Lessons of empirical space weather forecast models based on solar data

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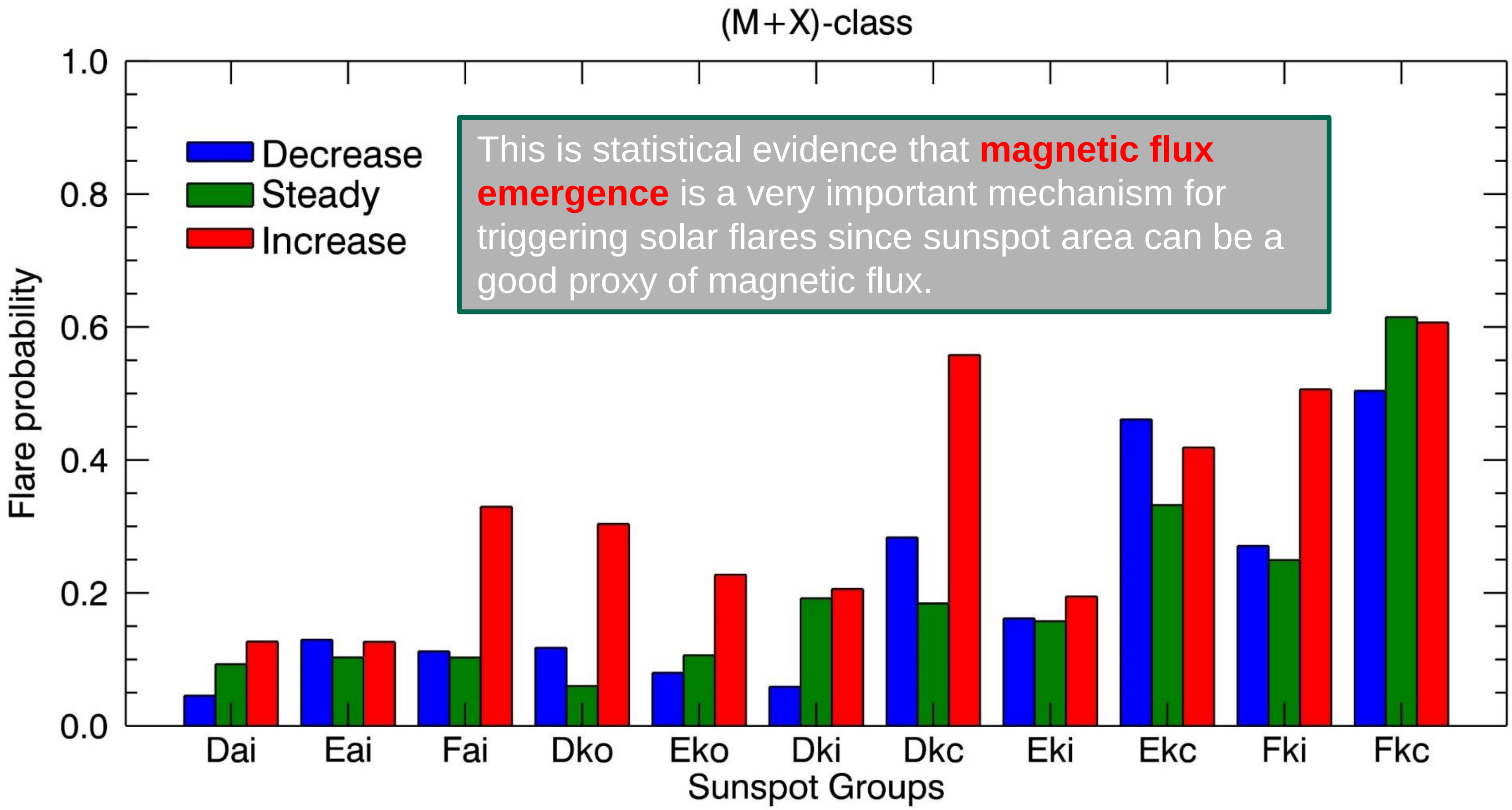
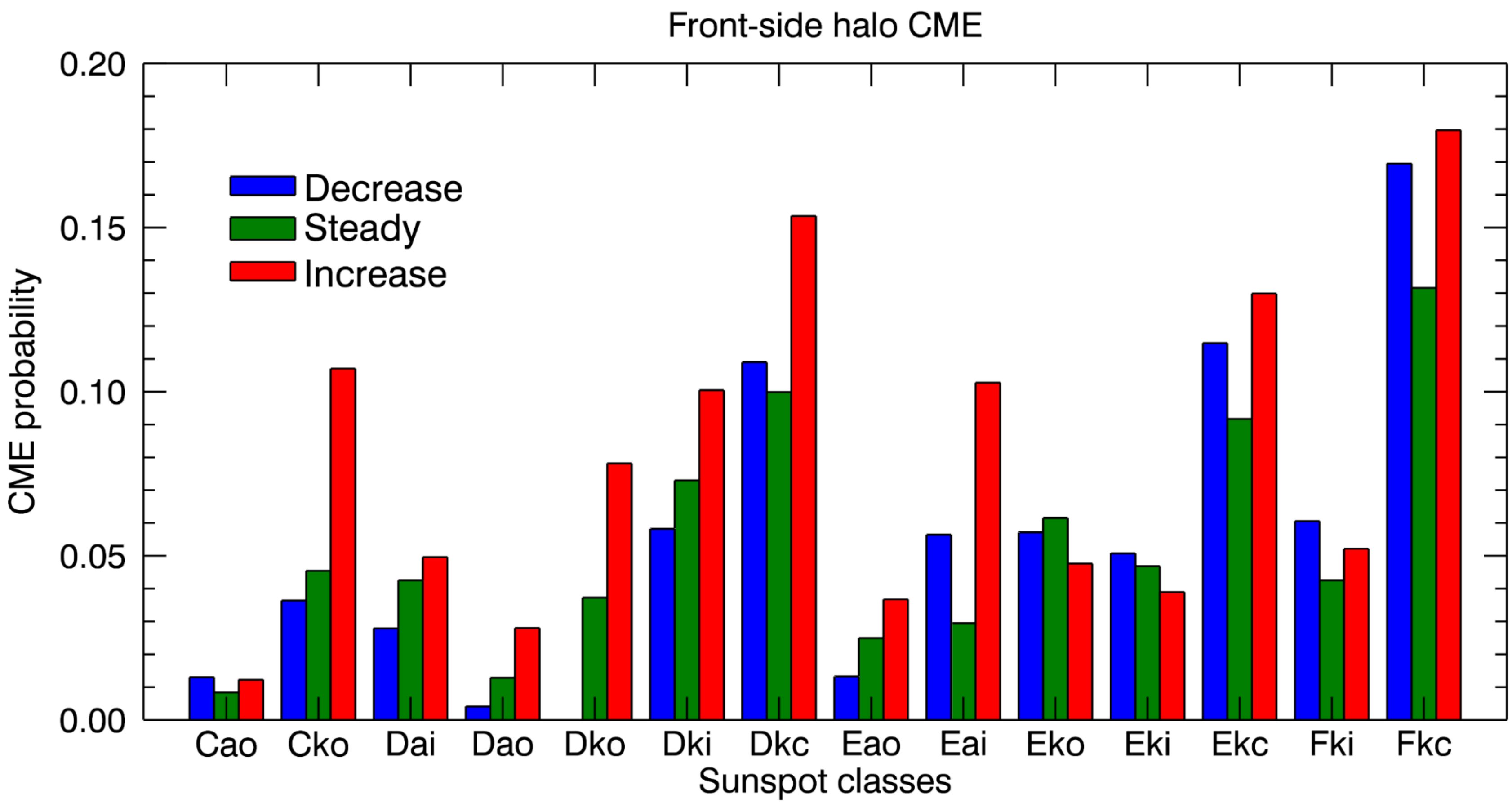
Flare probability as a function of sunspot class and its area change (Lee et al. 2012)



