A SEARCH FOR POSSIBLE CORRELATIONS BETWEEN PHOTOMETRIC AND ATMOSPHERIC PARAMETERS

Based on observations collected with the Swiss telescope
at the European Southern Observatory, La Silla, Chile
and with the GOES 8 satellite

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ABSTRACT
Following a study by Erasmus & Stank (1997), it has been shown that weather satellite data can be used for reliable estimates and forecasts of the atmospheric cloud cover and water content at the two Chilean ESO observatories, located at Paranal and La Silla.

This report describes a search for possible correlations between these satellite data and the high-quality photometric extinction coefficients obtained with the Swiss telescope at La Silla, having in mind possible forecasts of the photometric quality of a given night in relation to short-term scheduling observations and efficient use of the ESO telescopes.

The conclusion of this report shows that, although the satellite images have proven their usefulness in the forecasts of cloud coverage, it seems not possible to use the same data in order to derive precisely enough the extinction curve in the visible, during photometric nights.

1 INTRODUCTION

In a modern astronomical observatory like Paranal, a reliable and continuous interpretation of weather satellite data is essential for efficient short-term scheduling and optimum use of the large 8.2-m telescopes, in both visitor and service modes.

In their pioneering investigation, Erasmus & Stank (1997) studied the feasibility and the development of software computer code for atmospheric cloud cover and water vapor estimates and forecasts. They have shown convincingly that weather satellite data can be used for reliable forecast of the atmospheric cloud cover and water content at the two Chilean ESO observatories, located at Paranal and La Silla.

The present report investigate a search for possible correlations between these weather satellite data and the high-quality photometric extinction coefficients obtained with the Swiss telescope at La Silla in the frame work of the Geneva photometric system.

2 DESCRIPTION DATA

2.1 Satellite data: GOES 8

The satellite data we use hereafter are the Upper Tropospheric Humidity (UTH) and the Transparent Cirrus (TC), defined as follow.

Upper Tropospheric Humidity (UTH). The UTH is the water vapor measurement derived from the earth brightness temperature at 6.7 μm. It corresponds to the mean relative humidity inside a layer extending approximately from 700 to 300 mB, i.e. from 3,000 to 10,000 meters above sea level. The UTH is commonly expressed in %, as the ratio of the air mixing ratio (in grams of water vapor to grams of air) to the saturation mixing ratio (computed at the mean temperature of the 400 mB level). The Precipitable Water Vapor (PWV) is obtained from the integral over pressure of the mixing ratio along the whole air column (see Erasmus & Stank 1997 for a more complete description).

Transparent Cirrus (TC). In addition to the precipitable water vapor, cirrus clouds also enter into the average UTH measured by the satellite. By comparison with a long term database of ground based measurements of cloudiness and water vapor at Paranal and La Silla, thresholds have been empirically determined to characterize three types of situations, which are displayed in Table 1:

Table 1. Three UTH types.

Type	Name	UTH criteria
1	clear sky	UTH $<$ 72 %
2	transparent cirrus	72 % $<$ UTH $<$ 150 %
3	opaque cirrus	UTH $>$ 150 %

The class of Transparent Cirrus (TC) has been introduced (Erasmus & Stank 1997) to explain cases when the observers would declare the sky as “photometric” but where the satellite and ground measurements of water vapor disagree. It is the purpose of the present study to determine to which extent such “transparent” clouds are related to increasing atmospheric extinction in the visible and whether or not such nights can be also classified as “photometric”.

Consequently, in the following, we use two quantities obtained from the satellites data: (i) the Upper Tropospheric Humidity (UTH) and (ii) the Transparent Cirrus TC.

2.2 Ground-based data: Geneva photometry

The ground-based data we use hereafter are the seven extinction coefficients measured with the Swiss telescope at La Silla by the Geneva Observatory photometry group (Burki et al. 1995). The Geneva photometric system is made of seven filters whose mean wavelength λ_0 and second-order moment μ are given (both in angström) in Table 2.

Table 2. Geneva photometric filters.

Filter	λ_0	μ
U	3463	159
B1	4015	188
B	4227	282
B2	4476	163
V1	5395	202
V	5488	296
G	5807	200

A mean value of the extinction coefficient $k(\lambda)$ is calculated for each night, more rarely each half-night, together with a standard deviation $\sigma_{k(\lambda)}$ which is an estimate of the variation of this extinction during a given night or half-night. Both $k(\lambda)$ and $\sigma_{k(\lambda)}$ can be used as estimates of the photometric quality of the night. See, e.g., Budding (1993) for a general description of astronomical photometry and Burki et al. (1995) and references therein for all details about Geneva photometry.

