



# Met Office Space Weather Programme

## Services - R&D - Partnerships

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# Overview

- **UK Space Weather Drivers**
  - Why Should the UK Met Office be Involved?
  - Building Relationships – Nationally & Internationally
  - Developing Operational Space Weather Services
- **R&D Activities**
  - Current Activities
  - Pulling Through Research into an Operational Environment
  - Future Plans and Collaboration
- **Summary**



# UK Space Weather Drivers

- **House of Commons Science & Technology Committee – addressed:**
  - Risk to UK Resilience
  - International Collaboration
- **Space Weather has become part of UK National Risk Assessment**
  - SEIEG (UK advisory group including Met Office) has provided an initial realistic worst case scenario
- **New UK Space Security Policy**
  - Includes Natural & Deliberate Damage
  - Will Set Future Context for Space Weather?



# Why Should the Met Office Be Involved?

- **Experience in Scientific Pull-Through**
  - we have experience in integrating science from many partners into a world-class modelling / forecasting system – Unified Model
- **Running Models and Services Operationally**
  - Existing Infrastructure
  - 24x7 Operations Centre and Operational Capability
  - Existing Comprehensive Delivery Channels
  - Existing Capability in Emergency Response



# Unified Modelling Approach

Deterministic & Ensemble Models

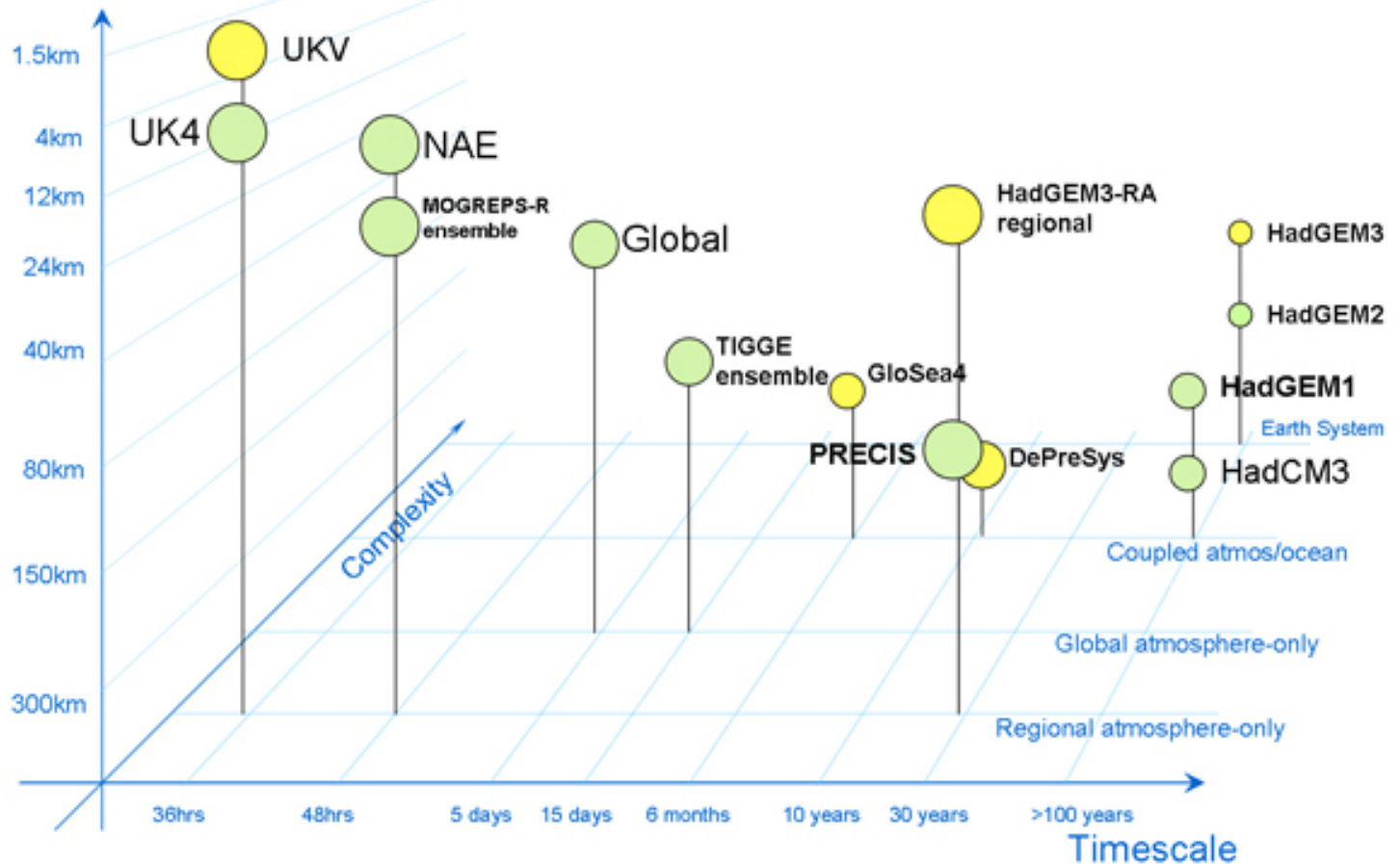
Higher model resolution doesn't necessarily equate to higher accuracy.

