

The What and the How of Operational Space Weather Forecasting

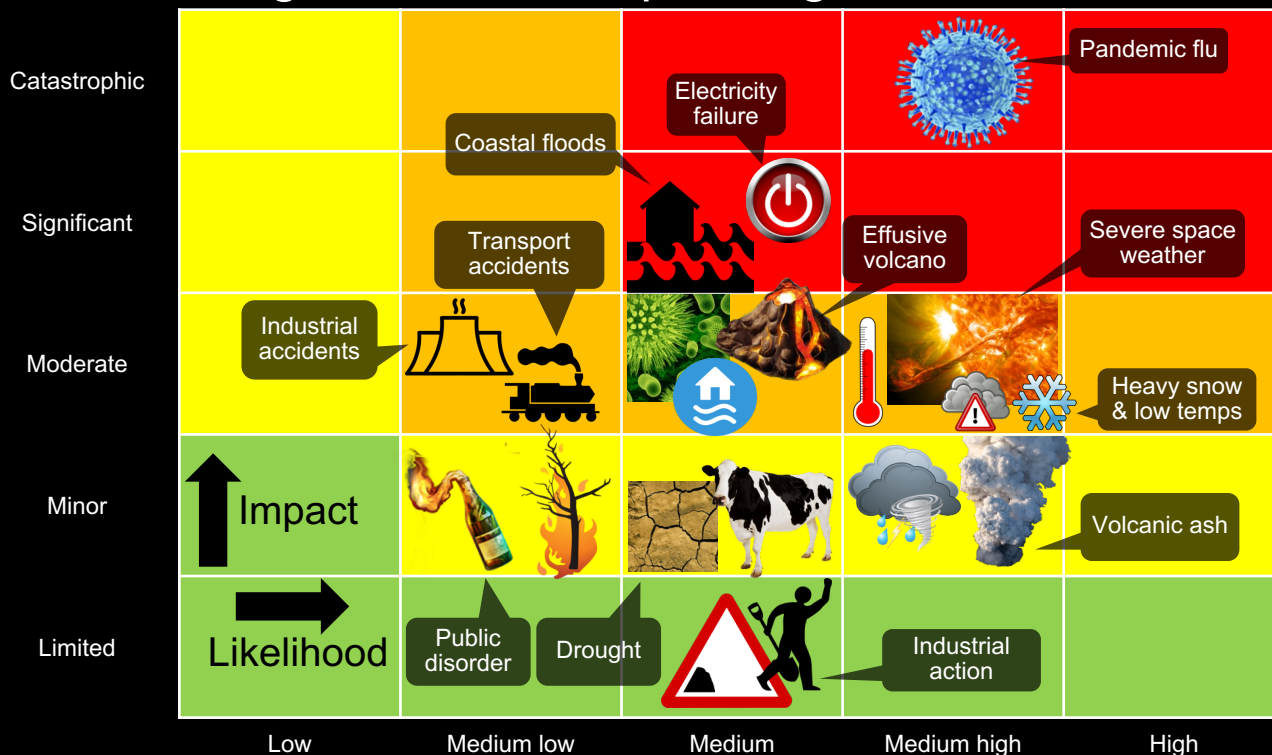
The work of MOSWOC and where we're going

