Solar Active Region Magnetic Parameters and Geo-effectiveness of Halo CMEs

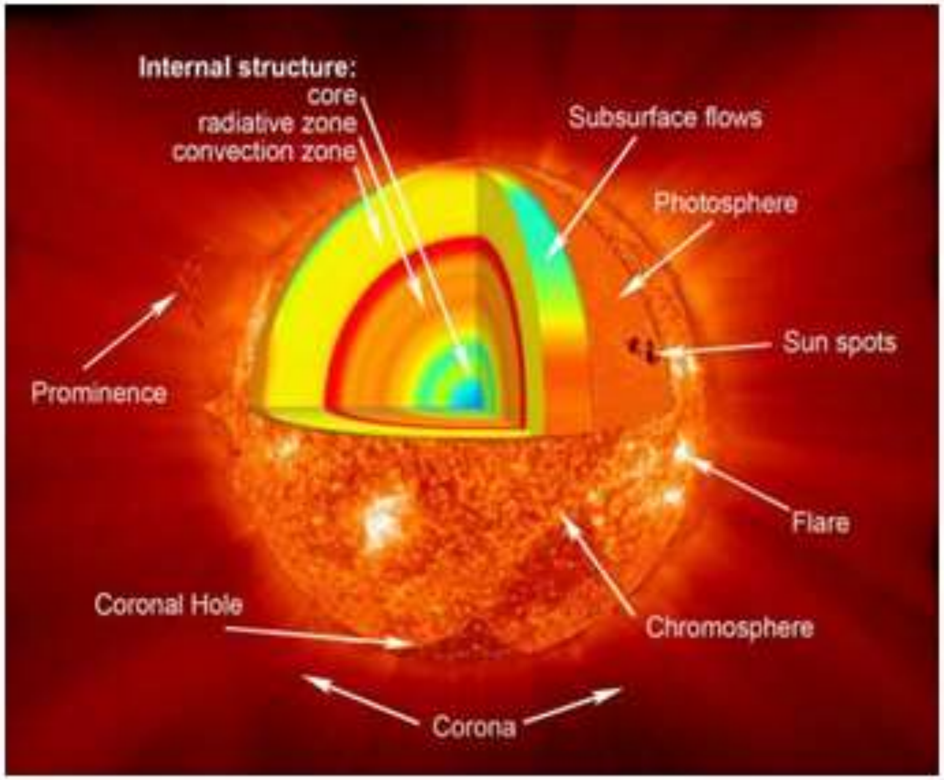
Presented by,
Vijayalakshmi Prakash
Research Scholar

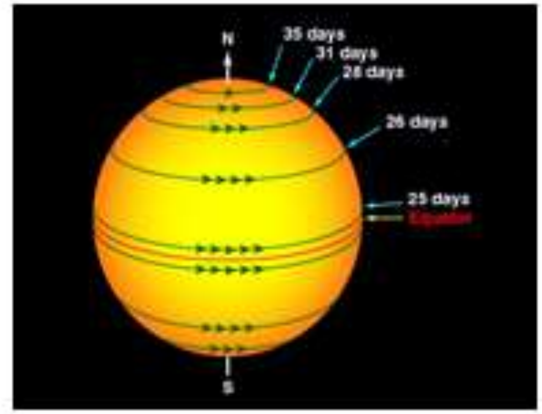
Research Supervisor
Dr. A. Shanmugaraju
Associate Professor
PG& Research Department of Physics
Arul Anandar college
Karumathur

Abstract

- There are well established relations between speed of interplanetary coronal mass ejection (V_{ICME}) and southward magnetic field (Bs) with the geomagnetic storm intensity (Dst). In this work, we explore the statistical correlation of the intensity of geomagnetic storm (Dst index) and southward magnetic component (Bs) with the magnetic parameters of the source active region (Space - weather HMI Active Region Patch, SHARP parameters) during 2011-2017 in solar cycle 24.
- The following results are obtained in this analysis: (i) active regions with strong and complex magnetic field structures are found to be associated with weak to intense storms (-6 to -223 nT) (ii) Significant correlations are found between some magnetic parameters of the source active region with intensity of storm and southward magnetic field component. (iii) Empirical relations are derived for storm intensity and southward magnetic component in terms of important source region magnetic parameters.
- These findings reveal the Sun-Earth connection of certain events and give some clues on improving our ability to connect the intensity of geomagnetic storms with CME kinematics and source region magnetic parameters.

Introduction about sun





Inner layers - the Core,

the Radiative Zone and

the Convective Zone.

Outer layers - the Photosphere,

the Chromosphere and

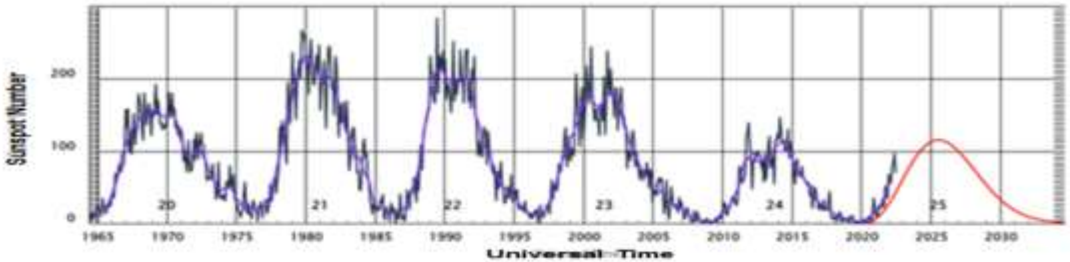
the Corona.

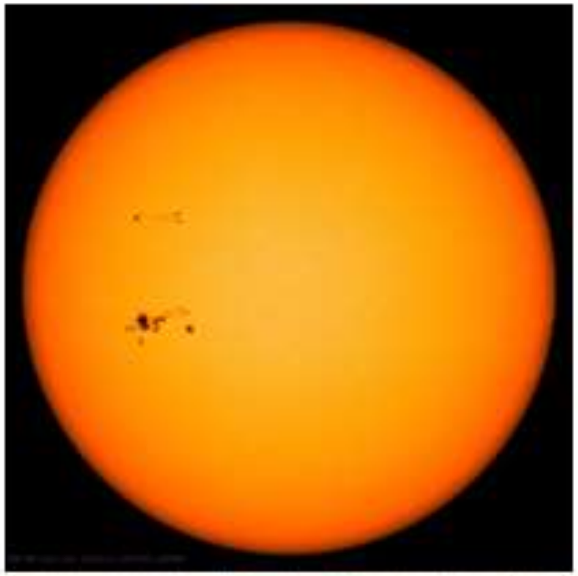
→Inner Layer- The Core (Inner core – Density 150 g/cm^3, Temperature 15 million k
Outer core- Density 20 g/cm^3, Temperature 7.5 million k)
The Radiative Zone- Density 20 -0.2 g/cm^3, Temperature 7-2 million k
The Convection Zone- Density 0.2 g/cm^3, Temperature 2 million k - 5800 k
→Outer Layers-The Photosphere-Density 2x10^{-7} g/cm^3, Temperature - 5800 k
The Chromosphere - Density 1x10^{-5} g/cm^3 ,Temperature – (4500 – 20,000 k)
The Corona - Density 1x10^{-10} g/cm^3 Temperature – above 2 million k

