System-scale observations and modelling of SW-M-I-T coupling

Time	Speaker	Title
10:30	Colin Waters	South and north hemisphere field aligned currents and magnetic fields from AMPERE
11:10	Daniel Billett	Large scale thermospheric density enhancements in relation to downward Poynting fluxes: statistics from CHAMP, AMPERE and SuperDARN
11:25	Jenny Carter	Height-integrated conductances over the course of an average substorm
11:40	**Coffee break**	
12:00	Martin Archer	Ripples going against the flow: how energy propagation determines the global structure of magnetopause surface waves
12:15	Andrey Samsonov	Geosynchronous magnetopause crossings and their relationships with magnetic storms and substorms
12:30	Sandra Chapman	Wavelet and network analysis of magnetic field variation and geomagnetically induced currents during large storms
12:45	Graziella Branduardi-Raymont	Global imaging of the Earth's magnetic environment: SMILE
13:00	**Lunch**	
13:30	**Poster session**	
14:30	Steve Milan	Dual-lobe reconnection and horse-collar auroras
14:45	Lauren Orr	Comparison of high latitude electric field models
15:00	Joe Borovsky	Solar wind-magnetosphere coupling: a system science approach
15:15	**Discussion**	

Posters

Author	Title
Téo Bloch	Deep-ensemble modelling of electron flux at the radiation belt's outer boundary with Bayesian neural networks
Alexandra Ruth Fogg	Solar wind control of Auroral Kilometric Radiation as measured by the Wind satellite

Abstracts

South and north hemisphere field aligned currents and magnetic fields from AMPERE

Colin Waters (University of Newcastle, Australia)

Spatially distributed, in-situ measurements of the geomagnetic field have been available from the low Earth orbit (780 km) Iridium satellite constellation for over 20 years. The Active Magnetosphere and Planetary Electrodynamics Experiment (AMPERE) value-adds the fluxgate magnetometer data from Iridium to provide science data products that include perturbation magnetic field and field aligned current spatial maps on minute time scales. These data reveal differences and similarities of the magnetosphere-ionosphere relationship, which may then be placed in context with additional ground and space-based observations.

The Iridium data quality will be described within the pre-AMPERE, AMPERE and NEXT time frames. Recent improvements to AMPERE data processing, that have focussed on the southern hemisphere data will be outlined. The revised AMPERE data products will be used to compare features of north/south magnetosphere-ionosphere coupling during active times.

Ripples going against the flow: how energy propagation determines the global structure of magnetopause surface waves

Martin Archer (Imperial College London), Michael Hartinger, Ferdinand Plaschke, David Southwood, Lutz Rastaetter

Impulsive solar wind transients, such as pressure pulses and shocks, excite surface waves on the magnetopause. While much of this surface wave energy is advected downtail by the magnetosheath flow, recently it has been shown that some of these waves can be trapped locally forming a standing wave between the northern and southern ionospheres. It appears that this process can occur across most of the dayside magnetopause, however, it is not clear how these surface waves can resist the advective effect of the tailward flow. Through multispacecraft observations, global MHD simulations, and analytic MHD theory we show that azimuthally standing magnetopause surface waves are possible between 9-15h MLT. In this region, surface waves with Poynting vectors directed towards the subsolar point can exactly balance the advective effect of the magnetosheath flow, leading to no overall energy flow. Further down the flanks, however, the waves cannot overcome advection hence travel downtail, seeding fluctuations at the resonant frequency which subsequently grow in amplitude via the Kelvin-Helmholtz instability. This trapping of magnetopause surface wave energy following the drivers of intense space weather may in turn have important implications on radiation belt, ionospheric, and auroral dynamics.

Large scale thermospheric density enhancements in relation to downward Poynting fluxes: statistics from CHAMP, AMPERE and SuperDARN

Daniel Billett (University of Saskatchewan), G. W. Perry, L. B. N. Clausen, W. E. Archer, K. A. McWilliams, S. Haaland, J. P. Reistad, J. K. Burchill, M. R. Patrick, B. K. Humberset, B. J. Anderson

Large thermospheric neutral density enhancements in the cusp region have been examined for many years. The CHAMP satellite for example has enabled many observations of the perturbation, showing that it is mesoscale in size and exists on statistical timescales. Further studies examining the relationship with magnetospheric energy input have shown that fine-scale Poynting fluxes are associated with the density perturbations on a case-by-case basis, whilst others have found that mesoscale downward fluxes also exist in the cusp region statistically.

