Solar-cycle Effect on the Geoeffectiveness of Magnetic Clouds

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Poor geoeffectiveness of cycle-24 magnetic clouds and sheaths
Different behavior of white-light CMEs and magnetic clouds in cycle 24

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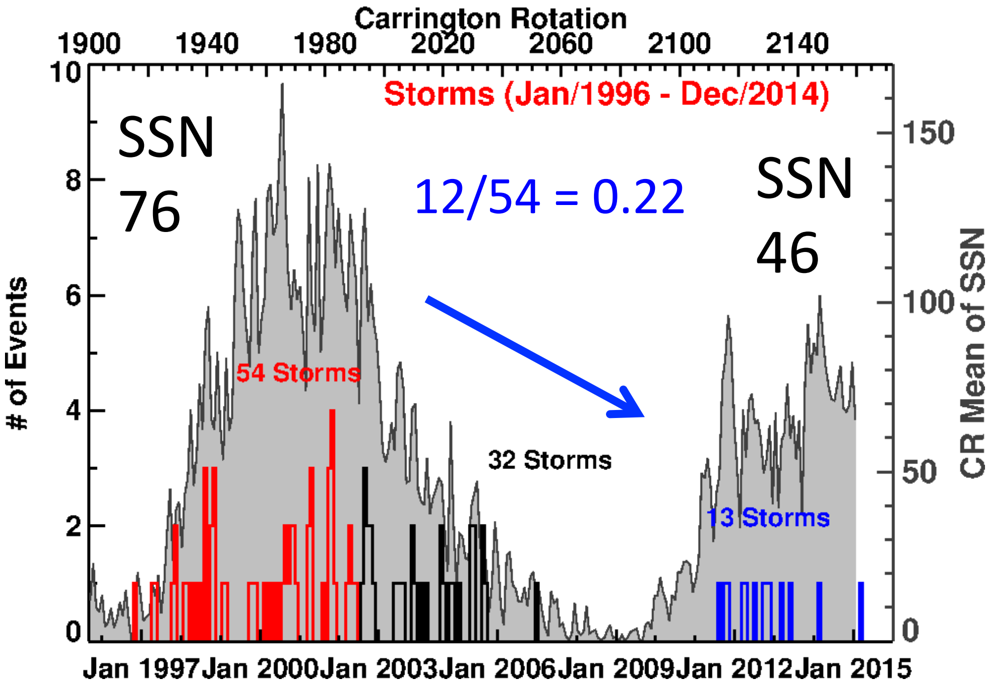
Gopalswamy et al. 2015 JGR in press
http://arxiv.org/abs/1510.00906

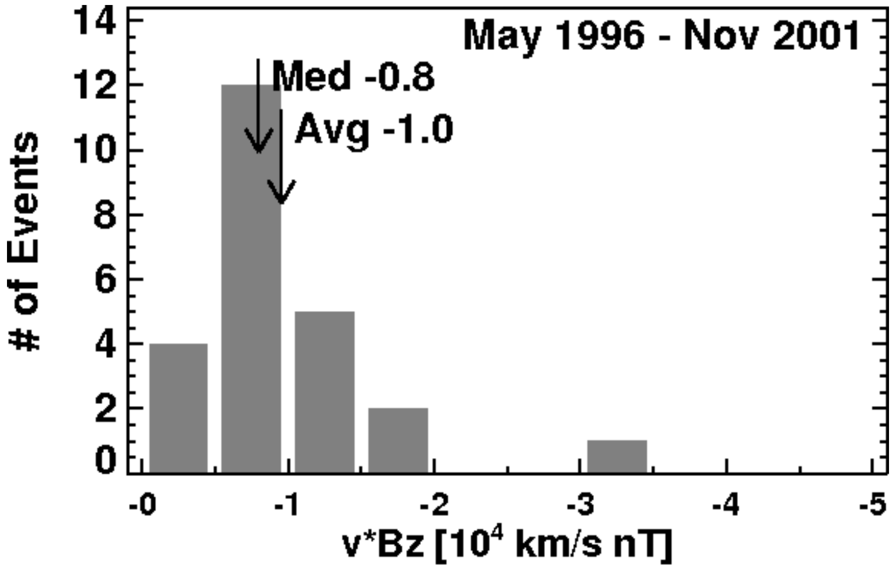
Motivation

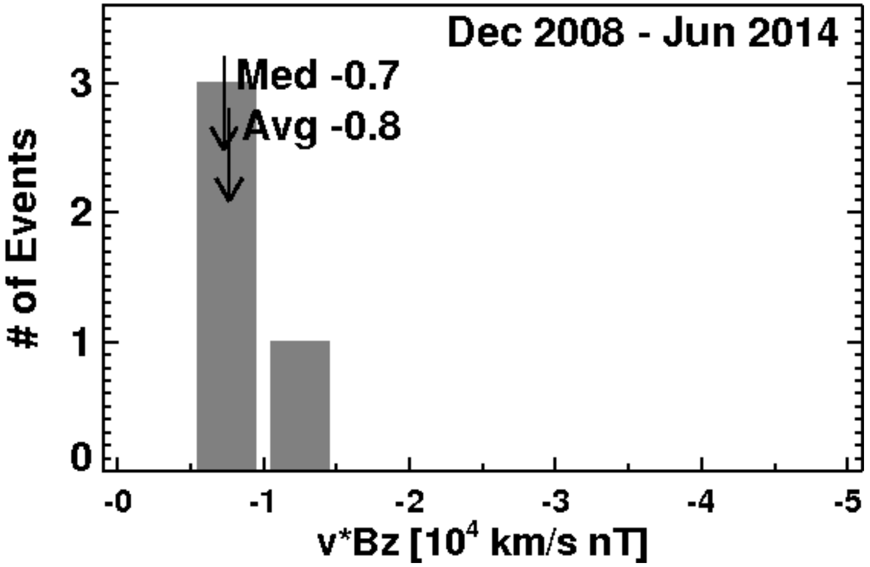
- Average sunspot number (SSN) in SC 24 dropped by 40% (76 to 46)
- # Fast and wide CME rate dropped by 25% (3.6/mo to 2.7/mo)
- # of major storms (Dst <-100 nT) dropped by 78% (54 to 12)
- Drop in neither SSN nor CME rate is consistent with the decrease in major storms



SC 23 SC 24

- Decrease in geoeffectiveness was explained by magnetic dilution of CMEs
- Statistical significance?

