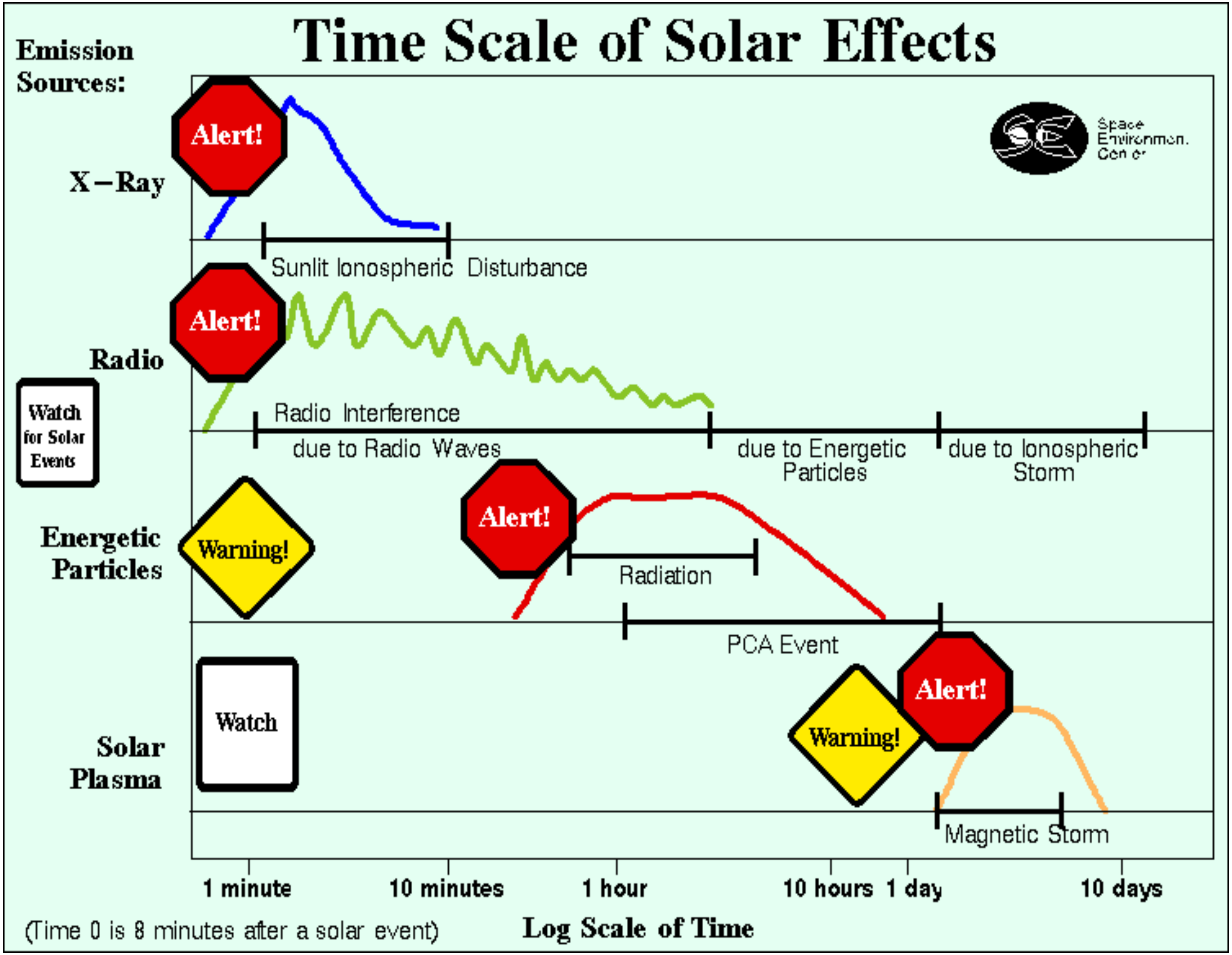


Time Scale of Solar Effects
Emission Sources:
X-Ray
Radio
Energetic Particles
Solar Plasma
Watch for Solar Events
Alert!
Alert!
Warning!
Alert!
Watch
Warning!
Alert!
Sunlit Ionospheric Disturbance
Radio Interference
due to Radio Waves
due to Energetic Particles
due to Ionospheric Storm
Radiation
PCA Event
Magnetic Storm
1 minute
10 minutes
1 hour
10 hours
1 day
10 days
(Time 0 is 8 minutes after a solar event)
Log Scale of Time

Contents

1. The forecast of solar flares and CMEs (Lee et al. 2012, Lee et al. 2015, Shin et al. 2015)

2. The forecast of solar proton events (Park et al. 2010, 2012, 2014, Ji et al. 2014)

3. The forecast of Geomagnetic Storms

    3.1 CME – Storm (Moon et al. 2005, 2009, Kim et al. 2005, 2008, 2010, Kang et al. 2006)

    3.2 Geo effective CME parameters (Lee et al. 2014)

    3.3 Comparison among cone models and a flux rope model (Na et al. 2013, Lee et al. 2015)

    3.4 WSA-ENLIL model with three cone types (Jang et al. 2014)

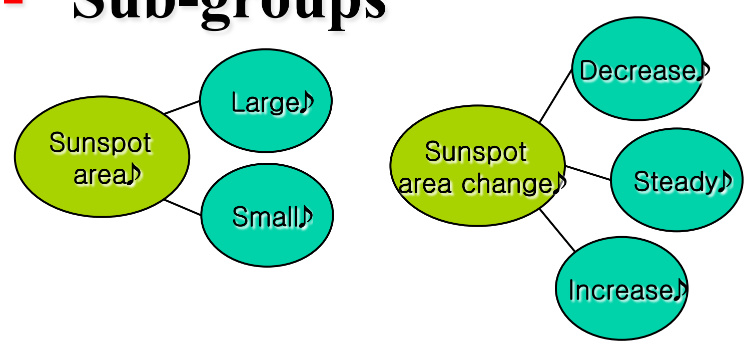
    3.5 Comparison of 2-D and 3-D CME parameters (Jang et al. 2015)

    3.6 Development of a full ice-cream cone model (Na et al. 2015)

1. Probabilistic Forecast of solar flares and CMEs (Poster CS-14)

Data & Analysis

- **Data**
  - NOAA's SRS data
    (McIntosh sunspot group, sunspot area, area change)
    * Area : a proxy of magnetic flux
  - NGDC flare catalog
    (C, M, and X-class flare)
- **Sub-groups**



Method

Calculating flare occurrence rate (the number of flares / the number of sunspot group ARs)

↓

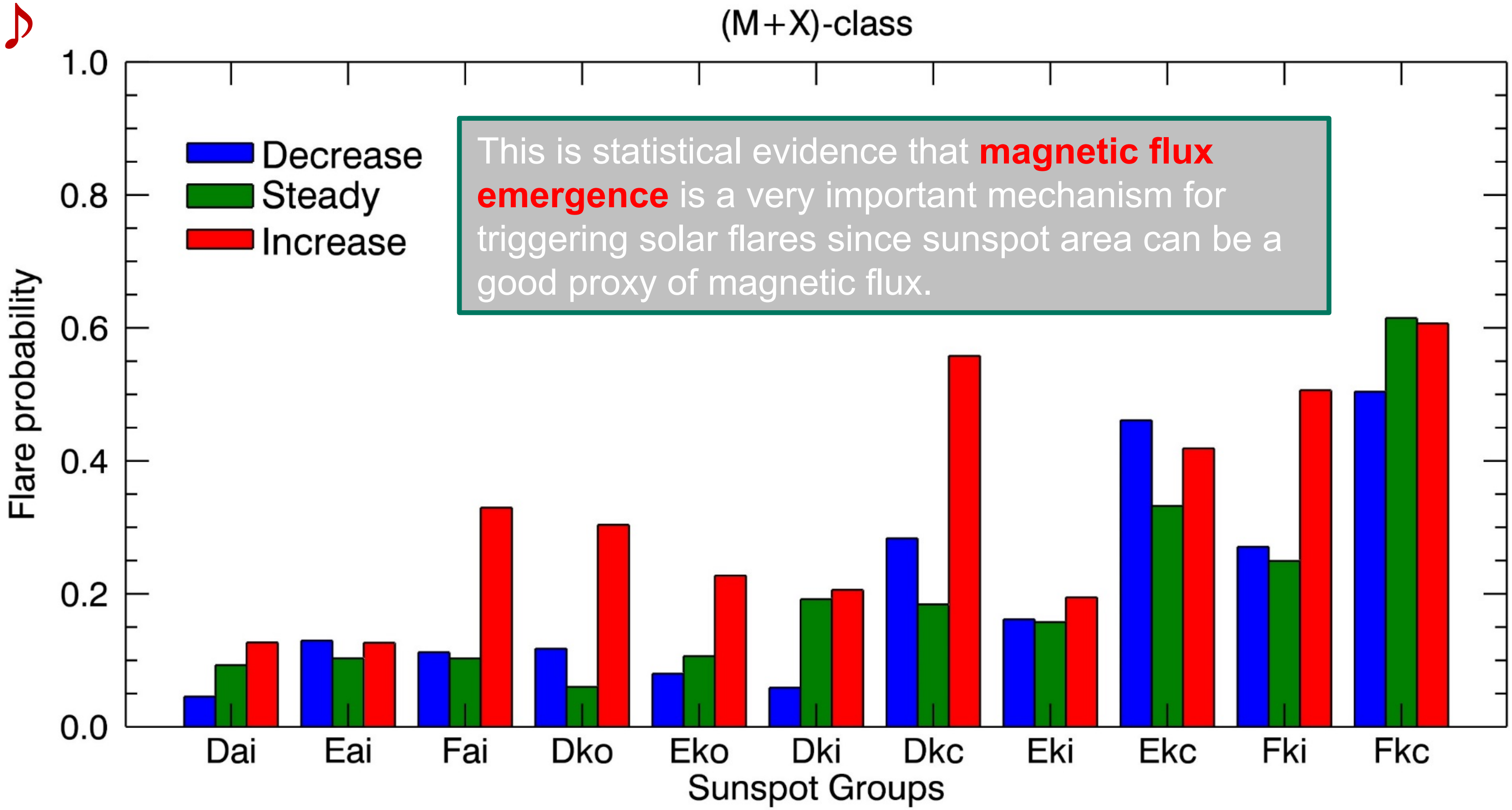
Calculating flare probability

↓

Solar flare probability depending on sunspot group area and its change

Flare probability as a function of sunspot class and its area change (Lee et al. 2012)♪