In this study, we use nearly 8 years of the overlapping SuperDARN and AMPERE datasets to generate global-scale patterns of the high-latitude and height-integrated Poynting flux into the ionosphere, with a time resolution of two minutes. From these, average patterns are generated based on the IMF orientation. We show the cusp is indeed an important feature in the Poynting flux maps, but the magnitude does not correlate well with statistical neutral mass density perturbations observed by the CHAMP satellite on similar spatial scales. Mesoscale height-integrated Poynting fluxes thus cannot fully account for the cusp neutral mass density enhancement, meaning energy deposition in the F-region or on fine-scales, which is not captured by our analysis, could be the primary driver.

Deep-ensemble modelling of electron flux at the radiation belt's outer boundary with Bayesian neural networks

Téo Bloch (University of Reading), Panos Tigas, Clare Watt, Matt Owens

As space-based infrastructure (and society's dependence on it) becomes more ubiquitous, it is ever-more important to be able to accurately model the environment in which spacecraft will pass their lifetime. For spacecraft in geosynchronous orbits or those which utilise electric orbit raising, specifically, understanding the outer (electron) radiation belt is critical.

There are a variety state-of-the-art radiation belt models each taking different approaches to understanding the radiation belts. One commonality between them is the importance of correctly quantifying the outer boundary – which acts as a time dependent source for the simulations. Previous work (T. Bloch et al., 2021, under review) quantified one aspect of this boundary, its location – nominally located at 8.25 RE, further out that most models currently use. This leaves the other curial aspect to be characterised - the electron distribution function at the boundary location. Our work addresses this latter aspect.

Given the relatively distant location of the boundary (well beyond geosynchronous orbit, or the apogee of RBSP), we use THEMIS SST data obtained in its vicinity. As the THEMIS spacecraft cannot always be in the correct location, we create a deep-ensemble Bayesian neural network model to map from fluxes measured from geosynchronous orbit by GOES to the boundary location. The model is additionally parameterised using solar wind and geomagnetic index data from OMNI. Our approach not only allows us to predict fluxes for 11 THEMIS SST energy channels simultaneously, but also produces probabilistic outputs with associated uncertainties.

On average, our model predicts the fluxes within a factor of 1.5 for the lower energies and with a factor of 2.5 for the higher energies. The correlation between our predictions and the measured values is 0.5-0.8 across the energy channels.

Solar wind-magnetosphere coupling: a system science approach

Joe Borovsky (Space Science Institute), Mick Denton

For analysis of the solar-wind-driven magnetosphere-ionosphere-thermosphere system, we have developed a methodology to reduce a state-vector description of a time-dependent driven system to a composite scalar picture of the activity in the system. The technique uses canonical correlation analysis (vector-vector correlations) to reduce the multidimensional time-dependent solar-wind state vector and the multidimensional time-dependent magnetospheric-system state vector to time-dependent driver and system and scalars, with the scalar describing the global response of the magnetospheric system to the solar wind. The magnetospheric state vector can contain ground-based information about the various current systems and can contain spacecraft-based information about the state of the magnetospheric particle populations. This description that is a reduction from the state vectors has advantages: low noise, high prediction efficiency, linearity in the described system response to the driver, and compactness. The scalar description of the magnetosphere also has robustness with respect to (a) storm-versus-quiet intervals, (b) solar maximum versus solar minimum, and (c) the various types of solar-wind plasma. We are now in the process of developing a single system-wide index to gauge magnetospheric activity.

Global imaging of the Earth's magnetic environment: SMILE

Graziella Branduardi-Raymont (Mullard Space Science Laboratory), C. Wang, S. Sembay, A. Samsonov, J. A. Carter, the SMILE Team

Charge exchange soft X-ray emission has been found to be produced in the interaction of solar wind high charge ions with neutrals in the Earth's exosphere; this has led to the realisation that imaging this emission will provide us with a global and novel way to study solar-terrestrial interactions. In particular, X-ray imaging will enable us to establish the location of the magnetopause. Variations of the magnetopause standoff distance indicate global magnetospheric compressions and expansions, both in response to solar wind variations and internal magnetospheric processes.

