Invisible sunspots and implications for the monitoring of Solar Active Regions

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AstroGrid study of region emergence and flare productivity

- AstroGrid – UK Virtual Observatory project – www.astrogrid.org
- Making integration and comparison of data from diverse sources transparent
- Enabling access and manipulation of large datasets and catalogues
Flare productivity of newly emerged paired/isolated Active Regions

- Use workflows to cross match catalogues of solar active regions and flares, to answer the question: Does emergence of a new region near another one increase flare productivity?

- AstroGrid workflows analysing USAF/Mt Wilson + GOES data: only small increase in flare productivity for paired regions (Dalla et al A&A 468, 1103, 2007)

<table>
<thead>
<tr>
<th>Subset</th>
<th>n of regions</th>
<th>$P$ (%)</th>
<th>$F$ (flares/4 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NERs</td>
<td>2115</td>
<td>21.7 ± 1.0</td>
<td>0.639 ± 0.017</td>
</tr>
<tr>
<td>NERs paired</td>
<td>675</td>
<td>24.3 ± 1.9</td>
<td>0.696 ± 0.032</td>
</tr>
<tr>
<td>NERs isolated</td>
<td>1440</td>
<td>20.5 ± 1.1</td>
<td>0.613 ± 0.020</td>
</tr>
<tr>
<td>companions</td>
<td>676</td>
<td>39.3 ± 2.4</td>
<td>1.745 ± 0.051</td>
</tr>
<tr>
<td>old regions</td>
<td>1516</td>
<td>39.7 ± 1.6</td>
<td>1.689 ± 0.033</td>
</tr>
</tbody>
</table>

$P$ = % of regions with flares

$F$ = mean flare number
Location of emergence of new regions

- USAF/Mt Wilson catalogue of sunspot groups for 24 years (Dec 1981 - Dec 2005) - 6862 regions
- For each NAR identify where/when region was first observed

- Displays strong East-West asymmetry
East-West asymmetry

- 825 new regions in [-60, -40]
- 177 new regions in [+40, +60]
Maunder paper (1907)

• First report of an East-West asymmetry in the location of emergence of sunspots: A.S.D. Maunder, 1907
• East-West asymmetry in sunspot areas also reported in the paper
East-West asymmetry explained

- Schuster (1911) explained Maunder’s data as a visibility effect.
- Minnaert (1939) introduced a graphical representation that makes the cause of the asymmetry clear:
Visibility function and number of regions observed

- \( N(\lambda) = \) number of regions observed to emerge in a unit bin at longitude \( \lambda \)

- \( N_1 = \) actual (constant) number of regions emerging in unit bin = actual rate of new region emergence

- \( N(\lambda) \) depends on the gradient of the visibility function \( s'(\lambda) \) and on the growth rate \( k \) of sunspot regions’ area

\[
N(\lambda) = N_1 \left[ 1 - \frac{\Omega}{k} s'(\lambda) \right]
\]

Schuster, 1911
Recent assumptions on visibility

• Results by Maunder and Schuster appear to have been forgotten in recent times – East-West asymmetry often ascribed to observer bias

• Furthermore, since Minnaert, it has been assumed that the visibility function is:

\[ s(\lambda) = \frac{1}{\cos(\lambda)} = \sec(\lambda) \]

• geometric (foreshortening) visibility function: very flat near \( \lambda = 0 \)
Our work

- Confirm that Schuster’s theory is in quantitative agreement with the data

- Use our asymmetry data to derive:
  - Visibility function
  - Growth rate/decay rate of sunspot regions
  - Quantify how many new emergences go completely undetected as a result of the visibility effect (invisible sunspots)
Locations of sunspot disappearances

- If the asymmetry in emergences is the result of poor visibility, a similar effect must be present for sunspot disappearance locations
Emergences + disappearances

\[ N(\lambda) = N_1 \left[ 1 - \frac{\Omega}{k} s'(\lambda) \right] \]

\[ n(\lambda) = n_1 \left[ 1 + \frac{\Omega}{l} s'(\lambda) \right] \]
Actual rate of region emergence

- For a symmetric visibility function, the following relations are expected to hold:

\[ N_+ + N_- = 2N_1 \]

\[ n_+ + n_- = 2n_1 = 2N_1 \]

\[ N_1 = 160.55 \pm 11.41 \]

\[ N_1 = 158.95 \pm 12.19 \]
Ratio of growth/decay rates

\[ N(\lambda) = N_1 \left[ 1 - \frac{\Omega}{k} s'(\lambda) \right] \]

\[ n(\lambda) = n_1 \left[ 1 + \frac{\Omega}{l} s'(\lambda) \right] \]

- \( k / l = 1.37 \pm 0.26 \) (from 16 longitude bins)
- On average, decay phase is only \(~1.4\) times longer than rise phase
- Fast rise + slow decay might be an observational effect
Derivative of visibility function

- Obtain $s'$ separately from emergences and disappearances data.
- Requires an assumption on the growth rate of sunspot regions $k$.

\[
N(\lambda) = N_1 \left[ 1 - \frac{\Omega}{k} s'(\lambda) \right]
\]
\[
n(\lambda) = n_1 \left[ 1 + \frac{\Omega}{l} s'(\lambda) \right]
\]
Visibility function

- Fit $s'$ expression:
  \[ s'(\lambda) = c_1 \tan^{-1}(c_2 \lambda) \]

- Integrate to find:
  \[ s(\lambda) = \frac{c_1}{c_2} \left[ x \tan^{-1} x - \frac{1}{2} \ln(1 + x^2) \right] + A_{\min} \]
  \[ x = c_2 \lambda \]

- Strong center-to-limb variation of visibility of small spots
- Visibility is much worse than expected from projection effects (geometrical, $\sec \lambda$)

Invisible sunspots

- 44% of new sunspots emerging between 0 and +60 are invisible

- The corresponding Active Regions are not given an Active Region number (unless they produce a flare) and are not monitored

An Active Region number is assigned to a region that satisfies one of the following criteria: (1) the region has been reported to have a sunspot group with first digit of its Modified Zurich Classification of C, D, E, F or H; (2) two or more reports confirm the presence of a Modified Zurich class A or B sunspot group; (3) the region produces a solar flare; or (4) the region is bright in $H_\alpha$ and exceeds 5 heliographic degrees in either latitude or longitude.

- Systematic bias affecting Western Active Regions

- Need for additional data for AR cataloguing
Apparent vs actual age of sunspots

• For the sunspots that are detected, actual times of emergence and decay can differ considerably from those that are observed.

• Sunspot’s lifetime is often underestimated – eg regions crossing in and out of the visibility curve.

• Distributions of sunspot lifetimes and decay times may need revising (Note: decay time distribution is used to infer mechanism of sunspot decay eg Martinez-Pillet et al, 1993).
Further questions

• Cause of the strong centre-to-limb variation of visibility – 3D structure of sunspots

• Will the same physical mechanism also affect larger spots and how?

• Visibility effects in magnetogram data?