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

Annual newsletter of VERSIM: a joint IAGA/URSI working group
Editor: Jacob Bortnik No. 33, December 2018

Dear VERSIM friends and colleagues,

As 2018 draws to a close, I would like to take a moment to reflect upon our remarkable community. Established in 1975, the "VLF/ELF Remote Sensing of Ionospheres and Magnetospheres" (VERSIM) working group was designed to be collaborative and multidisciplinary, operating under the joint auspices of what we now call URSI Commissions G and H, and IAGA Divisions II and III. Although originally intended to focus on passive electromagnetic probing of the magnetosphere, the VERSIM group has grown substantially and now encompasses a diverse range of interest areas and approaches. As you'll read in the following pages of the 2018 VERSIM end-of-year newsletter, core VERSIM topics such as magnetospheric plasma density sensing through passive observation of whistlers are still strongly represented, but with a modern twist. Data sets are now gathered continuously in tremendous volumes, at over a dozen ground stations and dissected with powerful automated techniques, as described by our Hungarian colleagues in their report. Remote sensing using ELF/VLF is extended to other natural phenomena such as earthquakes, volcanoes, solar eclipses, energetic electron precipitation, and are even shown to be an effective sensor of transformer malfunctions related to space weather, as described by our colleagues from the UK and New Zealand. Analytical techniques are evolving too: new approaches for analyzing VLF wave data beyond the traditional amplitude and phase have been developed (e.g., US report from Georgia Tech), new theories for unexplained observations of VLF phenomena in DEMETER data have been put forth (e.g., Russian report from the Space Research Institute of RAS), and new "big data" methods such as neural networks and Ensemble Kalman Filtering are increasingly being applied to VLF/ELF data sets.

In March of this year, we were fortunate to gather as a community for the 8th biennial VERSIM workshop, expertly hosted by our friends and colleagues at the Polar Geophysical Institute in the city of Apatity, Murmansk region, Russia (http://pgi.ru/conf/versim2018). Among the talented group of young scientists in attendance, Dr. Evgenii Shirokov was selected for the Young Scientist award.

In closing, I urge you to read this newsletter carefully, reach out, and form collaborations with some of our extraordinary colleagues! I wish you all the very best for a successful and productive 2019.

Jacob Bortnik, IAGA co-chair of VERSIM

Mark Clilverd, URSI co-chair VERSIM

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

We continue our project to detect whistlers 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.

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. No solution has been found to remove it. A new team is actually at the station to 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).

Wooden table with the VLF instrument inside, taken in December 2018 at the Princess Elisabeth Antarctica station.

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.

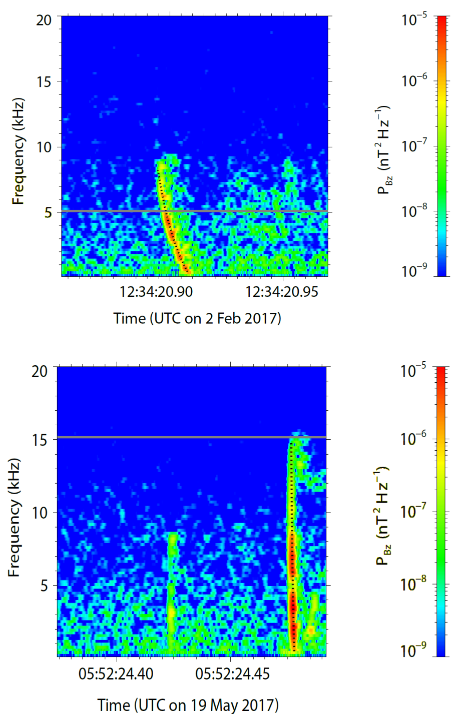
Our group at the Institute of Atmospheric Physics of the Czech Academy of Sciences and at the Charles University continued to investigate electromagnetic waves using spacecraft measurements and ground-based experiments. Examples of our results obtained in 2018 are given below.

We reported the first observations of Jovian rapid whistlers [1]: a form of dispersed atmospherics at extremely short timescales of several milliseconds to several tens of milliseconds. The measurements were conducted by the Waves instrument on board the Juno spacecraft. We have identified over 1,600 whistlers recorded during close approaches to Jupiter at radial distances below 5 Jovian radii. We detected up to four lightning strokes per second, similar to rates in thunderstorms on Earth.

We analyzed equatorial noise (EN) emissions with a quasiperiodic modulation of the wave intensity [2]. These EN emissions were recorded by the Van Allen Probes spacecraft. We have found that the events are sometimes effectively confined to low-density regions. Their spatial extent is typically lower than about 0.25 R_E in radial distance and within about 1 hour in magnetic local time. Modulation periods of these events decrease with increasing plasma number density up to about 100 cm^{-3}.

We also investigated the influence of lightning-generated whistlers on the overall intensity of electromagnetic waves measured by the low orbiting DEMETER spacecraft at frequencies below 18 kHz [3]. Whistler occurrence rates were evaluated using an onboard neural network designed for automated whistler detections. We have shown that especially during the night and particularly in the frequency-geomagnetic latitude intervals with a low average wave intensity, contribution of lightning-generated whistlers to the overall wave intensity is significant.

We presented the first conclusive evidence of intense lion roar emissions in Saturn's magnetosheath [4]. Emissions are narrow-banded with a peak frequency of about 16% of the local electron gyrofrequency. Our observations of lion roars outside the terrestrial environment suggest that they are a solar-system-wide phenomenon capable of existing in a broad region of the parameter space.



Caption: Examples of observed Jovian rapid whistlers. Frequency–time power spectrograms of the magnetic field fluctuations. Burst mode record measured at altitudes of a) 25,100 km and b) 7,380 km, respectively above the 1 bar level. The horizontal grey lines show the local proton cyclotron frequency calculated from measured ambient magnetic field magnitude. The black dotted lines were calculated from a field-aligned propagation model of electromagnetic waves in a cold plasma.

References:

1. Kolmašová, I., M. Imai, O. Santolík, W. S. Kurth, G. B. Hospodarsky, D. A. Gurnett, J. E. P. Connerney, S. J. Bolton (2018), Discovery of rapid whistlers close to Jupiter implying lightning rates similar to those on Earth. Nature Astronomy 2, 7, 544–548, https://doi.org/10.1038/s41550-018-0442-z.
2. Nemec, F., Santolík, O., Boardsen, S. A., Hospodarsky, G. B., & Kurth, W. S. (2018). Equatorial noise with quasiperiodic modulation: Multipoint observations by the Van Allen Probes spacecraft. J. of Geophys. Res., 123, 4809–4819, https://doi.org/10.1029/2018JA025482.
3. Záhlava, J., Nemec, F., Pincon, J. L., Santolík, O., Kolmašová, I., & Parrot, M. (2018). Whistler influence on the overall very low frequency wave intensity in the upper ionosphere. J. Geophys. Res.: Space Physics, 123, 5648–5660. https://doi.org/10.1029/2017JA025137.
4. Píša, D., Sulaiman, A. H., Santolik, O., Hospodarsky, G. B., Kurth, W. S., & Gurnett, D. A. (2018). First observation of lion roar emission in Saturn's magnetosheath. Geophys. Res. Lett., 45, 486–492, https://doi.org/10.1002/2017GL075919.

