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New meteorological model for air pollution transport models

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Preface and acknowledgements

This note was prepared for the twenty third session of the Steering Body of EMEP (Co-operative programme for monitoring and evaluation of the long range transmission of air pollutants in Europe). It presents the new dedicated meteorological model (PARLAM-PS) for use by the EMEP/MSC-W air pollution dispersion models. The new meteorological model is based on the HIRLAM/PARLAM numerical weather forecast system, operational at the Norwegian Meteorological Institute. This note presents validation of results from PARLAM-PS and compares its performance with that of the previous meteorological models used at MSC-W. PARLAM-PS has been used for the first time this year to prepare 1997 meteorological data input to the EMEP Eulerian acid deposition model. Calculations were carried out on a Cray T3E computer at the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway. We are especially grateful to Jan Erik Haugen and Dag Bjørge and Anstein Foss for their invaluable help in constructing and implementing the PARLAM-PS model. Thanks are also due to our colleagues from the Section for Meteorology of the Research and Development Department at DNMI for their help in the analysis of data verification.

Contents

1. Introduction

Meteorological data is one of the key input parameters to atmospheric dispersion models. Therefore, the accuracy and appropriate spatial and temporal resolution of meteorological fields is crucial for improving the quality of a chemical transport model to simulate dispersion of pollutants in the atmosphere. A number of studies on the effect of meteorological data resolution and parameterization (see e.g. Brandt *et al*. (1998), Nasstrom and Pace (1998)) emphasize the importance of adequate meteorological input for long-transport modelling.

The meteorological input data for EMEP modelling was up to January 1996 taken routinely from the Numerical Weather Prediction (NWP) model at the Norwegian Meteorological Institute (DNMI). From 1985 through 1991 a NWP model version with 150 km horizontal resolution and 10 vertical layers was employed. Between 1991 and 1996 a dedicated 50 km version LAM50E (Limited Area Model 50 km, Europe) with 20 vertical layes used for preparing meteorological data for the MSC-W modelling. Up to 1998, EMEP one-layer Lagrangian models were routinely used for computing long-range transport of acidifying pollution and ozone in Europe. Meteorological fields were then interpolated to 150 km grid employed in the Lagrangian model. In addition to the information from the NWP model, the Lagrangian model made use of analysed mixing height fields based on radiosonde measurements, and analysed observed precipitation fields over most land areas combined with modelled precipitation over sea areas.

In 1996, DNMI introduced the HIRLAM model operationally. HIRLAM forecasting system (HIgh Resolution Limited Area Model) is a Nordic/Dutch/French/Irish/Spanish co-operation on short-range numerical weather prediction. This international collaboration between the European countries is aimed at an efficient and comprehensive research, update and development of the model. From January 1996, a special version of the HIRLAM model, EUROLAM, was introduced at the Norwegian Meteorological Institute for use by the EMEP/MSC-W models. The model uses a rotated latitude-longitude grid with a terrain following hybrid p-σ vertical co-ordinate system. At difference from the operational HIRLAM model, the EUROLAM model has an increased vertical resolution in the boundary layer. EUROLAM has 31 levels in the vertical direction with 10 levels within the boundary layer and a horizontal resolution of 0.5 x 0.5 degrees. The larger model domain and especially its extension toward the east and south-east allowed an extension of the EMEP calculation domain. Thus, the model area of the EMEP Lagrangian acid deposition model was extended in 1996 to include Cyprus, the entire Turkey and the Mediterranean Sea.

However, the EUROLAM model employs a spherical horizontal projection which is different from a polar-stereographic projection used by EMEP. This implies that the meteorological data from the HIRLAM model had to be interpolated to be used in the EMEP models.

In addition to the different horizontal projection, the vertical resolution used EUROLAM and EMEP Eulerian models is also different. EUROLAM is formulated in a hybrid σ-p vertical coordinate, whilst the both EMEP Eulerian acid deposition and photooxidant model uses σ-coordinate. Spatial interpolation of the meteorological fields computed by EUROLAM may give rise to mass conservation errors (Trendberg, K.E.,1991) which can be an important drawback in the Eulerian formulation of EMEP models.

The need for a high quality meteorological input to 3-D transport models initiated in 1998 a new project aimed at creating a new EMEP meteorological data base. This work was carried out in a valuable cooperation with our colleagues at the Section for Meteorology of the Research and Development Department at the DNMI. The parallelized version of the HIRLAM model (PARLAM) was reformulated in the same polar stereographic projection and vertical σ-coordinate as used by the dispersion models. The new dedicated meteorological model PARLAM-PS (Polar-Stereographic version of PARLAM) has been verified for 1997 against observations and compared with the operational HIRLAM/PARLAM model. Starting from February 1999, the model has been run operationally at the DNMI and is intended to be used at MSC-W for preparing meteorological data for the EMEP/MSC-W dispersion models.

In this note we give a short description of the PARLAM forecasting system and the modifications to the model. Furthermore, results of the verification of PARLAM-PS against observations and comparison with the operational HIRLAM model are analysed. A detailed list of the meteorological parameters - input to the EMEP Eulerian models is presented. Finally, the most significant differences between the meteorological fields computed by EUROLAM and LAM50E and their implications for pollutant transport modelling are documented.

2. Short description of the HIRLAM (PARLAM) forecasting system

HIRLAM (HIgh Resolution Limited area Modelling) is a short range weather forecasting system. Currently, the HIRLAM system is used operationally in Denmark, Finland, Ireland, the Netherlands, Norway, Spain, and Sweden.

Its main components are an analysis system, model initialization, a prognostic model, and post-processing. The analysis technique is optimum interpolation and are intended for an intermittent data assimilation system which continuously takes new available observations of geopotential, wind components and relative humidity into account when generating initial fields for the forecast. In addition, preprocessing procedures to construct start-up and boundary fields are available. Lateral boundary values for HIRLAM are taken from the ECMWF global forecasting system.

The forecasting model is formulated in a rotated spherical latitude-longitude grid with the resolution of 0.5° (appr. 50 km) horizontally and employs a hybrid p-σ system in the vertical. The vertical modelling domain extends to ca.10 hPa and is resolved with 30 layers.

The HIRLAM forecasting model is based on the primitive equations with the hydrostatic approximation applied. The prognostic variables are horizontal velocity components (U,V), temperature (T), surface pressure (P_s), specific humidity (q), and cloud liquid water (q_l). Among seven governing equations, five are prognostic (momentum, termodynamic energy, and continuity equations for mass, moisture and cloud liquid water), and two diagnostic equations (hydrostatic equation and equation of state for an ideal gas). The dynamical equations are discretized on a Arakawa C-grid with velocity components calculated in grid points halfway between pressure- and temperature points. Advection is calculated by a semi-Lagrangian numerical scheme, and an implicit 6-order scheme for horizontal diffusion is applied (McDonald, 1994).

Physical parameterization of radiation, turbulence, stratiform condensation, convection and surface exchange processes is included. Radiation scheme serves to calculate net radiation at the surface and temperature tendencies in the atmosphere caused by longwave (infrared) and shortwave (solar) radiation (Sass *et al*., 1994). Surface fluxes are calculated using a drag coefficient formulation, using Monin-Obukov similarity theory in the atmospheric boundary layer. Calculation of the fluxes above the lowest model level are based on a mixing length formulation (Louis *et al*., 1982). For parameterization of condensation, cloud and precipitation two alternative schemes are applied: Kuo convection scheme and Sundqvist scheme for stratiform condensation (Sundquist *et al*., 1989). A detailed description and documentation of the HIRLAM modelling system can be found in Gustavsson (1993), HIRLAM Documentation Manual (1996), and a number of HIRLAM Technical Reports.

In 1995 an operational parallel version of the HIRLAM code (PARLAM) was successfully developed at the DNMI (Bjørge and Skålin, 1995).

3. Modifications to the PARLAM weather prediction model

In order to avoid mass conservation errors derived from interpolation of the meteorological wind fields, the PARLAM model has been reformulated to the same horizontal projection and vertical coordinates as those employed in the EMEP/MSC-W pollution transport models.

The new PARLAM version, named PARLAM-PS, uses the same polar-stereographic projection and covers a domain of 170x133 grid squares with 50 km resolution (Figure 3.1). A description of the polar-stereographic projection can be found in Appendix A. σ-coordinates are used in the vertical direction. The model is resolved with 20 vertical layers (up to 100 hPa) with 9 layers being below 850 hPa in order to achieve a higher resolution of boundary layer processes which play an essential role for the air pollution transport.

In order to improve temporal interpolation in the dispersion models, 3 hour resolution has been chosen for meteorological data, instead of 6 hour resolution used earlier.

Furthermore, changes have been introduced in the output of 3-D cloud cover. In the original PARLAM version, instantaneous cloud cover values were predicted. That could be inconsistent with the simultaneousely predicted precipitation amount which was accumulated since the forecast initiation time. This might result in situations when non-zero precipitation occured together with cloud-free sky. In order to ensure consistency between cloud cover and precipitation at any output time, averaged over every 3 hour period cloud cover is now considered.

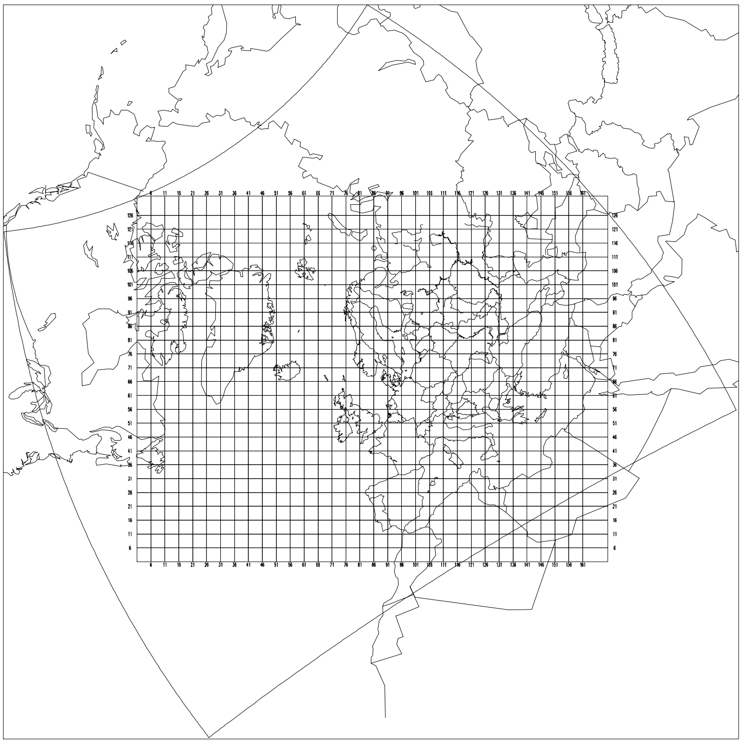


Figure 3.1 The modelling domain of HIRLAM/PARLAM (the largest area) and PARLAM-PS (smaller gridded area)

4. Run of PARLAM-PS for 1997.

PARLAM-PS has been run for 1997 in order to prepare meteorological input to the Eulerian acid deposition model for routine calculations of transboundary air pollution in Europe.

