The Global Response of the Terrestrial Magnetosphere during Storms and Substorms: Specialist Discussion Meeting Abstract List

Sandra C Chapman
University of Warwick

Solar cycle dependence of extreme space weather

Extreme space weather events significantly disrupt systems for power distribution, aviation, communication and satellites and estimates of the frequency of occurrence of the largest super-storms are highly uncertain. They are driven by large scale plasma structures emitted from the solar corona but their impact depends on a variety of factors. The number of major solar eruptions varies with the cycle of solar (sunspot) activity although large amplitude eruptions do occur even when the magnetic activity cycle is at a minimum. However, the approximately 11 year cycle of solar activity modulates overall geomagentic activity and each solar cycle is unique, with distinct amplitude and duration. Here we analyse the aa index, which tracks the geomagnetic response at the earth's surface, over the last 14 solar cycles. We find that the largest 1% and 0.1% of aa values (the 99th and 99.9th percentiles) all occurred within a well-defined region of aa and sunspot number and that super-storms generally correspond to the 99.9 aa percentile being well above 200nT, a value that was not reached during the last anomalously weak solar cycle. The Carrington super-storm lies within this region, consistent with the same underlying properties as other historical super-storms. Since future solar cycles are predicted to be weaker than in the past, our results suggest that the risk of a severe space weather event is also much lower than in the past.

Andrei Samsonov
University College London

Variations of solar wind parameters, Earth's magnetospheric size and geomagnetic activity over the last five solar cycles

We use both solar wind observations and empirical magnetopause models to reconstruct time series of the magnetopause standoff distance for nearly five solar cycles. Since the average annual interplanetary magnetic field (IMF) Bz is about zero, the magnetopause standoff distance on this time scale depends mostly on the solar wind dynamic pressure. The annual IMF magnitude correlates well with the sunspot number (SSN) with a zero time lag, while the annual solar wind dynamic pressure correlates reasonably well with the SSN but with 2-3 year time lag. The 11-year solar cycles in the dynamic pressure variations are superimposed on an increasing trend before 1991 and a decreasing trend between 1991and 2009. The same trends occur in the sunspot number, IMF magnitude and magnetospheric geomagnetic activity indices while opposite trends are seen in the magnetospheric size. We select events with daily average Dst less than -50 nT, which correspond to magnetic storms, and study the dependence of the events distribution on solar wind parameters. Finally, we discuss the forthcoming Solar wind Magnetosphere Ionosphere Link Explorer (SMILE) space mission which will investigate the global dynamic response of the Earth's magnetosphere to the impact of the solar wind by making observations of the magnetopause, cusp and auroral activity.

Joseph Eggington

Imperial College London

Time-Varying Magnetopause Reconnection during Sudden Storm Commencement: Global MHD Simulations

Magnetic reconnection is a key driver of magnetospheric dynamics at Earth. The full 3-D nature of reconnection is highly complex, occurring predominantly along the magnetic separator: a continuous line along which differing magnetic topologies meet and which is terminated by magnetic null points. The global reconnection rate is determined by the length of the separator and the parallel electric field along its extent, which are highly sensitive to changes in driving conditions. Using the Gorgon MHD code, we implement an algorithmic approach to tracing out the separator in a simulation of sudden storm commencement due to an interplanetary shock. We identify the location and evolution of the reconnection region as the shock propagates through the magnetosphere, demonstrating how severe distortion of the magnetopause surface allows mass and energy transport further downtail and with much greater intensity than during typical solar wind conditions. The impact on the ionosphere is shown, and the resulting time- and latitude- dependence of stormtime enhancements in region-I field-aligned currents and potential patterns are explored. Finally, we repeat the same simulation with various dipole tilts from 0° (i.e. equinox) up to 30° (i.e. northern summer), highlighting the role of onset time in determining the global response.

Robert Shore

British Antarctic Survey

Comparing the Geomagnetic Precursors of Sawtooths and Substorms

We compare the time history and spatial localisation of geomagnetic precursors to both sawtooth and substorm events. To do this we apply machine learning techniques to a reanalysis of surface-measured magnetic field perturbations. We obtain the spatial and temporal features which characterise substorms and sawtooths. We assess and contrast these features for the hour preceding the event onset, and two hours following onset. For both event types, we see a noticeable change in the features at 20 minutes prior to onset. However, there appears to be no striking morphological difference in these precursor features between sawtooths and substorms.