Time lagged Ensembles

Reality of Shannon Entropy



Atmospheric grid length





# Met Office Ambitions

- **Operational Delivery Partner for UK Space Weather Prediction Service**
  - Building Upon Existing Infrastructure & Skills
- **Aim to Collaborate - Not Replicate**
  - To work with Scientific and Delivery Partners – in UK, but also Internationally (EU, US, NASA, NOAA, AFWA)
  - Build upon existing European partnerships i.e. with EUMETSAT / ECMWF / ATMOP
  - Consistency across Civil / Defence Customers



# Multi-Hazard / Multi-Agency Partnership

(Chemical, Biological, Radiological, Nuclear, Volcanic (ADG) ), Cyclones  
- now developing Space Weather Forecasting Capability



**British Geological Survey**  
NATURAL ENVIRONMENT RESEARCH COUNCIL



**National Centre for Atmospheric Science**  
NATURAL ENVIRONMENT RESEARCH COUNCIL



NOAA - Space Weather Prediction Centre



**Centre for Ecology & Hydrology**  
NATURAL ENVIRONMENT RESEARCH COUNCIL



**Environment Agency**



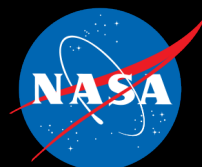
**Ordnance Survey**<sup>®</sup>



**National Oceanography Centre**  
NATURAL ENVIRONMENT RESEARCH COUNCIL



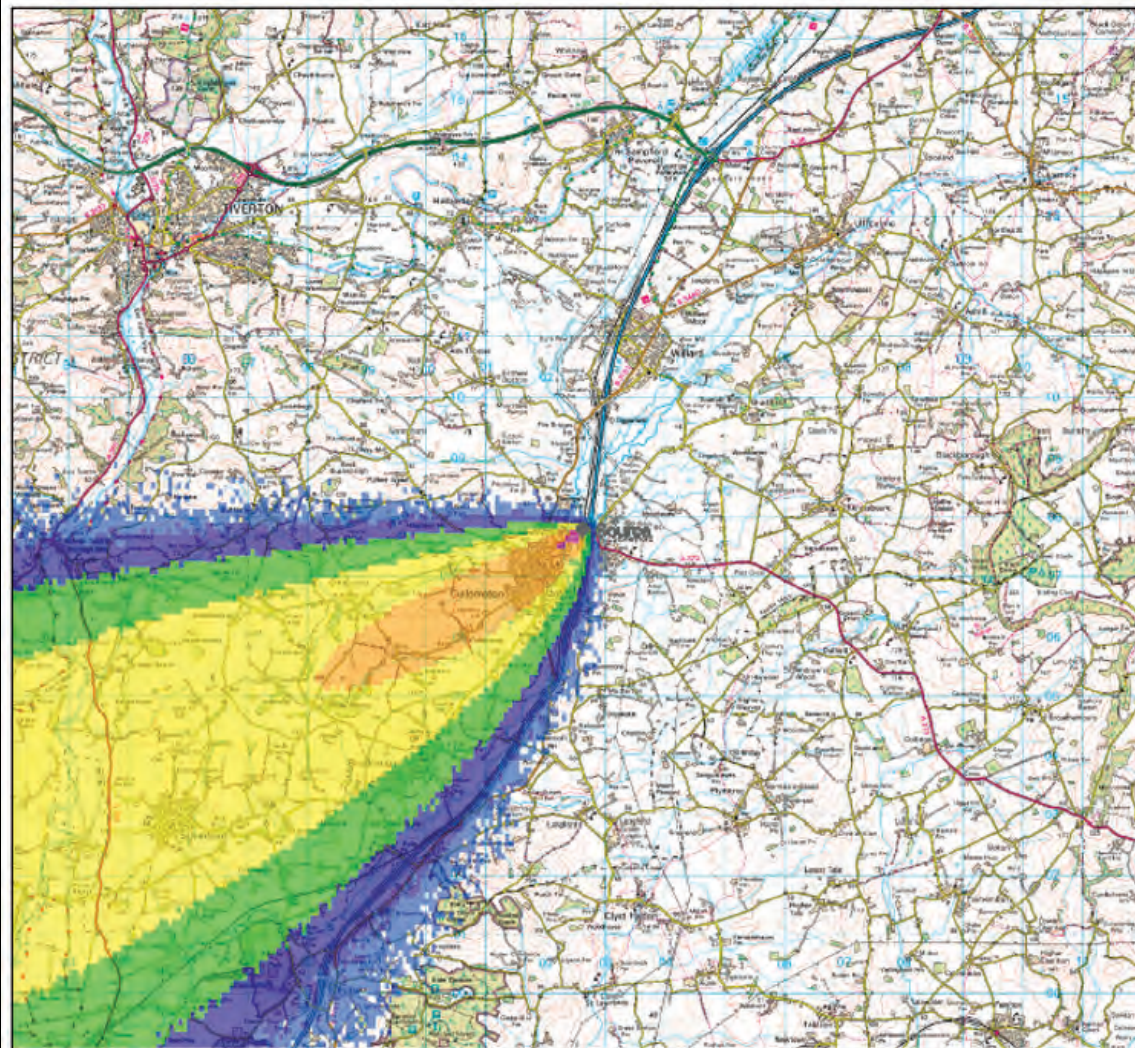
**Health Protection Agency**



Developing partnership with NASA CCMC



