Abstracts

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Testing the Current Paradigm for Space Weather Prediction with Heliospheric Imagers.

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Abstract: Currently, space weather forecast centers around the world, such as the UK Met Office and NOAA/SPWC, issue CME arrival time forecasts using numerical models initiated by photospheric and coronagraph data only. Heliospheric imagers (HIs), which provide a wide-angle view of the outer corona and inner heliosphere, offer the only direct observations of solar wind plasma between the solar corona and Earth orbit.
Rather than using the commonplace J-Map approach to track CMEs in HI, we develop an improved tracking technique based on analysis of the whole heliospheric image. Predictions of the arrival of CMEs in geospace from the resulting elongation-time profiles requires the use of a CME geometric model, such as Harmonic Mean, Self-Similar Expansion, or Ellipse Evolution to convert from elongation to radial distance. However, the efficacy of these geometric models, even when constrained by prior coronagraph observations, does not compare favourably with a SWPC forecast of the same event. We argue that these results imply that the assumptions of the CME geometric models are routinely invalidated and question their utility in a space weather forecasting context.
These results argue for several possible courses of action, including deployment of a polarising heliospheric imager for future L5 and L1 operational space weather forecasting missions. Such polarising heliospheric imagers will allow for the direct extraction of CME geometry, including asymmetries and other leading-edge distortions that cannot be incorporated into the CME geometric models mentioned above; this will allow for improved spatial tracking of CMEs. In addition, for both a polarising or an unpolarised heliospheric imager, these results argue for the continuing development of more advanced techniques such as assimilative modelling and ensemble pruning methods.

R.D. Bentley.
EUV Imagers and XRS-type instrumentation.
Mullard Space Science Laboratory, University College London.

Abstract: A mission to L5 provides an opportunity to extend the interval during which we can study different regions on the Sun that might produce geo-effective emissions in the near future. The viewpoint will ensure that when active regions emerge over the limb – as seen from Earth – we will already have an understanding of where they are in their life cycle.
The options that need to be considered for an EUV imager at L5 will be discussed together with the need to plan all the remote sensed imaging of the disk as a set. What features are important to observe, the choices of wavelength, spatial and temporal resolution and the trade-offs that could be made in order to match the constraints of a service mission.
We will outline on the options for an XRS-type instrument that will allow the magnitude of flares not visible from the Earth to be determined. We will also highlight the importance of ensuring that all the observations from L5 are directly comparable with those made from the Sun-Earth line in order to simplify interpretation.

Doug Biesecker (1) and KiChang Yoon (2).
Ground Station Support for Existing and Future L1 and L5 Missions.
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Abstract: We will begin with an overview of the existing ground stations being used to receive real-time data from the DSCOVR, ACE, and STEREO spacecraft. We will address the station capabilities and potential suitability for tracking future L1 and L5 missions. This will then reveal any deficiencies or gaps that will need to be addressed in order to support future missions. We will discuss existing plans or proposals for filling these gaps of which we are aware. Final plans for fulfilling ground station tracking needs will depend on having final decisions on spacecraft location, data rates, encoding schemes, and downlink frequency. In general, tracking needs for future L1 missions are already available, with certain caveats. Depending on the L5 mission design, it seems likely that new capabilities will be needed to ensure continuous data reception.

M.M. Bisi (1), J. Magdalenic (2), and N. Gopalswamy (3).
WG7: Space-Based Radio Instrumentation for Future L1 and L5 Space-Weather Missions.
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(2) Royal Observatory of Belgium, Brussels, Belgium.
(3) NASA Goddard Space Flight Center, Greenbelt, MD, USA.

Abstract: This presentation provides a brief overview of the current and expected future capabilities for space-based radio-waves instrumentation and potential future data products from a L5 in tandem with L1 spacecraft combination hosting such instrumentation. Some basics of the requirements are also discussed.

M.M. Bisi (1) and A. Pevtsov (2).
WG3: Complementary Ground-Based Instrumentation/Data to Space-Weather Missions.
(1) STFC RAL Space, Harwell Campus, Didcot, UK,
(2) NSO, USA.

Abstract: Ground-based instruments will provide a wealth of observational data to enhance the scientific outcome of a dedicated space-weather L5 mission and to support the space-weather research and operational forecasts. For example, ground-based radio observations of the Sun, corona, inner heliosphere, and ionosphere (e.g. through the capitalisation of the Worldwide Interplanetary Scintillation Stations - WIPSS - Network, or via dedicated solar and solar-radio-burst radio systems) in combination with advanced tomographic and/or MHD modelling. As another example, in combination with modelling (e.g. MHD and surface flux transport), routine full disk magnetographic data could be used for better representation of solar polar fields and for instrument inter calibration. Multi-wavelength magnetography could also be used to characterise the flow of magnetic energy, electric currents, and helicity through solar atmosphere. Full-disc imaging instruments could serve as the reference for the background changes (e.g. early warning for changes occurring from L5 vantage). High- and ultra-high resolution data from present and future large aperture telescopes (e.g. NST, DKIST) would provide a critical information about small-scale physical processes and magnetic field topology in flare/CME source regions. A combination of ground-based and L5 observations could help in understanding the structure of various solar features (e.g. prominence on the limb for L1 viewing point may appear as filament for L5 and vice versa). If an L5 mission includes instruments capable of helioseismic measurements, in combination with ground-based observations this would open an opportunity for probing overshoot region at the base of the convection zone.

Y.V. Bogdanova (1), N. Guerrini (2), S. Woodland (1), H. Araujo (3), R. Irshad (1), D. Griffin (1, 4), and P. Daly (5).
Development of a miniaturised energetic particle detector for Space Weather applications.
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(4) Now at: UNSW Canberra, School of Engineering & IT, Campbell, ACT 2612, Australia,
(5) European Space Agency, Space Environments and Effects Section, ESTEC, 2200 AG, Noordwijk, The Netherlands.

Abstract: Energetic particles in the near-Earth space, i.e. within Solar Energetic Particle events (SEP), are of crucial importance for Space Weather research and operations. Thus, SEP measurements can be used for the assessment of the source regions at the Sun (impulsive SEP events), as well as for the assessment of the shock propagation through the heliosphere associated with the CMEs (gradual SEP events) and can therefore provide advance warning of CME shocks. These measurements are also required in order to monitor the health of the spacecraft itself and to mitigate technological effects of Space Weather, which are damaging to the satellite electronics and human health. It is important to monitor the energetic particle population over extended energy range, as different components of the SEPs are causing different effects, i.e., keV electrons causing surface charging, keV–MeV electrons causing internal charging and MeV–GeV ions causing single event effects. Measurements of energetic particles are necessary on both L1 and L5 missions, and provision of such data are required by many customers as outlined in the ESA SSA SWE Segment Customer Requirement and System Requirement Documents.
Here we report on the status of a miniaturised energetic particle detector, the Highly Miniaturised Radiation Monitor (HMRM), which is under development at the STFC. The instrument is based on the use of bespoke application-specific CMOS Active Pixel Sensors. This technology was selected in order to reduce the noise of the signal, as well to simplify data processing and minimize mass and volume of the instrument. The instrument concept comprises a telescopic configuration of active pixel sensors enclosed in a titanium shield, with an estimated total mass of 100-200g. The detector is designed as a real-time radiation monitor which provides additional scientific data sets, such as reconstructed spectra of high-energy particle population, with energy coverage of 35 keV – 6 MeV for electrons and 600 keV – 500 MeV for protons. A descoped version of the HMRM instrument is flying on the UK TechDemoSat-1.
In this paper, we present the initial concept of the instrument, discuss development progress, present the results of the instrument calibrations and tests, including tests with radiation sources, and discuss potential ways forward in the development of miniaturised energetic particle sensors.

V. Bothmer.
Lagrange - An L5, L1 tandem mission concept.
Institute for Astrophysics, University of Göttingen, Göttingen, Germany.

