British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Gateway to the Earth

Analysis of parameters of coronal mass ejections available in near real-time for operational space weather forecasting

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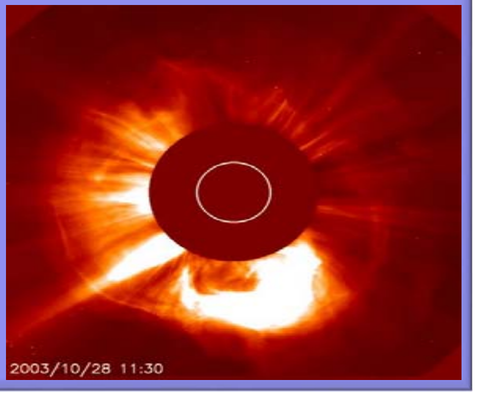
Previous studies

- Mostly use SOHO LASCO CME catalog (CDAW)
- Useful and important work in understanding CME properties....but compiled manually and not available in near real-time
- Known differences between CDAW and CACTus [e.g. Yashiro et al. *Ann. Geophys*. 2008, and Robbrecht & Berghmans, *A & A*, 2004]
- So, can we come up with some useful statistics about geoeffectiveness of CMEs for use in an operational setting?

Forecasting resources

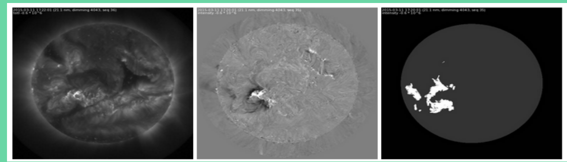
Data:

- LASCO images
- STEREO (ish)
- PROBA2
- ACE
- GOES
- SDO
- ...



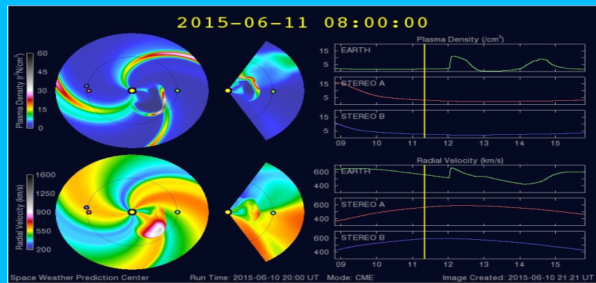
Automated products

- CACTus
- SEEDS
- CORIMP
- Solardemon



Other prediction tools:

- Drag based model
- StereoCAT
- WSA Enlil
- …



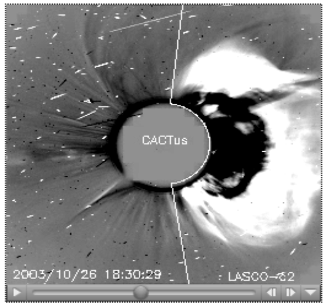
CACTus CME catalog

CACTUS
A software package for 'Computer Aided CME Tracking'

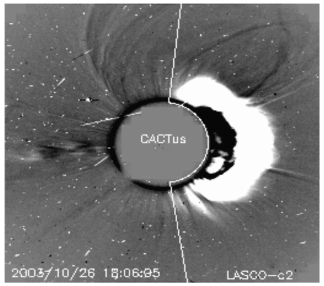
Details and graphs for CME0049

```
# CME |          t0      | dt0| pa | da |  v  |  dv | minv| maxv| halo?
  0049|2003/10/26 18:06| 02 | 271| 164| 1117| 0327| 0578| 1644|  II
```

CME Movie :: Download ::



Sample Image



Robbrecht & Berghmans,
Astron. & Astrophys. 2004

- Near real-time automated CME detection tool
- Provides an estimate of:
  - Onset time
  - Duration of liftoff
  - Principal angle
  - Angular width
  - Median velocity
  - Variation of velocity (1 sigma)
  - Lowest velocity detected
  - Highest velocity detected

Process

- Used CMEs from the CACTus catalog between 1998-2009
- Searched through SWPC daily reports of solar geophysical activity
- If a CME was considered at the time to be heading towards Earth (at least in part) it is marked as Earth-directed
- Combination of SWPC reports, GOES X-ray lists and the HELIO context service used to identify associated flares and filaments (and their location)
- Arrivals at Earth identified using combination of Richardson & Cane ICME list, ACE shock list, Kp index and SWPC summaries up to 5 days after an event

How do we define a storm?

