Correlation in f_0F_2 and $M(3000)F_2$ variations in South-West Europe

Benito A. de la Morena ([1]), **Luis F. Alberca** ([2]), **José G. Sole** ([2]), **José M. Vilaplana** ([3]) **and Edward S. Kazimirovsky** ([4])

([1]) *Atmospheric Sounding Station, INTA/CEDEA, Mazagón, Huelva, Spain*
([2]) *Ebro Observatory, Roquetes, Tarragona, Spain*
([3]) *Associate Collaborator, Atmospheric Sounding Station, INTA/CEDEA, Mazagón, Huelva, Spain*
([4]) *Institute of Solar-Terrestrial Physics, Academy of Sciences, Irkutsk, Russia*

Abstract
A statistical analysis of the variations of the hourly daily values of the $M(3000)F_2$ with the corresponding values of critical frequencies f_0F_2 was provided for two similar ionosondes (Digisonde-256) located in El Arenosillo and Geophysical Observatory Ebro (both in Spain). Data for winter 1993/1994 and summer 1993 are presented. It is shown that for hour-to-hour variations (both seasons) and for day-to-day variations in summer the correlation is poor and contradictory but for the day-to-day variations in winter months the correlation is significantly higher and positive.

Key words *radio propagation – ionosphere*

1. Introduction

The main element of the PRIME project is the study of the space-time variability of the F_2-layer characteristics which are very complicated and cannot be represented analytically. F_2 layer ordinary-wave critical frequencies f_0F_2 and the $M(3000)F_2$, the maximum-usable-frequency factor for a distance 3000 km are among the basic ionospheric data used in predictions and modellings.

It is known that f_0F_2 is connected only with maximum electron concentration, but $M(3000)F_2$ depends on the height of maximal electron concentration *hp*. Nevertheless, it has been assumed that there is the close correlation between these two parameters which may be used successfully for forecasting.

On the other hand, PRIME project investigations showed (Kouris *et al.*, 1994a,b) that these ionospheric characteristics are poorly correlated and the daily values of the factor $M(3000)F_2$ cannot be estimated from the f_0F_2 by using a simple linear equation. Moreover, even the daily deviations from correspnding monthly median values have a different trend and also a different behaviour with respect to the solar activity (Kouris *et al.*, 1994c). The preliminary conclusion was made for some European stations (Slough, Lannion, Poitiers and Rome); data and authors have recommended a more extensive study for other stations and years before making final conclusions.

This is why we provided a similar statistical analysis for two Digisondes-256 located in South-West Europe, INTA Atmospheric Sounding Station «El Arenosillo» (37°6′N; 6°42′W) and Geophysical Observatory Ebro (40°49′N; 0°2′W).

Mailing address: Dr. Benito A. de la Morena, Atmospheric Sounding Station, INTA/CEDEA, 21130 Mazagón, Huelva, Spain; e-mail: morenacb@inta.es

2. Data and analysis

Hourly daily values of the factor $M(3000)F_2$ were correlated using the simple linear regression coefficient R.

Two procedures to study the relationship between the M-factor and f_0F_2 were the following:

1) the linear regression equation is fitted by the least squares method to the M values for every hour of the day throughout the given month of a given year at a given station and the corresponding values of f_0F_2 (hour-to-hour variations);

2) the same linear regression is fitted by the least squares method to the M hourly values for every day of a given month of a given year at a given station and the corresponding values of f_0F_2 (day-to-day variations).

The form of the estimated regression will be: $y = a_0 + a_1 * x$. If we note:

SSE = Sun Square Error;
MSE = Mean Sum Error;
$SSTO$ = Total Sum of Square;
SSR = Regression Sum of Square;
n = number of cases:
p = calculated parameters (a_0 and a_1 in our case).

Then:

Free Degree DF	
$n-p$	$SSE = \Sigma\,(y_i - \hat{y}_i)^2$
$n-1$	$SSTO = \Sigma\,(y_i - \bar{y})^2$
$p-1$	$SSR = \Sigma\,(\hat{y}_i - \bar{y})^2$
	$SSTO = SSE + SSR$

$$\hat{\sigma}^2 = \frac{SSF}{n-p} = MSE = \frac{\Sigma\,(y_i - \hat{y}_i)}{n-p}$$

$$S^2\,(a_1) = \frac{MSE}{\Sigma\,(x_1 - \bar{x})^2}$$

$$MSR = \frac{SSR}{p-1}$$

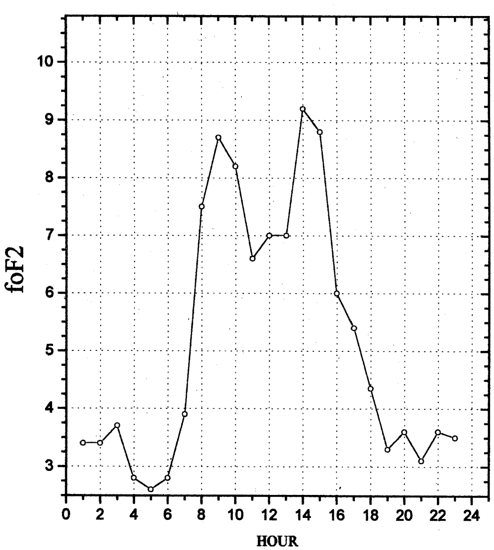

Fig. 1a. An example of hour-to-hour variation of f_0F_2 for January 12, 1994 in Ebro.

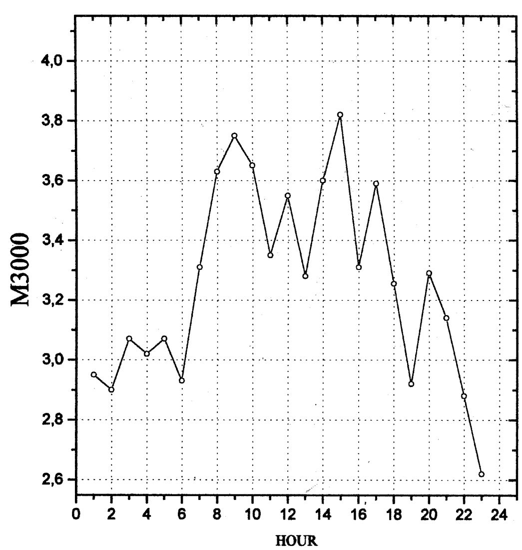

Fig. 1b. An example of hour-to-hour variation of M-factor for January 12, 1994 in Ebro.

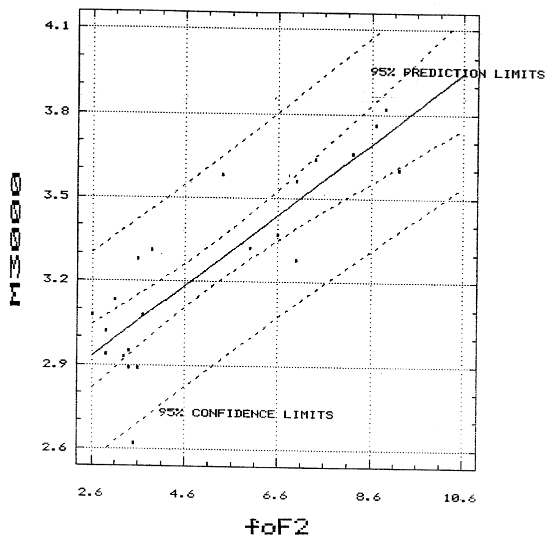

Fig. 1c. An example of linear regression line for hour-to-hour variations for January 12, 1994 in Ebro.