Consequently, we use 14 quantities obtained from the ground-based photometric data: seven extinction coefficients, namely k(U), k(B1), k(B), k(B2), k(V1), k(V), and k(G), along with their corresponding standard deviations $\sigma_{k(U)}$, $\sigma_{k(B1)}$, $\sigma_{k(B)}$, $\sigma_{k(B2)}$, $\sigma_{k(V1)}$, $\sigma_{k(V)}$, and $\sigma_{k(G)}$.

2.3 Useful data

Since the amount of satellite data does not cover the whole year but sample different seasonal weather patterns and since the Swiss telescope at La Silla is operated only during photometric nights, the intersection between the satellite and ground-based data is rather small. Eventually, we have three sets of data, corresponding to 15 measurements in June 1993, 20 measurements in December 1993, and 16 measurements in March 1994.

Since the extinction coefficient $k(\lambda)$ is the mean, calculated for each night or half-night, together with its mean standard deviation $\sigma_{k(\lambda)}$, all corresponding satellites data measured during the time interval corresponding to the Geneva photometric data have been averaged: all quantities represent the mean for a given night or half-night. The time interval centered on the middle of the night or half-night, within which we average the available satellite data, is equal to $= \pm 0.1$ day $= \pm 2.4$ hours. Consequently, one half-night corresponds to about 5 hours, and a full night to 10 hours. One half-night may represent either the photometric part of an otherwise mediocre night, or one of the two halves of an excellent long photometric night.

Tables 3, 4, and 5 contain the satellite and ground-based data for June 1993, December 1993, and March 1994, respectively. The first column gives the date (year, month, day), the second column gives the date in modified Julian day minus 2,440,000 days. Columns 3 to 9 give the extinction coefficients and their standard deviations when available. Columns 10 and 11 give the Transparent Cirrus (TC) and the Upper Tropospheric Humidity (UTH).

TABLE 3. JUNE 1993 DATA

Date	MJD	k(U) sk(U)	k(B1) sk(B1)	k(B) sk(B)	k(B2) sk(B2)	k(V1) sk(V1)	k(V) sk(V)	k(G) sk(G)	TC	UTH
19930614	9152.99	0.642	0.336	0.281	0.224	0.151	0.161	0.132	17.53	44.92
		0.005	0.005	0.003	0.007	0.008	0.004	0.008		
19930614	9153.18	0.639	0.339	0.282	0.234	0.160	0.164	0.147	13.33	41.47
		0.005	0.004	0.004	0.003	0.004	0.004	0.004		
19930618	9157.14	0.630	0.341	0.277	0.238	0.160	0.157	0.152	0.00	27.31
		0.020	0.018	0.018	0.022	0.019	0.019	0.018		
19930619	9158.17	0.618	0.325	0.263	0.224	0.145	0.141	0.133	0.00	20.05
		0.008	0.007	0.006	0.009	0.007	0.006	0.007		
19930620	9159.08	0.621	0.323	0.265	0.222	0.143	0.142	0.133	2.00	32.40
		0.009	0.006	0.007	0.005	0.006	0.005	0.008		
19930622	9160.99	0.651	0.340	0.281	0.230	0.154	0.160	0.137	15.05	46.46
		0.003	0.006	0.002	0.003	0.004	0.002	0.004		
19930622	9161.07	0.650	0.346	0.284	0.243	0.165	0.166	0.155	18.10	50.49
		0.009	0.005	0.008	0.004	0.006	0.006	0.007		
19930623	9162.00	0.656	0.346	0.284	0.236	0.157	0.162	0.145	56.62	57.12
		0.007	0.006	0.003	0.009	0.004	0.005	0.006		
19930623	9162.18	0.673	0.373	0.311	0.268	0.191	0.194	0.183	42.39	52.90
		0.010	0.006	0.009	0.009	0.007	0.009	0.010		
19930624	9163.01	0.620	0.325	0.267	0.220	0.145	0.145	0.128	6.24	44.23
		0.006	0.008	0.007	0.009	0.012	0.009	0.013		
19930624	9163.18	0.631	0.337	0.275	0.234	0.159	0.156	0.147	10.05	50.49
		0.010	0.005	0.006	0.005	0.006	0.006	0.007		
19930625	9164.08	0.619	0.326	0.265	0.224	0.147	0.145	0.135	1.33	28.35
		0.012	0.010	0.008	0.011	0.008	0.009	0.010		
19930627	9165.99	0.622	0.324	0.264	0.221	0.141	0.144	0.130	0.57	22.08
		0.012	0.011	0.005	0.010	0.011	0.007	0.009		
19930627	9166.20	0.628	0.330	0.270	0.228	0.151	0.150	0.139	1.14	24.50
		0.008	0.008	0.010	0.008	0.008	0.009	0.010		
19930628	9167.17	0.615	0.321	0.259	0.217	0.142	0.139	0.129	0.00	20.05
		0.011	0.009	0.006	0.008	0.008	0.007	0.010		

This table contains the satellite and ground-based data (15 measurements) for June 1993. The first column gives the date (year, month, day), the second column gives the date in modified Julian day minus 2,440,000 days. Columns 3 to 9 give the extinction coefficients and their standard deviations when available. Columns 10 and 11 give the Transparent Cirrus (TC) and the Upper Tropospheric Humidity (UTH).