4.1. The setup for PARLAM-PS run

The evolution of forecast errors validation and personal communications with colleagues at the section for Meteorology, the decision was made to run 12 hour forecasts. Since the humidity fields are not treated by the initialization scheme, but taken directly from the analysed values, the model needs 6-12 hours spin-up time to establish a balance between the humidity and the dynamical variables. In practice it means that the precipitation will be unerestimated at at least during the first six hours of forecast. Thus, the use of 12 hour forecasts has been justified as it is gives a rather good balance between spin-up errors and errors derived from longer forecasts.

12-hour forecasts are generated four times a day: at 00, 06, 12, and 18 UTC. A number of selected parameters are taken out every 3 hours. To create a contiguous 3 hourly meteorological series +9 and +12 hour predicted parameters from each run were stored. Since precipitation in the present model is calculated as accumulated during an entire (12 hour) forecast period, we also needed +6 hour calculated precipitation in order to derive 3-hourly precipitation. For example, 3-hour precipitation at 9 and 12 UTC was derived from the 12 hour forecast generated at 00 UTC as folows:

$$\mathrm{Pr\_acc}_{3h}(\text{ at 12 UTC}) = \mathrm{Pr\_acc}(00 + 12) - \mathrm{Pr\_acc}(00 + 9)$$

$$\mathrm{Pr\_acc}_{3h}(\text{ at 9 UTC}) = \mathrm{Pr\_acc}(00 + 9) - \mathrm{Pr\_acc}(00 + 6)$$

The PARLAM-PS model was run on a Cray T3E computer at the Norwegian University of Science and Techology (NTNU) in Trondheim, Norway. The processing time for all computations related to one day simulation was about 30 minutes (elapsed time) when 14 processors were allocated for the task.

To prepare for the operative runs the model needs input files describing surface orography and climatology in the modelling domain, and boundary conditions. Since the PARLAM-PS modelling domain does not coinside with that of HIRLAM, i.e. its lower left corner extends beyond the HIRLAM domain, additional surface and climatological data were needed. HIRLAM monthly climate fields had to be interpolated from spherical to polar-stereographic grid and modified using DNMI parameters, i.e. topography, sea surface temperature and snow/ice cover. To create the boundary files, analysis data were fetched from the MARS archive at ECMWF. Synoptic files were also supplied, and used in the model in an assimilation stage.

Table 4.1 shows the meteorological fields stored from PARLAM-PS both at standard pressure levels, model σ-levels and at the surface. The storage needs for simulation results, including all the parameters from Table 4.1, for one day are 160 MB, or about 58 GB for the whole year.

Table 4.1 Meteorological fields for 1997 calculated with PARLAM-PS and stored at EMEP/MSE-W (3-hourly).

	3-dimensional meteorological fields	
	Fields at 11 pressure levels	Unit
Z	geopotential height	m
θ	potential temperature	°K
U	wind component along x-axis	m/s
V	wind component along y-axis	m/s
Rh	relative humidity	%
	Fields at 20 σ-layers	
θ	**potential temperature**	°K
U	**wind velocity component along x-axis**	m/s
V	**wind velocity component along y-axis**	m/s
$\dot{\sigma}$	**vertical wind velocity in σ coordinate**	1/s
q	**specific humidity**	kg/kg
q_l	**liquid cloud water**	kg/kg
Pr	**precipitation (accumulated from the top)**	mm
Cl	**cloud cover**	%
Cu	convective cloud cover	%
	Surface parameters	
z_s	topography	m
z_0	**roughness**	m
Ps	**surface air pressure**	hPa
T_2	**temperature at 2 m height**	°K
U_{10}	x- wind component at 10 m height	m/s
V_{10}	y- wind component at 10 m height	m/s
Prt	total precipitation (accumulated from the start of the prognose)	mm
Prl	frontal precipitation (-------# -----------# ------------# --------)	mm
Prc	convective precipitation (-------# -----------# ---------- # ---)	mm
Ts	temperature at the surface	°K
Tsoil	temperature under the surface (in the upper soil layer of 7.2 cm)	°K
Tscl	climatological deep soil temperature	°K
sw	soil water	m
swd	deep soil water conent	m
Fs	**surface flux of sensible heat**	W/m^2
Fl	surface flux of latent heat	W/m^2
Fm	**surface stress**	N/m^2

*) In bold letters - meteorologocal parameters input to the Eulerian dispersian model

The meteorological input used by the EMEP Eulerian acid deposition model (parameters from Table 4.1 written in bold) requires ca. 22 GB for a year.

The meteorological parameters at standard pressure levels (geopotential height, wind, temperature and relative humidity) and surface parameters such as surface pressure, temperature and relative humidity at 2 m height, horizontal wind conponents at 10 m, total cloud cover, and accumulated precipitation were used for the model verification against observations. The model results are stored at DNMI on a tape robot system.

4.2. Meteorological data to the EMEP Eulerian models.

A complete meteorological data set necessary as input to the EMEP Eulerian models is 3-hourly prognoses for all the model levels and the surface level (highlighted in the Table 4.1). The three-dimensional fields are wind (horizontal and vertical components), potential temperature, humidity, cloudiness, cloud liquid water, and precipitation. The two-dimensional surface fields include temperature at 2 m, surface pressure, surface stress and flux of sensible heat, and roughness parameter.

3-D meteorological fields are given as average values in 20 layers in the vertical direction and grid averages in the horizontal domain, except for horizontal wind components which are given on "staggered" grid, i.e. describe the fluxes between two adjacent grids. Since both the meteorological model PARLAM-PS and the EMEP Eulerian models are now formulated in the same coordinates, the meteorological parameters can be directly used in the transport model.

5. Validation of the PARLAM-PS model.

In order to verify the new meteorological model PARLAM-PS, a number of both surface and 3-D parameters have been compared with observations. In addition, PARLAM-PS has been compared with EUROLAM model which was previousely used in EMEP/MSC-W dispersion models. Differences in forecasts made by PARLAM-PS and EUROLAM models are expected to originate from their choice of horizontal and vertical coordinates.

Comparison has been performed for four different weeks in 1997: 1-7 January, 1-7 April, 1-7 July, and 1-7 October.

5.1. 3-D meteorological parameters

Geopotential height and horizontal wind at 850 hPa and 500 hPa from PARLAM-PS and EUROLAM has been compared with observations from 9 radio-sonde stations (TEMP-observations). The stations have been selected to represent possibly different areas in Europe. They are Bordeaux, Gothenburg, Copenhagen, Milano, München, Murmansk, Riga, Sofia, and Warszawa. 12-hour forecasts generated at 00 and 12 UTC have been compared with observations at 12 and 00 UTC correspondinly. To study both systematic and nonsystematic forecast errors, we have analysed bias, i.e. average error, and stanard deviation of error (STDE) which characterises reliability of the forecast.

Geopotential height is predicted fairly well by both EUROLAM and PARLAM-PS. However, PARLAM-PS tends to give somewhat lower overall values.

850 hPa geopotential is generally underestimated in January and overestimated in July and October by both models, though the bias is relatively small (within 0.5 -1 %). In April there found both negative and positive biases. STDE appears better for the both models in July and October, with PARLAM-PS performing somewhat better in these months (for example see Appendix B, Figure B1).
500 hPa geopotential is also systematically underpredicted in January and April and overpredicted in July and October, with small biases within 0.1-0.5 %. Performance of the models varies from station to station, but results generally are rather close.

Wind speed is often underestimated by the two models at these levels in all the seasons.
Bias and STDE in wind at 850 hPa does not show any systematic pattern in the models' performance at different stations during the year. Relative bias varies between 0 and 50%. July seems to be most difficult month for both models to predict wind speed. Generally, 850 wind speed predictions in January and July by the models may be rather different, while in April and October the models show very similar results (see Appendix B, Figure B2).

Calculated by both models wind speed at 500 hPa compares with measurements noticeably better than 850 hPa wind, and the results are somewhat better in cold seasons. However, no particular conclusions on which model performs better could been drawn.

5.2. Surface layer meteorological parameters

Predicted with PARLAM-PS and EUROLAM values of pressure at the sea level, temperature at 2 m, wind speed at 10 m, and 12-hour accumulated precipitation have been verified against observations at 11 SYNOP stations. The stations are Athen, Berlin, Kiev, London, Madrid, Moskva, Oslo, Paris, Roma, Warszawa, and Wien. 12-hour forecasts generated at 00, 06, 12, and 18 UTC have been compared with observations at 12, 18, 00 and 06 UTC.

Mean sea level pressure (MSLP) compares fairly well between the models and with observations. PARLAM-PS predicts somewhat lower MSLP than EUROLAM in January and October, and higher in April and July. The both models tend to slightly overestimate the MSLP in all the months except for January (Appendix B, Figure B3).

Wind at 10 m height is systematically underestimated by the both models in Berlin, Paris, Waszawa and Wien with lagest biases and STDE in Berlin and Wien (Appendix B, Figure B4). At the other stations the models tend to overestimate 10 m wind, showing worst results in Moscow and Oslo. For all the stations, PARLAM-PS appeares to give better results in April and July.

Temperature at 2 m height is systematically underpredicted by PARLAM-PS and EUROLAM. The underestimation is especially pronounced in January and April, when negative biases are found at practically all the analysed stations. In July and October positive biases are registered in Moscow, Warszawa, Paris, Rome and Wien. PARLAM-PS seems to predict lower 2 m temperature more often and shows slightly larger STDE. The models give a rather similar prediction of 2 m temperature in April, July, October at most of the stations, while results in January are rather different (Appendix B, Figure B5). The descrepancies between the two models are found largest in Rome for all the months.

12-hour accumulated precipitation is in average underestimated by the models in October (except from Berlin), and overestimated in April and July (Appendix B, Figure B6). The overestimation is found to appear mainly due to the situations when precipitation is predicted, but does not occur. While the underestimation often results from prediction of lower precipitation amount during the precipitation event. Since precipitation events are rather episodic, one week periods appear too short for a credible intercomparison of the models and evaluation of their performance.