Steve Milan

University of Leicester

Substorm onset latitude and the steadiness of magnetospheric convection

We study the role of substorms and steady magnetospheric convection (SMC) in magnetic flux transport in the magnetosphere, using observations of field-aligned currents (FACs) by the Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE). We identify two classes of substorm, occurring at high and low latitudes, which show different nightside FAC morphologies. We identify the low latitude onsets (65 deg magnetic latitude) as those that experience convection braking in the auroral bulge region due to enhanced ionospheric conductance. We show that the high latitude substorms (above 65 deg magnetic latitude), which do not experience braking, can evolve into steady magnetospheric convection events if the interplanetary magnetic field (IMF) remains southwards for a prolonged period following onset. We conclude that during periods of ongoing driving, the magnetosphere displays repeated substorm activity or SMC depending on the rate of driving and the open magnetic flux content of the magnetosphere prior to onset. We speculate that sawtooth events are an extreme case of repeated onsets. Our results provide an explanation for the differing modes of response of the terrestrial system to solar wind-magnetosphere-ionosphere coupling by invoking friction between the ionosphere and atmosphere.

Lauren Orr

University of Warwick

Directed network of substorms from SuperMAG ground-based magnetometer data

Identifying the full spatio-temporal evolution of the substorm ionospheric current system is now possible utilising the full set of 100+ magnetometers collated by SuperMAG. We use this magnetometer data to obtain dynamical directed networks for isolated substorms for the first time. Directed networks flag correlation between a magnetometer pairs' vector magnetic field perturbations (a network connection) and determine the time lag at which correlation is maximal. If we assume spatial correlation reflects ionospheric current patterns, the network properties test different models of current systems evolution during a substorm. We focus on network connections (patterns of spatial correlation) within and between three specific regions in the nightside. These regions are around, east and west of the onset location. We select two substorms which have at least seven magnetometers in each of these regions and we find a time-sequence of the emergence of spatial correlation which in turn provides information on the formation and dynamics of ionospheric current patterns.

John Coxon

University of Southampton

Tailward propagation of magnetic energy density variations with respect to substorm onset times

During geomagnetic substorms, around 10^15 J of energy is extracted from the solar wind and processed by the Earth's magnetosphere. Prior to the onset of substorm expansion phases, this energy is thought to be largely stored as an increase in the magnetic field in the magnetotail lobes. How, when and where this energy is stored and released within the magnetotail is unclear. Using data from the Cluster spacecraft and substorm onsets from SOPHIE technique for identifying substorm phases (Forsyth et al., 2015), we examine the variation in the lobe magnetic energy density with respect to substorm onset for 541 isolated onsets. Based on a cross-correlation analysis and a simple model, we deduce the following: On average, the magnetic energy density increases approximately linearly in the hour preceding onset and decreases at a similar rate after onset. The timing and magnitude of these changes varies with downtail distance, with observations from the mid-tail (≲9 RE) showing larger changes in the magnetic energy density that occur ~20 minutes after changes in the near-tail ≳9 RE). The decrease in energy density in the near-tail region is observed before the ground onset identified by SOPHIE, implying that the substorm is driven from the magnetotail and propagates into the ionosphere. The implication of these results is that energy in the near-tail region is released first during the substorm expansion phase, with energy conversion propagating away from the Earth with time.

Richard Horne

British Antarctic Survey

Effects of multiple substorms on the radiation belts during a fast solar wind stream event

Multiple substorms are often observed during the passage of a fast solar wind stream resulting in an enhanced electron population at tens to hundreds of keV inside geostationary orbit. Here we show an example of such an event and then consider a realistic worst case. We show how repeated substorms excite plasma waves which react back on the electron distribution to accelerate a fraction of the population to MeV energies. We modulate the flux at the low energy boundary to simulate injection events and show that the timescale for acceleration to MeV energies is much longer than the timescale for each injection. We find that the MeV flux tends towards a value that is comparable to a 1 in 150-year event found from an independent statistical analysis of electron data. The resulting charging current would exceed NASA and European recommended guidelines on spacecraft design. Approximately 2.5 mm of Al shielding would be required to reduce the internal charging current to below the NASA recommended guidelines, much more than is currently used. We conclude that satellites at geostationary orbit are more likely to be at risk from fast solar wind stream event than a Carrington type storm.