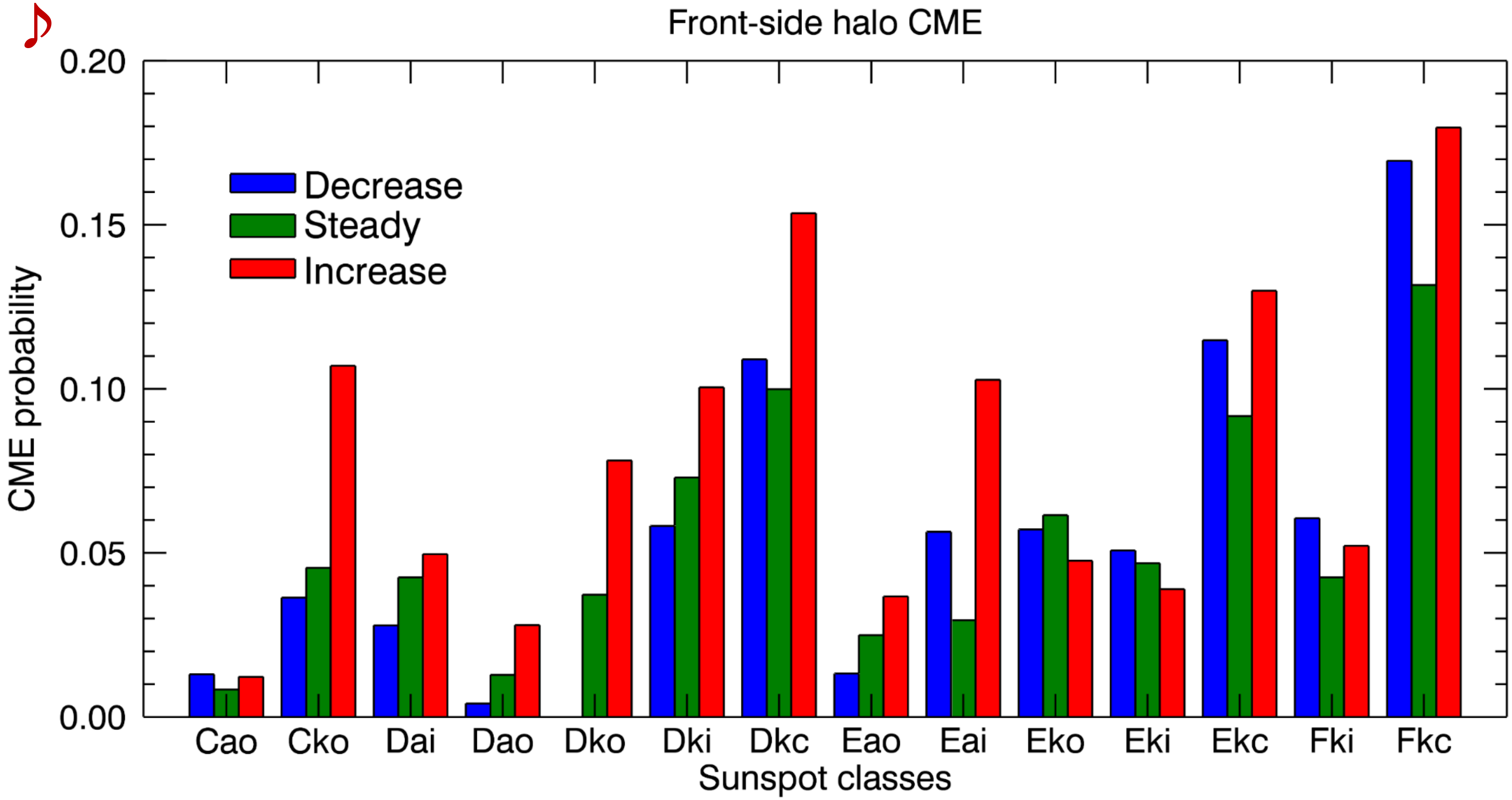
♪



In case of "Increase" sub-groups, the flare probability higher than those of other sub-groups.

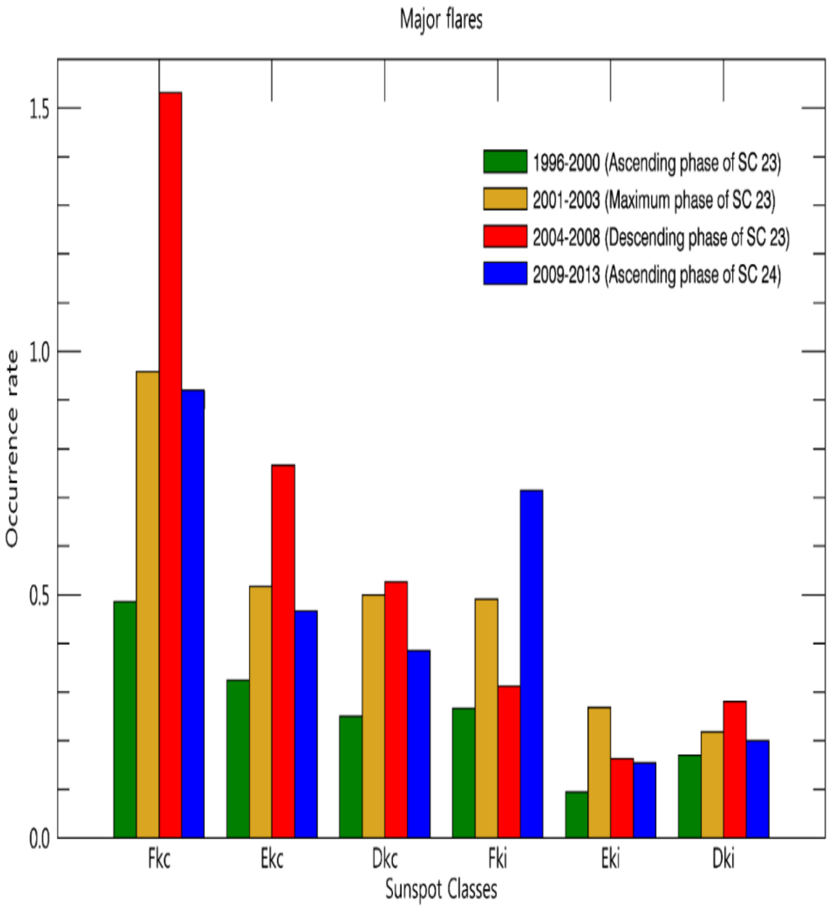
CME probability as a function of sunspot class and its area change (Lee et al. 2015)♪

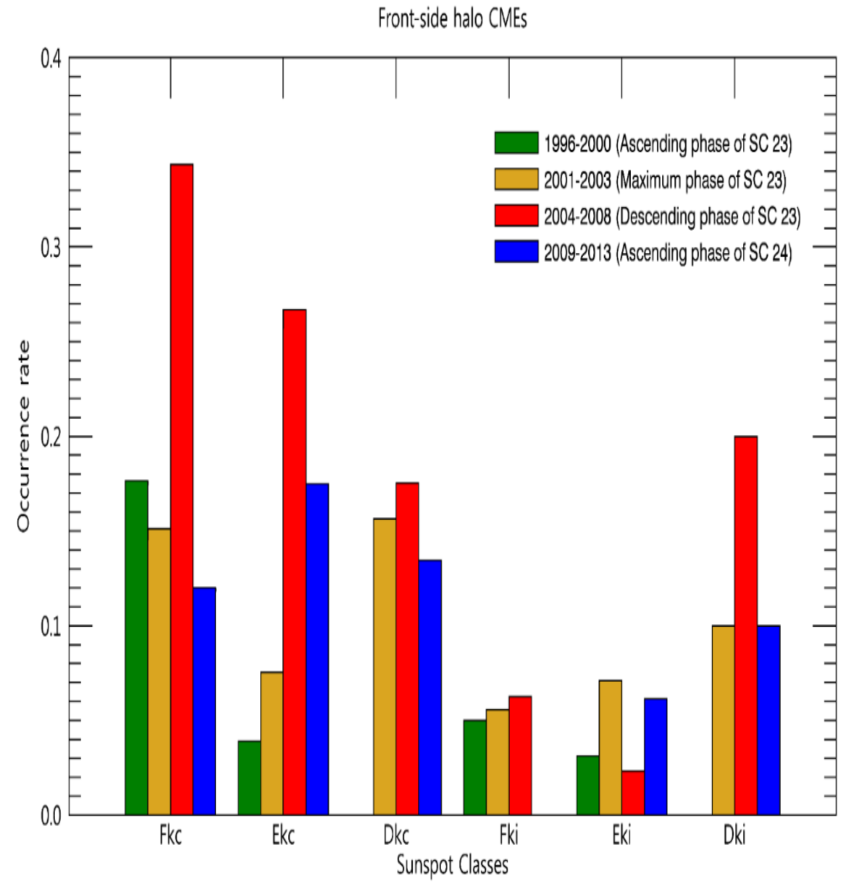
♪



We point out that the CME probability is high when sunspot area is remarkably changed (Especially, Dkc, Ekc, and Fkc classes).

Solar cycle phase effect of the occurrence rates of major flares and halo CMEs (Lee et al. 2015)





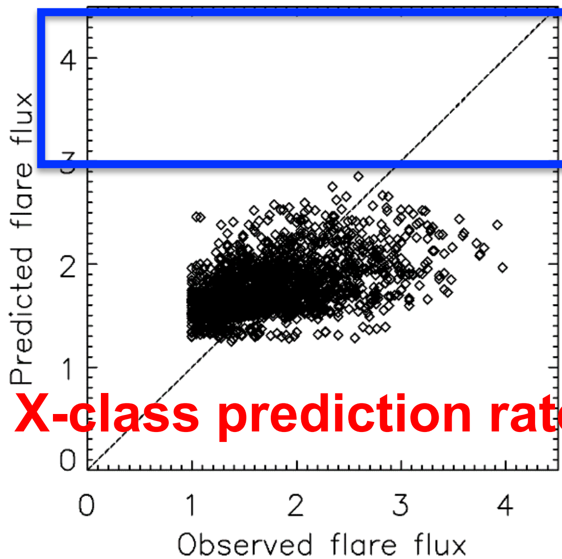
We find that the occurrence rates of major flares and halo CMEs for 6 active sunspot classes are noticeably higher in the descending phase of solar cycle 23 than those in the other phases.

Daily Maximum Flare Flux Forecast Models for Strong Solar Flares (CS-23, Shin et al. 2015)

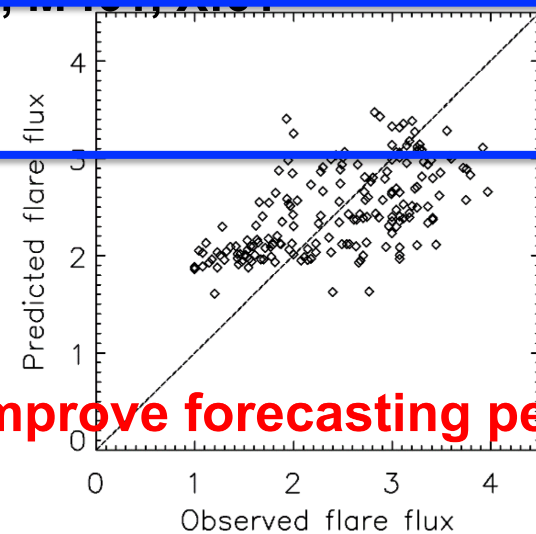
Previous Studies
Using all flaring data tends to underestimate flares.
Ex) C : 1000, M : 500, X : 100

Our study : Using same 61 numbers of each flare class make the model improve the performance of strong flares. → C :61, M :61, X:61

X-class



X-class prediction rate 0%



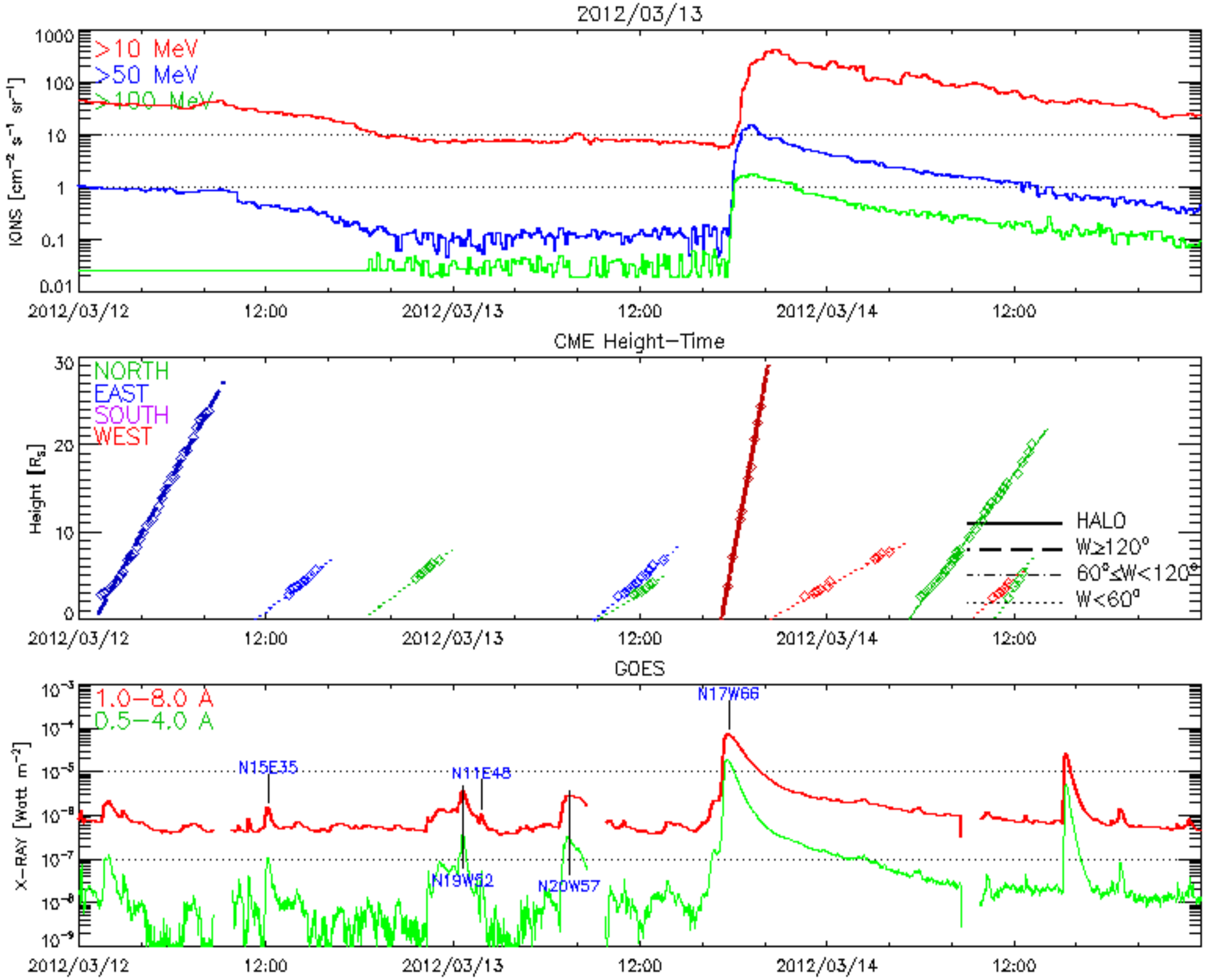
Improve forecasting performan

$$|log_{10}(\text{observed flux}) - log_{10}(\text{forecasted flux})| \le 0.5$$

	MLR	ANN
M-class	0.707	0.617
X-class	0.581	0.677

2. Forecast of Solar Proton Events

SPEs having a flux of > 10 MeV protons equal to and greater than 10 particles cm^{-2} sec^{-1} $ster^{-1}$ (the unit: pfu)



