Effect of the Solar Cycle on Typical CME Properties During 1995-2023

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1. Introduction

Coronal Mass Ejections (CMEs) are violent events corresponding to strong magnetic structures erupting from the outermost part of the Sun: the corona.

The CMEs' substructures are the Sheath and the Magnetic Ejecta (ME). In addition, we consider the pre-CME solar wind (Pre-SW) and the Wake. Significant efforts have been made to classified CMEs based on its substructural properties (for example, **Salman et al. 2020** for the sheath structure or **Richardson & Cane, 2010** for the ME-type).

For this project, we consider CMEs measured *in situ* over two decades (1995 – 2023) by multiple spacecraft as listed in the Helio4Cast catalog **(Mostl et al. 2020)**.

We study the statistical properties of over 1000 CMEs to understand the effects of Solar Cycle (SC) on CMEs properties. This work shall be extended for further probing of the influence of SC phase on CME properties .

2. Method

We use the statistical approach known as the superposed epoch analysis (**SEA)** to determine the statistical properties of the sub-structures of CMEs profile.
Such example of this, is as below:

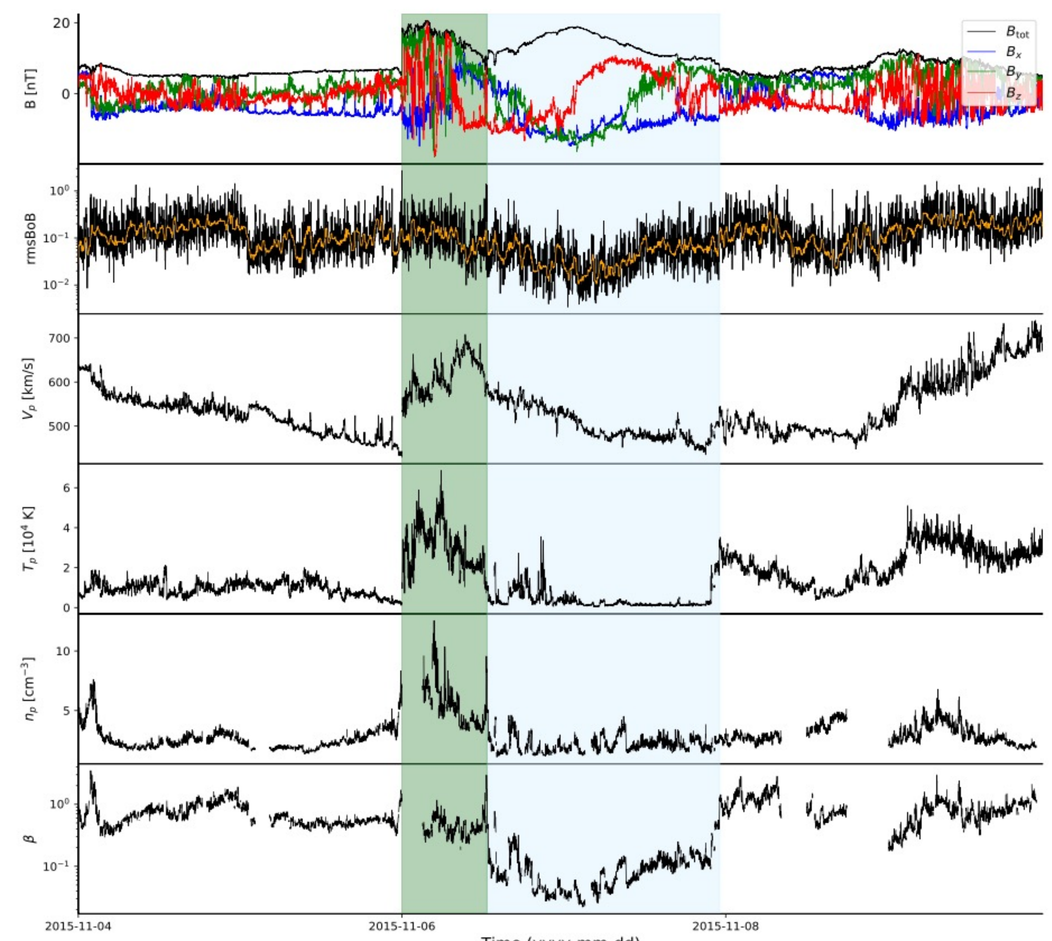

Figure 1: An example CME observed by ACE. From top to bottom: B_{tot} and its components, B over B_{rms} , velocity V_p, Temperature T_p, proton density n_p and plasma parameter β **(Regnault et al. 2020).**

3. CMEs in Active Phase (AP) & Quiet Phase (QP)

The Sunspot Number (SSN) threshold set for the active phase (AP) is 70 with 457 events and 30 for the quiet phase (QP) with 335 events.