R = Cross correlation for y *vs.* x. We can interpret R^2 as a determination coefficient:

$$R^2 = \frac{SSR}{SSTO} = \frac{SSTO - SSE}{SSTO} = 1 - \frac{SSE}{SSTO}.$$

If $R^2 = 1$, we have no residuals and each point is on the regression line. On the other hand; if $R^2 = 0 \Rightarrow SSE = SSTO \Rightarrow$ No relation exists between x and y; and the regression line will be over the mean of y ($\bar{y}$).

Standard error of estimation =

$$= \left[\frac{\Sigma (y_i - \hat{y}_i)^2}{n-p}\right]^{1/2} = \left[\frac{SSE}{n-p}\right]^{1/2} = [MSE]^{1/2}.$$

It is possible to test if our regression is significant or not.

The examples of hour-to-hour variations for the given month and given day are shown in fig. 1a,b and the corresponding regression line in fig. 1c.

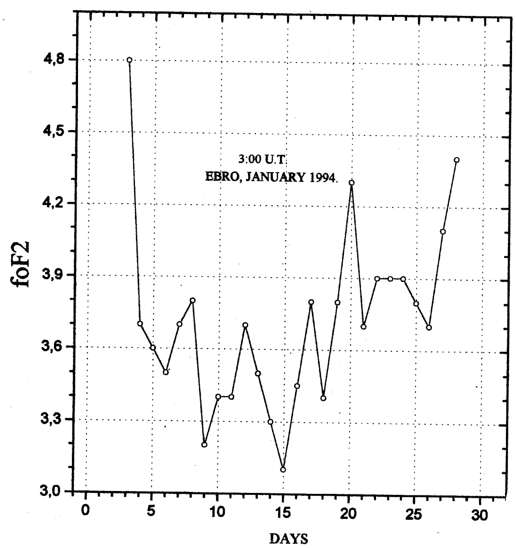

Fig. 2a. An example of day-to-day variation if f_0F_2 for the given month and given hour.

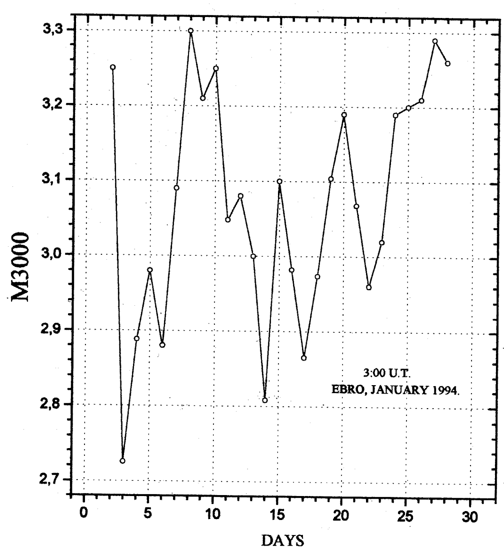

Fig. 2b. An example of day-to-day variation of M-factor for the given month and given hour.

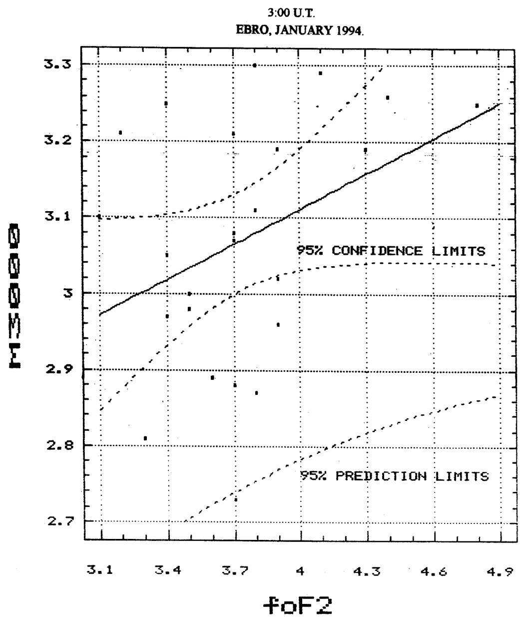

Fig. 2c. An example of linear regression line for day-to-day variations for the given month and given hour.

The examples of day-to-day variations for the given month and given hour are shown in fig. 2a,b and corresponding regression line in fig. 2c.

The data for winter and summer months were available and we chose July 1993 and January 1994 for both stations and in addition December 1993 for El Arenosillo.

3. Results and discussion

The results of the statistical analysis according to the procedures above mentioned are reported in figs. 3a-d and table I for hour-to-hour variations and in figs. 4a-d and table II for day-to-day variations. These results confirm in principle the results of the similar analysis accomplished recently (Kouris *et al.*, 1994a).

For hour-to hour for both seasons and for summer day-to-day variations, the correlation is poor and contradictory, therefore no linear correlation between M and f_0F_2 can be established having a significant value for prediction purposes. Only for day-to-day variations in winter months is the correlation significantly higher and positive.

The surfaces for $M(3000)F_2$ and f_0F_2 are shown in fig. 5a,b. From these figures we can see that the global behaviour for f_0F_2 is more or less usual during January for both stations, but for $M(3000)F_2$ the daily variation is not so regular. During July the two parameters change sometimes more abruptly and unexpectedly, their behaviour seems to be random and it seems evident that we will not find a linear relation between f_0F_2 and $M(3000)F_2$ variations.

Sometimes we had some unexpected and unusual peaks which may have been instabilities of equipment.

We can ascertain the winter-summer differences in the behaviour of regression line coefficient and correlation coefficient. There were also significant differences between two Spanish stations (Ebro and El Arenosillo) for the same days or months. These differences may be due to latitudinal or longitudinal variations of ionospheric parameters.

Some abrupt changes of correlation coefficient for day-to-day variations (*i.e.*, January 19, 1994 in Ebro), if they are not artefacts, may be connected with unusual variations of M-factor due to the influence of the meridional thermospheric circulation on the hmF_2. But this hypothesis must be investigated further. The same kinds of non-linear regression may be tested in the future for M-f_0F_2 relationships.

Recently (Kouris *et al.*, 1994d), the correlation between propagation factor M and f_0F_2 was investigated again using hourly monthly median values for solar cycles 20 and 21. The authors showed that $M(3000)F_2$ and f_0F_2 in principle are linearly dependent, although a significant hysteresis was observed between them. Furthermore, the analysis shows that the two ionospheric characteristics had a different behaviour. Because the reason for this different behaviour is not yet evident, it would be interesting to continue and extend the investigation in this field.

