., Rodger, C. J., Lotz, S. I., Sannikov, D. V., Cherneva, N. V., Raita, T., **Darrouzet, F., Ranvier, S.**, and Moore, R. C. (2019), The source regions of whistlers, Journal of Geophysical Research: Space Physics, 124, 5082–5096. https://doi.org/10.1029/2019JA026559.

**CZECHIA**: Report prepared by Ivana Kolmasova (iko@ufa.cas.cz), Frantisek Nemec (frantisek.nemec@gmail.com), and Ondrej Santolik (os@ufa.cas.cz), Institute of Atmospheric Physics of the Czech Academy of Sciences, Prague and Charles University, Prague.

Our group at the Department of Space Physics, Institute of Atmospheric Physics of the Czech Academy of Sciences and at the Faculty of Mathematics and Physics of the Charles University continued to investigate electromagnetic waves using spacecraft measurements and ground-based experiments. Examples of our results obtained in 2019 are given below.

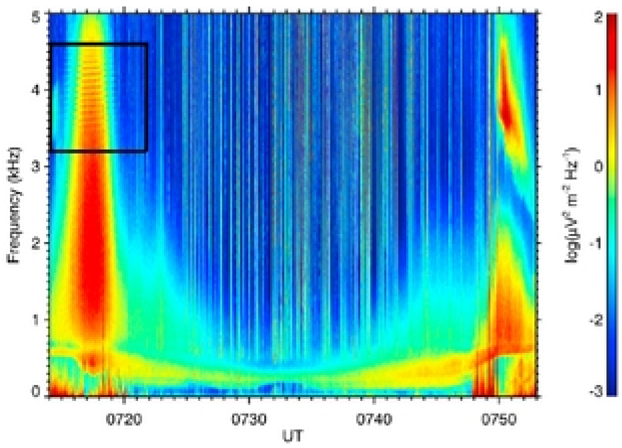
We analyzed contribution of thunderstorms to the intensity of very low frequency electromagnetic waves in the inner magnetosphere, where these waves can influence energetic particles trapped in the radiation belts [1]. DEMETER spacecraft measurements at low altitudes and Van Allen Probes measurements in the equatorial region at higher altitudes were used together with a ground-based estimate of lightning power penetrating through the ionosphere. We showed that strong lightning activity substantially affected the wave intensity in a wide range of L-shells inside the plasmasphere. The effect was observed mainly between 500 Hz and 4 kHz, and it was stronger in the evening/night sectors, consistent with higher lightning occurrence rates, and easier wave propagation through the ionosphere.




*Regional distribution of source lightning (excess matches) and transmission rate (TR) for whistlers detected at Humain (Belgium) station (showing its conjugate region near Cape Town, South Africa). The concentric circles represent distances of 1,000, 2,000, and 3,000 km from the conjugate point. (Adapted from Koronczay et al. [2019]).*

Statistics based on Cluster spacecraft measurements show that in the outer radiation belt, lower band whistler mode waves propagate predominantly unattenuated parallel to the magnetic field lines up to midlatitudes, where ray tracing simulations indicate highly attenuated waves with oblique wave vectors. We explained this behavior by a presence of ducts which can be weak and thin enough to be difficult to detect by spacecraft instrumentation and, at the same time, strong enough to guide whistler mode waves in a cold plasma ray tracing simulation. After adding a tenuous hot electron population, we obtained a strong effect of Landau damping on unducted waves, while the ducted waves experienced less damping or even growth [2]. Consequently, the weighted average of amplitudes and wave normal angles of a mixture of ducted and unducted waves results in strong quasi-parallel waves, consistent with the observations.

We presented concurrent observations from Polar-orbiting Operational Environmental Satellite, Radiation Belt Storm Probes, Global Positioning System, and ground-based instruments, showing concurrent EMIC waves, sub–MeV electron precipitation, and a global dropout in electron flux. We used a test particle simulation to demonstrate that the observed waves are capable of scattering electrons at energies as low as hundreds of keV into the loss cone through nonlinear trapping, consistent with the experimentally observed electron precipitation [3].




*An example of frequency-time spectrogram measured by the DEMETER spacecraft where an MLR event was detected. The event occurred on 5 February2009 between about 07:15:30 and 07:20:00 UT in the frequency range between about 3.2 and 4.6 kHz (marked by the black rectangle).*

We have also investigated magnetospheric line radiation (MLR) and quasiperiodic (QP) emissions. Data from the DEMETER spacecraft were used to analyze their properties, such as MLR frequency spacing, QP modulation period, and QP intensity as functions of geomagnetic activity and solarwind parameters. We have shown that influence of the analyzed parameters on QP emissions is different for QP events with modulation periods shorter/longer than 20 s. While the properties of QP events with long modulation periods are significantly related to the geomagnetic activity and solar wind parameters, no such dependences are observed for events with short modulation periods. This suggests that there might be two types of QP emissions generated by two different mechanisms. It is further shown that there seems to be no relation between the properties of QP and MLR events observed at the same times [4].