SPE forecast

High-priority forecast now cast models for NOAA/SWPC(2003)

SPE occurrence probability depending on flare parameters

		E31-E90°	E30-W30°	W31-W90°
X-class (85)	T< 0.3h	10.8% 9/83	25.3% 19/75	13.8% 11/80
	T≥ 0.3h	19.2% 9/47	32.1% 18/56	44.2% 19/43

		E31-E90°	E30-W30°	W31-W90°
M-class (81)	T< 0.3h	0.3% 3/1057	0.7% 8/1174	1.5% 15/1005
	T≥ 0.3h	3.6% 11/306	3.5% 13/376	11.7% 31/265

Impulsive time: flare peak time – SPE peak time

(Park et al., 2010)

SPE occurrence probability depending on CME parameters

- CME speed and angular width (# of SPEs/# of CMEs)

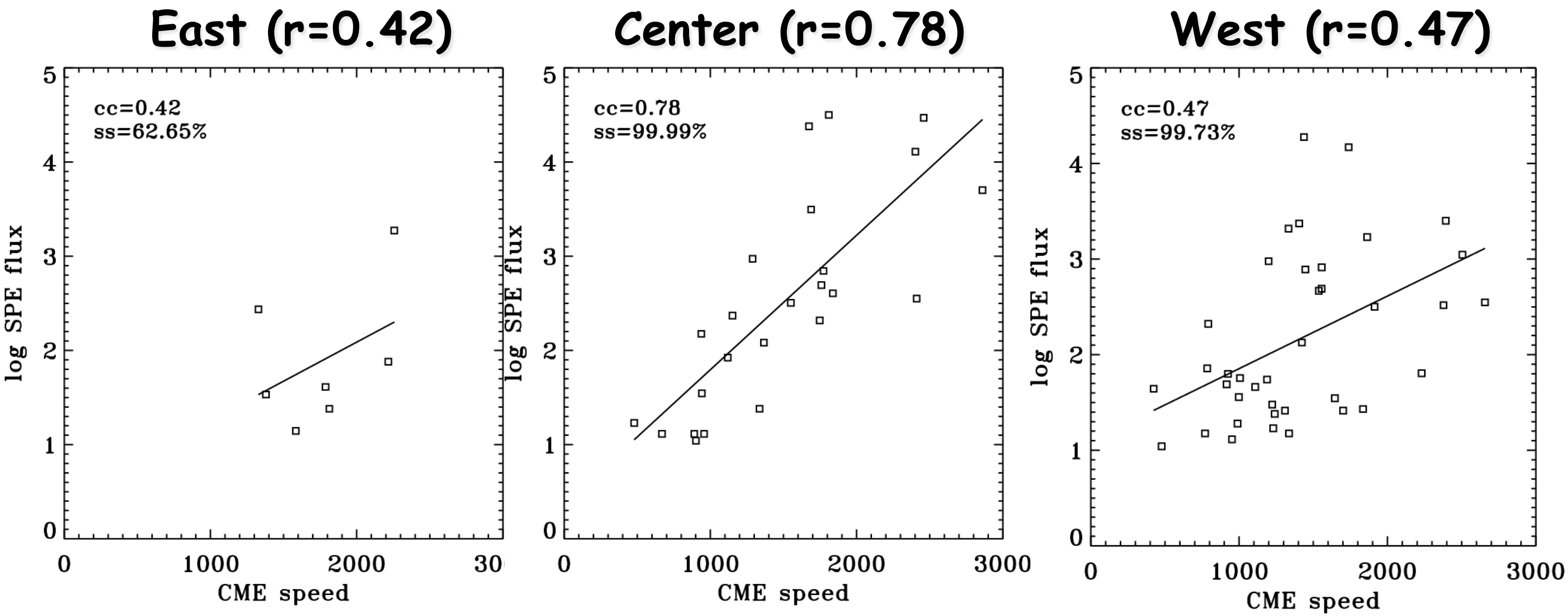
CME	400 ≤ V <1000km/s	1000≤ V<1500km/s	V ≥ 1500km/s
Partial CME (120– 359°)	0.9% (4/434)	8.2% (8/89)	20.7% (6/29)
Halo CME	5.9% (11/185)	21.3% (19/89)	36.1% (30/83)

Front CME	400 ≤ V <1000km/s	1000≤ V<1500km/s	V ≥ 1500km/s
Partial CME (120 – 359°)	1.8% (4/225)	11.3% (7/62)	27.3% (6/22)
Halo CME	9.2% (11/119)	25.0% (17/68)	45.5% (30/66)

(Park et al., 2012)

The relationship between SPE Peak Flux and solar activities

- SPE peak flux and CME speed on longitude



(Park et al., 2012)

SPE occurrence probability depending on flare and CME parameters (Poster CS-13)

- Flare flux, location, CME speed, and angular width

Full Halo

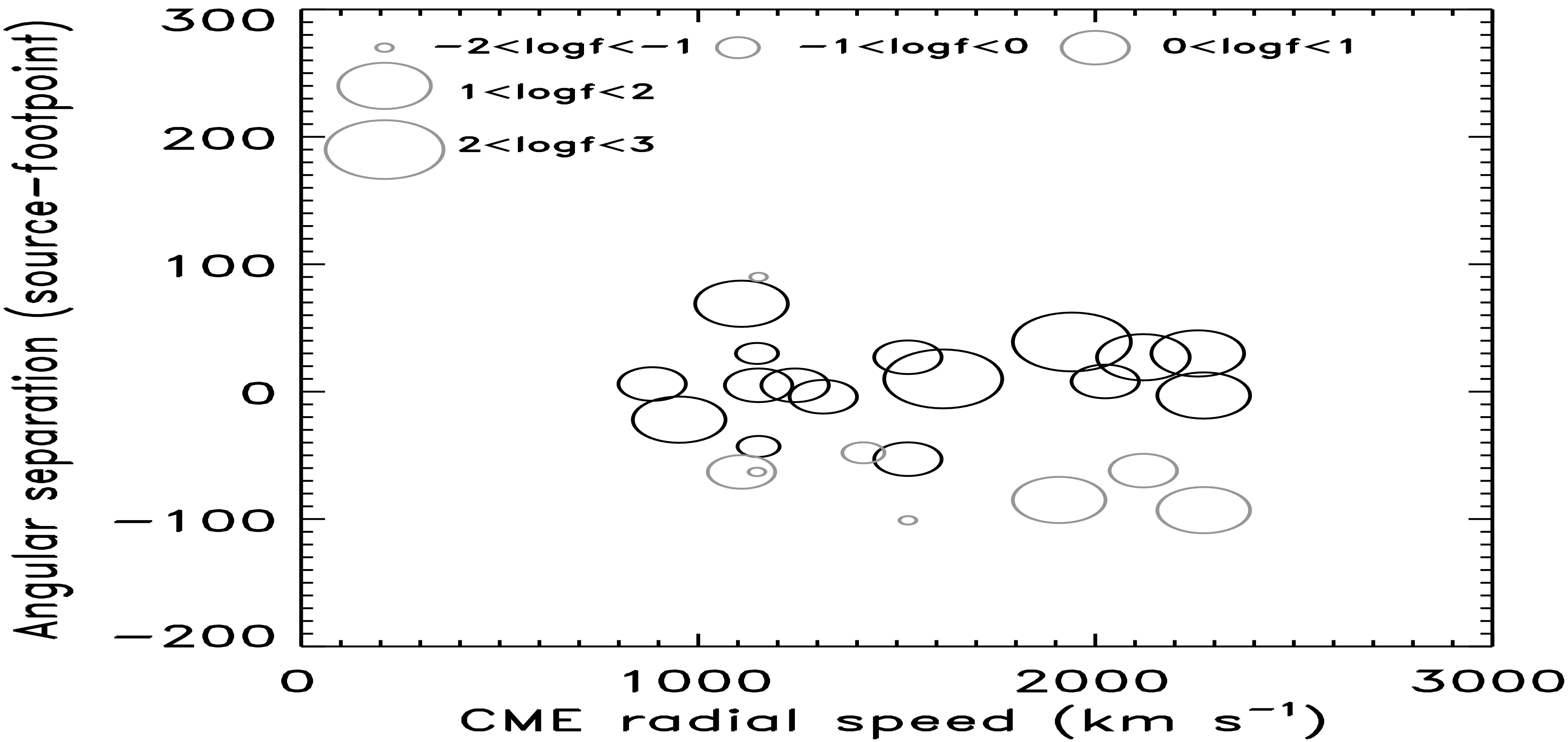
		V < 1000km/s	V ≥ 1000km/s
West	f≥M5	33% (6/18)	57% (20/35)
	F<M5	11% (4/37)	32% (11/34)
East	f≥M5	0% (0/9)	30% (8/27)
	F<M5	0% (0/40)	17% (4/23)

Partial Halo

		V < 1000km/s	V ≥ 1000km/s
West	f≥M5	8% (1/13)	42% (5/12)
	F<M5	4% (3/82)	11% (3/28)
East	f≥M5	0% (0/2)	0% (0/11)
	F<M5	1% (1/90)	0% (0/23)

(Park et al., 2014)

The relationship among CME radial speed, angular separation, and SEP peak flux (Park et al. 2015)



We find that most of strong proton events occur when their angular separations are closer to zero, supporting that most of the proton fluxes are generated near the CME noses rather than their flanks.