# Atmospheric Dispersion Group – NAME III



## NAME Dispersion Model



Exercise Wyvern

Model Version : NAME version 812  
Run Name : wyvern\_05  
Run Time : 1951UTC 05/10/2004  
Met Data : Regional  
Release location : multiple sources  
Start of release : 08/10/2004 01:00:00  
End of release : 08/10/2004 01:00:00  
Release rate : multiple sources  
Release height : 0 to 100m agl

Species : IRIDIUM-192  
Averaging Period : Accumulated  
Field : Total deposition  
Vertical limits : Boundary layer  
Time ending : 08/10/2004 02:00:00  
Units : Bq/m<sup>2</sup>



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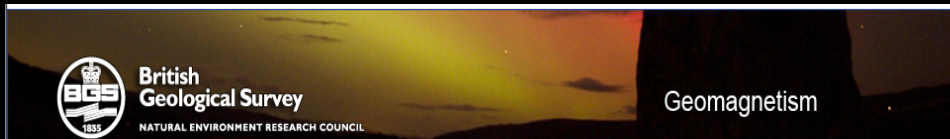


# Developing Space Weather Services

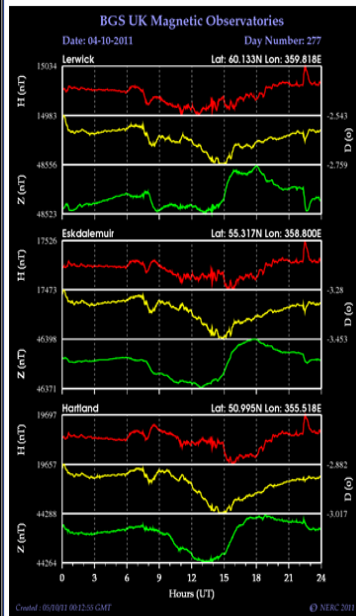
- Receiving Space Weather data and alerts from NOAA SWPC and BGS - access to BGS Magnetometers
- Already including Space Weather as part of our All Hazards Guidance Product to UK Government
- Forecaster training is underway – a number of forecasters have spent time at NOAA SWPC
  - We are developing Space Weather as part of our Forecaster Professional Development Programme
  - Developing Forecasting Tools
- Developing further an Internal Guidance Product
- Research to Identify Stakeholder Requirements in UK



