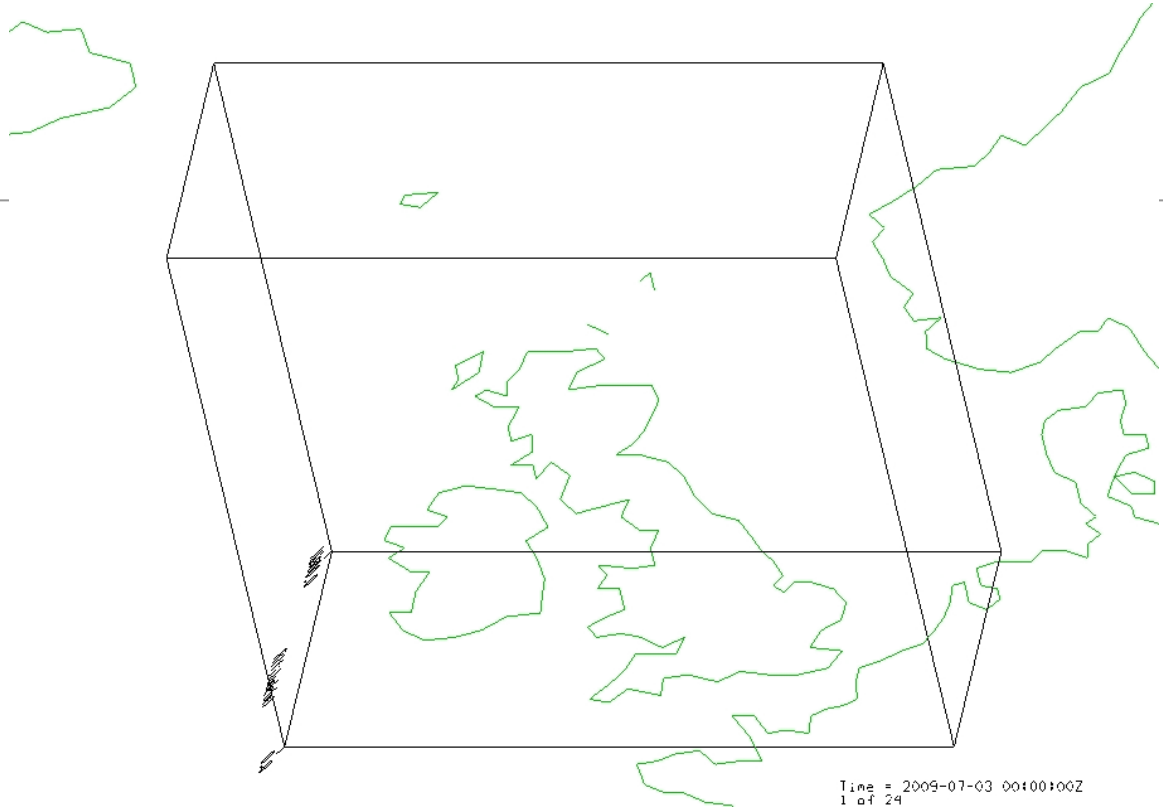

Air Quality Forecasting: WRF-ARW and CMAQ

Dr Clare Allen and Dr Andrea Fraser

Thursday 16th July 2009: **UK Air Quality Forecasting Seminar**

Acknowledgements: Paul Willis and Tim Murrells

WRF - CMAQ model development for UK AQ Forecasts

Introduction

Overview of the WRF-CMAQ Model

Using the recent heat wave and period of elevated ozone
27th June to 4th July 2009

- **WRF** Meteorology Forecast
- **CMAQ** AQ Forecast

Future Plans

WRF-CMAQ Forecast system

Weather Forecast

Advances Research - Weather Research and Forecasting (ARW-WRF)

Initiated using NCEP – Global Forecasting System (GFS) real-time data updated every 3 hrs

Emissions data

EMEP - 50km
NAEI - 1km
Biogenic Potential Inventory
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Emissions data can be manipulated to represent different scenarios

Community Multiscalar Air Quality (CMAQ) **Model**

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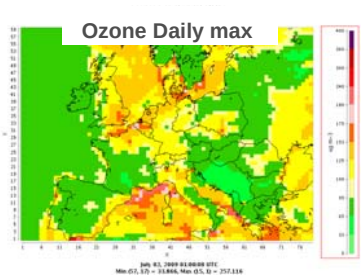
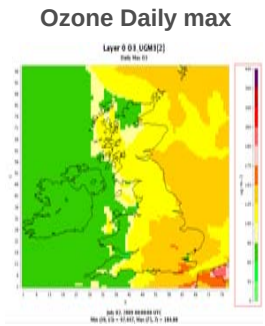
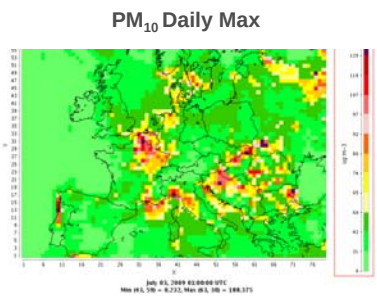
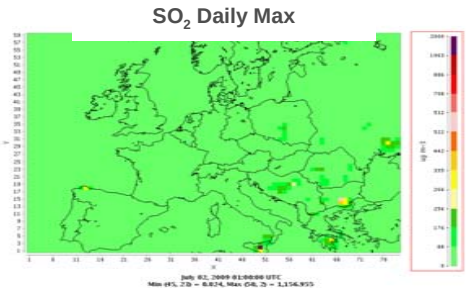








Weather Research and Forecasting Model

- **Weather Research and Forecast model developed by National Center of Atmospheric Research**

- **Advanced Research WRF (WRF-ARW)**

- **3D Eulerian model**

- **Solve compressible, nonhydrostatic Euler equations**

- **Prognostic variables:**
  - Horizontal and vertical wind components
  - Cloud microphysics: hydrometeors
  - Potential temperature perturbation
  - Surface pressure of dry air

- **Lin et al. cloud microphysics scheme:**
  - A sophisticated scheme that has ice, snow and graupel processes
  - Suitable for real-data high-resolution simulations

- **Cumulus parameterisation:**

- **Timestep used 72 seconds**

- **High resolution topography data utilised**

- **Resolution: 48km, 12km, 4km**

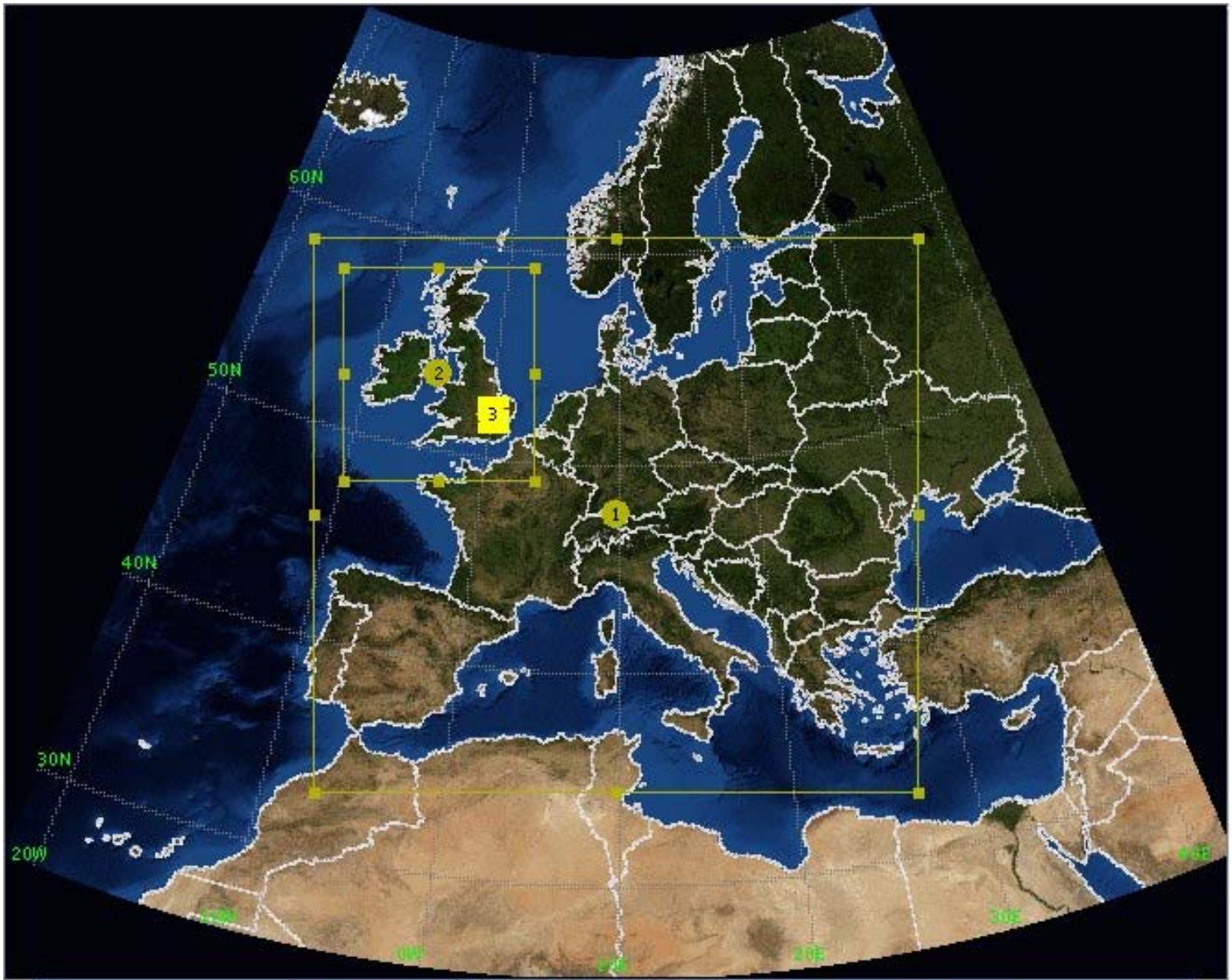
- **Number of vertical levels: 48 levels**

- **AEA utilises the WRF for both retrospective and forecast modelling**

WRF-ARW input data

- **Use Global Forecasting System Data (GFS) as input data**
  - Resolution 0.5^{o} by 0.5^{o}
  - Gives initial model conditions
  - Constrains WRF-ARW meteorology by nudging back to the GFS data every 6 hours
  - Includes:
    - 48 levels for:
      - Pressure
      - Temperature
      - Relative Humidity
      - Horizontal u and v wind components
      - Vertical w wind component
    - Surface:
      - Soil moisture
      - Soil temperature
      - Albedo
      - Green Fraction
      - Land use

Domains used

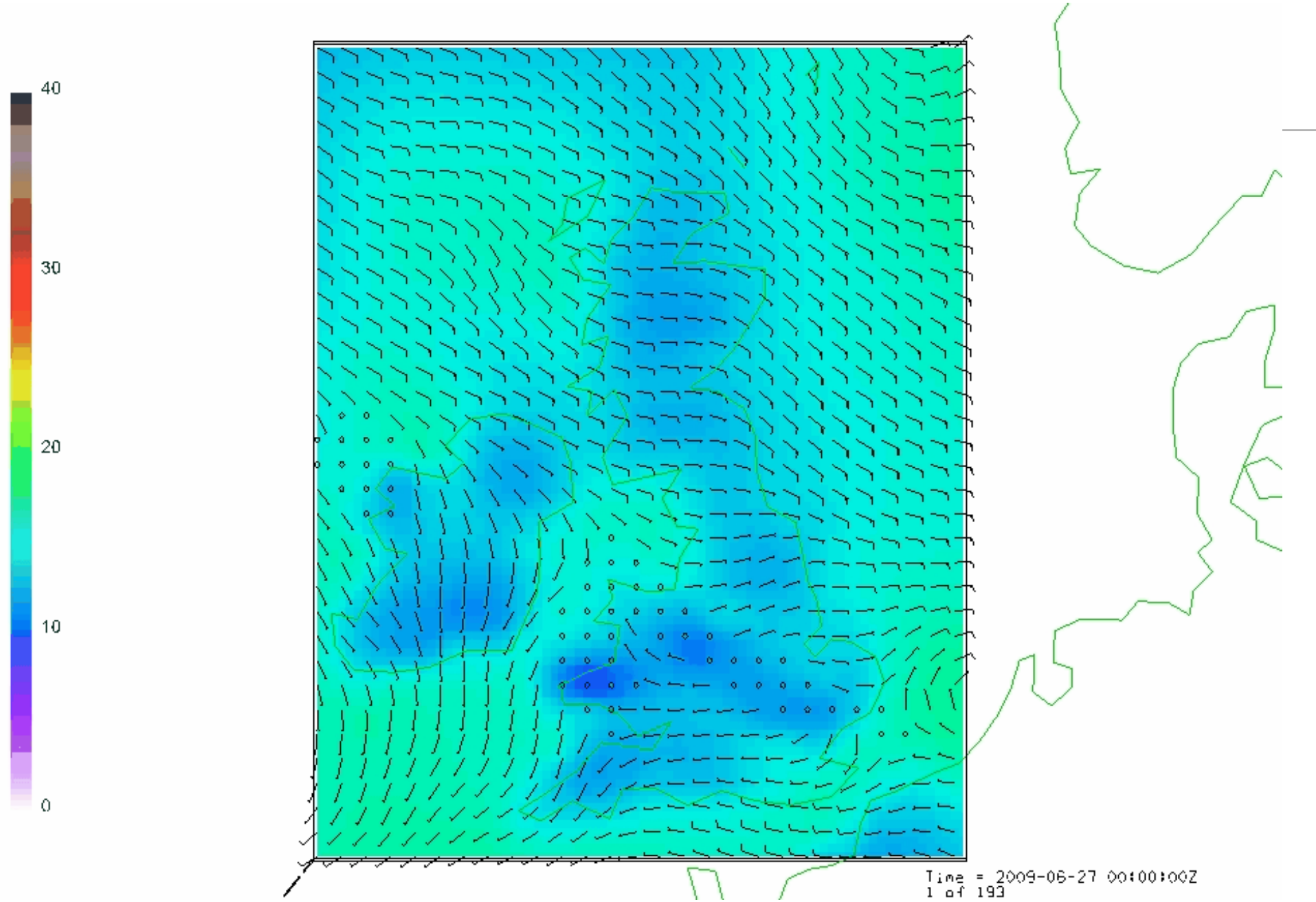


Recent June – July 2009 Heat wave

- From 27th June 2009 to 4th July 2009
- Maximum temperature of 31.8°C recorded in Surrey 30th June

