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

Annual newsletter of VERSIM: a joint IAGA/URSI working group
Editor: Andrei Demekhov No. 36, December 2021

Dear VERSIM friends and colleagues,

As a small gift to you for the coming year 2022, I am bringing our annual newsletter to your kind attention.

We have been much more accustomed to living in a pandemic world, and our travel opportunities have still been greatly restricted. However, meetings of both our aupporting associations, IAGA and URSI, have happened successfully (the first one purely online and the second one, in a hybrid format). The huge development of online meeting technologies has given some of us more chances to participage in meetings that otherwise would have been unreachable. Overall our community has kept a high momentum, and we continued to develop very interesting collaborations among us. The reports compiled below present a good evidence of the vibrance of our group. I am most grateful to all of you who supports our working group by sharing your relevant research and related news, both in the annual and regular newsletters.

As a part of this preface, I am happy to insert a message about our 2022 biennial meeting.

Dear VERSIM colleagues,

We're happy to inform you that the next VERSIM workshop will be held on 07-11 November 2022 in Sodankylä, Finland. VERSIM returns to its origins to celebrate its 10th anniversary at the Sodankylä Geophysical Observatory (SGO).

The format of the conference will be hybrid, but we are hoping most of you will be able to join us on site. The webpage for the workshop will open some time in January 2022. However, we can already tell you now that the abstract deadline will be the end of July 2022.

This year will also be the first VERSIM School! This will be held on the weekend just before the workshop (05-06 November 2022). We plan to have tutorial talks on different VERSIM topics complemented by activities to learn more about instruments used by the community. This school will be open to anyone who is interested in learning the basics of VERSIM topics.

Message from the "preliminary" LOC (Jyrki, Claudia and Craig).

As usual, I hope you will read this newsletter with interest, for learning something new about the activities and results of our community, and perhaps for finding ways for new collaborations.

Please take care and have a happy, healthy, and successful 2022!

Andrei Demekhov,
IAGA co-chair

Mark Clilverd,
URSI co-chair

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

We continue our project to detect whistler waves with 2 VLF antennas that are part of AWDAnet, the Automatic Whistler Detector and Analyzer system's network. This network covers low, mid and high magnetic latitudes including conjugate locations. It has been initiated by Dr. J. Lichtenberger (Hungary).

A VLF antenna installed in October 2010 in Humain, Belgium (Lat~50.11°N, Long~5.15°E), detects whistlers and determines electron densities along propagation paths. This VLF antenna is made of two perpendicular magnetic loops, oriented North-South and East-West and with an area of approximately 50 m^2 each. We continue the monitoring of the data obtained with this instrument and fix regular problems (change the vr2 data logger in Spring 2021).

A second VLF antenna has been installed in January-February 2016 at the Belgian Antarctic station Princess Elisabeth (Lat~71.57°S, Long~23.20°E). This antenna is composed of two search coils, without a mast in order to withstand the weather at such latitudes. Due to a power shut down, the instrument was off from 14 May 2021. It has been restarted on 14 November 2021 by the team of the 2021-2022 expedition. Very few whistlers are detected due to high level of electromagnetic perturbations.

References:

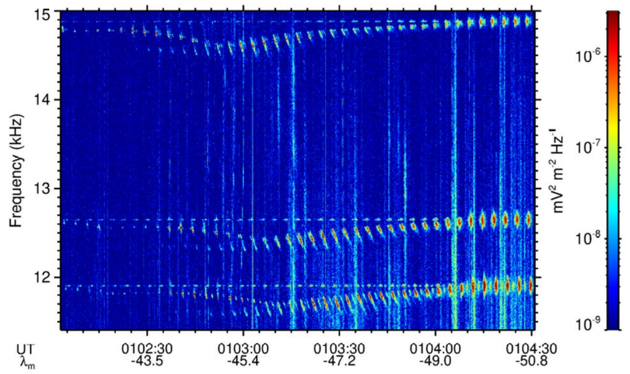
Vander Vorst, A. et al., 100 Years Of Radio Science Acivities In Belgium, Chap. 2 in: P. Wilkinson, P. S. Cannon, and W. R. Stone (Eds.), "100 Years of the International Union of Radio Science", ISBN:9789463968034, URSI Press, Gent, Belgium, 2021, pp. 34-51.

CZECHIA: Report prepared by Ivana Kolmašová (iko@ufa.cas.cz), František Němec (frantisek.nemec@mff.cuni.cz), and Ondřej Santolík (os@ufa.cas.cz), Institute of Atmospheric Physics of the Czech Academy of Sciences and Charles University, Prague.

Our group at the Department of Space Physics, Institute of Atmospheric Physics of the Czech Academy of Sciences and at the Faculty of Mathematics and Physics of the Charles University continued to investigate inner magnetospheric electromagnetic waves using ground-based experiments and spacecraft measurements. Examples of our results obtained in 2021 are given below.

We inter-calibrated wave analyzers onboard the Van Allen Probes and Arase spacecraft [1] using a fortuitous case of simultaneous observations of strong whistlers at frequencies between a few hundred hertz and 10 kHz, which were generated by the same lightning strokes, and which propagated to the two spacecraft along very similar paths. Measured amplitudes of the magnetic field fluctuations agreed within ∼14% precision of our analysis, corresponding to 1.2 dB. Although the current archived electric field measurements showed twice larger amplitudes on Arase than on the Van Allen Probes, they matched within ∼33% precision (2.5 dB) once the newest results on the interface of the antennas to the surrounding plasma were included in the calibration procedures. Ray tracing simulations helped us to build a consistent scenario of wave propagation to both spacecraft reflected by a successful inter-calibration of the polarization and propagation parameters obtained from multicomponent measurements.

In our case study [2] we contributed to the discussion of sources of plasmaspheric hiss, known as a shaping agent for the Earth radiation belts. We found hiss to be triggered from whistlers of different spectral properties. Whistlers with the lowest observed dispersion arrive to different spacecraft with time delays indicating their origin in the northern hemisphere. Positions of source lightning discharges are then found using the time coincidences with the Word Wide Lightning Location Network data from three active thunderstorm regions in Europe. We find that subionospheric propagation of lightning atmospherics is necessary to explain the observations. Geographic locations of their ionospheric exit points then determine spectral properties of resulting unducted whistlers and triggered hiss. By this well documented chain of events starting with a lightning discharge in the atmosphere we confirm that magnetospherically reflecting whistlers and hiss triggered from them are among possible sources of plasmaspheric hiss.



Frequency-time spectrogram of power spectral density of electric field fluctuations from the time when the spacecraft was located in the southern hemisphere. The discrete transmission pattern of the Alpha navigation transmitters can be identified at the three frequencies (about 11.9, 12.6, and 14.9 kHz). Transmitter signals with gradually decreasing and later increasing frequencies were observed in addition to the expected constant-frequency signals.

We presented an analysis of signals transmitted by the Alpha navigation very low frequency transmitters operating at mid-latitudes and detected by the DEMETER spacecraft at an altitude of about 660 km [3]. We found that, due to a Doppler shift, the observed signal frequencies can be at times rather different from the radiated frequencies (Figure). This indicates wave propagation at large wave normal angles close to the resonance cone. Simultaneous observations of the same signal with different Doppler shifts revealed three distinct ways of signal propagation: (i) ducted propagation, (ii) unducted propagation, and (iii) propagation interpreted as only partially ducted. We showed the peculiarities of VLF signal propagation throughout the magnetosphere and demonstrated that Doppler shifts can be used to estimate the wave normal angles.

