C.1.2.3 Sources and drivers of solar activity and disturbances

It is commonly believed that the principal driver of solar disturbances is stressed magnetic field. The stresses are released in the solar corona producing flares and coronal mass ejections (CME). The source of these stresses is believed to be in the solar interior. Flares usually occur in areas where the magnetic configuration is complex, with strong shears, high gradients, long and curved neutral lines, etc. This implies that the trigger mechanisms of flares are controlled by critical properties of magnetic field that lead eventually to MHD instabilities. But what kinds of instability actually govern, and under what conditions they are triggered are unknown. With only some theoretical ideas and models, there is no certainty of how magnetic field is stressed or twisted inside the Sun or just what the triggering process is.

Magnetic configuration and mechanisms of solar flares. Vector magnetic field measurements can be used to infer field topology and vertical electric current, both of which are essential to understand the flare process. Observations are required that can continuously track changes in magnetic field and electric current with sufficient spatial resolution to reveal changes of field strength and topology before and after flares. HMI will provide these unique measurements of the vector magnetic field over the whole solar disk with reasonable accuracy and at high cadence.

FACTS:

Nature of flares: energy buildup; instability development.

Observation of flares: pre-flares (30 minutes to hours); impulsive (2 minutes to hours); duration (10 minutes to hours) – long duration events usually associate with change of large-scale field such as CMEs. So continuity of observation for a few hours in good cadence is needed.

Tasks: topology of magnetic field before and after events (from vector field, EUV observation); free energy buildup before events (test models – emerging with twisted-already flux or surface shear motion seen in brightness images); change of magnetic field before and after events (observation of magnetic field; extrapolation of coronal structure); coupling of large-scale and small-scale fields (extrapolation of magnetic field for various scales, helicity conservation and transportation, from vector field observation and EUV images).

REQUIREMENTS:

Samples: more than 5 major (M or X –class) flares for every type flares (compact and two-ribbons).

Observation: vector magnetic field (accuracy is of the highest priority, especially for azimuth angle and strength of transverse component; 2 arcsec resolution; 10 minutes cadence; 6 hours interval); line-of-sight magnetograms (1 arcsec resolution; 5 minutes cadence; 6 hours interval); brightness images (5 minute cadence; 6 hours interval); EUV images (temporal and spatial resolutions are of highest priority; 2 minutes cadence; more than 1 hour duration); coronagraph images (temporal resolution is of priority, better than 10 minutes; longer than 1 hour interval).

Calculation: coronal magnetic extrapolation (10 minutes cadence); coronal and solar wind models (60 minutes cadence).

Emergence of magnetic flux and solar transient events. Emergence of magnetic flux is closely related to solar transient events. MDI, GONG, and BBSO data show that there can be impulsive yet long-lived changes to the fields associated with eruptive events. Emergence of magnetic flux within active regions is often associated with flares. Emerging magnetic flux regions near filaments lead to eruption of filaments. CMEs are also found to accompany emerging flux regions. Further, emergence of isolated active regions can proceed without any eruptive events. This suggests that magnetic flux emerging into the atmosphere interacts with pre-existing fields leading to loss of magnetic field stability. Observations of electric current and magnetic topology differences between newly emerging and pre-existing fields will likely lead to the understanding of why emerging flux causes solar transient events. Vector polarimetry provided by HMI will enable these quantitative studies.

FACTS:

Nature of emerging magnetic flux: emerging of active regions; emerging magnetic flux within active regions.

Observation of emerging magnetic flux: quickly emerge firstly (in the first 30 minutes), slow down in the coming 6 hours, and stop after 10 hours; strong transverse component of magnetic field; downflows seen at footpints; flux emerging within active regions often associated with flaring activity which is limited to the procedure of emerging; whether emerging of active regions causing eruption of nearby filaments depends on orientations of newly active regions and background field (favor for reconnection).