- For the purposes of this study we categorise storms according to the NOAA G-scales
- We concentrate on storms of G2 and above (i.e. Kp ≥ 6-)

Scale	Description	Effect	Physical measure	Average Frequency (1 cycle = 11 years)
G 5	Extreme	**Power systems:** Widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. **Spacecraft operations:** May experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. **Other systems:** Pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.).	Kp = 9	4 per cycle (4 days per cycle)
G 4	Severe	**Power systems:** Possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. **Spacecraft operations:** May experience surface charging and tracking problems, corrections may be needed for orientation problems. **Other systems:** Induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.).	Kp = 8, including a 9-	100 per cycle (60 days per cycle)
G 3	Strong	**Power systems:** Voltage corrections may be required, false alarms triggered on some protection devices. **Spacecraft operations:** Surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. **Other systems:** Intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.).	Kp = 7	200 per cycle (130 days per cycle)
G 2	Moderate	**Power systems:** High-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. **Spacecraft operations:** Corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. **Other systems:** HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.).	Kp = 6	600 per cycle (360 days per cycle)
G 1	Minor	**Power systems:** Weak power grid fluctuations can occur. **Spacecraft operations:** Minor impact on satellite operations possible. **Other systems:** Migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine).	Kp = 5	1700 per cycle (900 days per cycle)

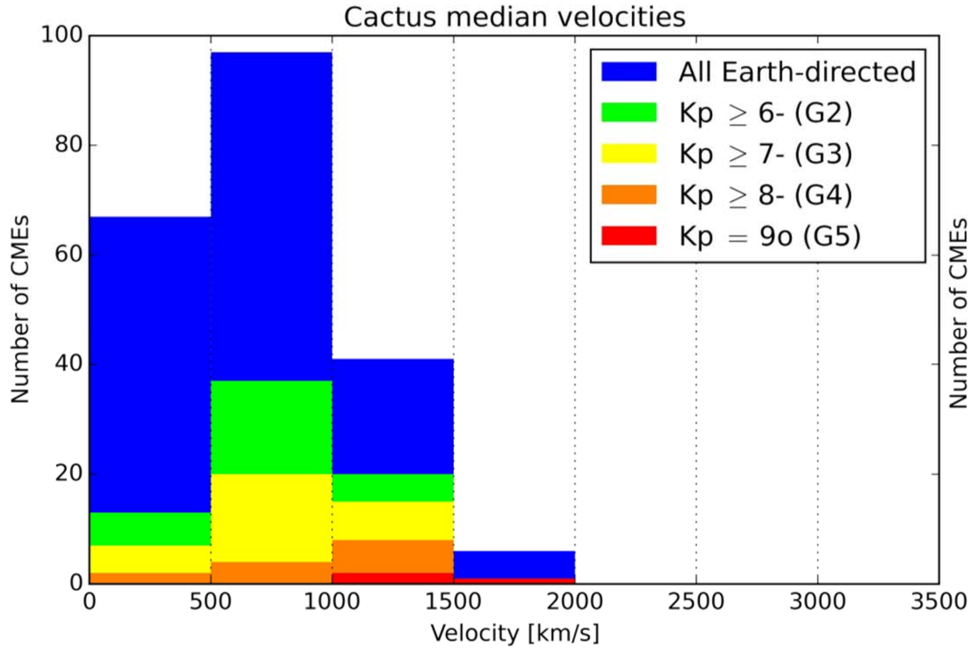
NOAA SWPC: www.swpc.noaa.gov/noaa-scales-explanation

