National Development Plan 2007 - 2013

Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

Environmental Research Centre
Report Series No. 11

AQUIRE - Air Quality Forecast and Statistics over Ireland

STRIVE

Environmental Protection Agency Programme

2007-2013

Comhshaol, Oidhreacht agus Rialtas Áitiúil
Environment, Heritage and Local Government

SSTI Strategy for Science, Technology and Innovation

Environmental Protection Agency

The Environmental Protection Agency (EPA) is a statutory body responsible for protecting the environment in Ireland. We regulate and police activities that might otherwise cause pollution. We ensure there is solid information on environmental trends so that necessary actions are taken. Our priorities are protecting the Irish environment and ensuring that development is sustainable.

The EPA is an independent public body established in July 1993 under the Environmental Protection Agency Act, 1992. Its sponsor in Government is the Department of the Environment, Heritage and Local Government.

OUR RESPONSIBILITIES

LICENSING

We license the following to ensure that their emissions do not endanger human health or harm the environment:

- waste facilities (e.g., landfills, incinerators, waste transfer stations);
- large scale industrial activities (e.g., pharmaceutical manufacturing, cement manufacturing, power plants);
- intensive agriculture;
- the contained use and controlled release of Genetically Modified Organisms (GMOs);
- large petrol storage facilities.

NATIONAL ENVIRONMENTAL ENFORCEMENT

- Conducting over 2,000 audits and inspections of EPA licensed facilities every year.
- Overseeing local authorities' environmental protection responsibilities in the areas of - air, noise, waste, waste-water and water quality.
- Working with local authorities and the Gardaí to stamp out illegal waste activity by co-ordinating a national enforcement network, targeting offenders, conducting investigations and overseeing remediation.
- Prosecuting those who flout environmental law and damage the environment as a result of their actions.

MONITORING, ANALYSING AND REPORTING ON THE ENVIRONMENT

- Monitoring air quality and the quality of rivers, lakes, tidal waters and ground waters; measuring water levels and river flows.
- Independent reporting to inform decision making by national and local government.

REGULATING IRELAND'S GREENHOUSE GAS EMISSIONS

- Quantifying Ireland's emissions of greenhouse gases in the context of our Kyoto commitments.
- Implementing the Emissions Trading Directive, involving over 100 companies who are major generators of carbon dioxide in Ireland.

ENVIRONMENTAL RESEARCH AND DEVELOPMENT

- Co-ordinating research on environmental issues (including air and water quality, climate change, biodiversity, environmental technologies).

STRATEGIC ENVIRONMENTAL ASSESSMENT

- Assessing the impact of plans and programmes on the Irish environment (such as waste management and development plans).

ENVIRONMENTAL PLANNING, EDUCATION AND GUIDANCE

- Providing guidance to the public and to industry on various environmental topics (including licence applications, waste prevention and environmental regulations).
- Generating greater environmental awareness (through environmental television programmes and primary and secondary schools' resource packs).

PROACTIVE WASTE MANAGEMENT

- Promoting waste prevention and minimisation projects through the co-ordination of the National Waste Prevention Programme, including input into the implementation of Producer Responsibility Initiatives.
- Enforcing Regulations such as Waste Electrical and Electronic Equipment (WEEE) and Restriction of Hazardous Substances (RoHS) and substances that deplete the ozone layer.
- Developing a National Hazardous Waste Management Plan to prevent and manage hazardous waste.

MANAGEMENT AND STRUCTURE OF THE EPA

The organisation is managed by a full time Board, consisting of a Director General and four Directors.

The work of the EPA is carried out across four offices:

- Office of Climate, Licensing and Resource Use
- Office of Environmental Enforcement
- Office of Environmental Assessment
- Office of Communications and Corporate Services

The EPA is assisted by an Advisory Committee of twelve members who meet several times a year to discuss issues of concern and offer advice to the Board.

An Ghníomhaireacht um Chaomhnú Comhshaoil

Is í an Gníomhaireacht um Chaomhnú Comhshaoil (EPA) comhlachta reachtúil a chosnaíonn an comhshaol do mhuintir na tíre go léir. Rialaímid agus déanaimid maoirsiú ar ghníomhaíochtaí a d'fhéadfadh truailliú a chruthú murach sin. Cinntímid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomh-nithe a bhfuilimid gníomhach leo ná comhshaol na hÉireann a chosaint agus cinntiú go bhfuil forbairt inbhuanaithe.

Is comhlacht poiblí neamhspleách í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) a bunaíodh i mí Iúil 1993 faoin Acht fán nGníomhaireacht um Chaomhnú Comhshaoil 1992. Ó thaobh an Rialtais, is í an Roinn Comhshaoil agus Rialtais Áitiúil a dhéanann urraíocht uirthi.

ÁR bhFREAGRACHTAÍ

CEADÚNÚ

Bíonn ceadúnais á n-eisiúint againn i gcomhair na nithe seo a leanas chun a chinntiú nach mbíonn astuithe uathu ag cur sláinte an phobail ná an comhshaol i mbaol:

- áiseanna dramhaíola (m.sh., líonadh talún, loisceoirí, stáisiúin aistrithe dramhaíola);
- gníomhaíochtaí tionsclaíocha ar scála mór (m.sh., déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta);
- diantalmhaíocht;
- úsáid faoi shrian agus scaoileadh smachtaithe Orgánach Géinathraithe (GMO);
- mór-áiseanna stórais peitreail.

FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

- Stiúradh os cionn 2,000 iniúchadh agus cigireacht de áiseanna a fuair ceadúnas ón nGníomhaireacht gach bliain.
- Maoirsiú freagrachtaí cosanta comhshaoil údarás áitiúla thar sé earnáil - aer, fuaim, dramhaíl, dramhuisce agus caighdeán uisce.
- Obair le húdaráis áitiúla agus leis na Gardaí chun stop a chur le gníomhaíocht mhídhleathach dramhaíola trí comhordú a dhéanamh ar líonra forfheidhmithe náisiúnta, díriú isteach ar chiontóirí, stiúradh fiosrúcháin agus maoirsiú leigheas na bhfadhbanna.
- An dlí a chur orthu siúd a bhriseann dlí comhshaoil agus a dhéanann dochar don chomhshaol mar thoradh ar a ngníomhaíochtaí.

MONATÓIREACHT, ANAILÍS AGUS TUAIRISCIÚ AR AN GCOMHSHAOL

- Monatóireacht ar chaighdeán aeir agus caighdeáin aibhneacha, locha, uiscí taoide agus uiscí talaimh; leibhéil agus sruth aibhneacha a thomhas.
- Tuairisciú neamhspleách chun cabhrú le rialtais náisiúnta agus áitiúla cinntí a dhéanamh.

RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

- Cainníochtú astuithe gáis ceaptha teasa na hÉireann i gcomhthéacs ár dtiomantas Kyoto.
- Cur i bhfeidhm na Treorach um Thrádáil Astuithe, a bhfuil baint aige le hos cionn 100 cuideachta atá ina mór-ghineadóirí dé-ocsaíd charbóin in Éirinn.

TAIGHDE AGUS FORBAIRT COMHSHAOIL

- Taighde ar shaincheisteanna comhshaoil a chomhordú (cosúil le caighdéan aeir agus uisce, athrú aeráide, bithéagsúlacht, teicneolaíochtaí comhshaoil).

MEASÚNÚ STRAITÉISEACH COMHSHAOIL

- Ag déanamh measúnú ar thionchar phleananna agus chláracha ar chomhshaol na hÉireann (cosúil le pleananna bainistíochta dramhaíola agus forbartha).

PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

- Treoir a thabhairt don phobal agus do thionscal ar cheisteanna comhshaoil éagsúla (m.sh., iarratais ar cheadúnais, seachaint dramhaíola agus rialacháin chomhshaoil).
- Eolas níos fearr ar an gcomhshaol a scaipeadh (trí cláracha teilifíse comhshaoil agus pacáistí acmhainne do bhunscoileanna agus do mheánscoileanna).

BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

- Cur chun cinn seachaint agus laghdú dramhaíola trí chomhordú An Chláir Náisiúnta um Chosc Dramhaíola, lena n-áirítear cur i bhfeidhm na dTionscnamh Freagrachta Táirgeoirí.
- Cur i bhfeidhm Rialachán ar nós na treoracha maidir le Trealamh Leictreach agus Leictreonach Caite agus le Srianadh Substaintí Guaiseacha agus substaintí a dhéanann ídiú ar an gcrios ózóin.
- Plean Náisiúnta Bainistíochta um Dramhaíl Ghuaiseach a fhorbairt chun dramhaíl ghuaiseach a sheachaint agus a bhainistiú.

STRUCHTÚR NA GNÍOMHAIREACHTA

Bunaíodh an Ghníomhaireacht i 1993 chun comhshaol na hÉireann a chosaint. Tá an eagraíocht á bhainistiú ag Bord lánaimseartha, ar a bhfuil Príomhstiúrthóir agus ceithre Stiúrthóir.

Tá obair na Gníomhaireachta ar siúl trí ceithre Oifig:

- An Oifig Aeráide, Ceadúnaithe agus Úsáide Acmhainní
- An Oifig um Fhorfheidhmiúchán Comhshaoil
- An Oifig um Measúnacht Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáide

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag ball air agus tagann siad le chéile cúpla uair in aghaidh na bliana le plé a dhéanamh ar cheisteanna ar ábhar imní iad agus le comhairle a thabhairt don Bhord.

AQUIRE – Air Quality Forecast and Statistics over Ireland

Environmental Research Centre Report

Prepared for the Environmental Protection Agency

by

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1 Introduction

The primary goal of the joint project was to develop an air quality forecast service for Ireland, with special emphasis on the model validation. This was done by using the EURAD (European Air Quality Dispersion) air quality prediction model system at the Rhenish Institute for Environmental Research (RIU) in a modified version. A major goal of this project was to carry out an intensive verification of the model forecast using observational data from the Irish air quality monitoring network. To improve the model performance, data assimilation techniques were applied, and a detailed model output statistics (MOS) system was developed. The project started on 1 December 2004 and it ended on 30 November 2007. Initially, an adequate emission module was implemented for the selected domains using data provided by Ireland to the European Monitoring and Evaluation Programme (EMEP). With these emission databases as input, the near-real-time forecast started on 7 April 2005. Later, a recalculation of the forecasts starting on 1 January 2005 was performed in order to complete the whole cycle for 2005. A complete analysis of 2005 and 2006 was carried out and published in technical reports provided for the Environmental Protection Agency (EPA) Ireland. An intensive verification procedure was carried out for 2006 comparing measured data (ozone (O_3), nitrogen dioxide (NO_2) and particulate matter ≤10 µm (PM_{10})) from the Irish air quality observational network with predicted concentrations. Specific model output statistics were developed in order to increase the reliability of the model output concentrations. The results of the Air Quality Forecast and Statistics over Ireland (AQUIRE) project are summarised in this final report and are described in the following chapters.

2 The EURAD Air Quality Forecast System

The air quality forecast service is provided by the multi-scale Eulerian chemical transport EURAD model system. The EURAD model has been well tested over the course of many case studies. The model system was extended for use as a forecast model and has run operationally since 1 November 2001 at the RIU in Cologne. The EURAD model is part of the ESA (European Space Agency) GSE–PROMOTE (Global Monitoring for Environment and Security (GMES) Services Element (GSE) Protocol Monitoring) atmosphere service and the FP6 GEMS (Framework Programme 6 Global and Regional Earth-system Monitoring using Satellite and *In-Situ* Data) consortium.

The key features of the EURAD model include:

- High flexibility for selecting forecast domains
- Advanced heterogeneous chemistry mechanisms with comprehensive aerosol and photo-oxidant chemistry
- Focalised and high-resolution forecasting by hemispheric/continental to regional scale (optionally 1 km resolution) nesting techniques with an integrated meteorological driver model
- Integrated advanced chemistry data assimilation system
- Has been proven as a daily routine forecast system for a number of users, including environmental protection agencies.

The EURAD air quality forecast system consists of three major components:

1. The PennState/NCAR Mesoscale Model Version 5 (MM5) which predicts the required meteorological variables
2. The EURAD Emission Module (EEM) which calculates the temporal and spatial distribution of the emission rates of the major pollutants
3. The EURAD Chemistry Transport Model (EURAD-CTM) which predicts the concentrations and deposition of the main atmospheric pollutants.

Figure 2.1 gives an overview of all major components of EURAD, its pre- and post-processors and the relevant input and output data sets.

The chemical mechanisms employed in the EURAD system are the so-called Regional Acid Deposition Model, version 2 (RADM2) and its successor the Regional Atmospheric Chemistry Mechanism (RACM). They have been completed by the aerosol mechanism MADE (Modal Aerosol-Dynamics model for EURAD). The RADM2 mechanism contains 63 reactive species treated in 158 chemical reactions. There is an option to run the code with the more sophisticated RACM chemistry as well. Detailed aqueous phase chemistry for the treatment of the air pollutants is incorporated. The horizontal and vertical transport is carried out using the fourth-order Bott advection scheme. Vertical mixing of the species is treated by an implicit vertical diffusion scheme. The sink at the lower boundary of the model is treated by wet and dry deposition parameterisation. The major driver for wet deposition is the predicted precipitation. The dry deposition is calculated via the deposition velocity for each species, which depends on the particle itself, the atmospheric dynamic and the given land-use type.

The EEM calculates the temporal and spatial distribution of the emission rates of the major pollutants from the available databases. The EEM was constructed to process different databases, ranging from continental down to local scale. The biogenic emissions are calculated online with respect to the given atmospheric condition (temperature, radiation, wind) and the given land-use type.

The meteorological forecast is obtained using the PennState/NCAR MM5. For initial and boundary conditions, the model uses the National Centers for Environmental Prediction Global Forecast System

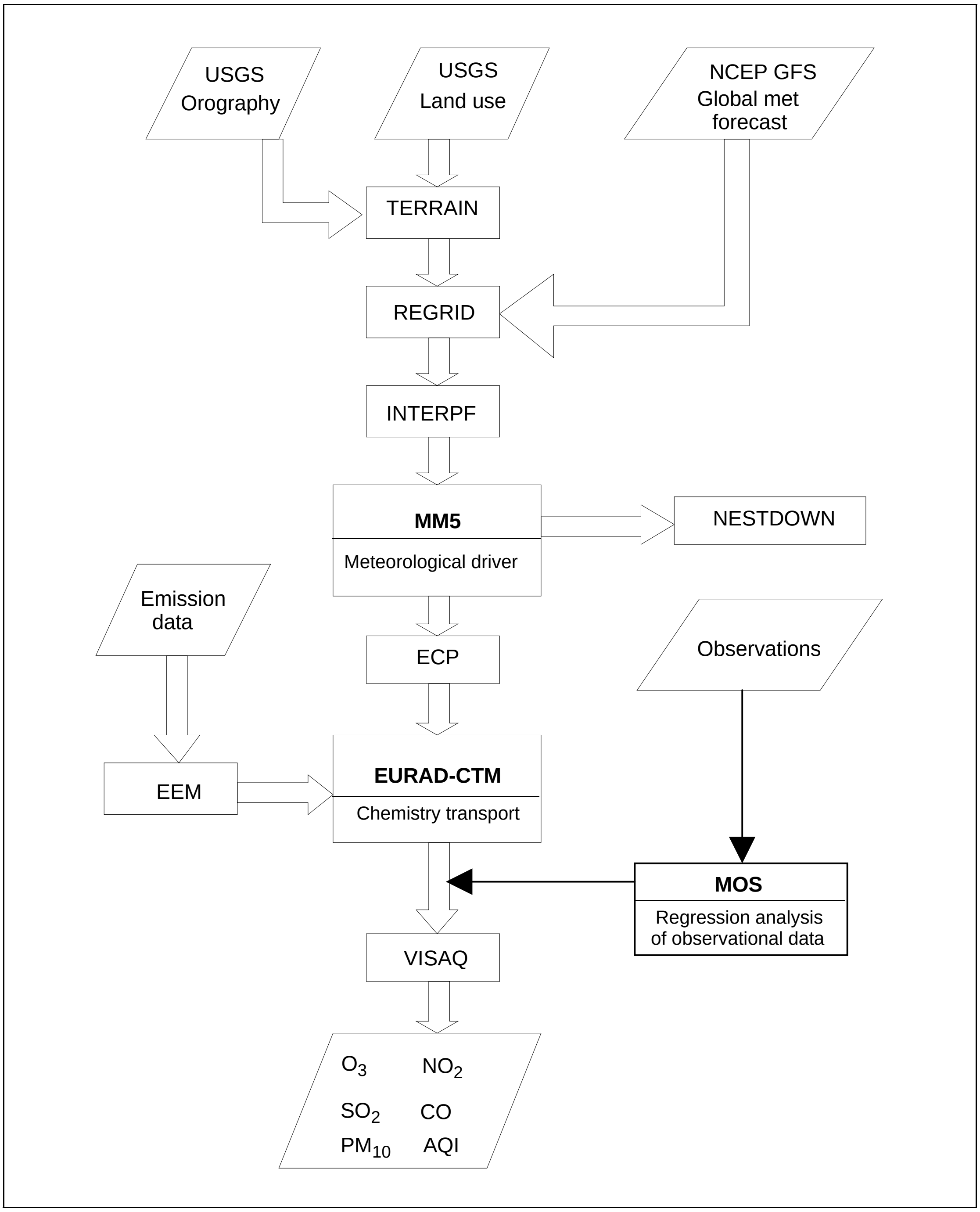


Figure 2.1. Overview of EURAD air quality forecast process.

(NCEP GFS) and interpolates the variables on the selected domains.

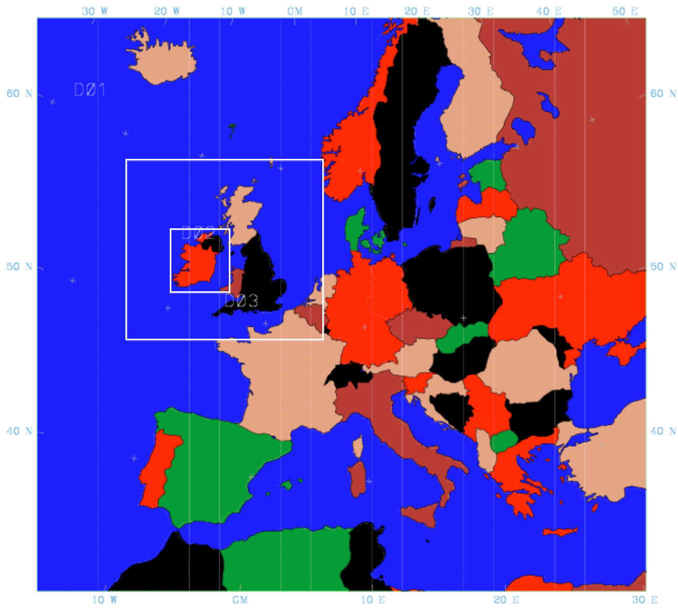
The forecast model system uses the method of nested simulations. This enables consistent modelling of air quality from small (local) to large (continental) scales. The required geographical information (orography, land-use type) is taken from the US Geological Survey (USGS) database with respect to the selected horizontal resolution. Applications with coarse resolution usually cover the major part of Europe. They can be zoomed down to regions the size of central Europe and fractions of it (e.g. province level). The model uses the terrain-following σ co-ordinate in the vertical, with 23 unequally spaced layers, the more dense resolution being used in the lowest part of the model. The model top in the operational mode is 100 hPa.

The default forecast system starts automatically with the download of the NCEP GFS global meteorological forecast via ftp (file transfer protocol). Every day an extensive amount of data is produced by the EURAD forecast system for Europe, Central Europe and the German State of Northrhine–Westfalia. This includes the meteorological prediction variables and the concentrations of the atmospheric constituents at all model levels. In order to be able to subsequently compare the modelled concentrations of air pollutants with the observational data, a considerable effort was made to accurately model the near-surface concentrations of the main air pollutants and to produce a combined Air Quality Index (AQI) for the above-mentioned domains. For assessment studies, the ranges for the concentration thresholds were selected according to the EU directives. These products are graphically processed and published on the EURAD website (http://www.riu.uni-koeln.de). The later described MOS system uses yearly observational data in order to minimise the model error.

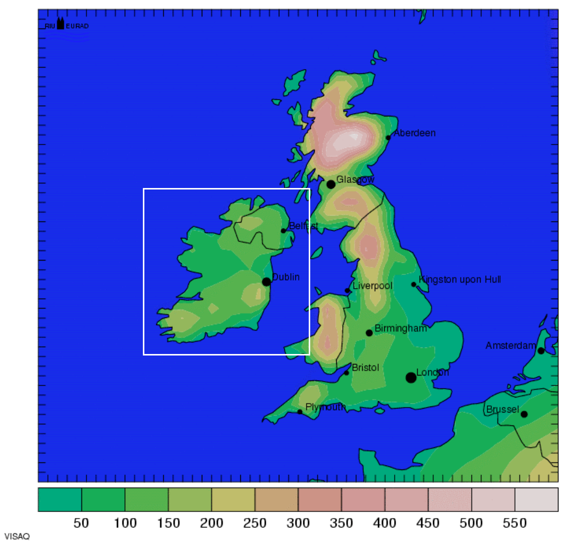
3 Model Configuration for Ireland's Air Quality Forecast

For Ireland's air quality forecast, the default operational model configuration was changed in order to focus on the domain that covers Ireland for the second nested domain with 5 km horizontal resolution. Therefore, the RIU standard configuration was modified in such a way that the first nested domain (D02, 25 km horizontal grid size) covers the region of the UK and Ireland, with an integrated domain of Ireland (Domain D03). Figure 3.1 illustrates the configuration of these domains. It shows the nested D02 and D03 domains in more detail together with the model terrain height.

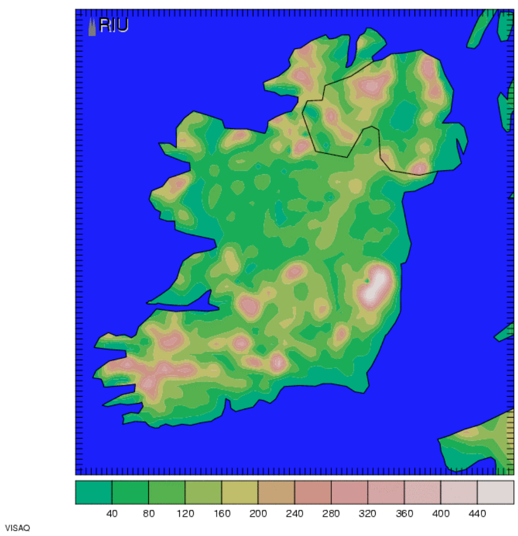
The domains are characterised by the parameters given in Table 3.1.



Domain D01



Domain D02



Domain D03

Figure 3.1. AQUIRE model configuration.

Table 3.1. Domain characterisation.

Domain	Region	Grid size	Horizontal grid points
D01	Europe	125 km	35 × 33
D02	Ireland/UK	25 km	56 × 51
D03	Ireland	5 km	85 × 91

4 Emission Database

In order to run the air quality forecast over Ireland, an explicit emission database was built for both the D02 and D03 domains. The EEM calculated the temporal and spatial distribution of the emission rates of the major pollutants from the available EMEP databases with regard to the 2005 emissions. In addition, the EPA Ireland provided an extended data set with point sources for the D03 domain. With these raw emission data sets, the EEM created different data files for different days of the week (workday, Saturday and Sunday) and for different months of the year. Within these files, hourly values of the emitting species were given for low-level and high-level sources. The horizontal distributions of the yearly emission rates for the D02 domain (UK and Ireland) are given in Figs 4.1–4.4 and those for the D03 domain (Ireland) are given in Figs 4.5–4.9.

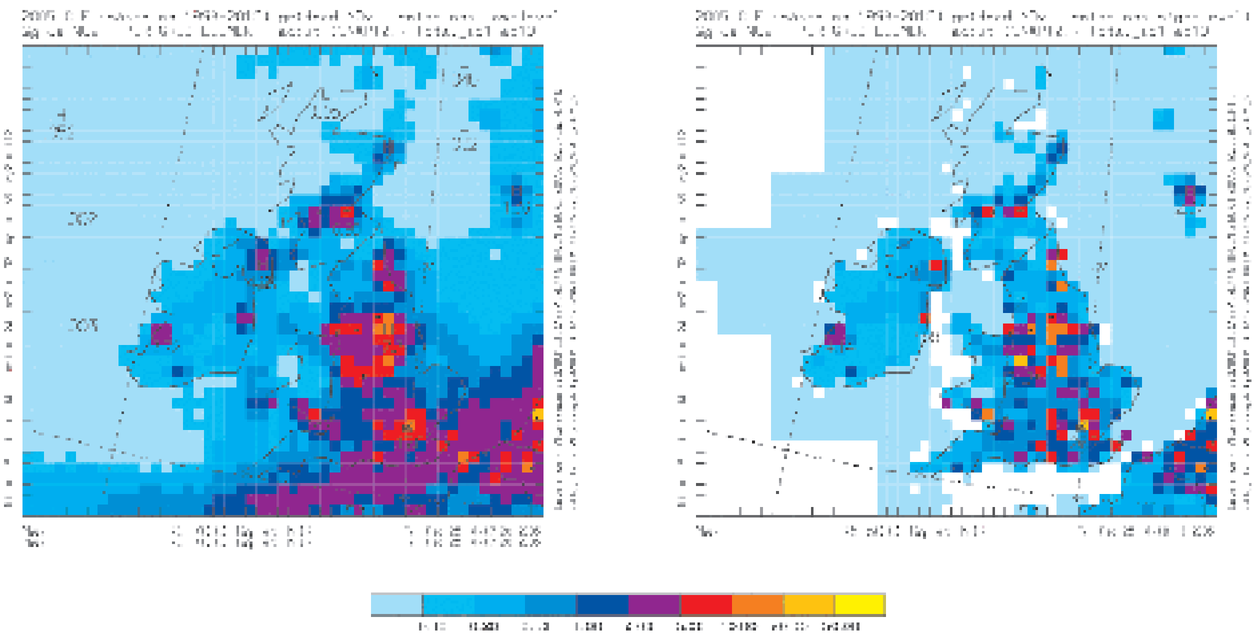


Figure 4.1. Nitrogen oxides (NO_X) yearly emission rates (Gg/year) for the D02 domain (UK and Ireland). Left: low-level emission, right: high-level emission.

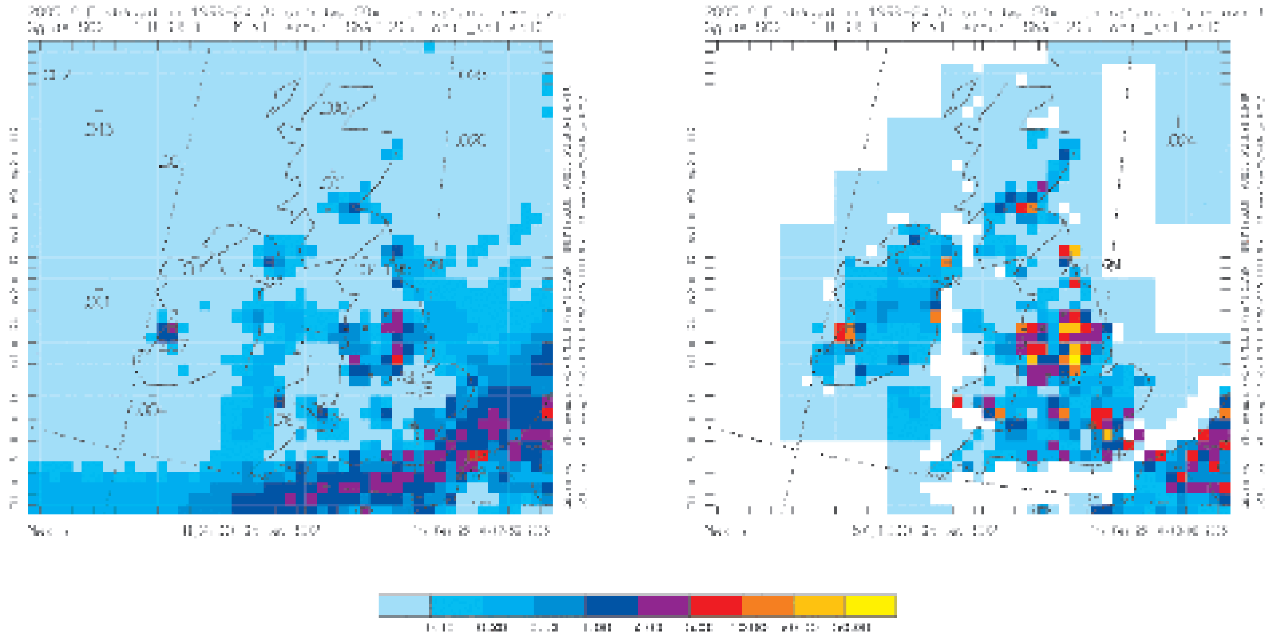


Figure 4.2. Sulphur oxides (SO_X) yearly emission rates (Gg/year) for the D02 domain (UK and Ireland). Left: low-level emission, right: high-level emission.

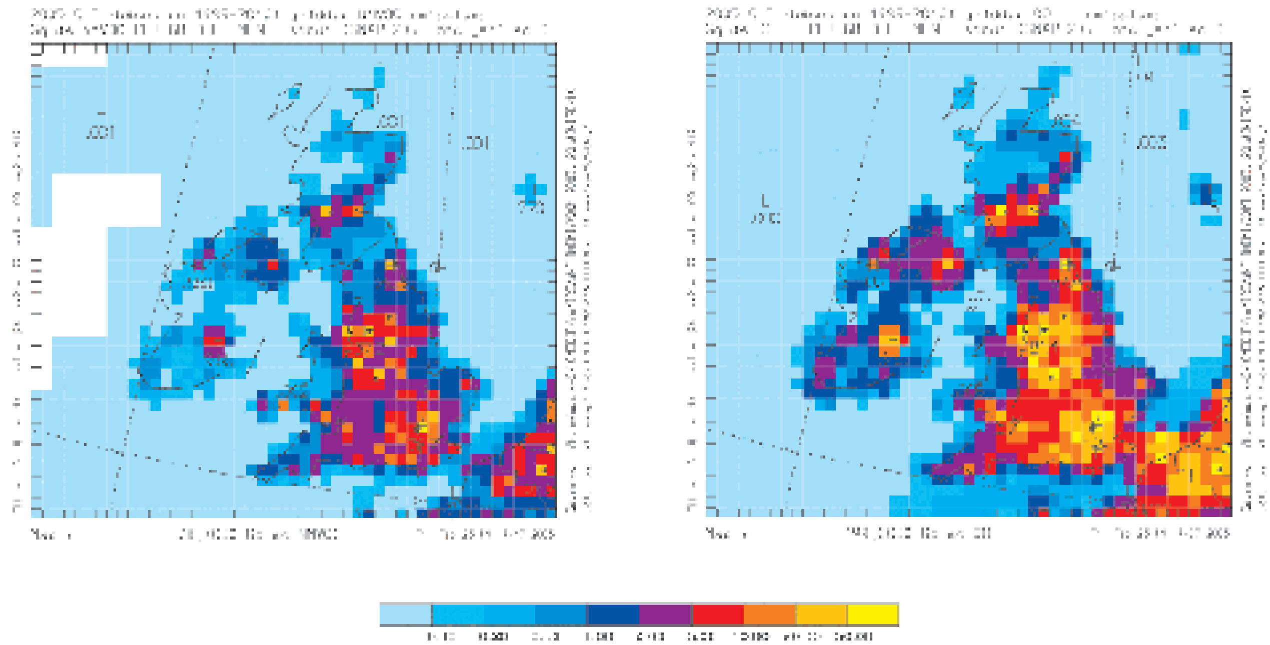


Figure 4.3. Yearly emission rates (Gg/year) for the D02 domain (UK and Ireland). Left: non-methane volatile organic compounds (VOCs), right: carbon monoxide (CO).