Abstract: lt is proposed to place a spacecraft at or near the triangular libration point L5 of the sun-earth system, which is in earth orbit by lagging behind the earth by 60°. The object is to observe, together with observations from near earth space, smallest to largest scale dynamic coronal and interplanetary events in three dimensions from their very beginning, so that the morphology of the phenomena can be investigated throughout their evolutionary life until they reach earth. A goal of this mission is to characterize interplanetary events in their early stages according to various parameters like speed, density enhancement, direction of main motion, general shape so that their motion and evolution can be extrapolated and the impact of the event on the earth's magnetosphere predicted.
An exemplary set of instruments that can meet these objectives consists of EUV/soft-X-ray coronal telescopes, coronagraphic and interplanetary white light cameras, and in situ monitoring sensors for characterizing magnetically controlled solar emissions, i.e. solar wind plasma and solar energetic particles. The in situ monitoring equipment allows to probe the internal structure of interplanetary interaction regions of any kind, investigate impulsive events on the sun, and helps forecasting the type and time of arrival at earth of any kind of corotating interplanetary event. The mass of the payload would be about 100 kg, and power consumption about 70 W. First estimates indicate that it would take a spacecraft of 1100 kg wet mass, launched into GTO as a fractional Ariane 5 payload, to deliver a spacecraft of 500 kg dry mass into orbit around L5. A three-axis stabilized spacecraft with pointing capability of half an arcminute would fulfil the requirements for this payload. If a spinning spacecraft with a despun high gain antenna would offer substantial advantages in cost and effort, then with some increased complexity on the payload side this would also suffice to meet the objectives.

V. Bothmer, N. Mrotzek, J. Hinrichs, and Nisticò G.

Forecasting CMEs in 3D - Multipoint vs single point observations.

Institute for Astrophysics, University of Göttingen, Göttingen, Germany.

Abstract: Over the past years the STEREO and SOHO missions have provided unprecedented observations of CMEs from multiple vantage points under different viewing angles. These data allow for the first time to analyse their 3D structure, including the effects on the ambient corona and solar wind in form of shock waves. The modelling results obtained from different perspectives by the STEREO and SOHO satellites have important implications for the development of future space weather forecasts through missions operating in the L5, L1 or a tandem orbit. Here we discuss the differences in the precision of arrival time predictions for CMEs and shocks depending on the number of perspectives, points of observations and fields of view as derived from analysis of a dedicated set of events.

Allan Sacha Brun (1), R. Barnabé (1,2), P. Charbonneau (2), A. Fournier (3), C.P. Hung (1,3), L. Jouve (4), A. Strugarek (1), and O. Talagrand (5).
SolarCast: a prediction tool for the 11-yr magnetic cycle and extreme flares events.
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(2) University of Montreal, Canada
(3) IPGP, France
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(5) LMD, France.

Abstract: We will present our recent efforts to develop state-of-the-art variational data assimilation methods to forecast the 11-yr cycle and extremes flares events based on physical models. SolarCast is decomposed into two applications: SolarPredict that assimilate solar surface data (sunspot number, butterfly like diagram, surface flows) into a dynamo model to predict the next 11-yr cycle and FlarePredict that assimilate Goes X-ray data into an avalanche model to predict extreme flares events. We will show the performance of the algorithms and discuss the future developments as well as our view of coordinated All around the Sun observations to improve our predictability performance.

James Chen.
A Minimum and Sufficient L5-L1 Platform for Forecasting Large CME-driven Geomagnetic Storms.
Plasma Physics Division, Naval Research Laboratory, Washington, DC.

Abstract: I discuss the "minimum and sufficient" input data for making accurate and timely forecasts of major geomagnetic storms caused by CME eruptions at the Sun. Specifically, a proof-in-principle calculation of the erupting flux rope model of CMEs (EFR) is presented to show that near-Sun CME trajectory (position-time) data from the L5 vantage point, and source location and photospheric magnetogram data obtained at L1 are sufficient to calculate the flux rope structure expanding to 1 AU in 3-D, including the arrival time, speed, size, magnetic field, and average plasma density and pressure of the flux rope. The direction of the apex expansion, magnetic field polarity, and flux rope orientation are obtained using pre-eruption magnetogram and EUV images. This then allows one to calculate predicted time series of the magnetic field and plasma parameters of the expanding flux rope as measured by a stationary "observer" (e.g., the earth). A CME event observed by STEREO-A/B is used to illustrate the calculation. Here, SECCHI-A data is used as a proxy for L5 data, and the calculated CME ejecta properties are compared with the observed STEREO-B (IMPACT and PLASTIC) data, serving as the proxy (in situ) L1 data. The agreement is good. For typical CMEs, the advance forecasting time is roughly 1/2–2/3 of the CME transit time from the Sun, 24–48 hour, but for very fast CMEs, it is shorter. The calculated flux rope dynamics include momentum coupling with a model solar wind (SW) medium. The method of solving the equations of motion is described. The resulting flux rope, however, is idealized and does not include any deformation. The model SW is simple and for any given CME, may not accurately describe the SW as encountered by the expanding structure in general. I will discuss the sensitivity of the solutions to the uncertainties in the input trajectory data and SW medium. CME trajectory data near the Sun contain remotely accessible information on the magnetic driving force acting on the CME structure itself. Correctly captured, the data provide the means to predict the trajectory and the evolution of CME magnetic field. Routine coronagraph observation at L5 would provide a unique vantage and necessary input data source for operational forecasting. The EFR-predicted flux rope/SW parameters at 1 AU have been used as input to drive the 3-D SAMI3-RCM ionospheric simulation model of SAMI3-RCM (Huba et al.).

M.C.M. Cheung (1), M.L. DeRosa (1), and the CGEM Team (2,3).
A Method for Data-Driven Global Models of the Solar Corona.
(1) Lockheed Martin Solar & Astrophysics Laboratory
(2) Space Sciences Laboratory, University of California, Berkeley
(3) Stanford University.

Abstract: We introduce the Constrained Surface Flux Transport (CSFT) Model, which evolves the surface field distribution by explicitly imposing electric fields. This method has the following advantages:

- It removes the needs for ad hoc source terms for introducing newly emerged active regions (ARs),
- Ensures magnetic flux balance, and
- the computed E-fields can be directly used as boundary conditions for coronal MHD or magnetofriction models (we will show an example) and removes the need for E-field inversions on radial magnetic field maps from traditional SFT models.

We also present a validated method for inverting observed time sequences of radial magnetic field maps with incomplete coverage (i.e. from Sun-Earth line and from the L5 perspective). Even with flux imbalance in the observable region of the solar surface, this inversion method generates electric fields which are spatially compact and do not introduce global flux imbalances. We demonstrate how E-fields computed using this method, when applied to our CSFT model, accommodates the rotation of ARs from behind the East limb onto the observable region without adversely impacting the global magnetic topology. The impact of having L5 coverage on this type of models will be discussed.

J.A. Davies, the SCOPE, and STEREO/HI teams.
European-led visible-light imaging coronal and heliospheric endeavours for an operational space weather mission.
STFC-RAL Space, UK.

Abstract: The most destructive space weather effects are associated with coronal mass ejections (CMEs) – in particular, as is increasingly becoming realised, when they act in concert with other CMEs or background solar wind structures such as stream interaction regions. As has been demonstrated, not least over the last decade since the launch of the STEREO mission, CMEs can be tracked in broad-band, visible light from the lower corona all the way out to 1 AU and beyond. Visible-light imaging of CMEs in the corona underpins current operational CME arrival predictions; equivalent imaging of the heliosphere – although not yet fully exploited in an operational sense – shows potential for improving those predictions. Visible-light imaging of the corona and heliosphere, particularly in the context of operational space weather services, are best undertaken from space, ideally beyond the confines of Earth-orbit. Analysis of such imagery from STEREO has demonstrated – although arguably it is not yet rigorously quantified – the value of an off-the-Sun-Earth line perspective for viewing Earth-directed CMEs in visible-light, particularly in addition to such observations taken from a near-Earth vantage point. In this presentation, we review the visible-light coronal and heliospheric imaging endeavours that are currently being undertaken within Europe, more specifically those targeted towards operational space weather opportunities.
Initially, in this presentation, we comment on the requirements for operational coronal and heliospheric imaging instrumentation. In particular, we then review the progress that has been made in terms of the development of the Solar Coronagraph for Operations (SCOPE) instrument, which is currently undergoing Phase A/B1 development by a consortium comprising the UK, Belgium and Germany. Finally, we outline a pathway for the development of an operational heliospheric imager (hopefully by the same consortium).

C.E. DeForest (1), J.A. Davies (2), M.M. Bisi (2), C.A. de Koning (3), C.J. Eyles (4), R.A. Harrison (2), B.V. Jackson (5), V.J. Pizzo (6), S.J. Tappin (2), and D.F. Webb (7).
Polarimeter to UNify the Corona and Heliosphere: a space-weather-relevant mission to image the corona and inner h eliosphere in 3-D.
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(2) Rutherford Appleton Laboratories, UK
(3) University of Colorado at Boulder, USA
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(5) Center for Astrophysics and Space Sciences, University of California at San Diego, La Jolla, CA, USA
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(7) Boston College, USA.