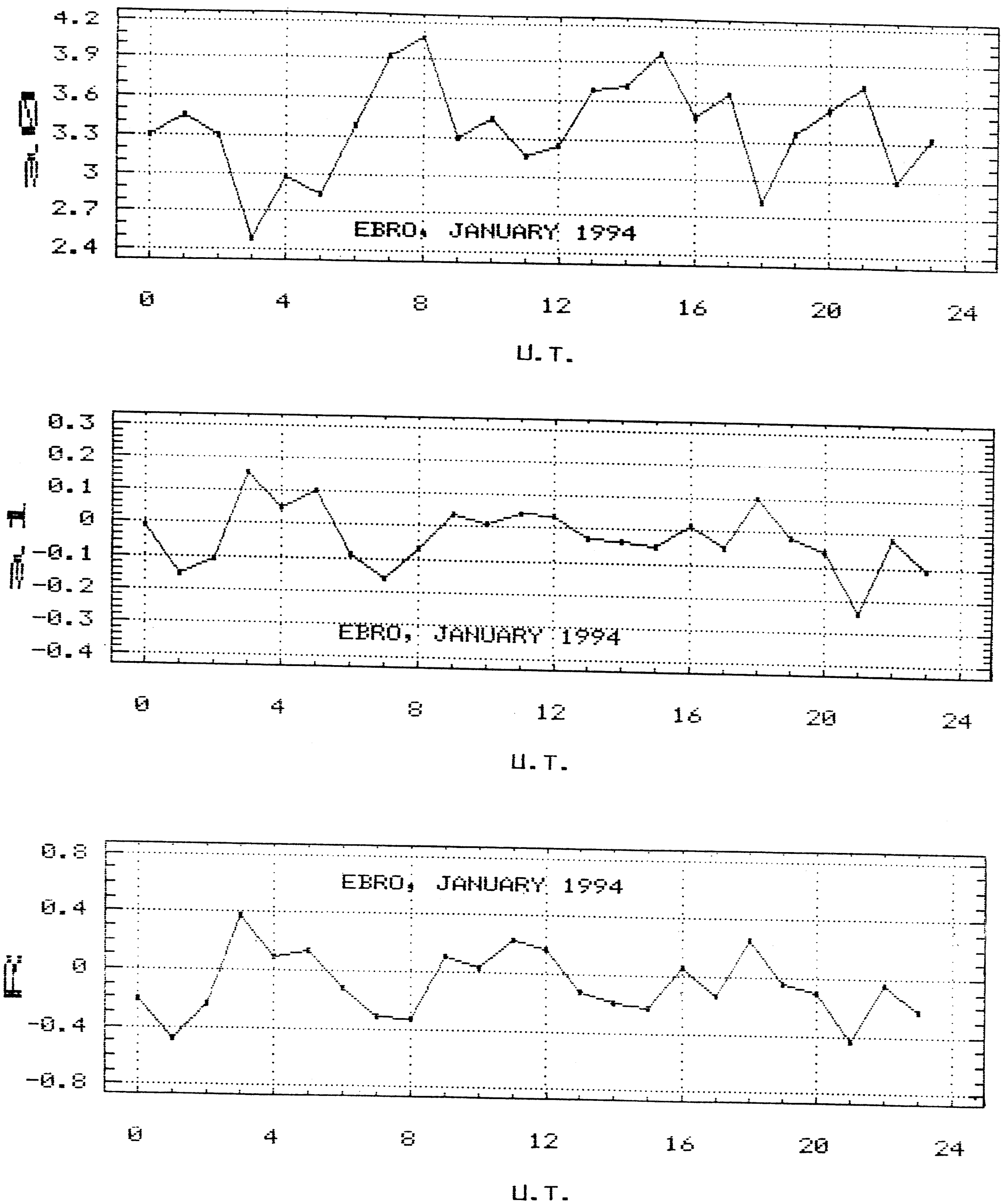

Fig. 3a. Ebro Observatory, January 1994. Hour-to-hour variations of the coefficient a_0, a_1 (regression equation) and correlation coefficient R. The maximal positive and negative correlations and minimal correlations are underlined in table I.

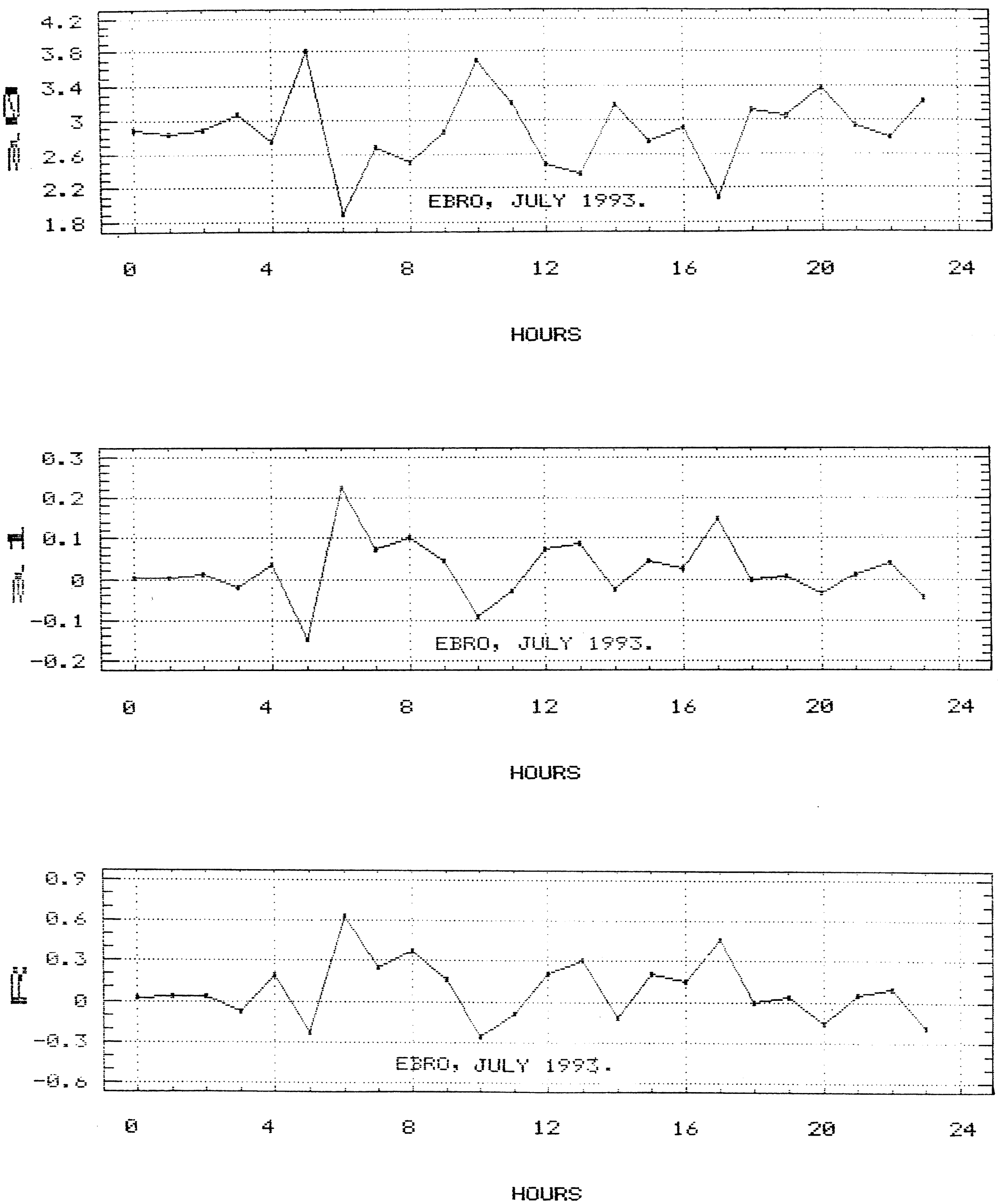

Fig. 3b. Ebro Observatory, July 1993. Hour-to-hour variations of the coefficient a_0, a_1 (regression equation) and correlation coefficient R. The maximal positive and negative correlations and minimal correlations are underlined in table I.