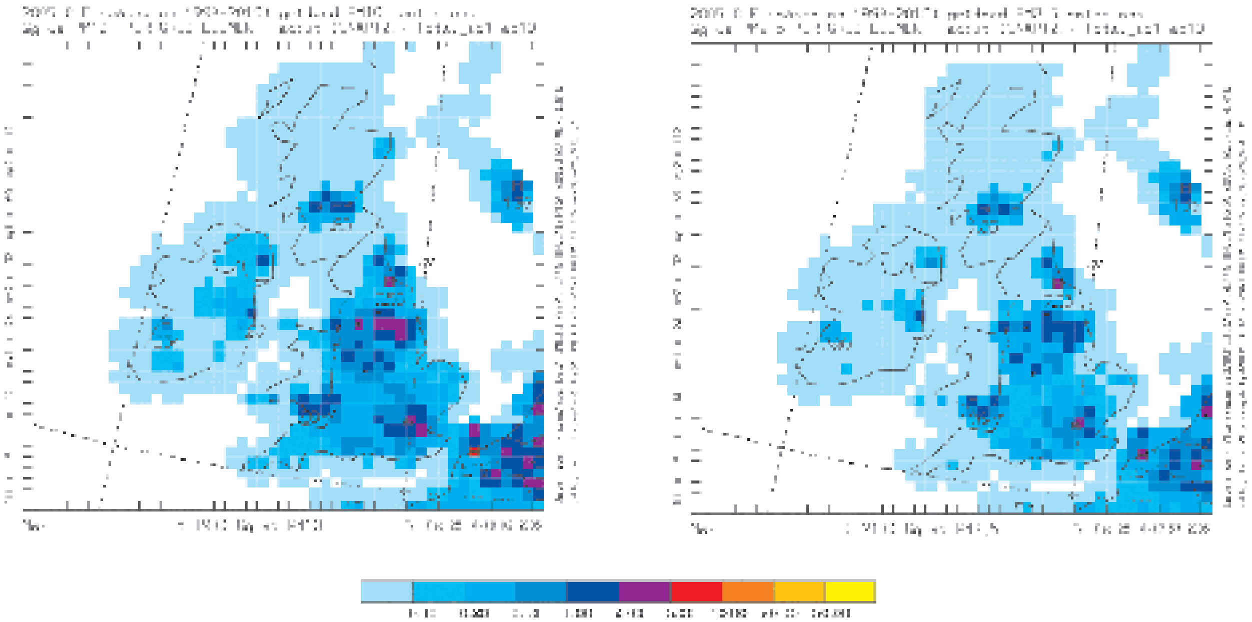


Figure 4.4. Yearly particle emission rates (Gg/year) for the D02 domain (UK and Ireland). Left: particulate matter ≤10 µm (PM_{10}), right: particulate matter ≤2.5 µm ($PM_{2.5}$).

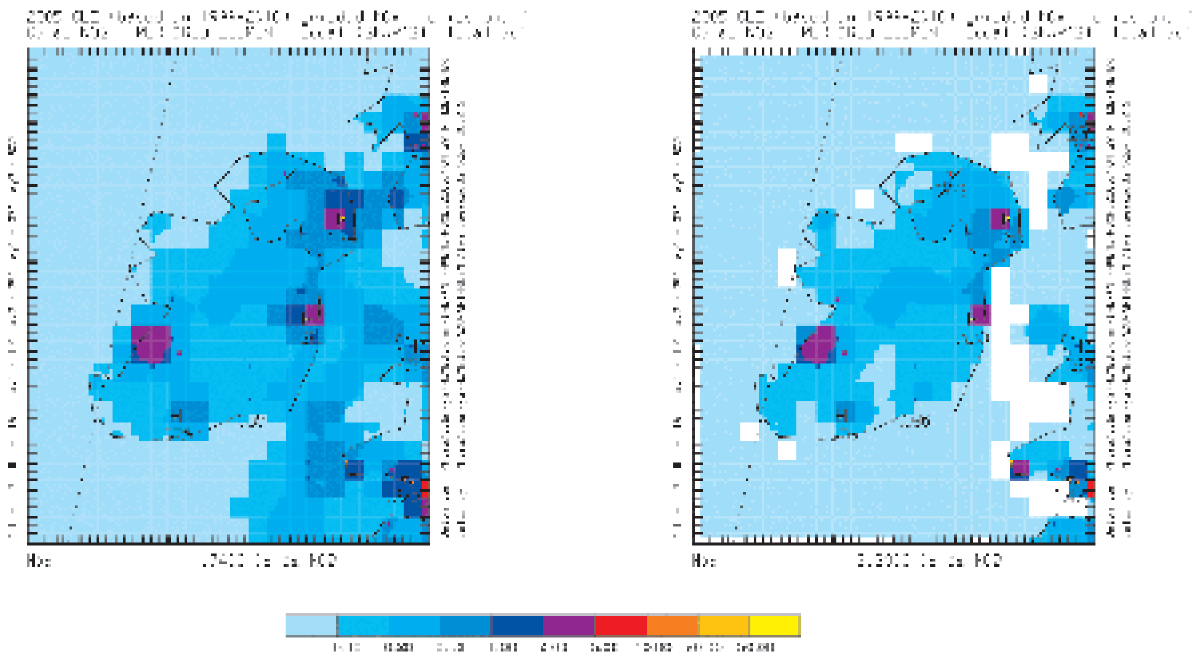


Figure 4.5. Nitrogen oxides (NO_x) yearly emission rates (Gg/year) for the D03 domain (Ireland). Left: low-level emission, right: high-level emission.

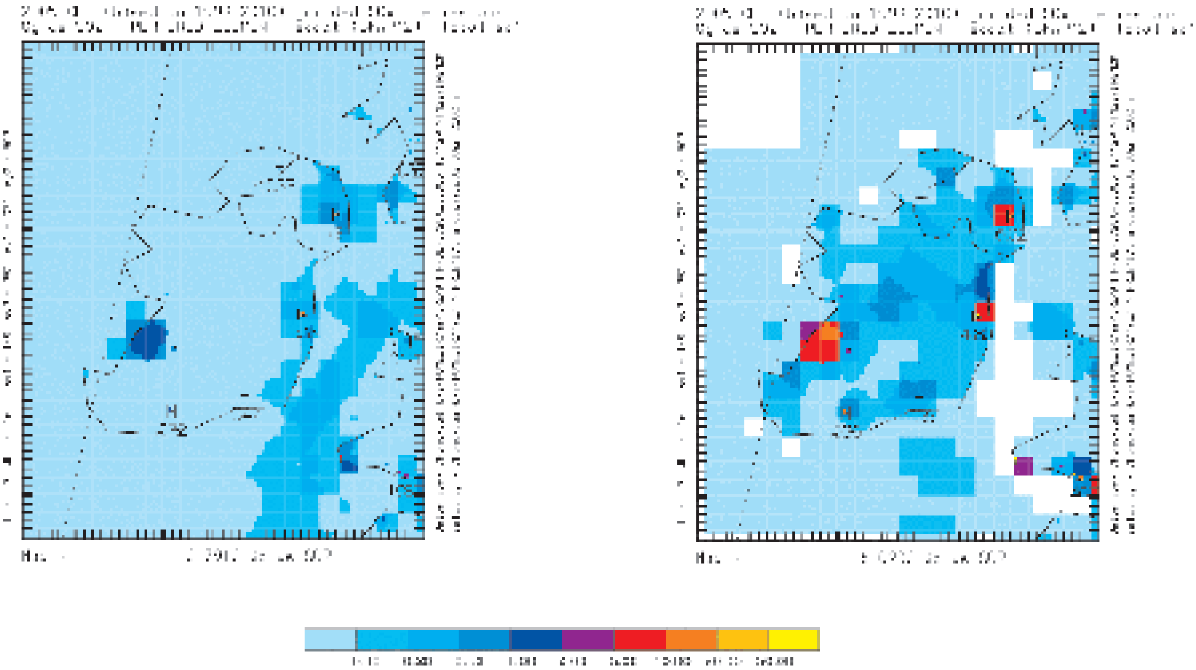


Figure 4.6. Sulphur oxides (SO_x) yearly emission rates (Gg/year) for the D03 domain (Ireland). Left: low-level emission, right: high-level emission.

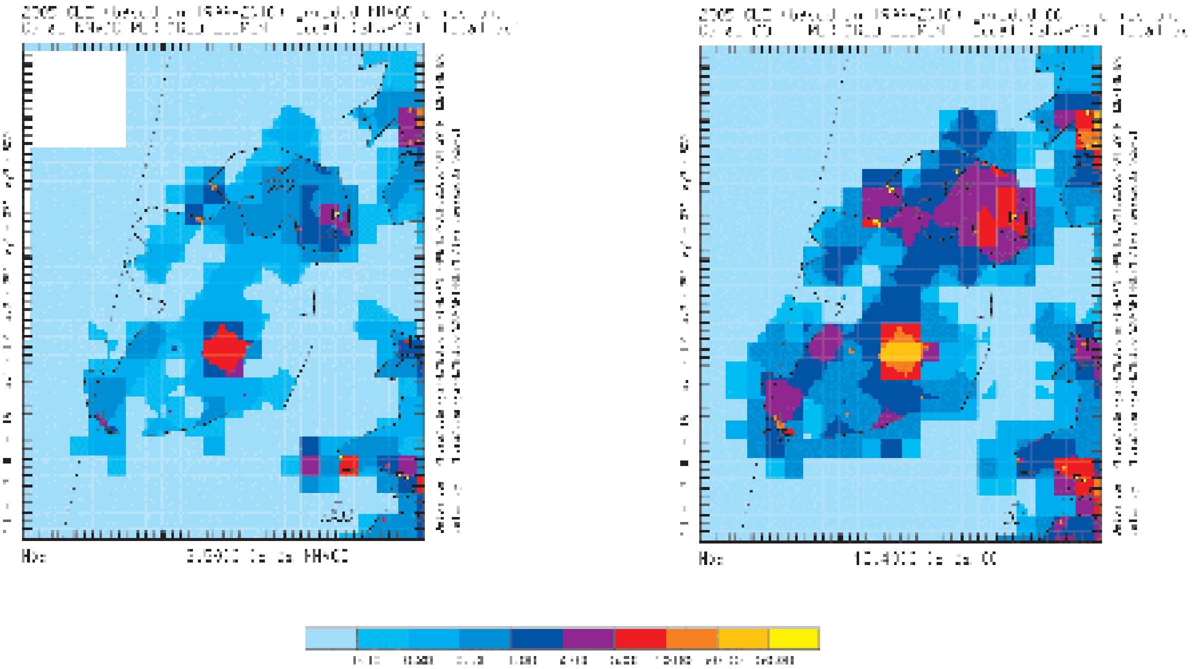


Figure 4.7. Yearly emission rates (Gg/year) for the D03 domain (Ireland). Left: non-methane volatile organic compounds (VOCs), right: carbon monoxide (CO).

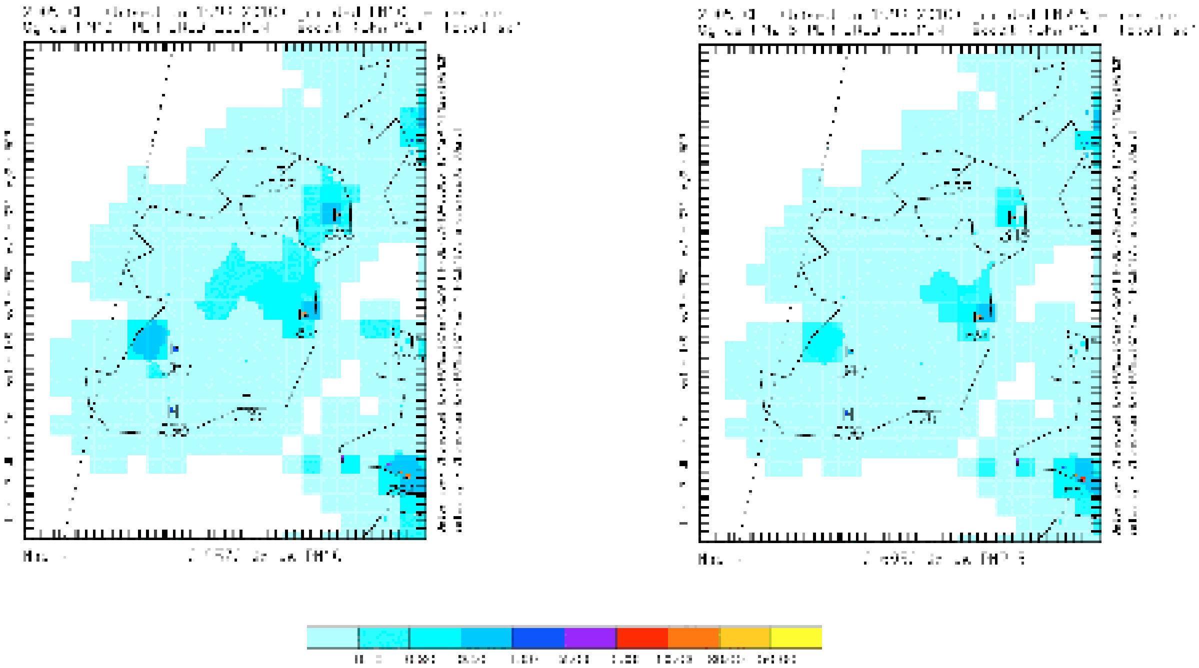


Figure 4.8. Yearly particle emission rates (Gg/year) for the D03 domain (Ireland). Left: particulate matter ≤10 µm (PM_{10}), right: particulate matter ≤2.5 µm ($PM_{2.5}$).

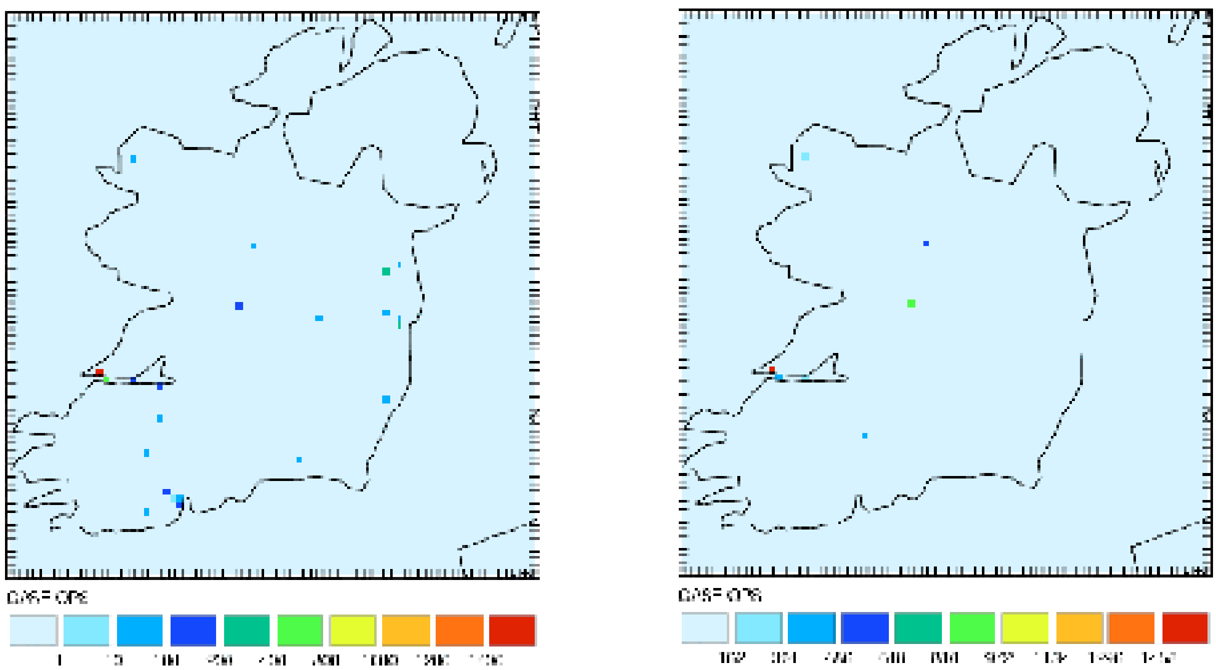


Figure 4.9. Point sources emission rates (Gg/year) for the D03 domain (Ireland). Left: nitrogen oxides (NO_x), right: particulate matter ≤10 µm (PM_{10}).

5 Daily Air Quality Forecast

On the basis of the calculated updated emission data for the selected domains, the air quality forecast ran daily, with a cycle of 72 h. The forecast ran quite stably, with a performance rate of 99% (for 2007). A daily check of the forecast was performed even on weekends with a shift service. The forecast started every day automatically at around 23:00 h UTC (Co-ordinated Universal Time) for the next day's cycle. It used the NCEP GFS data of 18:00 h UTC of the day prior to the first forecast day. Figure 5.1 shows an example of the record for a forecast cycle containing all major modules and pre- and post-processor programs within the EURAD air quality system for 16 November 2007.

During the test phase of the Irish air quality forecast, there were a small number of days during which problems occurred within the forecast cycle. These problems arose due to unexpected failures with respect to the new domain structures. These problems in the initial phase have been solved and the air quality forecast has been stable. Thus, every day, the air quality forecast is ready at around 04:30 h CET (Central European Time) and the graphics produced by the VISAQ module are sent to the EURAD-RIU web page via a special link:

http://db.eurad.uni-koeln.de/prognose/cuki_e.html
– air quality forecast for the D02 domain

http://db.eurad.uni-koeln.de/prognose/cire_e.html
– air quality forecast for the D03 domain

http://db.eurad.uni-koeln.de/prognose/muki_e.html
– meteorology for the D02 domain

http://db.eurad.uni-koeln.de/prognose/mire_e.html
– meteorology for the D03 domain

http://db.eurad.uni-koeln.de/prognose/tcuki_e.html
– chemograms for the D02 domain for the UK cities London, Glasgow, Birmingham, Liverpool, Edinburgh, Sheffield, Leeds and Bristol

http://db.eurad.uni-koeln.de/prognose/tcire_e.html
– chemograms for the D03 domain for the Irish cities Dublin, Cork, Limerick, Galway, Waterford, Dundalk, Bray and Kilkenny.