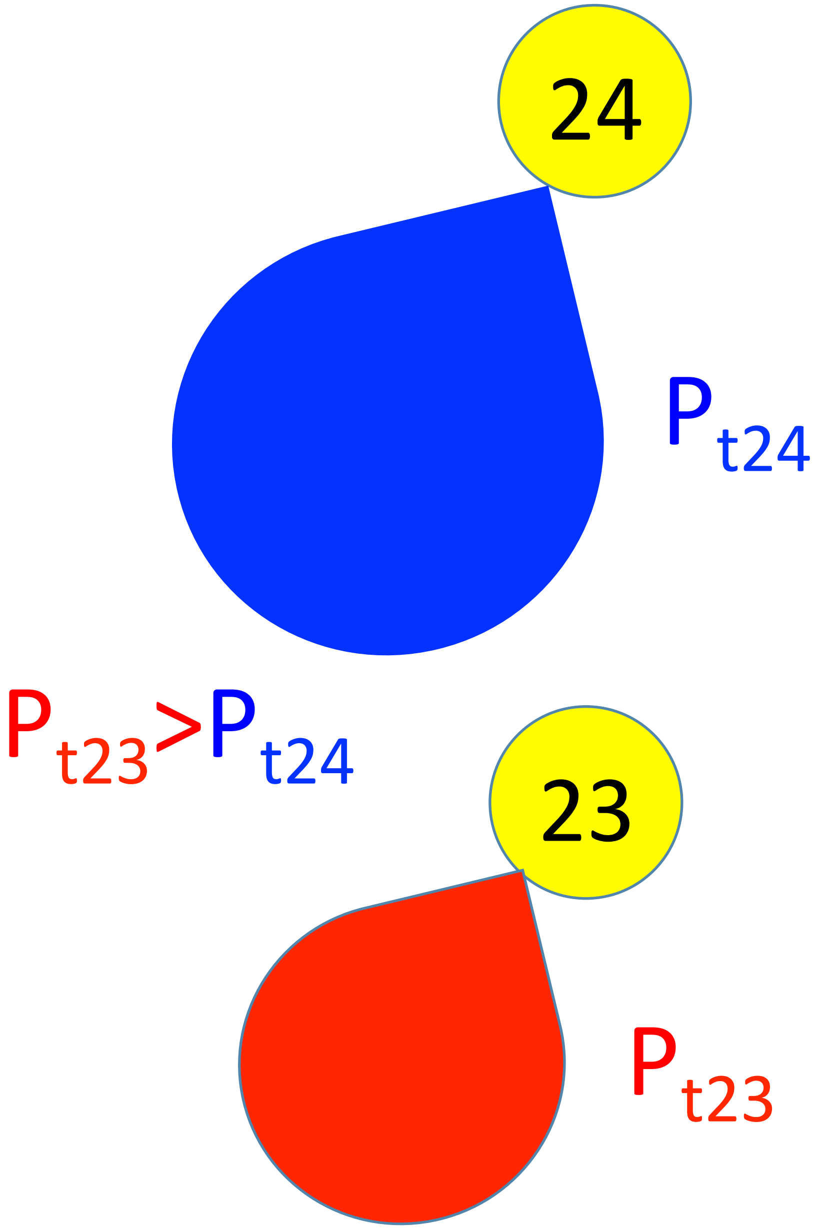


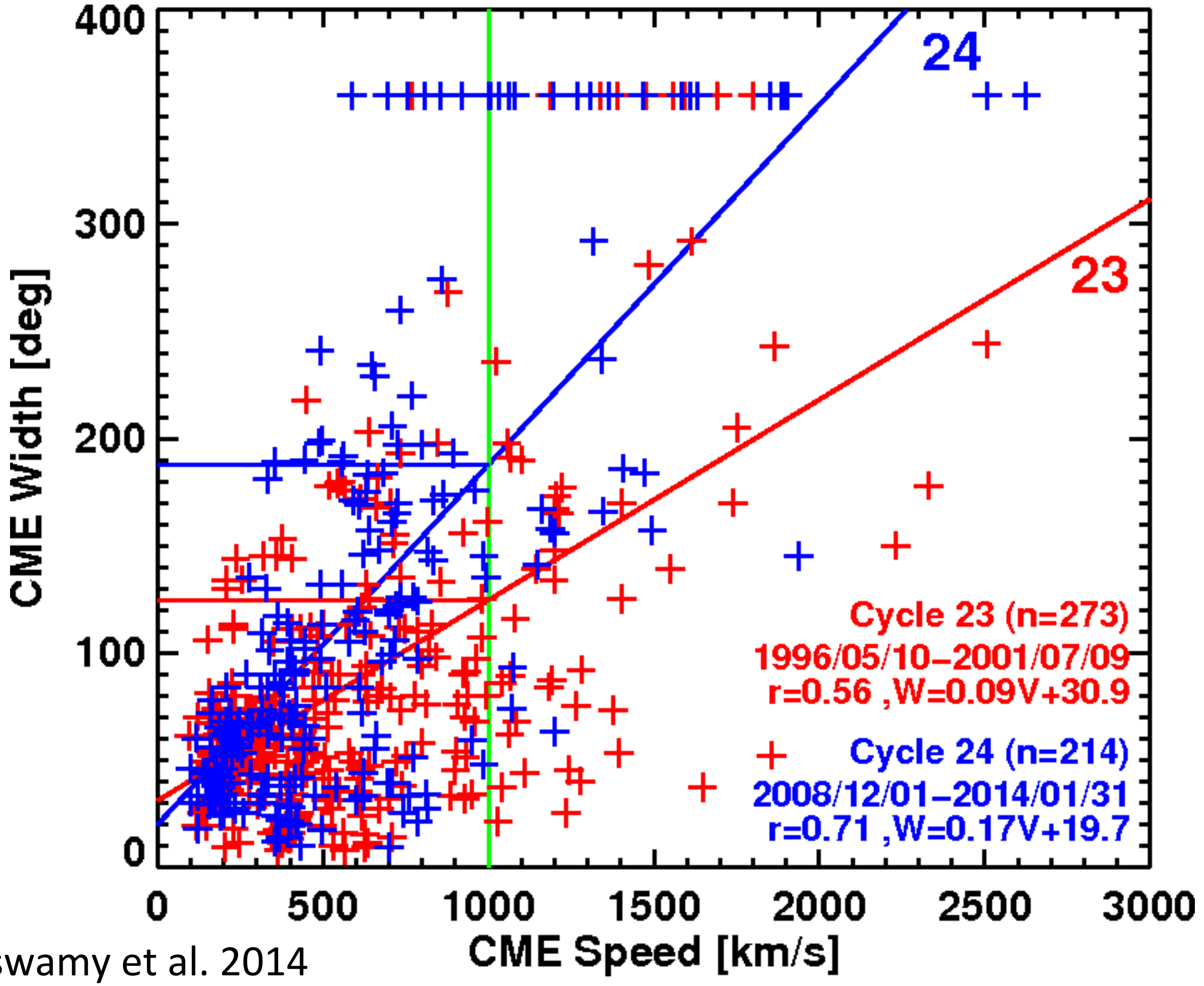


Gopalswamy et al. 2014 GRL

Magnetic dilution due to
anomalous expansion of CMEs

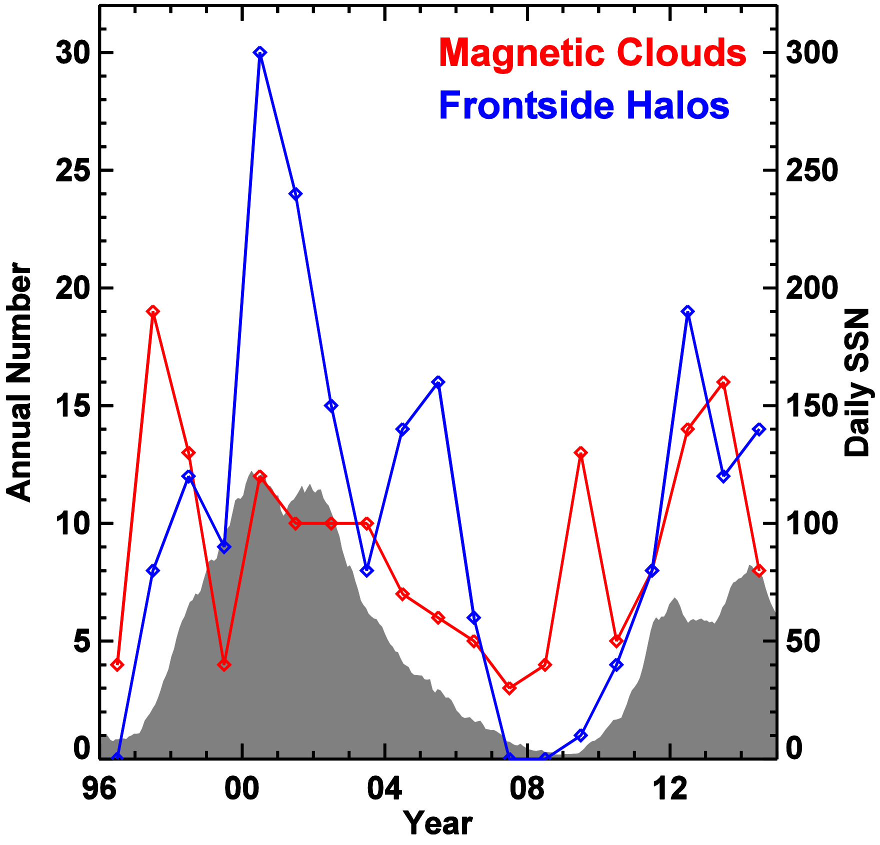
Anomalous Expansion due to Weak Heliospheric Pressure





Gopalswamy et al. 2014

Magnetic Clouds in Cycles 23 and 24



- 65 MCs in SC 24 vs. 68 in SC 23 (first 73 months in each cycle)
  267 frontside halos in SC 24 vs. 264 in SC 23
- MC and Halo CME abundances relative to SSN were higher in cycle 24

	Cycle 23*	Cycle 24	Ratio (24/23)
SSN	76	46	0.61
#MCs	68 (0.89/SSN)	65 (1.41/SSN)	0.96 (1.58)
#Front Halos	264 (0.048/SSN)	267 (0.080/SSN)	1.01 (1.67)

*First 73 months are compared in each cycle

Measure MC and sheath properties, derive parameters such as VBz and expansion rate in cycles 23 and 24

MC: enhanced magnetic field, smooth rotation in By or Bz, low proton temperature or beta (Burlaga et al. 1981)

MC Properties In Solar Cycles 23 and 24

Param[a]	Cycle 23 (n=68)			Cycle 24 (n=65)			R^d	D^e	P^f
	Mean	Conf. Int.[c]	Med	Mean	Conf. Int.[c]	Med			
B_t	16.54	14.87 to 18.20	14.55	12.33	11.23 to 13.43	12.20	0.75	0.3995	0.000
B_z	-10.90	-12.43 to -9.37	-10.35	-7.80	-8.93 to -6.67	-7.50	0.72	0.2710	0.012
$\|B_z\|$	13.33	11.93 to 14.72	11.75	10.23	9.24 to 11.21	9.70	0.77	0.2572	0.020
V	473.9	439.9 to 507.8	445	402.1	384.5 to 419.7	399	0.85	0.2833	0.007