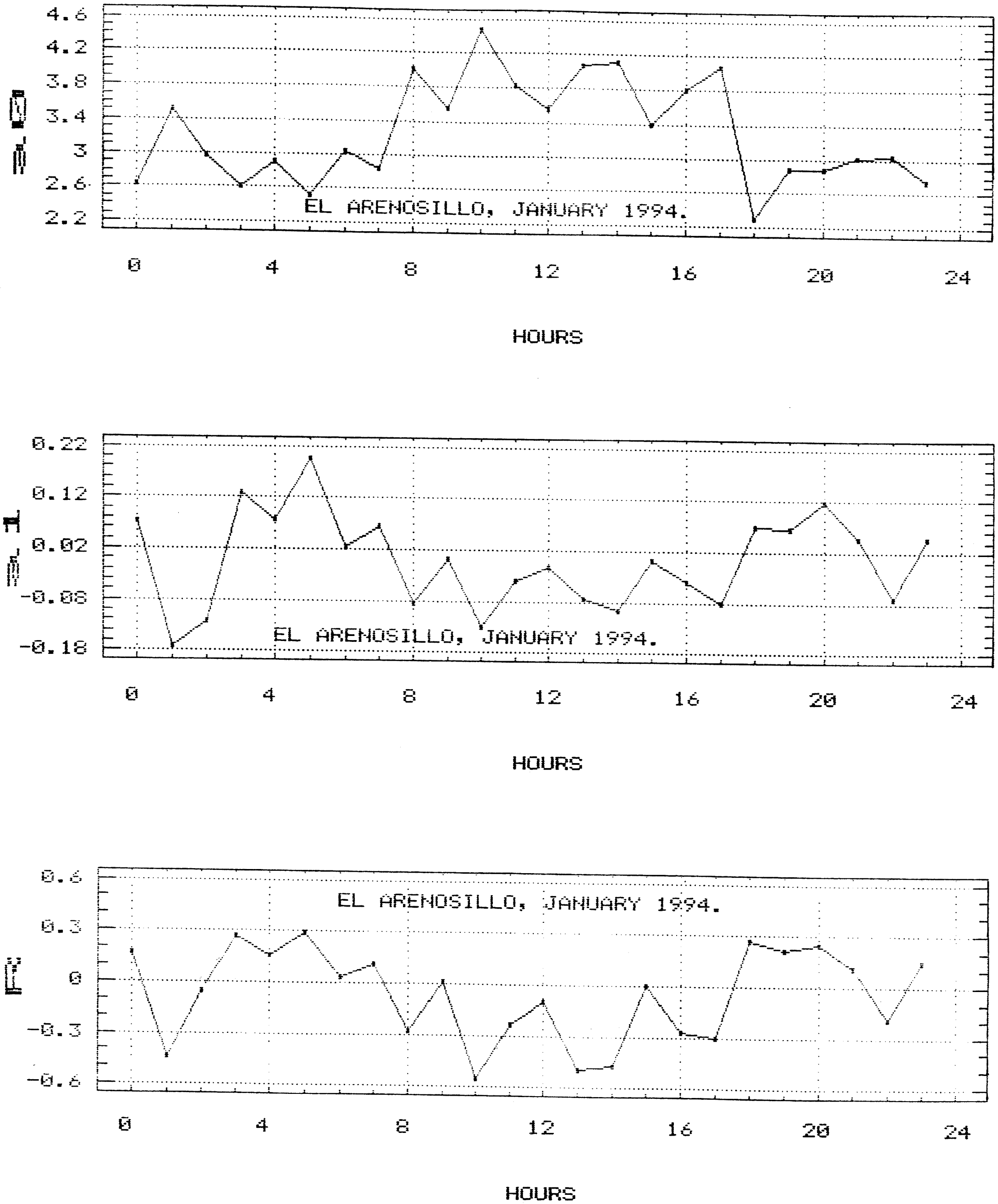

Fig. 3c. El Arenosillo, January 1994. Hour-to-hour variations of the coefficient a_0, a_1 (regression equation) and correlation coefficient R. The maximal positive and negative correlations and minimal correlations are underlined in table I.

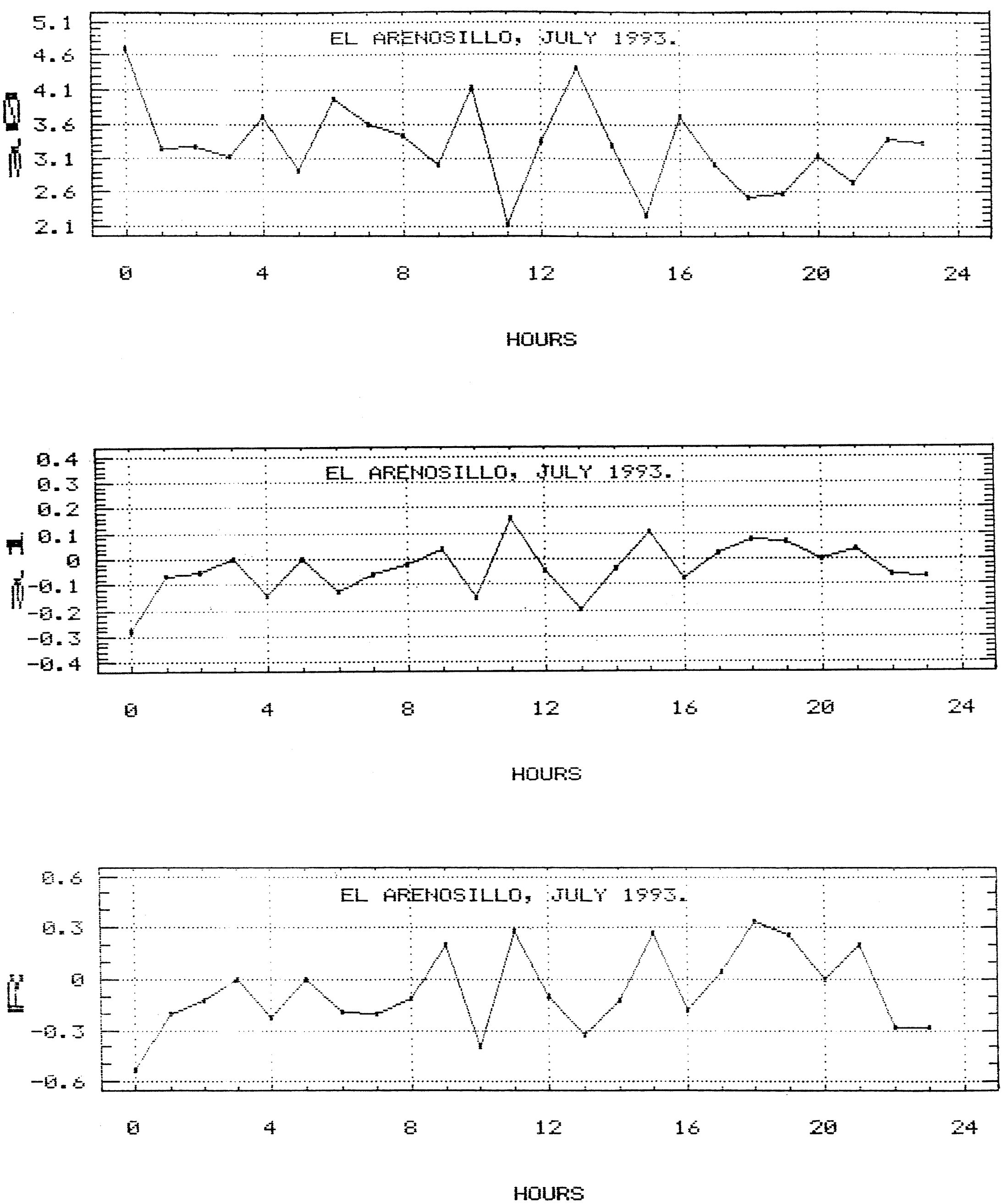

Fig. 3d. El Arenosillo, July 1993. Hour-to-hour variations of the coefficient a_0, a_1 (regression equation) and correlation coefficient R. The maximal positive and negative correlations and minimal correlations are underlined in table I.