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)

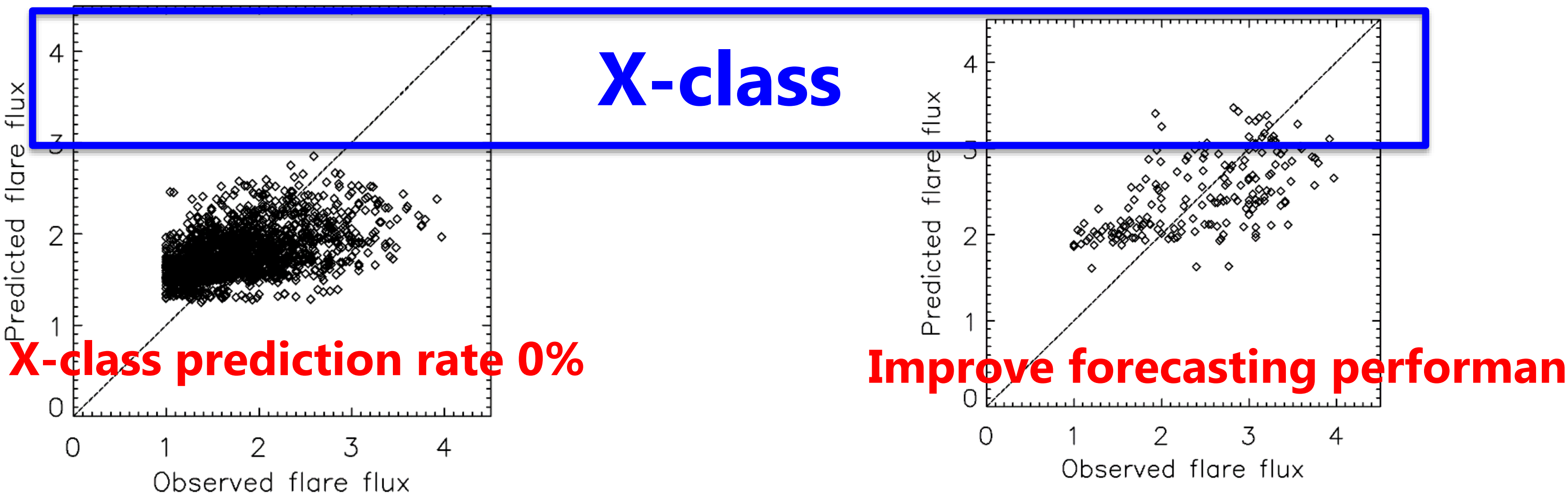


We point out that the CME probability is high when sunspot area is remarkably changed (Especially, Dkc, Ekc, and Fkc classes).

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



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

	MLR	ANN
M-class	<u>0.707</u>	0.617
X-class	0.581	<u>0.677</u>

Lessons for solar eruptions

There are several important input parameters for the prediction of solar storms :

1) sunspot area : magnetic flux
2) sunspot complexity : non-potential parameters
3) sunspot area change : magnetic flux change
4) solar activity history : flare strength of the previous day
5) solar cycle effect : interaction among ARs

: which parameter is more important ?

To make a neural network forecast model for rare events such as X-class flares, we need a carful training using the same number of events for each flare class.