VB_z	-5119	-6098 to -4139	-4362	-3078	-3558 to -2599	-2904	0.60	0.3373	0.001
$\int VB_z$	-2910	-3429 to -2392	-2450	-1853	-2172 to -1535	-1595	0.64	0.2969	0.013
V^b_{exp}	51.0	33.78 to 68.22	42.50	25.28	14.62 to 35.93	25.00	0.50	0.2425	0.033
F_{exp}	1.053	1.038 to 1.068	1.050	1.032	1.020 to 1.045	1.030	**0.98**	**0.1769**	**0.225**
ζ	0.621	0.519 to 0.722	0.625	0.640	0.545 to 0.736	0.610	**1.03**	**0.1157**	**0.867**
P_t	155.8	123.9 to 187.7	121.8	92.17	77.58 to 106.8	79.70	0.59	0.4283	0.000
N_p	7.549	6.540 to 8.557	7.100	6.897	5.970 to 7.824	5.800	**0.91**	**0.1441**	**0.464**
Size	0.224	0.202 to 0.246	0.230	0.174	0.151 to 0.197	0.170	0.78	0.2704	0.012
Δt	21.99	19.56 to 24.42	21.45	19.19	16.68 to 21.70	18.00	**0.87**	**0.1762**	**0.229**
D_{st}	-65.54	-78.29 to -52.79	-56.00	-33.37	-42.27 to -24.47	-22.00	0.51	0.3318	0.001

SC 23 vs. 24

$V_{exp} = V_{LE} - V_{TE}$

$F_{exp} = V_{LE} / V_c$

$= 2V_{LE} / (V_{LE} + V_{TE})$

$\Delta t = t_{TE} - t_{LE}$

$\zeta = V_{exp} L / \Delta t V^2_c$

No significant change in F_{exp}, Δt, ζ, and N_p

What Changed (decreased): B_t, B_z, V, VB_z, V_{exp}, P_t, *size*, D_{st}

SC 24 MCs are barely geoeffective

Dst dropped by 49%

Sheath Properties in SC 23 and 24

Table 3. Kolmogorov Smirnov (KS) Test Results for Sheath Properties in Solar Cycles 23 and 24

