An Update on Space Weather Phenomena during the Weak Solar Cycle 24

N. Gopalswamy[1], P. Mäkelä[1,2] , S. Yashiro[1,2]
[1]NASA Goddard Space Flight Center, Greenbelt, MD 20771
[2]The Catholic University of America, Washington DC 20064

IES2017 Alexandria, VA May 9, 2017

Outline

- Weakness of Solar Cycle 24 and Implications for Cycle 25
- Paucity of Intense geomagnetic storms
- Paucity of high-energy solar energetic particle events
- Both are caused by coronal mass ejections, but the CME rate has not declined significantly
- SSN down by ~43%
- Two SSN peaks in SC 24 and the associated space weather events
- How can all these be tied together: Tenuous Heliosphere

Solar Activity Variation

Sunspot activity will be delayed in the northern hemisphere in cycle 25

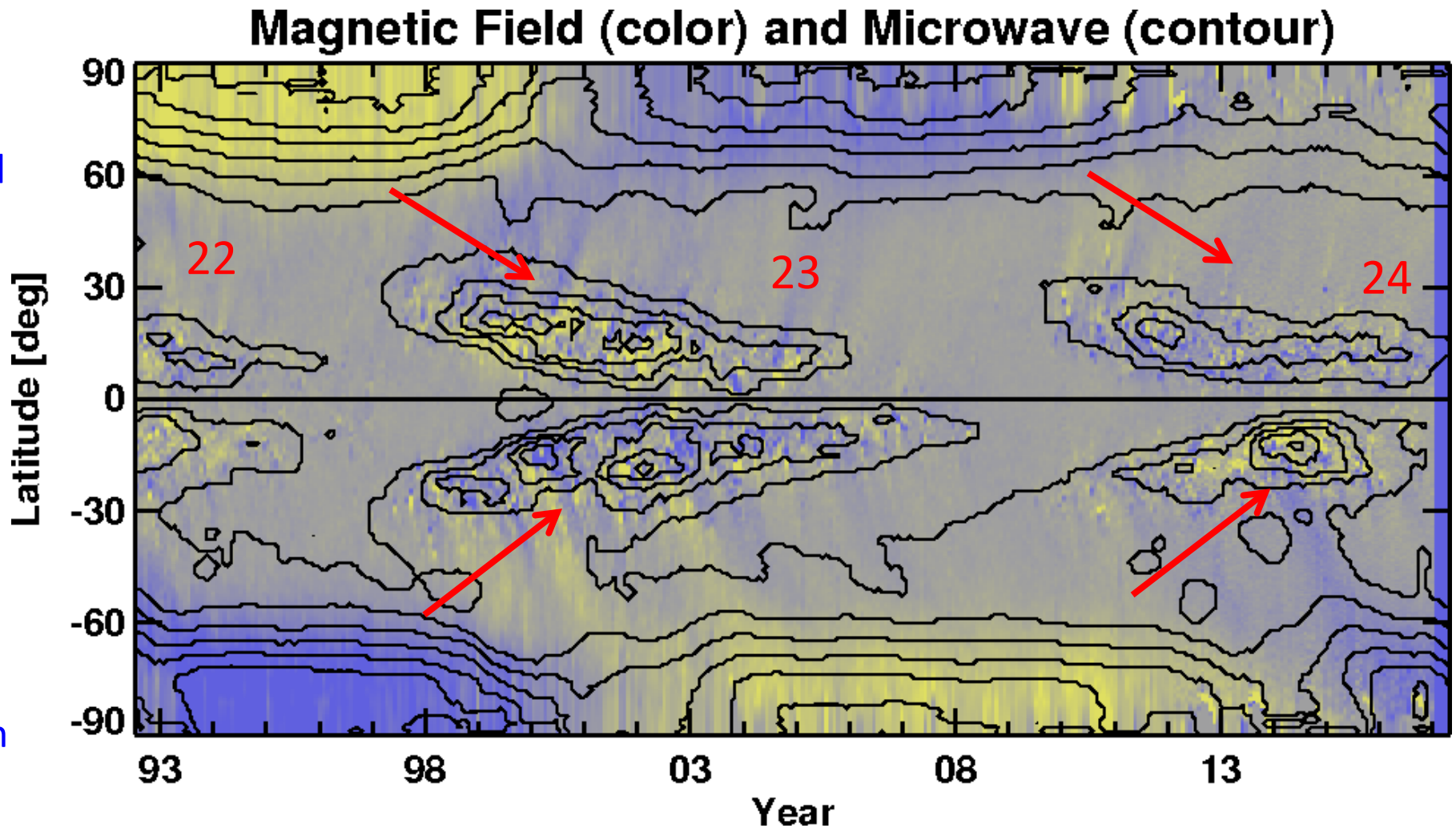
Yellow: positive Blue: negative polarity

Solar activity variation is a property of the solar dynamo

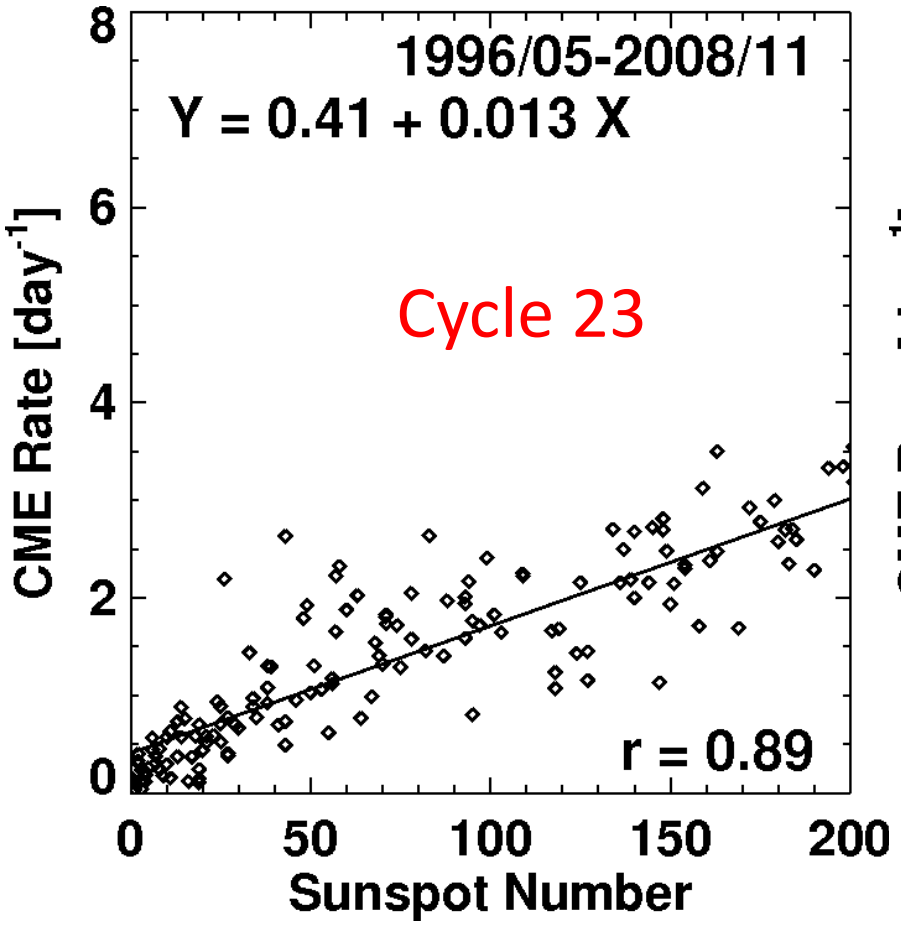
The dynamo converts poloidal field into toroidal field (i.e., sunspot field) and vice versa

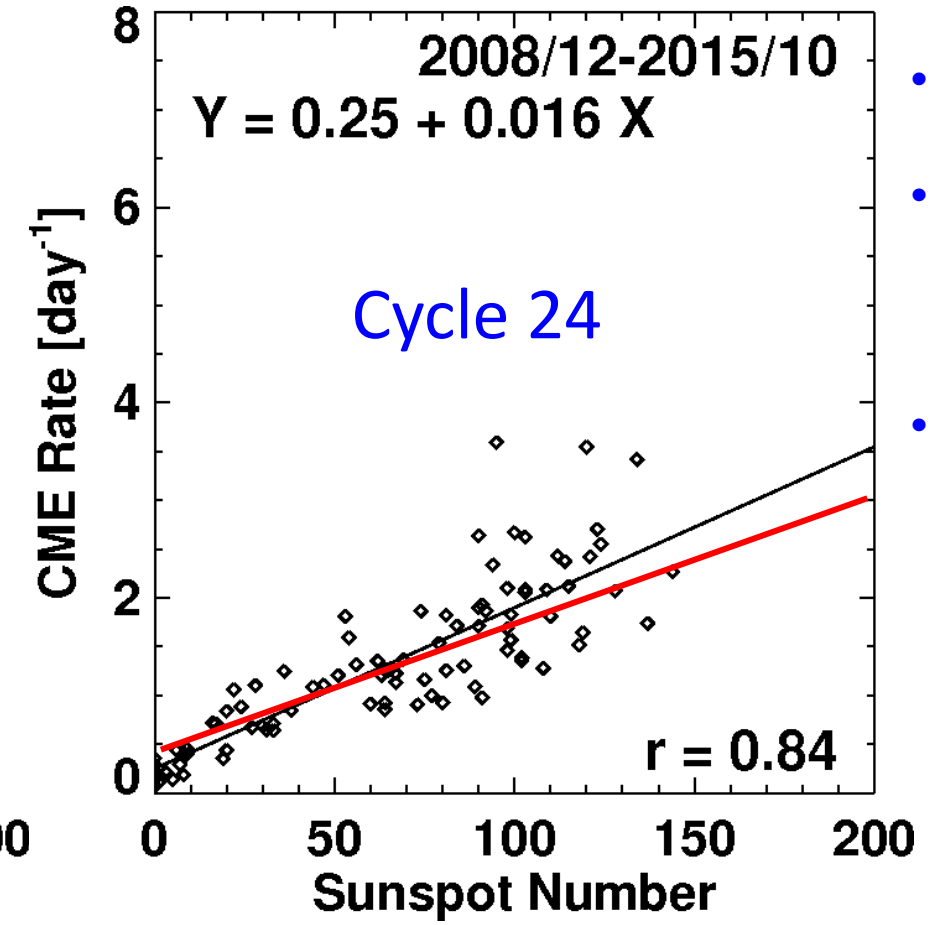
Polar fields in cycle 23 were weak leading to low sunspot activity in cycle 24

Huge north-south asymmetry in the polar field strength: No significant polar B in the north Implications for cycle 25!