Abstract: PUNCH (Polarimeter to Unify the Corona and Heliosphere) is a proposed LEO mission to unify understanding of the corona and solar wind, through deep-field, three-dimensional (3-D) imaging of the outer corona and inner heliosphere. PUNCH's science objectives are organized around understanding both the transient ejecta and geoeffective events that are of interest to space weather users, and also the ambient solar wind itself - which steers and guides those ejecta. PUNCH will view CME evolution and propagation from the mid-corona (6 Rs) to solar distances of 1 AU and beyond, with sufficient sensitivity to resolve density tracers of magnetic structure in 3-D. It will also measure solar wind velocity profiles at the top of the corona, essentially continuously. PUNCH science is highly relevant to space weather prediction, and will demonstrate deployment of the additional predictive information available from a polarizing wide-field imager. We present a high-level overview of mission design, instrument structure, flight resources, and ground processing necessary to support a wide-field instrument, with an eye toward how the concepts in PUNCH could be adapted and adopted for a future L1 or L5 space-weather monitoring mission.

C.E. DeForest (1), J.A. Davies (2), M.M. Bisi (2), C.A. de Koning (3), C.J. Eyles (4), R.A. Harrison (2), V.J. Pizzo (5), S.J. Tappin (2), and D.F. Webb (6).
Polarized Heliospheric Imaging for Space Weather Tracking from L1 and/or L5.
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(2) Rutherford Appleton Laboratories, UK
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(4) University of Valencia, Spain
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Abstract: [This oral presentation and discussion would best fit into the session on remote-sensing instrumentation.]
We discuss the state of the art and capability of polarized heliospheric imaging for space weather prediction, and the individual advantages of an L1, an L5, or an L1/L5 combined system. Polarized heliospheric imaging has the potential to revolutionize space weather prediction via 3-D tracking in much the same way that terrestrial satellites revolutionized storm prediction via 2-D tracking. Briefing all parties on the state of the art will advance the workshop goals by enabling mission requirements specification and instrument design for a critical space-weather prediction tool.
Imaging of Thomson-scattered sunlight from CMEs, CIRs, and the solar wind is now recognized as essential to predicting geoeffectiveness and arrival time of space weather phenomena. Direct visual tracking overcomes the difficulties of modeling. Wide-field unpolarized imaging has been demonstrated with the pathfinder science missions Coriolis/SMEI and STEREO/HI, and is ready for operational deployment although work to merge the observations into predictive systems is ongoing. Polarimetry is ready for demonstration deployment, and has the potential to greatly improve both (A) 3-D location, by overcoming line-of-sight confusion effects seen with STEREO; and (B) geoeffectiveness predictions, by yielding direct measurements of CME flux rope chirality in transit. We will discuss advantages, requirements, and mission impact (from a mass and data standpoint) of a polarizing heliospheric imager instrument to be flown at L1, L5, or (to best effect) both locations simultaneously.

J.P. Eastwood (1) and D. Kataria (2).
An update on activities pertaining to WG6: In-situ instrumentation.
(1) Space and Atmospheric Physics, The Blackett Laboratory, Imperial College London, London SW7 2AZ
(2) Mullard Space Science Laboratory, Holmbury St. Mary, Dorking, Surrey, RH5 6NT.

Abstract: At the 2015 workshop 'Science from an Operational Mission: An L5 Consortium Meeting' held in London, a series of working groups were identified to address specific details regarding measurement requirements and instrumentation that might fly on an operational L5 and/or L1 space-weather mission. A particular focus was examining the science that might be achieved from these L5 given the measurements that might be available. Furthermore, developing a clearer understanding of the utility of in situ measurements was considered important. Here we briefly review progress in this area since the 2015 workshop and discuss the general conclusion that in situ measurements are a crucial part of the L5 payload to retain existing capability as well as develop new services.

J.P. Eastwood, C.M. Carr, T.S. Horbury, H. O'Brien, P. Brown, and B. Whiteside.
Magnetic field measurements at L1 and L5.
Space and Atmospheric Physics, The Blackett Laboratory, Imperial College London, London SW7 2AZ.

Abstract: Space weather represents a societal risk with a potentially major economic impact, specifically because of possibly prolonged power outages caused by geomagnetic storms. Although it is well known that major geomagnetic storms are caused by the interaction of coronal mass ejections (CMEs) with the Earth's magnetosphere, the CME geoeffectiveness is fundamentally controlled by its magnetic field structure. Large geomagnetic storms can also be caused by Stream Interaction Regions (SIRs); like CMEs, SIR geoeffectiveness depends on its magnetic field structure. In both cases, the magnetic field must be measured in situ, so that more accurate predictions of CME/SIR geoeffectiveness can be made. Consequently, multiple studies have concluded that a magnetometer must be part of the primary payload carried by a space weather mission operating at both L1 and L5, with similar measurement requirements. In this contribution we review the requirement for a magnetometer at the L1 and L5 points, and examine how magnetic field data is used for real-time monitoring, assimilation into heliospheric simulations, and forecasting of magnetospheric conditions. We present both current and expected future capabilities of magnetometer instruments and conclude that previous science mission heritage provides a technical solution that meets space weather mission requirements.

A.N Fazakerley (1), S.R. Thomas (1,2), R.T. Wicks (1,3), and L. Green (1).
Evaluating the Skill of Forecasts of the Near-Earth Solar Wind using a Space Weather Monitor at L5.
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(2) Department of Meteorology, University of Reading, Reading, Berkshire, U.K.
(3) Institute for Risk and Disaster Reduction, University College London, London, U.K.

Abstract: Forecasting space weather is an essential activity for increasing the preparedness and resilience of modern technological infrastructure. It has been proposed that measurements of solar wind parameters (including velocity, density and magnetic field) made from a spacecraft positioned at L5 would contribute to improved forecasts of space weather at Earth on a timescale of a few days. We have studied four intervals of data from the STEREO and ACE missions to investigate the quality of predictions of solar wind properties at one spacecraft based on measurements made at a second spacecraft separated by $\sim 60^\circ$ in heliolongitude, the same angular separation as from L5 to Earth. Using the technique of forecasting skill scores which is widespread in meteorological forecasting, we find that it is possible predict the solar wind properties at Earth much more effectively using observations from L5, rather than using a persistence forecast based on data from upstream monitors at L1 from one solar rotation before. The forecasting skill improves further if we exclude times when one or the other spacecraft is affected by a ICME, as it is rare for the same ICME to be seem at both spacecraft. Our study supports the argument that data from in situ solar wind instruments at L5 can improve the warning time and accuracy of forecasts of solar wind and interplanetary magnetic field conditions at Earth, and thus of the likelihood of calm or adverse space weather conditions at Earth. Experienced teams in the UK are capable of providing the required instrumentation to measure the solar wind and the interplanetary magnetic field at L5 and L1.

A. Grasso (1), M. Scheper (1), Y. Bogdanova (2), J.A. Davies (2), R.A. Harrison (2), M.M. Bisi (2), M.A. Hapgood (2), A. Héritier (3), O. Turnbull (3), D. Riley (3), R. Wright (3), M. Gibbs (4), D. Jackson (4), and S. Kraft (5).
Mission Architectures for Space Weather Monitoring from the Sun-Earth Lagrange Points L1 and L5.
(1) OHB System AG, Bremen, Germany,
(2) STFC, RAL Space, Harwell, Oxford, United Kingdom,
(3) Deimos Space UK Ltd, Harwell, Oxford, United Kingdom,
(4) Met Office UK, Exeter, Devon, United Kingdom,
(5) ESOC - European Space Agency, Germany.

Abstract: As part of the Space Situational Awareness (SSA) Programme, ESA has initiated a study to define a system to monitor, predict and disseminate Space Weather (SWE) information and to generate alerts to a wide community in sectors like space-based communications, broadcasting, weather services, navigation and terrestrial communications and infrastructure.

The Sun-Earth Lagrangian L1 and L5 orbits provide unobstructed views of the Sun and hence are optimal observation points for space weather payloads. Necessary space weather observations like the in-situ measurement of the upstream solar wind plasma and the interplanetary magnetic field (IMF) are only possible from space with a spacecraft outside the Earth's magnetosphere. Spacecraft that currently enable monitoring of solar events and/or the IMF and solar wind from the L1 point are ACE, Wind, DSCOVR and SOHO. These missions (with the exception of DSCOVR) are well beyond their original design life time and need replacement to ensure continuity of the measurements; this is especially true for remote-sensing as DSCOVR does not carry any such instrumentation. Continuous observations from L5 have not been implemented thus far and would significantly enhance space weather forecasting capabilities by observing the state of that region of the solar surface yet to rotate in the L1 field of view, and (through additional side-on viewing) by the very much improved coronal mass ejection tracking and propagation prediction capabilities.