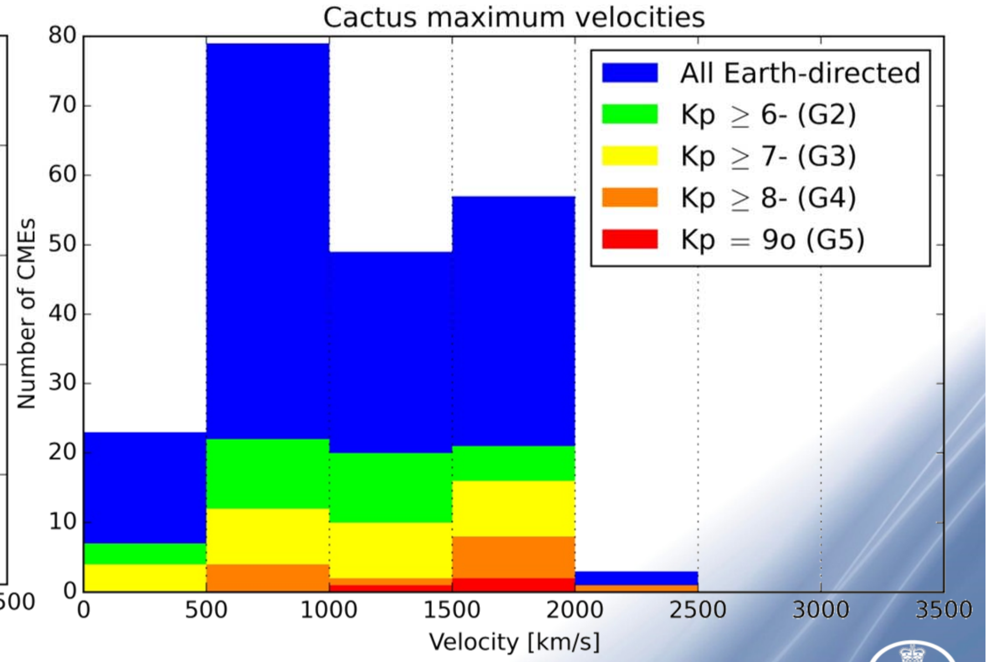
Data summary

- 9809 total CMEs in this time period
- 264 Earth-directed CMEs identified
- 53 of which arrived in combination with other CMEs
- A further 16 were not considered to be Earth-directed but did arrive at Earth
- In total 114 led to storms ≥ G2
- Excluding those that arrived in combination 71 led to storms ≥ G2

