RAS Specialist Discussion Meeting 10th March 2023

Solar control of energy transport and deposition in the terrestrial magnetosphere - ionosphere system

Venue: Royal Astronomical Society, Burlington House / Zoom

Chairs: Alexandra R. Fogg, Harneet K. Sangha, James E. Waters

Schedule

10:30-10:40	Alexandra Fogg	Welcoming remarks, accepting presentations for open discussion
Morning Session, Chair: Alexandra R. Fogg		
10:40-11:00	Steve Milan	The association of cusp-aligned arcs with plasma in the magnetotail implies a closed magnetosphere
11:00-11:20	Chiara Lazzeri	Statistics of Solar Wind Parameters and Geomagnetic Indices Associated with Southward IMF Turnings.
11:20-11:40	Simona Nitti	Unveiling the Mystery of X-ray Variability in the Exosphere: Neutral Hydrogen or Solar Wind?
11:40-12:00	Daniel Whiter	Variation of the auroral peak emission height with the solar wind and IMF
12:00-13:30	Lunch	
Afternoon Session, Chair: James E. Waters		
13:30-14:00	Jenny Carter (*invited*)	The SMILE Ground-based and Additional Science Working Group
14:00-14:20	Mike Lockwood	Universal Time effects on energy flow in the magnetosphere
14:20-14:40	Maria-Theresia Walach	Electrodynamic coupling of the magnetosphere-ionosphere-thermosphere in the context of Whole Atmosphere Modelling
14:40-15:00	Andrey Samsonov	Simulations of the magnetospheric response to southward IMF turnings
15:00-15:35	Open Discussion – Chair: Alexandra Fogg	Off-the-cuff presentations welcomed on *Community Resources: event lists, datasets, code packages…*

Abstracts list (in chronological order)

S. E. Milan, M. K. Mooney, G. E. Bower, M. G. G. T. Taylor, L. J. Paxton, I. Dandouras, A. N. Fazakerley, C. M. Carr, B. J. Anderson, and S. K. Vines	<u>The association of cusp-aligned arcs with plasma in the magnetotail implies a closed magnetosphere</u> We investigate a fifteen-day period in October 2011. Auroral observations by the SSUSI instrument onboard the DMSP F16, F17, and F18 spacecraft indicate that the polar regions were covered by weak cusp-aligned arc emissions whenever the IMF clock angle was small, <45 degrees, which amounted to 30% of the time. Simultaneous observations of ions and electrons in the tail by the Cluster C4 and Geotail spacecraft showed that during these intervals dense (~1 /cc) plasma was observed, even as far from the equatorial plane of the tail as |Z| ~ 13 Re. The ions had a pitch angle distribution peaking parallel and antiparallel to the magnetic field and the electrons had pitch angles that peaked perpendicular to the field. We interpret the counter-streaming ions and double loss-cone electrons as evidence that the plasma was trapped on closed field lines, and acted as a source for the cusp-aligned arc emission across the polar regions. This suggests that the magnetosphere was almost entirely closed during these periods. We further argue that the closure occured as a consequence of dual-lobe reconnection at the dayside magnetopause. Our finding forces a significant re-evaluation of the magnetic topology of the magnetosphere during periods of northwards IMF.
C. Lazzeri, A. Samsonov, C. Forsyth, G. Branduardi-Raymont	<u>Statistics of Solar Wind Parameters and Geomagnetic Indices Associated with Southward IMF Turnings.</u> The interplanetary magnetic field (IMF) and, in particular, its z-component, Bz, play a crucial role in the interaction between the solar wind and the Earth's magnetosphere. While Bz is southward, enhanced reconnection at the magnetopause allows the transfer of energy, mass, and momentum from the magnetosheath to the magnetosphere. In the OMNI database we find 98 southward turnings (STs) preceded by 30 minutes of northward IMF with Bz > 3nT and followed by southward IMF with Bz < -3 for 30 minutes with a 5 minutes transition. Some case studies are discussed before conducting a statistical analysis of the whole sample. Distributions of solar wind parameters are obtained and used to characterize the ranges and trends associated with STs. This analysis is performed separately for events that occurred in proximity to coronal mass ejections (CMEs) and corotating interaction regions (CIRs), the main drivers of space weather. The solar wind dynamic pressure, plasma pressure and proton density parameters are