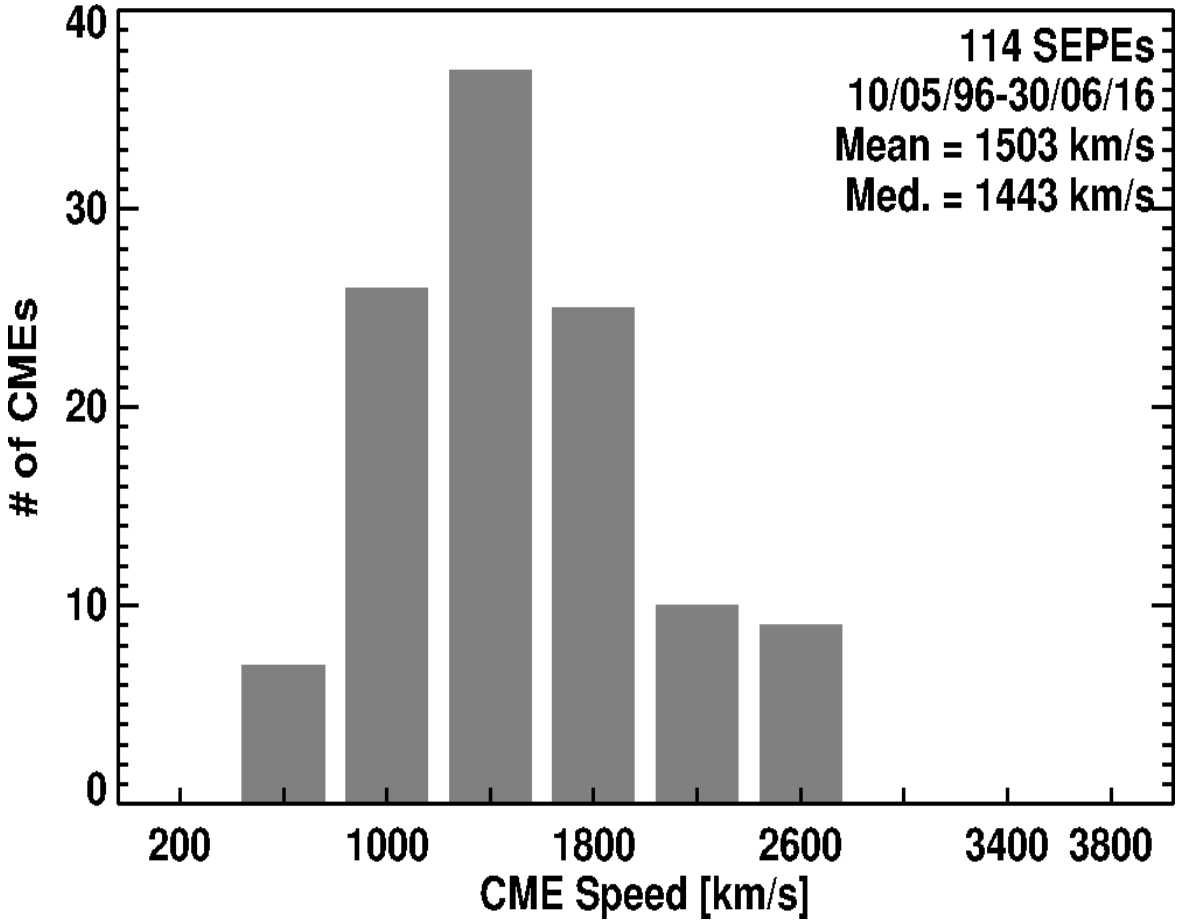
CME Rate vs. SSN in the Two Cycles

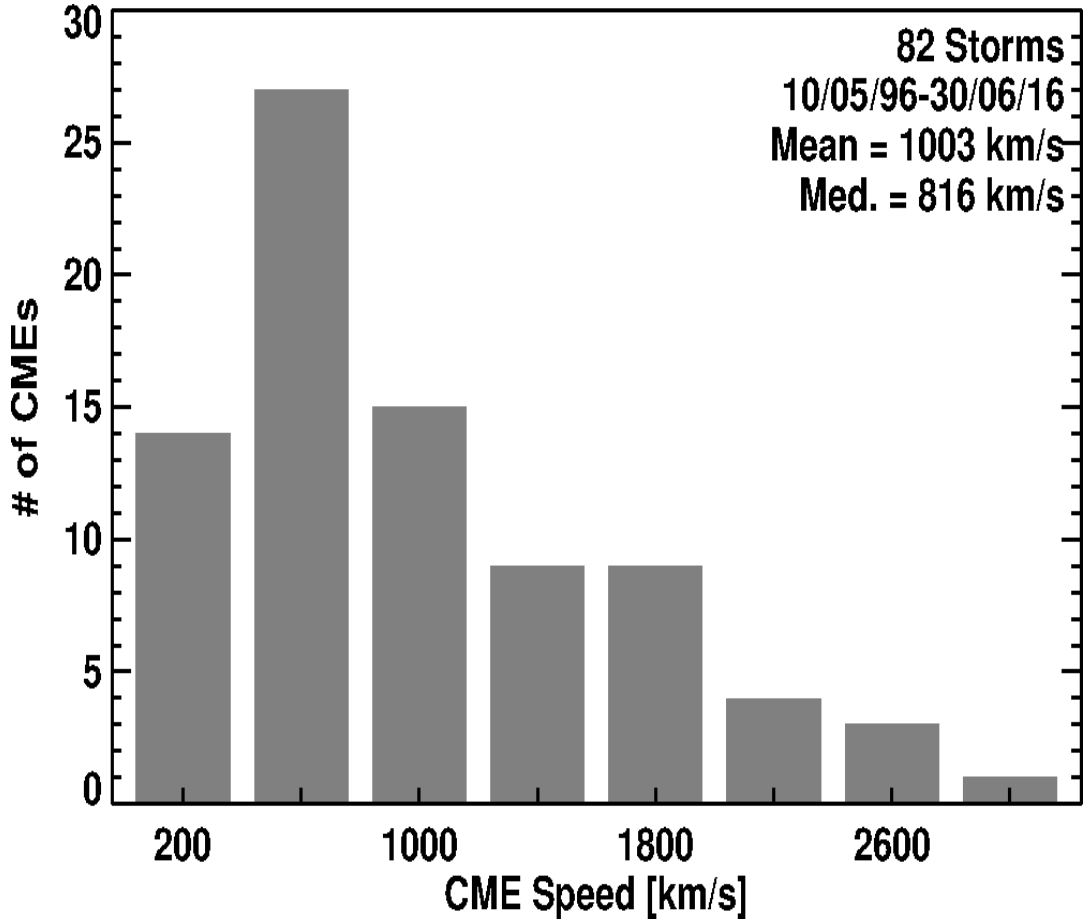




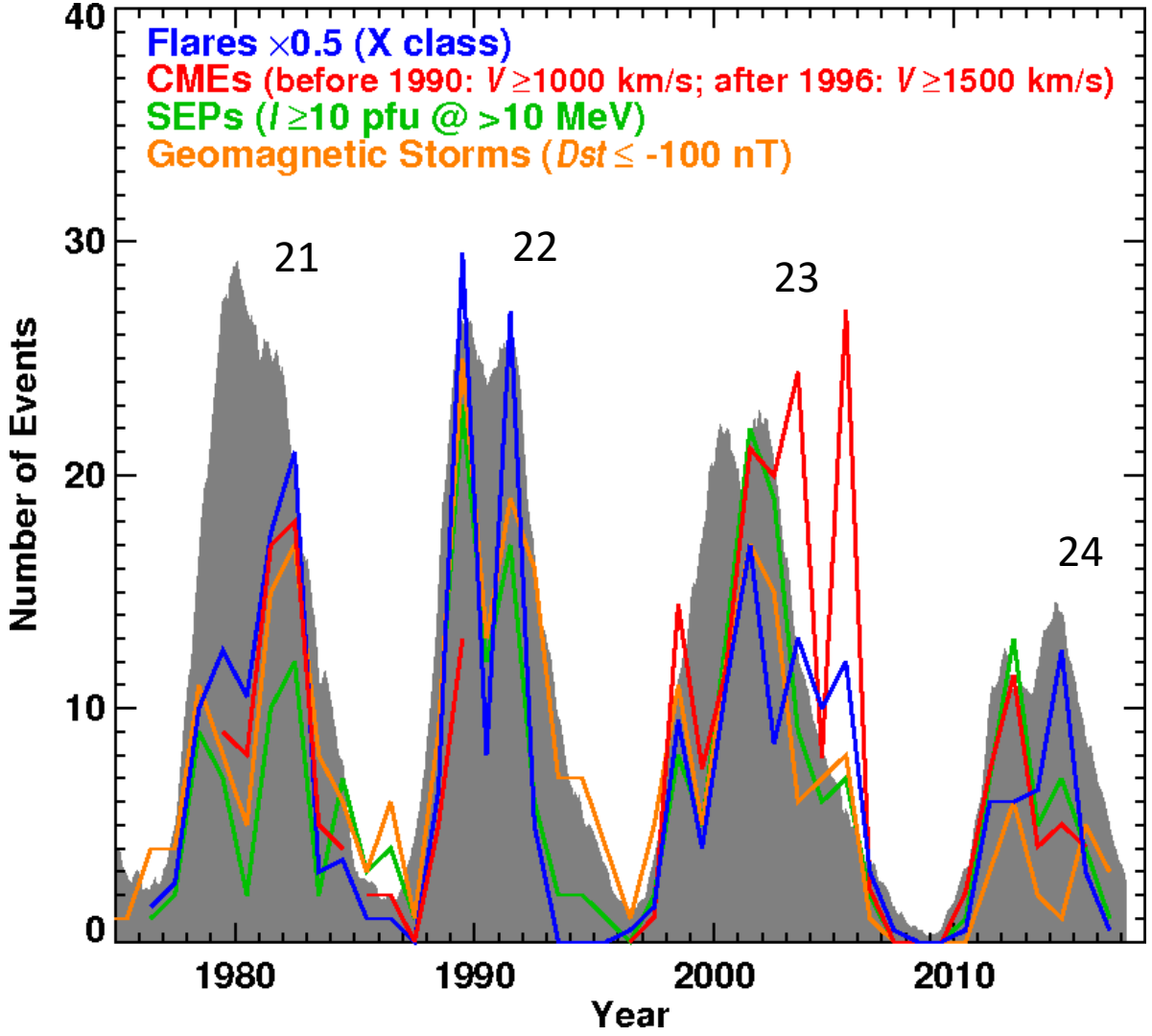
- Smaller SSN obvious in SC 24
- Slightly weaker correlation in SC 24: Discordance between CME rate and sunspot number
- CME rate increased more rapidly with SSN in SC 24