The L1 mission baseline architecture as derived in this study takes heritage from the LISA Pathfinder mission concept. The spacecraft will be injected into low Earth orbit by the future European VEGA-C launcher, and will perform a transfer injection manoeuvre with the help of a transfer stage. For the L5 mission architecture, the satellite will be directly injected to the final trajectory using the future ESA Ariane 6-2 launcher.

Both missions will carry imagers and in-situ instruments allowing the observation and measurement of the interplanetary medium and solar conditions. In addition, the definition study investigates the possibility of carrying a Near Earth Object (NEO) imager to detect NEOs posing a threat to the Earth.

Concluding, this paper will describe the mission architectures and preliminary mission definitions enabling the continuation of space weather monitoring outside the Earth's magnetosphere. We will show the current outline of the satellite and ground station system definition, which is based on European heritage, and which can then be used in a next step of a feasibility study.

L.M. Green (1), S. Yardley (2), and L. van Driel-Gesztelyi (1).
Long-term evolution of active regions: using remote sensing instrument at L5 and L1 to monitor CME occurrence.
(1) Mullard Space Science Laboratory, University College London, Holmbury St. Mary, Dorking, Surrey, RH5 6NT
(2) Solar and Magnetospheric Theory group, School of Mathematics and Statistics, University of St. Andrews.

Abstract: Throughout their lifetimes, active regions are locations of magnetic activity. This activity is monitored and forecast using remote sensing instruments, typically at the L1 point. However, the level and type of activity is dependent on the evolutionary stage of the active region. Since active regions can have lifetimes from days to months, understanding and forecasting solar activity that poses a space weather threat requires observations from the L5 point to build the time-history of active regions before they become Earth-facing. This talk will look at why monitoring the time-history of active regions is important and whether knowing where the active region is in its lifetime helps understand the likelihood of CME activity and what the CME characteristics might be. In order to meet the aim of improved space weather forecasting associated to the impact of CMEs, EUV coronal imaging and photospheric magnetic field data must be used from both the L5 and the L1 positions.

E. Haggarty.
Operations at L5 or L1 The Challenges of 24/7/365 Working.
Spacecraft Management Authority — Space Directorate — Secure Communications — CIS, Airbus Defence and Space, Hawthorn Site, Corsham, Wiltshire, UK.

Abstract: General: The aim of this presentation is to ensure that discussion of the Operations Concept of L5 or L1 missions of significant duration extends beyond the scientific selection of equipment and the design of the Spacecraft Bus and Ground Segment initial capability and into the long-term supportability of an Operational mission. As a Satellite Communications provider charged with a delivery target of 99.998% reliability, I can say with confidence that the generation of an Operations Concept that provides such a level of robust and continuous service is no mean challenge. It is of practical value at the Mission Concept phase to consider the levels of Trained Manning that will need to attained for the Launch and Commissioning stages, as well as the On-Station Operations and Disposal. The outline form of the International Agreements supporting the missions, as well as the requirement for long-term leasing of interconnectivity services and the policies for equipment refresh and obsolescence management need to be considered.
Instrumentation: Distinct from the instrument types selected for a SpaceWx Stations at L1 or L5, the creation of missions with the intent of providing service over a decade requires detailed consideration of many other issues. I'd like to offer a 'Pragmatic Operator' viewpoint to counterpoint scientific considerations which I'm certain will be well presented.

C.J. Henney (1), C.N. Arge (2), and K. Shurkin (3).
Global Solar Magnetic Maps.
(1) Air Force Research Laboratory, Space Vehicles Directorate, Kirtland AFB, NM,
(2) NASA Goddard Space Flight Center, Greenbelt, MD,
(3) Institute for Scientific Research, Boston College, Chestnut Hill, MA.

Abstract: Global solar magnetic maps are the primary input data driver of coronal and heliospheric models. Though full-disk solar magnetograms are now typically available with high temporal cadence, the estimation of the global magnetic field distribution continues to be a challenge since less than half of the solar surface is viewable via spectropolarimetric measurements at any given time. The absence of solar far-side magnetic field observations, along with the lack of quality polar data, results in temporal and spatial discontinuities within global maps at the east-limb boundary and at the poles. The ADAPT (Air Force Data Assimilative Photospheric flux Transport) model is currently being updated to utilize line-of-sight and vector magnetograms, along with helioseismic far-side detections, from the Helioseismic and Magnetic Imager (HMI) to create global radial field distribution maps. The Polarimetric and Helioseismic Imager (PHI) on Solar Orbiter, along with a future full-disk magnetograph at L5, will provide uniquely vital input to the ADAPT model via magnetograms from the far-side and different polar latitude regions. In this presentation, we discuss the progress and challenges towards incorporating near-side and far-side data within ADAPT to model and forecast the solar wind, F10.7 (i.e., the solar 10.7 cm radio flux), and extreme ultraviolet (EUV) irradiance.

G.C. Ho.
A Concept for Real-Time Solar Wind Monitor at Multiple Locations at 1 AU.
The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, U.S.A.

Abstract: The Johns Hopkins University Applied Physics Laboratory (JHU/APL) pioneered real-time solar wind monitor (RTSW) by working with NOAA to incorporate that capability on the Advanced Composition Explorer (ACE) spacecraft. Built by APL and launched in 1997, ACE is still orbiting at L1 and provides valuable solar wind measurement that currently cannot be replaced by other asset. Over the years, APL has been working on the next generation RTSW concept that is based on our experience on ACE, Stereo and Van Allen Probe missions. Our current concept provides in-situ bulk plasma, particles, and fields measurements as well as coronagraph remote sensing on a three-axis platform at the L1 location as well as a second, equivalent measurement set in the quadrant trailing Earth in its 1 AU orbit. This concept presents a path to a permanent solution to the NOAA solar and upstream monitoring space weather requirements presently being met by NASA's ACE, SOHO, STEREO and NOAA's DSCOVR.

R.A. Howard (1), R.A. Harrison (2), A. Vourlidas (3), and J.A. Davies (2).
WG1: Development strategies for coronagraphs and heliospheric imagers for deployment at L1 and L5.
(1) NRL, Washington DC, USA.
(2) STFC RAL Space, Harwell Campus, Oxfordshire, UK.
(3) Johns Hopkins University Applied Physics Laboratory, MD, USA.

Abstract: Studies of L1 and L5 space weather mission concepts have been pursued on either side of the Atlantic: the US DSCOVR follow-on mission, the UK Carrington mission, mission studies in the context of the ESA SSA programme, to name but a few. Virtually all of these concepts call for a coronagraph as a core element of the mission payload; a heliospheric imager is seen as key to most L5 concepts, as well as some L1 concepts. Although in broad agreement, these studies do come to somewhat different conclusions not only in terms of the composition of the payload, but also in terms of the more detailed instrument definition. It is timely to debate these differences, such as the deployment of a heliospheric imager at L1 and the optimal field-of-view of the coronagraph, in an open forum.

Within the recent ESA SSA L1/L5 mission studies, a set of observational requirements were formulated that led to instrument prioritization and definition; this can be compared with the planning for the DISCOVR follow-on mission. Do we agree on the observational requirements on either side of the Atlantic? This is a particularly important question if we are to collaborate on a joint L1/L5 concept in the future, as is being championed by ESA.

Other areas for discussion include the following:

- Much current debate is focused around the idea of adapting science instrument concepts for operational use; how appropriate is this?
- Are there any major technological bars to taking instruments currently in flight or due for launch on upcoming science missions, and adapting for operational usage?
- What advances are required to exploit coronagraph and heliospheric imaging data more effectively, in the near and further future, for space weather application?
- What is the roadmap for demonstrating those developments, such as polarized heliospheric imaging, that are potentially beneficial for space weather operations?

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B.V. Jackson (1), A. Buffington (1), P.P. Hick (1), H.-S. Yu (1), and M.M. Bisi (2).
ASHI, an All Sky Heliospheric Imager for L1.
(1) Center for Astrophysics and Space Sciences, University of California at San Diego, La Jolla, CA, USA.
(2) San Diego Supercomputer Center, University of California, San Diego, La Jolla, CA, USA.
(3) RAL Space, STFC Rutherford Appleton Laboratory, Harwell Campus, Oxfordshire, UK.