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)

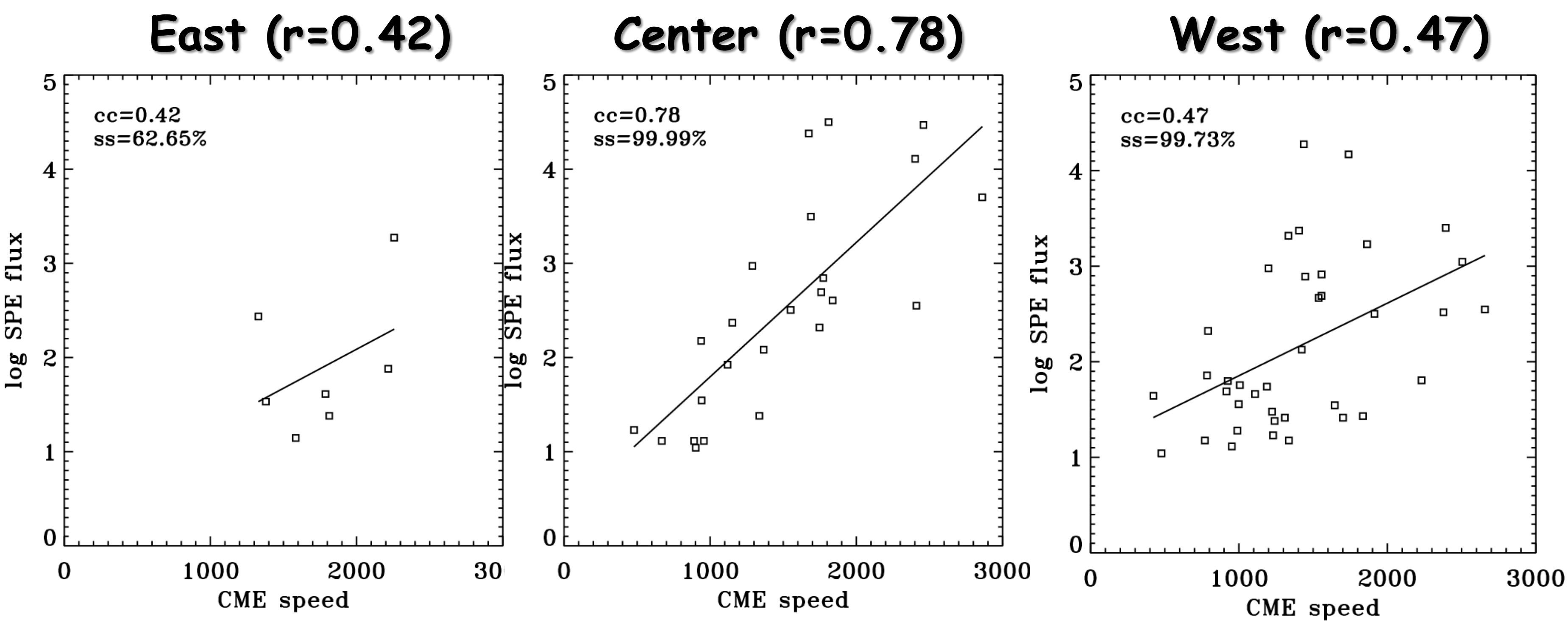
CME	400 ≤ V <1000km/s	1000≤ V<1500km/s	V ≥ 1500km/s
Partial CME (120– 359°)	0.9% (4/434)	8.2% (8/89)	20.7% (6/29)
Halo CME	5.9% (11/185)	21.3% (19/89)	36.1% (30/83)

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

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

Full Halo

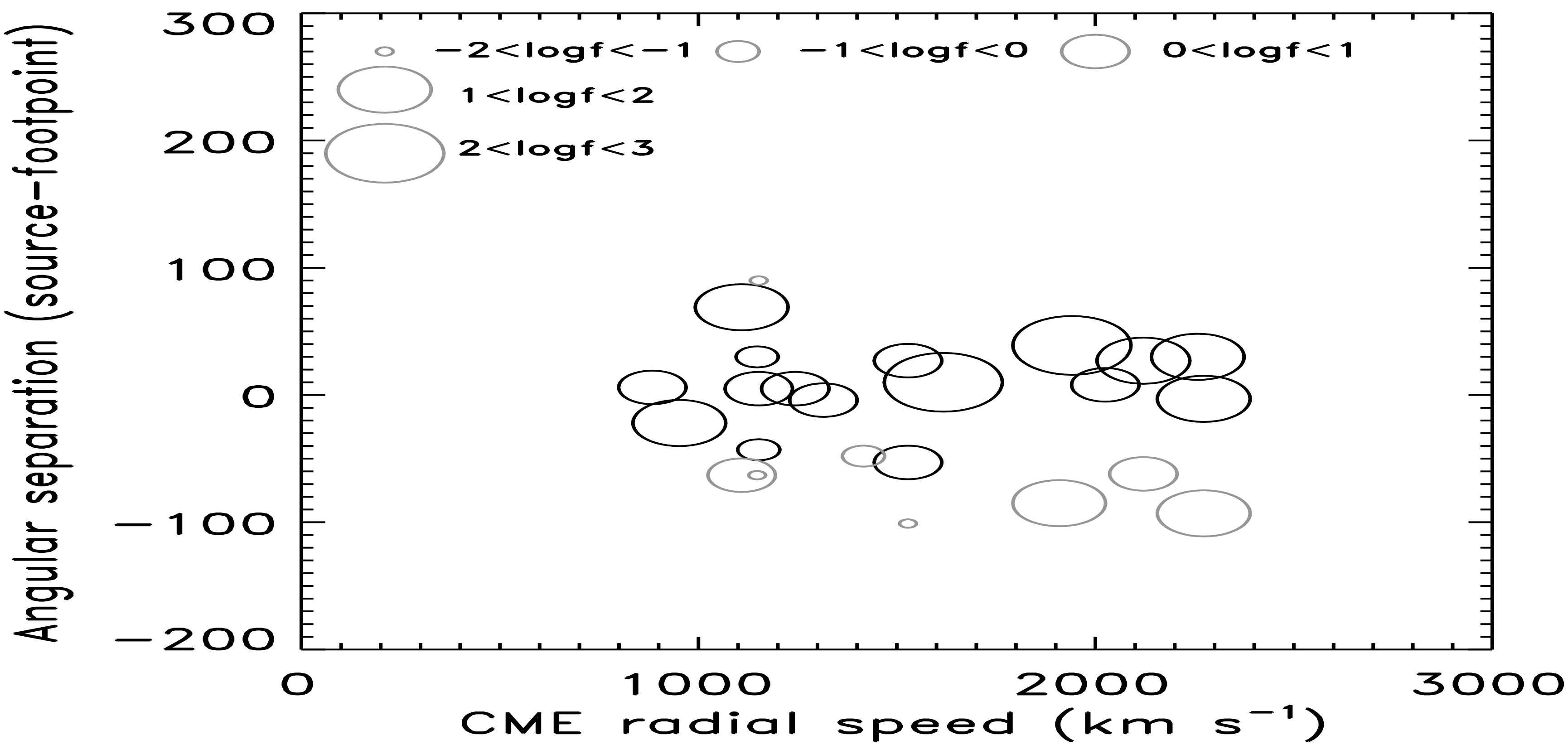
		V < 1000km/s	V ≥ 1000km/s
West	f≥M5	33% (6/18)	57% (20/35)
	F<M5	11% (4/37)	32% (11/34)
East	f≥M5	0% (0/9)	30% (8/27)
	F<M5	0% (0/40)	17% (4/23)

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.