Velocity

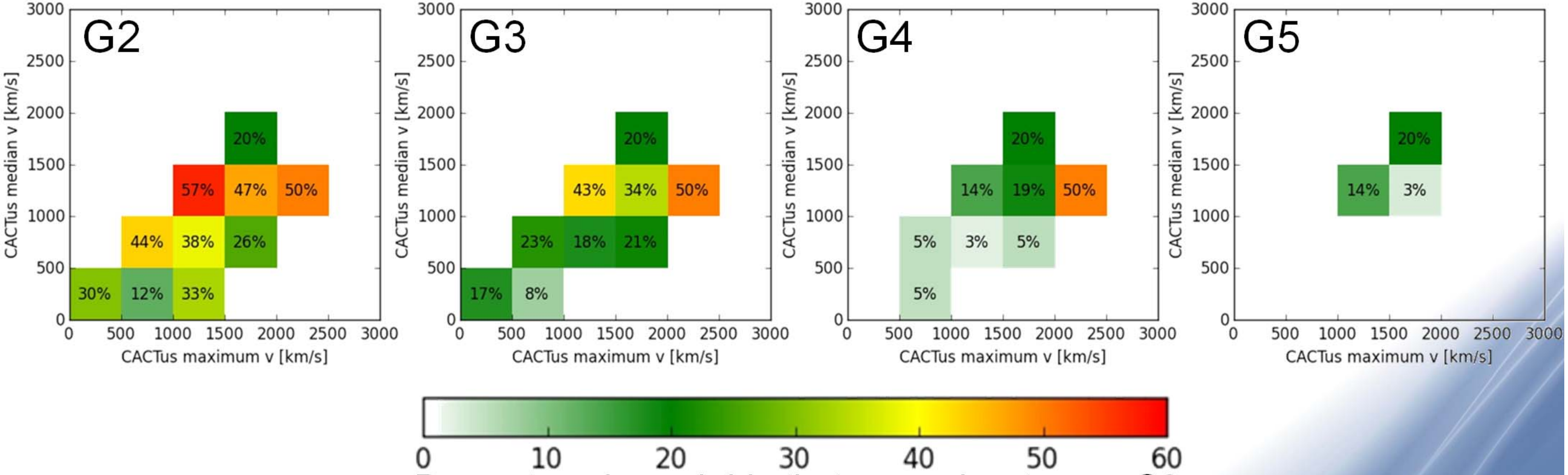
- In bins of 500km/s





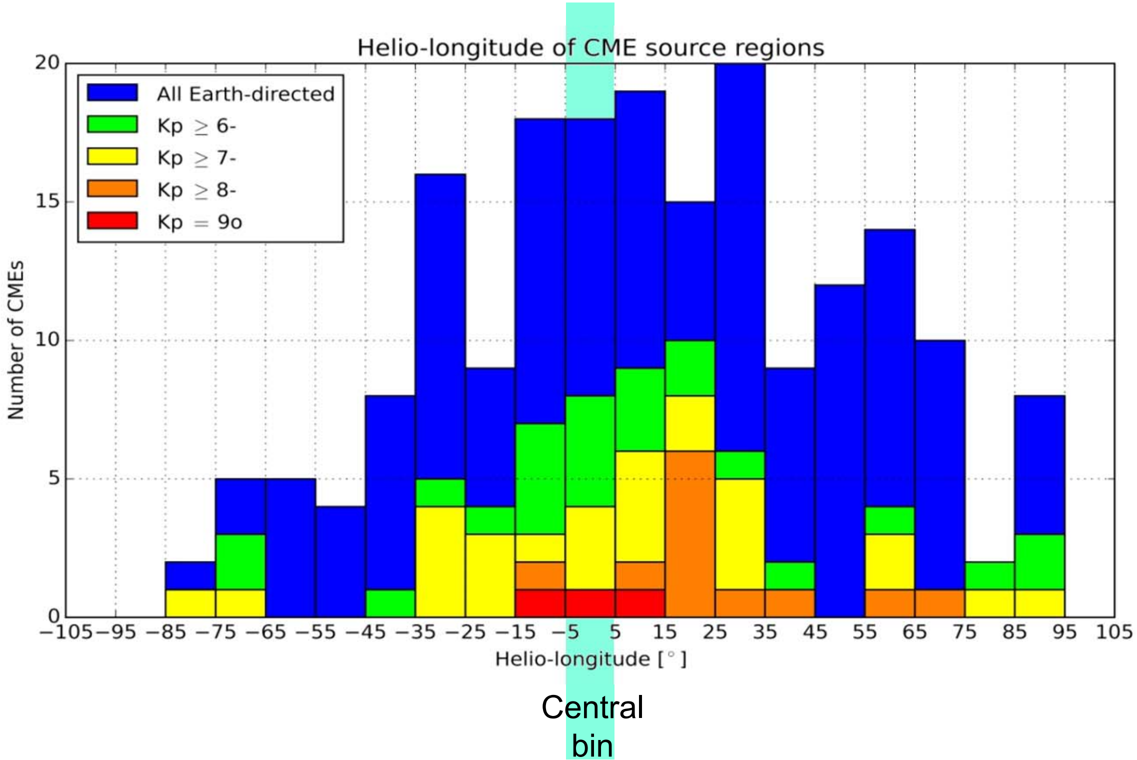
Combined velocity

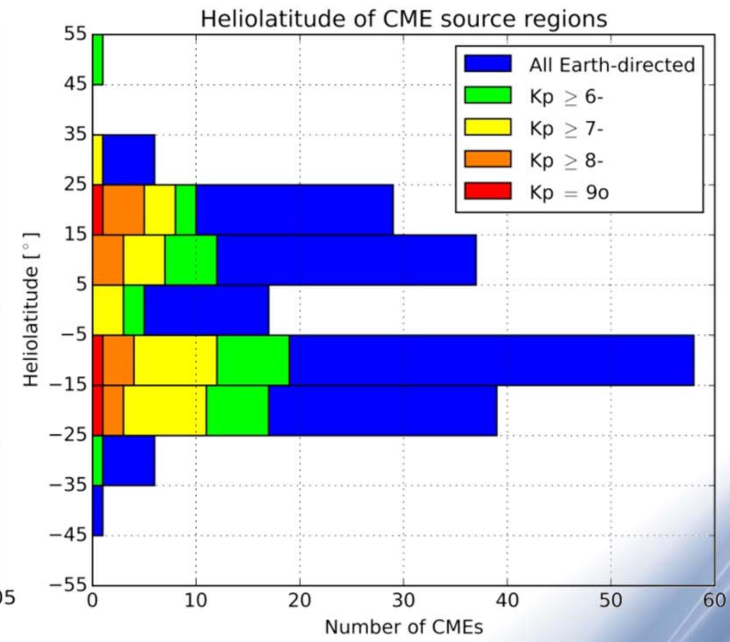
- CACTus maximum velocity against CACTus median velocity



Percentage in each bin that caused a storm ≥ G2