Tasks: process of emerging of magnetic flux within active regions; emerging of active regions (structure of emerging magnetic field – Omega or U loops, energy buildup, and adjustment of magnetic configuration by rotation, motion to follow Hale law with vector and line-of-sight magnetograms, brightness and EUV images); structure of emerging flux regions (structure & topology of magnetic field inferred and computed by vector data, EUV observation, and coronal field extrapolation); interaction of newly emerging flux and pre-existed field (both in small-scale and large-scale) in order to understand its role for flare, eruption of filaments, and/or CMEs; formation, structure, stability of filaments: (1) formation (as short as 15 min, reappearance after eruption in one hour or less, test scenarios of shear motion, reconnection, twisted-already before emerging by using vector field data, brightness images and EUV images); (2) magnetic configuration (structure & topology from vector field data & EUV data); (3) stability (kink instability: buildup of twist by shear motion or by merging of newly emerged, twisted-already fluxes, based on vector data, brightness & EUV images).

REQUIREMENTS:

Samples: more than 5 examples for emerging of active regions, emerging flux regions within active regions, emerging of active regions near filaments (within 20 degree).

Observations: vector magnetic field (accuracy for transverse component and azimuth angle is of high priority; 10 min cadence; 2 arcsec resolution); line-of-sight magnetograms (1 min cadence; 2 arcsec resolution; for detecting emerging and evolution of magnetic flux such as motion, cancellation, etc.); brightness images (1 min cadence for LCT); EUV (temporal, spatial resolution is of priority, no worse than 10 min cadence, 2 arcsec resolution to discern structure and behavior of emerging for magnetic flux, longer than 1 hour duration); coronagraph images(temporal resolution is of priority- no worse than 10 minutes for inner coronal images; longer than 1 hour interval).

Calculation: coronal magnetic extrapolation (10 minutes cadence); coronal and solar wind models (60 minutes cadence).

C.1.2.4 Links between the internal processes and dynamics of the corona and heliosphere

The highly structured solar atmosphere is predominately governed by magnetic field emerged from in the solar interior. Magnetic fields and the consequent coronal structures occur on many spatial and temporal scales. Intrinsic connectivity between multi-scale patterns increases coronal structure complexity leading to variability. For example, CMEs apparently interact with to the global-scale magnetic field, but many CMEs, especially fast CMEs, are associated with flares, which are believed to be local phenomena. Model-based reconstruction of 3-D magnetic structure is one way to estimate the field from observations. Models using vector field data in active regions provide the best match to the observations. More realistic MHD coronal models based on HMI high-cadence vector-field maps as boundary conditions will greatly enhance our understanding of how the corona responds to evolving, non-potential active regions.

Complexity and energetics of the solar corona. Observations from SOHO and TRACE have shown a variety of complex structures and eruptive events in the solar corona. However, categorizing complex structures has not revealed the underlying physics of the corona and coronal events. Two mechanisms have been proposed to generate stressed magnetic fields: photospheric shear motions and emerging magnetic flux; and both may, in fact, be at work on the Sun. But which plays the dominant role and how the energy injection is related to eruptive events is unknown. Magnetic helicity is an important characteristic of magnetic complexity and its conservation intrinsically links the generation, evolution, and reconnections of the magnetic field. HMI will provide data to allow estimations of injections of energy and helicity into active regions the vector magnetic field and the velocity field (from helioseismology and correlation tracking). Observations from SDO AIA and White-light Coronagraphic Imager (WCI) will show the subsequent response and propagation of complexity into the corona and heliosphere, relating the build-up of helicity and energy with energetic coronal events such as CMEs.

FACT:

Nature of solar corona: dynamic, highly-structured, with low plasma-beta (~10^-3), Alfven speed above active regions is 300km*s^-1 (10km*s^-1 in the photosphere), containing free energy to be released during eruptive events.

Observations: re-organized coronal structure duplicates the previously eruptive structure (re-formation of streamer after CMEs, re-formation of filaments after flares, re-formation of sigmoids after flares in ten minutes to days.); structured and dynamic in all scales for the photospheric magnetic and velocity fields (analyzed and simulation studies show simple magnetic field distribution and large-scale motion in the photosphere can produce complex and fine-scale-structured corona); twisted-already flux before it emerges into the photosphere & corona (observation and local helioseismology results).

