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

Annual newsletter of VERSIM: a joint IAGA/URSI working group
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Dear VERSIM colleagues,

As we near the end of 2015, I take a moment to pause and reflect on the state of our field and our community. ELF/VLF science is vibrant and the community is incredibly active. Receivers stretch across the globe, and numerous satellites encircle the Earth (and other planets!), collecting data of unprecedented quality making the present time truly unique in the history of ELF/VLF science.

This year we conducted a VERSIM poll, asking the question "what is the essential background required for a VERSIM scientist?", for example what are the top ten publications that a young scientist would need to read in order to be able to communicate effectively with other VERSIM scientists? The response was fantastic, and I'm delighted at the resources we were able to gather. The first place was a tie going to Helliwell's classic 1965 book, and the outstanding review by Barr et al. [2000, JASTP]. Second place was split between Stix's [1962] book on plasma waves, and the exposition on wave-particle interactions published by Lakhina and Tsurutani in 1997. Other prominent works were Owen Storey's 1953 "whistler" paper, the work of Kennell and Petscheck [1966] and various books by Budden, Walker, Gary, and Ratcliff among others. The full results of the survey will be announced in early 2016 via the VERSIM email and published on the VERSIM website.

Next year we will be holding our 7th VERSIM workshop in the coastal city of Hermanus, South Africa over the period 19-23 September 2016. The VERSIM workshops are always a special time for our community to get together and I would encourage everyone to attend.

In closing, the following reports are a reflection of the breadth of ELF/VLF science, and the strength of our community. I urge you to read through the various reports and take note of the many projects going on. I've included the email addresses of the contributors so reach out and form collaborations!

I wish you all the very best for a successful and productive 2016.

Jacob Bortnik, IAGA co-chair of the VERSIM working group
Mark Clilverd, URSI co-chair of the VERSIM working group

BELGIUM: Report by Dr. Fabien Darrouzet (Fabien.Darrouzet@oma.be) on behalf of Sylvain Ranvier, Hervé Lamy, and Johan De Keyser, Belgian Institute for Space Aeronomy (IASB-BIRA), Brussels, Belgium.

Pictures of the material that will be send to Antarctica.

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.

This antenna is 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). We are still investigating the reasons of recent electromagnetic perturbations and possible solutions to improve the data quality.

We will install another antenna at the Belgian Antarctic station Princess Elisabeth (Lat~71.57°S, Long~23.20°E), with the help of Dr. J. Lichtenberger. This antenna is composed of two search coils, without a mast in order to withstand the weather at such latitudes. We will go to Antarctica in January 2016 to make the installation and proceed to first tests. Then the antenna will record whistlers automatically and the data will be downloaded next year.

CZECH REPUBLIC: Report by Ivana Kolmasova (iko@ufa.cas.cz) and Ondrej Santolik (os@ufa.cas.cz), representing the Institute of Atmospheric Physics CAS and Charles University in Prague.

Our group at the Institute of Atmospheric Physics CAS and at Charles University in Prague continued to investigate electromagnetic waves using spacecraft measurements and related ground-based experiments. Examples of our results obtained in 2015 are given below.

We have used the complete data set of the wave measurements provided by the STAFF-DWP wave instrument onboard the TC-1 spacecraft for the analysis of characteristics of banded whistler-mode emissions [1]. Our entire data set has been collected within 30 degrees of geomagnetic latitude at L-shells between 2 and 12 and below 4 kHz. We have found most cases of chorus-like banded emissions at L ≤10 on the dawnside and dayside. The upper band emissions (above one half of the equatorial electron cyclotron frequency) occur almost twenty times less often than the lower band and their average amplitude is almost three times smaller than for the lower band. Intense upper band emissions cover smaller L-shell, MLT and magnetic latitudes regions than intense lower band emissions. The intense nightside and dawnside chorus-like banded emissions were observed at low magnetic latitudes, while the intense dayside and duskside emissions were mostly found at higher magnetic latitudes. The amplitudes of dayside lower band slightly increase as they propagate away from the geomagnetic equator and are smaller than chorus amplitudes on nightside and dawnside. The power spectral density, the amplitude of the lower band and its frequency bandwidth and its occurrence rate significantly increase with increasing geomagnetic activity, while all these parameters for the upper band are not so strongly dependent on a variability of the geomagnetic activity.

We have also used the data of the THEMIS - D spacecraft collected in an active equatorial source region of whistler mode chorus rising tones [2]. Rising tones have been analyzed in terms of spectral and polarization characteristics, with special emphasis on wave normal angles. The latter exhibit large variations from quasi-parallel to oblique, even within single bursts, but seem to follow a definite pattern. We have also discussed the frequently observed splitting of chorus bursts into a lower and an upper band around one half of the local electron cyclotron frequency. At chorus frequencies close to the gap, we have found significantly lowered wave planarities and a tendency of wave normal angles to approach the Gendrin angle.

We have conducted a statistical investigation of occurrence of equatorial noise (EN) emissions using 10 years of data collected by the STAFF-SA instruments on board the four Cluster spacecraft [3]. The data set covers the period from January 2001 to December 2010. We have developed selection criteria for the visual identification of these emissions and we have compiled a list of more than 2000 events found during the analyzed time period. The evolution of the Cluster orbit enables us to investigate a large range of McIlwain's parameter, from about $L \sim 1.1$ to $L \sim 10$. We have demonstrated that equatorial noise emission can occur at almost all analyzed L-shells. However, the occurrence rate is very low (<6%) at L-shells below $L = 2.5$ and above $L = 8.5$. EN mostly occurs between $L = 3$ and $L = 5.5$, and within 7° of the geomagnetic equator, reaching 40% occurrence rate. This rate further increases to more than 60 % under geomagnetically disturbed conditions. Analysis of occurrence rates as a function of magnetic local time (MLT) shows strong variations outside of the plasmasphere (with a peak around 15 MLT), while the occurrence rate inside the plasmasphere is almost independent on MLT. This is consistent with the hypothesis that EN is generated in the afternoon sector of the plasmapause region and propagates both inward and outward.

