# Met Office Space Weather Operations and R&D

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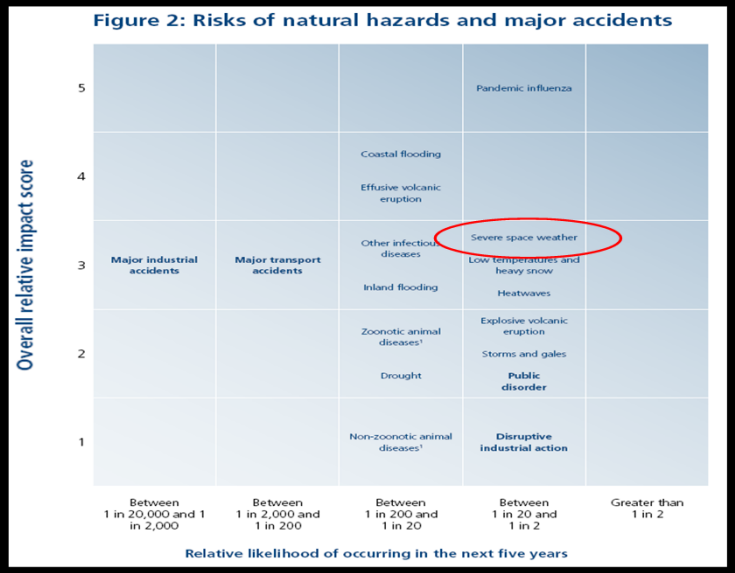
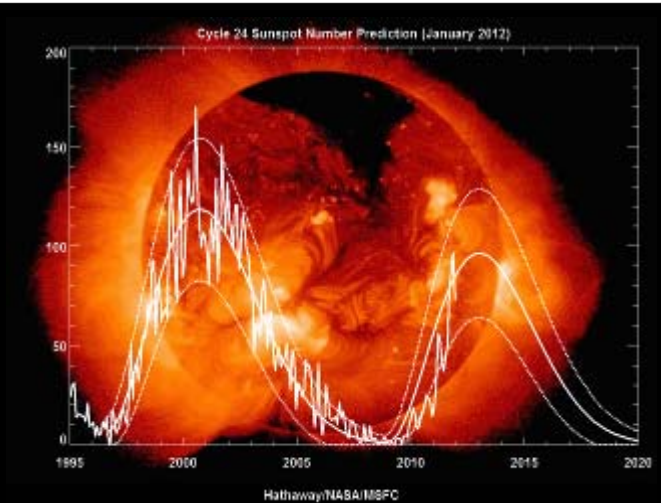
WMO / ISES Meeting, August 9-10 2014, Moscow, Russia

# Met Office Motivation?




## 2010

- Increasing interest within UK Government
  - Max coinciding with Olympics
- Space Weather placed on NRR
- NOAA approached Met Office
  - Met Office become back-up to SWPC
- Desire to demonstrate increased value of 24x7 operations

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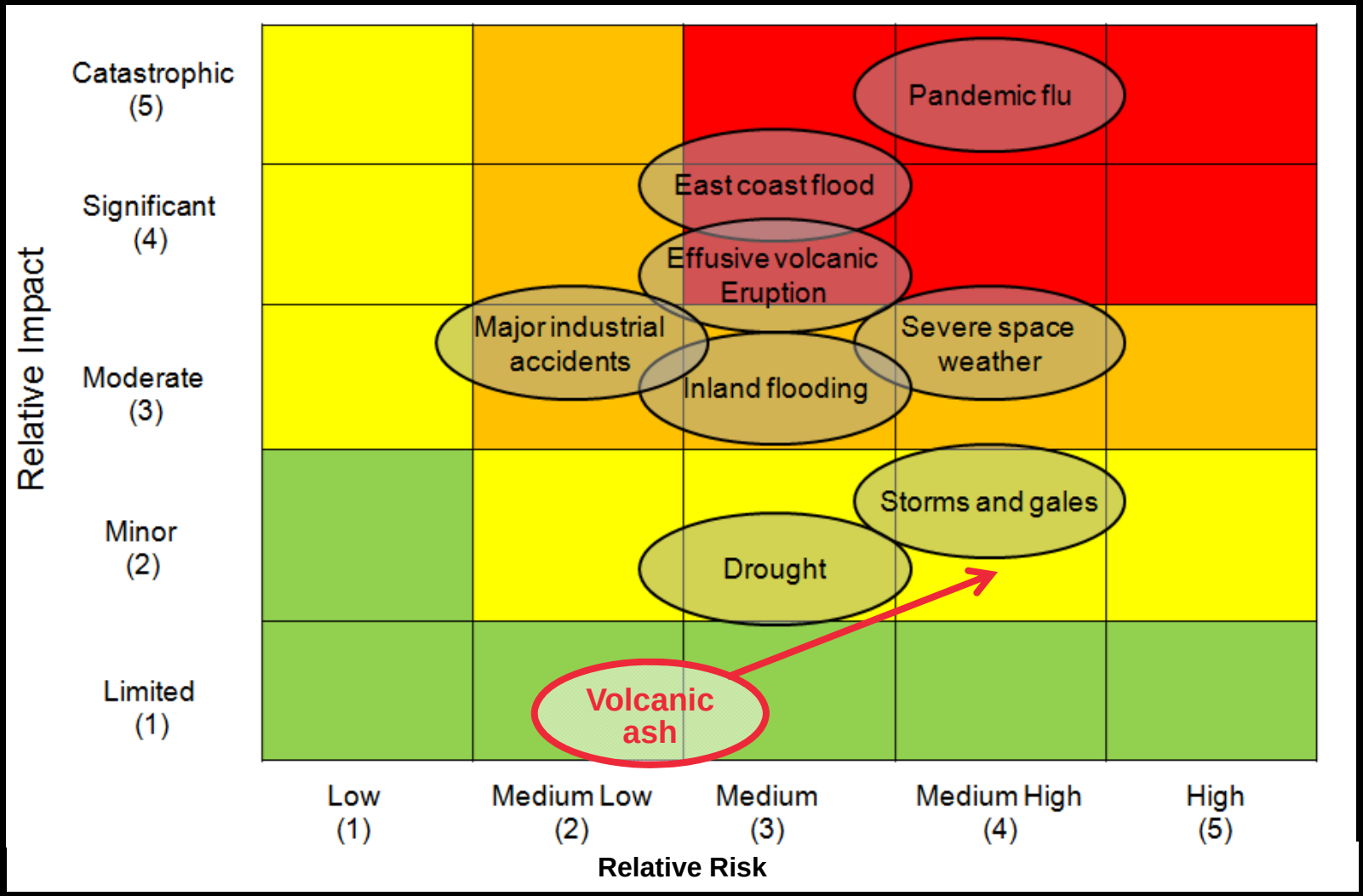
# National Risk Register