Table I. Linear regression and correlation coefficient R for every hour. $M(3000) = a_0 + a_1 * f_0F_2$.

Hour	a_0	a_1	R	N	a_0	a_1	R	N
	a) Ebro Observatory, January 1994				**b) Ebro Observatory, July 1993**			
0	3.297	−0.010	−0.214	28	2.981	0.004	0.023	25
1	3.448	−0.155	−0.477	28	2.842	0.005	0.037	28
2	3.296	−0.107	−0.235	29	2.886	0.012	0.040	29
3	2.490	0.155	0.372	24	3.070	−0.021	−0.081	30
4	2.978	0.045	0.091	28	2.761	0.036	0.187	29
5	2.849	0.101	0.140	28	3.801	−0.148	−0.226	30
6	3.389	−0.087	−0.125	29	1.888	0.223	0.621	26
7	3.927	−0.163	−0.321	27	2.674	0.072	0.250	28
8	4.068	−0.069	−0.333	28	2.503	0.103	0.367	25
9	3.298	0.032	0.098	29	2.856	0.046	0.162	26
10	3.415	0.007	0.035	31	3.699	−0.093	−0.263	22
11	3.166	0.043	0.219	28	3.204	−0.028	−0.097	22
12	3.241	0.034	0.157	27	2.473	0.075	0.212	26
13	3.680	−0.030	−0.115	27	2.376	0.087	0.301	27
14	3.716	−0.038	−0.190	27	3.179	−0.025	−0.124	28
15	3.978	−0.053	−0.222	28	2.757	0.045	0.207	30
16	3.477	0.018	0.052	29	2.905	0.028	0.145	29
17	3.664	−0.049	−0.137	28	2.097	0.146	0.460	28
18	2.829	0.102	0.254	29	3.107	−0.001	−0.006	30
19	3.370	−0.016	−0.041	27	3.035	0.007	0.042	28
20	3.549	−0.056	−0.104	27	3.376	−0.034	−0.160	29
21	3.737	−0.242	−0.433	22	2.942	0.012	0.051	26
22	2.991	−0.017	−0.044	25	2.801	0.042	0.098	23
23	3.334	−0.112	−0.222	27	3.221	−0.044	−0.185	25
	c) El Arenosillo, January 1994				**d) El Arenosillo, July 1993**			
0	2.633	0.073	0.163	23	4.697	−0.278	−0.527	30
1	3.519	−0.173	−0.440	23	3.232	−0.066	−0.206	30
2	2.978	−0.124	−0.052	23	3.265	−0.054	−0.120	30
3	2.612	0.129	0.264	23	3.106	−0.003	−0.005	30
4	2.902	0.076	0.159	23	3.713	−0.144	−0.231	30
5	2.519	0.196	0.295	23	2.933	0.000	−0.001	29
6	3.047	0.022	0.036	22	3.967	−0.130	−0.190	12
7	2.845	0.064	0.112	22	3.610	−0.060	−0.201	30
8	4.002	−0.087	−0.277	22	3.441	−0.026	−0.110	29
9	3.548	0.002	0.013	23	3.021	0.035	0.198	27
10	4.473	−0.129	−0.551	23	4.121	−0.147	−0.397	24
11	3.815	−0.040	−0.235	23	2.145	0.157	0.282	27
12	3.567	−0.015	−0.103	22	3.340	−0.048	−0.104	27
13	4.076	−0.073	−0.499	23	4.409	−0.197	−0.331	28
14	4.125	−0.097	−0.475	23	3.283	−0.041	−0.119	29
15	3.388	0.001	0.004	24	2.268	0.102	0.268	28
16	3.807	−0.041	−0.271	23	3.703	−0.075	−0.184	30
17	4.083	−0.080	−0.301	23	3.003	0.020	0.048	29
18	2.296	0.070	0.270	23	2.518	0.078	0.336	30
19	2.871	0.063	0.208	22	2.577	0.067	0.257	28
20	2.876	0.116	0.246	23	3.114	0.000	0.000	28
21	3.020	0.045	0.108	23	2.753	0.037	0.205	29
22	3.044	−0.072	−0.195	23	3.385	−0.063	−0.281	29
23	2.738	0.046	0.144	23	3.330	−0.068	−0.279	30

N = Number of date.