3. Forecast of Goemagnetic Storms
3.1 CME – Geomagnetic Storm

: Prediction in 2-3 days advance

Q

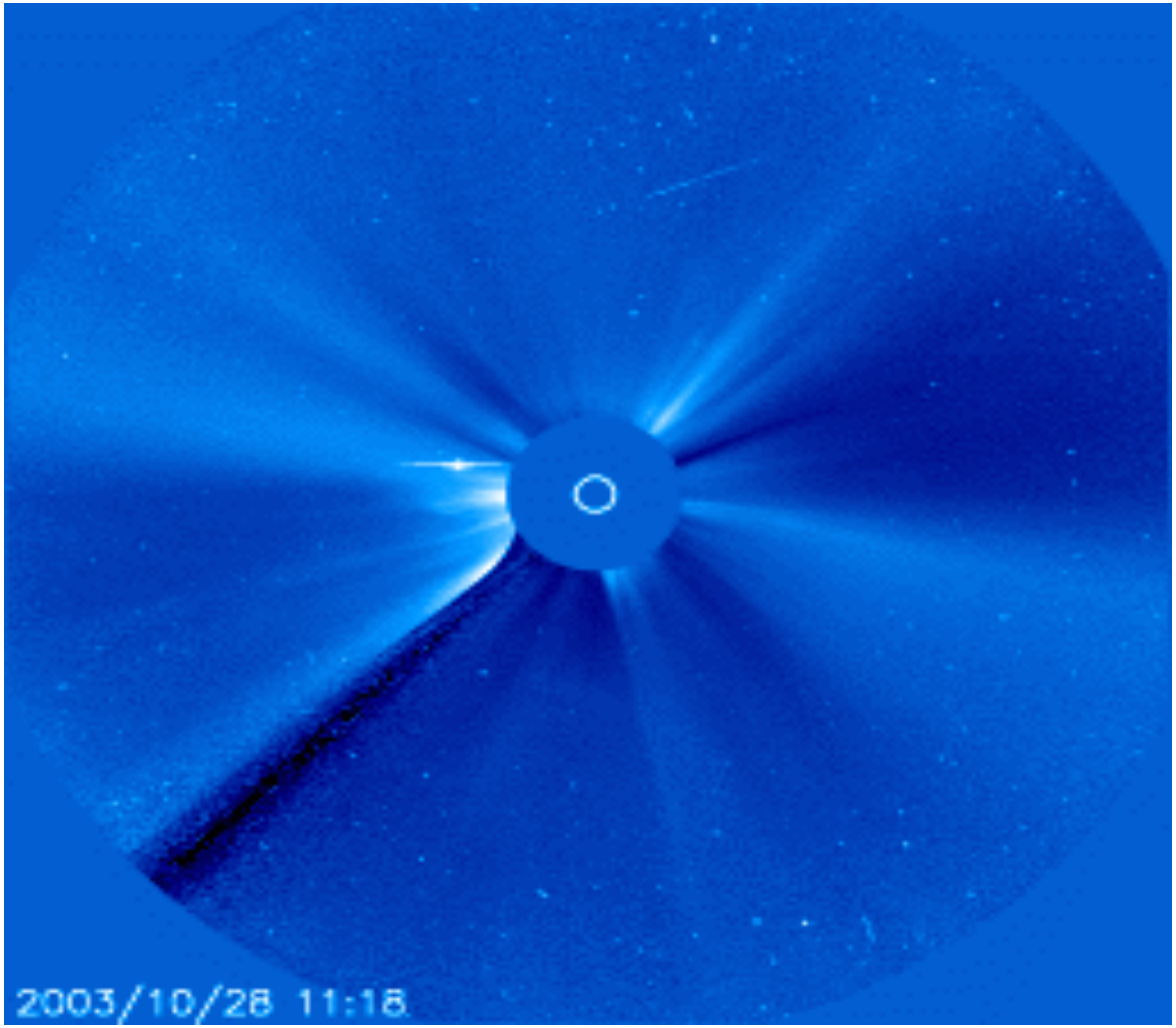
What CME parameters are important for geomagnetic storms ?

A

CME Speed and Location

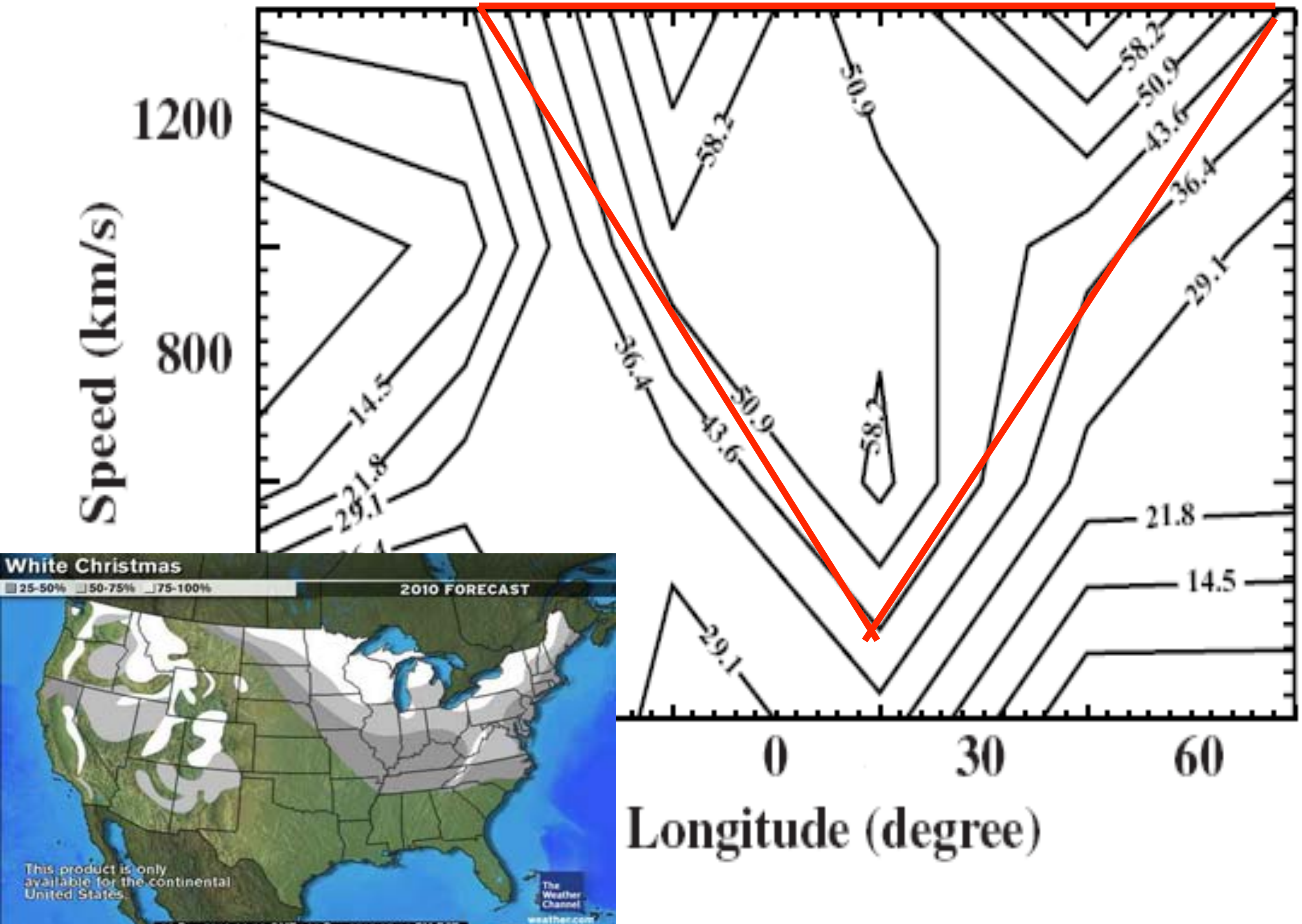
CME Earthward Direction

CME Field Orientation



How do you know if this CME would produce a geomagnetic storm ?

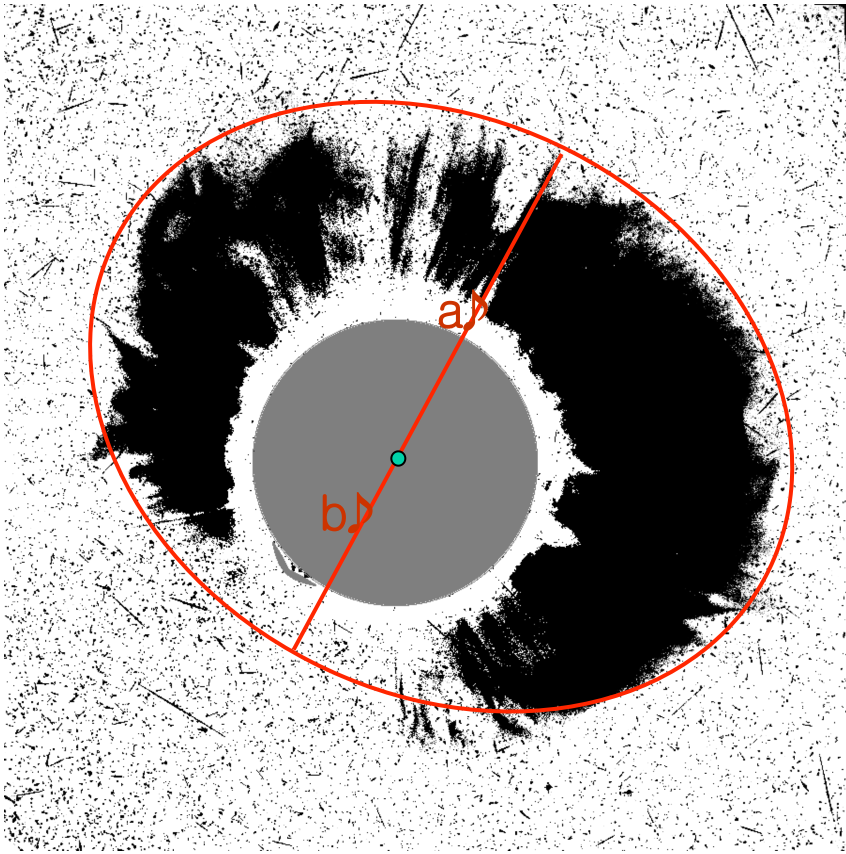
Probability Map of geoeffective halo CMEs : P(L=0,700km/s) is 50 % (Kim et al. 2005)♪