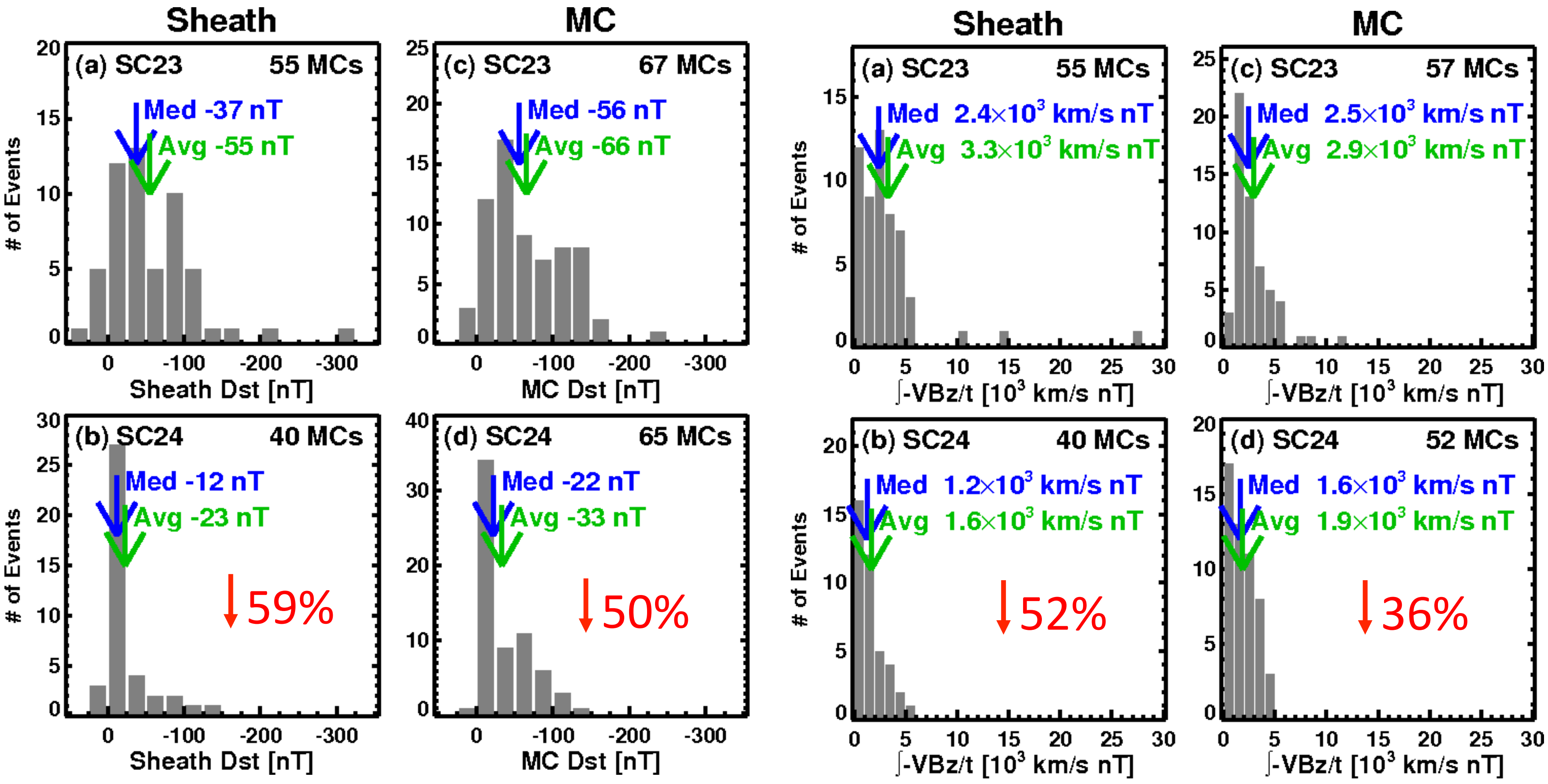
Param[a]	Cycle 23 (n=55)			Cycle 24 (n=40)			R^c	D^d	P^e
	Mean	Conf. Int	Median	Mean	Conf. Int.	Median			
B_t	19.18	15.76 to 22.59	15.00	13.24	11.19 to 15.28	11.55	0.69	0.3318	0.009
B_z	-14.23	-17.26 to -11.19	-11.90	-8.92	-11.17 to -6.679	-7.7	0.63	0.3727	0.002
$\|B_z\|$	15.87	12.82 to 18.92	13.10	11.47	9.584 to 13.37	9.7	0.72	0.3250	0.011
V	539.5	494.4 to 584.7	484	447.4	417.1 to 477.8	426.5	0.83	0.2932	0.029
VB_z	-8101	-10840 to -5363	-5600	-3988	-5251 to -2726	-3040	0.49	0.3659	0.003
$\int VB_z$	-3260	-4381 to -2131	-2370	-1634	-2060 to -1208	-1245	0.50	0.3364	0.008
P_t	272.9	182.1 to 363.6	168.8	135.2	96.18 to 174.3	93.60	0.50	0.3432	0.006
N_p	15.25	12.85 to 17.65	13.20	12.90	10.85 to 14.95	11.35	**0.85**	**0.1932**	**0.319**
Δt	11.19	9.40 to 12.98	10.70	9.635	7.948 to 11.32	9.2	**0.86**	**0.1273**	**0.821**
D_{st}	-55.18	-71.45 to -38.92	-37.00	-22.75	-33.63 to -11.87	-12.00	0.41	0.4409	0.000

No significant change in Δt and N_p

What Changed (decreased):
B_t, B_z, V, VB_z, P_t D_{st}

Dst dropped by 59%; SC 24 MCs are not geoeffective on the average!

