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

Annual newsletter of VERSIM: a joint IAGA/URSI working group
Editor: Jacob Bortnik No. 31, December 2016

Dear VERSIM colleagues,

As we enter the final days of 2016, I'd like to pause and reflect on the many events of the past year. ELF/VLF science continues to be at the forefront of space physics research, playing vital roles in areas such as radiation belt dynamics, magnetic reconnection, lightning detection and location, remote sensing of ionospheric and magnetospheric structures, and many others. VERSIM-related sessions were held at AGU, EGU, AOGS, SCAR, EWASS, ICGPSRO, SCOSTEP/VarSITI, and URSI, and our 6th VERSIM workshop (Jan 2014, Dunedin, New Zealand) was featured on the IAGA front page for the past few months, and is still featured as of this writing.

One of the main highlights of the past year was the successful completion of the 7th VERSIM workshop (Hermanus, South Africa, 19-24 Sept 2016). The workshop attracted 55 participants from 16 different countries, and accommodated 69 abstracts. The workshop was held in conjunction with a radiation belt meeting, devoting the last 2-3 days to synergistic discussions of wave-particle interactions involved in radiation belt physics. A historical overview of the VERSIM group by Prof. Craig Rodger was recorded and hosted here: https://www.youtube.com/watch?v=27Xf8k7_jZQ

Additional highlights this year included the publication of Don Carpenter's book describing space research at Stanford during 1950 to 1990", and the successful launch on Dec 20, 2016 of JAXA's ERG satellite. Of the many VERSIM-related meetings coming up in 2017, I draw your attention to the General Assemblies of our two parent organizations, the IAPSO-IAMAS-IAGA joint Assembly in Cape Town, South Africa, http://www.iapso-iamas-iaga2017.com/, and the 32nd URSI General Assembly and Scientific symposium in Montreal Canada, http://www.ursi2017.org/. I also note with sadness the passing of our long-term colleague, Dick Dowden, on 15 Dec 2016.

In closing, I note again the vibrancy of our VERSIM community. The reports that follow represent just a small fraction of the myriad of activities going on, and I would urge you to read them carefully, reach out, and form collaborations! I wish you all the very best for a successful and productive 2017.


Jacob Bortnik, IAGA co-chair of VERSIM


Mark Clilverd, URSI co-chair VERSIM

CHINA: Report prepared by Dr. Yiqun Yu (yiqunyu17@gmail.com), Beihang University, Beijing, China

Dr. Yiqun Yu has been working on implementing a new ionospheric precipitation module within the geospace general circulation model (GGCM), while collaborating with Dr. Vania Jordanova from Los Alamos National Laboratory, USA. The keV diffusive precipitating electrons resulted from wave-particle interactions in the plasmasheet/ring current can significantly change the ionospheric conductivity, which can further regulate the magnetosphere-ionosphere coupled dynamics. Understanding those complicated processes requires a self-consistent treatment of the coupled system. Unlike many other global models that simply approximate the precipitation from MHD parameters for the conductivity calculation, we used a kinetic ring current model RAM-SCB (Ring current Atmosphere interaction Model with Self-Consistent Magnetic field) to determine pitch angle dependent electron precipitation by using whistler-mode wave associated diffusion coefficients. This new precipitation module therefore enables a more physical-based connection between the magnetospheric precipitation and ionospheric electrodynamics. It is found that pitch angle diffusion coefficient is quite robust in capturing the temporal and spatial distribution of keV electron precipitation at the ionospheric altitudes, and allows for a better understanding of the interactions within the circulation system. Comparisons with precipitation calculated from applying electron lifetime (inferred from the above diffusion coefficients) indicated that lifetime method is not as valid during disturbed time especially when the particle distribution is highly anisotropic.

With this new electron precipitation module we have updated the stand-alone ring current model RAM-SCB to include a self-consistent electric field, namely RAM-SCB-E, establishing self-consistency between the hot plasma and both electric and magnetic fields.

References:

1. Yu, Y., V. K. Jordanova, A. J. Ridley, J. M. Albert, R.B.Horne, and C. A. Jeffery (2016), A new ionospheric electron precipitation module coupled with RAM-SCB within the geospace general circulation model, J. Geophys. Res. Space Physics, 121, doi:10.1002/2016JA022585.
2. Yu, Y., V.K. Jordanova, A.J. Ridley, G. Toth, R. Heelis (2017), On the self-consistent electric field newly developed in the RAM-SCB-E model: effect of electric field methods on modeling the mid-latitude ionosphere and inner magnetosphere dynamics, J. Geophys. Res. Space Physics, to be submitted.

CZECHIA: Report prepared by Frantisek Nemec (frantisek.nemec@gmail.com), Ondrej Santolik (os@ufa.cas.cz) and Ivana Kolmasova (iko@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 related ground-based experiments. Examples of our results obtained in 2016 are given below.

