Solar-terrestrial relation and space weather

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Space weather is the time varying environmental conditions within the solar system, including the solar wind, and especially the space surrounding the Earth, including conditions in the near-Earth space defined by the magnetosphere down to the ionosphere and thermosphere. Space weather is distinct from the terrestrial weather of the Earth's atmosphere (troposphere and stratosphere). The science of space weather is focused in two distinct directions: fundamental research and practical applications. The term space weather was not used until the 1990s. Prior to that time, activities now known as space weather were considered to be part of physics or aeronomy or space exploration.
HELIOSPHERE = Solar wind + Interplanetary magnetic field (IMF)

Solar wind is constant streaming of the solar plasma from the uppermost layers of the solar atmosphere. It is interrelated to interplanetary magnetic field, a continuation of the solar mag. field into the interplanetary space. The space dominated by the two defines heliosphere.

http://www.nasa.gov
In situ measurements of solar wind and IMF

- Advanced Composition Explorer (ACE)

- IMF components

- Solar wind parameters
In situ measurements of solar wind and IMF

Advanced Composition Explorer (ACE)

“QUIET” PERIOD (background)
In situ measurements of Solar wind and IMF

<table>
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<tr>
<th>DOY</th>
<th>vs. Multiple Variables</th>
<th>64-sec Averages -- Plot created Nov 09 2014</th>
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<td>DISTURBANCE</td>
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<td>Elm/sec</td>
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<td>Degrees (Kahm)</td>
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<td>1/cm^3</td>
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Solar wind parameters

IMF components

Advanced Composition Explorer (ACE)
Solar wind & IMF modulate cosmic ray flux

Moscow neutron monitor (Izmiran)

On short scales

And long scales
Solar wind & IMF modulate cosmic ray flux

Smoothed Sunspot Number Monthly Averages

Counts/Hour/100

Thule, Greenland, Neutron Monitor
Bartol Research Institute, University of Delaware
27-day Averages - data through November 2013

R. Pyle, March 2013
Long term Solar activity: 11 year Solar activity cycle

Solar activity is reflected by the change in the sunspot number (cca 11 year cycles), in EUV images of solar corona – increased number of bright active regions (towards the solar maximum).
Long term Solar activity: 11 year Solar activity cycle

Sunspots correspond to areas of enhanced magnetic field

Long term Solar activity: 22 year Solar activity cycle

Hale’s polarity law:
- sunspots come in pair of opposite polarity
- opposite leading polarities at opposite hemispheres
- leading polarities change with every cycle
  => 22 year cycle

Long term Solar activity: Solar dynamo process

- It is widely believed that the Sun's magnetic field is generated by a magnetic dynamo within the Sun.

- **dynamo** – conversion of kinetic into electromagnetic energy
Short term Solar activity – Solar storms

We observe violent changes in the Solar atmosphere

EUV Imager AIA onboard Solar Dynamics Observatory (SDO)
Short term Solar activity – Solar storms

We observe violent changes in the Solar atmosphere

Release of the magnetic energy

EUV Imager AIA onboard Solar Dynamics Observatory (SDO)

http://www.nasa.gov
Solar storms: Solar flares

Eruptive phenomena in the solar atmosphere: they emit a broad spectrum of electromagnetic radiation (from radio waves to gamma rays)

Most often seen in EUV, X ray and H-alpha line

Also release solar energetic particles (SEPs)
Solar storms: Prominences

Eruptions of plasma from lower layers of the solar atmosphere (denser and cooler),
Time scales from hours to weeks
Solar storms: Coronal Mass Ejections (CMEs)

Magnetized plasma ejection from the solar corona (seen in coronagraphs and heliospheric imagers by white light emitted by scattered electrons as it moves through)

Composite of EUV imager, coronagraph & heliospheric imager onboard Solar Terrestrial Observatory (STEREO)
Solar storms: CME-flare-prominence connection

Magnetic field structure (CME) starts to expand due to loss of equilibrium

Stretching of the overlying magnetic field, reconfiguration (MAGNETIC RECONNECTION)