Harneet Sangha

University of Leicester

Bifurcating Region 2 Currents and Sub-Auroral Polarization Streams

We analyse the magnetosphere-ionosphere (MI) field-aligned currents (FACs) associated with substorms using the Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE). We observe a new phenomenon seen in the AMPERE dataset, which we believe to be the formation of a new region 2 (R2) current in the dusk sector, which occurs following substorm onset. We propose that the phenomenon seen in the FACs is formed when plasma injections enter the inner magnetosphere during the substorm expansion phase. This is also thought to be the production mechanism of sub-auroral polarization streams (SAPS), which are strong westward flows in the dusk sector mid-latitude ionosphere, hence we suggest our event is also associated with SAPS. We present examples of concurrent observations of flow channels by the Super Dual Auroral Radar Network (SuperDARN) of ground-based ionospheric radars.

Martin Archer

Queen Mary University of London

Long-lasting decreasing-frequency poloidal field line resonances following geomagnetic storms

Sonification and citizen science are techniques little used in space physics but can offer effective navigation, mining, and analysis of large datasets. By combining both methods, school students' aural exploration of GOES magnetometer data has identified long-lasting narrowband poloidal ULF waves across the dayside with decreasing frequencies. We present one event in detail, which occurred during the recovery phase of a CME-driven geomagnetic storm. Simultaneous plasma density measurements from the THEMIS spacecraft revealed that the decreasing frequencies were due to the refilling of the plasmasphere. Based on the waves' properties, Van Allen Probes observations during the storm and the lack of ground magnetometer signatures, we conclude that an internal process, such as the ion bounce resonance, likely generated the waves. While thought to be rare, further exploration of the audio revealed many similar events following other major storms, thus these types of ULF wave event are much more common than previously thought.

Hayley Allison

British Antarctic Survey/University of Cambridge

Rebuilding the Earth's Electron Radiation Belts Following the 17 March 2013 Flux Drop-out Event

The Earth's Electron Radiation Belts are a dynamic environment and can change dramatically on short timescales. Drop-out events are sudden depletions of electron flux that cover a broad range of energies. Substorms can supply new electrons to the radiation belt region, which are then energised by a number of processes. From Van Allen Probes observations, we see storm time drop-out events followed by a rapid recovery of the electron flux, likely a result of both radial diffusion and whistler mode chorus wave acceleration. Here we use the BAS Radiation Belt Model to explore how enhancements in the low energy seed population can lead to rebuilding the radiation belts for the 17 March 2013 storm event. Seed population electrons are accelerated to higher energies by chorus waves before being redistributed by radial diffusion. By using a low energy boundary condition derived by POES data we encompass the whole radiation belt region, employing an open outer boundary condition. This approach isolates the contribution of seed population changes and allows electron flux variations over a broad range of L* to be studied.

Sarah Bentley

University of Reading

Upper bounds on the wave power driving radial transport of electrons in Earth's radiation belts

The electron population of Earth's outer radiation belt is highly variable. Ultra-low frequency (ULF, 1-15 mHz) plasma waves drive the transport and acceleration of these electrons, playing a role in the dramatic reconfiguration of the radiation belts under extreme conditions. ULF waves are strongly driven by coupling between the solar wind and magnetosphere, and both ground-based and in situ observations of these waves provide a crucial component for their effect on electrons.

To identify what extreme values of ULF wave power can be supported by Earth's magnetosphere (and their resultant effect on the electron population) we turn to a new probabilistic model of ULF waves. Constructed with fifteen years of data, this identifies the probability distribution that ground-measured ULF wave power will be drawn from, given contemporary solar wind conditions. Designed to quantify the underlying variability in these waves, we can identify upper and lower bounds of wave power given extreme solar wind driving conditions. We compare this upper bound to in situ observations.

Aisling Bergin

University of Warwick

Observational constraints on the distribution long-tail for F10.7 and geomagnetic indices over the last 5 solar maxima