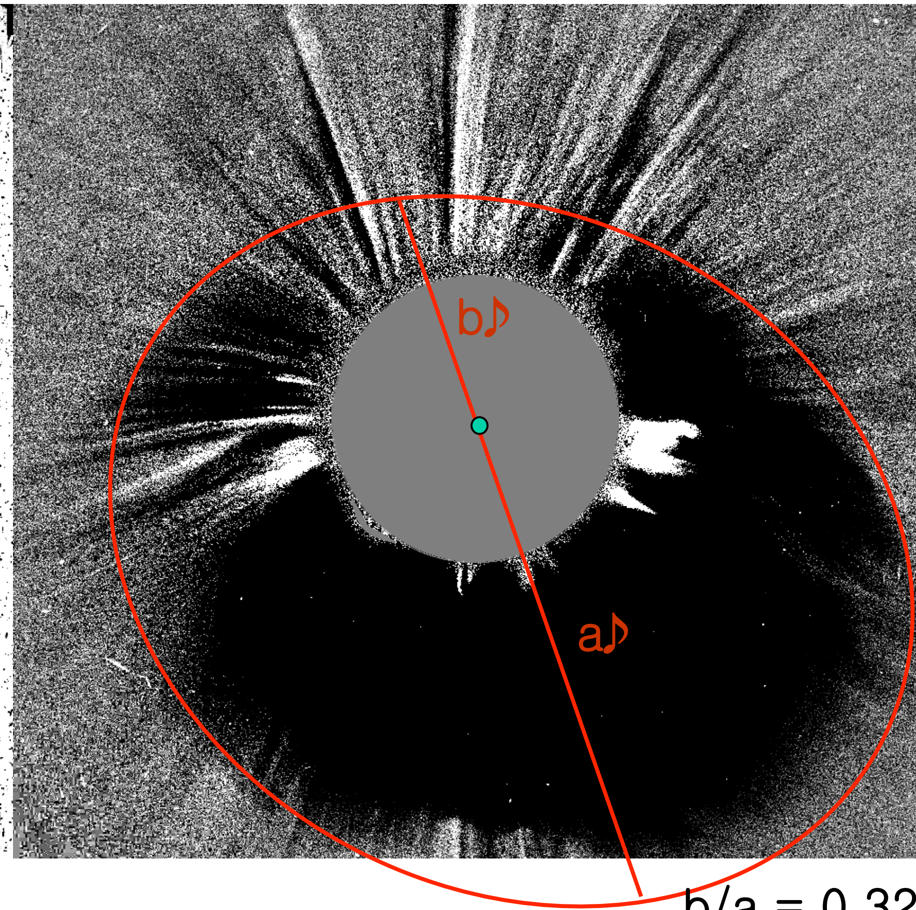
Earthward Direction of CME

A new quantitative direction parameter (Moon et al. 2005)♪

- **Degree of symmetry : (D=b/a)**

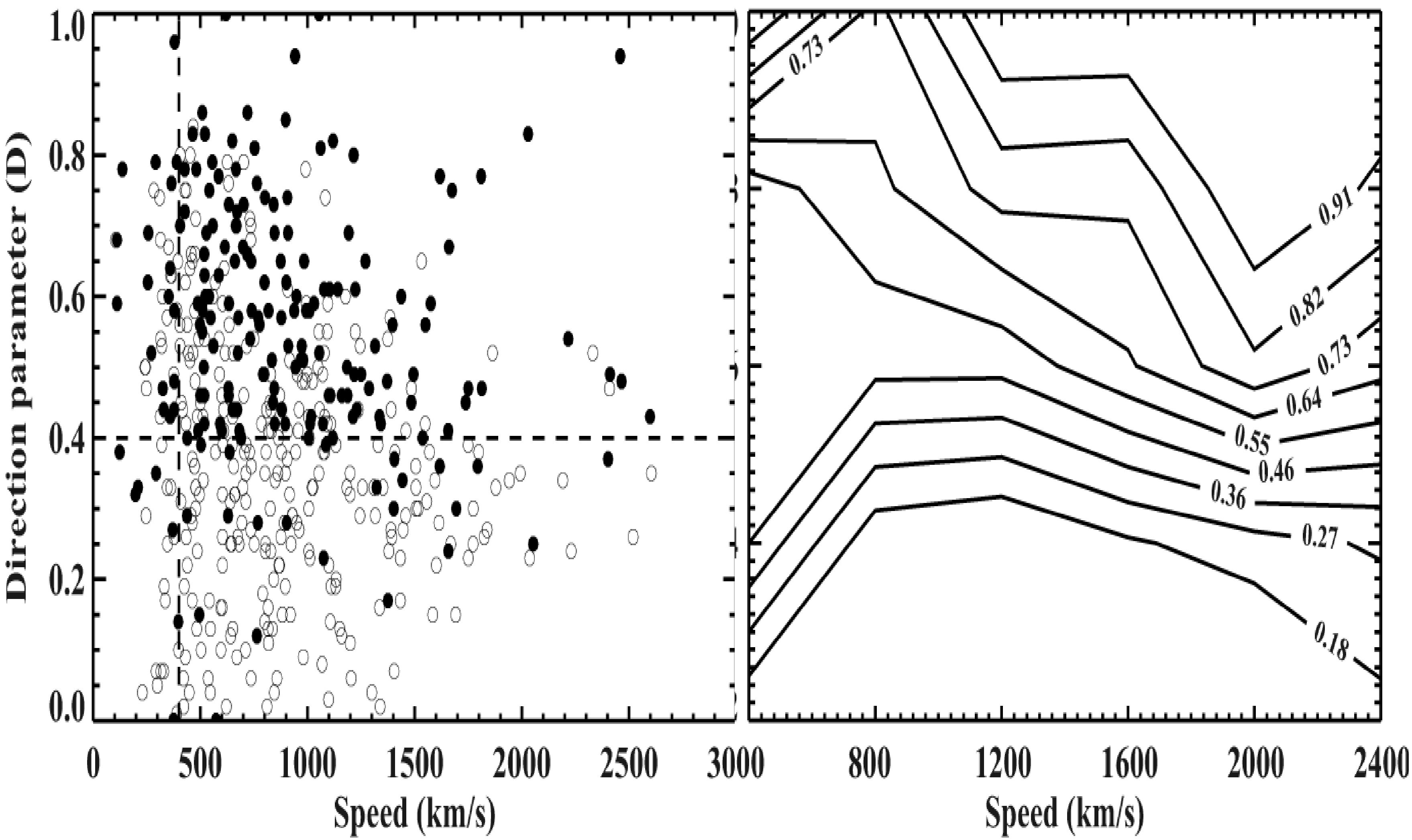


b/a = 0.64 ♪

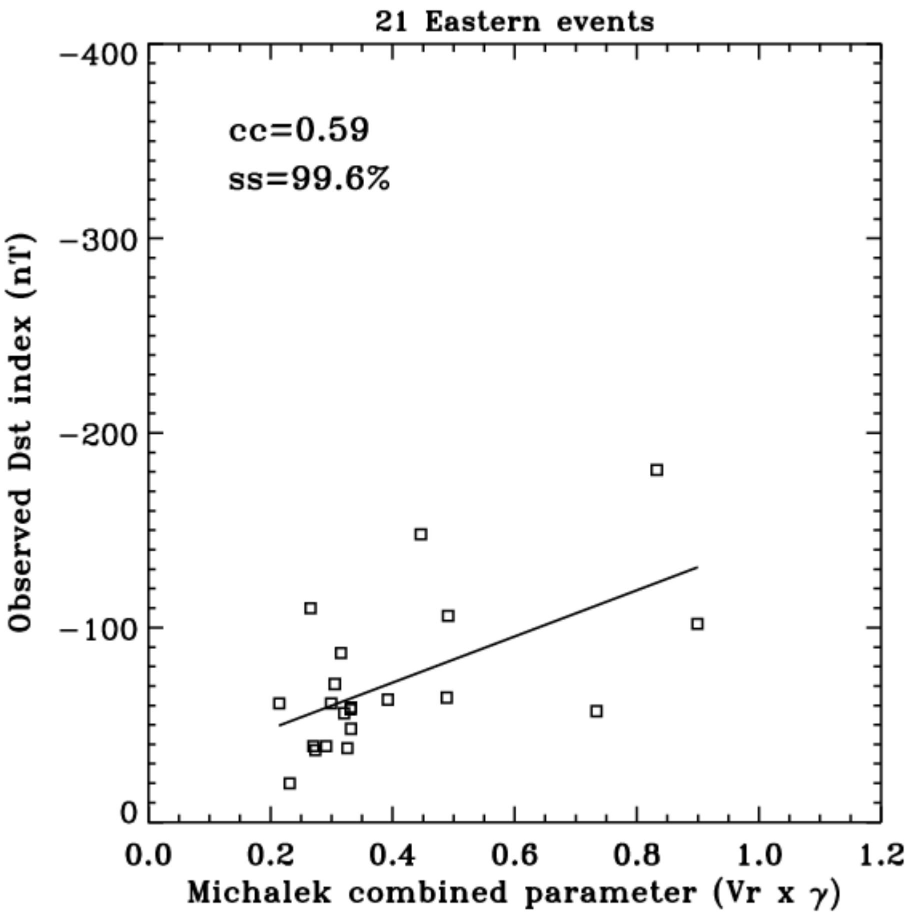


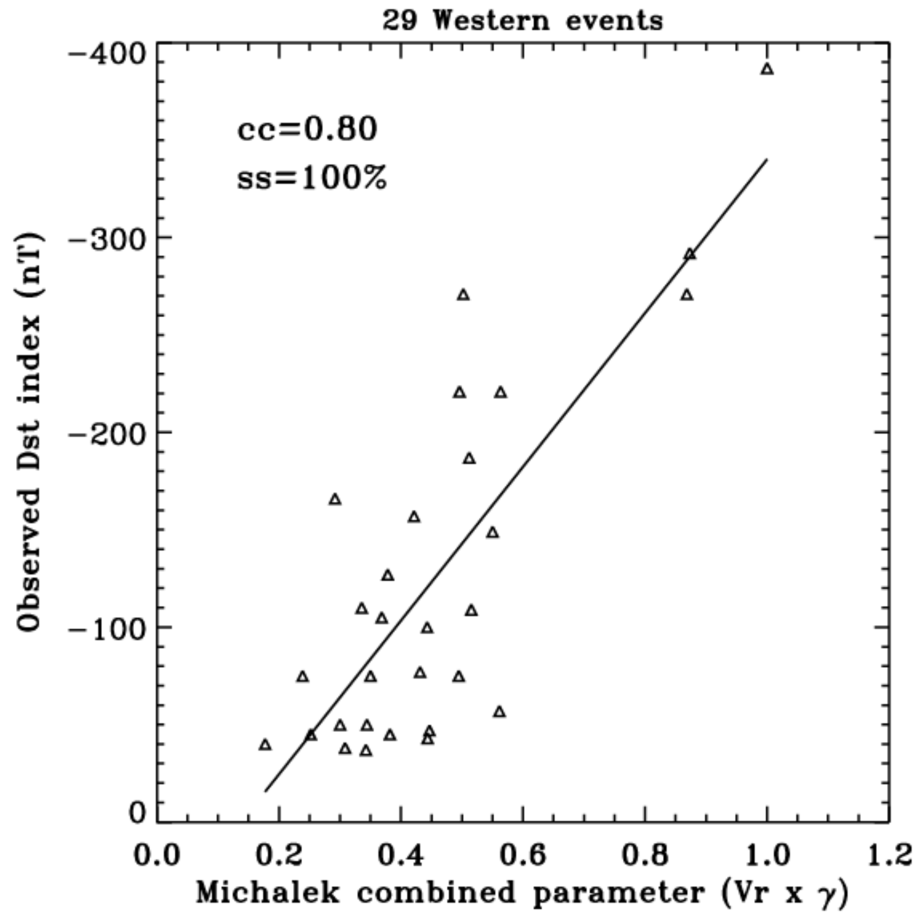
b/a = 0.32♪

Probability map of geoeffective CMEs



3.2 Geoeffective CME parameters (Lee et al. 2014)





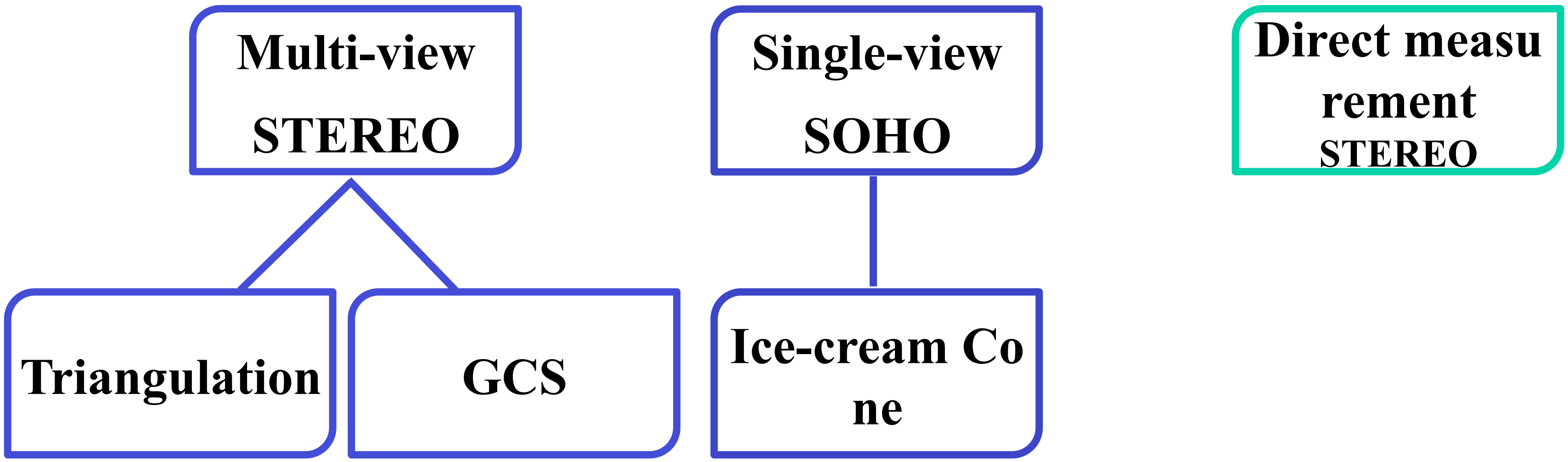
Super geomagnetic storms (Dst ≤ -200 nT) only appeared in the western region.