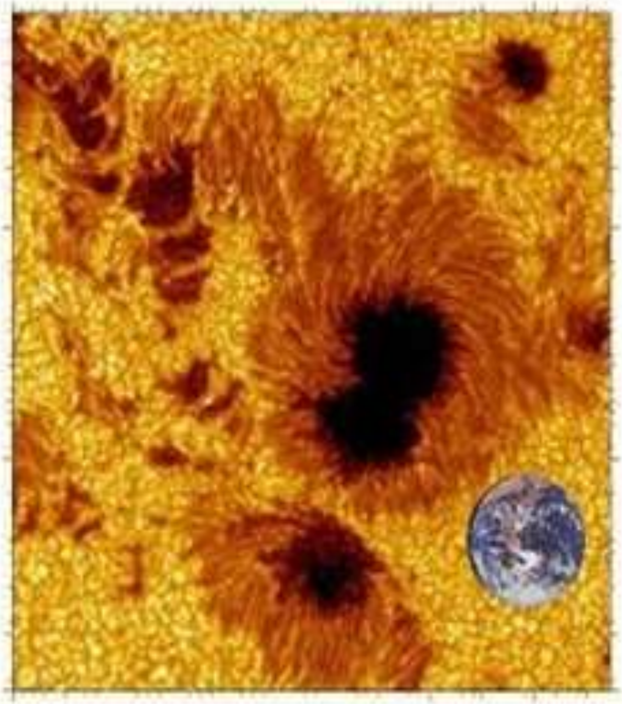
SUNSPOT

- Sunspots are the temporary dark spots on the surface of the sun.
- Sunspot activity about every 11 year solar cycle.
- Highest number of sunspot during a cycle is solar maximum, lowest activity is solar minimum.
- SIZE : 1500 km to 50,000 km (Earth diameter is 12,742 km)
- Temperature : 3800 K

Solar cycle

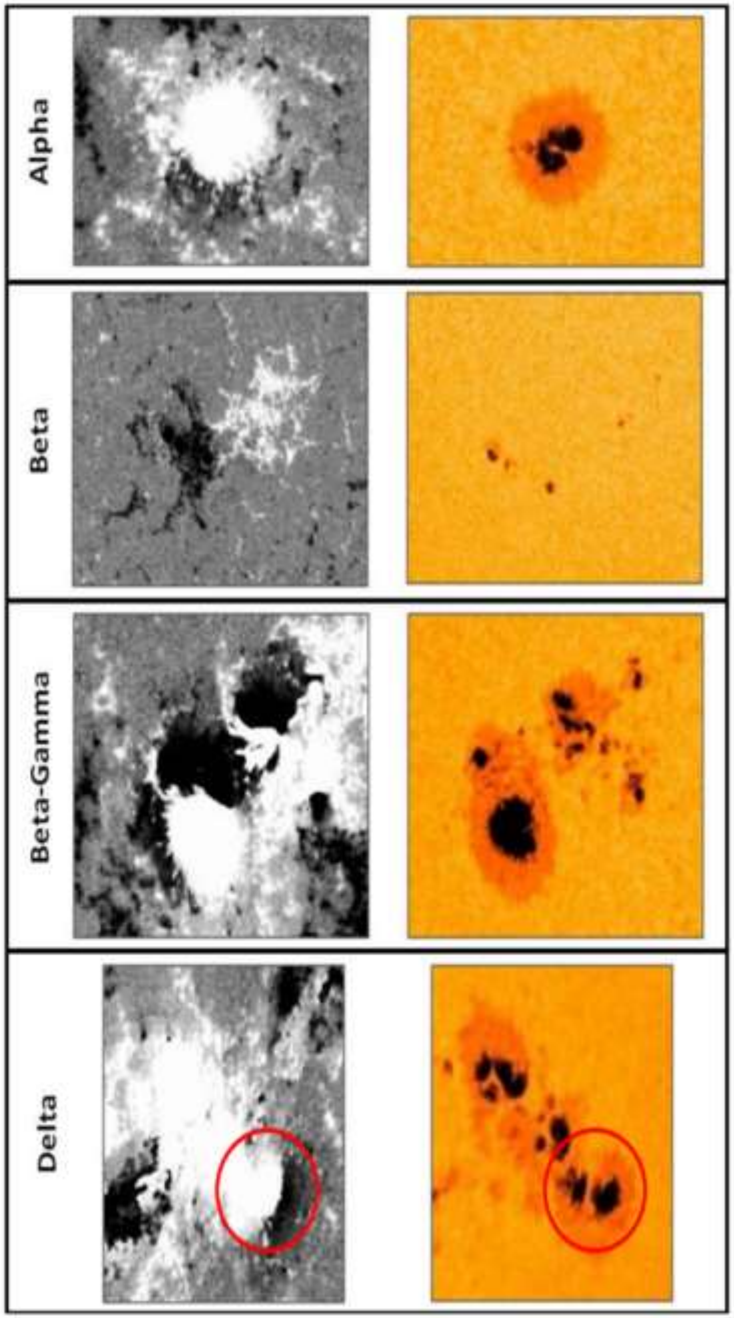






Hale classification

- The Hale class describes the magnetic complexity of an active region.
- α – Alpha:
  A unipolar sunspot group.
- β – Beta:
  A sunspot group that has a positive and a negative polarity (or bipolar) with a simple division between the polarities.
- γ – Gamma:
  A complex region in which the positive and negative polarities are so irregularly distributed that they can't be classified as a bipolar Sunspot group.
- β-γ – Beta-Gamma:
  A bipolar sunspot group but complex enough so that no line can be drawn between spots of opposite polarity.
- δ – Delta:
  The umbrae of opposite polarity in a single penumbra.
- β-δ – Beta-Delta:
  A sunspot group with a general beta magnetic configuration but contains one (or more) delta sunspots.
- β-γ-δ – Beta-Gamma-Delta:
  A sunspot group with a beta-gamma magnetic configuration but contains one (or more) delta sunspots.
- γ-δ – Gamma-Delta
  A sunspot group with a gamma magnetic configuration but contains one (or more) delta sunspots.