Total cloud cover from PARLAM-PS is a 3-hourly average and therefore cannot be compared accurately. A very general conclusion can be made that PARLAM-PS predicts on average reasonable cloud cover values (Appendix B, Figure B7)..

5.3. Summary statistics of predicted meteorological parameters.

The PARLAM-PS model has been run operationally since 3 February, 1999. Statistical analysis of the model performance have been made for the period from 3 February to 10 June 1999. Summary statistics were averaged over EWGLAM (European Working Group on Limited Area Modelling) stations for predicted by PARLAM-PS and operational HIRLAM model (OPR) 3-D and surface meteorological parameters.

3-D meteorological fields

Figure 5.1 compares RMSE (root mean square of error), STDE (standard deviation of error), and bias for +12 hour forecast of geopotential, wind, temperature, and relative humidity by PARLAM-PS and HIRLAM (OPR) as a function of pressure.

In general, the two models give fairly close predictions at lower levels, but with the height the differences increase. Standard deviations of error are very similar up to 200-100 hPa, and above that level they are noticeably larger for PARLAM-PS due to its lower upper level of 100 hPa compared to 10 hPa in HIRLAM.

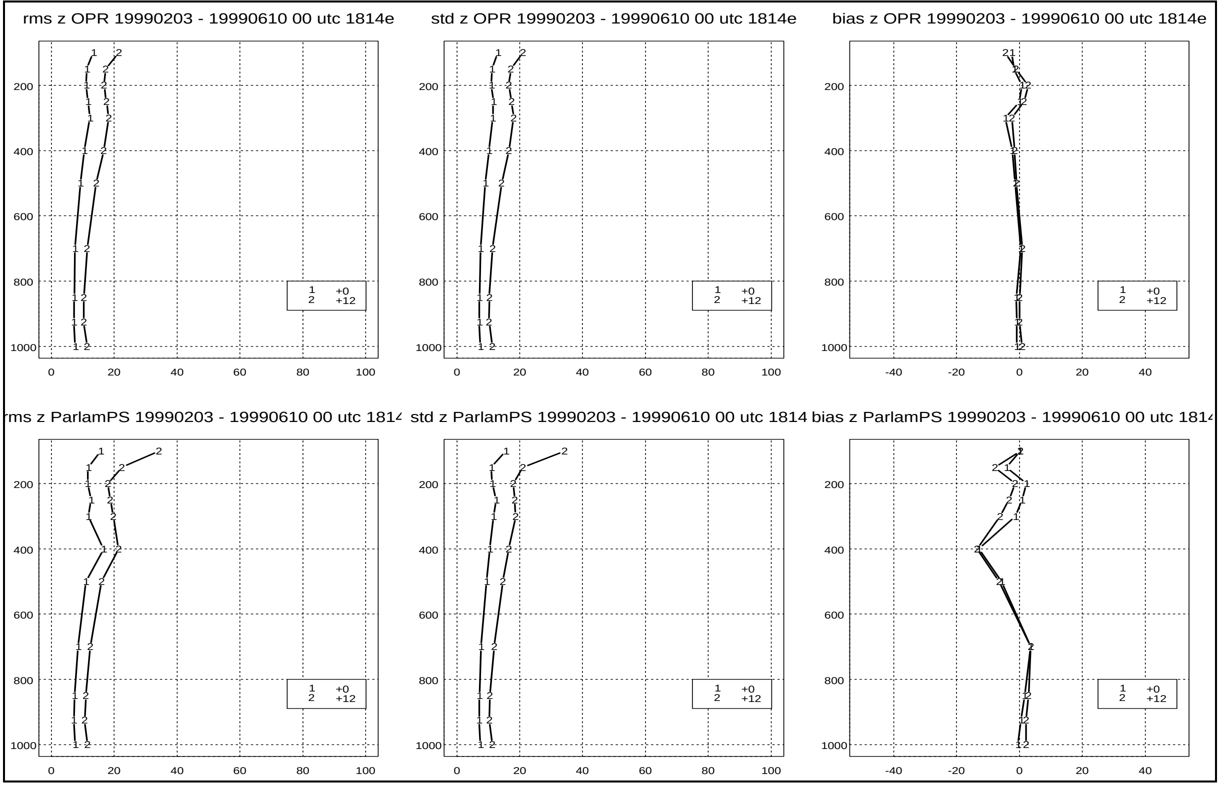
The largest discrepancies are found for geopotential and temperature. PARLAM-PS appears to systematically underestimate geopotential height above ca. 600 hPa with the largest negative bias of 10-13 m at 400 hPa level.

This is consistent with the negative bias in temperature in the layer between 700 and 400 hPa. In the boundary layer and above 400 hPa a systematic overprediction by PARLAM-PS of temperature is registered. These systematic differences at higher levels between the two models are related to the boundary relaxation inaccuracies and result from the different vertical extension of the models domain, i.e. HIRLAM extends up to 10 hPa, while PARLAM-PS has an upper lock at 100 hPa. That means that erroneous numerical waves when reflected from the upper boundary propagate downwards to lower levels in PARLAM-PS and are particularly pronounced for geopotential and temperature, but the biases do not exceed on average 0.5%. The standard deviation of errors for these fields are registered quite similar. It increases somewhat above 400-300 hPa, and particularly at 50 hPa for PARLAM-PS. Standard deviations of error for temperature also increase close to the surface.

Systematic errors in wind field predicted by PARLAM-PS and HIRLAM are rather similar, but underestimation of wind between 400 and 200 hPa and overestimation elsewhere are somewhat larger by PARLAM-PS, even though the bias is within $\pm 1 \, {}^{m}\!/_{s}$. Standard deviations of error are virtually the same and are largest in the layer 600-200 hPa for the both models.

Bias and STDE are practically the same for the fields of relative humidity as predicted by PARLAM-PS and HIRLAM. Negative bias of less than 10% are found between 900 and 400 hPa, while at the surface relative humidity is ca. 6% overestimated. Systematic errors in wind field predicted by PARLAM-PS and HIRLAM are rather similar. STDE has its maximum of 15-20% at 800 and 400 hPa.

(a)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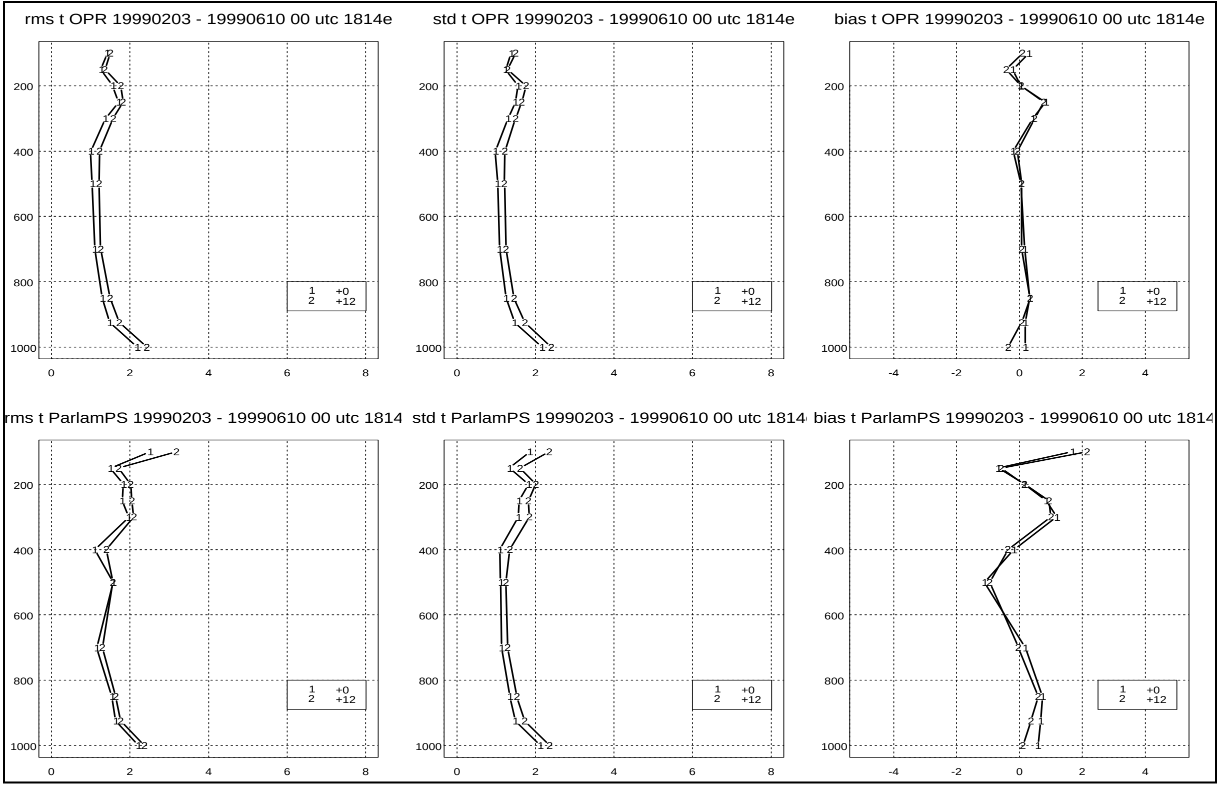
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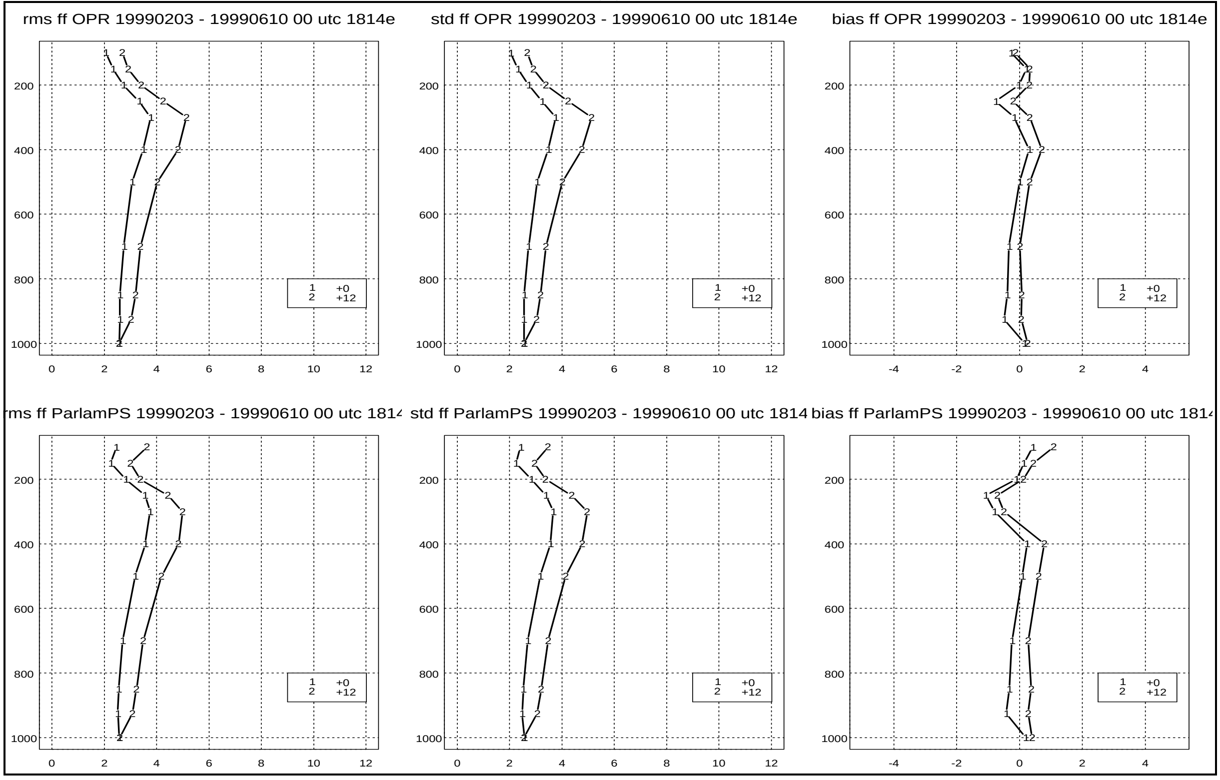
(c)