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# Identifying the risk

- Royal Academy of Engineering report
- Extreme space weather – Carrington event
  - Electricity
    - ~13 transformers damaged in UK
    - 2 coastal nodes could experience disconnection
    - Possible short blackouts in urban areas
  - Impact on Satellites, Aviation, GNSS, comms also assessed


- Need for further technical and **forecast** mitigation

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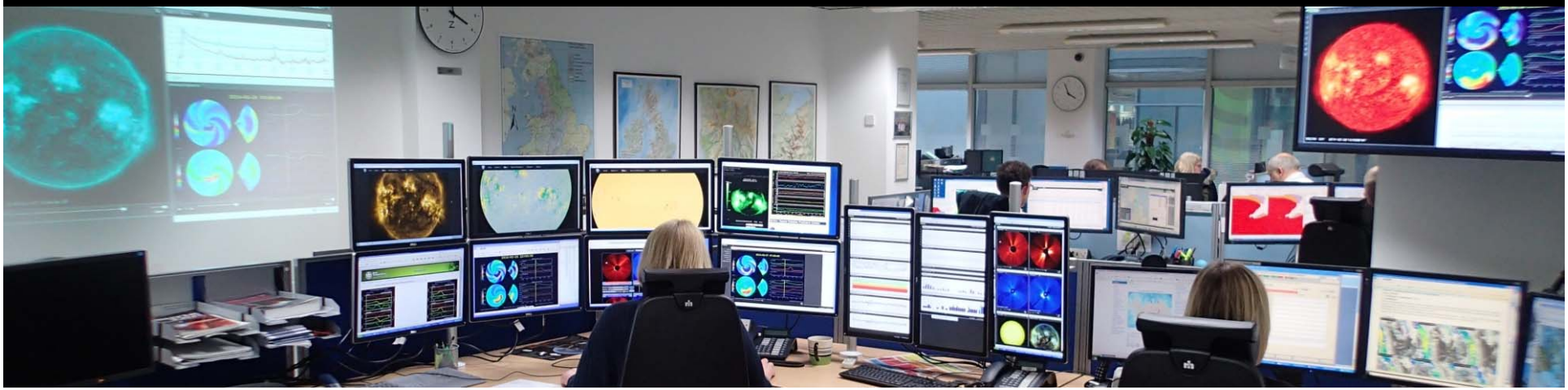
# Met Office Space Weather Operations Centre

- Embedded in Met Office Hazard Centre
  - 24x7x365 – 29 April’14 ✓
  - Full capability autumn ’14
  - New member of ISES
- Collaborate with academia not replicate
- Operational collaboration with NOAA SWPC & BGS
  - Daily forecast coordination
- Add UK-centric advice and impacts



# NOAA impact scales

| Category | | UK Effect | US and Global Effect | Physical measure | Average Frequency (1 cycle = 11 years) |
|---|---|---|---|---|---|
| Scale | Descriptor | Duration of event will influence severity of effects | | | |
| Geomagnetic Storms | | | | Kp values* | Number of storm events when Kp level was met; (number of storm days) |
| G 5 | Extreme | **Power systems:** Localised voltage control and protective system problems may occur.<br><br>**Spacecraft operations:** may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites.<br><br>**Other systems:** HF (high frequency) radio propagation may be impossible in many areas for one to two days, GPS satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as 40° geomagnetic lat. | **Power systems:**widespread voltage control problems and protective system problems can<br><br>**Spacecraft operations:** may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites.<br><br>**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<br><br>(4 days per cycle) |
| G 4 | Severe | **Power systems:** No impact on UK power grid.<br><br>**Spacecraft operations:** may experience surface charging and tracking problems, corrections may be needed for orientation problems.<br><br>**Other systems:** HF radio propagation sporadic, GPS satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as 45° geomagnetic lat. | **Power systems:** possible widespread voltage control problems and some protective systems will<br><br>**Spacecraft operations:** may experience surface charging and tracking problems, corrections may be needed for orientation problems.<br><br>**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<br><br>(60 days per cycle) |
| | | **Other systems:** migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine)**. | | | |