For each of the species covered under EU air quality directives (O_3, NO_2, SO_2, CO, PM_{10} and benzene (C_6H_6)), the daily maxima, the maximum 8-h running mean and the maximum 24-h running mean were calculated for the near-surface concentrations and are presented graphically. In addition chemograms (time

```
Forecast Start: 2007 11 16 00 UTC
Start Forecast at:            Thu Nov 15 23:03:50 CET 2007
All input files ready at:     Thu Nov 15 23:03:51 CET 2007
REGRID   Domain 01 done at:   Thu Nov 15 23:05:20 CET 2007
INTERPF  Domain 01 done at:   Thu Nov 15 23:05:23 CET 2007
MM5V3    Domain 01 done at:   Thu Nov 15 23:07:06 CET 2007
ECP      Domain 01 done at:   Thu Nov 15 23:07:16 CET 2007
NESTDOWN Domain 02 done at:   Thu Nov 15 23:08:32 CET 2007
ECTM4    Domain 01 done at:   Thu Nov 15 23:19:14 CET 2007
----------------------------------------------------------
MM5V3    Domain 02 done at:   Thu Nov 15 23:20:25 CET 2007
ECP      Domain 02 done at:   Thu Nov 15 23:21:18 CET 2007
NESTDOWN Domain 03 done at:   Thu Nov 15 23:24:30 CET 2007
ECTM4    Domain 02 done at:   Thu Nov 15 23:58:16 CET 2007
graphics Domain 02 done at:   Fri Nov 16 00:06:23 CET 2007
----------------------------------------------------------
MM5V3    Domain 03 done at:   Fri Nov 16 01:32:58 CET 2007
ECP      Domain 03 done at:   Fri Nov 16 01:34:48 CET 2007
ECTM4    Domain 03 done at:   Fri Nov 16 04:15:26 CET 2007
graphics Domain 03 done at:   Fri Nov 16 04:30:07 CET 2007
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Figure 5.1. Example of a forecast cycle record.

series of the major pollutants) are presented for the main cities in Ireland.

The AQUIRE project produced complete daily forecast cycles for 2005–2007. A detailed analysis for 2005 and 2006 was prepared and reported within the 01/2006 and 01/2007 technical reports. Within these reports special episodes of PM_{10} transboundary pollution were also reported. In Figs 5.2–5.8 a detailed survey of the air quality situation over Ireland is given by analysing the daily air quality forecast over Ireland with the EURAD model system. The analysis covers all of 2006.

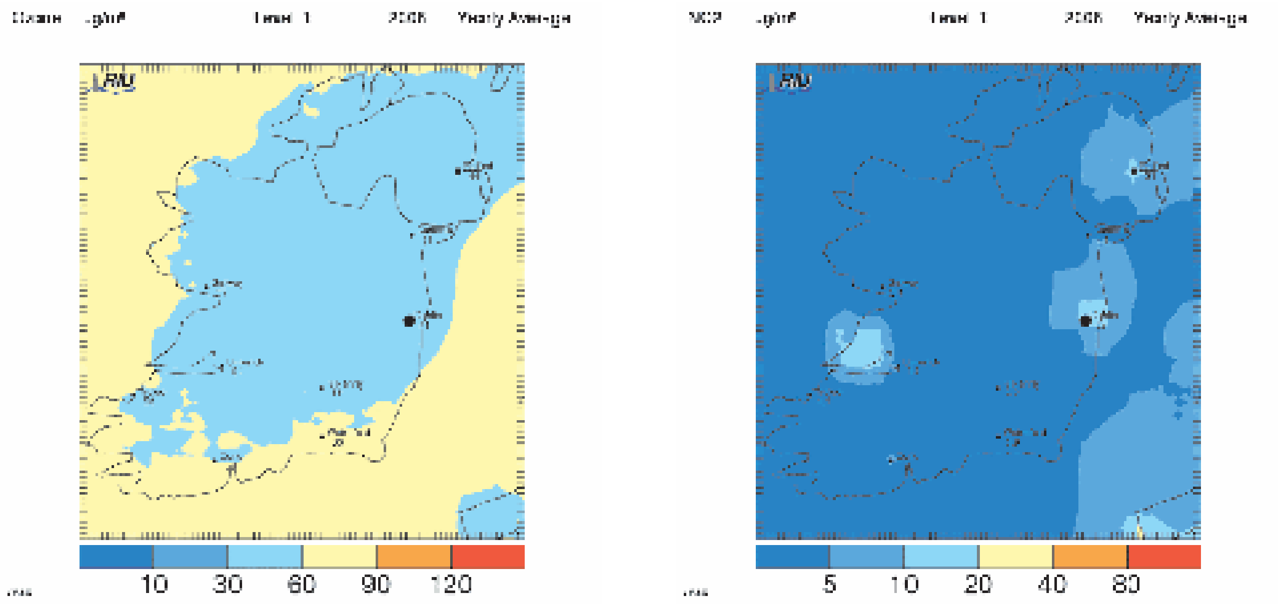


Figure 5.2. Air quality forecast analysis: yearly average of ozone (O_3) (left) and nitrogen dioxide (NO_2) (right) for the year 2006.

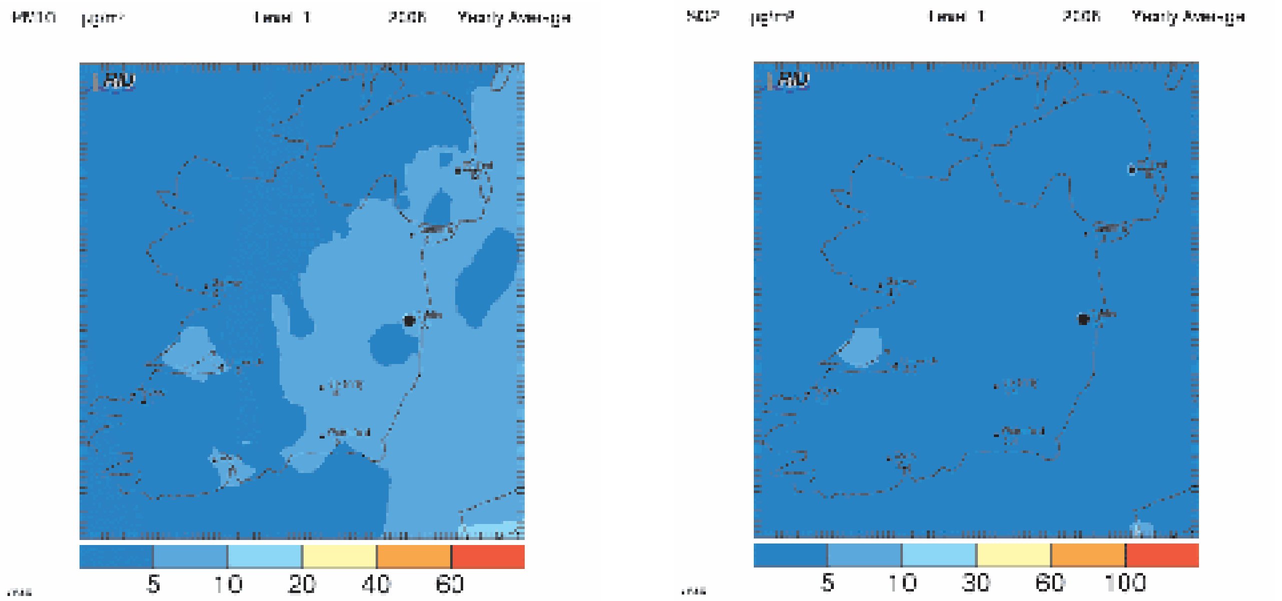


Figure 5.3. Air quality forecast analysis: yearly average of particulate matter ≤10 µm (PM_{10}) (left) and sulphur dioxide (SO_2) (right) for the year 2006.

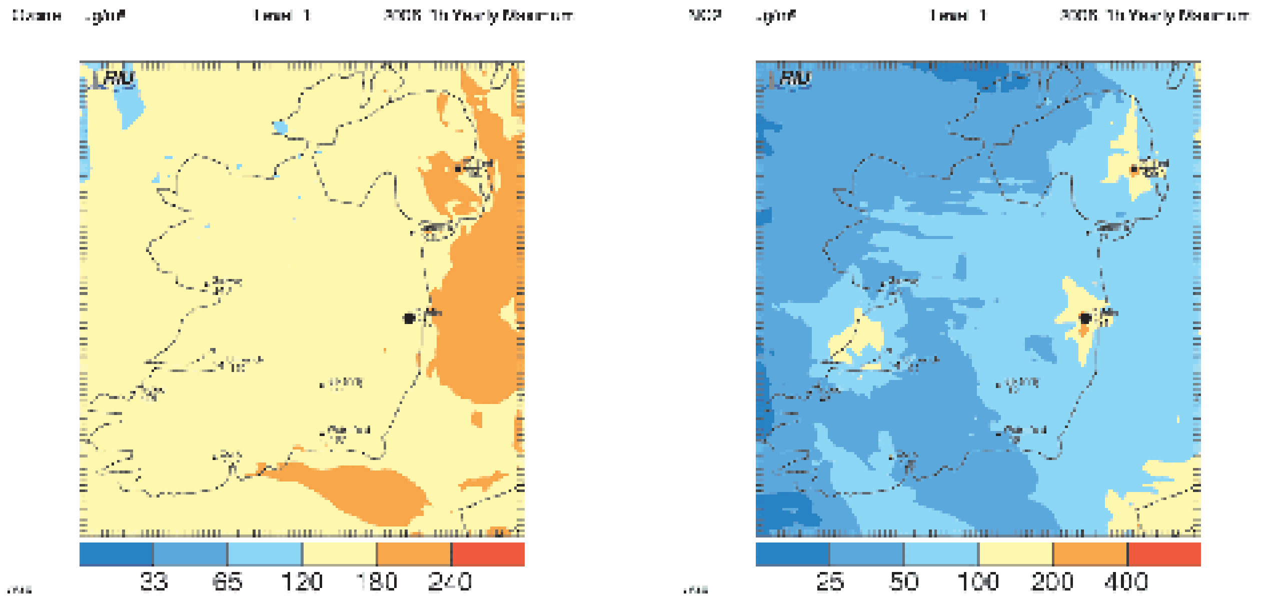


Figure 5.4. Air quality forecast analysis: yearly 1 h maximum of ozone (O_3) (left) and nitrogen dioxide (NO_2) (right) for the year 2006.

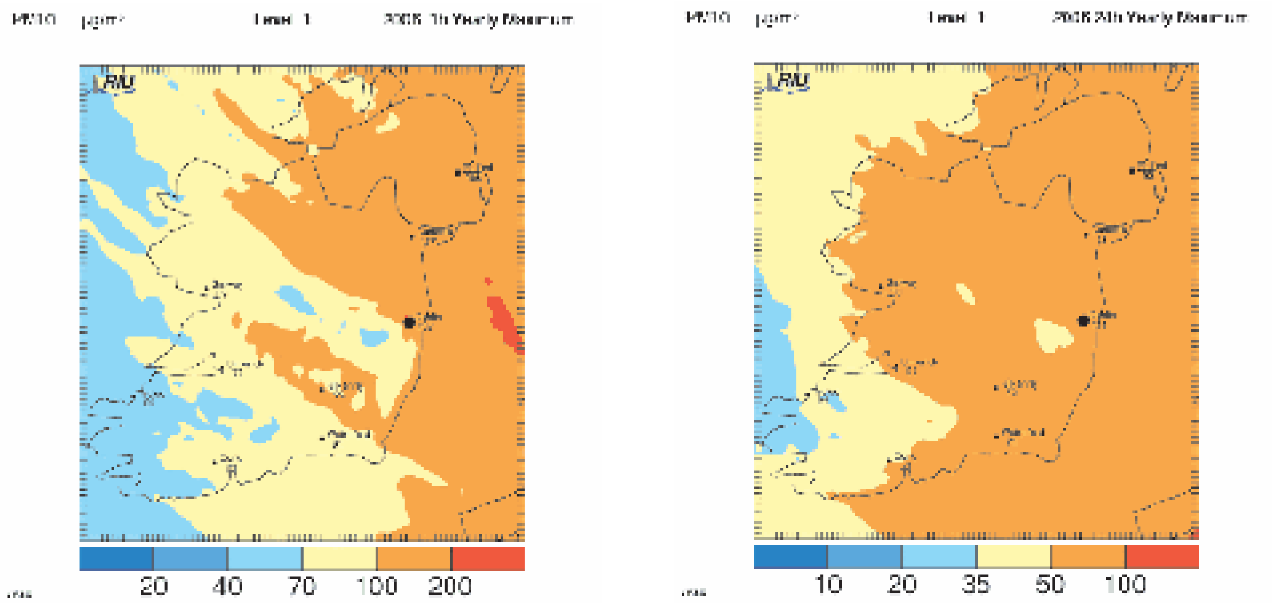


Figure 5.5. Air quality forecast analysis: yearly maximum of particulate matter ≤10 µm (PM_{10}). Left: 1 h mean maximum, right: 24 h mean maximum for the year 2006.

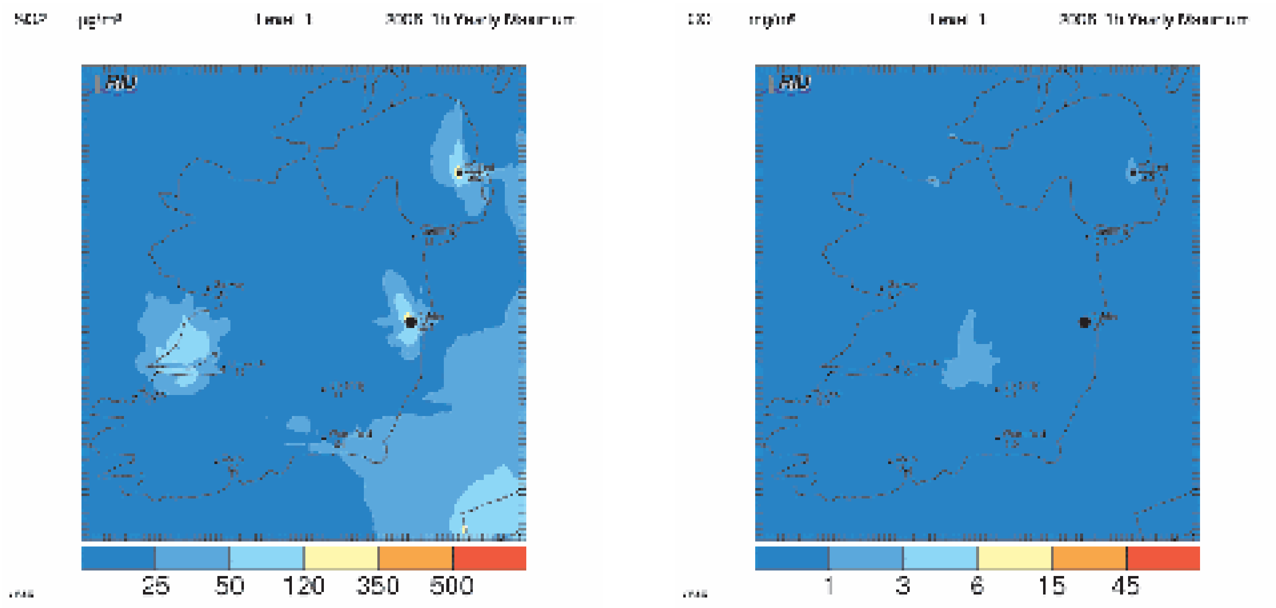


Figure 5.6. Air quality forecast analysis: yearly 1 h maximum of sulphur dioxide (SO_2) (left) and carbon monoxide (CO) (right) for the year 2006.

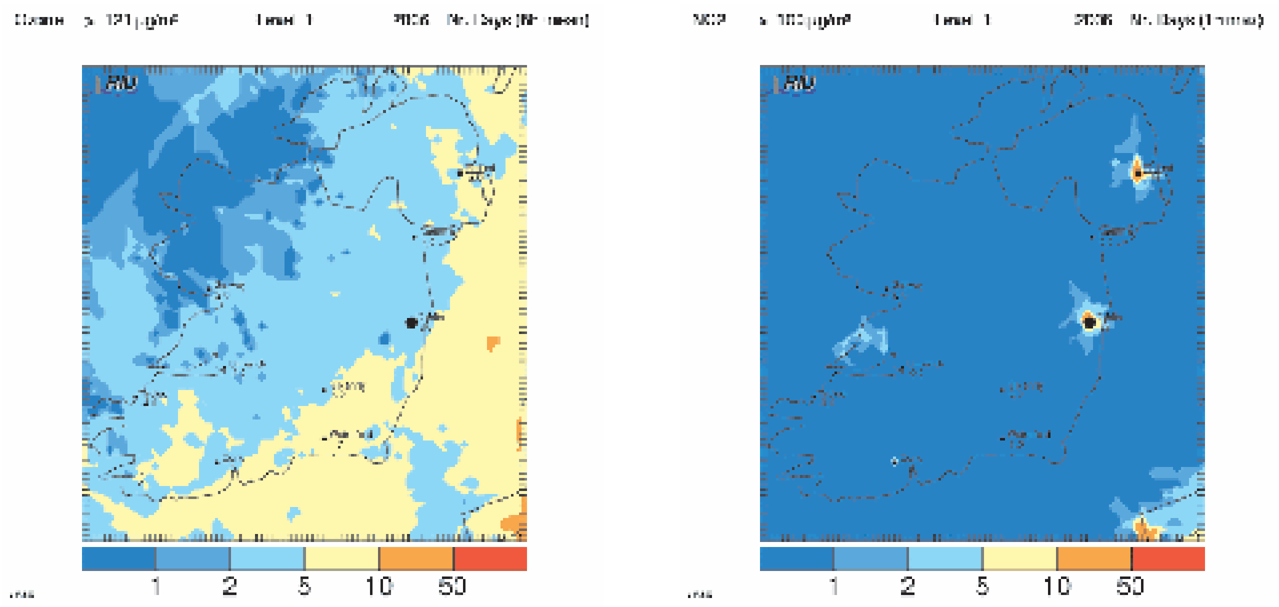


Figure 5.7. Air quality forecast analysis: number of days where the maximum 8 h mean of ozone (O_3) exceeds 120 µg/m³ (left) and number of days where the maximum 1 h mean of nitrogen dioxide (NO_2) exceeds 100 µg/m³ (right) for the year 2006.

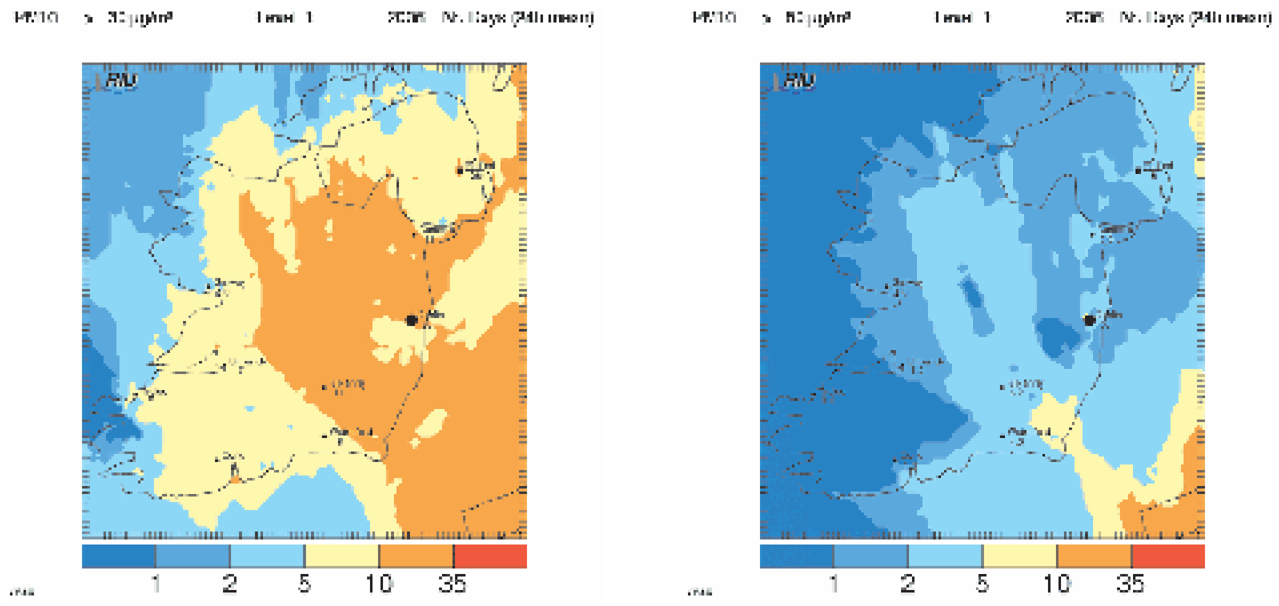


Figure 5.8. Air quality forecast analysis: number of days where the maximum 24 h mean of particulate matter ≤10 µm (PM_{10}) exceeds 30 µg/m³ (left) and number of days where the maximum 24 h mean of PM_{10} exceeds 50 µg/m³ (right) for the year 2006.

6 Validation of the Forecast

A validation process was carried out to verify the air quality forecast using measurement data for O_3, NO_2 and PM_{10} from several stations in Ireland. Figure 6.1 displays the locations of the observational network of the EPA Ireland. Table 6.1 lists the available measurements (marked by ‘x’) for all the atmospheric constituents delivered by the EPA Ireland.

6.1 Monthly Validation

Examples of the monthly verification of the EURAD Irish air quality forecast are shown in Figs 6.2–6.13. Since SO_2 and CO do not play any role in the critical levels in the air quality scenario for Ireland, only O_3, NO_2 and PM_{10} forecast concentrations are compared with actual measurements and the meteorological parameters. Within these figures the following parameters are shown (from top to bottom): daily mean of O_3, NO_2, PM_{10}, 2-m temperature, wind speed, wind direction, relative humidity and mixing height. Blue represents forecast values, and black the observation value of the concentrations. For the meteorological parameters, dark grey represents daily maximum values and light grey the daily parameter mean. The time series comparisons are shown for two stations which represent typical behaviour for an urban site (Dublin Rathmines) and for a rural site (Kilkitt). Note that there are gaps in the observational data for both stations.

For O_3, the forecasts of both stations demonstrate good agreement with observations. The time series for NO_2 only show apparent values for the urban site; the values in the rural sites are very low compared with limit values. Thus, a substantial comparison for the NO_2 concentration is only possible for the urban sites. Nevertheless, for rural sites the statistical values have also to be determined for NO_2. On some days very high over-prediction can be found when comparing the Dublin Rathmines site for early January and early February. The meteorology may account for these

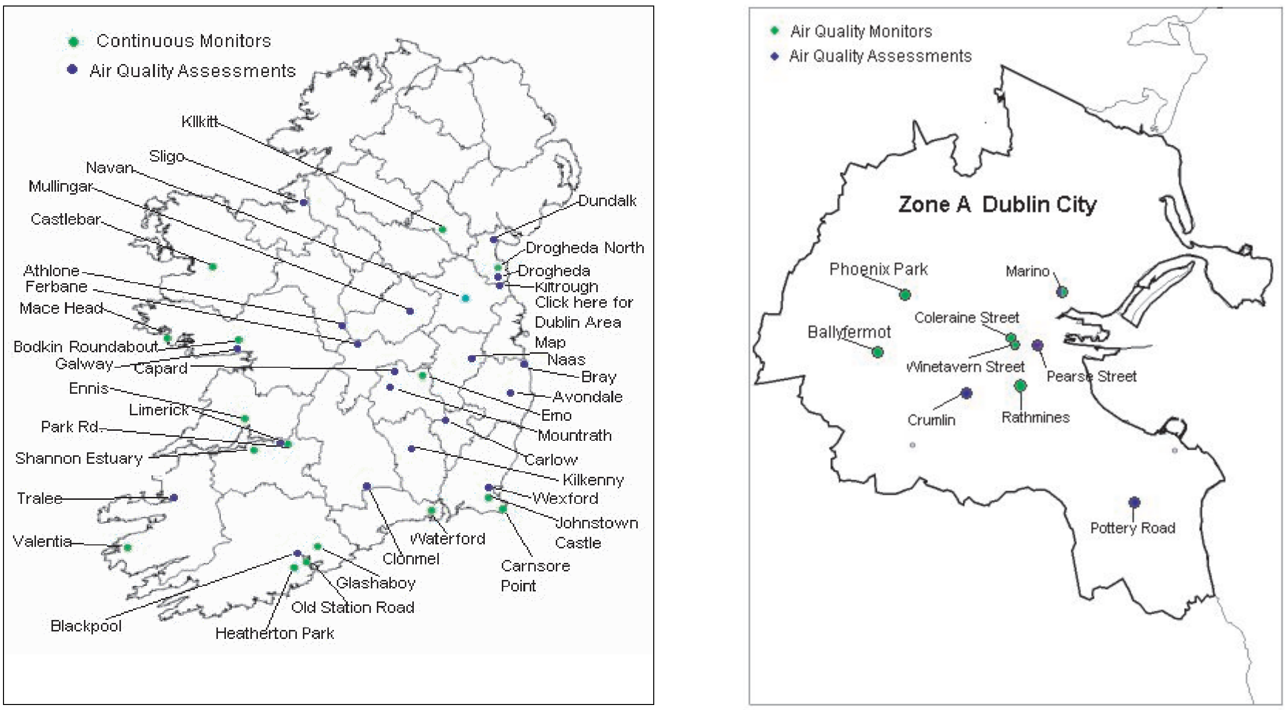


Figure 6.1. EPA Ireland air quality network.

Table 6.1. EPA Ireland air quality network and distribution of measurements for 2006.

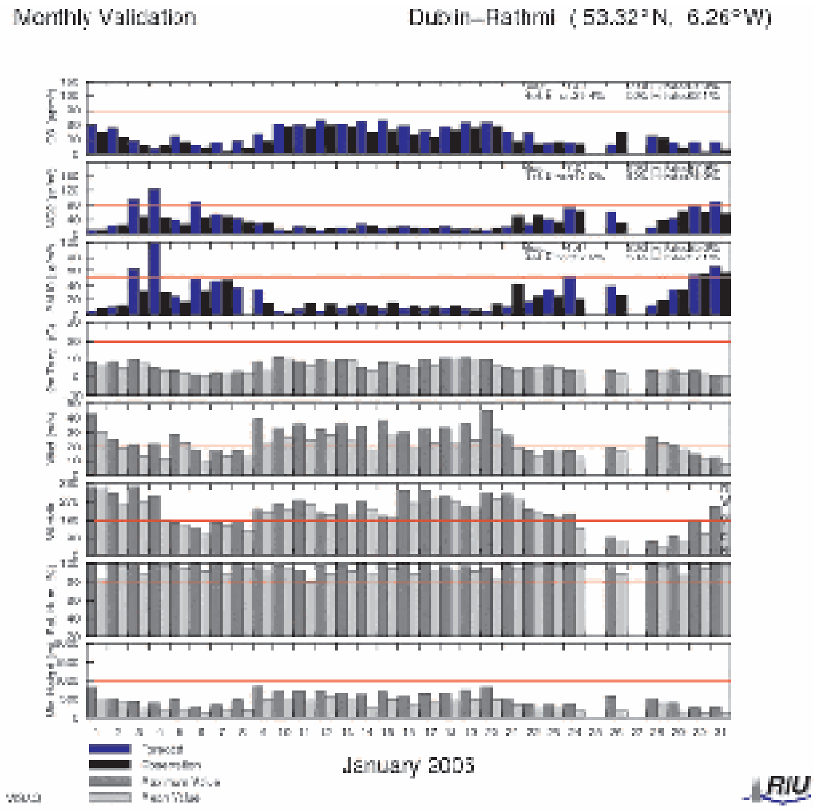
Station	O_3 (1 h)	NO_2 (1 h)	SO_2 (1 h)	CO (1 h)	PM_{10} (1 h)	PM_{10} (24 h)
Dublin Rathmines	×	×	×		×	×
Dublin Coleraine St		×		×		×
Dublin Phoenix Park						×
Dublin Winetavern St						×
Dublin Marino						×
Dublin Ballyfermot						×
Cork City	×	×	×	×		
Cork Old Station Rd						×
Cork Heatherton Park						×
Galway Headford Rd						×
Galway Bodkin Roundabout						×
Kilkitt	×	×	×			×
Glashaboy	×	×				
Limerick	×	×				
Ennis		×	×		×	×
Bray		×				×
Ferbane		×				×
Mace Head	×					
Valentia	×					
Emo Court	×					
Shannon			×			
Castlebar						×
Kilrough						×
Wexford	×					×

