Near-real time Coronal Mass Ejection Alerts as part of an Early Warning Forecasting System for Solar Energetic Particle (SEP) events

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ABSTRACT

The NCAR Mauna Loa Solar Observatory (MLSO) COSMO K-Coronagraph (K-Cor) issues near-real time coronal mass ejection (CME) alerts to the community and to NASA's Community Coordinated Modeling Center Solar Energetic Particle (SEP) scoreboard for use by the NASA Space Radiation Analysis Group in support of the Artemis mission. K-Cor was designed to study CME onset and dynamics. The field-of-view is 1.05 to 3 R_0 at 15-second cadence. Data are fully processed in less than 2 minutes using a fully automated pipeline that includes CME detection. The K-Cor field-of-view, high time cadence and low latency processing, combine to provide an early warning CME detection as part of a SEP forecasting system, as pointed out by St. Cyr et al. (2017). Most of the K-Cor alerts were issued ***before*** the CME entered the LASCO field-of-view. When LASCO data latency is included, we show that K-Cor alerts can provide the first warning of in-progress CMEs tens of minutes to an hour before the CME can be seen in LASCO at the Space Weather Prediction Center (SWPC). We discuss the CME detection system and present statistics on performance. We discuss ongoing work to improve performance and highlight the benefit of ground-based coronagraph network (ngGONG mission).

MOTIVATION

SEPs are highly energized particles from the Sun moving at relativistic speeds. They pose radiation hazards to astronauts, aircraft crews, and satellites, and impact airline, DoD, and HF radio communications. Minutes count in SEP forecasting. The NCAR COSMO K-Coronagraph is ideally suited to be part of an early warning forecasting system for SEP events (see St. Cyr et al. 2017). ***K-Cor provides the first detection of an in-progress CME in near-real time.*** This is possible due to its low latency, high cadence (15 sec), unique white light field-of-view, and CME-detection. The histogram at right shows K-Cor near-real time CME alerts are issued with an avg data latency of 2 min 33 sec.

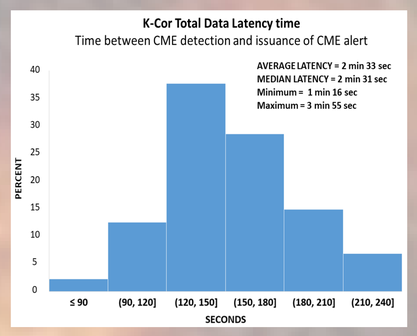
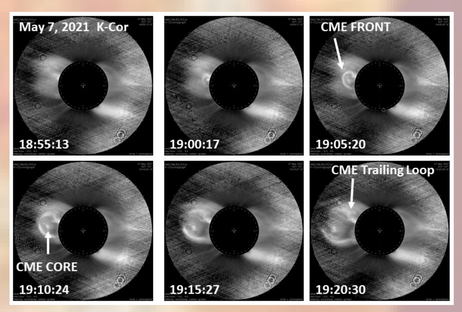


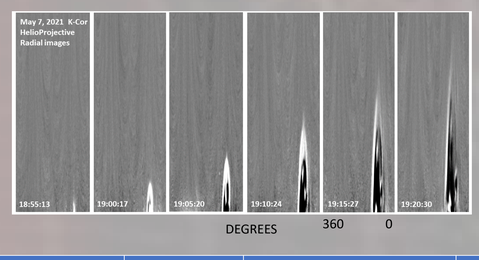
Figure 1: Histogram of K-Cor latency times for automated CME alerts issued in near-real time.

METHOD

K-Cor automated data processing includes CME detection developed by Thompson et al. 2017, based on the Solar Eruptive Event Detection System (SEEDS). It uses fully calibrated K-Cor polarization brightness (pB) images that are mapped to helioprojective-radial polar (HPR) coordinates and averaged over 33 seconds and over 3°, to increase signal. 5-minute running-differences are created and examined over time to identify brightness changes with height in a region. A CME alert is issued when a leading edge with at least 5 measured points, an inferred speed of >=20 km/s, and a fit with a std. deviation < 0.05 R_0 is identified. **The alert provides the time of the K-Cor image, the height of the leading edge in solar radii, the position angle of the CME, and an initial speed measurement.** *See Thompson et al. 2017.*



Transform to HPR coordinates to ID and track CME



FAR LEFT: K-Cor images of May 7, 2021 SEP-CME. NEAR LEFT: K-Cor images transformed into HPR coordinates. X-axis is position angle from 0 to 360 deg RIGHT TO LEFT. Y-axis is height in solar radii.

