Study on the Triggering Process of Solar Flares based on Hinode and SDO Observation

Collaborators:

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Overview

1. Our Study
   - Flare Trigger Model (Kusano+[2012])
   - Observational Verification (Bamba+[2013, 2014])

2. Case Study (NOAA AR 12192)

3. Discussion:
   Current Status of Flare Observation with Hinode and Requirements to Space Weather Forecast
1. Our Study

- Our Flare Trigger Model (Kusano, Bamba et al. 2012)

- Internal reconnection between large-scale sheared magnetic field and small magnetic field can trigger solar flares.

- The conditions of flare occurrence are characterized by two parameters:
  - The shear angle of the global magnetic field of the active region: $\theta$
  - The azimuthal angle of the small scale triggering flux: $\phi$
Summary of our numerical simulation, “Flare Phase Diagram”

- **Flare Occurrences**
  - ◇: Yes, □: No

- **Opposite Polarity Type**
- **Reversed Shear Type**

![Flare Phase Diagram](image)

- **OP-Type**
- **RS-Type**

- **Shear angle of a global magnetic field**
  - \( \theta \) (degree)

- **Azimuth of small triggering flux**
  - \( \varphi \) (degree)

- **Flare Occurrences**
  - Yes, No

- **E_k**
  - 0.5, 1.0, 1.5, 2.0, 2.5 \( \times 10^{-2} \)
Observational Verification (Bamba et al. 2013, 2014)

- **Abstract:**
  We identified the “flare trigger region” of four major flares. We confirmed that the triggering process of each flare are consistent with either OP- or RS-type of our flare trigger model.

- **Event Criteria:**
  - Period: October 2006 - July 2011
  - Location: within ±750 arcsec from the solar disk center
  - Magnitude: larger than M5.0

- **Event List:**

<table>
<thead>
<tr>
<th>Event No.</th>
<th>Date</th>
<th>Start Time</th>
<th>Active Region (NOAA AR)</th>
<th>X-ray Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13 Dec. 2006</td>
<td>02:14 UT</td>
<td>10930</td>
<td>X3.4</td>
</tr>
<tr>
<td>2</td>
<td>14 Dec. 2006</td>
<td>22:07 UT</td>
<td>10930</td>
<td>X1.5</td>
</tr>
<tr>
<td>3</td>
<td>13 Feb. 2011</td>
<td>17:28 UT</td>
<td>11158</td>
<td>M6.6</td>
</tr>
<tr>
<td>4</td>
<td>15 Feb. 2011</td>
<td>01:44 UT</td>
<td>11158</td>
<td>X2.2</td>
</tr>
</tbody>
</table>
Data Sets:
Hinode/Solar Optical Telescope (SOT)

- **Chromospheric images**
  - flare ribbon, pre-flare brightenings
  - Wavelength: 3968Å (Ca II H)
  - Pixel size: 0.108 arcsec/pixel

- **Stokes-V/I images**
  - photospheric (LOS) magnetic field
  - Wavelength: 6302Å (FeI), 5896Å (Na D)
  - Pixel size: 0.16 arcsec/pixel

- **Vector magnetograms**
  - photospheric magnetic field
  - Wavelength: 6301.5Å and 6302.5Å with a sampling 21.6 mÅ
  - Pixel size: 0.16 arcsec/pixel
Analysis Method:

- We selected the Ca-line image which is temporally closest to the Stokes-V/I image.

- We overlaid chromospheric strong emission contours and PILs over the Stokes-V/I image.

- We investigated the spatial and temporal correlation between strong brightening in chromosphere and photospheric magnetic field configurations.
Result: (1) confirm existence of “the flare trigger region”

**OP-type:** X3.4 flare on 2006 Dec. 13

- 2006-12-12 23:50 UT
- 2006-12-13 01:48 UT
- 2006-12-13 02:22 UT

**RS-type:** M6.6 flare on 2011 Feb. 13

- 2011-02-13 15:00 UT
- 2011-02-13 16:50 UT
- 2011-02-13 17:30 UT

Background: Stokes-V/I image (white/black = positive/negative)
- Green: Polarity Inversion Line (PIL)
- Red: Chromospheric Emission
The definition of the shear angle $\theta$ and the azimuth $\phi$

- **Point $O$** is defined as the nearest point to the last chromospheric emission contour before the flare onset.
- **Vector $N$** is defined as a vector normal to the global PIL of the active region at point $O$.
- **Vector $n$** is defined as a vector normal to the local PIL of the trigger region.