SEPs and GM Storms Require Fast CMEs



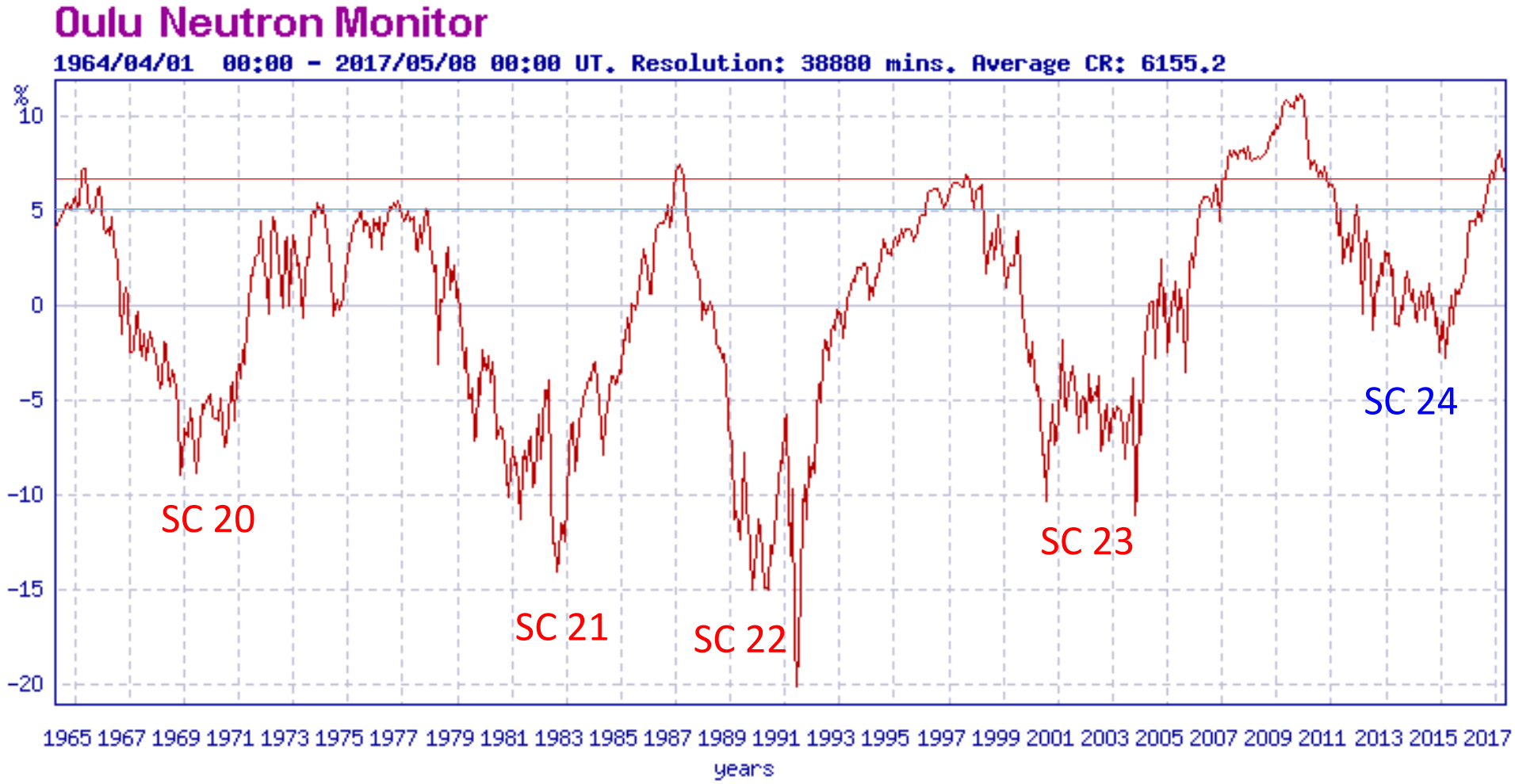


SWx Sources: Cycle 24 Compared to Previous Cycles

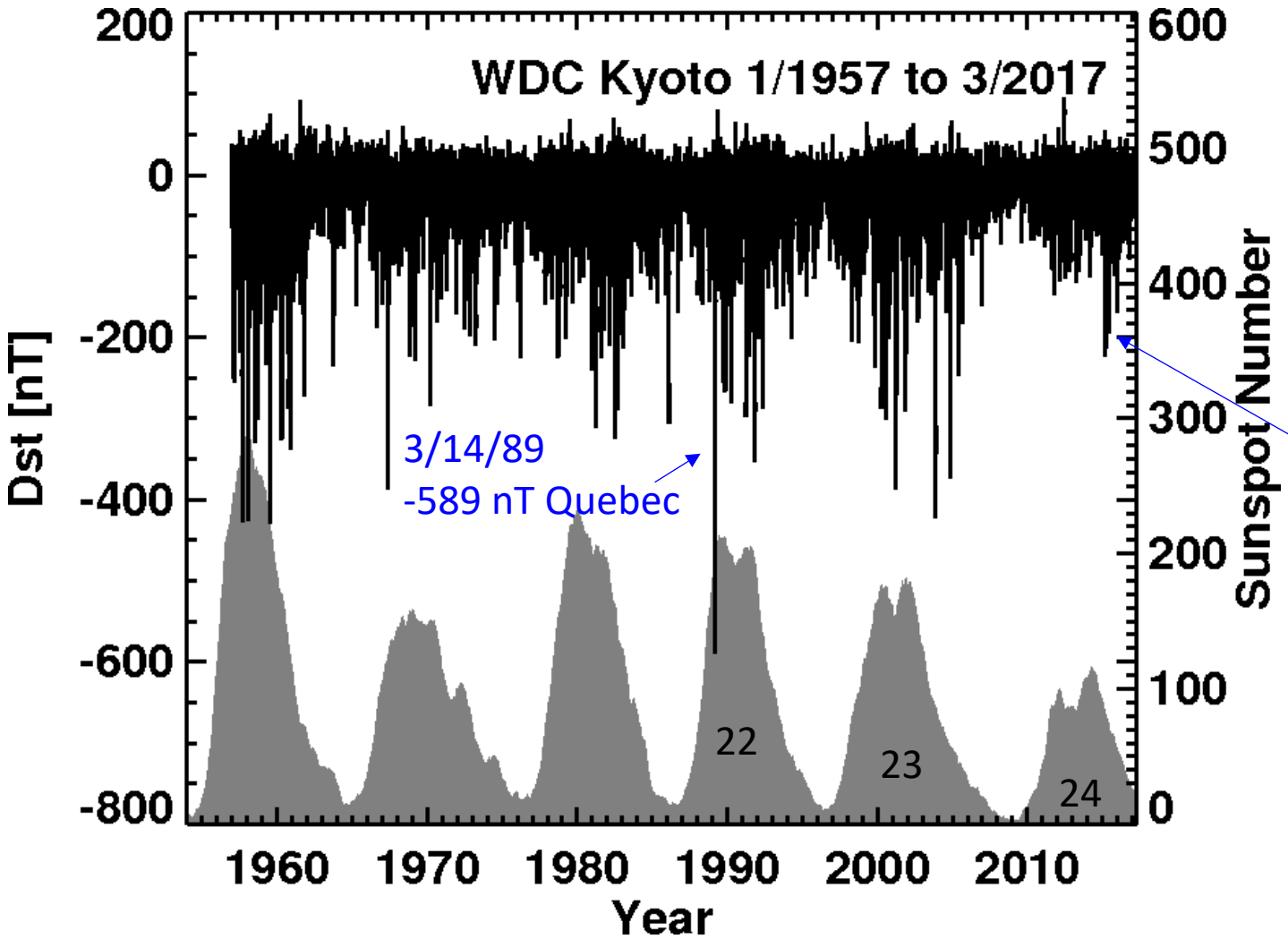


- Cycle 24 is clearly very mild
- CME and sunspot activity have discordant behavior
- between the two sunspot number peaks
- More fast CMEs during the first peak, but a smaller SSN
- But X-class flares are more during the second peak
- Number of SEP events, magnetic storms similar to CMEs
- Many confined flares during the second peak (e.g. AR 12192)

Cosmic Rays Arriving in Big Numbers!