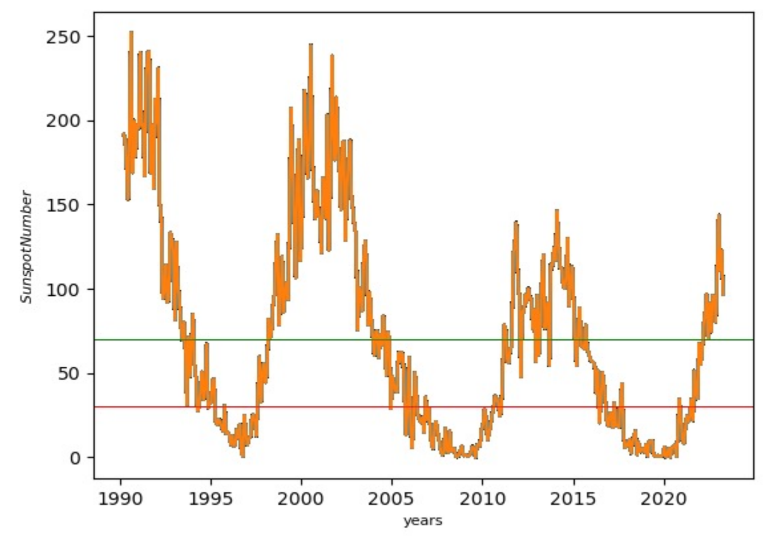

Figure 2: AP and QP SSN threshold plot

Boundary	B_{mag}		Plasmas	
	AP	QP	AP	QP
Pre-SW	453	331	400	306
Sheath	319	210	312	197
ME	453	331	446	321
Wake	453	331	445	315

Table1: Number of events for each substructure per solar cycle phase.

4. Result

SEA is conducted on the CMEs categorized by SSN thresholds defined above and the number of CMEs events per substructures or boundaries for AP and QP are given in table 1:

The plot below gives the properties of the CMEs that we study during Active and Quiet Phase.

We perform a triple epoch SEA. We use the normalized time by taking 1 epoch as the sheath duration and 2 for the ME length.

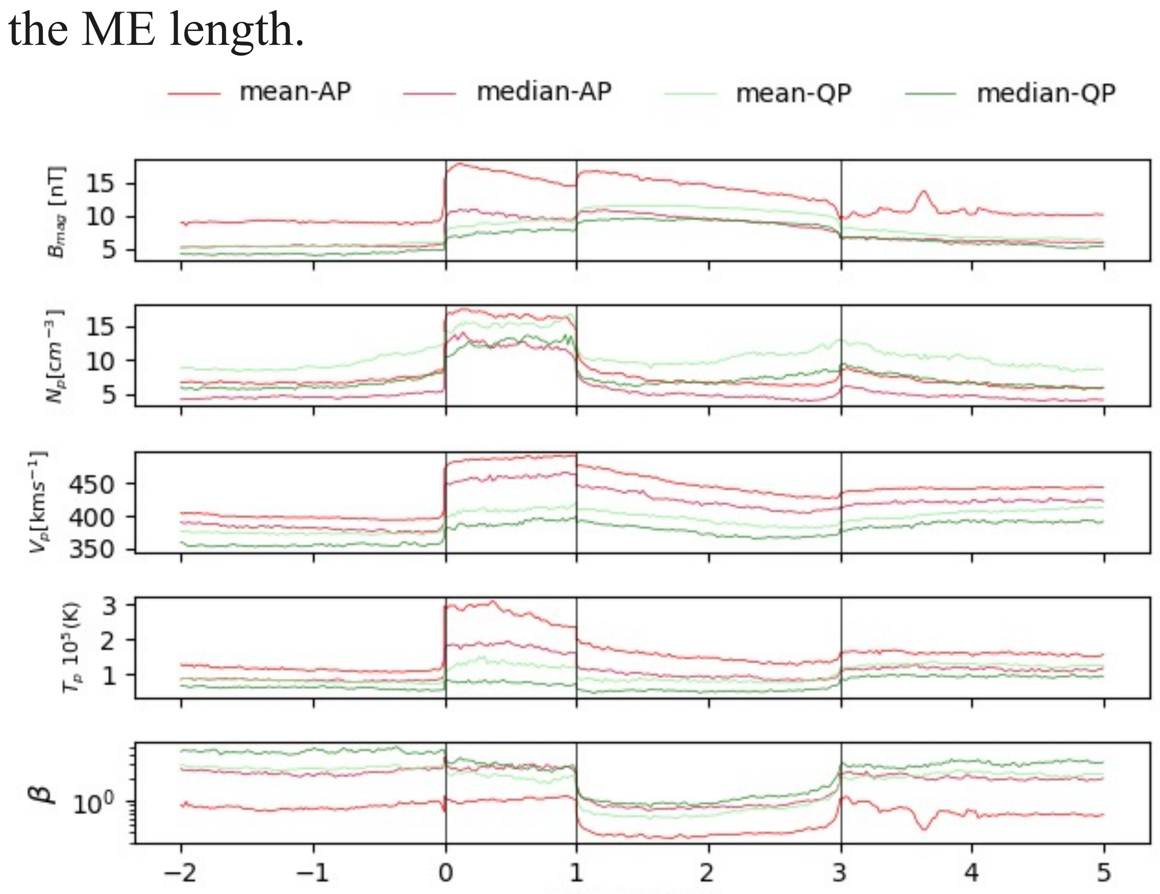

Figure 3: The SEA Combine plot for Active and Quiet Phases.