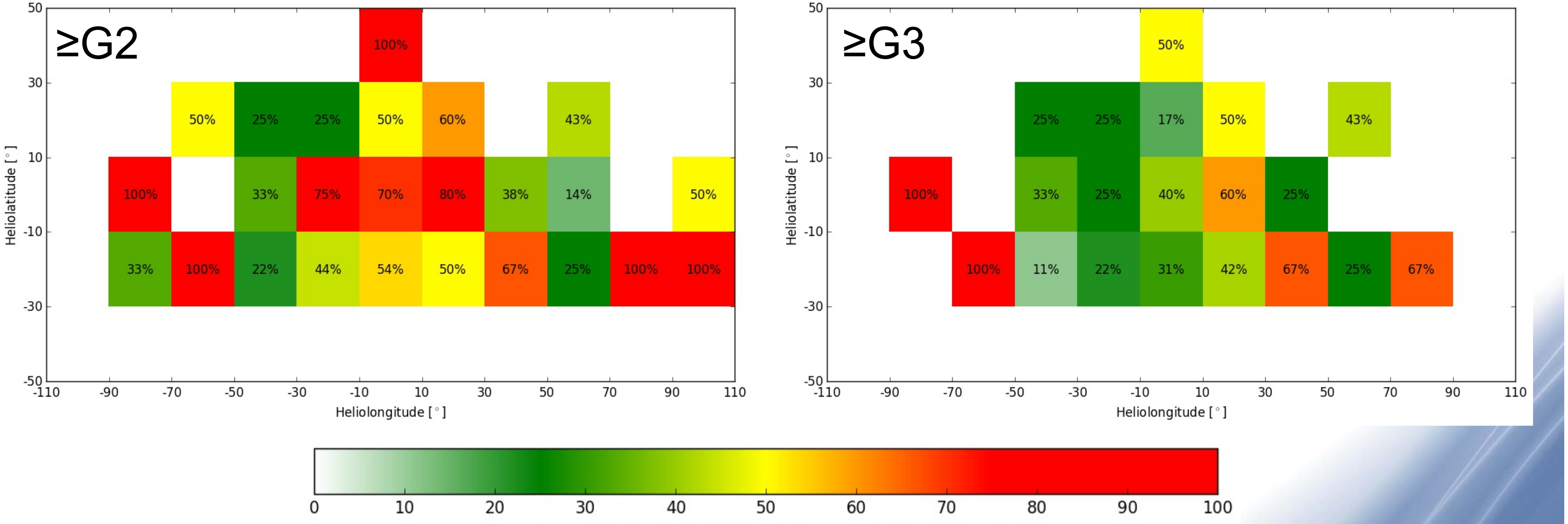
Location


Helio-longitude of CME source regions
All Earth-directed
Kp ≥ 6-
Kp ≥ 7-
Kp ≥ 8-
Kp = 9o
Number of CMEs
0
5
10
15
20
−105 −95 −85 −75 −65 −55 −45 −35 −25 −15 −5 5 15 25 35 45 55 65 75 85 95 105
Helio-longitude [°]
Central bin