# Services

Met Office Space Weather Forecast

## Space Weather Forecast

Issued on Tuesday, 14 January 2014 at 00:50 UTC

This guidance document provides a four day assessment of Space Weather events. This is a non-scientific document issued daily at 01:00 UTC but it will be updated if there are significant changes. Stated probabilities are for reaching or exceeding given levels. For more information about space weather impacts please see http://www.metoffice.gov.uk/spaceweather

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**Headline: Earth is currently experiencing high speed solar wind but geomagnetic activity is low. A moderate class flare occurred late last night.**

### Space Weather Activity over the past 24 hours

Solar activity was moderate; the largest flare detected was a moderate flare at 21:51 UTC on the 13th January 2014, emitted from a sunspot which has now rotated onto the western limb. Due to its position it is difficult to classify but it is thought to be a complex sunspot. There are 5 other categorised sunspots on the visible disc, all smaller and less magnetically complex. Despite high average solar wind speeds the magnetic polarity remains positive and geomagnetic activity has been quiet to unsettled. Solar radiation levels remain below S1 level.

### Four Day Space Weather Forecast Summary

Solar activity is expected the remain low, initially with a 45% chance of further moderate class flares and only 10% chance of extreme class flares from the same complex sunspot. The risk of large flares falls further from Day 2 when this sunspot rotates off the western limb. Any further significant flares from this sunspot even after it rotates off the visible disc may lead to a solar radiation storm. The probability remains relatively high at 40% on Day 1 and 30% on Day 2, but decreases after that. Geomagnetic activity will remain unsettled on Day 1, but will be quiet from Day 2 onwards as the influence of the solar wind diminishes.

Page Break

Met Office Space Weather Forecast

### Geomagnetic Storms

| Geo-Magnetic Storm / Probability (Exceedance) | Level | Past 24 Hours (Yes or No) | Day 1 (00-24 UTC) (%) | Day 2 (00-24 UTC) (%) | Day 3 (00-24 UTC) (%) | Day 4 (00-24 UTC) (%) |
|---|---|---|---|---|---|---|
| Minor or Moderate | G1 to G2 | No | 30 | 20 | 10 | 1 |
| Strong | G3 | No | 05 | 01 | 01 | 01 |
| Severe | G4 | No | 01 | 01 | 01 | 01 |
| Extreme | G5 | No | 01 | 01 | 01 | 01 |

### Radio Blackouts - X Ray Flares

| X Ray Flares / Probability (Exceedance) | 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) (%) |
|---|---|---|---|---|---|---|
| Active | R1-R2 M-Class | No | 45 | 10 | 10 | 10 |
| Very Active | R3 to R5 X-Class | No | 10 | 01 | 01 | 01 |

### Solar Radiation Storms - (High Energy Protons):

| Radiation Storms / Probability (Exceedance) | Level (cm-2sr-1s-1-) | Past 24 Hours (Yes or No) | Day 1 (00-24 UTC) (%) | Day 2 (00-24 UTC) (%) | Day 3 (00-24 UTC) (%) | Day 4 (00-24 UTC) (%) |
|---|---|---|---|---|---|---|
| Active | ≥ S2 * | No | 40 | 30 | 1 | 1 |
| Very Active | ≥ S3 * | No | 10 | 5 | 1 | 1 |

* S2 ≥ 10 MeV protons ≥ 100 pfu. S3 ≥ 10 MeV ≥ 1000 pfu and/or ≥ 50 MeV ≥ 10 pfu. (pfu = $cm^{-2}sr^{-1}s^{-1}$)

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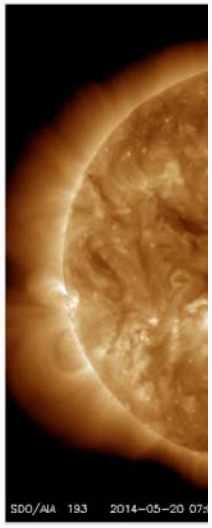
FORECASTER OVERVIEW

**Moderate Radio Blacko**
M-class flare likely over t
ACE at 2130 UTC possibl

Solar activity is expected to
large sunspot groups AR205
become more geo-effective
start ACTIVE but then becor
equatorial small coronal ho
thought to be minimal. Witl
view a proton event seems
background values.

SOLAR TIMELAPSE

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# Space Weather Energy

## FORECASTER OVERVIEW

**Moderate Radio Blackout observed this morning.** Further M-class flare likely over the next few days. Sudden impulse at ACE at 2130 UTC possible CME from 3rd May.

Solar activity is expected to remain moderate over the coming days the large sunspot groups AR2055 and AR2056 rotate around the disc and become more geo-effective. Geomagnetic activity is expected to stay start ACTIVE but then become generally QUIET. There are a couple equatorial small coronal holes visible on the disc but their impact is thought to be minimal. With AR2051 now rotated completely out of view a proton event seems unlikely now and electrons should stay a background values.