We have investigated more than 2000 EN events compiled in [3] and found that a clear quasiperiodic (QP) time modulation of the wave intensity is present in more than 5% of events [4]. We have performed a systematic analysis of these EN events with QP modulation of the wave intensity. Such events usually occur in the noon-to-dawn magnetic local time sector. Their occurrence seems to be related to the increased geomagnetic activity, and it is associated with the time intervals of enhanced solar wind flow speeds. The modulation period of these events is on the order of minutes. Compressional ULF magnetic field pulsations with periods about double the modulation periods of EN wave intensity and magnitudes on the order of a few tenths of nanotesla were identified in about 46% of events. We have suggested that these compressional magnetic field pulsations might be responsible for the observed QP modulation of EN wave intensity, in analogy to VLF whistler mode QP events.

We have used a low-altitude DEMETER spacecraft data for the analysis of Power Line Harmonic Radiation (PLHR), i.e., electromagnetic waves radiated by electric power systems on the ground [5]. We have focused on frequencies corresponding to the first few harmonics of the base power system frequencies (50 Hz or 60 Hz, depending on the region). We have shown that the intensities of electromagnetic waves detected at these frequencies at an altitude of about 700 km are significantly enhanced above industrialized areas. The frequencies at which the wave intensities are increased are in excellent agreement with base power system frequencies just below the satellite location. PLHR effects are less often detected in the summer, as the ionospheric absorption increases, and also, the radiation is obscured by lightning generated emissions. The analysis of the measured frequency spectra reveals that although intensity increases at low odd harmonics of base power system frequencies are routinely detected, low even harmonics are generally absent.

We have also used the DEMETER data set for a systematic study of unusual very low frequency (VLF) radio events with a reduced intensity observed in the frequency-time spectrograms [6]. They occur exclusively on the nightside. During these events, the intensity of fractional hop whistlers at specific frequencies is significantly reduced. These frequencies are usually above about 3.4 kHz (second Earth-ionosphere waveguide cutoff frequency), but about 20% of events extend down to about 1.7 kHz (first Earth-ionosphere waveguide cutoff frequency). The frequencies of a reduced intensity vary smoothly with time. We have inspected 6.5 years of DEMETER data, and we identified 1601 such events. The overall geographic distribution of the events is shifted by about 3000 km westward and slightly southward with respect to the areas with high long-term average lightning activity. We have demonstrated that this shift is related to the specific DEMETER orbit, and we have suggested its qualitative explanation by the east-west asymmetry of the wave propagation in the Earth-ionosphere waveguide.

Ground-based broadband measurements (ELF to HF, http://bleska.ufa.cas.cz) continued, in collaboration with Laboratoire Souterrain a Bas Bruit, Rustrel, France, to monitor thunderstorm activity on the summit of La Grande Montagne (1028 m, 43.9410ºN, 5.4836ºE), Plateau d'Albion. Our HF instrumentation consisting of four broadband antennas allows us to perform HF interferometric measurements. Our ELF-VLF antennas (consisting of two perpendicular magnetic loops and a spherical electric antenna) are connected to the ELMAVAN receiver which is being prepared for the Resonance multi-spacecraft mission.

As a part of preparatory activities for the TARANIS spacecraft mission and in collaboration with several French institutions grouped in the SOLID project lead by the LERMA Laboratory (Observatoire de Paris) we have installed a broadband antenna and an analyzer (5kHz – 37 MHz) in the northern part of Corsica in September 2015. Up to now we have collected many interesting records of signals generated by in-cloud processes, which will be completed by the LMA (Lightning Mapping Array) data.

Our proposal to build a VLF receiver for measurements on Mars has been accepted by the European Space Agency (ESA) in November. This is a good basis for extending the VERSIM ground-based activities to the surface of another planet. The wave analyser module will be developed and built at the Institute of Atmospheric Physics in Prague. It will be a part of the MAIGRET instrument which will be placed on the ExoMars 2018 Surface platform. The Wave analyser module will be dedicated for the measurement of magnetic-field fluctuations in the frequency band from 100 Hz to 20 kHz. The scientific questions which we plan to address have never been answered by direct measurements of the fluctuating magnetic fields in the appropriate range of frequencies directly on the surface of the planet. We plan to detect and characterize electromagnetic radiation propagating from the interplanetary space down to the surface of the planet and possible electromagnetic radiation from electric discharges in the Martian dust storms.

[1] Macusova, E., O. Santolik, N. Cornilleau-Wehrlin, K. H. Yearby (2015), Bandwidths and amplitudes of chorus-like banded emissions measured by the TC-1 Double Star spacecraft, Journal of Geophysical Research: Space Physics, 120, 2, pp. 1057-1071.

[2] Taubenschuss, U., O. Santolík, D. B. Graham, H. Fu, Y. V. Khotyaintsev, and O. Le Contel (2015), Different types of whistler mode chorus in the equatorial source region, Geophys. Res. Lett., 42, 8271–8279, doi:10.1002/2015GL066004.

[3] Hrbackova, Z., O. Santolik, F. Nemec, E. Macusova, N. Cornilleau-Wehrlin (2015), Systematic analysis of occurrence of equatorial noise emissions using 10 years of data from the Cluster mission, Journal of Geophysical Research: Space Physics, 120, 2, pp. 1007-1021.

[4] Nemec, F., O. Santolik, Z. Hrbackova, J. S. Pickett, and N. Cornilleau-Wehrlin (2015), Equatorial noise emissions with quasiperiodic modulation of wave intensity, J. Geophys. Res.

Space Physics, 120, 2649–2661, doi:10.1002/2014JA020816.
[5] Nemec, F., M. Parrot, and O. Santolík (2015), Power line harmonic radiation observed by the DEMETER spacecraft at 50/60 Hz and low harmonics, J. Geophys. Res. Space Physics, 120, 8954–8967, doi:10.1002/2015JA021682.
[6] Záhlava, J., F. Nemec, O. Santolik, I. Kolmasova, M. Parrot, and C. J. Rodger (2015), Very low frequency radio events with a reduced intensity observed by the low-altitude DEMETER spacecraft, J. Geophys. Res. Space Physics, 120, doi:10.1002/2015JA021607.