Particle acceleration from the reconnection site – SEPs & electromagnetic radiation (Solar flare)

CME liftoff enabled by reducing the tension of the overlying field, plasma pile-up at the front

Prominence material trapped by the poloidal magnetic flux

Temmer et al. (2010)
Solar storms: CME-flare-prominence connection

CME three part structure:
1. Bright front - compressed material at the leading edge
2. Dark cavity - low-density, magnetic bubble
3. Bright core – dense prominence gas
Solar storms: CME-flare-prominence connection

EUV imager EIT and LASCO C3 coronagraph onboard SOHO
(left-real, right-running difference)

Time correspondence between Solar flare and CME

X ray flux measurement from GOES satellite
Solar storms consequences for space weather?
In situ measurements of Solar wind and IMF

DOY vs. Multiple Variables
64-sec Averages -- Plot created Nov 09 2014

DISTURBANCE

IMF components

Solar wind parameters

Advanced Composition Explorer (ACE)
Solar storms consequences at/near Earth

SOLAR FLARES

Electromagnetic radiation ~ 8 min

Solar energetic particles ~ 0.5 hour

CMEs

Plasma carrying magnetic field ~ day

Influence on the IONOSPHERE

John Emmert/NPL Astrobiologyonline magazine
Solar storms consequences at/near Earth

CMEs when they come to Earth can interact with geomagnetic field => geomagnetic storms, particles injected into the ionosphere

www.forskning.no (University of Oslo)
(Other) Solar storms consequences

- Planets – influence on planetary magnetospheres/ionospheres
- Comets – influence on cometary “magnetosphere”
- Solar wind - disturbed
- Interplanetary magnetic field - disturbed
- Cosmic rays – galactic CRs reduced, solar energetic particles
- Satellites – can be damaged, even failure of operations
- Astronauts – can be in danger
- … - power blackouts, GPS failure, increased radiation dose on transpolar flights, pipeline degradation, AURORAE…

Plenty of motivation for forecasting…
Forecasting long-term solar activity

Mostly empirical – prediction of the new cycle based on the preceding one(s); Employing solar dynamo theory?
Forecasting sunspot emergence

Helioseismology (doppler shift of photospheric absorption lines - acoustic waves)

The upper layer shows the photospheric magnetic field, and the lower layer shows the acoustic travel-time perturbations detected at a depth of about 60,000 km.
Forecasting solar flare eruptions

Based on the photospheric field measurements and/or pattern recognition

From www.flareforecast.com
Forecasting CME arrival and/or solar wind and IMF conditions

Empirical and analytical (drag-based) for arrival, numerical (MHD) models for arrival + conditions (but evolution of B not solved!)

Enlil model at http://ccmc.gsfc.nasa.gov
Forecasting solar wind-magnetosphere coupling

WINNDM results at http://ccmc.gsfc.nasa.gov

numerical models that use *in situ* measurements as input

Predicting risk for power lines, pipelines, satellite operations, radiation dosage....
COMBINE EVERYTHING

Solar-interplanetary-terrestrial connection
Hvar Observatory
(Faculty of Geodesy, Uni. Zagreb, Croatia)

solar group (6; theory & obs.):
- solar eruptive phenomena
- solar rotation & other large-scale phenomena

stellar group (3; obs.):
- variable stars
- Be stars

equipment:
- double solar t. (white light + H alpha)
- 65 cm photometric t.
- 1 m multi-purpose t.
The Observatory at Hvar Island
Collaboration network

- Zagreb
- Hvar
- Ondrejov
- Uni. Graz
- Tatr. Lomn.
- Uni. Oslo
- Uni. Kiel
- AIP
- KIS
- DTU
- ISSI Bern
- Meudon
- ROB
- UCLAN
- Uni. Oslo
- Uni. Kiel
- AIP
- KIS
- DTU
- ISSI Bern
- Meudon
- ROB
- UCLAN
Collaboration network

Uni. Washington (LSST-comets)

GSFC

NRL

MLSO

AFRL
Thank you for your attention!