(d)

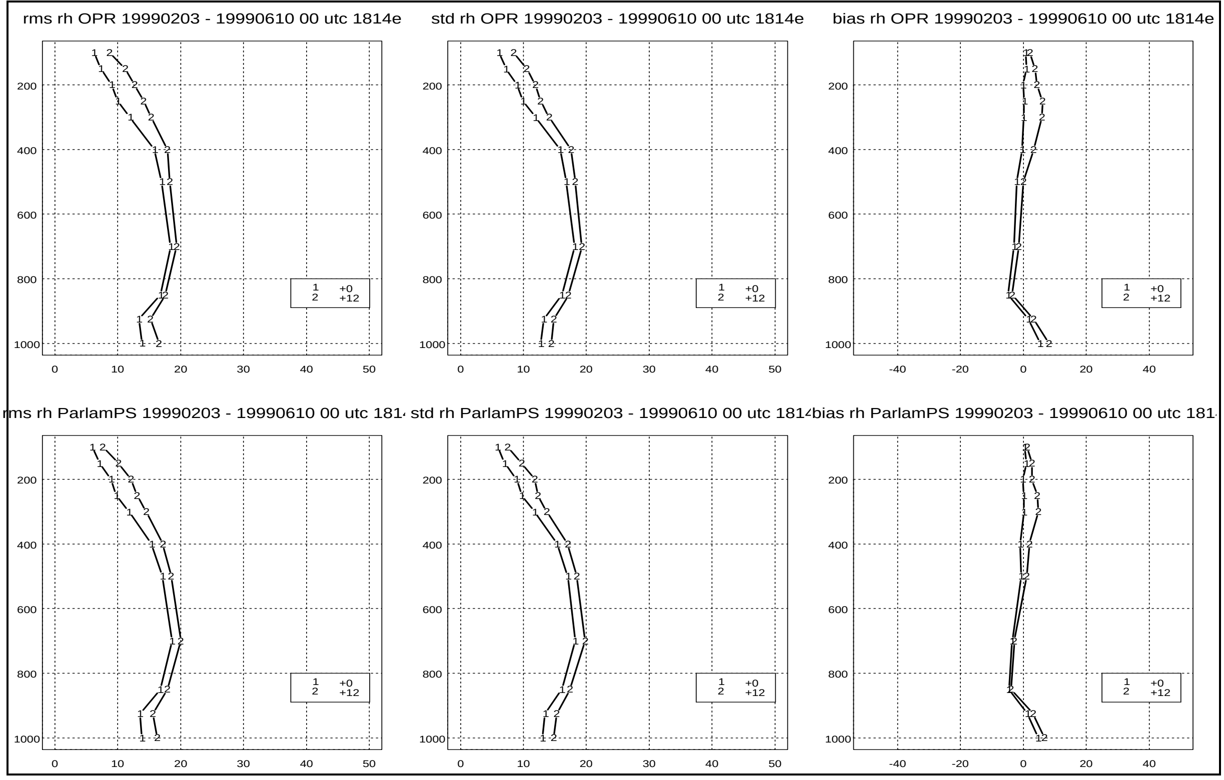


Figure 5.1 Summary statistics for 12-hour forecast of geopotential (a), temperature (b), wind (c), and relative humidity (d) by PARLAM-PS and HIRLAM (OPR) averaged over EWGLAM stations for the period 3.02-10.06.1999 (forecasts are generated at 00 UTC)

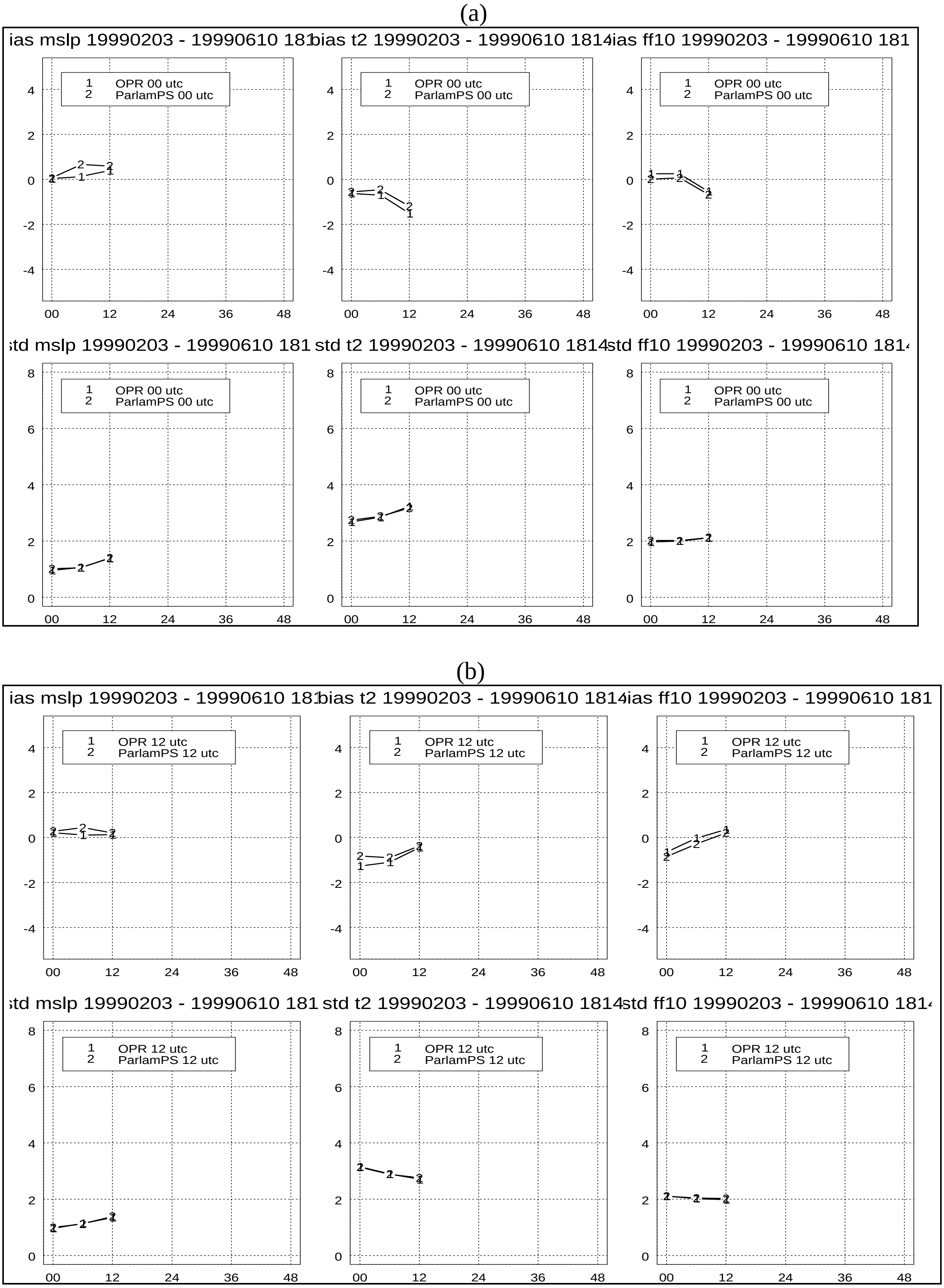


Figure 5.2 Summary statistics for 12-hour forecast of MSLP, temperature at 2 m, and wind at 10 m by PARLAM-PS and HIRLAM (OPR) averaged over EWGLAM stations for the period 3.02-10.06.1999: (a) generated at 00 UTC, (b) generated at 12 UTC.

Surface fields

Figure 5.2 presents the averaged over stations bias and STDE of mean sea level pressure, temperature at 2 m, and wind at 10 m for PARLAM-PS and HIRLAM as functions of forecast length.

The prognose errors of the both models for those fields are characterized by the same STDE value, which is registered largest for 2 m temperature.
Similar slight positive biases is found for mean sea level pressure field. Systematic underestimation of temperature at 2 m is somewhat smaller for PARLAM-PS, and for the both models predicted at 00 UTC temperature compares better with observations. Wind at 10 m at 12 UTC is typically underestimated by ca.1 m/s by the both models, and it is slightly overestimated at 00 UTC. In these cases, PARLAM-PS tends to predicted somewhat lower wind velocity, thus, giving better prediction of wind at the noon and little worse at midnight.

6. Comparison of EUROLAM and LAM50E.

In 1998, calculations of transboundary concentrations and depositions for the period of 1985-1996 with the EMEP Lagrangian acid deposition model were performed based on meteorological data from LAM50E model. Besides, calculations for 1996 were also made with use of meteorology derived from EUROLAM model (EMEP Status Report 1/98). It was found that the modelled for 1996 concentration and deposition fields were noticeably different as calculated with the different meteorological input from LAM50E and EUROLAM. In particular, pronounced differences were registered for dry and, especially, wet deposition fields.