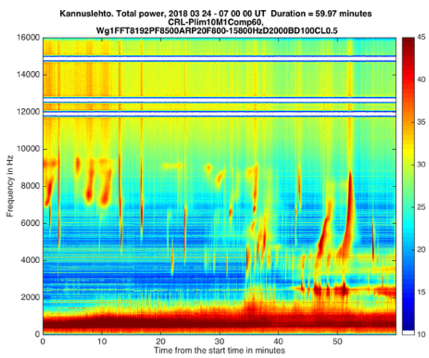
FINLAND: Report prepared by Dr. Jyrki Manninen (Jyrki.Manninen@sgo.fi), Sodankylä Geophysical Observatory, University of Oulu, Finland, www.sgo.fi

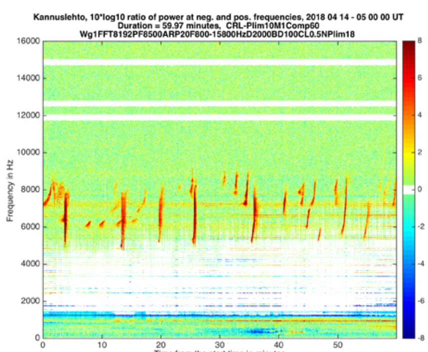
Winter 2017-2018 ELF-VLF campaign started on 1 September 2017 and ended on 26 April 2018. The campaign had one longer break (19 Oct – 8 Nov 2017) due to broken electric generator. Another shorter gap was 7-11 March 2018. In spite of all the campaign lasted altogether 212 days. This autumn we started our campaign already on 29 August 2018, because we wanted to record ELF-VLF data during Japanese ARASE satellite campaign. So far, we have had only one half-day gap. 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@sgo.fi. We can make a vast amount of different kind of analysis for our ELF-VLF data.

Some new results will be shown in EGU GA in April 2019 and IUGG GA in July 2019.





A couple of 1-hour examples of high-frequency events. Left one is total power at 07-08 UT on 24 Mar 2018. Right one is polarization at 05-06 UT on 14 Apr 2018.

References:

1. Manninen, J., N.G. Kleimenova, T. Turunen, and L.I. Gromova (2018). New high-fre¬quency (7–12 kHz) quasi-periodic VLF emissions observed on the ground at L ~ 5.5. Ann. Geophys., 36, 915–923, doi:10.5194/angeo-36-915-2018

There were also several oral and poster presentations in 2018.

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

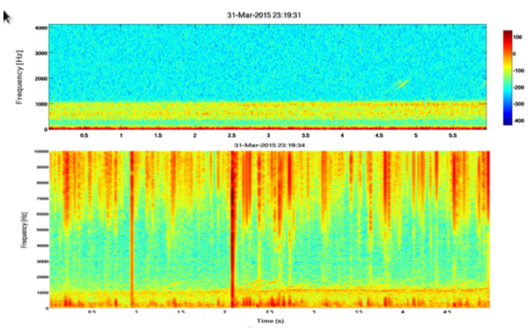
Our group continued the theoretical modeling and model-calculations of monochromatic and transient (Ultra Wide Band) electromagnetic signals and are seeking a solution of the electromagnetic wave propagation in general relativistic situations (coupled solution of the Maxwell and Einstein equations).

We have made a statistical survey on the source regions of whistlers using the huge database of AWDANet collected from 2002. The study includes ~100 million whistler traces detected at 15 ground stations. The causative lightnings strokes were mapped to the lightning data in the WWLLN database using a direct comparison of times based on the minimum and maximum travel times of the source sferic, set individually for each stations. Separate maps of source locations and the density of the source lightnings were created for each stations as well as maps of whistler transmission rates. The latter ones maps the probability of whistler generation from a lightning at a location.

We have developed a method to evaluate the energetic electron density from frequency sweep rate of chorus waves. The method uses relativistic linear growth-rate of plasma waves to estimate parallel momentum and average perpendicular velocity of the energetic electron, producing maximum linear wave growth. Based on these values, the optimum wave amplitude was derived from frequency sweep rate of chorus element using nonlinear wave growth theory. From the optimum wave amplitude, the energetic electron density was calculated. The method was first verified by comparing the estimated energetic electron density derived from in-situ (EMFISIS) chorus measurements with measured energetic electron densities from HOPE particle measurements. The method was completed with the extension of the procedure using ground based (Halley) chorus waves.

We have completed a feasibility study for ESA on ideal wave measurements on nanosatellites. The study confirmed that it is feasible to perform full (six components) wave measurements in the low frequency band(0-40kHz) and intermittent one in RF (40kHz-108MHz) on small size factor (12U-27U) cubesats and transmit all raw data to the ground using high speed X-band data telemetry. We plan to implement such wave measurements on real satellite.

We have continued the preparation of Chibis-AI microsatellite with Russian partners to study the terrestrial lightnings. A phase-A study has been completed on two microsatellites (Trabant A and B), also with Russian partners, to study the equatorial ionosphere. Here the planned SAS3-T wave experiment uses a similar approach we have developed in the ESA feasibility study to transmit all raw data collected in VLF-LF bands to the ground.



	HOPE particle data	EMFISIS chorus inversion	AWDANet chorus inversion
N_h/N_c,	0.0003+0.0001 -0.0002	0.0004+-0.0001	0.0003+0.0001 -0.0000

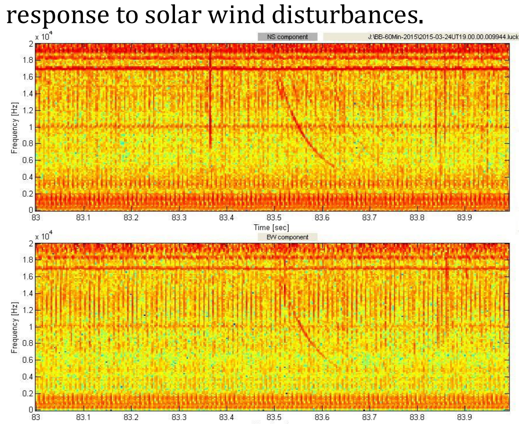
Comparison of the ratio of hot and cold electron densities derived from HOPE measurements with the densities estimated from simultaneous chorus event recorded on Van Allen Probes (upper panel) and on the ground (Halley, middle panel).