Issued 8 May 2014 at 12:00

## WARNINGS AND ALERTS

| | Active alerts | Warnings |
|---|---|---|
| Geomagnetic | - | - |
| Radio blackout | - | R1 21:00 20/05 03:00 21/05 |
| Proton flux > 100 MeV | S1 11:23-now | - |
| Proton flux > 10 MeV | - | - |
| Kp | - | - |
| Kuk | - | - |
| Electrons | - | - |

## GEOMAGNETIC STORM FORECAST

Probabilities of geomagnetic storms

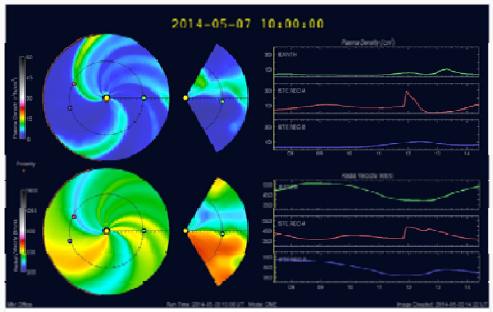
| Probability | Level | Past 24 h. | Day 1 | Day 2 | Day 3 | Day 4 |
|---|---|---|---|---|---|---|
| Minor or moderate | G1 to G2 | No | 65 | 05 | 05 | 05 |
| Strong | G3 | No | 45 | 01 | 01 | 01 |
| Severe | G4 | No | 01 | 01 | 01 | 01 |
| Extreme | G5 | No | 01 | 01 | 01 | 01 |
| | | | % | % | % | % |

### Geomagnetic commentary

The largest flare over the last 24 hours was M1.2 flare at 16:29 UTC from AR2051 which has revolved around the western limb. With one beta-gamma spot (AR2055) and one beta-gamma-delta spot (AR2056) there is still a risk of further M-class flare activity over the next few days.

Issued 8 May 2014 at 12:00

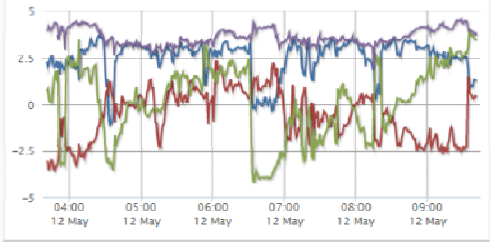
## ENLIL



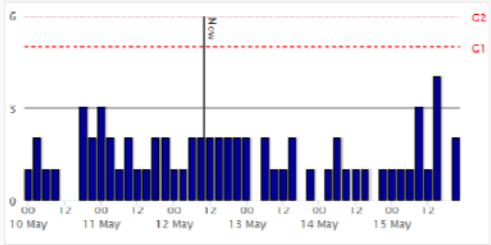

No Earth directed CMEs have been observed. Maximum solar wind speed is 500 km/s

Issued 8 May 2014 at 12:00

## ACE MAGNETOMETER




## BGS 3-HOURLY KP INDEX

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# Space weather models at the Met Office

- Sun to Earth:  WSA Enlil
- At the Sun:  CME analysis tools
- Van Allen Belts (1,000-60,000km):  SPACECAST
- Geosynchronous orbit (~35,000km):  REFM
- Ionosphere (50-600km):  MIDAS
- Ionosphere (D-region , 50-90km):  D-RAP

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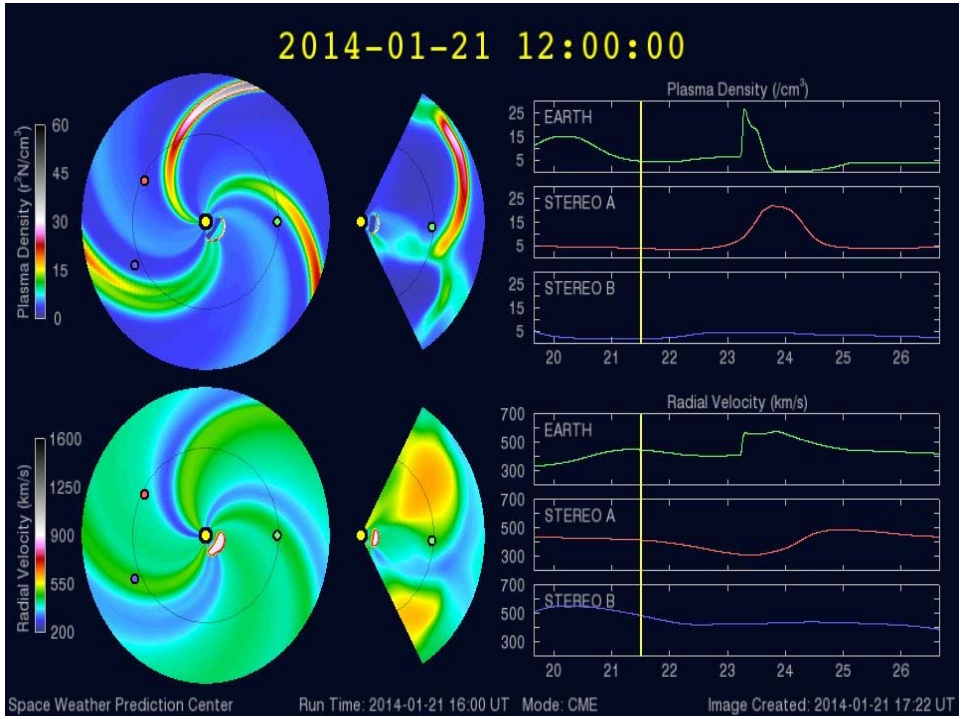
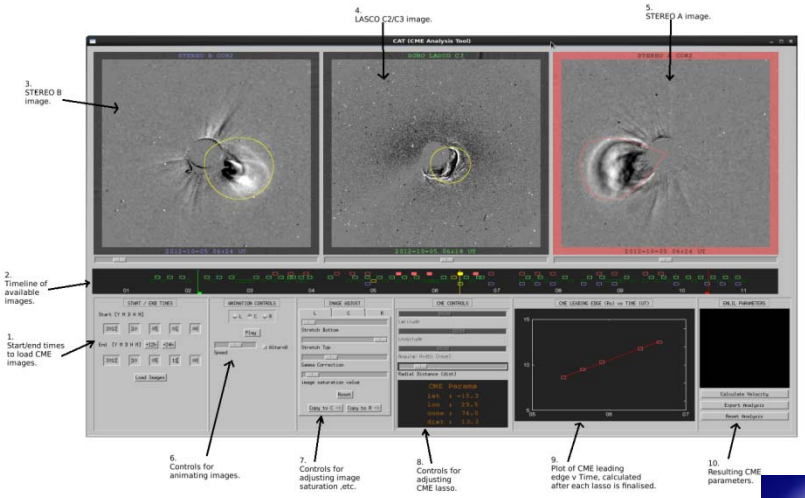
# WSA Enlil model




