Air quality forecasting in Europe

Richard Engelen
ECMWF
• Introduction
  Using European Collaboration to forecast air quality

• Copernicus Atmosphere Monitoring Service
  From satellite observation to air quality forecast

• The global view
  Using NWP principles for atmospheric composition forecasting

• The regional view
  Seven know more than one

• Applications
  How is the information being used
European Air Quality Directive

- Sets targets for exposure levels of different pollutants that EU member states have to comply with
- Member states have to monitor air quality with prescribed standards and report to the European Commission
- Modelling may be used for monitoring purposes to reduce the number of measurement stations by up to 50%
- There is the possibility to discount natural sources of pollution when assessing compliance against limit values
Annual mean PM10 concentrations for 2013
National AQ forecasting

United Kingdom

Dolly Air Quality Index — Wednesday 20/07/2016

France

Netherlands
CONSIDERING the importance for the **European economy** of a considerable improvement in medium-range weather forecasts;

CONSIDERING that the scientific and technical research carried out for this purpose will provide a **valuable stimulus to the development of meteorology in Europe**;

CONSIDERING that the improvement of medium-range weather forecasts will **contribute to the protection and safety of the population**;

CONSIDERING that, to achieve these objectives, **resources on a scale exceeding those normally practicable at national level are needed**;

CONSIDERING the importance that the establishment of such a centre can have for the **development of European industry** in the field of data processing,

HAVE DECIDED to establish a **European Centre for Medium-Range Weather Forecasts**

**Can we apply the same concept to air quality forecasting in Europe?**
Combine observations with state-of-the-art data assimilation and forecasting systems to provide air quality information on the global and regional scale.

Make optimal use of existing expertise and infrastructure in Europe.
From satellite observation to air quality forecast

COPERNICUS ATMOSPHERE MONITORING SERVICE
CAMS IN A NUTSHELL

Space Agencies

CAMS

In-situ component

National scale
**OPERATIONAL TIMELINESS**

**Space**
MOPITT observes the atmosphere

**NCAR**
Retrieves carbon monoxide concentrations

**ECMWF**
Global data assimilation and forecast for the next 5 days

**Anywhere**
Daily AQ forecast for Europe for the next 4 days

**Meteo-France**
Model ensemble processing

**7 regional centres**
Regional air quality forecast
<table>
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<tr>
<th>Portfolio</th>
<th>Product groups</th>
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<tr>
<td>A. Regional products</td>
<td>European AQ NRT analyses</td>
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<td>European AQ NRT forecasts</td>
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<td>European AQ interim reanalyses</td>
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<td>European AQ reanalyses</td>
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<tr>
<td>B. Global products</td>
<td>Global atmospheric composition NRT analyses</td>
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<tr>
<td>(troposphere and stratosphere)</td>
<td>Global atmospheric composition NRT forecasts</td>
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<td>Global atmospheric composition reanalyses</td>
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<td>C. Supplementary products</td>
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<td>Solar radiation</td>
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<td>Climate forcings</td>
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<td>D. Emissions products</td>
<td>Anthropogenic emissions</td>
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<td>Fire emissions</td>
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</tbody>
</table>

- Data
- Charts
- Policy reports
- Validation reports
- Documentation
Using NWP principles for atmospheric composition forecasting

THE GLOBAL ELEMENT
GLOBAL SYSTEM

Composition-IFS

Observation operators

4D-Var

Meteorology

Chemical module

Chemical module

Aerosol module

Aerosol module

GHG module

GHG module

European Commission
CURRENT STATUS

- 40 km horizontal resolution at 60 model levels
- Two 5-day forecasts per day
- Output species: O$_3$, CO, NO, NO$_2$, PAN, HNO$_3$, CH$_2$O, SO$_2$, CH$_4$, C$_5$H$_8$, C$_2$H$_6$, OH, C$_3$H$_8$, CO$_2$, aerosol (dust, sea salt, organic matter, black carbon, sulphates)
- TM5 chemical module – simple aerosol bin scheme – linearized stratospheric ozone
Data assimilation – combining model and observations

![Diagram showing data assimilation process]

- **First guess**
- **Observation**
- **Analysis**
- **Assimilation window**
- **Assimilation**