Electromagnetic waves observed in the inner magnetosphere at frequencies between about 0.5 and 4 kHz sometimes exhibit a quasiperiodic (QP) time modulation of the wave intensity with modulation periods from tens of seconds up to a few minutes. We used a large set of more than 2,000 of these events identified in the low-altitude DEMETER spacecraft data [4] to check for energetic electron flux variations matching the individual QP wave elements. We succeeded to identify energetic electron precipitation bursts corresponding to quasiperiodic emission peaks. Interaction regions occurred at L-shells between about 4 and 6 and have dimensions of about 0.6–1.2 Earth radii. Individual wave elements exhibited a fine inner structure corresponding to the wave bouncing between the hemispheres.

Wave growth of electromagnetic ion cyclotron (EMIC) emissions observed in the outer magnetosphere is mainly controlled by compression events resulting from solar wind dynamic pressure pulses. During such events wave growth is expected to be maximum close to the magnetopause. In previous studies, distribution of EMIC waves was analyzed according to their distance from the Earth, which is inadequate for studying the magnetopause region. We mapped a data set of EMIC waves observed by Time History of Events and Macroscale Interactions during Substorms (THEMIS) spacecraft according to their distance from a case-by-case modeled magnetopause [5]. Distance to the magnetopause organized compression-driven electromagnetic ion cyclotron (EMIC) wave observations better than L value. EMIC waves in the magnetosphere were the most frequently observed close to the magnetopause model. In this region EMIC waves were more frequent in the noon and dawn sectors than in the afternoon.

The principal component analysis was used to describe very low-frequency wave intensity measured by the low-altitude spacecraft DEMETER [6]. First principal components were shown to correspond to the overall wave intensity measured in individual frequency-latitude spectrograms. First principal component coefficients around the times of fast forward interplanetary shock arrivals exhibited systematic variations.

We analyzed perturbations in a hot electron distribution caused by nonlinear interactions with a model chorus element with fine structure [7]. A stripe structure of phase space density depletions and elevations are observed, associated with individual subpackets. We analyze the decrease of particle flux in this depression and estimate the energy resolution, pitch angle resolution, time resolution and geometric factor of particle analyzers needed to observe the perturbation. We conclude that particle detectors on current or recently operating spacecraft are always lacking in at least one of these parameters, which explains the missing direct observations of sharp phase space density depressions during chorus-electron nonlinear resonant interaction. However, with a dedicated experiment and appropriate measurement strategy, such observations are within the possibilities of the current technology.

Similarity of the simulated density perturbation and a step function mathematical model is used to draw an analogy between the backward wave oscillator regime of chorus generation and the nonlinear growth theory.

References:

1. Santolík, O., Miyoshi, Y., Kolmašová, I., Matsuda, S., Hospodarsky, G. B., Hartley, D. P., et al. (2021). Intercalibrated measurements of intense whistlers by Arase and Van Allen Probes. Journal of Geophysical Research: Space Physics, 126, e2021JA029700. https://doi.org/10.1029/2021JA029700
2. Santolík, O., Kolmašová, I., Pickett, J. S., & Gurnett, D. A. (2021). Multipoint observation of hiss emerging from lightning whistlers. Journal of Geophysical Research: Space Physics, 126, e2021JA029524. https://doi.org/10.1029/2021JA029524
3. Němec, F., Santolík, O., & Parrot, M. (2021). Doppler shifted Alpha transmitter signals in the conjugate hemisphere: DEMETER spacecraft observations and raytracing modeling. Journal of Geophysical Research: Space Physics, 126, e2020JA029017. https://doi.org/10.1029/2020JA029017
4. Němec, F., Hajoš, M., Parrot, M., & Santolík, O. (2021). Quasiperiodic emissions and related particle precipitation bursts observed by the DEMETER spacecraft. Journal of Geophysical Research: Space Physics, 126, e2021JA029621. https://doi.org./10.1029/2021JA02962
5. Grison, B., Santolík, O., Lukačevič, J., & Usanova, M. E. (2021). Occurrence of EMIC waves in the magnetosphere according to their distance to the magnetopause. Geophysical Research Letters, 48, e2020GL090921. https://doi.org/10.1029/2020GL090921
6. Bezděková, B., Němec, F., Parrot, M., Kruparova, O., & Krupar, V. (2021). Using principal component analysis to characterize the variability of VLF wave intensities measured by a low-altitude spacecraft and caused by interplanetary shocks. Journal of Geophysical Research: Space Physics, 126, e2021JA029158. https://doi.org/10.1029/2021JA029158
7. Hanzelka, M., Santolík, O., Omura, Y., & Kolmašová, I. (2021). Measurability of the nonlinear response of electron distribution function to chorus emissions in the Earth's radiation belt. Journal of Geophysical Research: Space Physics, 126, e2021JA029624. https://doi.org/10.1029/2021JA029624

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

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

The D-region ionospheric response during the lifespan (10–19 December 2020) of a recent severe category 5 tropical cyclone (TC) Yasa in the South Pacific was analysed by using the very low frequency (VLF, 3-30 kHz) signals from NPM, NLK, and JJI transmitters recorded at Suva, Fiji. Results indicate enhanced lightning and convective activity in all three regions (eyewall, inner rainbands, and outer rainbands) during the TC Yasa. Prominent eyewall lightning was observed just before the TC started to weaken following its peak intensity. Analysis of VLF signal amplitudes showed both negative and positive perturbations (amplitudes exceeding ±3σ mark) lasting for more than 2 hours with maximum change in the daytime and nighttime signal amplitudes of -4.9 dB (NPM) and -19.8 dB (NLK), respectively. The signal perturbations were wave-like, exhibiting periods of oscillations between ~2.2-5.5 hours as revealed by the Morlet wavelet analysis.

The waveguide model analysis of four VLF transmitter signals: 1) NWC, Australia (19.8 kHz), 2) NPM, Hawaii (21.4 kHz), 3) JJI, Elbino, Japan (22.2 kHz) and 4) NLK, Seattle, USA (24.8 kHz) propagating over long propagation paths to Suva, Fiji, has been carried out using the VLF amplitude and phase data recorded during 2014. The Transmitter Receiver Great Circle Path distances to the receiving station are 6.69 Mm for NWC, 5.07 Mm for NPM, 7.50 Mm for JJI and 9.43 Mm for NLK transmitter signal. Our results show good consistency between experimental and theoretical values of waveguide mode parameters for the west-east (W-E) (NWC/JJI-Suva) and east-west (E-W) (NLK/NPM-Suva) component of the VLF propagation paths. The waveguide mode parameters estimated in our work were found to be higher for the E-W component of the VLF propagation path compared to the W-E component path. We have also employed Long Wave Propagation Capability (V2.1) code to estimate the daytime and nighttime signal strength and daytime to nighttime signal strength ratio (EDN) for all four VLF transmitter signals.