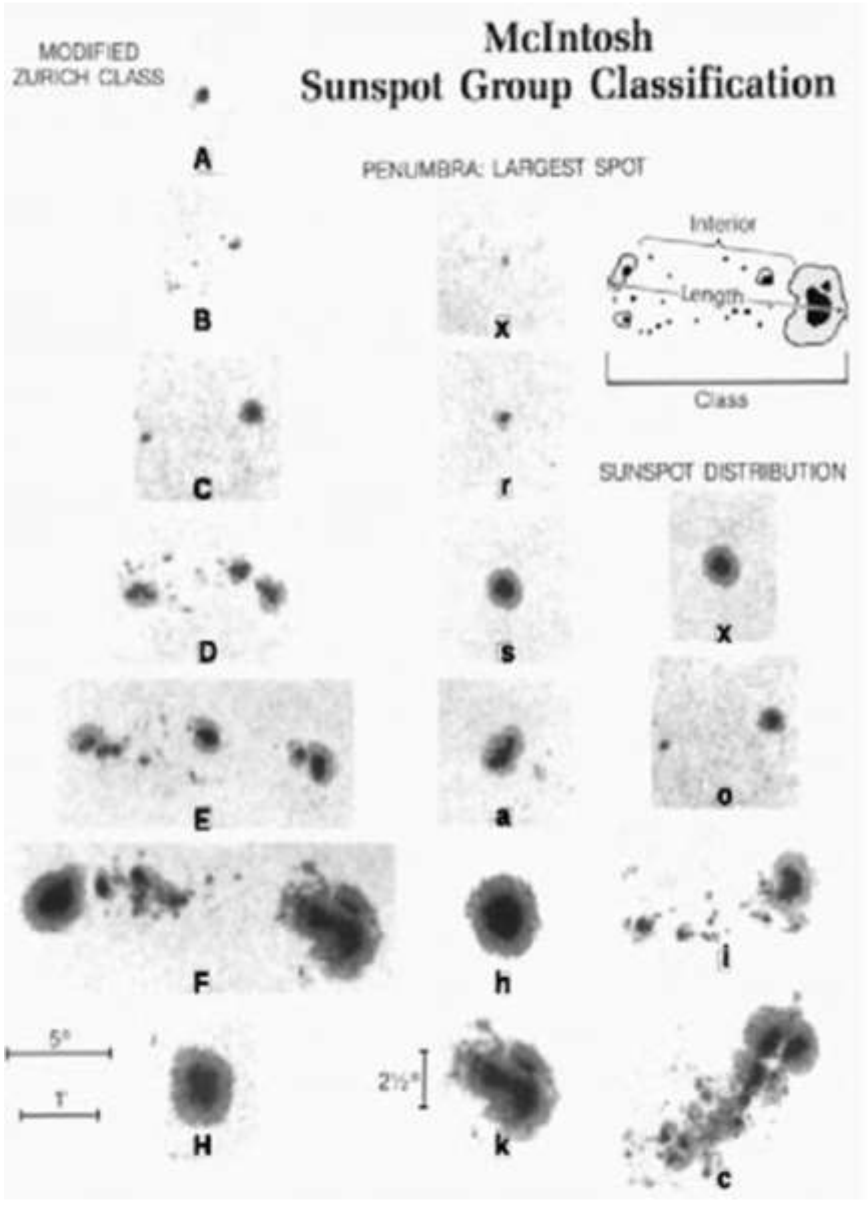
McIntosh classification

- The McIntosh class describes the complexity of the sunspot group

The 3 component McIntosh classification : general form 'Zpc',

- 'Z' is the modified Zurich Class,
- 'p' describes the penumbra of the principal spot,
- 'c‘ describes the distribution of spots in the interior of the group.
- There are 60 valid McIntosh classifications

  Examples: Dao, Eao, Ekc, Fai, F kc, Fko.

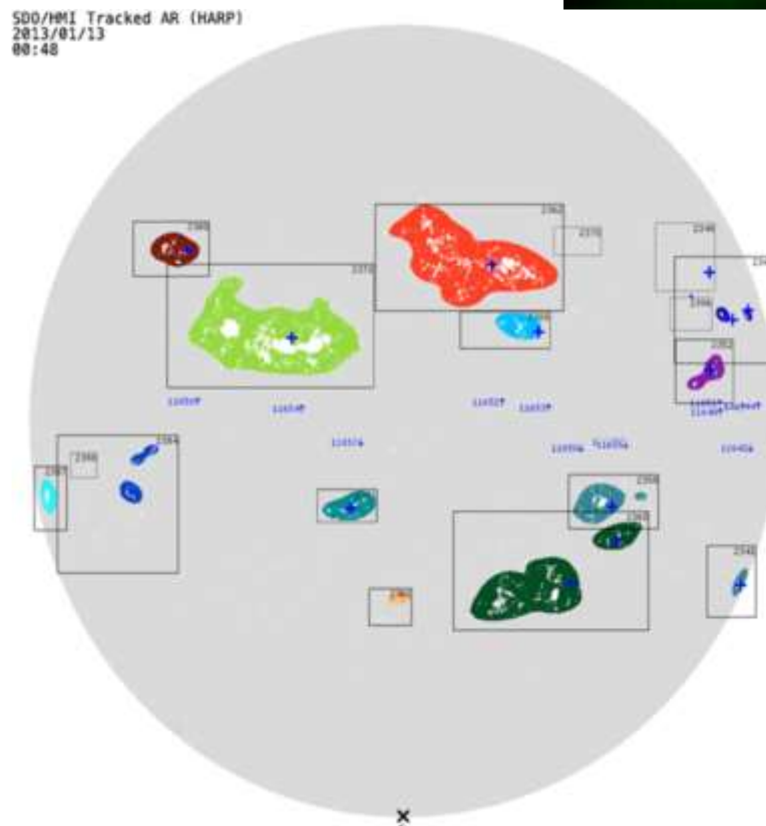


SHARP parameters (Space weather HMI Active Region Patch)

Active region on the sun is an area with an especially strong magnetic field.

Most solar flares and coronal mass ejection(CME) occur from active regions

- SHARP is a set of various space weather quantities calculated from the photospheric vector magneto gram data .
- HARPs→HMI Active Region Patches
- Welsch et al. (2009) and Bobra et al. (2014)