Tasks: complex of corona (topology & structure of coronal magnetic field in both small-scale and large-scale fields for various sizes of magnetic features, from active regions to streamers, based on various models from potential field model to more realistic models such as non-linear force-free model & MHD simulation experiments; buildup & transfer of magnetic helicity in various-size magnetic features; dynamic & evolution of coronal structure in various sizes & time-scale); energetics of solar corona (energy buildup in the corona by testing effects of surface shear motion & emerging magnetic flux; buildup & development of instability).

REQUIREMENTS:

Observations: vector magnetic field data (accuracy for strength and azimuth angle is of higher priority, 10min cadence, 10 hours duration, 2 arcsec resolution); line-of-sight magnetograms (1 min cadence, 2 arcsec resolution, 10 hours duration); brightness images (1 min cadence, 2 arcsec resolution, 10 hours duration); EUV images (temporal and spatial resolution is of higher priority, no worse than 10 min cadence, 2 arcsec resolution, 6 hours duration); coronagraph images (temporal resolution is of priority- no worse than 10 minutes for inner coronal images; longer than 1 hour interval).

Calculations: coronal magnetic extrapolation (10 minutes cadence); coronal and solar wind models (60 minutes cadence).

Large-scale coronal field estimates. Models computed from line-of-sight photospheric magnetic maps have been used to reproduce coronal forms that show multi-scale closed field structures as well as the source of open field that starts from coronal holes but spreads to fill interplanetary space. Modeled coronal field demonstrates two types of closed field regions: helmet streamers that form the heliospheric current sheet and a region sandwiched between the like-polarity open field regions. There is evidence that most CMEs are associated with helmet streamers and with newly opened flux. HMI will provide uniform magnetic coverage at a high cadence, and together with simultaneous AIA, WCI and STEREO coronal images will enable the development of coronal field models and study of the relationship between pre-existing patterns, newly opening fields, long distance connectivity, and CMEs.

FACT:

Nature of large-scale coronal field: multi-scale closed field structure & the source of open field, which vary in areas and locations in different phases of the sun.

Observation: high speed solar wind originates from areas with open field such as coronal holes, while CMEs occur associated with helmet streamer.

Tasks: source of open field (investigated by potential field, non-linear force-free field calculations, and MHD simulation experiments); two types of large-scale closed fields (structure & topology of these closed fields; roles of these fields for CMEs and solar wind); structure of active regions in reference with large-scale field (structure & topology of active regions; their association with CMEs and solar wind).

REQUIREMENTS:

Samples: different phases of the sun, from solar minimum to maximum; plus more than 5 examples for every type of CMEs associated with active regions and filaments.

Observations: vector data (accuracy is of high priority, 10 min cadence, 10 arcsec resolution); line-of-sight magnetograms (precise is of highest priority, no worse than 0.3 gauss, 10 min cadence, 10 arcsec resolution); EUV images (10 min cadence, 1-6 hours duration); Coronagraph images (temporal resolution is of higher priority- no worse than 10 minutes for inner coronal images; longer than 1 hour interval).

Calculations: coronal magnetic extrapolation (10 minutes cadence); coronal and solar wind models (60 minutes cadence).

Coronal magnetic structure and solar wind. MHD simulation and current-free coronal field modeling based on magnetograms are two ways to study solar wind properties and their relations with coronal magnetic field structure (Figure C.6). These methods have proven effective and promising, showing potential in applications of real-time space weather forecasting. It has been demonstrated that modeling of the solar wind can be significantly improved with increased cadence of the input magnetic data. By providing full-disk vector field data at high cadence, HMI will enable these models to describe the distribution of the solar wind, coronal holes and open field regions, and how magnetic fields in active regions connect with interplanetary magnetic field lines.

