ULF Wave Modeling, Effects, and Applications Focus Group

Co-Chairs: Michael Hartinger, Kazue Takahashi, and Brian Kress

The "Ultra Low Frequency Wave Modeling, Effects, and Applications" (UMEA) focus group started this year. Our goal is to bring researchers in different areas together to address broad questions of interest to many GEM FG: What excites ULF waves? How do they couple to the plasmasphere/ring current/radiation belt? What is their role in magnetosphere-ionosphere coupling?

UMEA held four breakout sessions – one standalone and three joint with other focus groups – with more than 30 presentations plus a few walk-ins. All sessions were well attended with 62 signups to our mailing list. Two tutorials on ULF wave modeling and observations were also presented in the Friday morning GEM plenary session, providing background and motivation for future UMEA activities.

1. Introducing the UMEA focus group

This session focused on introducing the UMEA focus group, discussing outstanding questions in ULF wave research, and planning future activities. The co-chairs introduced themselves and the FG, with Michael Hartinger discussing this year's joint sessions, the ULF wave modeling challenge effort, and other activities. The rest of the session was devoted to presentations on recent progress and outstanding questions in ULF wave research.

Kazue Takahashi showed how recent multi-spacecraft observations provide us with a great opportunity to advance our understanding of the generation mechanisms of ULF waves in the ring current and the effects of the waves on particles. Mark Engebretson reported on new developments and unanswered questions regarding EMIC waves. Recent statistical studies based on observations from the Van Allen Probes are providing a somewhat different view of their occurrence in MLT and in location relative to the plasmapause than what has been observed at synchronous orbit. Limited satellite and ground-based coverage of these highly localized waves constitutes a major barrier to studies of the effect of these waves on ring current ions and radiation belt electrons. Allison Jaynes showed coordinated observations demonstrating the link between ULF waves, whistler mode chorus, and particle precipitation/pulsating aurora; more satellite-ground conjunction observations are needed to better understand the link between ULF waves and the aurora and the many ways ULF waves can modulate precipitation.

A common theme in these presentations was the value of coordinated investigations with multiple instruments placed on the ground and in situ. Toshi Nishimura presented results from past observational campaigns coordinating ground stations (radars, all sky imagers, ground magnetometers) and satellites to characterize ULF waves and their impact on the magnetosphere-ionosphere system; he further proposed a future campaign/ISR world day proposal for 2018 to examine dawn-asymmetries in ULF wave properties. Discussion after this talk revealed the most favorable satellite/ground configurations for addressing different science questions.

Most of the rest of the session focused on ULF wave modeling and data-model comparisons. Seth Claudepierre presented Pc3-5 ULF wave modeling (LFM) and observations (Van Allen

Probes), highlighting the important role that the plasmasphere plays in ULF wave dynamics. He argued that statistical ULF wave power maps from observations provide a benchmark for validating global MHD modeling of ULF waves. Scot Elkington discussed recent progress modeling ULF wave interactions with the radiation belt. Radial diffusion and test particle simulations have revealed much about these interactions, but many open questions remain. Measurements of several wave properties are needed to better understand/model the interactions: frequency spectrum, radial profile, azimuthal extent, propagation direction, azimuthal wave number, driving mechanism.

Finally, several walk-in talks occurred at the end of the session. Alexander Drozdov showed new modeling results comparing radiation belt responses using different radial diffusion coefficients. Xueling Shi showed a case study with coordinated observations of Pi2 pulsations from THEMIS spacecraft, ground magnetometers, and mid-latitude SuperDARN radars at a substorm onset, suggesting a global plasmaspheric virtual resonance. Peter Chi showed MMS satellite observations of ULF waves with very large azimuthal wave numbers, as well as observations of the global distribution of poloidal waves using a very large satellite constellation. Chih-Ping Wang presented a Pi2 event associated with a substorm onset, using THEMIS, GOES, RBSP, and ground magnetometers to investigate whether inner magnetospheric Pi2 is directly driven or excited by resonance, finding multiple lines of evidence consistent with cavity mode resonance.

2. Magnetospheric signatures of dayside transients

This session was joint with the "Dayside Kinetic Processes in Global Solar Wind-Magnetosphere Interactions" and "Transient Phenomena at the Magnetopause and Bow Shock and their Ground Signatures" FGs. There were 8 presentations, and throughout the session discussion topics included (1) preferred driving conditions/magnetopause perturbations for triggering different magnetospheric signatures and (2) modeling the ULF response to localized magnetopause indentations.

Slava Merkin presented results from the effort coupling the high-resolution version of the LFM global magnetosphere with Sasha Ukhorskiy's test particle simulation. The work was done primarily by Kareem Sorathia at JHU/APL and showed that losses of magnetospheric energetic particles (100 keV protons and O+ ions) at the magnetospheric flanks were enhanced by the well-developed Kelvin-Hemholtz instability. De-sheng Han discussed throat aurora, using statistical analysis to show that auroral features relate to scales of ~3RE in the equatorial plane and are the ionospheric signatures of the interaction of cold magnetospheric ions with dayside magnetopause reconnection. This implies that throat aurora may provide important information on studying the interaction of cold magnetospheric plasma with magnetopause reconnection. Boyi Wang discussed the driving mechanisms of poleward moving auroral forms (PMAFs) with coordinated all sky imager and satellite observations, showing a strong statistical relationship with southward turnings of the IMF (72%), with a response time of ~8 minutes. Boyi Wang also discussed the dayside auroral response on closed field lines to an IMF discontinuity, using multiple satellites in the dayside magnetosphere, magnetosheath, and solar wind. They associated the IMF discontinuity with a localized, propagating magnetopause compression, brightening/azimuthal propagation of dayside diffuse aurora, and localized magnetospheric ULF