Weakest Geomagnetic Activity in the Space Age

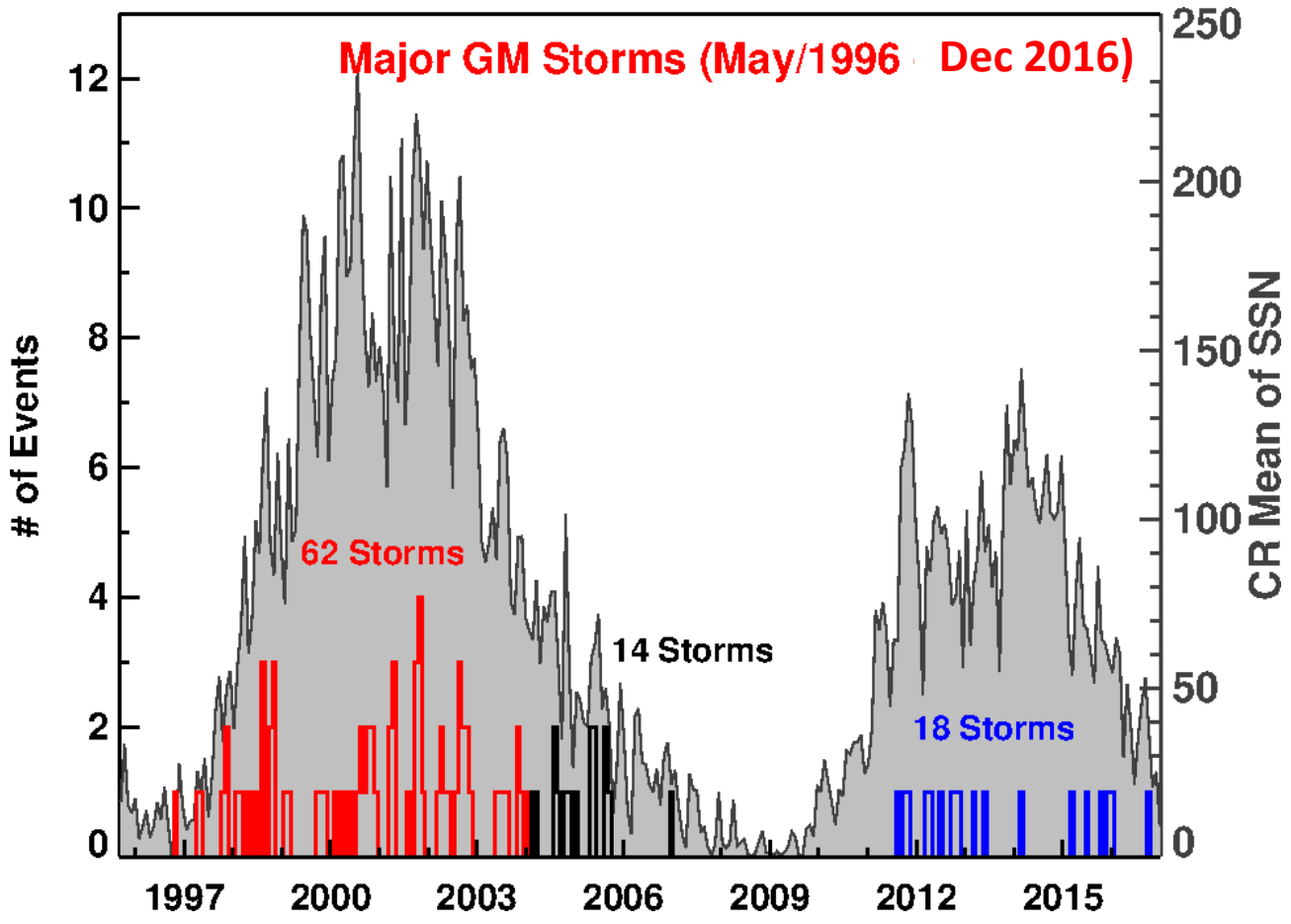


Two largest storms
-223 nT
2015/03/17
-204 nT
2015/06/23

Comparing Cycles 23 and 24: Storms with Dst < -100 nT

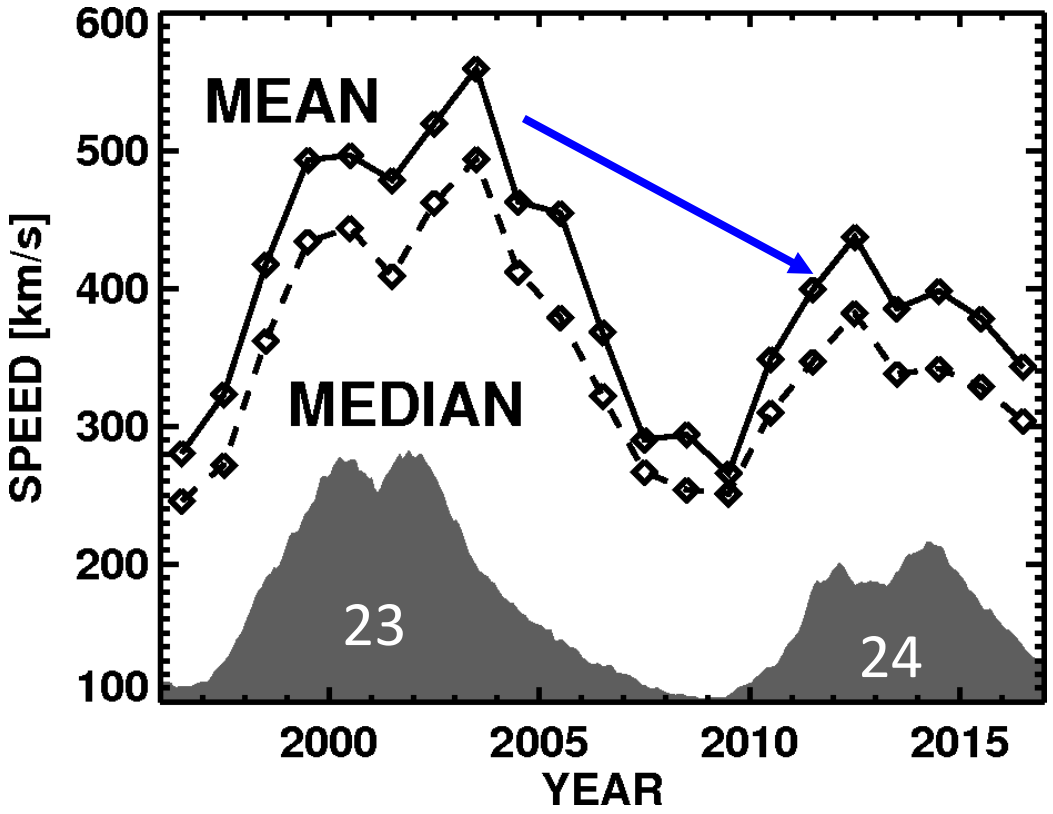
	Cycle 23	Cycle 24	Ratio
Dst< -100	62 (0.56/SSN)	17 (0.27/SSN)	0.27
SSN	111.24	62.94	0.57
FW CMEs	4.18/mo	2.75/mo	0.66

Only 2 CIR Storms!

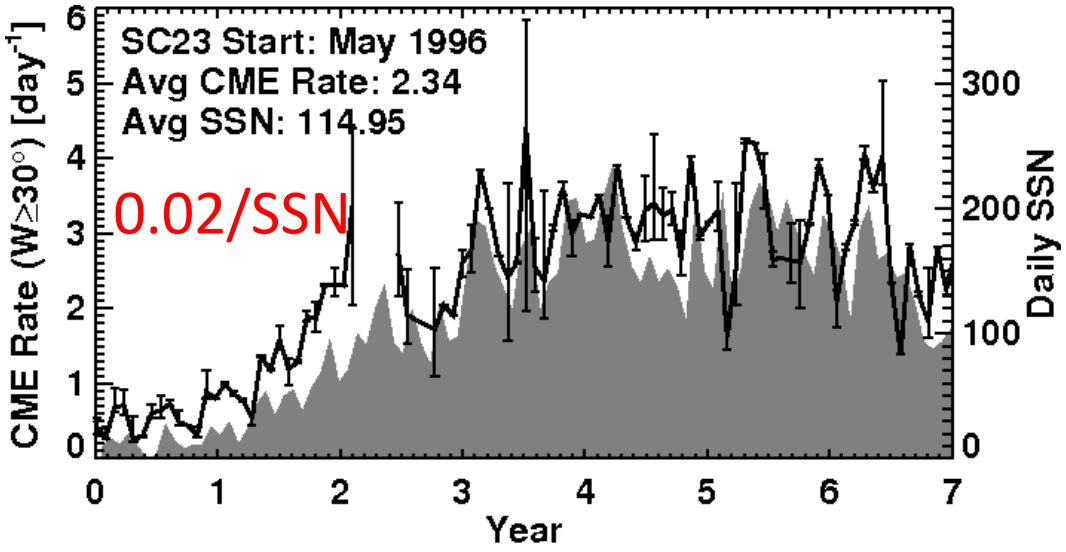


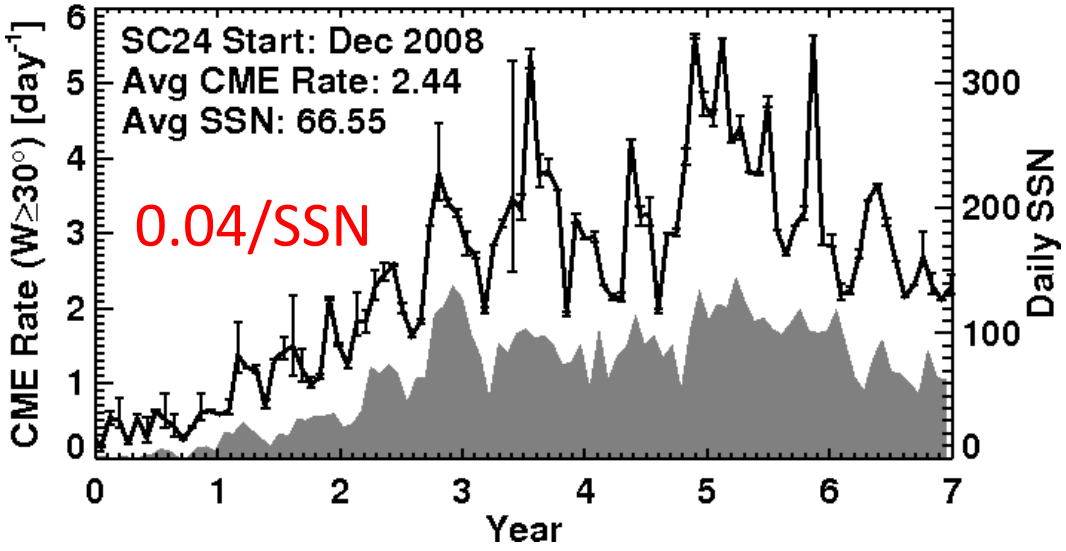
The 73% drop in the number of major storms is much larger than the
43% drop in SSN or
34% drop in fast and wide CMEs

Fast (V≥900 km/s) and wide (W≥60deg) typically cause major storms



SSN & CME Rate (W≥30°)



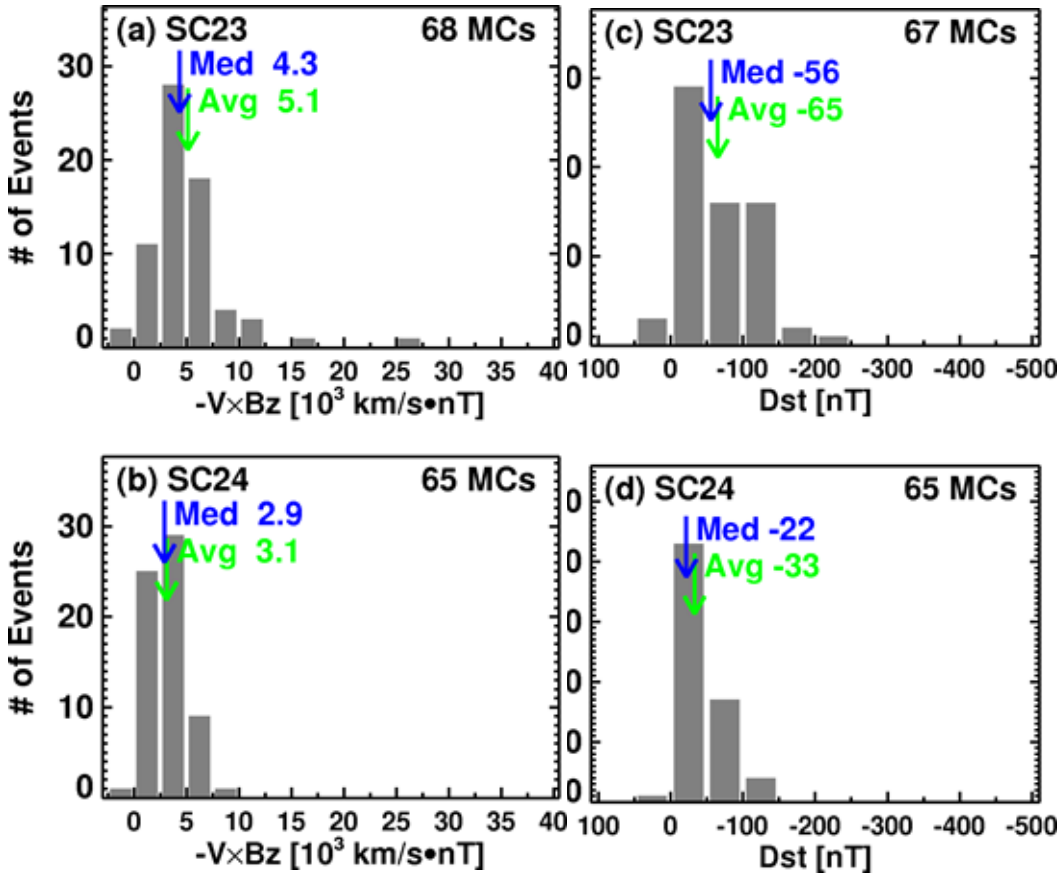


CME rate did not decline in cycle 24

- Higher when normalized to SSN
- Halo CMEs have similar occurrence rate
- Only fast and wide CMEs declined by 34%
- Not enough to account for 72% drop in the number of major storms

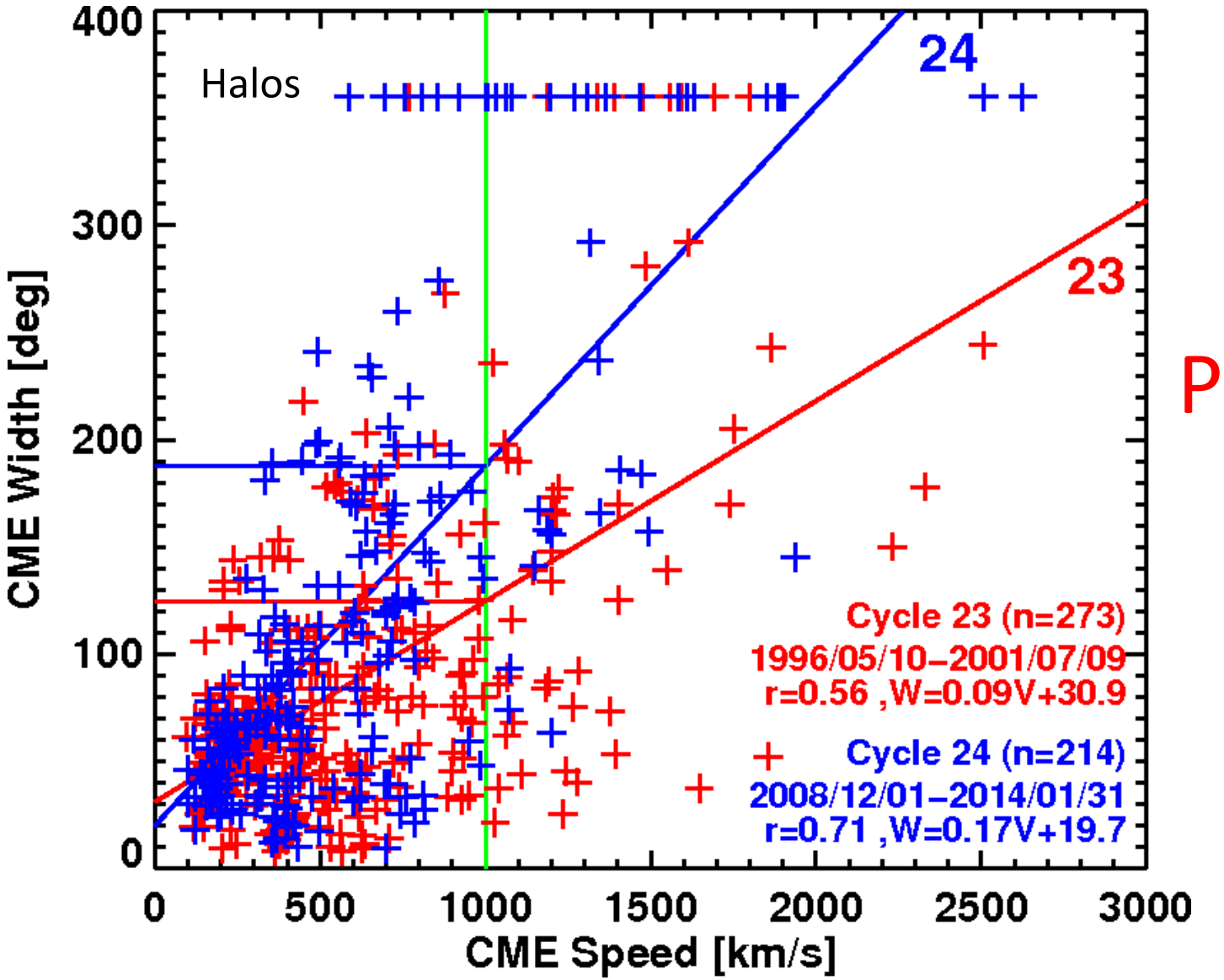
Why Low Geoeffectiveness?