References:

1. Juhász, L.; Omura, Y.; Lichtenberger, J.; Friedel, R.H. (2018): Evaluation of plasma properties from chorus waves observed at the generation region, submitted to Journal of Geophysical Research: Space Physics, https://arxiv.org/abs/1811.09586
2. Koronczay, D., Lichtenberger, J., Juhász, L., Steinbach, P., & Hospodarsky, G. B. (2018). VLF transmitters as tools for monitoring the plasmasphere. J. of Geophys. Res: Space Physics, 123. https://doi.org/10.1029/2018JA025802

INDIA: Report prepared by Prof. Ashok K. Singh (aksphys@gmail.com), University of Lucknow, Lucknow, India

As earlier, our group is still active in the study of ELF/VLF waves. Presently, ELF/VLF phenomena (tweeks and whistlers) are widely being used as remote sensing tool to explore mid/upper atmosphere as the ELF/VLF waves are reflected by the ionosphere. The D-region of ionosphere (60-100 km) depending upon the solar zenith angle, solar flux, season and latitude wherein collisions between charged particles and neutrals dominate the dynamics of the region is being actively monitored by ELF waves. It is preferred over VLF transmitter's technique because of their limited spatial coverage along the propagation path due to fixed number of VLF transmitters. Since wave velocity is a function of electron density, the dispersion characteristics of VLF whistlers have been widely used to derive medium parameters because either they are fundamental for a number of ionospheric/ magnetospheric processes such as gyro-resonant wave-particle interaction, electron acceleration and precipitation from radiation belts, non-linear wave-wave interaction with Alfvén waves or they featured as a valuable tool to study the structure of the ionized terrestrial environment and their dynamics in response to solar wind disturbances.



Caption: Spectrogram of whistlers recorded at our ground based station, Lucknow

Reference:

1. Singh, A.K., U. P. Verma, and Asheesh Bhargawa (2018), Remote Sensing of Mid/Upper Atmosphere using ELF/VLF Waves, Global Journal of Science Frontier Research: A, Physics and Space Science, 18, 11-21.

INDIA: Report prepared by Dr. Devbrat Pundhir (devbratpundhir@gmail.com), RBS Engineering Technical Campus, Bichpuri, Agra.

Our research project on ULF/VLF and TEC anomalies associated with seismic activities sponsored by Ministry of Earth Sciences, New Delhi is running in final phase of completion and it will be wound up in March, 2019. In the final year of this project we have analysed mostly the ULF data obtained by the search coil magnetometer installed in the agriculture fields of the college. The data analysed for two specific months of April, 2012 and September, 2013 in which large earthquakes of magnitude M = 8.5 and M = 7.8 occurred in Indian subcontinent (Indonesia and China) show ULF amplitude bursts associated with these earthquakes which involve signals of ultra low frequency $f \approx 0.1$Hz. An example of such bursts occurring in X (North-South) and (East-West) components of the magnetometer is shown in Fig.1.

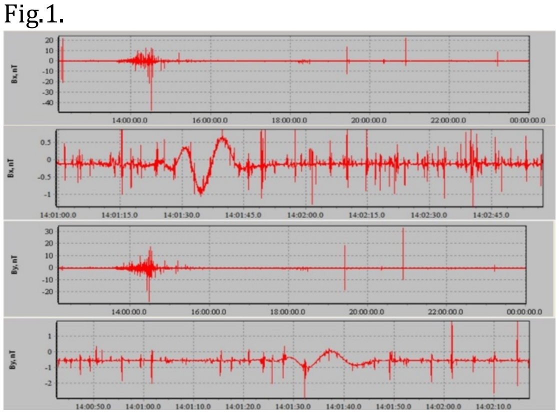


Figure 1. ULF bursts and associated signals in X, Y components of the magnetometer recorded on 11 April, 2012 (Day of Chinese earthquake M = 8.5)

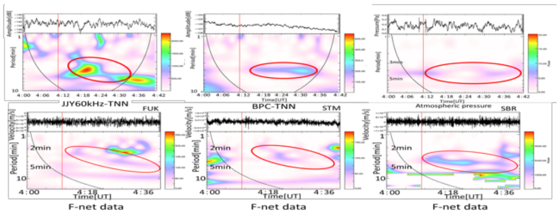
An interesting point that has come out of these results is that the bursts have not been observed as precursors, unlike to those of VLF and TEC data in which the anomalies appeared 9 to 11 days prior to the main shock. In the ULF data the anomalies are either co-seismic or occurred after the shock. This problem is under investigation. The polarisation and PSD analyses of the ULF bursts have confirmed their association with the earthquakes.

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

Our group of AVON (Asia VLF Observation Network) project have continued to observe wide band VLF waves radiated from ground lightning and manmade LF/VLF standard radio waves in 5 countries; Taiwan, Thailand, Indonesia, Philippines, and Vietnam. Our results in 2018 are shown as follows.

We reported the first observations of ~100-s periodic oscillations of intensity in LF standard radio waves after the 2011 Tohoku Earthquake [1]. Based on a simulation of the neutral atmosphere and the wave-hop method, the oscillations were caused by acoustic waves excited by Rayleigh waves. The amplitude of the D-region electron density variations during the oscillation was estimated to be about 1% compared to the background electron density.

We also report variations in intensity of LF transmitter signals after volcanic eruptions of Sakurajima (31.59°N, 130.66°E), Japan, on 6 June, 2014. The LF propagation paths are JJY 60 kHz - Tainan (TNN, Taiwan), and BPC (68.5 kHz) – TNN. The Sakurajima volcanic eruptions occurred at 04:11 UT on 6 June, 2014. Based on wavelet spectra, the both LF intensities had a period of 3-5 minutes during 04:12-04:20 UT after the eruptions (Figure). We compared the LF intensities with atmospheric pressure data obtained by an infrasonic meter observed by Sakurajima Volcano Research Center, Kyoto University, and seismic waves in the National Research Institute for Earth Science and Disaster Resilience (NIED) Full Range Seismograph Network of Japan (F-net) data (Fukue:FUK, Sotome:STM, and Sefuri:SBR) located close to the Sakurajima volcano. The atmospheric pressure had the similar period of 3-5 min during 04:18-04:42 UT. The vertical velocity of the seismic waves had a period of 2-5 min during 04:12-04:47 UT. The similar period of the LF intensities, atmospheric pressure, and seismic waves could be caused by acoustic resonance between the Earth surface and lower thermosphere.



Caption: (upper) Waveforms, and (lower) wavelet spectra of intensities of LF JJY60kHz-TNN and BPC-TNN paths, atmospheric pressure, and vertical velocity of seismic waves at three F-net stations. The red circles show similar periods of 3-5 minutes simultaneously.