Health problems associated with heatwaves

- **Unable to quickly adapt to changing temperature patterns**
- **Relatively more deaths occur in the first days of a heatwave**
- **Higher levels of particulate matter and ozone**
- **Main causes of illness and death during a heatwave:**
  - **Respiratory diseases**
  - **Cardiovascular diseases**
- **Estimated average 75 extra deaths per week per degree of increase in temperature during summer 2006 in England**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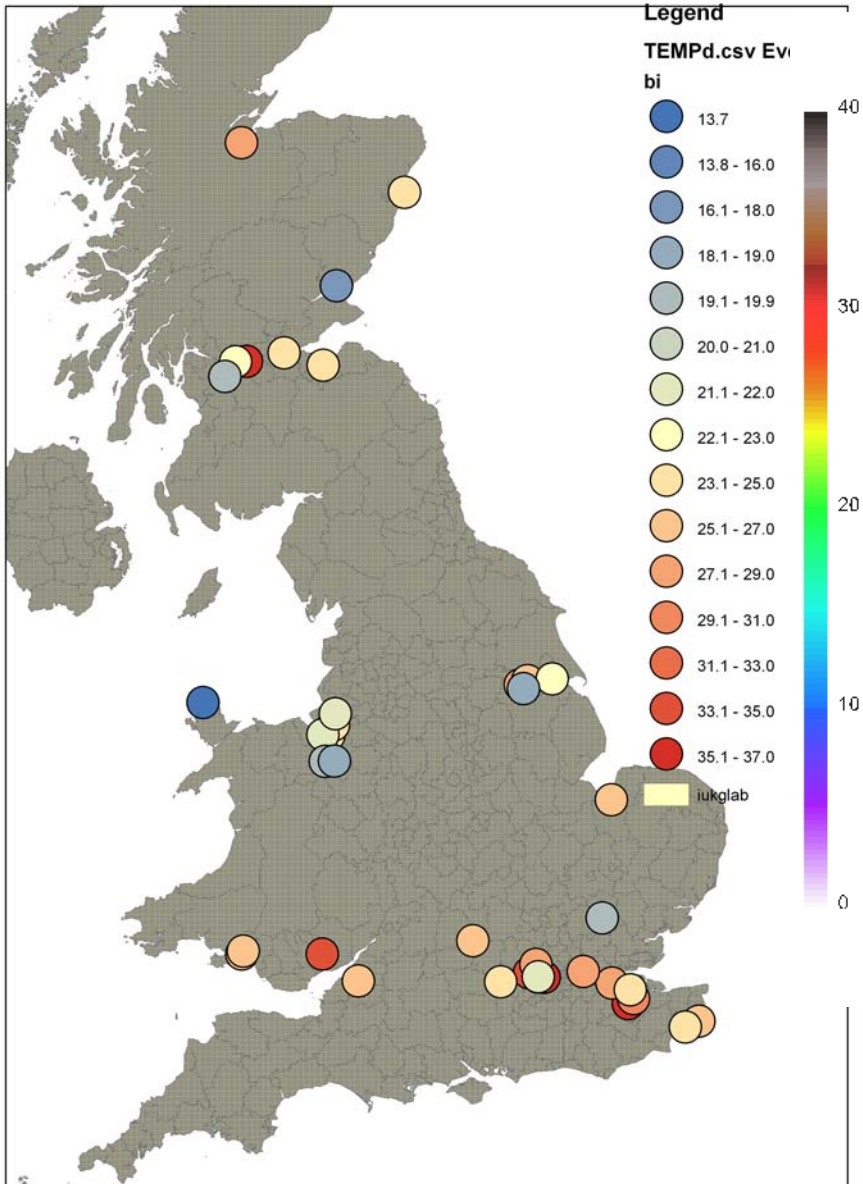
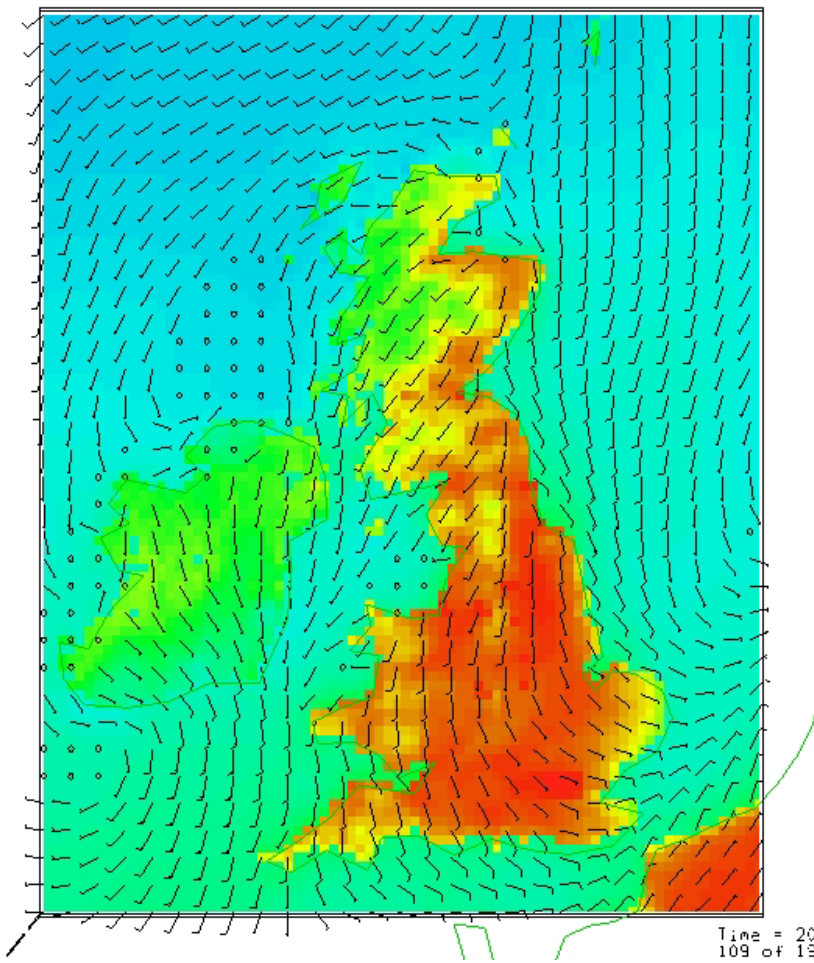
1st July 2009 12:00





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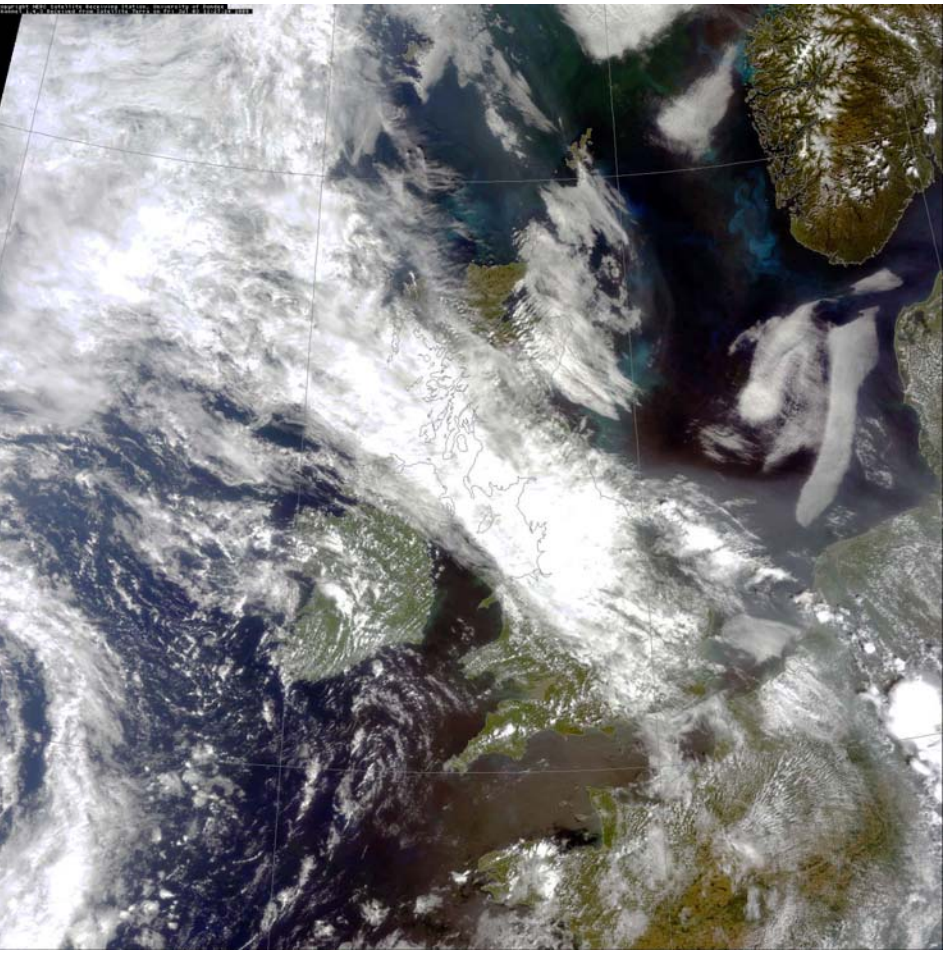