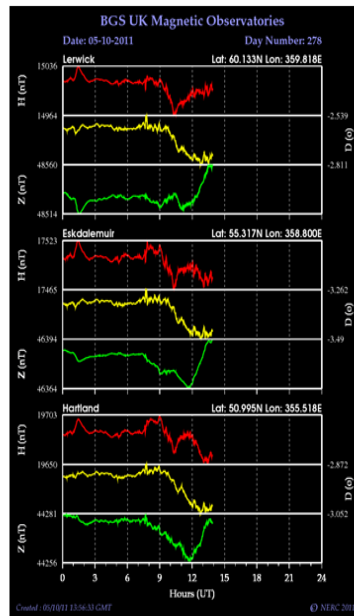
# BGS - Geomagnetic Data



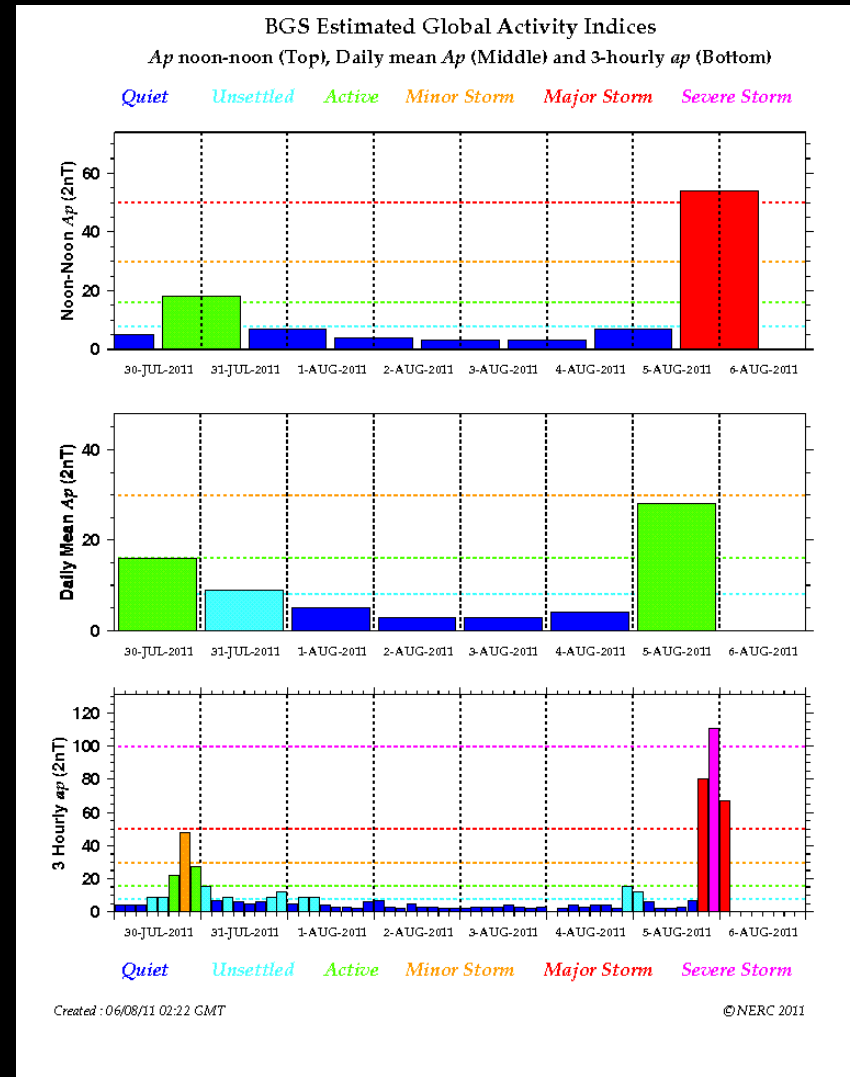
Space Weather Resources : Local and Global Geomagnetic Activity



Yesterday's UK Observatory magnetograms. Click to enlarge.



Today's UK Observatory magnetograms. Click to enlarge.