Abstract: We intend to map the topology and predict the shapes and time histories of heliospheric structures in the plasma parameters, density and velocity, as structures move outward from the Sun and surround Earth. This will allow for improvements in the full three-dimensional (3-D) tracking of potential space-weather-causing events from the Sun, to the Earth and beyond, and elsewhere in the solar system. To achieve this, we have developed ASHI, an All-Sky Heliospheric Imager for future Space Weather missions. ASHI's primary applicability is to view the inner heliosphere from deep space as a photometric system. The zodiacal-light photometers on the twin Helios spacecraft, the Solar Mass Ejection Imager (SMEI) on the Coriolis satellite, and the Heliospheric Imagers (HIs) on the Solar-TErrestrial RElations Observatory (STEREO) twin spacecraft, all point the way towards an optimum instrument for Thomson-scattering observations. The specifications for such systems include viewing the whole sky starting beyond a few degrees of the Sun, and covering a hemisphere or more of sky. With an imager mass of about 2.5 kg per system (two are required for near-completer sky coverage), 10-minute exposures, 20 arc-second pointing, and low power consumption, this type of instrument has been a popular option for recent NASA Mission concepts such as STEREO, Solar Orbiter, Solar Probe Plus, and EASCO. A key photometric specification for such imagers is 0.1% differential photometry which enables the 3-D reconstruction of density starting from near the Sun and extending outward. A proven concept using SMEI analyses, ASHI will provide an order of magnitude better resolution in three dimensions over time. As a new item we intend to include velocity in this concept, and for a heliospheric imager in deep space, provide high-resolution comparisons of in-situ density and velocity measurements obtained at the spacecraft, to structures observed remotely. In practice we find that 3-D velocity determinations allow a better-timing depiction of heliospheric structures, especially those that are not Earth directed, and we discuss the simple concept behind this as well as the instrument progress, characteristics, and specifications to date.

Curt A. de Koning.
The Value of Polarimetry in the Coronagraph Field of View.
University of Colorado at Boulder/CIRES-SWPC.

Abstract: Submitted to the "Remote Sensing Instrumentation"
As with any forecasting effort that depends on modeling, the most accurate space weather forecast requires the most complete and accurate model inputs. In the case of Wang-Sheely-Arge (WSA)-Enlil, the operational model currently employed at NOAA/SWPC and the UK Met office, the inputs include the background solar wind conditions, and the CME size, speed, and direction of propagation. As demonstrated by attempts to model the Carrington-like event of 23 July 2012 [Cash et al., 2016, doi:10.1002/2015SW001232], the inclusion of de-projected CME mass as a model input is also critical for accurately forecasting extreme events.
We discuss how polarimetry in the coronagraph field of view can be used to calculate a de-projected CME mass. We compare this method for calculating CME mass to the two spacecraft technique of Colaninno and Vourlidas [2009, doi:10.1088/0004-637X/698/1/852]. In particular, we highlight how a de-projected CME mass can be calculated with polarimetry even if only a single viewpoint is available.
Previous work on polarimetry in the coronagraph field of view has shown how single-view polarimetry, complemented by solar surface observations, can be used to reconstruct a CME. This current work, combined with the previous work, demonstrates the important role that polarimetry has as an independent technique in reconstructing CME morphology, kinematics, and energetics. This latter point is particularly important within the context of the workshop's goals. We suggest that polarizing coronagraphs provide a high degree of redundancy, which is an important consideration in an operational mission. In the case of failure of a single coronagraph, a polarizing coronagraph could be used to obtain a 3D reconstruction of a CME, which is necessary for an accurate forecast. However, if only a non-polarizing coronagraph were available, space weather forecasters would be reduced to a 2D reconstruction of a CME, which would set back forecasting to the pre-STEREO era. Hence, we suggest that a coronagraph with polarimetric capability should be deployed at both L1 and L5.

M. Kuznetsova (1), I. Sokolov (2), A. Taktakishvili (1), M. Jin (2), M.L. Mays (1), A. Pulkkinen (1), and B. Thompson (1).
L1-L5 CME structure and dynamics reconstruction challenge.
(1) NASA Goddard Space Flight Center,
(2) University of Michigan.

Abstract: The L1–L5 in tandem missions will bring unprecedented opportunity to improve space weather modeling and forecasting capabilities. Developing of new techniques to reconstruct structure and dynamics of Coronal Mass Ejections (CMEs) using remote observations at L1 and L5 is an important component of getting ready to effectively utilize observational data from new missions and to maximize return on investments. The presentation will discuss an opportunity to employ state-of-the-art simulations of CME initiation and evolution in solar corona as a testbed for analysis of planned remote observations from L1–L5 missions. The SWMF/AWSoM-R global MHD model of solar corona and heliosphere developed at the University of Michigan has been recently implemented at the Community Coordinated Modeling Center (CCMC) for runs-on-request. Simulated CMEs can have a variety of shapes, structures and may propagate in different directions. Simulation output post-processing tools include generation of synthetic coronograph images corresponding to different instruments at different locations. Such synthetic coronograph images corresponding to proposed instruments at L1 and L5 together with simulated 3D evolution of solar corona can be utilized to test different CME reconstruction techniques and to analyze sensitivity to different coronagraph scattering functions, output cadence and other characteristics.

Andreas Lagg (1), S.K. Solanki (1), A. Gandorfer (1), J. Woch (1), J. Hirzberger (1), J.C. del Toro Iniesta (2), W. Schmidt (3), T. Appourchaux (4), and the SO/PHI team.
The Polarimetric and Helioseismic Imager on Solar Orbiter.
(1) Max-Planck-Institut für Sonnensystemforschung, Justus-von-Liebig-Weg 3, 37077 Göttingen, Germany,
(2) Instituto de Astrofísica de Andalucía (CSIC), Apdo. de Correos 3004, E18080 Granada, Spain,
(3) Kiepenheuer-Institut für Sonnenphysik, Schöneckstrasse 6, D-79104 Freiburg, Germany,
(4) Univ. Paris-Sud, Institut d'Astrophysique Spatiale, UMR 8617, CNRS, Bâtiment 121, 91405, Orsay Cedex, France.

Abstract: The Solar Orbiter is the next solar physics mission of the European Space Agency, ESA, in collaboration with NASA, with a launch planned in 2017. The spacecraft is designed to approach the Sun to within 0.28 AU at perihelion of a highly eccentric orbit. The proximity with the Sun will also allow the Sun to be observed at uniformly high resolution at EUV and visible wavelengths. Such observations are central for learning more about the magnetic coupling of the solar atmosphere. At a later phase in the mission the spacecraft will leave the ecliptic and study the enigmatic poles of the Sun from a heliographic latitude of up to 33.5 degrees.

A central instrument of Solar Orbiter is the Polarimetric and Helioseismic Imager, SO/PHI. It will do full Stokes imaging in the Landé g=2.5 Fe I 617.3 nm line. SO/PHI is composed of 2 telescopes, a full-disk telescope and a high-resolution telescope. The latter will allow observations at a resolution as high as 200 km on the solar surface. SO/PHI will also be the first solar polarimeter to leave the Sun-Earth line, opening up new possibilities. As such it is a pathfinder for a magnetograph at L5.

In this presentation an introduction to the science goals and the capabilities of SO/PHI will be given, as well as a brief overview of the instrument and of the current status of its development. A version of SO/PHI reduced to a single telescope could serve as a prototype for a magnetograph on an L5 mission.

T. Laitinen and S. Dalla.
Next-Generation modelling of Solar Energetic Particles.
Jeremiah Horrocks Institute, University of Central Lancashire, Preston, UK.

Abstract: Solar Energetic Particles (SEPs), accelerated during solar eruptions, constitute a radiation hazard for astronauts, flight crew, communications and technology in the space environment and polar regions in the atmosphere. SEPs also carry the fingerprints of the solar events that produced them, through the temporal evolution, spectrum and elemental composition of the event. Thus, analysing SEP measurements can provide information on both the hazard due to the SEPs themselves, and the flare and the coronal mass ejection (CME) causing the SEPs to be accelerated. The SEPs propagate stochastically in the turbulent interplanetary medium before reaching Earth. Thus, to evaluate the properties of the CMEs and flares from the SEP observations, SEP propagation models must be used. In traditional SEP propagation models, the SEPs propagate along the interplanetary magnetic field, the Parker spiral, in 1D. However, recent multi-spacecraft SEP observations have demonstrated the significance of particle propagation across the Parker spiral (Dresing+ 2012). New models have been developed to explain the new observations, with advanced physics in form of cross-field diffusion (Zhang+2010), drifts due to the Parker spiral shape (Marsh+2013), and spreading across the Parker spiral due to turbulent meandering of the field lines (Laitinen+2016). In this presentation, we discuss these next-generation SEP propagation models, and their significance for estimating the risk that the SEPs constitute. In particular, the L5/L1 combination of SEP-observing instruments, in combination with these models, can enhance our ability to predict the event-integrated SEP fluence that is needed to evaluate the total radiation dose due to a solar eruption: The current single-spacecraft observations and 1D SEP propagation models cannot evaluate the effect of co-rotation of the SEP-filled magnetic flux tubes with SEP intensities that depend on heliolongitude. We will also discuss the significance of multi-point SEP measurements, offered by the L5/L1 combination of SEP instruments, in evaluating the properties of potentially Earth-bound CMEs.