SEP-CME RESULTS

TAKEAWAY: Nearly all K-Cor CME alerts are issued BEFORE the CME has entered the LASCO field-of-view

Richardson recently updated his SEP event list (private communication) which included **31 SEP-associated CMEs** that occurred during times when K-Cor was observing. **Of these 31 CMEs:**

20 had valid K-Cor CME alerts
- 2 had alerts of nearby CME
- 7 were faint CMEs in K-Cor and missed by the detection code
- 2 were too faint to be seen in K-Cor

The 20 CME alerts are shown in the table at right. ***All but 4 of the alerts were issued before the CME was visible in the LASCO data.*** In the 4 cases the CME core, rather than the front, was being tracked.

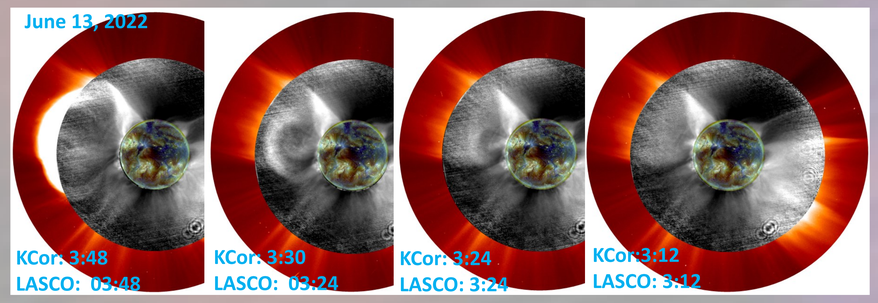
When latency is included K-Cor provides ~1 hour warning (avg).

DATE OF SEP-associated CME	Time CME Alert issued Includes K-Cor latency	Time of LASCO first CME image	Time between LASCO and CME alert RED: detection after CME in LASCO BLACK: detection before CME in LASCO	Time between LASCO and alert INCLUDES 40-min LASCO latency
12/9/2013	19:36:57	19:36:05	> 0 min 52 sec	< 39 min 8 sec
12/16/2013	20:49:09	21:39:14	< 50 m 05 sec	< 90 m 05 sec
2/11/2014	19:00:39	19:24:05	< 23 m 26 sec	< 63 m 26 sec
9/24/2014	21:04:20	21:30:06	< 25m 46 sec	< 65m 46 sec
10/14/2014	18:50:24	18:48:06	> 2 min 18 sec	< 37 min 42 sec
2/8/2015	22:30:10	22:36:06	< 5 min 54 sec	< 45 min 54 sec
3/15/2015	01:29:58	01:48:05	< 18 min 7 sec	< 58 min 7 sec
1/1/2016	23:11:55	23:24:04	< 12 min 9 sec	< 52 min 9 sec
4/18/2017	19:31:23	19:48:05	< 16 min 42 sec	< 56 min 42 sec
5/7/2021	19:07:06	19:24:05	< 16 min 59 sec	< 56 min 59 sec
7/9/2021	17:37:43	17:48:05	< 8 min 22 sec	< 48 min 22 sec
7/15/2021	21:31:18	21:36:05	< 4 min 47 sec	< 44 min 47 sec
11/1/2021	01:25:14	02:00:06	< 34 min 52 sec	< 74 min 52 sec
1/31/2022	23:48:21	00:12:05	< 23 min 44 sec	< 63 min 44 sec
2/2/2022	00:22:15	01:25:48	< 63 min 33 sec	< 103 min 33 ec
3/10/2022	19:25:59	18:48:05	> 37 min 54 sec	< 2 min 6 sec
3/31/2022	18:45:57	19:12:05	< 26 min 8 sec	< 66 min 8 sec
5/11/2022	18:35:33	18:36:05	< 0 min 32 sec	< 40 min 32 sec
6/13/2022	03:03:37	03:12:11	< 8 min 34 sec	< 48 min 34 sec
10/2/2022	20:38:27	20:36:05	> 2 min 22 sec	< 37 min 38 sec
AVG time between CME Alert and LASCO 1st image			**< 14 min 49 sec before LASCO**	**< 54 min 49 sec before LASCO**

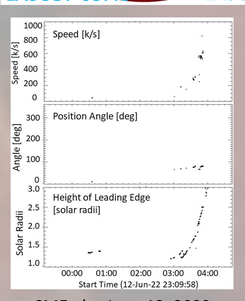
K-COR CME ALERTS:

Nearly all K-Cor CME alerts are issued **BEFORE** the CME has entered the LASCO field-of-view

When LASCO latency is included **K-Cor provides nearly 1 hour warning (avg).**



At Left: Composite images of **June 13, 2022** CME: AIA (multi-color), K-Cor (b/w), LASCO C2 (red)