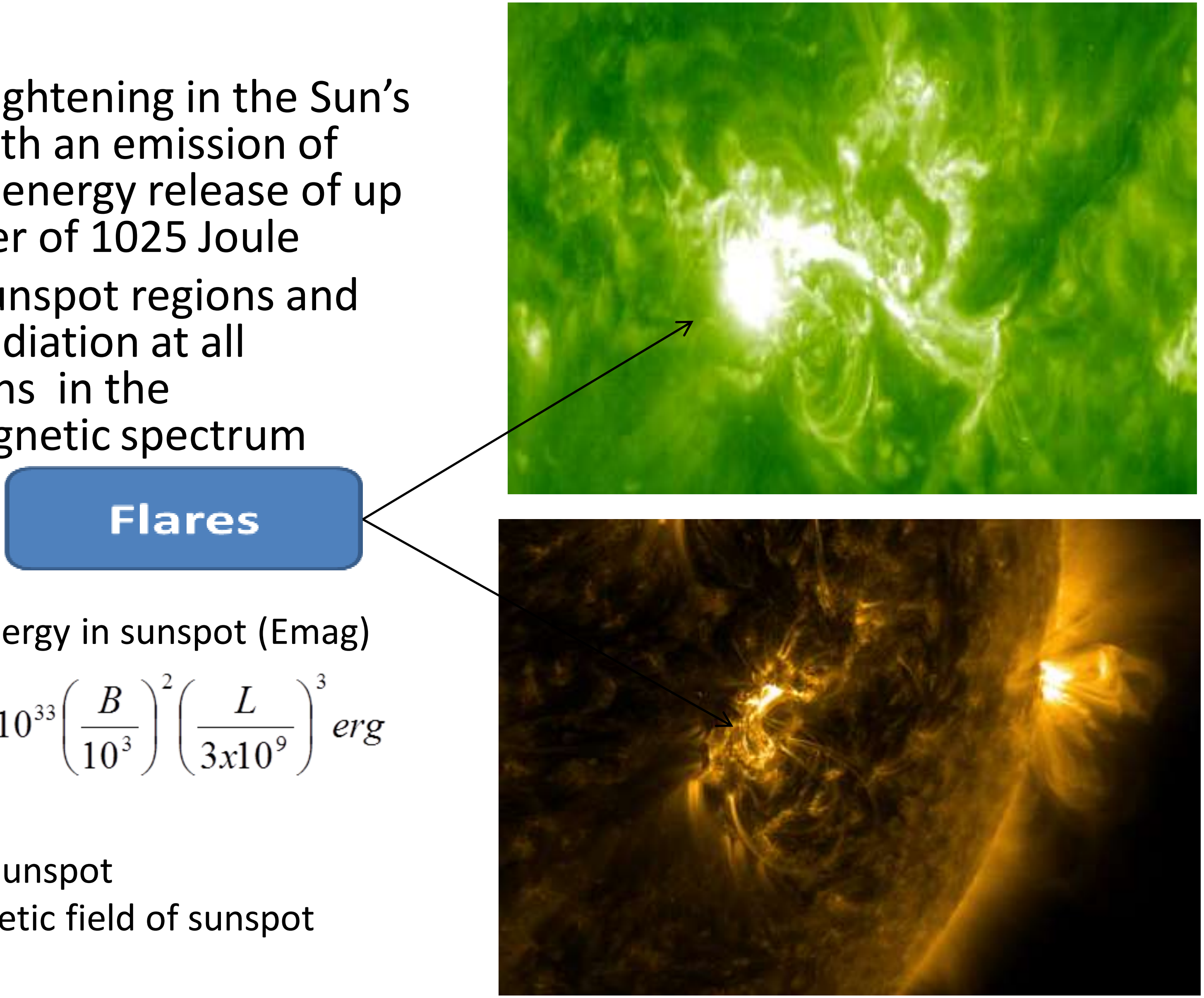


S.No.	Keyword	Description	Units	Formula
1	USFLUX	Total unsigned magnetic flux	Mx	$\Phi = \sum \lvert B_z \rvert dA$
2	MEANGAM	Mean angle of field from radial	Degrees	$\overline{\gamma} = \frac{1}{N} \sum \arctan\left(\frac{B_h}{B_z}\right)$
3	MEANGBT	Mean gradient of total field	GM/m	$\overline{\lvert \nabla B_{tot} \rvert} = \frac{1}{N} \sum \left(\sqrt{\left(\frac{\partial B}{\partial X}\right)^2 + \left(\frac{\partial B}{\partial Y}\right)^2} \right)$
4	MEANGBZ	Mean gradient of vertical field	GM/m	$\overline{\lvert \nabla B_z \rvert} = \frac{1}{N} \sum \left(\sqrt{\left(\frac{\partial B_z}{\partial X}\right)^2 + \left(\frac{\partial B_z}{\partial Y}\right)^2} \right)$
5	MEANGBH	Mean gradient of horizontal field	GM/m	$\overline{\lvert \nabla B_h \rvert} = \frac{1}{N} \sum \left(\sqrt{\left(\frac{\partial B_h}{\partial X}\right)^2 + \left(\frac{\partial B_h}{\partial Y}\right)^2} \right)$
6	MEANJZD	Mean vertical current density	mA/m²	$\overline{J_z} \alpha \frac{1}{N} \sum \left(\frac{\partial B_Y}{\partial X} - \frac{\partial B_X}{\partial Y} \right)$
7	TOTUSJZ	Total unsigned vertical current	A	$J_{z_{total}} = \sum \lvert J_z \rvert dA$

S.No.	Keyword	Description	Units	Formula
8	MEANALP	Mean characteristic twist parameter	M/m	$\alpha_{total} \alpha \frac{\sum(J_z.B_z)}{\sum(B_z^2)}$
9	MEANJZH	Mean vertical current helicity	G^2/m	$\overline{H_c} \alpha \frac{1}{N} \sum B_z.J_z$
10	TOTUSJH	Total unsigned vertical current helicity	G^2/m	$H_{C_{total}} \alpha \sum \lvert B_z.J_z \rvert$
11	ABSNJZH	Absolute value of the net vertical current helicity	G^2/m	$H_{C_{abs}} \alpha \lvert \sum B_z.J_z \rvert$
12	SAVNCPP	Sum of the absolute value of the net current per polarity	A	$J_{z_{sum}} \alpha \lvert \sum B_z^+ J_z dA \rvert + \lvert \sum B_z^- J_z dA \rvert$
13	MEANPOT	Mean photoshperic magnetic free energy density	erg / cm^3	$\overline{\rho} \alpha \frac{1}{N} \sum \left(B^{obs} - B^{pot}\right)^2$
14	TOTPOT	Surface integral of photospheric magnetic free energy density	erg / cm	$\rho_{tot} \alpha \sum \left(B^{obs} - B^{pot}\right)^2 dA$
15	MEANSHR	Mean shear angle	Degrees	$\overline{\Gamma} = \frac{1}{N} \arccos\left(B^{obs}.B^{pot} / \lvert B^{obs} \rvert \lvert B^{pot} \rvert\right)$
16	SHRGT45	Fraction of Area with shear > 45°	--	Area with Shear > 45^{o} / total area

Solar Flares

- Sudden brightening in the Sun's surface with an emission of enormous energy release of up to the order of 1025 Joule
- Occur in sunspot regions and produce radiation at all wavelengths in the electromagnetic spectrum



Total magnetic energy in sunspot (Emag)

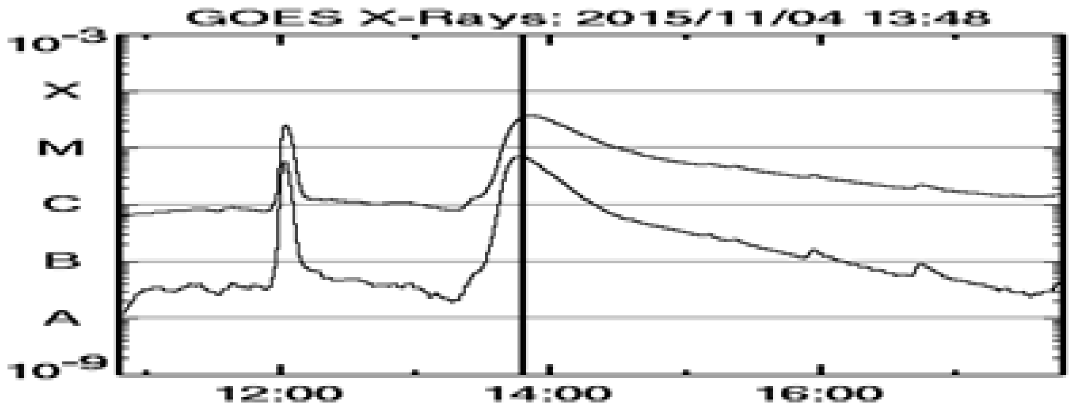
$$E_{mag} \approx \left(\frac{B^2}{8\Pi}\right)L^3 \cong 10^{33}\left(\frac{B}{10^3}\right)^2\left(\frac{L}{3x10^9}\right)^3 erg$$

