Air Quality Forecasting:
WRF-ARW and CMAQ

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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
BPI - 50km
Emissions data can be manipulated to represent different scenarios

Community Multiscalar Air Quality (CMAQ) Model
A ‘One Atmosphere’ Chemical Transport Model including:
Advection, Diffusion, Chemical Transformation, Deposition, Aerosol formation, Emissions

Ozone Daily max
Ozone Daily max
PM$_{2.5}$ Daily Max
SO$_2$ Daily Max
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° by 0.5°
  - 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
1st July 2009 12:00
3rd July 2009 12:00
The WRF-ARW outputs are fed into the CMAQ model to produce the Air Quality Forecast
UK Air Pollution Levels
WRF-CMAQ Forecast system

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Ozone Daily max
Ozone Daily max
PM$_{10}$ Daily Max
SO$_2$ Daily Max
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 Forecast system

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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

Annual emissions for NOₓ, PM, CO, NH₃, VOC and SO₂ 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

27\textsuperscript{th} June to 4\textsuperscript{th} July 2009
Ozone daily max. 27th – 28th June 2009
Ozone daily max. 29\textsuperscript{th} – 30\textsuperscript{th} 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

Model Lullington Heath

Obs Lullington Heath

LB Model Ladybower

LB Obs Ladybower
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 into Google Earth
Thank you. Any Questions?
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Gas species
Ozone NO₂
SO₂ VOC

Particulate matter
PM₁₀ PM₂.₅
Organic PM components
Inorganic PM components

Wet and Dry deposition
Nitrogen, Sulphur

Boundary Conditions
Initially using STOCHEM
Developing to use data from PROMOTE or GEMS

Emissions data
EMEP - 50km
NAEI - 1km
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Emissions data are manipulated to represent different scenarios
What is CMAQ used for at present?

**Daily UK Air Quality Forecast**
For: Ozone, NO\textsubscript{2}, PM\textsubscript{10}, SO\textsubscript{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