Lessons for SPE events

The probability of SPE occurrence strongly depends on CME/flare parameters.

There are several important input parameters for the prediction of SPEs :

1) CME speed
2) source location : peak near 60W
3) CME angular width

: which parameter is more important ?

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 ?

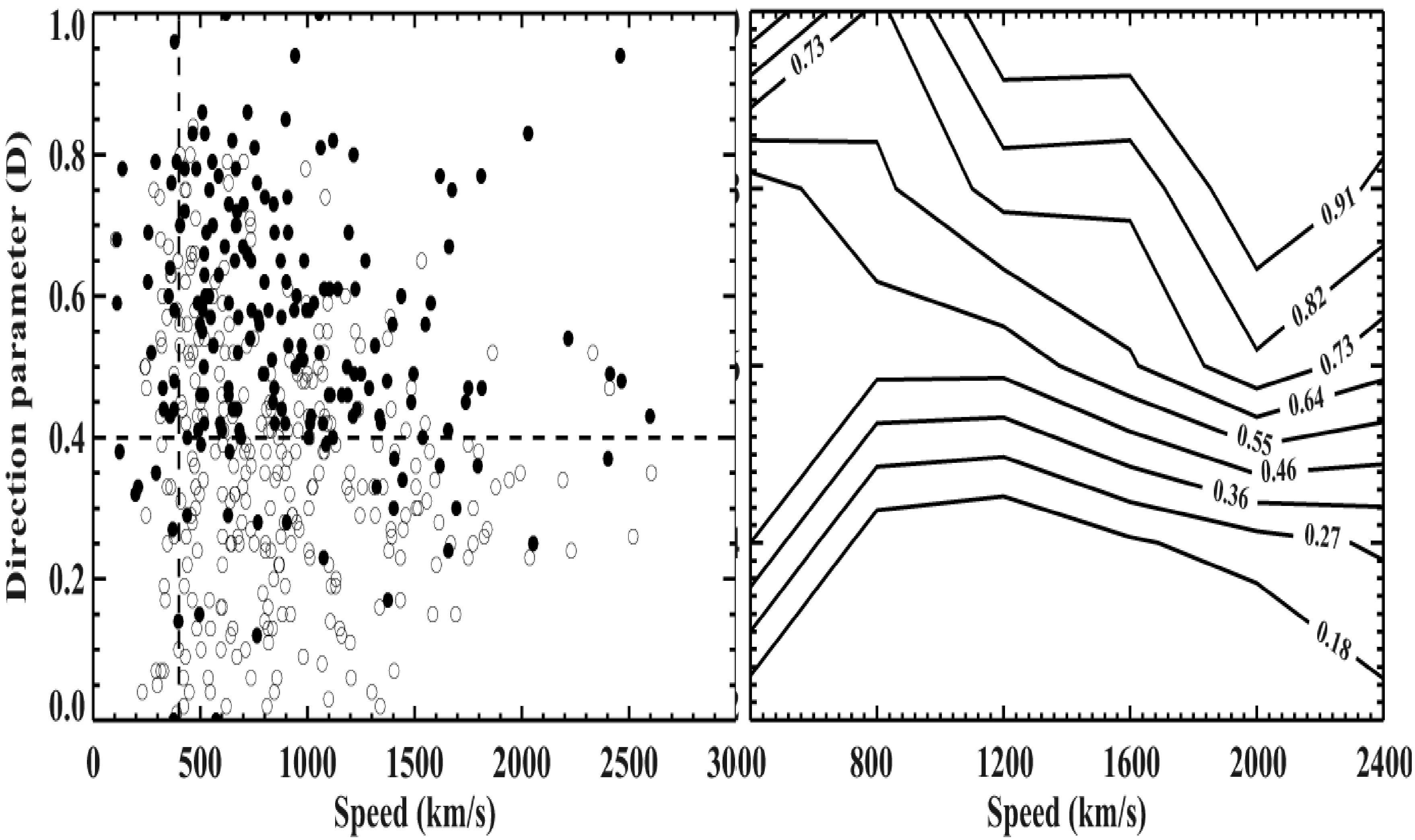
A

CME Speed and Location

CME Earthward Direction

CME Field Orientation