FIJI ISLANDS: Report by Dr.Sushil Kumar (kumar_su@usp.ac.fj), School of Engineering and Physics, The University of the South Pacific, Suva, Fiji Islands

We continue participating in the World Wide Lightning Location Network (WWLLN) since our joining in 2003. Using the WWLLN setup we are recording the narrowband data on six transmitter signals using SoftPAL data acquisition system. The response of the D-region low latitude ionosphere for extreme space weather event of 14-16 December 2006 associated with a X1.5 solar flare and an intense geomagnetic storm (*Dst* = -146 nT) using VLF signals from NWC (19.8 kHz) and NPM (21.4 kHz) transmitters monitored at Suva (Geog. 18.10°S, 178.40°E), Fiji, was studied (please see *J. Geophys. Res. Space Physics,120, 788–799, doi:10.1002/ 2014JA020751.*). The reduction in VLF signals strength is attributed to increased signal attenuation and absorption by the Earth-ionosphere waveguide due to storm-induced D-region ionization changes. The long duration of the storm effect results from the slow diffusion of changed composition/ ionization at D-region altitudes compared with higher altitudes in the ionosphere.

We also record the ELF-VLF data using the Atmospheric Weather Electromagnetic System for Observation Modeling and Education (AWESOME) only during some complain periods. A student has submitted his PhD thesis on D-region investigations using the data both from AWESOME and SoftPAL.

Automatic Whistler Detector system (AWD) which is able to detect and analyze whistlers in quasi-real-time has been running for last two months at Suva using the signal from WWLLN system. Whistlers have also been observed at low latitudes, where the field lines do not emerge from the ionosphere. However, the propagation characteristics of low latitude whistlers are poorly understood thus they have not been used effectively as a diagnostic for the low latitude ionosphere. We are thankful to Prof. János Lichtenberger, Department of Geophysics and Space Sciences, Eötvös University, Budapest, Hungary, for providing the guidance and support in the running of the AWD system.

The Research and International office of the University of the South Pacific (USP) has released its electronic research repository of the research (publications) generated during the staff affiliation with USP. For details please visit http://repository.usp.ac.fj/

FINLAND: Report by Dr. Jyrki Manninen (Jyrki.Manninen@sgo.fi) Sodankyla Geophysical Observatory, Sodankyla, Finland.

This year one ELF-VLF campaign is organised and it going on. This campaign stated on 29 October, and the plan is to continue at least till 17 Jan 2016. The previous campaign was from 13 Nov 2014 till 9 Jan 2015. 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 some one is interested in.

Some new results were shown in IUGG General Assembly held in Prague, Czech Republic.

This year 3 papers related to ELF-VLF observations were published. First paper (Kleimenova et al., 2015, doi: 10.1134/S001679321503010X, in GA) is presenting the results of nontypical VLF hiss burst on 8 Dec 2013. Second paper (Manninen et al., 2015, doi: 10.5194/angeo-33-991-2015, in AG) is showing a case study of the afternoon "mushroom-like" hiss on 8 December 2013.

Third paper (Titova et al., 2015, doi: 10.1002/ 2015GL064911, in GRL) reports on QP VLF emissions observed simultaneously at Kannuslehto and on Van Allen Probe. One interesting thing is that ground-based data and satellite data have one-to-one correlation during almost one hour, although the ionospheric projection of the satellite was located west of Scotland, i.e., the distance between these observations was about 2,500 km.

As it was mentioned in the previous VERSIM newsletter in 2014, our current analysis program contains better filtering for major sferics and totally new filters for PLHRs. This analysis was now tested with AWDA data (Eötvös Univ., Budapest, Hungary), and first results were very promising. However, more data is needed and hopefully soon we will get some AWDA data with 100 kHz sampling from Tvarminne (Southern Finland). After longer tests we can say if this analysis could be implemented to other systems, too.

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.

HUNGARY: Report by Prof. János Lichtenberger (lityi@sas.elte.hu), Space Research Group, Eötvös University, Budapest, Pázmány Péter sétány 1/A., H-1117 Hungary.

The Space Research Group of Eötvös University continued the theoretical modeling and model-calculations of monochromatic and transient (Ultra Wide Band) electromagnetic signals and the evaluation and comparison of the results with the measured data-base recorded at terrestrial stations and on board of satellites.

In the field of the theoretical model development of the full wave solutions of the Maxwell's equations, further work is made on the general solution of the electromagnetic wave propagation in general relativistic situations, especially to find new type of solutions.

The real-time operation of the Automatic Whistler Detector and Analyzer Network has been continued this year. We are working on the improvements of input data quality and error estimation. The processing of the archive whistlers collected by AWDANet since 2002 has also been continued – this may take years to complete. The calibration of equatorial electron densities obtained from whistler inversion with in-situ cold plasma measurements has been extended with further comparisons and it was complemented with a new procedure based the Russian Alpha VLF transmitters' signal. We have started another calibration procedure based on Cluster WHISPER data.

We are preparing the extension of the network with a new VLF receiver at the Belgian Antarctic base, Princess Elizabeth (L=5.7). The base is the first one in the AWDANet outside the average plasmapause location. Though it is well known that whistlers recorded on the ground propagate inside the plasmapause, there are historic whistler data from IGY and the years after recorded outside the plasmasphere (Greenland and Antarctica). The other major goal here is to record choruses and connect the waves recorded at the ground to the physical parameters at the zone of generation at the equatorial region in the radiation belts. The installation takes place in the 2015-16 Antarctic Summer

The pre-launch activity of the BepiColombo MMO PWI continued during the last year. After completing the final design of the Intelligent Signal Detection Module (ISDM) of the MMO PWI, and its successful on board application in Chibis and Relek/Vernon programmes, ISDM routine was also tested in magnetometer (MAG) records of the NASA Messenger spacecraft's magnetospheric data. The automatic identification of ULF wave emissions associated to interaction zones was successful.

The growing number of the AWDANet stations, and volume of detected and analyzed ground whistlers as well as recent space recorded whistlers, allowed to start extensive, comparative study in the mass whistler data base. This complex work aims to give more reliable picture on VLF wave propagation (e.g. estimating the extent of the wavefronts in different segments of the prop.), resolving still open questions in whistler generation (e.g. sources), temporal variations in occurrences.

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

INDIA: Report submitted by Prof. Ashok Kumar Singh (aksphys@gmail.com), *Dept. of Physics, University of Lucknow, India*.