	found to be higher than average, and so are the flow speed and the jumps in Bz, for events in the vicinity of CMEs. Additionally, the turnings do not appear to be associated with distinct changes in solar wind parameters. The magnetospheric response to a ST is analysed using the SML, SMU, SYM-H and PC indices. These are indicators of different types of magnetospheric activity, and thus different approaches are taken to analyse their behaviour. Focus is put on finding the maximum responses of the indices and their corresponding timescales. The relationship between the turnings and space weather phenomena such as magnetic storms and substorms is also analysed. The results reveal that storms and substorms followed respectively 47% and 59% of the STs, and that CME-related STs showed the strongest index response, with the second highest response found in CIR-related STs.
S. Nitti, J. A. Carter, S. Sembay, D. Koutroumpa, R. Modolo, S. E. Milan, R. Desai	<u>Unveiling the Mystery of X-ray Variability in the Exosphere: Neutral Hydrogen or Solar Wind?</u> The process of Solar Wind Charge Exchange (SWCX) occurs when solar wind heavy ions interact with neutral atoms, which may result in the emission of X-ray and ultraviolet photons at energies characteristic of the incoming ions. The SMILE mission, due for launch in 2025 and led by the European Space Agency and the Chinese Academy of Sciences, includes the Soft X-ray Image (SXI) in its payload. Its main function is to detect soft X-ray emissions from the Earth's magnetosheath and northern cusp regions in the energy range of 0.2-2.5 keV, where most of the SWCX emissions are found. As part of the preparations for SXI data analysis, we compare previous observations of X-ray emission from the dayside magnetosheath using the X-ray astronomical observatory, XMM-Newton. In this study, we aim to verify whether models of X-ray emissions based on test particle (TP) simulations are able to approximate SWCX emissions more accurately than previous attempts using magnetohydrodynamic (MHD) simulations, which have sometimes not well reproduced the observed X-ray lightcurves. We compare observed and modelled lightcurves for our sample of XMM-Newton observations, with a variety of lines of sight through the MHD and TP simulation boxes. Fine-scale structure within the dayside magnetosheath, present in the TP simulations suggest that localised density enhancements may explain some of the X-ray observations, although further investigations under dynamic conditions are required.

D. Whiter, N. Partamies, K. Kauristie	<u>Variation of the auroral peak emission height with the solar wind and IMF</u> The energy of precipitating auroral electrons reaching the atmosphere is influenced by conditions in the solar wind, but the nature of the energy transfer from the solar wind to the atmosphere is complex. Using a novel automated method, we have made hundreds of thousands of measurements of the peak emission height of the aurora from coincident camera images with overlapping fields of view acquired during 1996-2007, and use these as a proxy for the characteristic energy of the precipitation. This data set allows us to investigate how the characteristic energy varies with solar wind and interplanetary magnetic field parameters, and test solar wind coupling functions for their ability to describe the depth of energy deposition in the atmosphere. We present some initial results from this investigation, and discuss possible reasons for the relationships we have identified.
J. A. Carter (*invited*)	<u>The SMILE Ground-based and Additional Science Working Group</u> Current observations of phenomena such as auroral emissions and field-aligned currents can be used to track magnetospheric-ionospheric coupling and the control imposed by the interplanetary magnetic field in the high-latitude ionosphere. Here, we examine some of that control through statistical studies, and also through a case study of a long-lived high-latitude cusp spot. We comment on a magnetohydrodynamic simulation used to estimate the contemporaneous field-aligned currents inside the polar cap during the appearance of this cusp spot. Global monitoring of geospace, combined with in situ observations, is crucial in making the next big leap in magnetospheric physics. We must examine the system holistically, at multiple spatial and temporal scales. Upcoming missions, such as the Solar wind Magnetosphere Ionosphere Link Explorer (SMILE), due for launch in 2025, will examine the large-scale dynamics of the solar-terrestrial relationship. SMILE will simultaneously monitor the movement of the magnetopause boundary and the subsequent response of the Northern Hemisphere ionosphere using two imaging cameras with offset field of views. These images will be complemented by two in situ instruments of an ion analyser and a magnetometer. The magnetopause is known to respond to changes in the incoming solar wind and interplanetary field, but this will be the first time that real-time images of this