Comparison of the input meteorological data to the Lagrangian model for 1996 derived from the LAM50E and HIRLAM/EUROLAM model revealed differences in a number of principal predicted parameters due to the differences in the models formulation, e.g. dynamical and physical parameterization schemes implemented. Unfortunately, at the moment it is not feasible to compare PARLAM-PS and LAM50E directly, as we do not yet have any overlapping year. However, as it was discussed in Chapter 4, PARLAM-PS and EUROLAM differ only in the spatial representation, and in general, results from the both models are quite similar, except for the highest levels. Therefore, the main differences between EUROLAM and LAM50E are expected to have place for PARLAM-PS. Knowing of these differences will be very helpful when analysing this year results from the Eulerian acid deposition model as compared with those based on LAM50E meteorology from last year (see e.g. Bartnicki,1999, and Olendrzynski, 1999). Therefore, the main findings and conclusions on the differences in predicted meteorological fields by EUROLAM and LAM50E models are documented and included in the present report.

- Total cloud cover - affects photochemical dissosiation rates; 3-D cloudiness also controls in-cloud sulphur oxidation in the Eulerian model.

When averaged for the entire EMEP area, monthly means of cloud cover predicted by EUROLAM are more than a factor of 2 larger than those predicted by LAM50E.

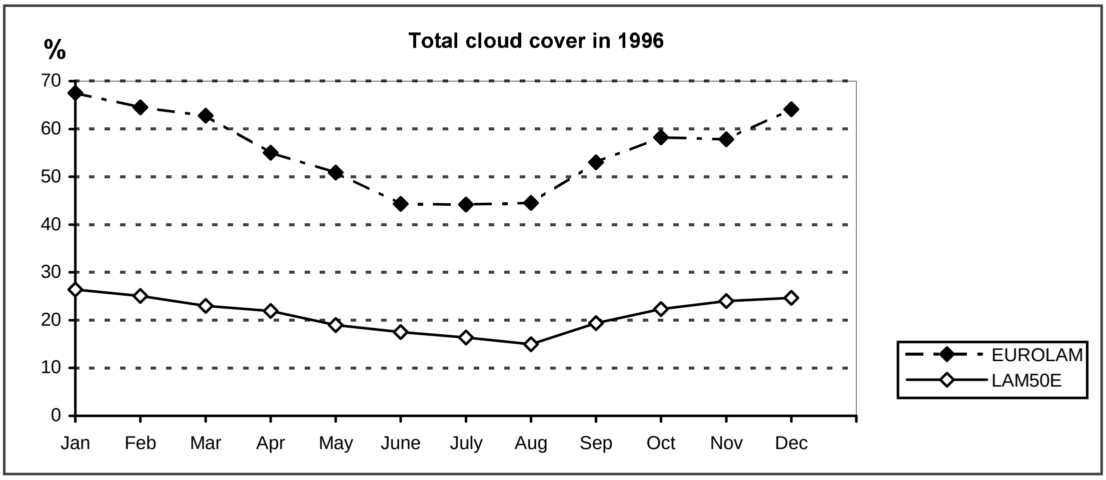


Figure 6.1 Monthly mean cloud cover in 1996 averaged over the EMEP domain

Verification of LAM50E and EUROLAM against observations at a number of European SYNOP and TEMP stations for winter (2.01-31.03) and summer (1.05-15.07) periods in 1996 (Sinselrud, 1996) showed that in winter LAM50E gives often too little clouds, while EUROLAM gives too much clouds. In summer the both models somewhat underestimate cloudiness. The verification for 1997 has proved some overestimation by EUROLAM of cloud cover in a January week in most of the stations, however, in July both negative and positive biases have been registered. Overall cloud cover predicted by EUROLAM were found larger than that by LAM50E.

Comparison of geographical distribution of predicted annual mean total cloud cover with climatological values (Warren *et al*., 1986) proved better correspondence of those calculated with EUROLAM model.

Increased cloudiness would effect photolysis rates and thus change NO/NO_2 ratio and, finally, ozone production in photooxidant models. It may also enhance sulphate particles production in the Eulerian acid deposition model.

- Precipitation - controls wet deposition

EUROLAM was found to predict considerably (up to 30-40%) larger than LAM50E amount of precipitation at the ground in the EMEP domain in 1996, especially from April to August (Figure 6.2). Most pronounced the differences were over sea areas and southern and eastern Europe (e.g. Spain, Italy, southern France, Greece). Sinselrud (1996) analysed 6-hour accumulated precipitation predicted by these models at some SYNOP stations and drew a conclusion that EUROLAM computed larger precipitation amounts in winter and summer due to both the increase of maximum values and more frequent occurency of precipitation events forecasted. Input precipitation fields to the Lagrangian model were prepared using as much as possible observation data. In this way, precipitation on seas taken directly from a NWP model was combined with analysed observed precipitation over land areas. Such corrected with observations monthly accumulated and averaged for the EMEP area precipitation is also presented in Figure 6.2 (dashed curves).

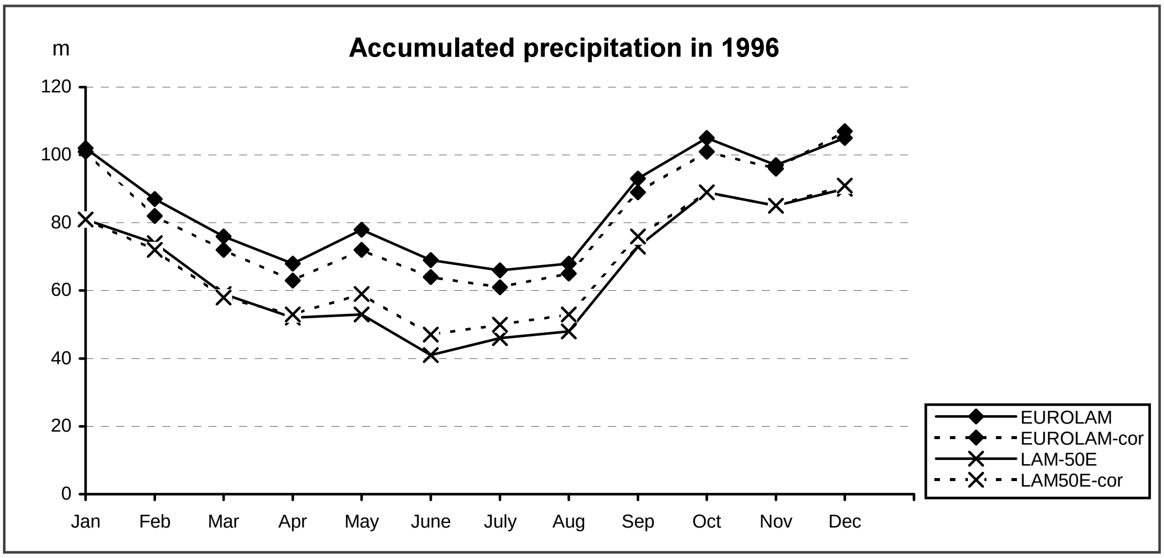


Figure 6.2 Monthly accumulated precipitation in 1996 averaged over the EMEP domain.

It shows that LAM50E tends to underestimate precipitation, while EUROLAM tends to overestimate it. The biases are seen largest during warm seasons. When empoloying EUROLAM meteorology, the Lagrangian acid deposition model computed wet depositions in 1996 appreciably higher than with use of LAM50E meteorology (see Appendix, Figure B8).

When using 3-D precipitation fields calculated by PARLAM-PS for 1997 in the Eulerian acid deposition model, it has been found that much greater portion of the released in a vertical column precipitation evaporates before reaching the ground, compared to that computed by LAM50E for 1996 (Olendrzynski, 1999). To find out the reasons of this difference the parameterization scheme of precipitation/evaporation in HIRLAM/PARLAM should be revised and verified thoroughly.

- Surface stress - affects dry deposition

Surface stress for the whole area is larger as calculated with the EUROLAM model (not shown here). In particular, greater differences of 40-50% are predicted by EUROLAM from April to November. Therefore, greater dry deposition rates of polutants are expected to occure when the new meteorology is employed. Calculations with the Lagrangian acid deposition model produced somewhat larger dry deposition in some areas, but the differences were not as significant as for the wet deposition.

- Turbulent heat flux - affects dry deposition

EUROLAM predicted 20-30% smaller overall turbulent heat flux (i.e. smaller dry deposition) from January to June, and 30-60% larger overall turbulent heat flux (i.e. larger dry deposition) from August to November model (not shown here).

- Vertical velocity on the top of the Boundary Layer - controls mass exchange with the free troposphere

Overall vertical velocity at 850 hPa level which is assumed to be a top of the Boundary Layer was calculated by EUROLAM to be rather large and negative during most of 1996.

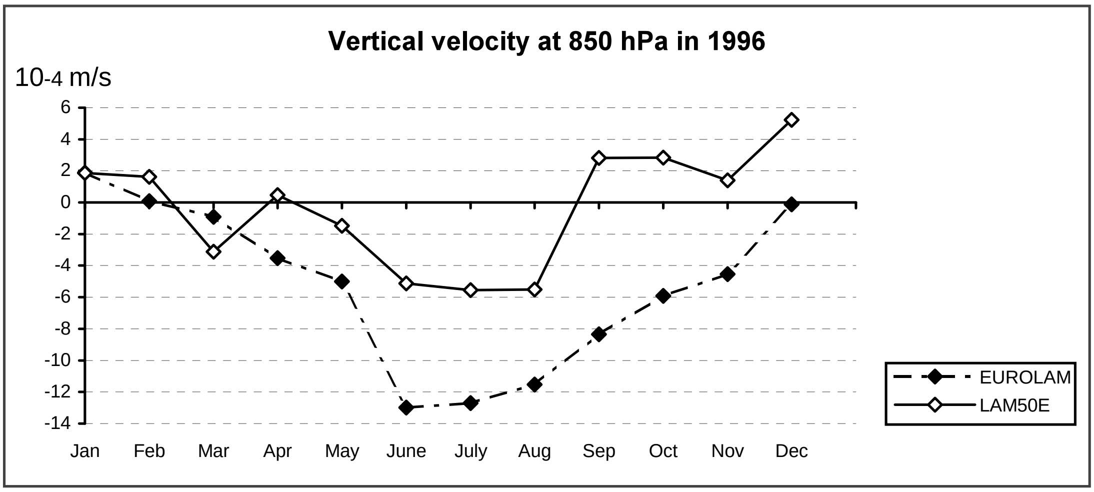


Figure 6.3 Monthly mean vertical velocity in 1996 averaged over the EMEP domain

Unfortunately, vertical velocity is not measured directly and therefore, can be verified indirectly through the divergence of horizontal wind. EUROLAM was found to predict better horizontal wind at 850 hPa (Sinselrud, 1996), therefore, we could expect a better prediction of vertical velocity. Generally, it calculates somewhat lower winds in summer, what corresponds well with the largest predicted negative vertical velocities. LAM50E was found to compute better wind fields at 500 hPa in summer and winter, but differences were insignificant. In the Lagrangian model a greater negative vertical velocity would mean a higher probability of the background concentrations from the free troposphere get mixed down to the model box.