FACT:

Nature of solar wind: open and closed coronal magnetic fields associated spatially with high and low speed solar wind.

Observations: source of open field associates with high speed solar wind; low-speed solar wind originates from closed field like streamers, while solar wind from active regions possesses particular properties though speed is low.

Tasks: coronal magnetic field (structure reproduced by potential field model, non-linear force-free field model, and MHD simulation experiments); local and global field (structure & topology of magnetic field for global field, active regions, from various models, including MHD simulation experiments using vector data as inputs); solar wind properties & structure of coronal magnetic field (nature of magnetic expansion along distance away from the sun, and their relationship with solar wind speed, abandons).

REQUIERMENTS:

Samples: different phases of the sun from solar minimum to solar maximum.

Observations: vector data (accuracy is of high priority, 60 min cadence, 10 arcsec resolution); line-of-sight magnetograms (precise is of highest priority, no worse than 0.3 gauss, 60 min cadence, 10 arcsec resolution); EUV images (1 hour cadence, 5 days duration); coronagraph images (I hour cadence, 5 days duration).

Calculations: coronal magnetic extrapolation (60 minutes cadence); coronal and solar wind models (60 minutes cadence).

C.1.2.5 Precursors of solar disturbances for space-weather forecasts

Variations in the solar spectral irradiance and total irradiance may have profound effects on life through their potential but poorly understood role in climate changes. The variation from cycle to cycle of the number, strength, and timing of the strongest eruptive events is unpredictable at present. We are far from answering simple questions like 'will the next cycle be larger than the current one?' 'When will the next large eruption occur?' Or even 'when will there be several successive quiet days?' As we learn more about the fundamental processes through studies of internal motions, magnetic flux transport and evolution, relations between active regions, UV irradiance, and solar shape variations we will be vigilant for opportunities to develop prediction tools. Nevertheless, there are several near term practical possibilities to improve the situation with HMI observations.

Determination of magnetic cloud Bs events. Potentially valuable information for geomagnetic forecasts - predictions of magnetic cloud Bs (southward field) events - can be obtained from the vector field measurements. Long intervals of large southward interplanetary magnetic field, Bs events, and high solar wind speed are believed to be the primary cause of intense geomagnetic disturbances with the Bs component the more important quantity. It has been shown that orientation in 'clouds' remains basically unchanged while propagating from the solar surface to Earth's orbit. This provides a plausible chain of related phenomena that should allow prediction to be made from solar observations of the geo-effectiveness of CMEs directed toward Earth. Estimates of embedded Bs will be significantly improved by incorporating frequently updated vector field maps into coronal field projections with the potential addition of coronagraphic observations from AIA, WCI, and STEREO.

FACT:

Nature of Bs events: the long duration of strong southward interplanetary magnetic field.

Observations for Bs events: goe-effective CMEs are usually halo or partial halo CMEs, but there is no preference for them to be fast CMEs, or to be associated with major flares, or to be associated with eruption of filament; major storms, on the other hand, are caused by fast CMEs.

Tasks: solar surface source regions of Bs events; relationship of helicity, structure, and complex of source regions with Bs events (no preference to be fast CMEs, etc means the nature of magnetic field of the source regions are probably of essence for Bs events.); connection of solar sources, solar phenomenon, and Bs events (magnetic links between solar source, solar phenomenon, and Bs events); propagation of solar eruptive events.

REQUIREMENTS:

Samples: more than 5 examples for Bs events.

Observations: vector data (accuracy is of high priority, 10 min cadence, 10 arcsec resolution); line-of-sight magnetograms (precise is of highest priority, no worse than 0.3 gauss, 10 min cadence, 10 arcsec resolution); EUV images (10 min cadence, 1-6 hours duration); Coronagraph images (temporal resolution is of priority- no worse than 10 minutes for inner coronal images with longer than 30 minutes interval, 30 min cadence for outer coronal images with longer than a few hours duration.).

Calculations: coronal magnetic extrapolation (10 minutes cadence); coronal and solar wind models (60 minutes cadence).