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

For other 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:

Atishnal Elvin Chand, Sushil Kumar (2021), Earth-ionosphere waveguide model parameters using very low frequency transmissions received in the South Pacific Region. IEEE Access, Vol, 9, 56653-56663, https://doi.org/10.1109/ACCESS.2021.307213

Kerrache, F., Nait Amor, S., & Kumar, S. (2021). Ionospheric D region disturbances due to FAC and LEP associated with three severe geomagnetic storms as observed by VLF signals. Journal of Geophysical Research: Space Physics, 126, e2020JA027838. https://doi.org/10.1029/2020JA027838

Ashneel Chandra and Sushil Kumar (2021), Sea Surface Temperature and Ocean Heat Content during Tropical Cyclones Pam (2015) and Winston (2016) in the Southwest Pacific Region, Monthly Weather Review, 149, 1173-1187. https://doi.org/10.1175/MWR-D-20-0025.s1

Ashneel Saran and Sushil Kumar (2021), Long-term trends of the F2-region at mid-latitudes in the Southern Hemisphere, Journal of Atmospheric and Solar-Terrestrial Physics, 220, 10,5683. https://doi.org/10.1016/j.jastp.2021.105683

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

Winter 2020-2021 ELF-VLF campaign started on 14 September 2020 and ended on 27 May 2021. The campaign had no long breaks at all. This autumn we started our campaign just on 7 September 2021 because we wanted to have ELF-VLF data during HEMERA balloon campaign launched from ESRANGE, Kiruna, Sweden. Current plan is to continue recordings over the summer 2022.

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

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

Due to Covid-19 pandemic our colleagues have not been able to visit SGO before July, when borders were gradually opened. However, the number of peer-reviewed papers during this year was reasonably good, because of 11 published papers listed in references. Also a lot of different activities have been planned for after-pandemic era.

10th VERSIM Workshop will be organised by Sodankylä Geophysical Observatory in Sodankylä area on 7-11 November 2022. We will also organise 2 days VERSIM school just before the Workshop (5-6 Nov 2022). Both school and workshop will be held in hybrid mode. Workshop web pages will be published in January 2022.

References:

1. Artemyev, A.V., A.G. Demekhov, X.-J. Zhang, V. Angelopoulos, D. Mourenas, Yu. V. Fedorenko, J. Manninen, E. Tsai, C. Wilkins, S. Kasahara, Y. Miyoshi, A. Matsuoka, Y. Kasahara, T. Mitani, Y. Shoichiro, K. Keika, T. Hori, S. Matsuda, S. Nakamura, M. Kitahara, T. Takashima, and I. Shinohara (2021). Role of ducting in relativistic electron loss by whistler-mode wave scattering. J. Geophys. Res., Space Physics, 127, e2021JA029851 https://doi.org/10.1029/2021JA029851

2. Demekhov, A.G., E.E. Titova, J. Manninen, A.S. Nikitenko, and S.V. Pilgaev (2021). Short-periodic VLF emissions observed simultaneously by Van Allen Probes and on the ground. Geophysical Research Letters, 48, e2021GL095476 http://dx.doi.org/10.1029/2021GL095476

3. Kolmašová, I., O. Santolík, P. Kašpar, M. Popek, A. Pizzuti, P. Spurný, J. Borovička, J. Mlynarczyk, J. Manninen, E.L. Macotela, P. Zacharov, R. Lán, L. Uhlíř, G. Diendorfer, A. Bennett, M. Füllekrug, and R. Slosiar (2021). First observations of elves and their causative super bolts in a small-scale continental winter thunderstorm. Accepted in J. Geophys. Res., Atmos.

https://doi.org/10.1029/2020JD032825

4. Macotela, E.L., M. Clilverd, T. Renkwitz, J. Chau, J. Manninen, and D. Banys (2021). Spring-fall asymmetry in VLF amplitudes recorded in the North Atlantic region: the fall-effect. Geophys. Res. Lett., 48, e2021GL094581 https://doi.org/10.1029/2021GL094581

5. Manninen, J., N. Kleimenova, T. Turunen, A. Nikitenko, L. Gromova, and Yu. Fedorenko (2021). New type of short high-frequency VLF patches ("VLF birds") above 4-5 kHz. J. Geophys. Res., Space Physics, 126, e2020JA028601. https://doi.org/10.1029/2020JA028601

6. Martinez-Calderon, C., Y. Katoh, J. Manninen, O. Santolik, Y. Kasahara, S. Matsuda, A. Kumamoto, F. Tsuchiya, A. Matsuoka, M. Shoji, M. Teramoto, I. Shinohara, K. Shiokawa, and Y. Miyoshi (2021). Multi-event study of ELF/VLF propagation using Kannuslehto and Arase conjuctions. J. Geophys. Res., Space Physics, 126, e2020JA028682. https://doi.org/10.1029/2020JA028682

7. Martinez-Calderon C., J.K. Manninen, J.T. Manninen, and T. Turunen (2021). A review of unusual VLF bursty-patches observed in Northern Finland. Earth, Planets and Space, 73:191

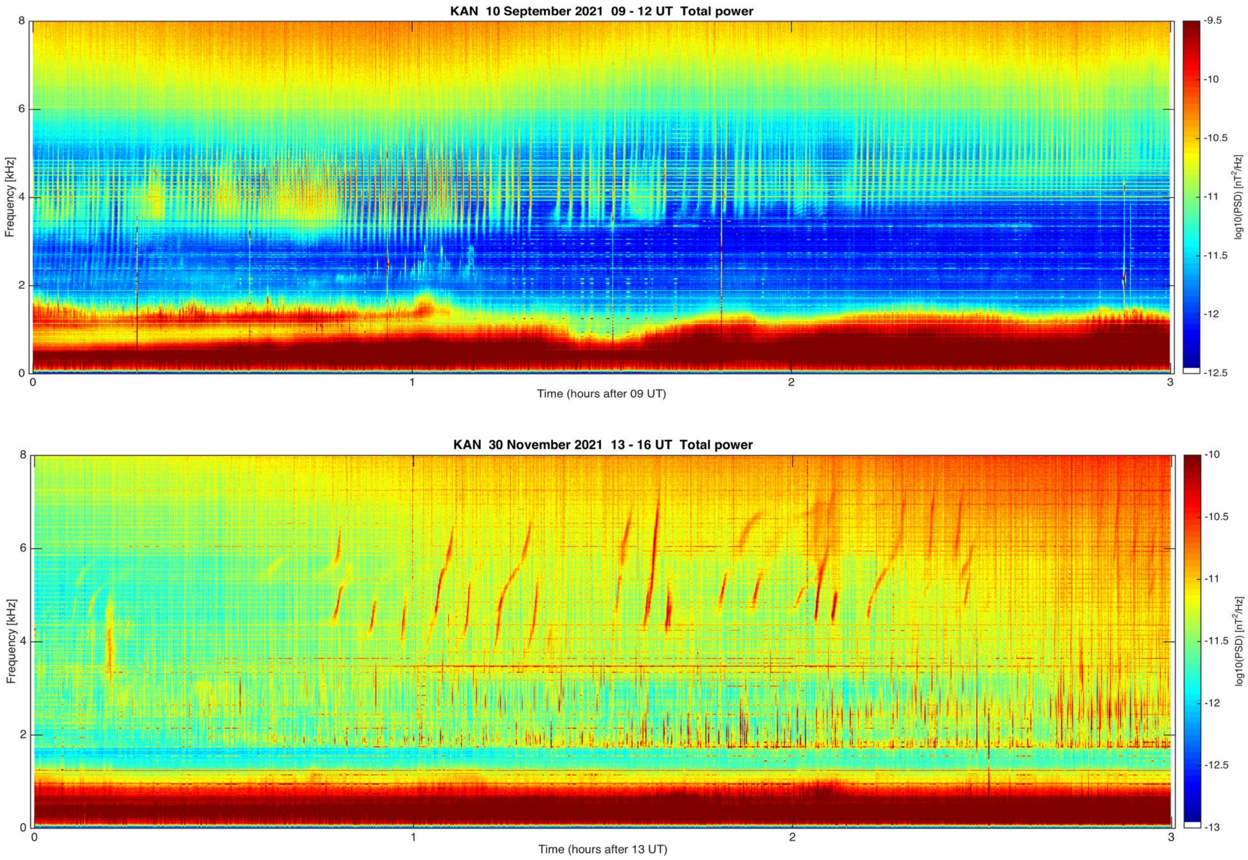
https://doi.org/10.1186/s40623-021-01516-y