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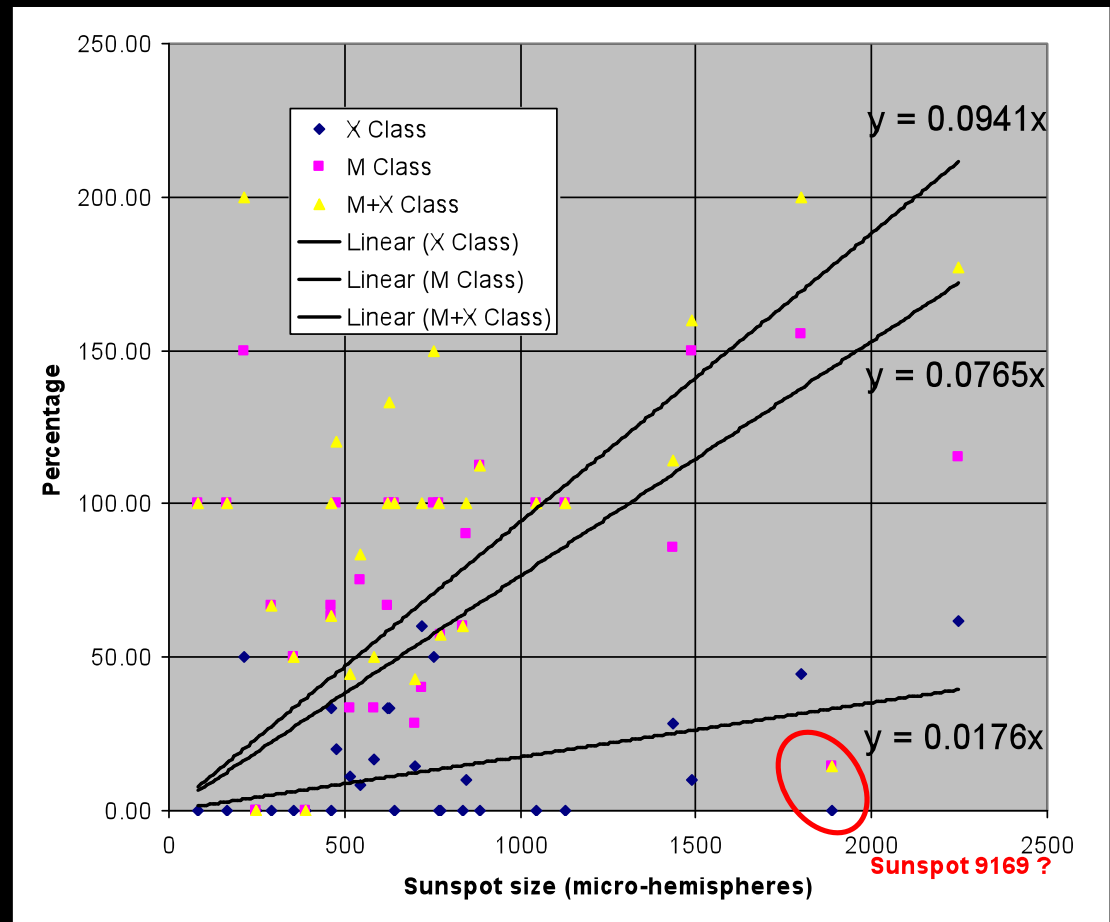
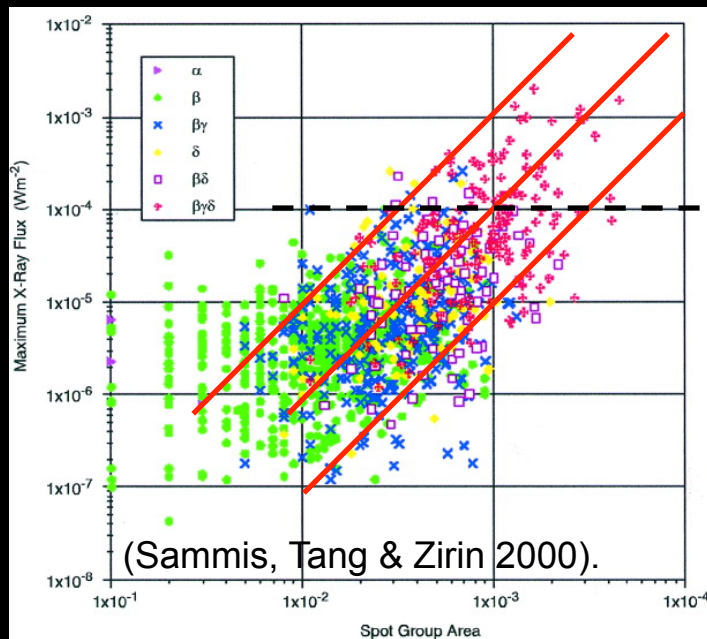


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# Developing Forecasting Tools

Plotting data (from NOAA) over last solar cycle to 2011/12 to relate daily percentage risk of M & X Class Flares - given  $\beta\gamma\delta$  classification and sunspot size in mhs.

How can this be refined given the wide spread of results?