over-predictions. They are associated with very low mixing heights and low wind speeds. The time series for PM_{10} clearly indicates several episodes with high concentrations for both sites. In particular, identified events are 3–9 January, 29 January–5 February, 21–25 March, 9–13 May, 13–19 October and 20–26 December. These events are accompanied by southerly or easterly winds: high polluted air from Central Europe and the UK reaches the island of Ireland and are responsible for the high PM_{10} (and NO_2) concentrations. The prediction of such events and the background values are very good for the urban site with a slight over-prediction. But for the rural site, although the transboundary events are relatively well forecasted, the predicted background values are noticeably lower than the observed values. This may be due to the absence of sea-salt parameterisation within the EURAD model.

6.2 Yearly Validation

The comparison of the predicted concentrations for the whole year is displayed in terms of scatter diagrams for several stations. The performance of the predicted values is expressed by calculating specific scores: bias, coefficient of determination R^2, hit rate within a 20% interval (HR_{20}) and hit rate within a 50% interval (HR_{50}) around the observed value. Table 6.2 summarises the scores for the different stations and concentration comparison.

The diagrams and the scores for O_3 (Figs 6.14–6.17) demonstrate the good agreement between forecast and observation at most of the stations. The good performance in O_3 forecast is expressed in the relatively high scores in Table 6.2.



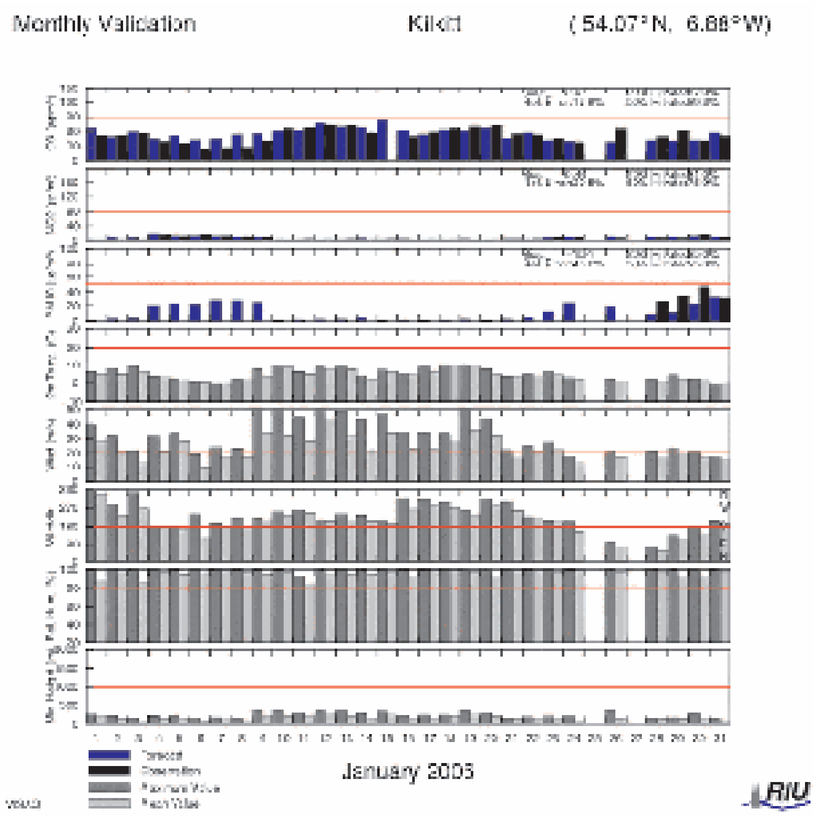
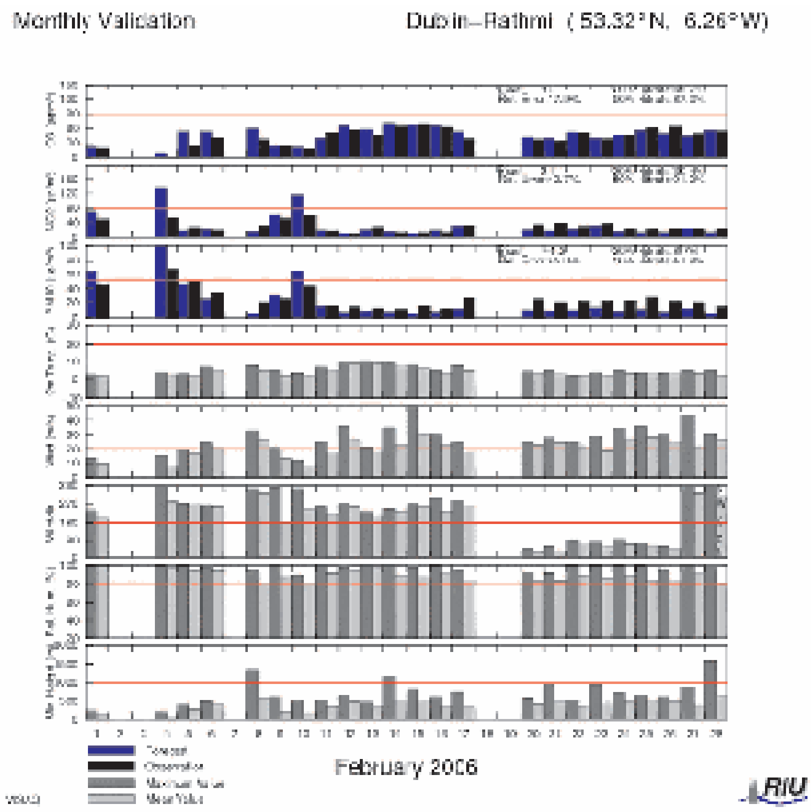


Figure 6.2. EURAD Irish air quality forecast: comparison between the observed and forecasted meteorological parameters at the Dublin Rathmines (top) and Kilkitt (bottom) stations for January 2006.



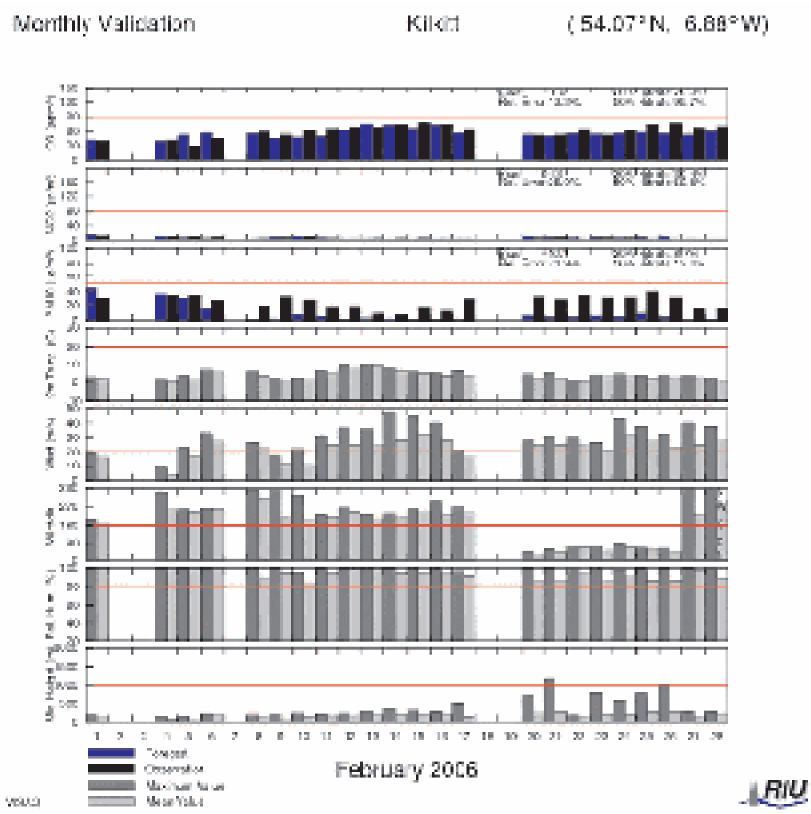
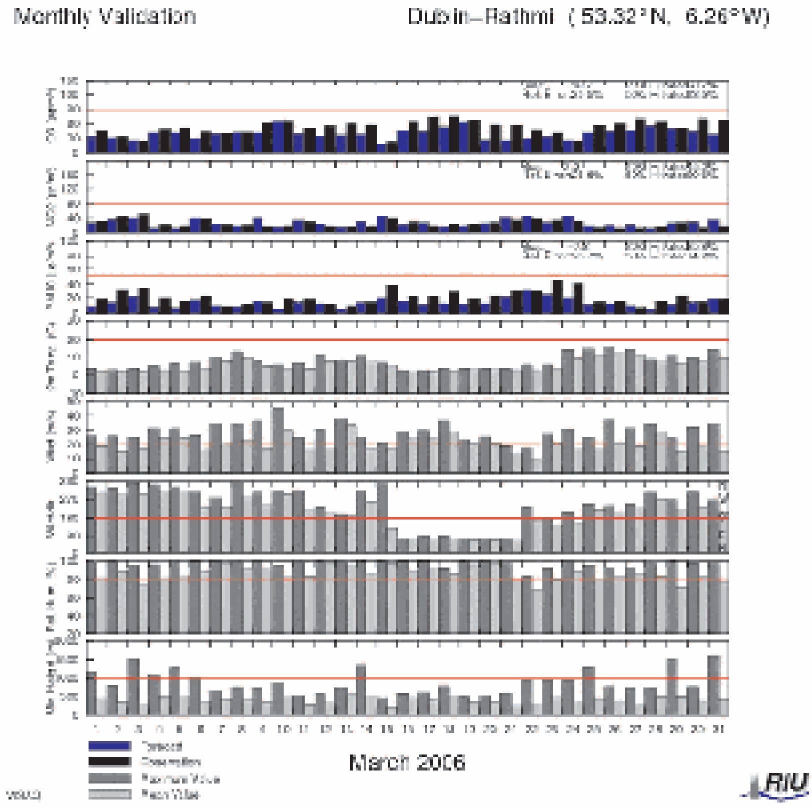


Figure 6.3. EURAD Irish air quality forecast: comparison between the observed and forecasted meteorological parameters at the Dublin Rathmines (top) and Kilkitt (bottom) stations for February 2006.



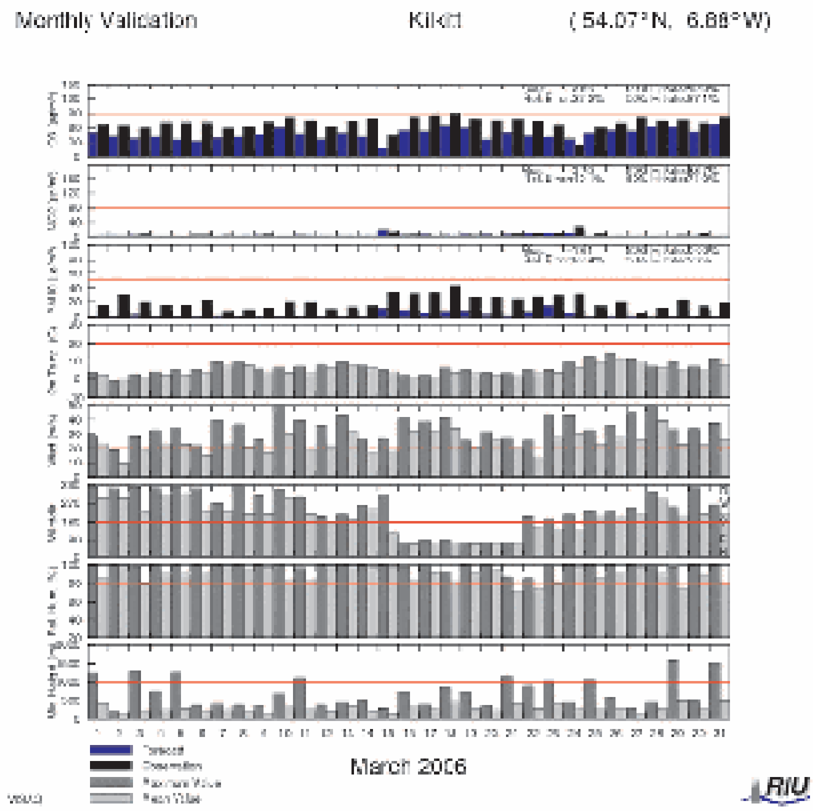
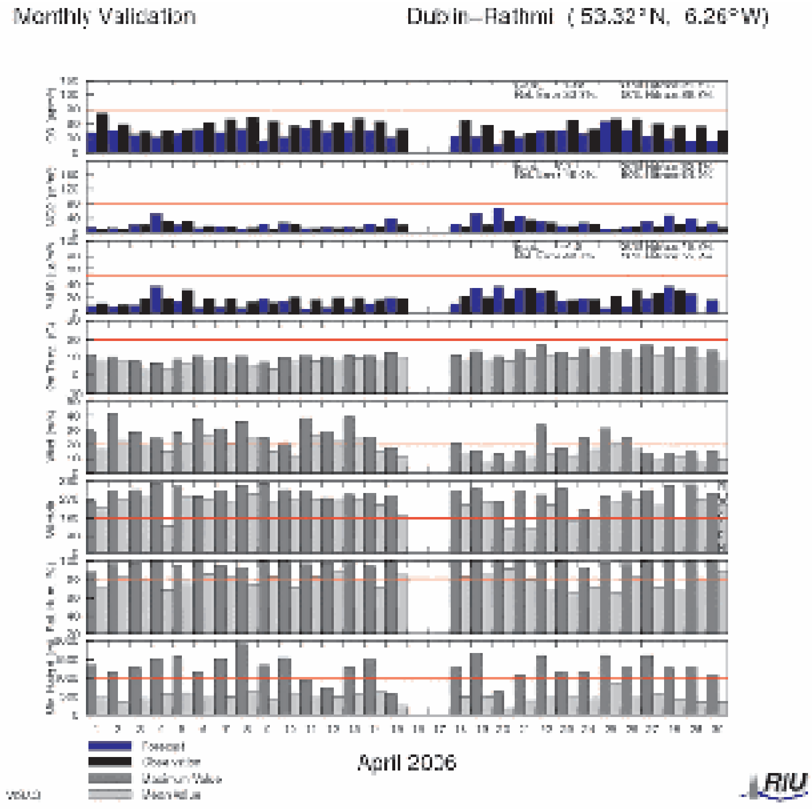


Figure 6.4. EURAD Irish air quality forecast: comparison between the observed and forecasted meteorological parameters at the Dublin Rathmines (top) and Kilkitt (bottom) stations for March 2006.



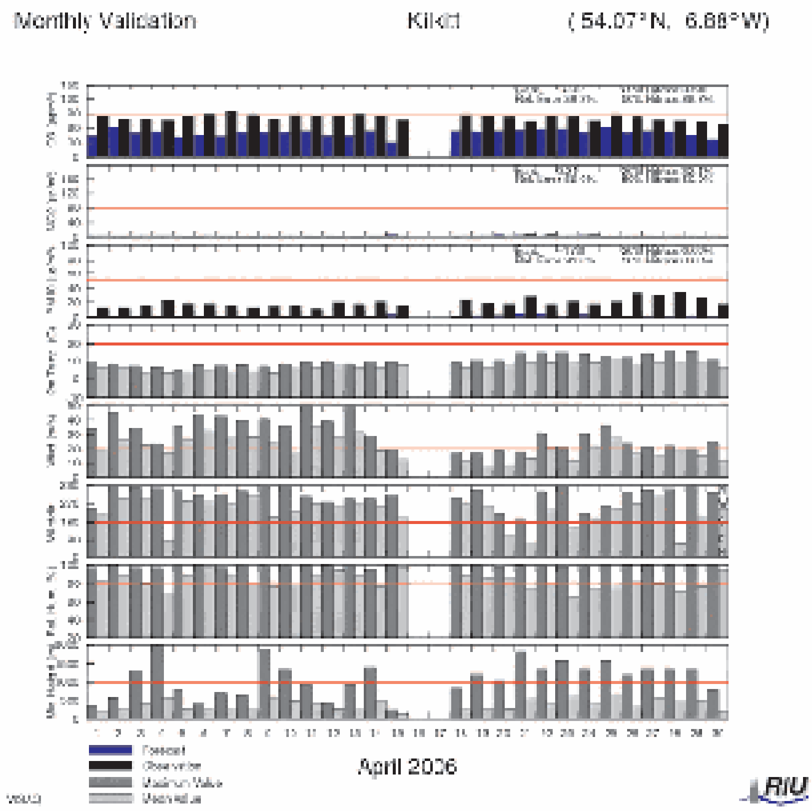
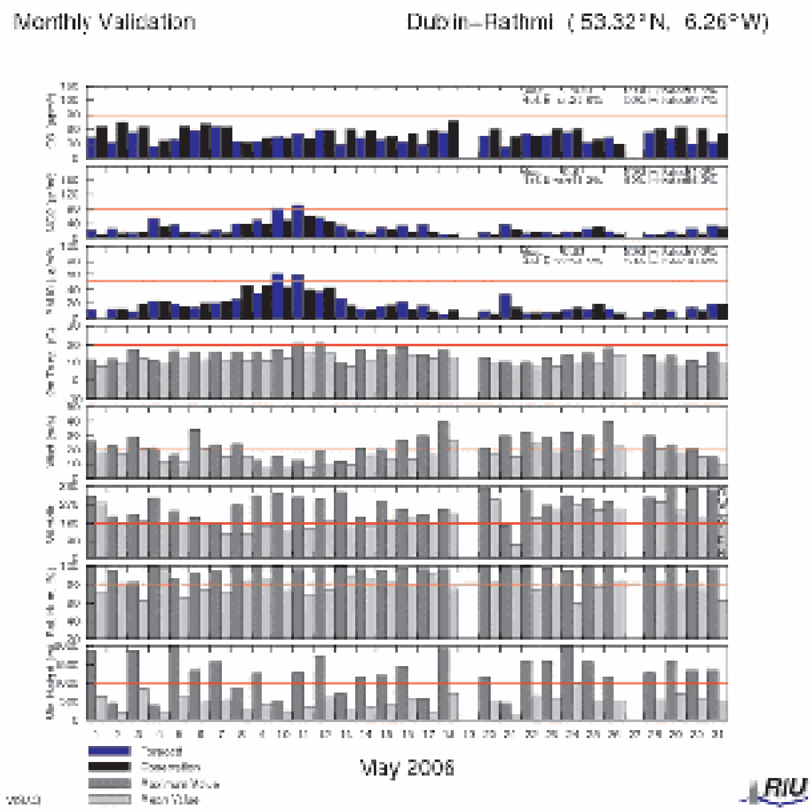


Figure 6.5. EURAD Irish air quality forecast: comparison between the observed and forecasted meteorological parameters at the Dublin Rathmines (top) and Kilkitt (bottom) stations for April 2006.



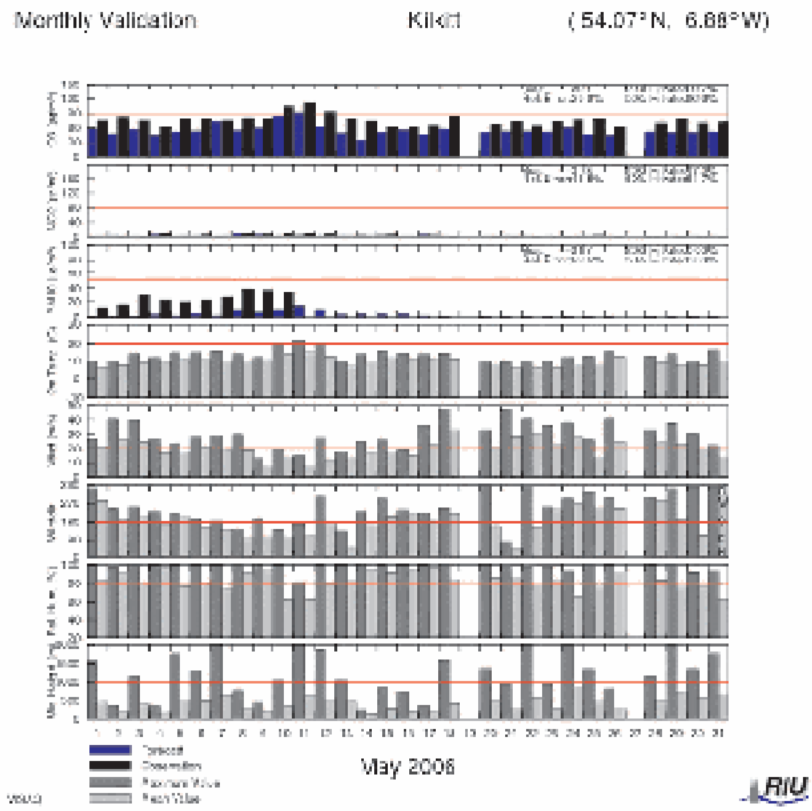
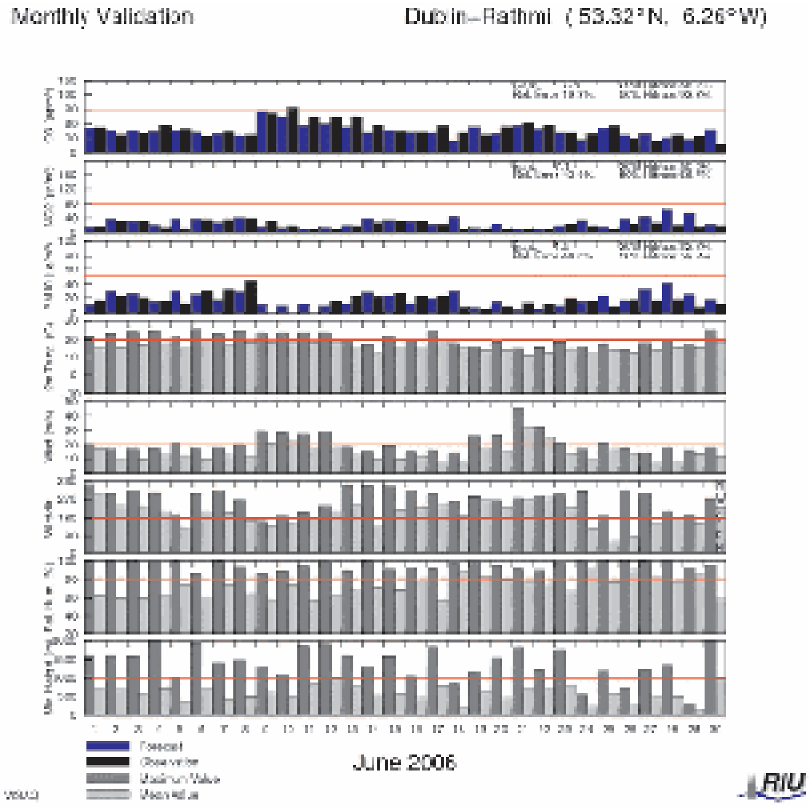


Figure 6.6. EURAD Irish air quality forecast: comparison between the observed and forecasted meteorological parameters at the Dublin Rathmines (top) and Kilkitt (bottom) stations for May 2006.



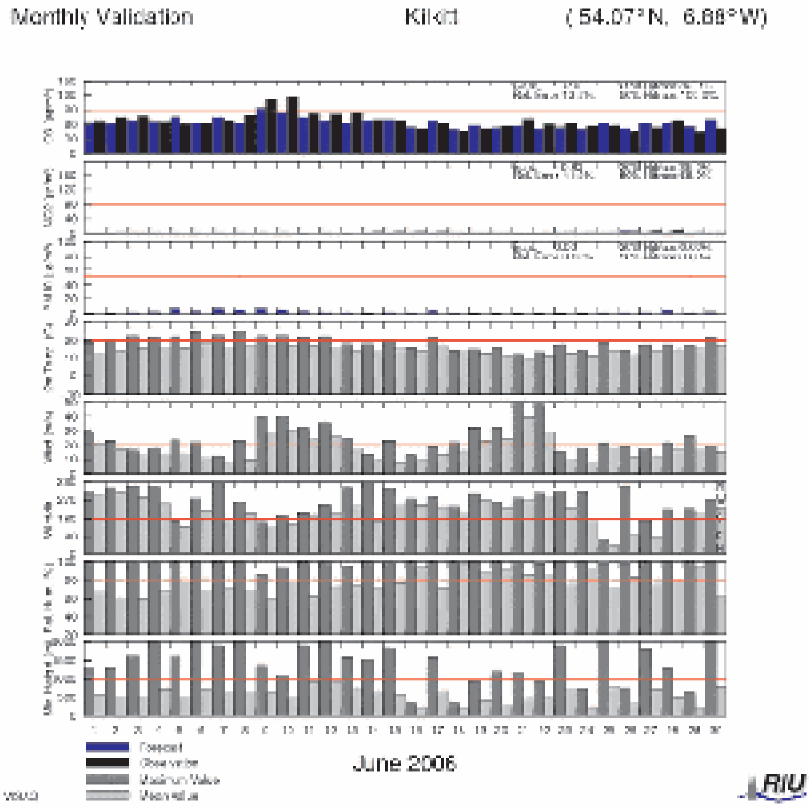


Figure 6.7. EURAD Irish air quality forecast: comparison between the observed and forecasted meteorological parameters at the Dublin Rathmines (top) and Kilkitt (bottom) stations for June 2006.

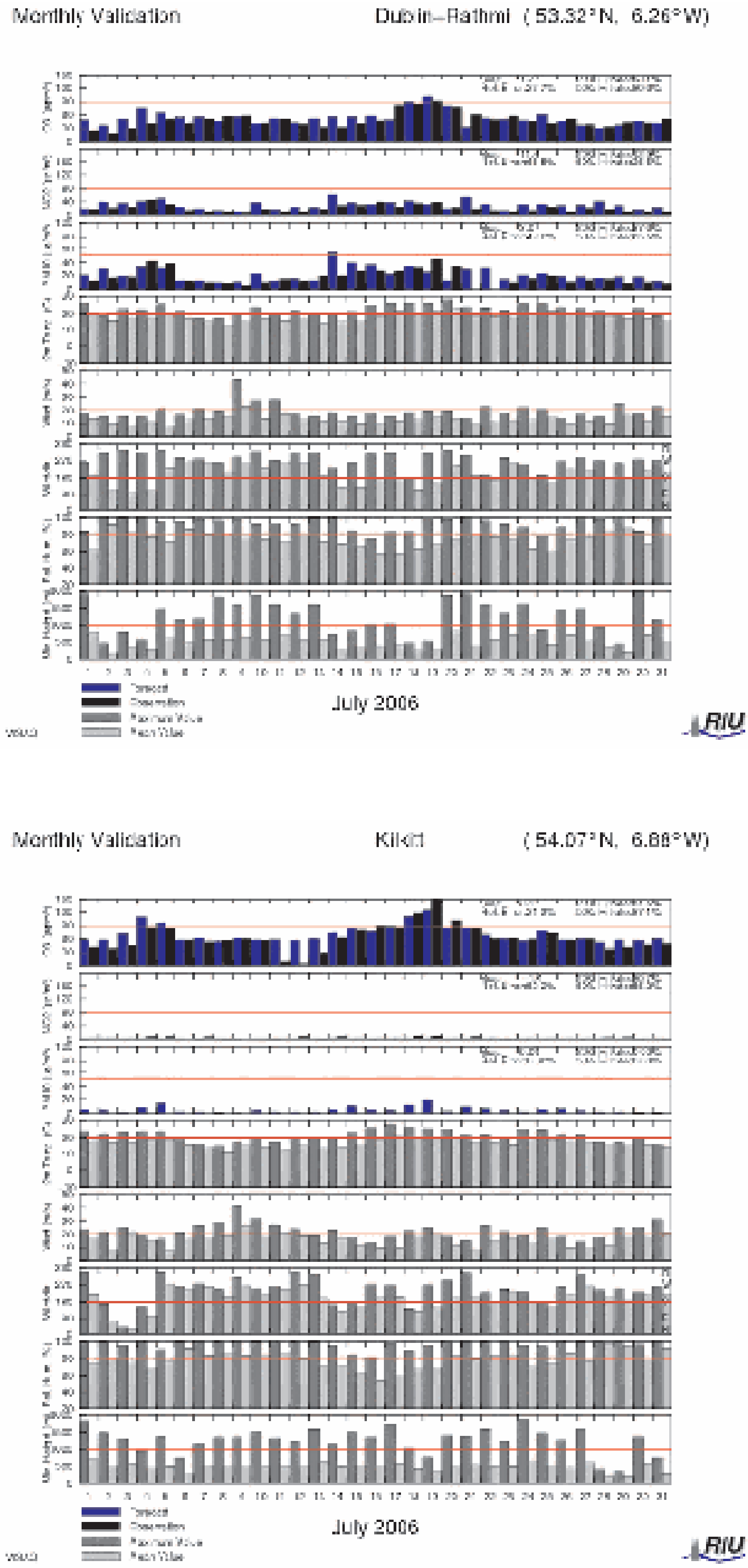
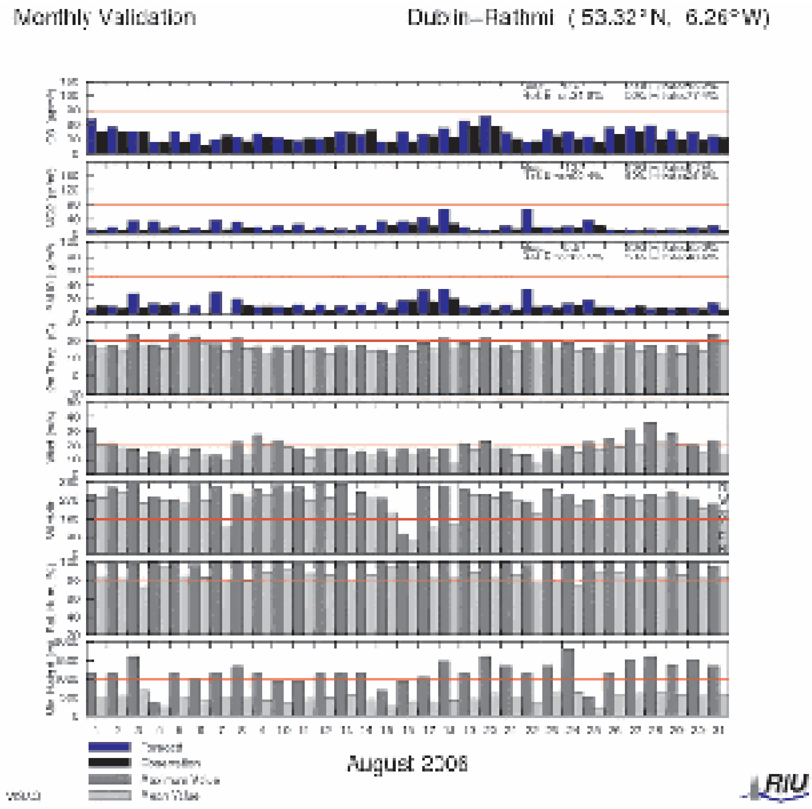


Figure 6.8. EURAD Irish air quality forecast: comparison between the observed and forecasted meteorological parameters at the Dublin Rathmines (top) and Kilkitt (bottom) stations for July 2006.



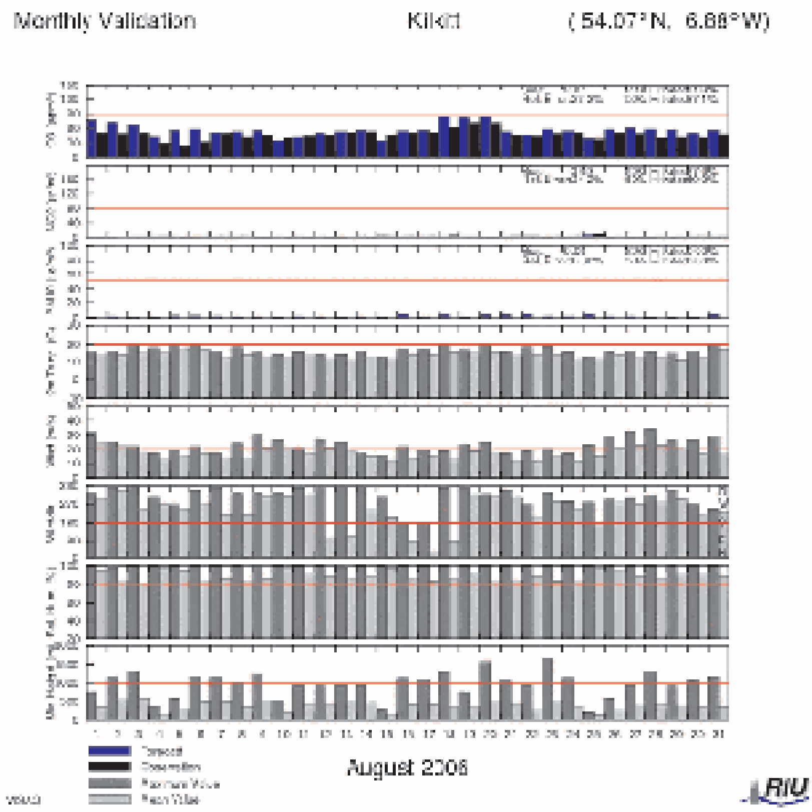
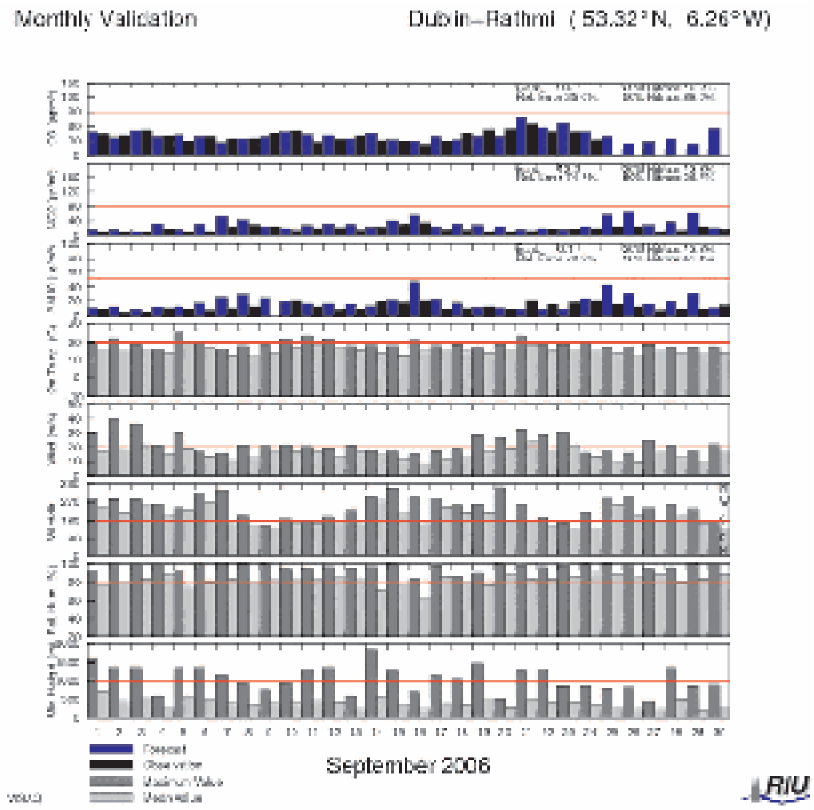


Figure 6.9. EURAD Irish air quality forecast: comparison between the observed and forecasted meteorological parameters at the Dublin Rathmines (top) and Kilkitt (bottom) stations for August 2006.



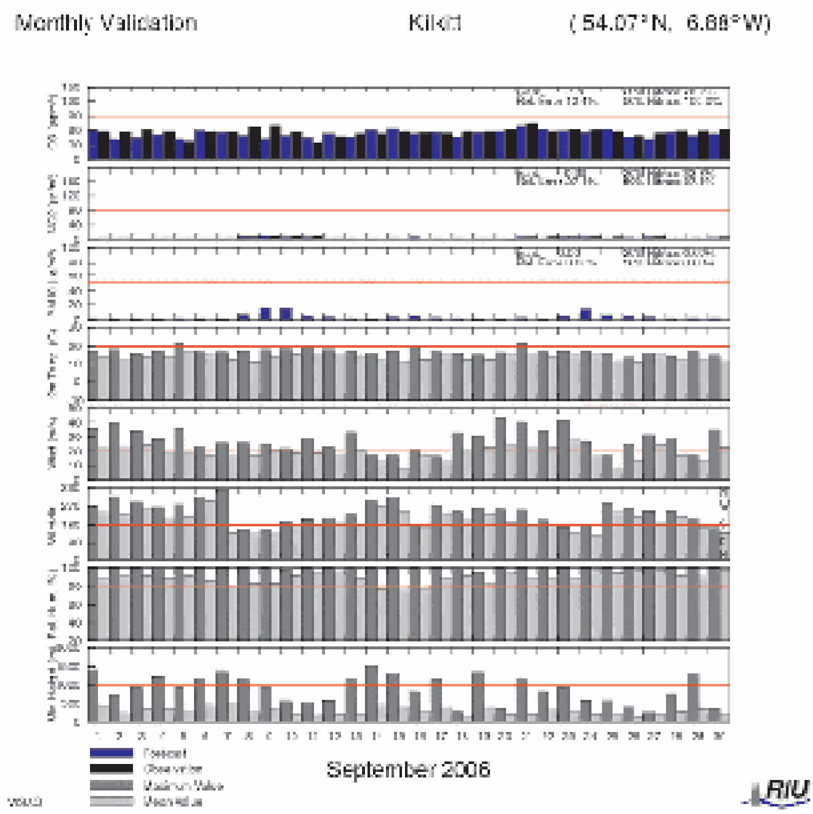
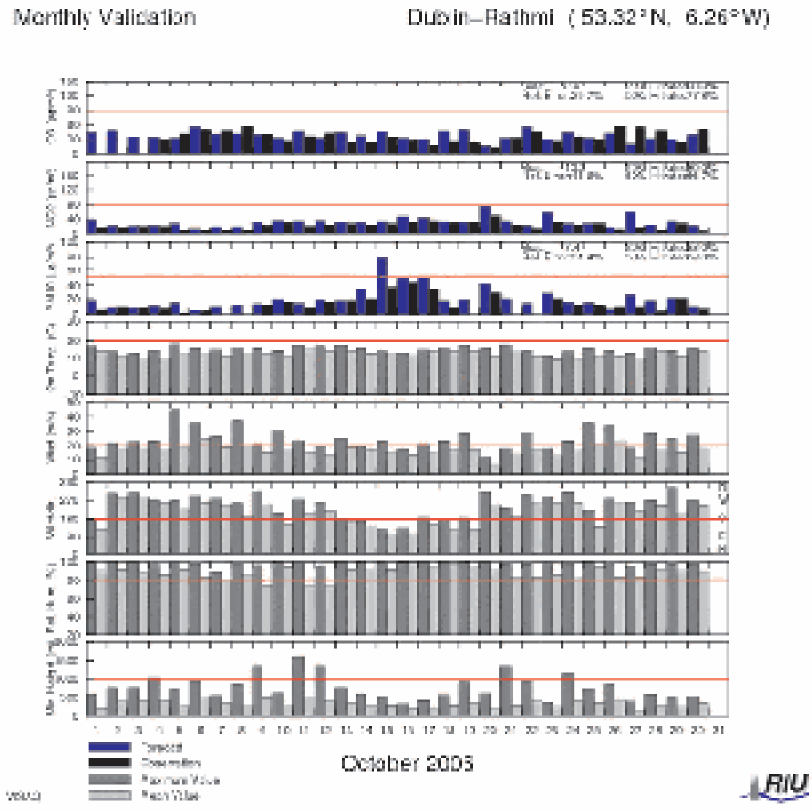


Figure 6.10. EURAD Irish air quality forecast: comparison between the observed and forecasted meteorological parameters at the Dublin Rathmines (top) and Kilkitt (bottom) stations for September 2006.



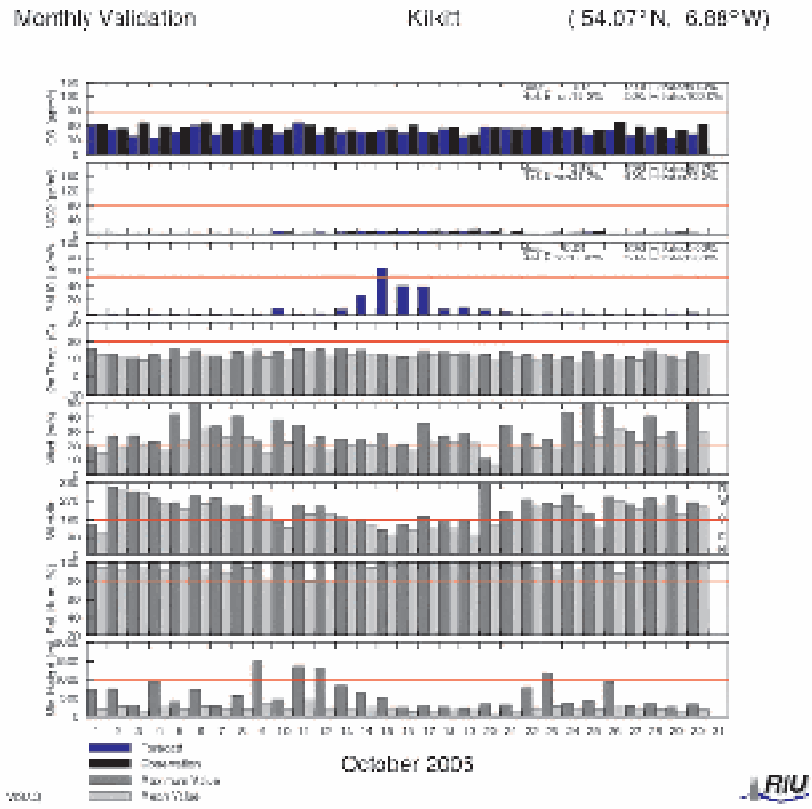
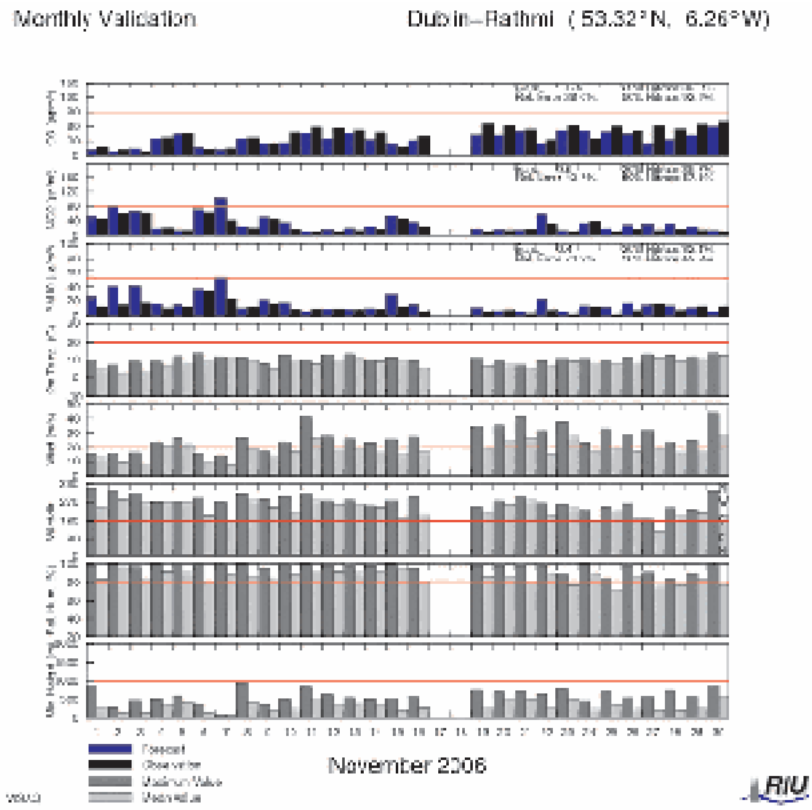


Figure 6.11. EURAD Irish air quality forecast: comparison between the observed and forecasted meteorological parameters at the Dublin Rathmines (top) and Kilkitt (bottom) stations for October 2006.



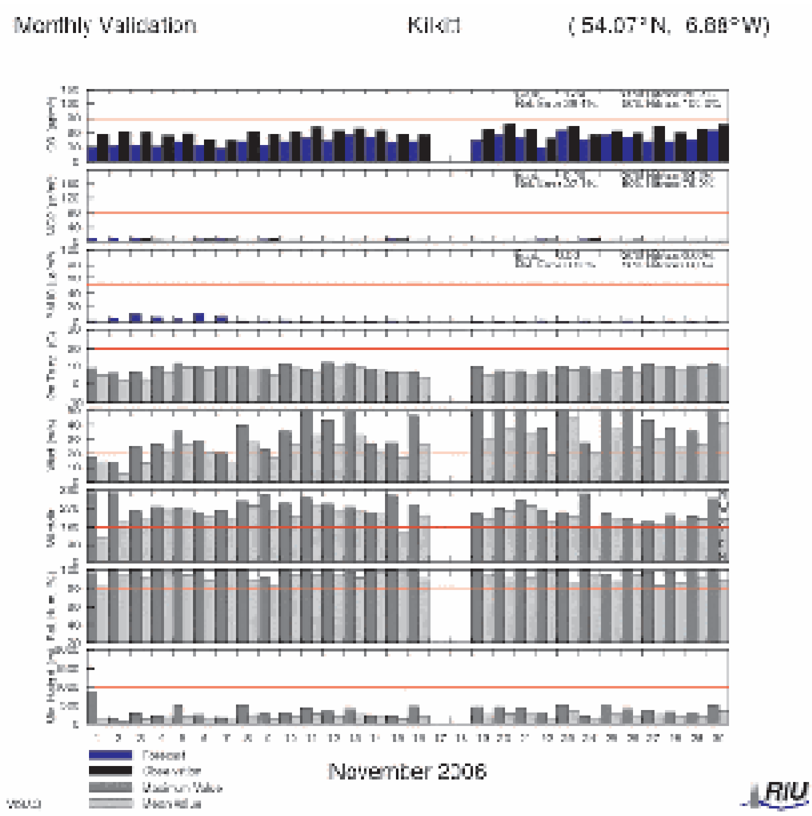
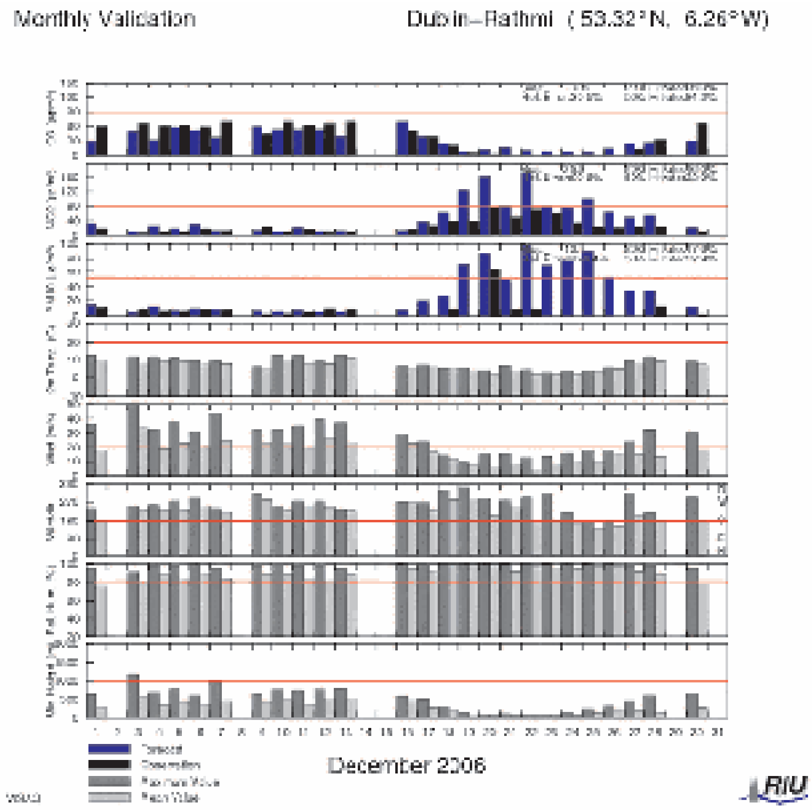


Figure 6.12. EURAD Irish air quality forecast: comparison between the observed and forecasted meteorological parameters at the Dublin Rathmines (top) and Kilkitt (bottom) stations for November 2006.



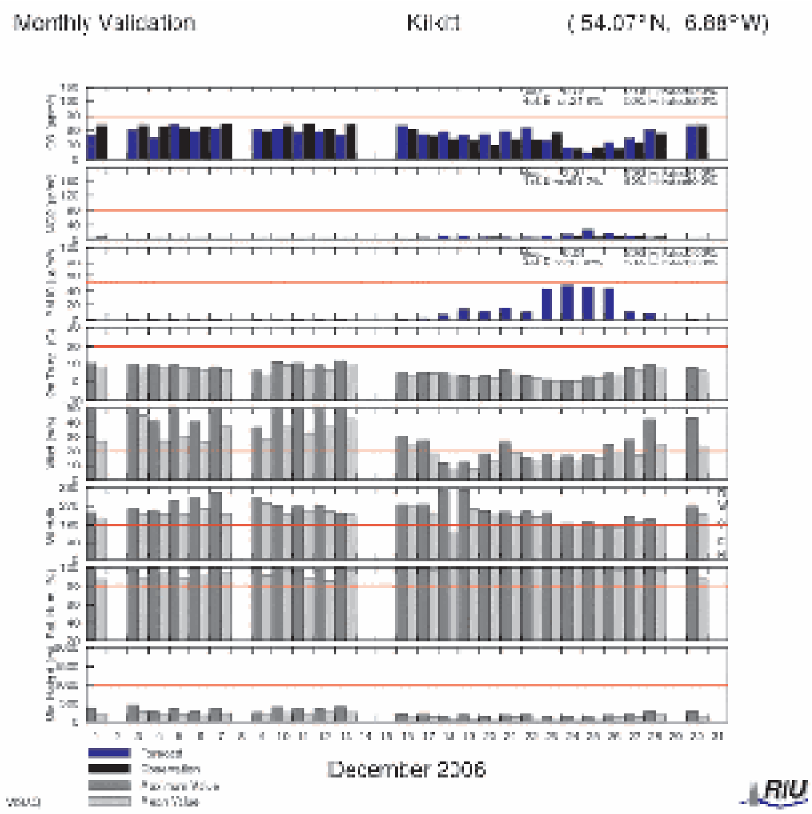


Figure 6.13. EURAD Irish air quality forecast: comparison between the observed and forecasted meteorological parameters at the Dublin Rathmines (top) and Kilkitt (bottom) stations for December 2006.

Table 6.2. Scores of the forecast performance.

Station	Bias (µg/m³)	HR_{20} (%)	HR_{50} (%)	R^2
O_3				
Dublin Rathmines	–2.4	45.9	91.5	0.52
Kilkitt	–7.4	52.3	96.8	0.38
Emo Court	4.4	45.6	95.1	0.31
Limerick	9.8	44.6	88.1	0.38
Cork City	20.3	29.6	72.9	0.36
Mace Head	–9.6	60.3	98.8	0.39
Valentia	–2.0	66.1	98.0	0.30
Wexford	11.5	41.7	93.9	0.37
Urban sites	**–2.4**	**45.9**	**91.5**	**0.52**
Rural sites	**3.4**	**49.1**	**92.5**	**0.36**
NO_2				
Dublin Rathmines	9.9	32.5	78.3	0.66
Dublin Coleraine St	–2.1	28.5	81.6	0.65
Kilkitt	–0.1	32.8	78.0	0.35
Ennis	0.8	19.3	56.8	0.58
Cork City	–16.1	5.2	21.3	0.60
Limerick	–11.4	2.1	13.3	0.35
Urban sites	**4.1**	**30.6**	**79.9**	**0.65**
Rural sites	**–7.1**	**14.4**	**41.2**	**0.27**
PM_{10}				
Dublin Rathmines	2.3	27.0	69.8	0.53
Dublin Coleraine St	– 1.0	28.5	77.2	0.46
Kilkitt	–17.5	3.1	6.3	0.23
Ennis	–16.9	1.4	7.6	0.09
Castlebar	–11.9	1.2	8.6	0.10
Galway	–17.5	6.3	14.7	0.35
Urban sites	**0.8**	**27.7**	**73.2**	**0.50**
Rural sites	**–16.9**	**2.5**	**8.5**	**0.11**

The comparison of the NO_2 concentrations displays a higher distributed pattern (Figs 6.18–6.20). There is a clear difference in the performance between rural and urban sites. The Dublin urban sites show a slight over-prediction with relative high values in the hit rates, whereas the rural sites display an under-prediction with fewer scores in the hit rates.