Dst Decline is Commensurate with VBz Drop

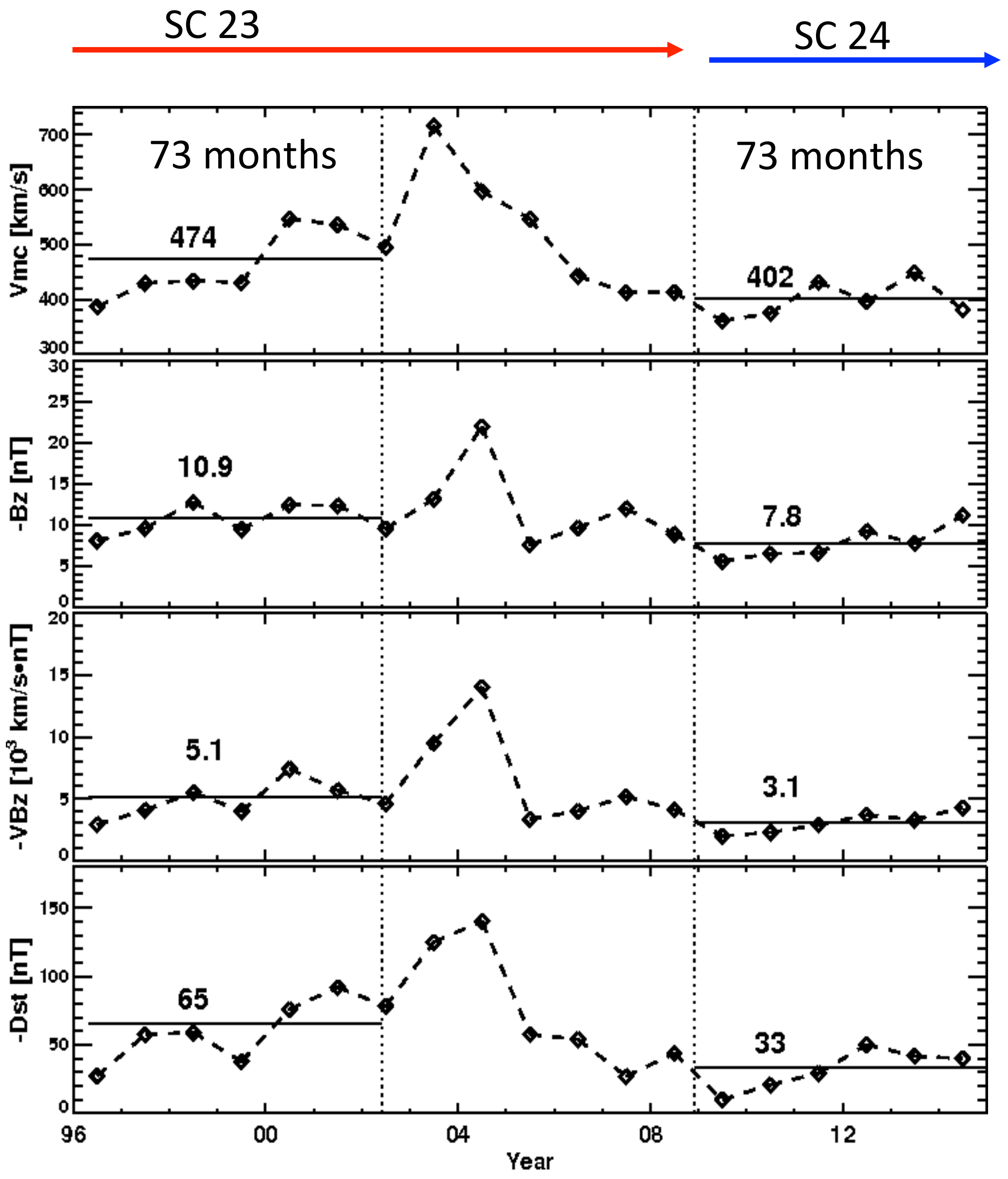


Dst drop in sheath similar to $(1/T)\int VB_z dt$

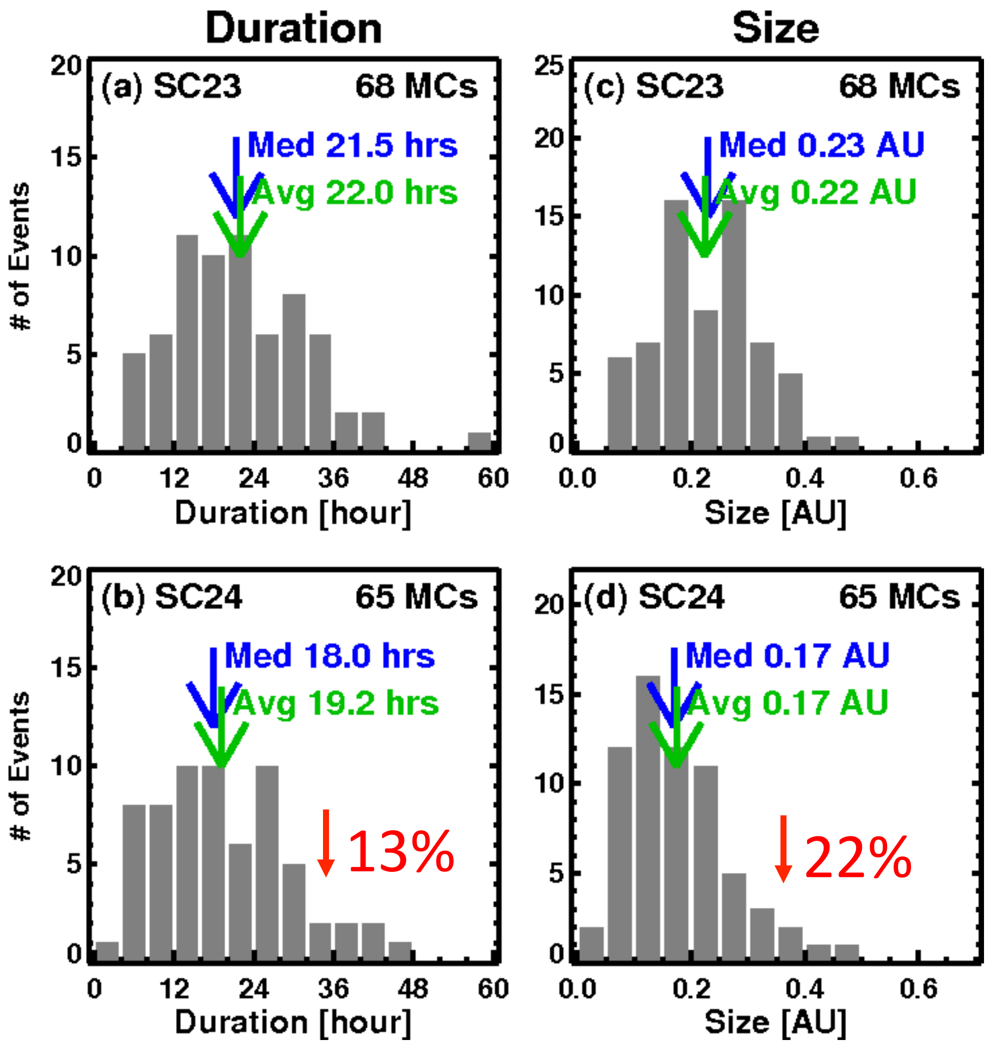
For MCs the $(1/T)\int VB_z dt$ drop is smaller – additional factors contribute to Dst in MCs

Inter & Intra Cycle Variations

- Both V and BzS declined resulting in VBz decline and hence Dst decline
- Consistent with previous conclusions based on major storms and the anomalous expansion
- However, the MC size at 1 AU is smaller in cycle 24 not consistent with wider CMEs near the Sun