- Temperature at 2 m height was often predicted lower by EUROLAM than LAM50E.

7. Summary and conclusions

A new dedicated meteorological model, PARLAM-PS, has been developed at the EMEP/MSC-W. The particular need for a new meteorological model was related to the change of EMEP operational transport model from a one-layer Lagrangian model to 3-D Eulerian model, which requires more meteorological parameters of a higher quality. The new meteorological model is based on the operational at the Norwegian Meteorological Institute HIRLAM weather forecast system which has been reformulated from a rotated spherical horizontal grid to the polar-stereographic projection, and from a hybrid η-coordinate to σ-coordinate used by EMEP Eulerian models. The usage in the both models of the same coordinate system has the great advantage as it secures from the mass conservation errors due to spatial interpolation of the meteorological mass and wind fields.

Verification of PARLAM-PS against observations at a number of selected EWGLAM stations for four week-periods in various seasons in 1997 has proved a quite satisfactory performance of the new model (see Chapter 4.2). Comparison of PARLAM-PS with the original HIRLAM/EUROLAM model has shown that in general the models compute quite similar 850 and 500 hPa geopotential, mean sea level pressure and temperature at 2 m. While calculated with the two models wind at 850 and 500 hPa and at 10 m, and especially 12-hour accumulated precipitation at some stations may differ considerably due to merely differences in the coordinate systems. However, no apparent conclusion on which model performs best can be made at this stage.

When averaged over the EWGLAM stations for the period 3.02-10.06.1999, the results from PARLAM-PS and HIRLAM are quite close. 3-D meteorological fields are predicted rather similar at lower levels, but show some differences at higher levels (see Chapter 4.3). Largest differences in 3-D fields are found in geopotential height and temperature, where PARLAM-PS systematically underestimates these parameters between 600 and 300 hPa. These systematic differences are related to the upper boundary relaxation problems. However, the bias in geopotential and temperature predicted by PARLAM-PS is on average less than 0.5 %, and thus, can be qualified satisfactory. The forecasts by the two models of surface meteorological parameters for EWGLAM stations are also fairly close.

The above analyses of PARLAM-PS performance justifies the use of the model for preparation of meteorological data to EMEP Eulerian dispersion models. Due to the formulation of the meteorological and dispersion models in the same horizontal and vertical coordinates, calculated by PARLAM-PS meteorological parameters can be used directly as input to the EMEP dispersion models. Moreover, the temporal resolution of meteorological data has been increased to 3-hourly input.

The comparison of HIRLAM/EUROLAM with LAM50E has revealed a number of differences in predicted meteorological fields which are important to take into account when analysing concentrations and deposition fields computed this year. The largest differences are found in cloud cover, precipitation, and surface fluxes of heat and momentum (see Chapter 6).

Complete 3-hourly meteorological data set for 1997 required as input to the EMEP Eulerian models has been calculated and stored in the tape-robot at DNMI. Based on the results the 1997 model run it is possible to recommend the use of PARLAM-PS in order to generate a complte and consistent meteorological data set for use by EMEP, starting back from 1990.

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Appendix:

A. Technical description of the EMEP grids

B. Figures:

B1. One week timeseries and statistics of the 850 hPa geopotential height at Warszawa in (a) January and (b) July, 1997.

B2. One week timeseries and statistics of the horizontal wind at 850 hPa at Murmansk in (a) January and (b) April, 1997

B3. One week timeseries and statistics of the mean sea level pressure at Berlin in January, 1997

B4. One week timeseries and statistics of the wind at 10 m at London in July, 1997

B5. One week timeseries and statistics of the temperature at 2 m at Moscow in (a) January and (b) July, 1997.

B6. One week timeseries and statistics of the 12 hour accumulated precipitation (in mm) at Paris in July, 1997

B7. One week timeseries and statistics of the total cloud cover at Berlin in July, 1997

B8. Wet deposition of oxidised sulphur in 1996 calculated by LAM50E and EUROLAM

Appendix A

Technical description of the EMEP grid.

The EMEP grid system is based on a polar-stereographic projection with real area at latitude 60°N. The EMEP program has used two different grid resolutions: 150x150 km^2 and 50x50km^2. In the following, a technical description of both EMEP grids is provided as well as the procedure to convert from one resolution to the other.

The 150x150km^2 grid

For the **150x150km^2 grid**, the latitude, ϕ, and longitude, λ, of any point (x,y) on the grid may be calculated as follows:

$$\Phi = 90 - \frac{360}{\pi}\arctan\left[\frac{r}{M}\right]$$

$$\lambda = \lambda_0 + \frac{180}{\pi}\arctan\left[\frac{x - xpol}{ypol - y}\right]$$

in which:

xpol = 3 (x co-ordinate of the North Pole)

ypol = 37. (y co-ordinate of the North Pole)

d = 150 km (grid length at 60°N)

ϕ_0 = 60°N = $\pi/3$ (defining latitude)

R = 6370 km (radius of the earth)

M = R/d[1 + sin(π/3)] = 79.24 (Number of grid distances between the North Pole and the equator).

r = $\sqrt{\left[(x - xpol)^2 + (y - ypol)^2\right]}$ (grid distance from the North Pole to point (x,y))

λ_0 = -32 (32 °W) (rotation angle, i.e. the longitude parallel to the y-axis)

The y-axis is oriented parallel to 32°W defined as a negative longitude if west of Greenwich.

The x and y co-ordinate in the EMEP grid of any given latitude and longitude can be found from:

$$x = xpol + M \tan\left[\frac{\pi}{4} - \frac{\phi}{2}\right]\sin(\lambda - \lambda_0)$$

$$y = ypol - M \tan\left[\frac{\pi}{4} - \frac{\phi}{2}\right]\cos(\lambda - \lambda_0)$$

Traditionally the EMEP 150x150 km^2 domain has included 39x37 points (that is, x varying from 1 to 39 and y varying from 1 to 37).

The extended EMEP 150x150 km^2 domain includes instead 44x37 points (that is, x varying from 1 to 44 and y varying from 1 to 37).

The 50x50km^2 grid

The **50x50km^2 grid** is defined from the same equations as above by simply redefining the following parameters:

xpol = 43.
ypol = 121.
d = 50 km
M = 237.73

Each 150x150 km^2 gridcell has been divided in nine 50x50 km^2 gridcells. Conversion from the 150km gridcells to the 50km gridcells can be obtained from:

$x_{50} = 3\ (x_{150}) + 34.$
$y_{50} = 3\ (y_{150}) + 10.$

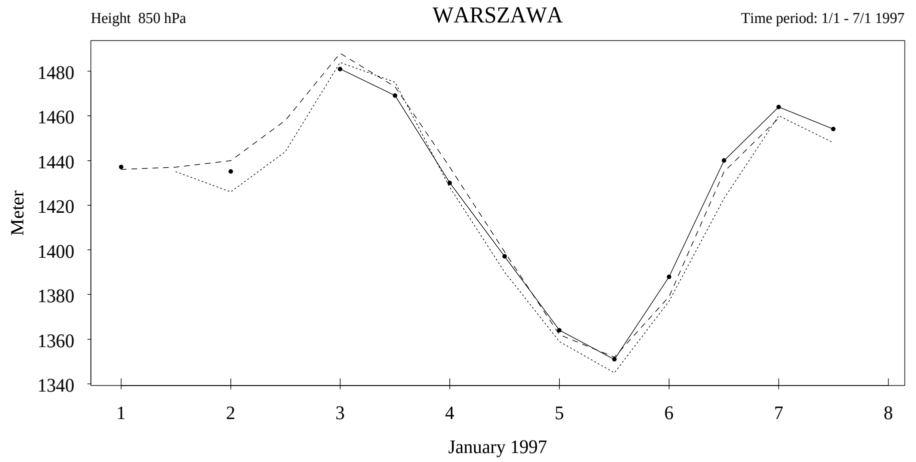
It should be pointed out that *x* and *y* co-ordinates calculated with the equations above coincide with the grid-square centre. Thus, if a grid-square has its centre co-ordinates (*i,j*), the co-ordinates (*x,y*) of its lower left and right corners are (*i*-0.5, *j*-0.5) and (*i*+0.5, *j*-0.5) respectively, and the co-ordinates (*x,y*) of its upper left and right corners are (*i*-0.5, *j*+0.5) and (*i*+0.5, *j*+0.5) respectively.

Traditionally the EMEP 50x50 km^2 domain has included 117x111 points (with x varying from 36 to 152 and y varying from 12 to 122).

The extended EMEP 50x50 km^2 domain includes instead 132x111 points (with x varying from 36 to 167 and y varying from 12 to 122).

Appendix B

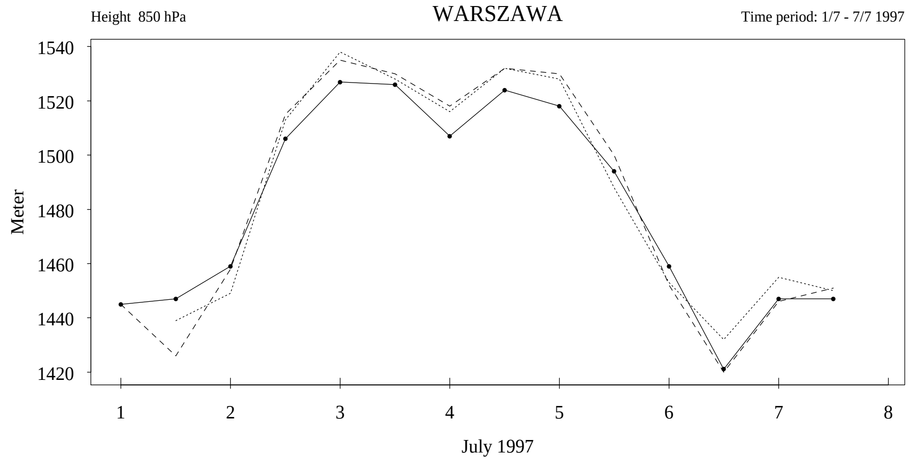
(a)



		Min	Mean	Max	Std	N
———	temp: 00,12	1351	1425.8	1481	41.9	12
·········	PARLAM-PS2: 00+12 12+12	1345	1422.6	1484	43.2	13
– – –	Eurolam2: 00+12 12+12	1352	1427.3	1488	42.1	13