waves with large amplitudes. Michael Hartinger discussed how the high-latitude ground magnetic response to an interplanetary shock depends strongly on the local ionospheric conductivity; inter-hemispheric comparisons from recently deployed Antarctic AAL-PIP magnetometers, Greenland magnetometers, and global MHD simulations show the response varies rapidly with location relative to the auroral oval. Hui Zhang presented HFA generated Pc3 ULF waves observed by multiple spacecraft and ground magnetometers. The ULF waves are standing Alfvén waves. The wave power of poloidal mode is stronger than that of toroidal mode. The Pc3 ULF waves were observed at dawn, noon and dusk sectors, indicating the magnetospheric response to the HFA is global. The goal of the work presented by Heli Hietala is to determine impact rates of magnetosheath high speed jets and their properties at the magnetopause, which can then be used as input to global magentospheric models. The high speed jets are related to kinetic foreshock processes, and drive significant local increases in dynamic pressure and ULF fluctuations at the magnetopause. The jets occur preferentially in radial IMF conditions, happening at rates as large as 9/hour with typical perpendicular scales of 1.34 RE. Alexa Halford spoke about BARREL observations of a solar energetic electron event. There were ULF oscillations observed with precipitation and it is yet unclear if this is due to the movement of the open closed boundary or processes within the magnetosheath as these same oscillations were not observed in the solar wind.

3. ULF wave modeling

This session was joint with the Modeling Methods and Validation FG. There were 7 presentations, and general discussion included the best ways to perform data-model comparisons (e.g., statistical results rather than event by event), the need for both idealized simulations and event simulations, and the need for models that can capture drift-bounce resonance in 3D and localized magnetopause indentations.

Lutz Rastaetter gave an overview of the ongoing ULF wave modeling challenge at CCMC, where ULF wave output is compared between several global MHD simulations with similar driving conditions: a monochromatic wave in the solar wind and continuum noise in the solar wind. Even with similar driving conditions, different simulations can produce very different output, and this is at least partially attributable to the different magnetospheric densities/Alfven speeds and ionospheric conductivities. Bob Lysak showed results from a 3D ULF wave model with height-resolved ionosphere and new ionospheric conductivities based on solar illumination. The results showed how hemispheric asymmetries in conductivity lead to quarter-wavelength standing Alfven modes. Michael Hartinger used global MHD simulations with different values for ionospheric conductivity (uniform, solar illumination, solar illumination plus auroral oval) to show the ground magnetic response to an interplanetary shock strongly depends on the local ionospheric conductivity. Kevin Urban discussed how ULF wave power observed at ground magnetometers in the Antarctic polar cap depends on IMF Bz, and that CGM coordinates do not organize ULF wave observations well. Colin Komar discussed recent modeling advances to self-consistently simulate the drift resonant interaction of radiation belt electrons in a bounce-averaged kinetic model coupled with a global magnetospheric MHD model. Rualdo Soto discussed ring current ion Pc5 wave modulations detected by RBSPICE on Van Allen Probes,

comparing with theory to attribute the modulations to the drift-mirror instability rather than bounce-resonance. Hyomin Kim statistically surveyed EMFISIS and RBSPICE data from the Van Allen Probes, finding that ULF wave power (in the Pc3 range) and Helium ion flux (85-142 keV) variations are highly anti-correlated mostly during quiet times. As the wave frequencies and the bounce periods of Helium ions in the energy levels are comparable, the results suggest that the bounce resonance interaction might play an important role in Helium ion scattering during quiet times.

4. ULF waves and nonlocal transport

This session was joint with the Quantitative Assessment of Radiation belt Modeling FG. There were 8 presentations, with discussion emphasizing the need for data-model comparisons – e.g., validating diffusion coefficients with event-specific wave measurements.

Greg Cunningham discussed radial diffusion in non-dipolar fields using the DREAM3D code with diffusion coefficients that assume dipole and non-dipole fields. Diffusion coefficients calculated for realistic (non-dipole) background fields better capture dropouts. Theodore Sarris presented observations and test particle simulations of outer belt electron radial transport, with different ULF wave properties – m number, monochromatic versus broadband frequency spectrum – producing very different types of radial transport/radial PSD profiles. Wen Li discussed the importance of pitch angle dependence on radial diffusion and the calculation of diffusion coefficients, comparing results from 3 simulations (with different assumptions for wave activity) plus observations for the 17 Mar 2015 event. Anthony Chan showed REM 3D simulation results indicating that drift shell splitting effects can reduce electron PSD enhancements during storms. Qianli Ma simulated the radial intrusion and slow decay of energetic electrons in the Earth's slot region by incorporating radial diffusion transport and hiss-induced pitch angle scattering processes. Solene Lejosne discussed RBSP and Arecibo ISR electric field measurements near L=1.4, showing electric fields consistent with plasma sub-corotation and discussing how measurements could be included in future diffusion coefficient calculations. Yan Song discussed the role of ULF waves in high energy particle acceleration in the auroral acceleration region, with future application of the theory to particle acceleration in the Earth’s radiation belts. Michael Hartinger discussed a statistical study of the azimuthal wave number associated with globally coherent ULF waves using ground magnetometer measurements.