Heliolatitude of CME source regions
All Earth-directed
Kp ≥ 6-
Kp ≥ 7-
Kp ≥ 8-
Kp = 9o
Heliolatitude [°]
55
45
35
25
15
5
-5
-15
-25
-35
-45
-55
0 10 20 30 40 50 60
Number of CMEs

Combined location

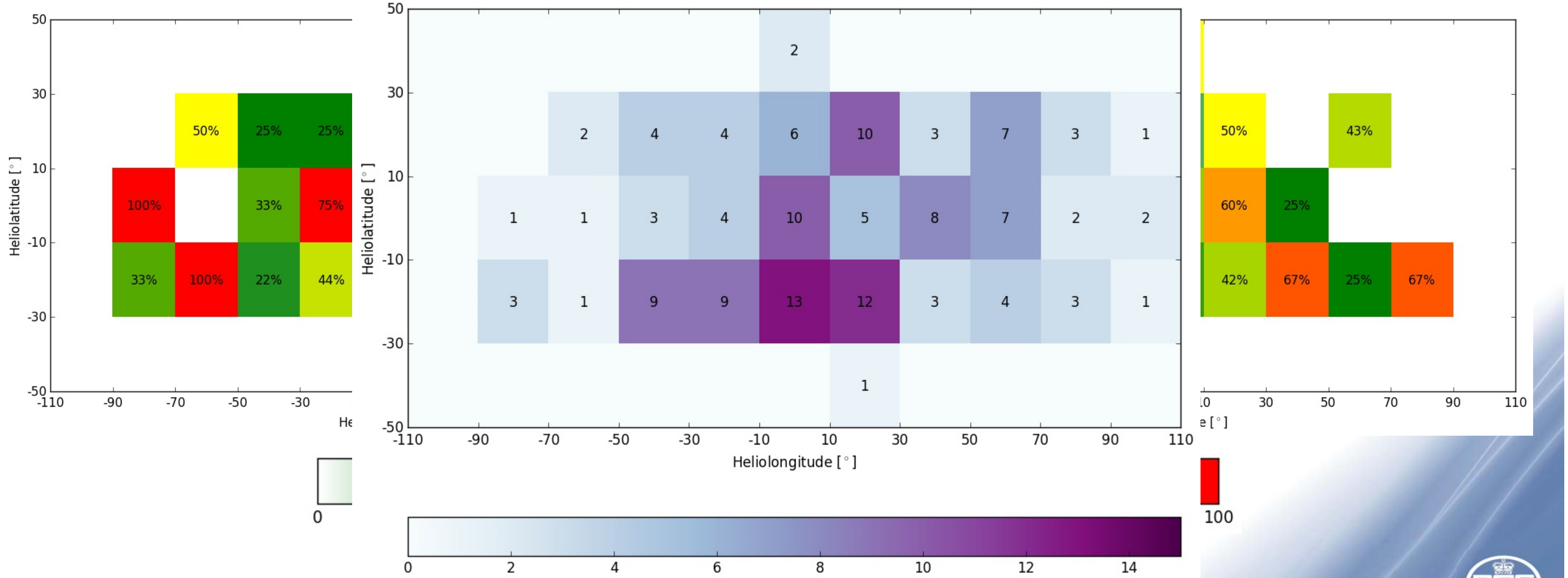
- Heliolongitude plotted against heliolatitude in 20° bins