We demonstrated, both theoretically and experimentally, that equatorial noise emissions can propagate from their magnetospheric generation region down to altitudes as low as about 700 km [1]. This happens especially during geomagnetic storms [2].We further analyzed propagation properties of the quasiperiodic (QP) emissions observed at low altitudes by the DEMETER spacecraft, and we demonstrated that the events observed close to the geomagnetic equator correspond to equatorial noise emissions with a QP modulation of the wave intensity [Hayosh et al., 2016]. Multipoint observations of QP emissions reveal that there may be significant differences in the exact timing of individual QP elements observed at different MLTs [Nemec et al., 2016]. We suggested that this might be due to finite azimuthal speeds of compressional ULF waves responsible for the QP modulation of the wave intensity. We also present new results on wave vectors and Poynting vectors of chorus rising and falling tones on the basis of 6 years of THEMIS observations. Poynting vectors are found to be almost parallel to B_0. We show, for the first time, that slightly oblique Poynting vectors are directed away from the Earth for rising tones and toward the Earth for falling tones [Taubenschuss et al., 2016]. We analyzed reflected EMIC-triggered emissions which were detected by the fleet of Cluster spacecraft [Grison et al., 2016].We also showed that the electromagnetic signals generated by in-cloud current pulses during the lighting initiation can travel up to 600 km in the Earth-ionosphere waveguide. Presence of ionosperically reflected waves at large distances indicate that these signals may have sufficient energy to escape the waveguide and be detected by satellite radio receivers [3].

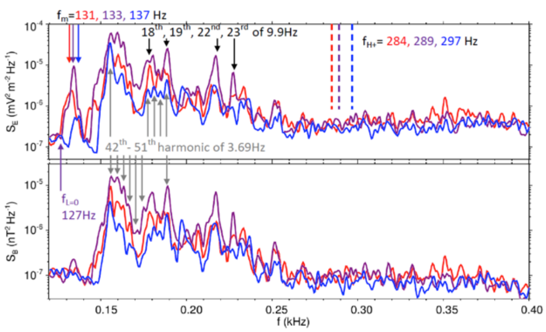


Figure showing a complex superposition of many harmonically spaced lines with different frequency spacings corresponding to a hypothetical sources of proton (He^+ or O^+) cyclotron harmonics located at different radial distances (three different 10-s long time intervals were used for the analysis)

References:

1. Santolik, O., M. Parrot, F. Nemec (2016), Propagation of Equatorial Noise to Low Altitudes: Decoupling From the Magnetosonic Mode, *Geophys. Res. Lett., 43,* 6694-6704, doi: 10.1002/2016GL069582.
2. Nemec, F., M. Parrot, O. Santolik (2016), Equatorial Noise Emissions Observed by the DEMETER Spacecraft During Geomagnetic Storms, *J. Geophys. Res. Space Physics, 121,* 9744-9757, doi:10.1002/2016JA023145.
3. Kolmašová, I., O. Santolík, T. Farges, S. A. Cummer, R. Lán, and L. Uhlíř (2016), Subionospheric propagation and peak currents of preliminary breakdown pulses before negative cloud-to-ground lightning discharges, *Geophys. Res. Lett.*, *43*, 1382–1391, doi:10.1002/2015GL067364.

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

Our group continue participating in the World-Wide Lightning Location Network (WWLLN) since our joining in 2003. Using the WWLLN setup we record the narrowband data on six transmitter signals using SoftPAL data acquisition system. We analyzed the VLF signal perturbations and D-region changes due to 22 July 2009 total solar eclipse (SE), 13-14 November 2012 total SE and 9-10 May 2013 annular SE, using VLF navigational transmitters signal observations at Suva, Fiji. Morlet wavelet analysis of signals amplitude showed strong wave-like signatures (WLS) associated with three SEs with period ranging 24-66 min but the intensity and duration of WLS showed no clear dependence on SE magnitude and type as shown in the Figure.

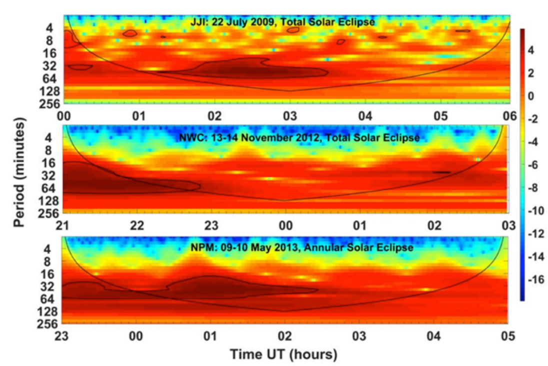


Figure showing how the Automatic Whistler Detector system (AWD) was run about two months at Suva using the signal from WWLLN system. We plan AWD to run more systematically during 2017. We acknowledge the support Prof. János Lichtenberger, in the running of the AWD system.

Under the Strategic Research Theme funding of our University a project has been approved to us to study the VLF perturbations associated with natural hazards particularly tropical cycles in Fiji and Samoa under which a new SoftPAL VLF system will be installed at university Campus in Samoa. The state of art ionospheric total electron content and scintillation recorded will be installed under a MoU with Institute of Ionosphere and Magnetosphere, School of Electronic Information, Wuhan University, China, which along with softPAL will help us study the lower and upper ionosphere together.

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

References:

1. Kumar, S., A. Kumar, A. K. Maurya, and R. Singh (2016), Changes in the D region associated with three recent solar eclipses in the South Pacific region, J. Geophys. Res. Space Physics, 121, doi:10.1002/2016JA022695.