- **Purpose:** Models solar wind speed & density from Sun to Earth (IMF modelled but no Bz input). Predicts CME arrival times at Earth,
- **Inputs:**
  - WSA uses solar magnetograms to model coronal magnetic field and provide inner BCs for Enlil.
  - CME analysis tools (NASA StereoCAT or NOAA CAT) calculate CME parameters using fit to STEREO A&B and LASCO images.
  - CME parameters input into Enlil
- **Output:** Run every 2hrs
- **Forecasts:** average error: +_ 7 hrs (Doug Biesecker); lead time: CME transit time – a few hrs



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# Other Products

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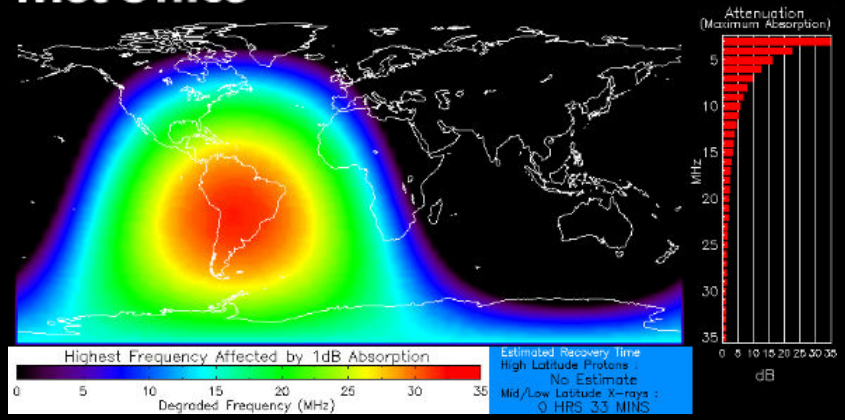
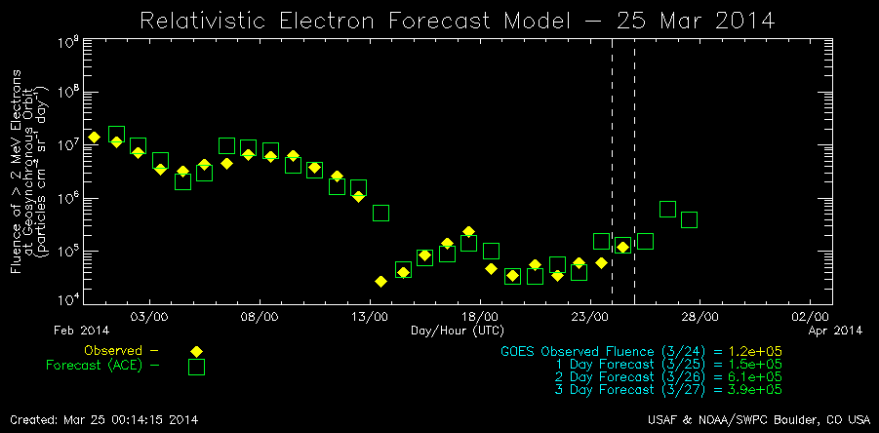