	movement will be tracked. Combining these large-scale responses with medium and fine-scale measurements at a variety of cadences by additional ground-based and space-based instruments will enable a much greater scientific impact beyond the original goals of the SMILE mission. We describe current community efforts to prepare for SMILE. We explore several science questions whereby only using a combination of both ground-based and space-based experimentation, in the context of SMILE measurements.
M. Lockwood, M. Owens, and L. Barnard	<u>Universal Time effects on energy flow in the magnetosphere</u> The eccentric nature of Earth's intrinsic magnetic field means that the response to a major increase in solar wind forcing depends on the Universal Time of its arrival. The most significant effect is that of inductive motions of the polar caps in a geocentric-solar frame caused by Earth's rotation. We use the example of the storm in early February 2022 that caused the loss of 38 out of 49 recently-launched Space-X Starlink satellites to demonstrate how the UT of event arrival changes the balance between direct energy deposition into the polar ionospheres and energy stored in the tail and subsequently released. This also changes the division of energy deposited in the two hemispheres.
M.-T. Walach, A. Grocott, W. Feng, D. Marsh, A. Aruliah, L. Orr, G. Lu	<u>Electrodynamic coupling of the magnetosphere-ionosphere-thermosphere in the context of Whole Atmosphere Modelling</u> Modelling the whole atmosphere from the surface to the ionosphere allows us to better forecast and understand our weather and climate. It is a scientific and computational challenge to model this complex system numerically with its many drivers and feedback loops. Recent efforts to improve whole atmosphere models include raising the altitude to incorporate improved representations of the ionosphere and thermosphere. The Whole Atmosphere Community Climate Model with thermosphere and ionosphere extension (WACCM-X) is one of the most comprehensive numerical models, spanning the range of altitude from the Earth's surface to the upper thermosphere (~700 km). WACCM-X can model the global ionosphere and thermosphere, whilst providing coupling between atmosphere layers through chemical, physical and dynamical processes. Using WACCM-X, we can explore the implications of this coupling for the climate and for the near space environment. The high-latitude ionosphere-thermosphere behaves dynamically during geomagnetically active times due to time-

	varying solar wind driving and internal magnetospheric dynamics. We present high- and mid-latitude observations from the Super Dual Auroral Radar Network, Incoherent Scatter Radars and Fabry-Perot Interferometers which observe the ionosphere-thermosphere system. We investigate observed plasma flows, which respond directly to solar wind driving, alongside WACCM-X model simulations which are nudged to a meteorological reanalysis dataset in the troposphere and stratosphere during a variety of solar storm conditions. We discuss these in the context of time-varying dynamics due to solar wind driving and investigate the expansion of the high-latitude convection to lower latitudes during geomagnetic storms. We show how changing the high-latitude ionospheric electrostatic potential at high latitudes in WACCM-X affects the neutral winds.
A. Samsonov, G. Branduardi-Raymont, N. Buzulukova, S. Milan, T. Sun	Simulations of the magnetospheric response to southward IMF turnings We study events in which a relatively long interval with a northward interplanetary magnetic field (IMF) is separated from a relatively long interval with a southward IMF by a solar wind directional discontinuity. The magnetosphere is quiet before the discontinuity arrives at the magnetopause, but then the magnetopause magnetic reconnection begins and the solar wind energy begins accumulating in the magnetotail. When the magnetic energy in the magnetotail exceeds a certain threshold, the nightside reconnection begins and magnetic flux in the tail decreases. First, we present MHD results for one artificial case to better understand the magnetospheric response for ideal solar wind conditions with constant plasma parameters. We show that the simulation reproduces the Dungey cycle. Second, we simulate two real events by using several MHD models and different ionospheric conductivities. We discuss the differences in the magnetospheric and ionospheric parameters between the models and observations.