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

Previous ELF-VLF campaign ended on 27 January 2016. It was the longest campaign so far. It lasted altogether 91 days without problems. Our current campaign is going on. This campaign started on 7 October, and the wish is to continue at least till mid-April 2017. Main reason is Japanese ERG satellite, which was launched on 20 December 2016. One Japanese high-speed auroral camera has been installed at SGO, and its main task is to observe pulsating aurora during ERG satellite conjunction above Scandinavia. The quick-look plots (24-h, 1-h, and 1-min) are available at http://www.sgo.fi/vlf/. 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.

A Peruvian PhD student (Liliana Macotela) has started her studies in University of Oulu and she has been working at SGO since 1 June 2016. She has worked earlier with Prof. Jean-Pierre Raulin in Brazil, and she is familiar with VLF transmitter signals. This is the reason why her PhD thesis will be related to the plasma physics, which can be studied using transmitter signals. Kannuslehto data contains more than 20 different VLF transmitter frequencies simultaneously.

Some new results were shown in 7th biennial VERSIM and Radiation Belt Symposia will be held from 19-24 September 2016 in Hermanus, Western Cape, South Africa.

One example of most recent events from current campaign is shown below.

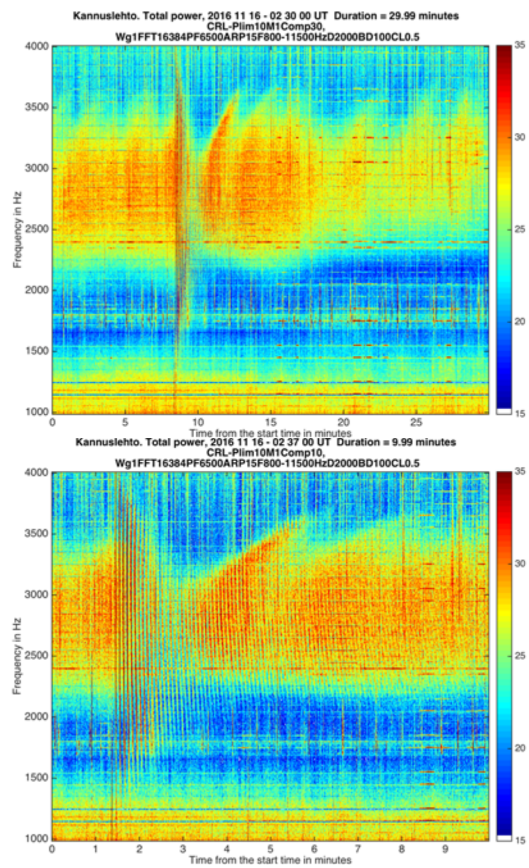


Figure showing the whistler echo train causing suppression of hiss. Hiss itself seems to have some dispersion above 3 kHz. 16 Oct 2016 at 0230 UT.

References:

1. Kozelov, B.V., J. Manninen, and E.E. Titova (2016). Pulsating aurora and quasi-periodic VLF hiss in the auroral zone morning sector: The event of December 30, 2011. Cosmic Research, 54, no 1, 40-46, doi:10.1134/S0010952516010111.
2. Nemec, F., B. Bezdekova, J. Manninen, M. Parrot, O. Santolik, M. Hayosh, and T. Turunen (2016). Conjugate observations of a remarkable quasiperiodic event by the low-altitude DEMETER spacecraft and ground-based instruments. J. Geophys. Res. Space Physics, 121, 8790–8803, doi:10.1002/2016JA022968.
3. Manninen, J., T. Turunen, N. Kleimenova, M. Rycroft, L. Gromova, and I. Sirviö (2016). Unusually high frequency natural VLF radio emissions observed during daytime in Northern Finland. Environ. Res. Lett., 11, 124006, doi:10.1088/1748-9326/11/12/124006.

There were also about 15 oral and poster presentations in 2016.

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's and Einstein equations).

This January, the Automatic Whistler Detector and Analyzer Network (AWDANet) has been extended a new, high-L station at Princess Elisabeth, the Belgian Antarctic base (L=5.7).
We refined the whistler source regions for the AWDANet nodes based on the improved trace finder algorithm and inversion procedure. The source region of whistlers recorded at Dunedin (New Zealand) that was considered anomalistic earlier, now seems to follow the general rules (the source region is near/around the conjugate point of the receiver), see the figure below. We have reprocessed the global AWDANet data to identify two-hop whistlers. This helps to interpret more reliably the modeled plasmaspheric parameters, and gives some hint on anomalistic behaviour (diurnal and seasonal variations in whistler counts) of certain nodes of the AWDANet.
We have adapted the whistler inversion algorithm to the Russian Alpha navigation signal recorded on board satellites (VAPs).
The initial estimation of whistler inversion parameters has been enhanced, all the three parameters (time of causative sferic, L-value, and equatorial electron density) can be estimated with high accuracy and this way, the inversion leads to more accurate results.

We have continued to analyze anomalistic or less understood VLF phenomena, using fine structure and spectral analysis in satellite data (DEMETER, RBSP/VAP).

We have started a joint analysis of UltraMSK data, recorded in Hungary (NCK, THY) and optical sprite observation (Sopron) were started with the scope of better describing the scattered effect of near-range transient mesospheric ionisations due to TLEs.

