British Geological Survey
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Statistics of Coronal Mass Ejections for use in Space weather Forecasting

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Forecasts of geomagnetic activity are vital for helping to protect vulnerable technological infrastructure. However, in an operational forecast situation we can have relatively little data with which to make a decision about the level of expected activity. Whilst advances in modelling techniques and increases in data availability are helping, there is still a knowledge gap and forecasts still depend heavily on the judgement of the forecaster. The aim of this work is to help forecasters put CMEs into context, based on past events, in a straightforward manner.

Method

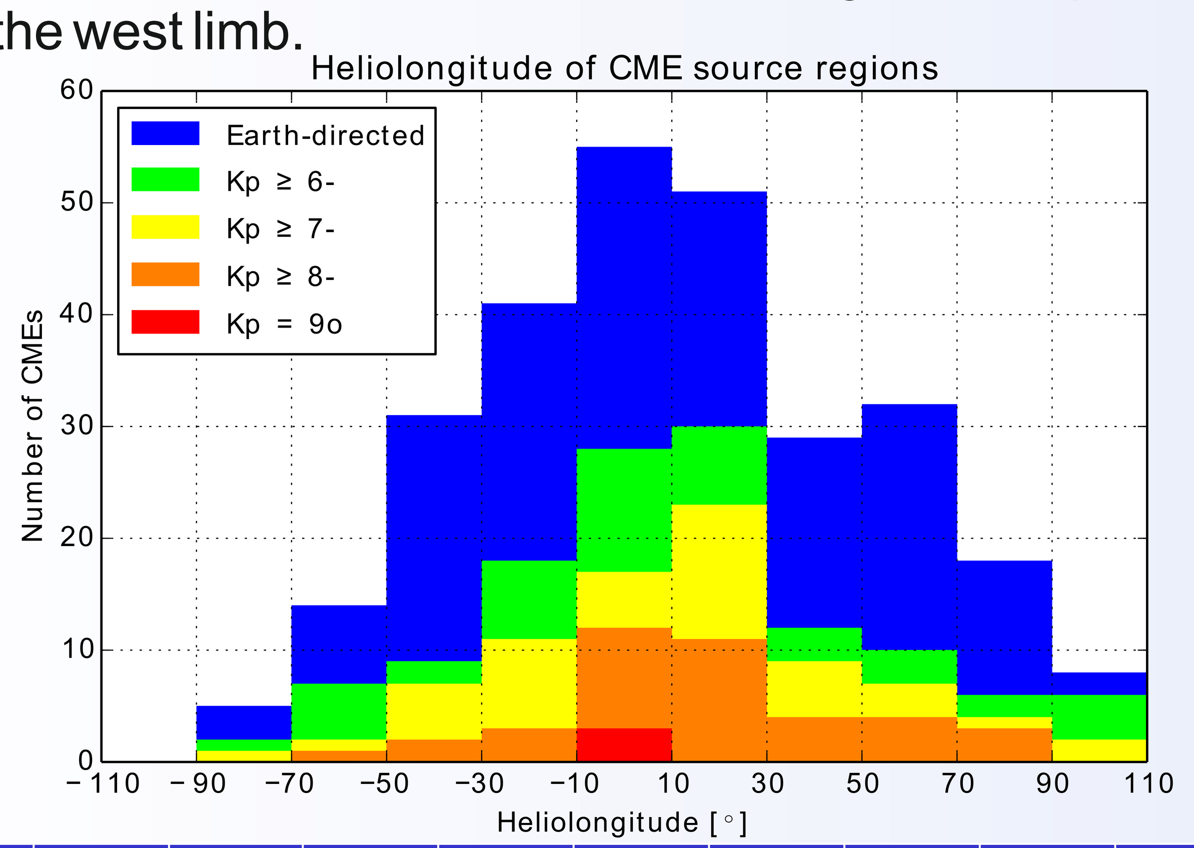
- Collected speed, angular width and position angle for all CMEs between Jan 1998-Dec 2009 from the LASCO CME catalogue [1]
- Used the NOAA Space Weather Prediction Centre reports to determine if the CME had an Earth-directed component
- For Earth directed CMEs we then found:
  - ⇨ Characteristics of the source (i.e. filament or flare)
  - ⇨ CACTus CME catalog [2] (near real time) information
  - ⇨ Date and time of arrival at Earth
  - ⇨ Highest Kp value after arrival [3]
- This was then cross referenced with all occurrences of Kp ≥ 6-
- We identified 301 CMEs with an Earth-directed component for further analysis

Issues

- In general CMEs with velocity < 500 km/s are not mentioned in the reports making it hard to determine if they were Earth-directed.
- As we are focussing on CMEs that may concern a forecaster, if a CME is not mentioned at all in any reports it is considered not to be Earth-directed for the purposes of this study.
- However, all CMEs mentioned in the reports as having potential to impact the Earth are included, no matter their velocity.
- The location used is the location of the source (flare/filament) which may not be the exact location of the CME itself.
- There are some gaps in the catalogues (due to data shortages) so this is not a complete record.