G. Lawrence, A. Pidgeon, and S. Reid.
Ground Segment considerations for an operational mission.
RHEA, R1-10, Building 103, Rutherford Appleton Laboratory, Harwell, Didcot, OX110QX, United Kingdom.

Abstract: The operational space weather monitoring mission will operate a dedicated sensor payload to capture the key measurements needed to monitor the Sun-Earth environment, but this purpose-designed space segment will require a complementary bespoke ground segment. The ground segment will enable telecommanding - to ensure the nominal operation of the spacecraft bus and payload - and telemetry - to retrieve the sensor measurements.

These sensor measurements also support the user-defined services. The key processes involved in turning the sensor-captured information into products that are used for operational user services take place in the ground segment. The ground-processing operations are based around a fundamental information flow of the nature

$$\text{Sensors} \rightarrow \text{Measurements} \rightarrow \text{Products} \rightarrow \text{Services} \rightarrow \text{Users}$$

and the ground segment must thus ensure:

- Nominal commanding and control of the satellite and its payload, via the network of ground stations
- Timely provision of the measurements into the data centre, for calibration and archive
- Prompt processing of the products within the data centre, and
- Reliable availability of the services via the data centre to the users

In this talk we will discuss some architectural options for how a dedicated architecture for an operational space weather mission ground segment could be realised. Examples from existing ground segment systems, got example MOIS and EGS-CC, are included to illustrate concretely how these complex systems can be realised.

James Lemen, Alan Title, Neal Hurlburt, and Cathy Chou.
Observing the corona and the solar magnetic field for space weather forecasting.
Lockheed Martin Advanced Technology Center, Palo Alto, CA, USA.

Abstract: Understanding the emerging magnetic field and its interaction in the solar corona are key for developing methods to forecast space weather. Accurate forecasts require a full knowledge of the global distribution of the magnetic field. STEREO EUVI observations have demonstrated the value of multiple views of the corona to assess trigger conditions for flares and CMEs, but to date, magnetograph observations are only available from instruments located on the Sun-Earth line. We discuss a concept for a next generation compact, space-based magnetograph that can be deployed at geocentric orbit, or at the L1 or L5 Lagrange points to enable greater observational coverage of the solar surface. We also consider EUVI coronal observations, and in particular, we present data acquired with the SUVI instrument on the recently launched GOES-16 satellite. Comparing the results from SUVI, SDO AIA, and STEREO EUVI informs the derivation of the coronal observational requirements for future space weather monitoring systems.

N. Lugaz (1) and UNH Space Science Center Team (1).
Particle and magnetic field detectors for L5 and L1 missions.
(1) University of New Hampshire, Space Science Center, Durham, NH, USA.

Abstract: The Space Science Center at the University of New Hampshire has several decades of experience in building space-based instruments, including most recently for STEREO, RBSP, MMS and GOES-R. Here, we present possible instrument designs, including a small-scale magnetometer, particle detector, heritage from STEREO and a LRO/CRaTER flight spare, that could provide low-cost options for L5-L1 tandem missions.

D. Mackay (1) and P. Riley (2).

Impact of an L5 Magnetograph on Nonpotential Solar Global Magnetic Field Modeling.

(1) Mathematical Institute, University of St Andrews, St Andrews, Fife, UK.
(2) Predictive Science Inc., San Diego, CA, USA.

Abstract: We present a theoretical study to consider what improvement could be obtained in global nonpotential modeling of the solar corona if magnetograph data were available from the L5 Lagrange point, in addition to from the direction of Earth. To consider this, we first carry out a “reference Sun” simulation over two solar cycles. An important property of this simulation is that random bipole emergences are allowed across the entire solar surface at any given time (such as can occur on the Sun). Next, we construct two “limited data” simulations, where bipoles are only included when they could be seen from (i) an Earth-based magnetograph and (ii) either Earth- or L5-based magnetographs. The improvement in reproducing the reference Sun simulation when an L5 view is available is quantified through considering global quantities in the limited data simulations. These include surface and polar flux, total magnetic energy, volume electric current, open flux, and the number of flux ropes. Results show that when an L5 observational viewpoint is included, the accuracy of the global quantities in the limited data simulations can increase by 26%–40%. This clearly shows that a magnetograph at the L5 point could significantly increase the accuracy of global nonpotential modeling and with this the accuracy of future space weather forecasts.

Emanuele Monchieri and Markos Trichas.
Airbus DS ESA Phase-0 L5 Spacecraft/Orbital Concept Overview.
Airbus.

Abstract: This presentation gives an overview of the L5 Spacecraft concept developed by Airbus Defence and Space UK in the frame of the ESA P2-SWE-X Phase-0 Study. The transfer strategy, the target operational orbit, and the ground support segment concept are addressed. An overview of the L5 spacecraft design is provided, including an outline of the major components of each subsystem. The design achieves all the ESA SWE requirements applicable to the L5 mission. Programmatics (i.e. technology developments and schedule) are briefly discussed for completeness.

Christian Möstl (1) and the HELCATS team.
Prediction of CMEs with heliospheric imagers verified with the Heliophysics System Observatory.
(1) Space Research Institute, Austrian Academy of Sciences, Graz, Austria.

Abstract: I will present results from the HELCATS project in which about 1000 CMEs on both STEREO spacecraft have been tracked as they propagated into the heliosphere. We have also gathered a database of 668 in situ observed CMEs during the same time frame from MESSENGER, VEX, Wind and STEREO. We check how the hits and misses and arrival times of CMEs predicted with HI geometrical modeling relate to the in situ parameters. These results show what to expect if an HI instrument on a L5 or L1 mission is used for CME forecasting. We find hat there is definitely room for improving the HI modeling.
This talk is relevant to the in situ instrumentation and to heliospheric imagers, and fits into the modeling session on Tuesday.

N.V. Nitta (1) and T. Mulligan (2).
Observations of Stealthy but Earth-affecting CMEs during the STEREO/SDO Era.
(1) Lockheed Martin Advanced Technology Center, Palo Alto, CA 94304 USA
(2) The Aerospace Corporation, Los Angeles, CA 90009 USA.

Abstract: We have long known about the existence of "problem" geomagnetic storms whose origins are elusive. In more general terms, not all the 1 AU disturbances can be clearly attributed to CMEs or HSS-related CIRs. When ICME signatures are found in in situ data, there is not always a flare or filament eruption on the Sun or even an obvious CME observed close to the Sun that correlates with the ICME within a reasonable time range. These ICMEs sometimes result in intense storms and there is a possibility that some of the more severe storms could be partly contributed by them. Therefore space weather prediction will not be complete without properly understanding these ICMEs. Since the solar cycle 23–24 minimum, several studies have discussed so-called "stealth CMEs" that apparently show no low coronal signatures (LCSs). With STEREO's second and third view points, it is now straightforward to determine their front-side origin and find when and where they form and accelerate, helping us isolate possible LCSs. Since 2010 SDO/AIA has been continuously taking full-disk EUV images in a wide temperature range and we expect to detect LCSs of all front-side CMEs. In reality, however, there are still many stealthy events whose LCSs are unclear or ambiguous. Phenomenologically, they start at high altitudes. It is also possible that they may represent more ideal processes (i.e. less magnetic reconnection leading to flare emission). Another clue is that they seem to involve multiple magnetic domains, including weak field and open field regions. In order to detect, forecast, and understand the eruption mechanisms behind these stealth CMEs, it is essential to monitor the global Sun continuously. The added platform at L5 is set to play a crucial role in this endeavor.

Paolo Pagano (1), Duncan Mackay (1), Anthony Yeates (2), Farid Goryaev (3), Vladimir Slemzin (3), and Gordon Gibb (4).
Combined Global NLFFF simulations and MHD simulations of flux rope ejections.
(1) University of St Andrews
(2) Durham University
(3) P.N. Lebedev Institute
(4) Edinburgh Parallel Computing Centre.