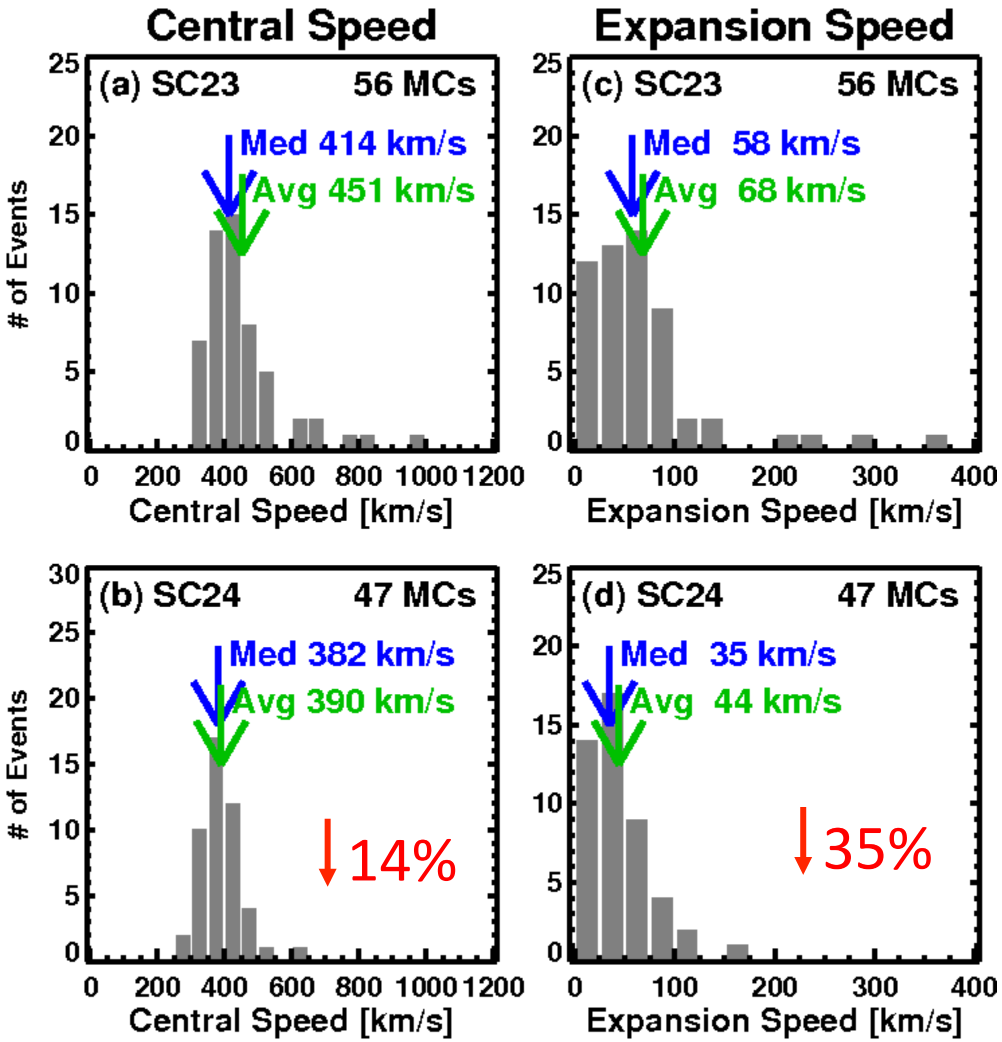
No change in duration, but decline in size



Kolmogorov-Smirnov Test:
Ratio of <Δt>: 0.87
D-statistic: 0.1762 (~D_c = 0.169)
Probability: 0.227 (null hypothesis that the dist. are the same cannot be rejected)

size ~ $V_c/2\Delta t$
V_c decline is significant, so is size decline

Consistency Check: Expansion Speed & Central Speed of MCs



$\zeta = V_{exp}L/\Delta t V^2_c$ (Gulisano et al. 2010)

$d\zeta/\zeta = dV_{exp}/V_{exp} - 2dV_c/V_c$

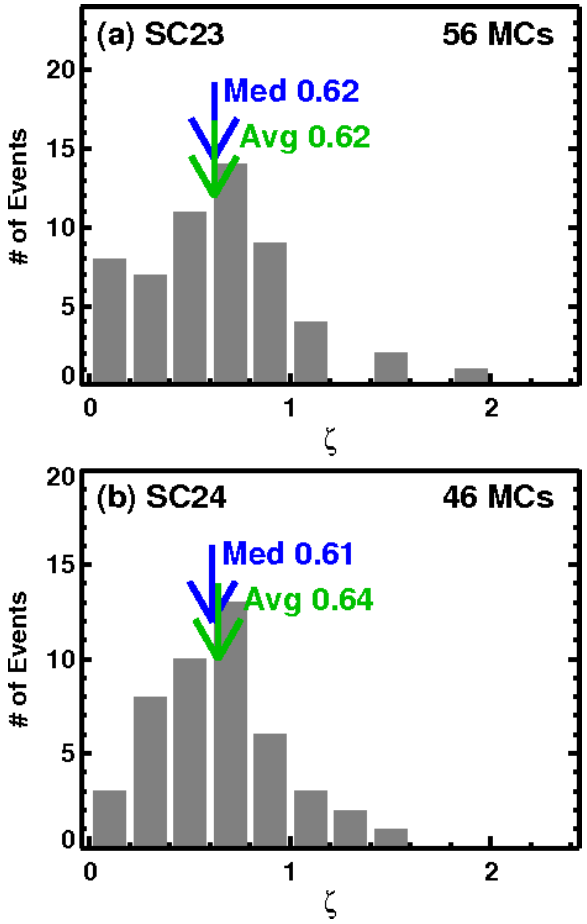
This is approximately satisfied: $d\zeta/\zeta \sim 0$