We have started the preparation of new nano- and microsatellite wave experiments (Chibis-AI, ISS/Obstanovka Phase-2 and Trabant) with Russian partners.

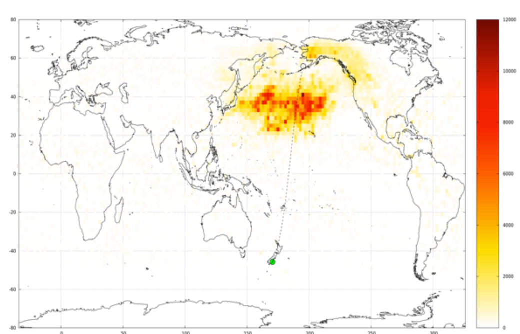


Figure showing source region of whistlers recorded at Dunedin, New Zealand (2009-2014)

INDIA: Prof. Ashok Kumar Singh (aksphys@gmail.com), Department of Physics, University of Lucknow, Lucknow, India

Ground based observation of tweeks and whistler waves are widely being used in upper space exploration. It has provided potential remote sensing tool in profiling of upper atmosphere as well as in obtaining medium parameters such as large scale electric field, electron density, electron content in a flux tube etc. Our group actively involved in the study various aspects of ELF/VLF waves at low latitude ground station Lucknow (Geom. Lat. 17.6^{0}N; Geom. Lon. 154.5^{0}E; L = 1.10), India. At present we are doing scientific analysis of some fascinating and good quality whistlers recorded on March 24/25, 2015 by Automatic Whistler Detector (AWD) system at our station. We are trying to make profile of the plasmasphere by obtaining the various medium parameters from VLF observations. We have analyzed the propagational characteristics of observed whistlers. Lightning locations indicates that these whistlers are generated in the opposite hemisphere. Most of the whistlers have travelled higher latitude (L varies between 1.5 and 3.0) and have been observed at lower latitude. We have tried to estimate the variation in intensity with increased whistler frequency and have found that the intensity decreases with successive increase in frequency of observed whistlers.

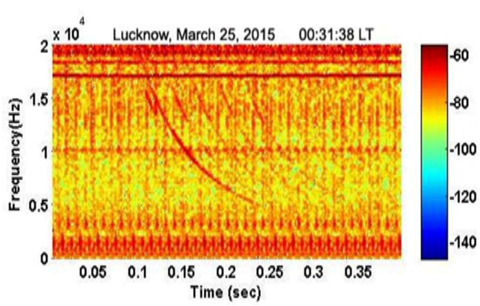


Figure showing a typical example of a group of whistlers observed at Lucknow, India.

References:

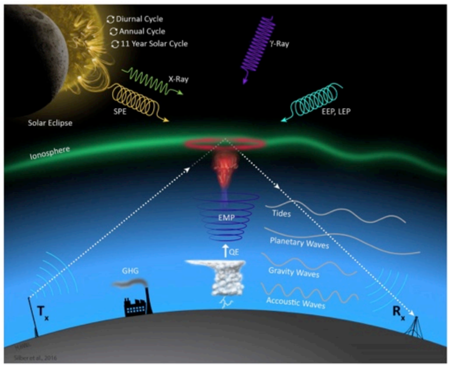
1. Raghvendra Singh, U. P. Verma and A. K. Singh (2016), Exploring Middle Atmosphere (D – Region) by Very Low Frequency (VLF) Waves, *International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS)*, 5 (6), 51-55.

2. A. K. Singh, U. P. Verma, R. Singh and J. Lichtenberger (2016), Remote Sensing of D-region Ionosphere using multimode tweeks, *Indian J. Physics*, 90(1), 1–7.

3. A. K. Singh attended and presented paper on "Propagational Features of Whistlers observed at Lucknow (L=1.10), India" at VERSIM & RBS conference held at SANSA, Hermanus, South Africa during September 19-24, 2016.

ISRAEL: Report prepared by Prof. Colin Price (cprice@flash.tau.ac.il), Tel Aviv University, Tel Aviv, Israel.

Recently Israel Silber has completed his PhD thesis on observations and modeling of VLF narrowband signals in Israel. As part of his thesis he has published 5 papers over the past years, including a recent review in Surveys of Geophysics that is summarized in the figure below. The research focused on studying the short and long term variability of the mesosphere – lower thermosphere (MLT) and D-region ionosphere. By combining temperature measurements (satellite and ground-based), lightning observations, airglow observations, solar radiation observations, together with VLF narrowband measurements, we managed to reveal and explain numerous variations in detected in VLF observations. While performing this research we also discovered an interesting result regarding the observed vertical magnetic field in the far VLF field. Unlike the theory that predicts very small vertical components of the VLF field resulting from distant transmitters, we found quite significant amplitudes in the vertical field. Such strong vertical fields may have implications for lightning detection, radio communications in the VLF, and the modeling of VLF propagation in the Earth-ionosphere waveguide.