Abstract: Magnetic flux rope ejections are considered the main progenitor of Coronal Mass Ejections (CMEs) from the Solar Corona where flux ropes are often rapidly ejected after a long period of stable equilibrium. These two contrasting time scales present a major problem for modelling actual configurations on the Sun. To tackle this we couple the Global Non-Linear Force-Free Field (GNLFFF) model - tailored to describe the slow magnetic evolution of the corona - with 3D MHD simulations - a general approach and can effectively model a fast flux rope ejection. We will present two applications of the coupling and discuss how future predictive capabilities would benefit from L5 mission magnetograms which will provide an additional 5-6 days of observations prior to that currently available. In the first application we focus on the global scale, where we model magnetic flux rope ejections in the global corona and the implications on Space Weather in terms of the plasma and magnetic field injected into the solar wind. This application aims at providing the next generation of Space Weather forecasts with more reliable boundary conditions. In the second application we use this technique to model the magnetic flux rope ejection observed on August, 2nd 2011 and describe the early stage of the following CME. This application aims at showing the potential of the technique when applied to a time series of magnetically complex active regions where the small scale and internal structuring are essential to describe the dynamic evolution.

Alexei Pevtsov (1,2), Mario Bisi (3), Anatoli Petrukovich (4), and Ying Liu (5).
L4+L5 Mission as an Ideal Project for International Collaboration.
(1) U.S. National Solar Observatory, Boulder, CO, USA.
(2) ReSoLVE Centre of Excellence, Space Climate research unit, University of Oulu, Oulu, Finland.
(3) RAL Space, STFC Rutherford Appleton Laboratory, Harwell Campus, Oxfordshire, UK.
(4) Space Research Institute, Russian Academy of Sciences, Moscow, Russia.
(5) State Key Laboratory of Space Weather, National Space Science Center, Chinese Academy of Sciences, Beijing, China.

Abstract: Having satellites positioned in-orbit at both Lagrangian L5 and L4 points offers several major advantages. For example, the L5 vantage point provides an early view of the solar surface, which Earth will be facing 4–5 days later. In turn, the L4 viewing point enables a better view of the source regions of eruptions responsible for SEPs affecting the near-Earth environment. Taken together, observations from L4 and L5 cover about 83% of solar surface, which will significantly improve both short- and long-term forecasts. However, in the most likely scenario that funding will support only a single L5 mission, not both, one alternative that the space weather community may want to explore is to encourage other spacefaring nations such as Russia, China, and India, to launch their own spacecraft to L4 in close coordination with the L5 mission. Launching two separate spacecraft to L4 and L5 will allow us to reap the benefits of having two new vantage points for space weather in addition to the L1 vantage point, to more-fully share the costs of such combined missions, and avoid the restrictions related to the transfer of technology (predominantly affected the L5 and L1 concepts to date).

Alexei Pevtsov (1,2) and 35 team members of WG2.
WG2: Magnetographs and Solar-Disk White-Light Imagers.
(1) U.S. National Solar Observatory, Boulder, CO, USA.
(2) ReSoLVE Centre of Excellence, Space Climate research unit, University of Oulu, Oulu, Finland.

Abstract: Synoptic magnetograms of the photospheric magnetic field are the "workhorse" of modern modelling of solar corona and the heliosphere, which makes a magnetograph one of the key instruments for space weather-oriented L1 and L5 missions. While some limited properties of magnetic fields (e.g., rough estimates about the magnetic connectivity and the field strength) can be inferred from imaging proxies, key information about the magnetic field in flare/CME source regions, energy content, potential eruptivity and the structural properties of erupting CMEs requires routine observations of the magnetic field. Broadband (white-light) images of the Sun can be derived from the magnetograph observations and will not require a separate instrument. This talk will summarize the discussions by this working group on a magnetograph's utility for space weather forecast and also the instrument requirements.

R.F. Pinto (1,2), B. Lavraud (1,2), Y. Liu (3), K. Segura (1,2), J. He (4), G. Qin (3), M. Temmer (5), J.-C. Vial (6), M. Xiong (3), J.A. Davies (7), A.P. Rouillard (1,2), V. Gnot (1,2), F. Auchre (6), R.A. Harrison (7), C. Eyles (7), W. Gan (8), P. Lamy (9), L. Xia (10), J.P. Eastwood (11), L. Kong (3), J. Wang (3), R.F. Wimmer-Schweingruber (12), S. Zhang (3), Q. Zong (4), J. Soucek (13), J. An (3), L. Prech (14), A. Zhang (3), P. Rochus (15), V. Bothmer (16), M. Janvier (17,6), M. Maksimovic (18), C.P. Escoubet (19), E.K.J. Kilpua (20), J. Tappin (7), R. Vainio (21), S. Poedts (22), M.W. Dunlop (3,4), N. Savani (23,24), N. Gopalswamy (24), S.D. Bale (25), G. Li (26), T. Howard (27), C. DeForest (27), D. Webb (28), N. Lugaz (29), S.A. Fuselier (30), K. Dalmasse (31), J. Tallineau (32), D. Vranken (32), and J. G. Fernández (33).

A small mission concept to the Sun-Earth Lagrangian L5 point for innovative solar, heliospheric and space weather science.

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(2) Centre National de la Recherche Scientifique, UMR 5277, Toulouse, France
(3) National Space Science Center, Chinese Academy of Sciences, Beijing, China
(4) Peking University, Beijing, China
(5) Institute of Physics, University of Graz, Austria
(6) Institut d'Astrophysique Spatiale, Orsay, France
(7) RAL Space, Didcot, UK
(8) Purple Mountain Observatory, Nanjing, China
(9) Observatoire de Marseille, France
(10) Shandong University, Weihai, China
(11) Imperial College, London, UK
(12) Christian Albrechts University, Kiel, Germany
(13) Institute of Atmos. Phys., Prague, Czech Rep.
(14) Charles University, Prague, Czech Rep.
(15) Centre Spatial de Liège, Belgium
(16) University of Göttingen, Germany
(17) University of Dundee, Scotland
(18) Observatoire de Paris, Meudon, France
(19) European Space Agency, The Netherlands
(20) University of Helsinki, Finland
(21) University of Turku, Finland
(22) Katholieke Universiteit Leuven, Belgium
(23) UMBC, Goddard Planetary Heliophysics Institute (GPHI), University of Maryland, Baltimore, USA
(24) NASA Goddard Space Flight Center, USA
(25) University of California, Berkeley, USA
(26) University of Alabama, Huntsville, USA
(27) Southwest Research Institute, Boulder, USA
(28) ISR, Boston College, Chestnut Hill, MA, USA
(29) University of New Hampshire, USA
(30) Southwest Research Institute, San Antonio, USA
(31) National Center for Atmospheric Research, Boulder, USA
(32) Qinetiq Space, Kruibeke, Belgium
(33) GMV, Tres Cantos, Spain.

Abstract: We present a concept for a small mission to the Sun-Earth Lagrangian L5 point for innovative solar, heliospheric and space weather science. The proposed INvestigation of Solar-Terrestrial Activity aNd Transients (INSTANT) mission is designed to identify how solar coronal magnetic fields drive eruptions, mass transport and particle acceleration that impact the Earth and the heliosphere. INSTANT is the first mission designed to (1) obtain measurements of coronal magnetic fields from space and (2) determine coronal mass ejection (CME) kinematics with unparalleled accuracy. Thanks to innovative instrumentation at a vantage point that provides the most suitable perspective view of the Sun-Earth system, INSTANT would uniquely track the whole chain of fundamental processes driving space weather at Earth. We present the science requirements, payload and mission profile that fulfill ambitious science objectives within small mission programmatic boundary conditions.

A. Pulkkinen (1), M. Kuznetsova (1), Y. Zheng (1), L. Mays (1), and A. Wold (1,2).
Off Sun-Earth line data usage in CCMC/SWRC space weather service to NASA robotic mission operators.
(1) NASA Goddard Space Flight Center, Heliophysics Science Division, Space Weather Laboratory, USA.
(2) American University, Washington, DC, USA.

Abstract: CCMC/SWRC operating at NASA Goddard Space Flight Center addresses NASA's unique space weather needs. One of the unique needs pertains to the fact that NASA operates assets throughout the heliosphere thereby necessitating a service that characterizes solar system-wide space weather conditions. For this, off Sun-Earth line STEREO imaging and in situ observations together with heliospheric CME simulations have played a major role in allowing CCMC/SWRC to build the service to its end-users. In this presentation, we will discuss the key elements of the CCMC/SWRC service to NASA missions and outline the key challenges posed by the end-user's unique space weather needs. We will also demonstrate how the team has used off Sun-Earth line observational capacity to move toward heliosphere-wide space weather characterization and forecasting capacity. Implications of possible future L5 mission executed in conjunction with "sister" L1 platforms are discussed as well.

Alan Title and Marc DeRosa.
Comments of Using Assimilated Synoptic Charts on the Sun-Earth line for Estimating the Heliospheric Field.
Lockheed Martin Advance Technology Center.