The recording and analysis of whistler waves and the VLF emissions at Physics Department, University of Lucknow, Lucknow (Geomag. Lat., 17.6^0 N, Geomag. Long., 154.5^0 E) are continued since 2010. The VLF antenna is made up of two perpendicular magnetic loops, oriented N-S and E-W directions. This antenna is part of AWDAnet, the Automatic Whistler Detector and Analyzer system's network. Very good quality whistlers and tweeks (higher harmonic) have been observed at our station. A typical example of a tweek and whistler observed at Lucknow is shown in the figure.

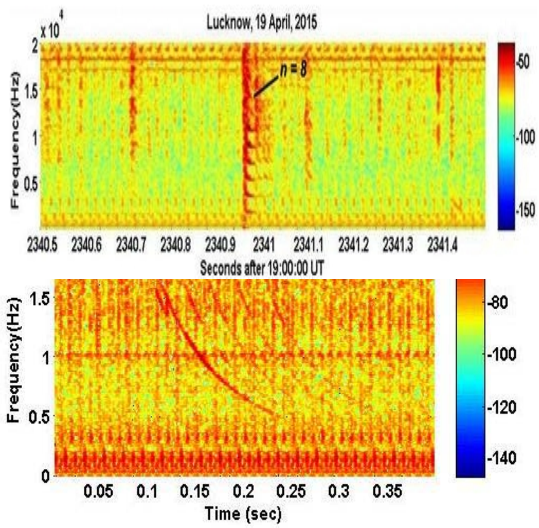

Fig.: A typical example of tweek and whistlers recorded at Lucknow, India

The ELF/VLF radio wave technique has demonstrated the potential to monitor changes in the bottom part of the D – region ionosphere as well as the middle of the magnetosphere. The amplitude and phase measurements of fixed frequency VLF signals transmitted from ground based transmitters are also being carried out to study the D-region perturbation phenomena caused by solar flares, particle precipitation, transient luminous events (TLEs) and Earthquakes. Apart from it some work on Atmospheric-Ionospheric coupling is also being carried out.

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

Colin Price and graduate student Israel Silber continue analysis of our ground-based observations of broadband and narrowband VLF waves. This year we have published a technical note in Radio Science (Silber et al., Radio Science, 2015) showing that the VLF (and ELF) vertical magnetic field in the far field can be very significant relative to the total field. According to theory we normally assume the vertical magnetic field is negligible compared with the horizontal magnetic field. We found that often the vertical field can be of the same magnitude, if not larger, compared with the horizontal field. We assign this "anomaly" to ground conductivity gradients and possible asymmetries in the Earth-ionosphere waveguide.

Another paper just accepted in ACPD, together with Craig Rodger, shows a clear semi-annual oscillation (SAO) in VLF narrowband data during nighttime hours (Silber et al., ACPD , 2015). The SAO is the most dominant oscillation during the night hours, while during the daytime the annual cycle dominate. We assign this SAO to transport of NOx from the thermosphere to the lower ionosphere. In addition to the SAO, we have also found evidence for gravity waves, acoustic waves, and other short term variability in our NB data.

Using our broadband data, together with the WWLLN lightning data in our region, we have analysed the waveforms of more than 700,000 sferics associated with WWLLN flashes and known locations. From this analysis we are attempting to learn about the variability of the D-region effective reflection height, as a function of azimuth, season and time of day. A paper is in preparation.

Together with graduate students Shay Frenkel and Maayan Harel, we continue our analysis of WWLLN data for studying tropical storms (SF) and African thunderstorms (MH). In addition, Laura Ihrlich from Germany is spending a semester internship with us analyzing fatal lightning accidents in Africa using the WWLLN data.

JAPAN: Report by Prof. Kazuo Shiokawa, Director of the Center for International Collaborative Research (CIRC), Nagoya University. (shiokawa@stelab.nagoya-u.ac.jp)

ELF/VLF measurements by ISEE, Nagoya Univ. at Athabasca (Canada) and Moshiri and Kagoshima (Japan)

Institute for Space-Earth Environmental Research (ISEE), Nagoya University has been making continuous measurements of ELF/VLF waves at Athabasca, Canada, since September 25, 2012 with a sampling rate of 100 kHz, in collaboration with the Athabasca University and Kanazawa University. The sampling rate was reduced to 40 kHz on November 12, 2015 to save disk space, but continuous measurement is still going on. ISEE also make routine 20-kHz ELF/VLF measurements at Moshiri and Kagoshima, Japan, since 1970s for 2-min every 30min (20min and 50min of each hour). Quick-look spectra of these observations and the data are available at http://stdb2.stelab.nagoya-u.ac.jp/vlf/.

Photo: Picture of the loop antenna at Athabasca, Canada (Nov.14, 2015).

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

We have conducted Asia VLF observation network (AVON) in South-East Asia: Tainan (Taiwan), Saraburi (Thailand), Pontianak (Indonesia), Los Baños (Philippines) and Hanoi (Vietnam) since 2007. The aim of the AVON is to investigate the D- and lower E-region ionosphere, lightning, and coupling between lightning and the lower ionosphere in South-East Asia. The VLF/LF receivers consist of an orthogonal loop, a monopole, and dipole antennas (Figure 1). Fourteen universities/institutes in Asia participate in AVON. AVON is one of ground-based observation networks for ERG satellite (the launch: July, 2016). You can see quick-look files of the VLF magnetic components and amplitude and phase of LF standard signals on Inter-university Upper atmosphere Global Observation NETwork (IUGONET, http://www.iugonet.org/en/index.html).

AVON Winter School 2015 was held in Chiba University during 2-6 February 2015. We invited 10 graduate students or young researchers from South-East Asia and lecture data analysis methods for estimations of reflection height in the D- and lower E-region ionosphere and lightning distribution, and for ray tracing, etc. This program was supported by "Japan-Asia Youth Exchange Program in Science" of Japan Science and Technology Agency (JST). In addition, we made a learning kit that consists of texts and movies and distributed it to a few institutes in South-east Asian countries.

We reported the first observation of daytime tweek atmospherics during magnetically quiet and storm days based on Japanese observation data (Ohya et al., JGR, 2015). We showed the occurrence rate and reflection height of the daytime tweeks. From calculations of strict solutions considering the ionospheric reflection coefficient, we suggested that the best conditions for daytime tweek observations are when the bottom side of the ionosphere is sharply defined and the ionospheric height is high.