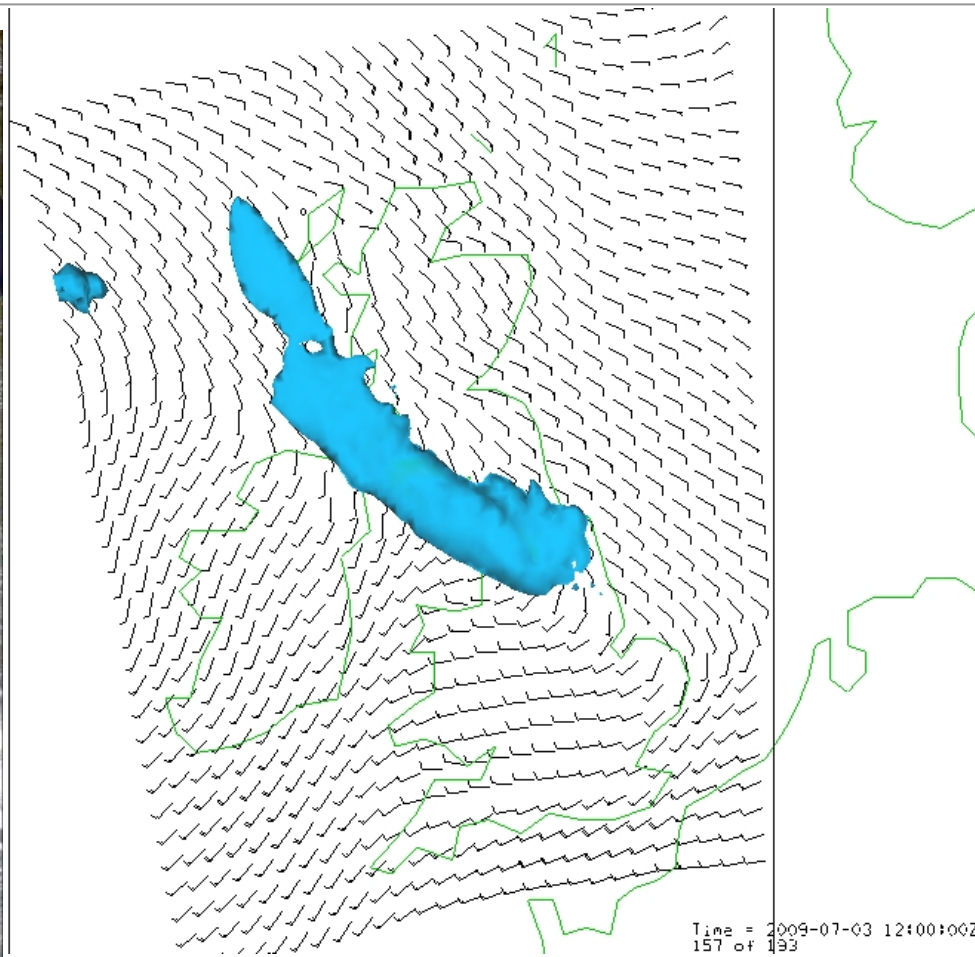

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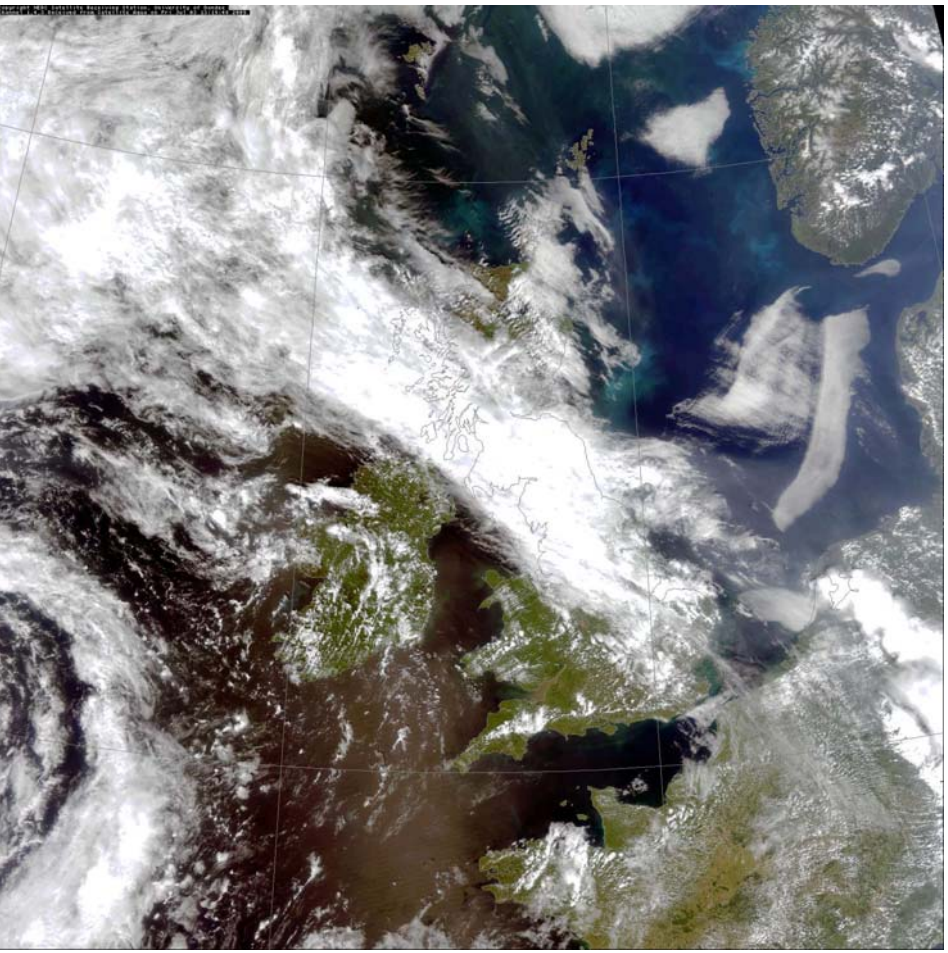

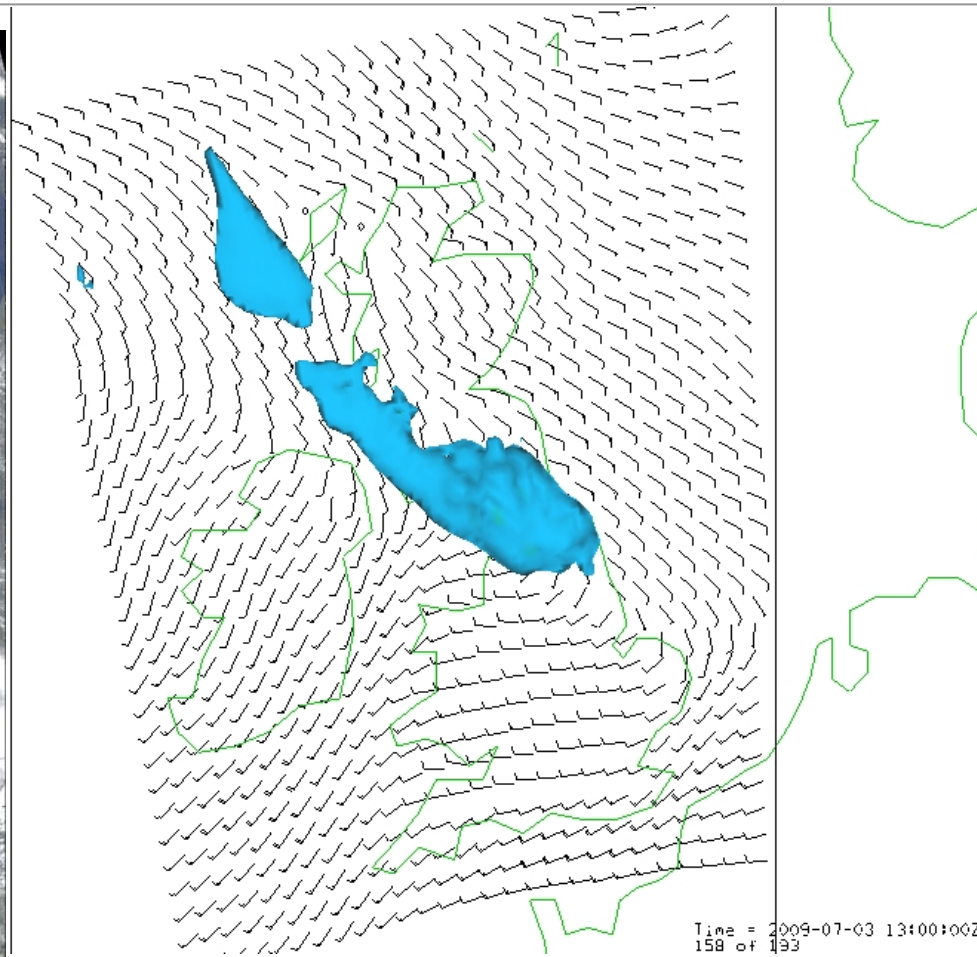

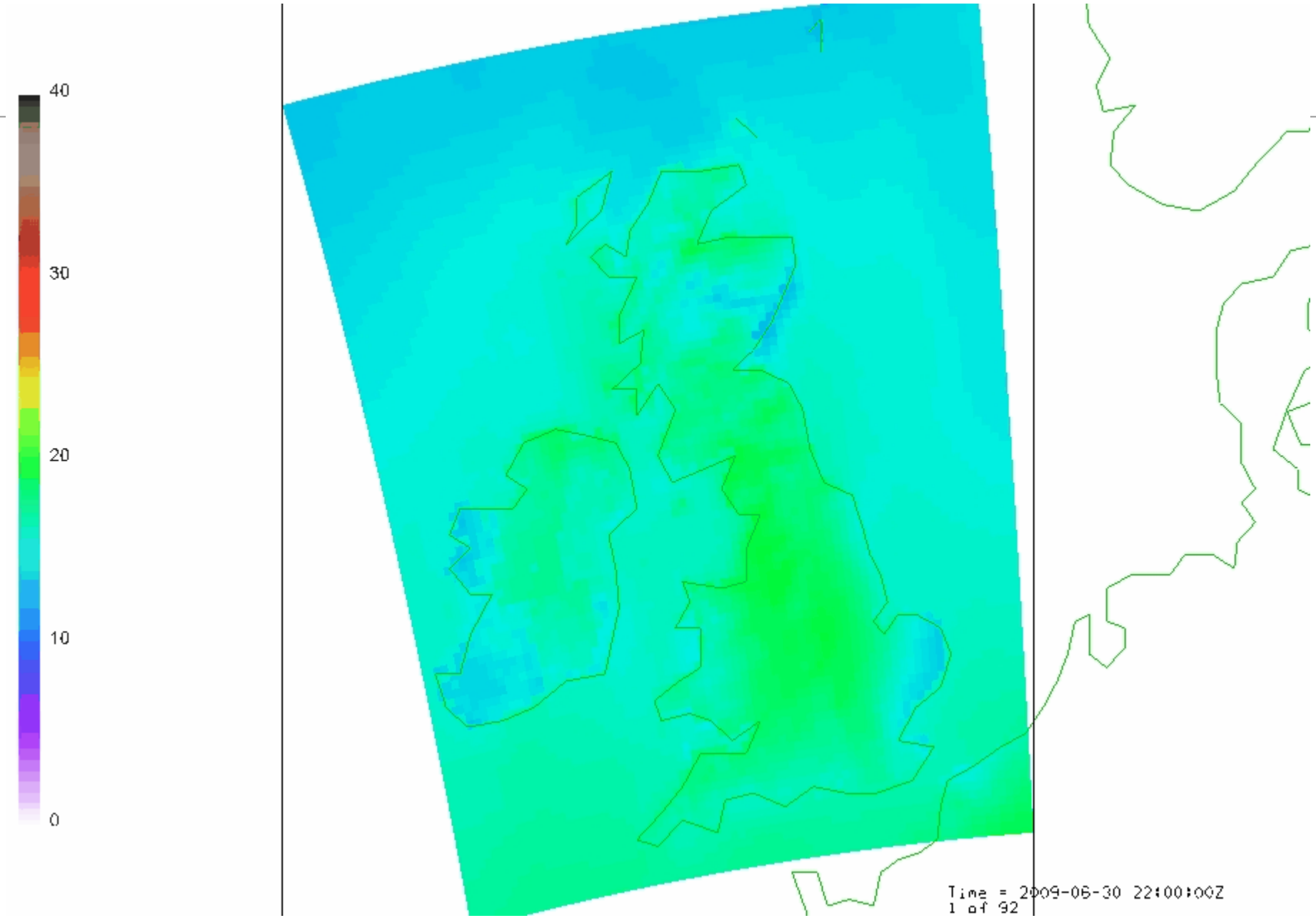
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1 of 92

The WRF-ARW outputs are fed into the CMAQ model to produce the Air Quality Forecast

UK Air Pollution Levels

WRF-CMAQ Forecast system

Weather Forecast

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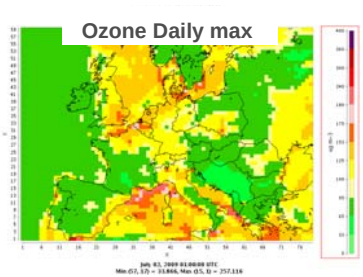
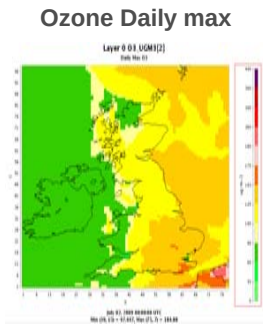
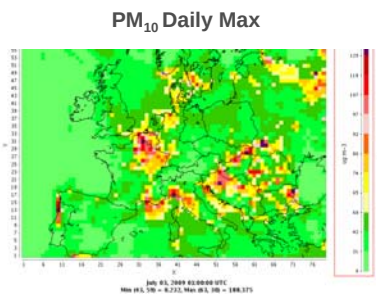
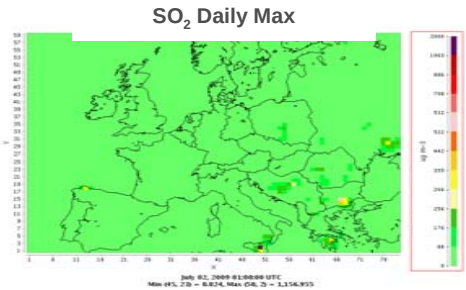