Probability map of geoeffective CMEs

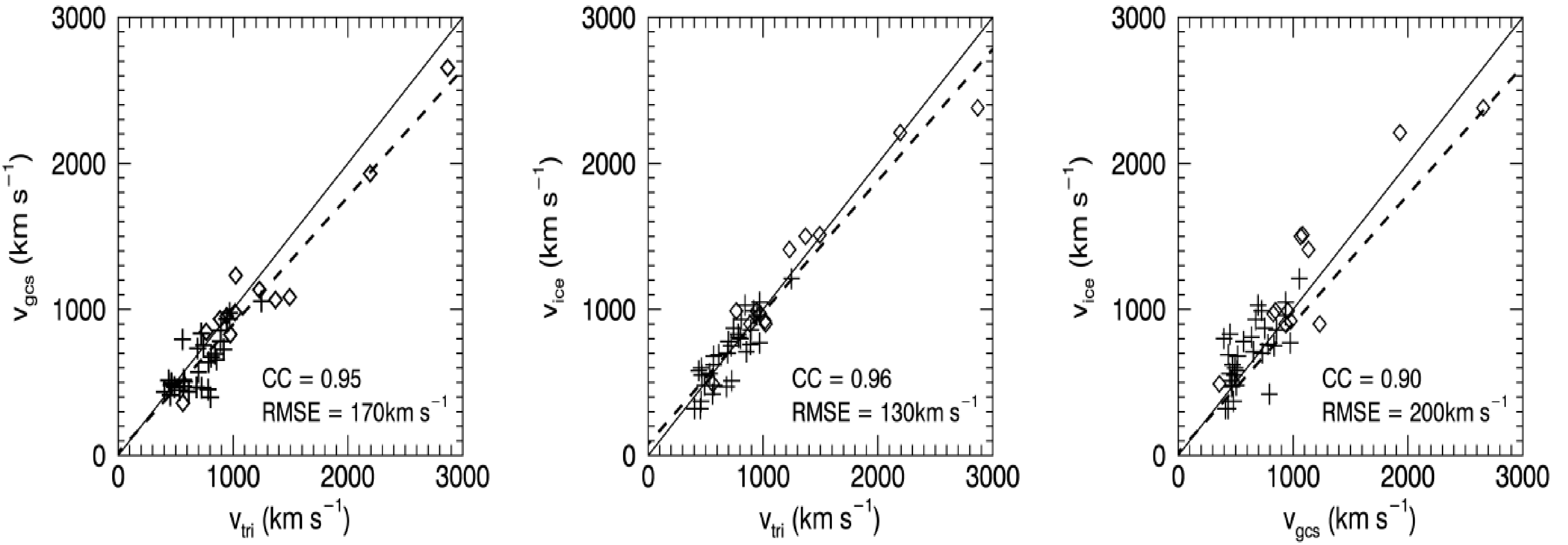


Dependence of Halo CME geoeffectiveness on location and magnetic field orientation

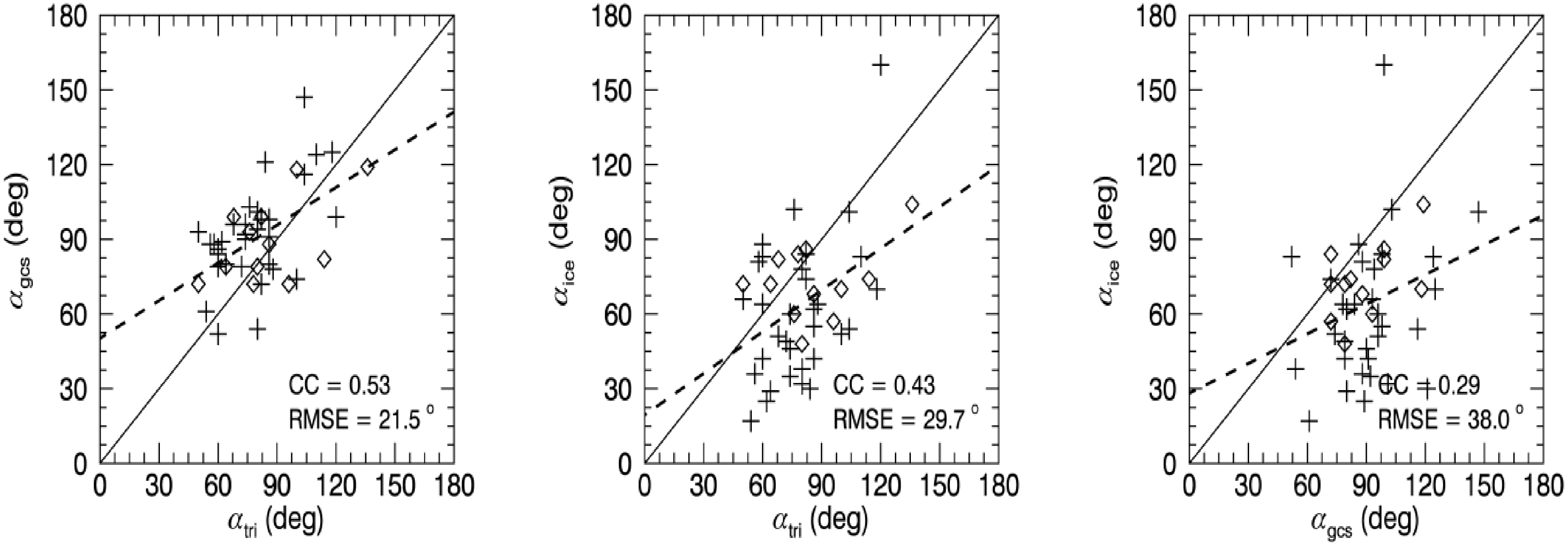
Dst index	Eastern + Northward	Eastern + Southward	Western + Northward	Western + Southward
≤ -50 nT (Moderate)	75% 6/8	81.8% 9/11	66.6% 6/9	83.3% 15/18
≤ -100 nT (Intense)	12.5% 1/8	36.3% 4/11	44.4% 4/9	55.5% 10/18
≤ -200 nT (Super)	0% 0/8	0% 0/11	0% 0/9	33.3% 6/18