8. Nikitenko, A.S., O.M. Lebed, Yu.V. Fedorenko, J. Manninen, N.G. Kleimenova, and L.I. Gromova (2021). Estimating the size and location of the region of scattering of the auroral hiss, according to data from high-latitude observations at three separated points. Bulletin of Russian Academy of Sciences: Physics, 85, No 3, 287-291, https://doi.org/10.3103/S1062873821030187

9. Tacza, J., K.A. Nicoll, E. Macotela, M. Kubicki, A. Odzimek, and J. Manninen (2021). Measuring global signals in the potential gradient at high latitude sites. Frontiers in Earth Science 8:614639. https://doi.org/10.3389/feart.2020.614639

10. Takeshita, Y., K. Shiokawa, Y. Miyoshi, M. Ozaki, Y. Kasahara, S.-I. Oyama, M. Connors, J. Manninen, C.A. Kletzing, V. Jordanova, D. Baishev, A. Oinats, and V. Kurkin (2021). Study of spatiotemporal development of global distribution of magnetospheric ELF/VLF waves using ground-based and satellite observations, and RAM-SCB simulations, for the March and November 2017 storms. J. Geophys. Res., Space Sci, 126, e2020JA028216. https://doi.org/10.1029/2020JA028216

11. Yahnina, T.A., A.G. Yahnin, T. Raita, J. Manninen, and J. Goldstein (2021). Localizing sources of Pc1



Two 3-hour examples of this autumn events. Upper panel presents daytime QP event on 10 Sep 2021 in frequency range of 0-8 kHz. Lower panel shows afternoon VLF bursty-patches on 30 Nov 2021 in frequency range of 0-8 kHz.

geomagnetic pulsations. Bulletin of Russian Academy of Sciences: Physics, 85, 287-291. https://doi.org/10.3103/S1062873821030308

There were also several oral and poster presentations held in PWING-ERG Conference and School, JpGU, and URSI GASS in 2021.

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

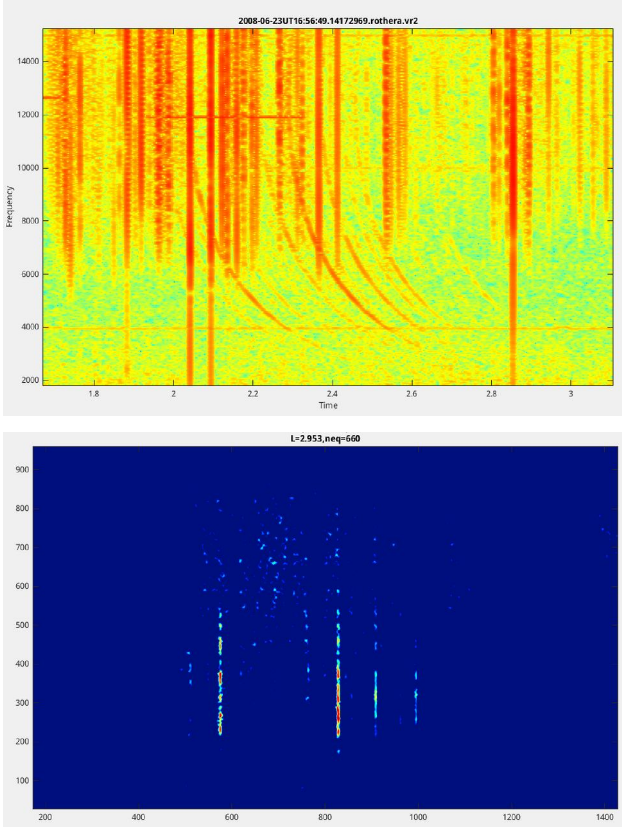
Our group continued the theoretical modeling and model-calculations of monochromatic and transient (Ultra Wide Band) electromagnetic signals and are seeking a solution of the electromagnetic wave propagation in general relativistic situations (coupled solution of the Maxwell and Einstein equations).

We have continued the development of Trabant and Chibis-AI mission with Russian partners and started the preparation of Obstanovka Phase-2 experiment for International Space Station, will extend the Obstanovka Phase-1 experiment [1] with three autonomous buoys placed to the far ends of ISS structure, allowing 3D wave tomography in VLF-LF bands.

This year, our major task was to continue the PLASMA project with the European Space Agency to develop plasmaspheric products for ESA Space Situational Awareness Programme using densities derived from AWDANet VLF and EMMA magnetometer network data as well as in-situ density data. The method of the derivation of equatorial electron density from whistlers to generate products for the project is now based on the reduction to sferic method, which is the"backpropagation" or "de-chirping" of the whistler to the originating sferic.

Reference:

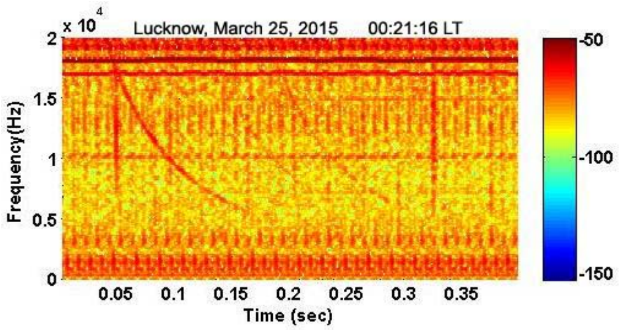
Klimov S.I., GRUSHIN Valery, BALAJTHY Kalman, BACHVAROV Dichko, Belyayev Serhiy, BERGMAN Jan, FERENCZ Csaba, GEORGIEVA Katya, GOUGH Michael, BELIKOVA Alla, BELYAKOVA Lyudmila, GRECHKO Tatiana, KONOSHENKO Viktor, KOREPANOV Valery, KIROV Boyan, LAPSHINOVA Olga, LICHTENBERGER János, MARUSENKOV Andriy, MORAWSKI Marek, SZEGEDI Péter (2021): Studying of space weather electromagnetic parameters of ionosphere in «Obstanovka 1-step» experiment on the Russian segment of the ISS Space Engineering and Technology 2021:1pp. 20-41. , 22 p. DOI: 10.33950/spacetech-2308-7625-2021-1-20-41



An example of the reduction to sferic method. (top) Original spectrogram of a multiple-stroke whistler group, (bottom) spectrogram of the de-chirped signal, where the whistler traces are transformed to sfrerics.

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

Whistlers (dispersed form of electromagnetic signal propagating along geomagnetic field lines through the magnetosphere) and tweeks (propagated into earth-ionosphere waveguide) yield information about medium parameters such as electron density, total electron content in a flux tube, electron temperature, electric field, etc. These parameters are successfully being used in remote sensing of upper atmosphere. In comparison to mid/high latitudes, the estimation of these parameters at low latitudes are not well documented, may be due the occurrence rate is large only during magnetic storm periods (when field aligned irregularities are enhanced) and they suffer from severe propagation conditions such as shorter path length, larger curvature gradients in the embedded magnetic field, duct excitation, trapping into and leakage from the ducts, duct spacings, ionospheric transmission and so on. As earlier, our group is still active in the study of ELF/VLF waves.