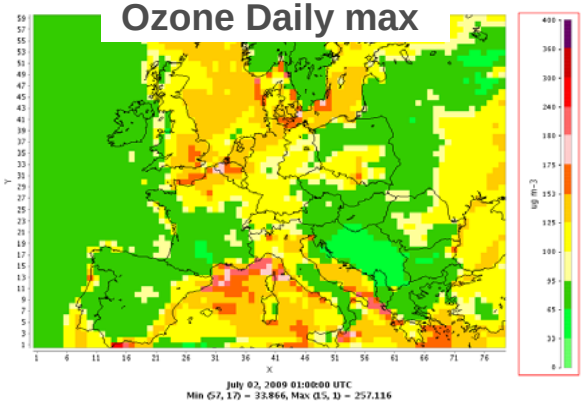




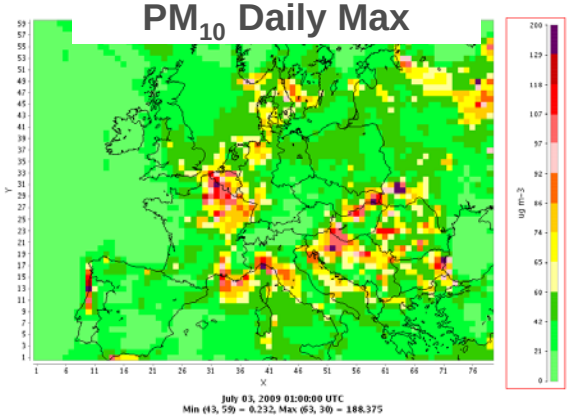


WRF-CMAQ AQ Forecasts – Daily Maximum 2nd July 2009

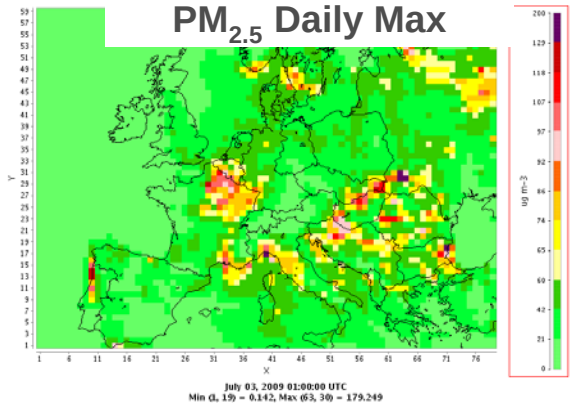
Ozone Daily max



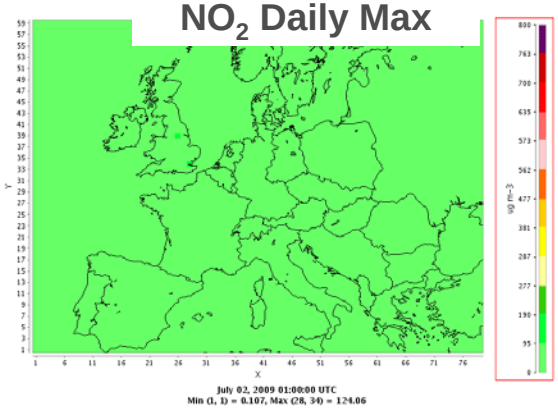
PM_{10} Daily Max



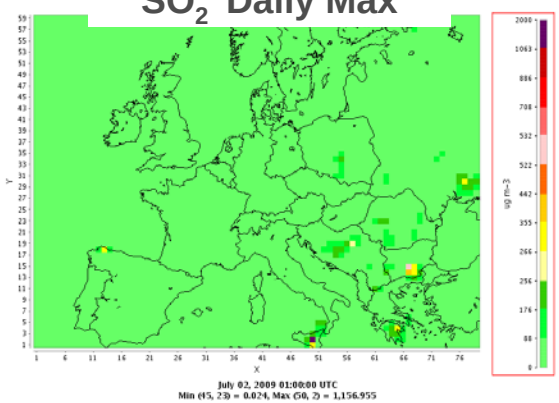
$PM_{2.5}$ Daily Max



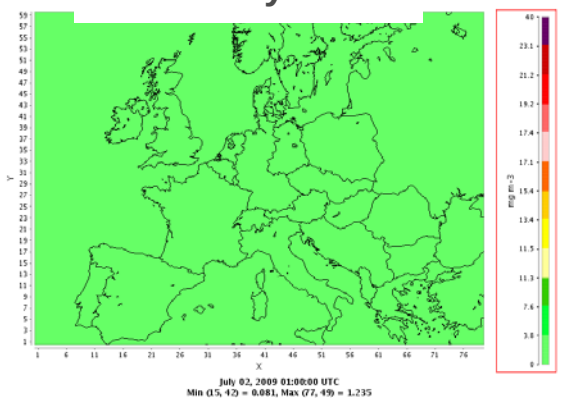
NO_2 Daily Max



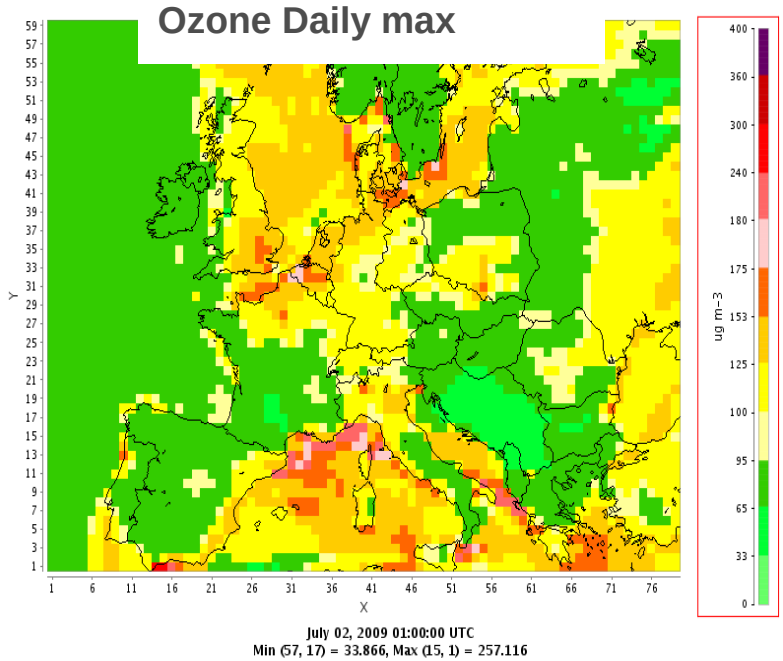
SO_2 Daily Max

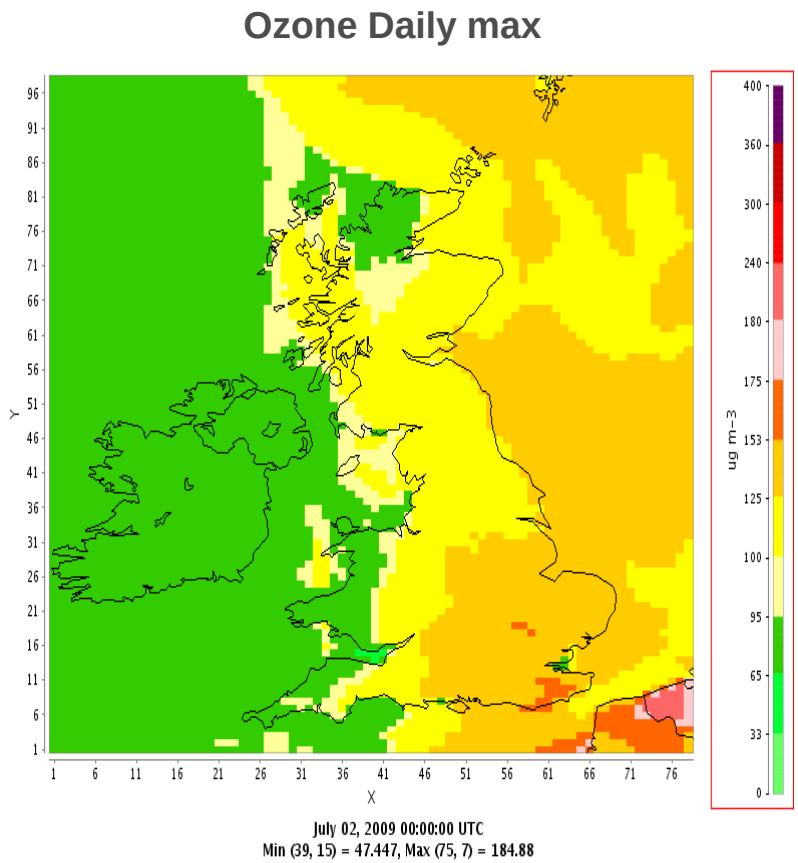


CO Daily Max



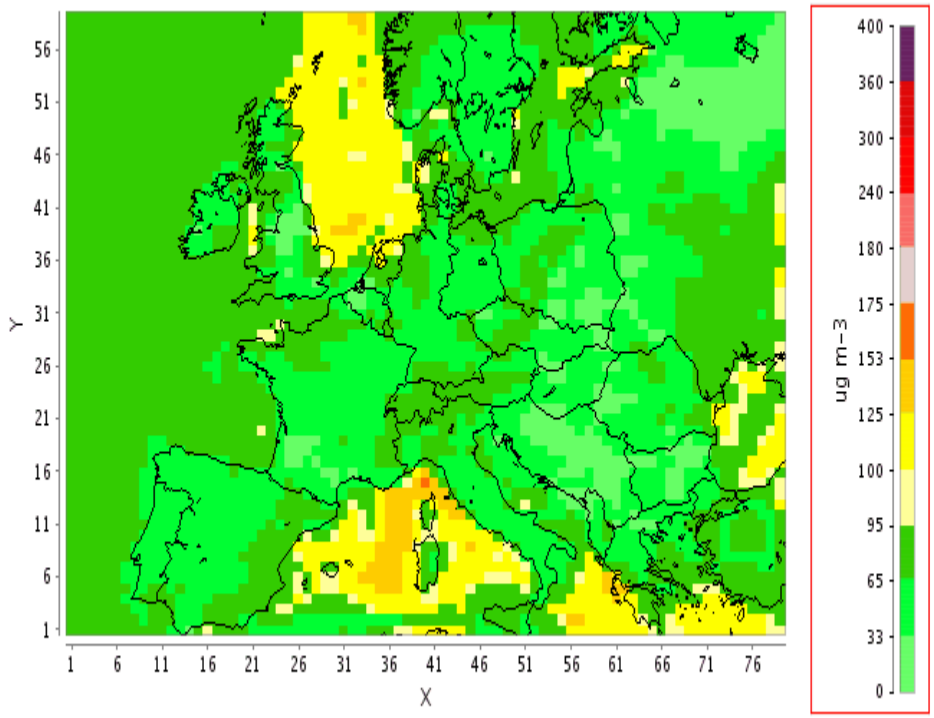
WRF-CMAQ AQ Forecasts – 2nd July 2009





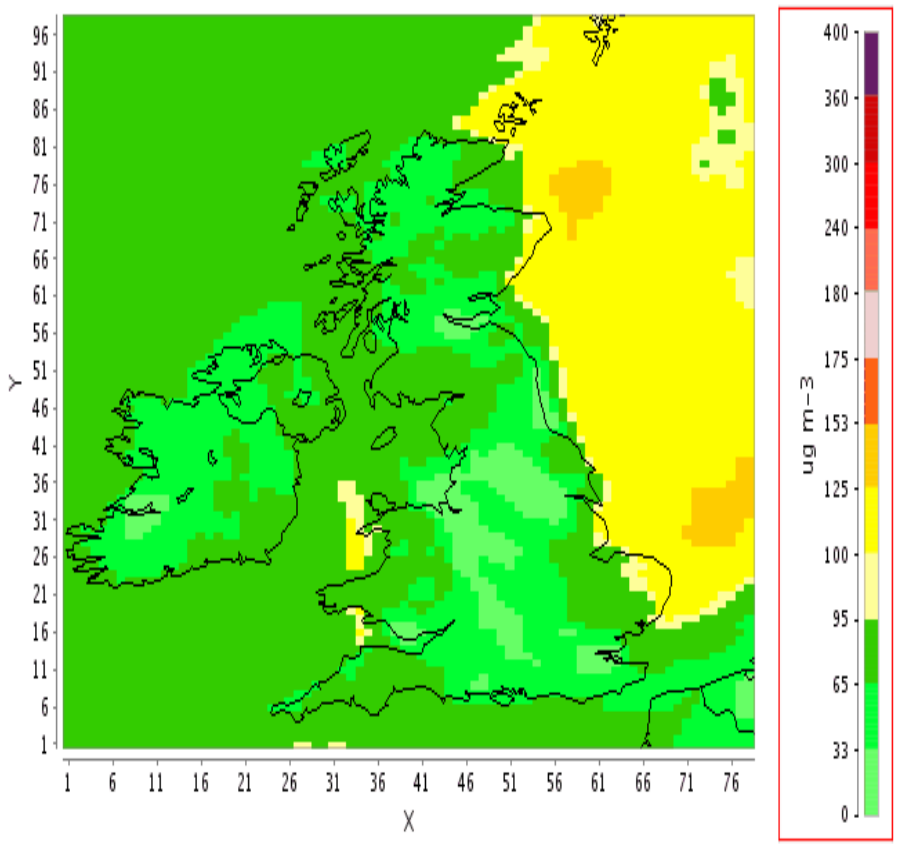
WRF-CMAQ AQ Forecasts – 2nd July 2009

Ozone



July 02, 2009 01:00:00 UTC
Min (77, 49) = 4.486E-4, Max (40, 15) = 156.847

Ozone



July 02, 2009 00:00:00 UTC
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WRF-CMAQ Forecast system

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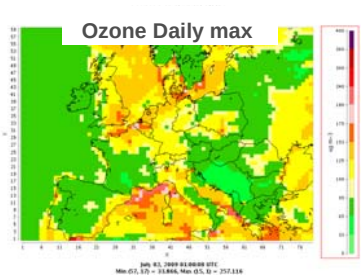

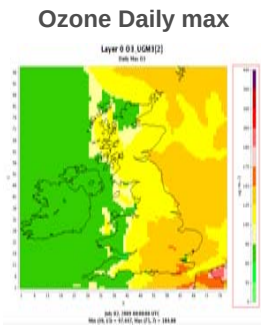

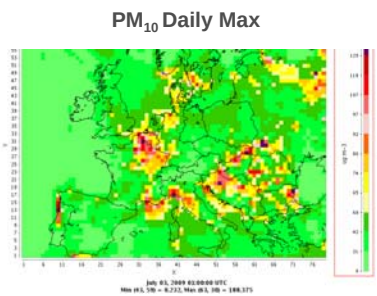

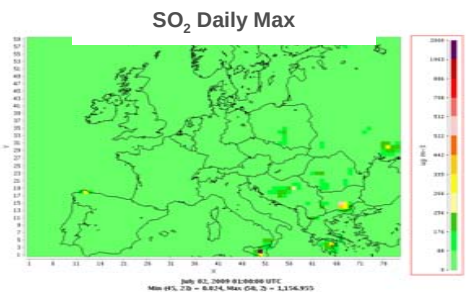

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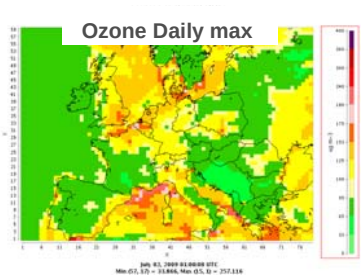
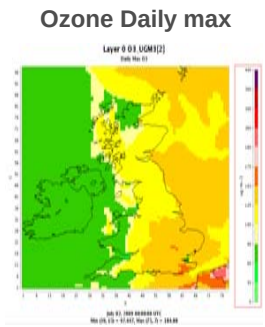
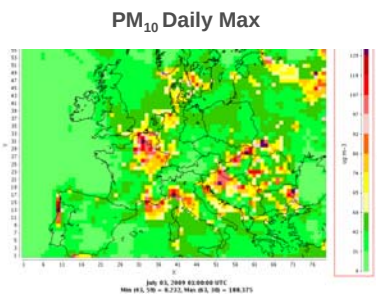
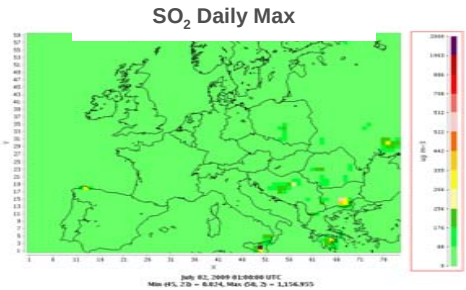