The same, and even more pronounced, behaviour is seen when comparing the forecasted PM_{10} concentrations with observations (Figs 6.21–6.23). There is a strong negative bias together with low hit rates at the rural sites, whereas when comparing the predicted values at the urban sites, a slight over-prediction is noticeable, with relatively high scores in the hit rates.

In general, there is a good performance in the O_3 prediction for all sites, a distinguishing behaviour in the performance for NO_2 and PM_{10} between urban and rural sites (Figs 6.24–6.26). This finding leads to the conclusion that special dependencies on meteorological conditions in the forecasted concentrations are obvious.

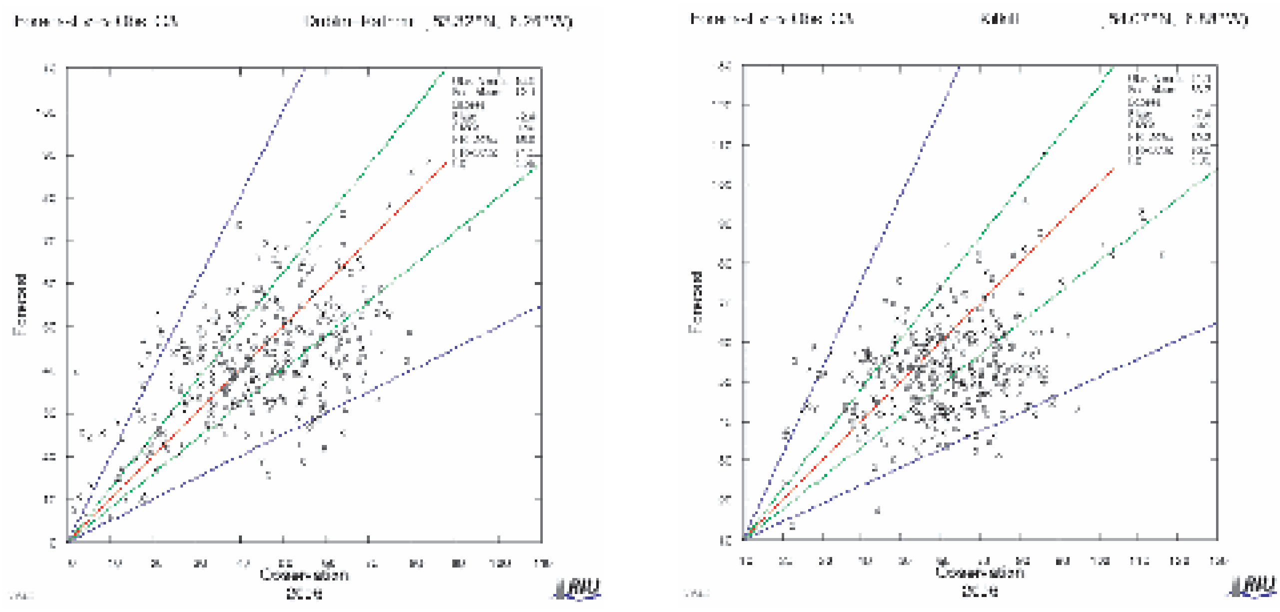


Figure 6.14. EURAD Irish air quality forecast: comparison between forecast and observed values for ozone (O_3) at the Dublin Rathmines (left) and Kilkitt (right) stations for 2006.

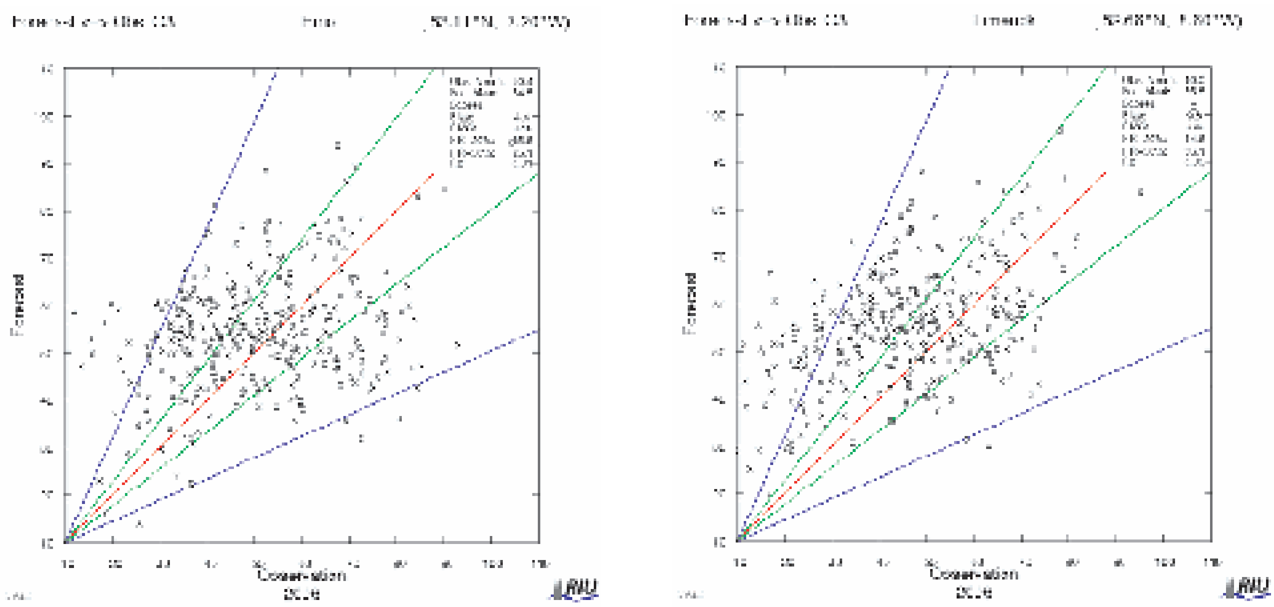


Figure 6.15. EURAD Irish air quality forecast: comparison between forecast and observed values for ozone (O_3) at the Emo Court (left) and Limerick (right) stations for 2006.

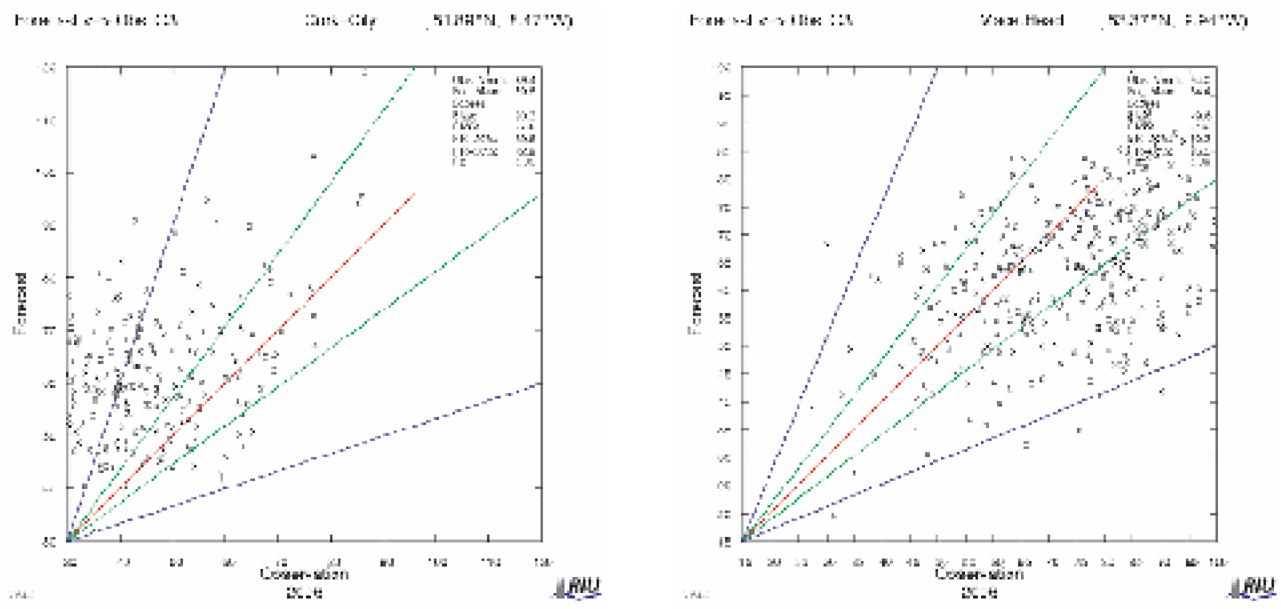


Figure 6.16. EURAD Irish air quality forecast: comparison between forecast and observed values for ozone (O_3) at the Cork City (left) and Mace Head (right) stations for 2006.

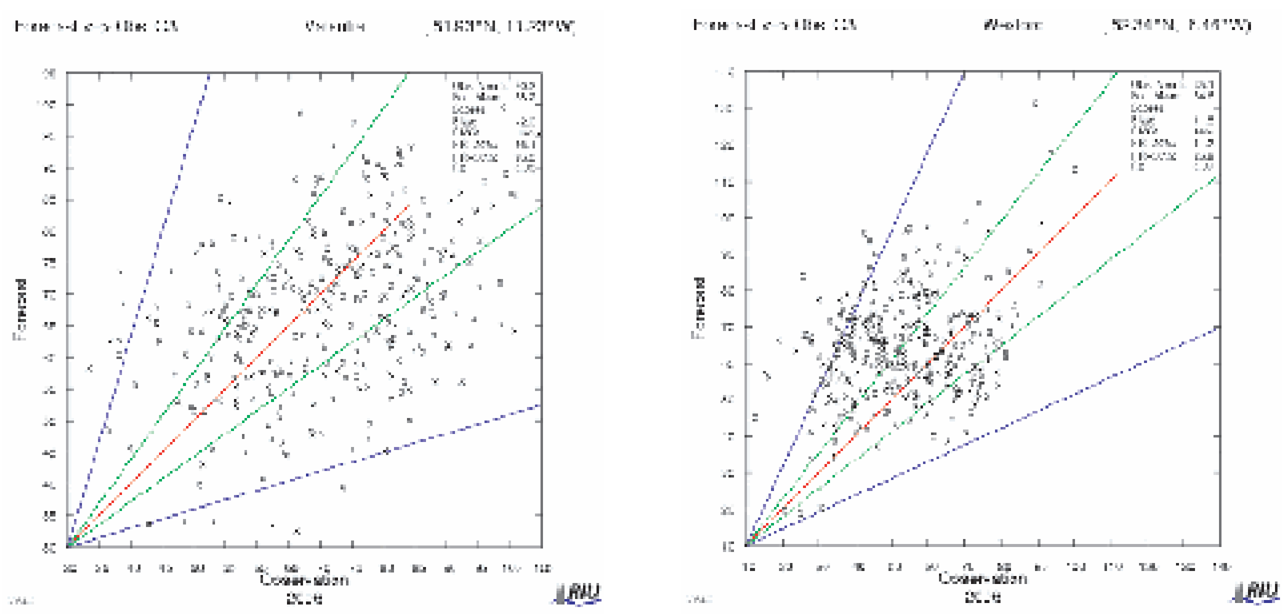


Figure 6.17. EURAD Irish air quality forecast: comparison between forecast and observed values for ozone (O_3) at the Valentia (left) and Wexford (right) stations for 2006.

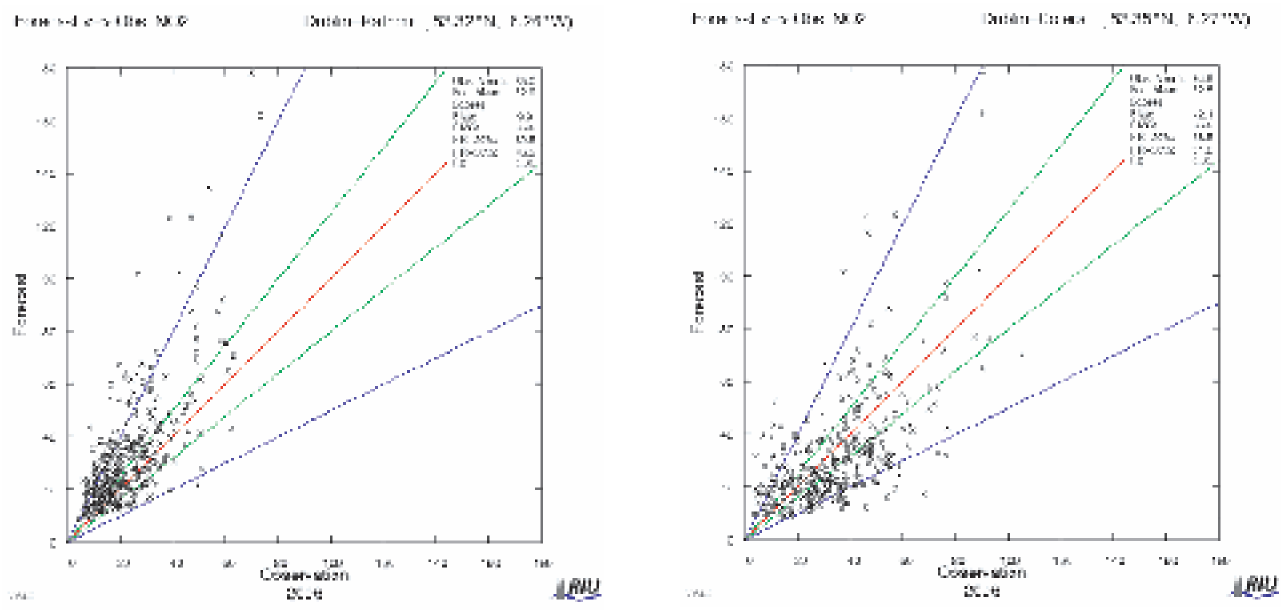


Figure 6.18. EURAD Irish air quality forecast: comparison between forecast and observed values for NO_2 at the Dublin Rathmines (left) and Dublin Coleraine St (right) stations for 2006.

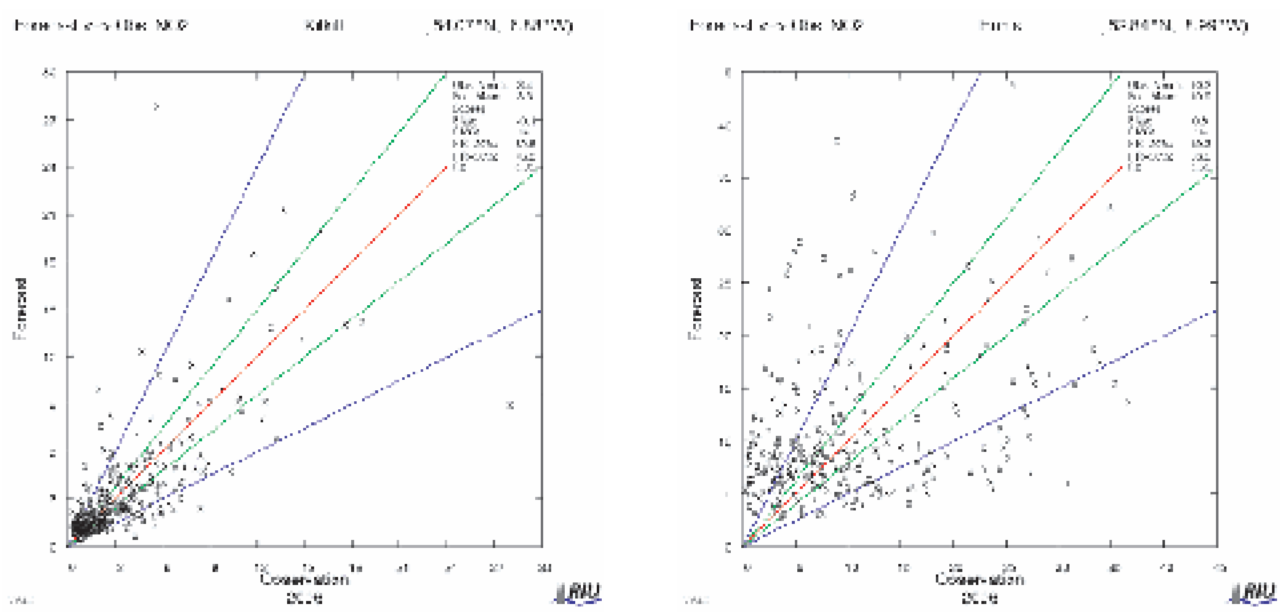


Figure 6.19. EURAD Irish air quality forecast: comparison between forecast and observed values for nitrogen dioxide (NO_2) at the Kilkitt (left) and Ennis (right) stations for 2006.

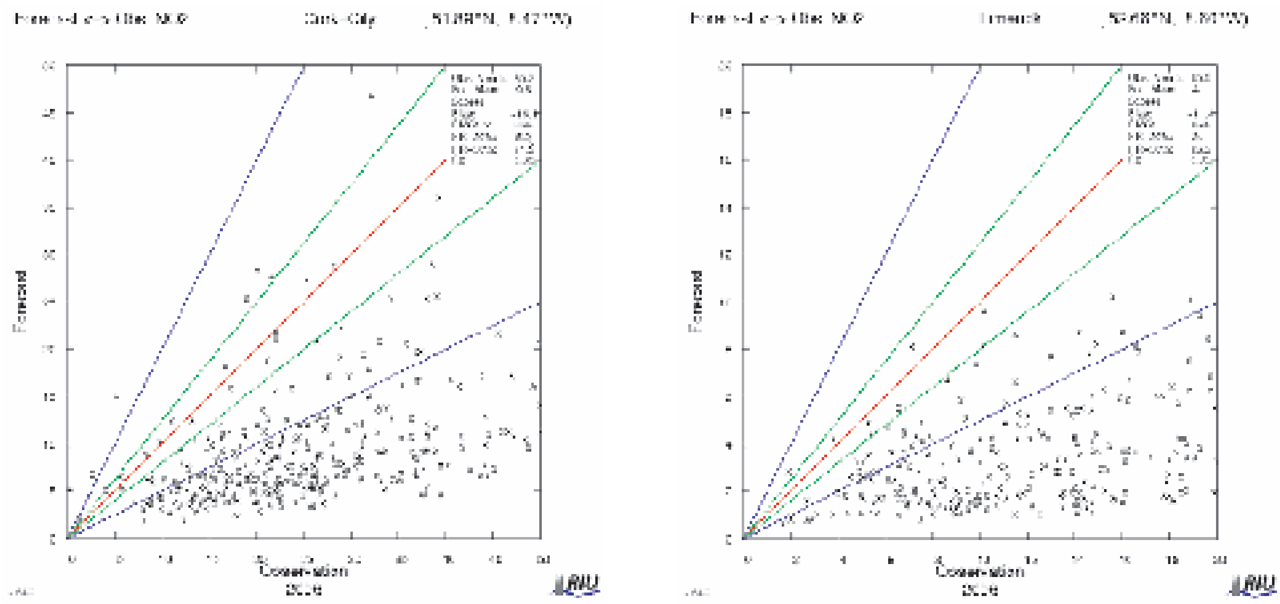


Figure 6.20. EURAD Irish air quality forecast: comparison between forecast and observed values for nitrogen dioxide (NO_2) at the Cork City (left) and Limerick (right) stations for 2006.

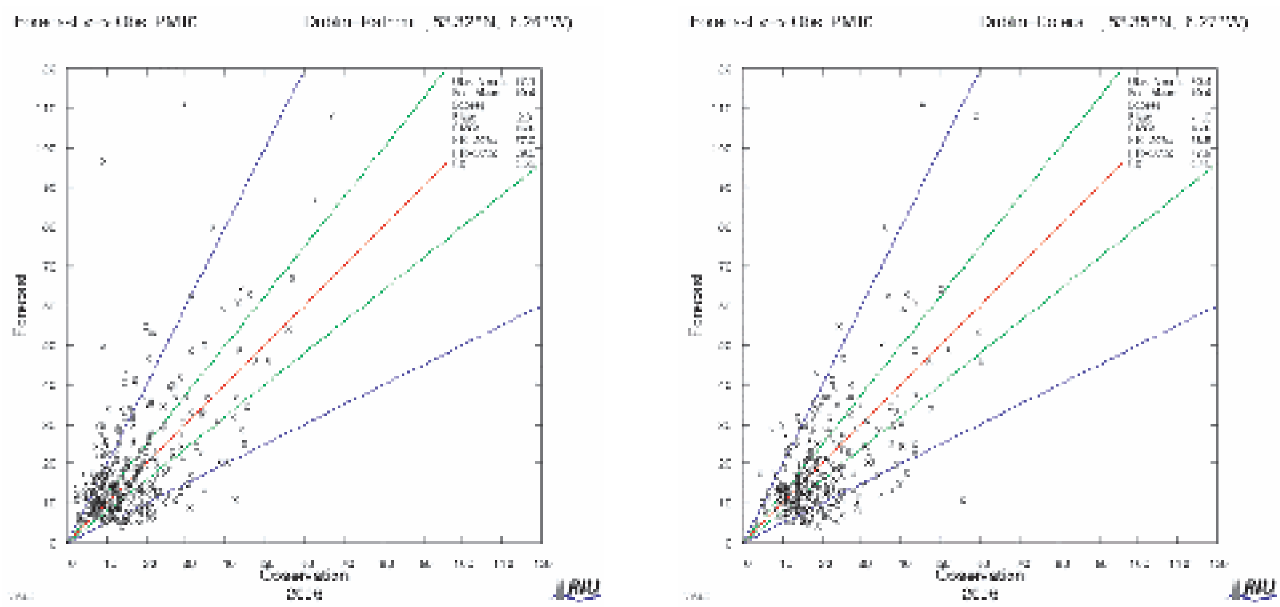


Figure 6.21. EURAD Irish air quality forecast: comparison between forecast and observed values for particulate matter ≤10 µm (PM_{10}) at the Dublin Rathmines (left) and Dublin Coleraine St (right) stations for 2006.

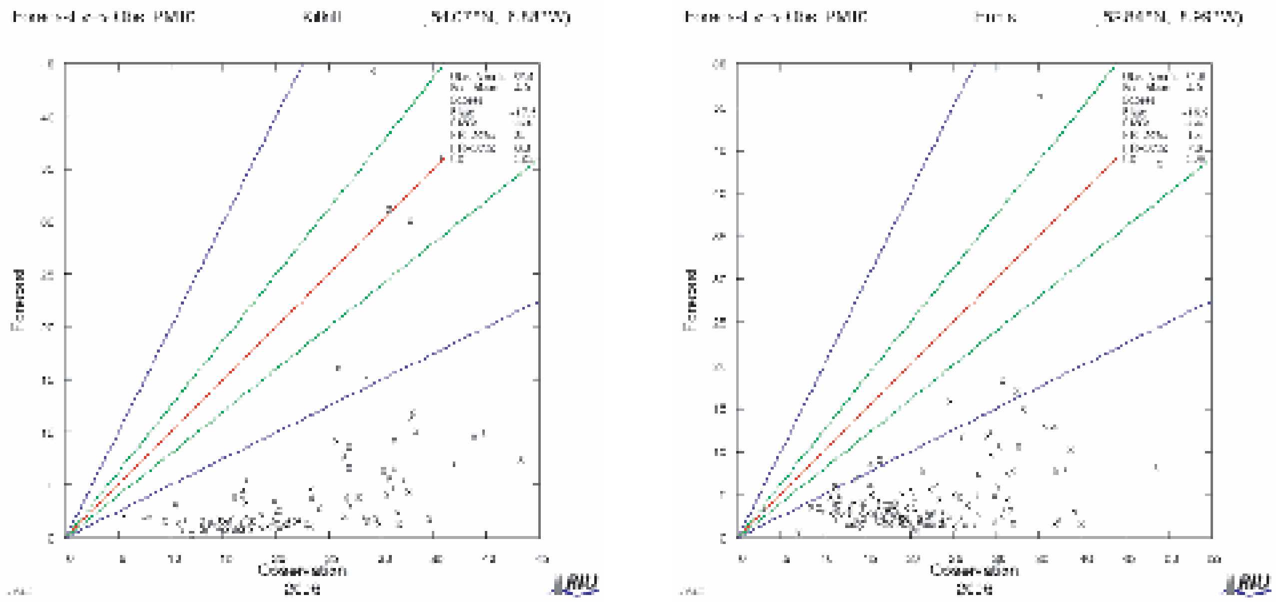


Figure 6.22. EURAD Irish air quality forecast: comparison between forecast and observed values for particulate matter ≤10 µm (PM_{10}) at the Kilkitt (left) and Ennis (right) stations for 2006.

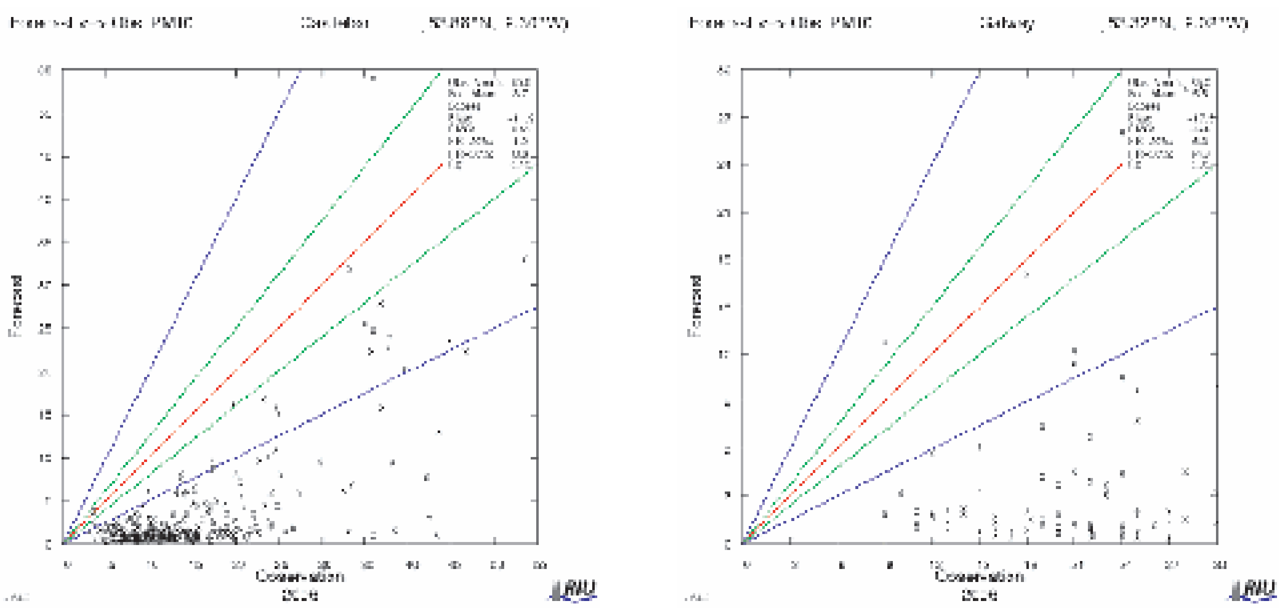


Figure 6.23. EURAD Irish air quality forecast: comparison between forecast and observed values for particulate matter ≤10 µm (PM_{10}) at the Castlebar (left) and Galway (right) stations for 2006.

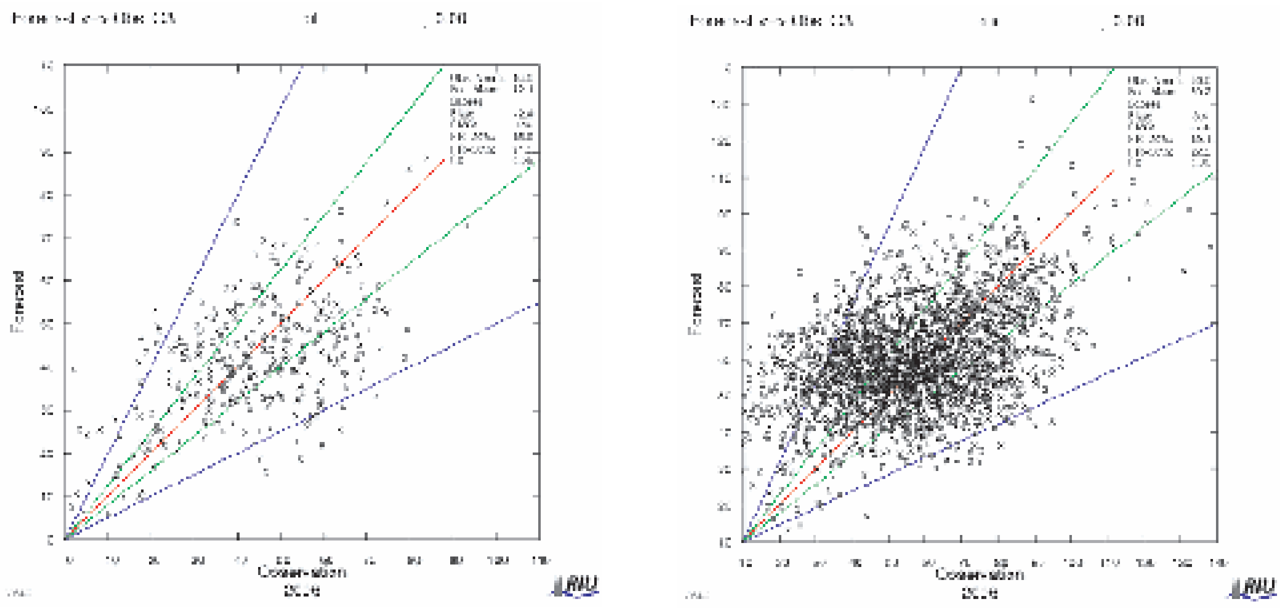


Figure 6.24. EURAD Irish air quality forecast: comparison between forecast and observed values for ozone (O_3) at the urban (left) and rural (right) stations for 2006.

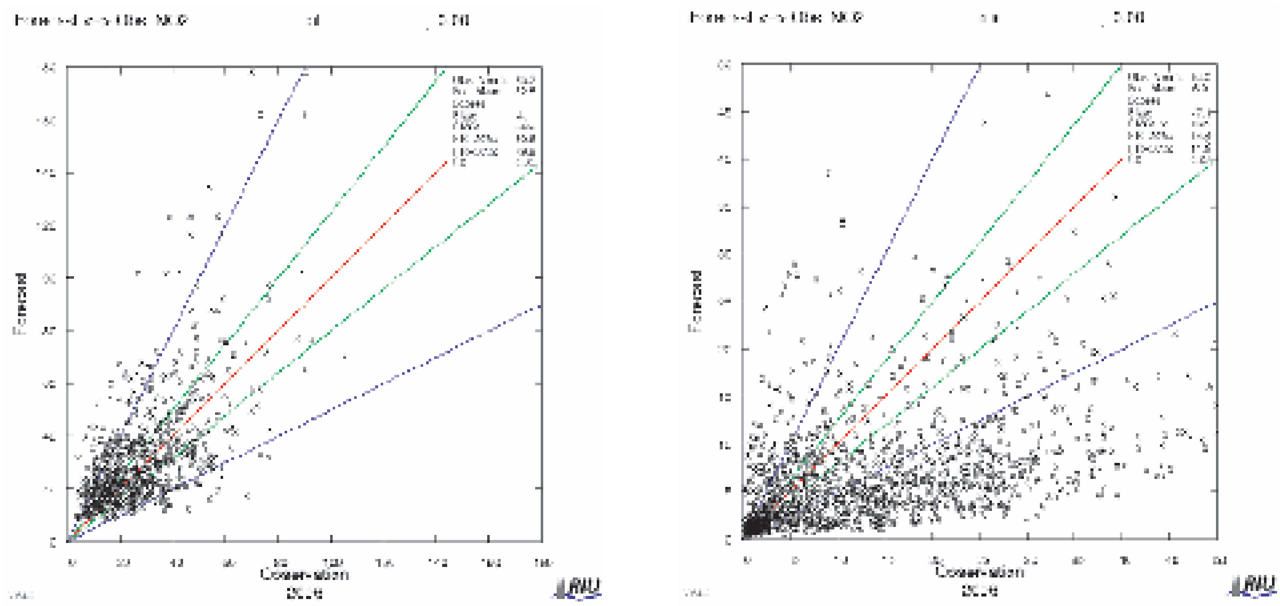


Figure 6.25. EURAD Irish air quality forecast: comparison between forecast and observed values for nitrogen dioxide (NO_2) at the urban (left) and rural (right) stations for 2006.

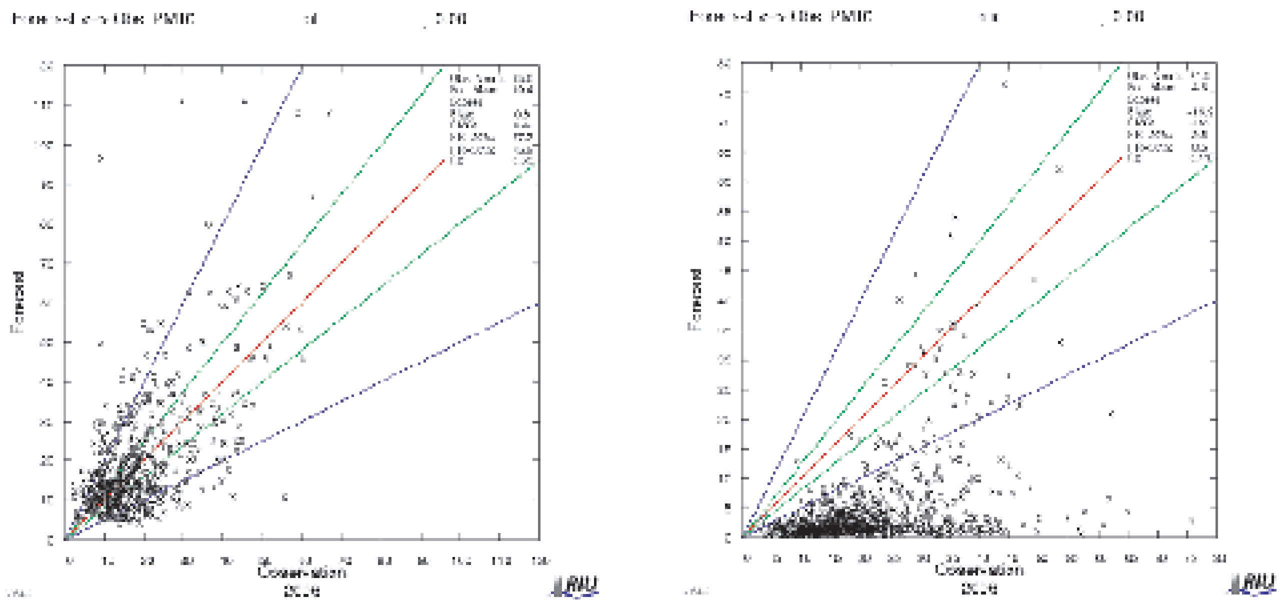


Figure 6.26. EURAD Irish air quality forecast: comparison between forecast and observed values for particulate matter ≤10 µm (PM_{10}) at the urban (left) and rural (right) stations for 2006.

7 Model Output Statistics

As seen in the validation procedure, strong discrepancies occur especially for NO_2 and PM_{10} when comparing the predicted values with observations at rural sites. These differences could be interpreted as systematic errors under typical weather conditions. This strongly favours the use of the MOS system, an omnipresent statistical technique that forms the backbone of modern weather forecasting. This technique can be transformed for chemical weather prediction models. The aim of this method is to eliminate systematic errors under variable meteorological conditions. First, the CART (Classification and Regression Trees) technique was considered for the MOS procedure for chemical forecasting. The CART technique uses a set of historical data from the model and the observations to construct decision trees which are then used to classify new data. First of all, a maximised tree is created which is later pruned to a right-sized tree. To create the maximised tree a splitting rule has to be defined. These splitting rules will be achieved via the bisection method with optimised predictors in a multivariate linear regression. At the end, a classification algorithm is achieved that has to be integrated into the air quality forecasting models. With this algorithm the application of the observed model data will be tested for different conditions and finally it should be a part of the whole forecast cycle. When testing this technique, problems arise when trying to automatically find the splitting rules.

By searching for typical errors and their dependencies to meteorological parameters is was found that the errors from Direct Model Output (DMO) show linear relations to meteorological parameters: i.e. to the daily mean 2-m temperature, 10-m wind speed, relative humidity at near-surface level and the mixing height of the model. Figures 7.1 and 7.2 display this relationship between the DMO error for PM_{10} and the meteorological parameters for the Dublin Rathmines station.

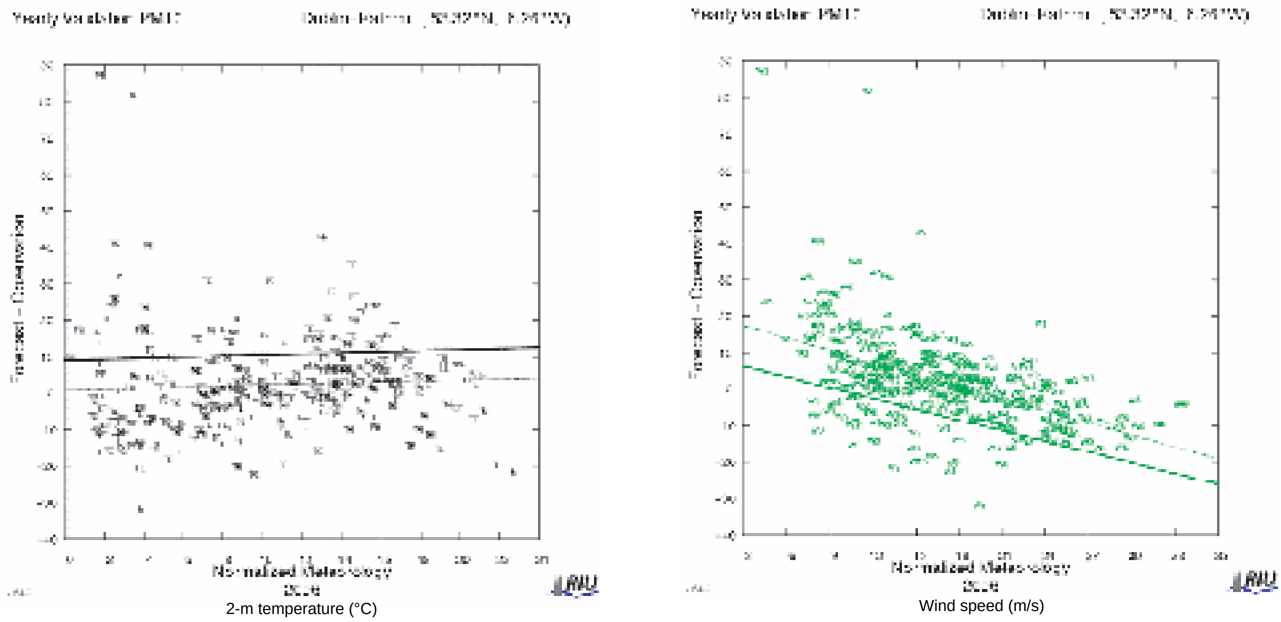


Figure 7.1. EURAD Irish air quality forecast: dependencies of Direct Model Output error of particulate matter ≤10 µm (PM_{10}) in relation to 2-m temperature (left) and wind speed (right) at the Dublin Rathmines station for 2006.

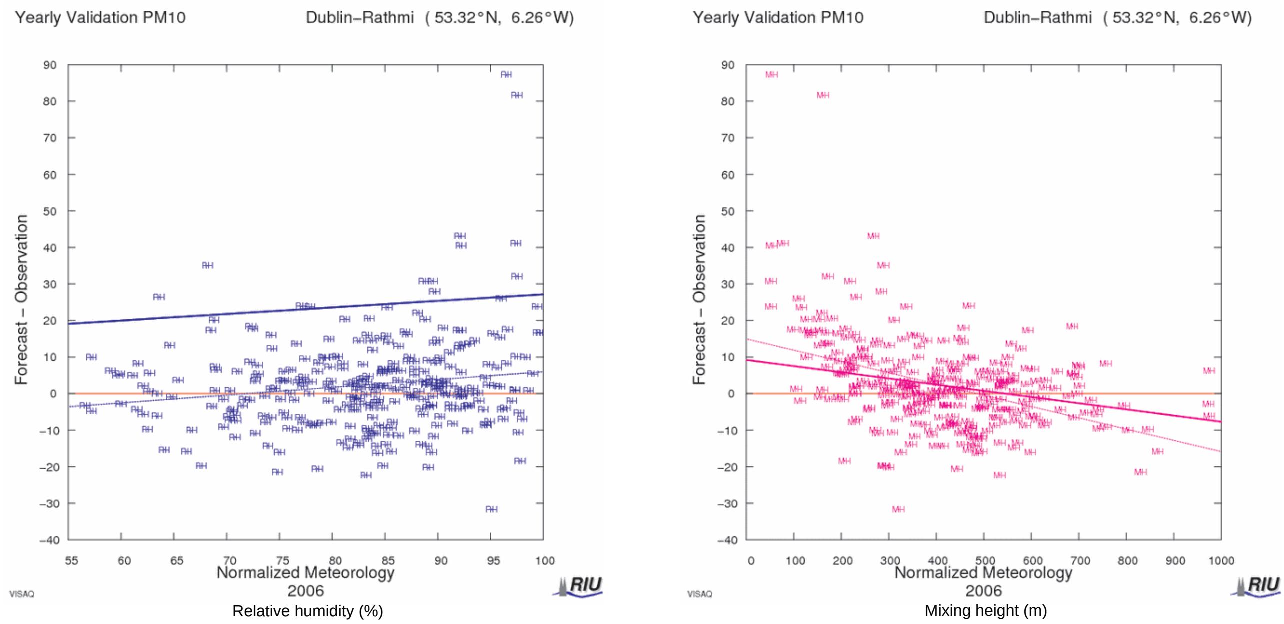


Figure 7.2. EURAD Irish air quality forecast: dependencies of Direct Model Output error of particulate matter ≤10 µm (PM_{10}) in relation to relative humidity (left) and mixing height (right) at the Dublin Rathmines station for 2006.

This procedure indicates that there is a single variant linear relationship between the DMO error and the selected meteorological variable, expressed in the regression line (dashed line) by using the least square method. This finding leads to the assumption to use a multivariate linear regression method (multiple regression) to find a relationship between the predictors (meteorological variables) and the DMO error. This procedure was done for O_3, NO_2 and PM_{10} for all available stations.