Where L → Size of sunspot

B → Average magnetic field of sunspot

Flare classification

Class	Flux(W/m^2)	Nature
A	$<10^{-7}$	Lowest
B	$\geq 10^{-7} < 10^{-6}$	Lowest
C	$\geq 10^{-6} < 10^{-5}$	Small
M	$\geq 10^{-5} < 10^{-4}$	Medium
X	$\geq 10^{-4} < 10^{-3}$	Biggest

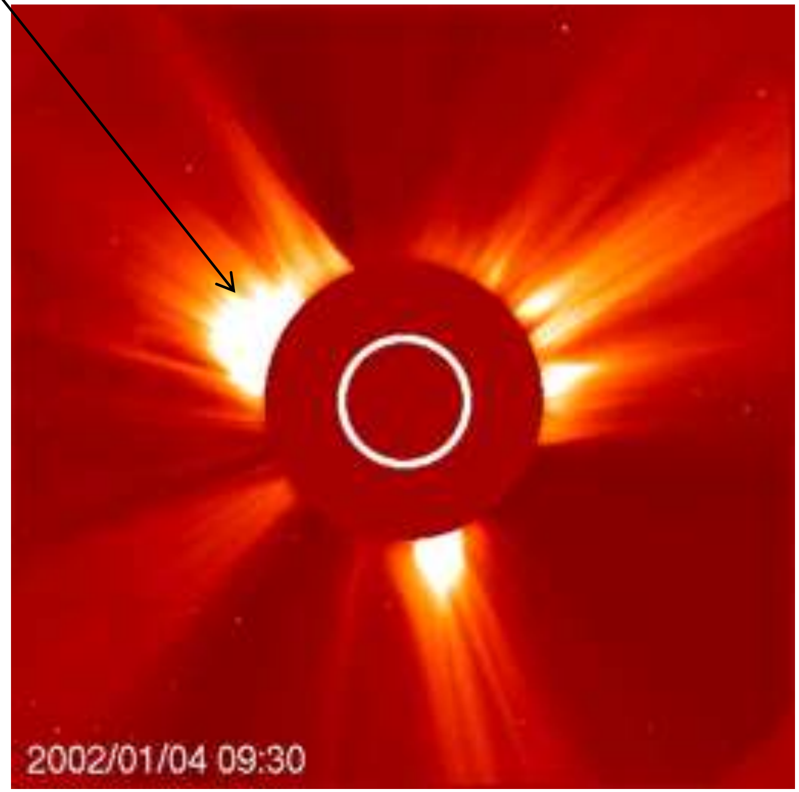


Flare properties:

Intensity
Rise time
Decay time
Duration

Coronal Mass Ejections

- Release large amounts of particles, energy and magnetic field from the Sun
- Types of CME :
- Halo , Partial halo and Limb



CME properties

Speed = dx/dt = 300 - 3000 km/s

Acceleration = dv/dt = -100 to +100 m/s^2

Mass = (10^{14} - 10^{16}) g

Kinetic energy = ½ MV^2 (upto 10^{32}) erg

Motivation of this work

- Many of the authors studied only relation between the ICME and geo-effectiveness properties (intensity in Dst and southward magnetic field -Bs component)
- Understanding the link between magnetic parameters of the solar eruptions and the geo-effectiveness properties is interesting to be studied for the with different sets of data.

Objectives of this work

→To identify the source region of geoeffective CMEs

→To analyse the properties of the active region magnetic properties (SHARP parameters).

→To analyse the dependence of the active region magnetic properties and geo-effectiveness properties of CMEs.

→To analyse the dependence of the kinematics of CMEs/ICMEs and geo-effectiveness properties of CMEs.

Data

→We selected the 31 front side halo CMEs from 2010 – 2017 in the solar cycle 24

→ Front side halo CMEs associated with each flare was obtained from the online catalog

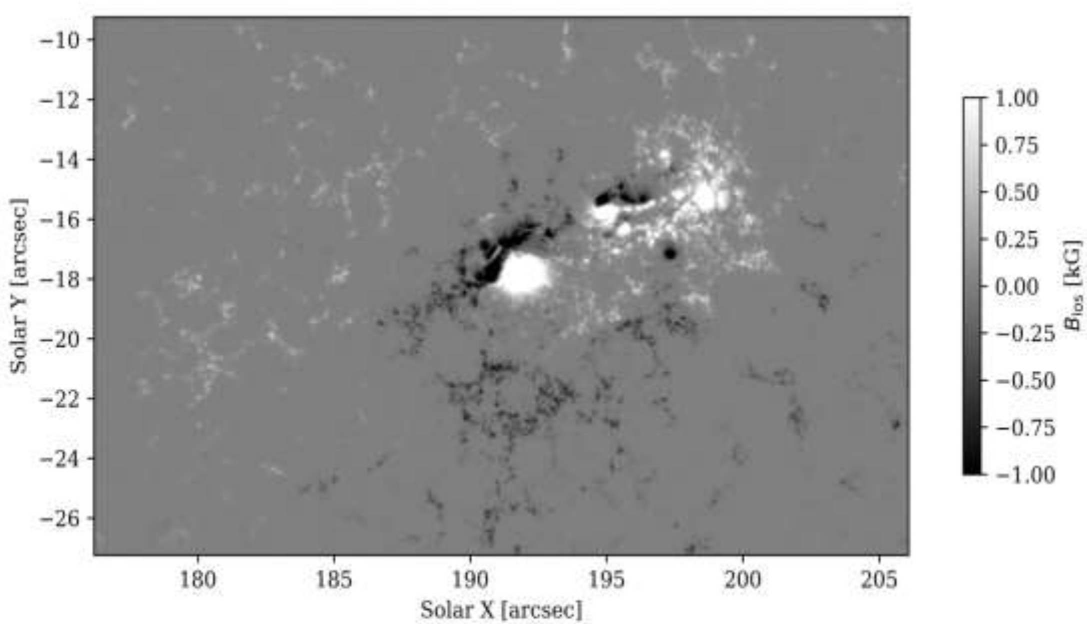
→ We utilized the magnetic parameters of source location of X-ray flares (Space-weather HMI Active Region Patch (SHARP)) (24 hours before the starting time of flare)

Selection Criteria

→Each active region should be identified by a separate HMI active region patches (HARP) number.

→In order to check the connection of the Dst index and southward magnetic component with the photospheric magnetic parameters, we perform a correlation study.