References
1. Ohya, H., Tsuchiya, F., Takishita, Y., Shinagawa, H., Nozaki, K., and Shiokawa, K. (2018), Periodic oscillations in the *D* region ionosphere after the 2011 Tohoku earthquake using LF standard radio waves. *Journal of Geophysical Research: Space Physics*, *123*. https://doi.org/10.1029/2018JA025289.

JAPAN: Report prepared by Dr. Fuminori Tsuchiya (tsuchiya@pparc.gp.tohoku.ac.jp), Planetary Plasma and Atmospheric Research Center, Tohoku University, Japan http://c.gp.tohoku.ac.jp/lf/

We have installed several VLF/LF receivers to monitor subionospheric propagation of transmitter signals (http://c.gp.tohoku.ac.jp/lf/). Some of these receivers are used to measure relativistic electron precipitations (REP) from radiation belts to the lower ionosphere. Recently, we found that perturbation in the subionospheric signal had significant correlations with pulsating aurora (Tsuchiya et al. 2018). As pulsating aurora is caused by wave particle interaction primary with whistler mode chorus wave, the correlations with pulsating aurora suggests the chorus wave also scatters relativistic electron and cause precipitation into the lower ionosphere. We also found the temporal and spatial correspondence of REP event with isolated proton aurora and Pc1/EMIC wave that accompanied rising-tone structure (Hirai et al. 2018). A good correspondence between the temporal variations of REP and EMIC waves in a time scales of a few tens of seconds is the direct evidence that each EMIC wave element caused a burst of precipitation. Comparison between subionospheric propagation and aurora phenomena occurred on the radio path is a strong probe to identify drivers of REP. Our radio observation is a part of the ERG-ground coordinated observation network (Shiokawa et al. 2017).

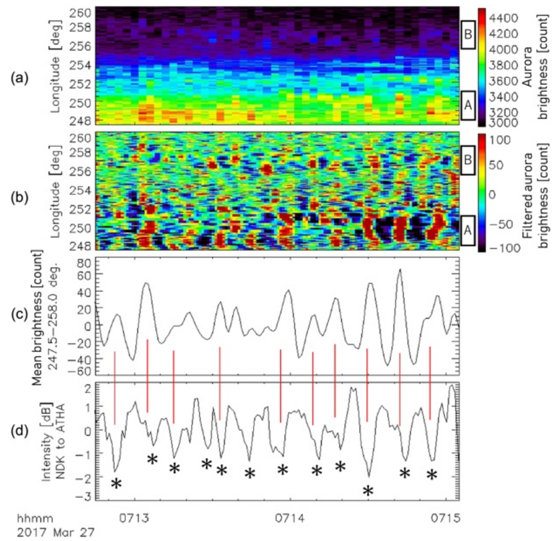


Figure: Comparison between aurora time variation along radio path and intensity of North Dakota (NDK) transmitter signal measured at Athabasca from 07:12:45 to 07:15:05 UT. (a) Aurora brightness along radio path derived from The Pas (TPAS) all-sky imager. Longitude ranges of pulsating aurora patches (A and B) are shown on right. (b) Same as panel a but shows aurora brightness passed through a HPF. (c) Variations in HP-filtered aurora brightness averaged along radio path. (d) HP-filtered amplitude change of NDK transmitter signal (Tsuchiya et al. 2018).

References:
1. Tsuchiya, F., Hirai, A., Obara, T., Misawa, H., Kurita, S., Miyoshi, Y., et al. (2018). Energetic electron precipitation associated with pulsating aurora observed by VLF radio propagation during the recovery phase of a substorm on 27 March 2017. Geophysical Research Letters, 45. https://doi.org/10.1029/2018GL080222
2. Hirai, A., Tsuchiya, F., Obara, T., Kasaba, Y., Katoh, Y., Misawa, H., et al (2018). Temporal and Spatial

Correspondence of Pc1/EMIC Waves and Relativistic Electron Precipitations Observed with Ground ‐ Based Multi ‐ Instruments on 27 March 2017. Geophysical Research Letters, 45. https://doi.org/10.1029/2018GL080126

3. Shiokawa, K., Katoh, Y., Hamaguchi, Y., Yamamoto, Y., Adachi, T., Ozaki, M., et al. (2017). Ground-based instruments of the PWING project to investigate dynamics of the inner magnetosphere at subauroral latitudes as a part of the ERG-ground coordinated observation network. Earth, Planets and Space. https://doi.org/10.1186/s40623-017-0745-9

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

We have had a very productive year. We had the largest number of papers published by the group for more than ten years, hosted the CHAMOS workshop, and also multiple other international visitors. As well as people coming to see us, members of the group have travelled overseas. Craig has appeared on New Zealand TV twice, and travelled New Zealand giving public lectures on Space Weather. Annika Seppälä is settling into life in New Zealand, and mostly retired Neil Thomson is still researching and publishing!

The students in the team have also been very successful. Aaron Hendry (now a former student), took up a postdoctoral fellowship with Ondrej Santolik at the Institute of Atmospheric Physics in the Czech Republic. Emma Duoma has submitted her PhD, with the final parts of the examination process to take place soon. Daniel Mac Manus has been awarded his MSc, and is going to return in 2019 to start a PhD. And our Honours research students, Harriet George and Emily Gordon, have started their research careers. Harriet was working on solar X-ray flares and their impact on subionospheric VLF propagation, and Emily on the polar atmospheric chemistry changes caused by solar proton events. Harriet will start up a PhD in Helsinki early next year, while Emily will start a MSc with Annika in 2019.

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 plasma wave drives of relativistic microburst events, which used VLF observations from the ground and space;
[2] Mark Clilverd's paper looking at stressed power network transformers due to geomagnetic storms - using wideband VLF observations. That paper was declared an editors highlight;
[3] Max van de Kamp's recent paper providing improved statistical representations of medium energy electron precipitation - specifically designed for incorporation for climate models.

Myles Thayer (left) and James Brundell on the summit of Observation Hill, Ross Island, Antarctica. Taken during the annual visit to maintain the VLF experiments.

References:

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2. Clilverd, M. A., C. J. Rodger, J. B. Brundell, M. Dalzell, I. Martin, D. H. Mac Manus, N. R. Thomson, T. Petersen, and Y. Obana, Long-Lasting Geomagnetically Induced Currents and Harmonic Distortion observed in

New Zealand during the 07-08 September 2017 Disturbed Period, *Space Weather*, 16, 704–717, doi:10.1002/2018SW001822, 2018.
3. van de Kamp, M., C. J. Rodger, A. Seppälä, M. A. Clilverd, and P. T. Verronen, An updated model providing long-term datasets of energetic electron precipitation, including zonal dependence, J. Geophys. Res., 123, 9891–9915, doi:10.1029/2017JD028253, 2018.

