In-canopy microclimate of Amazonian forest and estimates of transpiration

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Abstract

The major constraint to estimate the forest transpiration using a multilayer model is the need for a specification of the in-canopy microclimate, namely air temperature and vapour pressure deficit for each layer. For predictive purposes the within canopy profiles were deduced as empirical linear functions of the same parameters measured over the forest and the layer height.

Transpiration calculated for hourly and daily periods using CLATTER routine agreed well with those obtained with the measured through-canopy values of weather variables, greatly reducing the data requirements without generating overestimates in transpiration.

Resumo

A estimativa da transpiração de florestas através de modelos de várias camadas tem como fator limitante a necessidade da especificação do microclima no interior da vegetação, principalmente os perfis da temperatura do ar e dos déficites de saturação. Com este objetivo, os perfis foram obtidos à partir de funções lineares empíricas dos mesmos parâmetros medidos sobre a floresta e da altura da camada.

Os cálculos da transpiração horária e diária utilizando-se a rotina CLATTER foram similares aos estimados através dos perfis medidos, reduzindo a quantidade de informações sem a introdução de erros apreciáveis.

1- Introduction

The efforts directed to the observation and modelling of the tropical rainforest micrometeorology, and the the effects of deforestation in the tropics over the global climate have increased substantially during the last decade(Shuttleworth et al. 1984a,b; Moore & Fisch, 1986; Roberts et al., 1990; Fitzjarrald et al., 1987; Sellers et al., 1989; Nobre et al., 1991).

However, in order to asses the forest transpiration, any model would need to recognize the differential eficiency of the vegetation layers(Shuttleworth et al., 1985). Whether the direct measurement is not possible or indeed the obtaintion of canopy air temperatures and humidities, to be used in a multilayer model, which is time-consuming and expensive, there is merit in evaluating the available data to simplify the transpiration estimates.

Recently, Roberts et al.(1993), showed that the calculation of the tropical forest transpiration is viable based on combination formulae , which in turn are dependent of physisiological and in-canopy weather data.

The objectives of this study are to evaluate whether the forest profiles of temperature and humidity deficits can be accuratly obtained from above-canopy data, and to verify how adequate is their use in a combination formulae, such as the CLATTER routine(Roberts et al., 1993), to estimate the transpiration rates of the rainforest.

2- Material and Methods

During the dry season of 1991 (August-September), the Reserva Ducke tower(Shuttleworth et al., 1984a; Roberts et al., 1990) was instrumented with six levels of aspirated psychrometers and anemometers at 35,30,25,20,15 and 5m height, recording 10 min average of air temperature, specific humidity and wind speed. Concurrently, an automatic weather station was in operation above the canopy(Bastable *et al.*, 1993), recording the hourly averages of the same parameters as well global and net radiation.

The measurements made over the Ducke forest(50 days of hourly averages), were split in two sets of odd and even days(Stewart, 1988), containing daylight values, as the final objective was the prediction of forest transpiration. The odd days set was used to fit the relationships between the air temperature(T_z) and specific humidity deficit(SD_z) measured at different heights(z)in the profiles and 45m level, via the least squares method, as follows:

$$T_z = a_z + b_z * T_{45} \qquad (1a)$$

$$SD_z = a_z' + b_z' * SD_{45} \qquad (1b)$$

, where T_{45} and SD_{45} are the temperatures and deficits in 45m.

For the same data set, a more general expression which included the heights(z) of measurements, as a second independent variable was fitted, attempting to obtain the profiles of temperature and humidity deficits as a function of the height and the same elements observed above the canopy(45m), in the form:

$$T_z = a + b * T_{45} + c * Z \qquad (2a)$$

$$SD_z = a' + b' * SD_{45} + c' * Z \qquad (2b)$$

The even days set was utilized as a control to verify the goodness of fit of the adjusted equations as well as to calculate the observed hourly transpiration rates with the CLATTER routine(Roberts et al., 1993), which were then compared with those based on the estimated profiles.

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3 - Results

3.1 - Profiles of temperature.

The overall average hourly values of air temperature are shown in Figure 1, which do not contain the standard errors, therefore the aparent gradients must be regarded as a qualitative description, as the differences between levels were not significant. The warmest layers were recorded in the range 25-35m, where the major leaf area concentration occurs(McWilliam et al., 1993; Roberts et al., 1993), and most of the solar radiation is absorbed.

The absence of gradients in those layers during afternoon indicates the efficient mixing reported by Shuttleworth et al.(1985). The 5m level decoupling is due to the low amount of radiation reaching the forest floor, c.d. 1% of the above canopy value (Shuttleworth et al., 1984b). Similar values of temperature were recorded in the levels 45m and 15m, which are in agreement with the gradients presented in Shuttleworth et al.(1985), corresponding to an outward flux of sensible heat, as reported in other tropical forests (Allen et al., 1972; Pinker, 1982; Thompson and Pinker, 1975).

The average profiles of air temperature for selected hours are in Figures 2, which show a broad maximum through the canopy, although the temperature in 30m layer was slightly higher during the afternoon, and the forest radiative cooling during the night, when the forest acts as a unique source of heat, because all layers had the same decrease in the temperature.

The fitted coefficients of Equations 1a for each level are shown in Table 1. The regressions are highly significant, and the slopes around 1 indicate that the intercepts can be regarded as offsets, with the exception of 5m layer which showed a marked decoupling, as pointed before. The results for the general relationship, i.e. Equation 2a, are in Table 3, whose cofficients are also highly significant.

The estimated profiles of temperature through the Equations 1a and 2a were compared with those measured, the even days data set, as shown in Figures 3, for each level. The agreement is better for the top levels, which presented the minor scattering, and both equations reproduced the observed patterns consistently, although for 5m the Equation 2a has produced the greatest discrepancies, overestimating the maximum temperatures, and underestimating the minimum temperatures as a consequence of the least squares method.

3.2 - Profiles of specific humidity deficits.

The overall average hourly values of humidity deficits are in Figure 4, and the selected hourly profiles in Figure 5. The same patterns observed for temperatures are followed by the humidity deficits, also showing a null gradient above 15m and the 5m layer strong decoupling, as well the similarity between 45m and 15m levels.

The fitted parameters of Equations 1b and 2b are shown in Tables 2 and 3 respectively. The coefficients were highly significant, with the exception of 5m level, and for the top layers the adjusted intercepts can be interpreted as the average offsets in relation to 45m. The comparissons between the estimated humidity deficits and the observed even days data set are in Figures 6. The differences between the estimates were more pronounced for deficits above 10 $g\ kg^{-1}$, and the outputs of Equation 2b overestimated the observed data as well the results of Equation 1b.

Athough both equations can reproduce sufficiently accurate estimates of humidity deficits above 25m level, the same is not true for lower layers, whose deficits were more adequately estimated using the Equations 1b, instead of the general relationship, but it depends of how sensitive is the application in which they may be used.

3.3 - The estimate of forest transpiration.

The estimated hourly profiles of air temperature and specific humidity deficit for the even days have been utilized to calculate the hourly rates of transpiration with the CLATTER routine(Roberts et al., 1993), and compared with those based on the observed data set.