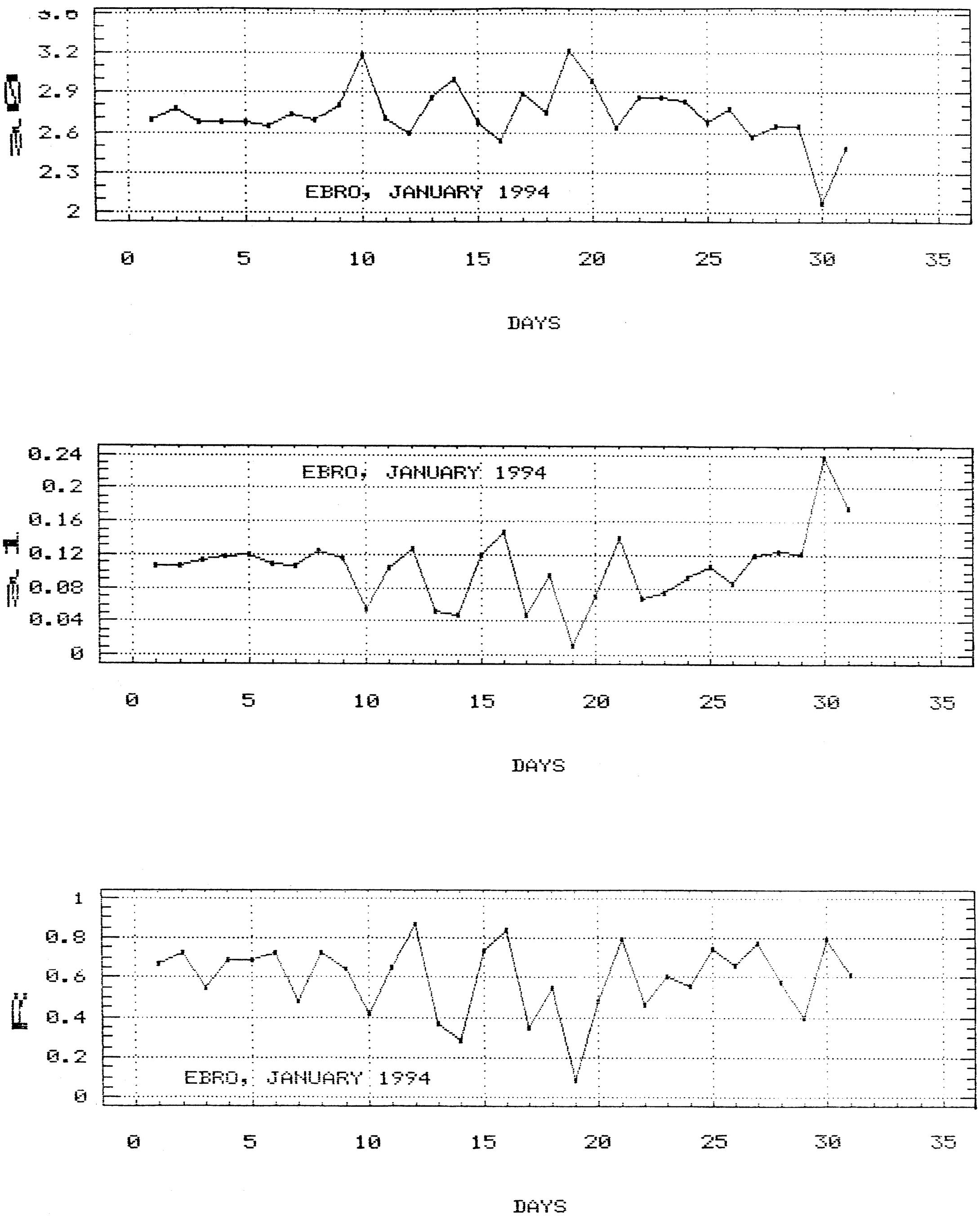

Fig. 4a. Ebro Observatory, January 1994. Day-to-day variations of the coefficient a_0, a_1 (regression equation) and correlation coefficient R. The maximal and minimal correlation are underlined in table II.

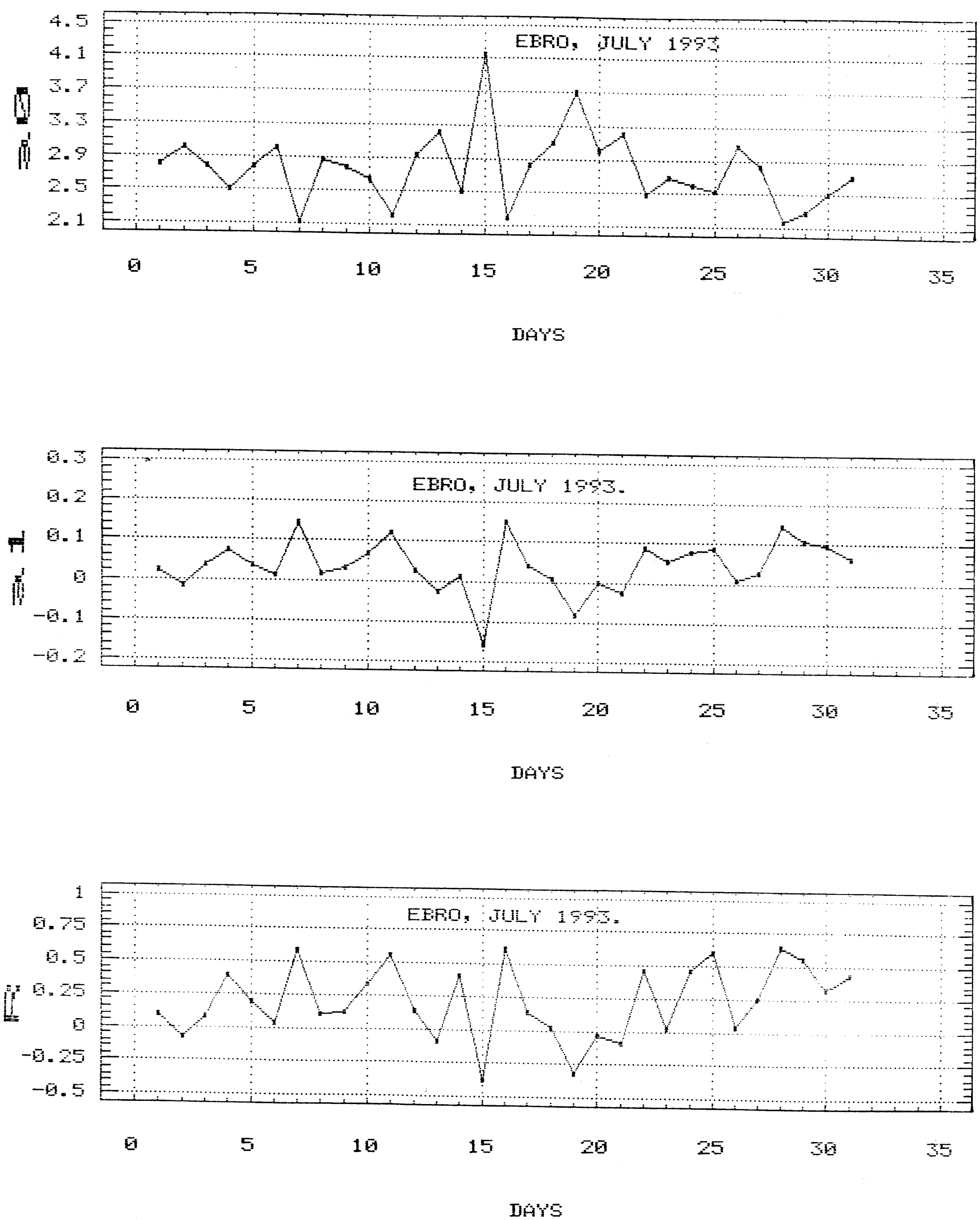

Fig. 4b. Ebro Observatory, July 1993. Day-to-day variations of the coefficient a_0, a_1 (regression equation) and correlation coefficient R. The maximal and minimal correlation are underlined in table II.