# Modelling - R & D



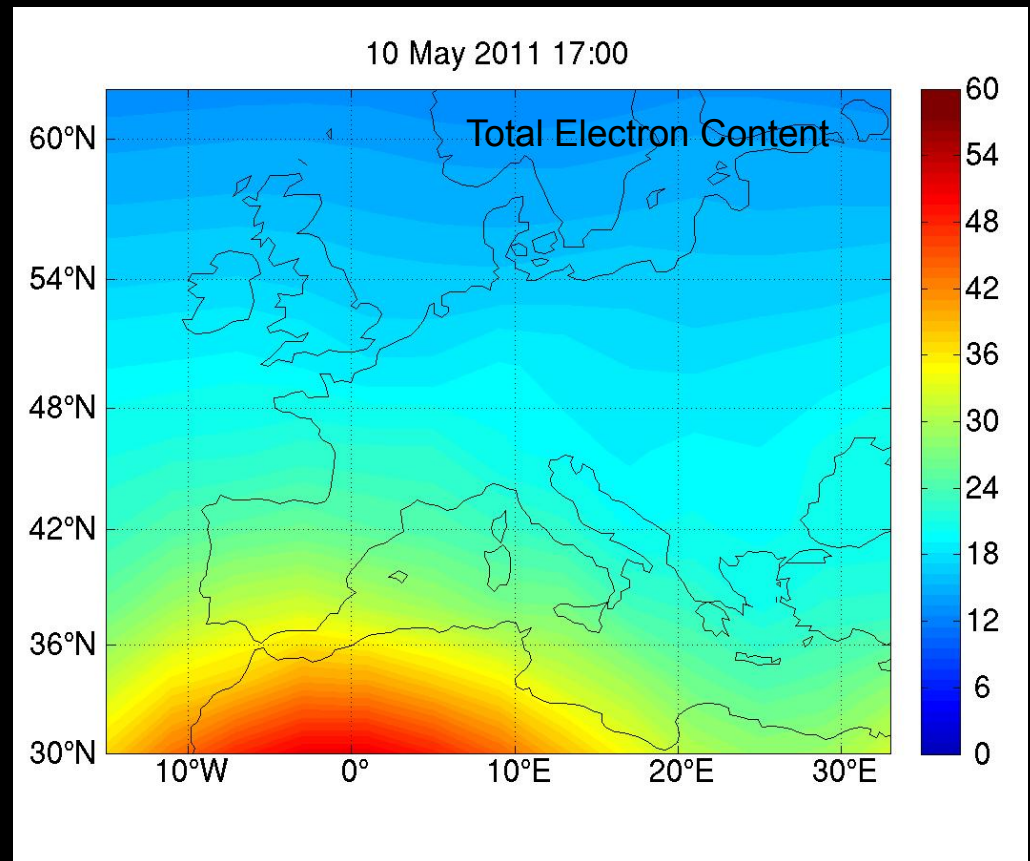
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# New Space Weather Products

- **Ionospheric analysis of European sector – from GPS data**
- Run at the Met Office (in association with Bath University). Presently run 3 days in arrears.
- We are in discussion with Bath University to run MIDAS operationally in near-real-time.
- European Sector MIDAS TEC product is being added to the new WMO Space Weather Portal.

## Multi-Instrument Data Analysis System (MIDAS)

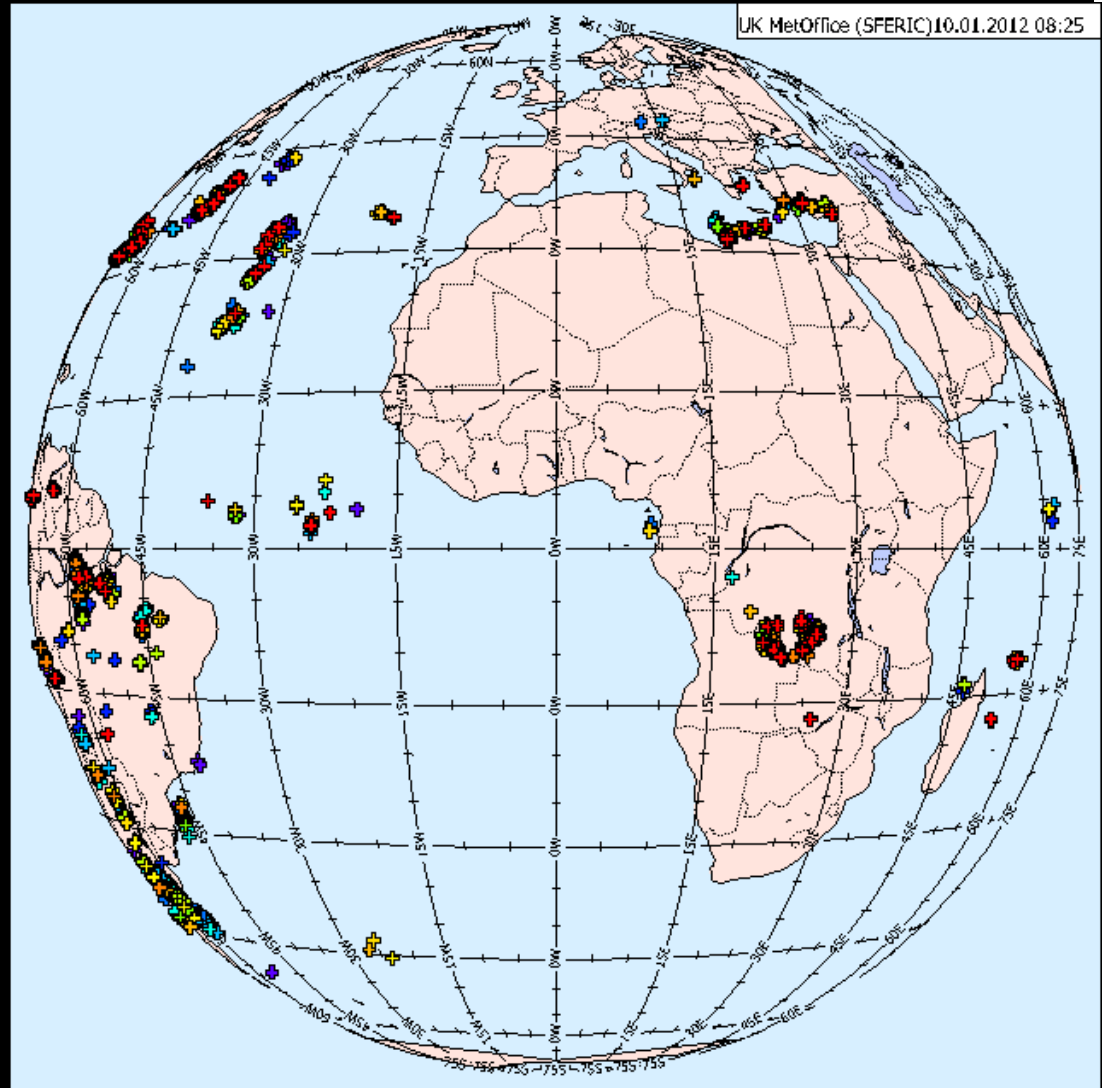
10/05/2011 (graphic - Met Office).