RUSSIA: Report prepared by Prof. Peter Bespalov (peter@appl.sci-nnov.ru), Institute of Applied Physics RAS, Nizhny Novgorod, Russia

We obtained new results of a theoretical study on two traditional problems connected with the excitation and propagation of ELF and VLF waves in the magnetosphere. The work we have done is characterized by the following abstracts.

A beam pulsed amplifier mechanism responsible for effective amplification of short very low frequency (VLF) electromagnetic pulses is proposed. Effective amplification near the magnetic equator outside the plasmasphere is considered. A conditional growth rate of short electromagnetic pulses is calculated. Obtained results can explain some important features of the oblique electromagnetic chorus emissions without hiss-like radiation background [1].

Trans-ionospheric propagation of the VLF electromagnetic wave from an altitude of 800 km to the Earth's surface is considered using the model of stratified media. The numerical solution of the wave equations for the midlatitude ionosphere model conditions is found. The wave field in the lower ionosphere is calculated using the full-wave approach. The wave field in the upper ionosphere is calculated using the matrix method of perturbations for a slightly inhomogeneous plasma. Energy reflection coefficient and the horizontal magnetic field amplitude of the wave on the ground surface are calculated. Peculiarities of the wave reflection and transmission at different times of the day are analyzed. The obtained results are important for studying the ELF/VLF emission phenomena observed both onboard satellites and in ground-based observatories [2].

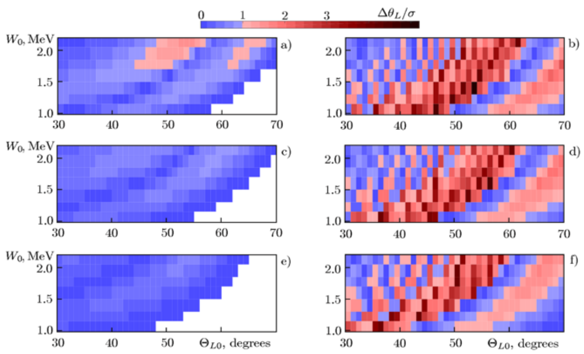
References:

1. Bespalov, Peter, and Savina, Olga (2018) An excitation mechanism for discrete chorus elements in the magnetosphere, Annales Geophysicae, 36, 1201-1206, doi: 10.5194/angeo-36-1201-2018
2. Bespalov, P.A., Mizonova, V.G., and Savina, O.N. (2018) Reflection from and transmission through the ionosphere of VLF electromagnetic waves incident from the mid-latitude magnetosphere, Journal of Atmospheric and Solar-Terrestrial Physics, 175, 40-48. doi: 10.1016/j.jastp.2018.04.018

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 continued studies of wave-particle interactions in the magnetosphere. We have studied [1] the dependence of the ***nonlinear resonant interaction of an ensemble of relativistic electrons in the Earth's radiation belts with EMIC waves*** on wave the amplitude profile. For a Gaussian wave packet the directional and diffusive particle transfer in the phase space are comparable, whereas the directional transfer can significantly (3 to 5 times) exceed the rms deviation for a constant-amplitude wave packet. The fraction of particles that can go into the loss cone after a single pass through the wave packet is about 1 to 2 percent. We analyzed [2] ***the effective length of the receiving electric dipole antenna*** mounted on a spacecraft on the parameters of spatial distribution of the charge in the effective source of quasi-electrostatic VLF chorus emissions. The effective length is inversely proportional to the square root of the distance from the model source to the receiving antenna along the group-velocity resonance cone, and may remain greater than the geometric length up to distances of tens of

thousands of km in the magnetosphere conditions. These estimates confirm the importance of the discussed effect for a correct interpretation of the data of electric wave measurements in the whistler mode range.
As the organizers of the VERSIM-2018 meeting, we were very much delighted to see our dear and respected colleagues in Apatity. We are most grateful to everyone who could come and contribute to the very interesting scientific program.



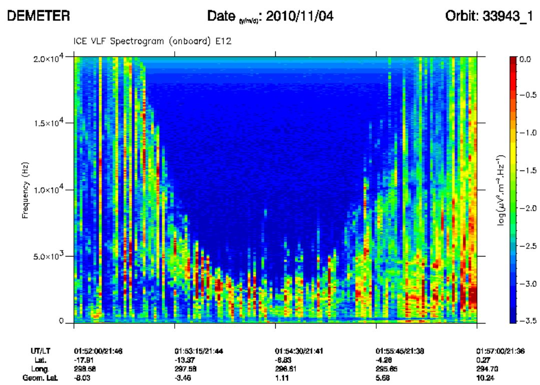
Caption: The ratio of the mean (absolute value) and rms deviation of the equatorial pitch angle for interaction of relativistic electrons with Gaussian (left) and constant (right) amplitude profiles of EMIC wave packet. Each row corresponds to a given wave packet position: the trailing edge at equator(a,b) and shifted by ¼ (c,d) and ½ (e,f) of packet length.

References:

1. Grach, V.S. and A.G. Demekhov (2018), Resonant Interaction of Relativistic Electrons with Electromagnetic Ion–Cyclotron Waves. II. Integral Parameters of Interaction Regimes, Radiophys. Quantum Electron., V.61, No.6, 389–401, doi:10.1007/s11141-018-9900-9.
2. Shirokov, E. A. and A. G. Demekhov (2018), Dependence of the Effective Length of a Receiving Antenna on the Space Charge Distribution in a Model Source of Quasi-Electrostatic Chorus Emissions, *2nd URSI Atlantic Radio Science Meeting (AT-RASC)*, Meloneras, 2018, doi: 10.23919/URSI-AT-RASC.2018.8471476

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

This report is based on the joint work of D.R. Shklyar, M. Parrot, and E.E. Titova.
VLF wave measurements performed on board the DEMETER satellite contain many known and then unknown wave phenomena observed in the upper ionosphere in the frequency band from hundreds Hz to 20 kHz. Apart from well-known sferics and electron and proton whistlers, generated by lightnings, the observations include magnetospheric line radiation, wedge-like spectra, ionospherically reflected proton whistlers first registered by DEMETER, and many other emissions. One of unusual wave phenomena registered in some cases over equatorial part of DEMETER orbit, which has not received an explanation yet, is U-shaped spectrum shown in the figure below. According to the measurements, this type of overview spectrum is observed simultaneously with unusually high plasma concentration. The explanation of this spectrum suggested in the present report is based on the assumption that the corresponding emission is formed by waves generated by lightning strokes, while the shape of the spectrum is determined by the features of VLF wave propagation and attenuation in the near-equatorial region of the upper ionosphere. Due to refraction properties of the ionosphere, lightning-induced waves in the near-equatorial region have large wave-normal angles which, however, are inside the resonance cone practically for all latitudes except the region of about one degree wide in latitude around the equator. Nevertheless, collisional damping of these waves is essential, and it increases with increasing frequency, which leads to appearance of the upper cut-off frequency in the spectrum. The enhancement of this effect with the increase of plasma density can be understood as follows. With the increase of electron plasma frequency the wave group velocity decreases and the wave spatial attenuation increases accordingly. That is why, passing the same distance from the generation region to the observation point on the satellite, the waves experience larger attenuation. These considerations are confirmed by numerical modeling of spectrogram



Spectrogram registered by the DEMETER satellite.