	Bias	Std.err.	RMSE	MAE	Max.abs.err.	N
PARLAM-PS2 - temp	-5.3	6.3	8.2	6.9	17	11
Eurolam2 - temp	0.4	5.3	5.3	4.4	9	11

(b)

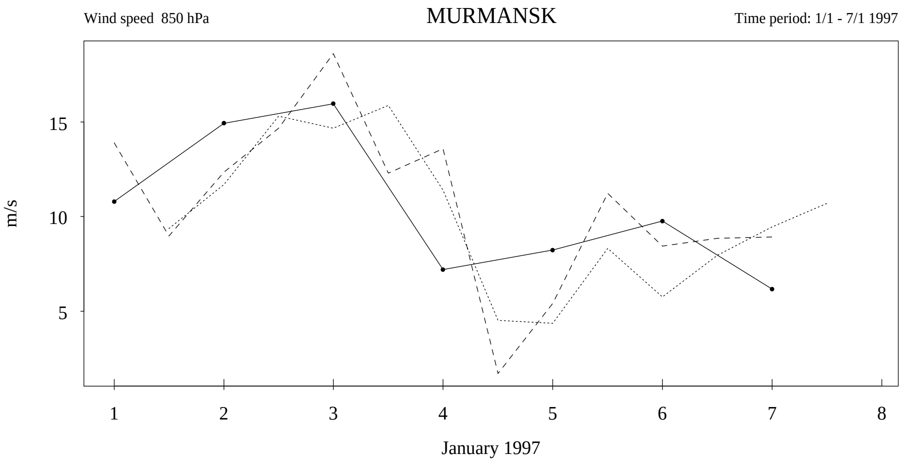


		Min	Mean	Max	Std	N
———	temp: 00,12	1421	1480.5	1527	37.4	14
·········	PARLAM-PS2: 00+12 12+12	1432	1486.2	1538	40.6	13
– – –	Eurolam2: 00+12 12+12	1420	1482.7	1535	43.6	14

	Bias	Std.err.	RMSE	MAE	Max.abs.err.	N
PARLAM-PS2 - temp	3	7.8	8.4	7.6	11	13
Eurolam2 - temp	2.2	8.6	8.9	6.6	21	14

Figure B1. One week timeseries and statistics of the 850 hPa geopotential height at Warszawa in (a) January and (b) July, 1997.

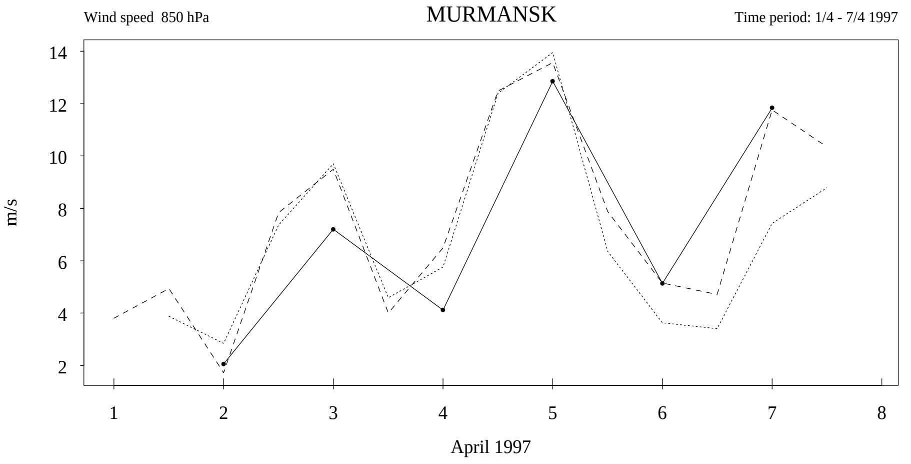
(a)



	Min	Mean	Max	Std	N
—— temp: 00	6.2	10.4	16	3.8	7
⋯⋯ PARLAM-PS2: 00+12 12+12	4.4	10	15.9	3.8	13
– – – Eurolam2: 00+12 12+12	1.7	10.7	18.6	4.3	13

	Bias	Std.err.	RMSE	MAE	Max.abs.err.	N
PARLAM-PS2 - temp	-0.8	3.7	3.8	3.3	4.2	6
Eurolam2 - temp	1.2	3.5	3.6	3.1	6.4	7

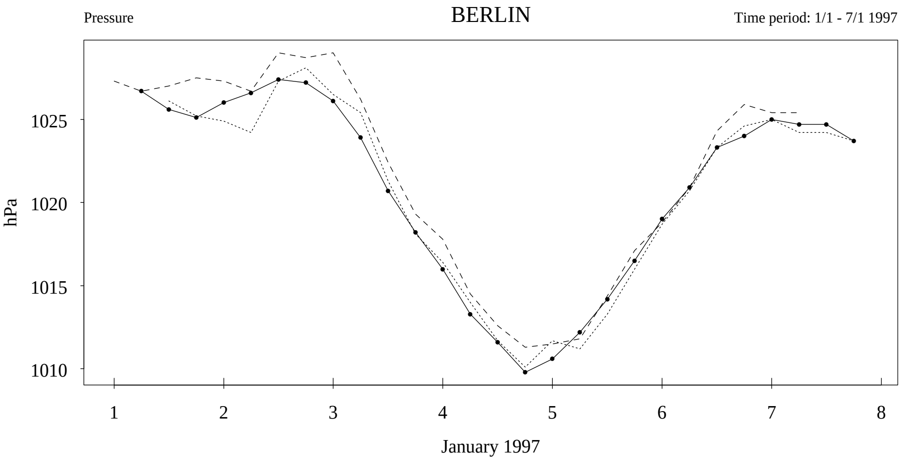
(b)



	Min	Mean	Max	Std	N
—— temp: 00	2.1	7.2	12.9	4.3	6
⋯⋯ PARLAM-PS2: 00+12 12+12	2.8	6.9	14	3.5	13
– – – Eurolam2: 00+12 12+12	1.7	7.4	13.6	3.6	14

	Bias	Std.err.	RMSE	MAE	Max.abs.err.	N
PARLAM-PS2 - temp	0	2.5	2.5	2	4.4	6
Eurolam2 - temp	0.8	1.2	1.5	1	2.4	6

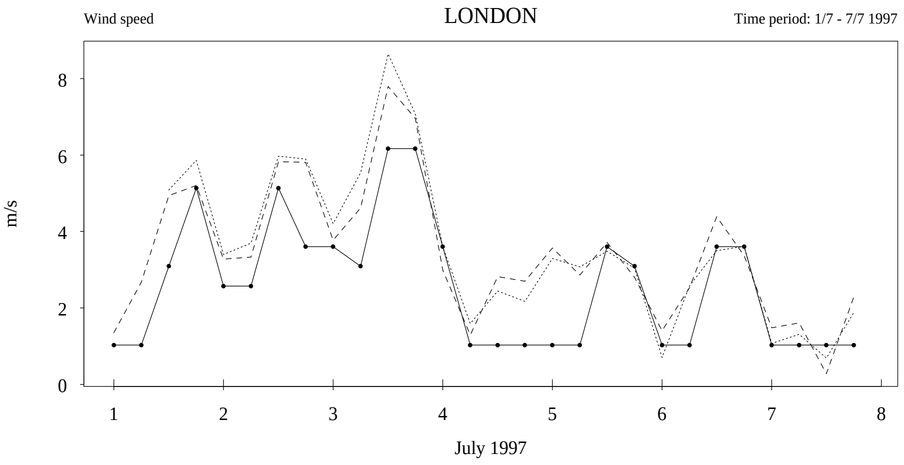
Figure B2. One week timeseries and statistics of the horizontal wind at 850 hPa at Murmansk in (a) January and (b) April, 1997.



	Min	Mean	Max	Std	N
——— synop: 12,18,00,06	1009.8	1020.9	1027.4	5.8	27
········ PARLAM-PS1: 00+12 06+12 12+12 18+12	1010.1	1020.6	1028.1	5.7	26
– – – – Eurolam1: 00+12 06+12 12+12 18+12	1011.3	1022	1029	6.1	27

	Bias	Std.err.	RMSE	MAE	Max.abs.err.	N
PARLAM-PS1 - synop	0	0.8	0.8	0.6	2.4	26
Eurolam1 - synop	1.1	0.8	1.4	1.1	2.9	26

Figure B3. One week timeseries and statistics of the mean sea level pressure at Berlin in January, 1997

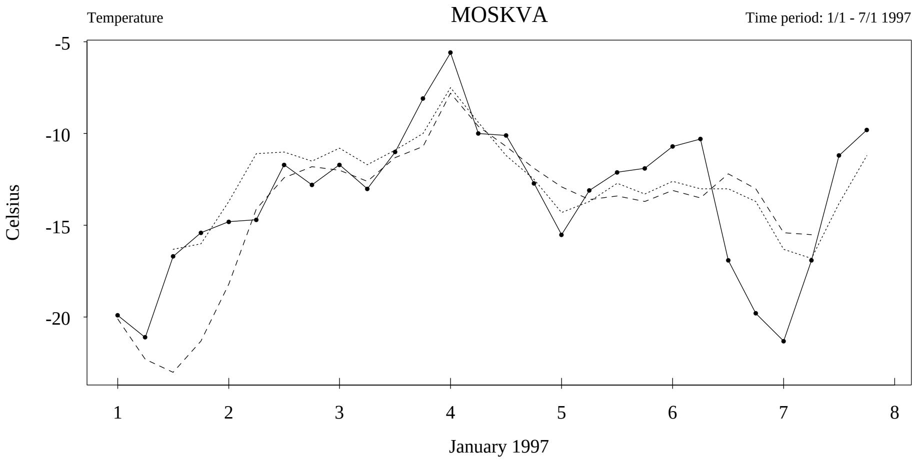


	Min	Mean	Max	Std	N
——— synop: 12,18,00,06	1	2.6	6.2	1.7	28
········ PARLAM-PS1: 00+12 06+12 12+12 18+12	0.7	3.6	8.6	2	26
– – – – Eurolam1: 00+12 06+12 12+12 18+12	0.3	3.4	7.8	1.8	28

	Bias	Std.err.	RMSE	MAE	Max.abs.err.	N
PARLAM-PS1 - synop	0.9	0.9	1.3	1	2.5	26
Eurolam1 - synop	0.8	0.9	1.2	1	2.5	28

Figure B4. One week timeseries and statistics of the wind at 10 m at London in July, 1997