Mark Gibbs, Head of Space Weather

9th Nov 2017, Uppsala

National risk register

The UK government response guide

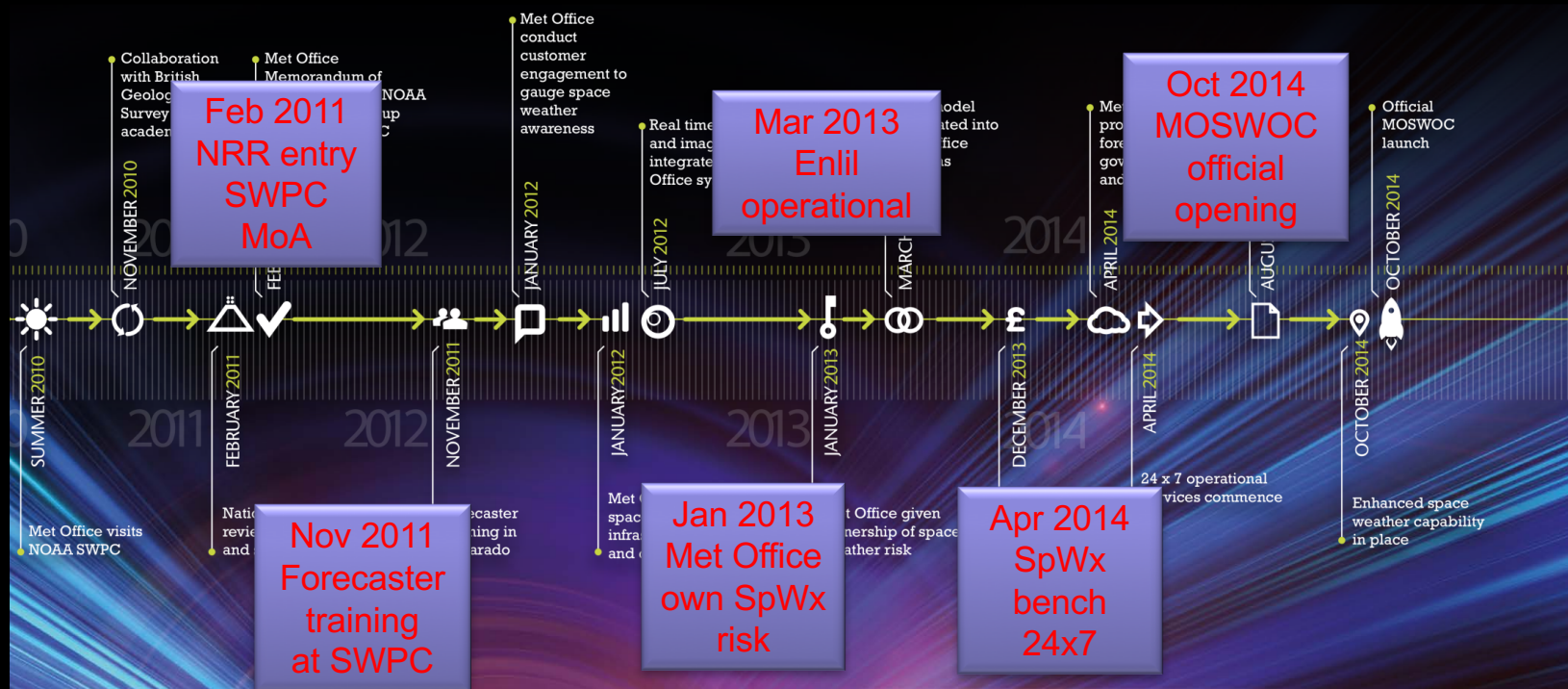


Cost?
£billions

Certainly
1 in 100yr

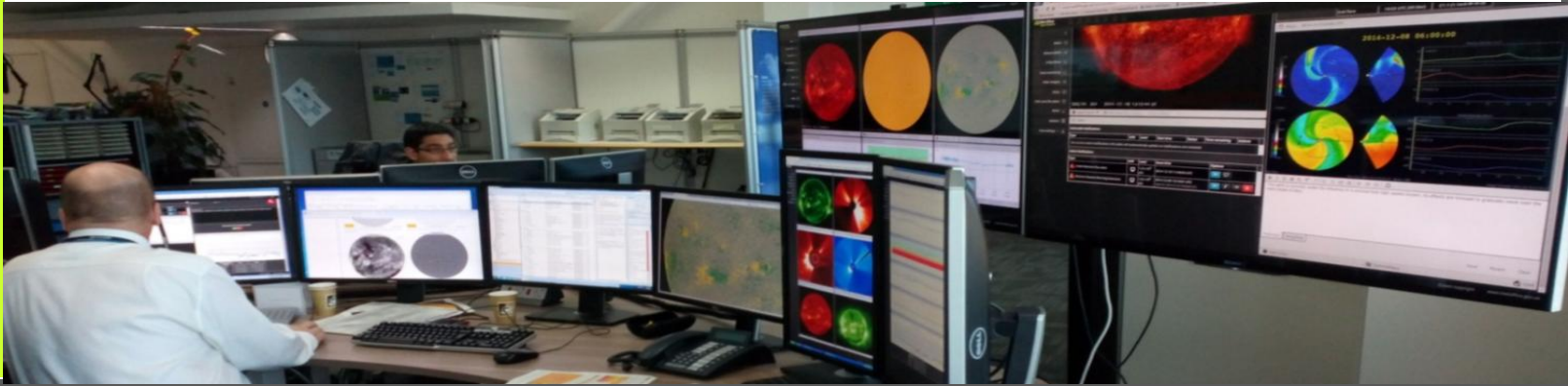
1 in 30 yrs?

A space weather journey through time



Met Office Space Weather Operations Centre (MOSWOC)

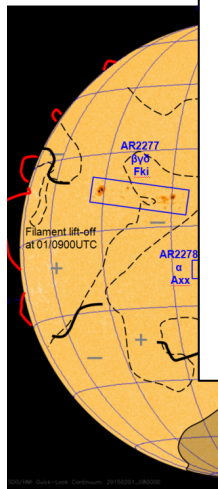
- Fully integrated within Met Office Operations Centre
- One of 3 centres manned 24/7 globally
 - NOAA SWPC & 557th
- 14 trained forecasters (1 dedicated + 1 on shift)
- 6 R2O, 5 IT developers & 4 Programme Office
- Runs models independently of US partners





Met Office

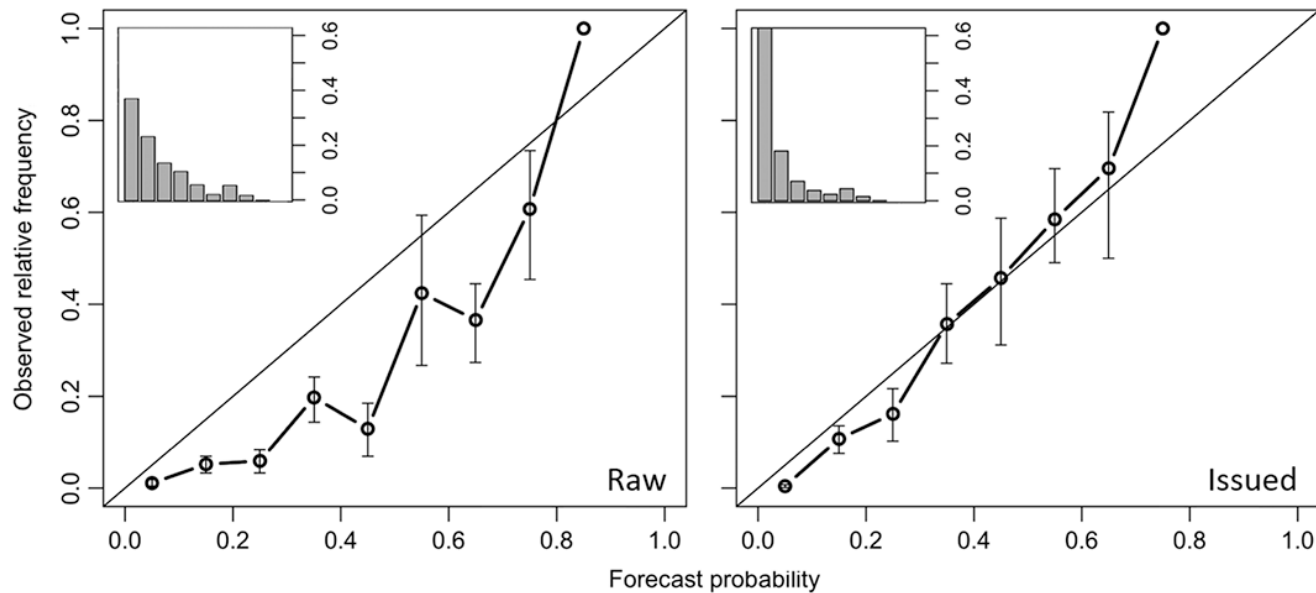
Solar disk analysis



No.	Loc	Lo	Area	Z	LL	NN	Mag Type	Growth	M	X	P
23xx	S13W23	102	20	Bxo	4	3	Beta	Increase	1	0	0
2393	N18W20	99	30	Hsx	1	1	Alpha	Nil	2	0	0
2394	N11E01	78	190	Cai	6	9	Gamma	Nil	12	0	1
2395	N12E51	28	40	Hsx	1	1	Alpha	Nil	2	0	0
2396	S18E42	37	270	Dai	9	12	Beta-Gamma	Increase	14	1	1
Total Raw %									28	1	2
Total Issued %									5	1	1