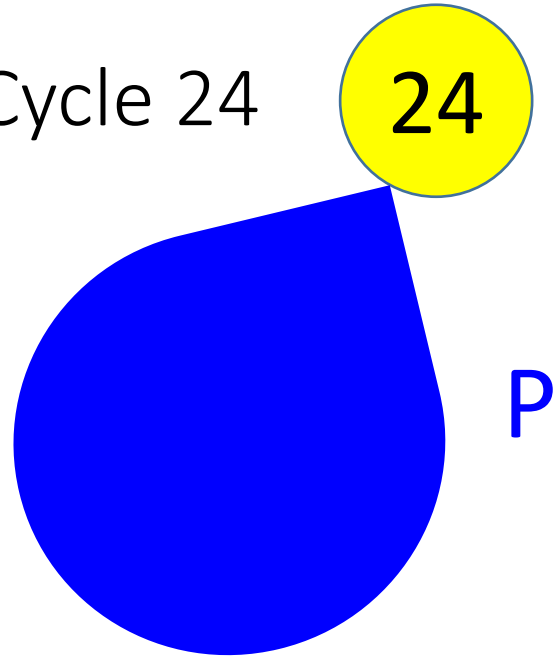
- Dst = -0.01VBz – 32 nT
- Reduction in VBz should lead to weaker storms
- We considered magnetic clouds that were detected at L1
- 68 in SC 23; 65 in SC 24
- Measured V and Bz
- VBz is down by 39%
- Dst is down by 49%



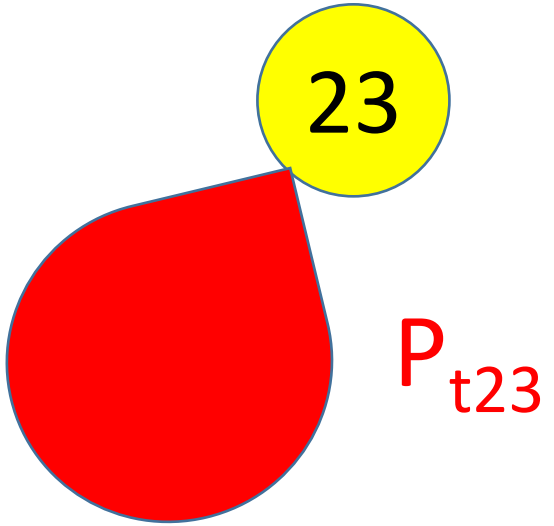
Gopalswamy et al. 2015

Why Low VBz? Anomalous Expansion of CMEs in Cycle 24





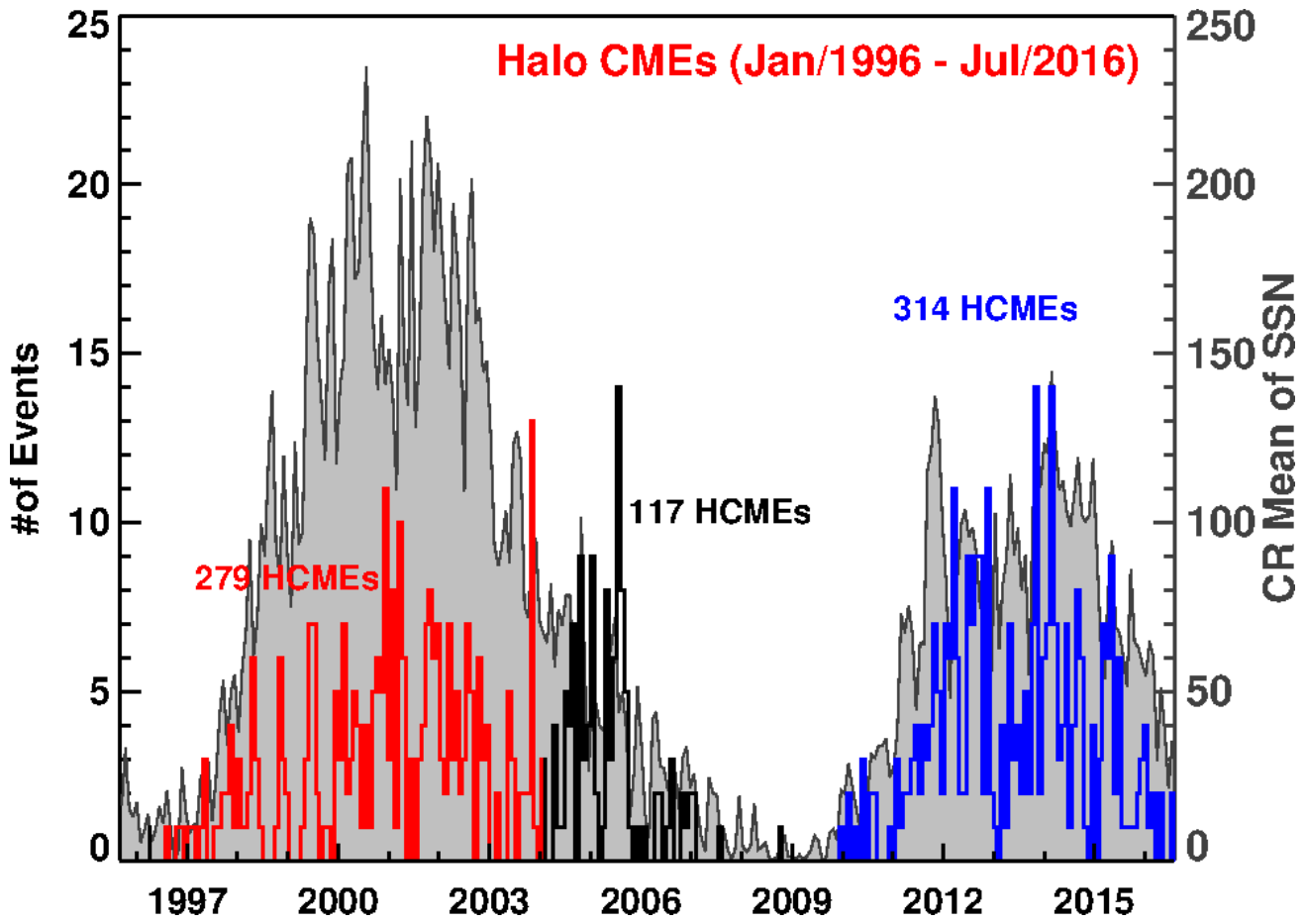
$P_{t23} > P_{t24}$



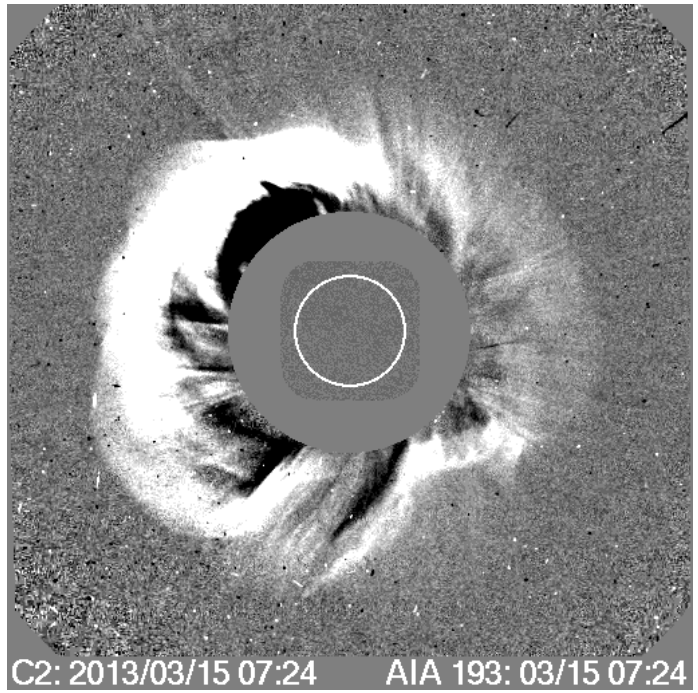
Slope is significantly different

For a given speed, cycle 24 CMEs are wider

Halo CMEs More Abundant in Cycle 24



- Cycle 23: 279/88.5 = 3.15 halos per month
- Cycle 24: 314/92 = 3.41 per month
- Another strong evidence for anomalous expansion