Spectrogram of whistler recorded at our ground based station, Lucknow

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

When I wrote this report in 2020 I expected that sometime in 2021 I would have the chance to meet members of the VERSIM community in person. While I understand some in-person international meetings have occurred, the New Zealand border remained essentially closed for all of this year, and none of the Otago based group has been able to physically attend. Three of us did go to Antarctica in November/December 2021, to work on our narrow-band (AARDDVARK) and wideband (WWLLN) VLF receivers installed at and near Scott Base. This required two weeks of isolation before departure from New Zealand, to keep COVID off the ice.

In 2021 we were able to attend some national in person meetings (the New Zealand Antarctic Science Conference and New Zealand Institute of Physics), but contact with the international community has been online only. A lot of effort and focus has gone into our new Solar Tsunami's research programme, focused on Space Weather impacts on energy networks, like power grids and gas pipelines. We now have a nifty new logo for that programme! The group is still active in radiation belt, D-region, and lightning research, collecting and analysing ground and space-based datasets.

SOLAR TSUNAMIS
PARAWHENUA KŌMARU

Despite the difficulties produced by COVID, we have a very good year for research outputs. I picked out three which span our more traditional VERSIM-linked activity:

[1] A Craig Rodger led paper looking at how trapped electron fluxes in the radiation belts change after clusters of substorms, showing the importance of chorus waves;

[2] An update on our earlier work showing how subionospheric VLF observations can be used to nowcast the magnitude of solar flares, and contrasting a "medium" length west to east path (NAA to SGO) with a "long" north to south path (NPM to Scott Base). The longer path produced better quality fits;

[3] Aaron Hendry's GRL which used GPS data to show how EMIC waves can lead to decreases in medium energy trapped electrons in the radiation belts (i.e., 100's of keV), as well as relativistic and ultra-relativistic electrons.

The Otago Space Physics Group updated our team picture on 30 July 2021. Shown in the photo from left to right: Ryan Davis, Daniel Mac Manus, Annika Seppälä, Zade Johnston, Chris Hill, Aaron Hendry, Romain Meyrand, Neil Thomson, Keeta Chapman-Smith, Craig Rodger, Anna Tarr, Jono Squire, Malcolm Crack, and Sam Belcher. Unfortunately, James Brundell had a prior commitment and could not attend the photo this year.

References:

1. Rodger, C. J., A. T. Hendry, M. A. Clilverd, C. Forsyth, and S. Morley (2021), Examination of Radiation Belt Dynamics during Substorm Clusters: Activity Drivers and Dependencies of Trapped Flux Enhancements, J. Geophys. Res., 126, e2021JA030003, https://doi.org/10.1029/2021JA030003 (in press).

2. Belcher, S. R. G., M. A. Clilverd, C. J. Rodger, S. Cook, N. R. Thomson, J. B. Brundell, and T. Raita (2021), Solar flare X-ray impacts on long subionospheric VLF paths, Space Weather, 19, e2021SW002820. https://doi.org/10.1029/2021SW002820

3. Hendry, A. T., C. J. Rodger, M. A. Clilverd, and S. Morley (2021), Evidence of sub-MeV EMIC-driven trapped electron flux dropouts from GPS observations,

Geophys. Res. Lett., 48, e2021GL092664. https://doi.org/10.1029/2021GL092664

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

We obtained new results of a theoretical study on the problem related to the VLF chorus excitation in the marginally stable daytime magnetosphere. This report is based on the joint papers of P.A. Bespalov with O.N. Savina (National Research University Higher School of Economic, Russia), and A.V. Savilov (Institute of Applied Physics RAS, Nizhny Novgorod, Russia). The papers we have published are characterized by the following abstracts.

We examined [1] the possibility of strong amplification of appropriate weak electromagnetic pulse in a magnetized plasma layer. Amplification occurs with the rate of instability of the hydrodynamic type through the beam plasma amplifier mechanism (BPA). This mechanism provide the excitation of intense rapidly changing radiation at an extraordinary plasma mode without a significant anisotropy of the distribution function. In a plasma with an nearly stable distribution of particles in the velocity space, the gain of radiation is determined by the plasma thermal to magnetic pressure ratio. Our simulations indicate the importance of the beam plasma amplifier mechanism for the interactions of active particle cloud with electromagnetic waves. Actually, a fraction of plasma shot noise can sharply amplify and turn into intense rapidly changing discrete emissions. Discrete emissions can be excited in the form of VLF chorus in the Earth's magnetosphere.

Cherenkov interaction between a wave pulse and a flow of electrons possessing a very wide velocity spread was considered [2]. We showed that if the wave pulse is short enough, and its group velocity is close to the phase velocity, then the effect of the slippage of the resonant electrons with respect to the wave pulse leads to the transformation of an inert electronic medium into an active one (absorbing or amplifying the wave pulse, depending on the slippage sign). This can be a mechanism of formation of short powerful electromagnetic pulses as a result of amplification of short-pulse weak noises by electron flows which, due to natural reasons, have a large velocity spread, namely, electron flows in the magnetosphere of planets.

References:

1. Bespalov, P.A. and Savina, O.N. (2021). Electromagnetic pulse amplification in a magnetized nearly stable plasma layer. Results in Physics, 28, 104607. https://doi.org/10.1016/j.rinp.2021.104607
2. Bespalov, P.A. and Savilov, A,V. (2021). Amplification of a slipping quasi-monochromatic wave pulse by an electron flow with a wide velocity spread. Physics of Plasmas, 28, 093303. https://doi.org/10.1063/5.0062652

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

We have been continuing studies of wave phenomena and wave-particle interactions in the magnetosphere, as a joint group from the two institutes (PGI and IAP RAS), in close collaboration with our VERSIM Colleagues. Below I mention only three selected results of these studies.

We found an event with simultaneous observations of VLF emissions with short-periodic bursts by Van Allen Probe near geomagnetic equator and Kannuslehto and Lovozero ground-based sites [Ref. 2 in Jyrki Manninen's report]. The repetition period and ground--spacecraft delay were consistent with guided whistler wave propagation between conjugate ionospheres. In contrast to lightning whistlers, the group velocity dispersion was not accumulated from one burst to another, thus implying a nonlinear mechanism of its compensation. Two regimes were observed. In one regime, Poynting flux direction alternates in the magnetosphere, and the burst period (2 s) is half of that detected on the ground (4 s), corresponding to a single wave packet bouncing along the field line. This regime is switched to the other one, with burst period unchanged in the magnetosphere but halved on the ground. In this second regime, no alternating Poynting flux direction is observed. The second regime corresponds to two symmetrically propagating wave packets synchronously meeting at the equator.

Jointly with our Japanese and US Colleagues, we analyzed the conditions of the EMIC wave generation and the dynamics of the wave source during a substorm event using a unique configuration of three spacecraft (Arase and two Van Allen Probes). All spacecraft were at approximately the same distance from the Earth, forming a chain across the evening local time sector. Analyzing parameters of the wave generation obtained from in situ measured proton distribution function, we came to the conclusion that the waves could be generated within the substorm area, sometimes close to, but not necessary at the spacecraft location. As the substorm expands in longitude, the EMIC wave source exhibits a longitudinal drift. When substorm expansion stops, the wave generation region expands due to the magnetic drift of protons injected during the substorm. The observed wave properties showed that the waves were able to precipitate energetic protons into the atmosphere. This was confirmed by observations of low orbiting satellites measuring proton precipitating fluxes.