Impacts of space weather include possible disruption to electrical power systems, aviation, communication systems and satellite systems. The climate of space weather is modulated by the solar cycle. Each solar cycle maximum exhibits its own duration and peak activity level. Key parameters such as the F10. 7 [1] index of solar coronal activity and the Dst and AE geomagnetic indices have been almost continuously monitored over the past five solar cycles. Recently Chapman et al. [2] showed that the distinct distribution long tail for these physical variables at each solar cycle maximum is approximately described by a single master distribution, along with the mean and variance of observations above a threshold specific to each variable, for each unique solar maximum. Here we use the observed last five solar maxima to test the possibility that this can be used to constrain the space weather climate that might occur in a future solar maximum. We use the observations from every set of four out of the last solar five maxima to hind-cast the distribution long-tail of the remaining solar maximum. We can then test the effectiveness of this hind-cast against the observed full return time distribution of large-to-extreme observations at that solar maximum. Chapman et al. analysed AE, DST, and F10.7 OMNI2 [3] records. We will in addition investigate the SuperMAG [4] indices which share the methodology used for AE and DST but have higher spatial and temporal resolution. Finally we establish to what extent this methodology can be used to infer the properties of the distribution long-tail of parameters as the next solar cycle is evolving, based on a sub-sample of observations early in the solar cycle maximum phase.

[1] The data were obtained from the LASP Interactive Solar Irradiance Data Center at http://lasp.colorado.edu/lisird/data/noaa_radio_flux/

[2] Chapman, S. C., Watkins, N. W., & Tindale, E. (2018). Reproducible aspects of the climate of space weather over the last five solar cycles. Space Weather, 16, 1128–1142. doi:10.1029/2018SW001884

[3] J.H. King and N.E. Papitashvili, Solar wind spatial scales in and comparisons of hourly Wind and ACE plasma and magnetic field data, J. Geophys. Res., Vol. 110, No. A2, A02209, 10.1029/2004JA010649.

[4] Gjerloev, J. W. (2012), The SuperMAG data processing technique, J. Geophys. Res., 117, A09213, doi:10.1029/2012JA017683.

Téo Bloch

University of Reading

Towards the Objective Classification of Coronal Hole and Streamer Belt Solar Wind

Geomagnetic storms and substorms are driven by the solar wind's interaction with Earth's magnetosphere. The accurate classification of solar wind data is thus imperative to the development of accurate statistical analyses for these complex processes.

We present a new solar wind classification scheme developed independently using unsupervised machine learning. The scheme aims to classify the solar wind into 3 types: coronal hole wind; streamer belt wind, and difficult-to-classify data. It is created using non-evolving solar wind parameters which are measured or derived from Ulysses' latitude-scan data, and subsequently applied to the whole of the Ulysses and ACE datasets. The scheme is built around the oxygen charge state ratio, proton specific entropy, carbon charge state ratio, the alpha to proton ratio, the iron to oxygen ratio, and the mean iron charge state.

The physical basis of the chosen parameters result in a reliable classification scheme grounded in the properties of the solar source regions. We demonstrate significant disparities (minimum ~7.5%, maximum ~16.5%) with the traditional speed thresholding approach.

Yulia Bogdanova

Rutherford Appleton Laboratory

Comparison of the most intense storms and substorm periods since year 2000

This study aims to examine the storm/substorm relationship and whether the extreme storms consist of a sequence of extreme substorms. Geomagnetic activity was investigated according to the different activity indices and it was shown that there is a large discrepancy in the top extreme events subsets and events ranking based on the indices derived from the measurements at the stations from different latitudes. One of the worst correlations between the ranks of the active periods was between extreme storm (based on the Dst index) and extreme substorm (based on the AL index) periods, with the correlation coefficient for top 100 events of 0.4. This result suggests a complex relationship between storms and substorms, for example, the total electromagnetic energy released over the sequence of substorms might be more important in the storm formation than the strength of an individual substorm. Dependencies from the solar wind parameters and solar wind drivers in form of the ICMEs and CIRs also have been examined and will be discussed.

Ravindra Tobias Desai

Imperial College London

The role of Global MHD and integrated radiation belt models in simulating extreme space weather events

The Van Allen radiation belts dynamically vary across timescales ranging from minutes to hours. Despite the multitude of Earth orbiting spacecraft, the magnetospheric and radiation belt response to extreme space weather events remains problematic to predict due to the sheer scarcity of these rare events, and the resultant lack of data thereof. Here, we employ the Gorgon global MHD, and Integrated Van Allen Radiation-belt (IVAR), models to characterise radiation belt behaviour during extreme magnetospheric configurations. We focus our simulations on the interaction between a strong fast-forward shock and the magnetosphere, as occurs during the initial onslaught of an Interplanetary Coronal Mass Ejection. The simulated shock-fronts propagating through the magnetospheric plasma are observed to induce large-scale non-diffusive transport and a range of competing processes. Outer belt and solar energetic particle populations are injected into lower L-shells with energies exceeding 50 MeV, whilst significant losses result from drift paths intersecting the highly distorted magnetopause surface. Bifurcated field-lines on the 'day-side' are shown to result in particles becoming trapped within off-equatorial field-strength minima, and a transiently reconnecting magnetotail on the 'night-side' modulates complex non-dipolar magnetic field topologies which further influence outer radiation belt populations. The global nature of these processes demonstrate the importance of these simulations for extreme event forcasting and for further interpreting the large multi-point data-sets obtained by in-situ spacecraft.