# ATD Net - Lightning Detection

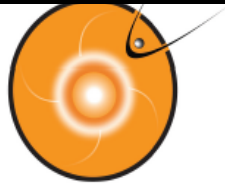
- Met Office ATD Net system detects VLF radio waves (sferics - 13 kHz) that are channelled around the world between surface and ionosphere.
- It may be possible to get additional information about the D Region height from the global network of sensors.
- Lightning detection may fill in some gaps where GPS data is lacking.





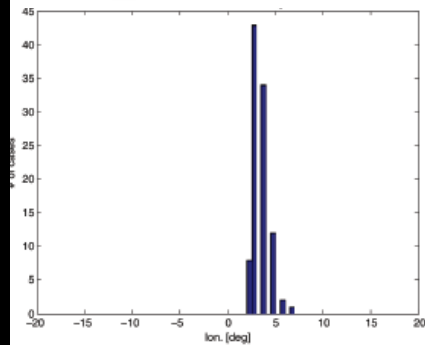
# Running Space Weather Products

- **WSA ENLIL Model** - we are in discussion with developers to obtain copy and hope to run the model operationally.
- Plan to set up an ensemble and assess performance in an operational environment.

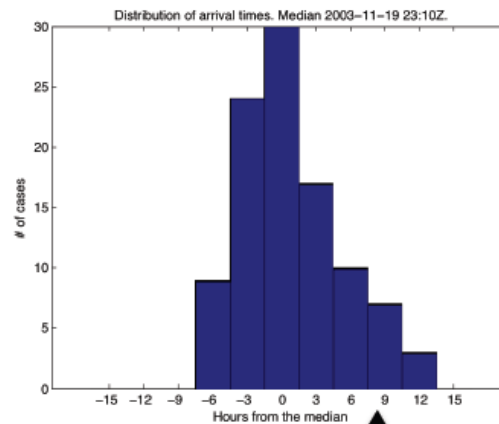


## Initial results – November 18, 2003 CME event

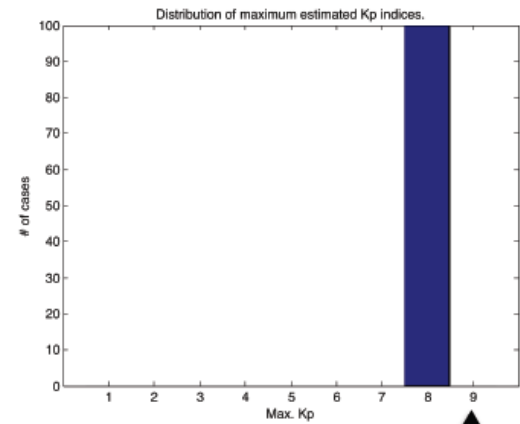
Antti Pulkkinen et (NASA CCMC).



Results based on 100 WSA-ENLIL v2.7 simulations carried out at CCMC.