Photo: AVON antennas in Pontianak (Indonesia): monopole (left), loop (mid), and dipole (right) antennas.

NEW ZEALAND: Reported by Prof. Craig J. Rodger (craig.rodger@otago.ac.nz), University of Otago, Dunedin, New Zealand.

We continue to operate the following experimental measurements locally in Dunedin: 1) the VLF Doppler Experiment which monitors whistler-mode signals from VLF transmitters that have propagated through the plasmasphere, predominantly inside whistler ducts, 2) several narrowband receivers (OmniPAL, AbsPAL, SoftPAL and Ultra MSK) which log changes in the phase and amplitude of powerful VLF communications transmitters (~16-30 kHz) to study subionospheric propagation, 3) an Automatic Whistler Detector and Analysis (AWDA) receiver operating in collaboration with Eötvös University, 4) a receiver and a central processing computer of the World Wide Lightning Location Network (WWLLN). We also operate UltraMSK narrow-band loggers and WWLLN receivers in Antarctica (near Scott Base, with support from Antarctica New Zealand), and at Ministik Lake (near Edmonton, Canada, with support from the University of Alberta). Narrow-band observations are also being made using some WWLLN receiver locations (Ascension Island, Fairbanks). We play a core role in the AARDDVARK global network of subionospheric VLF monitors and also, in real-time, as part of the WWLLN lightning consortium.

In 2015 Neil Thomson travelled to Canada and Denmark to make measurements of the powerful VLF transmitters. These campaigns are focused on understanding the typical electron number density profiles of the D-region, and particularly to determine the profiles suitable to describe subionospheric VLF propagation. Neil will be retiring from the Otago academic staff in 2016, but plans to continue his research activity free from the constraints of teaching. In November 2015 James Brundell and Space Physics PhD student Emma Douma travelled to Scott Base. Their goals were to undertake maintenance on the AARDDVARK antenna and to install a new WWLLN receiver due to the bad magnetic field noise levels in the "radio quiet" site.

This year the Space Physics Group had 3 PhD students, Aaron Hendry, Kathy Cresswell-Moorcock and Emma Douma, all of whom had Craig Rodger as the lead supervisor. Aaron has been working on energetic electron precipitation from EMIC waves, sensed by POES LEO satellites and AARDDVARK. Aaron spent some of this year at the British Antarctic Survey (Cambridge, UK) and attended the IUGG conference in Prague. Kathy Cresswell-Moorcock started her PhD in December 2014, and is currently looking at the impact of solar flares on VLF propagation. Kathy was supported the US National Center for Atmospheric Research to travel to Boulder mid-year to join their Summer Advanced Study Program entitled "Climate, space climate, and couplings between". Emma Douma began her PhD in March 2015 and is working on electron precipitation in strong diffusion events; she is currently focused on relativistic electron microbursts.

Craig Rodger has been on sabbatical since mid-May 2015. He has spent most of the time period in the USA, supported by a Fulbright New Zealand Fellowship, and hosted by the University of Iowa (Craig Kletzing) and Colorado University in Boulder (Scot Elkington). Craig returns to New Zealand in late November, but then he will travel to the UK and Finland before heading to the AGU Fall Meeting.

The Otago Space Physics gruop will be branching into some new research areas in the near future; late in 2015 we learnt we had been awarded a new research contract to investigate Geomagnetically Induced Currents. We will be focusing on the >10 years of measurements of these currents which are available in New Zealand, and constructing a model to study the likely effect of such currents during extreme geomagnetic storms.

In 2015 the group published the following papers, ranging across a wide range of research fields. Several of these arose out of graduate student research projects! Obviously we feel this was a very good year for us:

1. Rodger, C. J., K. Cresswell-Moorcock, and M. A. Clilverd, Nature's Grand Experiment: Linkage Between Magnetospheric Convection and the Radiation Belts, J. Geophys. Res., doi:10.1002/2015JA021537, (in press), 2015.
2. Rodger, C. J., A. T. Hendry, M. A. Clilverd, C. A. Kletzing, J. B. Brundell, and G. D. Reeves, High-resolution in-situ observations of electron precipitation-causing EMIC Waves,

Geophys. Res. Lett., doi:10.1002/2015GL066581, (in press), 2015.
3. Záhlava, J., F. Němec, O. Santolík, I. Kolmašová, M. Parrot, and C. J. Rodger, Very low frequency attenuation events observed by the low-altitude DEMETER spacecraft, J. Geophys. Res., doi:10.1002/2015JA021607, (in press), 2015.
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RUSSIA: Report from Prof. David Shklyar (david.shklyar@gmail.com) on behalf of the Space Research Institute of RAS, Moscow, Russia (IKI), including Elena Titova, Ilya Kuzichev, and Dmitry Vavilov.

Wave effects related to altitude changes of ion composition in the ionosphere.

Wave-modes that can propagate in magnetoactive plasma in the frequency band below the proton gyrofrequency depend crucially on ion composition. Adding a new sort of ions leads to appearance of a new resonance frequency at which the index of refraction tends to infinity, as well as a new cutoff frequency at which the index of refraction turns to zero. At the same time, the topology of the refractive index as the function of frequency is changed; in particular, a new propagating branch appears above the cutoff frequency. A question arises about the excitation of this wave mode in the presence of a wave propagating at this frequency in another wave mode, in other words, the question about a forced mode conversion. Since the second mode appears at small values of the refractive index, the consideration of this problem requires full wave approach. Even though it is clear from physical point of view that this process is hardly possible, since the waves with very different wave vectors (although the same frequency) cannot interact inefficient, a strict mathematical description of the problem is not trivial. This process has been studied in the frame of the general problem of formation of proton whistlers.

Linear mode conversion is another important wave effect related to the variation of plasma composition. This effect is also closely related to the theory of formation of proton whistlers in the ionosphere, where ion composition changes with altitude. Linear conversion of Alfven and magnetosonic waves has earlier been studied for the case of quasi-longitudinal propagation, using the method of successive approximations [Bud'ko, N.I., B.S. Ryabov (1977). Geomagnetism i Aeronomiya, v. 17, p. 751.] The case of vertical propagation at arbitrary angle with respect to the ambient magnetic field has been considered by Bellyustin [Bellustin, N.S. (1978). Radiophysics and Quantum Electronics, v. 21 (4), p. 487] by means of phase integrals and analytical extension. We have solved this problem using numerical methods, with real profiles of ion concentrations and collision frequencies taken from up-to-date modes. Likewise the analytical solution of the problem, its numerical solution contains a number of nontrivial moments.