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**FIJI:** Report prepared by Sushil Kumar (kumar_su@usp.ac.fj), The University of the South Pacific (USP), Suva, Fiji.

Our group continues participating in the World-Wide Lightning Location Network (WWLLN) since our joining in 2003. We continue recording narrowband very low frequency (VLF) signals of six transmitters using the SoftPAL data acquisition system located at Physics, USP, Suva (18.15°S, long. 178.45°E) which was started in the year 2006. Last year, we added two more SoftPAL stations in Apia, Samoa, and Port Villa, Vanuatu, where our university has its regional campuses.

Motivated with amplitude perturbations of local origin on the VLF transmitter signals (NPM, NLK, NAA, and JJI) observed during tropical cyclone (TC), Evan, 9–16 December 2012, a collaborative work was carried on ionospheric disturbances during the simultaneous presence of two to three Large Meteorological Systems, classified as hurricanes and tropical storms, in the Atlantic Ocean from August to November 2016. The ionospheric disturbances were detected by on VLF signals from two North American transmitters observed in Algiers (36.75∘N, 03.47∘E). The results showed clear anomalies in the amplitude both at nighttime and in the daytime.

The effects of solar flares on the propagation of subionospheric VLF signals from NWC and NLK transmitter stations monitored at a low-latitude station, Suva, Fiji, between December 2006 and December 2010 (an unprecedented solar minimum of solar cycles 23 and 24) and between January 2012 and December 2013 (moderate solar activity at the peak of solar cycle 24) were analyzed to find solar flare time D-region changes. A comparative analysis of the ionospheric D-region parameter changes carried out for this location shows a greater increase in the electron density gradients and a decrease in the reference height during the low-solar activity period than during the moderate-solar activity period, for the same class of flares. We also analyzed D-region ionospheric response to 22 July 2009 total solar eclipse by modeling 19.8 kHz signal from NWC VLF navigational transmitter received at five stations located in and around the eclipse totality path in the Indian, East, Asian, and Pacific regions. The study contributes to explain observations of wave-like signature in the D-region during an eclipse and difference in the eclipse effect in the different latitude-longitude sectors.

A new Global Navigation Satellite Systems station for Ionospheric Monitoring and Precise Point Positioning (PPP) Research under normal and space weather conditions, has been installed in Physics under an MoU between School of Engineering and Physics (SEP), USP, and the School of Electronics and Information Engineering (SEIE), Beihang University, China. Please visit for details: http://www.usp.ac.fj/news/story.php?id=3219

For details please visit USP's electronic research repository http://repository.usp.ac.fj/ and research our research group web http://sep.fste.usp.ac.fj/index.php?id=15705