Reference:
Shklyar, D. R., Parrot, M., & Titova, E. E. (2018). U-shaped spectrograms registered by the DEMETER satellite: Observational features and formation mechanism. *J. Geophys. Res.: Space Physics*, *123*, 7077–7088. https://doi.org/10.1029/2018JA025656

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

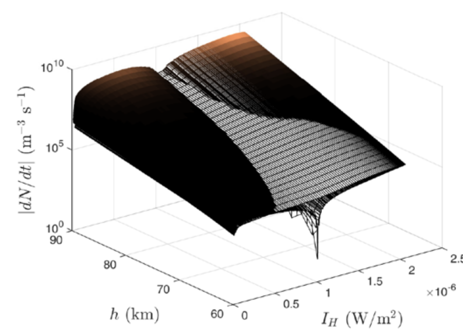
Researchers from Serbia continued to analyze the data recorded by two VLF/LF receivers located in the Institute of Physics in Belgrade. We carried on with investigations of the D-region perturbations induced by solar X-ray flares [1] and earthquakes, and we started studies of the D-region influence on satellite signals. Also, a study of the D-region disturbances induced by a solar eclipse has been published this year [2].
The paper [1] is focused on analyses of differences in contribution of photons of various wavelengths in photoionization processes within the D-region altitude domain. In this study, we apply a spectral analysis of X radiation detected by the GOES satellite using the CHIANTI model and we study the electron density properties occurring in photoionization and recombination regimes.

The eclipse-related perturbations in the ionospheric D-region were presented in an integrated study of four independent observations performed on 20 March 2015 in Belgrade [2].

During this year we focused our research on the D-region influence on satellite signals. The results of this study are presented in a paper submitted to a journal and were reported at scientific meetings. In addition, our current investigation is directed to analysis of the low ionospheric disturbances at the time around the Kraljevo earthquake in 2010.

We participated in several international conferences and have been appointed as Guest Editors (Vladimir Srećković and Aleksandra Nina) for the Special Issue of the MDPI journal Data - Astrophysics & Geophysics: Research and Applications.

Our activities continued within national projects, VarSITI, and COST actions: Big Data Era in Sky and Earth Observation (BIG-SKY-EARTH), and Time Dependent Seismology (TIDES). We initiated and participated in re-joining of Serbia to the IUGG. Also, we have joined activities of the COST Action Atmospheric Electricity Network: coupling with the Earth System, climate and biological system (ELECTRONET).



Caption: Surface plot of the electron density time derivative dN/dt versus altitude h and radiation flux I_H detected in the GOES-14 energy canal in the wavelength domain 0.05 – 0.4 nm.

References:

1. Nina, A., V.M. Čadež, J. Bajčetić, S.T. Mitrović and L.Č. Popović, Analysis of the Relationship Between the Solar X-Ray Radiation Intensity and the D-Region Electron Density Using Satellite and Ground-Based Radio Data, Solar Phys., vol. 293, issue 4, (2018), 64 (1-19), doi:10.1007/s11207-018-1279-4
2. Ilić, L., M. Kuzmanoski, P. Kolarž, A. Nina, V. Srećković, Z. Mijić, J. Bajčetić,

and M. Andrić (2017), Changes of atmospheric properties over Belgrade, observed using remote sensing and in situ methods during the partial solar eclipse of 20 March 2015, J. Atmos. Sol.-Terr. Phys., vol. 171, (2018), 250-259 , doi: 10.1016/j.jastp.2017.10.001

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

BAS report to VERSIM – December 2018

As with last year we will start with a summary, and finish with the details. The main issue at BAS has been the continued closure of the Halley Station, Antarctica through 2018. This is due to the ice-shelf, on which the base sits, cracking in several directions. This has affected VLF broadband recordings (VELOX), lightning (WWLLN), whistler detection (AWD), and 'Ultra' narrow band. During 2018 no standard VLF data collection has taken place at Halley. However, stand-alone low-powered systems to cover the broad and narrow band recordings were installed in February, and *might* have run through the year. Investigations into how successful those installations have been will take place in the next few weeks. The anticipation is that standard VLF data collection will take place at Halley in 2019 – assuming we can successfully install a reliable autonomous power system in January 2019.

BROADBAND RECORDINGS in Antarctica:
Whistler-detection and data collection has continued Rothera (L=2.9) throughout 2017 using the Hungarian Automatic Whistler Detection (AWD) system. BAS also continues to operate another AWD site, at Eskdalemuir in Southern Scotland (L=2.7), although for the majority of 2018 the data collection has been intermittent due to on-going network issues. These sites continue to operate beyond the lifetime of the PLASMON FP7 project which finished in August 2014.

VELOX RECORDINGS at Halley, Antarctica:
Unfortunately, as we reported last year, the quasi-continuous (since 1992) recordings of VLF activity in 10 ELF/VLF bands, at 1-s resolution (VELOX and VELOXNET) were stopped at Halley in 2017. In order to compensate for the loss of this dataset, we have begun to collect UltraVELOX broadband data at Halley (hopefully), Rothera, Seattle, and Ottawa. This dataset is partially equivalent to VELOX recordings, with 46Hz bin resolution up to a maximum frequency of 48 kHz, 0.2-10 sec time resolution depending on site, amplitude only. An UltraVELOX system has been run in Dunedin (by Otago Space Physics Group) to look for power transformer harmonic radiation during geomagnetic storms, and a description can be found in *Clilverd et al., Space Weather, 2018*, although many of our readers might remember the equivalent talk given at the excellent VERSIM meeting in Apatity in March.

NARROW-BAND RECORDINGS:
'Ultra' narrow-band recordings have continued at Rothera (Antarctica), the Australian Casey station (Antarctica), Forks, Seattle (USA), Ottawa, St Johns, and Churchill (all Canada), Eskdalemuir (Scotland), Sodankyla (Finland), Reykjavik (Iceland), and Ny Alesund (Svalbard) throughout 2018.