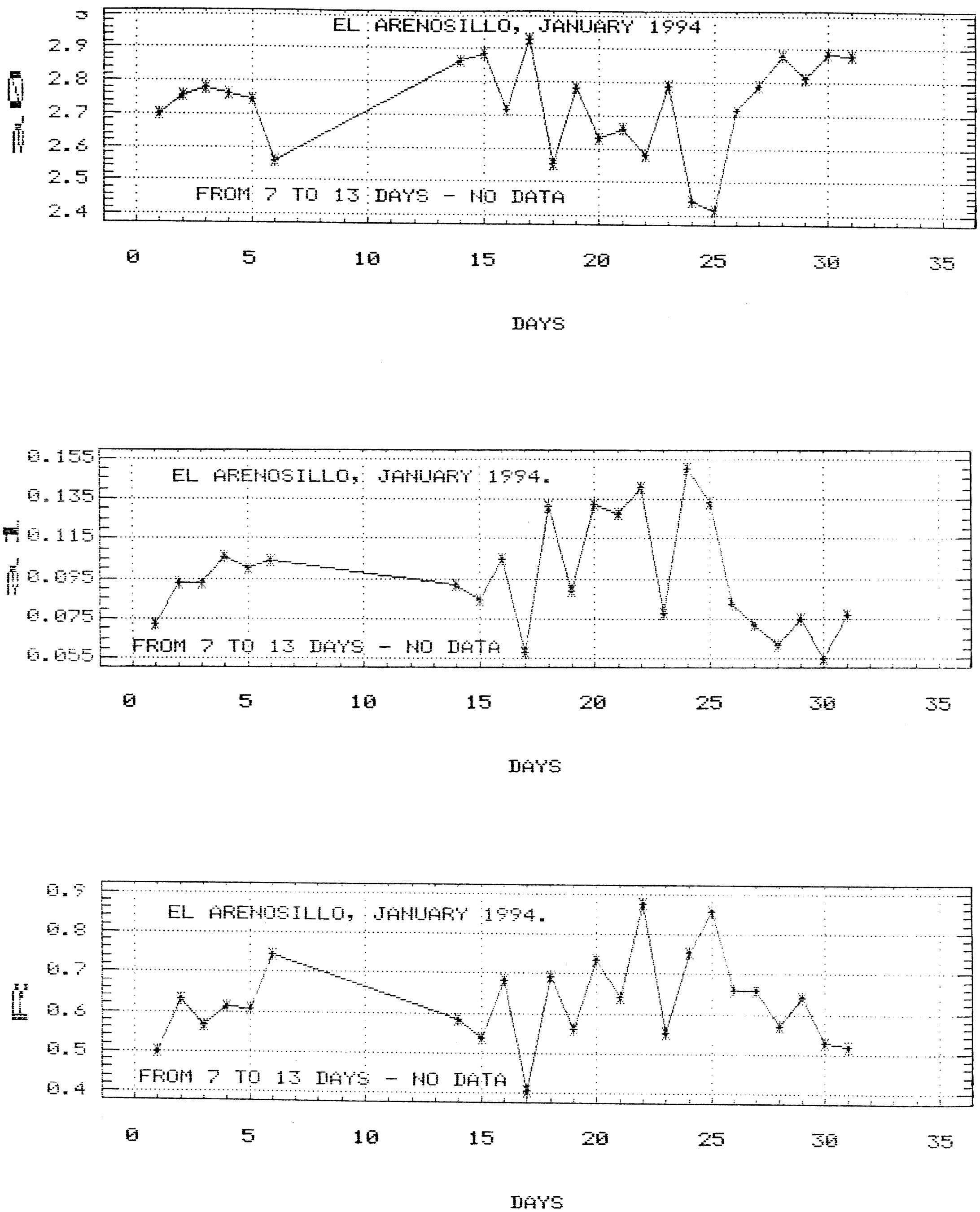

Fig. 4c. El Arenosillo, January 1994. Day-to-day variations of the coefficient a_0, a_1 (regression equation) and correlation coefficient R. The maximal and minimal correlation are underlined in table II.

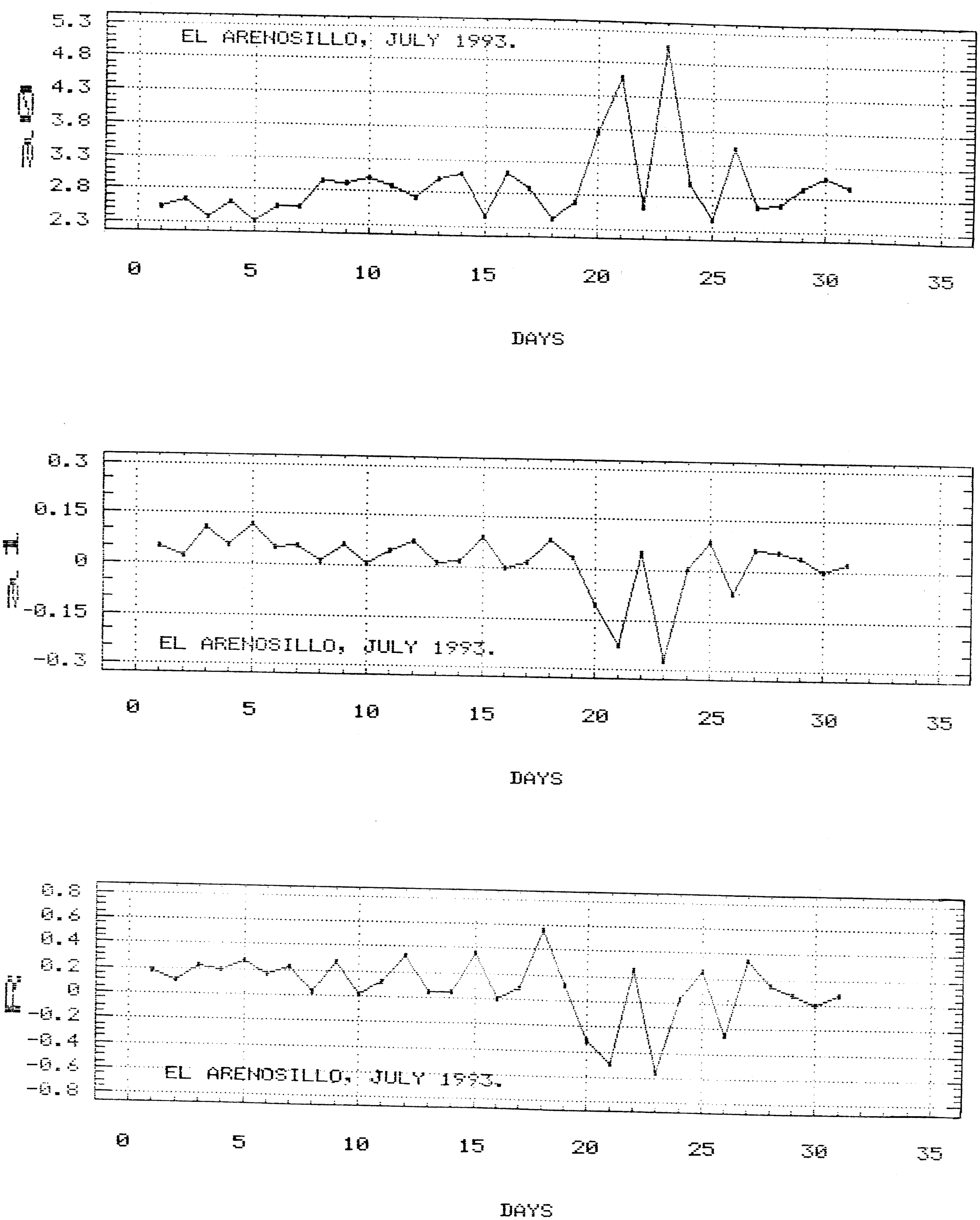

Fig. 4d. El Arenosillo, July 1993. Day-to-day variations of the coefficient a_0, a_1 (regression equation) and correlation coefficient R. The maximal and minimal correlation are underlined in table II.