**DRAP** gives real-time prediction of the absorption (radio propagation) conditions in the D-region.

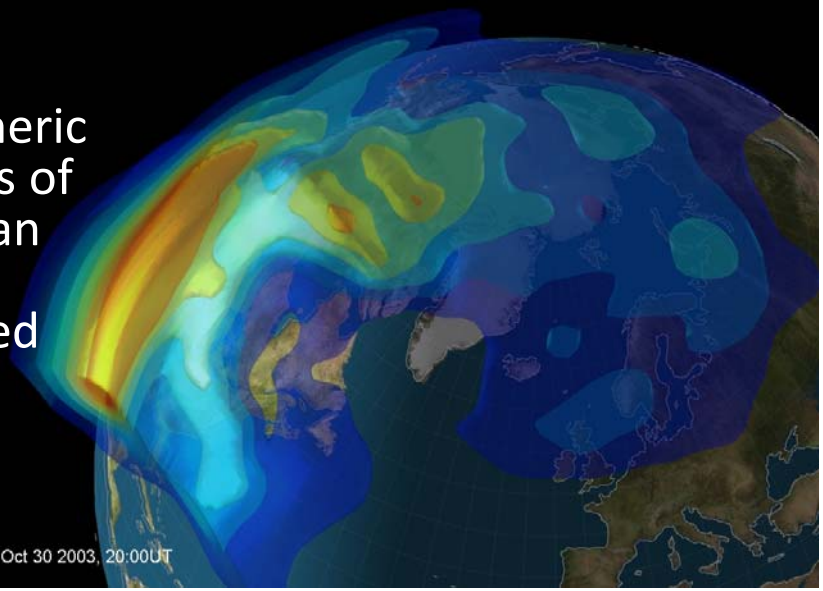



**REFM** provides daily electron fluence forecasts at GEO orbit.

SPACECAST

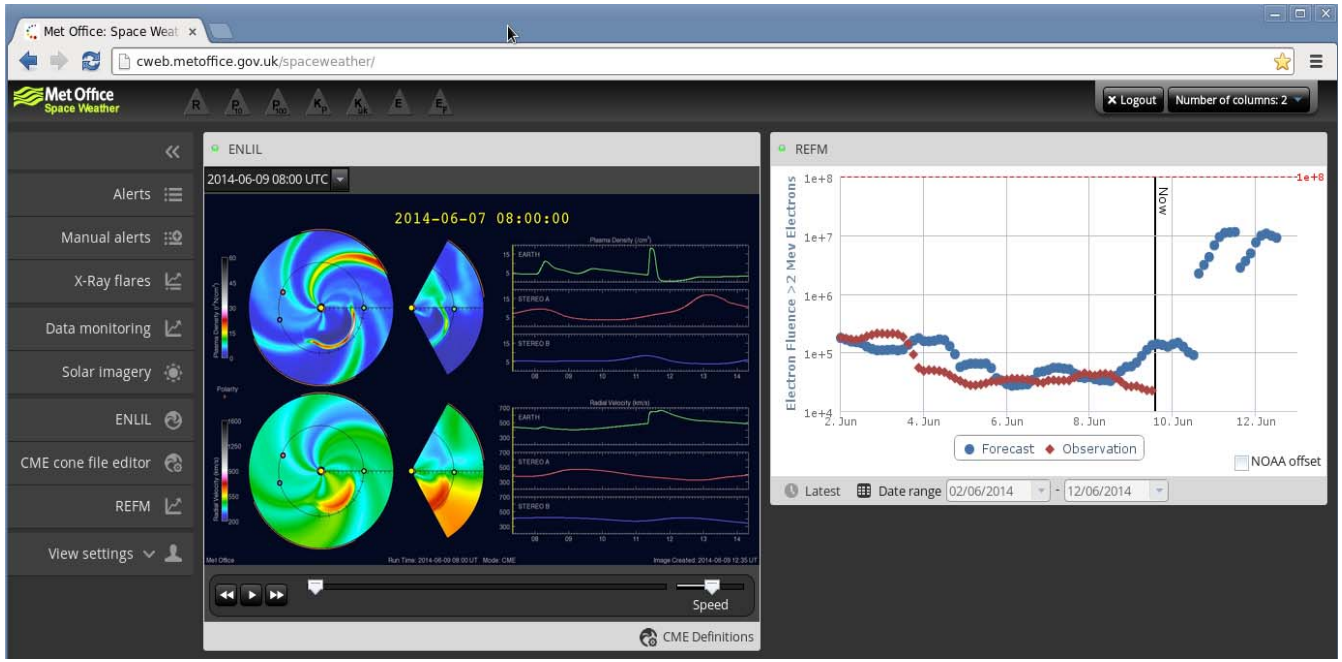
FP7 project provides forecasts of particle radiation to aid satellite operation.

Ionospheric analyses of European sector produced using **MIDAS**.



# Verification

- Currently planning archiving of data for verification.
- REFM is currently compared with GOES fluence data on internal webpages.
- Plan to compare Enlil density & velocity with STEREO A, STEREO B & ACE.
- Metrics tables to show that forecasters are adding value to models.
- Verification of alerts, warnings & forecasts using methods already in use e.g. for flood forecasting.




*Met Office internal webpages*

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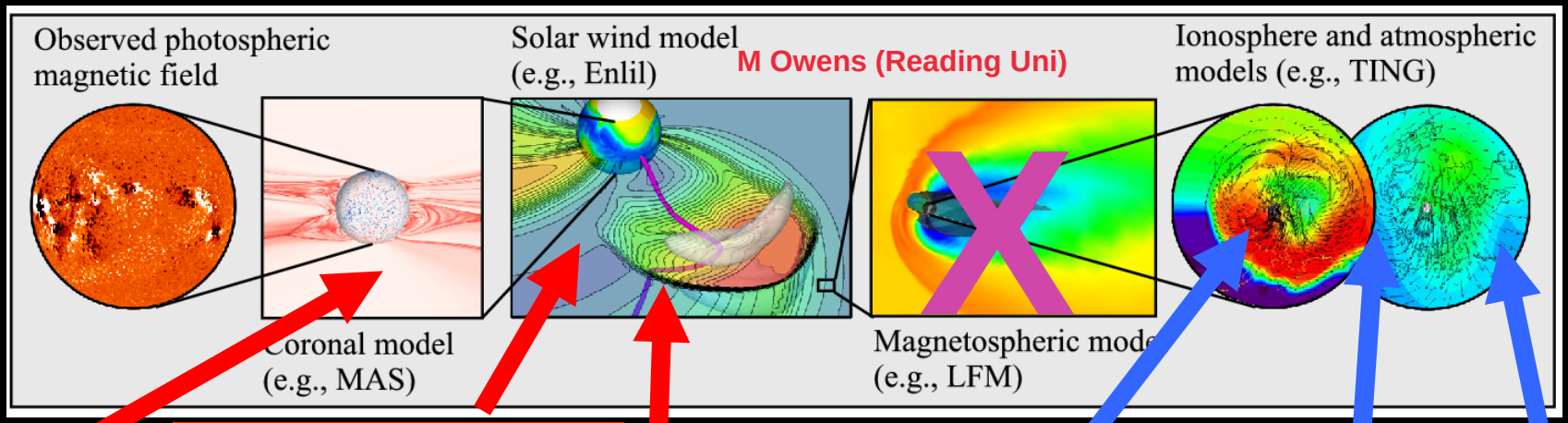
# Modelling from Sun to Earth: Current R&D Status