RESULTS



SHARP vector magnetogram of AR 12297 on 2015 March 15 from where a CME erupted. The vertical grey colour bar shows the values of line of sight magnetic field (B_{los}**).**

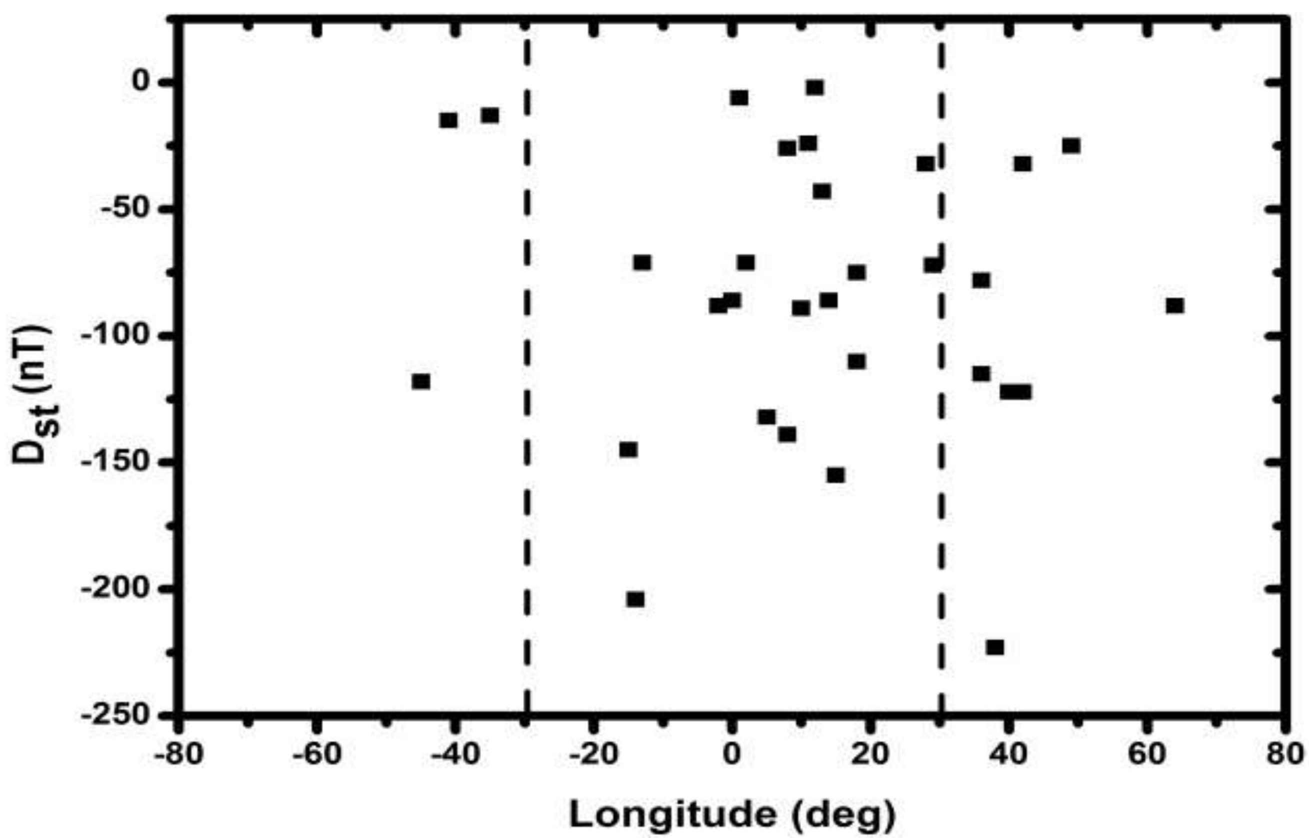
→ Total unsigned magnetic flux (ϕ_{AR}) in Mx,

→ Absolute value of the net vertical current helicity (H_c) in G^2/m,

→ Sum of the absolute value of the net current per polarity (J_z) in A,

→ Surface integral of photospheric magnetic free energy density (ρ_{tot}) in erg/cm, respectively.

Solar source longitude and Dst index



Linear Fitting & Correlation

Y= a+bx

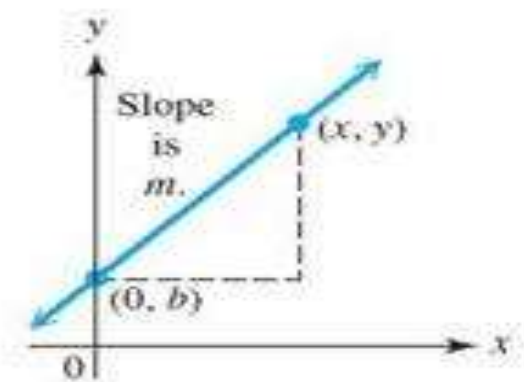
Where, Y→ Y- Co-ordinates,

X→ X- Co-ordinates

b →Slope, a → Y-intercept

$$a = \frac{(\sum Y)(\sum X^2) - (\sum X)(\sum XY)}{n(\sum X^2)(\sum X)^2}$$

$$b = \frac{n(\sum XY) - (\sum X)(\sum Y)}{n(\sum X^2) - (\sum X)^2}$$



Correlation Co-efficient Value

$$R = \left(\frac{S_X}{S_Y}\right) b$$

S_X→ Standard deviation value of X

S_Y→ Standard deviation value of Y

Where,

$$S_X = \sqrt{\frac{\sum (X - \bar{X})^2}{n-1}}$$

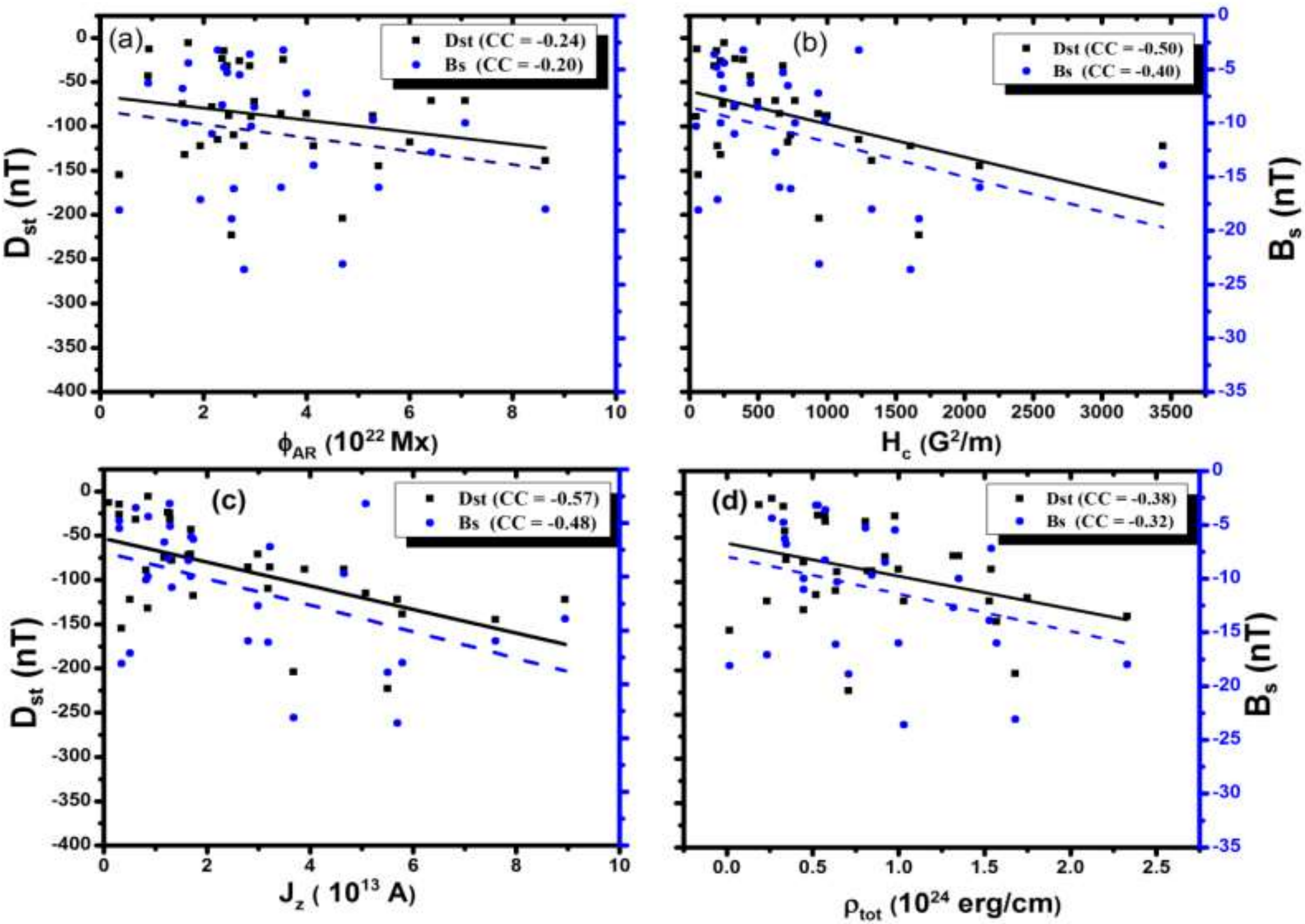
$$S_Y = \sqrt{\frac{\sum (Y - \bar{Y})^2}{n-1}}$$