Dependence of Halo CME geoeffectiveness on location and magnetic field orientation♪

Dst index	Eastern + Northward	Eastern + S outhward	Western + Northward	Western + Southward
≤ -50 nT (Moderate)	75% 6/8	81.8% 9/11♪	66.6% 6/9♪	83.3% 15/18♪
≤ -100 nT (Intense)	12.5% 1/8	36.3% 4/11♪	44.4% 4/9♪	55.5% 10/18♪
≤ -200 nT (Super)	0% 0/8	0% 0/11♪	0% 0/9♪	33.3% 6/18♪

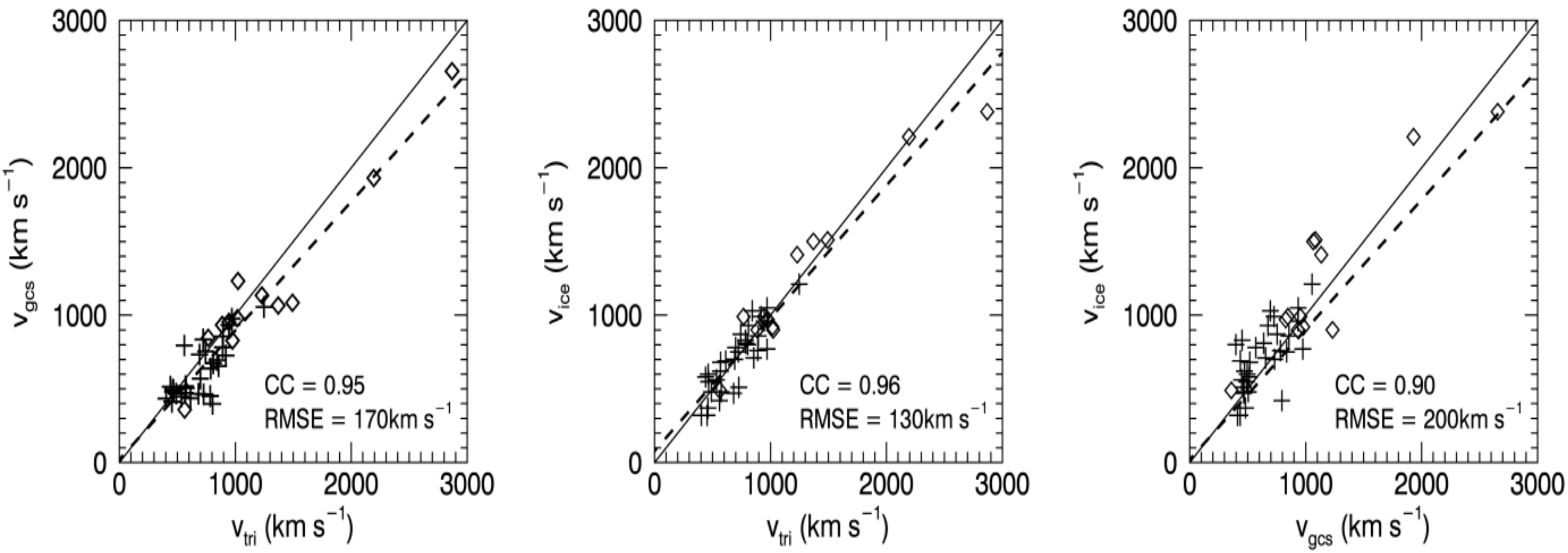
Super geomagnetic storms (Dst ≤ -200 nT) only appeared in the western and southward magnetic field events.♪

3.3 Comparison of cone models and a flux rope model (Poster CS-30, Lee et al. 2015)♪

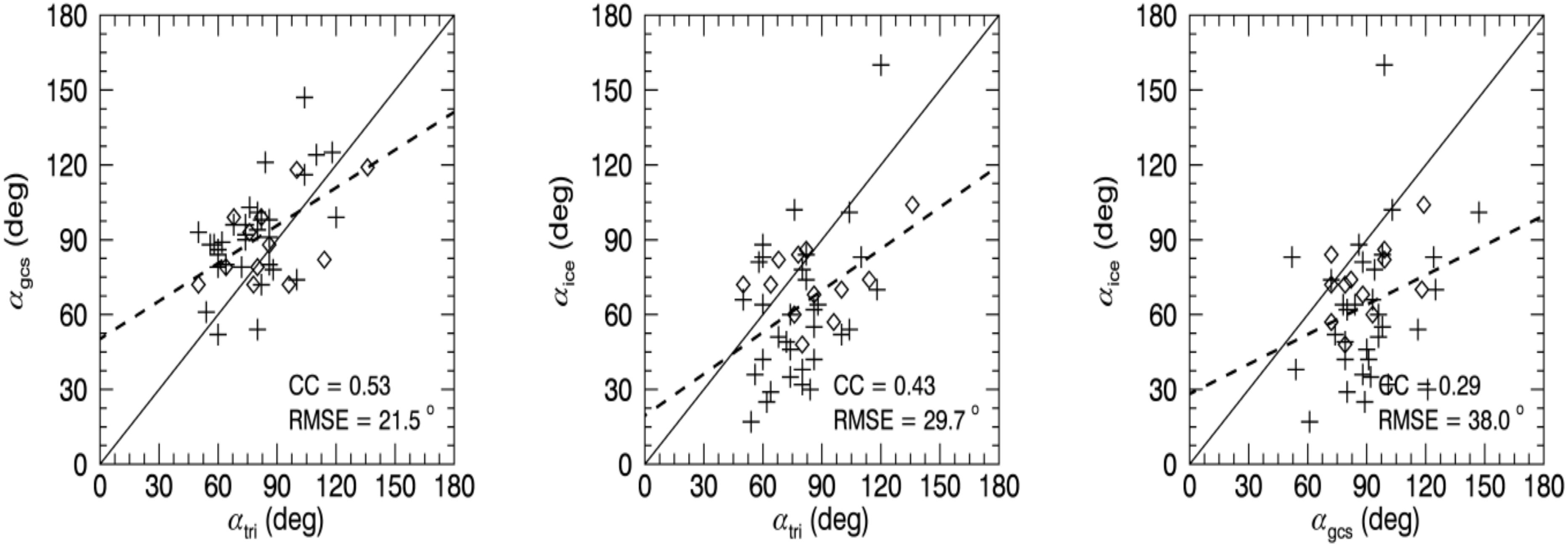


3-D CME parameters : Radial velocity, Angular width, Source location

➢ **Comparison of the radial velocities of the CMEs from three geometrical methods**

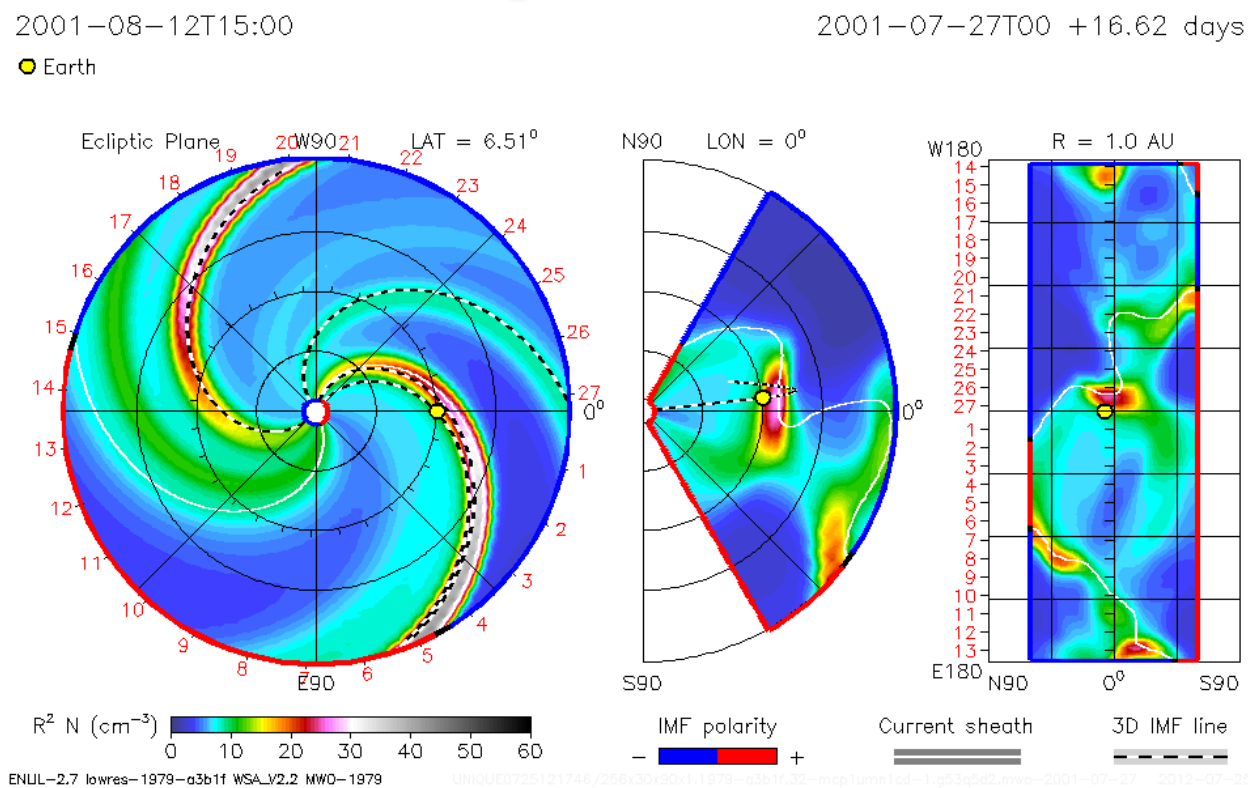


➢ Comparison of the angular widths of the CMEs from three geometrical methods



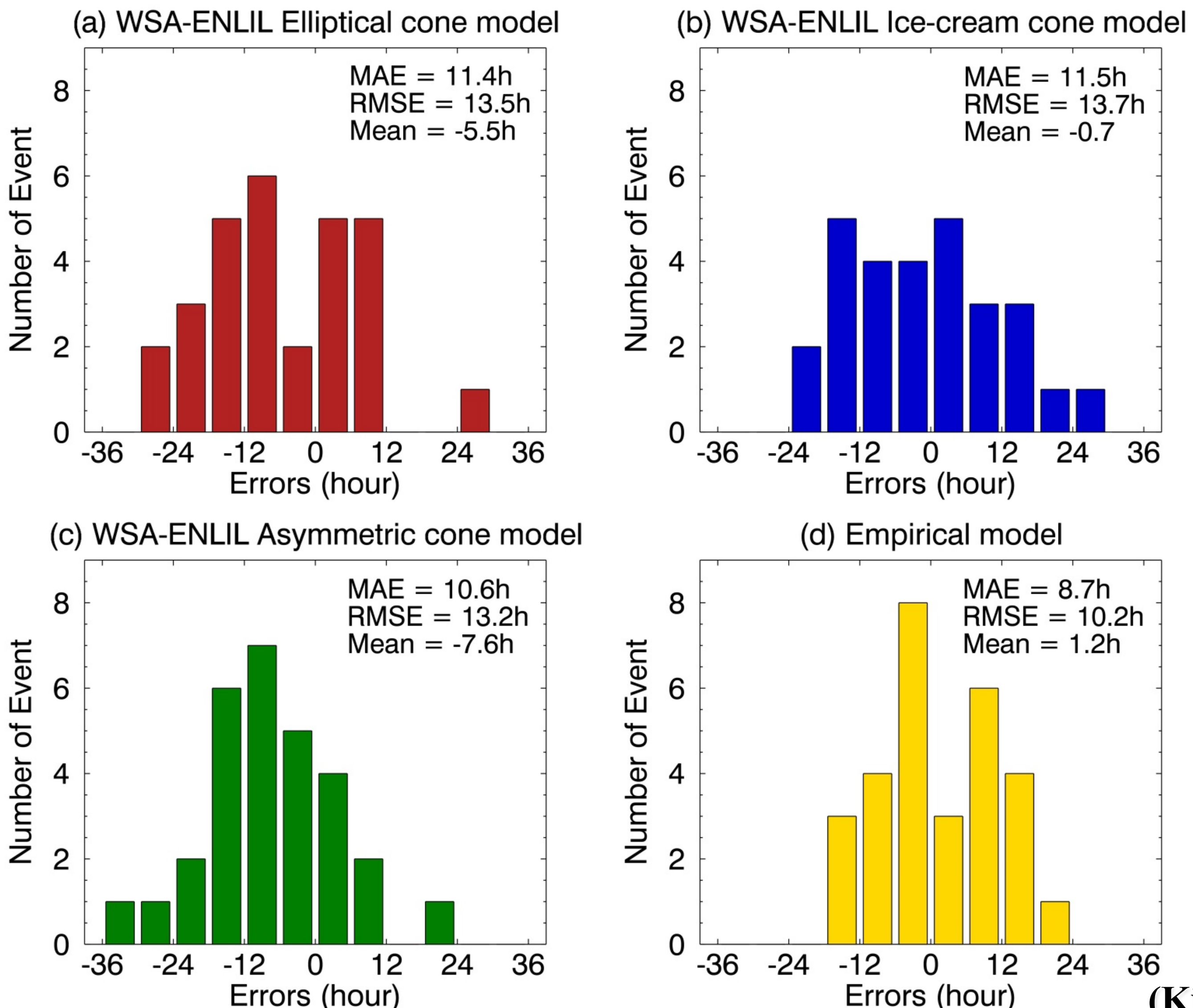
3.4 WSA-ENLIL model with three cone types (First prize of NASA/CCMC contest 2013, Jang et al. 2014)