7.1 Multiple Regression

The relationship between the response variable (DMO error) and the dependent variables can be expressed as:

$$Y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} \ldots + \beta_p x_{ip} + \varepsilon_i$$

where β_n, $n = 0,\ldots,p$ are the regression coefficients with i observations and with p co-variables; ε_i is the residual error. This is a linear system of equations in the form:

$$\underline{Y} = \underline{X}\,\underline{\beta} + \underline{\varepsilon}$$

with

$$\underline{Y} = \begin{pmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_i \\ \vdots \\ Y_n \end{pmatrix} \in \mathbb{R}^{n\times 1},\ \underline{\epsilon} = \begin{pmatrix} \epsilon_1 \\ \epsilon_2 \\ \vdots \\ \epsilon_i \\ \vdots \\ \epsilon_n \end{pmatrix} \in \mathbb{R}^{n\times 1} \quad \text{and} \quad \underline{\beta} = \begin{pmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \\ \vdots \\ \beta_j \\ \vdots \\ \beta_p \end{pmatrix} \in \mathbb{R}^{(p+1)\times 1}$$

The matrix $\underline{X}$ can be written as:

$$\underline{X} = \begin{pmatrix} 1 & x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1p} \\ 1 & x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{2p} \\ \vdots & & \vdots & \ddots & & \ddots & \vdots \\ 1 & x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{ip} \\ \vdots & & \vdots & \ddots & & \ddots & \vdots \\ 1 & x_{n1} & x_{n2} & \cdots & x_{nj} & \cdots & x_{np} \end{pmatrix} \in \mathbb{R}^{(n\times(p+1))}$$

As a solution of the minimisation problem one obtains the vector of the estimated regression coefficients ***b*:**

$$\underline{b} = \begin{pmatrix} b_0 \\ b_1 \\ b_2 \\ \vdots \\ b_j \\ \vdots \\ b_p \end{pmatrix} = (\underline{X}^T\underline{X})^{-1}\underline{X}^T\underline{Y}$$

Thus the estimated values for $\underline{Y}$ can be expressed as:

$$\underline{\hat{Y}} = \underline{X}\underline{b} = \underline{X}(\underline{X}^T\underline{X})^{-1}\underline{X}^T\underline{Y}$$

The performance of the regression can be expressed by the coefficient of determination R^2:

$$R^2 = \frac{SS_{Reg}}{SS_{Total}} = 1 - \frac{SS_{Res}}{SS_{Total}} = 1 - \frac{RSS}{SS_{Total}}$$

with

$$SS_{Reg} = \sum_{i=1}^{n}(\hat{Y}_i - \overline{Y})^2 \, , \quad \overline{Y} = \frac{1}{n}\sum_{i=1}^{n} Y_i$$

and

$$SS_{Res} = RSS = \sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2$$

and

$$SS_{Total} = \sum_{i=1}^{n}(Y_i - \overline{Y})^2$$

With the knowledge of the estimated regression coefficients of the multivariate regression one can obtain a new estimate for the corrected forecast (DMOE):

$$DMOE_i = (F - O)_i = b_0 + b_1x_{1i} + b_2x_{2i} + ... + b_px_{pi}$$

where F is the forecasted and O is the observed value. Or in terms of the selected dependent meteorological variables:

$$DMOE_i = (F - O)_i = b_0 + b_1TEM_i + b_2WIN_i + b_3RH_i + b_4MH_i$$

where *TEM* is the 2-m temperature, *WIN* is the 10-m wind speed, *RH* is the relative humidity and *MH* is the mixing height at the location and measurement *i*. Thus, one can find a new corrected forecast value Φ_i:

$$\Phi_i = F_i - (b_0 + b_1TEM_i + b_2WIN_i + b_3RH_i + b_4MH_i).$$

The multiple regressions have been carried out separately for the urban and rural stations and are applied for the whole D03 domain. The calculated regression coefficients together with the coefficient of determination are summarised in Table 7.1.

These coefficients are applied to the calculation of new forecast values at each station. The results are shown in Section 7.2.

7.2 Results for the MOS

The regression coefficients were applied to each station forecast values and the results in the form of scatter diagrams are shown for O_3 (Figs 7.3–7.6), NO_2 (Figs 7.7–7.9) and PM_{10} (Figs 7.10–7.12). Figures 7.13–7.15 show the comparison between the rural and urban sites for O_3, NO_2, and PM_{10}, respectively.

Table 7.1. Regression coefficients and coefficients of determination.

	b_0	b_1	b_2	b_3	b_4	R^2
O_3						
Urban sites	–57.9318	0.7420	–0.2981	0.5680	0.0136	0.29
Rural sites	–60.8299	1.2292	–0.5424	0.6542	0.0197	0.40
NO_2						
Urban sites	–2.2760	–0.1892	–1.6401	0.4252	–0.0002	0.38
Rural sites	–10.0499	0.5017	0.0925	0.0006	–0.0115	0.24
PM_{10}						
Urban sites	8.8570	0.1533	–0.9517	0.1507	–0.0154	0.32
Rural sites	–24.7865	0.0607	–0.1450	0.1388	–0.0061	0.21

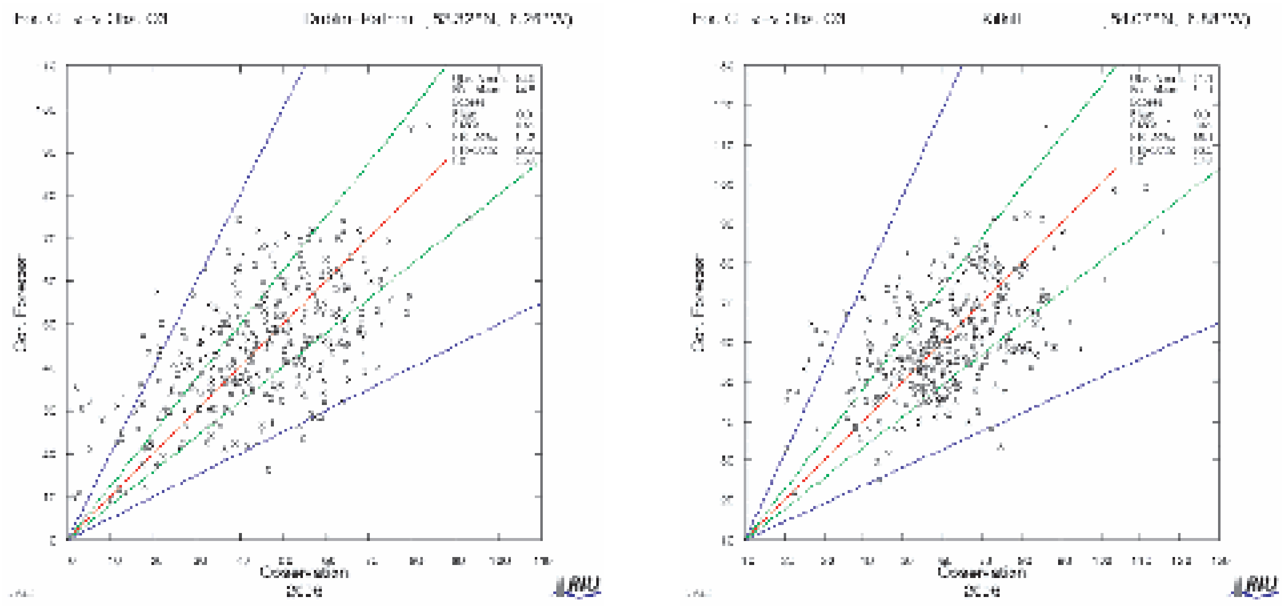


Figure 7.3. EURAD Irish air quality forecast: comparison between forecast and observed values for ozone (O_3) at the Dublin Rathmines (left) and Kilkitt (right) stations for 2006.

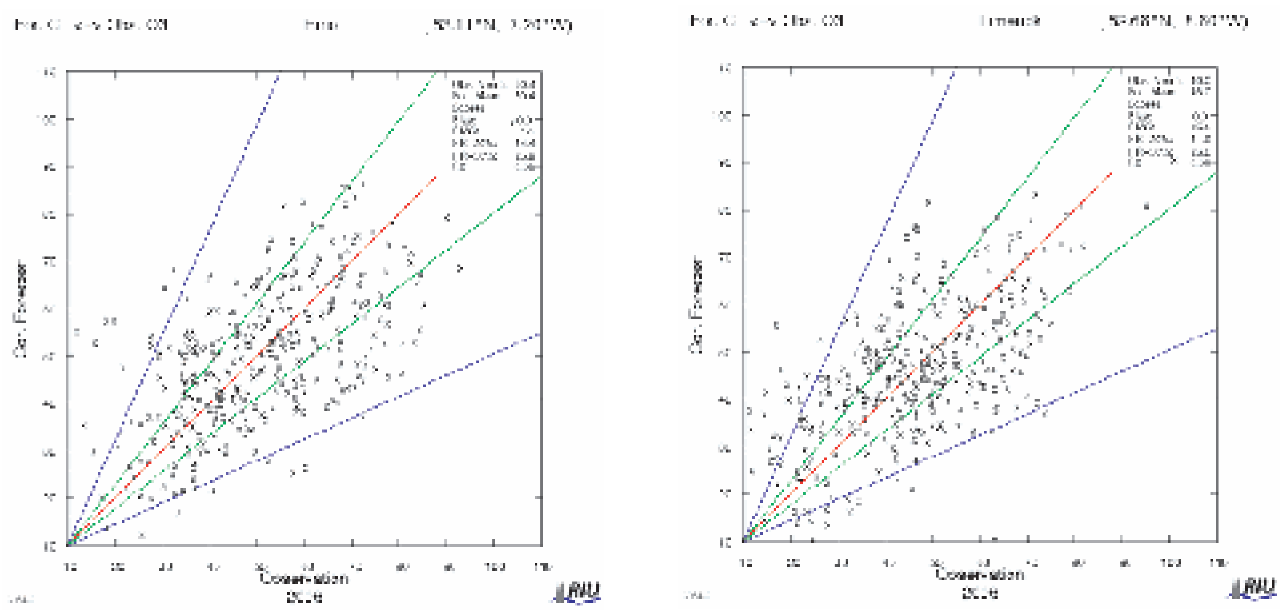


Figure 7.4. EURAD Irish air quality forecast: comparison between forecast and observed values for ozone (O_3) at the Emo Court (left) and Limerick (right) stations for 2006.

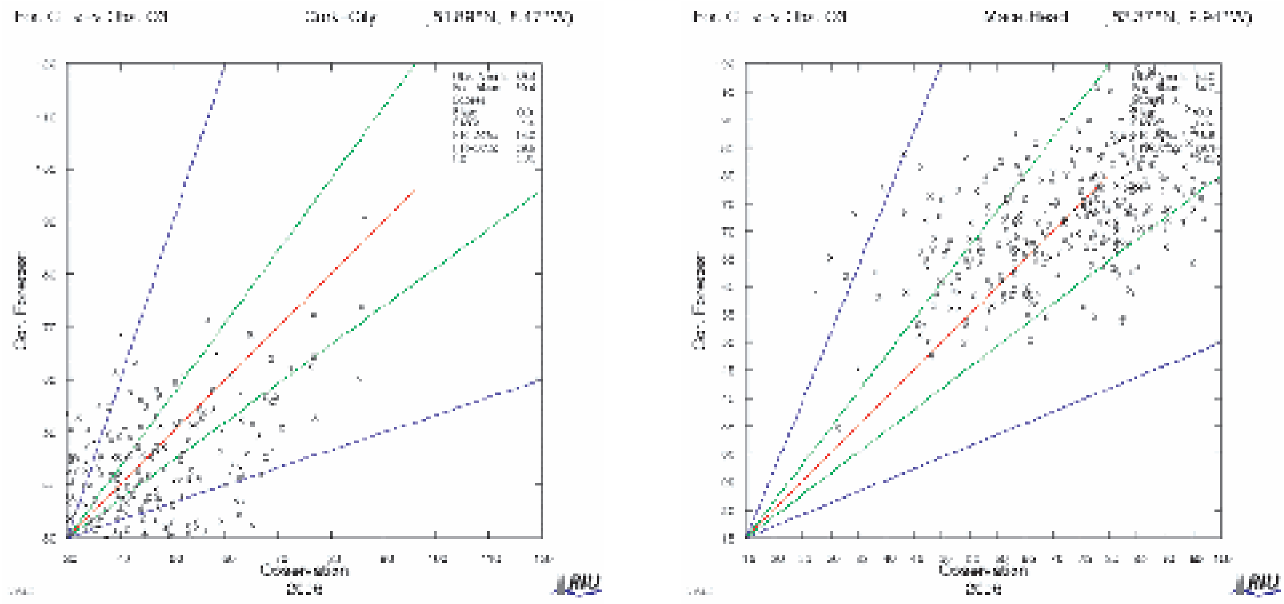


Figure 7.5. EURAD Irish air quality forecast: comparison between forecast and observed values for ozone (O_3) at the Cork City (left) and Mace Head (right) stations for 2006.

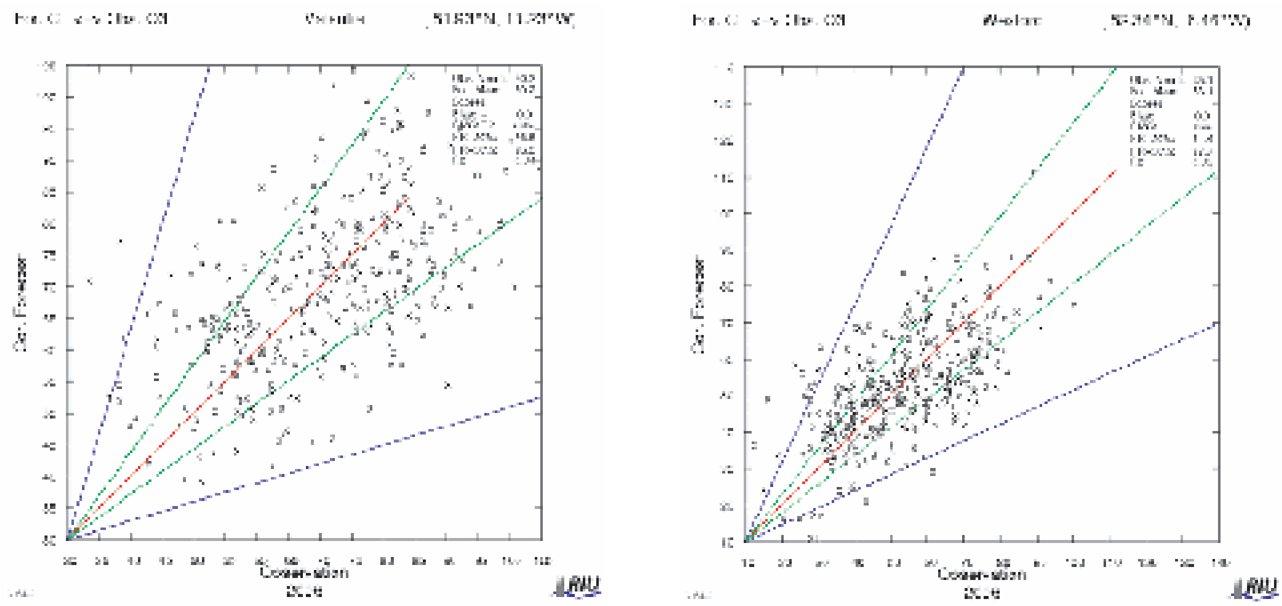


Figure 7.6. EURAD Irish air quality forecast: comparison between forecast and observed values for ozone (O_3) at the Valentia (left) and Wexford (right) stations for 2006.

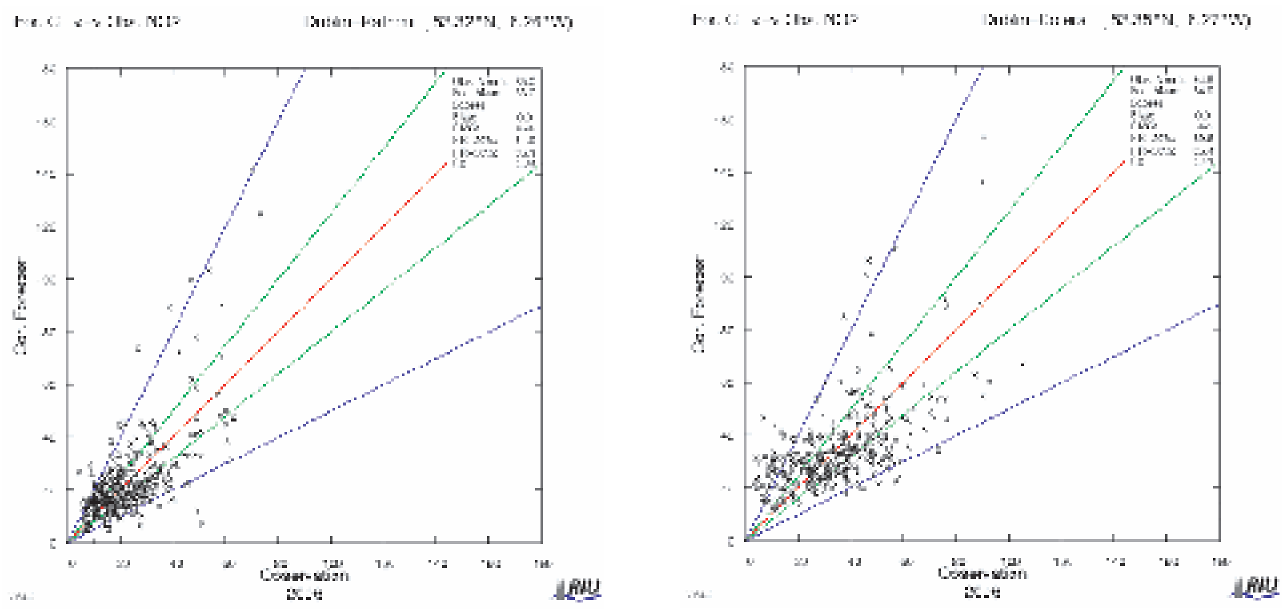


Figure 7.7. EURAD Irish air quality forecast: comparison between corrected forecast and observed values for nitrogen dioxide (NO_2) at the Dublin Rathmines (left) and Dublin Coleraine St (right) stations for 2006.

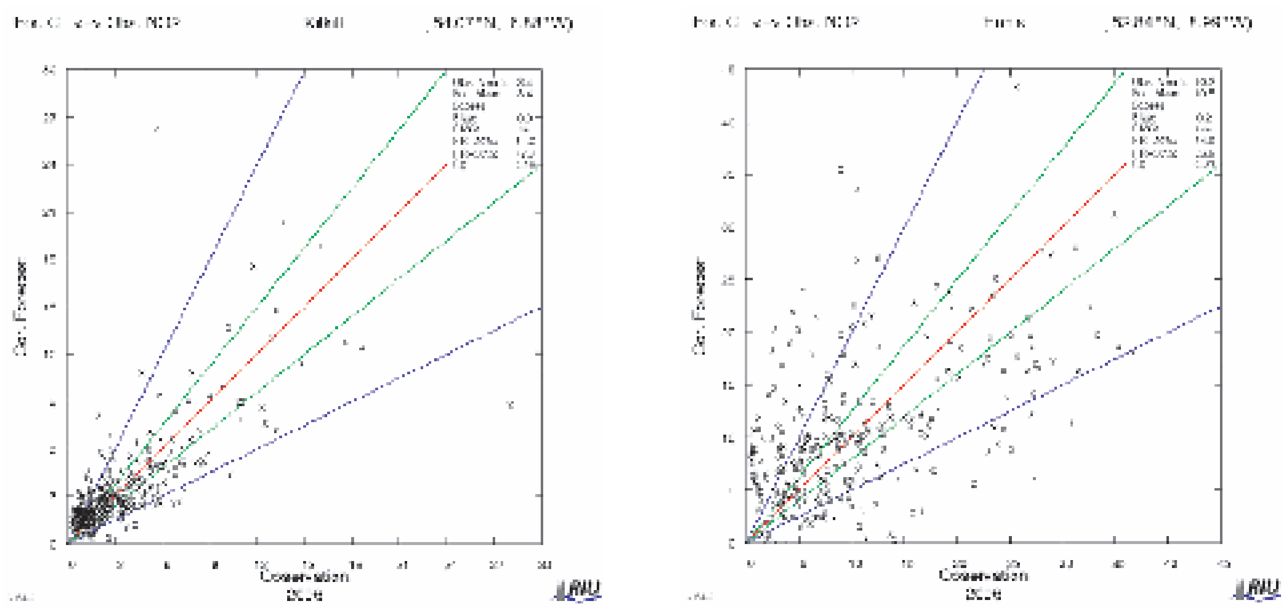


Figure 7.8. EURAD Irish air quality forecast: Comparison between forecast and observed values for nitrogen dioxide (NO_2) at the Kilkitt (left) and Ennis (right) stations for 2006.

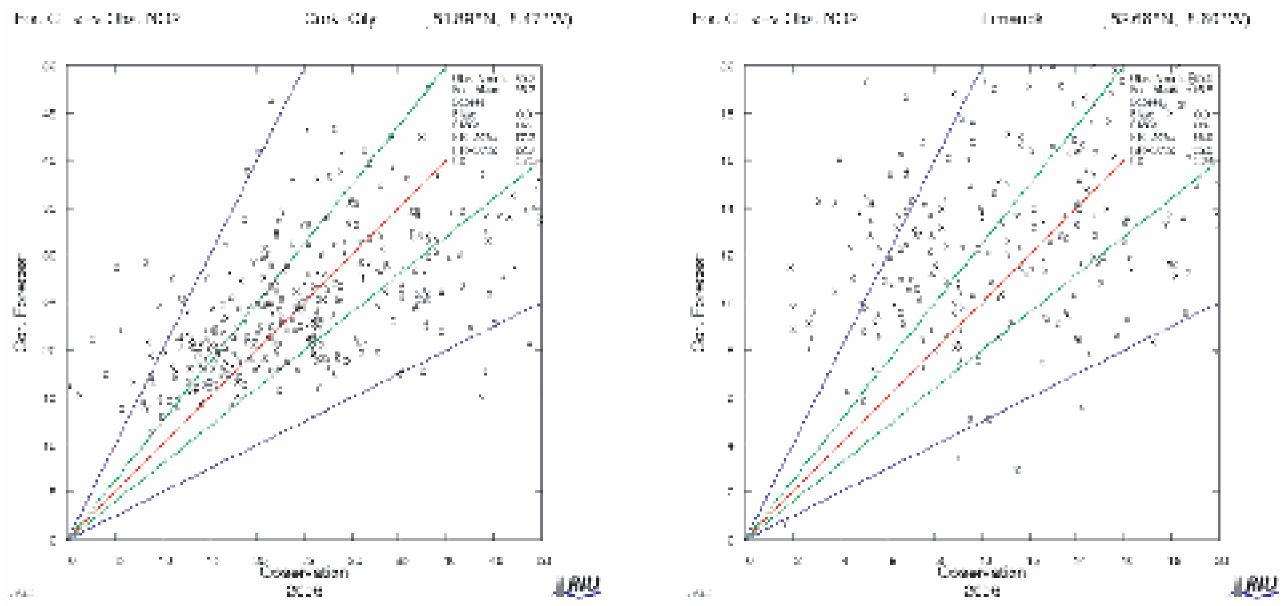


Figure 7.9. EURAD Irish air quality forecast: comparison between forecast and observed values for nitrogen dioxide (NO_2) at the Cork City (left) and Limerick (right) stations for 2006.

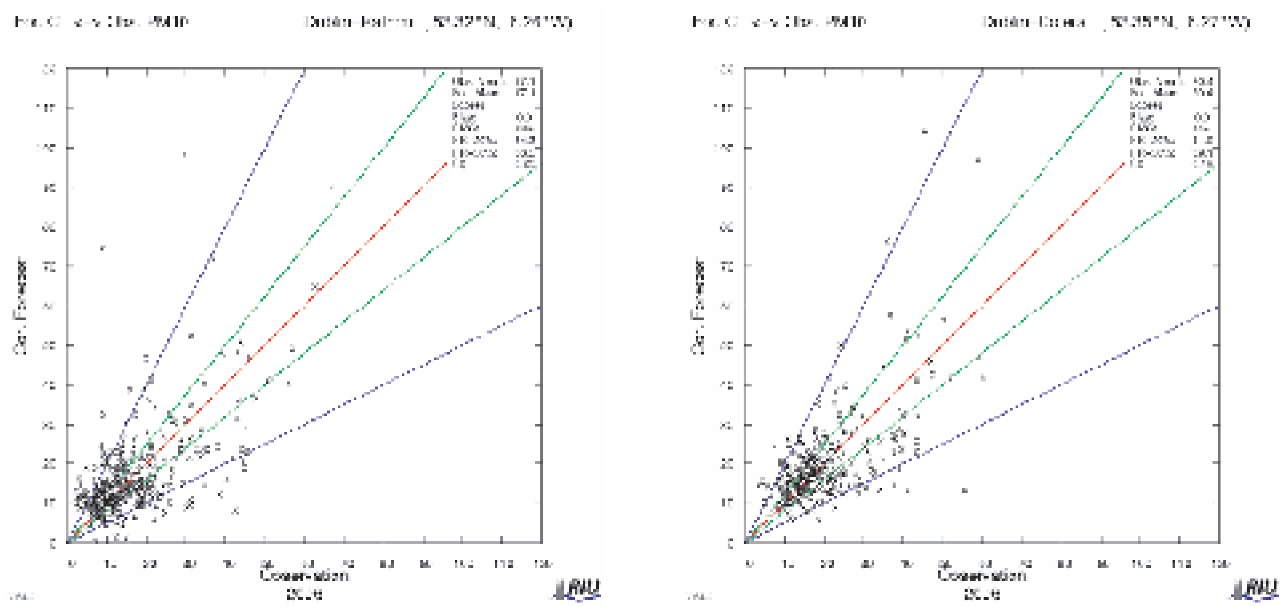


Figure 7.10. EURAD Irish air quality forecast: comparison between forecast and observed values for particulate matter ≤10 µm (PM_{10}) at the Dublin Rathmines (left) and Dublin Coleraine St (right) stations for 2006.

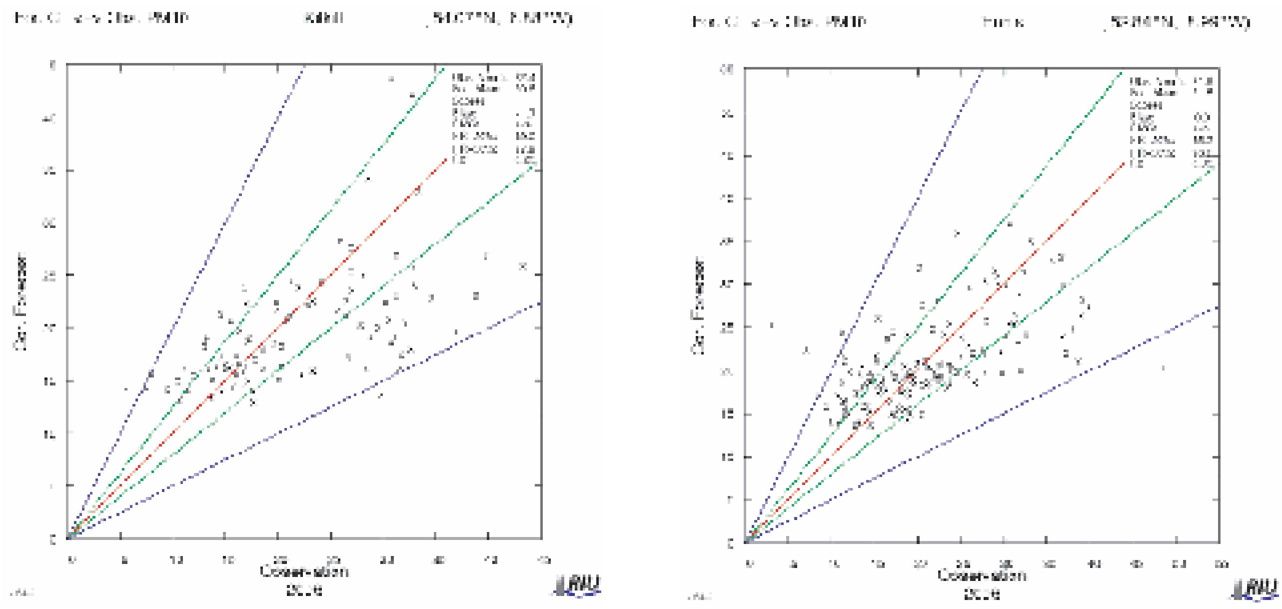


Figure 7.11. EURAD Irish air quality forecast: comparison between forecast and observed values for particulate matter ≤10 µm (PM_{10}) at the Kilkitt (left) and Ennis (right) stations for 2006.

