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

maybe the second half will be better . . .

• 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
Proxies for Solar Activity

EVE/SDO He II 304 Daily Average

What do we do when there is no data?
Proxies for Solar Activity:
Sunspot Number

- Very extensive database
- Noisy; modest correlation with irradiance observations
- Recent Reference
  - Clette et al, SSR, 2014

source: WDC-SILSO, Royal Observatory of Belgium, Brussels
http://sidc.be/silso/home
Proxies for Solar Activity: F10.7 cm Radio Flux

- Extensive database (from 1932)
- Good correlation with irradiance observations

References
- Tapping, Space Weather, 2012
- Tapping, JGR, 1987


can become non-linear; add 81-day mean to regression
Problem: F10.7 is too popular! Atmospheric Models Often Use F10.7 as an Input

How is the solar spectrum specified?

- Namelist variables point to 2 files specifying solar forcing
    - Solar and geomagnetic parameters used for aurora, UBCs, and wavelengths shorter than Lyman-α
  
  ```
  > grep solar_Parms_file CaseDocs/atm_in
  solar_Parms_file = '/fis/cgd/cseg/csm/inputdata/atm/wacccm/phot/wa_smax_c100517.nc'
  ```

- `solar_data_file`: ts, ssi, tsi_ref, ssi_ref
  - Covers wavelengths longer than Lyman-α
  - Time-variation of total solar irradiance, as well as variability with λ

  ```
  > grep solar_data_file CaseDocs/atm_in
  solar_data_file = '/fis/cgd/cseg/csm/inputdata/atm/cam/solar/spectral_irradiance_Lean_1610-2009_ann_c100405.nc'
  ```

Dan Marsh, Mike Mills/NCAR
Proxies for Solar Activity:
Mg Core-to-Wing Ratio

Morrill et al. 2008, 2011a,b [HRTS9/NRL]
Proxies for Solar Activity:
Mg Core-to-Wing Ratio

- More limited database (from 1978)
- High correlation with irradiance observations
- Must be observed from space → composite time series

References
- DeLand & Marchenko, JGR, 2013
- Viereck & Puga, JGR, 1999
- http://www.iup.uni-bremen.de/UVSAT/Datasets/mgii

source: http://www.iup.uni-bremen.de/gome/solar/MgII_composite.dat
Proxy Irradiance Models: NRLSSI

References
- Lean et al. 2011
- Lean 2000
- Lean et al. 1997

\[ F(\lambda, t)/F(\lambda)_{ref} - 1 = a(\lambda) + b(\lambda) \times [Mg(t)/Mg_{ref} - 1] + c(\lambda) \times [SB(t)/SB_{ref} - 1] \]

with the coefficients \(a(\lambda), b(\lambda)\) and \(c(\lambda)\) determined from multiple linear regression of detrended time series.

http://lasp.colorado.edu/lisird/nrlssi/
Proxy Irradiance Models: SATIRE-S


SATIRE-S uses full-disc magnetograms and continuum images of the Sun to quantify the fractional disc area coverage by different surface components (quiet Sun, sunspot umbrae, sunspot penumbras, faculae and network) as well as their spatial distribution.

The most recent version of the model uses the data from the NSO KP (1974-1999), SoHO/MDI (1999-2009) and SDO/HMI (since 2010)

http://www2.mps.mpg.de/projects/sun-climate/data.html
Proxy Irradiance Models: FISM

- Based mainly on SEE/TIMED observations
- GOES SXR light curves are used to generate a flare component
- References
  - Chamberlin et al, 2007, 2008a,b

Example Application to Total Electron Content

Qian et al. 2008
A Quick Comment on Regression

A good regression doesn’t provide the lowest $\chi^2$, it returns probabilistic results.

how do I represent $y(x)$ as a smooth function?

$$y(x) = \sum_{m=1}^{M} w_m \phi_m(x)$$

$$\phi_m(x) = \exp \left[ -\frac{(x - x_m)^2}{\sigma^2} \right]$$

emphasis on chi-squared encourages overfitting
A Quick Comment on Regression

- Determine optimal model complexity by considering points excluded from determining the fit parameters.
A Better Way: Gaussian Process Regression

• Gaussian Process Regression
  - Non-parametric; use covariance to describe the model
    \[ K_{i,j} = \sigma_j^2 \exp\left[-\frac{(x_i - x_j)^2}{2\ell^2}\right] \]
  - Bayesian: probabilistic predictions

• Reference:
  - http://www.gaussianprocess.org/
  - http://videolectures.net/pyGPs - A Package for Gaussian Processes
Proxies for Solar Activity: Total Unsigned Magnetic Flux


Example from EIT and MDI on SoHO
Proxies for Solar Activity:
Total Unsigned Magnetic Flux


Example from EIT and MDI on SoHO
magnetic flux is hard to measure at the limb

Use projected Carrington Map instead
Daily Magnetic Proxy  \[ \Phi_r = \sum B_r \cdot A \]
Comparisons with Existing Proxies
Forecasting Solar Activity: Autoregression