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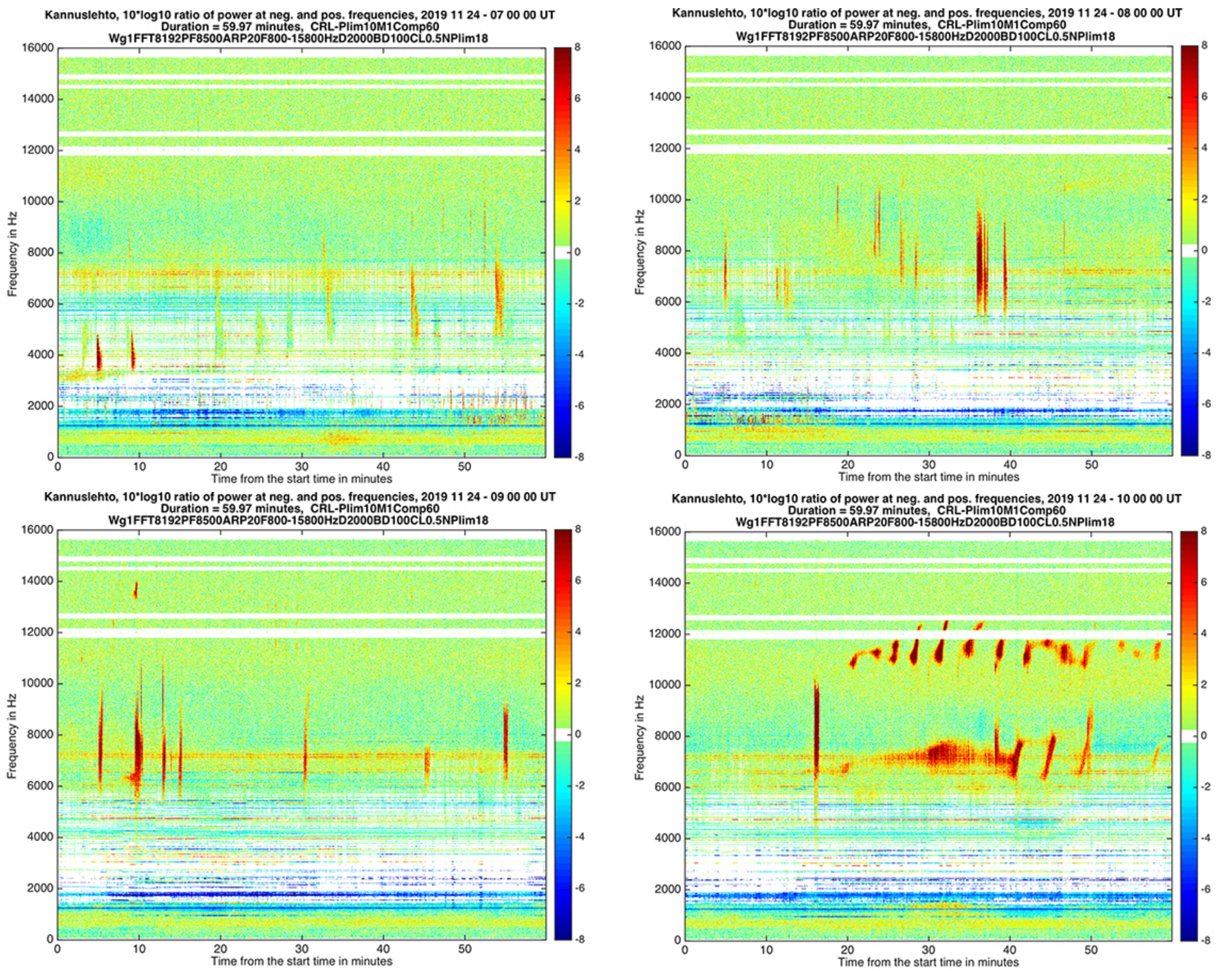
**FINLAND:** Report prepared by Dr. Jyrki Manninen (Jyrki.Manninen@oulu.fi), Sodankylä Geophysical Observatory, University of Oulu, Finland, www.sgo.fi

Winter 2018-2019 ELF-VLF campaign started on 29 August 2018 and ended on 26 April 2019. The campaign had no long breaks at all. This campaign was the longest one, so far. The campaign lasted altogether 241 days. This autumn we started our campaign on 4 September 2019, because we wanted to record ELF-VLF data during Japanese ARASE satellite campaign. Current plan is to continue recordings till the end of April.

The quick-look plots (24-h, 1-h, and 1-min) are available at http://www.sgo.fi/vlf/. During the campaign, new plots are updated within a few days after recording. The frequency range of quick-look plots is from 0 to 16 kHz, while the data contain the range from 0 to 39 kHz. Upper band is available if someone is interested in.

It should be reminded that now all quick-look plots, what are in our server, have been analysed with both PLHR and sferics filters. If you are interested in our data, just contact Jyrki.Manninen@oulu.fi. We can make a vast amount of different kind of analysis for our ELF-VLF data.

A vast number of ELF-VLF related colleagues have been visiting SGO during the year. This can be seen in number of peer-reviewed papers, too. Year 2019 was reasonably good in science, because of 9 published papers listed in references.




*Four hours examples of high-frequency events. All are polarization plots (red = R and blue = L) at 07-11 UT on 24 Nov 2019. Note that the highest frequency of single event is 14 kHz.*

MSc. Liliana Macotela has made her PhD thesis almost ready. Her dissertation will be most probably in April 2020 in Sodankylä.

SGO's director Dr. Esa Turunen retired in September 2019, and a new director started on 7 October 2019. New director is Prof. Eija Tanskanen, who has worked in Finnish Meteorological Institute Helsinki, NASA Goddard (USA), as professor in University of Bergen (Norway), as visiting professor in Aalto University Helsinki. She is an expert on geomagnetism and solar-terrestrial physics.

Some new results will be shown in 9th VERSIM Workshop in March 2020.

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2. Lebed O.M., Yu.V. Fedorenko, N.G. Kleimenova, J. Manninen, and A.S. Nikitenko (2019). Modeling of auroral hiss propagation from the source region to the ground. Geomagn. Aeron., 59, no.5, 577-586, doi:10.1134/S0016793219050074