Publication related to the presented results:
D. I. Vavilov, D. R. Shklyar, Wave effects related to altitude changes of ion composition in the ionosphere, (to be published in Radiophisics and Quantum Electronics).

SERBIA – Institute of Physics, University of Belgrade, Belgrade, report by Aleksandra Nina (sandrast@ipb.ac.rs).

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

1. The most significant results were obtained in the analysis of short-term disturbances of the low ionosphere during impact of gamma ray bursts (GRBs) [1]. Our study is based on statistical analysis of 6 signals in periods around satellite detection of 54 considered GRB events. For the first time, we shown that short-term perturbations caused by this astrophysical phenomenon are present in the low ionosphere. A procedure for extraction of short-term peaks from the signal noise is given in this paper. This procedure is universal: it can be applied to studies of different events, different time periods and temporal resolution of considered signals which make it applicable to other studies.

2. We continue to analyze changes in D-region plasma parameters during the influence of solar X-flares. We developed the procedure for calculations temperature changes after the termination of X- flare impact [2]. Also, quantitative analysis of the contribution of Lyα line in photoionization during maximum of X flare intensity is given in [3].

3. We begin with the analysis of the radio signals propagation in wide frequency band in the perturbed D-region [2].

Our results were presented at two international conferences: X Serbian conference on spectral line shapes in astrophysics [4-6], and Natural disasters - links between science and practice [7]. Also, our investigations are shown in the meeting of COST Action TD1403 “Big Data Era in Sky and Earth Observation” (WG1) [8].

During this year we continued studies related to the connection between variations in the low ionosphere with tropospheric and lithospheric changes.

In addition two national projects, our research is a part of COST Actions TD1403 since 2015.

All activities will be continued, and the results obtained this year will be involved in two PhD dissertations, one master thesis and two final exams.

1. Detection of short term response of the low ionosphere on Gamma Ray Bursts, Nina, A., S. Simić, V. A. Srećković, and L. Č. Popović Geophysical Research Letters, (2015), 42, 8250–8261 doi:10.1002/2015GL065726

2. Ionospheric D-region temperature relaxation and its influences on radio signal propagation after solar X-flares occurrence,J. Bajčetić, A. Nina, V.M. Čadež, B.M. Todorović Thermal Science, (2015), doi:10.2298/TSCI141223084B

3. Contribution of solar hydrogen Lyα line emission in total ionization rate in ionospheric D-region during the maximum of

solar X-flare A. Nina, V. M. Cadez, J. Bajcetic, Serbian Astronomical Journal, (2015), doi: 10.2298/SAJ150828003N

4. Contribution of Ly photoionization to ionization rate and electron density changes in the ionospheric D-region disturbed by solar X-flares A. Nina, V. M. Cadez, J. Bajcetic X Serbian conference on spectral line shapes in astrophysics, June 15-19, 2015, Srebrno jezero, Serbia Book of Abstracts, Eds. L.C. Popovic, M. S. Dimitrijevic and S. Simic Astronomical Observatory, Belgrade, 2015, 53

5. Variability of D-region photoionization induced by Lyα radiation. A. Nina, V. M. Cadez, J. Bajcetic and M. Andric X Serbian conference on spectral line shapes in astrophysics, June 15-19, 2015, Srebrno jezero, Serbia Book of Abstracts, Eds. L.C. Popovic, M. S. Dimitrijevic and S. Simic Astronomical Observatory, Belgrade, 2015, 54

6. VLF remote sensing of the lower ionospheric disturbances caused by intense solar radiation V. A. Sreckovic, A. A. Mihajlov, D. M. Sulic, A. Nina and Lj. M. Ignjatovic X Serbian conference on spectral line shapes in astrophysics, June 15-19, 2015, Srebrno jezero, Serbia Book of Abstracts, Eds. L.C. Popovic, M. S. Dimitrijevic and S. Simic Astronomical Observatory, Belgrade, 2015, 66

7. Low ionospheric perturbations and natural hazards A. Nina, V. M. Č., L. Č. Popović, D. Jevremović, M. Radovanović, A. Kolarski, V. A. Srećković, J. Bajčetić, B. Milovanović, A. Kovačević, The International Conference "Natural disasters - links between science and practice. У. Б. Б. ISBN 978-5-7103-3078-4. 23-24. April 2015, Saransk, Russia, 313-318.

8. The database obtained from measurements by Belgrade VLF receiver station and their application in the study of low ionosphere and detections different geo- and astrophysical phenomena, A. Nina COST Actions TD1403 “Big Data Era in Sky and Earth Observation” Belgrade MC and all WG Meetings, March 30-31,2015 http://serv2015o.aob.rs/static/themes/blackandwhite/static/doc/Belgrade%20Databases.pptx

SLOVENIA: Reported by Vida Zigman (vida.zigman@ung.si) University of Nova Gorica, Nova Gorica, Slovenia.

Retired, but still affiliated to UNG through research activities. Continues to be interested in the study of VLF wave propagation along the Earth-ionosphere waveguide: VLF detection of solar flares and proton events in particular. In the capacity of Proba2 project liaison scientist and in collaboration with the Proba2 team of the Royal Observatory of Belgium currently works on the study and modelling of the solar specific and spectral irradiance during solar flares. The task is to assess the irradiance ionization efficiency, which depends on the flare spectral composition, and to obtain the height-dependent ionization rate due to wavelength bandpasses pertaining to instruments on board of different space missions, like LYRA on Proba2 and ESP on SDO.

UNITED KINGDOM Report prepared by Dr. Mark Clilverd (macl@bas.ac.uk), British Antarctic Survey, Cambridge, UK. (URSI co-chair of VERSIM)

BROADBAND RECORDINGS in Antarctica:
Whistler-detection and data collection has continued at Halley (L=4.5) and Rothera (L=2.9) throughout 2015 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 2015.

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 2015.

The software VLF Doppler system has continued at Rothera station, Antarctica (L=2.8) in 2015, 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 2015, hosted by SANSA, Hermanus.