WRF Forecast

CMAQ Forecast

CMAQ operates as an off line AQ Model

The UK forecast is nested within a European forecast

At present is used as a 48 km European grid and a 12 km UK grid

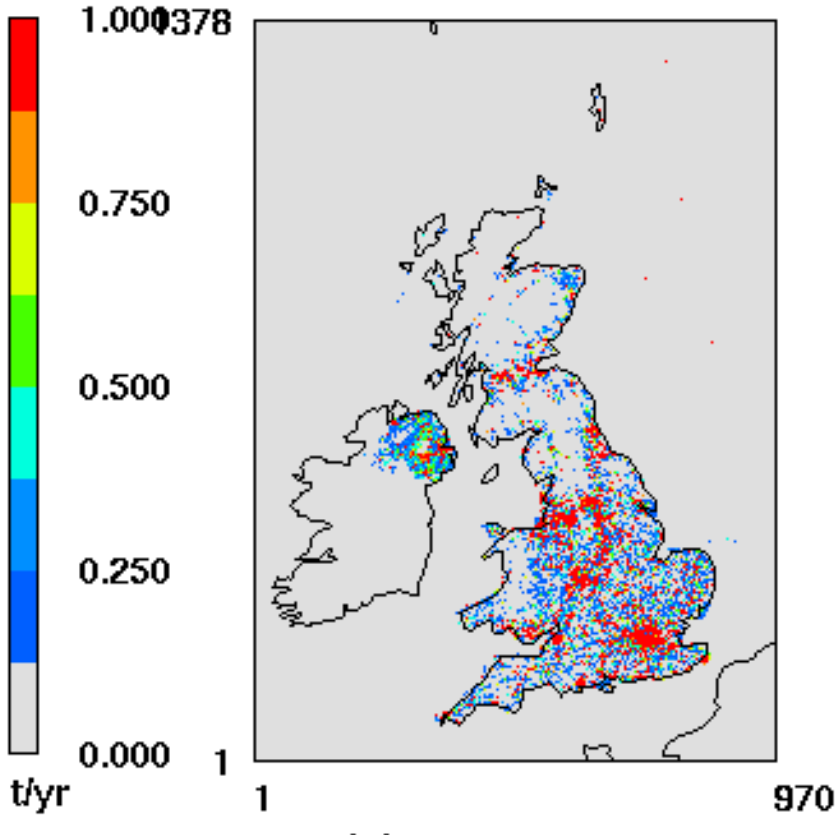
In addition to the Meteorology, Emissions data are required

Emissions for CMAQ

NAEI PM_{10}

Annual emissions for NO_x PM CO NH_3 VOC and SO_2 are processed using standard temporal factors into hourly emissions ready for the AQ model

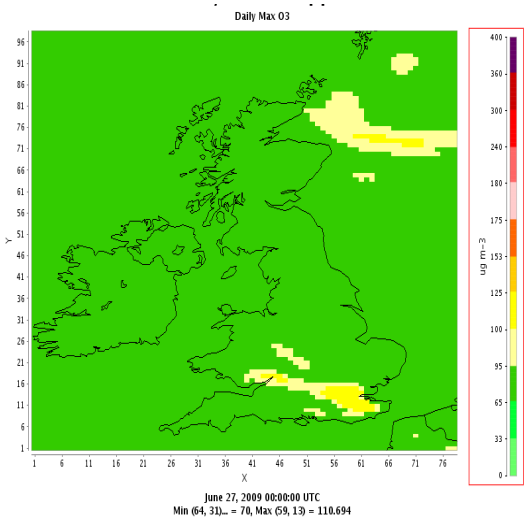
- UK National Atmospheric Emissions Inventory (NAEI), available at 1km resolution
- EMEP emissions are used for Europe, available at 50km resolution
- Natural emissions are calculated using a Biogenic Potential Inventory

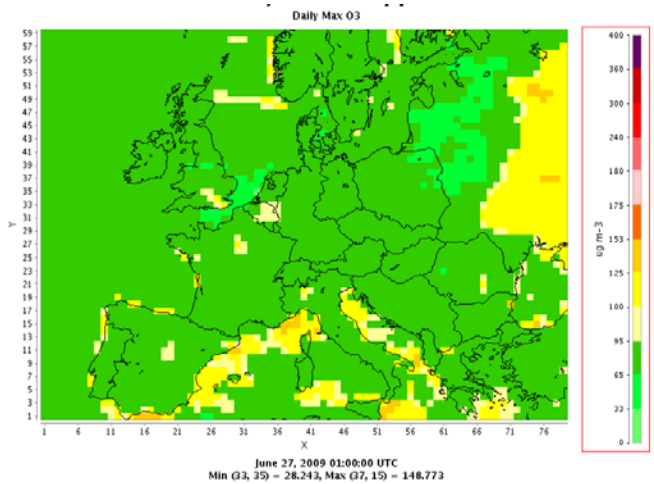


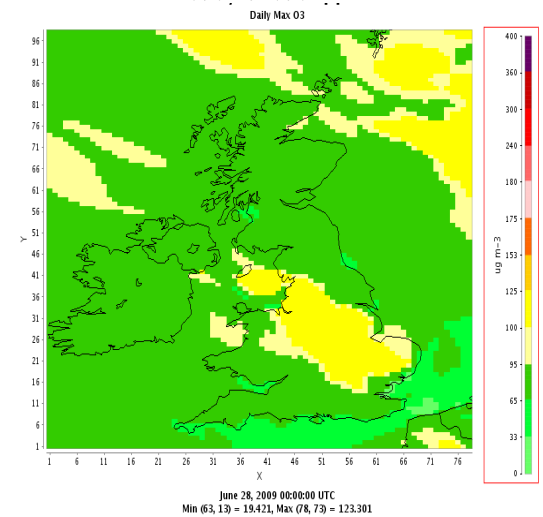
During the recent period of elevated ozone