Heliolongitude

Most Earth-directed CMEs originate from the central 20° on the Sun's disc, and CMEs in the western hemisphere are more likely to be Earth-directed than those in the east. CMEs in the western hemisphere (particularly heliolongitudes of 10°-30°) are also more likely to cause storms than other bins, although the largest storms (Kp ≥ 8-) follow CMEs from the centre of the Sun. It is also worth noting that CMEs occurring on the limbs which are big enough to have an Earth-directed component also have an increased chance of causing storms, particularly from the west limb.



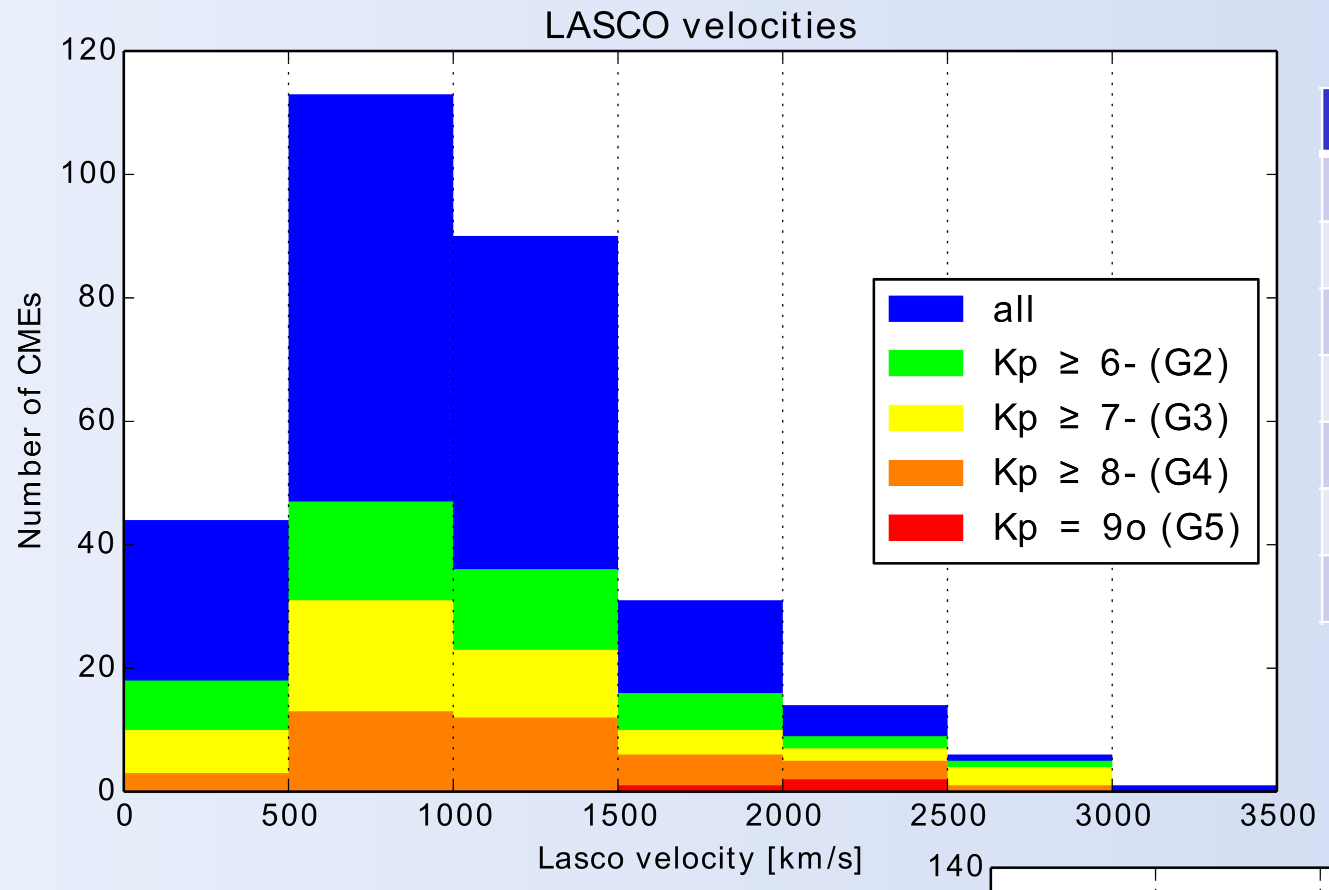
Kp	< -90	-90 to -70	-70 to -50	-50 to -30	-30 to -10	-10 to 10	10 to 30	30 to 50	50 to 70	70 to 90	> 90
≥6-		40.0	50.0	29.0	43.9	50.9	58.8	41.4	31.3	33.3	75.0
≥7-		20.0	14.3	22.6	26.8	30.9	45.1	31.0	21.9	22.2	25.0
≥8-			27.1	6.5	7.3	21.8	21.6	13.8	12.5	16.7	
=9o						5.5					