Colin Forsyth

MSSL, UCL

The global response of the radiation belts to substorms

Earth's radiation belts house a population of MeV energy electrons – a population that must be result from the acceleration of plasma captured from the solar wind or escaping from the ionosphere. The number of electrons making up the radiation belts varies over timescales from minutes to days. Typically, increases in the radiation belt population are linked to geomagnetic activity such as storms and substorms. The prevailing framework for enhancements in the radiation belts is that substorm activity in the magnetotail injects electrons with energies of 10s keV into the inner magnetosphere which acts as a source of whistler mode waves which can subsequently accelerated part of the ambient electron population to relativistic energies. However, statistical studies have shown that only 50% of substorms result in an increase in the radiation belt population. Using a measure of the total number of electrons in the radiation belt derived from NASA's Van Allen Probes, we examine to what extent geomagnetic activity and solar wind driving can predict increases in the radiation belt and examine how the radiation belts can change under different levels of geomagnetic activity.

Heather McCreadie

Aberystwyth University

Autonomous Curve Fitting of the Dst index during Geomagnetic Storms

A technique has been developed to fit all types of geomagnetic storms identified in the Dst. A lognormal fitting procedure may be used to describe any storm by setting the lognormal standard deviation to greater than 0.9. The fit needs to be constrained around the peak time and the scaling factor determined. This will enable an autonomous method for fitting any type of storm within the Dst. The unique factor identifying the relationship between the main and recovery phase of a storm is the lognormal mean.

Lars Mejnertsen

Imperial College London

Determining the effect of Carrington-level events at the Earth's Magnetosphere using Global MHD Simulations

The global response of the Earth's magnetic field to adverse space weather events is of great interest in terms of magnetospheric physics and to understand how to mitigate its impact on infrastructure. A Carrington-level geomagnetic storm is expected to cause significant damage to both space and ground infrastructure through a variety of processes. Of particular interest is the impact on power grids, and the occurrence of strong substorm activity.

The strength, location and complexity of ground induced currents will depend on the local geology, the magnetospheric dynamics, and the Earth's magnetic field structure. However, with a return period timescale of ~100 years the internal field may undergo non-negligible change. Hence, it is important to understand what the impact of a Carrington-level event would be for reasonable variations on centennial timescales.

Using the global MHD code, Gorgon, we simulate the magnetosphere when subjected to a Carrington-level event, and examine the magnetospheric and ground response to the extreme individual substorm events for different locations and internal fields. By modelling the whole magnetosphere, a comprehensive view is analysed, and the probable duration and geographical footprint can be localised. The sensitivity of the magnetospheric response to changes in the internal field is also examined.

Michaela Mooney

MSSL, UCL

Evaluating Auroral Forecasts Against Satellite Observations

During periods of high geomagnetic activity, particles precipitating into the upper atmosphere can cause auroral emission and affect long-range radio communications, whilst the accompanying geomagnetic storm could potentially induce strong currents in oil pipelines and electricity transmission lines at ground level. These effects may impact industry sectors such as aviation, energy and defence. Forecasting the location and probability of aurora is therefore of interest to many end users. In addition, forecasting when the aurora may be visible can also be a key tool in promoting public awareness and engagement with space weather. The OVATION Prime-2013 auroral precipitation model (Newell et al., 2014) is currently in operation at the UK Met Office and delivers a 30-minute forecast of the probability of observing the aurora in the polar regions of the northern and southern hemispheres. Using techniques developed for atmospheric weather forecast verification, we evaluate the performance of this operational implementation of OVATION against the boundaries of auroral emission regions determined by the far-ultraviolet (FUV) observations of the auroral oval captured by the IMAGE satellite over the period 2000-2002.