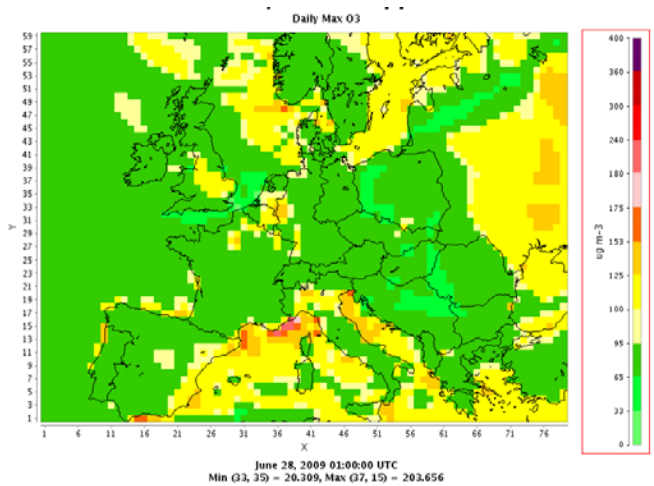
27th June to 4th July 2009

Ozone daily max. 27th – 28th June 2009

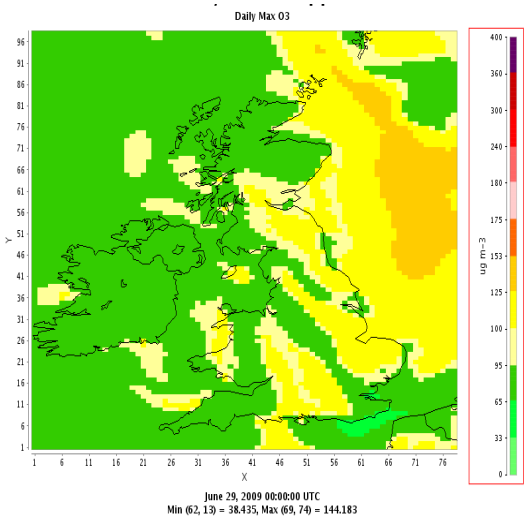


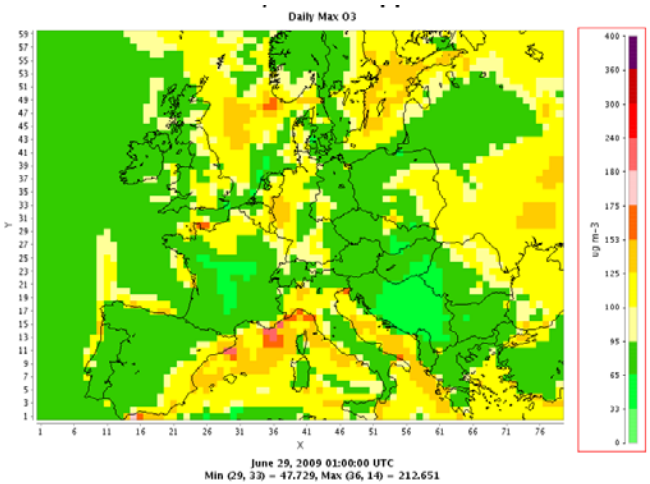


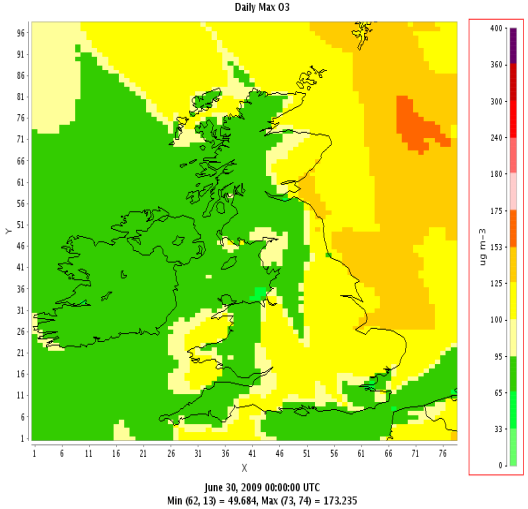


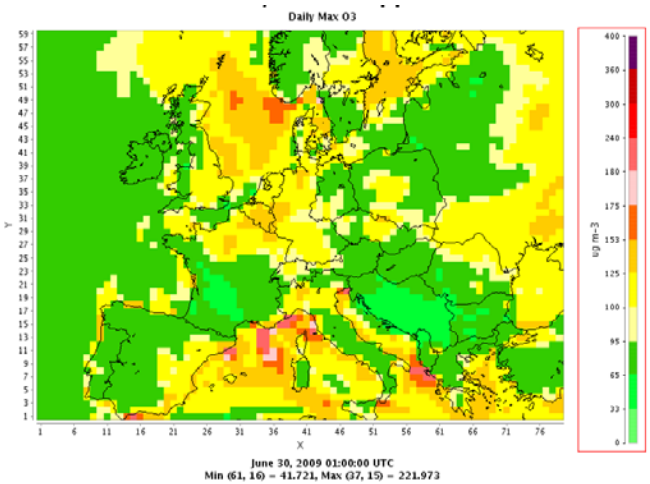


Ozone daily max. 29th – 30th June 2009

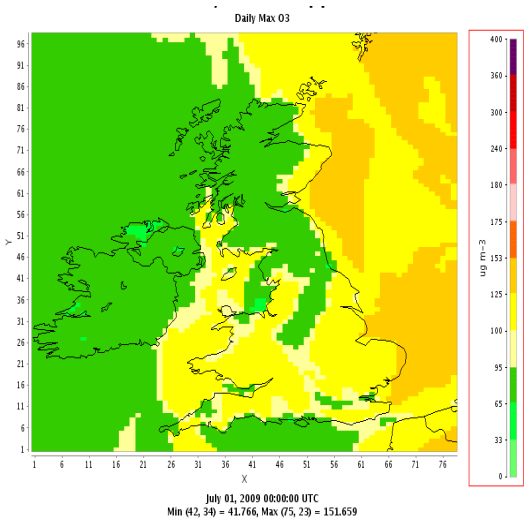


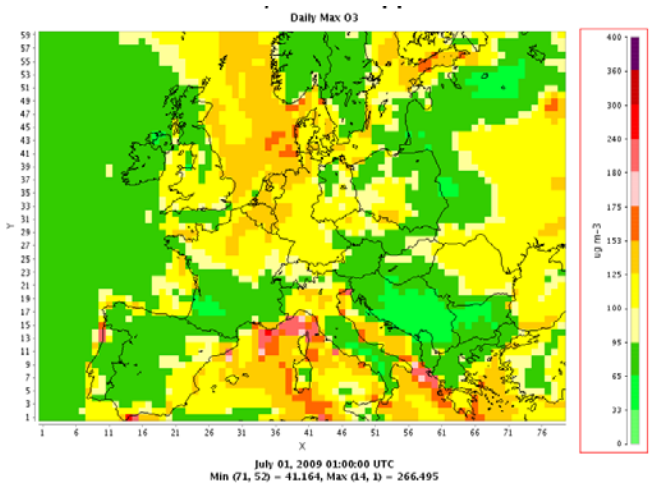


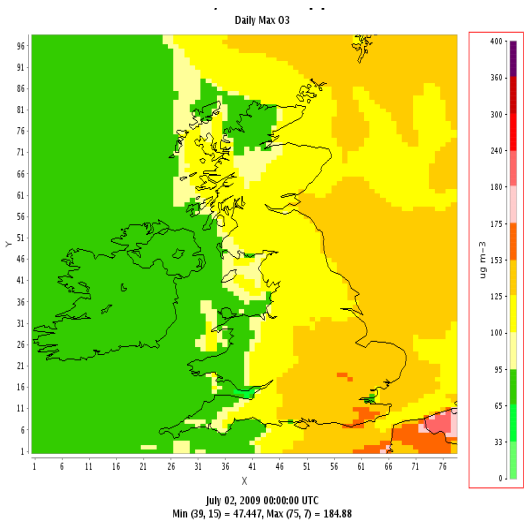


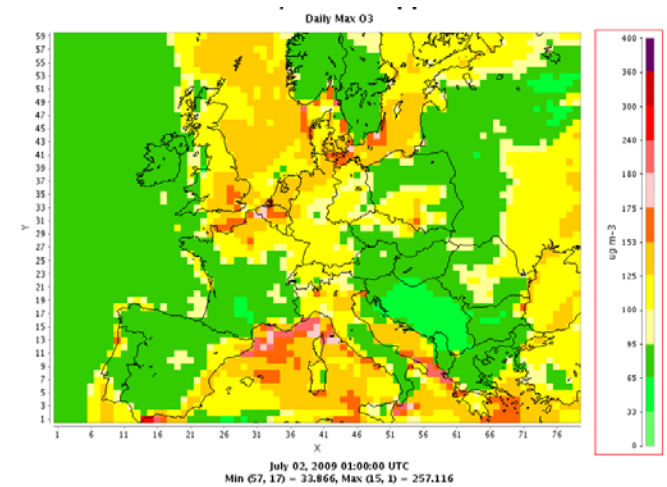


Ozone daily max. 1st -2nd July 2009

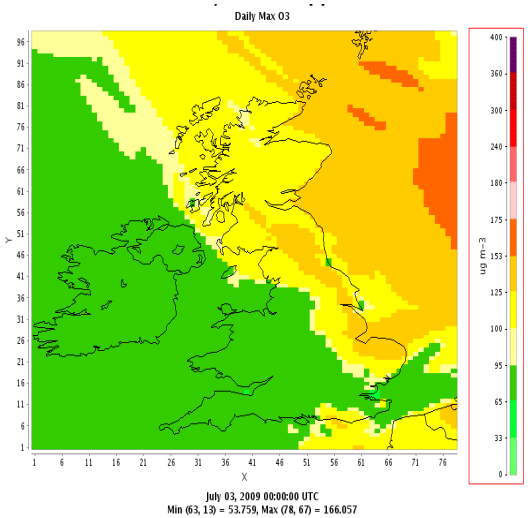


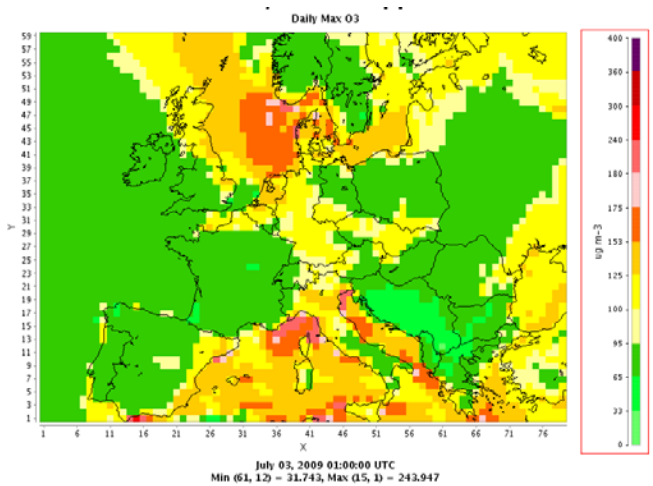


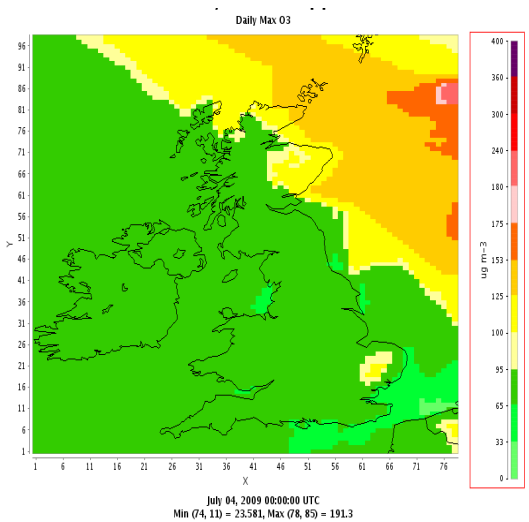


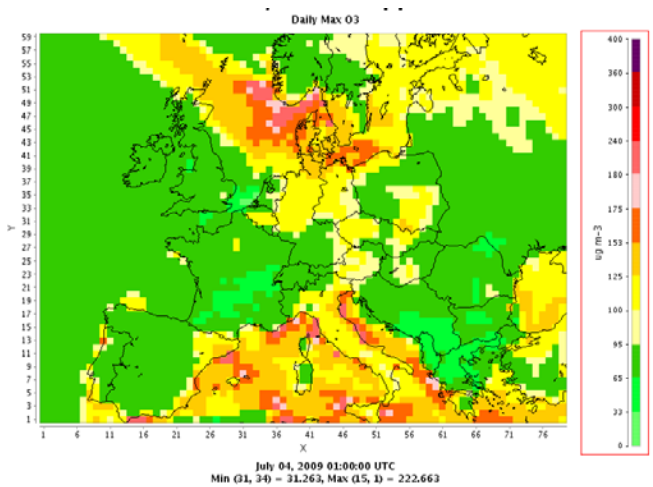


Ozone daily max. 3rd – 4th July 2009