- **The WSA-ENLIL model is the three-dimensional MHD numerical code, to simulate corotating and transient SW disturbances in the heliospheres.**



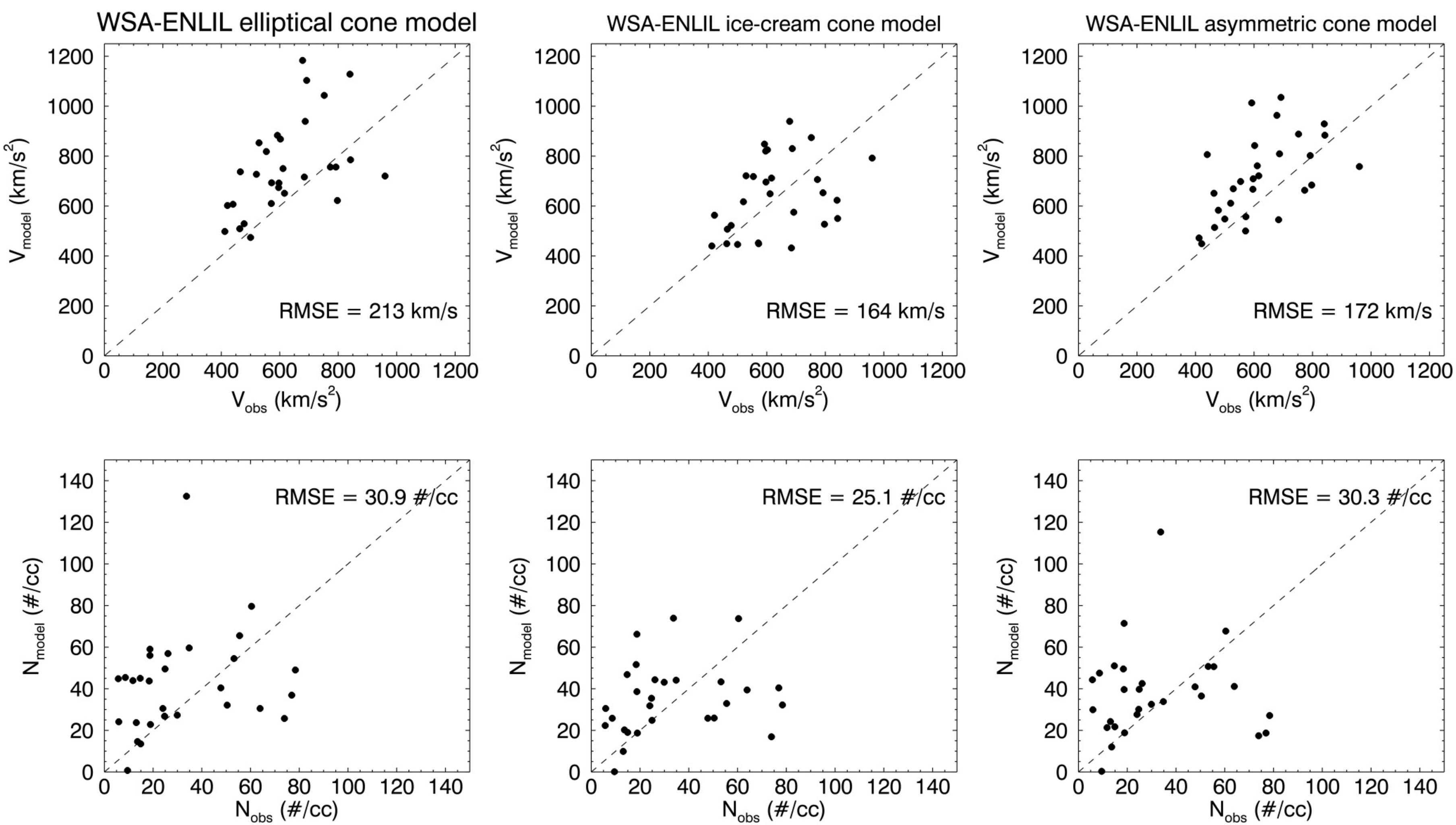
http://iswa.ccmc.gsfc.nasa.gov/

Travel time error $(T_{model} - T_{obs})$

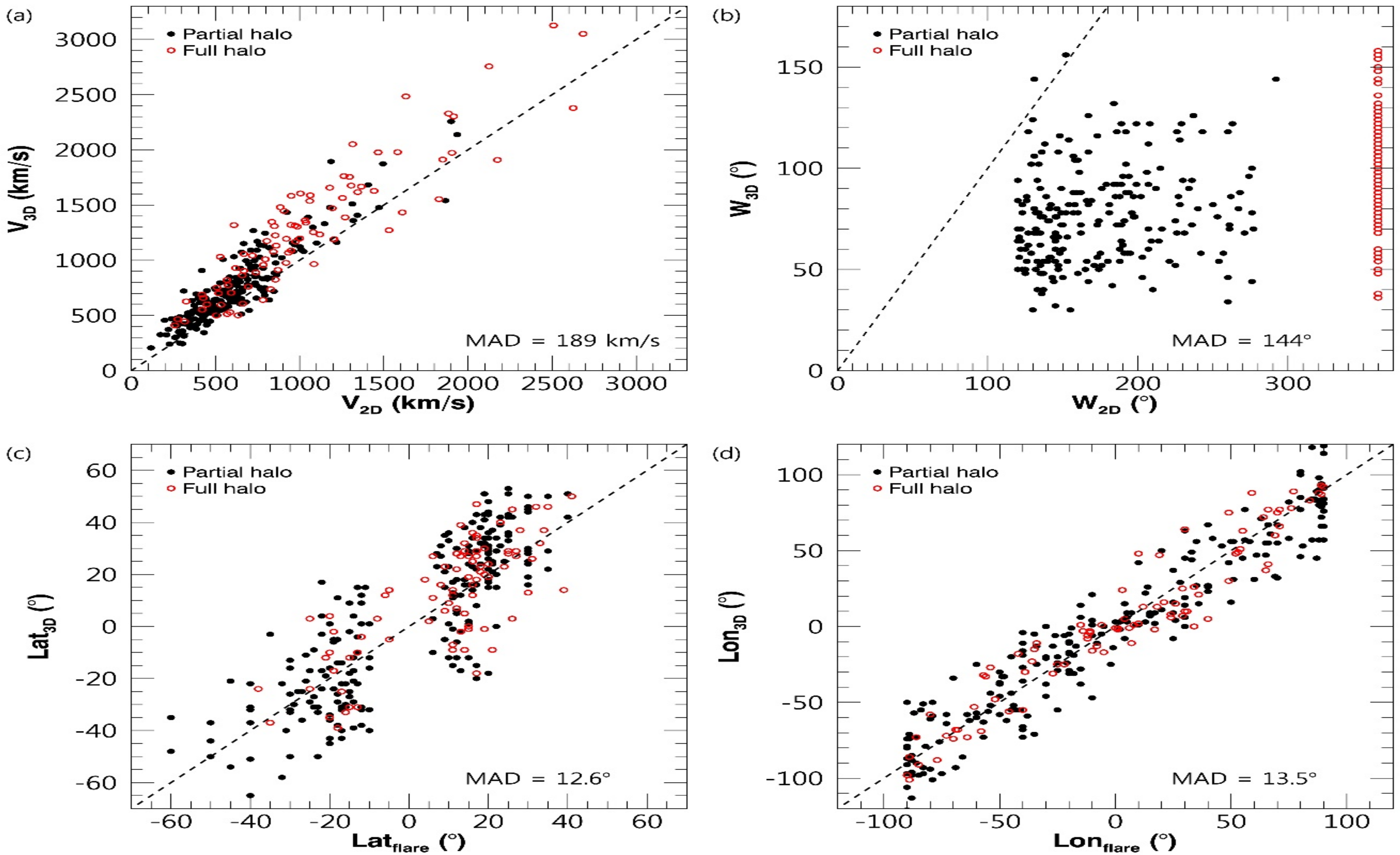


(Kim et al. 2007)

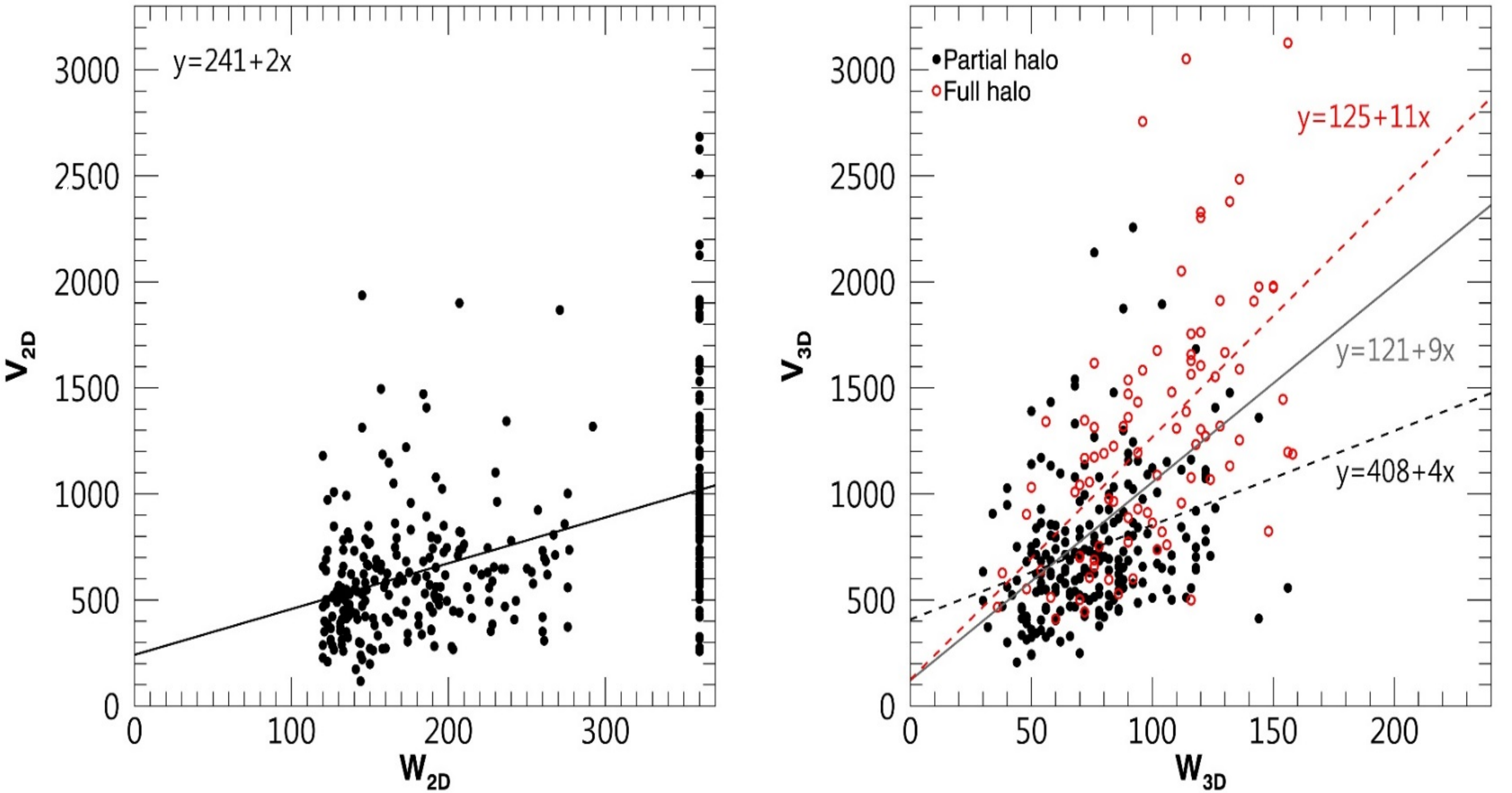
Comparison between model results a nd observation♪