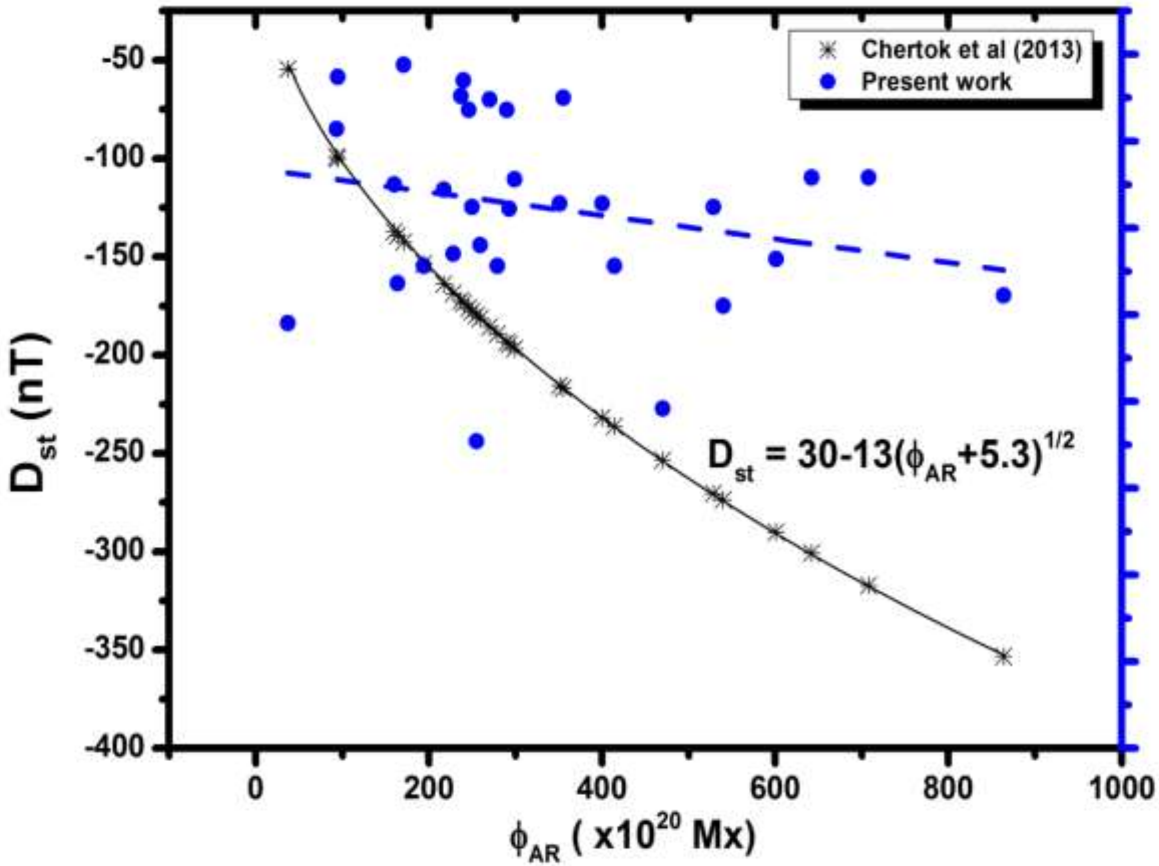
The ranges of correlation co-efficient value is -1 to +1