X Ray Flares	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC)	Day 2 (00-24 UTC)	Day 3 (00-24 UTC)	Day 4 (00-24 UTC)
Probability (Exceedance)			(%)	(%)	(%)	(%)
Active	R1-R2 M Class	N	5	10	10	15
Very Active	R3 to R5 X Class	N	1	1	1	5

Forecaster intervention

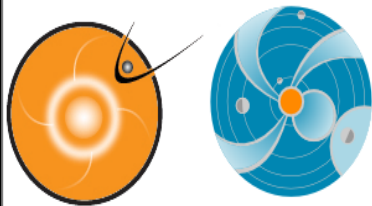
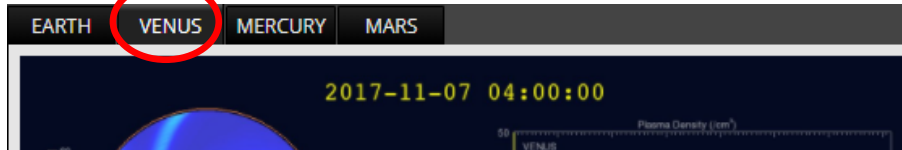


Murray, S. A., S. Bingham, M. Sharpe, and D. R. Jackson (2017), Flare forecasting at the Met Office Space Weather Operations Centre, Space Weather, 15, 577–588, doi:[10.1002/2016SW001579](https://doi.org/10.1002/2016SW001579).



Met Office

Heliosphere



CME ScoreBoard

CME: 2017-10-18T07:00:00-CME-001

Actual Shock Arrival Time: 2017-10-21T03:00Z

Observed Geomagnetic Storm Parameters:

CME Note: These predictions are for STEREO-A. Not for the Earth!

Predicted Shock Arrival Time	Difference (hrs)	Confidence (%)	Submitted On	Lead Time (hrs)	Predicted Geomagnetic Storm Parameter(s)	Method	Submitted By	
2017-10-19T20:00Z	-31.00	----	2017-10-18T16:36Z	58.40	----	WSA-ENLIL + Cone (Met Office)	Met Office (Met Office)	Detail
2017-10-19T18:12Z (-7.0h, +7.0h)	-32.80	----	2017-10-18T16:43Z	58.28	----	WSA-ENLIL + Cone (GSFC SWRC)	Leila Mays (GSFC)	Detail
2017-10-20T03:00Z	-24.00	----	2017-10-18T21:40Z	53.33	----	SARM	Marlon Nunez (UMA)	Detail
2017-10-19T21:44Z	-29.27	----	---	---	----	Average of all Methods	Auto Generated (CCMC)	Detail