Cartoon showing the many uses of VLF narrowband signals to study anomalies from internal and external sources (Silber et al., 2016)

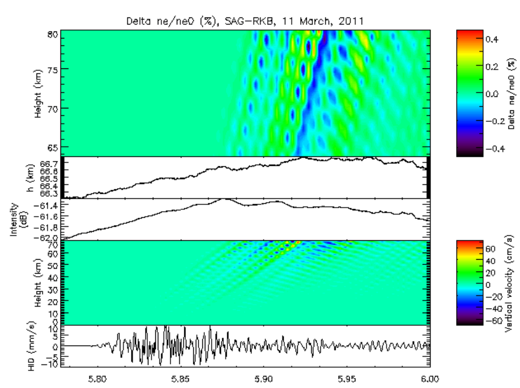
References:

1. Silber, I., C. Price and C. Rodger, 2016: Semi-annual oscillation (SAO) of the nighttime ionospheric D-region as detected through ground-based VLF receivers, *Atmospheric Chemistry and Physics*, 16, 3279-3288.
2. Silber, I., C. Price, C. Schmidt, S. Wust, M. Bittner and E. Pecora, 2016: First ground-based observations of mesopause temperatures above the Eastern Mediterranean, Part 1: Multi-day oscillations and tides, *J. Atmos. Solar-Terr. Phys.*, doi 10.1016/j.jastp.2016.08.014.
3. Silber, I., and C. Price, 2016: On the use of VLF narrowband measurements to study the lower ionosphere and mesosphere-lower-thermosphere, *Surveys in Geophysics*, DOI 10.1007/s10712-016-9396-9.

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

Our AVON (Asia VLF Observation Network) group has been making continuous measurements of LF/VLF/ELF waves at Tainan (Taiwan), Saraburi (Thailand), Pontianak (Indonesia), Los Banos (Philippines), and Hanoi (Vietnam) since December, 2007. 14 Universities/institutes participate in the AVON project. The antennas consist of a monopole antenna, a dipole antenna, and an orthogonal loop antenna. The sampling frequency of LF/VLF transmitter signals is 200 kHz, while that of VLF/ELF waves radiated from lightning discharges is 100 kHz. In addition, the LF transmitter signals of the JJY, BPC, NWC, etc. have been observed at two stations in Japan. The AVON is one of the ground-based observation networks for the ERG satellite launched on 20 December, 2016.

We report the first observation of about 100-s periodic oscillations of intensity and phase in two LF transmitter signals over Japan at 05:52-05:56 UT (about 5 minutes and 42 seconds after the mainshock onset on 11 March, 2011, M9.0). The two LF propagation paths of JJY-Saga (SAG, 60 kHz) to Rikubetsu(RKB) and BPC(China, 68.5 kHz) to RKB paths were used, where the minimum distances between the epicenter and the LF propagation paths were 430.2 km and 562.0 km, respectively. The change amount of the intensity and the reflection height were about 0.1 dB and 50 m, respectively. The numerical simulations of seismic waves and neutral atmosphere showed that electron density at 70 km heights started to oscillate by the change amount of the electron density normalized by the background electron density of about 0.4 % with the periods of about 110-140 s at 05:52 UT on 11 March, 2011. The results suggest that the 100-s LF periodic oscillation was caused by the vertical propagation of the acoustic waves excited by the seismic Rayleigh waves.



From the upper panel, *delta ne/ne0* (%) by the simulation, *h* (km) and intensity (dB) of SAG-RKB path, the vertical velocity (cm/s) of the neutral atmosphere by the simulation, and the vertical velocity (mm/s) of the seismic waves at HID station close to the LF receiver.

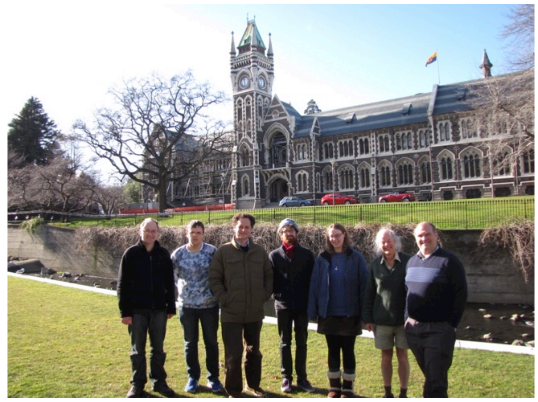
NEW ZEALAND: Report prepared by Dr. Craig J. Rodger (craig.rodger@otago.ac.nz), University of Otago, Dunedin, NZ; http://www.physics.otago.ac.nz/nx/space/space-physics-home.html

Another fairly active year for the Otago Space Physics group. The main change has come with the formal retirement of Neil Thomson on 8 April 2016, after 38 years on the academic staff. However, Neil still comes into work almost every day, and is still working with us on our New Zealand Geomagnetically Induced Currents (GIC) research project. Tim Divett joined the group as a PostDoc at the start of April, and Daniel Mac Manus in February as an Honours student. Both are also focused on the NZGIC project.

Space Physics PhD student Emma Douma attended her first international conferences in Santa Fe, New Mexico (GEM-CEDAR 2016), Golden Sands, Bulgaria (ISROSES-III), and Hermanus, South Africa (7th VERSIM Workshop). This large amount of travel was strongly helped along by her winning the Edward and Isabel Kidson Scholarship. At the VERSIM workshop it was declared Emma had given the best presentation by a Young Scientist and will be nominated for the IAGA Young Scientist Award. She heads back to Antarctica with James Brundell in February 2017.