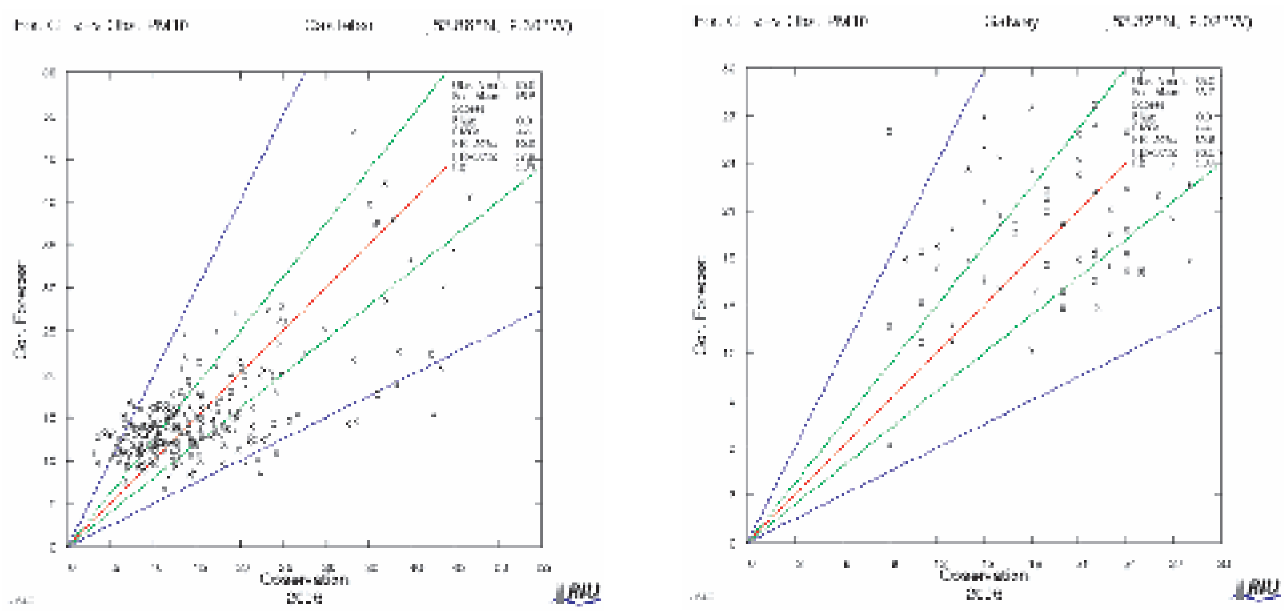


Figure 7.12. EURAD Irish air quality forecast: comparison between forecast and observed values for particulate matter ≤10 µm (PM_{10}) at the Castlebar (left) and Galway (right) stations for 2006.

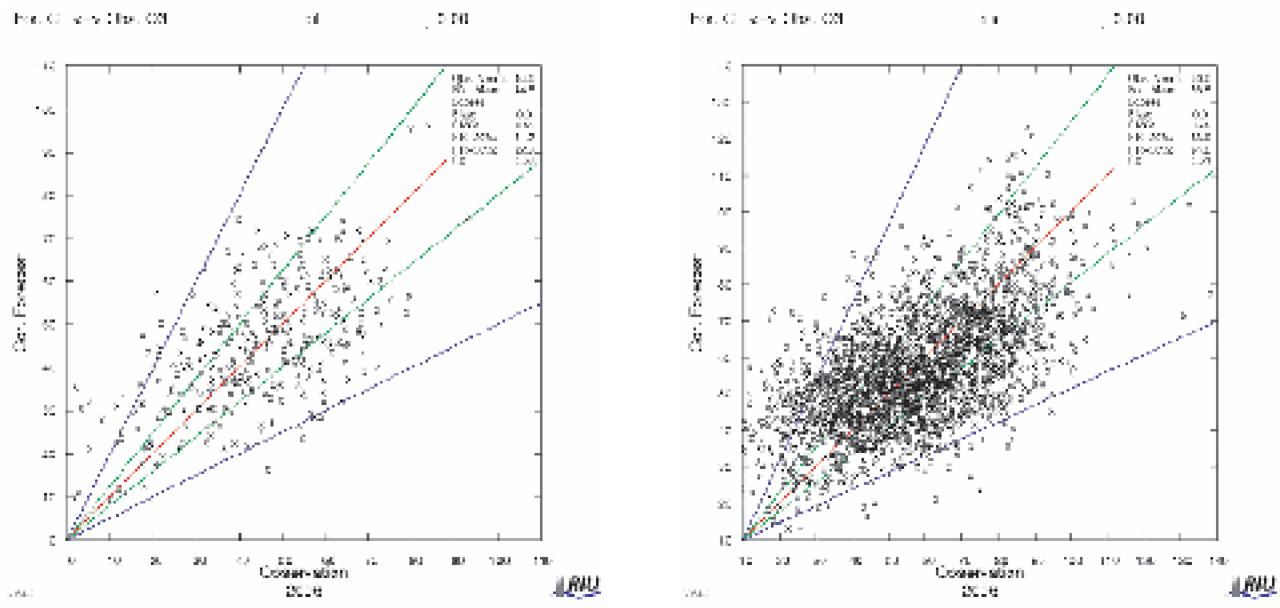


Figure 7.13. EURAD Irish air quality forecast: comparison between forecast and observed values for ozone (O_3) at the urban (left) and rural (right) stations for 2006.

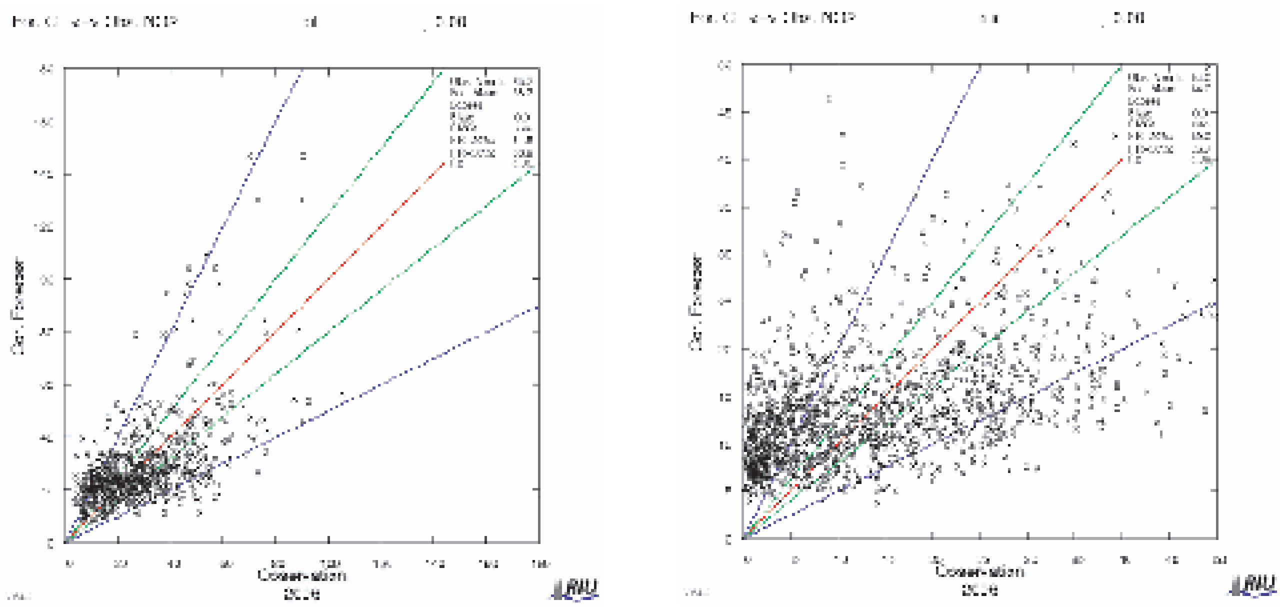


Figure 7.14. EURAD Irish air quality forecast: comparison between forecast and observed values for nitrogen dioxide (NO_2) at the urban (left) and rural (right) stations for 2006.

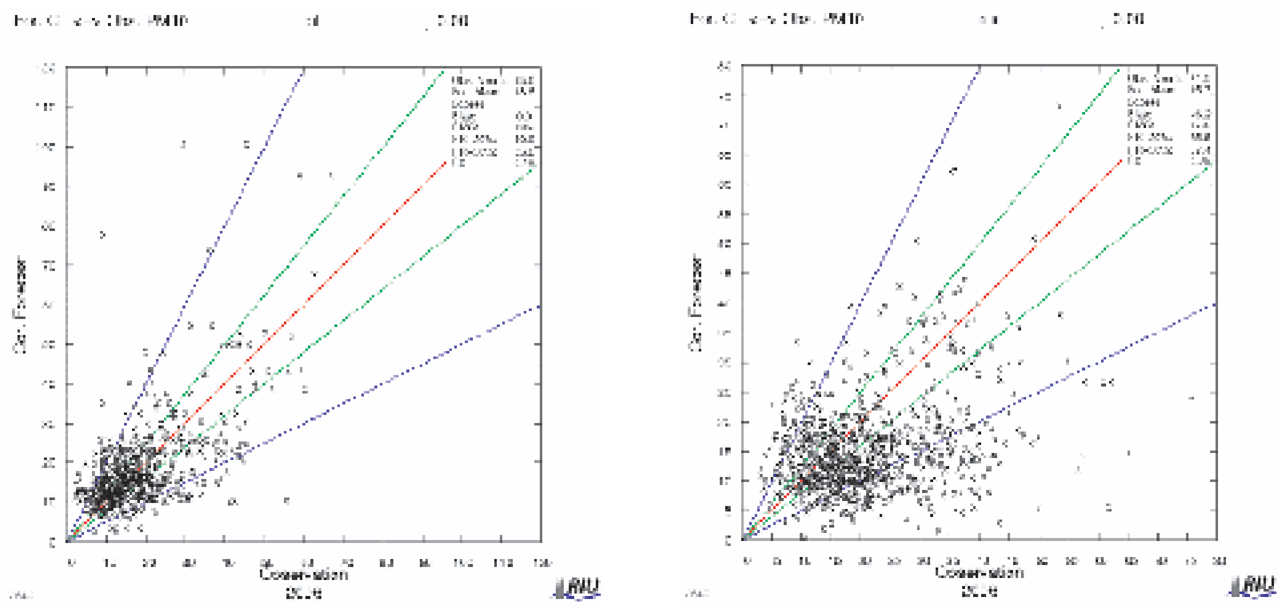


Figure 7.15. EURAD Irish air quality forecast: comparison between forecast and observed values for particulate matter ≤10 µm (PM_{10}) at the urban (left) and rural (right) stations for 2006.

As seen in these figures, the performance of the model output increases significantly for all three selected forecasted products. Table 7.2 summarises all the scores for the corrected forecast at all stations and for the combined urban and rural stations. A substantial improvement in the forecast values is seen for NO_2 and, in particular, for the rural sites PM_{10} values. This is particularly clear regarding the hit rates.

In order to compare directly the improvement of the forecast via MOS, in Table 7.3 the hit rates for the forecasted are opposed to the MOS supported forecast.

7.3 Yearly Analysis with MOS Support

The model output statistic algorithm delivers regression coefficients for rural and urban regions, respectively. Thus, these coefficients can be applied to correct the raw forecast data for the whole D03 domain for 2006. On each grid point the correction term was calculated according to the land-use type in the model, whether rural or urban type is dominating in the grid cell. The correction term is then applied at each near-surface grid cell for each hour in the year. Thus, new yearly maxima, yearly means and exceedances were calculated for O_3, NO_2 and PM_{10}. Figures 7.16–7.26 show these improved analyses for 2006. In order to compare directly the discrepancies between the raw data (or DMO) analysis with the analysis supported by MOS, both approaches are shown in the figures. As seen in the statistics for the stations, the greatest differences can be seen within the analysis of the NO_2 and PM_{10} concentrations. In particular, a remarkable increase in the PM_{10} background concentrations is evident. This may be due to the absence of sea-salt parameterisation within the DMO of the raw forecast data set.

Table 7.2. Scores of the model output statistics (MOS)-corrected forecast performance.

Station	Bias (µg/m³)	HR_{20} (%)	HR_{50} (%)	R^2
O_3				
Dublin Rathmines	0.0	51.7	92.7	0.57
Kilkitt	0.0	65.1	96.5	0.47
Emo Court	0.0	54.4	95.9	0.52
Limerick	0.0	51.9	93.6	0.59
Cork City	0.0	44.0	89.2	0.38
Mace Head	0.0	78.8	99.1	0.23
Valentia	0.0	76.8	98.0	0.34
Wexford	0.0	61.4	97.7	0.33
Urban sites	**0.0**	**51.7**	**92.7**	**0.57**
Rural sites	**0.0**	**53.9**	**94.6**	**0.51**
NO_2				
Dublin Rathmines	0.0	31.9	88.1	0.34
Dublin Coleraine St	0.0	39.6	85.4	0.41
Kilkitt	0.0	31.0	77.6	0.19
Ennis	0.0	24.9	63.2	0.61
Cork City	0.0	47.2	92.7	0.75
Limerick	0.0	36.9	85.0	0.84
Urban sites	**0.0**	**31.5**	**80.9**	**0.36**
Rural sites	**0.0**	**19.0**	**53.7**	**0.39**
PM_{10}				
Dublin Rathmines	0.0	34.3	80.8	0.20
Dublin Coleraine St	0.0	41.9	89.1	0.19
Kilkitt	0.0	49.0	97.9	0.20
Ennis	0.0	55.2	96.6	0.30
Castlebar	0.0	40.9	87.9	0.31
Galway	0.0	52.6	96.8	0.37
Urban sites	**0.0**	**40.9**	**83.6**	**0.19**
Rural sites	**0.0**	**25.6**	**67.4**	**0.32**

Table 7.3. Comparison of the scores (MOS, model output statistics).

Station	Raw forecast		MOS-supported forecast	
	HR_{20} (%)	HR_{50} (%)	HR_{20} (%)	HR_{50} (%)
O_3				
Dublin Rathmines	45.9	91.5	51.7	92.7
Kilkitt	52.3	96.8	65.1	96.5
Emo Court	45.6	95.1	54.4	95.9
Limerick	44.6	88.1	51.9	93.6
Cork City	29.6	72.9	44.0	89.2
Mace Head	60.3	98.8	78.8	99.1
Valentia	66.1	98.0	76.8	98.0
Wexford	41.7	93.9	61.4	97.7
Urban sites	45.9	91.5	51.7	92.7
Rural sites	49.1	92.5	53.9	94.6
NO_2				
Dublin Rathmines	32.5	78.3	31.9	88.1
Dublin Coleraine St	28.5	81.6	39.6	85.4
Kilkitt	32.8	78.0	31.0	77.6
Ennis	19.3	56.8	24.9	63.2
Cork City	5.2	21.3	47.2	92.7
Limerick	2.1	13.3	36.9	85.0
Urban sites	30.6	79.9	31.5	80.9
Rural sites	14.4	41.2	19.0	53.7
PM_{10}				
Dublin Rathmines	27.0	69.8	34.3	80.8
Dublin Coleraine St	28.5	77.2	41.9	89.1
Kilkitt	3.1	6.3	49.0	97.9
Ennis	1.4	7.6	55.2	96.6
Castlebar	1.2	8.6	40.9	87.9
Galway	6.3	14.7	52.6	96.8
Urban sites	27.7	73.2	40.9	83.6
Rural sites	2.5	8.5	25.6	67.4

Green shading: <10% improvement; yellow shading: >10% and ≤20% improvement; all other values: no improvement.

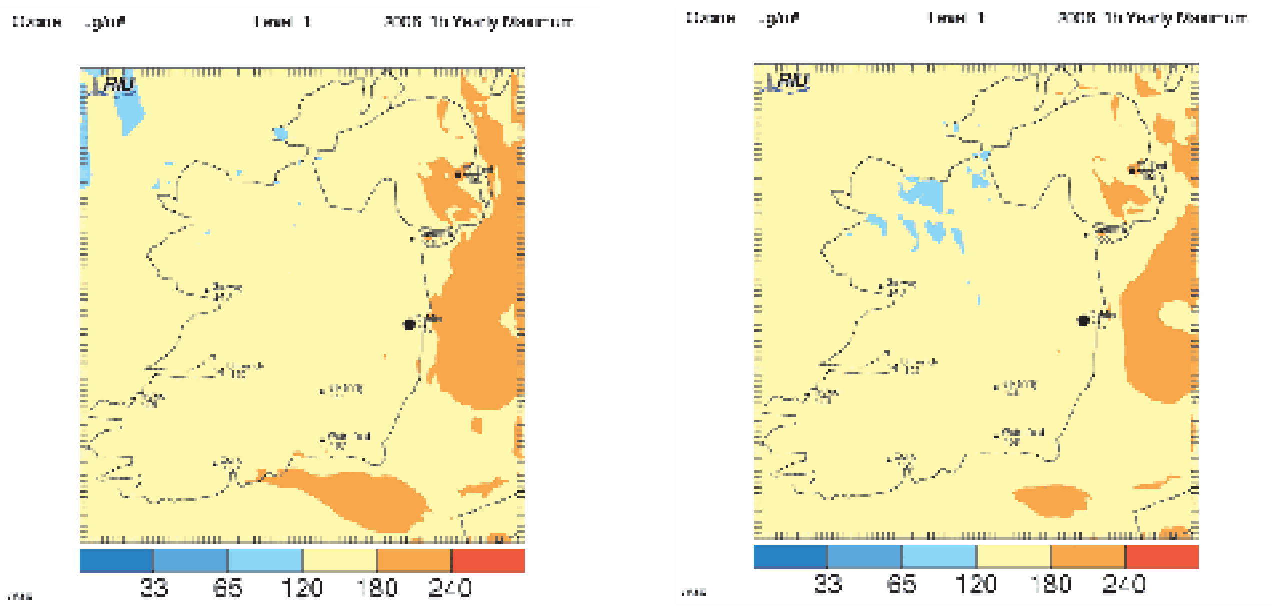


Figure 7.16. Air quality forecast analysis: 1-h yearly maximum of ozone (O_3) for the raw forecast (left) and for the model output statistics (MOS)-supported forecast (right) for 2006.

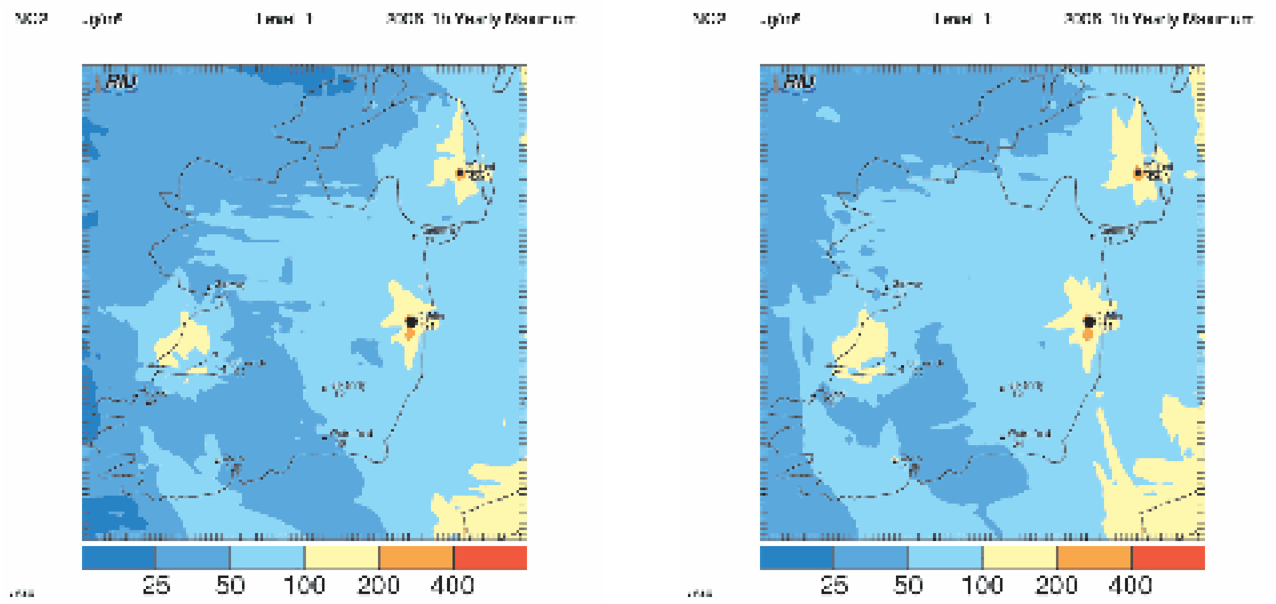


Figure 7.17. Air quality forecast analysis: 1-h yearly maximum of nitrogen dioxide (NO_2) for the raw forecast (left) and for the model output statistics (MOS)-supported forecast (right) for 2006.

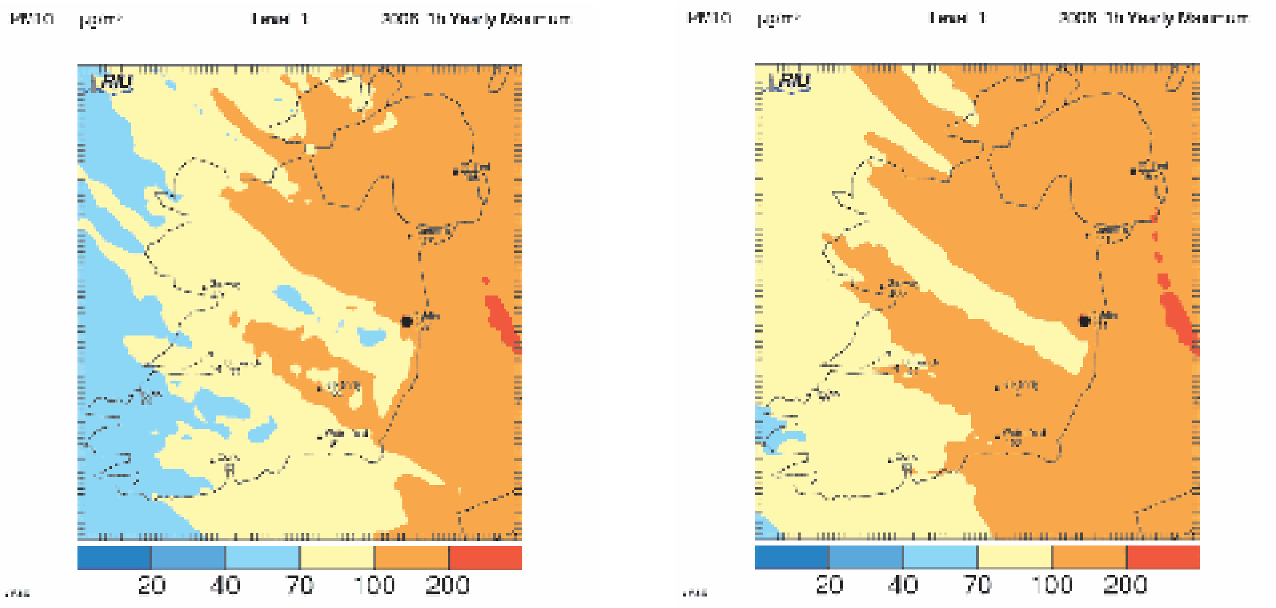


Figure 7.18. Air quality forecast analysis: 1-h yearly mean maximum of particulate matter ≤10 µm (PM_{10}) for the raw forecast (left) and for the model output statistics (MOS)-supported forecast (right) for 2006.

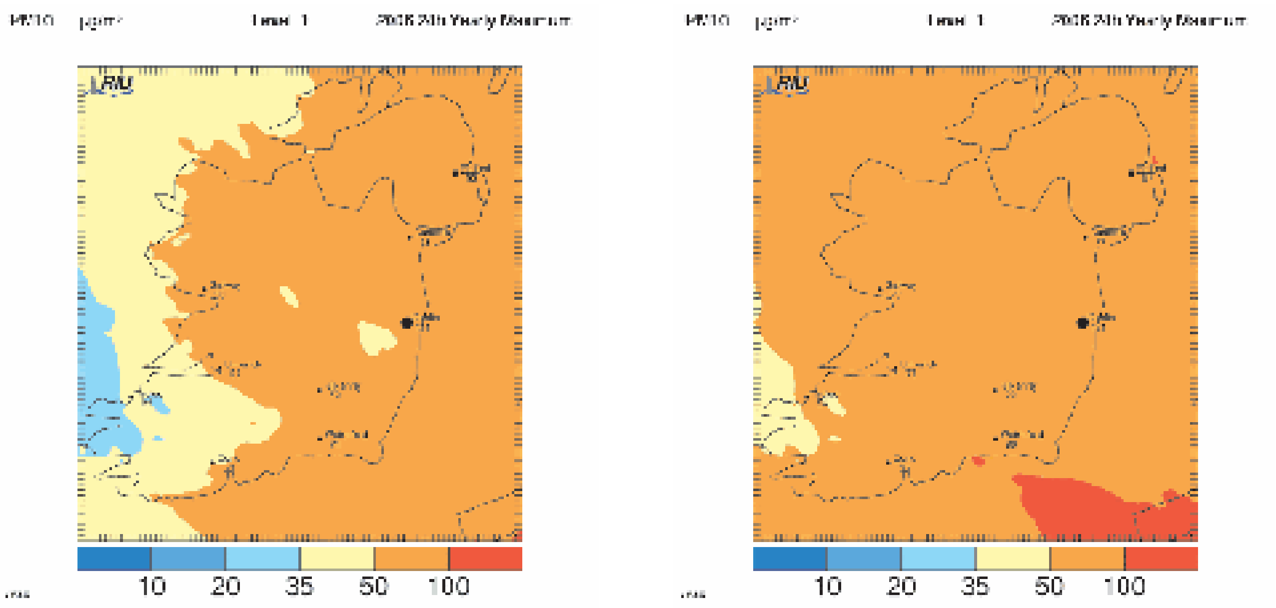


Figure 7.19. Air quality forecast analysis: 24-h yearly mean maximum of particulate matter ≤10 µm (PM_{10}) for the raw forecast (left) and for the model output statistics (MOS)-supported forecast (right) for 2006.

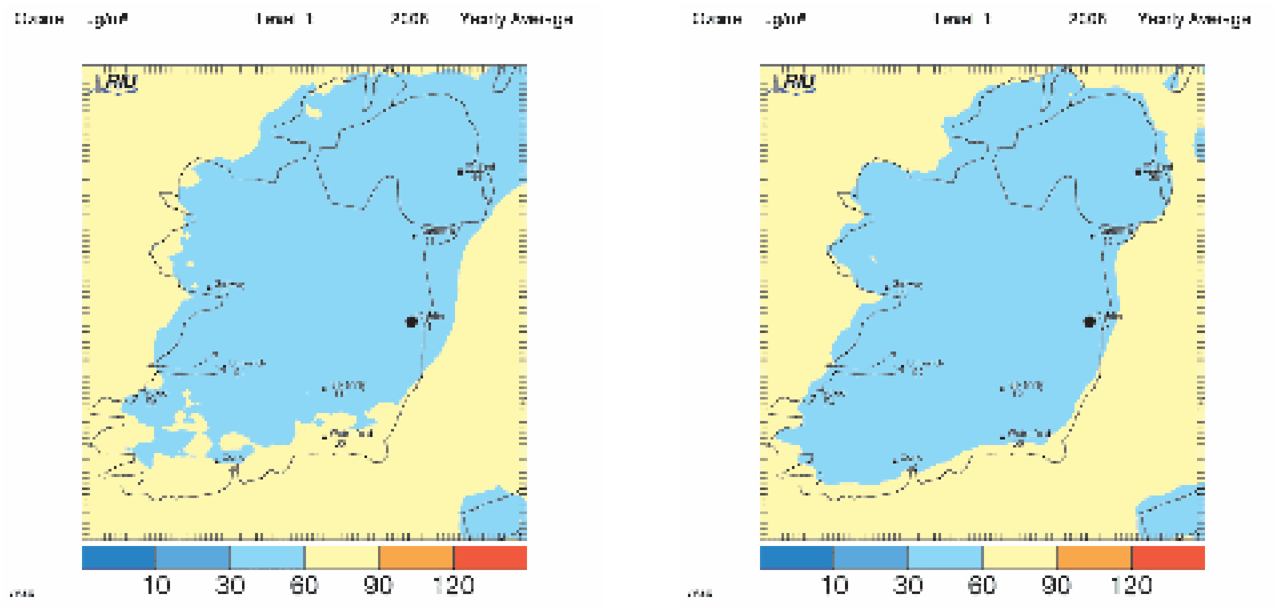


Figure 7.20. Air quality forecast analysis: yearly average of ozone (O_3) for the raw forecast (left) and for the model output statistics (MOS)-supported forecast (right) for 2006.

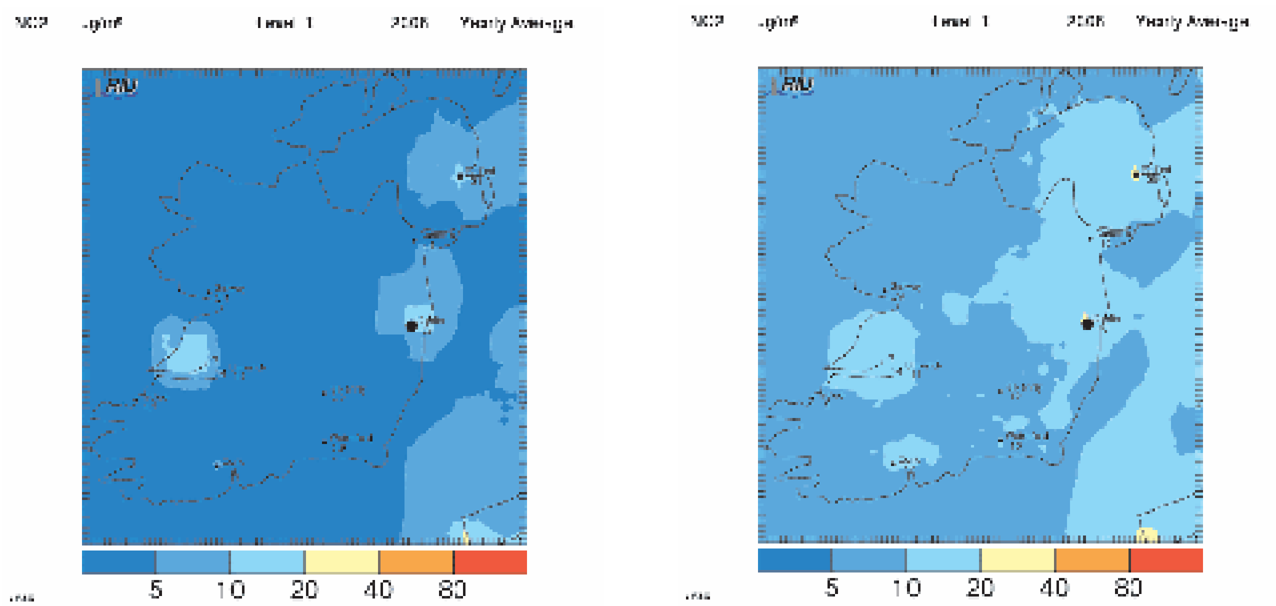


Figure 7.21. Air quality forecast analysis: yearly average of nitrogen dioxide (NO_2) for the raw forecast (left) and for the model output statistics (MOS)-supported forecast (right) for 2006.

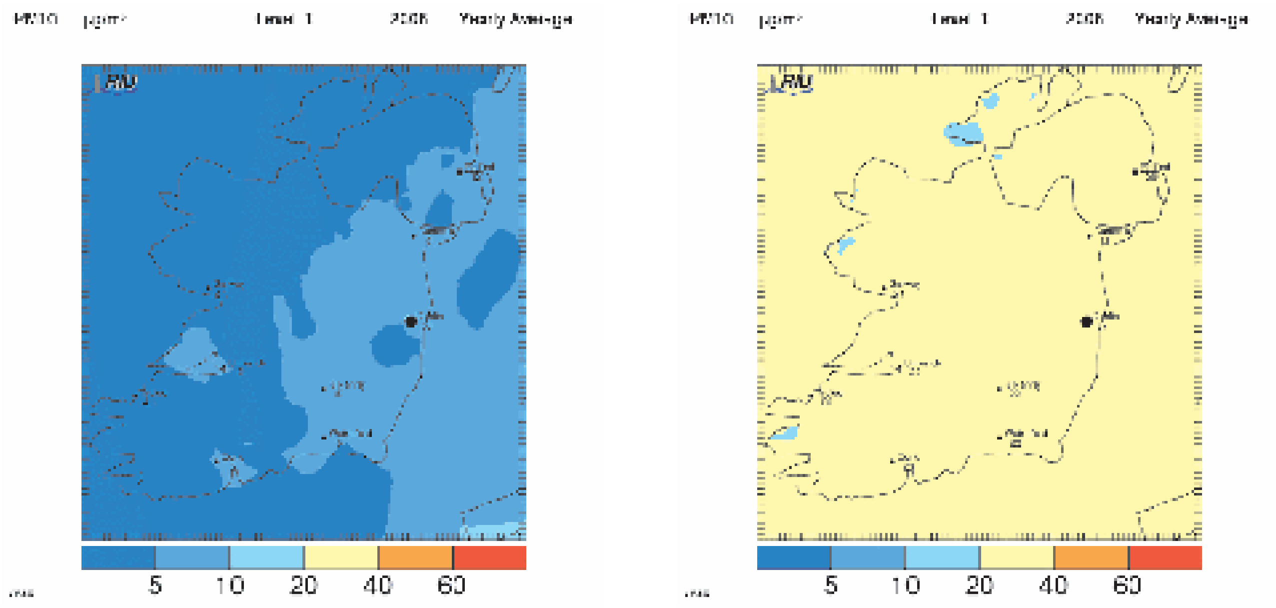


Figure 7.22. Air quality forecast analysis: yearly average of particulate matter ≤10 µm (PM_{10}) for the raw forecast (left) and for the model output statistics (MOS)-supported forecast (right) for 2006.