Met Office

## Goal: Coupled Sun to Earth models with DA for much enhanced forecast capacity




WSA Enlil Ensembles

Solar wind persistence model for benchmarking / validation (Owens et al, 2013; Kohutova)

Improved methods of tracking solar wind features (Tucker-Hood)

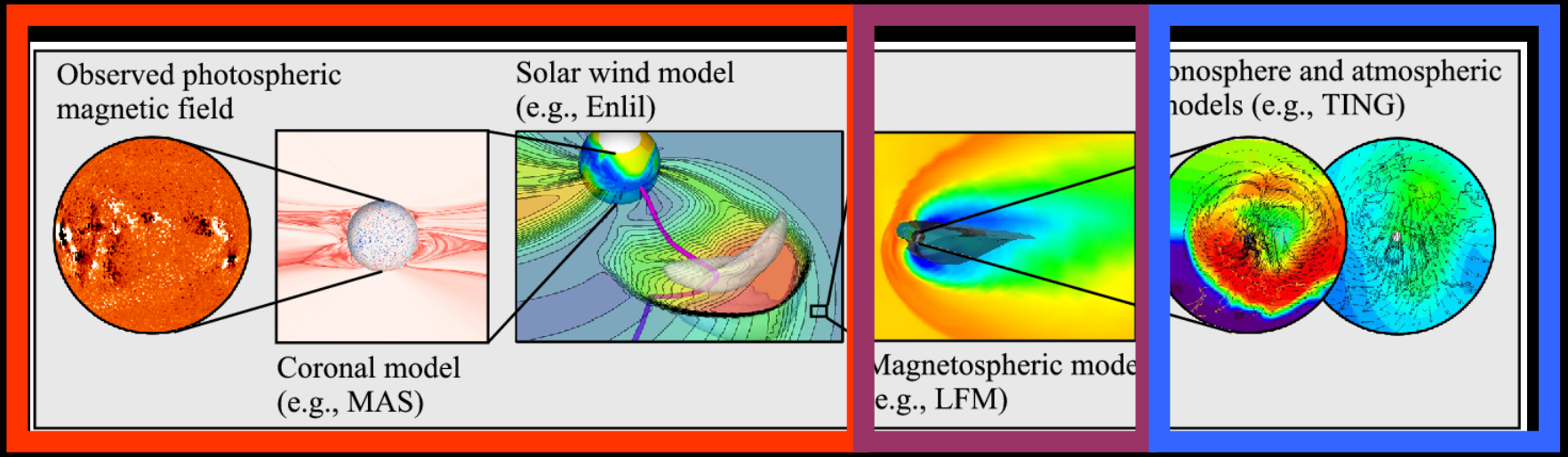
Real time regional TEC (MIDAS)

Thermosphere: DA and ionosphere coupling

Whole atmosphere model plans

# Modelling from Sun to Earth: Future System

## Goal: Coupled Sun to Earth models with DA for much enhanced forecast capacity




"WSA Enlil"-like model: ensembles & improved solar wind via DA

→

Implement existing or new magnetosphere model

→

Coupled thermo / ionosphere DA. Whole atmos UM

↓

Apps (eg GIC models)

- Flares
- SEPs – model driven by Enlil, flare detection

←---------- near real time forecast verification ----------→

# Summary

- Met Office Space Weather services available and being developed  - 24/7 forecasting as of April.
- Associated R&D programme shall lead to pullthrough of improved services and operational forecasts.
- Large challenges call for interdisciplinary collaborations which utilise the skills of partners to maximum effect.

# Questions and answers

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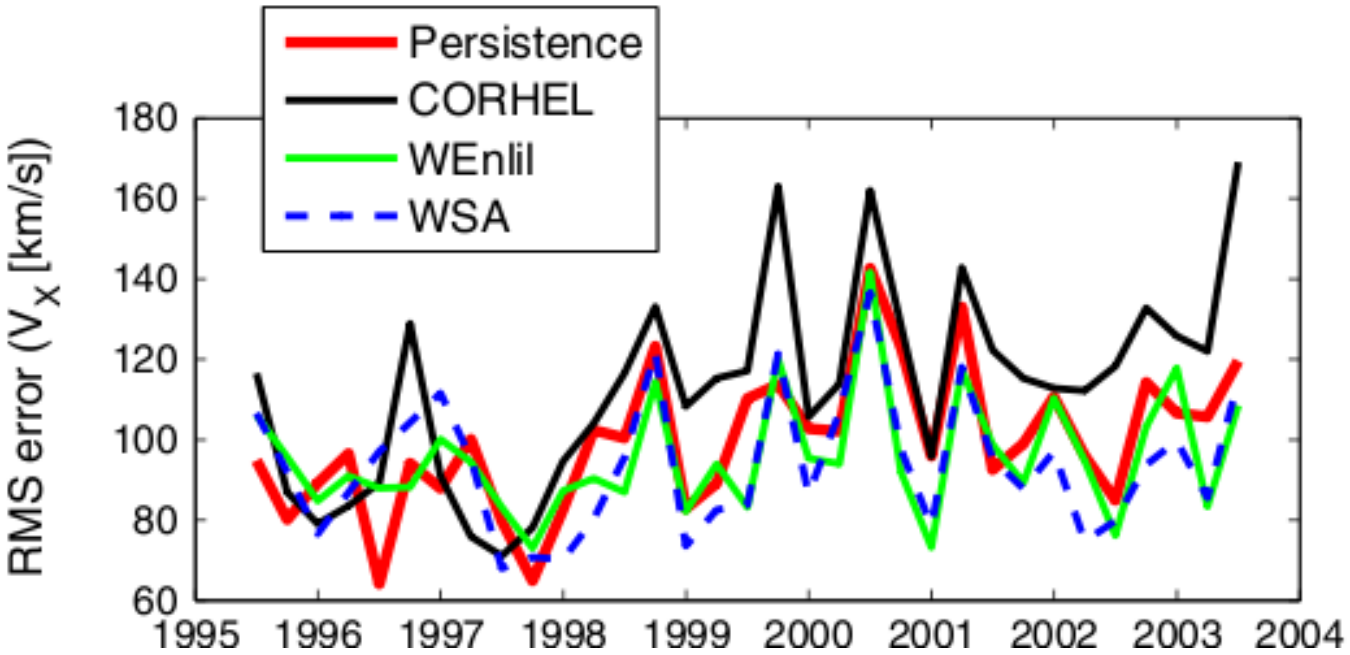
# Met Office Space Weather Research & Development - Extra Slides