Space Physics PhD student Aaron Hendry has had to forgo travel this year, and is now focused on writing up. He had a major step forward with the publication of his recent paper [1] showing very strong evidence for EMIC-waves driving energetic and relativistic electron precipitation. He currently has a follow-up GRL in review, focused on the properties of these events.

Unfortunately, our other PhD student, Kathy Cresswell-Moorcock, had to withdraw from her studies, but after a paper based on her work was accepted in JGR [2]. The biggest factor this year for Craig Rodger has been him becoming Head of Department. While this is said to be only a 50% commitment, the new role seems to be taking more time than that!



Group photo taken outside the Physics Building on 29 July 2016. In the photo from right to left: James Brundell, Daniel Mac Manus, Tim Divett, Aaron Hendry, Emma Douma, Neil Thomson, and Craig Rodger.

References:

1. Hendry, A. T., C. J. Rodger, M. A. Clilverd, M. J. Engebretson, I. R. Mann, M. R. Lessard, T. Raita, and D. K. Milling (2016), Confirmation of EMIC wave-driven relativistic electron precipitation, J. Geophys. Res. Space Physics, 121, 5366–5383, doi:10.1002/2015JA022224.
2. Rodger, C. J., K. Cresswell-Moorcock, and M. A. Clilverd (2016), Nature's Grand Experiment: Linkage between magnetospheric convection and the radiation belts, J. Geophys. Res. Space Physics, 121,171–189, doi:10.1002/2015JA021537

RUSSIA: Report prepared by Dr. David Shklyar (david@iki.rssi.ru) and Dr. Elena Titova (lena.titova@gmail.com), Space Research Institute of RAS, Moscow, Russia

In 2016 we studied the interaction between energetic protons of the Earth's radiation belts and quasi-electrostatic whistler mode waves. The nature of these waves is well known: whistler waves, which are excited in the magnetosphere due to cyclotron instability, enter the resonant regime of propagation and become quasi-electrostatic, while their amplitude significantly increases. Far enough from the equator, where perpendicular component of the wave normal vector and proton transversal velocity increase substantially, the nonlinear interaction between these waves and energetic protons becomes possible. We show that plasma inhomogeneity may destroy cyclotron resonance between wave and proton on the time scale of the order of particle gyroperiod which in fact means the absence of cyclotron resonance; nevertheless, the interaction between waves and energetic particles remains nonlinear. In this case, particle dynamics in the phase space has the character of diffusion; however, the diffusion coefficients are determined by the averaged amplitude of the wave field, but not by its resonant harmonics. For real parameters of the waves and magnetospheric plasma, proton pitch-angle diffusion leading to their precipitation from the magnetosphere becomes essential.

Reference:

Shklyar, D. R., and E. E. Titova (2017), Proton interaction with quasi-electrostatic whistler mode waves in an inhomogeneous plasma (magnetosphere), Geomagnetism and Aeronomy, 57(1), 24–31.

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

Activities of researchers from several institutions in Serbia continued analyzing the data recorded by two VLF/LF receivers located in the Institute of Physics in Belgrade.

In addition, we started to monitor ionosphere by radio waves with Tektronix RSA 306 spectrum analyzer at the University of Defence in Belgrade.

We have been continued investigations of the D-region perturbations during the solar X-ray flares [1,2], gamma-ray bursts and tropical depressions influences, and have been started to study the D-region contribution in TEC variations during the solar flares [3].

In this period our attention was also focused on analyses of data recorded in periods of the earthquakes. We joined the COST action Time dependent seismology (TIDES) and participated in training school within this project in Portugal.

In addition to TIDES, our activities were made within two national projects and COST action Big Data Era in Sky and Earth Observation (BIG-SKY-EARTH). We participated in several conferences and I was participating in the short term scientific mission in Geophysical Center at Dourbes (part of the Royal Meteorological Institute of Belgium) sponsored by BIG-SKY-EARTH COST Action.

During this year, Aleksandra Kolarski finished her PhD at the Faculty of Mining and Geology of the University of Belgrade, Miljana Todorović Drakul finished her PhD (including study related to the D-region) at the Faculty of Civil Engineering of the University of Belgrade (Department of geodesy and geoinformatics) and Jovan Bajčetić is waiting for the completion of the administrative procedure for the approval of the PhD dissertation at the Faculty of Technical Sciences, University of Novi Sad. Vesna Čvorić has started her PhD at the Faculty of Physics, University of Belgrade.

References:

1. Nina A. (2016), Electron Density Characteristics in Ionospheric D-Region During Solar X-Ray Flare, in Solar Flares: Investigations and Selected Research, Nova Science Publishers, New York
2. Sulic D.M., Sreckovic V. A. and Mihajlov A. A., Analysis of the Ionospheric D-Region Disturbances in Response to the Effects of Solar X-Ray Flares, in Solar Flares: Investigations and Selected Research, Nova Science Publishers, New York
3. Todorovic Drakul M., Cadez V. M., Bajcetic J., Popovic L. C., Blagojevic D. and Nina A. (2016), Behaviour of electron content in the ionospheric D-region during solar X-ray flares, Serb. Astron. J. 193, 11 – 18, doi: 10.2298/SAJ160404006T

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

BAS report to VERSIM – December 2016

BROADBAND RECORDINGS in Antarctica:
Whistler-detection and data collection has continued at Halley (L=4.5) and Rothera (L=2.9) throughout 2016 using the Hungarian Automatic Whistler Detection (AWD) system. BAS also continues to operate a third 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:
Continuous (since 1992) recordings of VLF activity in 10 ELF/VLF bands, at 1-s resolution (VELOX and VELOXNET) have been maintained at Halley in 2016.