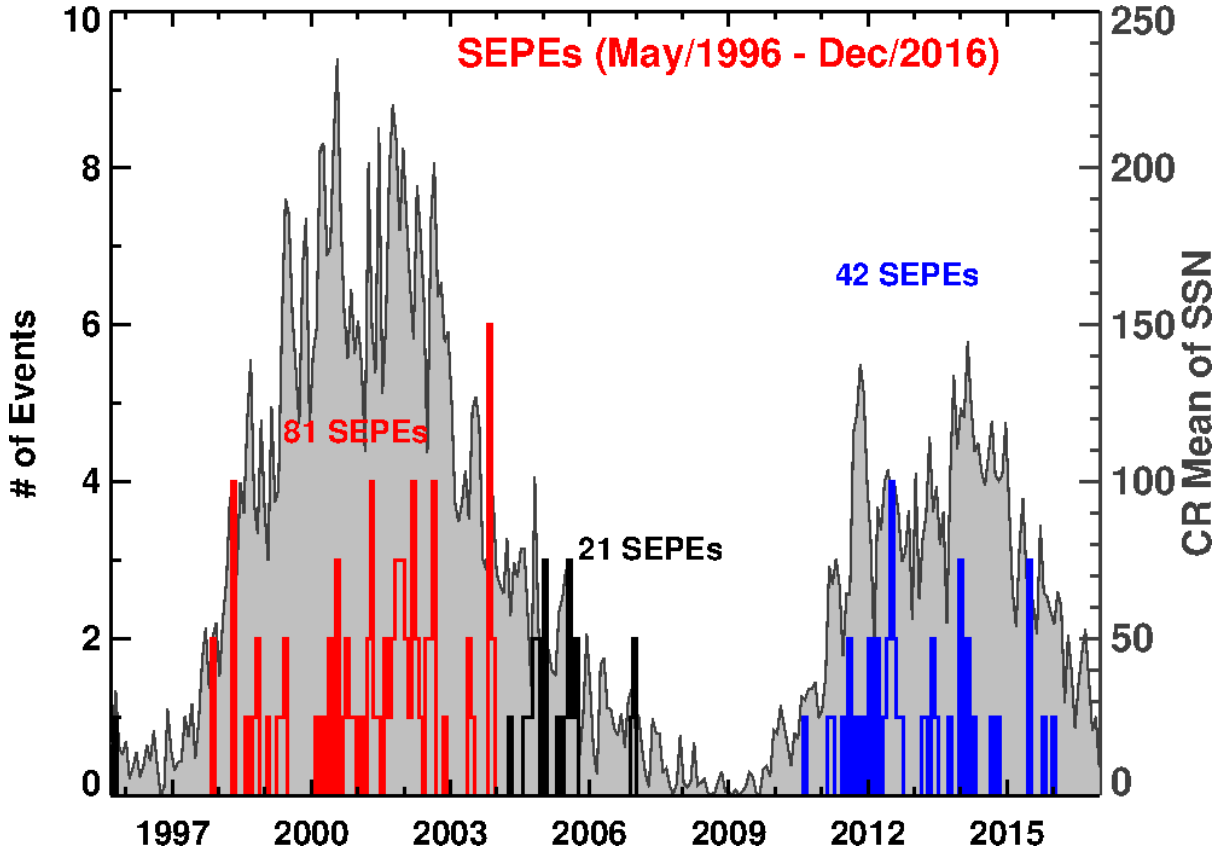


Solar Energetic Particles

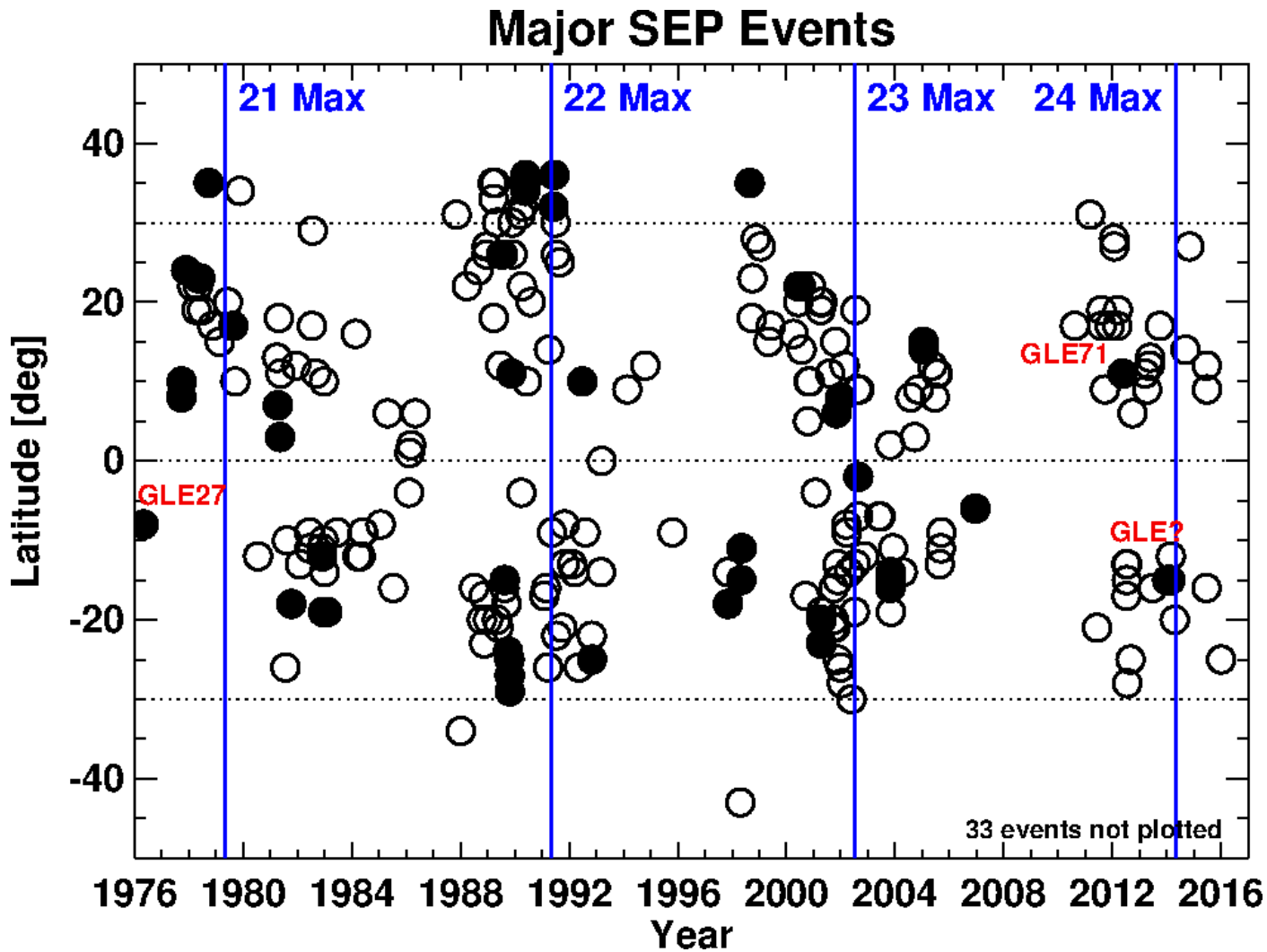
SEPs	Cycle 23*	Cycle24	Ratio
>10 MeV	81 (0.73/SSN)	42 (0.67/SSN)	0.52
>500 MeV	27 (0.24/SSN)	9 (0.14/SSN)	0.33
>700 MeV (GLE)	13 (0.12/SSN)	2 (0.03/SSN)	0.15

- Low-energy SEP events drop (48%) ~ to SSN
- >500 MeV SEP events dropped by 67%
- >700 MeV SEPs dropped by 85%
- These cannot be explained by the 34% drop in FW CMEs

>10 MeV SEP events



Lack of High-energy SEP events



State of the Heliosphere

Parameter	SC 23	SC 24	% Decline
Pt (x 10^3 pPa)	273.12	174.84	36
B (10^2 nT)	7.39	5.81	21
N (cm^-3)	786.54	648.44	18
T (x10^5 K)	5.18	3.93	24
Va (km/s)	584.25	499.45	15

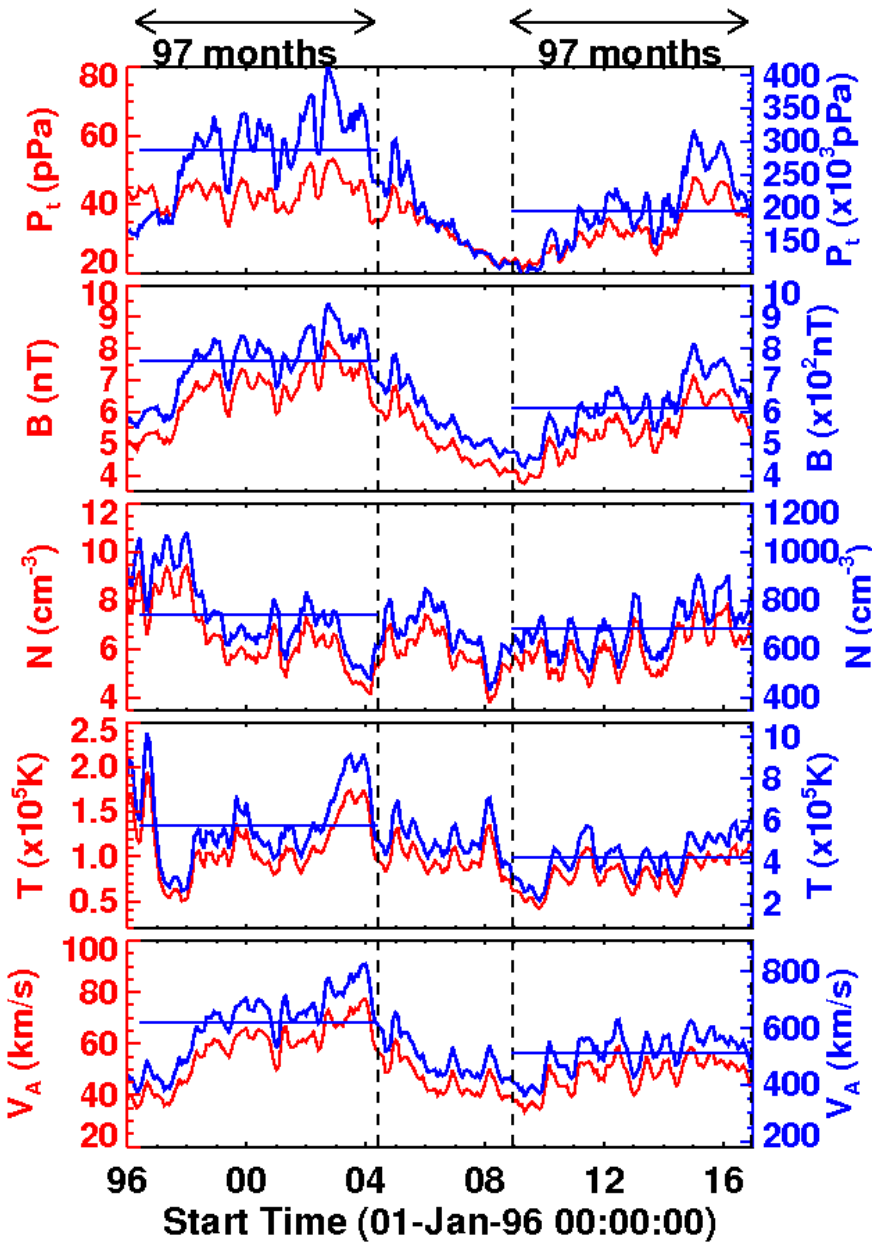
36%

21%

18%

24%

15%



Gopalswamy et al. 2014 GRL (updated)

- Reduced Pt → CME expansion and MC B dilution
- Reduced B → MHD compression → weaker CIRs

→ Reduced acceleration efficiency (Kirk, 1994)
dE/dt ∝ B (rate of energy gain)

- Reduced Alfven speed near Sun

→No major reduction in the # SEP Events

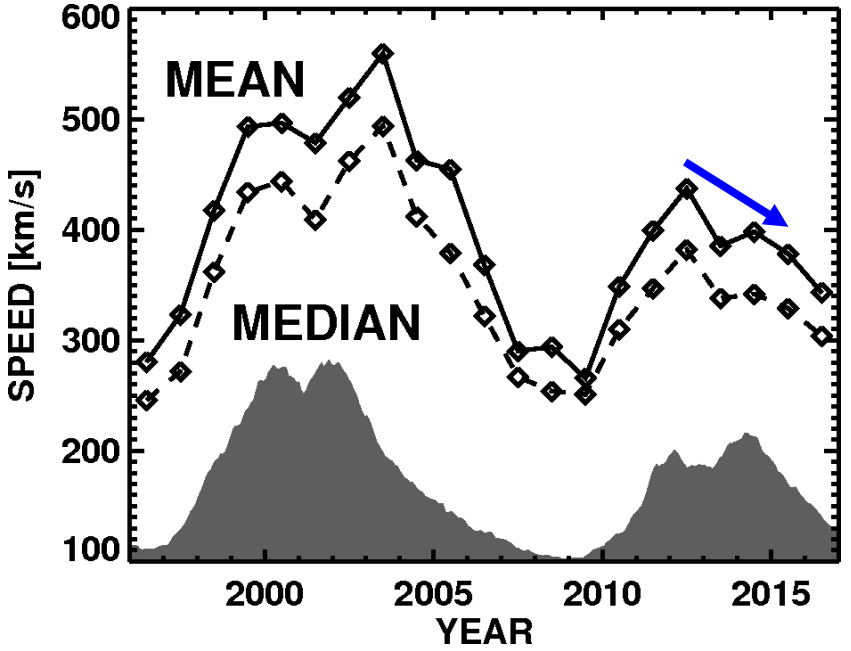
Two SSN Peaks of Cycle 24

Table 1. Summary of solar activity in 2012 and 2014

	2012	2014
Peak SSN	67	90
#Halo CMEs	84	63
#DC Halos	17	14
#Western Halos	21	10
#FW CMEs	58	52
#LSEP Events	15	7
#Major storms	6	1
#DH-km Type II	19	16
DC Halo <V>ª	975 km/s	753 km/s
Western Halo <V>	1088 km/s	781 km/s
DH-km <V>	1543 km/s	1201 km/s