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

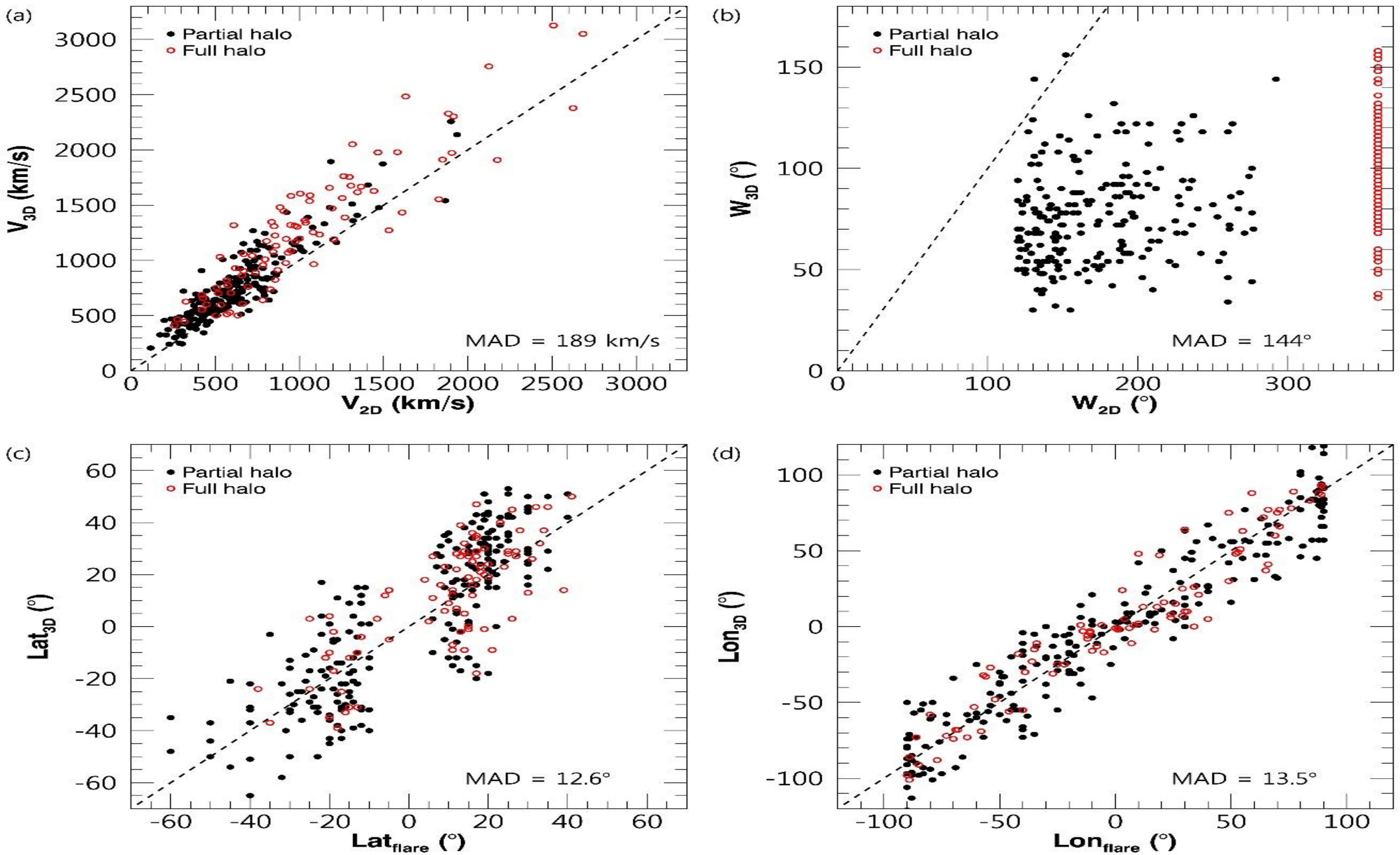
➢ Comparison of the radial velocities of the CMEs from three geometrical methods



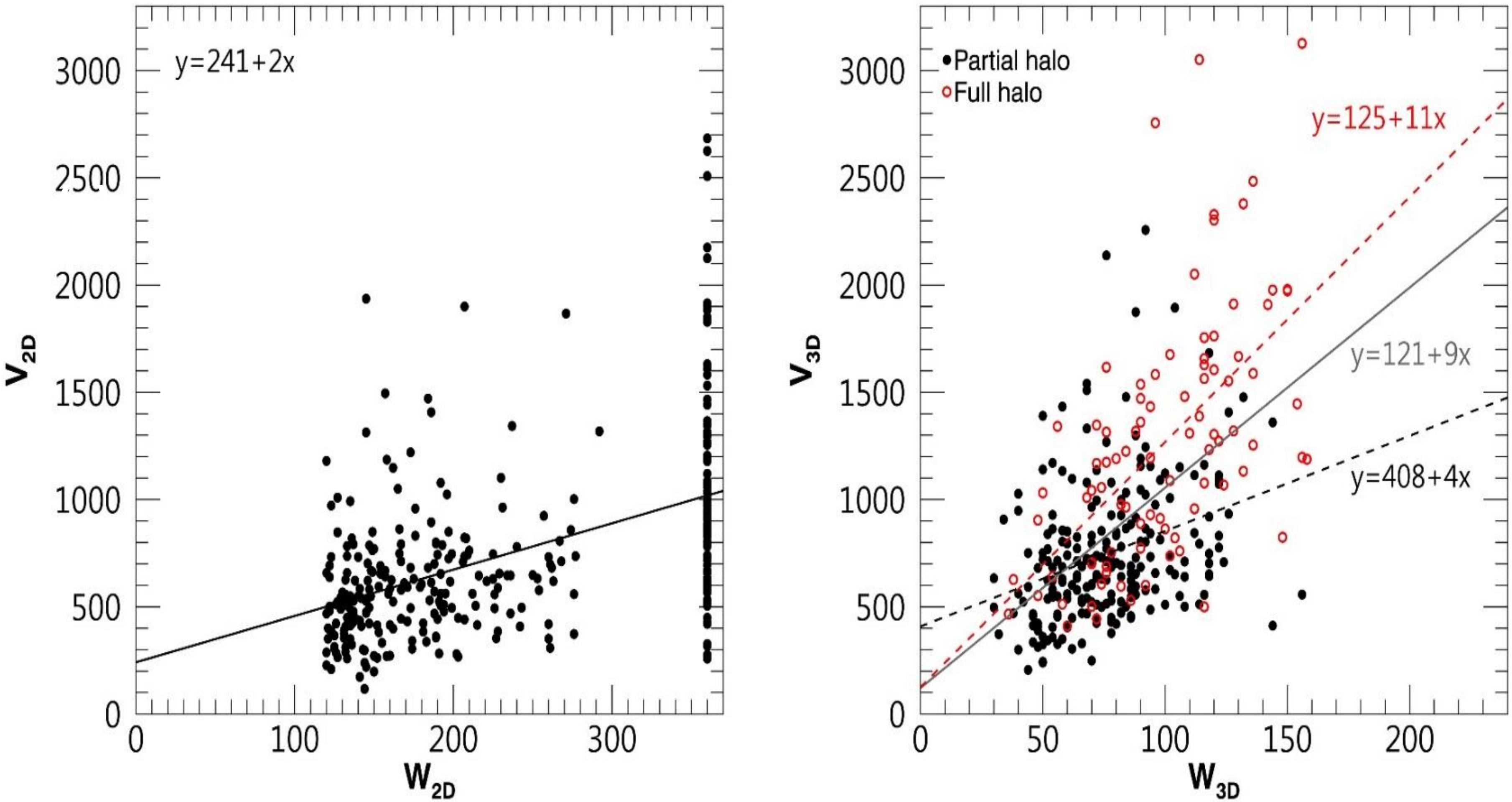
➢ Comparison of the angular widths of the CMEs from three geometrical methods



