The Solar Irradiance

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Solar irradiance variability:
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Three points to remember
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... plays an important role in the Earth's upper atmosphere
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... is driven by variations in the magnetic field
Solar irradiance variability: Three points to remember

... plays an important role in the Earth’s upper atmosphere

... is driven by variations in the magnetic field

... is determined by the structuring of the solar atmosphere
An Application: The Orbital Debris Problem
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Video courtesy of Analytical Graphics, Inc. www.agi.com
Outline

- Total Solar Irradiance
  - Measurements
  - Application to climate change
- Solar Spectral Irradiance
  - The Solar Atmosphere
    - Soft X-rays
    - Extreme Ultraviolet
    - Ultraviolet
    - Visible/Infrared
  - Overview of observations
  - Application to satellite drag
- Common proxies for solar activity
- Proxy irradiance models
- A quick note on regression
  - Training/Test/Validation
  - Gaussian Process Regression
- The magnetic flux as a proxy
- Forecasting solar activity
  - Autoregression
  - Magnetic flux transport
- Emission processes
  - Optically thin line emission
- Semi-empirical models
  - Differential emission measure
- My 2 cents on useful tools and skills
Overview of the Solar Spectral Irradiance

Total Solar Irradiance: The Sun’s radiated power integrated over all wavelengths
The Total Solar Irradiance: Measurements and Composites

Solanki, Krivova, & Haigh, Annual Reviews, 2013
TSI Variations During a Period of Very High Solar Activity

TSI is often anti-correlated with solar activity

MDI/SoHO
October - November 2003

TSI Variations During a Period of Very High Solar Activity

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Solar forcing is comparable in magnitude to other inputs. Greenhouse gases drive secular trend.
Overview of the Solar Spectral Irradiance

NRLSSI Model Judith Lean
Soft X-Rays: < 50 Å

- Generally formed at high temperatures (> 2MK)
- Very high contrast between quiet and active sun → strong variation over solar rotation and solar cycle
- Flares contribute significantly to variability
- Optically thin
- Limited measurements
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XRT/Hinode
September – November 2014

Very high contrast between quiet and active Sun
EVE/SDO Flare Irradiance
SXT/Yohkoh Images Over a Solar Cycle
SXT/Yohkoh Images Over a Solar Cycle
Example SXR Irradiance Solar Cycle Time Series
Daily XRS/GOES 1 – 8 Å

No continuous, spectral irradiance measurements that completely cover < 50 Å
Example SXR Irradiance Spectrum
New Observations from X123


MinXSS: LASP CubeSat
X123 SXR Detector
2015 launch

Infer spectra from emission measure model?
Extreme Ultraviolet: 50 – 1200 Å

- Formed at chromospheric, transition region, coronal, and flare temperatures
- Optically thin and thick lines and continua
- Moderate contrast between quiet and active sun → moderate variation over solar rotation and solar cycle
- Many measurements

EVE/SDO EUV Spectral Irradiance

1 Å spectral resolution
10s cadence
50-1050 Å coverage
2010 - present
EUV: 50 – 1200 Å: EVE/SDO Irradiance Spectrum

EVE MEGS A/B 11–NOV–2011 12:00

Coronal lines
e.g., Fe IX 171, Fe XII 195

He II continuum
He II 304

Lyman continuum
Lyman lines

Transition region lines
e.g., C III 977, O V 629, O VI 1032, Ne VIII 770
EIS/Hinode
22mÅ resolution
Spatially Resolved Flare

Spectra are complicated!
within ~ 1 Å 0 V, Fe XI, Ca XVII

EUV Atlas Papers
EIS - Brown et al 2007
CDS - Brooks et al. 1999
SUMER - Curdt et al. 2001
The Extreme Ultraviolet Imaging Spectrometer on Hinode

Solar Min

Si VII 275.37 Å
Fe XII 195.12 Å
Fe XV 284.16 Å

Solar Max

Fe XV 284.16 Å

Solar Min
EUV: 50-1200 Å
Transition Region

strong limb-brightening

SUMER/SoHO S VI 933 Å
May 12 – 13, 1996
EUV: 50 – 1200 Å
Chromosphere

reduced AR/QS contrast relative to SXR

AIA/SDO He II 304 Å
October 2014

SUMER/SoHO Lyman ε 937 Å
August 11 – 12, 1996

intensity doesn't limb-brighten
EUV: 50 – 1200 Å
Chromosphere

AIA/SDO He II 304 Å
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intensity doesn’t limb-brighten
Example EVE/SDO EUV Irradiance Time Series

- Fe XVI 335.31 Å
- Fe XIV 211.32 Å
- Fe XII 195.12 Å
- He II 303.72 Å
Example Ultraviolet Spectrum: 1200 – 4000 Å

SUSIM UARS Solar and Deuterium Lamp Spectra

Solar spectrum
1.1 nm resolution

D2 lamp spectrum
5 nm resolution

Irradiance (mW/m²/nm)

wavelength (nm)
Ultraviolet: 1200 – 4000 Å

SOT/Hinode Ca II H Line
Ultraviolet: 1200 – 4000 Å

SOT/Hinode Ca II H Line
Example UV Irradiance Time Series
SUSIM/UARS
Visible Spectrum:
5770 K Blackbody
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An Application: The Orbital Debris Problem
Solar EUV Irradiance Variations

SDO/AIA 30.4 nm

0-103 nm Irradiance (TIMED/SEE)

John Emmert, NRL

Thermospheric Density Response
NRLMSISE

$\ln \rho$

Density Change

John Emmert, NRL
Solar EUV Irradiance Variations

Thermospheric Density Response
NRLMSISE

John Emmert, NRL
Connections Among Space Environment Components

Photons (+Solar Wind) - Gas - Forces - Satellites and Debris

Solar EUV and FUV Irradiance

Solar Wind

Total Solar Irradiance

Lower Atmosphere

Thermospheric Density

Thermospheric Wind and Composition

Gravity

Drag Force

Solar Radiation Pressure

Satellite Trajectory

Tracking Observations

Many Objects

Owner/Operator Maneuvers

Satellite Mass, Shape, Material, Attitude

Collision Prediction and Avoidance

Catalog Maintenance

The irradiance and the atmosphere are just part of the problem!
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