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Regionalisation of meteorological parameters

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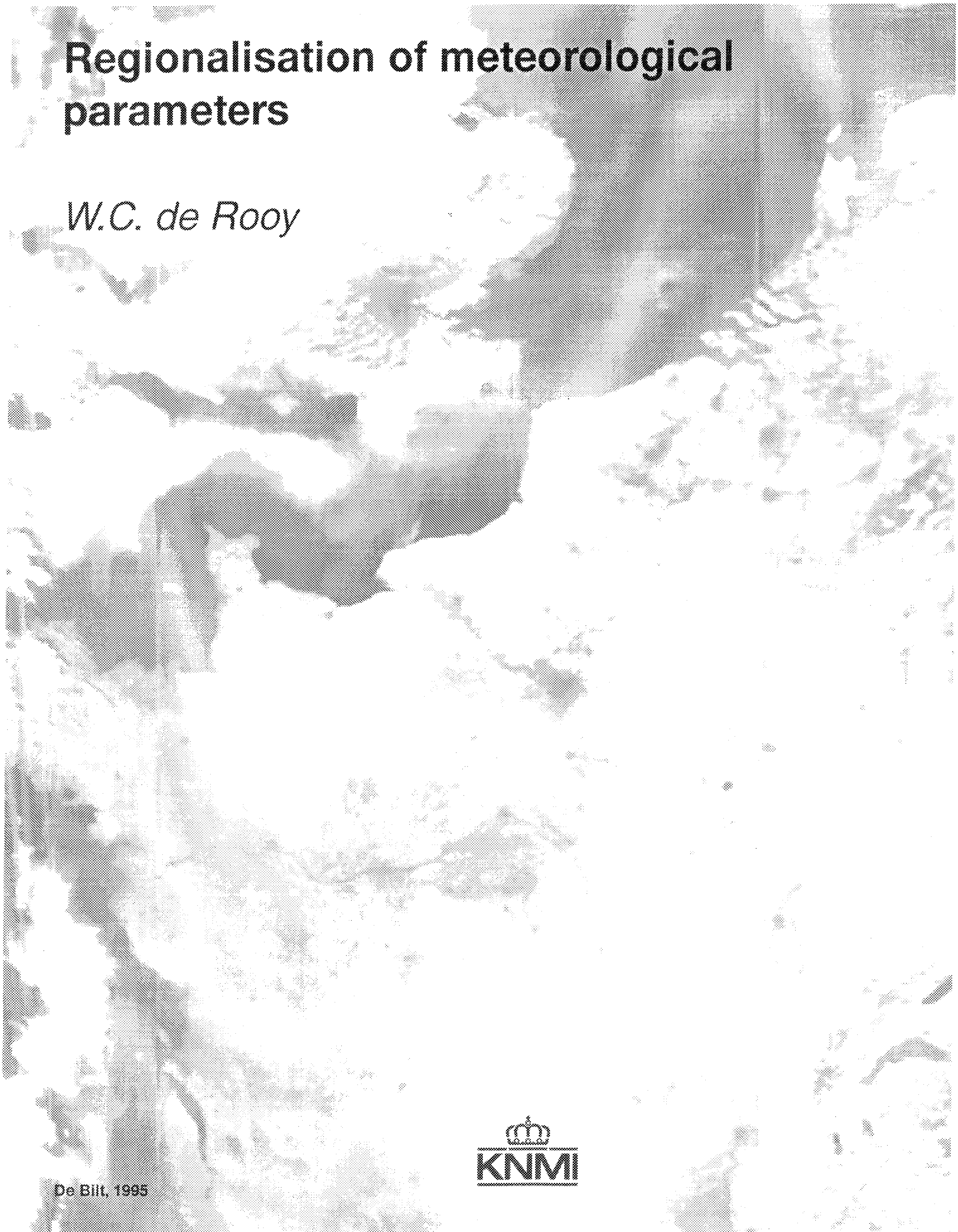

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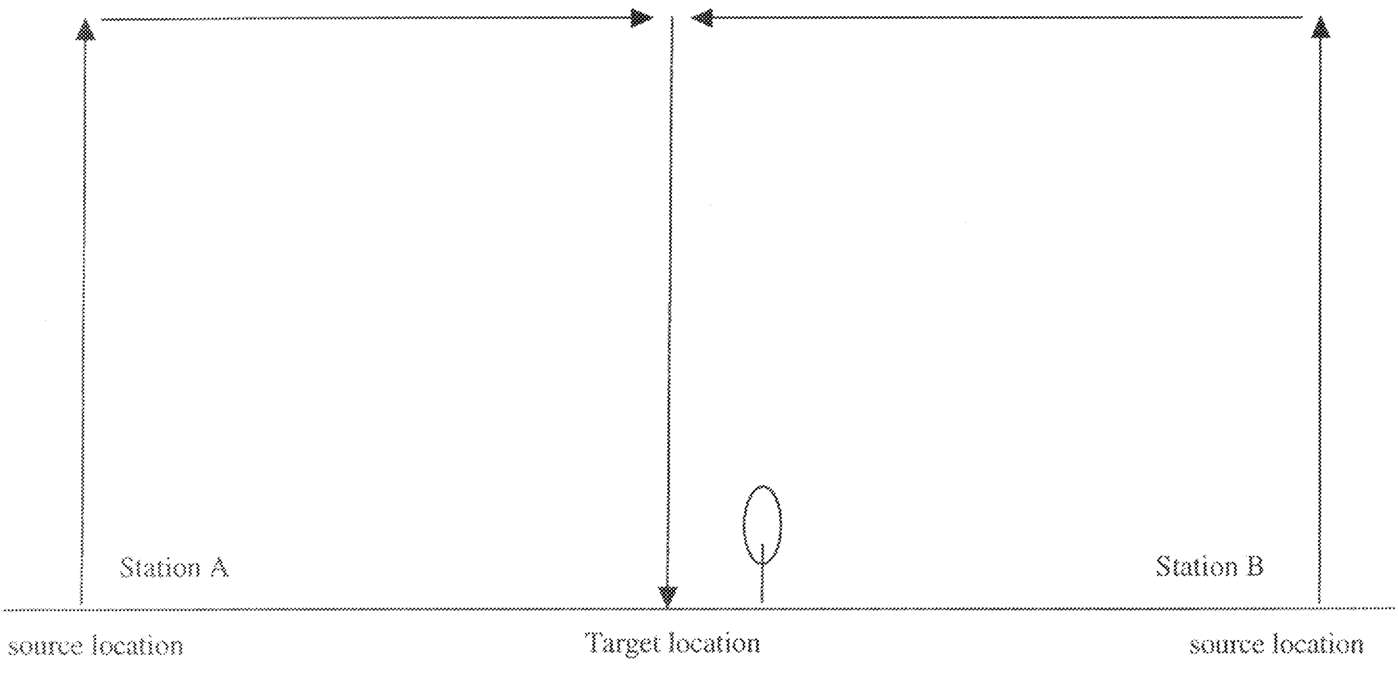


Contents

Abstract

The problem of calculating meteorological parameters at a certain location using observations from surrounding measurement stations is considered. Rather then a simple horizontal interpolation of the observations at the surrounding stations, we deal with an Alternative Interpolation Method (AIM). In this method the influence of local properties can be dealt with. First the observations at the surrounding stations are transformed upwards to a certain reference height, subsequently interpolated horizontally at this reference height and finally transformed downwards to the height desired at the target location. For the transformations upward and downward Monin Obukhov similarity functions are used with estimated surface fluxes using routine synoptical observations. Hourly observations of the year 1992 are used.

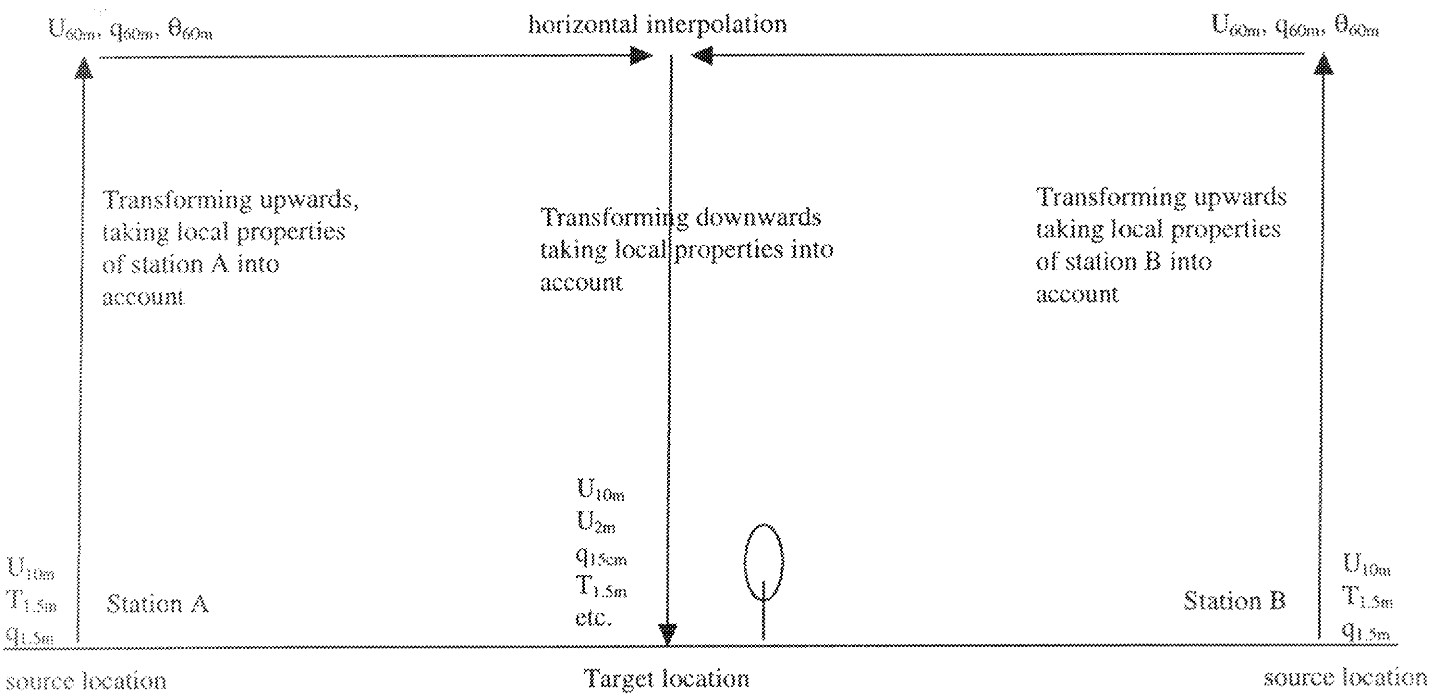
Various aspects of the AIM are studied. Situations are described where the upward and downward transformations will be less accurate (mostly in stable situations). Results from the AIM are compared with results from direct horizontal interpolation. As far as temperature and specific humidity are concerned, differences between these two interpolation methods are generally largest during night-time (stable) situations. Estimates of temperature and specific humidity at the target location using the AIM, showed an increased scatter in comparison with the estimates obtained by direct horizontal interpolation. For estimates of the wind speed a small decrease in the scatter can be seen when using the AIM. However for estimates of all meteorological parameters (temperature, specific humidity and wind speed) the average bias decreases when the AIM is used instead of direct horizontal interpolation. The results presented in this paper are promising for applications where biases are important, e.g. for the calculation of long term averages.

1 Introduction

This paper deals with the problem of regionalisation of meteorological data. Regionalised meteorological data valid for a specific location becomes more and more important (think of agriculture, fog, recreation, slipperiness of roads etc.). The most simple way to provide this data is horizontal interpolation of observations or model output.
One of the reasons why regionalised meteorological data obtained by direct horizontal interpolation may be useless is that observations of meteorological parameters are valid only for a single location. This can be illustrated by interpolating observations of wind speed at 10 metres above short grass to a location situated in a forest. The observed wind speed in the forest will be lower than the wind speed resultant from the interpolation. In a similar way temperature and specific humidity are dependent on local properties. There are many local circumstances, such as surface roughness, albedo, cloudcover, wind speed itself and soil moisture which influence temperature, wind speed and specific humidity.
By transforming observations upwards from synoptical height to a certain reference height (using local circumstances) we hope to strip most of the local character from the observations. In other words, observations from different locations transformed up to this higher reference height are assumed to show less horizontal variation than the observations at their original (synoptical) height.

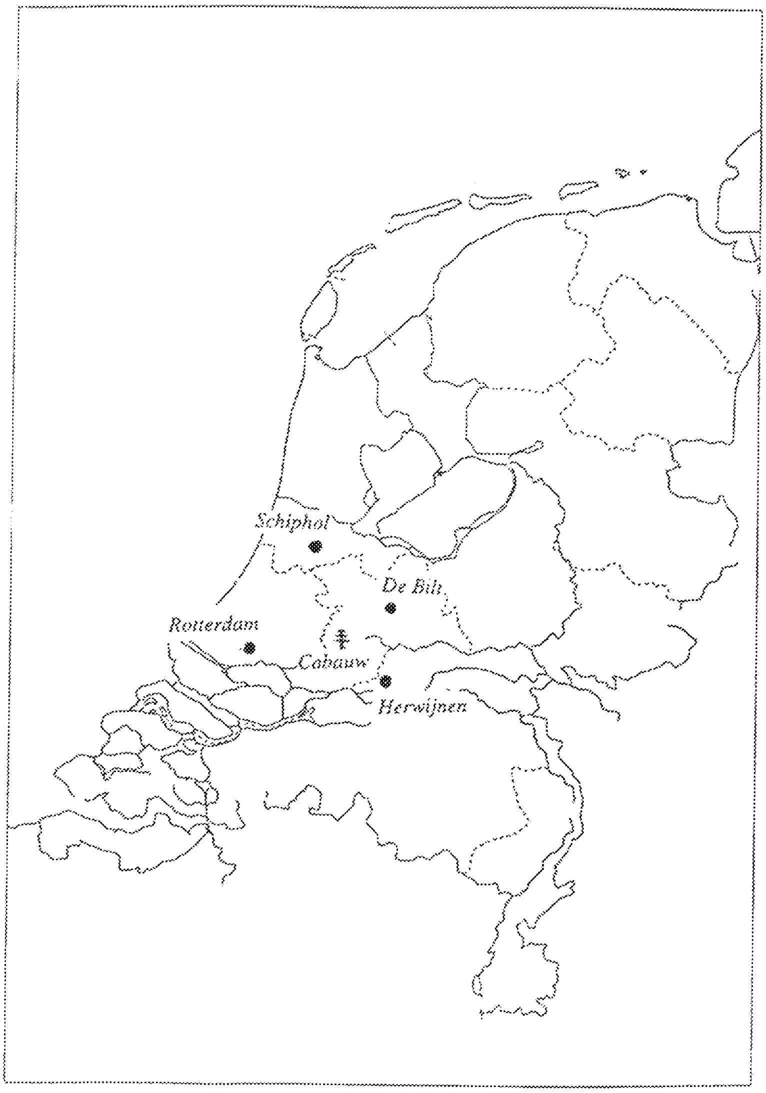
Let us presume that the synoptic observations of temperature ($T_{1.5m}$), specific humidity ($q_{1.5m}$) and wind speed (U_{10m}) are transformed up to a certain reference height. These values at reference height are interpolated horizontally to the target location and subsequently translated downwards, this time using characteristics of the target location (fig.1.1). From hereon this Alternative Interpolation Method will be abbreviated as AIM.

Fig. 1.1 The alternative interpolation method (AIM) with reference height at 60 metres



In this paper the synoptic observations of the 4 KNMI (Royal Netherlands Meteorological Institute) stations surrounding Cabauw (fig. 1.2) are transformed upwards and interpolated to the Cabauw location. Because in Cabauw observations from a 200m high tower are available, these interpolated values at various reference heights, could be compared with observations. Finally the values at reference height in Cabauw are transformed downwards again this time using the local properties in Cabauw in order to add the local character back into the observations.

Fig. 1.2 Positions of the KNMI stations (as far as they concern the study presented in this paper)



For the upward and downward transformations, Monin Obukhov similarity functions are used with estimated surface fluxes using routine synoptical observations. The software routines used for the upward and downward transformations form part of the so called "fluxlibrary" <2,3,4,5,6>. These flux routines are described shortly in §2.1. In §2.2. the sensitivity of the fluxroutines for changes in the input parameters, is discussed for their use in the AIM. The performance of the flux routines is studied in §3.1 (surface fluxes) and §3.2 (vertical profiles) using observations of the Cabauw tower.
In section 4 and 5 experiments are described involving not only observations in Cabauw, but also measurements of the 4 surrounding stations. In §4.2 the effect of the upward transformation is investigated qualitatively by looking at the differences in meteorological parameters between one station and the Cabauw tower at synoptical heights and 80 metres. The assumption that meteorological parameters vary more smoothly at greater heights (being less influenced by surface forcings), and could therefore be interpolated more accurately, is tested in §4.3. Finally in section 5 the performance of the AIM is compared with direct horizontal interpolation, for the parameters $T_{1.5m}$, $q_{1.5m}$ and U_{10m}.

Readers just interested in the performance of the AIM in comparison with direct horizontal interpolation can limit themselves to sections 5 and 6. Sections 3 and 4 are meant for further research purposes.

2 The flux routines

2.1 A short description of the flux routines

For the transformation upward and downward in the AIM, routines from the so-called fluxlibrary <2,3,4,5,6> are used. These routines are based on Monin-Obukhov similarity theory and a parameterization of the surface radiation and energy budget. The flux profile relations include stability corrections from Holtslag and de Bruin <7>. The latent heat flux (LE) is parameterized by a modified Priestley Taylor equation <4,8>:

$$LE = \alpha[\frac{S}{S+1}(Q^{*} - G) + \beta\rho L\Delta q_{d} u_{*}] \qquad (1)$$

where: α = empirical constant which is a function of the moisture availibility (in this paper α is assumed to be 1 (corresponding to grassland with sufficient water supply))

- L = the latent heat of water vaporazation
- E = evaporation
- S = the slope of the saturation enthalpy curve
- Q^{*} = net radiation
- G = soil heat flux
- $\beta\rho L\Delta q_{d} u_{*}$ = taken as a constant of 20 $\frac{W}{m^2}$
- β = empirical constant
- ρ = the air density
- Δq_{d} = that part of the humidity deficit ($q_{saturation}(T) - q(T)$) that is not correlated with ($Q^{*} - G$)
- u_{*} = friction velocity

The flux routines need the following standard synoptical input <6>:

- latitude/longitude coördinates [degrees]
- time (month, day, hour, minute)
- roughness length (z_0 [m])
- wind speed measuring height [m]
- wind speed [m/s] at this height
- temperature [°C]
- cloud cover [fraction ranging from 0 to 1]
- downward short wave radiation [W/m^2] If this parameter is not available it will be parameterised automatically.

A more detailed description of this required input is given in the introductions of section 3 and 4.

The flux routines compute the friction velocity (u_*), the temperature scale (T_*), the specific humidity scale (q_*), the latent and sensible heatflux (LE and H) and the Obukhov length (L).
Using these, observations can be transformed to other heights by again using the flux profile relations from Holtslag and de Bruin <7>:

$$U_{zm} = \frac{u_*}{k} * [\ln(\frac{z}{z_0}) - \Psi_M(\frac{z}{L})] \quad (2)$$

$$\theta_{zm} = \theta_{1.5m} + \frac{\theta_*}{k} * [\ln(\frac{z}{1.5}) - \Psi_H(\frac{z}{L}) + \Psi_H(\frac{1.5}{L})] \quad (3)$$

$$q_{zm} = q_{1.5m} + \frac{q_*}{k} * [\ln(\frac{z}{1.5}) - \Psi_H(\frac{z}{L}) + \Psi_H(\frac{1.5}{L})] \quad (4)$$

where: U_{zm}= wind speed at z metres
θ_{zm}= potential temperature at z metres
q_{zm}= specific humidty at z metres
u_*= friction velocity
q_*= specific humidity scale
θ_*= potential temperature scale
L = Obukhov length
k = von Karman constant (=0.4)
ψ_H= correction for stability for moisture or heat
ψ_M= correction for stability for momentum

Two minor changes are introduced in the flux routines. They are described in Appendix B.

2.2 Sensitivity of the flux routines for changes in the input parameters

In this paragraph the sensitivity of upward (to 60m) and downward transformations, using the flux routines, for changes in local circumstances is investigated. The experiments are illustrated by figures. For a particular day and hour, wind speed at 10 metres (U_{10m}) and specific humidity and temperature at 2 metres (q_{2m} and T_{2m}) are transformed upward to 60m with certain input parameters and subsequently transformed downward, with one or more input parameters changed, to their original height. The difference in T_{2m}, q_{2m} and U_{10m} before and after the upward and downward transformations show us the effect of changing a particular input parameter on T_{2m}, q_{2m} and U_{10m}. The main goal of this paragraph is to distinguish situations where we can expect significant differences between the AIM and direct horizontal interpolation. Naturally the experiments do not cover all possible situations, but they give a general insight in the response of the flux routines to certain changes in the input. Results of this paragraph are useful for interpreting the results of section 4 and 5 where the AIM is verified.

Effects of changes in the following parameters (for night-time and daytime situations separately and under different wind speed conditions) are studied:

- -Modified Priestley Taylor parameter, α (default =1.0)
- -Incoming short wave radiation, Kin
- -Cloud cover, NN
- -Roughness length, z_0
- -Bulk soil heat transfer coefficient, A_G (default = 5.0 $[\frac{W}{m^2K}]$)

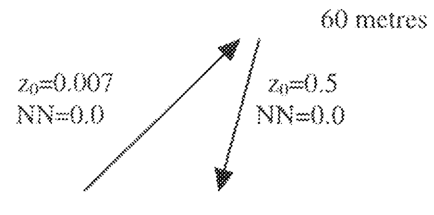
The meteorological input parameters and the changes in these input parameters are realistic.
It is important to keep in mind that the experiments show us the sensitivity of the flux routines for changes in the parameters mentioned above. The real atmosphere however may respond quite differently.

Daytime

Cabauw observations valid for 7-7-1992 12:00 are chosen as default. The following meteorological parameters have been used as input for daytime experiments unless others are mentioned in the figures:

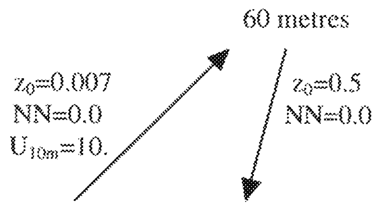
date	= 92070712
q_{2m}	= 8 [g/kg]
U_{10m}	= 3.5 [m/s]
T_{2m}	= 20 [°C]
Kin	= 855 [W/m²] during upward and downward transformation

Experiment 1 z_0 effect with low wind speeds



input	output
q_{2m}= 8 [g/kg]	q_{2m}=8.17 [g/kg]
U_{10m}= 3.5 [m/s]	U_{10m}=2.73 [m/s]
T_{2m}= 20 [°C]	T_{2m}=20.09 [°C]
Kin= 855 [W/m²]	

Experiment 2 z_0 effect with moderate wind speeds



input	output
q_{2m}= 8 [g/kg]	q_{2m}=7.82 [g/kg]
U_{10m}= 10.0 [m/s]	U_{10m}=7.6 [m/s]
T_{2m}= 20 [°C]	T_{2m}=19.69 [°C]
Kin= 855 [W/m²]	

Experiment 1
In experiment 1 the upward transformation is done in more unstable circumstances than the downward transformation, due to the change in z_0. "More unstable" implies that the gradient of temperature or specific humidity is concentrated in a shallower layer near the surface. As a consequence, temperature and specific humidity will decrease less during the upward transformation than they increase during downward transformation. As a net result, temperature and specific humidity at 2 metres have increased after the upward and downward transformation, but the differences are small.

Wind speed decreased substantially more during the downward transformation than it increased during the upward transformation.

A similar increase in T and q after transformation is seen when:

- the incoming short wave radiation, Kin, is not prescribed but parameterized
- the cloud cover NN is changed from 0.0 to 1.0 for upward and downward transformation
- a combination of both changes mentioned above (except T which decreases to 19.92 °C)
- U_{10m} is decreased to 0.5 m/s
- NN=1 for upward and 0 for downward transformation (Kin stays prescribed)
- NN=0 for upward and 1 for downward transformation (Kin stays prescribed)
- A_G=5 (sandy clay) for upward and 0.2 (new feathery snow (not very realistic)) for downward transformations (Kin prescribed or not).

For all the variations on experiment 1 mentioned above, the changes in wind speed, temperature and specific humidity have the same sign. Moreover changes are small for temperature and humidity, and substantial for wind speed.

The impact of changing A_G is small because the soil heat flux is small compared to other fluxes during daytime.

Experiment 2

The only difference in input between experiment 1 and 2 is the increase of U_{10m} to 10 m/s.

At first sight it may be surprising that the temperature and specific humidity differences in experiment 2 are opposite to the differences in experiment 1. An explanation can be given if we look at the flux profile relationships ((2),(3),(4)). Let us concentrate on temperature (for specific humidity an analogous explanation can be given).

$$\Delta\theta_{12} = \frac{\overline{w'\theta'}}{ku_*}[\ln(\frac{z_2}{z_1}) - \Psi_H(\frac{z_2}{L}) + \Psi_H(\frac{z_1}{L})] \qquad (5)$$

$$\frac{z}{L} = \frac{zk\frac{g}{T}\overline{w'\theta'}}{-u_*^3} \qquad (6)$$

where:

θ_1 = potential temperarture at height z_1

$\Delta\theta_{12} = \theta_1 - \theta_2$

$\overline{w'\theta'}$ = vertical kinematic eddy heat flux

u_* = friction velocity

L = Obukhov length

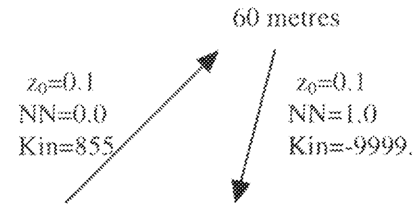
g = acceleration due to gravity

k = von Karman constant

If we assume that the vertical kinematic eddy heat flux is constant (which is not that strange because the incoming radiation is prescribed), then it becomes clear that u_* changes the temperature difference in two opposite ways. In experiment 2 at large wind speeds, corresponding to large values of u_*, the stability corrections for heat can be neglected because z/L is very small (6). In other words, high wind speeds tend to make the vertical profile neutral. The temperature difference becomes inversely proportional to u_*.(see (5) without stability corrections) The transformation upwards is done with a smaller value for u_* (because z_0 is smaller), resulting in a greater temperature difference during the upward transformation. So after the upward and downward transformation, the temperature at 2 metres will be decreased.

In experiment 1 the effect of the stability correction dominates, resulting in a net temperature increase in comparison with the original value for T_{2m}..

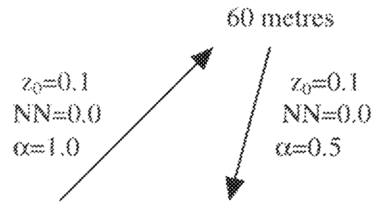
Experiment 3 Cloud cover effect



input	output
q_{2m}= 8 [g/kg]	q_{2m}=7.48 [g/kg]
U_{10m}= 3.5 [m/s]	U_{10m}=3.35 [m/s]
T_{2m}= 20 [°C]	T_{2m}=19.31 [°C]
H = 123.9 [W/m2]	H = 19.8 [W/m2]
LE = 313.5 [W/m2]	LE = 82.8 [W/m2]

Experiment 3 shows us the effect of changing the cloud cover. Kin is prescribed only in the upward transformation. The fluxes of sensible and latent heat alter dramatically. The difference for q_{2m} and T_{2m} is larger than in the previous experiments but still rather small.

Experiment 4 Modified Priestley Taylor parameter, α, effect



input	output
q_{2m}= 8 [g/kg]	q_{2m}=7.36 [g/kg]
U_{10m}= 3.5 [m/s]	U_{10m}=3.5 [m/s]
T_{2m}= 20 [°C]	T_{2m}=20.46 [°C]
Kin = 855 [W/m2]	
H = 123.9 [W/m2]	H = 225.5 [W/m2]
LE = 313.5 [W/m2]	LE = 128.6 [W/m2]

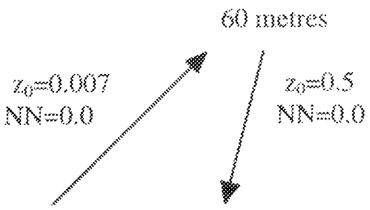
The impact of changing the modified Priestley Taylor parameter (1) from 1.0 (grassland with sufficient water supply) to 0.5 (relatively dry range-grassland) during the downward transformation is significant for q_{2m} and rather small for T_{2m}. The results of experiment 4 are the same if Kin is not prescribed.

Night-time

Cabauw observations valid for 24-7-1992 3:00 are chosen as default. The following meteorological parameters have been used as input for night-time experiments unless they are mentioned in the figures:

date	= 92072403
q_{2m}	= 9 [g/kg]
U_{10m}	= 3.5 [m/s]
T_{2m}	= 17 [°C]

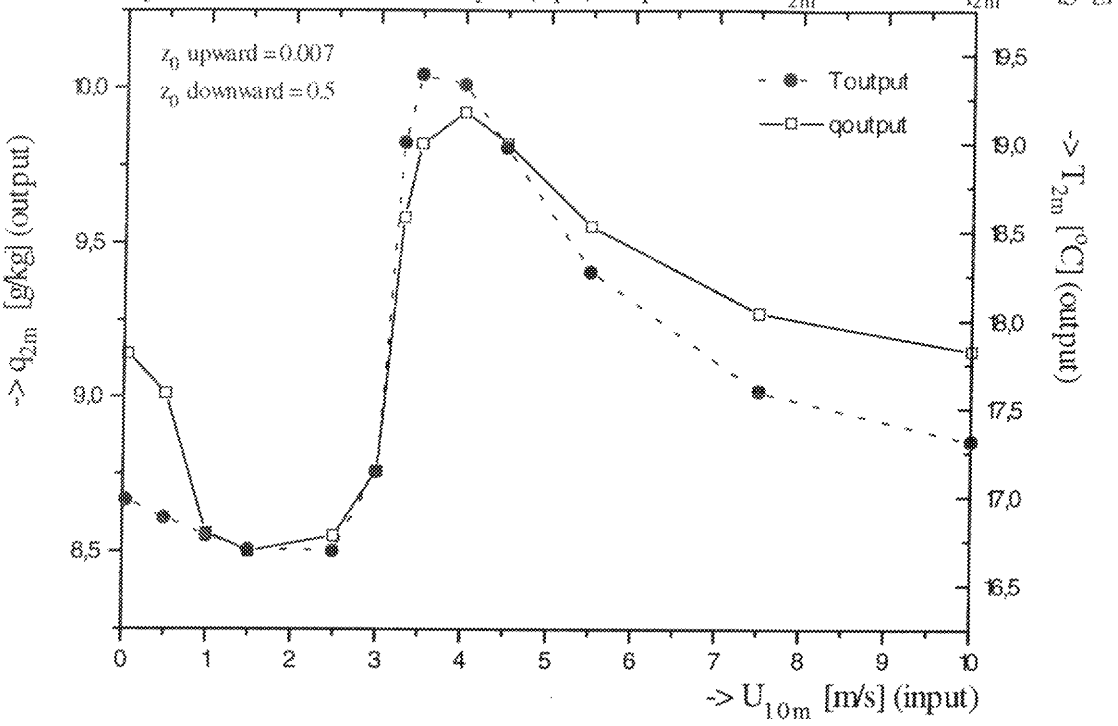
Experiment 5 z_0 effect



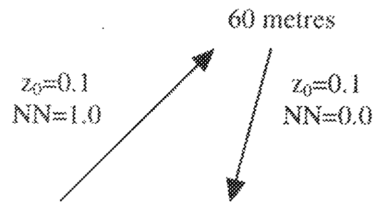
input	output
q_{2m}= 9 [g/kg]	q_{2m}= 9.81 [g/kg]
U_{10m}= 3.5 [m/s]	U_{10m}=3.49 [m/s]
T_{2m}= 17 [°C]	T_{2m}=19.38 [°C]
H = -14.4 [W/m2]	H = -41.6 [W/m2]
LE = -11.4 [W/m2]	LE = -27.4 [W/m2]

The results of experiment 5 show us a large impact on temperature and humidity when z_0 is changed. The wind speed remains unaltered!
However, the results of experiment 5 are highly dependent on the prescribed U_{10m} as input, as can be seen in in fig. 2.1. As in experiment 2, the difference in T_{2m} and q_{2m} is the net result of positive and negative effects in the flux profile relationships. It is hard to say if fig. 2.1 is realistic, but it can be concluded that in stable situations the sensitivity of the flux routines for changes in z_0 can be large, as far as temperature and specific humidity are concerned. Wind speed is less sensitive to changes in z_0 during stable situations.

Fig. 2.1 The results of experiment 5 under different windspeed conditions
The T_{2m} and q_{2m} resultant from the upward and downward transformations (Toutput and qoutput), are plotted as a function of the windspeed (input). Input values: T_{2m} = 17°C and q_{2m} = 9 [g/kg]

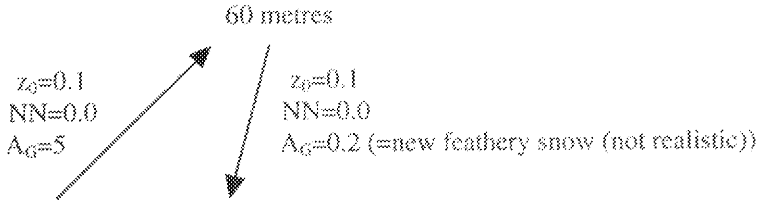


Experiment 6 Cloud cover effect



input	output
q_{2m}= 9 [g/kg]	q_{2m}= 7.89 [g/kg]
U_{10m}= 3.5 [m/s]	U_{10m}=2.68 [m/s]
T_{2m}= 17 [°C]	T_{2m}=14.36 [°C]
H = -17.6 [W/m2]	H = -15.1 [W/m2]
LE = -0.2 [W/m2]	LE = -12.1 [W/m2]

Experiment 7 Bulk soil heat transfer coefficient, A_G effect



input	output
q_{2m}= 9 [g/kg]	q_{2m}=8.0 [g/kg]
U_{10m}= 3.5 [m/s]	U_{10m}=3.18 [m/s]
T_{2m}= 17 [°C]	T_{2m}=15.04 [°C]
H = -28.8 [W/m2]	H = -25.36 [W/m2]
LE = -24.56 [W/m2]	LE = -26.58 [W/m2]

-α effect

In §3.2 it will be suggested to increase α during night-time. It is not simple to investigate the effect of changes in α, the Modified Priestley Taylor parameter, during night-time because this parameter is worked implicitly into the formulas for stable situations in the flux routines. Therefore no experiments are presented here concerning the α effect during night-time.

Summarizing the results of the experiments it can be stated that transformations of temperature and specific humidity upward and downward using the flux routines, are sensitive to changes in local input parameters during stable (night-time) situations, and relatively insensitive during unstable and neutral situations. Hence for temperature and humidity, the greatest advantage of the present AIM, in comparison with direct horizontal interpolation, can be expected for stable situations.
Upward and downward transformations of wind speed can be sensitive for changes in local input parameters during all stability situations.

3 Performance of the flux routines in Cabauw

In this section the performance of the flux routines is discussed. An extensive dataset containing hourly synoptic observations of the year 1992 is used. Because an "all weather interpolation system" is needed we excluded as little data as possible. An hour is skipped only if essential data was missing or of bad quality.
The observations used in this paper, can be divided in so called Cabauw tower observations <1> and routine observations (the later are available from the climatological service of the KNMI). In this section experiments are discussed involving Cabauw tower observations only. A description of the routine observations can be found in §4.1.
All Cabauw tower observations are half hourly means and available only for Cabauw. Measurements are available at 0.6, 1.5, 10, 20, 40, 80 and 200 metres height. Specific humidity is measured indirectly by highly accurate psychrometers. All kinds of radiation measurements are done, but no observations of cloud cover are available in the Cabauw tower dataset.

The flux routines require the input as described in section two. Whenever no short wave radiation was available it was parameterised <4>. Results of the flux routines including this parameterisation are labelled with "par", like Hflxpar and Leflxpar. Since no local cloud cover observations were available in Cabauw, the averaged cloud cover is taken of three weather stations around Cabauw. An effective roughness length (gustiness derived <9>) depending on wind direction (18 sectors) and season (summer = May - September and winter = October - April) is used.

The results are presented by the month. A selection of plots is presented in this section.

3.1 Surface fluxes of sensible (H) and latent heat (LE)

A good representation of the surface fluxes is very important. The fluxes from the flux routines are used in the AIM to calculate profiles of temperature, humidity and wind speed.
Comparisons are made between surface fluxes obtained by using the flux routines and "observed" fluxes obtained by using the profile method <2>. From September till December 1992 also flux observations obtained with the Bowen ratio method <17> were available.

In this paragraph scatterplots of a typical summer month (August 1992) and a month where the LE is underestimated and the H overestimated (April 1992) are presented.

Fig. 3.1 Comparison of measured half hourly averages of the sensiblet heat flux, H, at Cabauw with estimates of H using the flux routines, for August 1992

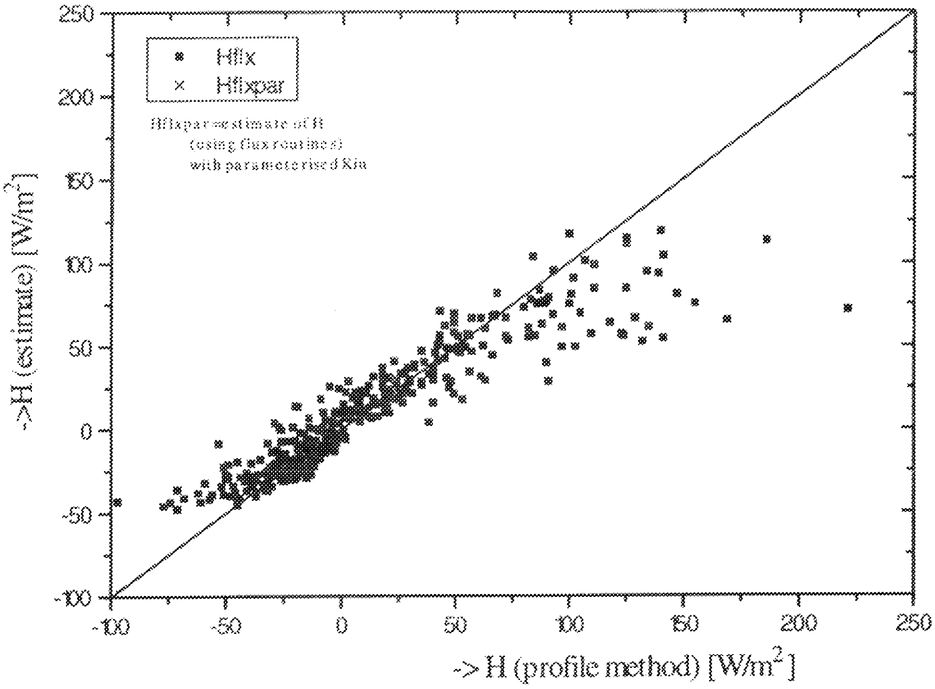


Fig. 3.2 Comparison of measured half hourly averages of the latent heat flux, LE, at Cabauw with estimates of LE using the flux routines, for August 1992

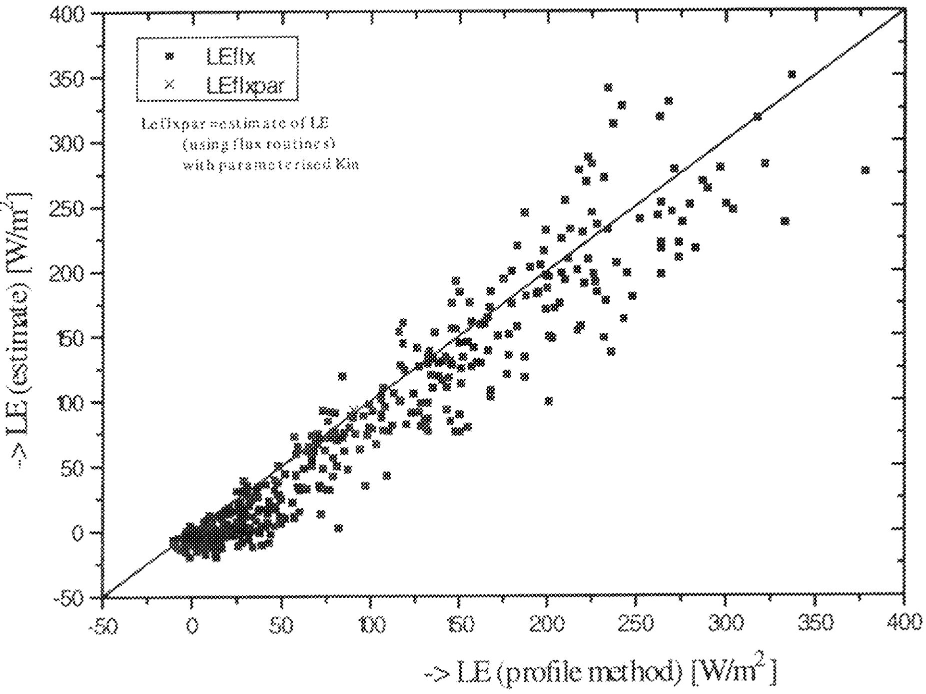


Fig. 3.3 Comparison of measured half hourly averages of the sensible heat flux, H, at Cabauw with estimates of H using the flux routines, for April 1992

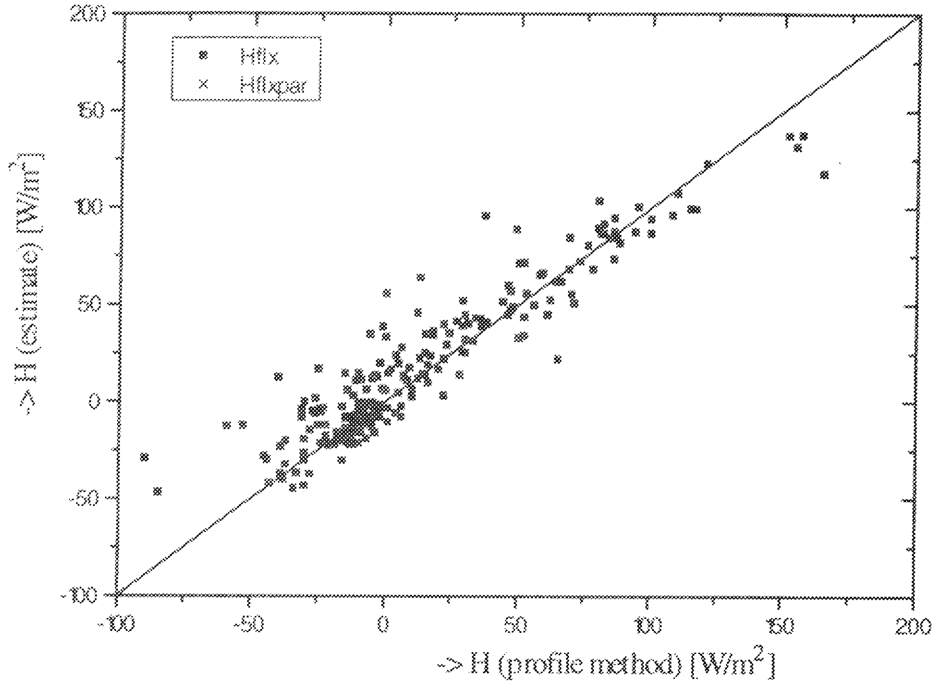


Fig. 3.4 Comparison of measured half hourly averages of the latent heat flux, LE, at Cabauw with estimates of LE using the flux routines, for April 1992

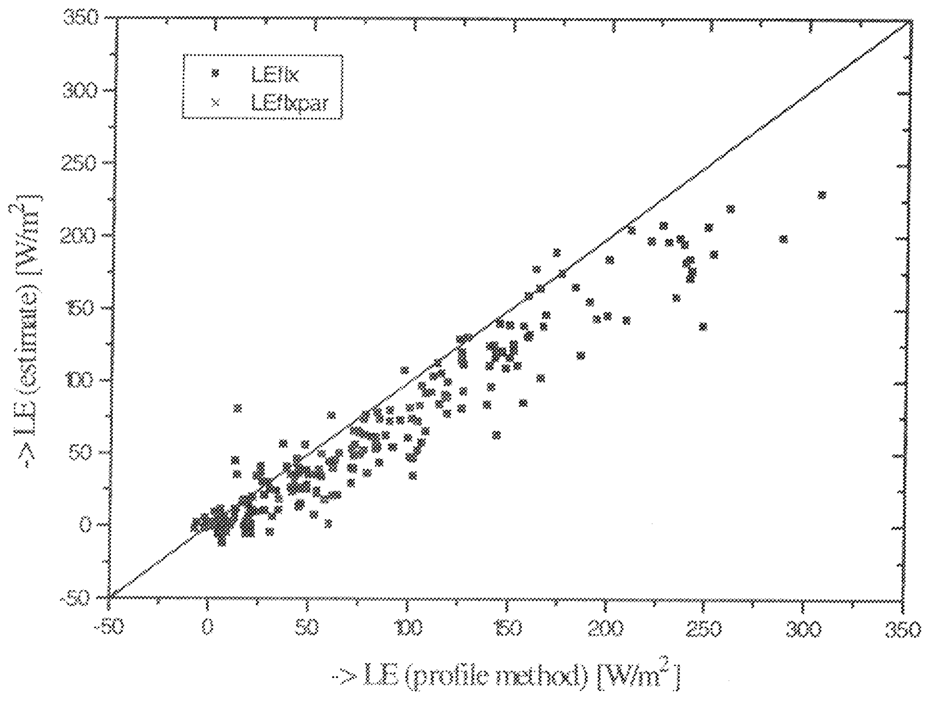
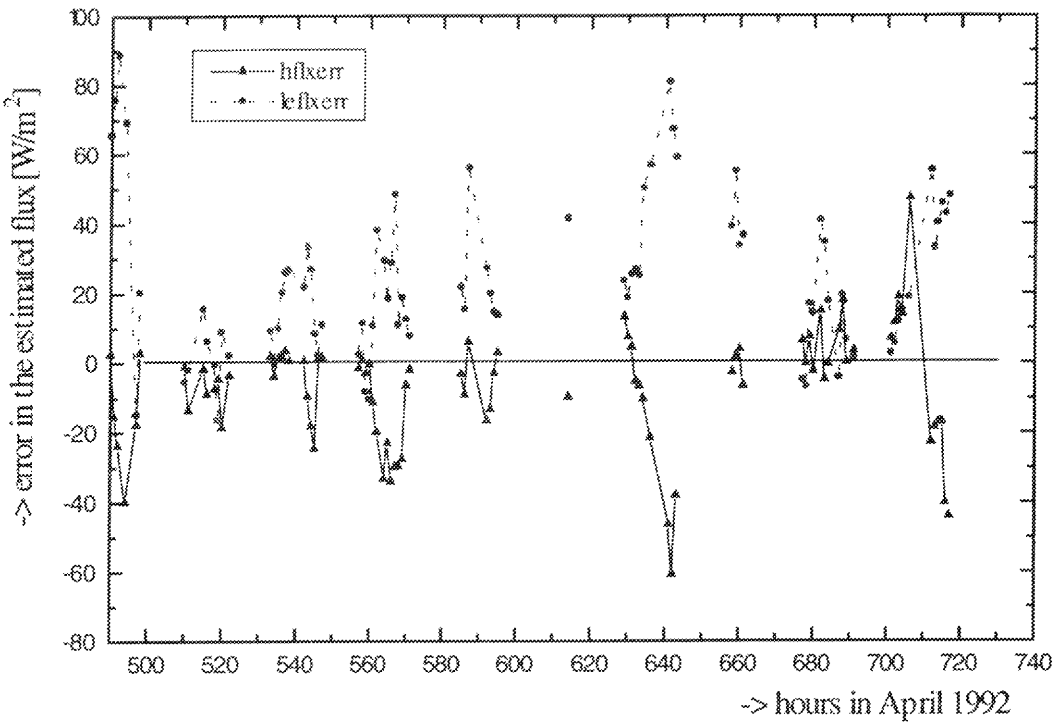


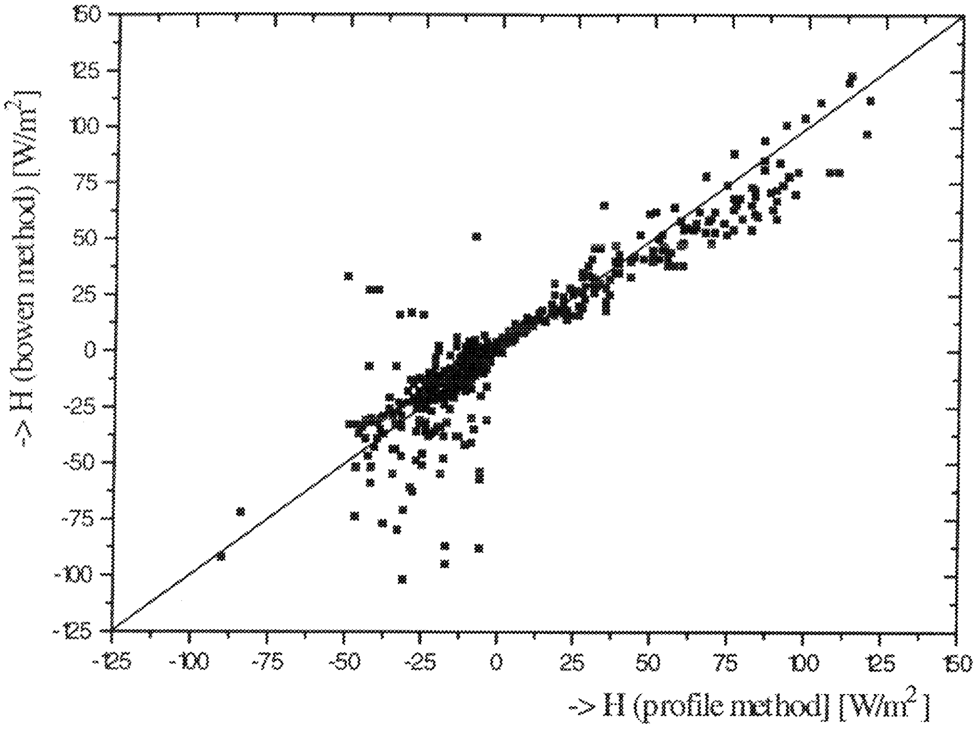
Fig. 3.5 Error in the estimated sensible heat flux (hflxerr) and latent heat flux (leflxerr)
(error = observation - estimate), for April 1992



As expected <8> the results illustrate that the Priestley Taylor equation for the latent heat flux (1) performs best in daytime summer month situations when (Q^*-G) is relatively large. But also in summer months, errors in the estimated flux can be large. These errors introduce noise in the AIM because the surface fluxes are used for the upward and downward transformations. In a next paper attempts to improve the skill of the estimated surface fluxes by using a Penman Monteith equation for the latent heat flux, will be described.
Latent heat fluxes are underestimated systematically during night time. Note that there are no physical arguments for the Priestley Taylor formulation during night time situations (because during night time the humidity deficit is not correlated with (Q^*-G), see (1)).

For April 1992 a clear underestimation of the LE and an overestimation of the H can be observed (fig. 3.3, 3.4 and 3.5). The available energy for LE and H is more or less correct (error in H + error in LE = 0, see fig. 3.5) but the partitioning between H and LE is wrong. In other words, the Bowen ratio, which is almost a constant in the modified Priestly Taylor equation used (1), is not correct. By taking the humidity deficit into account (Penman Monteith equation) the Bowen ratio may be better adapted <15>.
The flux routines seem to have an upper limit for H of 150 W/m^2. In the summer months June, July and August of 1992 however, these H > 150 W/m^2 are "observed", using the profile method. Unfortunately there were no "Bowen ratio" heat fluxes of summer months to check this upper limit. In the same way there seems to be a lower limit of -50 W/m^2 (e.g. fig. 3.1) when the heat flux is calculated with the flux routines. As can be seen in fig. 3.6 there are also sensible heat fluxes calculated with the "Bowen ratio method" which indicate that sensible heat fluxes really can drop below -50 W/m^2 in Cabauw.

Fig.3.6 Comparison of the sensible heatflux (H) in Cabauw calculated using the Bowen ratio method and the profile method, for September 1992



The correlation between observations and estimates of H and LE decreases somewhat when the short wave radiation, Kin, is parameterised. But there seems to be no bias associated with this parameterisation.

In table 3.1 Root Mean Square Errors, RMSE (Appendix A) of estimated surface fluxes are plotted. May and June are skipped because of the poor quality of the flux observations. Different RMSE are made:

Hfluxbowen:	comparison between observations of H using the Bowen ratio method and estimates of H using the flux routines
Hfluxprof:	comparison between observations of H using the profile method and estimates of H using the flux routines
Hfluxpar:	comparison between observations of H using the profile method and estimates of H using the flux routines including parameterisation of Kin

Abbreviations beginning with Leflux have analogous meanings to the ones up here.

Table 3.1 RMSE of surface flux estimates [W/m^2]

	9201	9202	9203	9204	9207	9208	9209	9210	9211	9212
Hflux-bowen	-	-	-	-	-	37.8 N=9	17.2 N=341	15.4 N=277	20.3 N=218	21.5 N=82
Hflux-prof	13.2 N=261	8.7 N=93	13.0 N=136	16.4 N=221	18.7 N=367	19.4 N=449	10.2 N=427	12.0 N=296	14.3 N=321	14.1 N=130
Hflux-par	-	12.8 N=248	17.1 N=306	-	-	-	-	-	-	-
LEflux-bowen	-	-	-	-	-	43.9 N=9	26.0 N=341	15.7 N=277	17.5 N=218	18.1 N=82
LEflux-prof	8.1 N=261	7.5 N=93	23.1 N=136	29.9 N=221	26.2 N=367	30.2 N=449	21.2 N=427	17.9 N=296	15.0 N=321	11.7 N=129
LEflux-par	-	14.2 N=248	21.6 N=306	-	-	-	-	-	-	-

The RMSE of the fluxes increase in summer months because on the average H and LE are larger in daytime summer month situations. Attempts have been made to produce relative errors but fluxes close to 0 dominate the monthly averaged relative error and make the results useless.
The RMSE seem to be larger when estimates are compared with "Bowen ratio" observations than with "profile method" observations. This is probably due to problems with the Bowen ratio method during transition hours (from stable to unstable situations and vice versa, see fig.3.6).

3.2 Vertical profiles of temperature, specific humidity and wind speed.

Using the flux routines with input from a certain height, the temperature, specific humidity and wind speed at other heights can be calculated using flux profile relations ((2),(3),(4)) . These estimates can be compared with measurements made at the Cabauw tower. For specific humidity this verification has not been done before. For wind speed and temperature this comparison has been made earlier <2,3>, but only for selected situations (restrictions for wind directions, wind speed > 1m/s, no rainfall, etc.).
Again a selection of the results is presented here. Unless mentioned otherwise, the estimated T, q and U at 80 metres are calculated using the flux routines, with standard synoptical input (U at 10m and T, q and Kin at 1.5m). In this paragraph estimates of U, T and q at 80m are discussed successively. Finally the estimates of these meteorological parameters at different heights are presented quantitatively. Root Mean Square Errors and biases of estimates of wind speed, specific humidity and temperature at different heights can be found in tables 3.2 and 3.3.

Estimates of wind speed at 80m

Fig. 3.7 Comparison of estimates, using the fluxroutines with near surface observations, and measurements of windspeed at 80 metres in Cabauw, for August 1992

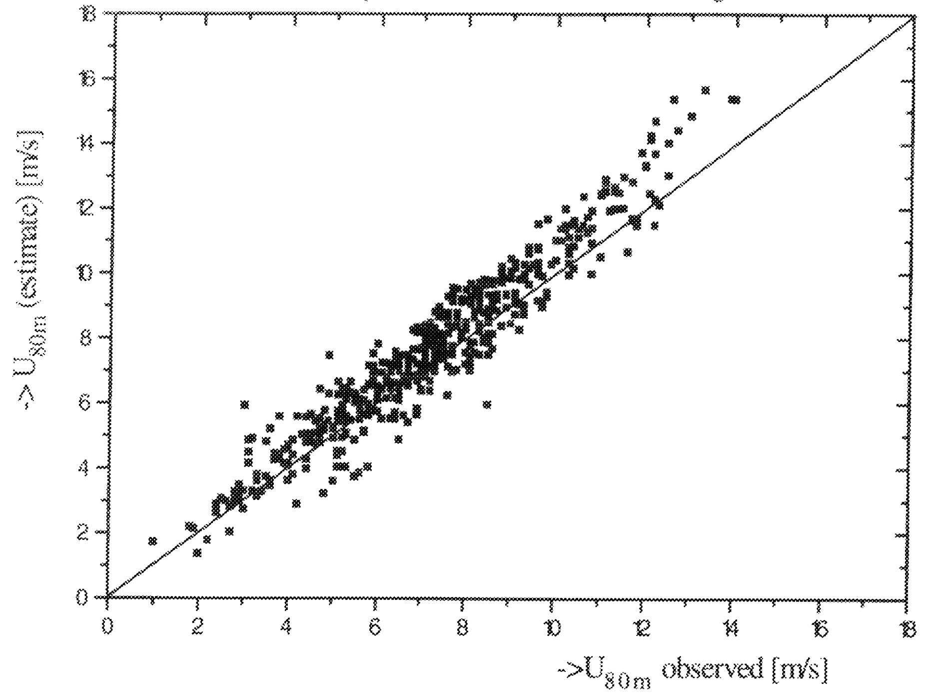


Figure 3.7 shows a characteristic scatterplot for wind speed. In comparison with fig. 3.7 the scatter increases for estimates of wind speed at 200m and decreases for wind speeds at 40 and 20m (see table 3.2).

For almost every month in 1992, the flux routines overestimated high wind speeds. Vertical profiles of meteorological parameters during high wind speed/neutral conditions are relatively easy to determine (no stability corrections). Therefore the overestimation of the high wind speeds in Cabauw is likely to be caused by invalid z_0 values.

In <3> the wind directions of the high wind speeds (Z-ZW) were excluded from the analysis because the error due to interference of the mast and boom with the wind measurements, would be unacceptably large (>2%). Holtslag found no systematical error for estimates of wind speed at 80m. The dataset used in this paper is corrected for errors due to the interference with the mast and the boom.

Estimates of temperature at 80m

Scatterplots of June, as a typical summer month, are presented here.

Fig. 3.8 Error in the estimate (using fluxroutines with near surface observations) of the temperature at 80 metres (error = T_{80m} observation - estimate), for June 1992

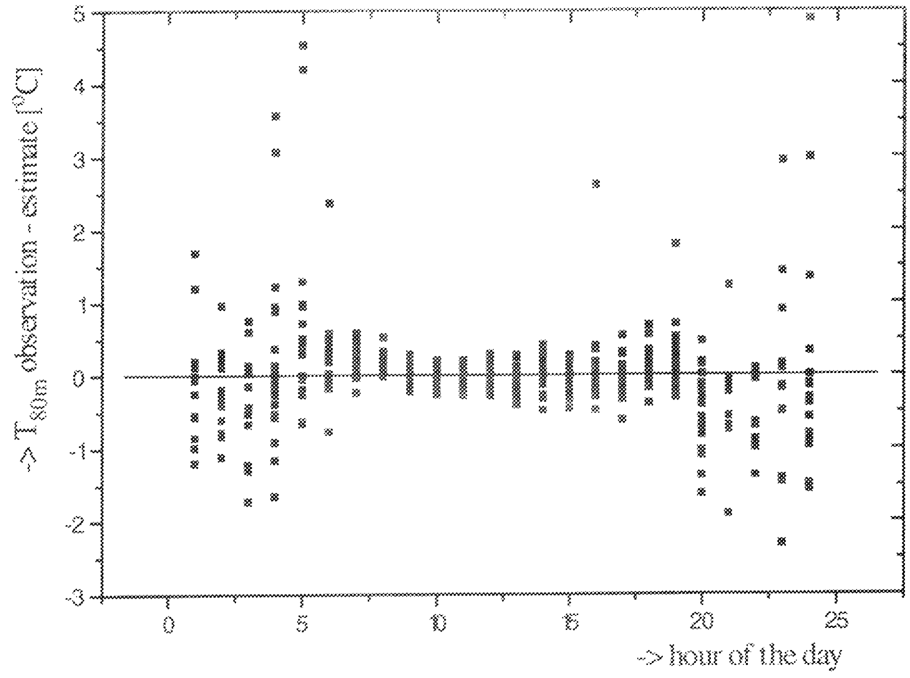
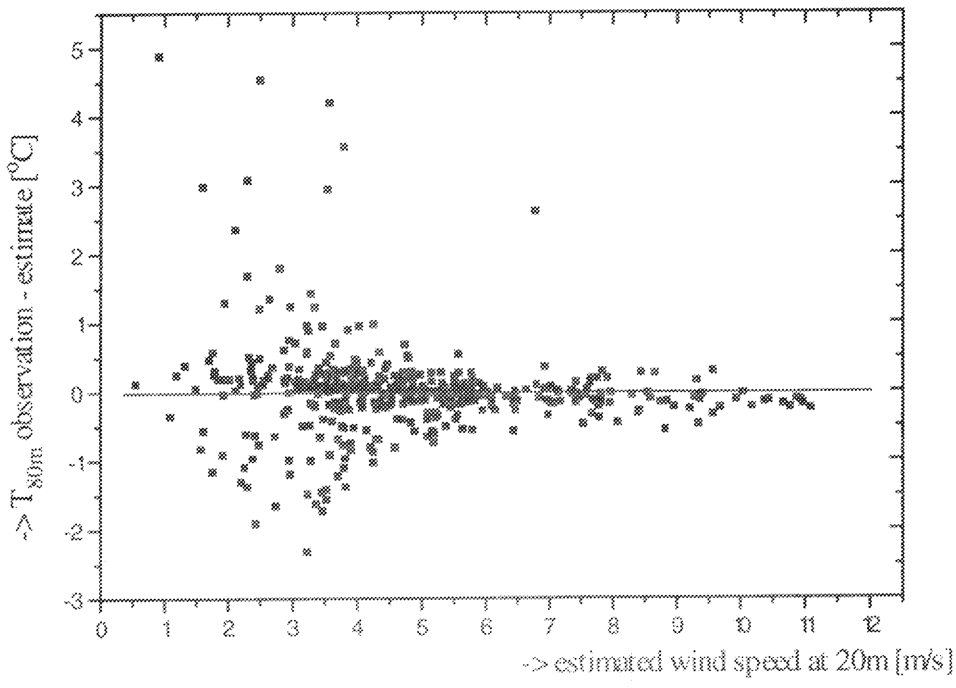


Fig. 3.9 The error in the estimated temperature at 80m (using fluxroutines with near surface observations) as a function of the estimated wind speed at 20m, for June 1992



In particular cases errors in the estimated T_{80m} can be as large as 8°C ! Figs. 3.8 and 3.9 (which are qualitatively the same for every month of 1992) show that significant errors are restricted to night time (stable) situations with low wind speeds However in figs. 3.8 and 3.9 one exception can be seen. Despite a wind speed of 6.8 m/s at 20 metres an error in the estimated temperature at 80m of 2.6 °C is observed. During this hour (16:00) a negative sensible heatflux of 50 W/m^2 and some rainfall was observed. Estimations of profiles during rainfall are extremely difficult. Note that many hours with rainfall are not included in this study because most of the time these observations are marked as "bad quality data" and rejected
Correlations between temperature errors and cloud cover are less clear (apparently non existent for most months). Maybe the fact that cloud cover at Cabauw is constructed by averaging the cloud cover from three nearby synoptical stations is confusing this issue a little.

Estimates of specific humidity at 80m

For most months the correlation between estimates and observations of specific humidity at 80m is better than was the case in June 1992 (shown in fig. 3.10).

Fig. 3.10 Comparison of estimated specific humidity (using flux routines with near surface observations) with observations of the specific humidty at 80 metres in Cabauw, for June 1992

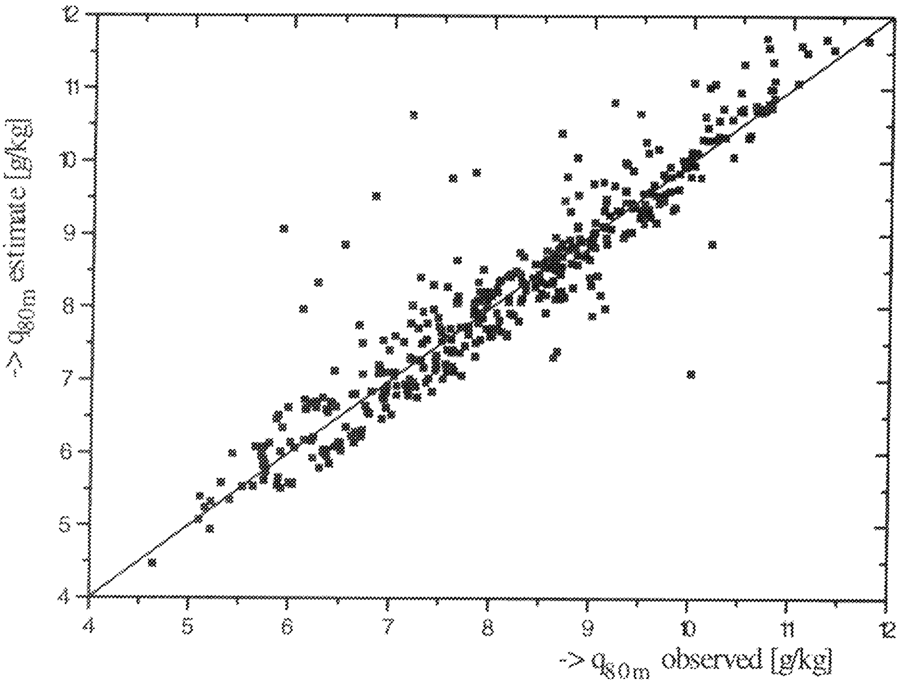
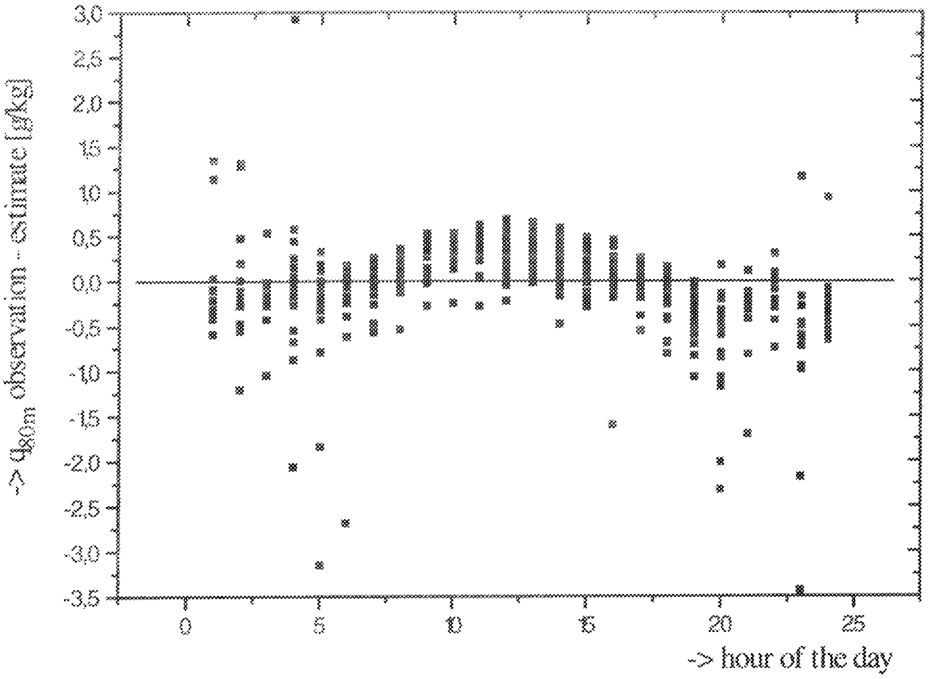


Fig. 3.11 Error in the estimated specific humidity (using the flux routines with near surface observations) at 80 metres (error = q 80m observation - estimate), for June 1992



As can be seen clearly from fig. 3.11, which is representative for all months in 1992, the worst estimates are again made during night time (stable) hours. Despite some (big) exceptions, there is definitely a negative bias during night time. This means that by transforming specific humidity from 1.5 to 80 metres during night time using the flux routines, the specific humidity at 80 metres is overestimated. This problem may be solved if the modified Priestly Taylor parameter α (which represents the availability of moisture in the soil for evaporation (1)) is changed from 1 to e.g. 1.2. 1.2 seems to be a reasonable value for night time according to <8>. An increase in α will increase the evaporation and this implies that the estimate of the specific humidity at 80 metres will decrease. As can be seen in scatterplots with latent heat flux estimates and observations (e.g. fig. 3.2), increasing the evaporation at night will improve the estimated LE for most months.

During daytime an interesting "mountain shape" in the specific humidity error can be observed in fig. 3.11. This "mountain shape" is most pronouncedly in summer months and decreases gradually when days are shortening in colder months. This daytime error has nothing to do with the parameterization of the net radiation (which has no systematical error) or a diurnal cycle of specific humidity (which is too small). The "mountain shape" error corresponds to an overestimate of large LE fluxes around noon (Which is indeed observed.

Quantitative results

In table 3.2 Root Mean Square Errors, RMSE, (Appendix A) of estimated T, q and U at different heights are plotted. Results for May are not presented because of the poor quality of observations in this month.
Various RMSE between observations and estimates are made. One example:

U200m: comparison between Cabauw tower observations of the wind speed at 200m and estimated wind speeds at 200m using the flux routines

Table 3.2 RMSE of wind speed [m/s], specific humidity [g/kg], temperature [°C], transformed from respectively 10, 1.5 and 1.5 metres using the flux routines.

	9201	9202	9203	9204	9206	9207	9208	9209	9210	9211	9212
U 20m	0.42	0.36	0.42	0.31	0.29	0.32	0.35	0.36	0.35	0.42	0.41
U 40m	0.73	0.66	0.74	0.57	0.49	0.56	0.61	0.59	0.65	0.72	0.72
U 80m	1.1	1.09	1.22	1.00	0.87	0.97	0.89	0.88	0.99	0.86	1.29
U200m	1.99	2.21	2.35	1.86	1.93	1.87	1.82	1.86	2.12	1.75	2.57
q 40m	0.14	0.20	0.26	0.27	0.35	0.41	0.35	0.27	0.27	0.11	0.13
q 80m	0.20	0.27	0.34	0.40	0.54	0.62	0.52	0.42	0.34	0.19	0.18
q 60cm	0.05	0.07	0.10	0.16	0.13	0.19	0.13	0.10	0.09	0.04	0.04
T 40m	0.31	0.61	0.69	0.74	0.48	0.72	0.37	0.35	0.60	0.35	0.45
T 80m	0.4	0.80	0.93	1.04	0.70	0.97	0.48	0.54	0.81	0.51	0.63
T 60cm	0.10	0.25	0.26	0.25	0.29	0.25	0.19	0.16	0.20	0.11	0.10

Generally a threshold of 20 times the local z_0 value (≈60cm) is recommended for using the flux profile relationships ((2),(3),(4)).
For the transformation from 1.5 to 0.6 metres a local roughness length, determined by the height of the local obstacles (here short grass => z_{0local}≈0.03m) should be used. For all the results in table 3.2, however, the roughness length used is an effective roughness length (which is much higher, ≈0.1m). Despite this, the flux routines perform well in transforming T and q from 1.5 to 0.6 metres.
It can be expected that transformations from 80 to 0.6 metres using the effective roughness length will lead to results comparable to the RMSE of U80m, T80m and q80m presented in table 3.2.
Transforming from 1.5 to 0.6 metres, the difference in height is only 90 cm, but one should keep in mind that gradients of T and q can be large between 0.6 and 1.5 metres.

Table 3.3 Biases (Appendix A) of wind speed [m/s], specific humidity [g/kg], temperature [°C] at 80m, transformed from respectively 10, 1.5 and 1.5 metres using the flux routines.

	9201	9202	9203	9204	9206	9207	9208	9209	9210	9211	9212
U80m	-0.733	-0.424	-0.593	-0.413	-0.270	-0.403	-0.449	-0.341	-0.144	-0.247	-0.783
q80m	-0.019	0.064	-0.035	-0.171	-0.058	-0.167	-0.216	-0.077	-0.010	-0.038	-0.005
T80m	-0.020	0.302	0.244	0.428	0.013	0.223	0.207	0.126	0.023	0.020	-0.213

These biases will be used in §4.3

To test the symmetry of the flux routines, to upward and downward transformations, experiments have been carried out where, instead of transforming upward, meteorological parameters are transformed downward from 80 metres to synoptical heights. The z_0 value used is the same one as with upward transforming. The errors made are about the same and biases have the opposite sign. So e.g. the 'mountain-shape' from fig. 3.11 turned into a 'valley-shape' if we transform specific humidity from 80 metres to 1.5 metres. Conclusion: the flux routines appear to be symmetrical.

4 Various aspects of the AIM

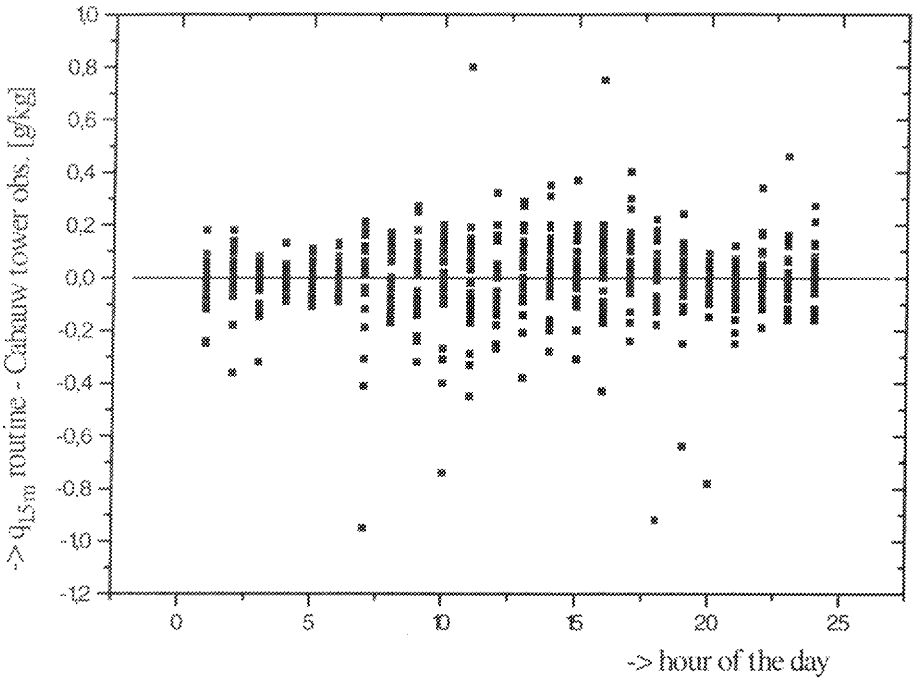
In this section experiments are described involving, not only observations in Cabauw, but also measurements of 4 surrounding stations (fig.1.2). For some experiments it was necessary to use different kinds of measurements in one experiment. This problem will be explained in §4.1.
Aspects of the AIM differing from direct horizontal interpolation (DIR) are investigated in detail. In §4.2 the effect of the upward transformation is investigated qualitatively by looking at the differences in meteorological parameters between one station and the Cabauw tower, at 1.5 and 80 metres height. The assumption that meteorological parameters vary more smoothly at greater heights (being less influenced by surface forcings), and could therefore be interpolated more accurately, is tested in §4.3.

4.1 The dataset

For some experiments, described in this section, it was necessary to use different kind of measurements in one experiment. Therefore it is important to know which observations are used and how they are used. The observations can be divided in so called Cabauw tower and routine observations (the later are available from the climatological service of the KNMI). The Cabauw tower observations are already described at the beginning of section 3.
In addition to the Cabauw tower dataset an extensive dataset of routine observations, containing hourly synoptic observations of the year 1992 was used. As with the Cabauw tower dataset, we excluded as little data as possible because an "all weather interpolation system" was needed. An hour was skipped only if essential data was missing or of bad quality.
Routine observations were available for all stations involved, including Cabauw. Wind speed and incoming short wave radiation (Kin) measurements are hourly means, while temperature, relative humidity and wind direction are 10 minute means. Specific humidity is measured using a capacitive instrument (except in Cabauw where a psychrometer is used). All observations are made at synoptical heights, i.e. 10 metres for wind speed and direction, and 1.5 metres for temperature and relative humidity. In Herwijnen and Cabauw cloud cover is not available. For Herwijnen observations of pressure are also missing. The cloud cover and pressure in Herwijnen are taken to be equal to the values in De Bilt which can lead (under exceptional circumstances) to significant inconsistencies in the dataset of Herwijnen. The cloud cover in Cabauw was taken as the average of the cloud cover observed at three nearby stations.

A comparison of routine observations for Cabauw with Cabauw tower observations will unavoidable lead to scatter. For example looking at the specific humidity at 1.5 metres in Cabauw according to the routine and Cabauw tower observations (fig. 4.1), some significant scatter can be observed (the conversions to specific humidity are done in a consistent way). This is caused by the fact that specific humidity is rather variable, and not a slowly changing parameter (as often thought). Changes in specific humidity of 3.5 g/kg in an hour or 1.5 g/kg in 10 minutes do occur. Sometimes these changes are measured at all heights in the Cabauw tower, or measured at the surrounding stations more or less simultaneously. So this phenomenon cannot be ascribed to measurement errors.
Whenever it was necessary to compare (transformed) routine data with Cabauw tower data in this section, it will be mentioned.

fig. 4.1 Difference between 10-minutes-mean (routine) and 30-minutes-mean (Cabauw tower) specific humidity observations in Cabauw, as a function of the hour of the day, for August 1992



4.2 Effect of the upward transformation

Here routine observations are compared with Cabauw tower observations (see §4.1)
The fact that, in the AIM, transformed observations of four stations are interpolated can obscure typical effects of the AIM. Therefore the effects of the upward transformation in the AIM are considered here by looking at Cabauw and only one other station.

The obvious effect, which will be pointed out in another form in §4.3, namely that the interpolation error at 80m is smaller than at 10m for high wind speeds, is nicely illustrated by fig. 4.2 and 4.3.

Fig. 4.2 The observed wind speed in Cabauw at 10m (half hour mean observation) plotted against the observed wind speed in De Bilt at 10m (hour mean observation), for January 1992

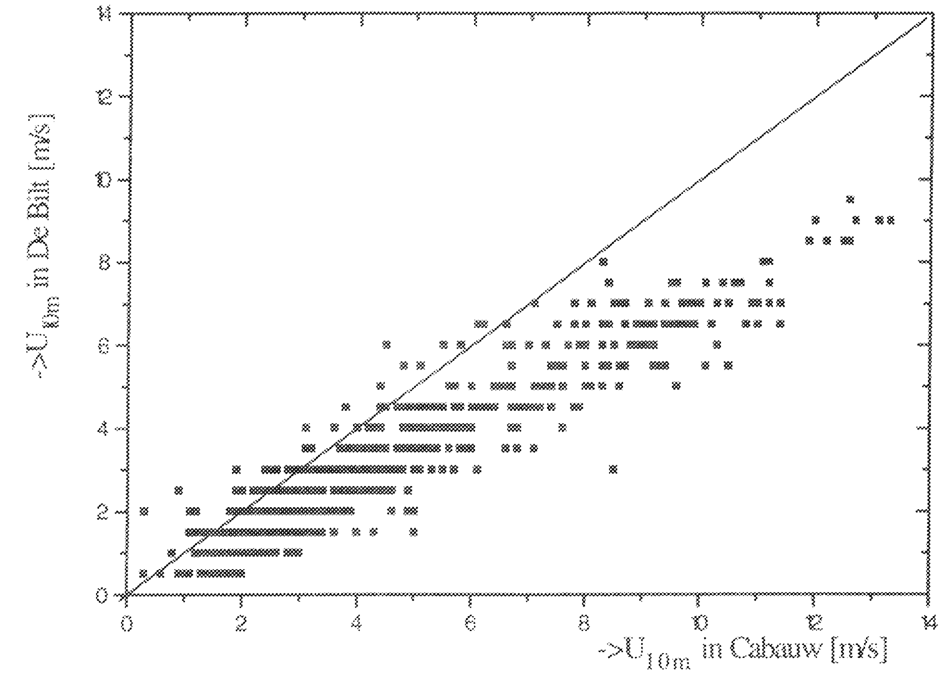
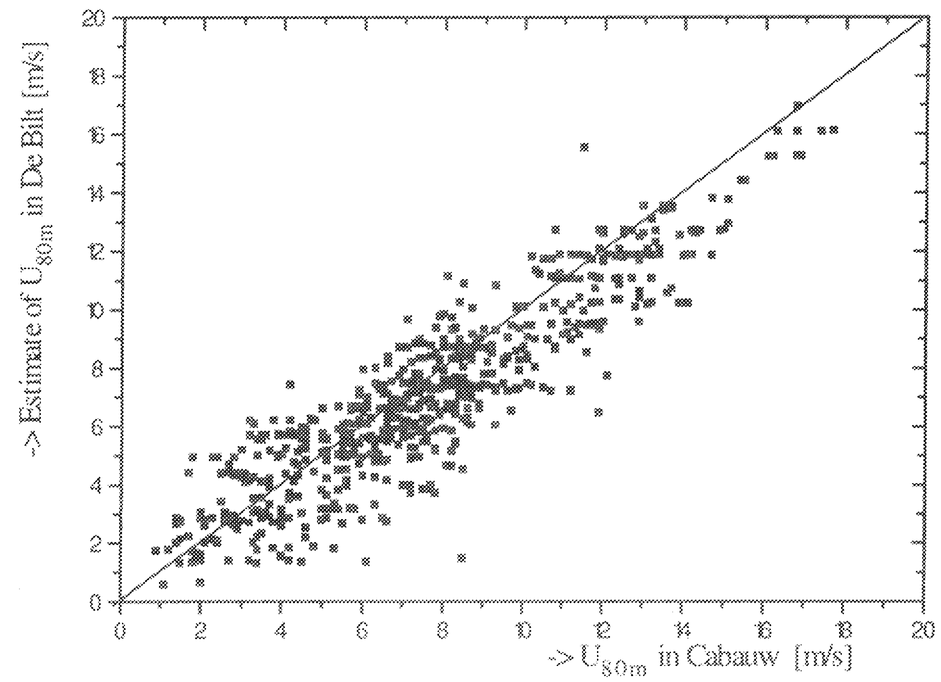


Fig. 4.3 The wind speed in Cabauw at 80m (half hour mean observation) plotted against an estimate of the wind speed in De Bilt at 80m (using the fluxroutines), for January 1992



Measurements of wind speed at 10m of stations De Bilt and Cabauw are plotted in fig. 4.2. In fig. 4.3 the observed windspeed at 80m in Cabauw is plotted against the estimated wind speed in De Bilt at 80m (using the flux routines). Station De Bilt is used because the differences in z_0 values between Cabauw and De Bilt are large.

It is obvious from fig. 4.2 and 4.3 that the bias for especially high wind speeds is decreased. These high wind speeds correspond with wind directions from 220° (SW) to 280° (W), where differences in z_0 between Cabauw (z_0=0.1) and De Bilt (z_0=1) are particular large. Before blowing the trumpet, however, we have to call to mind §3.2 where it was stated that the flux routines overestimated high wind speeds at 80m for almost every month. So part of the desired effect may be caused by a systematic bias produced by the flux routines. However it is likely that the overestimate of wind speed at 80m in Cabauw is caused by wrong z_0 values in Cabauw (for the upward transformation in De Bilt z_0 values in De Bilt are used). Hence this overestimate would be eliminated during the downward transformation (§3.3) and in chapter 5 (fig. 5.2) we will see that after the downward transformation there is still an effect which increases the high wind speeds in Cabauw in comparison with the surrounding stations.
The effect illustrated in fig. 4.2 and 4.3 is qualitatively the same if observations in Schiphol, Rotterdam or Herwijnen are transformed upwards instead of the observations in De Bilt.

Unfortunately, for T and q such a clear desirable effect can not be found. What is most striking in figures such as fig. 4.4 and 4.5 is the fact that the scatter at 80 metres is larger than at 1.5 metres. However for some months there seems to be a visible improvement of the bias in T and q due to the upward transformation. Fig. 4.4, 4.5 show a smaller bias for medium and high temperatures at 80 metres. Maybe this is caused by differences between Cabauw and De Bilt in cloud cover or z_0 values. Unfortunately this cloud cover effect is weakened during the downward transformation because the cloud cover in Cabauw is taken as the average of 3 stations.

Fig 4.4 The temperature at 1.5m in Cabauw (half hour mean observation) plotted against the temperature at 1.5m in De Bilt (hour mean observation), for August 1992

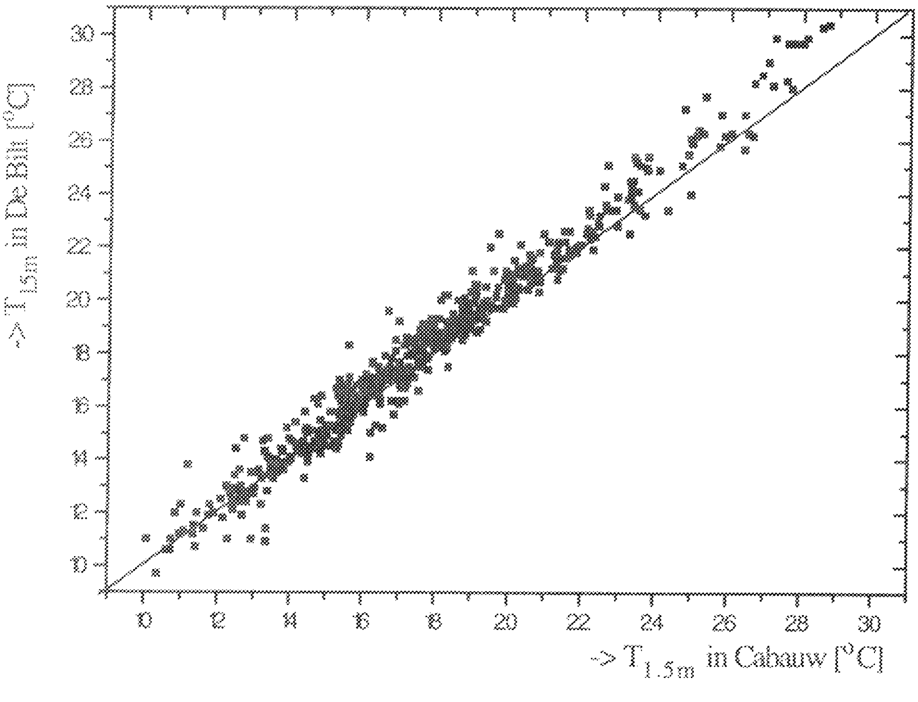
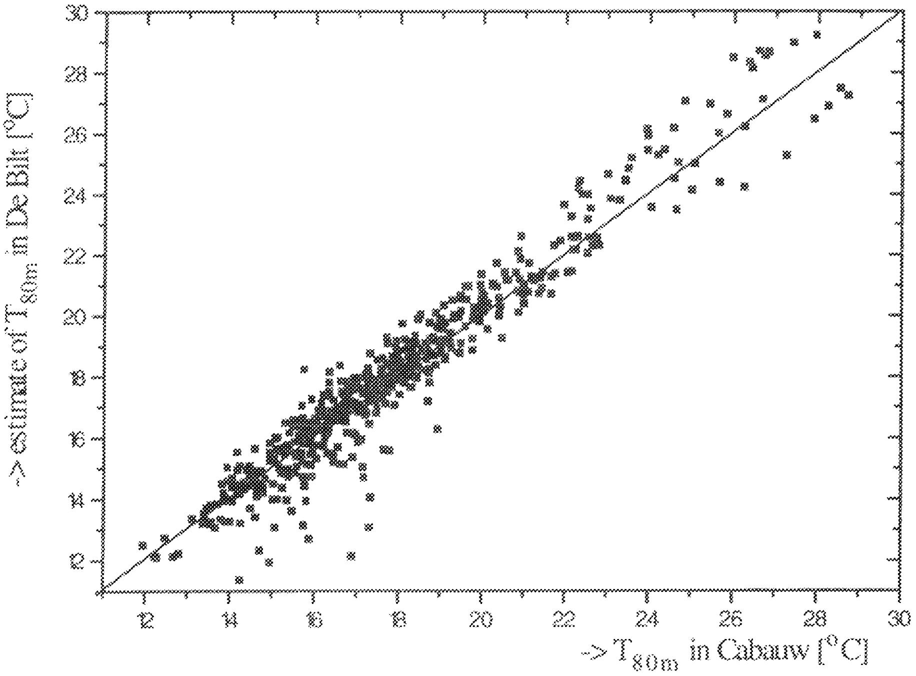


Fig 4.5 Temperature at 80m in Cabauw (half hour mean observation) plotted against an estimate of the temperature at 80m in De Bilt (using flux routines), for August 1992



Upward transformation has impact on the total range of temperature and specific humidity values.

4.3 Horizontal smoothness and interpolation errors

In section 1 we assumed that fields of temperature, specific humidity and wind speed vary more smoothly at greater height than near the surface. Because of this these parameters could be interpolated more accurately.

A simple approach to this phenomenon is that local changes, induced by surface forcings, are weakened when they are transported through the (surface layer) air, because this air has a capacity for momentum, temperature and humidity. The Monin-Obukhov theory, used in the flux routines, makes the assumption that the vertical profiles are in equilibrium with the underlying surface. Unfortunately this is normally not true for stable atmospheric situations where, because of the weak vertical mixing, the upper atmosphere responds slowly to surface forcings. Therefore a large homogeneous terrain up the stream is required for stable atmospheric situations to guarantee equilibrium.

In general we expect (and hope) that the atmosphere will be less influenced by the surface at greater heights, even during night-time (for wind speed this is generally accepted).

In this paragraph, the smoothness of a horizontal field is characterised by the standard deviation.

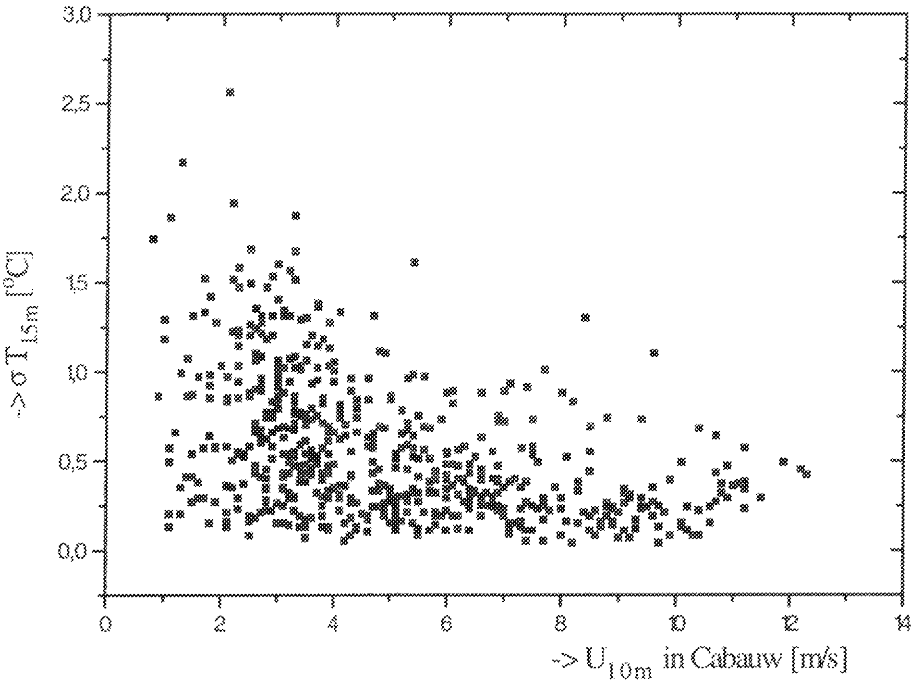
$$\sigma = \frac{\sqrt{\sum_{a=1}^{4}(x_a - \bar{x})^2}}{4} \qquad (7)$$

- σ = standard deviation of a temperature, specific humidity or wind speed field
- a = station (Herwijnen, De Bilt, Schiphol or Rotterdam)
- x = observed temperature, specific humidity or wind speed
- $\bar{x}$ = the average temperature, specific humidity or wind speed taken of Herwijnen, De Bilt, Schiphol and Rotterdam

Routine observations of Herwijnen, De Bilt, Schiphol and Rotterdam are used. For non-synoptical heights the observations had to be transformed upward using the flux routines.
Again it is stated that the change in standard deviation moving to greater heights is caused by the flux routines. Unfortunately there is only one observation tower at our disposal, so the "real" standard deviation of the atmosphere at non-synoptical heights could not be measured directly.

From the routine dataset standard deviations (7) of temperature (T) and specific humidity (q) observed at 1.5 metres and wind speed (U) observed at 10 metres can be calculated. If the σ of a field is larger, a greater profit or impact of the AIM might be expected in comparison with straightforward horizontal interpolation (only if the increase of the σ is a consequence of increased localness of the observations, e.g. greater difference in cloud cover between the stations).
Before describing the correlations between the σ of $T_{1.5m}$, $q_{1.5m}$ and U_{10m} and the hour of the day (or stability condition), it has to be noted that these correlations can be weak for certain months.
For most months and for all parameters the standard deviation is relatively small during neutral conditions (as during the transition from day to night or from night to day. In agreement with this the standard deviation of T and q (not U) generally decreases with increasing wind speed. This is illustrated by fig. 4.6 (typical for T and q). These results are in agreement with <13>, who found that differences in U, T and q between forest and agricultural fields are small in neutral atmospheric conditions but increase with increasing (un)stability.

Fig. 4.6 The standard deviation, σ(T) of the observed temperature at 1.5m as a function of the observed windspeed at 10m in Cabauw, for February 1992



During the winter months the σ of T and q is largest during night-time, despite the fact that temperatures are low then. In the summer months the σ of T and q is relatively large during night-time and especially mid-day time. As far as temperature is concerned, the latter may (partly) be caused by the fact that temperatures are relatively high round noon.

Under what circumstances are interpolation errors, caused by simple horizontal interpolation of synoptic (routine) observations large? To check this up, routine observations (U_{10m}, $T_{1.5m}$ and $q_{1.5m}$) of 4 stations surrounding Cabauw (fig. 1.2) are interpolated horizontally to Cabauw where they are compared with routine observations in Cabauw. The results of this experiment are in agree with the behaviour of the σ of the synoptical observations, i.e. for most months the interpolation error is relatively small during neutral conditions and increases with (un)stability depending on the season. Despite this no correlation could be observed (in scatterplots) between the σ and the interpolation error. Therefore the assumption made in section 1 that more smoothed fields (smaller σ) would lead to improved interpolation results, cannot be supported by the results of this study.
Some of the extremely large interpolation errors can be explained by the occurrence of fronts or showers. In heavy showers, temperature may drop suddenly with up to 10 degrees Celsius, or remain almost the same. It is very difficult to predict this effect. It is possible, but outside the context of this study, to take the effect of thermal fronts into account.

The change in standard deviation due to upward transformation is illustrated by fig. 4.7, 4.8 and 4.9. These figures are representative for all months of 1992.

Fig. 4.7 Difference between the standard deviation, σ in the specific humidity field at 80 and 1.5 metres ($\sigma_{q_{80m}} - \sigma_{q_{1.5m}}$), for August 1992

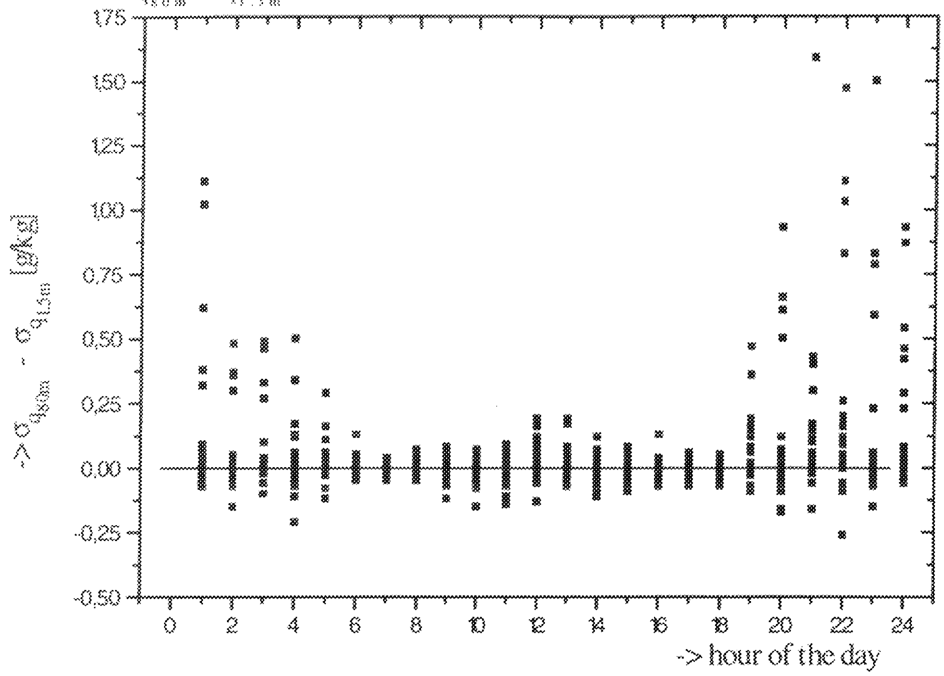


Fig. 4.8 Difference between the standard deviation, σ of the temperature field at 80 and 1.5 metres ($\sigma_{T_{80m}} - \sigma_{T_{1.5m}}$), for August 1992

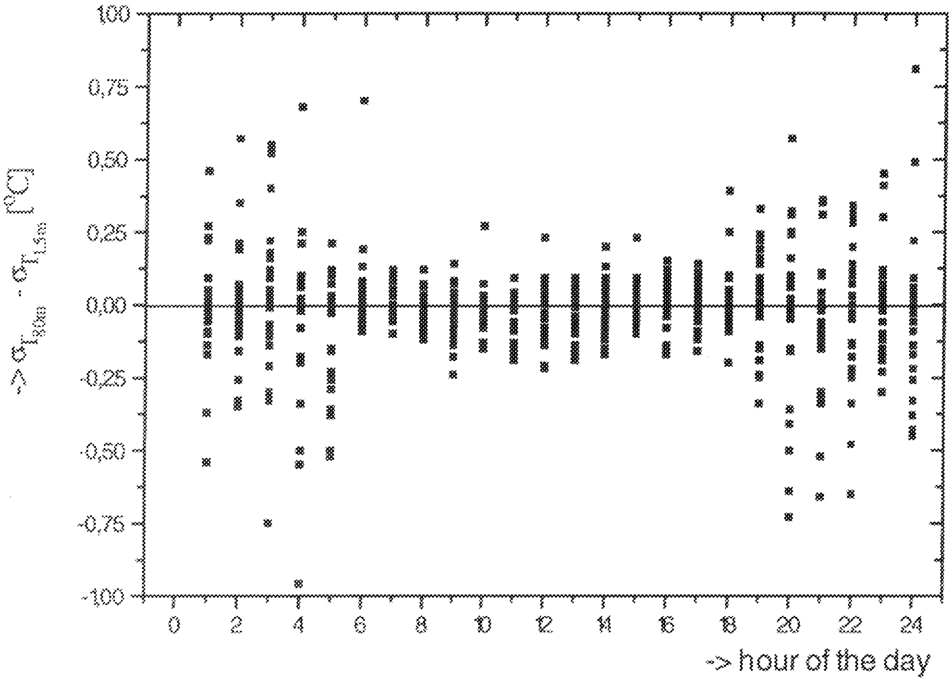
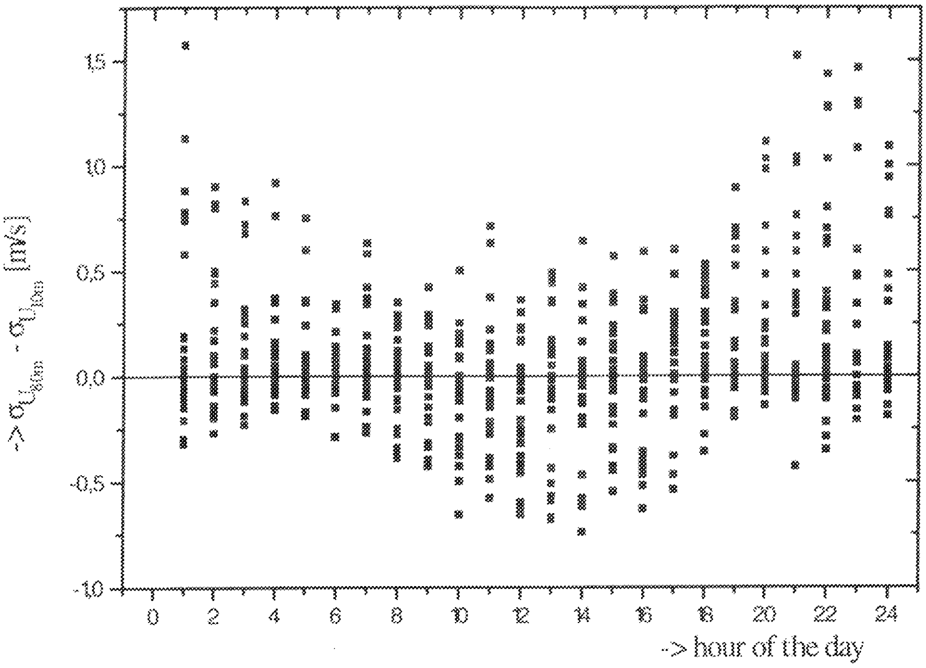


Fig. 4.9 Difference between the standard deviation, σ of the wind speed field at 80 and 10 metres ($\sigma_{U_{80m}} - \sigma_{U_{10m}}$), for August 1992



Looking at figs. 4.7, 4.8 and 4.9, it is obvious that in many cases the standard deviation does not decrease when U, t or q is transformed upwards. However, before drawing conclusions from figs. 4.7, 4.8 and 4.9, one should remember that the parameters themselves change in magnitude during the upward transformation. Wind speed increases during upward transformations. Temperature decreases during day time (unstable) and increases during night-time (stable) situations. Specific humidity decreases during unstable situations and can increase or decrease during stable situations. For all of these parameters the relative σ could be calculated (dividing the σ by the mean of the parameter). For temperatures round 0 °C this leads to very large relative errors. Furthermore it is not clear whether it is the <u>relative</u> σ that is important for this study.
As stated before, it is known for wind speed only (e.g. <9>) that the horizontal σ (relative and non-relative!) must decrease for greater heights. Fig. 4.9 shows that, using the flux routines for the upward transformation, there might be a small average decrease of the σ in the wind speed during day time.
As far as temperature and specific humidity are concerned, changes in the σ due to the upward transformation are small during day time. Under neutral conditions (during the transition from day to night or vice versa) there is almost no impact of the upward transformation on the σ of T and q.
During night-time the σ in the temperature field may increase and decrease. No particular circumstances can be pointed out when a decrease will be found (purely random changes would probably not generate so much of a decrease in the σ). The σ in the q field only increases during night-time (except for some small decreases).

Are the interpolation results better at 80 metres than they are at synoptical heights?
The answer to this question might tell us something about how successful the upward transformations in the AIM has been in stripping the local character of the observations of the surrounding stations. In this part of the AIM stretch (the upward transformation) most environment characteristics are better known (in this study mainly NN and Kin). Some input parameters for the flux routines are less accurately known at the location of the downward transformation (in this study in Cabauw).
So transforming only upwards and verifying at 80 metres, possibly makes it easier to show some beneficial effect of the AIM. However it is not strictly necessary, for making the AIM profitable, that

these values at 80 metres are correct! The 80 metres values are just "in between values" and the errors made during the upward transformations are compensated to a large extent during the downward transformations. For example looking at fig. 4.10, one hour can be seen where the interpolation error for temperature at 80m is almost 8 °C larger than the interpolation error at 1.5m. This hour corresponds with a strong inversion in Cabauw ($T_{1.5m}$=12.57 °C and T_{80m} = 21.38 °C). It is likely that the flux routines underestimated the inversion at all the surrounding stations during the upward transformation (this issue will be discussed at the end of this paragraph), resulting in an increased interpolation error at 80m. When this bad estimation of T_{80m} in Cabauw is transformed downwards again, the flux routines will again underestimate the inversion and the error will be reduced considerably.
The interpolation error at synoptical height is the resultant from a horizontal interpolation of (routine) observations of U_{10m}, $T_{1.5m}$ and $q_{1.5m}$ at the surrounding stations (fig.1.2), to Cabauw where they are compared with Cabauw tower observations of U_{10m}, $T_{1.5m}$ and $q_{1.5m}$ For the interpolation error at 80m the routine observations at the surrounding stations are transformed upward, using the flux routines, and subsequently interpolated to Cabauw where they are compared with Cabauw tower observations at 80m

Fig. 4.10 Difference in interpolation error at 80m and 1.5m (intp. err. T_{80m} - intp. err. $T_{1.5m}$), for July 1992
Intp. error at 80m = (Cabauw tower obs. 80m) - (hor. intp. 80m estimates using flux routines)
Intp. error at 1.5m = (Cabauw tower obs. 1.5m) - (hor. intp. 1.5m routine observations)

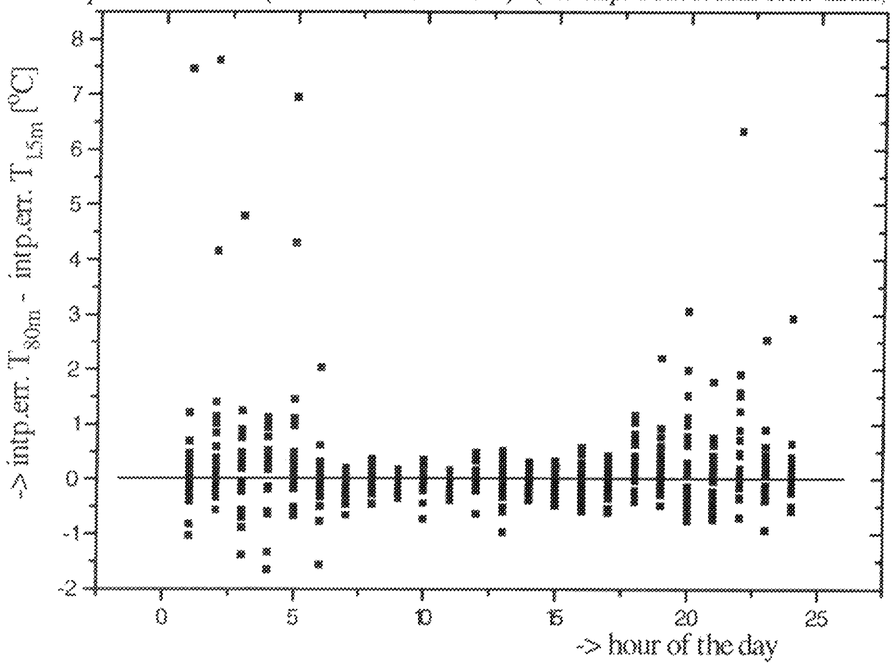


Fig. 4.11 Difference in interpolation error at 10 and 80m. (intp. err. U_{80m} - intp. err. U_{10m}), for January 1992
Intp. error at 80m = (Cabauw tower obs. 80m) - (hor. intp. 80m estimates using flux routines)
Intp. error at 10m = (Cabauw tower obs. 10m) - (hor. intp. 10m routine observations)

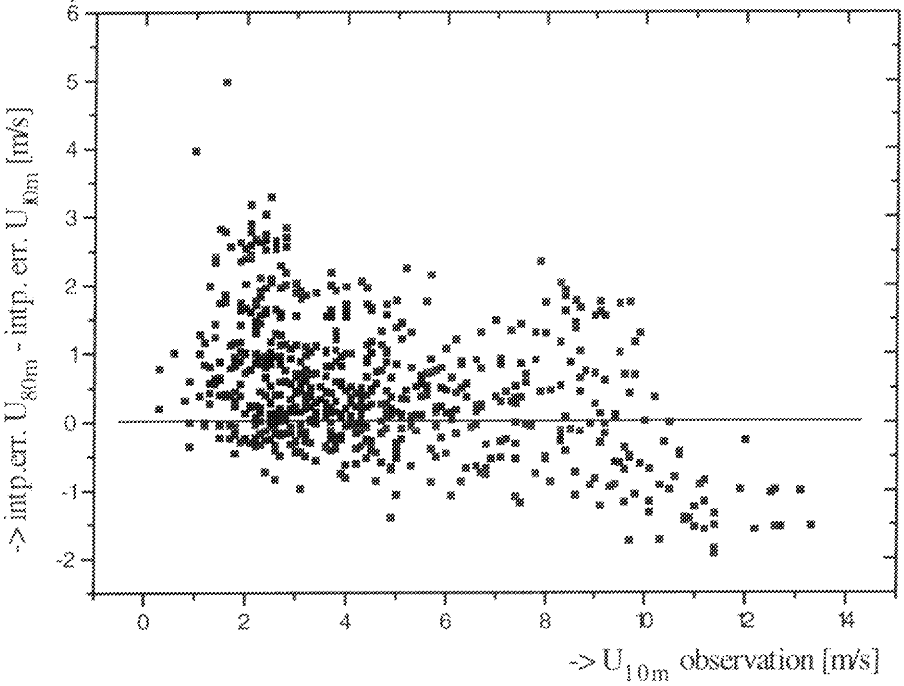
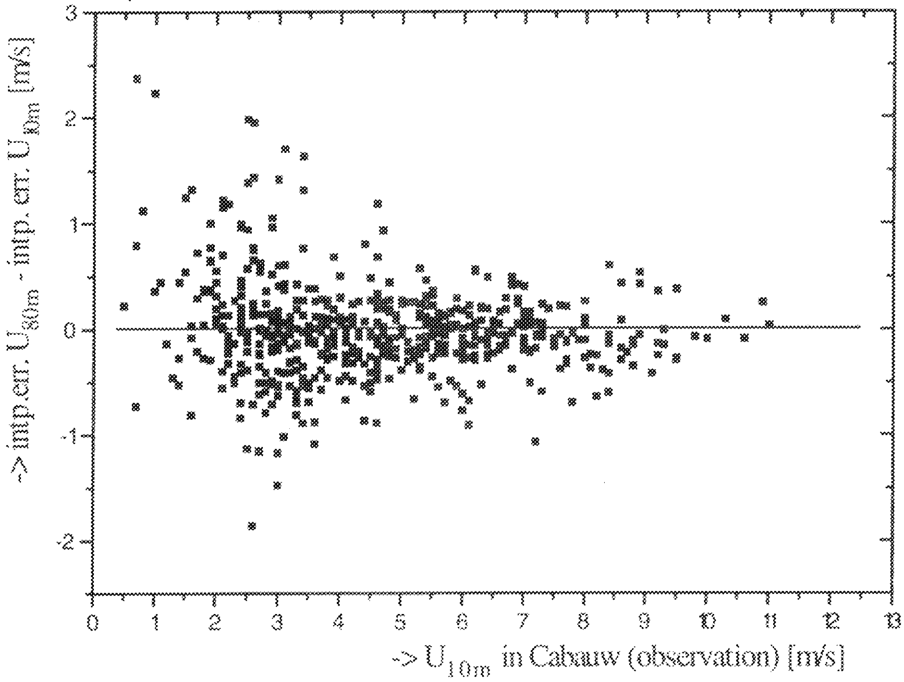


Fig. 4.12 Difference in intp. error at 80 and 1.5m (intp. err. T_{80m} - intp. err. $T_{1.5m}$), for August 1992
Interpolation error at 80m = (Cabauw obs. 80m) - (hor. intp. 80m estimates using fluxroutines)
Interpolation error at 1.5m = (Cabauw obs. 1.5m) - (hor. intp. 1.5m observations)



In summary the main results of the comparison between the interpolation errors at synoptical and 80 metres height:

Wind: For high wind speeds the interpolation error at 80 metres height is smaller than the interpolation error at 1.5 metres (fig. 4.11).
T and q: During night-time, stable, situations interpolation errors for T and q are normally bigger at 80 metres than at 1.5m. Differences between interpolation errors at 1.5 and 80m are mostly small during day time (fig. 4.10). Interpolation errors for T and q at 80 and 1.5 metres are the same under high wind speed conditions (fig.4.12). Because the calculated vertical profiles of T and q are almost perfectly for high wind speed/neutral conditions (fig. 3.9) it can be stated that, under the limiting conditions of this study, a perfect AIM would give no effect in comparison with direct horizontal interpolation at high wind speeds. In other words, measurements of T and q at 80 metres are just as locally defined as T and q at 1.5 metres at high wind speed/neutral conditions.

As could be expected the effect of the upward transformations on the interpolation error increases when the transformation height increases and vice versa. These results are not presented.

What are the results concerning the interpolation errors per month quantitatively expressed? Let us consider the standard deviation with respect to the mean error, SD (representing the scatter with respect to the mean error, see Appendix A) and the bias (Appendix A).
Different SD and biases are made:

Udir: comparison between U_{10m} observed in Cabauw (Cabauw tower observations) and estimates of U_{10m} in Cabauw using direct horizontal interpolation

U80m: comparison between U_{80m} observed in Cabauw (Cabauw tower observations) and estimates of U_{80m} in Cabauw made by horizontal interpolation of upward transformed (to 80m) routine observations

Abbreviations of other comparisons have analogous meanings.

The meaning of U+, T+ and q+ in table 4.2 will be explained in Appendix C.

Table 4.1 SD of temperature [°C], specific humidity [g/kg] and wind speed [m/s] in Cabauw

	9201	9202	9203	9204	9206	9207	9208	9209	9210	9211	9212
Udir	0.737	0.678	0.879	0.725	0.679	0.752	0.820	0.749	0.838	0.883	0.700
U80m	1.226	1.193	1.324	1.329	1.161	1.161	1.253	1.236	1.338	1.143	1.325
qdir	0.114	0.127	0.177	0.216	0.414	0.374	0.358	0.248	0.188	0.132	0.124
q80m	0.188	0.377	0.409	0.461	0.671	0.664	0.615	0.572	0.205	0.326	0.249
Tdir	0.392	0.471	0.505	0.498	0.524	0.516	0.465	0.518	0.499	0.381	0.441
T80m	0.879	0.931	0.788	1.273	0.893	1.051	0.638	0.750	1.069	0.667	0.939

Table 4.2 Biases of temperature [°C], specific humidity [g/kg] and wind speed [m/s] in Cabauw

	9201	9202	9203	9204	9206	9207	9208	9209	9210	9211	9212
Udir	0.237	0.298	0.200	0.145	0.043	0.156	0.275	0.313	0.103	0.314	0.212
U80m	-0.539	-0.126	-0.465	-0.242	-0.062	-0.225	-0.161	0.139	-0.082	0.009	-0.577
U+	-0.496	-0.126	-0.393	-0.268	-0.227	-0.247	-0.174	-0.028	-0.041	0.067	-0.571
qdir	-0.181	-0.151	-0.130	-0.073	-0.315	-0.316	-0.362	-0.280	-0.209	-0.186	-0.250
q80m	-0.191	-0.066	-0.142	-0.241	-0.386	-0.500	-0.585	-0.380	-0.182	-0.223	-0.245
q+	-0.200	-0.087	-0.165	-0.244	-0.373	-0.483	-0.578	-0.357	-0.219	-0.224	-0.255
Tdir	-0.312	-0.394	-0.195	-0.194	-0.177	-0.294	-0.390	-0.115	-0.194	-0.208	-0.140
T80m	-0.572	0.029	0.080	0.382	-0.185	-0.036	-0.098	-0.014	-0.051	-0.043	-0.438
T+	-0.332	-0.092	0.049	0.234	-0.164	-0.071	-0.183	0.011	-0.171	-0.174	-0.353

-SD of T,q and U

The SD of T,q and U all show a clear increase at 80m in comparison with the SD at synoptical heights (remember U increases during the upward transformation).

-Biases of U, T and q

A clear bias can be observed.The specific humidity and temperature values resultant from the direct horizontal interpolation are generally higher than the observed values in Cabauw. Wind speed in Cabauw is underestimated by the horizontal interpolation. These biases of T, q and U are consistent with the fact that z_0 values are, on the average, lower in Cabauw than at the surrounding stations (see experiment 1 & 5 in §2.2). The measuring instruments for the humidity in Cabauw are different from the ones used in the surrounding stations (§4.1). This may also be an explanation for the systematic bias in the specific humidity between Cabauw and the surrounding stations. It is known that, at high humidity levels, the capacitive humidity measurement instruments (used at the surrounding stations in 1992) may overestimate the humidity. However, the bias appears at all humidity levels.

No obvious improvement of the biases at 80m in comparison with the biases at synoptical heights can be observed.

The biases from table 3.3 and 4.2 can be combined in a way that is explained in Appendix C. As a result of this combination it can be stated that the errors made during the upward transformations are, to a large extent, independent of location (in this study) and not caused by wrong input parameters (unless these input parameters have the same errors for all the stations, which is unlikely)). An exception has to be made for high wind speed values (probably due to wrong z0 values in Cabauw §3.2). The errors caused by the upward transformations seem to be determined by the weather conditions and are partly due to imperfections in the flux routines under certain weather conditions.

Side-note: For some conditions, e.g. when the air at 80m has totally different characteristics from the air at synoptical heights due to differential advection (during certain night time, stable situations), 0-D diagnostic 'models' such as the flux routines will always be incapable in producing correct vertical profiles.

For this study there seems to be no clear advantage of interpolation at 80m instead of interpolation at synoptical heights if we look at the absolute (non-relative) bias and scatter.

As stated before, it is not a priori necessary that the estimated values at 80m are correct. However it seems reasonable to conclude that at this point in the AIM (after the upward transformations in the surrounding stations and the interpolation at 80m to Cabauw) there is no indication of some beneficial effect of the AIM due to the elimination of the local character of the observations in the surrounding stations.

5 AIM versus horizontal interpolation

In this section the performance of the complete AIM will be discussed. I.e. the routine observations (at synoptical heights) in Rotterdam, Schiphol, De Bilt and Herwijnen are transformed upwards to some reference height, subsequently interpolated (at this reference height) horizontally to Cabauw and finally transformed downwards again to synoptical heights in Cabauw (fig. 1.1). The results of the AIM are compared with results of direct horizontal interpolation of the routine observations in Rotterdam, Schiphol, De Bilt and Herwijnen to Cabauw.
There is no need for Cabauw observations at non-synoptical heights in this section, so only routine observations (§4.1) are used. An exception has to be made for the results in table 5.3 and 5.4 where Cabauw tower observations (section 3) are used.
For most experiments presented in this section 60 metres was chosen as reference height because for wind at this height horizontal variability (in a 5*5 km^2 block) is normally small <9> and the surface layer theory, which is used for the upward transformations, is still applicable in most cases. The height where meteorological parameters are more or less horizontally homogeneous, depends on the parameter itself, the atmospheric stability and the underlying land. Large areas of land can affect the profiles in the mixed layer <13,14>. Because air has a smaller capacity for momentum than for temperature and humidity, changes in the surface will effect the wind speed at greater heights. This is an argument in favour of using a greater height for wind speed than for temperature and humidity,<13>. The effects of changing the reference height in the AIM are studied in this section.

<u>Inputparameters for the downward transformation in Cabauw</u>
In practice, using the AIM, wind direction, downward short-wave radiation (Kin), cloud cover and pressure are not available for the target location (in this study Cabauw). The cloud cover at the target location might be determined by means of satellite pictures or short-term advection cloud models. In the study presented in this paper the cloud cover and Kin for Cabauw are obtained by horizontal interpolation of the observed cloud cover and Kin at the surrounding stations (fig.1.2). Because observations of the cloud cover were not available in Cabauw, the effect of taking the observed cloud cover instead of the interpolated cloud cover at the target location, could not be investigated. So the possibilities, in the present study, for the AIM to add the local character (due to the cloud cover) back into the observations during the downward transformations, are limited.
For the direction of the wind in Cabauw, the observed wind direction in Herwijnen is taken. Taking the wind direction in Cabauw instead of Herwijnen showed no significant effect on the experiments (and resulted in the same z_0 value in Cabauw for most cases).
For the pressure in Cabauw the observed pressure in De Bilt is taken. The effects of using this pressure value can be neglected for the purpose of this study.

Firstly it is important to note the fact that differences between the AIM and direct horizontal interpolation are generally very small in this verification, and using these flux routines. Some characteristic figures:

Fig. 5.1 Estimates of the specific humidity at 1.5m in Cabauw obtained by direct horizontal interpolation (DIR) and by the AIM (via 60m), for September 1992

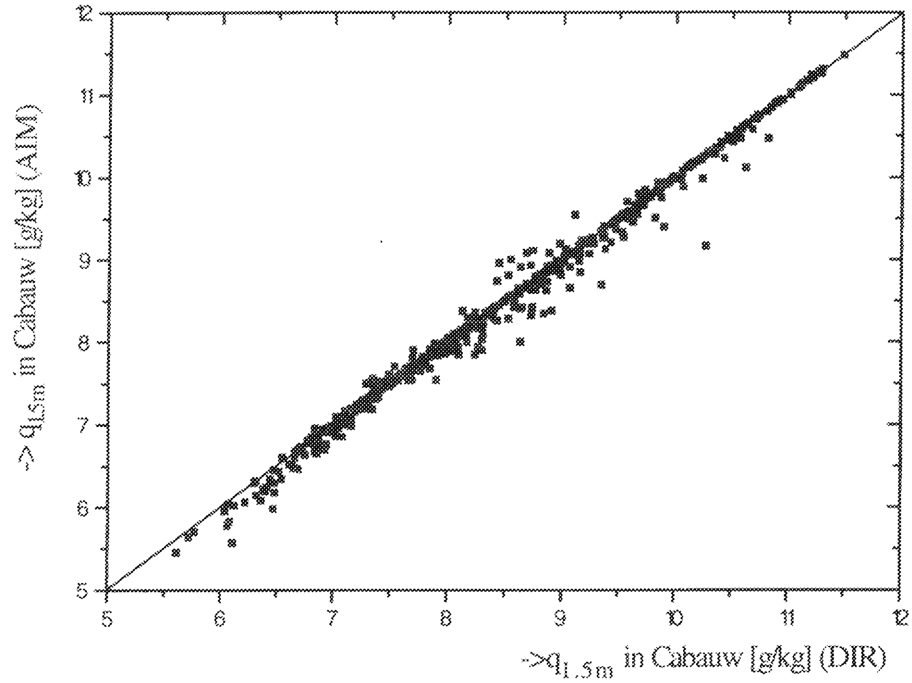
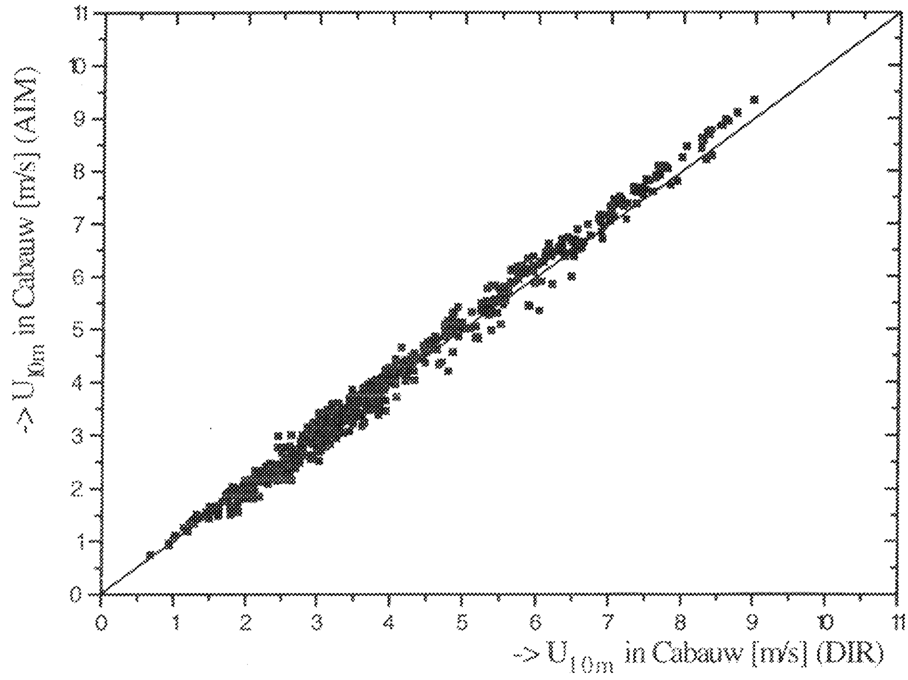


Fig. 5.2 Estimate of the wind speed at 10m in Cabauw obtained by direct horizontal interpolation (DIR) and by the AIM (via 60m), for Sepember 1992



For temperature a figure looking similar to fig. 5.1 could be presented (with differences between AIM and DIR up to 2 °C for September 1992).

Because the range of values for U and q is large, the scatter in fig. 5.1, and 5.2 may be visually underestimated. At high wind speeds, estimates of U_{10m} in Cabauw are systematically higher, using the AIM than they are with direct horizontal interpolation (fig.5.2) for almost every month in 1992. This can be explained by the fact that z_0 values are generally lower in Cabauw than in the surrounding stations.
Differences between the AIM and direct interpolation increase a little if the transformation height is taken to be 80 or 200 metres instead of 60m.

Finally we approach the most important outcome of this study. Is the AIM able to perform better than direct horizontal interpolation?
Let us first look at the difference in interpolation error between the AIM and the direct horizontal interpolation method as a function of the time of day. The interpolation error is defined as; the routine observation in Cabauw minus the estimated U_{10m}, $T_{1.5m}$ or $q_{1.5m}$ in Cabauw using the AIM or direct horizontal interpolation.

Note that the absolute values of the interpolation errors are subtracted in fig. 5.3 and 5.4 and therefore positive values in these figures correspond to improvements in the interpolation error if the AIM is used instead of simple horizontal interpolation.

Fig. 5.3 Improvement (difference in the interpolation error) in the estimate of $T_{1.5m}$ in Cabauw, by using AIM (via 60m) instead of DIR, as a function of the hour of the day, for August 1992

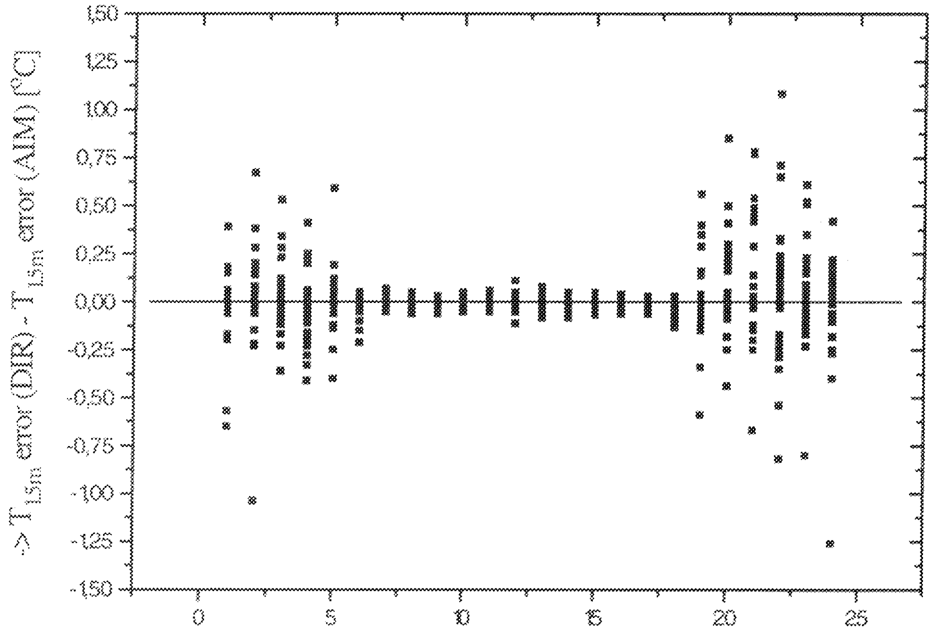
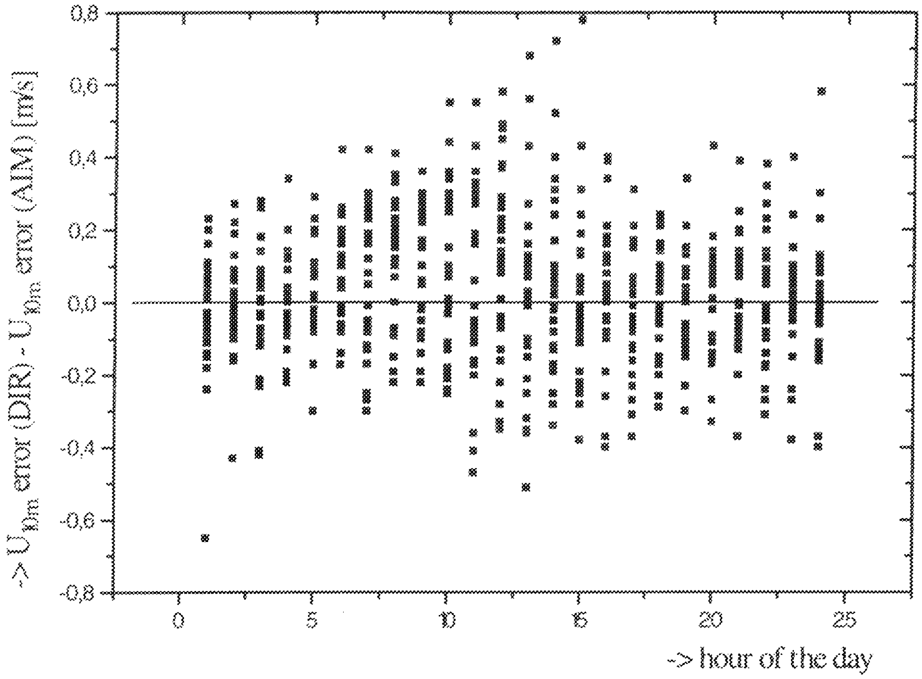


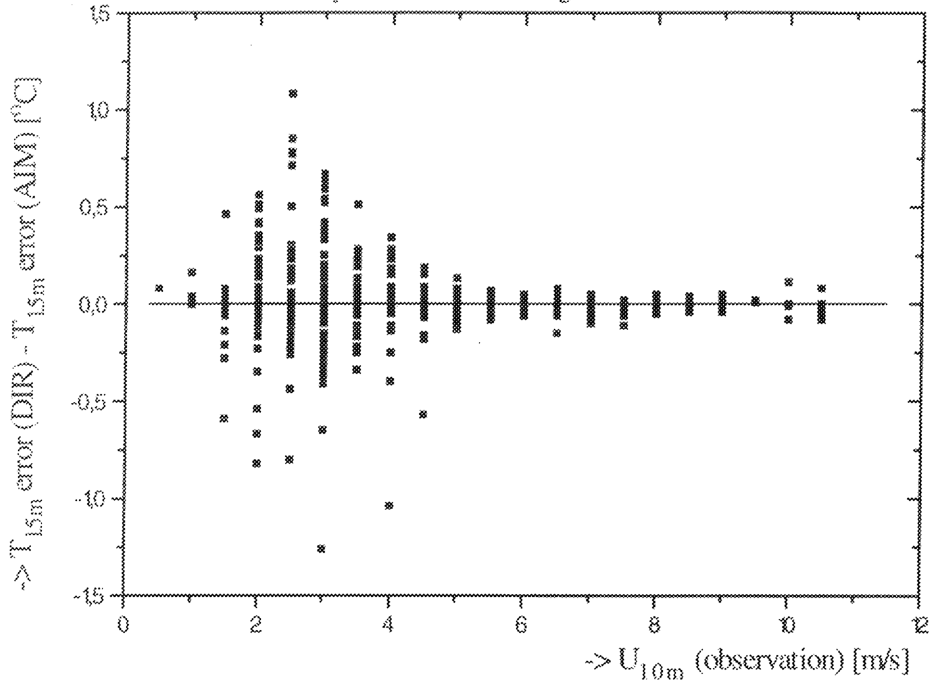
Fig. 5.4 Improvement (difference in interpolation error) in the estimate of U_{10m} in Cabauw, by using the AIM (via 60m) instead of DIR, as a function of the hour of the day, for August 1992



Figures 5.3 and 5.4 are characteristic for every month of 1992. For specific humidity a plot looking similar to fig. 5.3 could be presented.
As can be expected after the results of §2.2, the significant differences are, as far as T and q are concerned, restricted to night time (stable) situations (fig.5.3). For none of the meteorological parameters an obvious overall improvement or deterioration appears. No particular circumstances can be pointed out when an improvement and when a deterioration will be found for a specific hour.

The differences in interpolation error for T and q between AIM and direct horizontal interpolation totally disappear at high wind speed/neutral conditions (see fig. 5.5).

Fig. 5.5 Improvement (difference in the interpolation error) in the estimate of $T_{1.5m}$ in Cabauw, by using the AIM (via 60m) instead of direct horizontal interpolation (DIR), as a function of the observed wind speed in Cabauw, for August 1992



So figures like fig. 5.3 and 5.4 show no "visible" average improvement using the AIM. What are the results quantitatively expressed in one value per month?
Let us consider the standard deviation with respect to the mean error, SD (representing the scatter with respect to the mean error, see Appendix A) and the bias (Appendix A).

Different SD and biases are made. Some examples:

U dir:	comparison between U_{10m} observed in Cabauw (routine observations) and estimates of U_{10m} in Cabauw using direct horizontal interpolation
U AIM (60m):	comparison between U_{10m} observed in Cabauw (routine observations) and estimates of U_{10m} in Cabauw using the AIM (via 60m)

Abbreviations of other comparisons have analogous meanings.

Table 5.1 Biases of temperature, specific humidity and wind speed in Cabauw calculated using the AIM (via 60 or 200 metres) or horizontal interpolation (dir)

	9201	9202	9203	9204	9206	9207	9208	9209	9210	9211	9212
U dir	0.352	0.318	0.190	0.193	0.046	0.075	0.190	0.202	0.008	0.142	0.072
U AIM (60m)	0.278	0.237	0.128	0.111	0.075	0.052	0.106	0.156	-0.001	0.031	-0.003
U AIM(200m)	0.270	0.205	0.097	0.093	0.083	0.038	0.094	0.152	0.000	0.033	0.025
q dir	-0.190	-0.185	-0.155	-0.151	-0.361	-0.397	-0.442	-0.351	-0.224	-0.222	-0.275
q AIM (60m)	-0.178	-0.166	-0.141	-0.132	-0.336	-0.362	-0.414	-0.323	-0.203	-0.213	-0.264
q AIM (200m)	-0.161	-0.132	-0.107	-0.088	-0.295	-0.302	-0.355	-0.265	-0.164	-0.196	-0.247
T dir	-0.339	-0.361	-0.225	-0.212	-0.181	-0.294	-0.365	-0.132	-0.212	-0.209	-0.195
T AIM (60m)	-0.309	-0.278	-0.186	-0.174	-0.166	-0.248	-0.323	-0.104	-0.162	-0.188	-0.179
T AIM (200m)	-0.283	-0.244	-0.168	-0.135	-0.158	-0.214	-0.273	-0.062	-0.109	-0.144	-0.131

Table 5.2 SD of temperature, specific humidity and wind speed in Cabauw calculated using the AIM (via 60 or 200 metres) or horizontal interpolation (dir)

	9201	9202	9203	9204	9206	9207	9208	9209	9210	9211	9212
U dir	0.727	0.599	0.759	0.640	0.594	0.647	0.666	0.656	0.750	0.736	0.588
U AIM (60m)	0.683	0.582	0.739	0.636	0.593	0.619	0.651	0.650	0.742	0.713	0.574
U AIM(200m)	0.670	0.597	0.742	0.650	0.599	0.626	0.659	0.685	0.767	0.733	0.581
q dir	0.130	0.133	0.185	0.255	0.465	0.496	0.401	0.274	0.211	0.148	0.134
q AIM (60m)	0.141	0.147	0.200	0.282	0.501	0.530	0.426	0.316	0.224	0.163	0.134
q AIM (200m)	0.179	0.211	0.271	0.336	0.563	0.604	0.503	0.424	265	0.210	0.154
T dir	0.377	0.473	0.580	0.505	0.548	0.546	0.526	0.540	0.494	0.386	0.382
T AIM (60m)	0.384	0.434	0.594	0.527	0.590	0.583	0.553	0.609	0.529	0.397	0.383
T AIM (200m)	0.393	0.457	0.605	0.525	0.608	0.585	0.559	0.646	0.543	0.416	0.425

-Biases T,q and U

In §4.3 it was already pointed out that the sign of the biases in Cabauw, corresponding with the direct horizontal interpolation method (table 5.1, Udir, qdir and Tdir) can be explained in terms of the generally lower z_0 values in Cabauw in comparison with the z_0 values in the surrounding stations.

For all months and all parameters the biases, using the AIM, show a, most of the time small, improvement. As far as T and q concerns, this improvement increases if the transformation height is raised to 200m. For wind speed translating to 200m shows no extra beneficial effect.

It is difficult to say if these improvements in the biases using the AIM, are significant. From pure statistical point of view these improvements are significant but it is possible that an error in the AIM accidentally compensates the systematic differences between the surrounding stations and Cabauw. This can be illustrated by an experiment where the z_0 value in Cabauw is fixed to some very low value. As a result of this experiment the SD and the bias of T and q improves substantially if the AIM is used instead of direct horizontal interpolation.

-SD wind speed

Using the AIM (60m) instead of direct horizontal interpolation, the SD of the wind speed improves for all months with, at the best 7% (9201). The improvements, are very small but the fact that the experiment is repeated so many times (almost every hour of 1992) makes the improvement more significant. The results show no extra improve if the transformation height is raised to 200m.

-SD temperature and specific humidity
SD of T and q in table 5.2 show that the scatter increases, especially in the summer months, using the AIM instead of direct horizontal interpolation. One exception can be seen for 9202 where the SD of the temperature is decreased with almost 9% using the AIM (the estimated sensible heat fluxes in Cabauw were particular good for this month).
Raising the transformation height from 60 to 200m increases the scatter in T and q.

One of the problems encountered in this study is that too many parameters which define the localness of the surrounding stations and Cabauw itself, like e.g. albedo or cloud cover, are unknown (or not well enough taken into account by the flux routines).
Another problem is that the differences between the stations involved are too small (look at the small biases and SD in table 5.1 and 5.2!) which makes it more difficult for the AIM to perform better than straight forward horizontal interpolation. E.g. the "distance-to-the-coast-effect" with westerly winds can be very substantial and is not taken into account by the AIM which is designed to compensate small scale effects (of course an algorithm for this "distance-to-the-coast-effect" could be included in the AIM). So the small scale effects must be large enough to outdo this kind of larger scale effects.

Side-note: Comparing Tdir and qdir in table 5.1 and 5.2 with Tdir and qdir in table 4.1 and 4.2, it is remarkable that using different observations (as in table 4.1 and 4.2, horizontal interpolation of routine observations compared with Cabauw tower observations) does not lead to increased biases and SD. This has probably something to do with the fact that Cabauw tower observations of T and q are averaged over a longer period (half an hour) and therefore representative for a larger area. Cabauw tower observations of U are averaged over a half hour while routine observations of U are 1 hour mean, so this may explain the fact that Udir in table 4.1 and 4.2 are generally higher than the Udir in table 5.1 and 5.2.

The AIM is also used to transform routine observations of $T_{1.5m}$ and $q_{1.5m}$ from the stations surrounding Cabauw, via 60m to estimates of T_{60cm} and q_{60cm} in Cabauw. These estimated values at 60cm in Cabauw are compared with Cabauw tower observations at 60cm. Results using the AIM can not be compared with results using direct horizontal interpolation because no observations at 60cm are available at the stations surrounding Cabauw.

Table 5.3 Biases of temperature and specific humidity at 60cm in Cabauw calculated using the AIM (via 60 metres) and compared with Cabauw tower observations

	9201	9202	9203	9204	9206	9207	9208	9209	9210	9211	9212
q60cmAIM(60m)	-0.140	-0.130	-0.076	0.012	-0.226	-0.175	-0.238	-0.200	-0.173	-0.161	-0.224
T60cmAIM(60cm)	-0.283	-0.410	-0.215	-0.333	-0.096	-0.247	-0.360	-0.150	-0.227	-0.251	-0.160

Table 5.4 SD of temperature and specific humidity at 60cm in Cabauw calculated using the AIM (via 60 metres) and compared with Cabauw tower observations

	9201	9202	9203	9204	9206	9207	9208	9209	9210	9211	9212
q60cmAIM(60m)	0.128	0.139	0.172	0.224	0.426	0.391	0.370	0.276	0.199	0.133	0.130
T60cm AIM(60m)	0.467	0.583	0.572	0.584	0.577	0.578	0.534	0.589	0.609	0.388	0.482

Table 5.3 and 5.4 show reasonable results for the estimates of T and q at 60cm using the AIM.

6 Discussion and conclusions

The performance of the flux routines, which probably determines to a large extend the success of the AIM, is investigated using hourly observations of the year 1992.
The flux routines turn out to be unable to produce values for the sensible heat fluxes (H) in excess of 150 [W/m^2] and less than -50 [W/m^2] (no strong inversions!). The latent heat flux (LE) is underestimated during night-time. Changing the modified Priestley Taylor parameter, α, from 1 to e.g. 1.2 during night-time <8> will improve this. The estimate of the bowen ratio, H/LE, can be significant in error (§3.1) with the Priestley Taylor formulation used in the flux routines (1).
Vertical profiles up to 200m of temperature (T), specific humidity (q) and wind speed (U) are generally estimated reasonably well. However errors in estimates of T and q can be very large (showers, thermal fronts, strong inversions). Estimates of T and q (up to 200m) are almost perfect under high wind speed/neutral conditions. During night-time, upward transformed q values are too high (consistent with the night-time error in LE). During day time there is an "hour of the day dependent" error in the upward transformed specific humidity (fig. 3.10). The errors made during the upward transformation are likely to be location-independent and determined by the actual weather conditions.
Transformations of temperature and specific humidity up and down with the use of the flux routines, are sensitive to changes in local input parameters during stable (night-time) situations and relatively insensitive during unstable and neutral situations. Up and downward transformations of wind speed can be sensitive to changes in local input parameters during all stability situations.

Some arguments for using the AIM instead of direct horizontal interpolation (DIR) are investigated.
The assumption that fields of T,q and U are more smooth at greater heights, and therefore more suitable for interpolation, cannot be supported by the results of this study. During high wind speed conditions the interpolation error decreases for U and stays unaltered for T and q if the horizontal interpolation is done at 80 metres instead of observation height. During other conditions the interpolation error at 80m will be generally larger than the interpolation error at observation height.
Differences between synoptical observations from different stations are relatively small during neutral conditions.

The differences between the AIM and DIR are generally very small in the study presented in this paper. As far as T and q are concerned these differences are even negligible during unstable and neutral conditions. Under the limiting conditions of the study presented here it can be stated that, at high wind speeds, a perfect AIM would give the same estimates of T and q as direct horizontal interpolation.
The scatter with respect to the mean error, represented by the standard deviation (SD), in the estimate of U decreases a bit, and of T and q increases, if the AIM (via 60 or 200m) is used instead of DIR. The bias however shows a small improvement for all parameters if the AIM is used. The AIM via 200m produces even smaller biases for T and q than the AIM via 60 metres. The possibility cannot be excluded that these improved biases are caused by accidental compensating effects. However, the improved biases can be explained in terms of the z_0, which generally has a lower value in Cabauw than in the stations surrounding Cabauw.

One of the main handicaps of the investigation presented in this paper is that the local differences between the origin and target stations are quite small. This makes it more difficult for the AIM to perform better than DIR. Larger scale effects (like "distance to the coast" effect), for which the AIM does not correct, dominate the interpolation errors and possible improvements disappear in the "large scale noise".
Another contribution to the noise comes from the flux routines itselves. This noise is caused by imperfections of the flux routines and insufficient possibilities to take the local circumstances into account. Of course, measurement errors contribute to the noise as well.

In the experiment presented in this paper, Cabauw is the target location of the AIM (fig. 1.1). I.e. the interpolated parameters have to be transformed downwards in Cabauw. The cloud cover in Cabauw is taken as the average of the stations surrounding Cabauw. This means that cloud cover is basically used only for the upward transformations, which (try to) eliminate the local character of the observations, and not for adding the local character to the estimate in Cabauw. In practice, the cloud cover at the target location will not be known, but for proving the usefulness of the AIM it would have been interesting to prescribe this observed cloud cover at the target location in an experiment. Satellite pictures or short term advection models can be used in practice to determine the cloud cover at the target location.

In a future investigation, an attempt will be made to improve the performance of the AIM with respect to DIR by:

-Improving the test conditions (bigger differences between the stations and better known local characteristics)

-trying to reduce the noise, introduced by the flux routines, and extend the possibilities of the flux routines to take the local properties into account, by incorporating the Penman-Monteith formulation for the latent heatflux

Some arguments for incorporating the Penman-Monteith formulation for the parameterisation of the latent heatflux, instead of the Priestly Taylor formulation:

If the AIM has proven to be profitable, it will be used to estimate meteorological parameters above all kinds of surfaces. The parameterisation of the latent heat flux used in the present flux routines, the modified Priestley Taylor formulation, is especially tuned for the use above grassland. Using this formulation above, e.g. some agricultural field, will require (a lot of) additional research. However there are many articles published about the use of the Penman-Monteith formulation for all kinds of vegetation. Moreover it is to be expected that the Priestley Taylor formulation is not applicable for tall vegetation <8>.

During night-time, when the difference between the AIM and DIR is expected to be large, the Priestly Taylor formulation is not based on valid physical arguments.

The estimated bowen ratio (H/LE), using the modified Priestley Taylor formulation, turned out to be significant in error for some months. By taking the humidity deficit into account (Penman-Monteith formulation) the bowen ratio may be better adapted <15>.

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Appendix A

The bias is defined as:

$$\text{bias} = \frac{\sum_{i=1}^{n}(x_i - y_i)}{N}$$

where: N = number of comparisons
x_i = observation
y_i =estimate

The Root Mean Square Error, RMSE, is defined as:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}(x_i - y_i)^2}{N}}$$

where: N = number of comparisons
x_i = observation
y_i = estimate

The standard deviation, representing the scatter with respect to the mean error, SD is defined as:

$$\text{SD} = \sqrt{\frac{\sum_{i=1}^{N}\{(x_i - y_i) - \overline{\varepsilon}\}^2}{N}}$$

where: N = number of comparisons
x_i = observation
y_i = estimate
$\overline{\varepsilon}$ = mean error ($= \overline{x_i} - \overline{y_i}$)

Note that: $\text{RMSE}^2 = \text{SD}^2 + \text{bias}^2$

Appendix B Minor changes in the flux routines

Two minor changes are introduced in the fluxroutines:

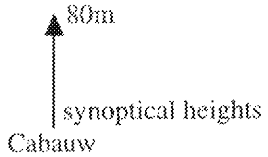
- At different places in the original source code "reals" are compared with "reals". For example in the line: IF (KIN .NE. -9999. .AND. KIN .LT. 0.) GOTO END
where KIN is declared as "real" variable.
If KIN (incoming short-wave radiation) equals -9999. it is missing and should be parameterised automatically. Because the real KIN is never exactly -9999. the program terminates unnecessary. By taking the nearest integer of the reals this problem is solved.
- Another problem encountered (giving a "floating point exception" error) was due to the specified accuracy of u_* in the iteration scheme. The original accuracy, namely $1*10^{-6} * |u_*|$ is changed into $1*10^{-3} * |u_*|$ (which is more then accurate enough).

Both changes are now implemented in the new "official" source code of the fluxlibrary.

Appendix C

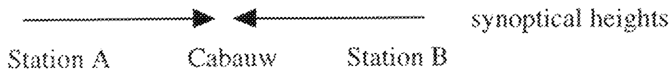
Consider the following biases (all including only Cabauw tower observations):

-1 Upward transformation in Cabauw (§3.2)



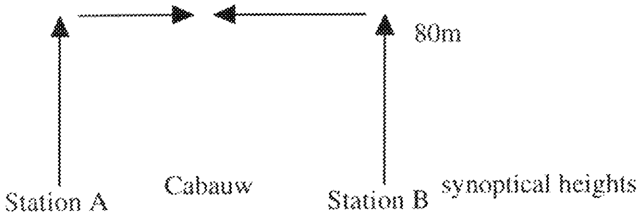
=> $bias_{Cabauw}$ (table 3.3, e.g. U80m)

-2 Direct horizontal interpolation of 4 stations surrounding Cabauw to Cabauw (see fig. 1.2)



=> $bias_{dir}$ (see table 4.2, e.g. Udir)

-3 Upward transformation + horizontal interpolation at 80m



=> $bias_{U,T,q80m}$ (see table4.2, e.g. U80m)

Station A and B represent Rotterdam, Schiphol , De Bilt and Herwijnen.

On the assumption that: -the monthly averaged bias for the upward transformation is approximately the same for all stations involved. (I.e. the $bias_{stationB}$ for the upward transformation to 80m ≈ $bias_{Cabauw}$)
-there is no difference, in terms of the absolute bias, in interpolating at 80 metres instead of interpolating at synoptical height.

it can be stated that: $bias_{U,T,q\,80m} \approx bias_{dir} + bias_{Cabauw} \equiv bias_{U,T,q+}$ (8)

So for example the bias U+ is simply defined as the sum of the biases fdir (table 4.2) and U80m (table 3.3). These U+, T+ and q+ , presented in table 4.2, have to be compared with respectively U80m, T80m and q80m in table 4.2 to check the equation mentioned above.
Equation (8) seems to be a good approximation for most months and all parameters despite the fluctuations in the biases from month to month. Some interesting consequences are presented in §4.3.

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