NARROW-BAND RECORDINGS:
'Ultra' narrow-band recordings have continued at Halley and 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 2016.

The software VLF Doppler system has continued at Rothera station, Antarctica (L=2.8) in 2016, 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 2016, hosted by SANSA, Hermanus.

WWLLN sites:
British Antarctic Survey has continued to operate three World Wide Lightning Location Network systems in 2016. Ascension, Rothera and Halley have successfully provided lighting location information all year.

Generally a good year of data collection, with a high percentage of up time on all instruments. Some data interruptions have started to show up during the latter half of the year. Churchill Ultra was hit by lightning in August, but was operational again by October. Eskdalemuir AWD has been off-air since mid-November due to network issues, and Reykjavik VLF Observatory has been off-air since October as the garage roof that it was sited on has been sold!

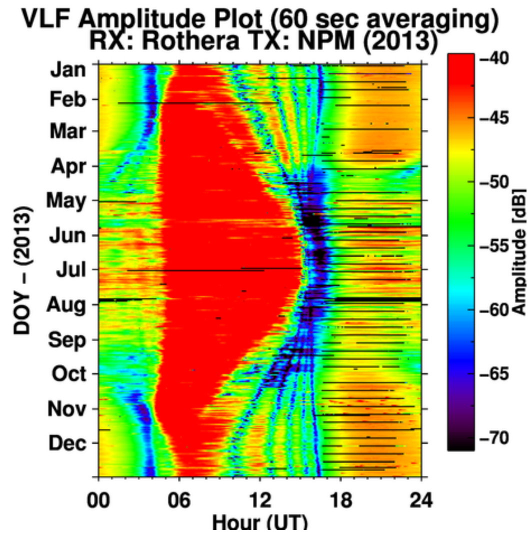


Figure (One year of Ultra amplitude data from the Hawaii transmitter received at Rothera Antarctica. Red levels occur during nighttime, black is transmitter off-air periods. Modal sunrise/sunset features, solar flares, St Patrick's Day storm effects can all be seen.)

References:

1. Clilverd, M A, C J Rodger, M Andersson, P T Verronen, and A Seppälä, Linkages between the radiation belts, polar atmosphere and climate: electron precipitation through wave particle interactions, in Waves, particles and storms in geospace, edited by I. Mann et al., Oxford University Press, ISBN: 9780198705246, November 2016.

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

The "radiation belts and waves" group at UCLA has had a productive year, studying various aspects of plasma wave excitation, propagation, and interaction with energetic particles. In studying wave excitation, An et al. [2016, GRL] reported on the excitation of whistler waves in a laboratory plasma, and Li et al. [2016, GRL] considered the generation of highly oblique whistlers in space, as well as quantifying new chorus wave properties near the equator using RBSP data [GRL, 2016]. Ni et al. [2016, GRL] studies the occurrence of butterfly distribution in the radiation belts (also J. Li et al. [2016, JGR, GRL] and Maldonado et al. 2016, GRL), and reviewed the origins of the Earth's diffuse aurora [2016, SSR]. The relationship between chorus and plasmaspheric hiss was reviewed in a book chapter by Bortnik et al. [2016] in the AGU monograph entitled "Low frequency waves in space plasmas", and another book chapter by Thorne et al. [2016] dealt with the effects of thermal plasma upon the diffuse aurora and radiation belts, in the monograph entitled "Magnetosphere-Ionosphere Coupling in the Solar System". Finally, a new technique paper was published by Bortnik et al. [2016, JGR] which described the use of machine learning in reconstructing a global, dynamical model of the inner magnetospheric environment based upon a long-duration time series of observations of some given physical quantity. An example of a reconstruction of electron number density is shown in the accompanying figure, based on several years of 3 THEMIS probes.

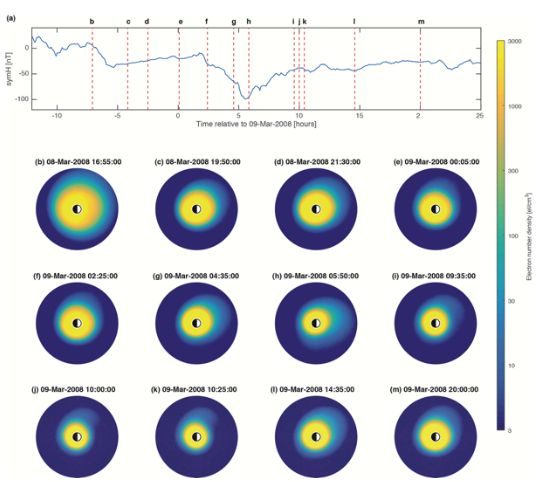


Figure taken from Bortnik et al. [2016, JGR, Figure 4] showing the reconstructed evolution of electron number density in the course of a moderate geomagnetic storm.