Observed 2011-11-20 08:00Z.



Observed max. Kp was 9



# Space Weather Research

- **“First Generation”**: develop an ionospheric analysis system based on an empirical model (MIDAS; Bath University) – build infrastructure, ionospheric nowcasts, independent assessments (**current / near future**).
- **“Second Generation”**: Plan to develop Data Assimilation (Kalman Filter) for thermosphere / ionosphere forecast / analysis system - based on a physical model – i.e. EU funded Advanced Thermosphere Modelling for Orbit Prediction (ATMOP project) – will use infrastructure from the above, and provide better ionospheric forecasts (at least for quiet periods). (**completion in 5 years**).

## ATMOP partners

DEIMOS Space Sociedad Limitada Unipersonal (DMS) Spain / Centre National De La Recherche Scientifique (CNRS) France / Collecte Localisation Satellites SA (CLS) France / Met Office (MET) UK / Centre National D'Etudes Spatiales (CNES) France / University College London (UCL) UK / Kybertec s.r.o. (KYB) Czech Republic / Royal Observatory of Belgium (ROB) Belgium







# “Second Generation” Plans

- Design of thermosphere / ionosphere Data Assimilation System (KF)
- Use Coupled Middle Atmosphere-Thermosphere-2 (CMAT 2 - UCL) model (but assimilation code is flexible enough to run with any model).
- Gathering Observations (and Quality Control)
  - **Thermosphere:** accelerometer inferred densities (from GOCE, GRACE, CHAMP satellites); Mean (Two-Line Element (TLE), radar) densities.
  - **Ionosphere:** Ground GPS & GPSRO, (& ATD Network?)
- Assimilation cycles:
  - rapid (15-30 mins) for available ionosphere data.
  - every 6 hrs for thermosphere – utilise thermosphere / ionosphere correlations so that better observed ionosphere can constrain thermosphere.



# Future Met Office Space Weather Research

- “**Whole Atmosphere**” – develop surface to exo-base model. better representation of lower / upper atmosphere interactions
- “**Sun to Ground**”: coupled solar – surface models plus coupled Data Assimilation (in collaboration with NOAA and / or other). Possibility of forecast capability up to ~ 5 days. (**>5 years**)



# “Whole Atmosphere” Modelling

- Model spanning the surface to thermosphere.
- Height range limited to region where Navier-Stokes equations are valid – the exo-base (~600-650 km). Above this level molecules follow ballistic trajectories and air no longer can be treated as continuous fluid.
- Models usually evolve from NWP / Climate models (full dynamics, physics) with additional thermospheric dynamics and physics.
- Coupled ionosphere (on “flux tubes” following field lines). Integration on neutral atmosphere grid is another option.



# “Sun to Ground” Modelling

- Plan to develop a coupled model system to represent whole Sun to Earth system.
- Challenging but possible (Sun to ionosphere already covered in CCMC suite).
- Data Assimilation also needed to enhance quality of models and for operational systems.
- Development of a new whole atmosphere model will be very expensive.
  - Partnerships being formed in the UK right now.
  - Further international partners also welcome!



# Coupled 'Sun to Ground' Model

Coronal Mass Ejections/ High-Speed Streams/ Co-rotating Interaction Regions

<1. Possible Solar GCM

6. Solar Wind Disturbance Propagation Model

Lead time 1 to 4 days

4. Geospace Model

6. Whole Atmosphere Model - Thermosphere / Ionosphere / lower atmosphere

Numbers indicate Technical Readiness Level  
9 = Mature and in operations  
1 = Far from mature (basic research)

Adapted from slide by Bill Murtagh (NOAA SWPC)



# Possible NASA CCMC / Met Office Collaborations

- WSA Enlil Model
  - CCMC already running ensembles (Antti Pulkkinen)
  - Met Office hoping to develop ensembles with NOAA SWPC WSA Enlil version (different CME initialisation).
  - Knowledge exchange between Met Office weather forecasting ensembles team & Space Weather scientists (NOAA & NASA).
  - Inter-comparison of results (including pull through of UK university research (i.e. Reading, RAL) into Met Office to run WSA ENLIL) and possibility of future joint developments.
- iSwa - Met Office interested in using this – presently discussing best way forward for visualisation – i.e. web version or other?
  - Met Office products expected to be offered to iSWA in future.



# Summary

- Met Office can contribute beneficially and substantially to Space Weather services and R&D.
- Met Office Space Weather services (with forecaster training) in development.
- Associated R&D programme will lead to pull through for improved services and operational forecasts.
- Large challenges call for interdisciplinary collaborations which utilise the skills of many partners to maximum effect.



# Questions and answers