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

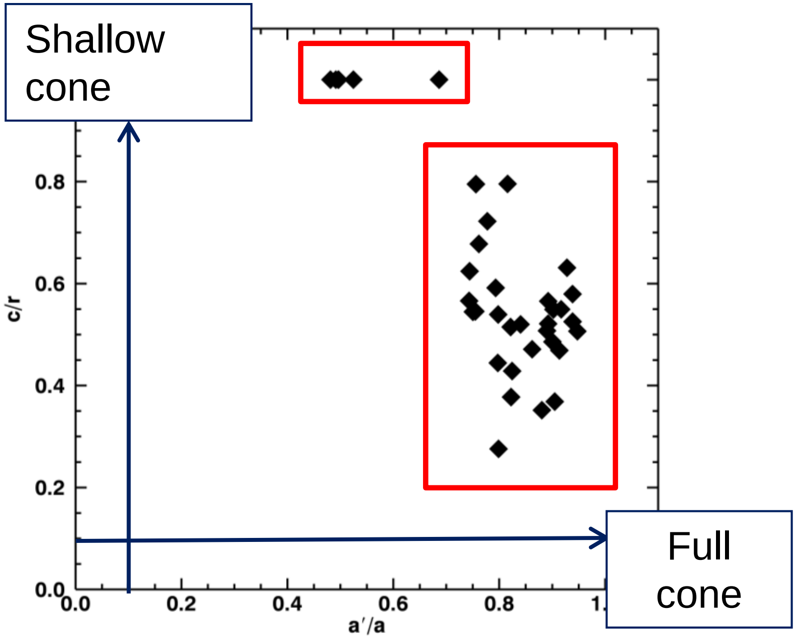


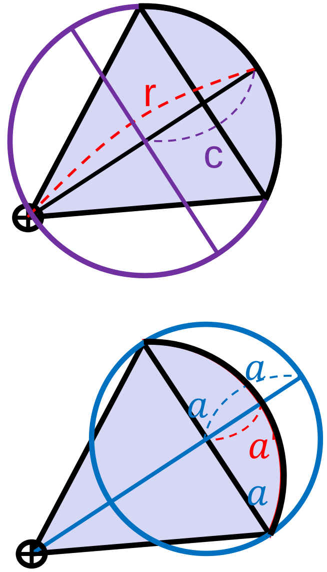
Comparison of speed-width relationship in 2-D and 3-D



3.5 Development of a full ice-cream cone model

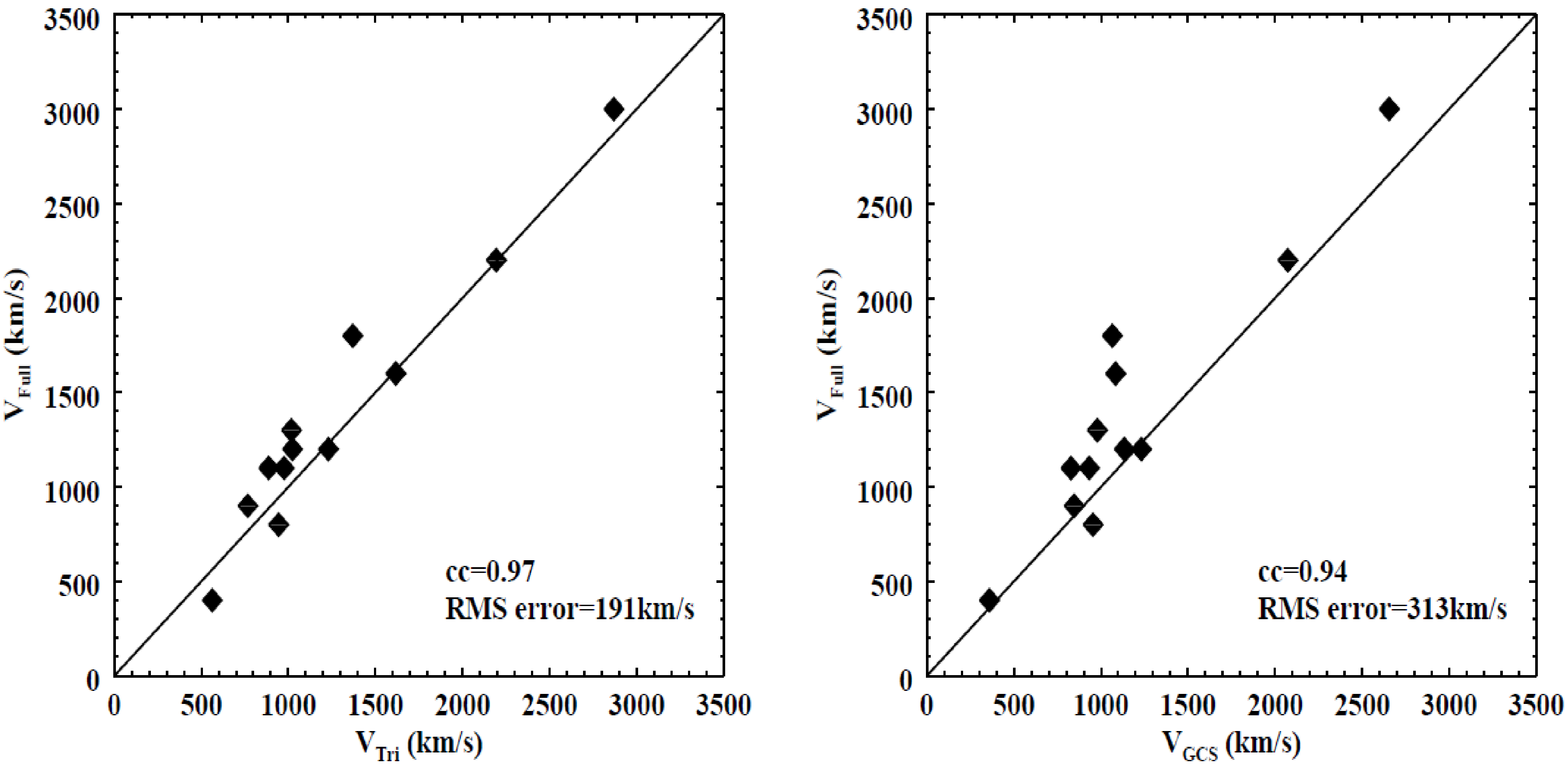
- **Cone shape parameters : 29 limb events**