ª<V> denotes average speed

- The number of space weather events during the first SSN peak is significantly higher
- The average speed of disk-center halo CMEs was ~23% lower during the second SSN peak (753 km/s vs. 975 km/s).
- This should reduce the probability of halo CMEs causing large geomagnetic storms
- The average speed of the SEP-associated halos during the first peak was 1680 km/s, while it was 1327 km/s during the second



Gopalswamy et al. 2015

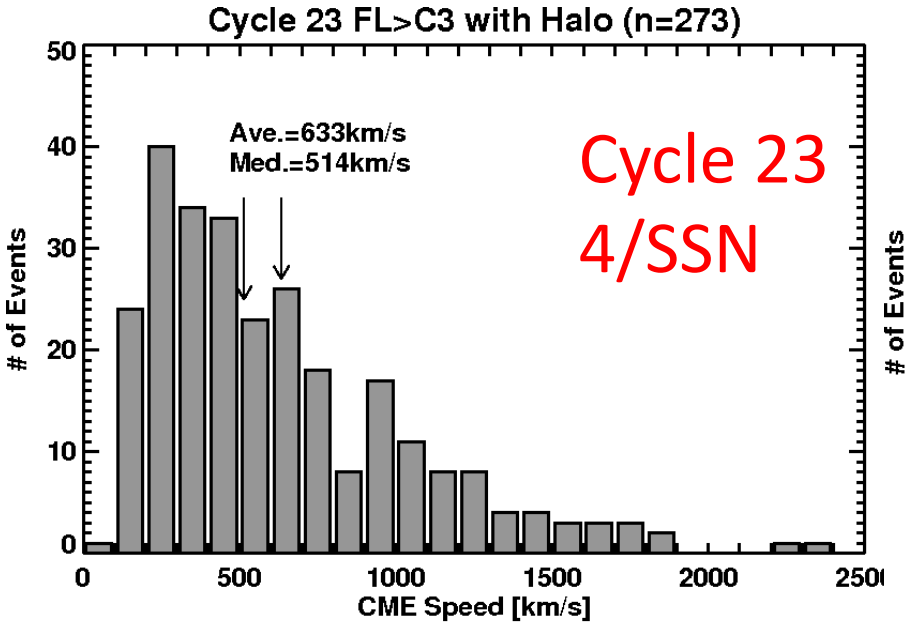
DC = Disk Center

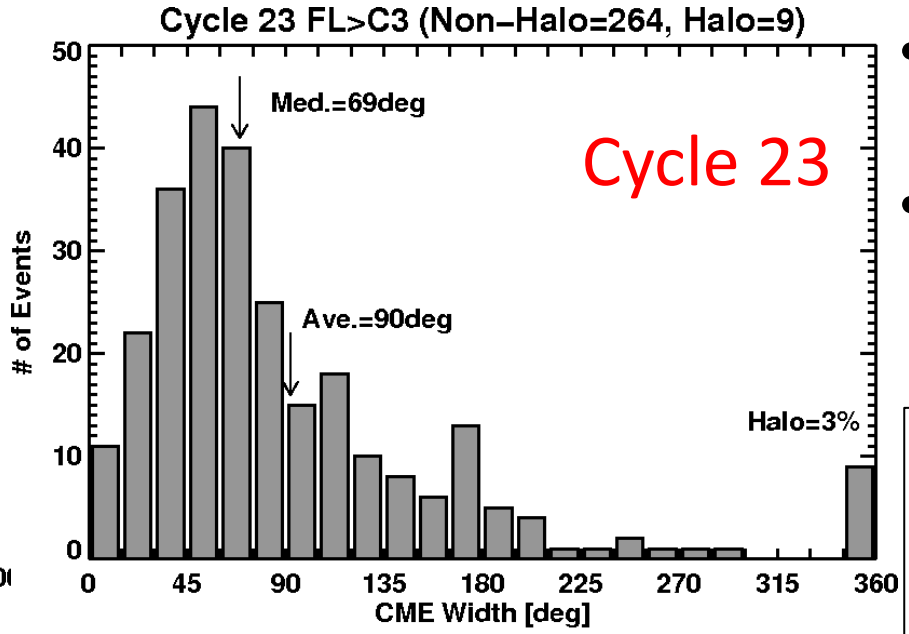
Summary

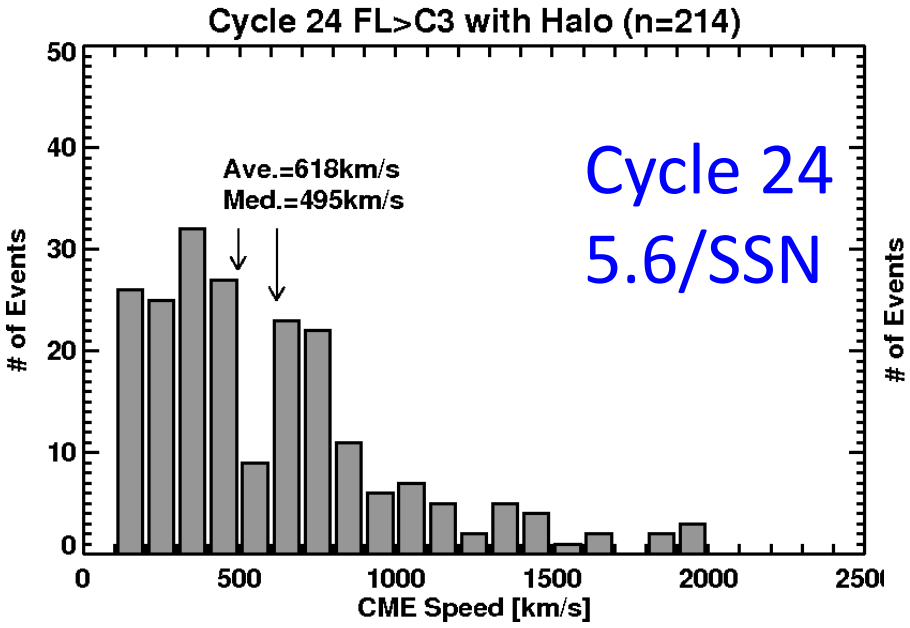
- Cycle-24 Space Weather is the mildest in the space era: altered state of the heliosphere and reduced rate of energetic CMEs
- Weaker and less frequent geomagnetic storms
- Weaker ICME field is due to weaker heliospheric total pressure
- Weaker sheath, CIR fields due to weaker heliospheric B
- Paucity of high-energy (>500 MeV, GLE) SEP events due to diminished efficiency of shock acceleration (weaker B)
- Discordant behavior between CME rate and sunspot number: lots of narrow CMEs, but smaller number of energetic CMEs in SC 24
- More space weather events during the weaker SSN peak in SC 24: due to rate of high-speed CMEs