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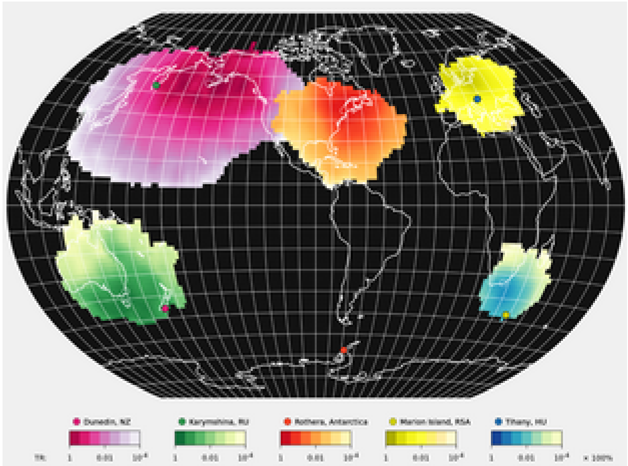
**HUNGARY**: Report prepared by Prof. János Lichtenberger(lityi@sas.elte.hu), Space Research Group, Department of Geophysics and Space Sciences, Eötvös University, Budapest, Hungary

Our group continued the theoretical modeling and model-calculations of monochromatic and transient (Ultra Wide Band) electromagnetic signals and are seeking a solution of the electromagnetic wave propagation in general relativistic situations (coupled solution of the Maxwell and Einstein equations).

We published the first result of our work statistically linking ground detected whistlers and causative lightning strokes. In this project, we processed 80 million whistler detections from AWDANet (together with 2 billion lightning strokes from WWLLN). We produced maps of the distribution of source lightning and the distribution of lightning-to-whistler transmission rates, for each whistler detector station. The results are in good agreement with expectations from theory and resolving earlier contradicting results.

We have started the preparation of Trabant mission with Russian partners to study the (equatorial) ionosphere and space weather. The mission will consists two identical microsatellites (m=~75kg). The satellites will be released by a Progress cargo rocket to a ~500km orbit in the same plane as of the ISS (51.2 degree inclination). The science instrument suit comprises a Hungarian ULF-ELF-VLF wave instrument (SAS3-T), a RF receiver, a electron density measurement and an electron and ion spectroscope. The majority of the raw wave data will be transmitted to the Earth by a Hungarian high speed X-band telemetry system. The two microsatellites will be injected into orbit in 2023-24.



*Geographical distribution of lightning to whistler transmission rates for whistlers detected at five ground-based stations.*

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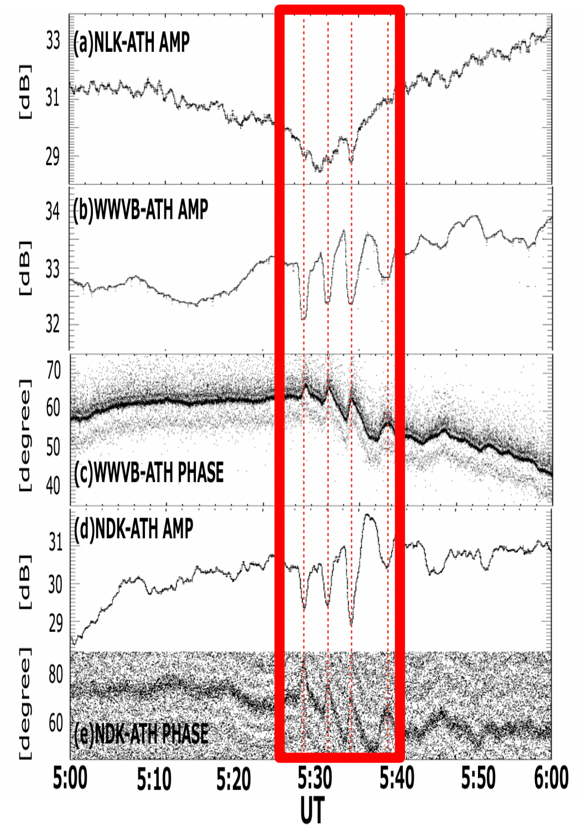
**JAPAN**: Report prepared by Dr. Hiroyo Ohya (ohya@faculty.chiba-u.jp), Chiba University, Chiba Japan

Our group of AVON (Asia VLF Observation Network) project have continued to observe wide band VLF waves radiated from ground lightning and manmade VLF/LF standard radio waves in 5 countries; Taiwan, Thailand, Indonesia, Philippines, and Vietnam. In addition to the AVON, we have used a VLF/LF standard radio wave network (http://c.gp.tohoku.ac.jp/lf/) for monitoring relativistic electron precipitations from radiation belts to the lower ionosphere operated by Dr. Fuminori Tsuchiya (Tohoku University, Japan). Our results in 2019 are shown as follows.