The software VLF Doppler system has continued at Rothera station, Antarctica (L=2.8) in 2018 receiving whistler mode and sub-ionospheric signals primarily from NAA (24.0 kHz). A similar Doppler system has been in operation at Marion Island, South Africa (L=2.9) during 2018, hosted by SANSA, Hermanus.

WWLLN sites:
British Antarctic Survey has continued to operate three World Wide Lightning Location Network systems in 2018. St Johns, Ascension, and Rothera have successfully provided lighting location information all year.

References:
Clilverd, M. A., C. J. Rodger, J. B. Brundell, M. Dalzell, I. Martin, D. H. Mac Manus, N. R. Thomson, T. Petersen, and Y. Obana, Long-Lasting Geomagnetically Induced Currents and Harmonic Distortion observed in New Zealand during the 07-08 September 2017 Disturbed Period, Space Weather, 16, 704–717, doi:10.1002/2018SW001822, 2018.

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

Our research group at UCLA had another productive year, studying the physical processes occurring in the Earth's inner magnetospheric environment through a combination of multi-spacecraft data analysis, laboratory experiments supplemented by numerical simulation, and techniques in machine learning.

A big theme this year was the nonlinear interaction between short, intense whistler-mode waves and energetic electrons as presented in Zhang et al. [2018; DOI: 10.1029/2018JA025390] who studied the properties of such waves, and Mourenas et al. [2018; DOI: 10.1029/2018JA025417] who quantified their effects on the particles showing that the effect was similar to quasilinear interaction but proceeded on much faster timescales. In another set of studies, it was shown that whistler-mode waves at dayside reconnection regions seem to precisely modulate the occurrence of Langmuir waves. Following up on this observation using a combination of satellite observations (Van Allen Probes and MMS), laboratory measurements (at UCLA's Large Plasma Device), and large-scale numerical simulations using Particle-In-Cell codes, it was shown that a single parameter, the ratio of electron resonant velocity and electron thermal velocity, controlled the fraction of the thermal electron distribution that would be trapped in the whistler wave's resonant island, and hence the type of electrostatic structure that would be generated, including Langmuir waves, electron holes, or double layers (see figure below). This work has been submitted for publication in the journal Physical Review Letters, and is currently in the final stages of the review process.

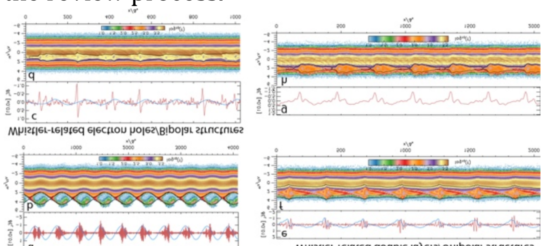
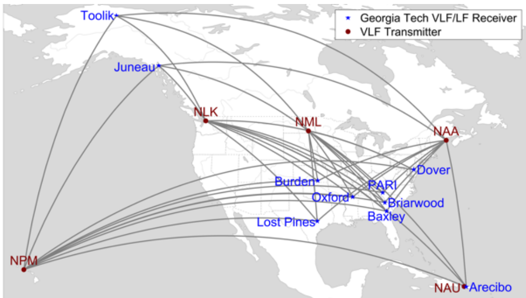


Figure caption: A simulation of the chorus-related electrostatic structures, with each pair of panels showing a snapshot of the electric field (red) and magnetic field (blue) waveforms as a function of the spatial coordinate x normalized to the grid spacing Δ_x, and the bottom panels show the Phase Space Density (PSD) in color, as a function of x, and $v_{||}/v_{th}$. (a,b) Langmuir waves observed at t_0=1540 ω_{pe}^{-1}, with v_R/v_{th} =3.2, (c,d) bipolar structures observed at t_0=1200 ω_{pe}^{-1}, with v_R/v_{th} =1, and (e-h) development of unipolar structures with v_R/v_{th} =2.1, observed at two different times (e,f) electron acoustic waves as t_1=1300 ω_{pe}^{-1}, and (g,h) developed unipolar structures at t_2=2500 ω_{pe}^{-1}.

UNITED STATES: Report prepared by Prof Morris Cohen (mcohen@gatech.edu), Georgia Tech, http://LF.gatech.edu

Our group published 4 papers on geophysical topics this past year (and a few others on topics outside geophysics), and we cite these 4 below. Paper #1 describes our observations. along with those of some colleagues, around the "Great American Eclipse" which took place in August 2017. Paper #2 describes a new way to analyze two-component magnetic field data for VLF transmitter recordings, going beyond amplitude and phase. It forms part of Nicholas Gross's PhD thesis which was completed in October 2018. The rest of his thesis work will be published in a journal sometime in the Spring, hopefully, on the topic of ionospheric remote sensing with VLF transmitters. Paper #3 lays out a detailed analysis technique to extract information from sferics. It forms part of Jackson McCormick's PhD thesis, which should be completed in early Spring 2019. Paper #4 is a detailed review of the design and performance, and some interesting example data, our new VLF/LF receiver, the next generation of the Stanford AWESOME, which has been transferred to Georgia Tech, and redesigned to improve the sensitivity and timing accuracy, and extend the frequency band to 500 kHz. This receiver is now deployed at 11 sites across the western hemisphere, and we are happy to share or save data in collaboration with any colleagues.

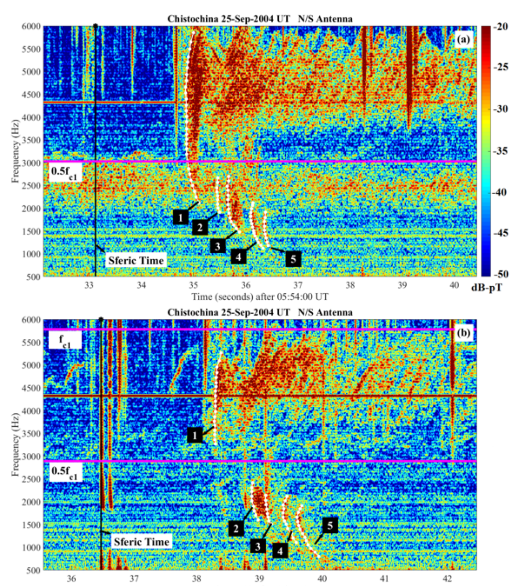


References:

1. Cohen M. B., N. C. Gross, M. A. Higginson-Rollins, R. A. Marshall, M. Golkowski, W. Liles, D. Rodriguez, J. Rockway (2018), The Lower Ionospheric VLF/LF Response to the 2017 Great American Solar Eclipse Observed Across the Continent, *Geophysical Research Letters*, 123, doi:10.1002/2018GL077351
2. Gross N. C., M. B. Cohen, R. K. Said, M. Golkowski (2018), Polarization Measurements of VLF Transmitters as an Ionospheric Diagnostic, *Journal of Geophysical Research Space Physics*, 122, doi:10.1002/2017JA024907
3. McCormick J. C., M. B. Cohen, R. K. Said, N. C. Gross (2018), Spatial and temporal ionospheric monitoring using broadband sferic measurements, *Journal of Geophysical Research Space Physics*, 122, doi:10.1002/2017JA024291
4. Cohen M. B., R. K. Said, E. W. Paschal, J. C. McCormick, N. C. Gross, L. Thompson, U. S. Inan, J. C. Chang (2018), Broadband Longwave Remote Sensing Instrumentation, *Reviews of Scientific Instruments*, 89, 094501

UNITED STATES: Report prepared by Associate Prof. Mark Golkowski (mark.golkowski@ucdenver.edu), Department of Electrical Engineering, University of Colorado Denver, Denver, CO, USA, http://www.ucdenver.edu/faculty-staff/mgolkows/Pages/default.aspx

With Dr. Vijay Harid (PhD 2014 Stanford University) joining the Department of Electrical Engineering as Assistant Professor last year, we have greatly enhanced our capabilities for investigating phenomena of the ionosphere and magnetosphere at the University of Colorado Denver. Two noteworthy results from the last year include a novel method of lower ionosphere sensing using ELF sferic group velocity [*Golkowski et al.,* 2018] and remote sensing of energetic electron anisotropy in the magnetosphere using whistler triggered chorus [*Hosseini et al.,* 2018a]. The ELF sferic work has emerged from our collaboration with the Krakow ELF Group (http://www.oa.uj.edu.pl/elf/) in Poland and our participation in the Polish WERA (Worldwide ELF Radiolocation Array) network. The WERA network includes ELF (0 – 350 Hz) receivers in Poland, Argentina, and Colorado, USA. The magnetospheric work has followed from revisiting high quality ground observations of upper band chorus triggering made in Alaska in 2004 (see figure). In the context of past ground observations, in 2019 we will be receiving a large archive of VLF observations made at Palmer Station from Stanford University. We plan to use these observations for studies of whistler mode emissions and also make them available to the community. Additional scientific efforts planned for the near future include self-consistent hybrid modeling of chorus generation and investigation of small scale cold plasma density irregularities in the magnetosphere.



Caption. Two very similar cases of lightning induced whistlers triggering upper band chorus. In each panel 5 distinct whistler traces have been identified with the first whistler triggering upper band chorus.

References:
Gołkowski, M., Sarker, S. R., Renick, C., Moore, R. C., Cohen, M. B., Kułak, A., et al. (2018). Ionospheric D region remote sensing using ELF sferic group velocity. *Geophysical Research Letters, 45*. https://doi.org/10.1029/2018GL080108.

Hosseini, P., Gołkowski, M, Harid, V. (2018), Remote Sensing of Radiation Belt Energetic Electrons Using Lightning Triggered Upper Band Chorus, *Geophysical Research Letters* [submitted mansiucript #2018GL081391]

Hosseini, P., M. Gołkowski, H. T. Chorsi, S. D. Gedney, and R. C. Moore (2018b) Using Eccentricity to Locate Ionospheric Exit Points of Magnetospheric Whistler Mode Waves. *IEEE Transaction on Geoscience and Remote Sensing*, *99*, 1-13 10.1109/TGRS.2018.2847605

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. This year we completed our studies of the 2017 Total Solar Eclipse. The VLF signal paths from the NML transmitter in North Dakota to Boulder and Bear Lake crossed directly over the eclipse track, and both sites observed amplitude perturbations of 10-15 dB, and phase perturbations of 100-150 degrees during the eclipse. Careful modeling work utilizing the solar occultation masks, ionization and chemistry modeling, and modeling of the VLF signals has shown that we can reproduce the VLF perturbations only if we include much more ionization down to 55 km altitude. Our analysis and modeling method provides a before-and-after estimate of the D-region electron density profile, and provides insight into the detachment rates in the lower D-region that are required to account for the higher-than-expected ionization. These results are being submitted to IEEE TGRS (Xu et al, 2019).

This year we also participated in the Remote sensing of Electrification, Lightning, And Mesoscale/microscale Processes with Adaptive Ground Observations (RELAMPAGO) campaign in Argentina from October-December 2018. This project aims to improve understanding of thunderstorm development, electrification, and lightning processes in the massive storms that form over the Cordoba region of Argentina. The LAIR provided four LF receivers (1—500 kHz) and eight electric field mills (EFMs) to monitor these thunderstorms and lightning. Collaborators at the nearby Pierre Auger Observatory made simultaneous observations of elves in the ionosphere. The campaign is only just wrapping up, so data analysis will come in 2019.

In radiation belt precipitation work, we have begun the development of a new technique to infer precipitation regions (the flux, energy spectrum, and temporal and spatial scales) using a network of narrowband VLF receivers. The overlapping transmitter-receiver paths provide a tomographic image of the D-region ionosphere. The measured phase as each receiver is input into our ensemble Kalman Filter (enKF)-based algorithm to estimate the state of the D-region with 2-degree (~200 km) resolution. Preliminary simulation studies (Figure 1) show that the method has promise. In 2019 we will work to refine this inversion method and pursue opportunities to build the network of VLF receivers.

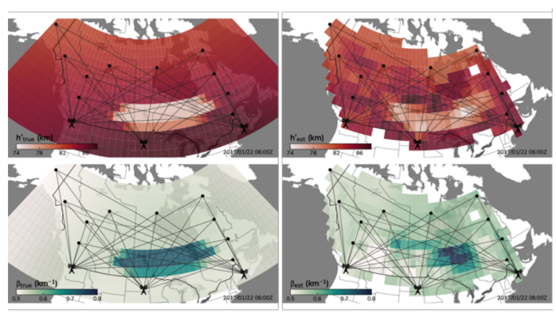


Figure 1: Example of enKF D-region inversion procedure. On the left are the "true" ionosphere h' and beta, shown as maps in grid cells. The black lines are VLF paths from transmitters to receivers. On the right are the "estimated" ionosphere h' and beta after the inversion procedure, using nothing but the VLF phase measurements. While imperfect, the method is able to discern the macro-structure of this simulated precipitation patch.

References:

1. W. Xu, R. A. Marshall, A. Kero, E. Turunen, D. Drob, J. Sojka, and D. Rice (2019), VLF Measurements and Modeling of the D-region Response to the 2017 Total Solar Eclipse, IEEE Transactions on Geoscience and Remote Sensing, submitted.

Best VERSIM wishes for a healthy, fun, and productive 2019!

Attendees of the 8th biennial VERSIM workshop (19-23 March 2018) photographed on the steps of the Polar Geophysical Institute, Apatity, Murmansk Region, Russia.