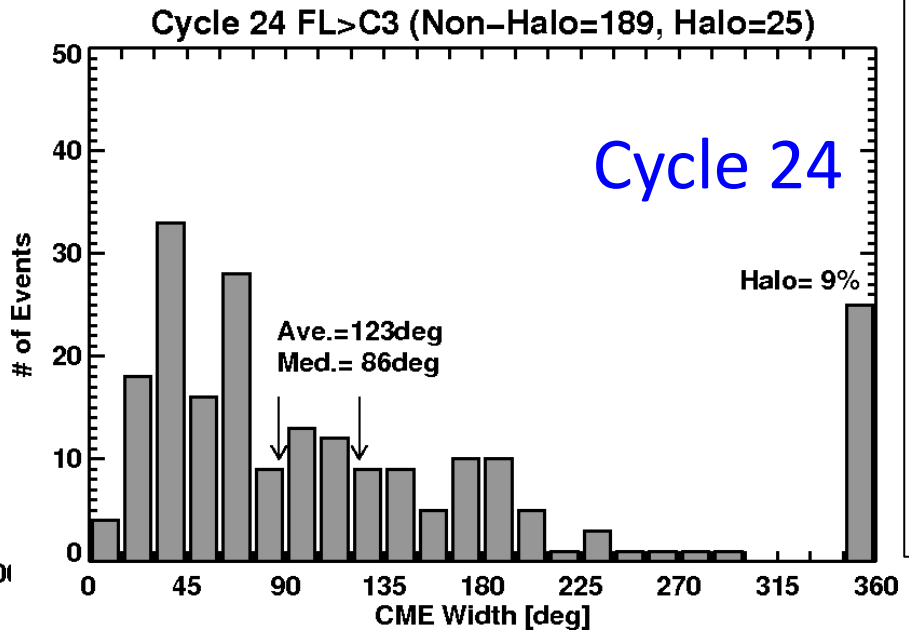
Backup slides

Width distribution is different in Cycle 24









- Limb CMEs to avoid projection effects
- CMEs associated with ≥C3.0 flares

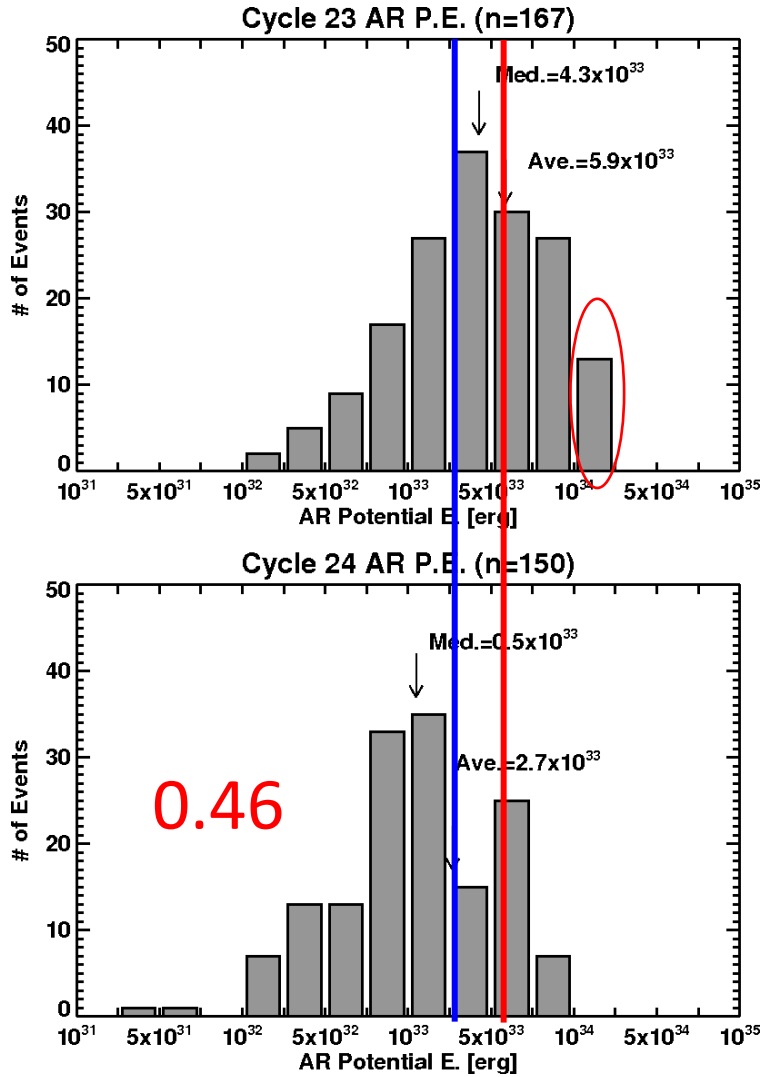
Similar Speed Distributions

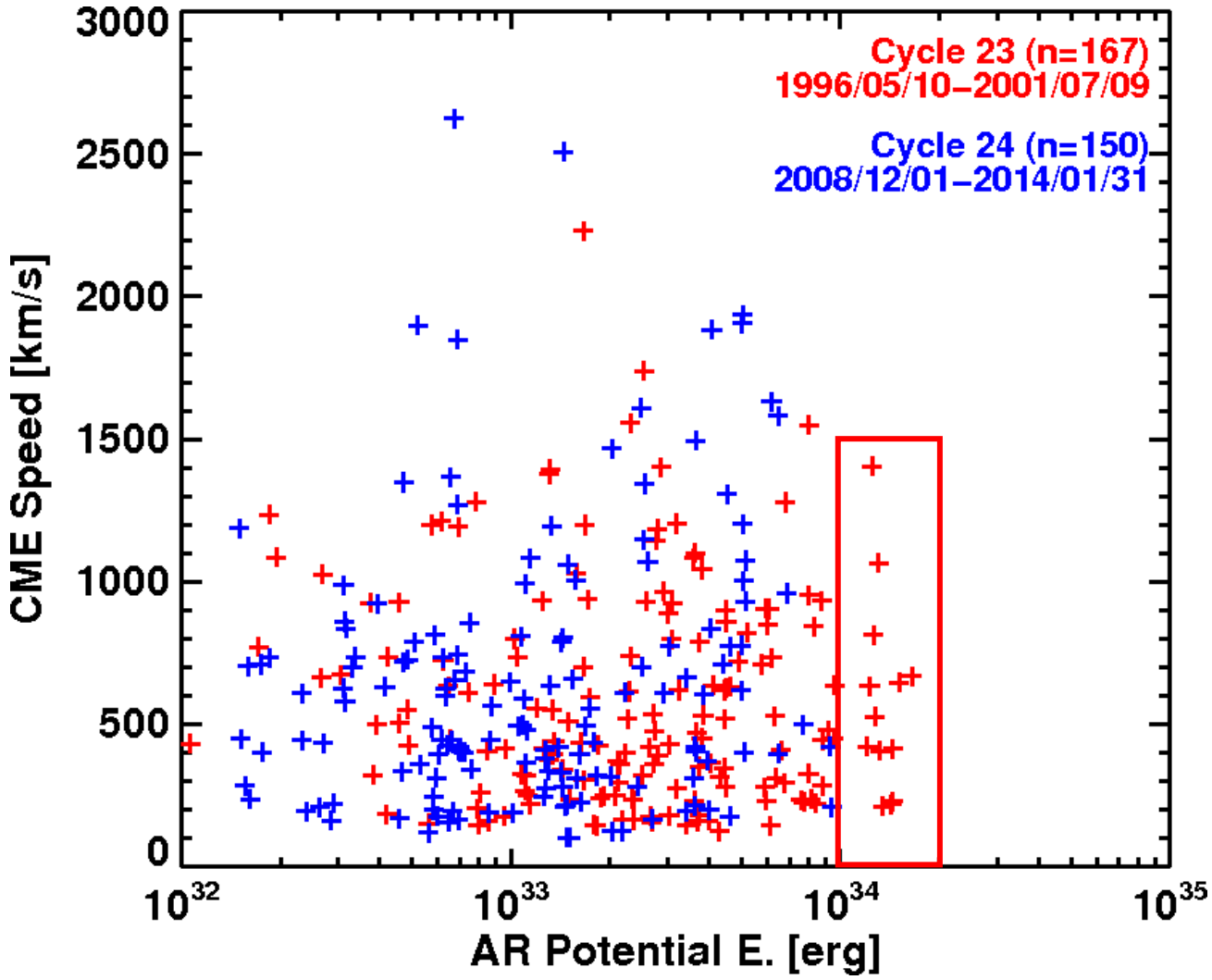
Different Width Distributions; Average width of non-halos is 37% higher in cycle 24

Three times more halos in SC24

Reduction in # CMEs
~ 27%
-a lot less than SSN drop

AR Potential Energy (Free-energy proxy)



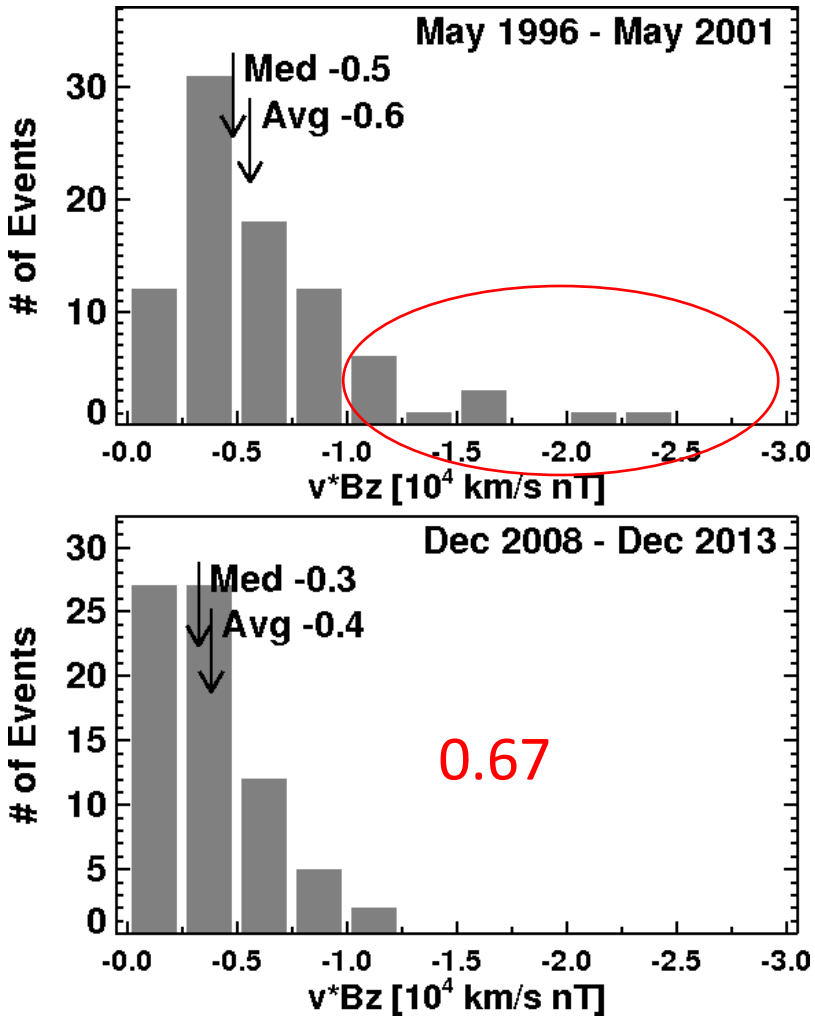


Weak Storm: Due to weak IP field

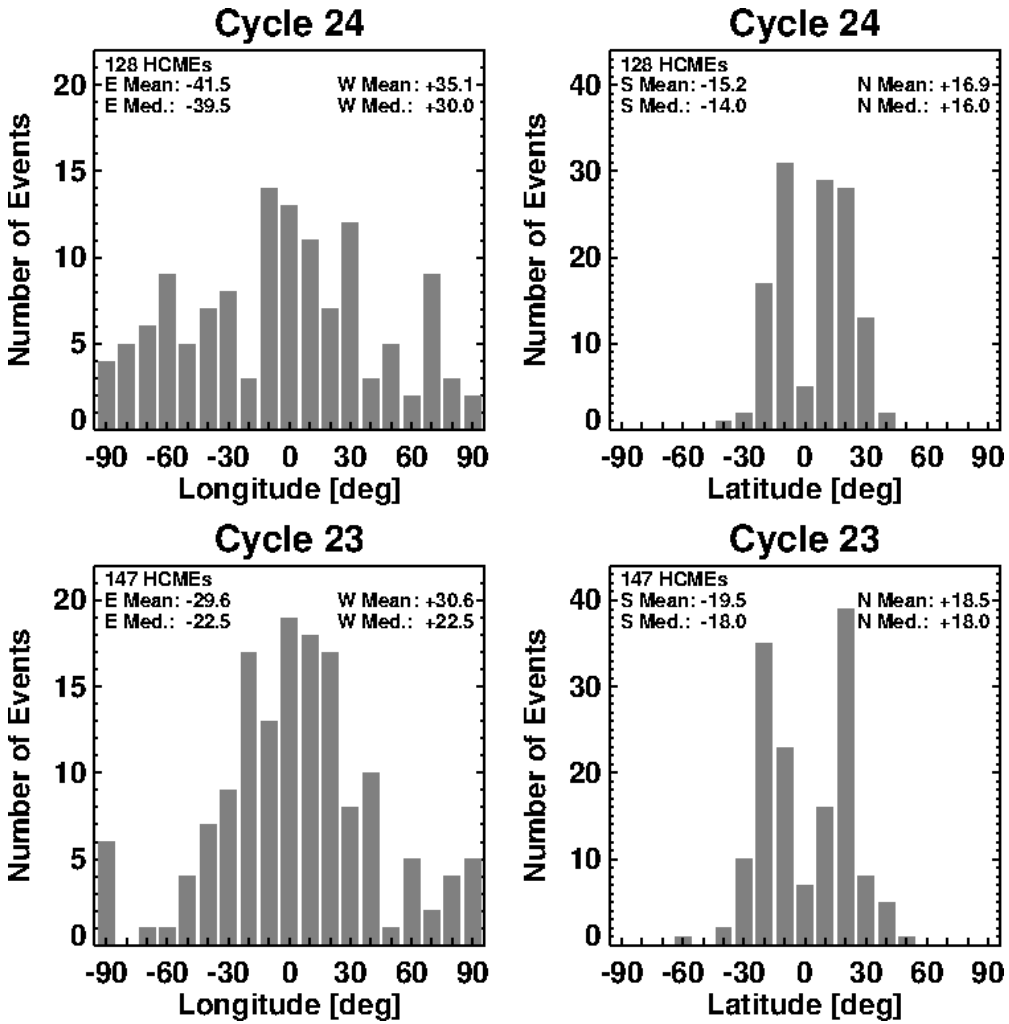
- Dst = 0.01 VBz – 32 nT (Gopalswamy 2010)

- Dst = - 140 nT (Most intense storm in cycle 24)
- VBz = -108/0.01 = - 1.08x10^4 km/s nT

- VBz = - 2.5x10^4 km/s nT (max value in cycle 23)
- Dst = - 282 nT (stronger storms in cycle 23)



Halos from Larger Central Meridian Distance



- Both Halo CME longitudes and latitudes are higher in SC 24
- This is an indication that CMEs expand more near the Sun
- Weaker heliosphere → less number of CIR storms