Percentage in each bin that caused a storm

Combined location

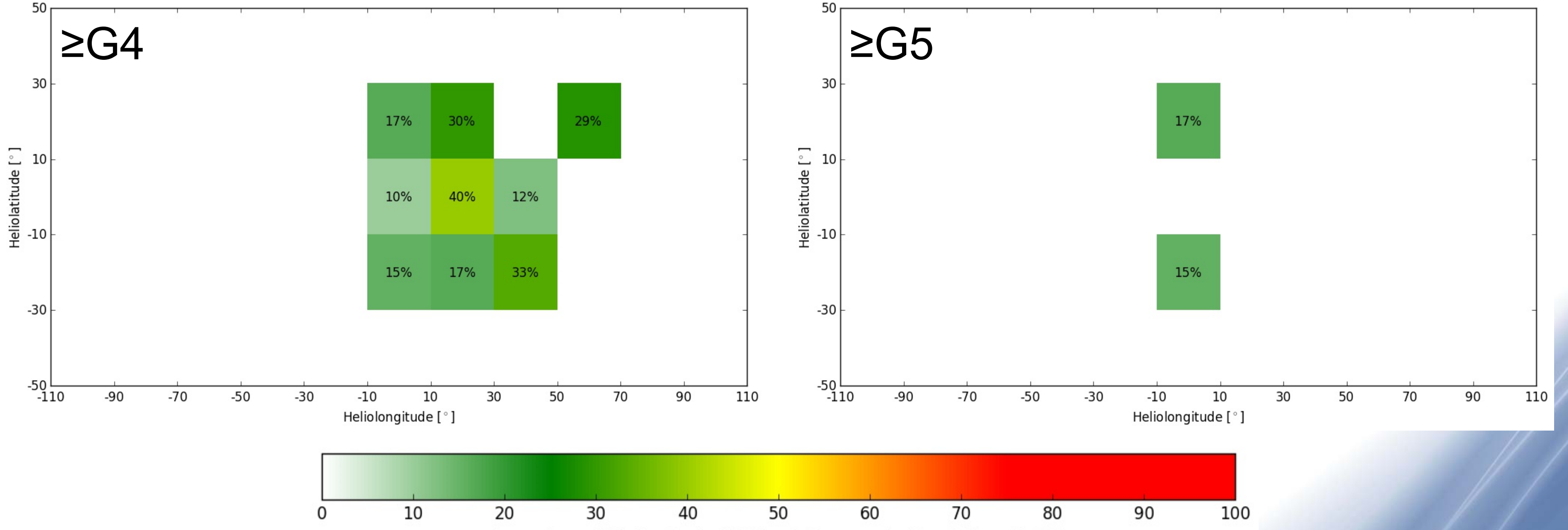
- Heliolongitude plotted against heliolatitude in 20° bins



Count of all CMEs in each bin

Combined location

- Heliolongitude plotted against heliolatitude in 20° bins



Percentage in each bin that caused a storm

Flares and Filaments

Flare Class	Total	≥ G2	≥ G3	≥ G4	= G5
B	7	29%			
C	46	9%	20%	7%	
M	88	16%	8%	3%	
X	42	5%	24%	14%	7%
Filament	25	20%	4%		

How does this relate to the scientific results?

- CACTus velocity estimates generally slower than CDAW & apparent saturation in velocities >2000km/s
- Kp 9 events have CDAW catalog velocities > 1500km/s (1000km/s for CACTus)
- More geoeffective CMEs in western hemisphere consistent with previous studies [e.g. Kim et al. *J. Geophys Res*. 2005, Zhang et al. *J. Geophys. Res.* 2007].

Summary

- Reviewed CACTus entries between 1998-2009
- 34% of individual 'Earth-directed' CMEs led to geomagnetic storms of G2 or above (Kp ≥ 6-)
- G5 (Kp = 9o) events only occur when:
  - Both median and max velocity estimates > 1000km/s
  - Associated flare in central 20° heliolongitude and between ±10-30° heliolatitude
  - Associated with X-class flares
- Tables could provide a quick guide for determining geoeffectiveness of CMEs in an operational environment.
- But...more data required to make fully robust statistics

Ideas for future work

- Extend to a longer time period
- Repeat with SEEDS [Olmedo et al. *Solar Phys*. 2008] and/or CORIMP [Byrne et al. *Astrophys. J.* 2012]
- Include other measures of geomagnetic activity to better determine GIC risk (e.g. dB/dt) [talk in session A18 at 9.45 Sat 27th]