If →-1 means negative correlation or anti- correlation

If →+1 means positive correlation

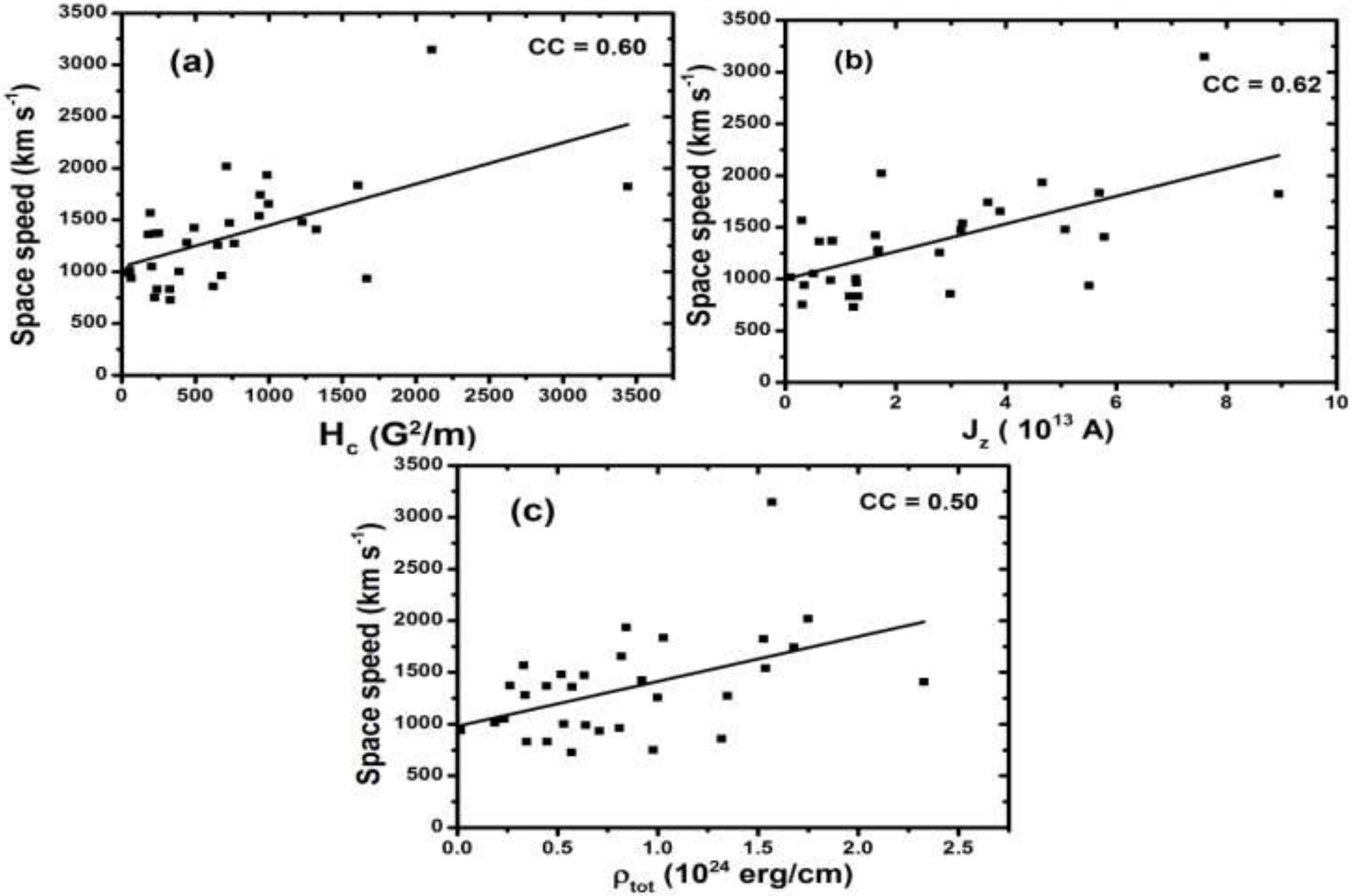
Correlation between active region magnetic parameters with D_{st} and B_s



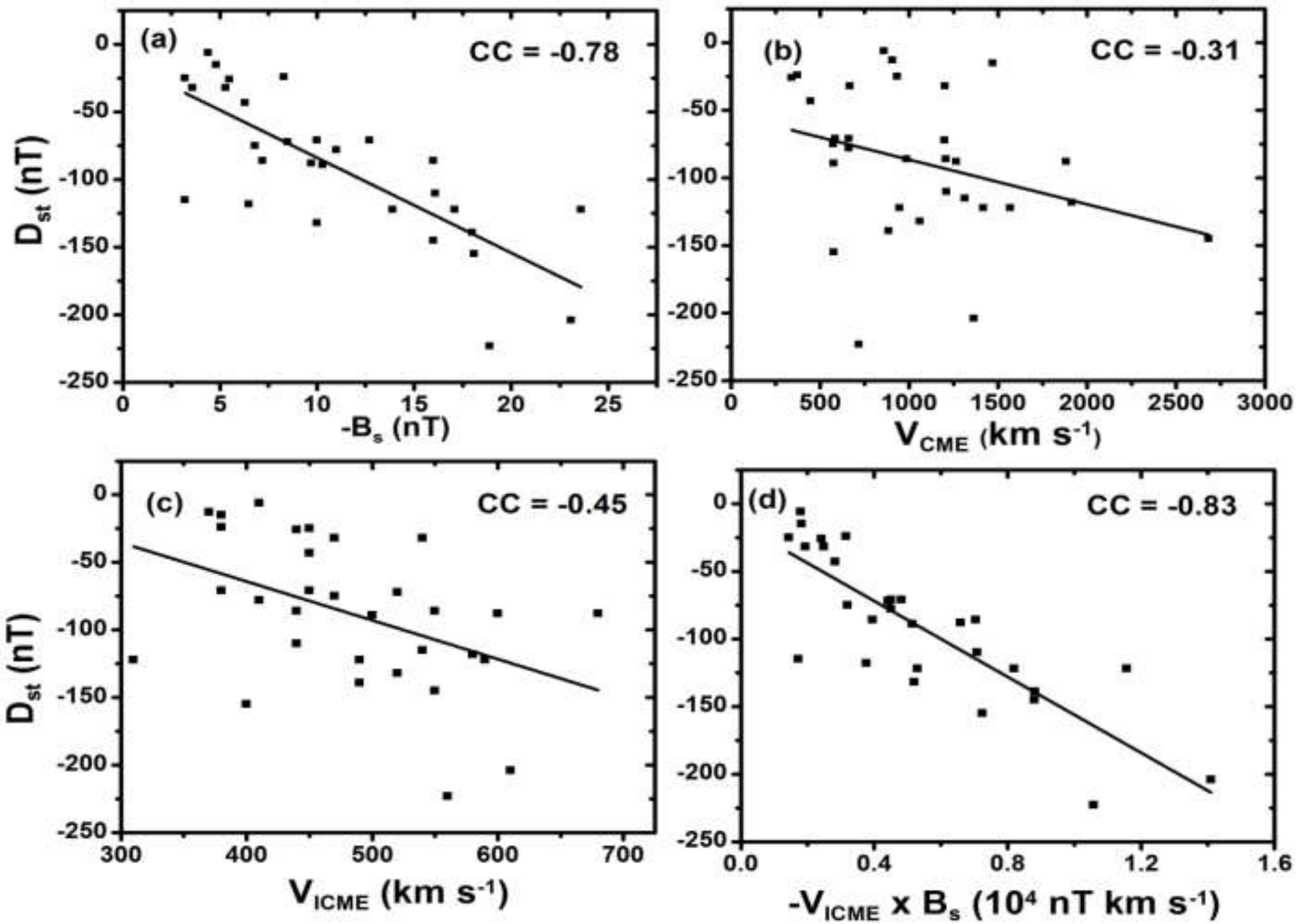


Relationship between the total unsigned magnetic flux and D_{st} index. The blue dashed lines indicate the linear regression fit to the data points. The black line with asterisk symbol indicates the fitting using the empirical formula for Dst index obtained by Chertok et al. (2013).

Correlation plots between the CME space speed and some SHARP parameters



Correlation of Dst index with B_s, speeds of CMEs and ICMEs



Conclusion

→Most of flares and their associated halo CMEs (26/31) were produced by complex sunspot groups like βγδ, βγ, and βδ Hale types and Ekc/Dkc/Fkc McIntosh classes. This implies that the most complex active regions seem to be the sources of strong flares and halo CME production.

→CMEs originating from the disk centre towards the west of the Sun have a higher chance of hitting the Earth's magnetosphere to produce stronger storms.

→Weak correlations exist for the Dst index and B_s component with the total unsigned magnetic flux, but moderate correlations exist for the strength of the storm and southward magnetic component B_s with the absolute value of the net vertical current helicity and the sum of the absolute value of the net current per polarity.

→The results of the study indicate a possible statistical relationship between the magnetic parameters of the source active regions and the geo-effectiveness of halo CMEs.

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