*(a) NLK-ATH intensity, (b) WWVB-ATH intensity, (c) WWVB-ATH phase, (d) NDK-ATH intensity, and (e)NDK-ATH phase at 05:00-06:00 UT on 4 June, 2017.*

We investigate the D-region signatures of the modulation due to the ULF waves using a network of VLF/LF standard radio waves in North America. The transmitter signals from NLK (USA, 24.8 kHz, L = 2.88), NDK (USA, 25.2 kHz, L = 2.98) and WWVB (USA, 60.0 kHz, L = 2.26) were observed by a receiver at ATH (Athabasca, Canada, L = 4.31). We show the first observations of oscillations in intensities and phases on the NDK-ATH and WWVB-ATH paths with periods of 3-4 minutes during a small substorm of 05:25-05:50 UT (22:25-22:50 LT) on 4 June, 2017 (the AE index = 140 nT) (Figure). When the solar wind dynamic pressure increased, the VLF/LF intensity decreased simultaneously, which suggests the whole magnetosphere was bumped by the solar wind. Based on ground-based magnetic observations, there were pulsations with the same periods with the VLF/LF oscillations both at high- and low-latitudes. The magnetic pulsations with period of 3 minutes moved westward with velocity of 66.4 km/s at L = 3-4. These results show that ULF excitation due to a substom around midnight is related to the modulation of energetic electron precipitation. We will present above the results in VERSIM Workshop 2020 held in Kyoto University, Japan.

**NEW ZEALAND**: Report prepared by Dr. Craig J. Rodger (craig.rodger@otago.ac.nz), University of Otago, Dunedin, NZ; [http://www.physics.otago.ac.nz/nx/space/space-physics-home.html](http://www.physics.otago.ac.nz/nx/space/space-physics-home.html)

We have had a very productive year, probably our biggest year for research outputs ever. Thank you to our collaborators and friends from across the globe who joined us on papers we led, or invited us to be part of scientific work they were undertaking. Together we do better science - and it is more fun.

Coming from a small country at the "Uttermost Ends of the Earth" we need to travel a lot to see our colleagues, and this year has been no exception, with trips to Finland, Japan, USA, Canada, UK, Belgium, and Antarctica. We have also hosted visitors from the UK, Japan, USA, and Czechia.

Our students have had a great year. Dr. Emma Duoma was awarded her PhD, along with a prize due to the quality of her thesis. Daniel Mac Manus has been working hard on his Space Weather focused research, primarily looking at the likely impact of extreme geomagnetic storms on the New Zealand power grid - in November Daniel presented his work at the European Space Weather Week in Liege, Belgium. Emily Gordon travelled to Boulder to be part of the CESM tutorial, Antarctica to work on our experimental equipment, and then to the AGU Fall Meeting. Emily has recently submitted her first paper. Finally, earlier this year former Otago student Harriet George has started her PhD in Helsinki - we wrote up the research she undertook in her Honours year (2018), and this was recently accepted by AGU's Space Weather.

Because of our research output successes this year, it was hard to pick three outputs to mention. I have chosen to focus on three which span our activity.

[1] Emma Douma's work on the intensity of relativistic electron microbursts, building on her research into the physical properties of these events;

[2] Harriet George's recent paper on using subionospheric VLF propagation to provide nowcasting of the occurrence and magnitude of solar X-ray flares - this addresses a need for global aviation;

[3] Neil Thomson's recent paper on whistler mode signals from VLF transmitters propagating in a non-ducted but repeatable way near the magnetic equator. Neil travelled to the Cook Islands in the mid-1990's to make these measurements, and has now written the work up!

References:

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*The Otago Space Physics Group updated our team picture on 23 August 2019. Shown in the photo from left to right: Annika Seppälä, Emily Gordon, Neil Thomson, and Tim Divett, Jono Squire, Daniel Mac Manus, James Brundell and Craig Rodger.*

**RUSSIA:** Report prepared by Dr. David Shklyar (david@iki.rssi.ru), Space Research Institute of RAS, Moscow, Russia

This report is from D.R. Shklyar and E.E. Titova. The results described in this report were obtained in collaboration with J. Manninen, M. Parrot, and J.-L. Pinçon.

Our research activities in 2019 were directed to investigation of a long-standing problem, which has previously been addressed by many scientists, namely, the influence of lightning - induced emission on the dynamics of the energetic electrons in the Earth's radiation belts. To date, most studies of the interaction of energetic electrons with whistler waves have been carried out either for quasimonochromatic waves, or in quasilinear approximation. Very few works in which coherent waves with a variable frequency had been considered were limited to the case of purely parallel propagation and/or to times less than or on the order of the particle bounce period. Our general aim in the investigation of the above stated problem is to abandon these simplifications that are poorly performed in a real situation. In 2019, a number of tasks in this direction were completed.

1. An estimation was made of the frequency of occurrence and distribution of lightning discharges around the globe, which plays a decisive role in assessing the influence of whistlers on particle dynamics in the radiation belts. This estimate was obtained from the analysis of the frequency of registration of short-fractional hop whistlers in the upper ionosphere based on the long-term observations of the low-orbiting DEMETER satellite using neural networks.