3.4 Comparison of CME 3-D parameters with 2-D ones (First prize of NASA/CCMC contest 2015, CS-24)



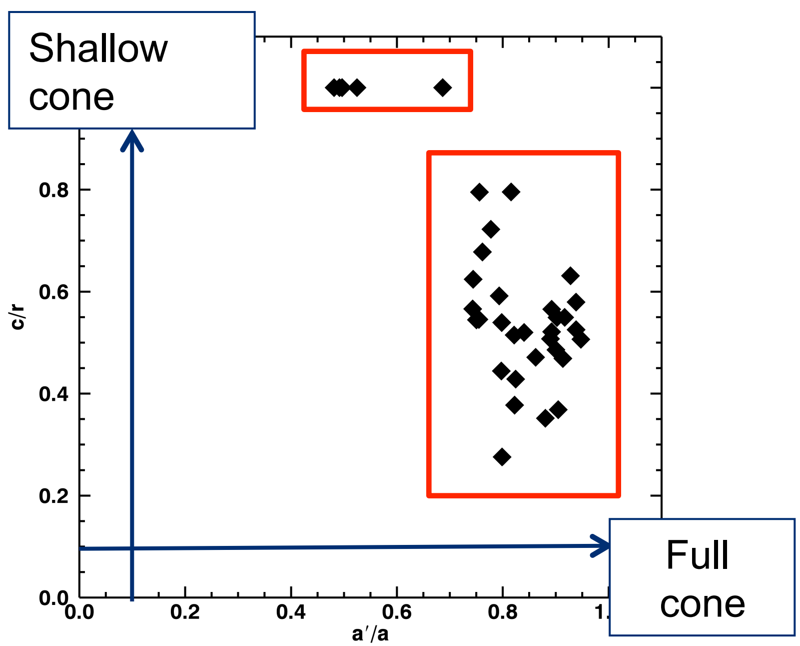
Comparison of speed-width relationship in 2-D and 3-D

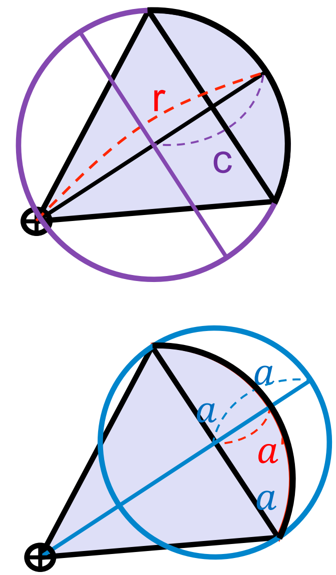


3.6 Development of a full ice-cream cone model

(Poster CS-08, Na et al. 2015)

- **Cone shape parameters : 29 limb events**



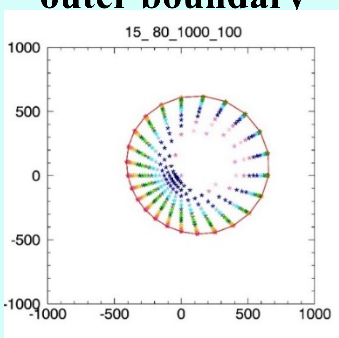


⇒ Most of the events are closer to the full cone type, which is consistent with Gopalswamy *et al.* (2009a) and Michalek *et al.* (2009).

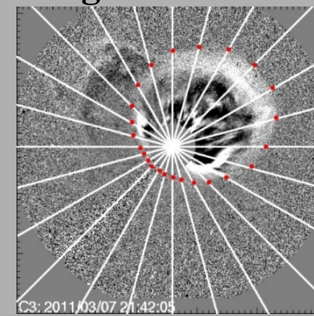
Input initial parameters:
V_0, $\alpha_0(2\omega_0)$,
source location
(ϕ_0, θ_0; near flare location)

Construct a cone for given initial values

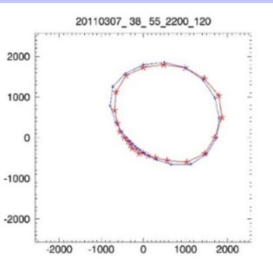
Project the cone on the sky plane
&
Select points comprising the outer boundary



Measure projection speeds (every 15°, 24 points) using the observation data

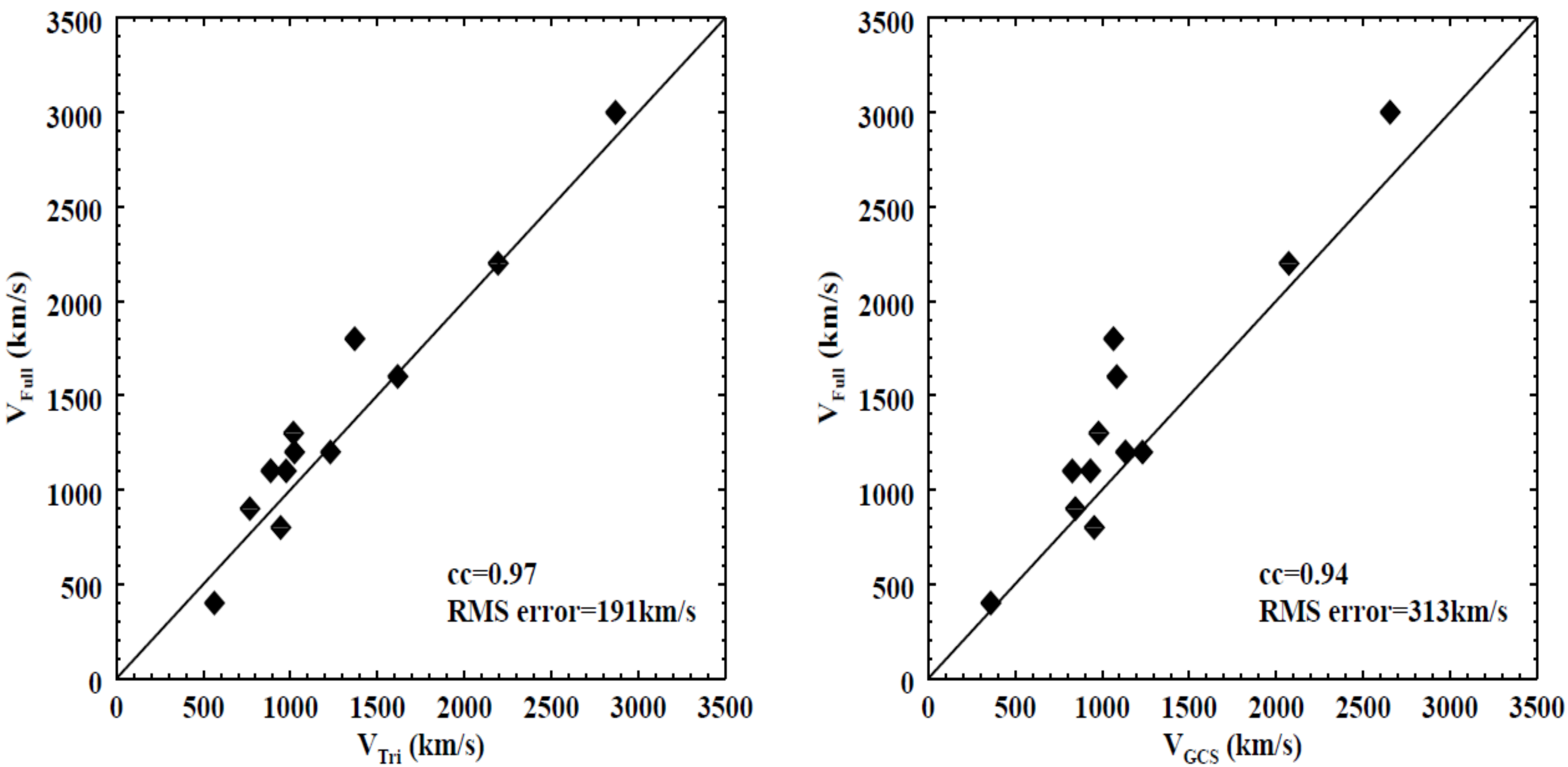


Minimize the difference between the estimated projection speeds with the observed one.

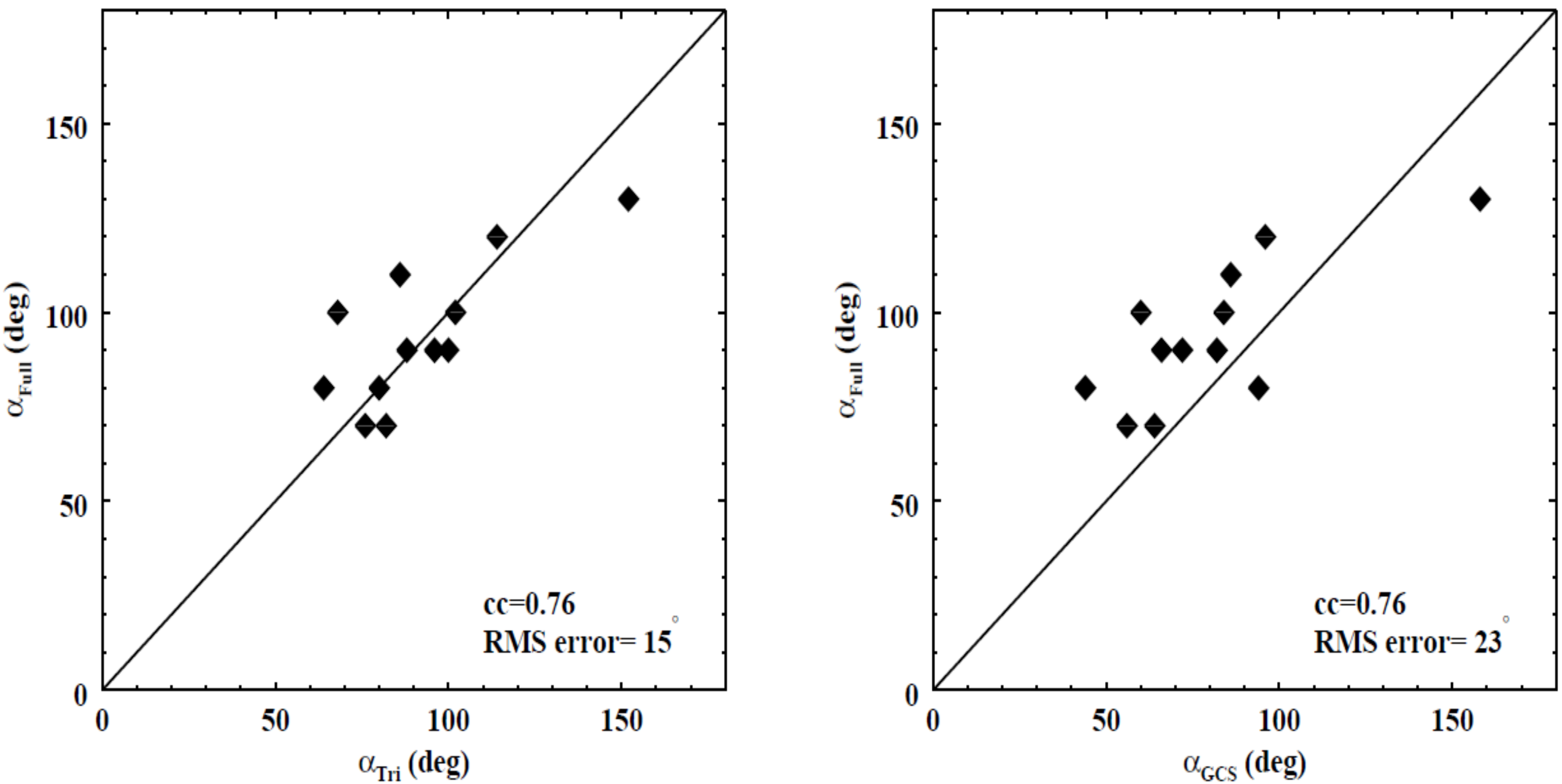


Output parameters:
V, α, source location (ϕ, θ),
angle $\gamma = \sin^{-1}(\sin\theta\cos\phi)$

Comparison of Full ice-cream cone model, Triangulation method, and GCS model: Velocity



Comparison of Full ice-cream cone model, Triangulation method, and GCS model: Angular width



Conclusion

- We have developed probabilistic forecast models of major flares and CMEs as well as daily flare peak flux forecast models for strong flares.
- We have developed a solar proton (S) forecast model depending on flare parameters (flare strength, duration, and longitude) as well as CME parameters (speed and angular width).
- We have presented the probability map of geoeffective CMEs depending on CME parameters.
- The geoeffectiveness of CMEs from eastern and western hemisphere is quite different from each other. All superstorms appeared in the western and southward magnetic field events.
- We have developed a full ice-cream cone model for CME 3-D parameters, which is more consistent with observations than the other cone types models.