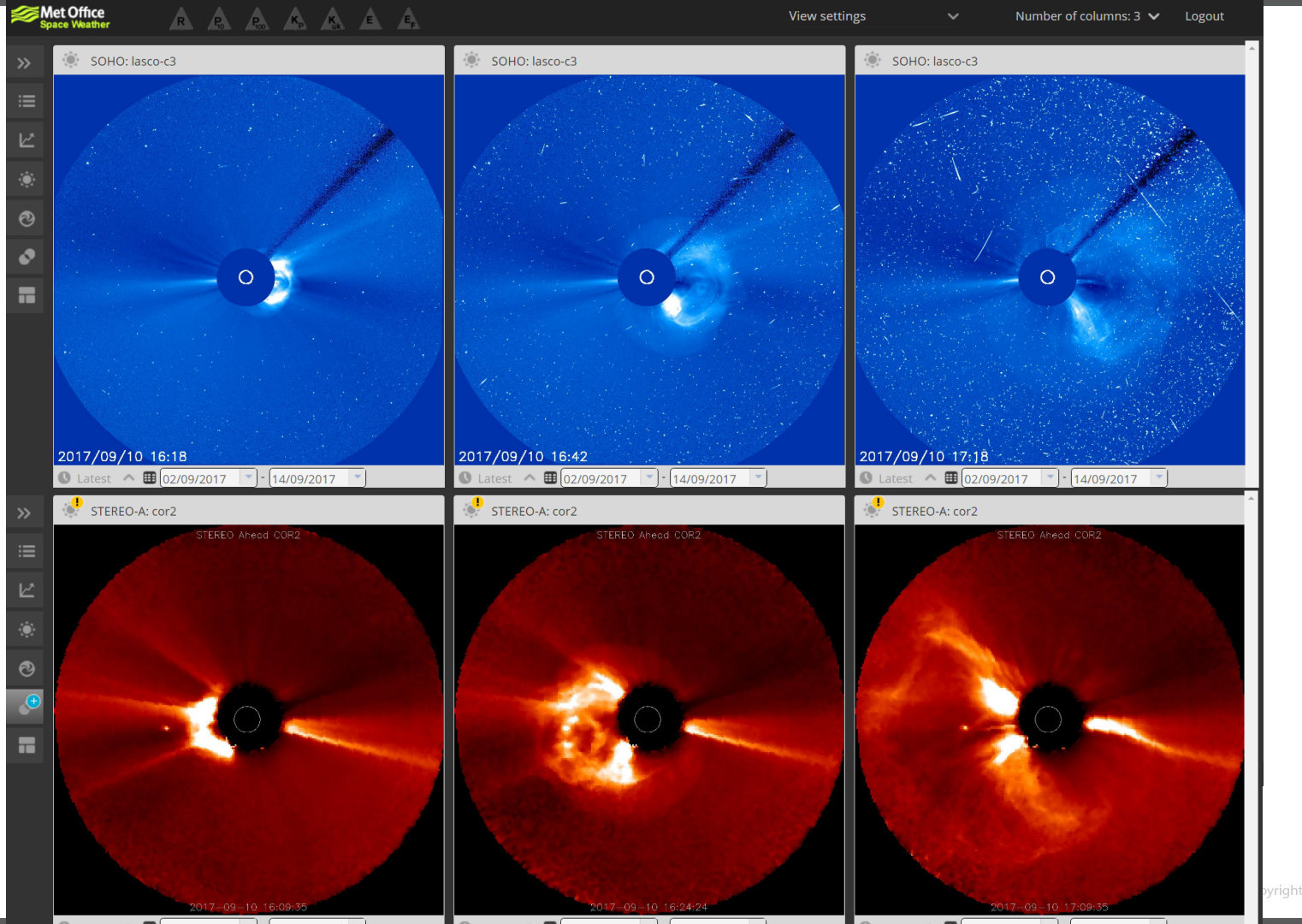




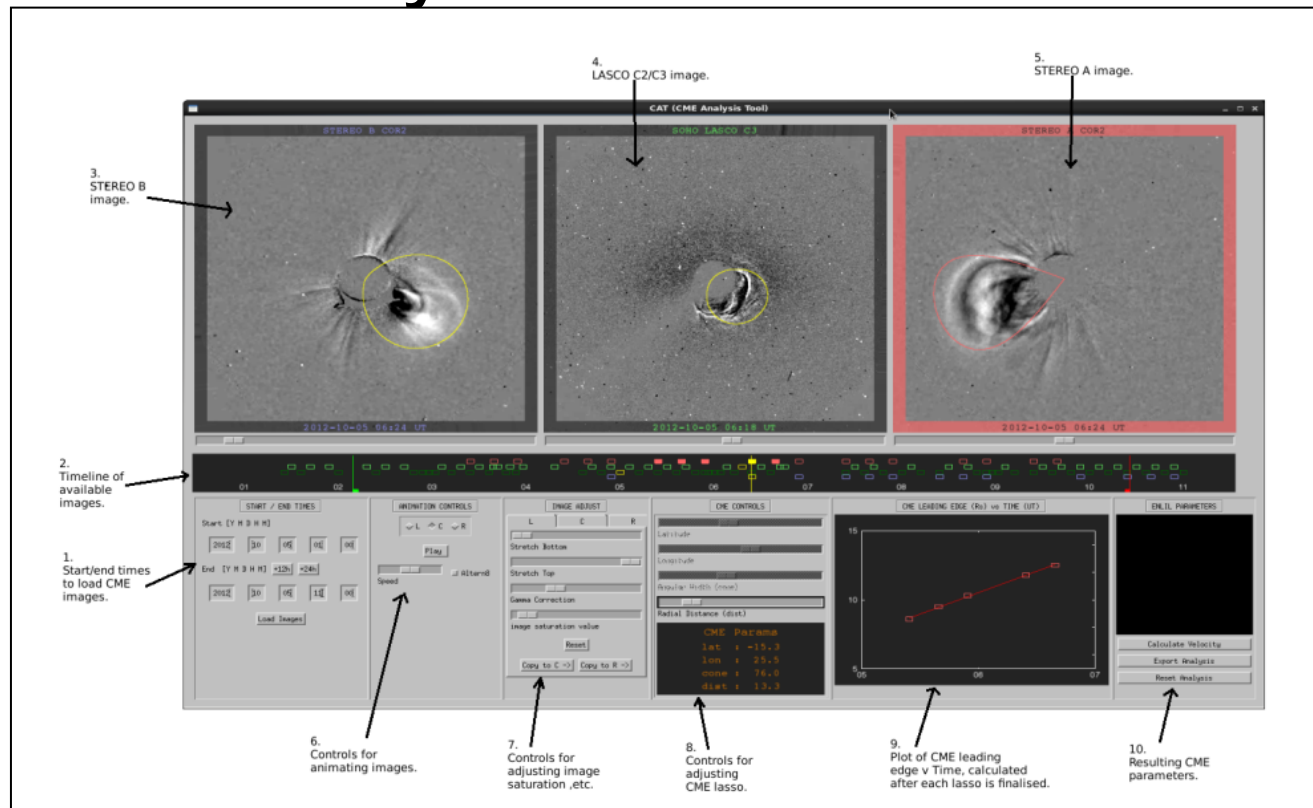
Met Office

AR2673
10 Sept 17

www.metoffice.gov.uk



CME analysis tools

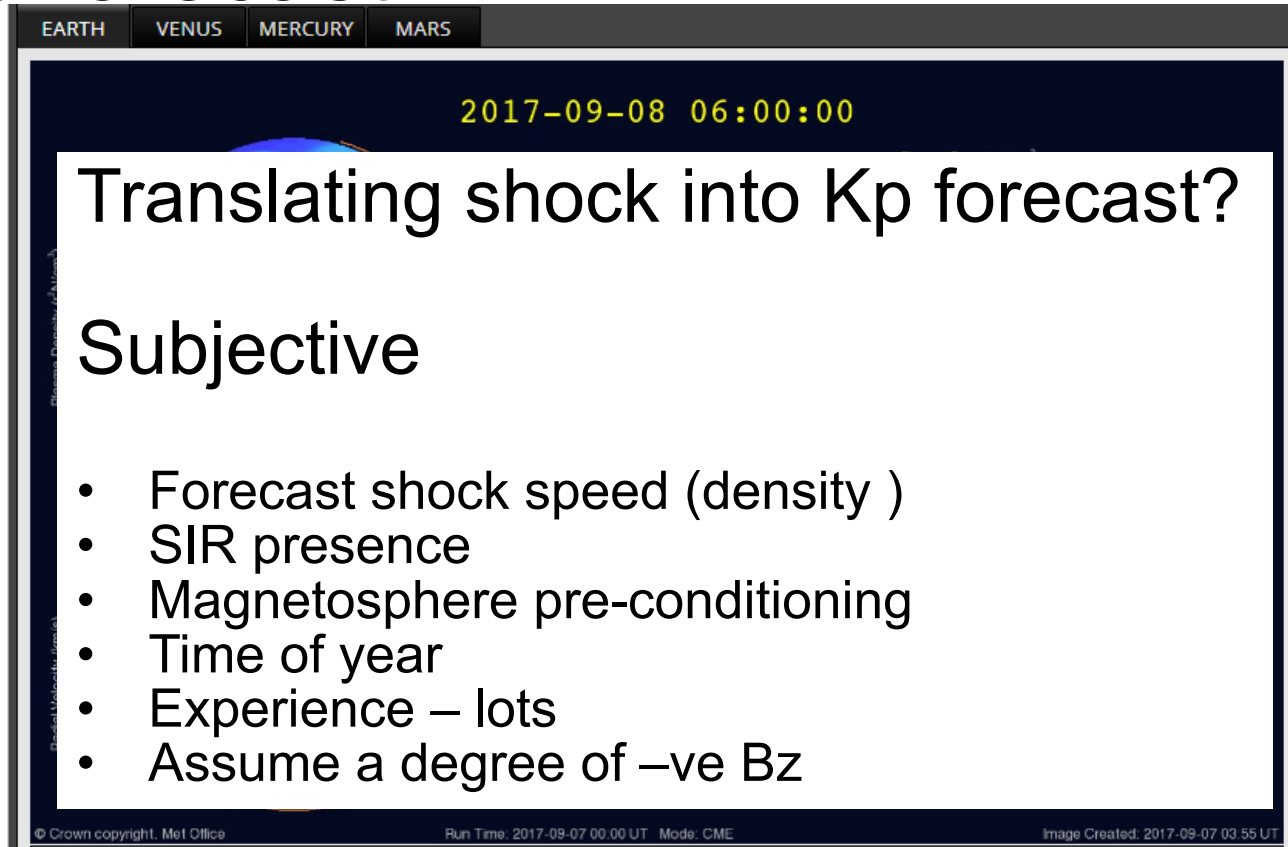


NASA
CCMC

SWPC

From
G Milward

