Solar Photospheric, Chromospheric and Coronal Observations for Space Weather Forecasting

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Large-scale structures in the solar atmosphere

Solar large-scale structures relevant for Space Weather forecasting:

- Active regions
- Filaments/prominences
- Coronal holes
Large-scale structures in the solar atmosphere

Two kinds of measurement to collect information about the Sun:

Remote Sensing and In-situ Measurement

(From a distance) (In place)
Key for remote sensing of the sun (and stars): Solar Spectrum

Complete solar spectrum

EUV part of solar spectrum
Solar Spectrum

True-Color Irradiance Spectrum 392 to 692 nm from Kitt Peak Residual Irradiance Atlas (Kurucz 2005)
Average temperature profile of the solar atmosphere

Plasma temperature is roughly related to height/atmospheric layer and related to spectral line.
Key to solar activity: solar magnetic field

Line-of-sight full disk magnetogram: 2d cut at photosphere

Global magnetic field (extrapolation): 3d structure
Key to solar activity: solar magnetic field

How to measure the solar magnetic field?

- In-situ: magnetometer
- Remote: magnetographs

Method: Zeeman Effect:

A magnetic field in a plasma produces:
- splitting of certain spectral lines (mostly photospheric and chromospheric)
- polarization of light
Key to solar activity: solar magnetic field

Zeeman Effect: (measuring magnetic fields)

**Longitudinal Zeeman Effect:**
the component of the magnetic field vector parallel to the line of sight produces **circular polarization**

**Transverse Zeeman Effect:**
the component perpendicular to the line of sight produces **linear polarization** of light
Key to solar activity: solar magnetic field

Full disk white light image (SDO)  
full disk line-of-sight magnetogram (SDO)
If we just have white light images and magnetograms:

Q: How do we know where magnetic fields are in the corona?
Key to solar activity: solar magnetic field

If we just have white light images and magnetograms:

Q: How do we know where magnetic fields are in the corona?

A1: Physical extrapolation
A2: Images of the corona: outline (some, not all) of the magnetic fields.
Key to solar activity: solar magnetic field

SDO full disk magnetogram and coronal 171 Å image:
Bright regions in corona are active regions (have stronger magnetic field than surrounding atmosphere).
Key to solar activity: solar magnetic field

Full disk image in H-alpha (from BBSO):

Filaments seen as dark absorption structures
Key to solar activity: solar magnetic field

High resolution image in H-alpha (Dutch Open Telescope)

Filaments seen as dark absorption structures
Over simplified diagram of an active region’s magnetic field

- Positive polarity
- Negative polarity
- Polarity inversion line (PIL, $B=0$)
- Magnetic field lines almost perpendicular to PIL
Over simplified diagram of a filament’s magnetic field:

magnetic field lines almost parallel to PIL
Key to solar activity: solar magnetic field

Notes on filaments:
Filament: on-disk magnetic structure (seen in absorption)
Prominence: same structure off limb (seen in emission)
Best wavelengths: H-alpha, He II 304, Fe XII 195 Å (EUVI, AIA, STEREO)
All filaments have a PIL (polarity inversion line)
But not all PILs are filaments!

Caution: full disk magnetograms give only the line-of-sight magnetic field – projection effects near the solar limb! (see ISWA layout of active region near the limb and near disk center, link on agenda web-page.)
Key to solar activity: solar magnetic field

- **Caution:** full disk magnetograms give only the line-of-sight magnetic field – remember the sun is a sphere and there are projection effects near the solar limb!
Key to solar activity: solar magnetic field

Solar magnetograms:

• Most full-disk magnetographs measure circular polarization only (MDI, HMI 45s, ground-based magnetograms like GONG); not very reliable beyond 60 deg from disk center!

• No magnetograph data on the far side of the sun.

• To produce global magnetograms use solar rotation (27.27 d rotation rate) to get synoptic maps of the photospheric magnetic field. Due to tilt angle of solar rotation axis, poles of the sun are also not well observed!
Key to solar activity: solar magnetic field

Find out more and 45 years encapsulated in one synoptic magnetograms:
https://solarscience.msfc.nasa.gov/dynamo.shtml

More on the use of these magnetic field maps in the talk by Nick Arge ('Coronal Modeling with WSA and ADAPT')
Solar eruptive events: flares and CMEs

• Energy is stored in the solar magnetic field (active regions and filaments): accumulated over a long period of time – days, weeks, months

• Energy is released in eruptive events (flares, CMEs): in a short time scale (minutes, hours)

• Magnetic energy is converted to thermal energy (and radiative energy) and kinetic energy (e.g. mass motion in CMEs and SEPs)
Solar eruptive events: flares and CMEs

• Solar Flares: Event that releases X-rays
• X-ray monitor on-board GOES spacecraft (in Earth orbit), full disk monitor (no spatial information of location of flare on the sun)
• Larger events radiate also in other wavelengths especially in UV, EUV (and radio) → use SDO/AIA images to determine location!
Solar eruptive events: flares and CMEs

Classical scenario for an eruption:

- Reconnection at the x-point (energy release)
- CME escapes upward, field-lines open up
- Post-eruptive loops appear below x-point (additional heating)
Solar eruptive events: flares and CMEs

**Caution:** the real sun is more complicated compared to the cartoon

- Everything is evolving in 3 dimensions.

Some eruptions show no/very little X-ray signature (particularly filament eruptions)
Some flares have no CMEs
Large scale structures in the corona

• Images: SDO AIA 193 A, STEREO EUVI 195 A (filter contains Fe XII 195 A line, T~1.5 MK)
• Line-of-sight magnetograms: polarity inversion line (PIL)

**Active Regions**: bi-polar, bright (emission), closed magnetic field (field lines perpendicular to PIL)

**Filaments**: bi-polar, dark (absorption), closed magnetic field (field lines parallel to PIL)

**Coronal hole**: uni-polar, dark (less dense), open magnetic field
Coronal signatures of CMEs

Data to use: SUVI, SDO AIA, STEREO EUVI (A & B)

• Brightening: flares, post-eruptive arcade (193 A), arcade foot-points (304 A, 193 A)
• Darkening: dimming (transient coronal holes), dark/absorbing/cool material rising (filament eruption)
• Off-limb: opening of closed coronal field lines, AIA 304 A; emission structure

Not a signature of SWx eruption: active region loop brightening; (small) flares
Coronal signatures of CMEs

Homework:

Good Case Study: 2014/02/18 – 2014/02/21 (use SDO AIA 211, 193, 304)

https://helioviewer.org/
Data Sources

• SDO: Solar Dynamics Observatory (https://sdo.gsfc.nasa.gov)
  • SDO AIA: Atmospheric Imaging Assembly; full disk coronal images (wavebands 171A, 193A, 304A, 211A, 131A,...)
  • SDO HMI: photospheric data (e.g. magnetograms)

• SOHO: Solar Mission at L1 (Lagrange point 1),
  • MDI – magnetograms,
  • EIT: coronal images,
  • LASCO: white light coronagraphs (C1,C2,C3)
Data Sources

  • STEREO A and B – currently only STEREO A
  • EUVI: full disk coronal images (195A, 304A)
  • Cor 2: white light coronagraphs
Data Sources

• BBSO: Big Bear Observatory
  • (www.bbso.njit.edu)
  • Ground-based solar observatory
  • Full disk images in H alpha
Data Sources

• GONG: Global Oscillation Network Group
  • Part of National Solar Observatory (NSO):
  • network of 6 ground-based solar observatories (around the world to continuously observe the sun)
  • https://gong.nso.edu
  • Full disk H alpha images, synoptic magnetograms
Data Sources

Glossary: