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KNMI

Abstract

This paper describes the research of predicting regional differences in ABL parameters with the multi-layer AMT-model. The results are also compared with the model output of ECMWF's NWP-model. First the background of this research is given. Subsequently three case studies are discussed and an objective comparison is given. The AMT-model is able to predict regional differences in ABL parameters but it has the same skill as the ECMWF-model. Nevertheless the AMT-model is a useful tool, which will give the forecaster a quick indication if regional differences will occur in the next 12 hours.

1 Introduction

During the evaluation of the multi-layer AMT-model (Air Mass Transformation), the question arose if the multi-layer AMT-model could forecast regional differences in boundary layer parameters. Another question was whether the multi-layer AMT-model has more skill than a NWP-model (Numerical Weather Prediction model) in predicting boundary parameters on such small scale. We decided to develop a system in which forecasts were made for five stations, spread over the Netherlands (see Fig. 1). During three months in the summer of 1989 model output was collected and examined. Three cases were taken from this set and studied in more detail. To obtain predictions from a NWP-model, data were retrieved from the MARS archive of the European Centre for Medium Range Weather Forecasts (ECMWF) in Reading (UK).

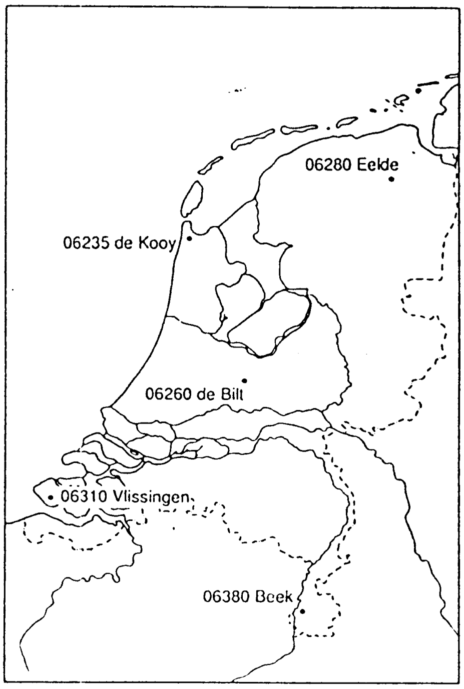

Fig. 1 The five stations used for the research of regional differences

The high resolution AMT-model was originally developed by Holtslag et al. (1990) at KNMI. A one-dimensional boundary layer model describes the evolution of the boundary layer along predicted trajectories. The Netherlands is situated close to the North sea. The effect of land-sea transitions is important for the properties of the air mass over the Netherlands. With the AMT-model we can calculate the changes in the ABL due to surface forcings along the trajectory. In this study, special attention will be given to the occurrence of regional differences.

We examined if the multi-layer AMT-model and the ECMWF-model are able to forecast regional differences. Therefore we compared the temperature and dew point depression at screen height and the low level cloud cover with observations. At location De Bilt we compare the profiles of temperature and humidity. The impact of the AMT-model in relation with the ECMWF-model in predicting regional differences is presented in scatter diagrams.

2 Background

2.1 Calculation of trajectories

To calculate the track of an air mass we use trajectories from United Kingdom Meteorological Office (UKMO), based on predicted wind fields from the fine mesh NWP-model. The trajectories are calculated backward, starting from the receptor point. The limited area model is described by Bell and Dickinson (1987).

The trajectories are calculated at four levels. There are three pressure levels defined at 850, 700 and 500 hPa. Because these trajectories experience vertical motion, the initial pressures will be different from the end pressure. The lowest trajectory is defined at a fixed σ-level, where $\sigma = p/p_0$. Here p is the actual pressure and p_0 is the surface pressure within the large scale model. We take $\sigma=0.975$ for the lowest trajectory, which means that this trajectory follows the larger scale topography at a height of about 200 m. We have used trajectories with a forecast period of 12 hours ahead. They start either at 00 GMT or at 12 GMT. This means that the trajectories will arrive during day and night time.

2.2 AMT-model

The AMT model describes the evolution of the boundary layer due to the exchange of heat, water vapour and momentum at the earth's surface and due to entrainment of air from above the ABL.

Evolution equations for potential temperature and relative humidity can be derived from K-theory (Troen and Mahrt, 1986). A numerical scheme to integrate these equations in time has been adopted from Oregon State University (H,-L Pan, 1987) and is modified according to the description in Holtslag et al (1990).Over sea the surface temperatures and the wind speed determine the transfer of heat, water vapor and momentum to the boundary layer. Over land the energy balance method is used to calculate the surface fluxes according to Holtslag and Van Ulden (1983) and Van Ulden and Holtslag (1985).

The calculation of the surface fluxes over land is influenced by the cloud cover. The cloud cover at middle and high level are obtained from the UKMO fine mesh model, while the ABL clouds are calculated in the model. Depending on the amount of moisture in the top at the boundary layer the cloud cover is estimated. The vertical component of the velocity plays an important role on the effect of mixing air from higher level to the boundary layer.

The definition of the land-sea mask is included in the AMT-model. Fig. 2 shows this land-sea mask. The horizontal resolution is 20 kilometers. From Fig. 2 it can be seen that the Lake IJssel is well represented by this land-sea mask.

2.3 ECMWF forecasts

The ECMWF-model is a global spectral model with a triangular truncation at zonal wavenumber 106 (T106). In the vertical 15 η-levels are defined. Near the surface this η-system approaches asymptotically the σ-system whereas it turns onto a pressure system at the highest levels An analysis is produced four times a day and once a day forecasts up to 72 hours ahead are calculated.

Forecasts of the ECMWF are stored in a special archive, the so-called MARS. The MARS archives include daily operational field data and we have retrieved predicted fields from that database. The fields are stored as complex amplitudes of spherical harmonics and after the retrieval they are transformed to a Gaussian grid. The gridpoint distance is about 1.5 degrees. We have selected gridpoints nearby the five receptor points. De Kooy and Vlissingen

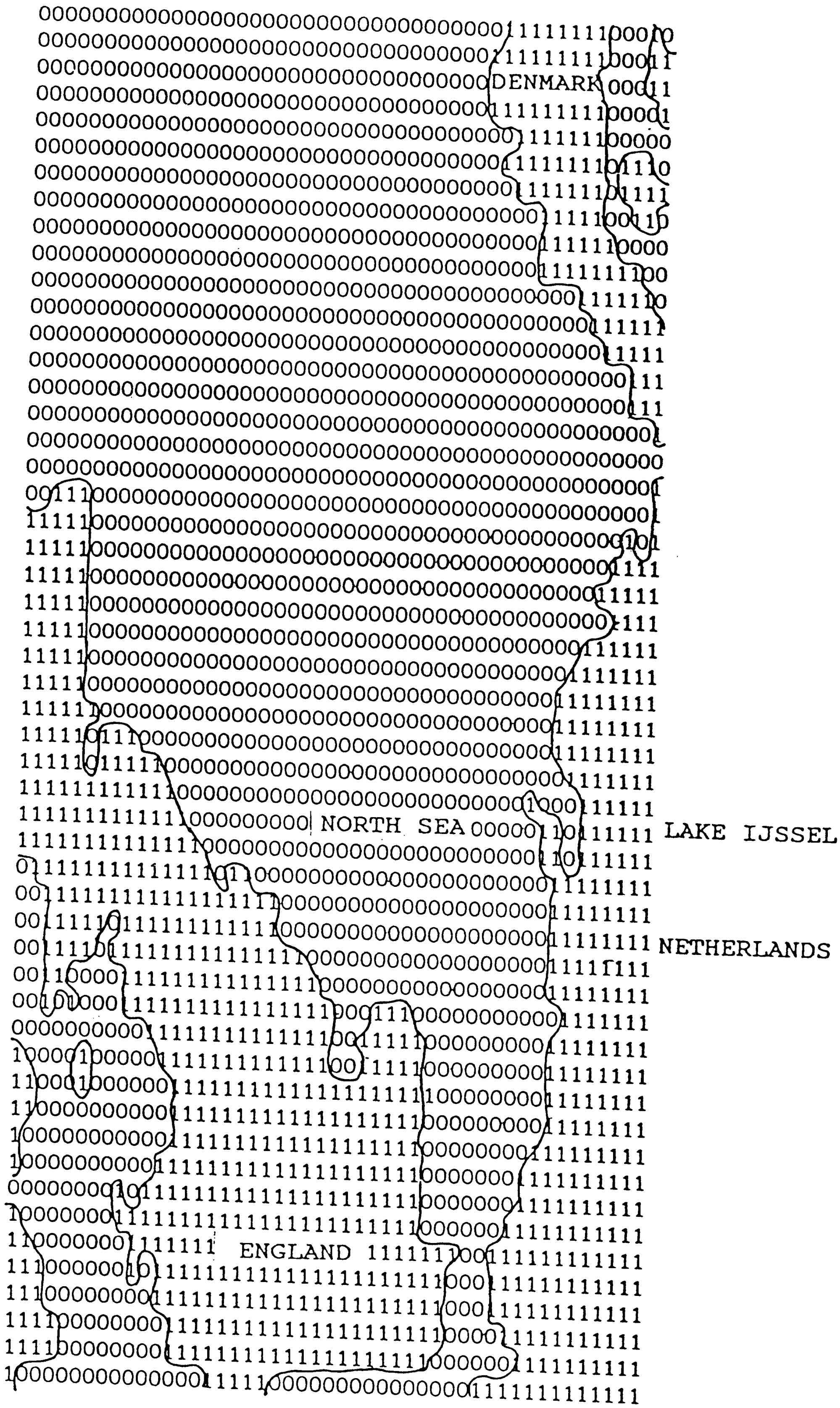

Fig. 2 Part of the land-sea mask as defined in the AMT-model

are typically sea points while the other stations are characterized as land points. The forecast period of the retrieved fields is 24 h. This means that the ECMWF-model is operationally available at the same time as the 12 h forecast of the AMT-model.

2.4 Geography and climate of the Netherlands

Before analyzing the regional differences of the predicted results, it is necessary to give a short overview of the geography and the climate of the Netherlands. The Netherlands is situated between 4 and 7 degrees E longitude and 51 and 53.5 N degrees latitude. To the west the country borders on the North Sea. In the middle of the Netherlands there is Lake IJssel which turns into the Dutch Shallows in the North. The Netherlands are extremely flat, only in the south east there are a few hills. Because a the western part of the Netherlands lies below the sea level, the soil must be regarded as saturated.

Since the prevailing winds are westerly, the Netherlands has a moderate sea climate. The average temperature is 2 degrees Celsius in winter and 17 degrees Celsius in summer. The annual rainfall is 700 mm, fairly evenly distributed over the year.

3 Case studies

3.1 Influence of the Lake IJssel in daytime conditions

On the 8^{th} of September 1989 from 0000 to 1200 GMT the weather in Western Europe was governed by two high pressure systems. The first one is situated above West Russia and the second one over the Atlantic, westward from Ireland. The wind in the Netherlands comes from easterly directions and the weather is fine.

All the trajectories originate in West-Germany. The vertical motion of the trajectories to De Bilt and Vlissingen is downwards all the time while the other trajectories show a small track where the vertical movement is upward for about 2 hours (Fig.3a). The trajectories are plotted with a dotted and a solid line when they go up and down respectively. Only the lowest trajectories are

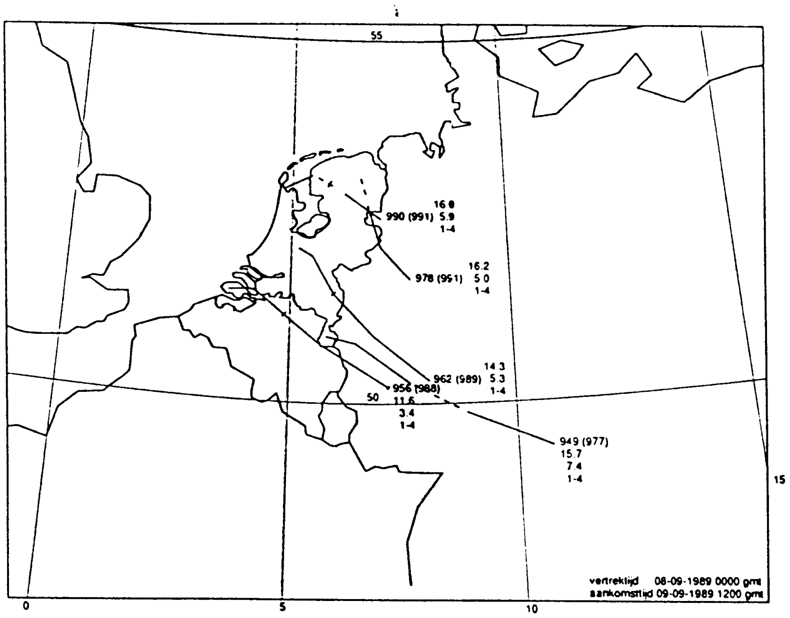

Fig. 3a 12 h trajectories arriving at 8 Sept 1989 12 h UTC
At the beginning the initial pressure and the endpressure (within parentheses) of the lowest trajectory are indicated. Further the initial values of temperature, dewpoint depression and ABL cloud cover are given.

presented because they are supposed to be representative for the advection of the Atmospheric Boundary Layer (ABL). The trajectories of Beek, Vlissingen and De Bilt start with wind speeds of 9-12 m/s, decreasing to 5-6 m/s at arrival time. The trajectories of De Kooy and Eelde start with wind speeds of 5 m/s. The wind decreases to 1 m/s but in the end it increases again to 4 m/s for De Kooy only ! The trajectory of De Kooy passes the northern part the Lake IJssel in about three hours. Apart from the trajectory of De Kooy, there are no clouds predicted on the middle and high level along the trajectories, so the largest part of the Netherlands will have clear sky conditions. In the following diagrams we present observations and predictions for five locations in the Netherlands according to the following format:

De Kooy Eelde
De Bilt
Vlissingen Beek

observation		ECMWF		AMT	
18.7	21.6	18.4	25.8	18.2	24.0
22.9		26.0		22.5	
22.1	21.9	19.5	25.0	23.8	20.4

Table 1 :Diagram of predicted and observed T_{2m} in the Netherlands

observation		ECMWF		AMT	
3.7	7.3	4.4	11.1	3.2	12.5
12.5		12.8		10.5	
11.1	11.7	7.7	13.9	12.7	8.2

Table 2: Diagram of predicted and observed $T-T_d$ in the Netherlands

No clouds were observed, nor predicted by any model in this case. So the low level cloud cover is in accordance with the observations. The temperature (table 1) and the dew point depression (table 2) show regional differences. De Kooy has the lowest T_{2m} and the smallest dew point depression, which is in good agreement with the observations. Vlissingen and De Kooy are regarded as seapoints by the ECMWF-model. The influence of the sea is over estimated and the advection of warm air from easterly directions is neglected. This leads to unrealistic regional differences.

During the first nine hours the circumstances are similar along the trajectories. Since there are no clouds the surface temperature is decreasing slowly due to radiative cooling of the soil. The heat and moisture flux are negative and the ABL is stable and has a height of 75 m. From 5.00 LT the sun rises and the surface temperature starts to increase steadily and the surface fluxes become positive. About 9.00 LT the trajectory of De Kooy arrives above Lake IJssel. The surface temperature of the water is 16.3 degrees Celsius while the air mass has already a temperature of 18.6 degrees Celsius. The ABL becomes stable and the boundary layer height decreases from 290 to 25 m. Because the temperature of the air mass is still higher than the sea surface the air mass cools slowly to the end value of 18.2 degrees Celsius.

3.2 Advection from land and sea at nighttime conditions

In this case of the 8^{th} of September 1989 from 1200 UTC to 9^{th} September 0000 UTC the weather situation is similar to the previous described case (see 3.1). The Netherlands is under the influence of a high pressure system. The wind blows from the North-East and varies from 6-12 m/s during the advection period. In the beginning the air mass is unstable and the ABL height reaches 1500 m.

Most trajectories (Fig. 3b) arrive over land, only the trajectory of De Kooy travels mainly over sea. The wind speed of that trajectory increases from 4 m/s in the beginning to 12 m/s in the end. In the northern part of the Netherlands the large scale model has predicted a cloud cover which varies from 1 to 3 octa's. In the rest of the country there are clear sky conditions. The vertical motion is completely upward for Vlissingen, while for Beek it is downward. The other trajectories partly experience downward and upward motion.

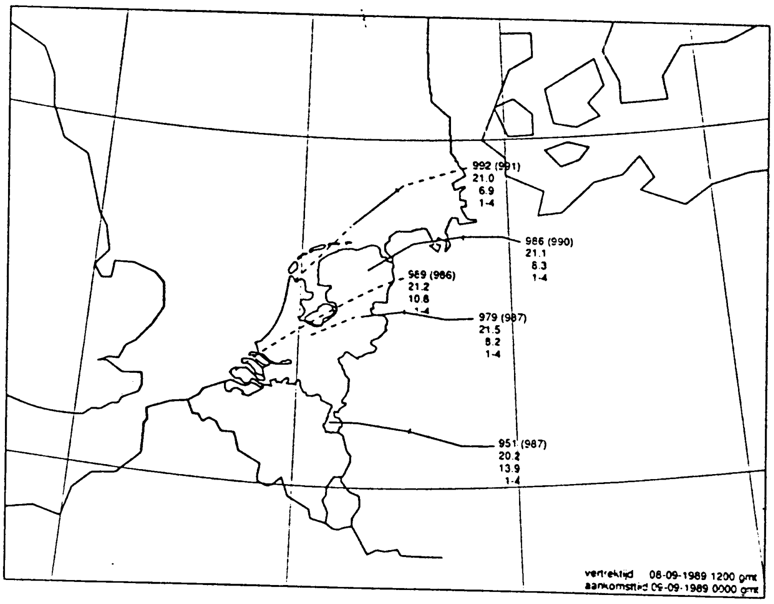

Fig. 3b 12 h trajectories arriving at 9 Sept 1989 00 h UTC

From the observations in table 4-6 we can see that there are no big regional differences. Only Beek and De Kooy differ from the rest. The boundary conditions for the trajectories of Eelde, De

Bilt and Vlissingen are similar. Because there are clear sky conditions with less wind the T_{2m} decreases, a ground inversion can be formed and the dew point depression decreases. The ECMWF-output shows differences between De Kooy and Vlissingen and the other stations. The temperature and the dew point depression are mainly determined by the sea surface temperature. The ECMWF-model predicts a lower temperature in Beek which can be also concluded from the observations.

The situation of the trajectory of De Kooy is different. The starting point is on the continent (Denmark) but after 40 minutes the ABL travels over sea . The wind speed increases in the end. In the beginning the ABL cools a little because the sea surface temperature is lower than the temperature of the ABL above land. After some time the temperature stabilizes and increases only slightly, due to higher SST when approaching De Kooy. The ABL is nearly neutral, while the other stations show a stable ABL with a ground inversion. From table 4 we can see that the predictions for Beek do not agree with the observations at all. Regarding the observations we may conclude that the local circumstances are extremely stable. Less wind than predicted and radiative cooling cause a big ground inversion. The AMT-model does not feel the decrease of the wind resulting in too much mixing which over estimated the temperature and the dew point depression.

observation			ECMWF			AMT		
17.0		14.6	17.0		15.5	18.0		15.6
	15.5			13.8			14.8	
17.1		12.5	17.6		10.7	15.9		16.3

Table 4 :Diagram of predicted and observed T_{2m} in the Netherlands

observation			ECMWF			AMT		
1.2		0.6	0.9		4.0	3.4		0.1
	1.5			5.4			2.0	
1.4		3.0	2.0		8.0	8.3		13.8

Table 5: Diagram of predicted and observed $T-T_d$ in the Netherlands

observation			ECMWF			AMT		
6		0	2		0	0		0
	0			0			0	
0		0	0		0	0		0 .

Table 6: Diagram of predicted and observed N_l (low level cloud cover) in the Netherlands

3.3 Advection from sea in a summer night

On the 29th of June 1989 00 h UTC a cold front has just passed over the Netherlands. The pressure is increasing and the vertical motion is downward. This mechanism explains why the moisture above the ABL is disappearing. Warmer air can contain more water vapor. Within twelve hours the air mass has completely changed. The trajectories (Fig. 3c) come from the North West and start at sea. The wind speed, according to the trajectories varies from 7-8 m/s in the beginning to 6-7 m/s at arrival time.

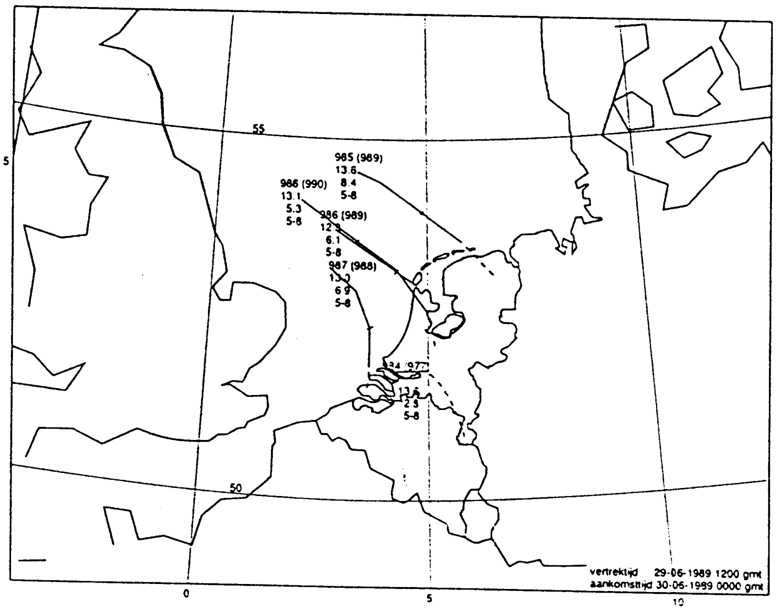

Fig. 3c 12 h trajectories arriving at 30 June 1989 00 h UTC

In the first six hours the vertical motion is downward, but after that period it changes sign and becomes upward. The predicted cloud cover on middle and high level is zero octa's, so there will be clear sky conditions over the Netherlands, except the trajectory of Beek which has a predicted cloud cover starting from 7 octa's in the beginning and decreasing to 1 octa in the end. After 20 minutes the trajectory of Beek arrives over land. At first the temperature rises and then the low clouds are formed, so the temperature stabilizes. About 20.00 local time the ABL has become stable and a ground inversion is formed. The ABL height is 100 m, the air becomes saturated and the AMT-model creates 1-4 octa's ABL clouds. Due to the ground inversion the dew point depression decreases to 0.4 degrees Celsius. From the SYNOP-report we know that fog patches are observed. From the diagrams in the tables (7-9) it is clear that the AMT-model results agree with the observations. From the ECMWF output we see that the tendency in the regional differences between land and sea stations can be found in the observations as well. The absolute values of all predicted parameters are better predicted by the AMT-model.

The trajectories of De Kooy and Vlissingen stay over sea during 12 hours. Since the sea is warmer than the air above, the moisture and heat flux remain positive. Moisture and heat are mixed into the boundary layer. The model exaggerates this process resulting in too high temperatures and too small dew point depressions. In fact the model generates too much turbulence. The trajectories of De Bilt and Eelde have travelled over land for two and one hours respectively, before arriving at the receptor point. Above sea low level clouds are formed. Coming over land the temperature stabilizes and start to decrease slightly and a ground inversion is formed. Because the trajectory of De Bilt stays longer above land the air has cooled much more than the air in Eelde.

observation		ECMWF		AMT	
10.5	7.4	12.0	8.5	13.7	9.6
6.5		10.0		8.5	
11.5	10.5	12.9	11.8	13.5	9.9

Table 7 :Diagram of predicted and observed T_{2m} in the Netherlands

observation		ECMWF		AMT	
3.9	0.4	5.9	4.2	6.1	4.1
0.0		3.0		2.5	
4.0	0.0	3.9	0	5.5	0.4

Table 8: Diagram of predicted and observed $T-T_d$ in the Netherlands.

observation		ECMWF		AMT	
8	4	0	0	5-8	0
0		0		0	
0	8	0	4	1-4	1-4.

Table 9: Diagram of predicted and observed N_l (low level cloud cover) in the Netherlands

The low level cloud cover is underestimated in station Eelde resulting in differences in T_{2m} and $T-T_d$. From the tables (8-9) we can see that the AMT-model indicates regional differences in the forecasted parameters. Moreover the dewpoint depression and the low level cloud cover are better predicted by the AMT-model than by the ECMWF-model.

4 Objective comparison of the model output

4.1 Predicted profiles for station De Bilt

Regional differences will occur mainly due to differences in the ABL. In the comparison as described in the previous section we assume that the air mass does not differ much from 850 mbar to 500 mbar over the Netherlands. In station De Bilt where daily radiosonde observations are available, we compare the profiles from the AMT- and ECMWF-model (see also Holtslag et al 1990).

On the 8th of September 1989 at noon (Fig.4a) the observed profile shows an unstable ABL. The ABL height of the observation is close to the AMT-model result and lies around 825 hPa. Near the inversion aloft there is small layer with dry air, which is also represented by the AMT-model. The ECMWF-model shows also an unstable ABL up to 825 hPa, but the area with the dry layer is not foreseen.

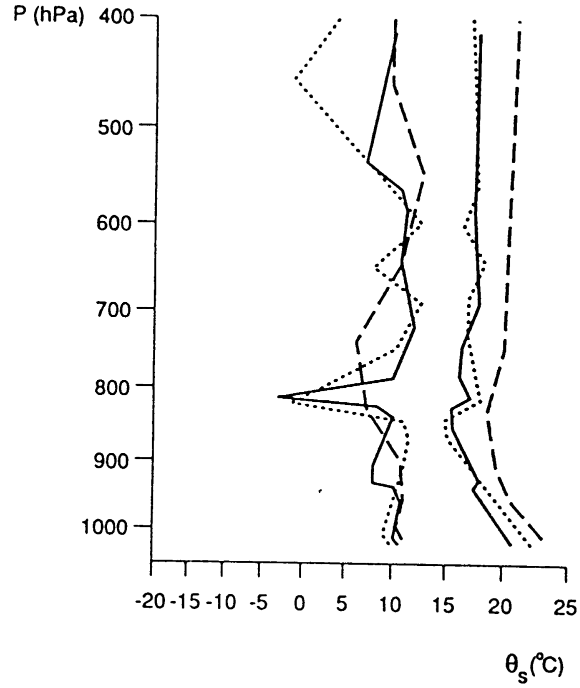

Fig.4a 8 September 1989 12 h UTC

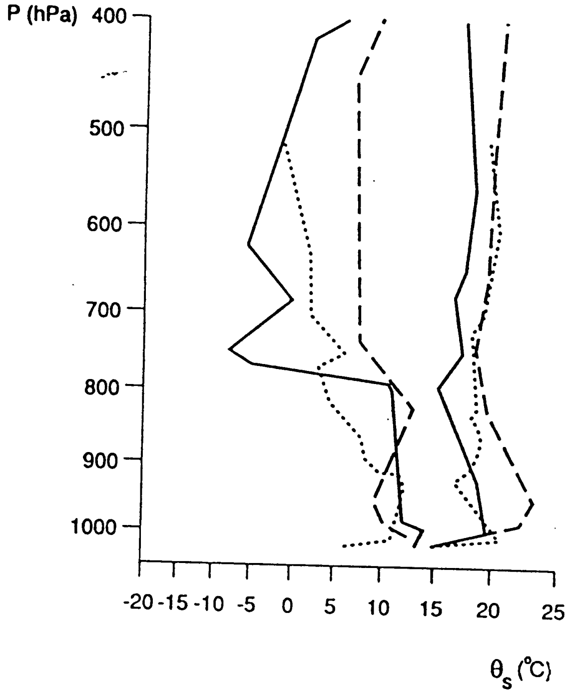

Fig.4b 9 September 1989 00h UTC

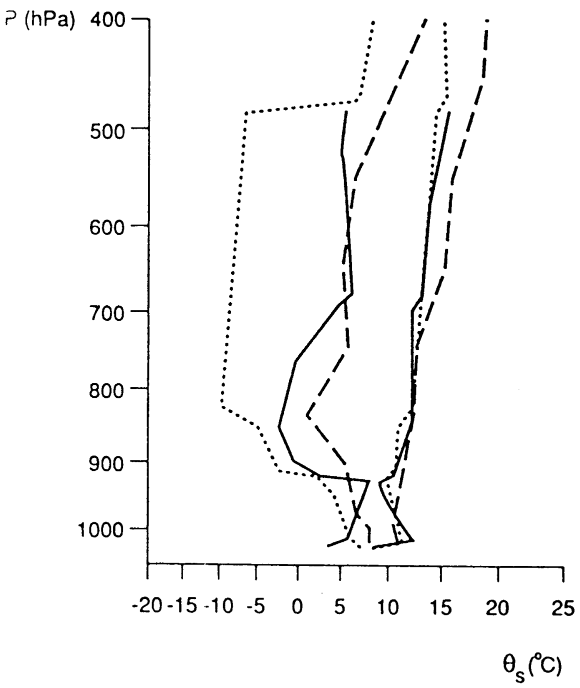

Fig.4c 30 June 1989 00 h UTC

—— Observed profile

······ AMT +12 h prediction

– – – ECMWF +24 h prediction

Here the humidity profile is at lhs and the temperature is at rhs

On the 9th of September 1989 at midnight (Fig.4b) the atmosphere has become stable, but the ABL height from the convective circumstances during day time can be easily recognised. At the surface level a ground inversion is formed. These characteristics are represented by both models. In the free atmosphere the air has become drier which is not predicted by the models.

On the 29th of June 1989 at midnight (Fig.4c) the observation shows a typical profile of a subsidence inversion. The air in the upper air is becoming warmer and drier. Due to radiative cooling at the surface level a ground inversion is formed. The air is nearly saturated. The AMT-model represents also the ground inversion, but the profile contains too much moisture in the upper air. The ECMWF-model shows a smooth profile with less details. The subsidence inversion is not well represented.

4.2 ABL parameters for the Netherlands

In this research we have chosen three parameters (temperature and dewpoint depression at screen height and ABL cloud cover) for the representation of the properties of the ABL In section 3 we have described three case studies. To determine the skill of the two models we focus on regional differences with station De Bilt, which is situated in the middle of the Netherlands. The results are summarized in so-called scatterplots.In Fig.5a, Fig.5b the observed and predicted regional differences are given of temperature and dew point depression respectively. The AMT- and ECMWF-model have about the same skill in predicting regional differences in temperature, but the forecast of the dew point depression is better represented by the ECMWF-model. The correlation coefficients and rms values are given in Table 10.

	n	AMT		ECMWF	
		cc	rms	cc	rms
T_{2m}.	12	0.76	0.54	0.74	0.76
T-Td	12	0.59	1.25	0.74	0.75

Table 10: Correlation coefficients and rms values for regional differences with De Bilt.

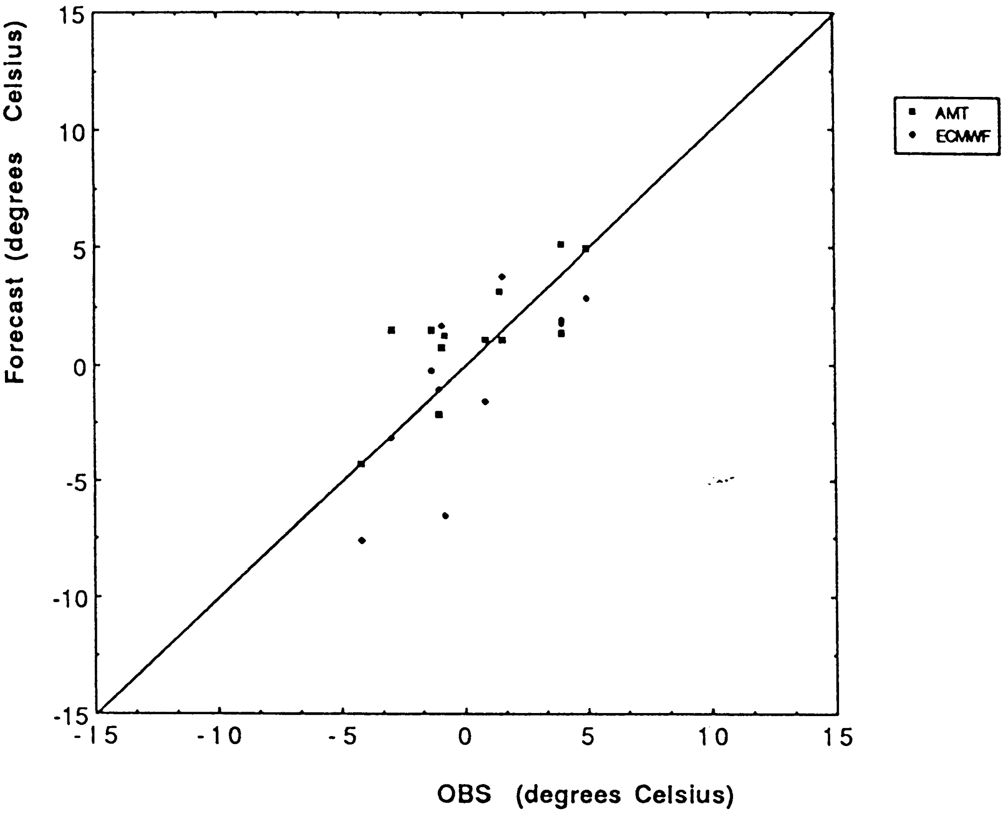

Fig. 5a Regional differences in T_{2m} with station De Bilt

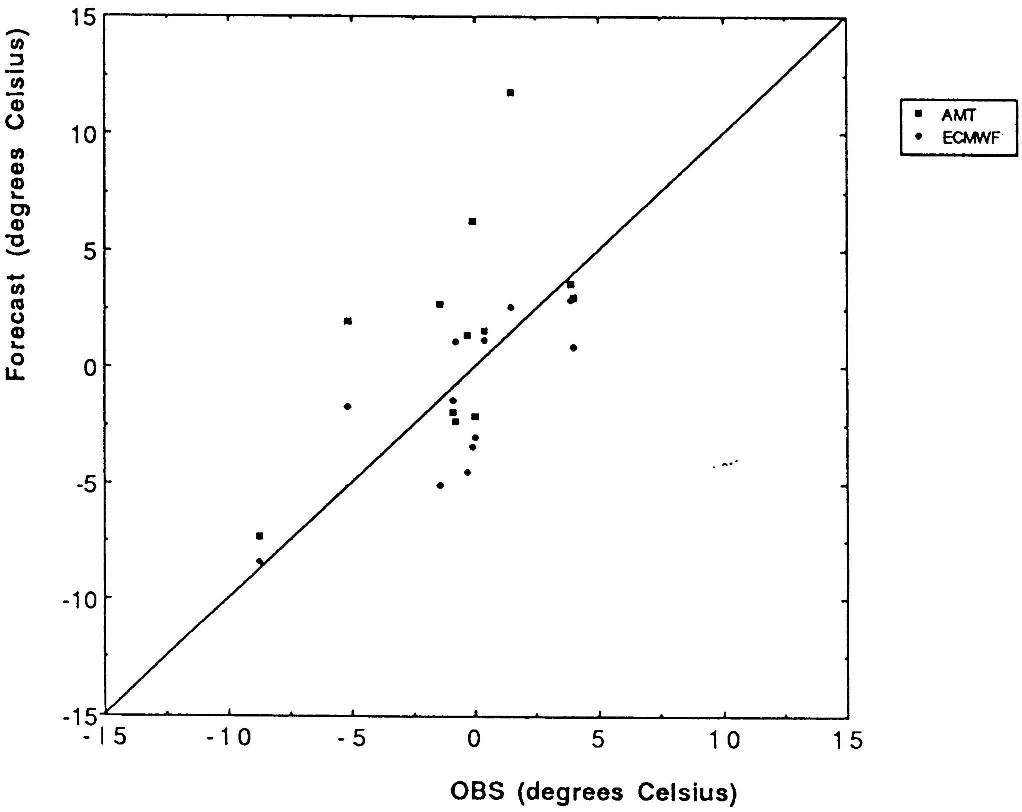

Fig. 5b Regional differences in $T-T_d$ with station De Bilt

The predictions of T-Td of the AMT-model are rather poor because one case has a very poor score and the sample is small (n=12).

5 Conclusions

Due to the horizontal resolution of the land-mask, the AMT-model is able to predict the regional differences caused by different surface forcing while passing over land or sea. The results are sensitive to the position of the land-sea transition of the calculated trajectory .

The AMT-model is based on a simple approach which can be run on a personal computer. It can be applied in other regions where land-sea discontinuities play an important role for the properties of the air mass.The AMT-model will give the forecaster at least an indication if regional differences will occur in the next 12 hours.

The AMT-model is able to forecast the temperature at screen height but it has the same skill as ECMWF's NWP-model. Although the cloud cover in the boundary layer is reasonably forecasted by the AMT-model, both AMT- and ECMWF-models are not optimal in forecasting the dew point depression at screen height. The treatment of moisture in physical models remains a difficult case and needs further attention in future research. Application of a higher order closure model might improve the representation of atmospheric moisture.

6 Acknowledgements

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