Abstract: In order to understand the magnetic structure of the heliosphere it is necessary to have a map of the magnetic field over the entire surface of the field. Unfortunately, this not possible with magnetographs only on the Sun-Earth line. To attempt to minimize this difficulty Schrijver and DeRosa (2003) developed Assimilated Synoptic Charts (ASC), These charts provide maps of the line-of-sight magnetic flux on the entire Sun. The charts are updated every six hours with a new magnetogram taken by the Heliospheric and Magnetic Imager (HMI) on the Solar Dynamics Observatory and the flux outside of the measured region is predicted using all of our present knowledge of flux dispersal and the small scale flux emergence. Magnetographs only accurately measure the magnetic flux in a 60 degree wide cone centered on the sub-solar point in the ASC, As the Sun rotates the sub-solar point moves across the ASC. Here we compare the flux in a the region current magnetogram, the measured flux and in the same band of Carringtion longitudes in the ASC last updated 7 days early, with the predicted flux,. The predicted region has evolved for about 20 days without the assimilation of new HMI data. The ratio of the predicted to measures flux is a measure of how different the flux in the ASC is in lower Carrington longitudes than is currently being measured by HMI. In the Figure below is a plot of the ratio for predicted to measured flux in cycle 23. In the figure shows scatter plots of the measured - predicted pairs for the northern (red), southern(green, and both (black) hemispheres. Both the predicted and measured fluxes have been corrected for the constant background flux that is continuously added in to the ASC. It can be seen when the flux is low the predicted and measured fluxes are comparable, but at times of high flux, near solar maximum, the mean ratio approaches 1/2. Note that there is considerable scatter about the best linear fit to the data.

Markos Trichas (1), Emanuele Monchieri (1), and Mark Gibbs (2).
IPSP Carrington-L5 Mission Study.
(1) Airbus
(2) Met Office.

Abstract: Airbus UK, in collaboration with the Met Office, RAL, MSSL, Imperial College and in consultation with NOAA, as part of UKSA's IPSP, carried out a study to design a fully operational space weather monitoring system that will ensure timely and accurate forecasts of space weather events.
The study addressed all of Met Office's and NOAA's requirements for an L5 operational SWE mission that will operate as part of a system of systems with NOAA's L1 planned mission. A particular focus for this study is cost/development time effectiveness and robustness of the system.
We will also present an analysis of the industrial, operational and financial advantages of a combined L1/L5 system that shares common platforms, subsystems and payloads, ensuring operational robustness and forecasting effectiveness.
A schedule analysis shows that the earliest launch could occur as early as 2021-22, assuming Phase A/B KO in early 2017.

A. Vourlidas.
L1, L5, or Neither? The Need for a Space Infrastructure Deployment Strategy to Enhance SpWx Operations.
JHU/APL, Laurel MD USA.

Abstract: Do we really need a mission to L5? Does a follow-on mission to L1 address the need of SpWx operations? The answer is 'yes' otherwise we would not be at this meeting. But, how can we be sure that these are the best steps forward? How can we decide on the optimal instrumentation?
We need a coherent strategy (followed by an action plan) on the Space Infrastructure required to move the SpWv Operational forward in concrete steps. In this talk, I will outline such a strategy focused on the operational, rather than research, Space Weather needs in terms of space infrastructure and sensor deployment. In other words, where should we be deploying Space Weather sensors to fill to obtain the best coverage for on-coming transients? What types of sensors do we need? How can we use the recent technology improvements, such as miniaturized spacecraft and sensors and unusual orbits to achieve our goals?
The talk aims to stir discussion, both during and after this meeting, and may be appropriate for the first session.

M.J. West (1), D. Berghmans (1), D.B. Seaton (2,3), B.J. Thompson (4), M. Kirk (4), E. Kraaikamp (1), and L. Krista (2,3).
EUV Imagers and Forecasting Tools.
(1) Royal Observatory of Belgium, Brussels, Belgium,
(2) NOAA NCEI, Boulder, Colorado, USA,
(3) CIRES/University of Colorado, Colorado, USA,
(4) NASA GSFC, Maryland, USA.

Abstract: Extreme-UltraViolet (EUV) imagers are an essential tool in a space weather forecasters repertoire, forming the basis of most forecasts. Instruments such as Coronagraphs are used for observing the dynamic behaviour in the Sun's atmosphere now. However, EUV imagers give us a glimpse of potential activity to come, increasing our ability to forecast over now-cast, as well as providing data to help us understand what we are seeing in magnetograph and coronagraph observations.
In this presentation I will quickly introduce our present, and future EUV imaging arsenal, including: AIA (SDO), SWAP (PROBA2), FSI (Solar Orbiter), EUVI (STEREO), SUVI (GOES-R), EIT (SOHO) and ESIO. I will discuss the benefits of each wavelength and the merits of the various fields-of-view available to us. As most of this technology has been tried and tested, I will discuss how these instruments might be best deployed in an L1 / L5 platform scenario, considering wavelength, FOV, physical size and power consumption. Finally, as our imaging and modelling capabilities improve EUV imagers will become essential to all forecasts. I will discuss some of the interesting tools that have been developed to track and understand features on the solar surface, including tracking coronal holes, coronal dimming and EUV waves, and what these mean for forecasting.

Thomas Woods, Frank Eparvier, James Mason, and Andrew Jones.
Condensing Solar X-ray and EUV Flare and Coronal Dimming Information Down to a Few Bytes for Lagrange-Point Space Weather Missions.
LASP / University of Colorado, Boulder, CO 80303, USA.

Abstract: For space weather research and operations, the magnitude of the solar X-ray irradiance is critical information that a coronal magnetic reconnection is in progress and serves as early warning for eruptions and potential release of solar energetic particles (SEPs). The solar transition region emissions, such as He II 304 Å, exhibit a strong impulsive phase, peaking prior to the X-ray gradual phase peak, if the flare is eruptive and thus is candidate for releasing a coronal mass ejection (CME). The cool corona emissions, such as Fe IX 171 Å, can then be used as a coronal dimming monitor to estimate the CME velocity and mass. A small instrument that we call the Solar Eruption Early Detection System (SEEDS) provides these critical flare and coronal dimming monitors using irradiance (full-disk) measurements. The solar X-ray sensor also includes a quadrant photodiode to also provide the flare location in addition to the flare magnitude. Because the SEEDS does not require imaging to provide the flare magnitude and location, impulsive phase monitoring for eruptions, and coronal dimming proxy for CME velocity and mass, the data output from SEEDS is only two bytes per second for 60-sec cadence. Because expensive deep space network (DSN) is required for Lagrange-Point missions, the SEEDS instrument is designed to provide the important space weather information that a traditional solar EUV imager would provide but with significantly lower data rates. The selection of the X-ray and EUV bands for SEEDS leverages knowledge gained from the NASA Solar Dynamics Observatory (SDO) mission, and the hardware design is flight proven with our NOAA GOES-R EUV X-ray Irradiance Sensors (EXIS) space weather operations instrument.

KiChang Yoon, Sunhak Hong, and Young-yun Kim.
KSWC's New challenges and Roles for supporting the L5 mission.
(1) Korean Space Weather Center, Radio Research Agency, Jeju, Republic of Korea.

Abstract: The Korean Space Weather Center (KSWC) of the National Radio Research Agency (RRA) is a government agency which is the official source of space weather information for Korean Government and the primary action agency of emergency measure to severe space weather condition. KSWC's main role is providing alerts, watches, and forecasts in order to minimize the space weather impacts on both of public and commercial sectors of satellites, aviation, communications, navigations, power grids, and etc.
We built ACE and STEREO satellite tracking antenna to get real time solar wind data and to support global space weather community since 2011.
We also suggest some collaborative suggestion for development of satellite sensor and concept of operation for data center which enable to receive, process and disseminate of L5 satellite data.

F.P. Zuccarello.
Towards a MHD instability tool for space weather forecasting.
Centre for mathematical Plasma Astrophysics, Department of Mathematics, KU Leuven, Celestijnenlaan 200B, B-3001 Leuven, Belgium.

Abstract: A magnetic flux rope embedded in a line-tied external magnetic field that decreases with height as z^{-n} is unstable to perturbations if the decay index of the field n is larger than a critical value. The onset of this instability, called torus instability, is one of the main mechanisms that can initiate coronal mass ejections.
In this talk, I will show how the onset of this instability can be studied both using magnetohydrodynamic (MHD) modelling and observational datasets. And how the comparison between the two approaches gives insight on how to combine space-born and ground-based observations to develop a tool for space weather forecast applications. In particular, I will show how simultaneous L1–L5 observations can be used to give better-contained estimates of the stability of an observed active region against the torus instability criterion.