The hourly and daily totals of forest transpiration are in Figures 7 and 8, respectively, which show the excellent agreement for both estimates. Besides the more accurate temperatures an humidity deficits produced by Equations 1 their use overestimated the hourly values, even though not significantly. In Figure 9 the differences between the control data and the simple and general regressions outputs are compared. For values below 0.1 mm h^{-1} the scatter is increased and were above 50% of the estimates based on measured profiles; however these periods have a lower weight in the daily totals and are prone to higher errors (Roberts et al., 1993). For the most important part of day i.e. wen the hourly transpiration rates were above 0.4mm h^{-1} the estimates are inside the ±10% range.

4 - **Discussion**.

The first attempt to correlate the Amazonian forest above-canopy and canopy air temperatures and humidities is found in Moore & Fisch(1986), who used succesfully the hourly changes in these variables measured above the canopy, to estimate of air sensible heat storage and latent heat storage in-canopy. This feature reflects the more uniform structure in the leaf-area distribution leading to more uniform profiles with no marked points of inflection, which are the result of a progressive capture of radiation through the canopy(Shuttleworth, 1989).

The accuracy of the transpiration rates based on estimated profiles is explained through the sensitivity analysis of CLATTER routine(Roberts et al., 1993), which showed that the limiting factors are the surface conductances and net radiation . To produce 5% of deviation in transpiration value it is necessary more than 25% deviation in humidity deficits or air temperatures.

The reduction of parameters to be measured achieved in this study could be improved if standard meteorological data observed in a nearby clearing would be used to predict the weather patterns over the forest(Hutjes et al., 1991, Dolman et al., 1988) , an approach which seems likely to be a worth-while research area.

The ABRACOS project, through the establishement of three distinct sites over the Amazon region, where weather stations recorded simultaneously the local climate in clearings and natural forests, will permit to extend this analysis to other sites, as well to verify the predictions for the forests based on the data obtained in different surfaces as the pastureland.

5 - **Conclusions.**

The high degree of correlation found between the Amazon forest above-canopy and bellow canopy air temperatures and specific humidity deficits, expressed through empirical functions, although site specific, indicate the possibility to adequately describe the in-canopy microclimate and estimate the transpiration rates over a complex forest type, as is the case of the tropical rainforest, which greatly reduced the number of parameters to be measured, without generating large errors.

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List of Figures

List of Tables

Table 1.
Coefficients(a=intercept; b=slope) of Equations 1a for temperatures at each level as a function of the temperature observed in 45m. Bracketed figures represent ± standard errors.

Level Height(m)	a	b	r^2
35	-1.34 (0.18)	1.07 (0.01)	0.989
30	-3.00 (0.27)	1.14 (0.01)	0.978
25	-2.71 (0.39)	1.11 (0.02)	0.951
15	-0.42 (0.45)	1.01 (0.02)	0.925
5	4.07 (0.41)	0.82 (0.02)	0.906

Table 2.
Coefficients of Equations 1b (a=intercept; b=slope) for specific humidity deficits(g kg^{-1}) at each layer as a function of the deficits observed in 45m. Bracketed figures represent ± standard error.

Level Height(m)	a	b	r^2
35	-0.31 (0.05)	1.08 (0.01)	0.985
30	-0.96 (0.08)	1.16 (0.01)	0.966
25	-1.18 (0.09)	1.14 (0.01)	0.958
15	-0.51 (0.10)	1.02 (0.02)	0.928
5	-0.80 (0.09)	0.59 (0.01)	0.860

Table 3.
Coefficients of Equations 2 (a=intercept; b and c slopes) for temperatures(T_z) and specific humidity deficit (SHD_z) as functions of the same elements observed in 45m and level height z (m). Bracketed figures represent ± standard errors.

	a	b	c	r^2
T_z	-1.65 (0.19)	0.04 (0.00)	1.03 (0.01)	0.940
SHD_z	-2.70 (0.09)	0.09 (0.00)	0.99 (0.01)	0.900

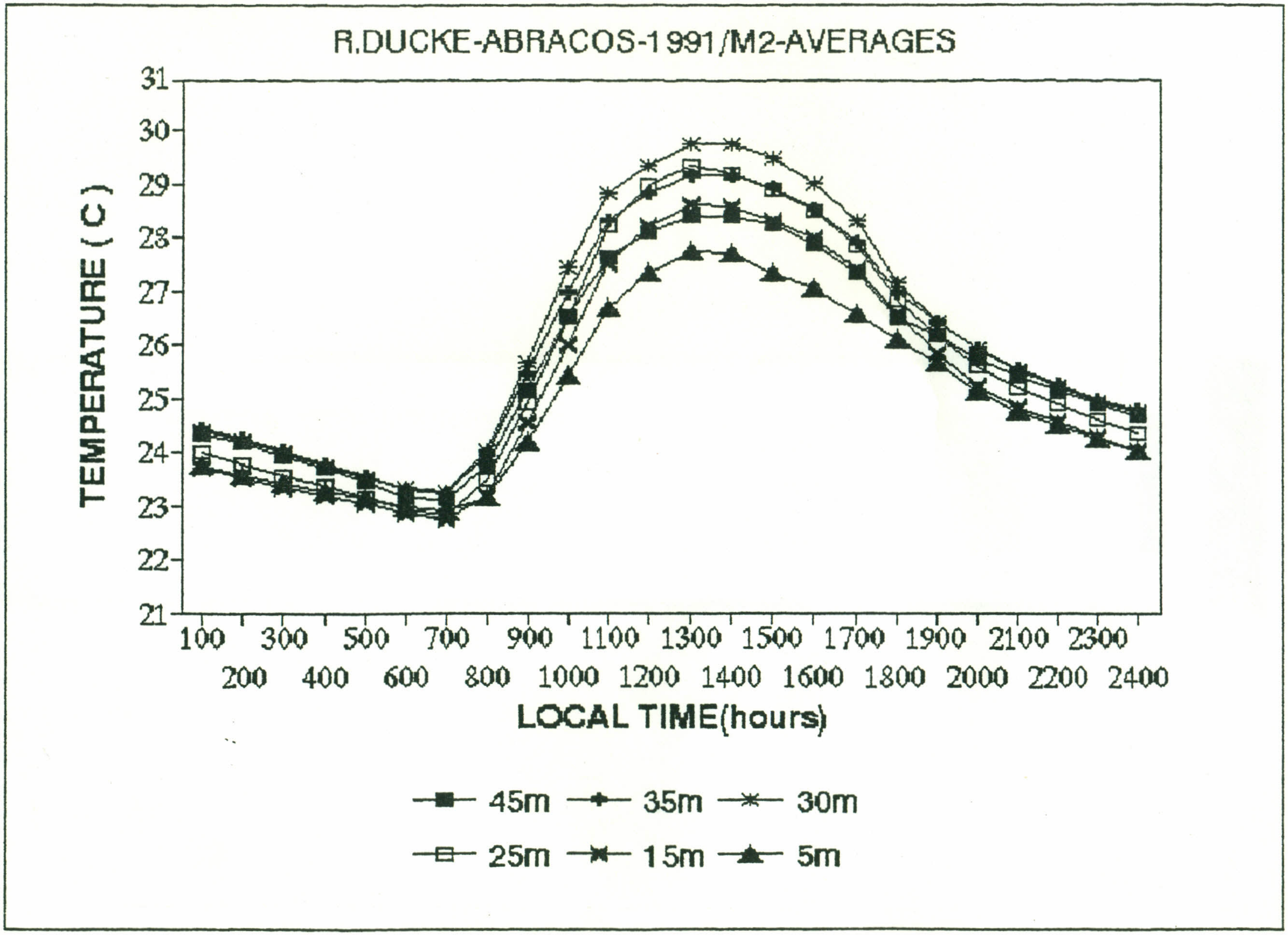
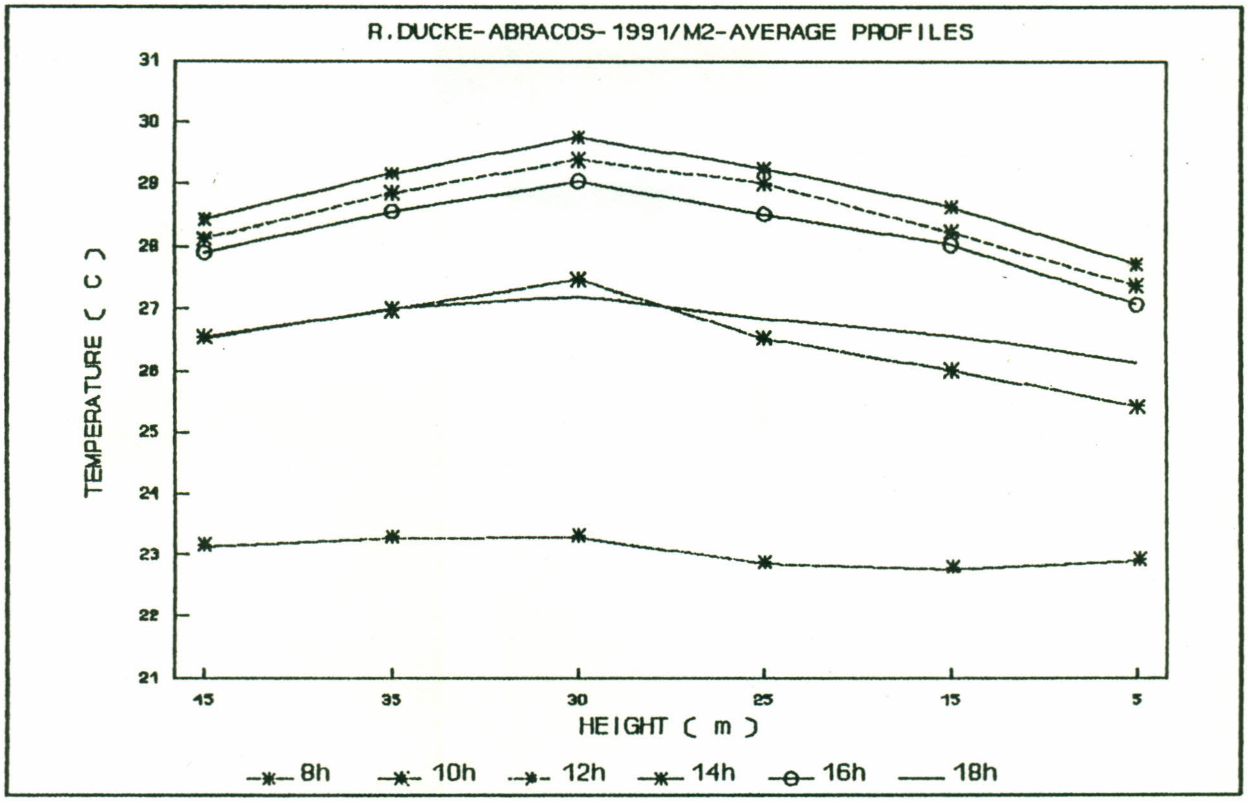
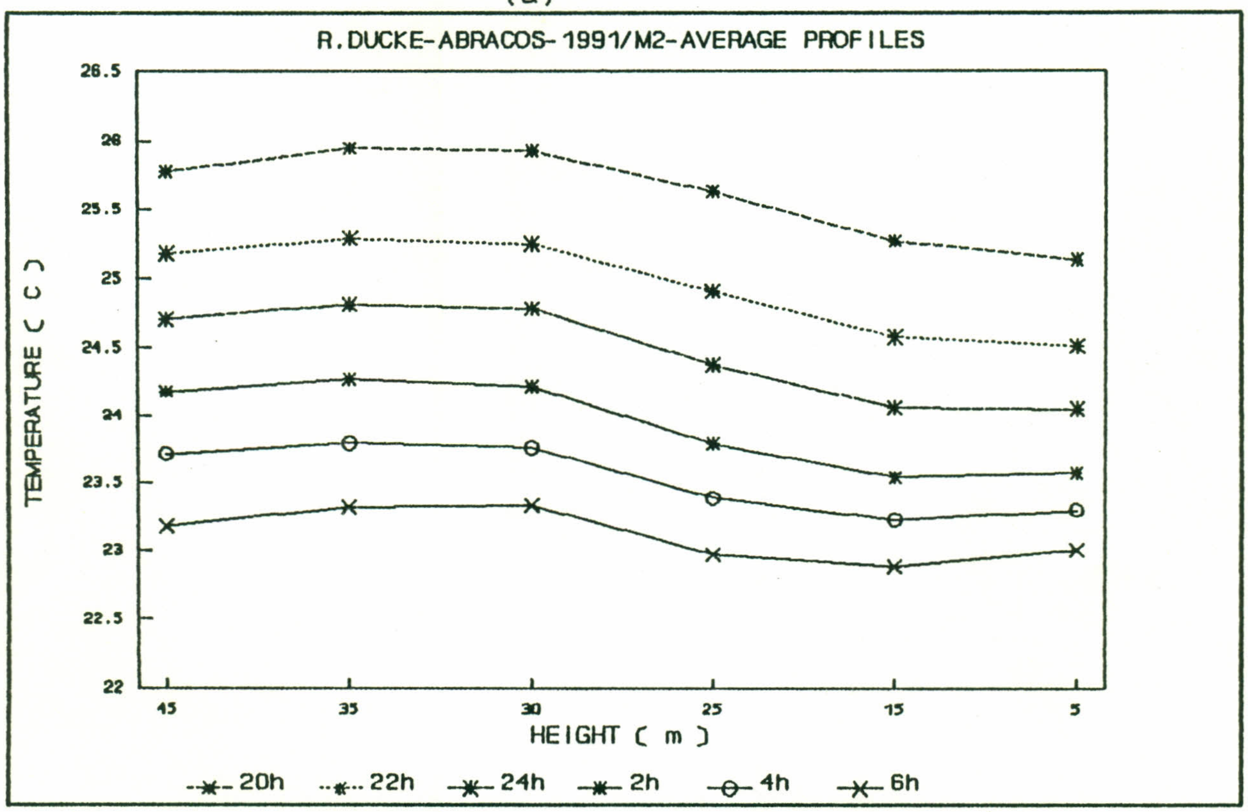

R.DUCKE-ABRACOS-1991/M2-AVERAGES
TEMPERATURE (C)
31
30
29
28
27
26
25
24
23
22
21
100 300 500 700 900 1100 1300 1500 1700 1900 2100 2300
200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400
LOCAL TIME(hours)
45m
35m
30m
25m
15m
5m

Fig 1

Fig. 2

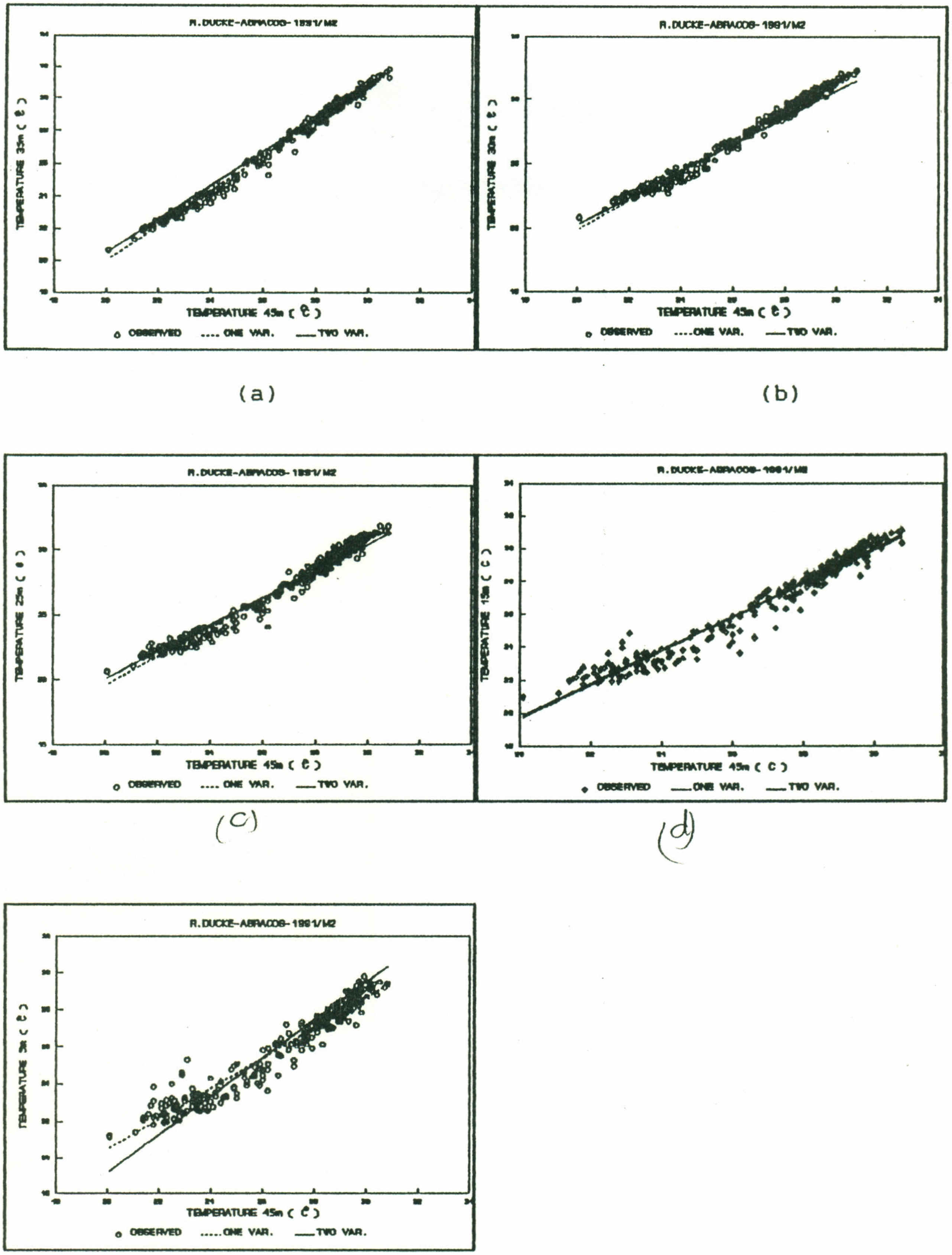

R.DUCKE-ABRACOS-1991/M2-AVERAGE PROFILES
TEMPERATURE (C)
31
30
29
28
27
26
25
24
23
22
21
45
35
30
25
15
5
HEIGHT (m)
8h
10h
12h
14h
16h
18h

(a)


R.DUCKE-ABRACOS-1991/M2-AVERAGE PROFILES
TEMPERATURE (C)
26.5
26
25.5
25
24.5
24
23.5
23
22.5
22
45
35
30
25
15
5
HEIGHT (m)
20h
22h
24h
2h
4h
6h

(b)

Fig 3


R.DUCKE-ABRACOS-1991/M2
TEMPERATURE 35m (C)
TEMPERATURE 45m (C)
o OBSERVED ..... ONE VAR. ___ TWO VAR.
R.DUCKE-ABRACOS-1991/M2
TEMPERATURE 30m (C)
TEMPERATURE 45m (C)
o OBSERVED ..... ONE VAR. ___ TWO VAR.
R.DUCKE-ABRACOS-1991/M2
TEMPERATURE 25m (C)
TEMPERATURE 45m (C)
o OBSERVED ..... ONE VAR. ___ TWO VAR.
R.DUCKE-ABRACOS-1991/M2
TEMPERATURE 15m (C)
TEMPERATURE 45m (C)
OBSERVED ___ ONE VAR. ___ TWO VAR.
R.DUCKE-ABRACOS-1991/M2
TEMPERATURE 3m (C)
TEMPERATURE 45m (C)
o OBSERVED ..... ONE VAR. ___ TWO VAR.

(a) (b) (c) (d) (e)

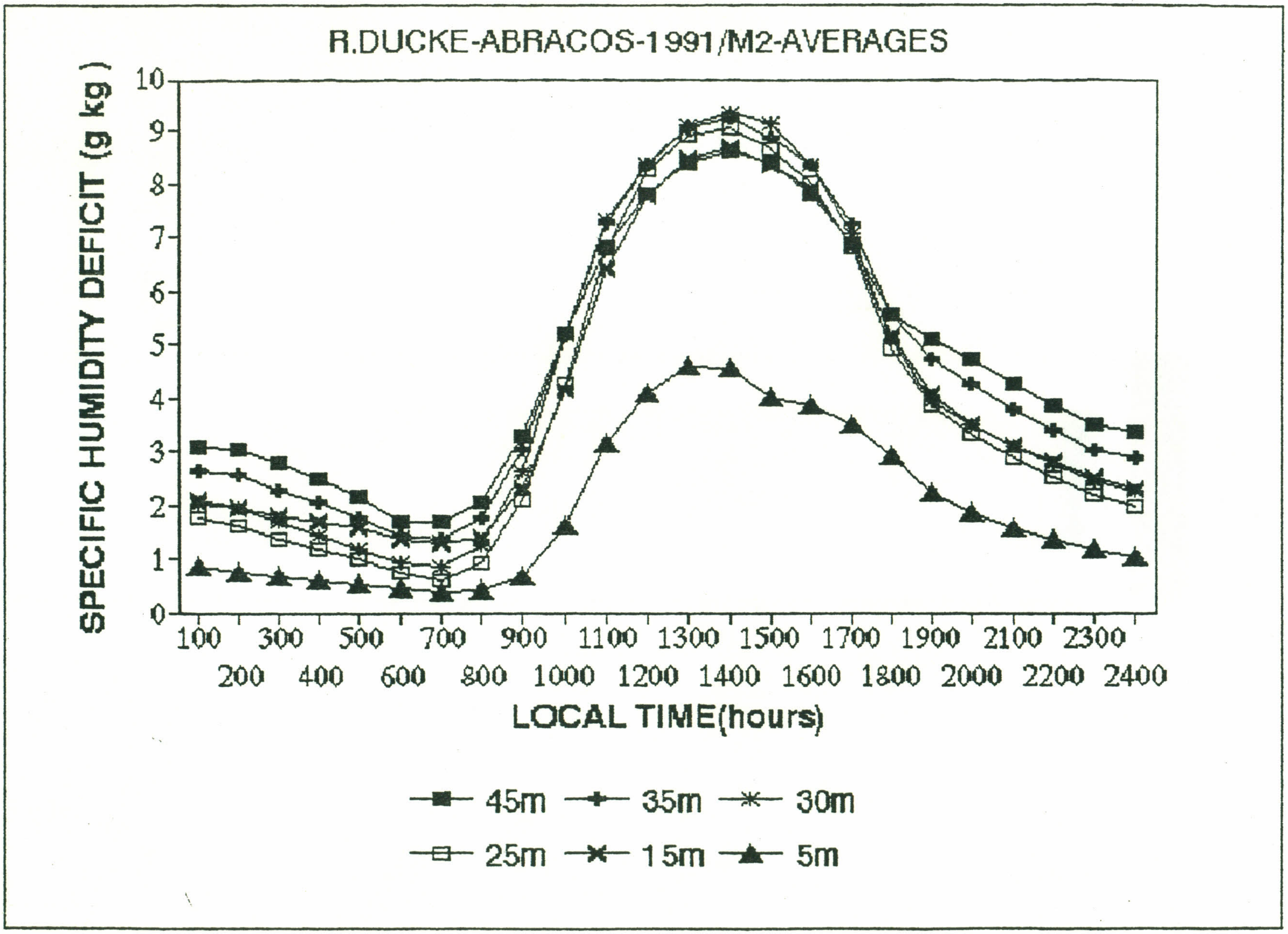
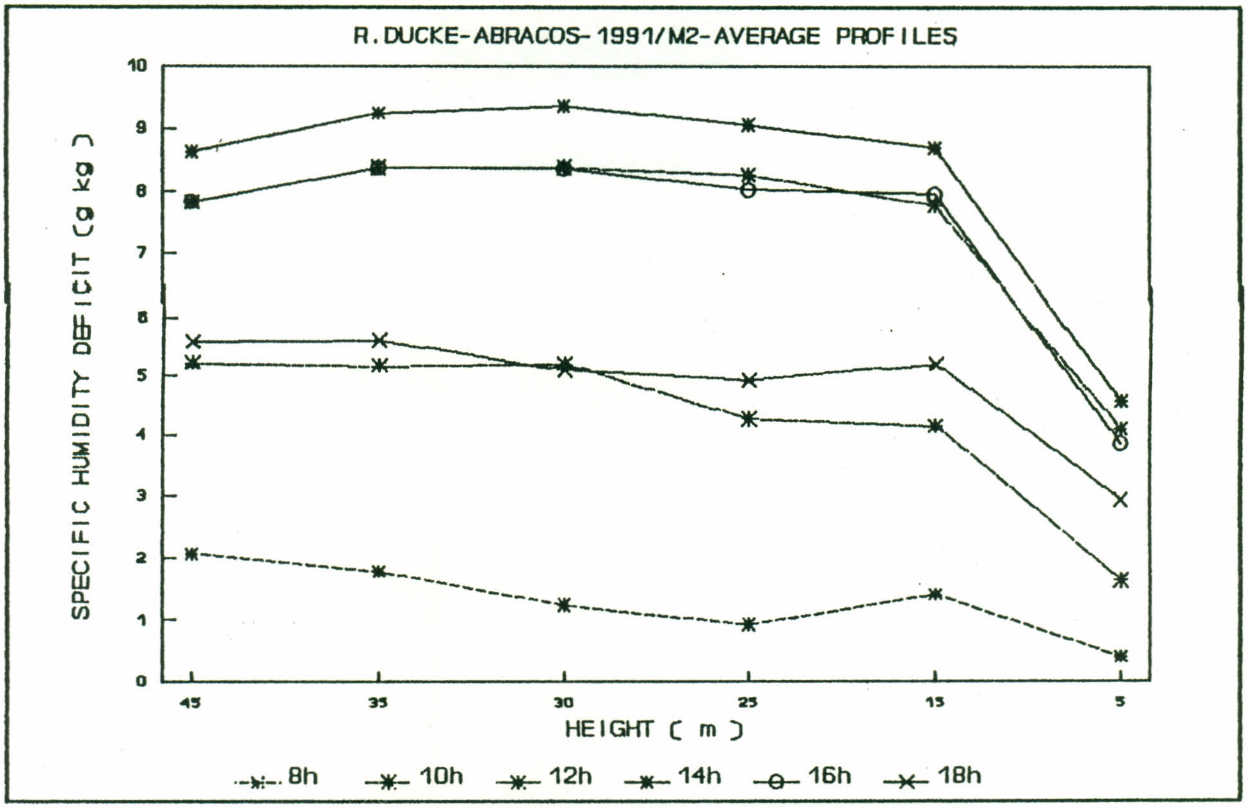
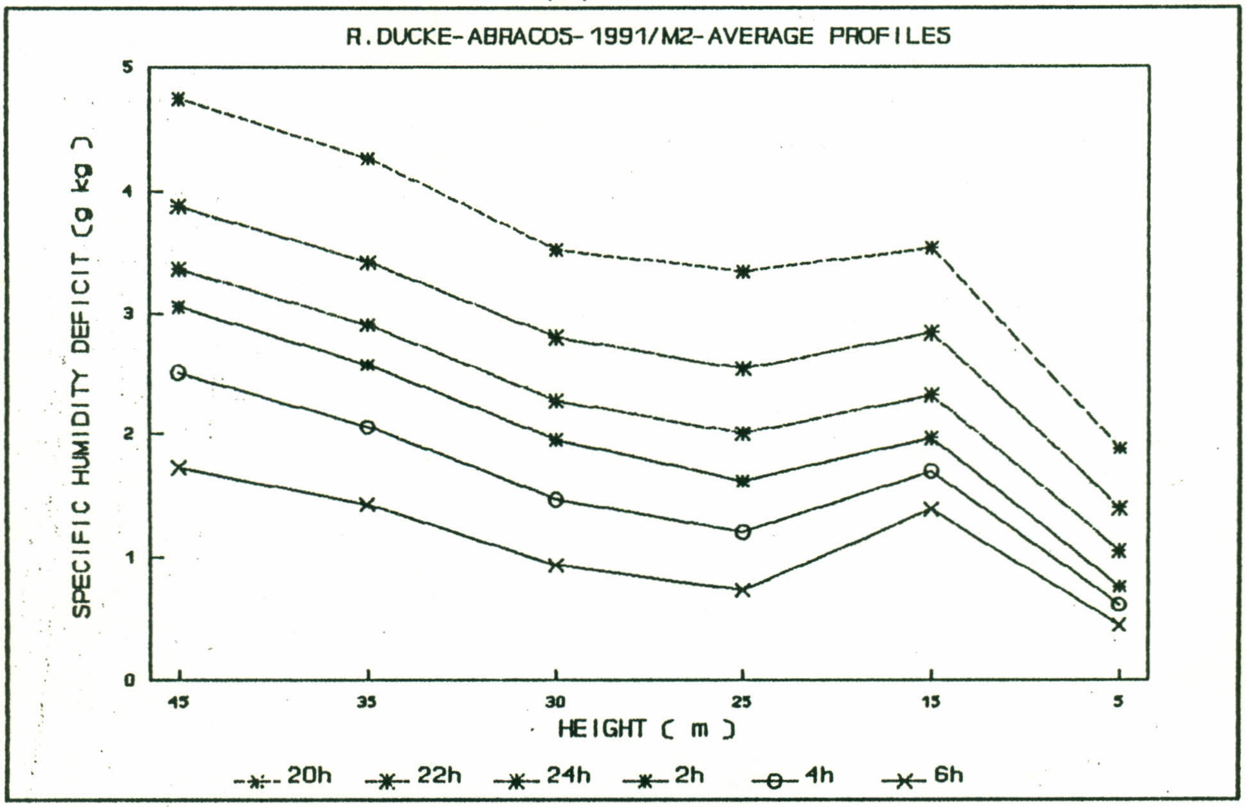

R.DUCKE-ABRACOS-1991/M2-AVERAGES
SPECIFIC HUMIDITY DEFICIT (g kg)
0
1
2
3
4
5
6
7
8
9
10
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
LOCAL TIME(hours)
45m
35m
30m
25m
15m
5m

Fig. 5

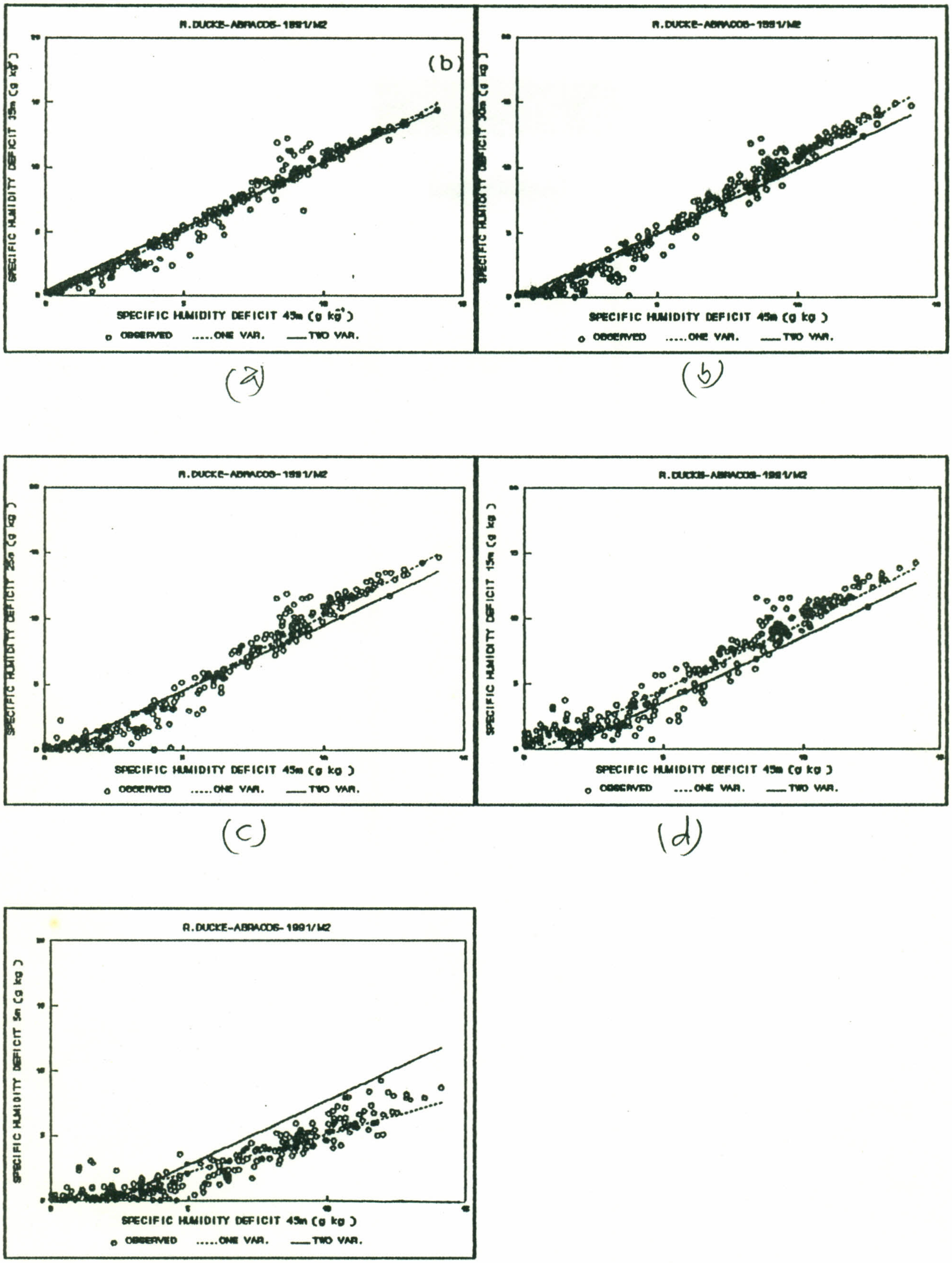

R. DUCKE-ABRACOS-1991/M2-AVERAGE PROFILES
SPECIFIC HUMIDITY DEFICIT (g kg)
HEIGHT (m)
10
9
8
7
6
5
4
3
2
1
0
45
35
30
25
15
5
8h
10h
12h
14h
16h
18h

(a)


R. DUCKE-ABRACOS-1991/M2-AVERAGE PROFILES
SPECIFIC HUMIDITY DEFICIT (g kg)
HEIGHT (m)
5
4
3
2
1
0
45
35
30
25
15
5
20h
22h
24h
2h
4h
6h

(b)

Fig. 6



R.DUCKE-ABRACOS-1991/M2
(b)
SPECIFIC HUMIDITY DEFICIT 35m (g kg⁻¹)
SPECIFIC HUMIDITY DEFICIT 45m (g kg⁻¹)
o OBSERVED .....ONE VAR. ___TWO VAR.
(a)
R.DUCKE-ABRACOS-1991/M2
SPECIFIC HUMIDITY DEFICIT 30m (g kg)
SPECIFIC HUMIDITY DEFICIT 45m (g kg)
o OBSERVED .....ONE VAR. ___TWO VAR.
(b)
R.DUCKE-ABRACOS-1991/M2
SPECIFIC HUMIDITY DEFICIT 25m (g kg)
SPECIFIC HUMIDITY DEFICIT 45m (g kg)
o OBSERVED .....ONE VAR. ___TWO VAR.
(c)
R.DUCKE-ABRACOS-1991/M2
SPECIFIC HUMIDITY DEFICIT 15m (g kg)
SPECIFIC HUMIDITY DEFICIT 45m (g kg)
o OBSERVED .....ONE VAR. ___TWO VAR.
(d)
R.DUCKE-ABRACOS-1991/M2
SPECIFIC HUMIDITY DEFICIT 5m (g kg)
SPECIFIC HUMIDITY DEFICIT 45m (g kg)
o OBSERVED .....ONE VAR. ___TWO VAR.
(e)

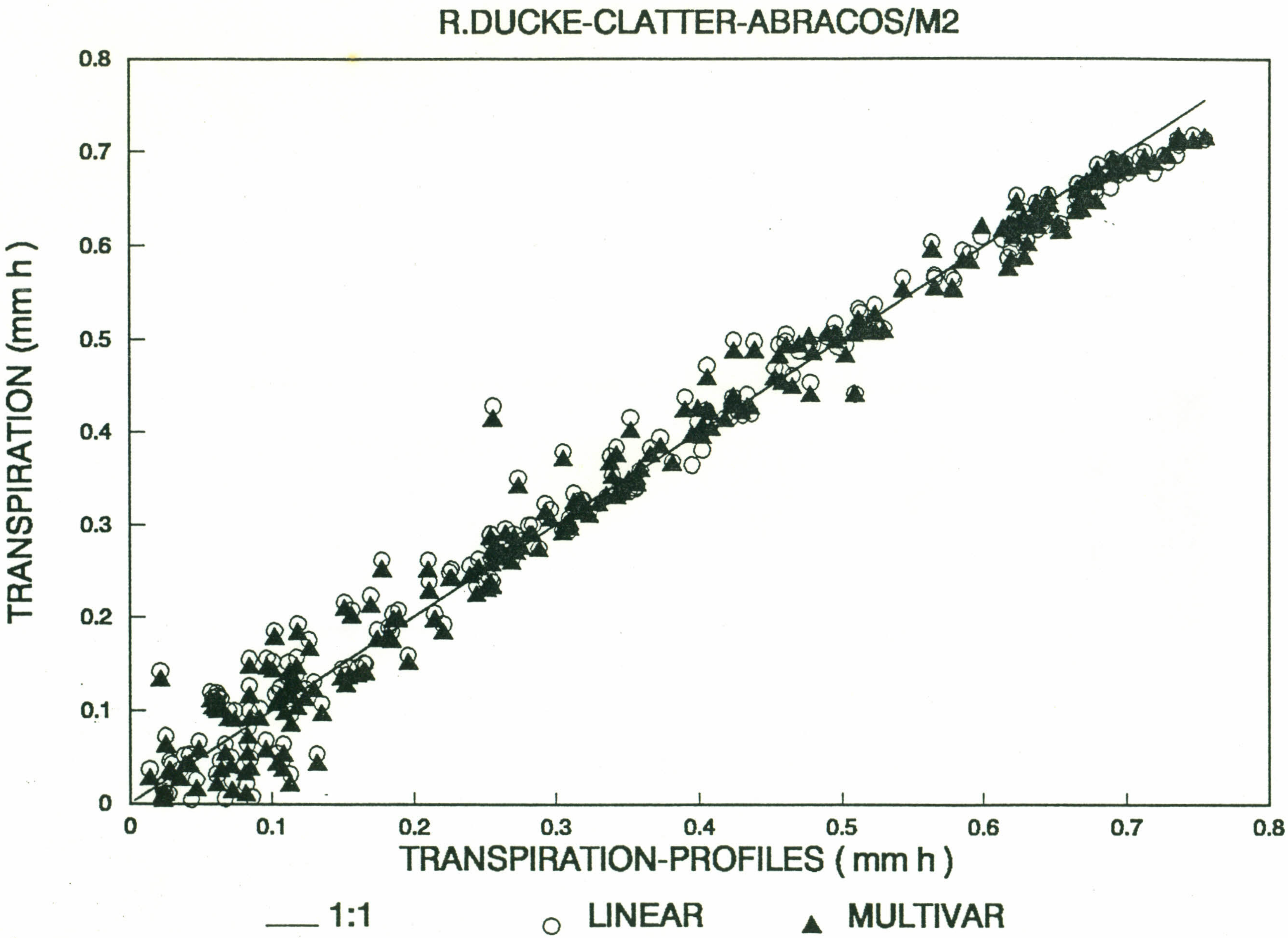
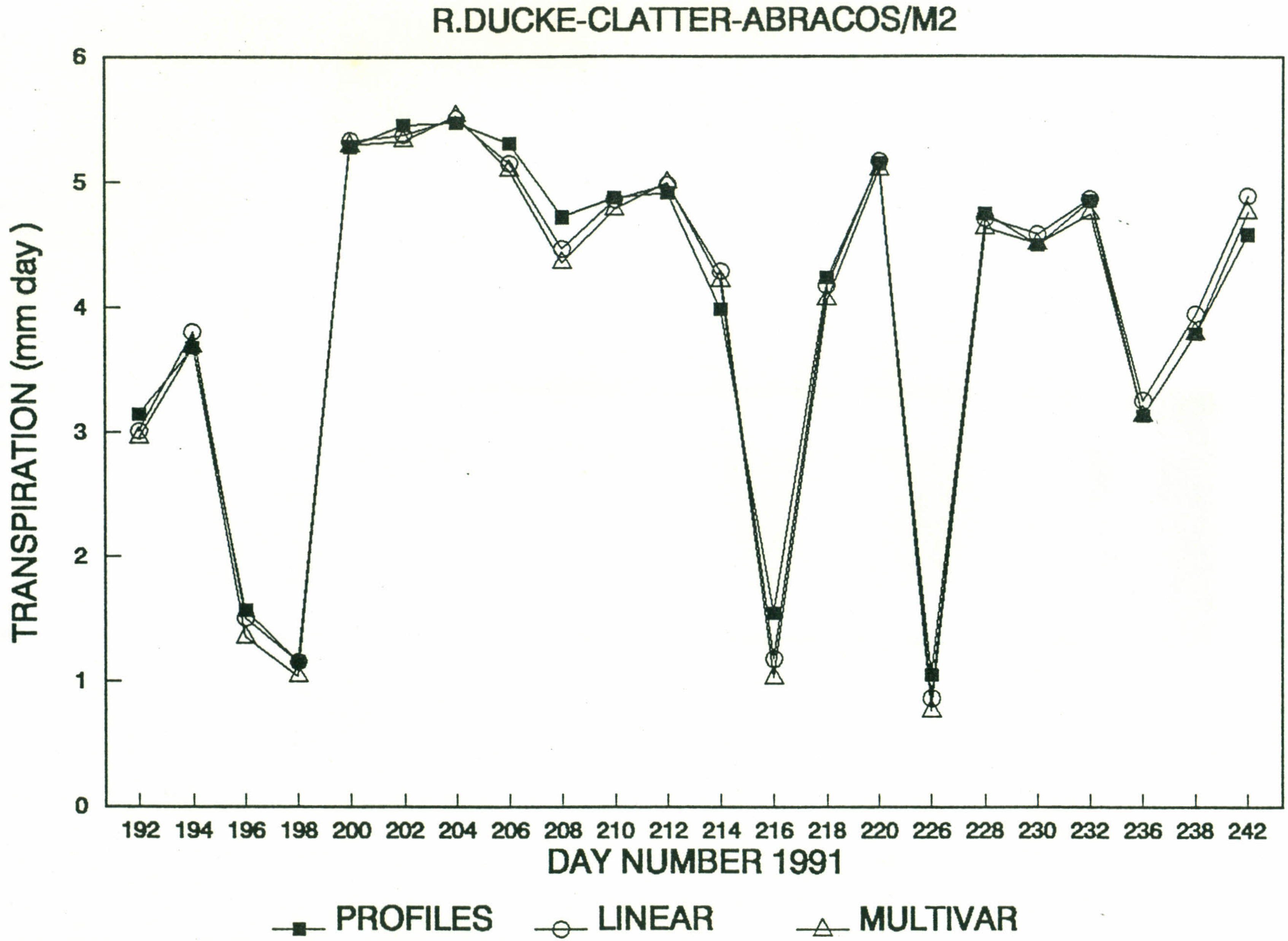

R.DUCKE-CLATTER-ABRACOS/M2
TRANSPIRATION (mm h)
TRANSPIRATION-PROFILES (mm h)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
1:1
LINEAR
MULTIVAR

Fig. 7



R.DUCKE-CLATTER-ABRACOS/M2
TRANSPIRATION (mm day)
0
1
2
3
4
5
6
192
194
196
198
200
202
204
206
208
210
212
214
216
218
220
226
228
230
232
236
238
242
DAY NUMBER 1991
PROFILES
LINEAR
MULTIVAR

Fig. 8

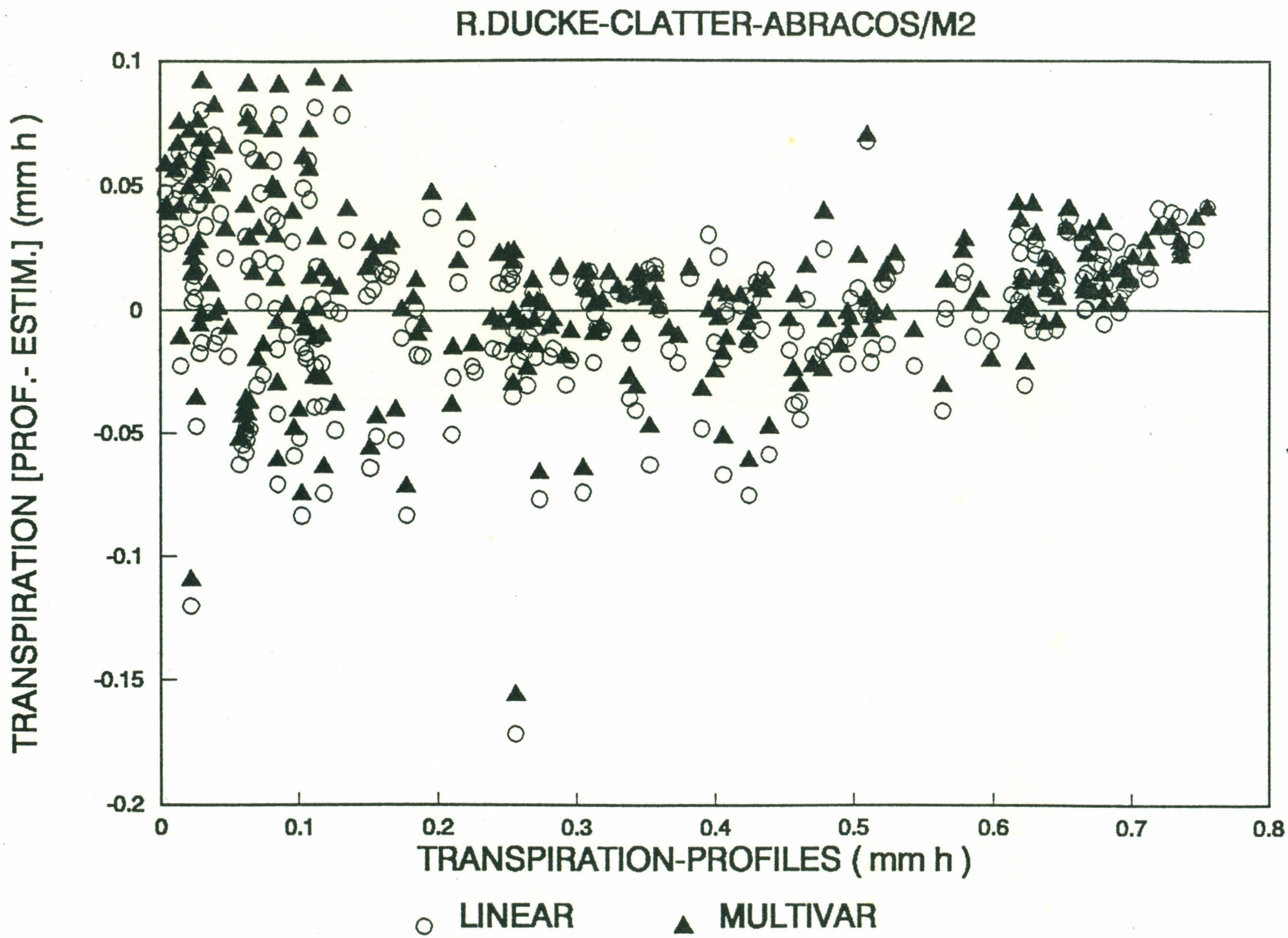

R.DUCKE-CLATTER-ABRACOS/M2
TRANSPIRATION [PROF.- ESTIM.] (mm h)
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
TRANSPIRATION-PROFILES (mm h)
LINEAR
MULTIVAR

Fig. 9