Michaela Mooney
MSSL, UCL
Examining Local Time Variations in the Gains and Losses of Open Magnetic Flux During Substorms

The open magnetic flux content of the magnetosphere varies during the substorm process as a result of dayside or nightside reconnection. The amount of open flux can be determined from the area of the polar cap, delineated by the poleward edge of the auroral oval or the open-closed field line boundary (OCB). This study presents a superposed epoch analysis of the location of the OCB and the change in the magnetic flux content in individual nightside MLT sectors during substorm growth, expansion and recovery phases. The results indicate that the OCB does not contract poleward uniformly in all nightside MLT sectors after substorm onset. The contraction of the OCB during the substorm expansion phase deforms the auroral oval from its average near-circular shape. Close to the substorm onset MLT sector, the OCB contracts immediately following substorm onset however the OCB in the dawn and dusk MLT sectors in continues to expand towards the equator for 20-80 minutes after substorm onset. Despite the continued increase in flux in the dawn and dusk MLT sectors after substorm onset, the total nightside flux content begins to decrease immediately at substorm onset.

Jonathan Rae
MSSL, UCL
Why are storm-time ULF waves special?

Wave-particle interactions play a key role in radiation belt dynamics. Traditionally, Ultra-Low Frequency wave-particle interaction is parameterised statistically by a small number of controlling factor for given solar wind driving conditions or geomagnetic activity levels. Here, we investigate solar wind driving of ultra-low frequency (ULF) wave power and the role of the magnetosphere in screening that power from penetrating deep into the inner magnetosphere. We demonstrate that, during enhanced ring current intensity, the Alfven continuum plummets, allowing lower frequencies to penetrate far deeper into the magnetosphere than during quiet periods. With this penetration, ULF wave power is able to accumulate closer to the Earth than characterised by statistical models. During periods of enhanced solar wind driving such as CME driven storms, where ring current intensities maximise, this provides a simple physics-based reason for why storm-time ULF wave power is different from non-storm time waves.

Neil Rogers
Lancaster University
Ionospheric and Magnetospheric Drivers of Extreme Geomagnetic Field Fluctuations

The statistics of unusually high rates of change in the horizontal component of the geomagnetic field (dB/dt) are a useful indicator of the likelihood of damaging geomagnetically induced currents (GIC) in ground-based infrastructure such as electricity networks. Using extreme value theory [Coles, 2001] we present a global model of the probability of extreme |dB/dt| based on several decades of measurements from 125 magnetometers worldwide, with time cadences (dt) ranging from 1 to 60 minutes.

The occurrence rate of peaks above the 99.97th percentile is a function of magnetic latitude, magnetic local time, month, sunspot number, and the direction of the field fluctuation. This information may be used to improve the extreme value model. The patterns of occurrence will be presented and compared with previously studied distributions of Sudden Commencements, Pc5 ULF waves, and substorm onsets, giving insight into the relative importance of these drivers in GIC modelling.

Reference:

S. Coles, An introduction to Statistical Modeling of Extreme Values, Springer-Verlag London ltd, 2001.

John Ross
British Antarctic Survey
On electron flux decay in the slot region after geomagnetic storms

During large geomagnetic storms, high energy electrons can be transported into the slot region and, possibly, the inner radiation belt. Here, these relativistic electrons can damage satellites. In the slot region, the electrons can persist for days to weeks while in the inner belt the timescales are much longer and can reach years. Understanding the decay process involved is therefore of great importance. It has been shown that wave-particle interactions play a significant role in electron precipitation though pitch-angle scattering, removing electrons from the belts. Here, we will explore the timescales that are attributed to plasmaspheric hiss and Very Low Frequency Transmitter waves in the slot region and inner belt. Longitude and MLT effects will be explored.

Jasmine Kaur Sandhu

MSSL, UCL

The Variability in Substorm – Ring Current Coupling

Substorms are a highly dynamic process that results in the global redistribution of energy within the magnetosphere. The occurrence of a substorm can provide the inner magnetosphere with hot ions and consequently intensify the ring current population. However, substorms are a highly variable phenomenon that can occur as an isolated event or as part of a sequence. In this study we determine the extent to which substorms enhance the ring current energy content and compare how the energy enhancement varies with substorm type.