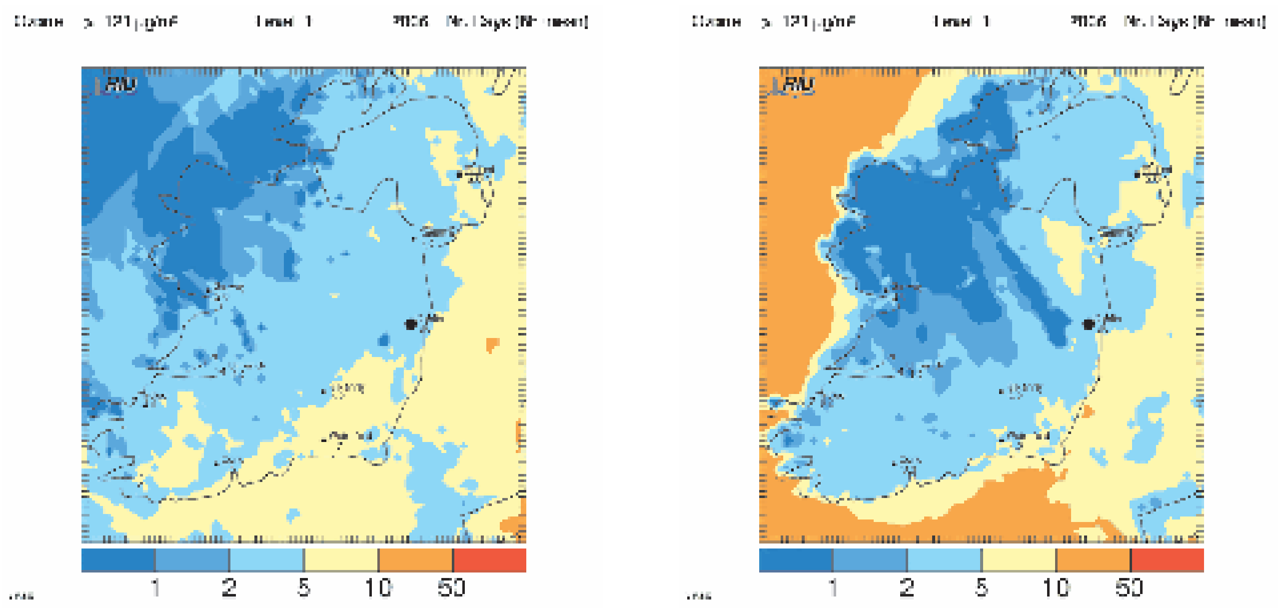


Figure 7.23. Air quality forecast analysis: number of days where the maximum 8-h mean of ozone (O_3) exceeds 120 µg/m³ for the raw forecast (left) and for the model output statistics (MOS)-supported forecast (right) for 2006.

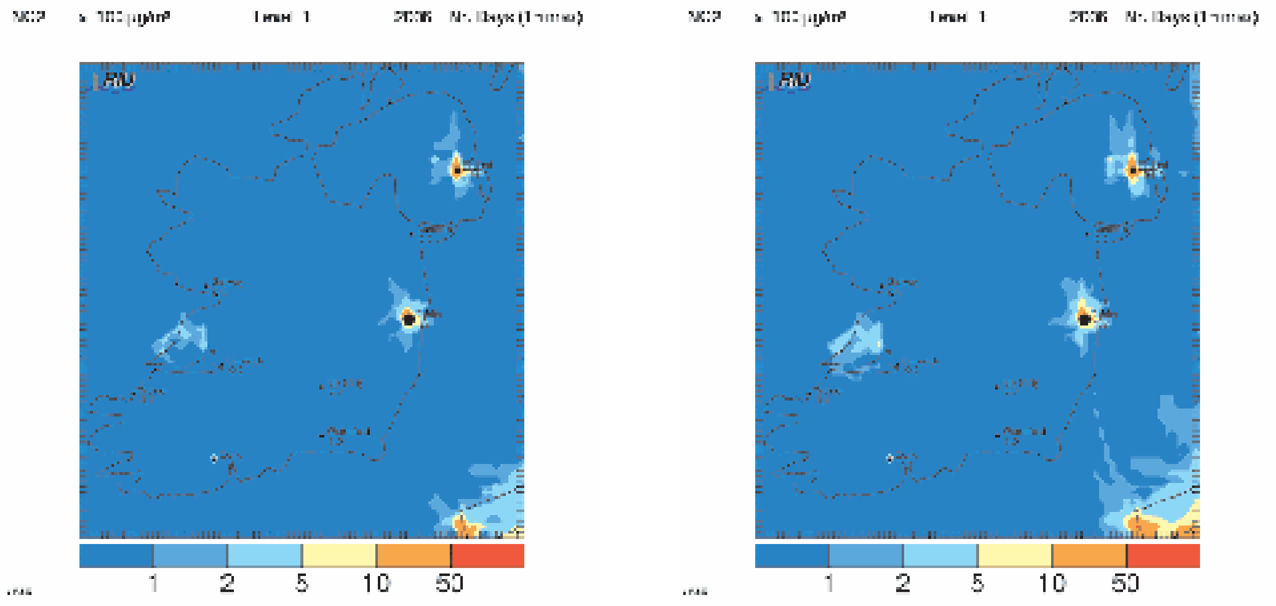


Figure 7.24. Air quality forecast analysis: number of days where the maximum 1-h mean of nitrogen dioxide (NO_2) exceeds 100 µg/m³ for the raw forecast (left) and for the model output statistics (MOS)-supported forecast (right) for 2006.

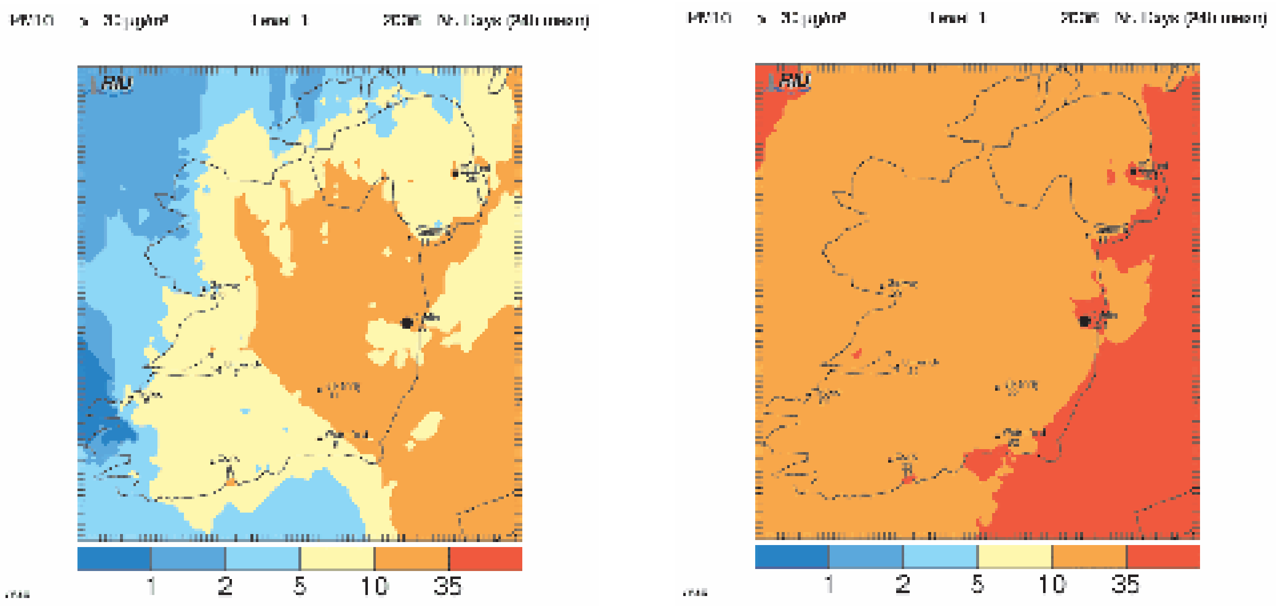


Figure 7.25. Air quality forecast analysis: number of days where the maximum 24-h mean of particulate matter ≤10 µm (PM_{10}) exceeds 30 µg/m³ for the raw forecast (left) and for the model output statistics (MOS)-supported forecast (right) for 2006.

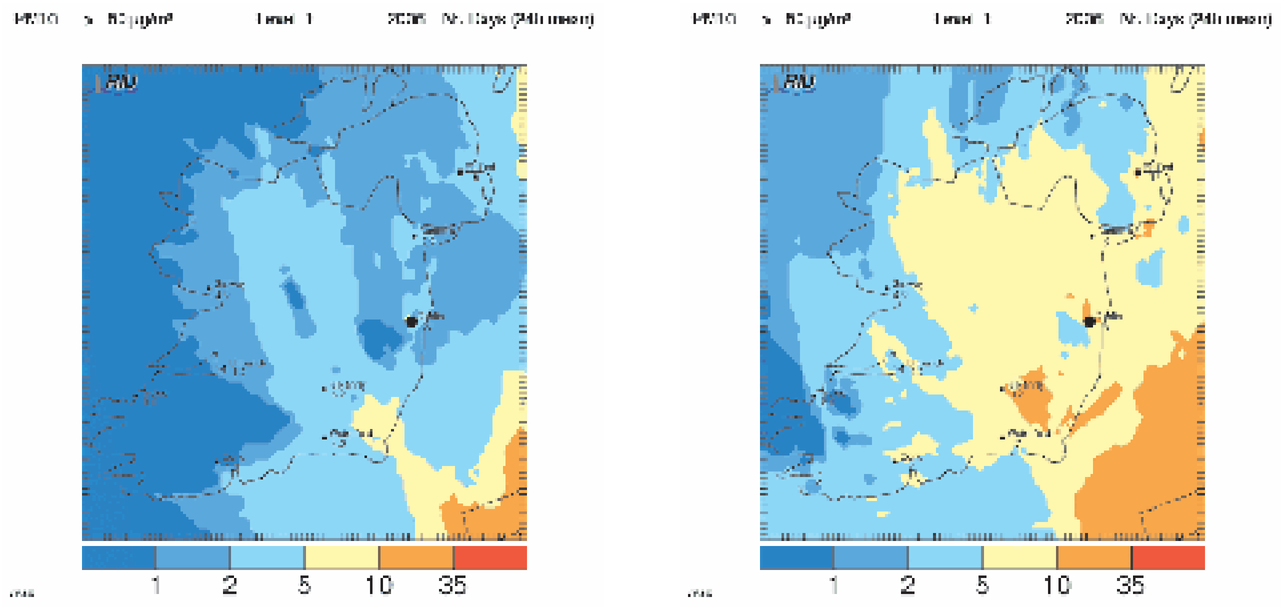


Figure 7.26. Air quality forecast analysis: number of days where the maximum 24-h mean of particulate matter ≤10 µm (PM_{10}) exceeds 50 µg/m³ for the raw forecast (left) and for the model output statistics (MOS)-supported forecast (right) for 2006.

7.4 MOS *vs* Two-Dimensional Variational Data Assimilation

Since the outcome of the MOS technique is applied to each grid cell within the model domain, one can find a homogeneous distribution of the corrected concentration fields for the whole domain. The distribution of the delivered observational data sets is relatively sparse for the stations.

The two-dimensional variational data assimilation approach is used within the regular RIU forecast for Germany and the German State Northrhine–Westfalia. A data set of more than 300 observational stations is available every hour for the German domain. Thus, a two-dimensional variational data assimilation is applied every day for the validation of the regular forecast over Germany. This approach was also tested for the Irish air quality forecast at selected days within 2006. Figures 7.27–7.32 demonstrate the differences between the raw forecast, the two-dimensional variational data assimilation approach and the MOS-supported forecast for selected species on selected days. The figures clarify that the two-dimensional variational data assimilation approach has little impact on the raw forecast data, whereas the MOS-supported approach delivers a more homogeneous and more likely distribution for the mentioned constituents, which are much closer to observational data. The distribution of the observation locations is not dense enough that the radius of influence of the observations could affect the background values.

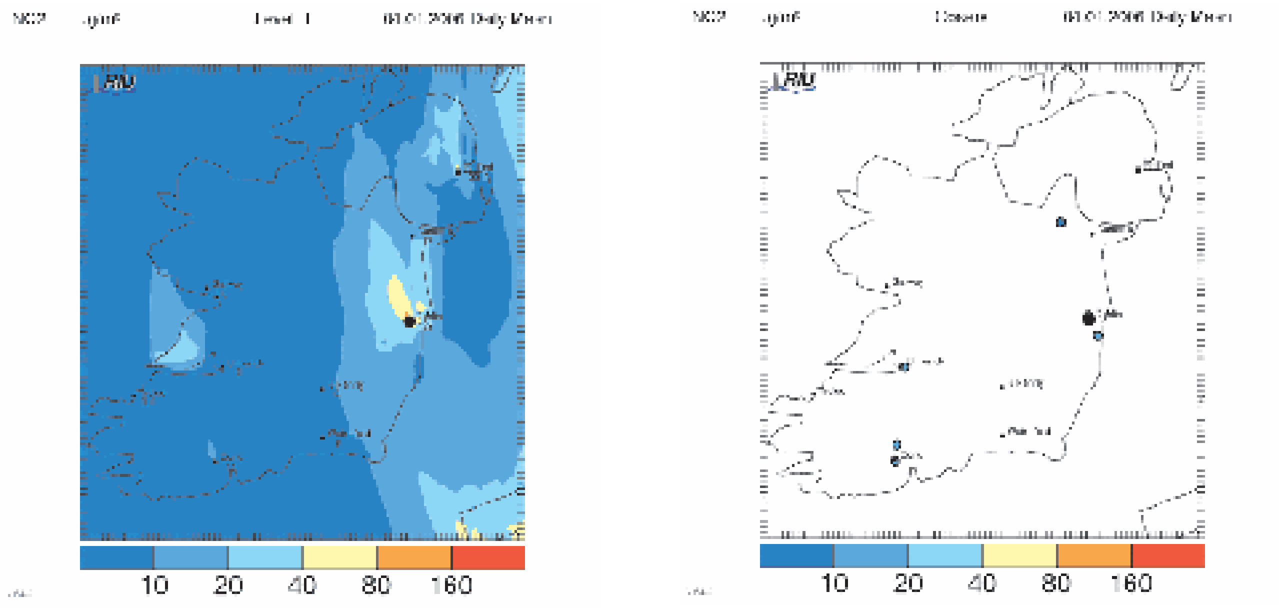


Figure 7.27. Air quality forecast analysis: daily mean for nitrogen dioxide (NO_2) on 4 January 2006 for the raw forecast (left) and for the station measurements (right).

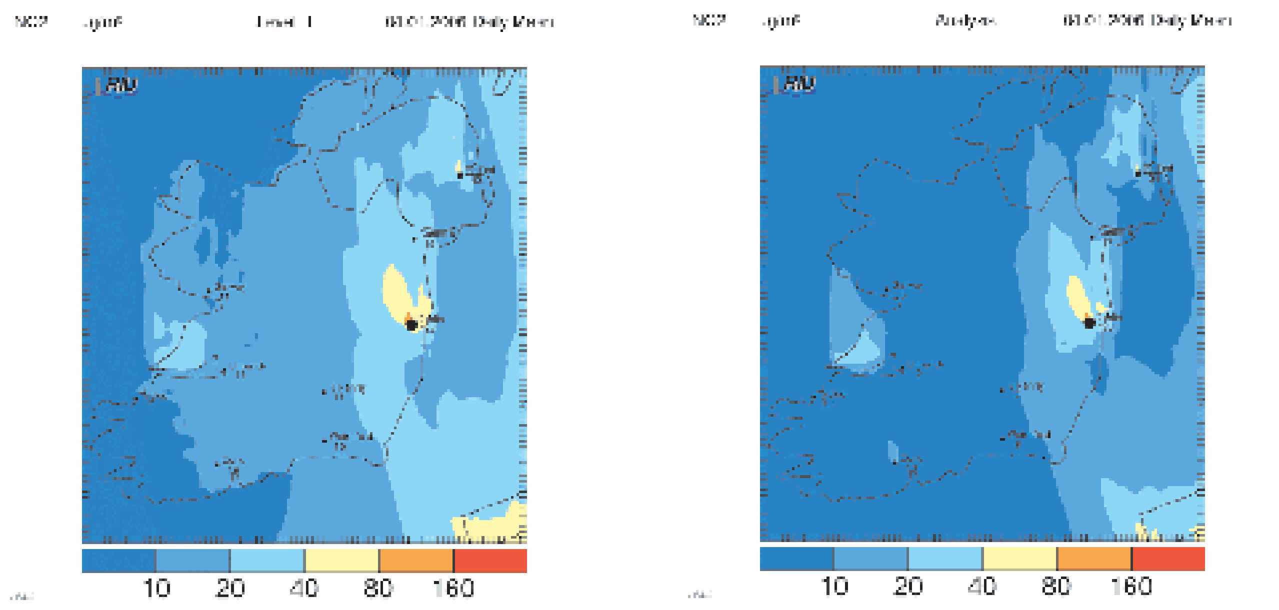


Figure 7.28. Air quality forecast analysis: daily mean for nitrogen dioxide (NO_2) on 4 January 2006 for the MOS supported forecast (left) and for the two-dimensional variational data assimilation analysis (right).

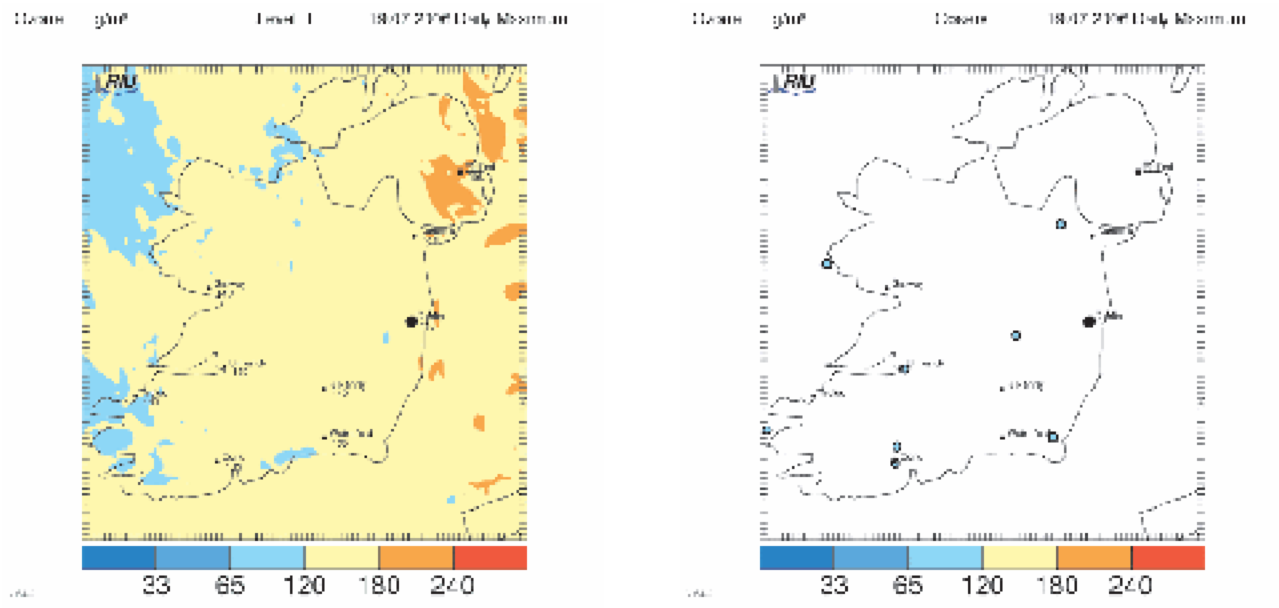


Figure 7.29. Air quality forecast analysis: daily maximum for ozone (O_3) on 19 July 2006 for the raw forecast (left) and for the station measurements (right).

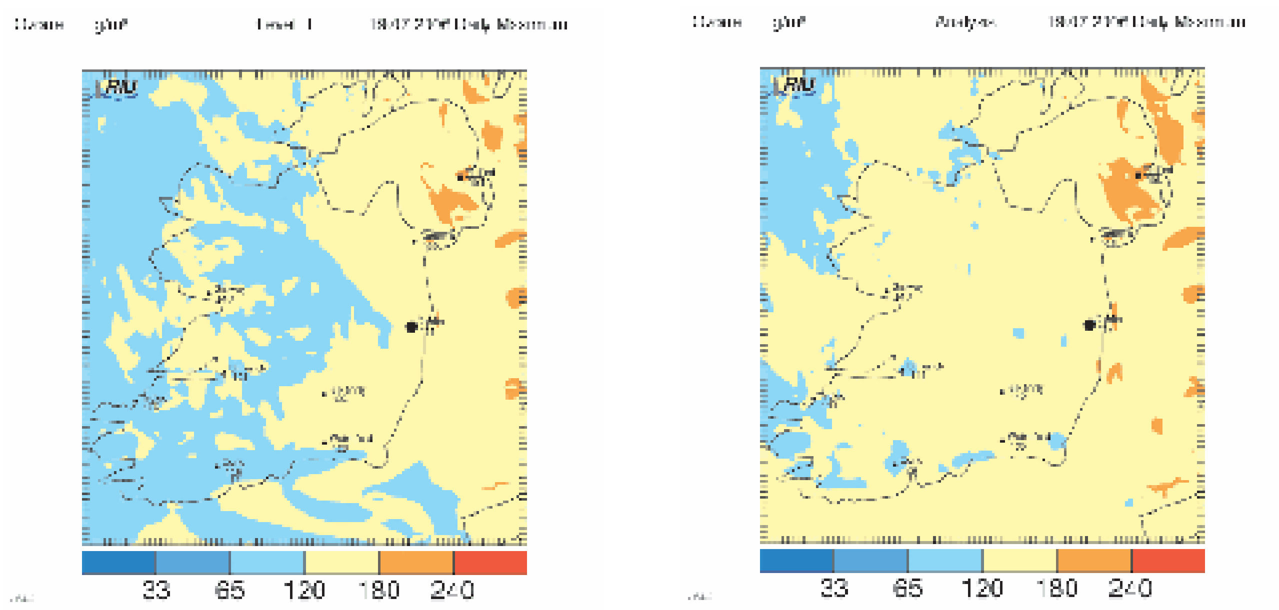


Figure 7.30. Air quality forecast analysis: daily maximum for ozone (O_3) on 19 July 2006 for the MOS-supported forecast (left) and for the two-dimensional variational data assimilation analysis (right).

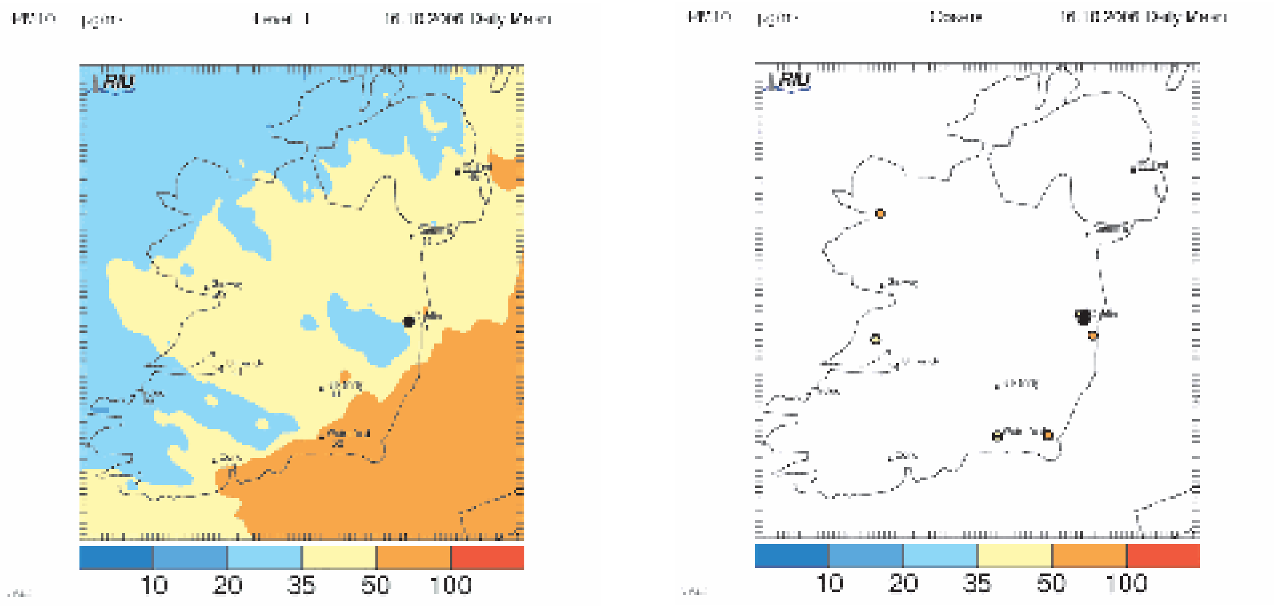


Figure 7.31. Air quality forecast analysis: daily mean for particulate matter ≤10 µm (PM_{10}) on 16 October 2006 for the raw forecast (left) and for the station measurements (right).

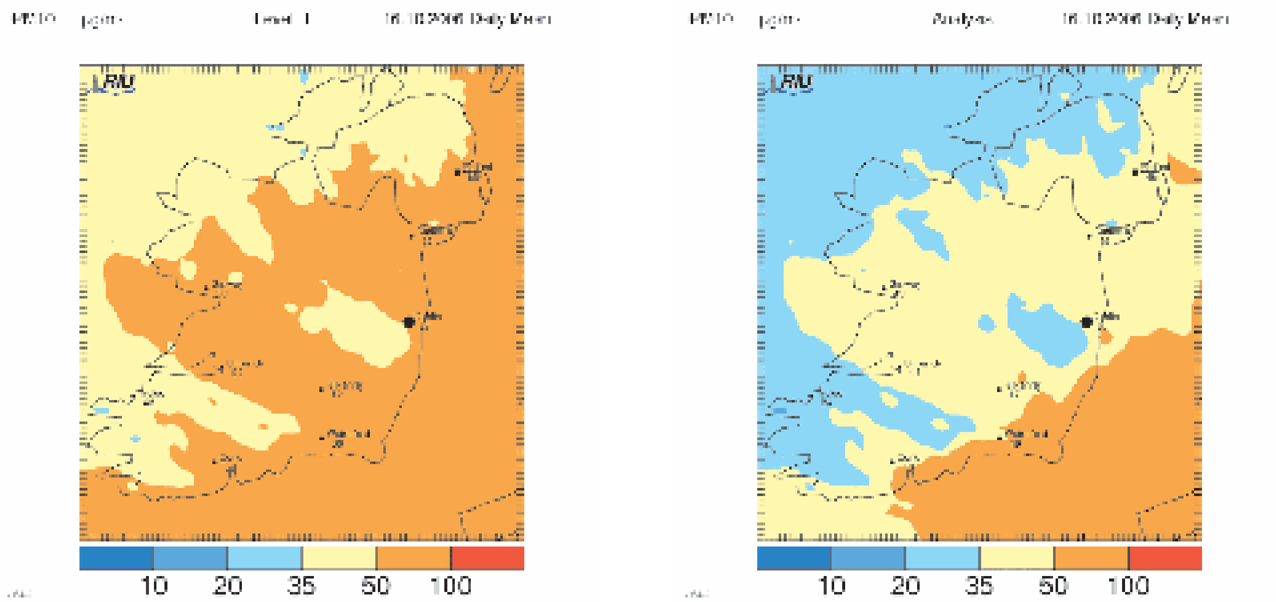


Figure 7.32. Air quality forecast analysis: daily mean for particulate matter ≤10 µm (PM_{10}) on 16 October 2006 for the MOS-supported forecast (left) and for the two-dimensional variational data assimilation analysis (right).

8 Conclusions and Outlook

The EURAD Irish air quality forecast system has been successfully implemented and is operational. An extended emission inventory for the selected model configuration was created to serve as input for the forecast system. After a test phase of several weeks, the forecast system has proved to be stable for the years 2005, 2006 and 2007 and still produces a significant amount of data on the main predicted atmospheric pollutants.

An intensive validation process was performed for 2006, taking into account observational data for the main species.

An MOS-based multivariate linear regression via meteorological parameters was implemented to identify systematic deficiencies of the forecast and observational system. After evaluation of the observational data, the MOS technique provided a correction term for selected stations and, by separation into two classes (urban and rural), it provides correction terms on each grid point of the model domain.

The results of this MOS-supported forecast are promising in terms of getting a more realistic general forecast, which becomes much closer to observational data.

Thus, the Irish air quality forecast system with the EURAD model could be a good tool for air quality assessment strategies and policy making.

For future studies, the air quality forecast system could be improved by implementing sea-salt parameterisations, which is essential for air quality forecasting of PM_{10} within the island of Ireland. The MOS should then be recalculated and improved for each additional option within the forecast system. In addition, the MOS technique could be extended to examine additional parameters which could be important for the understanding of typical deficiencies of direct model output.

National Development Plan 2007 - 2013

The EPA's Environmental Research Centre (ERC) was established as a centre of excellence under the National Development Plan (NDP) to build capacity in environmental data handling, modelling, assessment and guidance. The objective of the ERC is to allow for a more structured approach to environmental research, through the development of advanced innovative techniques and systems to address priority environmental issues and thereby support environmentally sustainable development.

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