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

References:

1. Yahnin, A. G., Popova, T. A., Demekhov, A. G., Lubchich, A. A., Matsuoka, A., Asamura, K., et al. (2021). Evening side EMIC waves and related proton precipitation induced by a substorm. Journal of Geophysical Research: Space Physics, 126, e2020JA029091. https://doi.org/10.1029/2020JA029091

2. Grach V. S., Demekhov A. G., Larchenko A. V. (2021). Resonant interaction of relativistic electrons with realistic electromagnetic ion–cyclotron wave packets, Earth, Planets and Space, 73, No.6. 129. https://doi.org/10.1186/s40623-021-01453-w

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

This report is from D.R. Shklyar, E.E. Titova. N.S. Artekha, and A.A. Luzhkovskiy.

Our research activities in 2021 were directed to investigation of resonant interactions between whistler-mode waves of various types and energetic electrons in the magnetosphere.

1. Magnetospherically reflected whistlers are one of the fascinating wave phenomena that originate from lightnings. Their interaction with magnetospheric plasma particles is of interest and importance. We have developed a theory that includes the main features of this interaction, namely, the space-time boundedness of wave packets representing magnetospherically reflected whistlers, and the variation of frequency, wave normal vector, and amplitude inside wave packets. Also included into consideration are the inhomogeneity of the ambient plasma and the geomagnetic field, as well as relativistic effects in particle dynamics. A particular emphasis has been placed on energy exchange between resonant particles as an intrinsic component part of wave-particle interaction in plasma.

2. Theoretical and experimental studies of the role of ground-based VLF transmitters in dynamics of energetic electrons of the Earth's radiation belts has been studied for decades. Resonant interaction of electrons with the transmitter signals leads to scattering of electrons in pitch angles, because of which part of them falls into the loss cone and precipitates into the atmosphere. Another possible effect of this interaction is the energy increase of some of the resonant electrons. Most of the research in the indicated direction was reduced to the analysis of particle motion in the field of transmitter signal, which was given, thus, the back effect of resonant particles on the wave field was not taken into account. As we have shown, considering this effect leads to results that differ significantly from those obtained in the approximation of a given field.

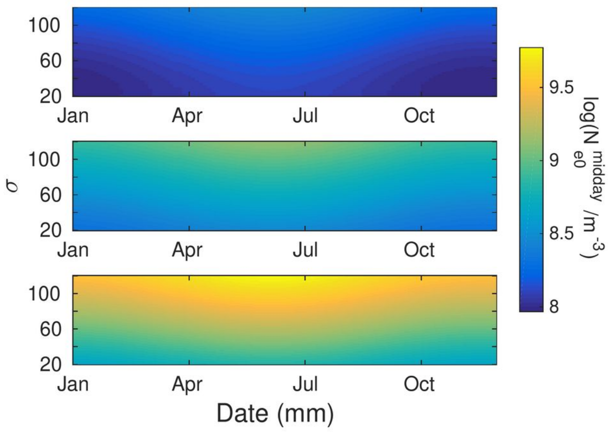
3. A method has been developed for solving the dispersion equation for whistler waves propagating along the external magnetic field, for the case when the distribution function is set numerically from satellite measurements of differential particle fluxes. This method does not imply a small growth (damping) rate in comparison with the wave frequency and allows the numerical specification of the distribution function. From a mathematical point of view, the difference, which allows us to remove the restriction on the smallness of the growth rate consists in the fact that for the analytic continuation of the velocity integral defining the dispersion equation, we use not the displacement of the contour of integration into the complex plane, but the principle of continuity. In this case, the integration with respect to velocity is always carried out along the real axis, on which the distribution function and its moments are given.

Reference:

Shklyar, D. R. (2021). A theory of interaction between relativistic electrons and magnetospherically reflected whistlers. Journal of Geophysical Research: Space Physics, 126, e2020JA028799. https://doi.org/10.1029/2020JA028799

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

We continued to analyze the data recorded by the VLF/LF receivers located in the Institute of Physics in Belgrade. We developed the Quiet Ionospheric D-region (QIonDR) model [1] which provides a procedure for determination of Wait's parameters on the sunspot number and season at midday, and determination of time evolution of these parameters during daytime. The upgrade of this model which gives procedure for the determination of quiet ionosphere parameters relating to the analysed area and the considered time period, and, consequently, allows for a more precise modelling of the D-region intensively perturbed by a solar X-ray flare is presented in [2]. Investigation of the solar X-ray flare disturbed D-region on propagation of a satellite signal is continued by research of its influence on SAR meteorology [3]. Finally, we continued investigation of VLF signal properties in the period before earthquakes and show that, similar like in the case of the amplitude, phase noise reduction started less then one hour before the four earthquakes of magnitudes greater than 4 [4].



QIonDR model: Dependencies of the electron density Ne at the altitudes of 70 km (upper panel), 75 km (middle panel), and 80 km (bottom panel) on season and the smoothed daily sunspot number σ.

During this year we continue activities in the European VLF/LF network INFREP, EUROPLANET and within the COST action "Atmospheric Electricity Network: coupling with the Earth System, climate and biological system" (we participated in organization of final meeting of this Action).

We participated in several international conferences and worked as Guest editors in the Special Issues of Frontiers in Environmental Sciences, Remote Sensing and Atmosphere: "Atmospheric disturbances: responses to phenomena from lithosphere to outer space," (Eds. Aleksandra Nina, Boško Milovanović, Slavica Malinović Milićević and Sergey Pulinets), "Extraterrestrial Influences on Remote Sensing in the Earth's Atmosphere" (Eds. Aleksandra Nina, Milan Radovanović and Luka Popović), and "Atmospheric Disturbances: Detecting, Modelling and Influences on Natural Phenomena and Propagation of Telecommunication, GNSS and EO Signal Propagation" (Eds. Aleksandra Nina, Giovanni Nico and Vladimir Srećković).

References:

1. Nina, A., G. Nico, S.T Mitrović., M. Radovanović and L.Č. Popović (2021), Quiet Ionospheric D-Region (QIonDR) Model Based on VLF/LF Observations, Remote Sens. 13, 483, https://doi.org/10.3390/rs13030483

2. Nina, A. (2021), Modelling of the electron density and total electron content in the quiet and solar X-ray flare perturbed ionospheric D-

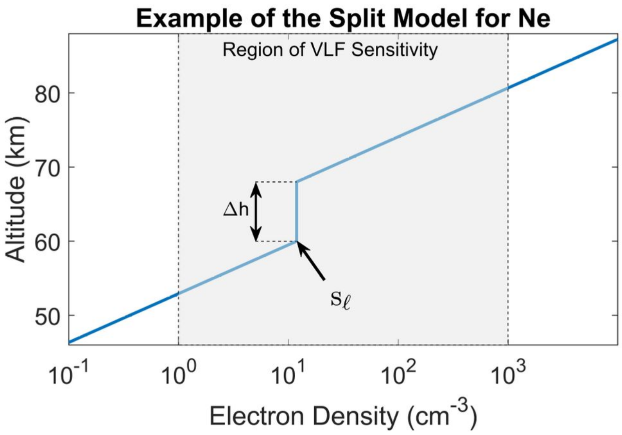
region based on remote sensing by VLF/LF signals, Remote Sens., accepted paper

3. Nina A., J. Radović, G. Nico, L. Č. Popović, M. Radovanović, P. F. Biagi and D. Vinković (2021), The Influence of Solar X-ray Flares on SAR Meteorology: The Determination of the Wet Component of the Tropospheric Phase Delay and Precipitable Water Vapor, Remote Sens. , 13, 2609. https://doi.org/10.3390/rs13132609

4. Nina, A., S. Pulinets, P.F. Biagi, G. Nico, S.T. Mitrović, M. Radovanović, L.Č. Popović (2021), Reduction of the VLF Signal Phase Noise Before Earthquakes, Atmosphere, 12, 444. https://doi.org/10.3390/atmos12040444

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

Let me first say that the WALDO database (http://waldo.world) is continuing to grow and add data. We are nearing 450 TB and have recently added a large amount of Siple Station experiment data from the 1970s and 1980s. It is available for anyone to download, free. If the online web interface is not sufficient so well or if you need wider access to a larger number of files for “Big Data” type analysis, please contact myself (mcohen@gatech.edu) or Mark Golkowski (mark.golkowski@ucdenver.edu), as we do have a way to make larger-scale data available to you.