2. Using the data of the Van Allen Probe A satellite on measurements of the fluxes of energetic electrons, their distribution function was determined, and wave growth rates were calculated without any model assumptions about the form of the distribution function. The dependence of the growth rate on the frequency along the satellite trajectory was calculated. The growth rate values were compared with the spatial and temporal variations of VLF emissions recorded on the satellite.

3. For the case of ducted propagation, the electromagnetic field of a series of three whistlers excited by one lightning discharge, which are formed as a result of reflections of waves from the Earth's surface in both hemispheres, was determined. This field was represented as a sum of three space-time-limited wave packets in which the frequency and wave vector depend on time and coordinate. The equations of motion of energetic electrons in the field of such a set of wave packets and an external inhomogeneous magnetic field were obtained and solved

numerically. On this basis, an explanation was proposed for the effect of VLF noise suppression by powerful whistlers.

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**RUSSIA**: Report prepared by Dr. Andrei Demekhov (andrei@ipfran.ru), Polar Geophysical Institute, Apatity, and Institute of Applied Physics RAS, Nizhny Novgorod, Russia

Our joint group from the two institutes (PGI and IAP RAS) has completed the second stage of the project funded by the Russian Science Foundation and devoted to studies of wave-particle interactions in the magnetosphere. For the VLF range, we developed and tested an algorithm for automatic recognition of chorus elements on dynamics spectra based on principles of mathematical morphology [1].

Dr. Boris Kozelov participated in a joint study [2] of chorus association with pulsating aurora (PsA) based on observations by the Arase satellite and a ground-based all-sky imager in Apatity, Kola Peninsula, Russia. In particular, a region of high correlation between PsA and chorus was continuously tracked within the field of view of the all-sky imager. The result showed that the high-correlation region and the modeled footprint of Arase moved in tandem. This strongly implies that the chorus and PsA electrons originated from the same local interaction region. In addition, the location of the high-correlation region showed sudden jumps, which were probably associated with the motion of the satellite through discrete spatial structures of plasma in the region of wave-particle interaction.

We also studied simultaneous observations of ELF/VLF and EMIC waves by Van Allen Probes in the daytime Earth's magnetosphere and on the ground during multiple compressions of the magnetosphere due to the fluctuations of the dynamic solar wind pressure. Each magneto-spheric compression lead to the generation of a wave burst in these frequency ranges. Based on data on the spectral and amplitude characteristics of the waves, measurements of the magnetic field, and the cold plasma density, we calculated the pitch-angle diffusion coefficients of protons and electrons in the vicinity of the loss cone. It is shown that ELF waves with frequencies of <1 kHz may be responsible for precipitation of energetic (>30 keV) electrons; VLF waves at frequencies of 2–5 kHz may be responsible for precipitation of electrons with energy of ~1 keV. We compared the particle energies that correspond to the maxima of the diffusion coefficient with the energies of the charged particles precipitating into the ionosphere determined from the low-orbit POES satellites data, and showed that they are in a good agreement with each other. The reference can be found in Jyrki Manninen's report [9].

On the award side, it was very pleasant to learn that the VERSIM nomination to Dr. Evgenii Shirokov was aproved by IAGA, and Evgenii has received the IAGA YS Award.

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**SERBIA**: Report prepared by Dr. Aleksandra Nina (sandrast@ipb.ac.rs), Institute of Physics Belgrade, University of Belgrade, Belgrade, Serbia

Researchers from Serbia continued to analyze the data recorded by the VLF/LF receivers located in the Institute of Physics in Belgrade. We carried on with investigations of the D-region perturbations induced by solar X-ray flares [1] and earthquakes, and we continued studies of the perturbed D-region influence on satellite signals [2]. The paper [1] is focused on analyses of the effective recombination coefficient in the D-region during increase of a solar X-ray flare intensity. The results obtained in [2] show that the delay of GNSS and SAR signals can be important in the perturbed D-region and, therefore, should be taken into account in modeling relevant for space geodesy.

During this year we focused our activities on joining to international efforts in investigation of relationship between the lower ionosphere disturbances and earthquakes. We joined to the European VLF/LF network INFREP, participated in organization of the EUROPLANET workshop “Integrations of satellite and ground-based observations and multi-disciplinarity in research and prediction of different types of hazards in Solar system” [3] and finished one study about the lower ionosphere disturbances at the time around the Kraljevo earthquake in 2010 (submitted manuscript).

INFREP


*The International Network for Frontier Research on Earthquake Precursors (INFREP) and the propagation paths of signals monitored in Belgrade. Receivers included in the INFREP are indicated as R, and transmitters of the monitored signals as T.*

During this year we participated in several international conferences and have been appointed as Guest Editors (Vladimir Srećković, Aleksandra Nina and Milan Radovanović) for the Special Issue of the MDPI journal Sustainability - Natural Disasters and Extreme Solar Energy.