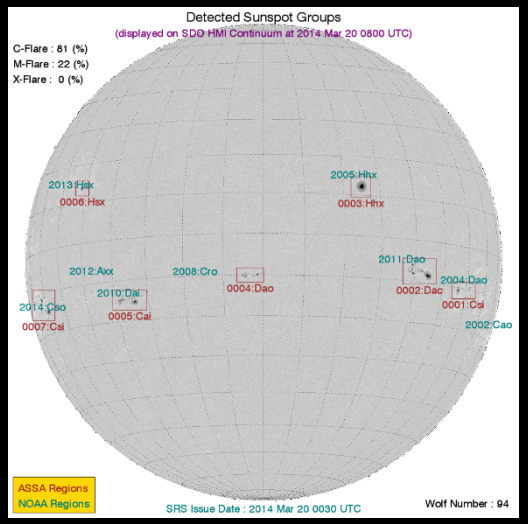
# Other solar wind modelling

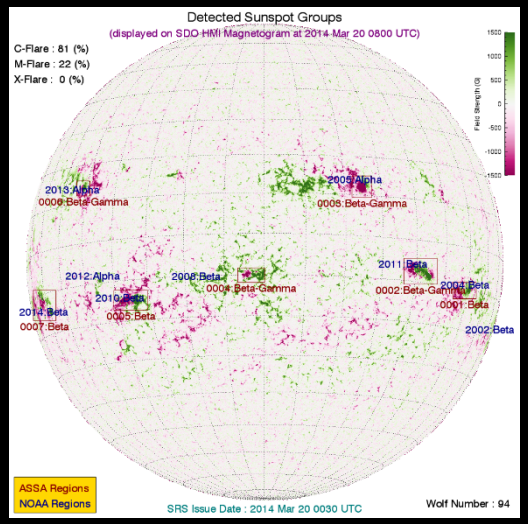
- solar wind persistence model – WSA Enlil benchmark and quick forecast tool
- CME drag model ensemble – quick heads up of CME arrival times for forecasters

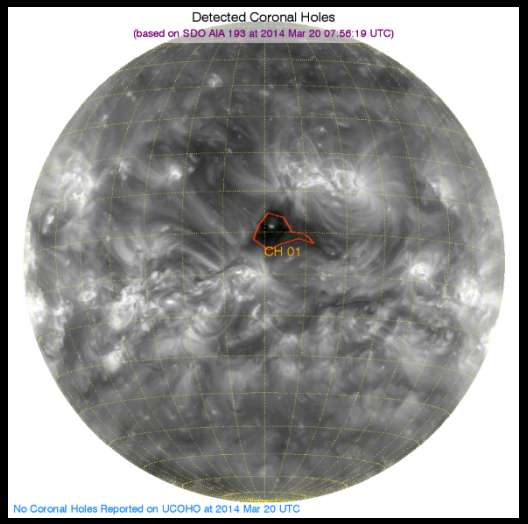


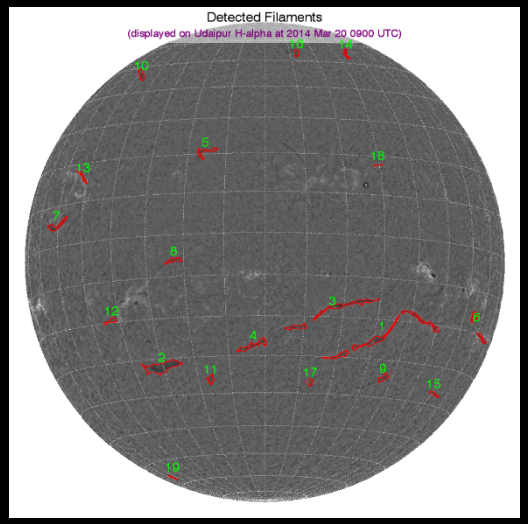

RMS error of various model predictions of solar wind speed, relative to a reference model (Owens et al, 2013)

# Active Region Tracking




- KSWC Automatic Solar Synoptic Analyser:
  - Magnetic classification,
  - Flare forecasting,
  - Coronal hole detection,
  - Filament detection.
- Further development in collaboration with Trinity College Dublin. (eg Solar Monitor Active Region Tracker (SMART; Higgins et al)

S. Murray