To predict collisions we need to forecast the solar irradiance

\[ X_t = \sum_{i=1}^{n} \varphi_i X_{t-i} + \epsilon_t \]

Autoregression

Autoregression Applied to F10.7

http://celestrak.com/SOCRATES/search.asp

<table>
<thead>
<tr>
<th>Action</th>
<th>NORAD Catalog Number</th>
<th>Name</th>
<th>Days Since Epoch</th>
<th>Max Probability</th>
<th>Dilution Threshold (km)</th>
<th>Min Range (km)</th>
<th>Relative Velocity (km/sec)</th>
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</thead>
<tbody>
<tr>
<td>Analysis</td>
<td>29479</td>
<td>HINODE (SOLAR-B) [+]</td>
<td>3.469</td>
<td>8.402E-07</td>
<td>0.564</td>
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<td>6.372</td>
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<td>COSMOS 2251 DEB [-]</td>
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<td>HINODE (SOLAR-B) [-]</td>
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<tr>
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<td>FENGYUN 1C DEB [-]</td>
<td>2.784</td>
<td>18.0514.140</td>
<td>18.0514.306</td>
<td>18.0514.476</td>
<td>14.977</td>
</tr>
</tbody>
</table>

Skill = 1 - \frac{MSE(model)}{MSE(reference)}

Also See: Tobiska et al. 2008
Forecasting Solar Activity: Autoregression

To predict collisions we need to forecast the solar irradiance.

$$X_t = \sum_{i=1}^{n} \varphi_i X_{t-i} + \epsilon_t$$

Autoregression

Skill = \frac{1 - \frac{\text{MSE(model)}}{\text{MSE(reference)}}}{\text{MSE(reference)}}

Autoregression Applied to F10.7

http://celestrak.com/SOCRATES/search.asp

Also See: Tobiska et al. 2008
Forecasting Solar Activity: Magnetic Flux Transport

- Flux Transport Processes
  - differential rotation
  - super granular diffusion
  - meridional flow
  - flux emergence and cancelation

- Example References
  - Worden & Harvey (2000) ADAPT
  - Schrijver & DeRosa (2003) PFSS_VIEWER
  - Upton & Hathaway (2014a,b)

Forecasting $F_{10.7}$ with solar magnetic flux transport modeling

C. J. Henney, W. A. Toussaint, S. M. White, and C. N. Arge

Upton & Hathaway Adveective Transport Model
Forecasting Solar Activity: Magnetic Flux Transport

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Upton & Hathaway Advective Transport Model
Magnetic Flux Transport: Incorporating Far Side Information

AR 12192

http://farside.nso.edu/
Magnetic Flux Transport:
Incorporating Far Side Information

AR 12192

http://farside.nso.edu/

STEREO
Magnetic Flux Transport: Incorporating Far Side Information

Magnetic Flux Transport: Incorporating Far Side Information

What do we do when there is limited spectral coverage?
Computing Line Intensities

\[ I_\lambda = n_u A_{ul} V \]
Computing Line Intensities

\[ I_{\lambda} = n_u A_{ul} V \]

transition rate

number density

volume

\[ I_{\lambda} = \frac{n_u}{n_{ion}} \frac{n_{el}}{n_H} n_e A_{ul} V \]

ionization fraction

level pop

elemental abund

emissivity

emission measure

\[ I_{\lambda} = \epsilon_{\lambda}(T_e) n_e^2 V \]

\[ I_{\lambda} = \int_{T_e} \epsilon_{\lambda}(T_e) n_e^2 \frac{dV}{dT_e} dT_e \]

need many lines

convert to an integral over temperature

\[ I_{\lambda} = \int_{T_e} \epsilon_{\lambda}(T_e) \xi(T_e) dT_e \]

inversion is noisy \Rightarrow regularize or smooth
\[ I_\lambda = \int_{T_e} \epsilon_\lambda(T_e) \xi(T_e) dT_e \]
Example DEM Calculation

\begin{align*}
\alpha &= 3.0 \pm 0.27 \\
\beta &= 7.0 \pm 1.73
\end{align*}
Example DEM Calculation

\[ \alpha = 3.0 \pm 0.27 \]
\[ \beta = 7.0 \pm 1.73 \]
Example SXR Irradiance Spectrum
New Observations from X123


MinXSS: LASP CubeSat
X123 SXR Detector
2015 launch
Example Emission Measure Distributions
EUV: 50-1200 Å

Chamberlin et al., GRL 2009
EVE Rocket and NRLEUV QS Model
Wrapping Up: What do I wish I knew when I was your age?

- Computation
  - IDL (for now) [“Modern IDL” Galloy]
  - python (for the future)
  - Java/C++/C (some compiled language)
  - Object oriented programming (even in IDL)
  - Version control (git or svn)
  - Algorithms

- Statistics
  - Bayesian inference

- How to write
  - “The Sense of Style” by Steven Pinker

- How to give a talk
  - “Presentation Zen” by Garr Reynolds
  - “Slide:ology” by Nancy Duarte

- Have mentors - three?
  - Someone senior
  - Someone your age
  - Someone younger

- Think about a day job
  - Soft money = proposals!

- Don’t be afraid