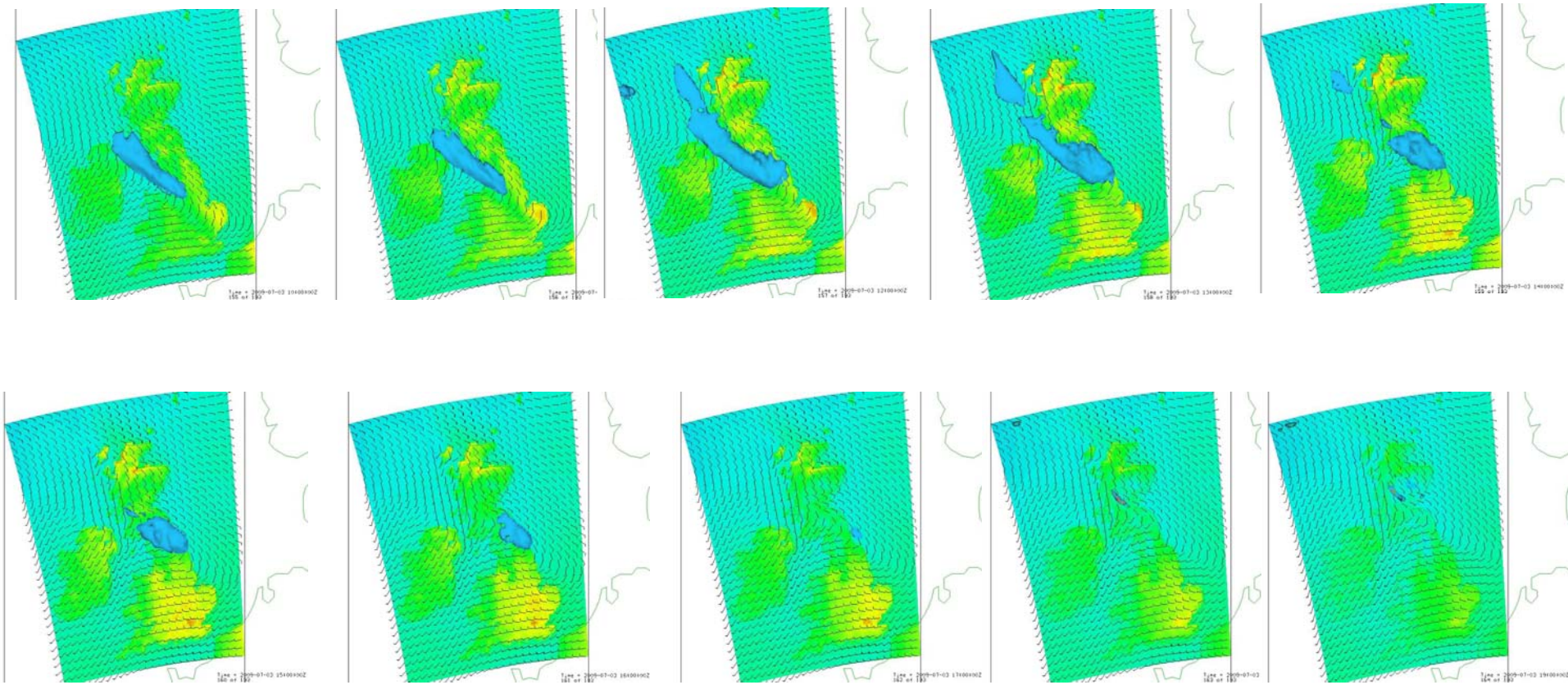




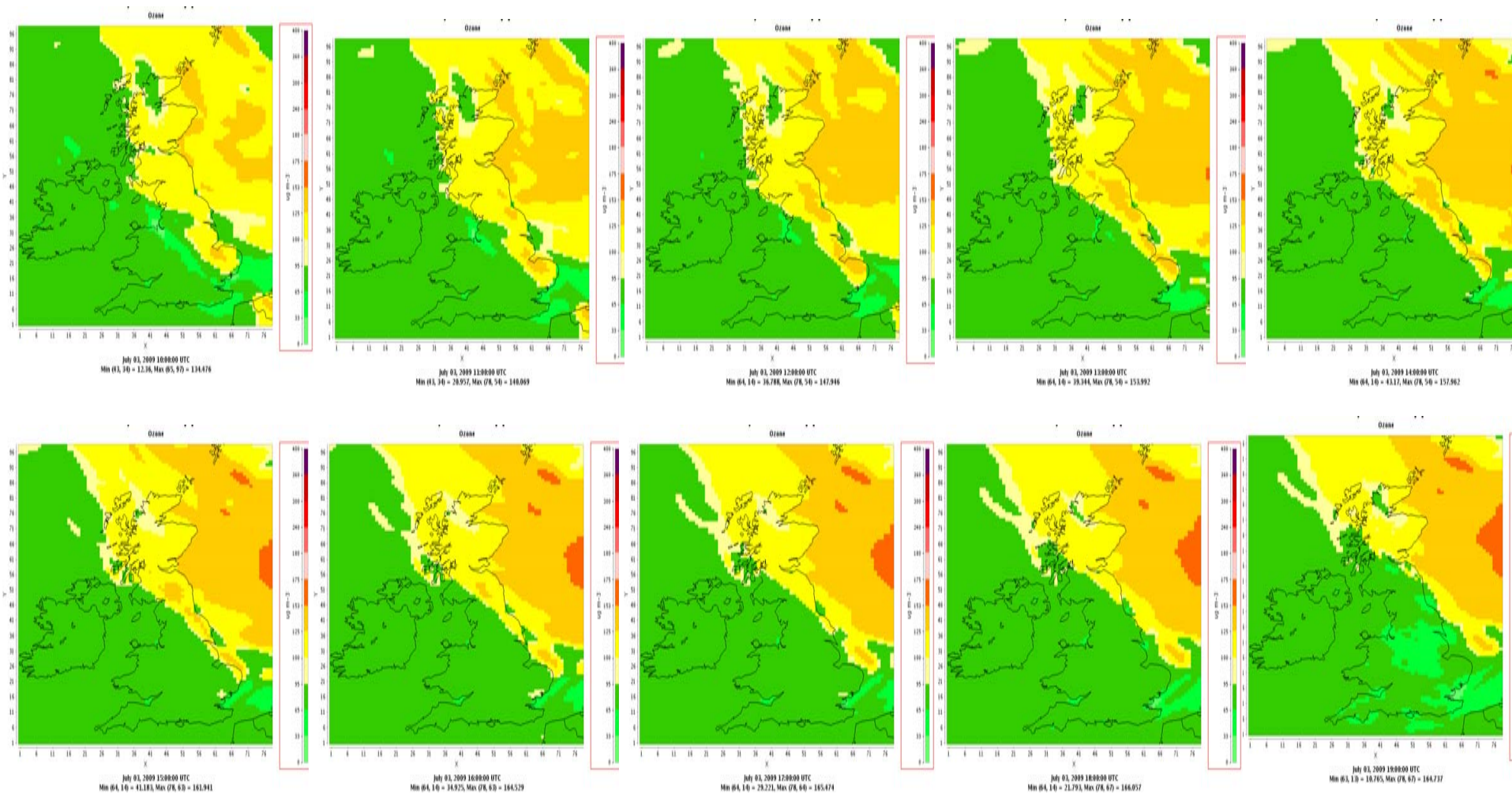




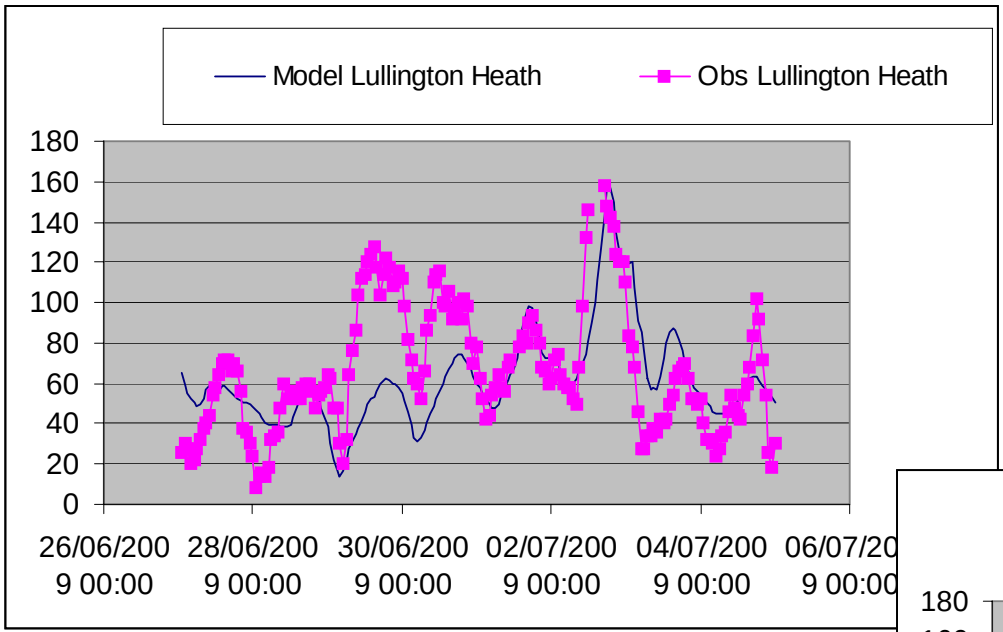
WRF – The end of the heat wave

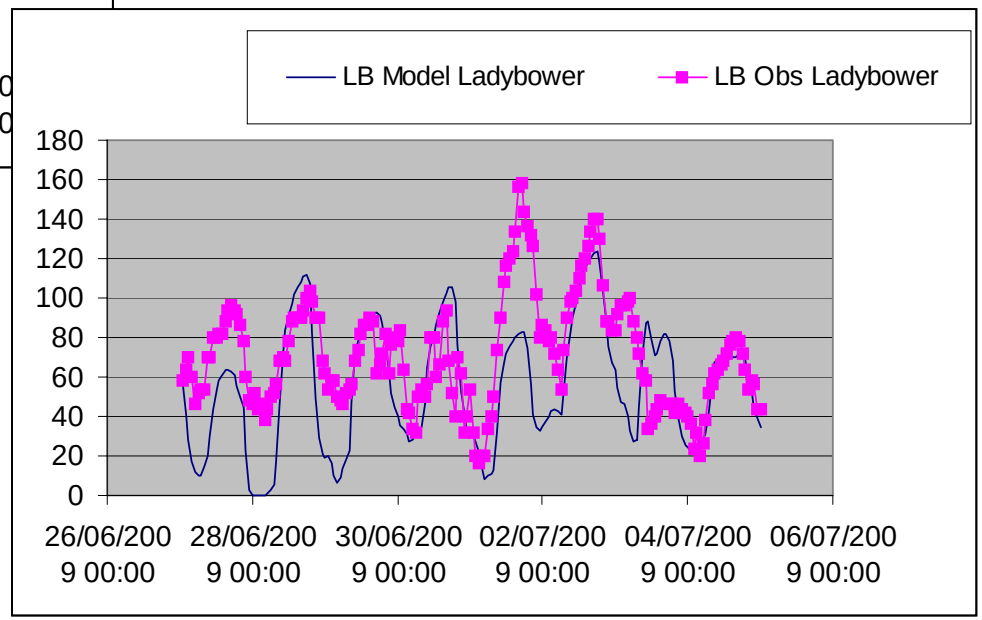


CMAQ – The end of the heat wave

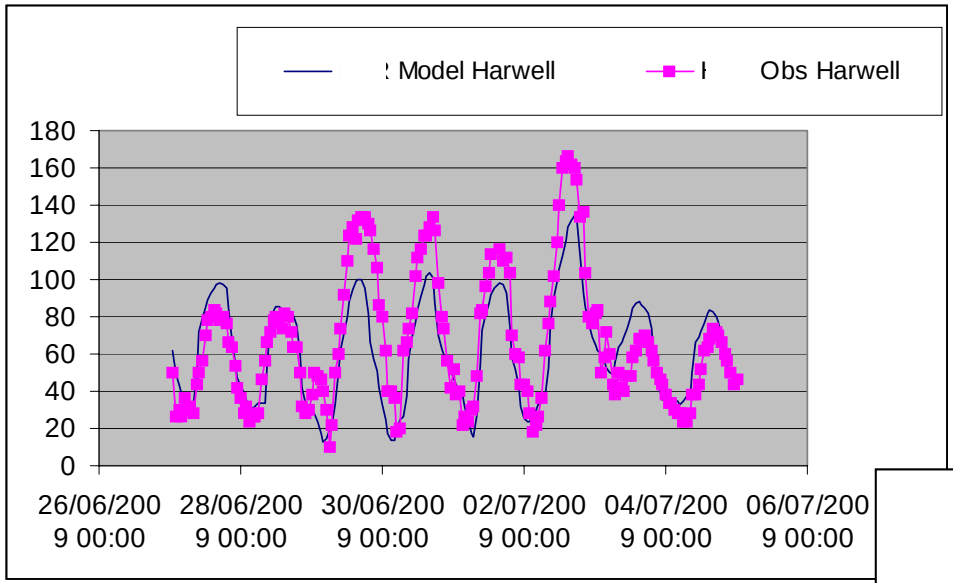


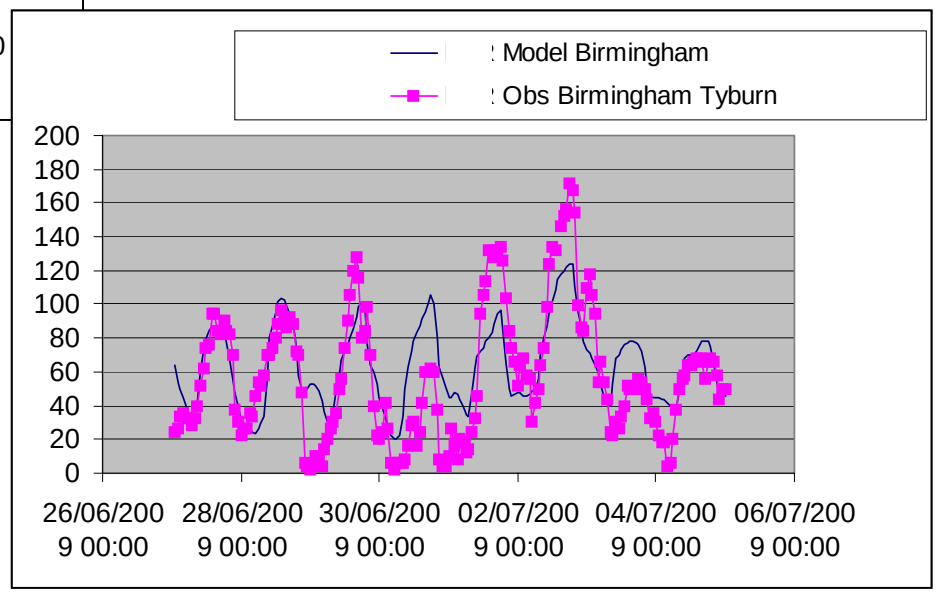
Comparison with Observations





Comparison with Observations





Summary of new model developments

Have demonstrated that can forecast poor air quality events

WRF-CMAQ

- 2-day European WRF-CMAQ forecasts are running daily
- 2-day UK WRF-CMAQ forecasts will be added soon
- Ongoing model evaluation

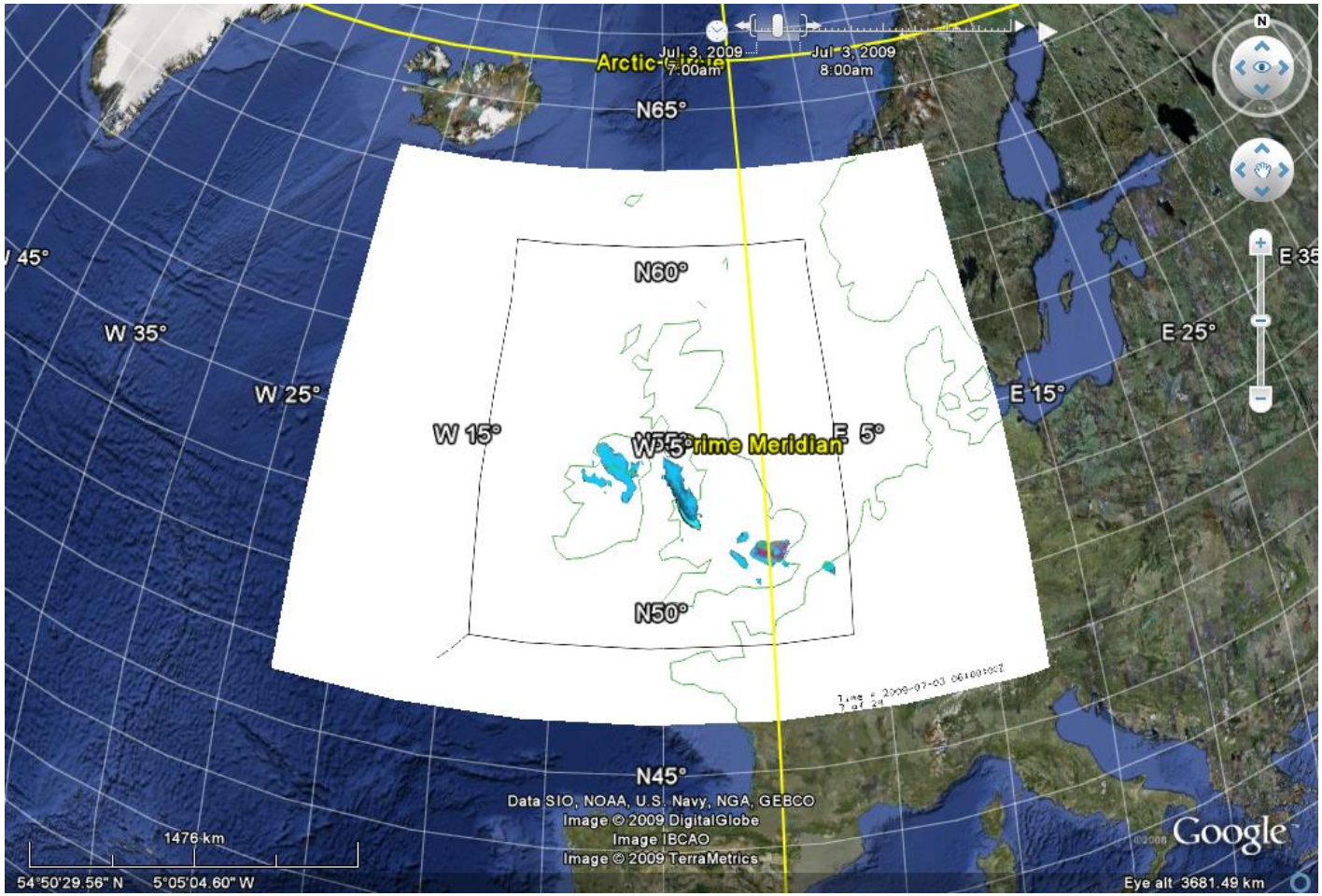
Future

- Continuous improvements alongside the evaluation
  - Emissions
  - WRF
  - CMAQ