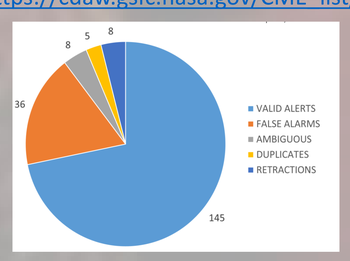


CME plot June 13, 2022

A final alert report is issued when the K-Cor CME is 'over'. The report includes the CME time-height trajectory, position and speed, ***providing information on CME acceleration in the low corona where the strongest CME-driven shocks form***. An example of the report plot for the June 13, 2022 CME is shown at left. A text file (not shown) with the data is also sent.
We are upgrading the software to send interim report updates every few minutes to provide more continuous, real time CME trajectory info. **These data can expedite the time needed to determine the CME speed from using only space-based coronagraphs.** LASCO cadence is 12 minutes. Forecasters need to wait for a second image to get an initial speed estimate and third image to get an initial acceleration estimate. K-Cor report information can expedite this wait.

K-COR CME ALERT STATISTICS

Mauna Loa issued 202 CME alerts between Jan 1 and Sep 30, 2022. Each of these alerts was later examined and K-Cor data were compared with LASCO observations and the information in the CDAW CME catalog https://cdaw.gsfc.nasa.gov/CME_list/ to assess if the alerts were valid or false alarms. Results are shown below.



- **Valid** – CME / ejecta visible in LASCO
- **False Alarm** – No obvious ejecta in LASCO
- **Ambiguous** – In a few cases it was not possible to deem an alert as valid or false. 1 case: CME in LASCO but KCor data is very noisy; 7 cases: KCor sees ejecta but tough to make direct connection with LASCO ejecta
- **Duplicates:** 4 cases: computer crash/reboot (A fix has been implemented to prevent this again); 1 case: human corrected typo
- **Retractions:** MLSO observers retracted 8 automated alerts in near-real time

K-COR IMPROVEMENTS:

Since 2019 improvements have been made to the K-Cor instrument to reduce noise. These include better objective lens cleaning and installation of 'ultra-black' light-absorbing materials to reduce stray light. Spar tracking has been improved to provide better solar-pointing. These improvements can be seen in the increased percentage of CME alerts for SEP-CMEs highlighted earlier in this poster. 11 of the 31 SEP-CMEs were missed. Of these, 10 of the misses were prior to 2019. **Since 2019, K-Cor alerts identified 11/12 (91.7%) of the SEP-CMEs occurring when K-Cor had data.**

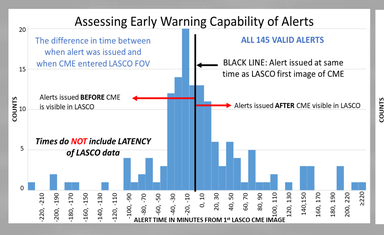
Current work includes reducing false alarms by 'identifying' rising material that stops or fades below 2 solar radii. Alerts sent for this type of material account for most false alarms. We are working to increase the number of valid alerts by improving subtraction image quality and modifying the detection thresholds used to find regions-of-interest.

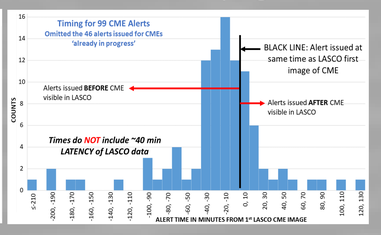
CCOR CORONAGRAPH GOES-U

The upcoming CCOR coronagraph will have lower data latency than LASCO [15 vs 40 minutes] but CCOR has a higher inner field-of-view [2.0 vs 3.6 solar radii]. ***CMEs will need to travel farther to be seen in CCOR***. This additional time significantly reduces the advantage of the lower CCOR latency. ***The K-Cor alerts will still provide useful early warning***.

GROUND-BASED CORONAGRAPH NETWORK

Ground-based provides very low latency, lower cost, and decades-long observations with instrument upgrades. ***The largest disadvantage is low duty cycle***. A ground-based coronagraph network can provide high duty cycle for CME-SEP forecasting. NCAR is a partner on the NSO next-generation GONG (ngGONG) mission that includes K-Cor and emission line coronagraphs (UCoMP). A network observes most CMEs, **AND** avoids the situation when a CME is in-progress when observations begin. In-progress CMEs cause alerts to be issued when the CME is higher in the corona. Near right shows 145 alerts that include 46 CMEs that were in-progress when K-Cor began. When those are removed, warning time increases (see far-right plot).
A network observes most CMEs and increases the avg warning time





CONTACT: If you would like to be added to the CME alert list, or if you want a copy of this poster, more detailed alert statistics, or other information please email Joan Burkepile [NCAR] at iguana@ucar.edu