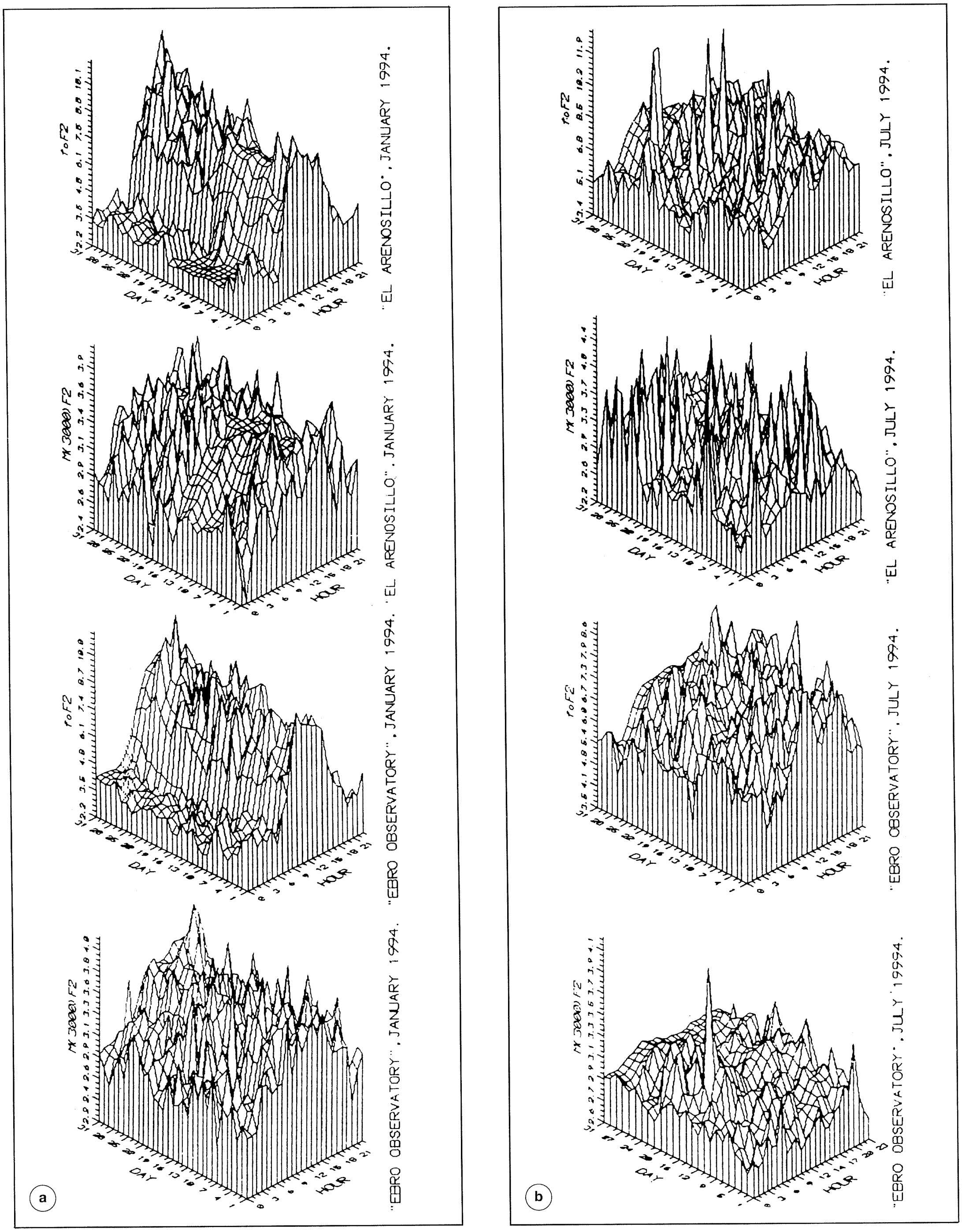

Fig. 5a,b. Daily global behaviour for f_0F_2 and $M(3000)$ during January (a) and July (b) in both stations.

Table II. Linear regression and correlation coefficient R for every day. $M(3000) = a_0 + a_1 * f_0F_2$.

Day	a_0	a_1	R	N	a_0	a_1	R	N
	a) Ebro Observatory, January 1994				**b) Ebro Observatory, July 1993**			
1	2.693	0.106	0.666	23	2.802	0.022	0.098	21
2	2.774	0.106	0.721	24	2.997	−0.016	−0.068	23
3	2.681	0.112	0.542	24	2.784	0.034	0.084	20
4	2.678	0.118	0.683	24	2.501	0.071	0.390	23
5	2.678	0.119	0.683	24	2.774	0.038	0.190	23
6	2.646	0.108	0.726	24	2.998	0.010	0.045	24
7	2.729	0.107	0.478	23	2.118	0.142	0.592	24
8	2.686	0.124	0.729	23	2.868	0.019	0.112	21
9	2.806	0.115	0.644	23	2.791	0.030	0.128	17
10	3.178	0.054	0.416	23	2.642	0.067	0.332	21
11	2.703	0.103	0.652	24	2.224	0.121	0.562	22
12	2.600	0.127	0.867	23	2.946	0.026	0.137	23
13	2.859	0.052	0.372	23	3.212	−0.023	−0.091	22
14	3.002	0.047	0.280	24	2.515	0.010	0.405	20
15	2.683	0.119	0.731	24	4.163	−0.157	−0.366	19
16	2.532	0.146	0.839	23	2.205	0.149	0.617	18
17	2.891	0.048	0.346	24	2.837	0.039	0.130	16
18	2.746	0.095	0.550	24	3.093	0.008	0.025	9
19	3.213	0.012	0.084	23	3.699	−0.081	−0.320	21
20	2.988	0.070	0.477	24	3.003	−0.004	−0.029	20
21	2.638	0.140	0.787	24	3.218	−0.026	−0.095	21
22	2.862	0.069	0.466	24	2.496	0.087	0.456	23
23	2.864	0.074	0.601	24	2.683	0.055	0.025	22
24	2.828	0.093	0.558	24	2.600	0.079	0.455	24
25	2.678	0.107	0.747	23	2.543	0.085	0.597	16
26	2.774	0.085	0.659	24	3.065	0.006	0.033	23
27	2.561	0.120	0.776	23	2.829	0.026	0.245	20
28	2.654	0.124	0.579	18	2.167	0.145	0.642	24
29	2.651	0.121	0.401	14	2.297	0.105	0.553	23
30	2.074	0.236	0.791	6	2.511	0.096	0.322	23
31	2.478	0.175	0.613	10	2.705	0.066	0.436	22
	c) El Arenosillo, January 1994				**d) El Arenosillo, July 1993**			
1	2.697	0.072	0.499	24	2.545	0.050	0.184	18
2	2.756	0.093	0.632	24	2.642	0.022	0.103	22
3	2.779	0.093	0.564	24	2.391	0.109	0.222	22
4	2.760	0.106	0.611	24	2.610	0.054	0.190	21
5	2.742	0.100	0.607	24	2.338	0.116	0.271	23
6	2.559	0.104	0.742	7	2.564	0.052	0.159	24
7	–	–	–	0	2.560	0.056	0.219	23
8	–	–	–	0	2.943	0.009	0.036	23
9	–	–	–	0	2.927	0.061	0.262	22
10	–	–	–	0	3.012	0.008	0.021	22
11	–	–	–	0	2.907	0.046	0.116	22
12	–	–	–	0	2.737	0.072	0.325	23
13	–	–	–	0	3.018	0.010	0.048	23
14	2.865	0.092	0.586	14	3.100	0.014	0.047	21

Table II (*continued*).

Day	a_0	a_1	R	N	a_0	a_1	R	N
15	2.886	0.084	0.539	24	2.472	0.091	0.359	22
16	2.718	0.105	0.684	24	3.110	−0.001	−0.003	23
17	2.933	0.058	0.405	24	2.901	0.015	0.082	23
18	2.551	0.131	0.694	23	2.440	0.082	0.560	21
19	2.785	0.089	0.559	24	2.708	0.034	0.120	23
20	2.631	0.132	0.736	24	3.744	−0.106	−0.322	23
21	2.660	0.127	0.640	24	4.578	−0.224	−0.494	23
22	2.583	0.141	0.873	23	2.632	0.051	0.256	23
23	2.789	0.078	0.551	24	5.053	−0.268	−0.563	22
24	2.447	0.150	0.752	24	3.007	0.006	0.025	23
25	2.420	0.133	0.856	24	2.483	0.083	0.255	22
26	2.714	0.082	0.657	24	3.555	−0.066	−0.254	24
27	2.788	0.072	0.660	24	2.672	0.059	0.345	22
28	2.881	0.062	0.569	24	2.692	0.056	0.150	24
29	2.810	0.075	0.642	24	2.957	0.038	0.068	9
30	2.885	0.055	0.530	24	3.118	0.002	0.006	18
31	2.880	0.077	0.520	24	2.993	0.022	0.081	24

N = Number of data.

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