Our activities started or continued within national projects, SCOSTEP projects (VarSITI and PRESTO), and COST actions: Accelerating Global science In Tsunami HAzard and Risk analysis, and Atmospheric Electricity Network: coupling with the Earth System, climate and biological system. Process of re-joining of Serbia to the IUGG is completed and we participate in our National Committee and in the IAGA.

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**UNITED KINGDOM**: Report prepared by Mark Clilverd (macl@bas.ac.uk), British Antarctic Survey, webpage ([https://www.bas.ac.uk/](https://www.bas.ac.uk/))

BAS report to VERSIM – December 2019

This year I am pleased to be able to say that the Halley Station, Antarctica, VLF experiments have operated throughout the whole of 2019 despite the base being unmanned. The autonomous power system (small jet engine) installed in January 2019 operated continuously throughout the year. Satellite communications were lost with the unmanned base towards the end of the year, resulting in a loss of WWLLN data from Halley, but Ultra, VELOXNET, UltraVELOX, and AWD data were successfully archived during that period.

BROADBAND RECORDINGS in Antarctica:
Whistler-detection and data collection has continuedat Halley (L=4.6) and Rothera (L=2.9) throughout 2019 using the Hungarian Automatic Whistler Detection (AWD) system. BAS also continues to operate another AWD site, at Eskdalemuir in Southern Scotland (L=2.7). These sites continue to operate beyond the lifetime of the PLASMON FP7 project which finished in August 2014.

VELOX RECORDINGS at Halley, Antarctica:
Recordings of VLF activity in 10 ELF/VLF bands, at 1-s resolution (VELOXnet) ran continuously at Halley in 2019. Halley VELOX data will stop being collected at the end of December 2019 due to IT restrictions on its operating system. However, we have collected broadband data using the VELOXnet upgrade capability, UltraVELOX, at

Halley, Rothera, Seattle, and Ottawa. This dataset is partially equivalent to VELOXnet recordings, with 46-93Hz bin resolution up to a maximum frequency of 48 kHz, 0.2-10 sec time resolution depending on site, amplitude only.

NARROW-BAND RECORDINGS:
'Ultra' narrow-band recordings have continued at Halley and Rothera (Antarctica), Forks, Seattle (USA), Ottawa, St Johns, and Churchill (all Canada), Eskdalemuir (Scotland), Sodankyla (Finland), Reykjavik (Iceland), and Ny Alesund (Svalbard) throughout 2019. BAS is also hosting Ultra data from Fairbanks, Alaska, collected as part of a collaboration with WWLLN. The data collection from the Australian Casey station (Antarctica) was permanently shut down in June 2019 after the removal of operational support by the Australian Antarctic Division.

The software VLF Doppler system has continued at Rothera station, Antarctica (L=2.8) in 2019 receiving whistler mode and sub-ionospheric signals primarily from NAA (24.0 kHz). BAS Doppler data from Rothera was included in a paper on very low latitude whistler mode signals from the Hawaiian transmitter, NPM (see reference below). A similar Doppler system has been in operation at Marion Island, South Africa (L=2.9) during 2019, hosted by SANSA, Hermanus.

WWLLN sites:
British Antarctic Survey has continued to operate four World Wide Lightning Location Network systems in 2019. St Johns, Ascension, and Rothera have successfully provided lighting location information all year, while Halley experienced a 2 month datagap during to the loss of network connectivity of the whole site.

Please contact Mark Clilverd (macl at bas.ac.uk) for details regarding on-line access to the datasets mentioned above.

Regards, Mark Clilverd

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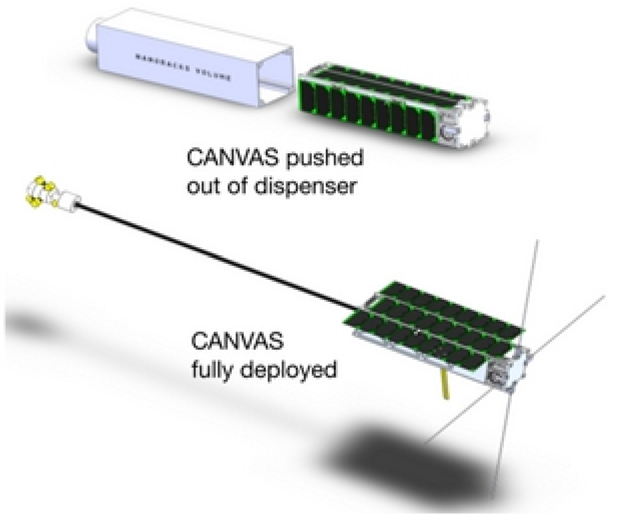
**UNITED STATES:** Report prepared by Prof. Robert Marshall (robert.marshall@colorado.edu), University of Colorado Boulder, Boulder, CO, USA

The Lightning, Atmosphere, Ionosphere, and Radiation belts research group (the LAIR) continues to make VLF/LF observations, conduct modeling studies, and build instrumentation. Our study of the 2017 solar eclipse and its effect on D-region chemistry was published [Xu et al, 2019]. We have continued work on D-region estimation using an ensemble Kalman filtering (enKF); a first publication was recently accepted for publication in IEEE TGRS [Gasdia and Marshall, 2019].