$dV_{exp}/V_{exp} - 2dV_c/V_c = -0.07$

$L = 1$ AU, $\Delta t \sim$ constant, so

$\zeta \sim V_{exp}/V^2_c \sim \Delta P_t/V^2_c$

Expansion speed and central speed plots exclude contracting events



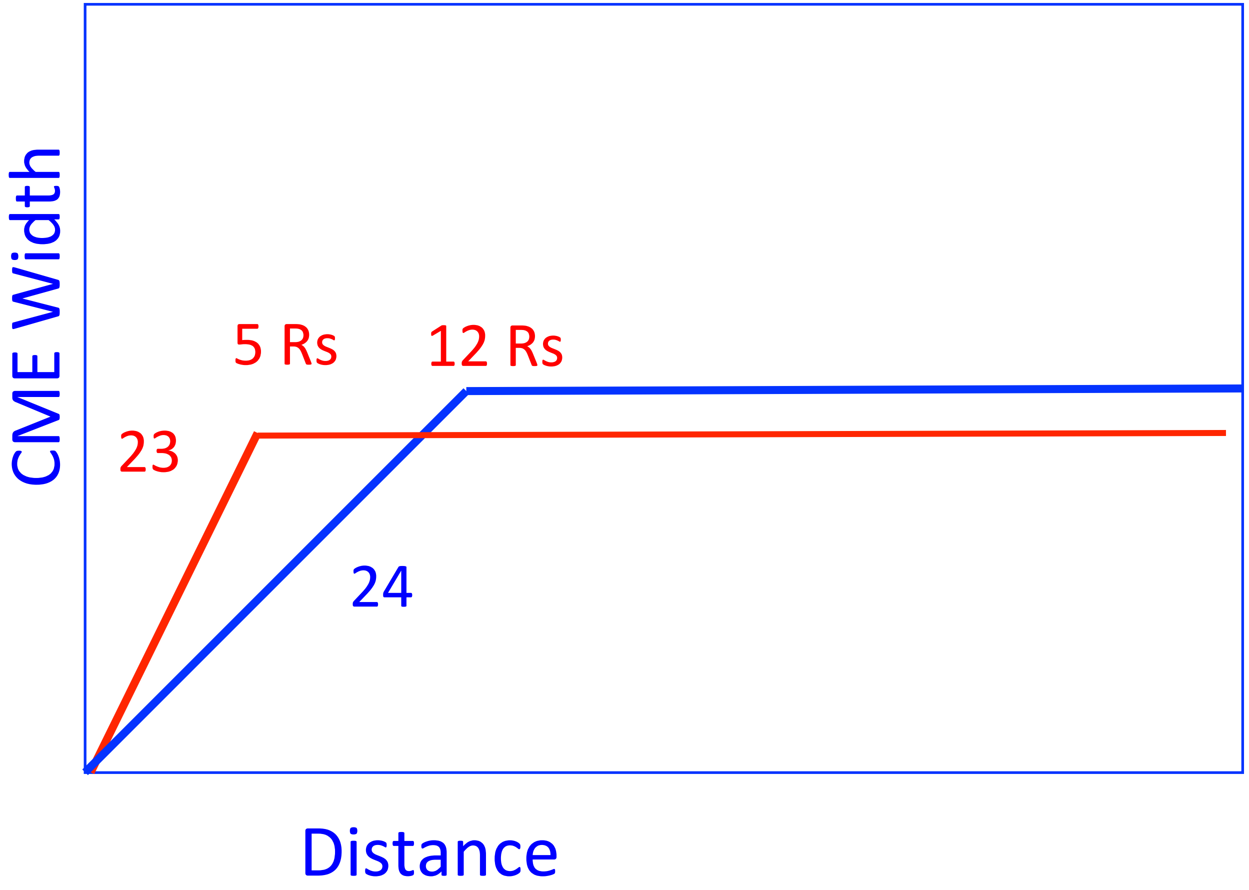
Expansion Rate is the Same Because Decrease in ΔP_t is Compensated by Decrease in MC Speed

	SC 23	SC 24	Ratio (24/23)
Ambient Pressure (pPa)	42.4	29.6	0.70
MC Pressure	139.8	91.7	0.66
ΔP_t	97.4	62.1	0.64
$\Delta P_t/V_c^2$	4.8e-4	4.1e-4	0.85
$\Delta P_t/(V_c^2 \Delta t)$	2.2e-5	2.1e-5	0.96

Pressure Balance Distance: Reconciling near-Sun and near-Earth Observations

- CME size in SC 24 is larger near the Sun, but MC size is smaller at 1 AU
- $S = S_o (L/L_o)^{\zeta}$; S_o is the initial FR size R at L_o (where FR - ambient pressure balance is reached Gulisano et al. 2010)
- $S_{24}/S_{23} = (S_{o24}/S_{o23})(L_{o23}/L_{o24})^{\zeta}$
- $S_{o24}/S_{o23} = W_{24}/W_{23} = 1.38$ (CMEs wider in SC 23; Gopalswamy et al. 2014)
- $S_{24}/S_{23} = 0.78$ (Observations at 1 AU, Gopalswamy et al. 2015)
- $\zeta = 0.64$
- $\rightarrow L_{o23}/L_{o24} = 0.41$
- $L_{o23} = 5$ Rs
- $\rightarrow L_{o24} = 12.2$ Rs. Pressure balance is reached at a larger distance in SC 24
- Flux rope size and CME width are defined differently. Measure main body?