- The azimuth $\phi$ is measured as the angle between vectors $N$ and $n$.
- The shear angle $\theta$ is measured as the angle between averaged transverse field and vector $N$. 
Results: (2) confirm the conditions of $\theta$ and $\phi$

$\phi$: $180^\circ \sim 186^\circ$, $\theta$: $70^\circ \pm 15^\circ \rightarrow$ OP-Type
flare occurrence:

- Yes
- No

RS-Type

OP-Type

flare occurrence

◊: Yes, □: No
Results: (3) comparison between Hinode and SDO

We applied the same analysis method to Hinode and SDO data, and compared these results. We confirmed that we can obtain same features by both Hinode and SDO.
Results: (4) suggestion of existence of another parameter
2006-12-13 00:24 UT

Y (arcsecs)

-90

-100

-110

-120

X (arcsecs)

300

320

340

360

B1

Magnetic Flux (Mx)

Ca II H Intensity

flare onset

start time (2006 December 13, 23:00 UT)
* M6.6 flare on 2011 Feb. 13 case

- Shear Angle (θ)
- Azimuth (φ)

Flare onset

2011-02-13 11:00 - 18:00 UT
What is the critical parameter(s) for flare occurrence ???
We identified “the flare trigger region” of four major flares using Hinode/SOT data. We confirmed that the triggering process of the each flare are consistent with either OP- or RS-Types of Kusano’s flare trigger model.

We confirmed that we can identify the small trigger region with SDO data as well. We can increase the number of event analysis with SDO data.

We suggested the existence of the other parameter (magnetic flux ??) which decide the timing of flare occurrence.
3. Discussion

How many flares were captured by Hinode so far?

<table>
<thead>
<tr>
<th>Year</th>
<th>XRT</th>
<th>SOT</th>
<th>EIS</th>
<th>Total flare no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006 (from 20 October)</td>
<td>160</td>
<td>171</td>
<td>68</td>
<td>432</td>
</tr>
<tr>
<td>2007</td>
<td>443</td>
<td>267</td>
<td>209</td>
<td>713</td>
</tr>
<tr>
<td>2008</td>
<td>24</td>
<td>8</td>
<td>7</td>
<td>134</td>
</tr>
<tr>
<td>2009</td>
<td>125</td>
<td>83</td>
<td>65</td>
<td>320</td>
</tr>
<tr>
<td>2010</td>
<td>690</td>
<td>264</td>
<td>125</td>
<td>1248</td>
</tr>
<tr>
<td>2011 (until 31 October)</td>
<td>1019</td>
<td>377</td>
<td>237</td>
<td>1937</td>
</tr>
<tr>
<td>Total event no.</td>
<td>2461</td>
<td>1170</td>
<td>711</td>
<td>4784</td>
</tr>
<tr>
<td>Observability</td>
<td>51.4%</td>
<td>24.5%</td>
<td>14.9%</td>
<td></td>
</tr>
</tbody>
</table>


because of ...

- limited field-of-view
- limited telemetry
- limitation of observatory-like operation
- limited flare predictability of flare occurrence etc.
What information do Hinode COs use for flare observation?

- **www.SolarMonitor.org**
  - today’s solar condition (SDO/HMI, AIA images),
  - sunspot evolution,
  - flare history of each AR, ...

- **Flare Watch from Max Millennium COs**
  - If the Major (or Great) Flare Watch is issued,
    Hinode “must” observe the flaring AR.
  - ** Flare hunting has the highest priority** in Hinode observation.

- We eventually decide the target region in an empirical manner.
- If a CO is not familiar to observational data, it is very difficult for them to select the target.
What kind of forecast do Hinode COs need?

- We need to use parameters which objectively evaluate flare probability.
- daily HARP mirror (http://st4a.stelab.nagoya-u.ac.jp/nlfff/nrt/)
  - Active-region parameters (Bobra et al. 2014, Sol. Pys)
  - We calculate all the parameters every day, and update the Web page before 9:00 JST (00:00 UT).
  - Hinode daily meeting start from 10:30 JST (01:30 UT).
  - We have a contact pass every evening (in JST), and we can change the S/C tracking curve in this timing.

Which is the most critical parameter?