Table 1. Percentage likelihood of geomagnetic storms for bins of heliolongitude

Velocity

For the estimates of linear velocity in the LASCO catalogue we find the largest number of Earth-directed CMEs have velocities of 500-1000km/s, and CMEs in this bin also caused the largest number of geomagnetic storms. However, the percentage likelihood of a CME causing a geomagnetic storm increases with velocity (Table 2). Whilst this analysis is useful these velocities are produced manually well after the event so these statistics are not helpful for forecasting. (Note the number of Earth-directed CMEs with v < 500km/s is probably underestimated).

The CACTus estimates of (median) velocity are generated automatically in near real-time, and are therefore more widely used for space weather forecasting. In general the CACTus estimates are lower than the LASCO velocities, but the 500-1000 km/s bin still has the largest number of Earth-directed CMEs and geomagnetic storms. Because the velocities fall into fewer bins, with CACTus never estimating velocities over 2000km/s during this study (Table 3), the percentage likelihood of a storm is reduced overall.

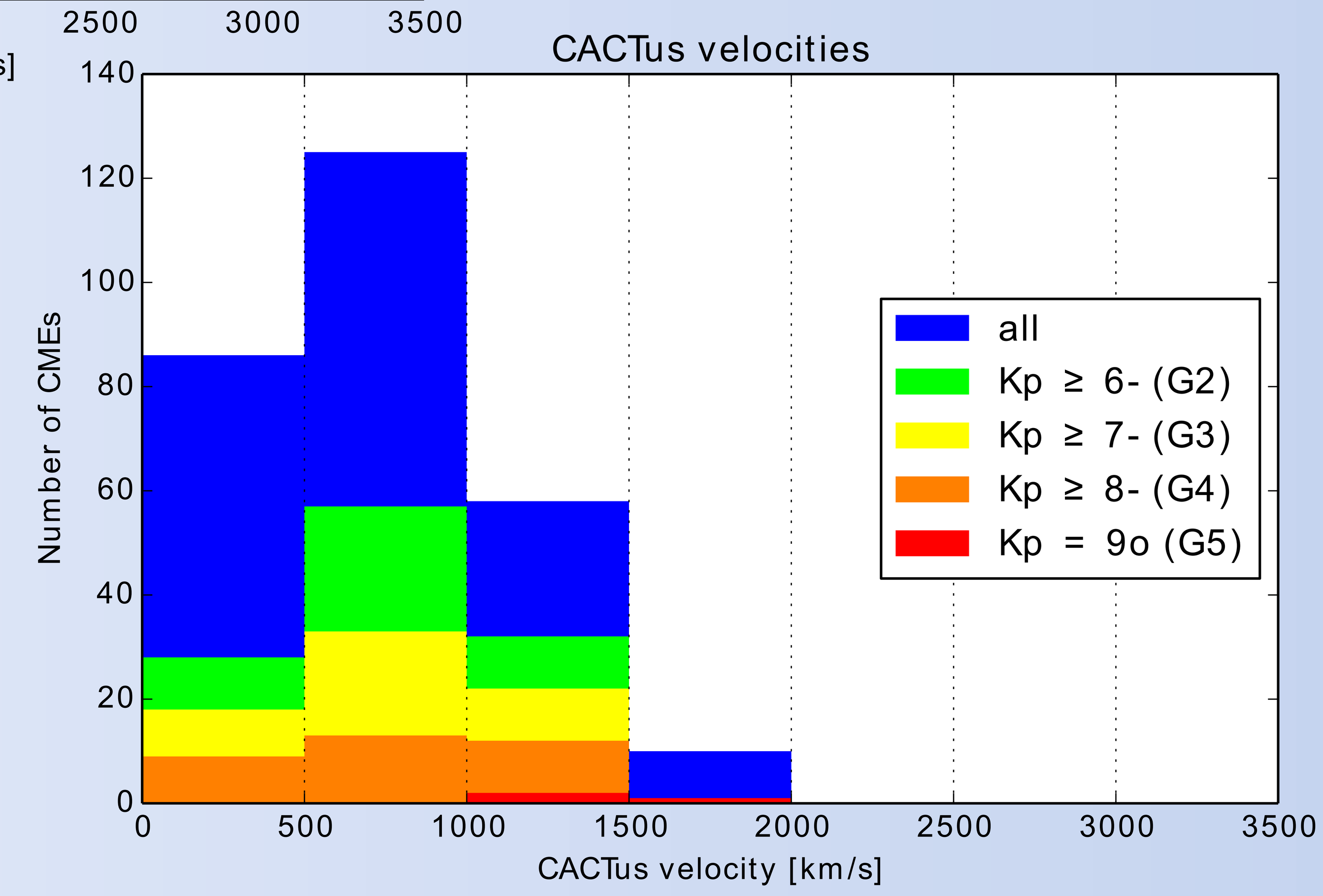


V [km/s]	Kp = 9o	Kp > 8-	Kp > 7-	Kp > 6-
< 500		6.8	22.7	40.9
500 - 1000		11.5	27.4	41.6
1000 - 1500		13.3	25.6	40
1500-2000	3.2	19.4	32.3	51.6
2000-2500	14.3	35.7	50	64.3
2500-3000		14.3	57.1	71.4
> 3000				

Table 2. Percentage likelihood of geomagnetic storms for LASCO velocities

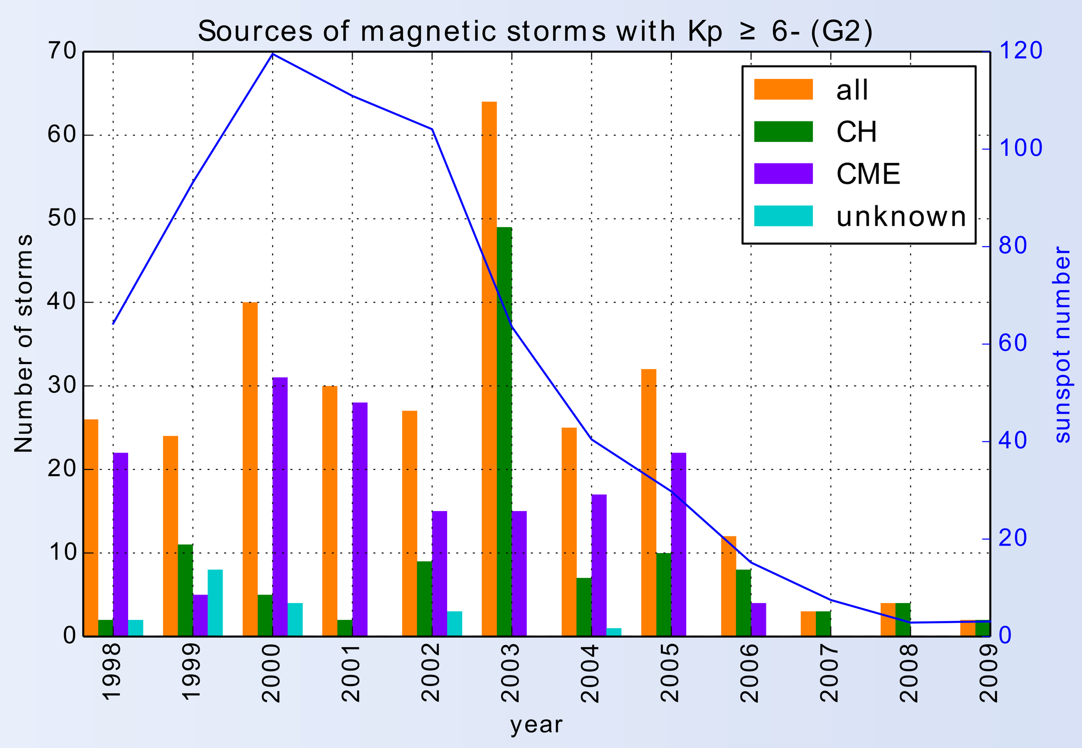
V [km/s]	Kp = 9o	Kp > 8-	Kp > 7-	Kp > 6-
< 500		10.5	20.9	32.6
500 - 1000		10.4	26.4	45.6
1000 - 1500	3.4	20.7	37.9	55.1
1500-2000	10.0	10.0	10.0	10.0
2000-2500				