WWLLN sites:
British Antarctic Survey has continued to operate three World Wide Lightning Location Network systems in 2015. 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. This is particularly pleasing after the 4 month power problems at Halley during August-November 2014.

UNITED STATES: Report submitted by Prof. Steven Cummer (cummer@duke.edu) Duke University, Electrical and Computer Engineering Department, Durham, NC USA

Our group continues to use VLF and LF radio emissions from lightning to measure key parameters of those lightning processes. We provided our measurements to research led by several different research groups, including studies of negative polarity sprites, gigantic jets, and the lightning-meteorology relationship, and we are always happy to contribute our data to other groups. Our own work in the past several years has largely focused on applications of VLF and LF radio measurements in three areas: terrestrial gamma ray flashes (TGFs), highly energetic in-cloud lightning, and radio mapping of in-cloud lightning structure.
Cummer et al. [GRL, 2015] analyzed LF lightning radio emissions at the time of TGFs to work towards a better understanding of the lightning context of TGF production. We searched our LF radio data for known Fermi-GBM TGFs to identify those where the TGF is surrounded by LF radio pulses that are sufficiently clear that their source altitude can be inferred from multiple ionospheric reflections. There are not many, but in Cummer et al. [GRL, 2015] we analyzed three and found that all of them follow a similar pattern: TGFs are produced several milliseconds after IC leader initiation and when the leaders had reached 1-2 km in length (see Fig. 1 for an example). In all cases the leader continued to propagate upward for several more km after the TGF ended. These measurements provide some key details of the lightning processes that occur before, during, and after TGF production.

Lyu et al. [GRL, 2015] examined detailed VLF and LF radio emissions from lightning identified by the NLDN as in-cloud, very high peak current (>150 kA) events. Quantitative features in the waveforms (mainly time scale and the presence of other emissions nearby in time) of these events naturally sort these in-cloud events into two classes: classic narrow bipolar events (NBEs), and a previously unappreciated class of lightning that we call energetic in-cloud pulses (EIPs). EIPs are very strong VLF radio sources because of their slower time scale compared to NBEs. The strongest EIPs, despite being an in-cloud process, radiate as much VLF energy as very strong cloud-to-ground strokes Both positive and negative EIPs exist (but positive is much more common), and the VLF-LF radio context shows that EIPs are produced during upward (for +EIPs) or downward (for –EIPs) propagation of a previously initiated negative leader. A small handful of previously reported TGFs are associated with very high peak current events that appear to be EIPs. We are working towards better understanding the link between these two unusual lightning processes.

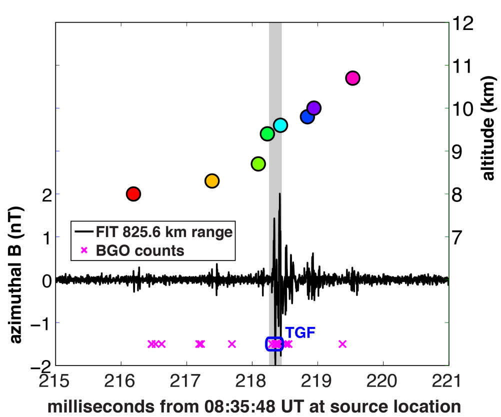

Fig 1: Example of IC leader altitude-time plot for TGF-producing lightning. The TGF is produced about 2 ms after the upward leader initiation, when the negative leader tip had

ascended 1.5 km from its initiation altitude. The leader continues upward for another 1.5 km after the TGF. Adapted from Cummer et al. [GRL, 2015].

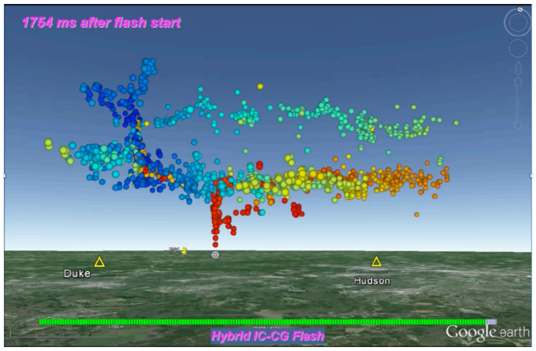

Fig. 2: Plot of low frequency LMA source points for a hybrid IC-CG lightning flash. Color reflects the time of the source (blue=old, red=current). This image was created using the data and processing approach described by Lyu et al. [GRL, 2014].

Lastly, Lyu et al. [GRL, 2014] showed that a compact VLF-LF sensor array could be used as a 3D lightning mapping array (LMA) and produces lightning images that are remarkably similar to VHF LMA images (see Fig. 2) despite the 1000x frequency difference. The key step is computing 2-station time differences with submicrosecond resolution via windowed cross-correlation, which is equivalent to broadband interferometry. This approach images both stepped and dart leaders and produces a fairly complete image of in-cloud and cloud-to-ground lightning channel development.

VLF publications led by our group in the last 12 months

McTague, L. E., S. A. Cummer, M. S. Briggs, V. Connaughton, M. Stanboro, and G. Fitzpatrick, A Lightning-Based Search for Nearby Observationally Dim Terrestrial Gamma-ray Flashes, Journal of Geophysical Research: Atmospheres, in press (2015).

Cummer, S. A., F. Lyu, M. S. Briggs, G. Fitzpatrick, O. J. Roberts, and J. R. Dwyer, Lightning leader altitude progression in terrestrial gamma-ray flashes, Geophysical Research Letters 42, 7792-7798 (2015).

Lyu, F., S. A. Cummer, and L. McTague, Insights into high peak current in-cloud lightning events during thunderstorms, Geophysical Research Letters 42, 6836-6843 (2015).

Lyu, F., S. A. Cummer, R. Solanki, J. Weinert, L. McTague, A. Katko, J. Barrett, and L. Zigoneanu, A low frequency near-field interferometric-TOA 3D lightning mapping array, Geophys. Res. Lett., doi:1002/2014GL061963, 2014.

Cummer, S. A., M. S. Briggs, J. R. Dwyer, S. Xiong, V. Connaughton, G. J. Fishman, G. Lu, F. Lyu, and R. Solanki, The source altitude, electric current, and intrinsic brightness of terrestrial gamma-ray flashes, Geophys. Res. Lett., doi:10.1002/2014GL062196, 2014.