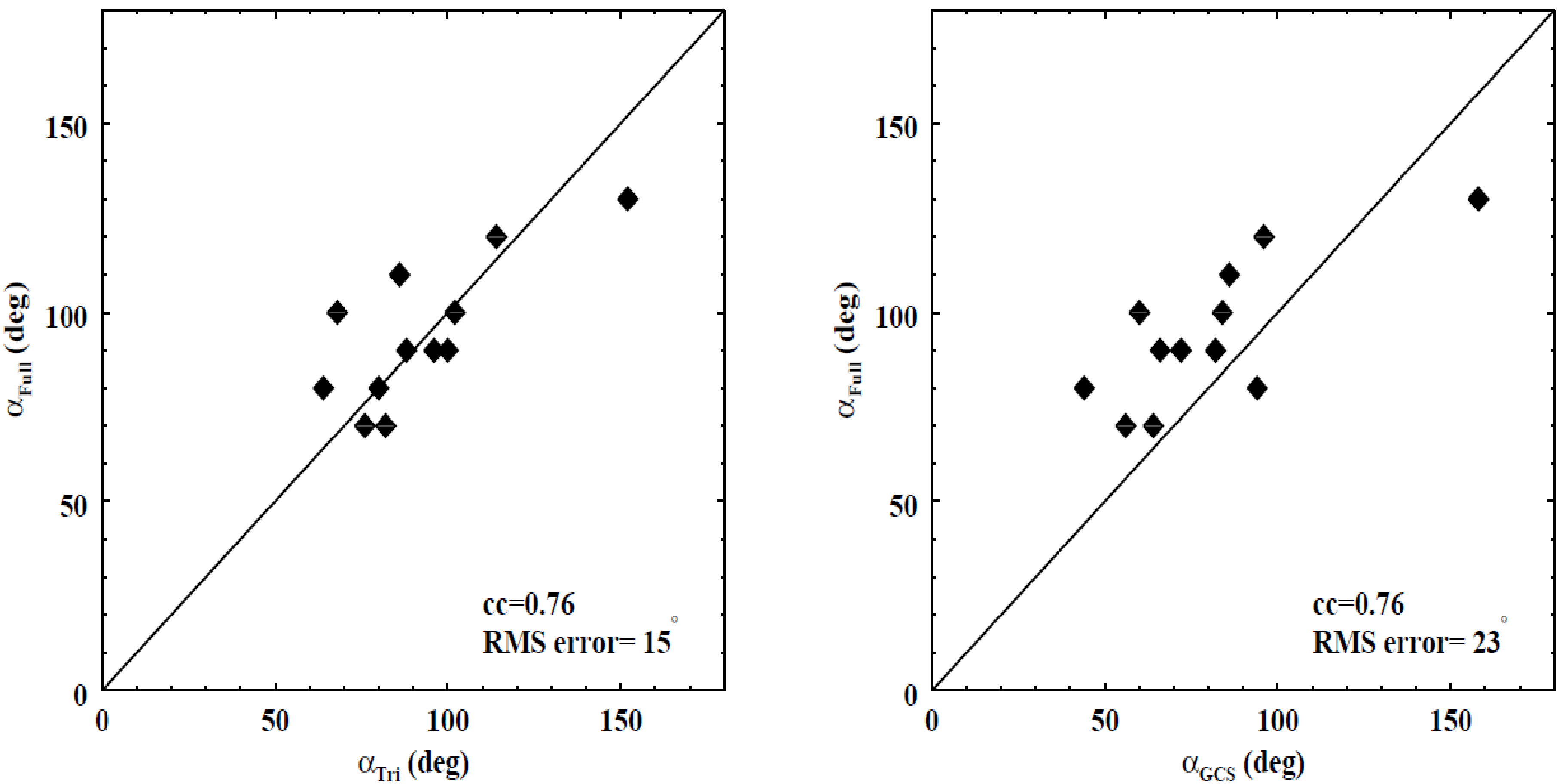


⇒ Most of the events are closer to the full cone type, which is consistent with Gopalswamy *et al.* (2009a) and Michalek *et al.* (2009).

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



Lessons for the prediction of geomagnetic storms

The probability map of geoeffective CMEs producing geomagtic storms can be successfully made using CME parameters.

There are several important CME parameters for forecasting geomagnetic storms:

1) CME speed
2) CME source location and direction : western / earthward
3) Magnetic field orientation : southward
4) Solar cycle dependence : 23 vs 24th cycle

It is necessary to have better input parameters (speed, width, location, density enhancement, and cavity ratio)for the physcis-based CME propagation models such as WSA-ENLIL model.