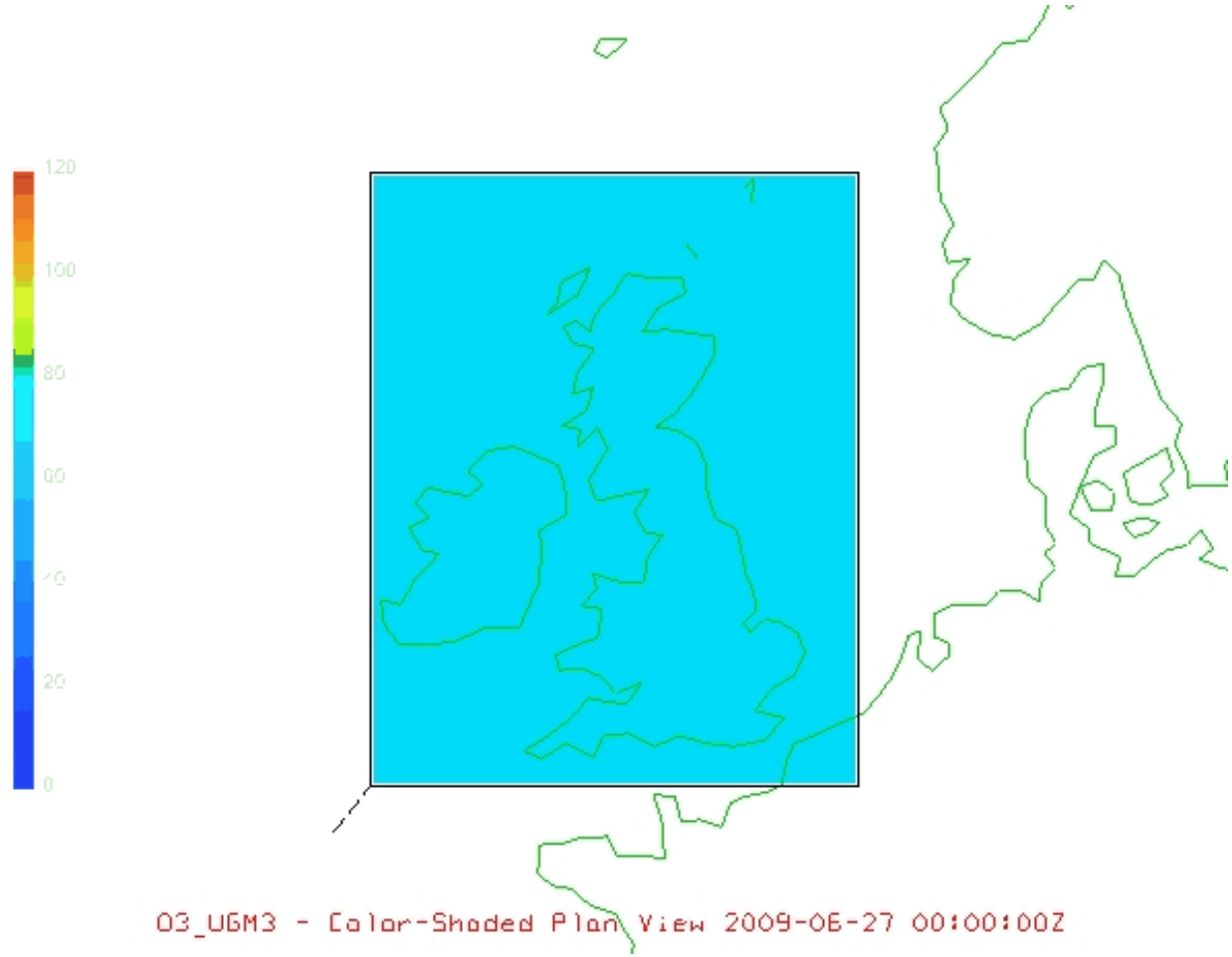
- AEA use CMAQ at 4km to for retrospective regional air quality - Evaluate the feasibility of AQ forecasts at 4km for regional areas
- Evaluate the potential to use the forecast as boundary conditions for other higher resolution urban models

Future work

- **Loading the model output in to Google Earth**



Thank you. Any Questions ?



WRF-CMAQ Forecast syste

Gas species
Ozone NO_2
SO_2 VOC

Particulate matter
PM_{10} $PM_{2.5}$
Organic PM components
Inorganic PM components

Advances Research - Weather Research and Forecasting (ARW-WRF)

Initiated using NCEP – Global Forecasting System (GFS) real-time data updated every 3 hrs

Wet and Dry deposition
Nitrogen, Sulphur

Community Multiscalar Air Quality (CMAQ) **Model**

A 'One Atmosphere' Chemical Transport Model including :

Advection, Diffusion, Chemical Transformation, Deposition, Aerosol formation, Emissions

Boundary Conditions

Initially using STOCHEM

Developing to use data from PROMOTE or GEMS

Emissions data

EMEP - 50km
NAEI - 1km
Biogenic Potential Inventory
BPI - 50km

Emissions data are manipulated to represent different scenarios

What is CMAQ used for at present ?

Daily UK Air Quality Forecast

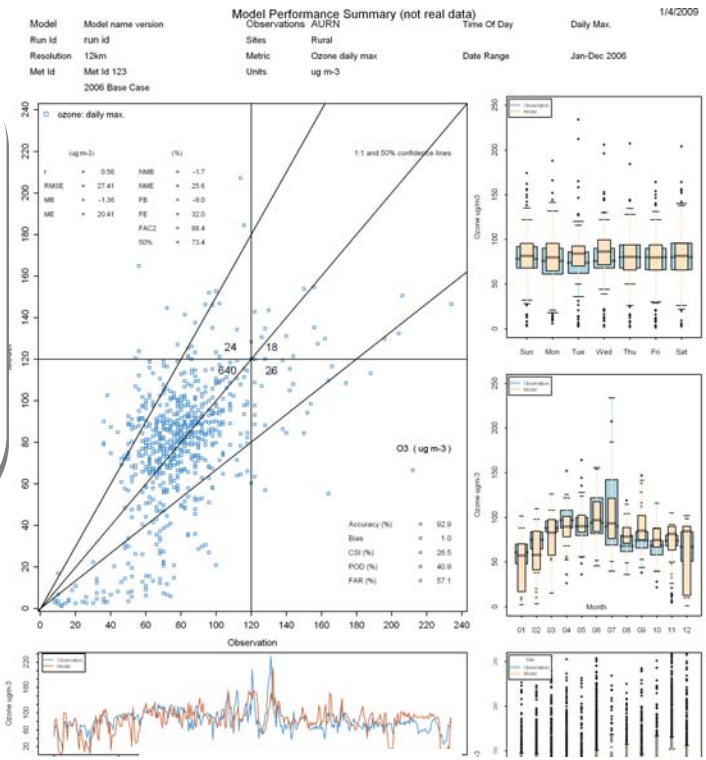
For: Ozone, NO_2, PM_{10}, SO_2, CO

Retrospective analysis of 2006

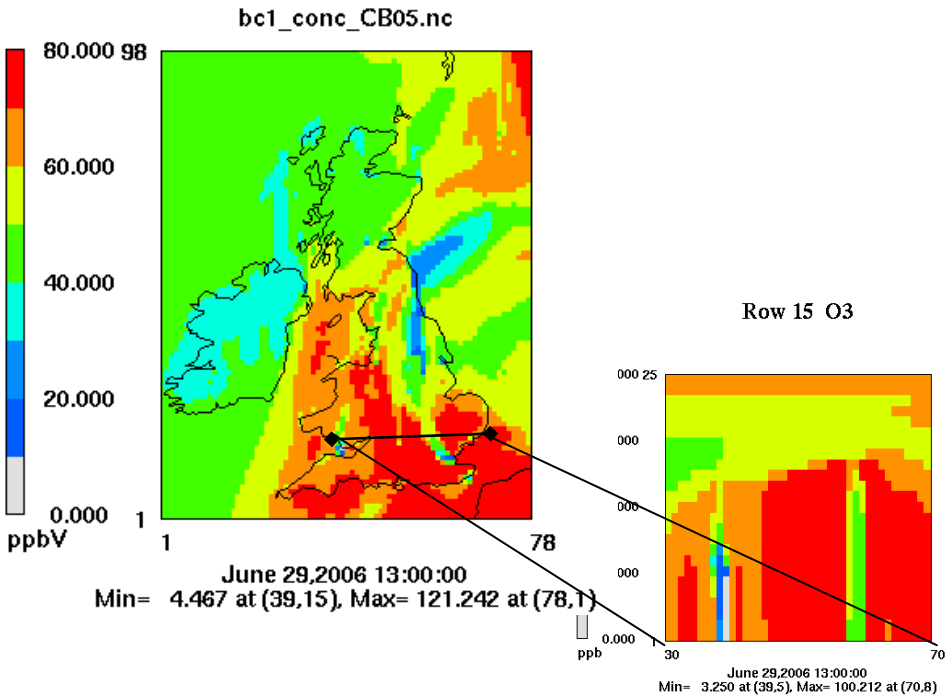
Evaluation of its suitability as a model for DEFRA applications.

Model Evaluation Protocol

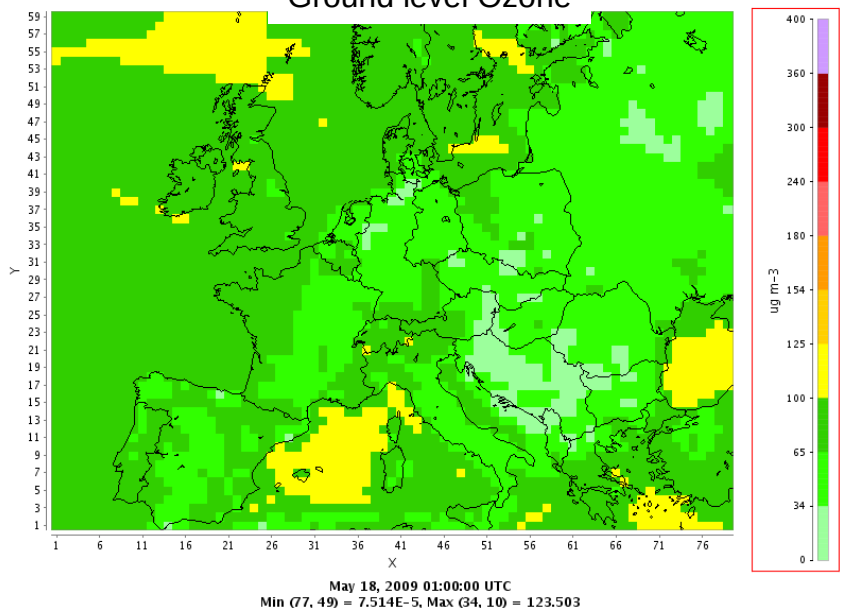
For scientific, operational and diagnostic evaluation for ground level ozone, acidification, eutrophication and urban air quality.
Development of a Model Performance Summary

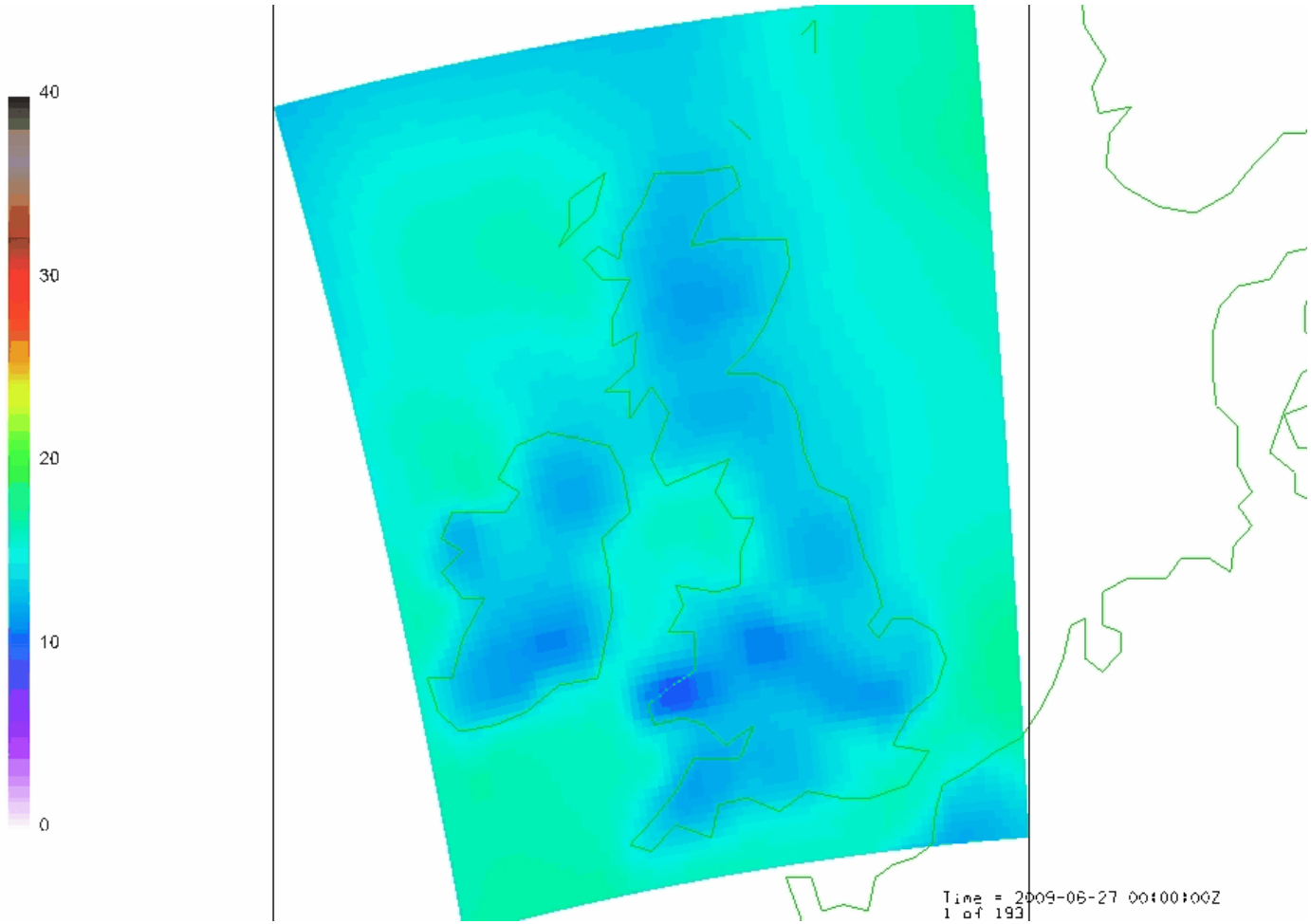


Ground level Ozone



Ground level Ozone

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