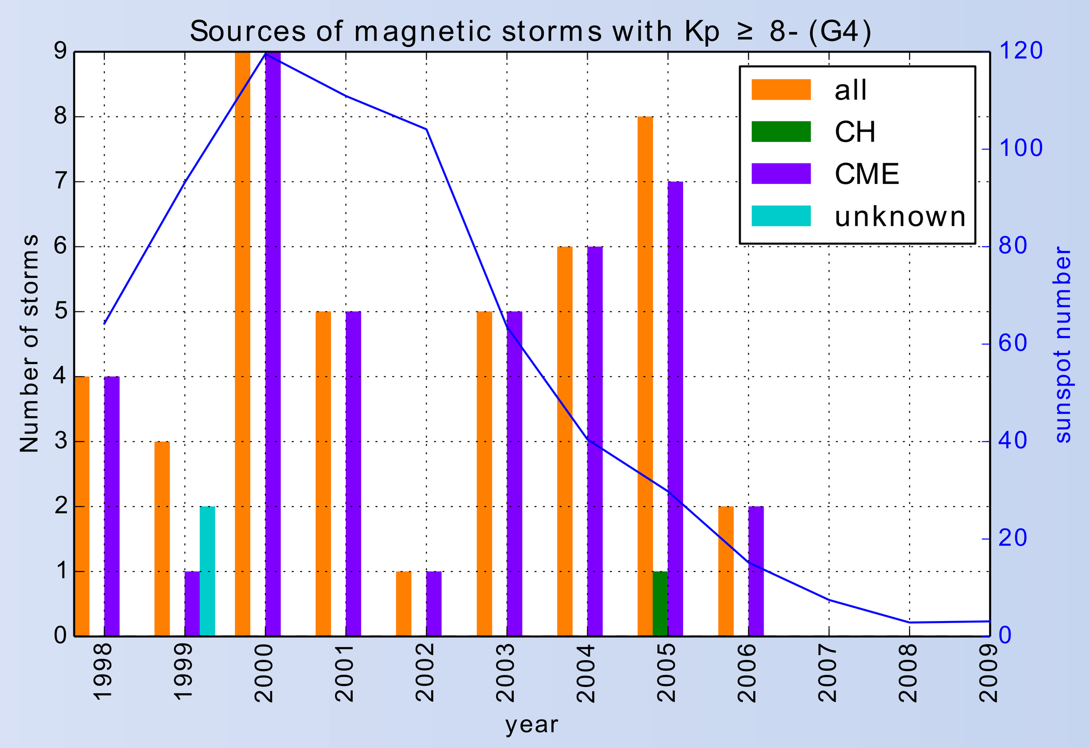
Table 3. Percentage likelihood of geomagnetic storms for CACTus velocities



Storm source

The plots below show the number of days when the maximum Kp reached 6- (left) or 8- (right) and over, the blue line indicates the solar cycle. In this data set the highest number of storms (Kp > 6-) occurs in 2003, during the descending phase of the solar cycle, mostly caused by coronal hole effects. Larger storms (Kp > 8-) are almost exclusively caused by CMEs with the highest number at solar maximum, although the number of CME related storms during the decending phase is also significant.





Summary & further work

Whilst many of these results may not come as a great surprise to most forecasters, being able to assess the statistical chance of a storm given a set of CME information is still a useful tool. In the future we intend to provide a multivariate analysis of CME features to make it easier for forecasters to assess the likely impact of a CME. We also intend to continue to improve and update the database with more recent CMEs.

Acknowledgements + references

1. LASCO CDAW CME catalogue: "This CME catalog is generated and maintained at the CDAW Data Center by NASA and The Catholic University of America in cooperation with the Naval Research Laboratory. SOHO is a project of international cooperation between ESA and NASA."
2. CACTus CME catalog - Robbrecht, E., Berghmans, D. Automated recognition of coronal mass ejections (CMEs) in near-real-time data, Astronomy & Astrophysics, 425, 2004.
3. Definitive Kp from GFZ Potsdam

Hot Spring MIST, Bath, 23-25 April 2014