Such soft X-ray imaging is one of the main objectives of SMILE (Solar wind Magnetosphere Ionosphere Link Explorer), a joint space mission by ESA and the Chinese Academy of Sciences, which is under development and is due for launch in 2024. From a highly elliptical polar orbit, simultaneously with the X-ray imaging, SMILE will provide continuous monitoring of the northern auroral oval in the UV, and in situ plasma and magnetic field measurements, in a new and global approach to studying the coupling of the solar wind with the terrestrial magnetosphere and ionosphere.

This presentation will introduce the scientific aims of SMILE and its payload, and show simulations of the images expected from SMILE's Soft X-ray Imager for different solar wind conditions, images from which we will extract the positions of the Earth's magnetic boundaries, in particular the magnetopause standoff distance.

Height-integrated conductances over the course of an average substorm

Jenny Carter (University of Leicester), Stephen Milan, Mark Lester, Larry Paxton, Brian Anderson

We track the progression of height-integrated conductances over the course of an average substorm in a narrow local time sector of the nightside polar cap. These conductances are calculated from the mean energy flux and energy flux of precipitation, as estimated from a ratio of auroral emissions of the Lyman Birge Hopfield long and short band obtained by multiple polar region crossings of the Defence Meteorological Satellite Program F16, F17, and F18 spacecraft. Contributing auroral emission data span 1 January 2005 to 31 December 2017. Both Pedersen and Hall conductances are considered, as well as the influence of the magnetic latitude of substorm onset. Substorm onset times and magnitudes are provided by the SuperMAG network. We compare superimposed epoch ordered conductances with similarly averaged field aligned currents from the Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE). Shortly before onset, conductances increase in a low latitude region, before an increase in conductance seen at all latitudes at the time of onset. The energy flux is shown to peak quickly after substorm onset, followed by mean energy. The conductances, energy flux, and mean energy are ordered by magnetic latitude of substorm onset, so that the lowest onset latitudes correspond to the highest value of any given parameter. Conductances recover quicker to pre-substorm levels for those substorms with higher onset magnetic latitudes.

Wavelet and network analysis of magnetic field variation and geomagnetically induced currents during large storms

Sandra Chapman (University of Warwick), Lauren Orr, Ciaran D. Beggan

During geomagnetic storms rapid magnetic variations cause large, sharp enhancements of the magnetic and geoelectric field at mid-latitudes. These present a potential hazard to grounded technology such as high voltage transformers, pipelines and railway systems. Spatiotemporal quantification can provide insight into the magnitude and configuration of their potential hazard. We use the Haar wavelet transform to localise in time and frequency the storm-time response in both European ground-based magnetometer measurements and modelled Geomagnetically Induced Currents (GICs) from the high voltage grid of the UK. Wavelet cross-correlation of the GIC in the grounded nodes is then used to build a time-varying network of GIC flow around the UK grid during storms including the 2003 Halloween storm. We find a highly intermittent (few 10s of minutes duration) long-range coherent response that can span the entire physical grid at most intense times. The spatial pattern of response seen in the GIC flow network does not simply follow that of the amplitude of the rate of change of B field. Coherent response is excited across spatially extended clusters comprised of a subset of nodes that are highly connected to each other, with a tendency for east-west linkages following that of the physical grid, simultaneous with the overhead presence of the auroral electrojet and the inducing component of the magnetic field. This can quantify the spatial and temporal location of increased hazard in specific regions during large storms by including effects of both the geophysical and engineering configuration of the high voltage grid.

Solar wind control of Auroral Kilometric Radiation as measured by the Wind satellite

Alexandra Ruth Fogg (Dublin Institute for Advanced Studies), Caitriona M. Jackman, James E. Waters, Xavier Bonnin, Laurent Lamy, Baptiste Cecconi, Karine Issautier

Auroral Kilometric Radiation (AKR) emanates from acceleration regions from which escaping particles also excite a number of phenomenon in the terrestrial ionosphere, notably aurorae. As such, AKR emission is a barometer for particle precipitation, indicating activity in the magnetosphere. Observations suggest that the emission is mostly limited to the nightside, relating to bursty tail reconnection events. In this study we investigate the relationship between upstream interplanetary magnetic field and solar wind conditions, and the onset and morphology of corresponding AKR emission. Additionally, we explore the delay time between the arrival of solar wind phenomena at the magnetopause, and the onset of related AKR emission and morphology changes. Connections between AKR and solar wind observations allude to solar wind driving of energetic particle precipitation at different local times. The WAVES instrument on the Wind satellite has provided measurements of radio and plasma phenomenon at a range of locations for over two decades, and in this study a recently developed method is utilised to extract AKR bursts from WAVES data, enabling quantitative examination of AKR emission over statistical timescales.