**Time**

**O₃ concentration**
### CURRENT SATELLITE USAGE

<table>
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<th>Species</th>
<th>Instruments</th>
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<td>Global system</td>
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<tr>
<td>O$_3$</td>
<td>OMI, SBUV, GOME-2, MLS, OMPS, S5p</td>
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<tr>
<td>CO</td>
<td>IASI, MOPITT, S5p</td>
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<tr>
<td>NO$_2$</td>
<td>OMI, GOME-2, S5p</td>
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<tr>
<td>SO$_2$</td>
<td>OMI, GOME-2, S5p</td>
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<tr>
<td>Aerosol</td>
<td>MODIS, PMAp, VIIRS, S3</td>
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<tr>
<td>CO$_2$</td>
<td>GOSAT, OCO-2</td>
</tr>
<tr>
<td>CH$_4$</td>
<td>GOSAT, IASI, S5p</td>
</tr>
<tr>
<td>GFAS fire emissions</td>
<td>MODIS, GOES, SEVIRI, VIIRS</td>
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</tbody>
</table>
The global system is best suited to assimilate enormous amounts of satellite data and provide the long-range transport of key pollutants.
Seven know more than one

THE REGIONAL ELEMENT
Why a model ensemble?
Modelling NO$_2$: what do you see?
All CAMS regional AQ models use the same emissions
All CAMS regional models are driven by the same meteorological fields from the operational ECMWF NWP system.

**Winter smog**

(PM, NOx, SO\textsubscript{2}...)

**Photochemical smog**

(O\textsubscript{3}, PM...)
Everyone knows this!

Yet, among current regional air quality forecasting systems, chemical boundary conditions are prescribed by:

- a single value at the four interfaces (+top) for some pollutants, 0 for others (!)
- climatological values from global models, monthly or seasonal
- 3d distributions from larger-scale models corresponding to the actual dates (re-analyses, analyses or forecasts), still not a majority
Boundary conditions
Chemical modelling

Turbulent mixing and convection

Advection

Wet deposition

Radiation and clouds

Sedimentation

Homogeneous and heterogeneous chemistry, including photochemistry

Chemical boundary conditions

Aerosol processes

Biogenic and anthropogenic emissions

Dry deposition
So we have constrained anthropogenic emissions, boundary conditions and meteorology...

Are models all providing the “same” short-range forecast for NO₂?

It is close... but not quite the same...

Local values can actually differ significantly: will there be high NO₂ in Paris?
And, actually, performance does vary depending on pollutants
Much more spread between models than for other species. In general, negative biases are seen against observations (missing processes? Missing sources?...). Also issues with correctly using boundary conditions from global model.
The ensemble median consistently outperforms any individual model!!!
The ensemble spread also provides an indication of the uncertainty.

This is especially useful when values approach or overshoot regulatory thresholds.

Is it likely or is it just one model forecasting these high values?
Resolution seems to matter; so why do we get away with 10km resolution for the regional models?
Studies show: “boundary” or “background” values are essential!
Air quality & health

The different factors (meteorology, pollutants...) need to be disentangled to target efficient policies. Note: health does not only relate to concentrations of pollutants, but also to exposure of people (which is in turn the main justification for very high resolution).
CAMS (20km), Northern Europe (7km), Gulf of Finland (3km), Helsinki (Gaussian finite line source dispersion model).
Street canyon modelling has been already pioneering in the early 1970s.
How is the information being used

APPLICATIONS
Local versus Imported PM$_{10}$

How much of the current pollution comes from within the city limits and can therefore be regulated by the local authorities?
What is the impact over time of PM$_{10}$ emissions within the city, within Germany, and within Europe on the concentrations in Berlin?
Policy applications

3-day Forecast $O_3$ Episode

For specific pollution episodes, we can do this on a country scale.

Country of origin:
- Mediterranean
- Italy
- Hungary
- Greece
- France
What happens to tomorrow’s ozone values if we reduce road traffic emissions by 30% (cut traffic roughly in half)? Reduced species: NO\textsubscript{x}, CO, NH\textsubscript{3}, VOCs, SO\textsubscript{2}, and PM.
Copernicus wants to stimulate the downstream market.

CAMS covers global and regional; the rest is up to national service providers and businesses.
Assimilation in CAMS WRF-Chem prediction

CAMS forecast/reanalysis as IC & BC

WRF-Chem 60x60km

Assimilation in CAMS

Satellite data

Air Quality Index (AQI)

WRF-Chem prediction

Satellite data

Air Quality Index (AQI)

CAMS forecast/reanalysis as IC & BC

WRF-Chem 60x60km

WRF-Chem prediction 20x20km

20x20km

Satellite data

7 x 7 km

Air Quality Index (AQI)

WRF-Chem prediction

20x20km

Satellite data

7 x 7 km

Air Quality Index (AQI)

Satellite data

Air Quality Index (AQI)
Questions?