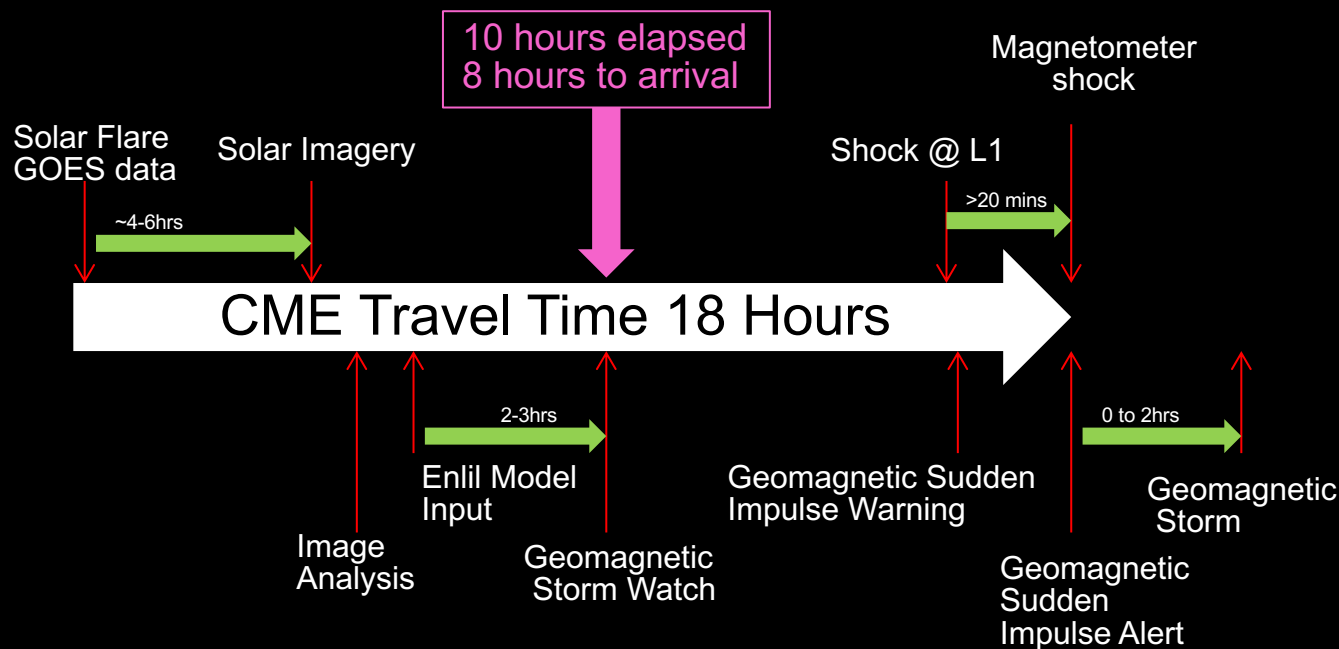
Kp forecast



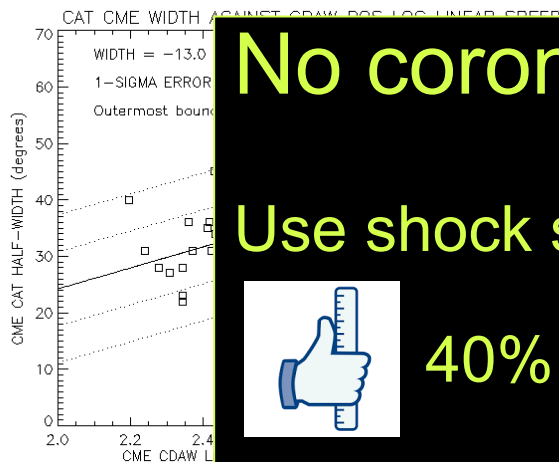
Reality

Producing 'good' forecasts
in the 'real World'

Benchmark



Little, or no, coronagraph imagery



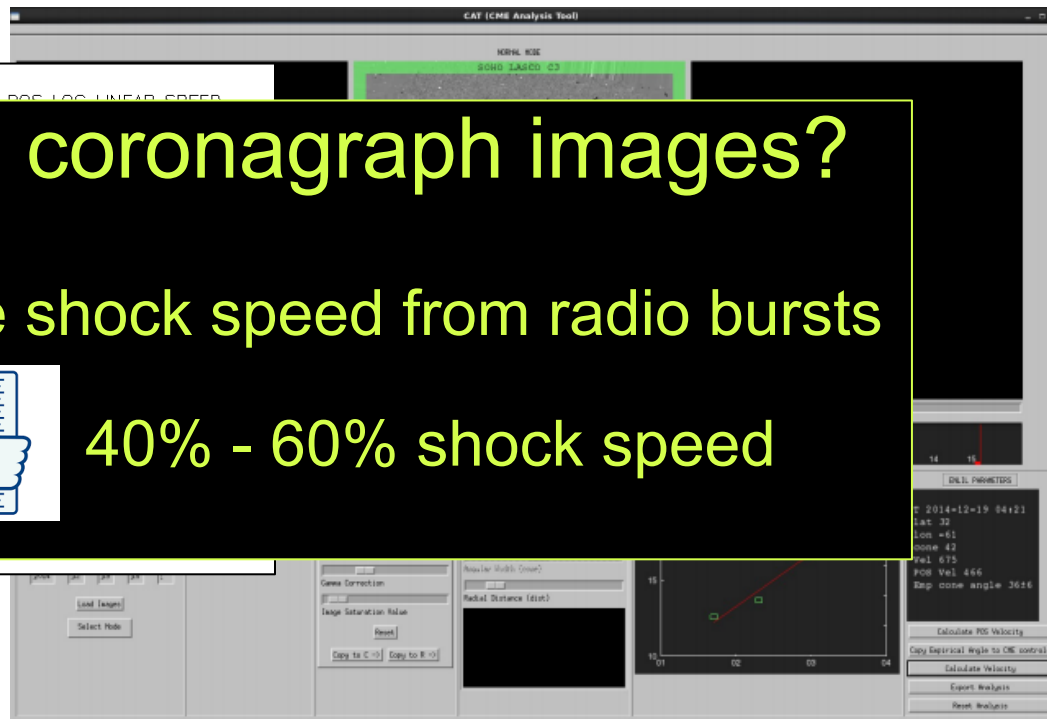
No coronagraph images?