Dual-lobe reconnection and horse-collar auroras

Steve Milan (University of Leicester), Jenny Carter, Gemma Bower, Suzie Imber, Larry Paxton, Brian Anderson, Marc Hairston, Benoit Hubert

We propose a mechanism for the formation of the horse-collar auroral configuration during periods of strongly northwards interplanetary magnetic field, invoking the action of dual-lobe reconnection (DLR). Auroral observations are provided by the Imager for Magnetopause-to-Auroras Global Exploration (IMAGE) satellite and spacecraft of the Defense Meteorological Satellite Program (DMSP). We also use ionospheric flow measurements from DMSP and polar maps of field-aligned currents (FACs) derived from the Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE). Sunward convection is observed within the dark polar cap, with antisunwards flows within the horse-collar auroral region, together

with the NBZ FAC distribution expected to be associated with DLR. We suggest that newly-closed flux is transported antisunwards and to dawn and dusk within the reverse lobe cell convection pattern associated with DLR, causing the polar cap to acquire a teardrop shape and weak auroras to form at high latitudes. Horse-collar auroras are a common feature of the quiet magnetosphere, and this model provides a first understanding of their formation, resolving several outstanding questions regarding the nature of DLR and the magnetospheric structure and dynamics during northwards IMF. The model can also provide insights into the trapping of solar wind plasma by the magnetosphere and the formation of a low-latitude boundary layer and cold, dense plasma sheet. We speculate that prolonged DLR could lead to a fully closed magnetosphere, with the formation of horse-collar auroras being an intermediate step.

Comparison of high latitude electric field models

Lauren Orr (Lancaster University), Adrian Grocott

The Space Weather Instrumentation, Measurement, Modelling and Risk: Thermosphere (SWIMMR-T) programme aims to improve the UK's ability to specify and forecast the thermosphere. AENeAS (Advanced Ensemble electron density [Ne] Assimilation System) is a physics-based, thermosphere-ionosphere, coupled, assimilative model, which makes possible thermospheric forecasts. Currently it uses empirical electric field climatology models but it is expected that modern electric field models will improve AENeAS functionality. We compare models derived from different datasets including spacecraft and ionospheric radar observations. Here we present quantitative comparison of the electric-field models across various time-scales for a variety of geophysical conditions. We explore methods of standardising the input parameters to the models to allow for fair comparison. We will discuss the similarities and differences found between these models, particularly the large disparities in transpolar voltage during storms.

Geosynchronous magnetopause crossings and their relationships with magnetic storms and substorms

Andrey Samsonov (Mullard Space Science Laboratory), Yulia Bogdanova, Graziella Branduardi-Raymont

We study increase in the magnetospheric activity related to geosynchronous magnetopause crossings (GMCs). We make a list of GMC events using the empirical magnetopause model (Lin et al., 2010) and hourly averaged OMNI data and find which solar wind and magnetospheric conditions accompany and follow the GMCs. The GMCs are mostly caused by the impact of interplanetary coronal mass ejections (ICMEs) and/or interplanetary shocks often with a strong increase in the density and a moderate increase in the velocity. We find that the average over all events SMU (SML), Kp, and PC indices reach maxima (minima) in 1 hour after the GMC beginning, while the delay of the minimum of the average Dst index is 5-8 hours. These average time delays do not depend on the strength of the storms and substorms. The GMC events are mostly followed by magnetic storms and substorms. We compare solar wind and magnetospheric conditions for GMCs connected with ICMEs and stream interaction regions (SIRs). Our study confirms that the ICME-related events are characterised by stronger ring current and auroral activity than the SIR-related events. The difference might be explained by the different behaviour of the solar wind velocity.