References:

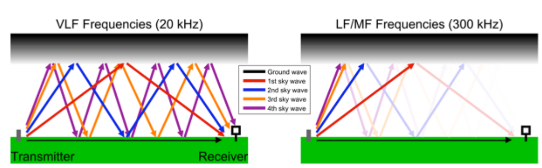
1. Bortnik, J., W. Li, R. M. Thorne, and V. Angelopoulos (2016), A unified approach to inner magnetospheric state prediction, J. Geophys. Res. Space Phys., 120, doi:10.1002/2015JA021733.
2. An, X., B. Van Compernolle, J. Bortnik, R. M. Thorne, L. Chen, W. Li (2016), Resonant excitation of whistler waves by a helical electron beam, Geophysical Research Letters, Volume 43, Issue 6, pp. 2413-2421, doi: 10.1002/2015GL067126.
3. Li, W., D. Mourenas, A. V. Artemyev, J. Bortnik, R. M. Thorne, C. A. Kletzing, W. S. Kurth, G. B. Hospodarsky, G. D. Reeves, H. O. Funsten, and H. E. Spence (2016), Unraveling the excitation mechanisms of highly oblique lower band chorus waves, Geophys. Res. Lett., 43, 8867–8875, doi:10.1002/2016GL070386.

UNITED STATES: Report prepared by Morris Cohen, mcohen@gatech.edu, Assistant Professor, Georgia Tech Institute of Technology, http://lf.gatech.edu

To heck with VERSIM, our group at Georgia Tech says let's go even higher to the "LF" band (30-300 kHz)! LVERSIM??

We have taken the AWESOME receiver previously at Stanford and modified it to extend the frequency range up to 500 kHz and improve the sensitivity by 10-20 dB., to include LF. When we did this we found that we were detecting a bunch of radio beacons around 300 kHz called NDGPS.

So we've been investigating those as a possible ionospheric remote sensing tool, similar to how VLF beacons (20-30 kHz) are used to detect Early VLF events and LEP events.. Now, I know what you're thinking…"But Morris…LF doesn't propagate nearly as efficiently as to VLF!!", to which I reply…"Exactly, my friend!"



This diagram shows why I think it's cool. On the left, you can see what happens with efficiently reflecting VLF. It is hard to work with when it comes to ionospheric remote sensing because it's SO efficient, that you can pick up a bunch of modes on any transmitter-receiver path, which all add up into a single number. Oh no!! That makes it hard to take, for example, the amplitude and phase of a VLF transmitter and infer the ionospheric electron density, it's the classic ill-posed problem.

But precisely because LF doesn't reflect so well, we have fewer surviving modes, and can potentially directly distinguish the individual modes, and maybe get a direct measurement of the ionospheric reflection coefficient on a continuous basis. So using LF waves is somewhere in between using VLF waves, which reflect extremely efficiently from the D-region, and using HF waves, which barely reflect if at all from the D-region.

We're writing this up now for publication so hopefully you'll see a lot more details soon enough.

We are still doing lots of VLF work, too, including remote sensing of sferics as an ionospheric diagnostic, characterizing the scattering pattern of Early VLF events and LEP events, analyzing DEMETER data as an ionospheric diagnostic, and have some new projects in mind for the future. But we'll just stop with one highlight for the sake of space.

Happy new year everyone, and please don't hesitate to reach out if you have any ideas for collaboration.

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

A new research group has been established at the University of Colorado Boulder, entitled the Lightning, Atmosphere, Ionosphere, and Radiation belts Laboratory (the LAIR). The group's research covers observations and simulations of lightning, thunderstorms, meteors, and radiation belt precipitation. This year we established our first VLF/LF receiver site at the National Center for Atmospheric Research (NCAR) Marshall field site (no relation) in South Boulder, co-located with an electric field mill (EFM) to study thunderstorm charging. We were visited by Professor Janos Lichtenberger of Eotvos University, Hungary, who installed his Automatic Whistler Detector (AWD) system at our site. A VLF receiver has also recently been installed at Elginfield, Ontario, Canada, in collaboration with Professor Peter Brown at the University of Western Ontario. This site will be used primarily to search for VLF emissions from meteors, and is co-located with Dr. Brown's Canadian Automated Meteor Observatory (CAMO) and Canadian Meteor Orbit Radar (CMOR) systems. In the next year, we plan to establish new VLF/LF sites in Colorado and neighboring states.

This year our group has made improvements to two key models. Our lightning electromagnetic pulse (EMP) model has been updated to enable simulation of VLF transmitter propagation in the Earth-ionosphere waveguide, and has been used to simulate the signals expected during ionospheric disturbances. This updated model is available to the community; interested uses should contact Dr. Marshall at the e-mail address above. Second, an electron Monte Carlo model has been updated to simulate atmospheric and ionospheric effects of radiation belt precipitation as well as artificial, man-made precipitation events. The model is used to determine electron density disturbances, optical emissions, X-ray emissions, and electron backscatter. Model predictions of electron density signatures have been compared with ground-based measurements with the Poker Flat Incoherent Scatter Radar (PFISR), and those results are in preparation for publication.

Best VERSIM wishes for a joyful, successful, and productive 2017!

The VERSIM workshop attendees photographed on the entrance steps of the South African National Space Agency (SANSA), before the conference banquet on Wednesday September 21st, 2016.