Use shock speed from radio bursts



40% - 60% shock speed

Credit
D Biesecker

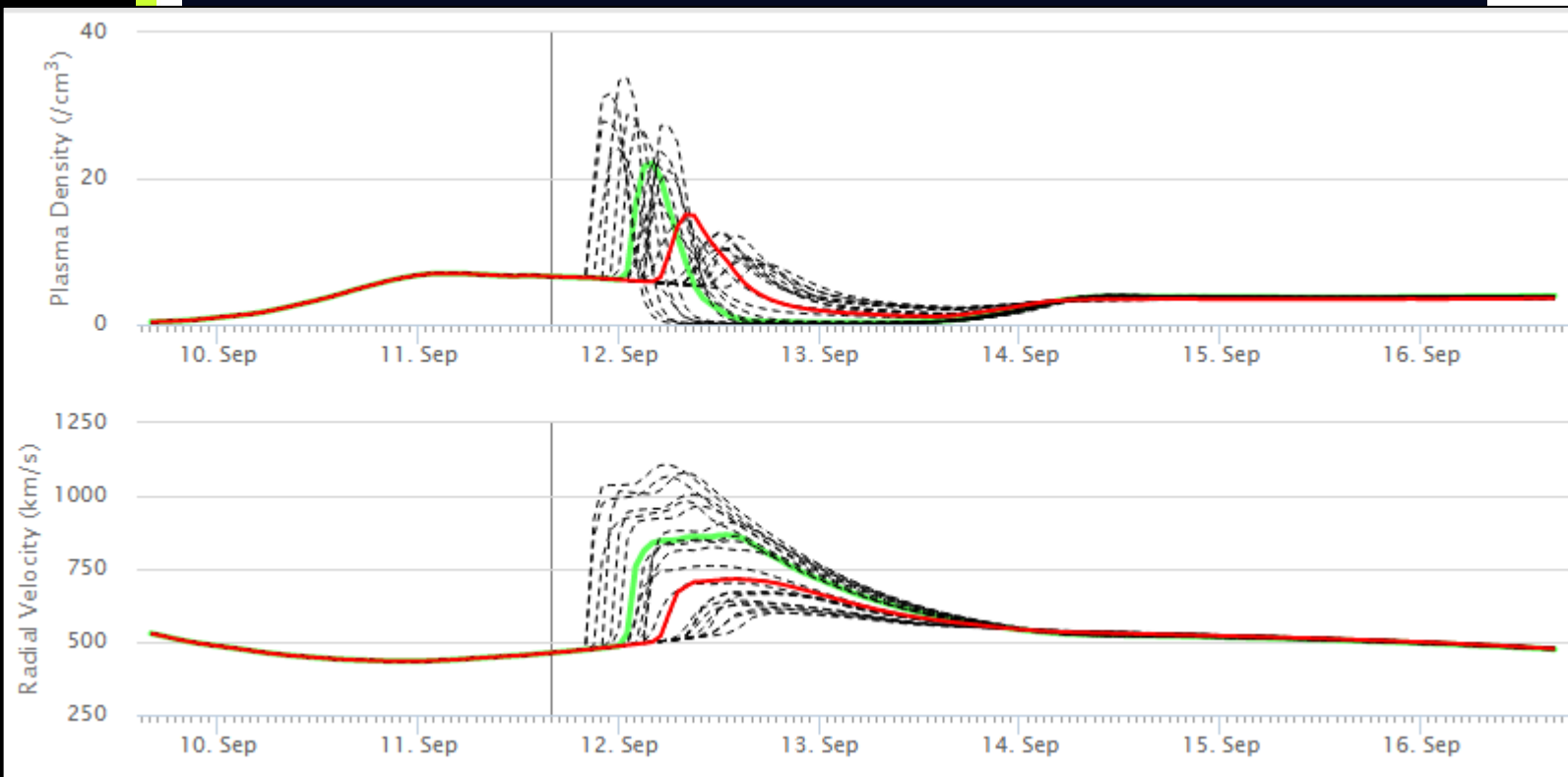




Met Office

ENLIL CME Ensemble

24 members - operational





Met Office

CME accuracy

CME: 2017-09-04T20:36:00-CME-001

Actual Shock Arrival Time: 2017-09-06T23:08Z

Observed Geomagnetic Storm Parameters:

Max Kp: 4.0

Dst min. in nT: -23

Dst min. time: 2017-09-07T09:00Z

CME Note: Associated with M5.5 flare from AR 12673. CME start time was updated from 2017-09-04T23:06Z. Note that there was also a CME starting on 2017-09-04T19:39Z that was slightly slower but in a similar direction and was likely "merged" with the faster 2017-09-04T20:36Z CME.

Predicted Shock Arrival Time	Difference (hrs)	Confidence (%)	Submitted On	Lead Time (hrs)	Predicted Geomagnetic Storm Parameter(s)	Method	Submitted By
2017-09-06T14:51Z (-7.0h, +7.0h)	-8.28	----	2017-09-05T01:38Z	45.50	Max Kp Range: 5.0 - 7.0	WSA-ENLIL + Cone (GSFC SWRC)	Leila Mays (GSFC)
2017-09-06T17:07Z	-6.02	----	2017-09-05T02:27Z	44.68	----	SARM	Marlon Nunez (UMA)

CME: 2017-09-06T12:24:00-CME-001

Actual Shock Arrival Time: 2017-09-07T22:30Z

Observed Geomagnetic Storm Parameters:

Max Kp: 8.0

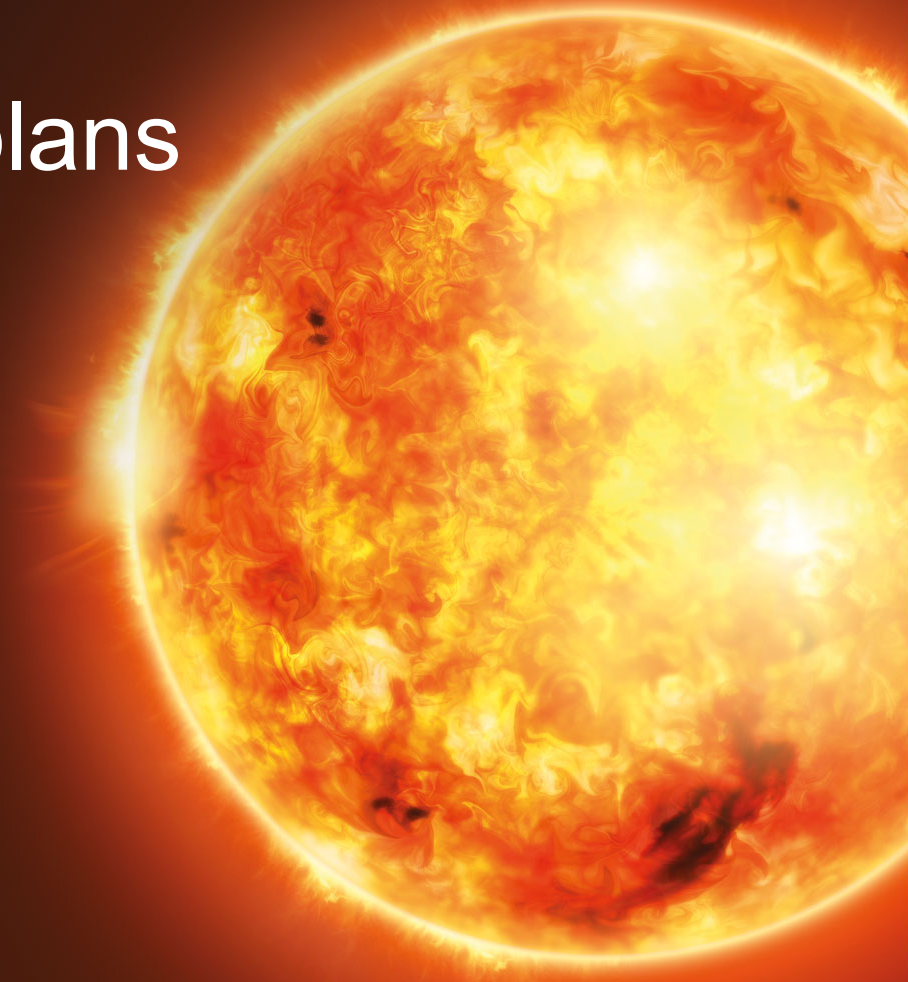
Dst min. in nT: -142

Dst min. time: 2017-09-08T02:00Z

CME Note: Associated with X9.3 flare from AR 12673.

Predicted Shock Arrival Time	Difference (hrs)	Confidence (%)	Submitted On	Lead Time (hrs)	Predicted Geomagnetic Storm Parameter(s)	Method	Submitted By
2017-09-08T18:27Z (-7.0h, +7.0h)	19.95	----	2017-09-06T17:23Z	29.12	Max Kp Range: 3.0 - 5.0	WSA-ENLIL + Cone (GSFC SWRC)	Barbara Thompson (GSFC)
2017-09-08T17:00Z (-12.0h, +12.0h)	18.50	80.0	2017-09-06T22:40Z	23.83	Max Kp Range: 4.0 - 6.0	Other (SIDC)	Yaireska Collado (GSFC)
2017-09-08T22:00Z	23.50	----	2017-09-06T23:24Z	23.10	Max Kp Range: 5.0 - 7.0	WSA-ENLIL + Cone (NOAA/SWPC)	Yaireska Collado (GSFC)
2017-09-08T10:25Z	11.92	----	2017-09-07T02:13Z	20.28	----	SARM	Marlon Nunez (UMA)
2017-09-08T06:00Z (-3.0h, +3.0h)	7.50	80.0	2017-09-07T05:00Z	17.50	Max Kp Range: 5.0 - 8.0	WSA-ENLIL + Cone (Met Office)	Met Office (Met Office)
2017-09-08T08:00Z (-3.0h, +3.0h)	9.50	70.0	2017-09-07T05:40Z	16.83	----	DBM + ESWF	Manuela Temmer (UNIGRAZ)
2017-09-08T13:00Z (-7.0h, +7.0h)	14.50	90.0	2017-09-07T08:25Z	14.08	Max Kp Range: 5.0 - 7.0	Other	Jingjing Wang (NSSC SEPC)
2017-09-08T07:32Z (-5.0h, +6.0h)	9.03	----	2017-09-07T08:33Z	13.95	----	DBM	Mateja Dumbovic (UNIGRAZ)
2017-09-08T10:16Z (-4.0h, +4.0h)	11.77	----	2017-09-07T09:00Z	13.50	----	EAM (Effective Acceleration Model)	Evangelos Paouris (UoA)
2017-09-08T16:30Z (+14.0h)	18.00	----	2017-09-07T12:32Z	9.97	----	EIEvo	Tanja Amerstorfer (SRI)
2017-09-08T15:48Z (-9.0h, +10.0h)	17.30	100.0	2017-09-07T14:53Z	7.62	Max Kp Range: 4.0 - 6.0	Ensemble WSA-ENLIL + Cone (GSFC SWRC)	Hayley Austin (CCMC)
2017-09-08T13:52Z	15.37	----	2017-09-07T15:46Z	6.73	----	SPM2	Xinhua Zhao (NSSC CAS)
2017-09-08T10:42Z	12.20	----	2017-09-07T15:55Z	6.58	----	SPM	Xinhua Zhao (NSSC CAS)
2017-09-08T06:00Z (-2.0h, +2.0h)	7.50	----	2017-09-07T16:30Z	6.00	----	Qoty IPS	Aleksandre Taktakishvili (GSFC)
2017-09-08T16:00Z	17.50	----	2017-09-09T12:59Z	-38.48	----	WSA-ENLIL + Cone (BoM)	Yaireska Collado (GSFC)
2017-09-08T12:46Z	14.27	84.0	---	---	Max Kp Range: 4.33333 - 6.5	Average of all Methods	Auto Generated (CCMC)

Development plans





Met Office

Heliospheric domain

Solar, corona, solar wind

- **ENLIL background wind upgrade**

- Implement ADAPT ensembles
- Replace WSA with NLFF model
- Inner boundary from IPS observations