A couple of relevant large projects of interest to the VERSIM community have recently started. Our group was awarded funding to develop a new CubeSat called Climatology of Anthropogenic and Natural VLF wave Activity in Space (CANVAS). This 4U CubeSat will use a three-axis search coil and two dipole antennas to measure VLF waves from Low Earth Orbit (see Figure). The mission is designed to measure upgoing whistler waves from lightning and VLF transmitters, in order to characterize their propagation through the ionosphere and their distribution throughout the magnetosphere. The mission will also likely measure hiss and chorus waves. The instrument and spacecraft are currently in development; launch is tentatively planned for 2021. Collaborators include CNRS in France and the Laboratory for Atmospheric and Space Physics (LASP) at CU Boulder.




*CANVAS spacecraft design. CANVAS will be released from the Nanoracks dispenser, after which the solar panels, UHF communications antenna, 3-axis search coil, and two-axis electric field antennas will be deployed.`*

Our group was also recently awarded NASA funding to develop the Atmospheric Effects of Precipitation through Energetic X-rays (AEPEX)

CubeSat mission. This mission will measure the flux, spectrum, and spatial scale of precipitation from the radiation belts by measuring the X-rays backscattered from the atmosphere. While it will not make direct measurements of waves in the magnetosphere, possible conjunctions with other spacecraft (including CANVAS) will enable new insights into the causes and consequences of radiation belt precipitation. AEPEX will likely launch in early 2022. Collaborators include LASP and the Universities of Calgary, Iowa, New Hampshire, and Washington.

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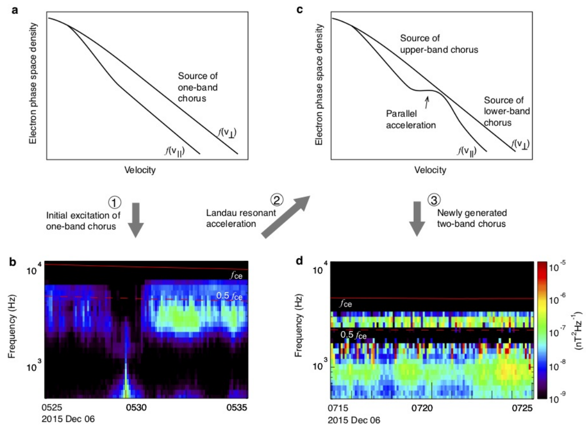
**UNITED STATES**: Report prepared by Prof. Jacob Bortnik (jbortnik@gmail.com), University of California at Los Angeles (UCLA), Los Angeles, California, United States.

The Bortnik Research Group at UCLA had an eventful 2019! On the one hand, work continued steadily, looking at some of the key physical processes occurring in the Earth's inner magnetospheric environment through a combination of multi-spacecraft data analysis, laboratory simulations supplemented by numerical simulation, and techniques in machine learning. On the other hand, we were saddened to lose our long-term leader, and one of the pioneers of radiation belt and plasma waves physics, Prof. Richard M. Thorne, who passed on July 12th 2019 after a prolonged battle with cancer.

A few big themes emerged in our research in 2019: the characteristics and dynamics of ultrarelativistic particles in the radiation belts (known as remnant belts) [*Pinto et al.*, 2019], the microscopic interactions of energetic electrons with plasma waves including an elegant explanation of time-domain structures [*An et al.*, 2019; *Zhang et al.*, 2019], and the applications of machine learning in Heliophysics [*Camporeale et al.*, 2019]. One of most interesting findings we had focused on a simple explanation of the development of the chorus two-band structure, involving the rapid extinguishing of the particle anisotropy due to Landau scattering (discussed in *Li et al.,* [2019] and the figure below). We look forward to a fun and fruitful 2020, which includes the much-awaited 9th VERSIM workshop in March 2020, in Kyoto, Japan.




*(After Li et al., 2019, Fig 5.) Schematic illustration of the generation mechanism of two-band chorus waves. a The anisotropic velocity distribution of freshly injected electrons and b the generation of one-band chorus emissions. c The electron distribution after Landau resonant acceleration taking place, resulting in two separate anisotropic parts, d The excitation of the upper and the lower band chorus emissions by the low-energy and high-energy anisotropic electrons, respectively. The red solid and dashed lines represent fce and 0.5 fce, respectively.*

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