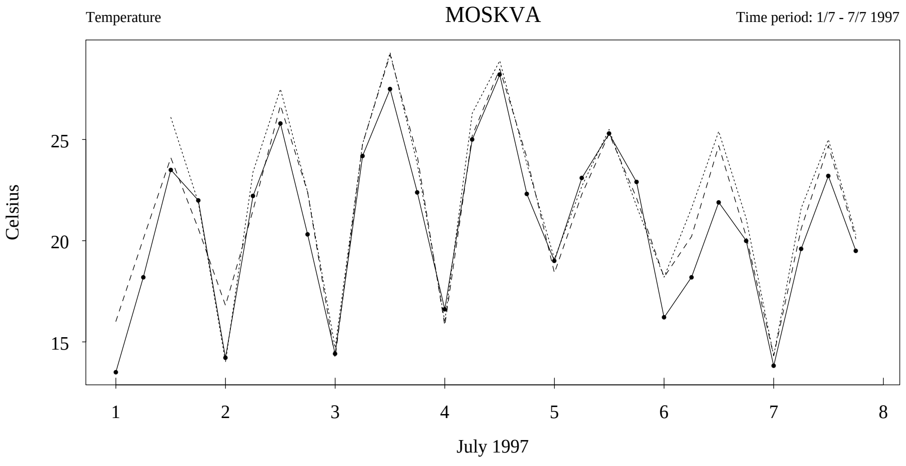
(a)



	Min	Mean	Max	Std	N
—— synop: 12,18,00,06	-21.3	-13.5	-5.6	3.9	28
········ PARLAM-PS1: 00+12 06+12 12+12 18+12	-16.8	-12.6	-7.5	2.2	26
– – – – Eurolam1: 00+12 06+12 12+12 18+12	-23	-14	-7.8	3.8	27

	Bias	Std.err.	RMSE	MAE	Max.abs.err.	N
PARLAM-PS1 - synop	0.4	2.2	2.3	1.7	6.1	26
Eurolam1 - synop	-0.3	3	3	2.2	6.8	27

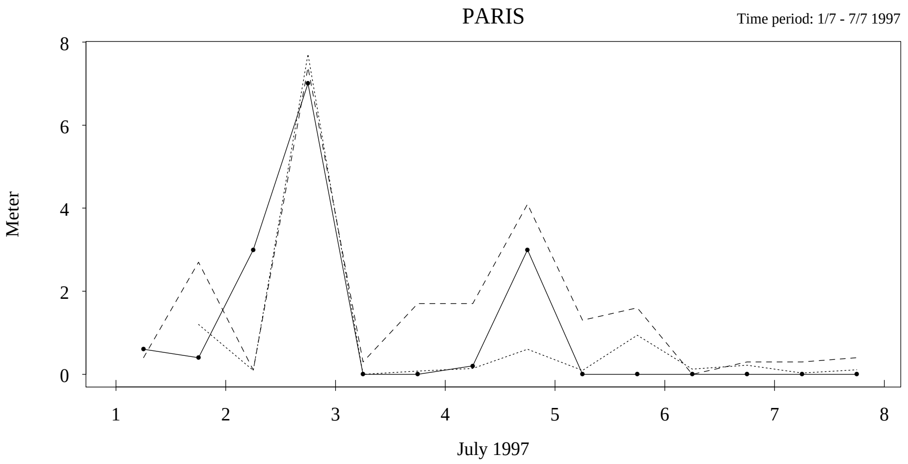
(b)



	Min	Mean	Max	Std	N
—— synop: 12,18,00,06	13.5	20.8	28.2	4.1	28
········ PARLAM-PS1: 00+12 06+12 12+12 18+12	14	22.3	29.3	4.3	26
– – – – Eurolam1: 00+12 06+12 12+12 18+12	14.2	21.6	29.2	4	28

	Bias	Std.err.	RMSE	MAE	Max.abs.err.	N
PARLAM-PS1 - synop	1.1	1.2	1.6	1.3	3.5	26
Eurolam1 - synop	0.8	1.2	1.4	1.2	2.8	28

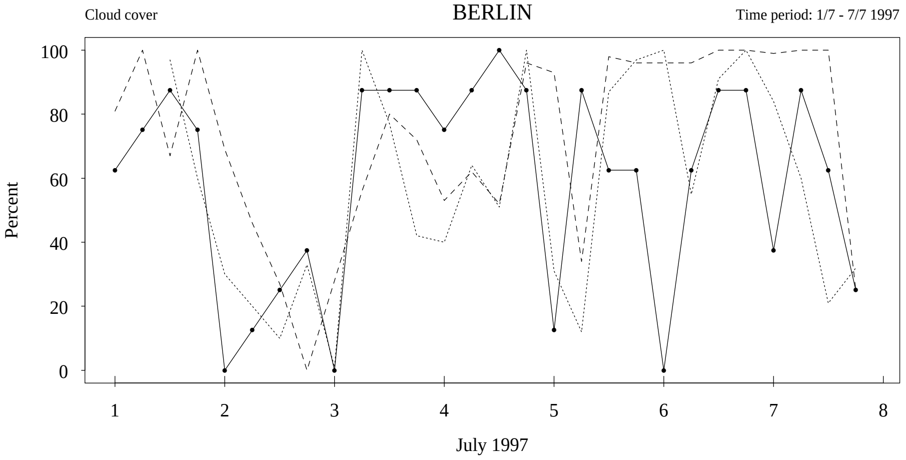
Figure B5. One week timeseries and statistics of the temperature at 2 m at Moscow in (a) January and (b) July, 1997.



	Min	Mean	Max	Std	N
—— synop: 18,06	0	1	7	2	14
········ PARLAM-PS1: 06+12 18+12	0	0.9	7.7	2.1	13
- - - - Eurolam1: 06+12 18+12	0	1.6	7.4	2	14

	Bias	Std.err.	RMSE	MAE	Max.abs.err.	N
PARLAM-PS1 - synop	-0.2	1.2	1.2	0.7	2.9	13
Eurolam1 - synop	0.6	1.2	1.4	1	2.9	14

Figure B6. One week timeseries and statistics of the 12 hour accumulated precipitation (in mm) at Paris in July, 1997



	Min	Mean	Max	Std	N
—— synop: 12,18,00,06	0	59.4	100	32.6	28
········ PARLAM-PS1: 00+12 06+12 12+12 18+12	1	57.5	100	32.9	26
- - - - Eurolam1: 00+12 06+12 12+12 18+12	0	72.4	100	29.6	28

	Bias	Std.err.	RMSE	MAE	Max.abs.err.	N
PARLAM-PS1 - synop	-1.2	35.2	35.2	25.8	100	26
Eurolam1 - synop	13	37.5	39.6	31.7	96	28

Figure B7. One week timeseries and statistics of the total cloud cover at Berlin in July, 1997 (instantaneous values for SYNOP and EUROLAM, and 12-hour averages for PARLAM-PS)

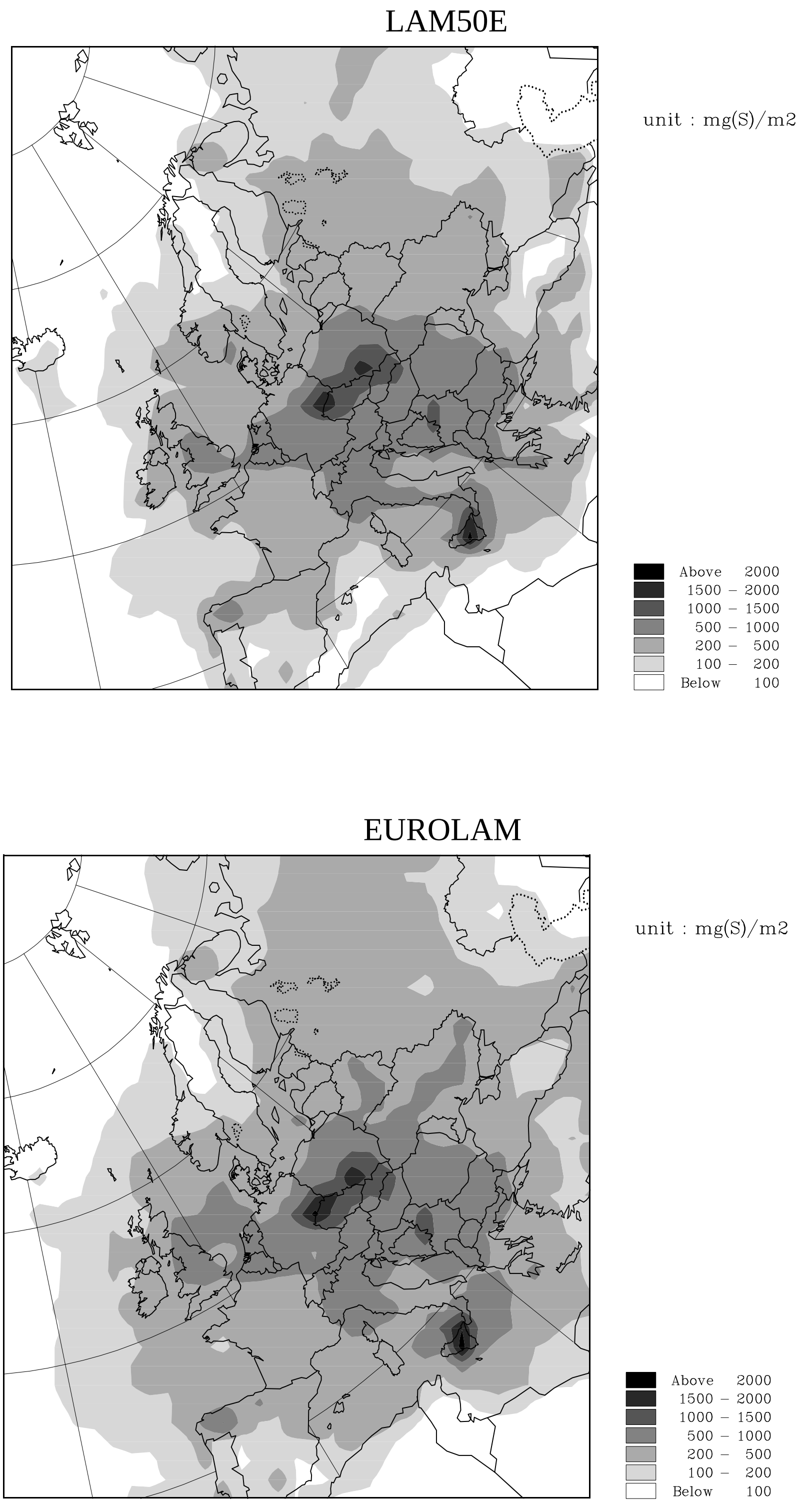


Figure B8. Wet deposition of oxidised sulphur in 1996 calculated by LAM50E and EUROLAM