The new 4-parameter ionosphere introduced by McCormick and Cohen [2021].

This year we continued our work in several areas, but amongst our papers this year, the ones we will highlight here are three, cited below, that relate to D-region ionospheric remote sensing with VLF.

McCormick and Cohen [2021] introduced a 4-parameter ionosphere, expanding the two-parameter Wait and Spies parameter to include the `ledge' that is visible in rocket data. Broadband sferics can be used to infer the four parameters, from which it is evident that the ledge is present during the daytime, but at nighttime a Wait-Spies ionosphere appears to be sufficient. An example of the model and its application to a full day of data are shown below.

Worthington and Cohen [2021] used DEMETER survey mode data to estimate the ionospheric Wait and Spies parameters, using the spatial pattern as the satellite flew over the NWC transmitter. In particular, the peaks and nulls of the transionospheric signal appeared to be a reliable indicator of the ionospheric state, at least in the region around the transmitter.

Richardson and Cohen [2021] expanded a previous machine learning model of D-region remote sensing with ground VLF receiver signals from VLF transmitters, as described by Gross et al [2020]. The new model now includes nighttime estimates and expands to dozens of days, allowing seasonal trends to be observed for mid latitudes.

We also published a more engineering-oriented paper describing a new antenna technique to generate low frequency waves with a time-varying antenna, but that's more outside the scope of VERSIM.

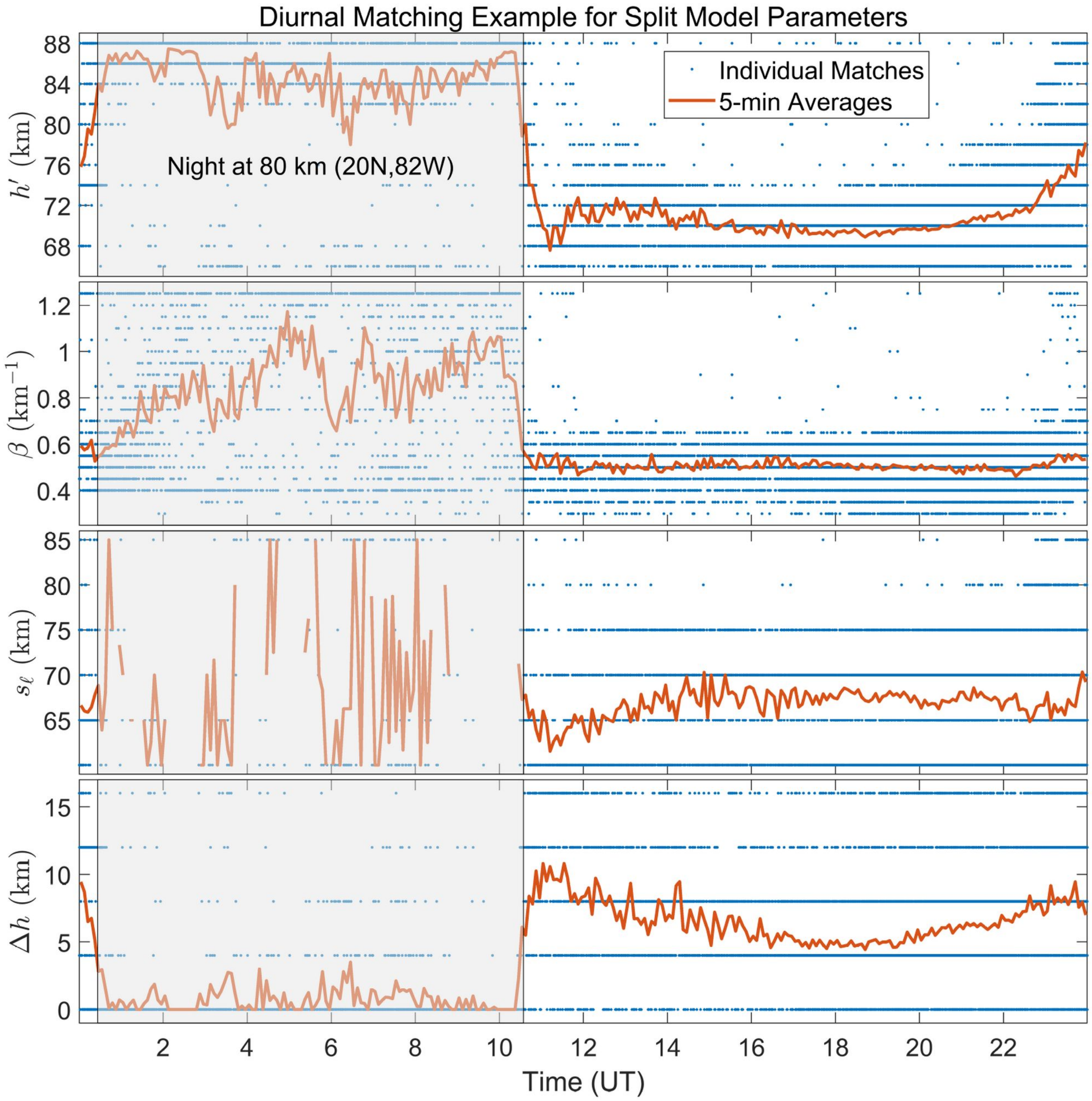
Wishing everyone a happy and healthy 2022, and we look forward to future collaborations!

References:

McCormick J. C., M. B. Cohen (2021), A new four-parameter D-region Ionospheric Model, Journal of Geophysical Research Space Physics, https://doi.org/10.1029/2021JA029849

Richardson D., M. B. Cohen (2021), Seasonal Variation of the D-region Ionosphere: Very Low Frequency (VLF) and Machine Learning Models, Journal of Geophysical Research Space Physics, https://doi.org/10.1029/2021JA02689

Worthington E., M. B. Cohen (2021), The Estimation of D-Region Electron Densities from Trans-ionospheric VLF Signals, Journal of Geophysical Research Space Physics, https://doi.org/10.1029/2021JA029256



24 hours of 4-parameter ionospheric remote sensing using sferics, from McCormick and Cohen [2021]

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

A few topics dominated the research of the UCLA Bortnik group this year: the application of machine learning (ML) techniques to Earth and space science problems has been gaining attention in the community and in response we have published a short opinion piece in Eos giving ten suggestion for applying ML in practical situations [Bortnik & Camporeale, 2021]. We have also developed a ML model of radiation belt fluxes [Chu et al., 2021] driven only be solar wind parameters and geomagnetic indices, which has now been deployed in real-time through our industry partners (spacewx.com). Plasmaspheric hiss continues to be a topic of fascination for our group, for both practical and scientific purposes. Aryan et al. [2021] developed a multiparameter model of chorus and hiss, Meredith et al. [2021] used a statistical database to show the connection between chorus and hiss at medium frequencies (~.1-2 kHz), and Fu et al. [2021] shows that hiss triggered by an interplanetary shock event appeared from multiple sources. A final topic of interest is wave-particle interactions in the magnetosphere, and in particular transitions between linear and nonlinear regimes. This was elegantly discussed in a book chapter by Thorne et al. [2021] (initiated by R. Thorne, and completed by J. Bortnik posthumously), and in the application to Landau-trapped electrons by kinetic Alfven waves leading to TDSs was studied by An et al. [2021].