- **ENLIL Data Assimilation**

- **Enlil boundary extension ~5 AU**

Jan 2018:
ENLIL
upgrade
(ADAPT /
NLFFF)

Spring
2019:
ENLIL
upgrade (II)
incl. IPS

- **Operational enhanced flare forecasting and solar analysis tools**

- **SPARX Operational SEP Forecasting**

2024:
ENLIL DA
(dependent
on L5)

May 2018:
SPARX
operational

Summer 2019:
Improved
operational flare
forecasts, solar
AR analyses

Near Earth domain

magnetosphere, radiation belts, thermosphere, ionosphere, upper atmosphere

- ***Aurora forecast implementation***
- ***Radiation belt model***
- ***Ionospheric scintillation model***
- ***Magnetospheric model***
- ***Raising UM roof to thermosphere***
- ***Ground E field model***
- ***Assimilative atmospheric radiation model***

Summer
2017:
Implement
OVATION
aurora
forecast

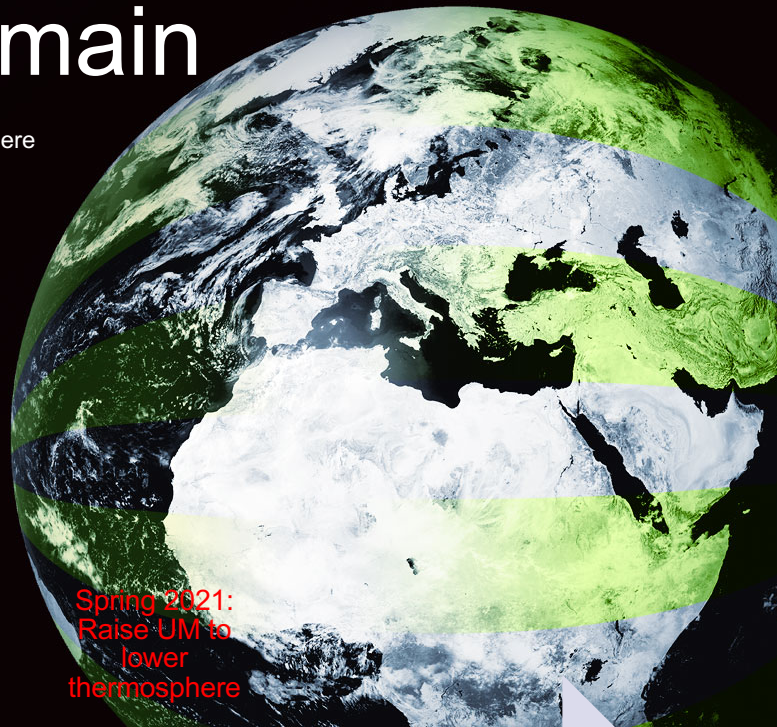
Dec 2018:
Implement
assimilative
atmospheric
radiation
model

Spring 2021:
Raise UM to
lower
thermosphere

Summer 2018:
Magnetosphere
model pre-
operational

Spring 2019
Electric field
model
implementation

2023 – Coupled
Sun to Earth
modelling
system





Met Office

Thoughts and issues


Subtitle:

What is going on in my head

What this project might want to consider

My thoughts and issues

- Good models + expert forecasters produce the best


Airbus D&S Skynet

Space Weather Product
 For Airbus D&S Skynet
 Forecast issued on: Sunday, 10 September 2017 Time of Issue 18:01 Local

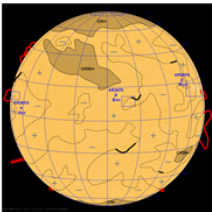
Airbus D&S Skynet –HOLI-RED
 Threat Origin: Active Region No. AR2673. Location: N11W94.


Probability of X-class Flares: 10 percent.
 Probability of M-class Flares: 30 Percent.

- **HOLI-BLUE** is issued when a Solar Feature has potential to cause Extreme Space Weather.
- **HOLI-PURPLE** is issued when a Solar Feature is expected to be a source of Extreme Space Weather.
- **HOLI-RED** is issued when a Solar Feature has produced Extreme Space Weather which demands SMA mitigating action.

Forecaster Comment: An R3 flare erupted from sunspot region AR2673. This was situated around the west limb of the solar disc. A proton response has been observed, with an S1 storm underway. There is a chance for a Strong S3 storm. Whilst a CME is possible, this has yet to be observed, and is unlikely to be Earth directed due to the location of the flare. However this requires further analysis.

Synoptic Map: 0800 UTC.





Airbus D&S Skynet

Space Weather Product
 For Airbus D&S Skynet
 Forecast issued on: Sunday, 10 September 2017 Time of Issue 18:01 Local

Airbus D&S Skynet –HOLI-RED
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My thoughts and issues

Met Office

Airbus D&S Skynet

Space Weather Product

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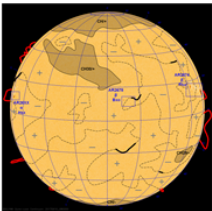
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Synoptic Map: 0800 UTC.



- Good models + expert forecasters produce the best forecasts
- Understand what the user wants and how they will use forecasts
 - UK National Grid don't want GIC forecasts
 - dB/dT or E field
- What do we do if/when LASCO fails
 - Use SDO imagery?
 - IPS?
 - Other?

My thoughts and issues (2)

- National Grid want 5 to 7 day ahead dB/dT forecasts
- Using magnetospheric model how to extend beyond 30 mins
- ENLIL (or EUHFORIA)
 - Carry a meaningful magnetic field
 - Can we determine what that magnetic field should be?
 - Realistic density
 - Output too 'smooth' add realistic 'synthetic' noise?
- Do we go for a statistical approach?
- Currently we discuss AR complexity
 - Can we better discriminate which ARs have potential for a significant eruption?

My thoughts and issues (3)

- How can we maximise benefit of CME ensembles
- How can we constrain an ENLIL ensemble
 - 24 CMEs * 12 ADAPT members
- After shock arrival – can we predict L1 Bz evolution?
- Better understand local storm intensification / sub-storms
 - Local dusk – midnight & pre-dawn periods
 - Predict sub-storm occurrence

Project challenge

- Balance between blue skies & applied? (customer focussed)
- Increasing our scientific understanding is vital
- How do we use this knowledge?
- How can we maximise value?



Met Office

Thank you

Any questions?