UNITED STATES: Submitted by Prof. Morris Cohen (mcohen@gatech.edu), Electrical and Computer Engineering, Georgia Institute of Technology, http://ece.gatech.edu/research/labs/lf/

The Georgia Tech LF Group is starting to deploy its LF receivers and make new measurements. These receivers are based closely on the Stanford AWESOME VLF receiver, but include a higher sampling rate, better sensitivity, and more accurate timing. The receivers have been deployed to three locations in the Southeast USA, two locations in Alaska (taken over from old Stanford sites), and a few more will be added in the coming months. The receivers are collecting both broadband and narrowband data and we are open to data sharing or collaboration. We are also hosting a postdoctoral scholar, Ajeet Maurya, who was won a prestigious Fulbright fellowship and will be visiting Georgia Tech for a year. Ajeet did his PhD with Rajesh Singh in the Indian Institute of Geomagnetism VLF group.

UNITED STATES: Submitted by Dr. Maria Spasojevic (mariaspasojevic@stanford.edu) from Stanford University.

Professor Emeritus Donald L. Carpenter has completed the text of a historical book titled "Very Low Frequency Space Radio Research at Stanford 1950 to 1990", with the sub-title "Discovery, Innovation, and Analysis, Supported by Field Work Extending from Antarctica to Alaska". It is a tribute to the work of Prof. Robert A. Helliwell who founded the Stanford VLF Group, and directed it through these four decades. The book contains 213 pages including a 12-page bibliography, also 256 images and illustrations. After being sent to the printers, by mid-December it had reached the proof-reading stage. Publication is expected in January 2016, and the book will then be available both in hardcover and in paperback formats. Its publication will be announced, with more details, in one of the bi-monthly VERSIM e-mailings.

UNITED STATES: Submitted by Dr. Whitman Reeve (whit@reeve.com), Anchorage, Alaska.

I owned and operated a telecommunications engineering company for about 40 years and then decided it was time to work on my own projects. I built a radio observatory in Anchorage but radio frequency interference has reduced my data quality to the point where I had to do that somewhere else. About 3 years ago I started building the Cohoe Radio Observatory and it will be put online next spring. CRO will have a geomagnetometer, seismometer and radio sensors that cover VLF to UHF, mostly for observing the Sun, Jupiter and Earth's ionosphere. I usually use my own data for my own studies, which are rather simple, but do contribute data to the ISWI e-Callisto project network.

As an example, a large trans-equatorial coronal hole transited the Sun's central meridian on 4 October and three days later (on UTC day 280) the ACE spacecraft and then Earth encountered its stream, which peaked slightly above 800 km/s. The CHHSS caused strong geomagnetic storm effects at Anchorage, Alaska about noon (UTC) on 7 October.

The figure shows a normalized magnetogram from Reeve Observatory, Anchorage, Alaska for 7 October. The day was magnetically very stormy starting mid-way through the 2nd synoptic period (0300 to 0600). The influence of the high-speed stream from the tans-equatorial coronal hole can be seen to start about 1200 and continue for over 8 h as Earth passed through it. The K-index shown along the top of the chart indicates the severity of the magnetic deviations during each 3 h synoptic period. The three axes BX, BY and BZ are sampled at 0.1 Hz rate with a SAM-III geomagnetometer:
http://www.reeve.com/SAM/SAM_simple.html

UNITED STATES: Report submitted by Prof. Jacob Bortnik (jbortnik@gmail.com), Department of Atmospheric and Oceanic Sciences, UCLA, USA.

Many changes have taken place in the UCLA group in the past year but the group is strong and vibrant and as productive as ever! The first big change is that Prof. Richard Thorne retired from teaching after what can only be described as an exceptional career at UCLA, spanning the 47 year stretch 1968-2015. Prof. Thorne will continue to be active in research, being heavily involved in various studies, as well as the Van Allen Probes and JUNO missions.

After a protracted search, the new faculty member in the UCLA group has been named and it is none other than yours truly (J. Bortnik), who officially started on Nov 1 2015.

On the research front, the UCLA group has continued to work on a variety of projects including the analysis of THEMIS, Van Allen Probes, GOES and POES data, numerical modeling of wave particle interactions, and laboratory excitation work. To highlight a few interesting results, we demonstrated a method to remote-sense plasmaspheric hiss using low-altitude precipitation on the POES satellite [Soria-Santacruz et al., 2015 JGR], showed the brief pulses of chorus are excited locally near the dayside magnetopause [Zhou et al., 2015 JGR] and mapped the local-time distribution of the repetition periods of chorus elements with our collaborator, Prof. Jih-Hong Shue [Shue et al., 2015 JGR]. We also continued our studies of wave-particle interactions with electromagnetic ion cyclotron (EMIC) waves [Ni et al., 2015 JGR; Denton et al., 2015 JGR], magnetosonic waves [Bortnik et al., 2015 GRL; Chen et al., JGR], and oblique whistler waves [Li et al. 2015 Phys fluids]. We also looked at the solar wind conditions that lead to efficient electron acceleration [Li et al., 2015 JGR], and dropouts [Gao et al., 2015 JGR]. We also found (what we believe to be the first) evidence for the connection between chorus at high L-shells on the dayside magnetopause and plasmaspheric hiss [Li et al., 2015 GRL]. Last but not least, a laboratory accomplishment that we are particularly excited about is the first excitation of chorus-like waves in a laboratory plasma, reported in Physical Review Letters in 2015 by Van Compernolle et al.

UNITED STATES: Report by Prof. Robert Moore (moore@ece.ufl.edu), Ionosphere Radio Laboratory at the University of Florida.

The Ionospheric Radio Lab (IRL) at the University of Florida, headed by Dr. R. C. Moore, operates ELF receivers in Greenland, Alaska, California, and Antarctica to perform observations of global thunderstorm activity and the Schumann resonances. The IRL also operates VLF receivers at a larger number of locations around the globe to study VLF propagation around the Earth and to perform VLF remote sensing of the D-region ionosphere. The group collaborates with the International Center for Lightning Research and Testing (ICLRT, PI: Dr. M. A. Uman) to perform rocket-triggered lightning experiments in north-central Florida. Lastly, the IRL conducted (and will once again conduct) high power ionospheric heating experiments at the HAARP transmitter in Gakona, Alaska.