5. Discussion

We used the mean and median values as proxies to better understand the CME behavior during both AP & QP.

- The B_{mag} and other plasma parameters in the sheath of AP CMEs show greater enhancement as compared to the QP.
  - This is consistent with the maximum speed of AP ME being on average 32km/s higher than that of QP ME. Faster CMEs are known to drive stronger sheaths.
- All parameters of AP MEs are higher than QP MEs except for the density n_p which is lower.
  - This is consistent with the results of **Regnault et al. 2020**.
  - This may reflect differences in initiation mechanisms.
- We observed higher temperatures at the ME front for AP compared to its rear, but slightly higher temperature at ME rear for QP compared to its front.
  - This implies that AP front is hotter than its rear but QP rear is slightly hotter than its front.
- The ME expansion speed during AP for the mean and median profiles are 42 km/s & 37 km/s and during QP it is 21 km/s & 11 km/s.
  - This suggests that the AP CMEs expand more during their propagation.
- Computing the distortion parameter (DiP, **Nieves-Chinchilla et al. 2018**), the AP mean and median DiP is 0.475, but for QP the mean and median DiPs are 0.505 & 0.495 respectively. This suggests that the ME during AP is less symmetric than during the QP.

6. Conclusion & Future work

We have been able to observe about 1000 CMEs profile for both Quiet and Active phases of solar cycle from Helio4Cat using Superposed Epoch Analysis.

Here we consider about 3 times more CMEs events from multiple spacecraft than what was studied by **(Regnault et al. 2020)** which is from a single probe ACE.

We shall perform the following tasks in the future:

- Classify CMEs of each phase based on observed boundary properties and temporal profiles associated with them.
- Perform SEA from Minimum Variance Analysis of CMEs.
- Observe CME profiles at different locations from the Sun **(fig 4)** below. The database contains CMEs that have been binned into 10bins with MESSENGER having more CMEs.

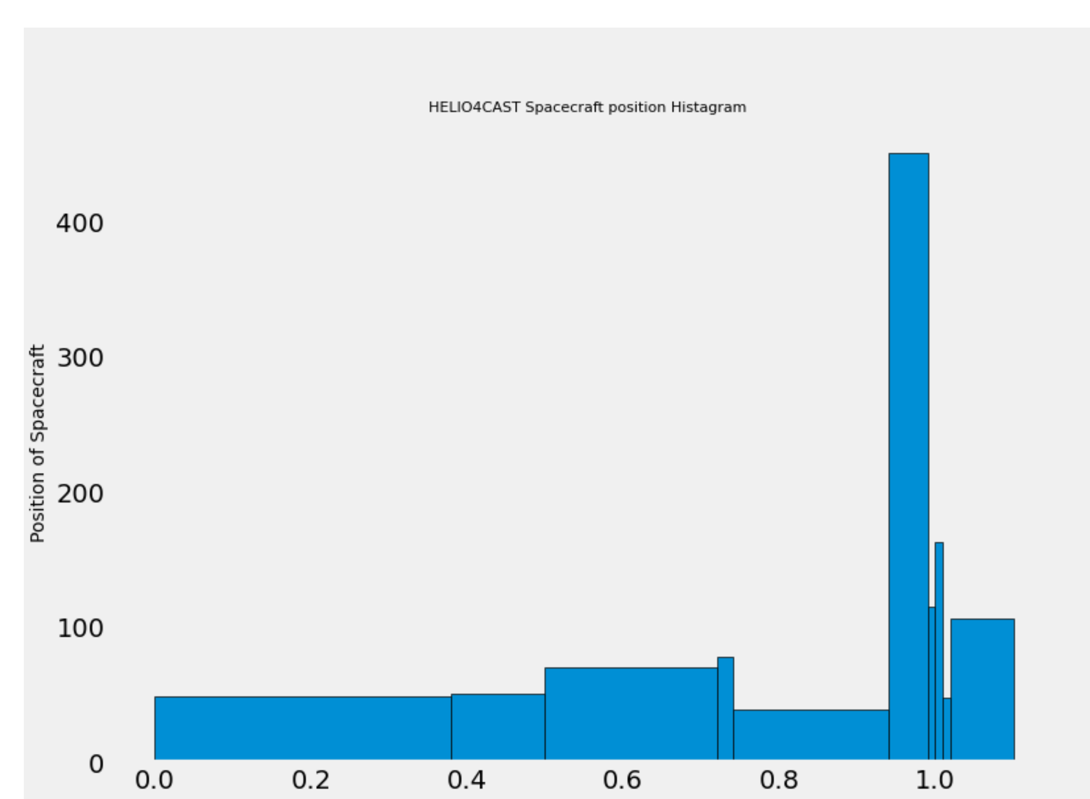

Figure 4: CMEs distribution based on spacecraft position.

7. Acknowledgement

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