Using Van Allen Probe observations, we quantify how the total ring current energy content changes during the substorm process. We find that ~ 9% of the total energy released at substorm onset is transferred into the ring current population, and energises the ring current by 17% on average. We establish that the ring current response to substorms is strongly dependent upon the current state of the ring current and the type of substorm activity. We present clear magnitude and local time differences that illustrate the complexity and variability of the substorm-ring current coupling, along with an interpretation of the details of this relationship.

Andy Smith

MSSL, UCL

In situ observations of magnetotail plasma waves at substorm onset

Magnetospheric substorms are a cycle of energy storage and release in the terrestrial magnetosphere. The growth phase describes the storage of energy, generated through interaction with the solar wind. Energy storage continues until the system reaches a state of instability, known as substorm onset. The explosive energy release that follows converts the stored magnetic and thermal plasma energy into plasma kinetic energy. The clearest indicator of this process, and the accompanying large-scale reconfiguration of the nightside magnetosphere, is a bright auroral display that is triggered in both the northern and southern hemispheres. Recent work has shown that the initial structure and brightening of the most equatorward auroral signature is related to an instability in the near-Earth magnetotail [e.g. Kalmoni et al., 2018]. In this work we present fortuitous in situ observations of instability-driven wave activity observed by the THEMIS spacecraft preceding substorm onset. We present several case studies describing the details of the alfvenic wave activity and changes in the local plasma population, comparing the results to those inferred from ground based observations of the aurora.

Frances Staples

MSSL, UCL

Estimating the global scale response of the magnetopause during storm-times

During geomagnetic storms, the flux of relativistic particles in the Van Allen radiation belts depends on a delicate balance of acceleration and loss mechanisms. Only 53 % of geomagnetic storms result in an increase in radiation belt flux, while 19 % result in decreases [Reeves et al. 2013]. During interplanetary shocks which drive geomagnetic storms, the magnetopause becomes significantly compressed, playing a substantial role in the depletion of magnetospheric plasma from the Van Allen Radiation Belts, via magnetopause shadowing. Rapid changes in solar wind conditions enable the real magnetopause to have a significant time-dependence which empirical models cannot capture.

We use a database of >42,000 spacecraft magnetopause crossings to determine how the real magnetopause differs from a statistical model, and under which conditions. We find that the observed magnetopause is on average ~10% closer to the radiation belts during periods of sudden dynamic pressure enhancement, such as during storm sudden commencement, with a maximum of 42% closer. Our results demonstrate that empirical magnetopause models such as the Shue et al. [1998] model should be used cautiously during interplanetary shock events which drive geomagnetic storms.

Rhys Thompson

University of Reading

Characterising the distribution of uncertainty in deterministic radial diffusion coefficient models during geomagnetic storms and substorms

In the Outer Radiation Belt, Ultralow frequency (ULF) wave driven radial diffusion is considered a dominant mechanism in the transport, acceleration and loss of high-energy electron populations. In many radiation belt models, radial diffusion is characterised by a radial diffusion coefficient generally assumed to be deterministic, proportional to ULF wave power and often parameterized by geomagnetic activity. Such parameterizations can conceal large variances of the underlying ULF wave power, forming a less robust description of ULF wave-particle interaction over long timescales.

We present a statistical study to better understand discrepancies between deterministic models and observed diffusion rates during geomagnetic storms, using ground magnetometer and in-situ GOES satellite data whose measurements are approximately co-located in L-Shell. We compare contemporaneous storm-time measurements of observed compressional magnetic and azimuthal electric radial diffusion coefficients with those produced by deterministic models. These comparisons characterize the distribution of uncertainty in deterministic models during storms and substorms at the L-Shell considered, which may be used in future stochastic parameterizations for improved accuracy.

Maria-Theresia Walach

Lancaster University

SuperDARN observations during geomagnetic storms and enhanced solar wind driving

The Super Dual Auroral Radar Network (SuperDARN) was built to study ionospheric convection at Earth and has in recent years been expanded to lower latitudes to observe ionospheric flows over a larger latitude range. This enables us to study extreme space weather events, such as geomagnetic storms, which are a global phenomenon, on a large scale.

We study the scatter observations from the SuperDARN radars during geomagnetic storm phases from the most recent solar cycle and compare them to other active times to understand what SuperDARN radar data we might expect during extreme conditions and to discern differences specific to geomagnetic storms and other geomagnetically active times.

We show that there are clear differences in the number of measurements the radars make, the maximum flow speeds observed and the locations where they are observed during the initial, main and recovery phase. These differences appear to be linked to different levels of solar wind driving.