We were excited to have successfully launched the VLF Trans-Ionospheric Propagation Experiment Rocket (VIPER) at 0115 UT, 27 May 2021, the first results of which were shown at the 2021 Fall AGU. Finally, J. Bortnik was humbled to receive the AGU Joanne Simpson Medal for Mid-Career Scientists at the 2021 Fall AGU, an award that rightfully belongs to the tremendously gifted friends and collaborators that he has had the honor to work with over the years.

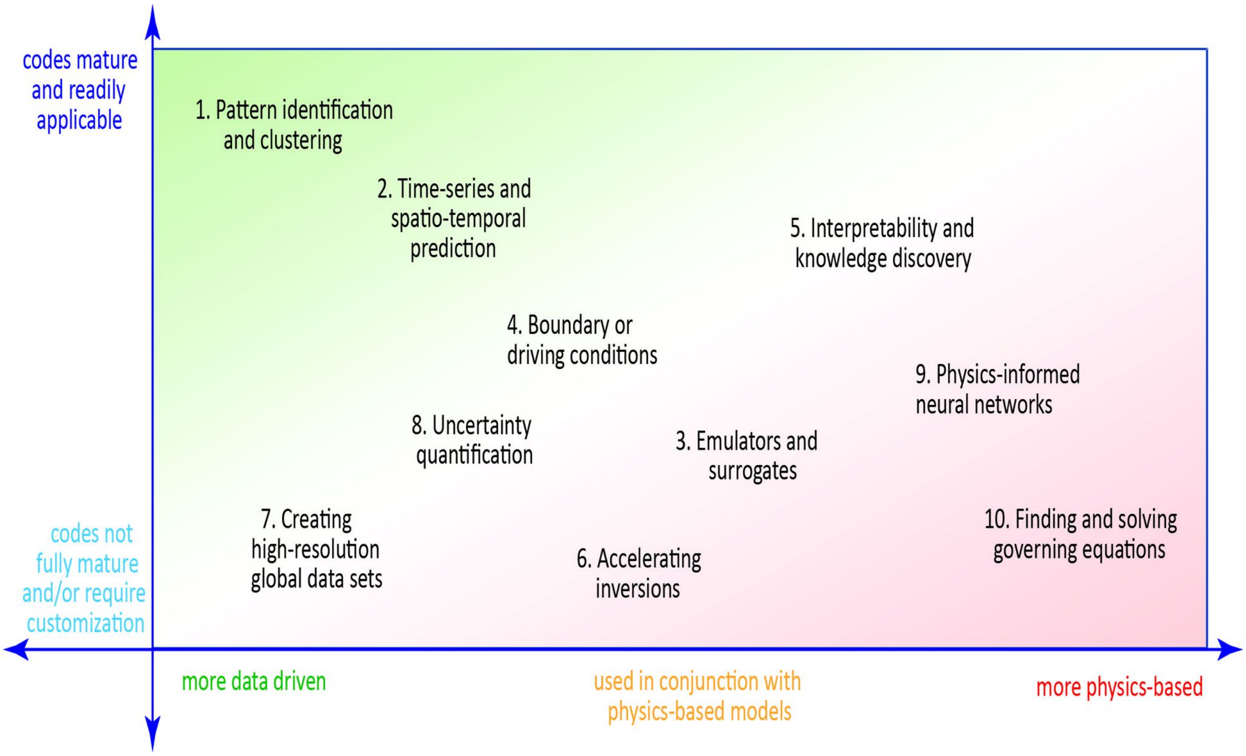
References:

1. Bortnik, J., & E. Camporeale (2021), Ten ways to apply machine learning in Earth and space sciences, Eos, 102, https://doi.org/10.1029/2021EO160257. Published on 29 June 2021.
2. Thorne, R. M., J. Bortnik, W. Li, and Q. Ma (2021), Wave-Particle Interactions in the Earth's Magnetosphere, Space Physics and Aeronomy, Volume 2, Magnetospheres in the Solar System. Romain Maggiolo (Editor), Nicolas André (Editor), Hiroshi Hasegawa (Editor), Daniel T. Welling (Editor), Yongliang Zhang (Editor-in-Chief), Larry J. Paxton (Editor-in-Chief). Geophysical Monograph Series, Vol. 259. ISBN: 978-1-119-50752-9, 800 pp. American Geophysical Union, Wiley, 2021, p.93
3. An, X., Bortnik, J., & Zhang, X.-J. (2021). Nonlinear Landau resonant interaction between kinetic Alfvén waves and thermal electrons: Excitation of time domain structures. Journal of Geophysical Research: Space Physics, 126, e2020JA028643. https://doi.org/10.1029/2020JA028643

VERSIM JOURNAL CLUB (INTERNATIONAL): Report prepared by Miroslav Hanzelka (mha@ufa.cas.cz), IAP CAS, Czechia; Lilla Juhász (lilla@sas.elte.hu), Eötvös U., Hungary; and Claudia Martinez-Calderon (claudia@isee.nagoya-u.ac.jp), ISEE, Nagoya U., Japan.

The VERSIM Journal Club (JC) is a platform for discussion between early-career scientists and senior scientists working in space physics. It was established during the 2018 VERSIM workshop in Apatity to help young scientists keep in touch in between workshops, and encourage informal discussion on topics related to the recent research and development in the community. During the online meetings of the JC, which take place approximately every month, a member of the group or a guest scientist presents new research results or reviews recent papers.

Since the foundation in April 2018, we have hosted 33 online presentations. Nine of those have taken place in 2021, with two special guests, Mark Gołkowski and Mark Clilverd. The students and early career scientists joining our sessions



(After Bortnik & Camporeale, 2021, Fig 1.) Ten ideas for applying ML in the Earth and space sciences, roughly organized by the degree of involvement of physics-based models (horizontal scale) and the degree to which ML codes are available and readily applicable versus being in development and requiring significant customization (vertical scale).

come from various countries across Asia, America, Europe and Oceania. We want to thank all our guests and attendees even though the schedule was not favourable for their time zone. We hope to expand our audience to all continents and to developing countries.

The topics of talks given in 2021 spanned a broad range of areas. Some of them were traditional and important VERSIM topics: ELF remote sensing of ionosphere and magnetosphere, ELF/VLF ground observations, connections between magnetosphere and atmosphere, identifying the source region of whistlers, and generation and spectral properties of EMIC waves. We also listened to interesting talks on new and exciting subjects: imaging of the STEVE auroras, auroral beats associated with chorus spectral structure, and the implications of geomagnetic perturbations for space weather. We are happy to report that each presentation was followed by a long and fruitful discussion, and we hope to see more people joining and exchanging their know-how and ideas.

To further promote the interaction between young scientists, we created a Slack group, which is a set of discussion channels for both professional and informal discussion. This replaces our previous WhatsApp group. Anyone interested in joining the JC (mailing list or Slack) can contact us at versim.jc@gmail.com.

More information on the past sessions can be found on our webpage:
http://www.iugg.org/IAGA/iaga_ursi/versim/journal_club.html.