Pressure Balance Farther from the Sun in SC 24

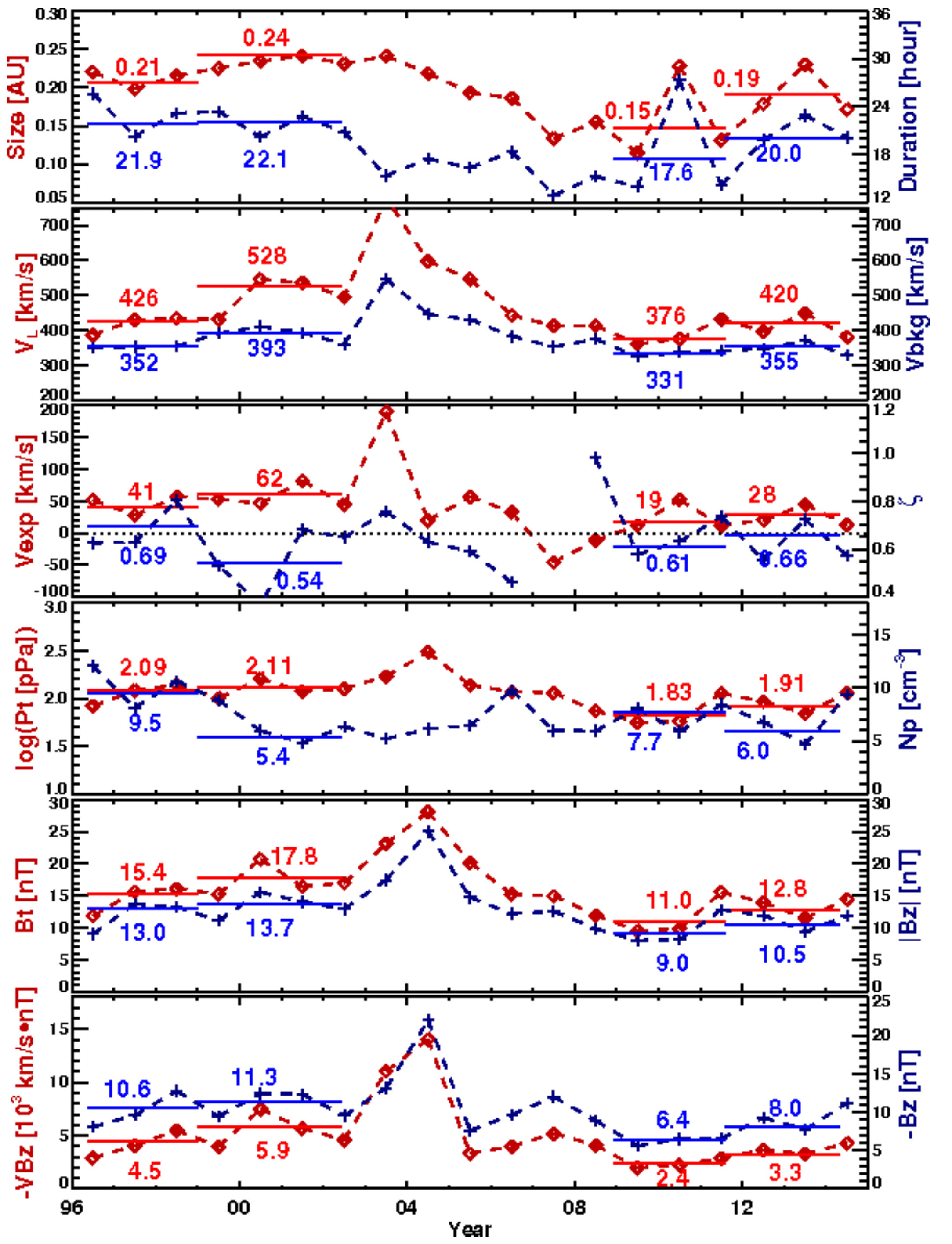


Flux Rope Size

$$S = S_o\,(L/L_o)^{\zeta}$$

Intra-cycle Variations

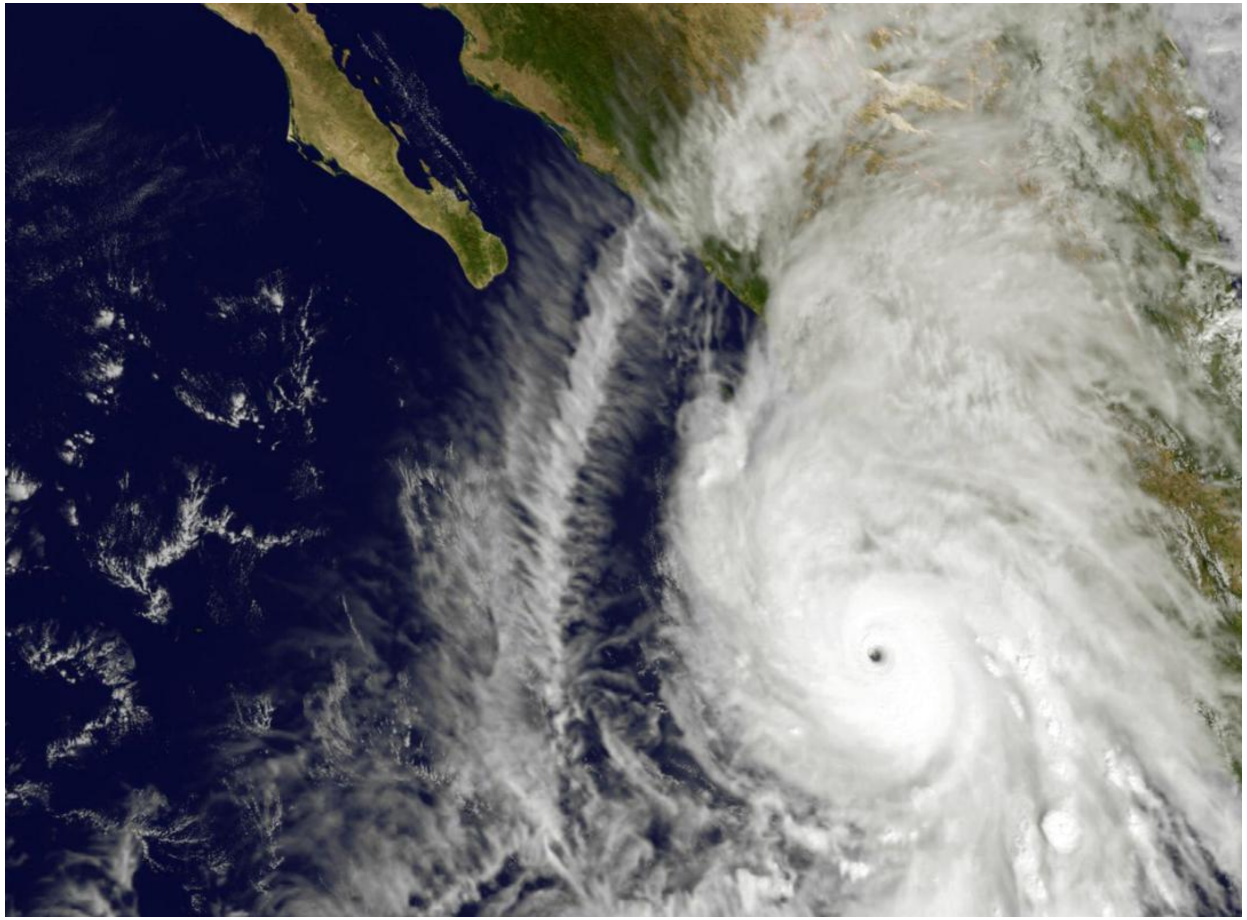
- The parameters (V_L, B_t, P_t, VB_z, B_z) that are directly linked to the solar sources show clear solar cycle variation
- The pressure balance happens at a larger distance from the Sun in SC 24 (12 Rs vs.5 Rs)
- Intense storms tend to occur during the maximum phase of solar cycles
- Smaller MC speed and expansion speed in SC24, consistent with smaller ΔP_t



Key Findings

- Intense storms tend to occur during the maximum phase of solar cycles
- The weaker geoeffectiveness can be directly attributed to the drop in VBz
- Bz reduction due to enhanced expansion in cycle 24
- Dilution of magnetic content occurs near the Sun
- The pressure balance happens at a larger distance from the Sun in cycle 24 (12 Rs vs.5 Rs). Explains the seemingly contradictory relationship between sizes at 1 AU and at the Sun
- The parameters (V_L, B_t, P_t, VB_z, B_z) that are directly linked to the solar sources show clear solar cycle variation
- Smaller MC speed and expansion speed in SC24, consistent with smaller ΔP_t

Hurricane Patricia



This satellite image taken at 1:45 p.m. EDT on Friday, Oct. 23, 2015, and released by NASA, shows the eastern quadrant and pinhole eye of Hurricane Patricia moving towards southwestern Mexico. The Category 5 storm is strongest ever in the Western Hemisphere, according to forecasters. (NOAA GOES Project/NASA via AP)

Scott Kelly
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Hurricane #Patricia approaches #Mexico. It's massive. Be careful! #YearInSpace

3:37 PM - 23 Oct 2015