TABLE 4. DECEMBER 1993 DATA

Date	MJD	k(U)	k(B1)	k(B)	k(B2)	k(V1)	k(V)	k(G)	TC	UTH
19931201	9323.15	0.623	0.329	0.288	0.243	0.150	0.161	0.142	0.00	8.89
19931202	9324.15	0.597	0.295	0.259	0.219	0.141	0.147	0.132	0.00	13.25
19931203	9325.15	0.584	0.291	0.243	0.200	0.116	0.130	0.114	0.00	17.24
19931204	9326.15	0.570	0.280	0.236	0.196	0.127	0.137	0.119	0.00	6.77
19931205	9327.15	0.581	0.268	0.237	0.193	0.131	0.141	0.126	0.00	9.48
19931206	9328.15	0.575	0.257	0.228	0.190	0.121	0.134	0.119	0.00	9.15
19931207	9329.15	0.583	0.260	0.233	0.193	0.124	0.135	0.116	0.00	15.28
19931208	9330.15	0.603	0.272	0.242	0.204	0.132	0.143	0.128	0.00	14.35
19931209	9331.15	0.612	0.309	0.261	0.210	0.114	0.121	0.107	0.00	3.94
19931210	9332.15	0.630	0.327	0.283	0.233	0.143	0.150	0.134	0.00	12.48
19931211	9333.15	0.644	0.343	0.295	0.245	0.147	0.155	0.141	0.00	17.30
19931212	9334.15	0.673	0.367	0.320	0.276	0.171	0.180	0.162	0.00	23.79
19931213	9335.15	0.664	0.353	0.313	0.262	0.160	0.171	0.154	0.00	28.19
19931215	9337.15	0.623	0.324	0.283	0.237	0.140	0.151	0.135	0.00	7.54
19931216	9338.15	0.611	0.312	0.272	0.225	0.136	0.150	0.132	0.00	11.08
19931217	9339.15	0.604	0.303	0.261	0.216	0.135	0.141	0.129	0.00	11.43
19931218	9340.15	0.625	0.319	0.275	0.229	0.141	0.149	0.135	0.00	7.98
19931219	9341.15	0.614	0.306	0.263	0.220	0.135	0.143	0.128	0.00	4.13
19931220	9342.15	0.613	0.298	0.268	0.225	0.141	0.149	0.135	0.00	8.83
19931221	9343.15	0.623	0.311	0.269	0.225	0.141	0.152	0.137	0.00	4.40

This table contains the satellite and ground-based data (20 measurements) for December 1993. The first column gives the date (year, month, day), the second column gives the date in modified Julian day minus 2,440,000 days. Columns 3 to 9 give the extinction coefficients; their standard deviations are available. Columns 10 and 11 give the Transparent Cirrus (TC) and the Upper Tropospheric Humidity (UTH).

TABLE 5. MARCH 1994 DATA

Date	MJD	k(U) sk(U)	k(B1) sk(B1)	k(B) sk(B)	k(B2) sk(B2)	k(V1) sk(V1)	k(V) sk(V)	k(G) sk(G)	TC	UTH
19940314	9426.19	0.595	0.322	0.252	0.216	0.135	0.132	0.127	18.15	27.69
		0.006	0.005	0.004	0.005	0.005	0.005	0.006		
19940315	9427.15	0.601	0.325	0.254	0.219	0.137	0.135	0.131	0.86	30.84
		0.011	0.005	0.005	0.004	0.005	0.004	0.003		
19940316	9428.21	0.603	0.323	0.257	0.216	0.137	0.137	0.127	0.19	25.59
		0.009	0.009	0.009	0.010	0.009	0.007	0.009		
19940317	9429.25	0.621	0.329	0.264	0.222	0.139	0.137	0.126	0.00	22.39
		0.019	0.013	0.009	0.011	0.008	0.007	0.008		
19940318	9430.20	0.636	0.336	0.278	0.229	0.142	0.143	0.126	51.43	57.09
		0.010	0.009	0.007	0.008	0.005	0.005	0.005		
19940319	9431.20	0.611	0.314	0.264	0.213	0.128	0.133	0.117	0.05	28.12
		0.014	0.007	0.010	0.006	0.008	0.008	0.008		
19940320	9432.07	0.651	0.367	0.293	0.255	0.165	0.159	0.144	0.00	13.85
		0.021	0.014	0.014	0.010	0.009	0.011	0.008		
19940320	9432.30	0.655	0.348	0.283	0.247	0.156	0.153	0.145	0.00	13.01
		0.015	0.009	0.008	0.007	0.007	0.009	0.008		
19940321	9433.09	0.650	0.359	0.293	0.257	0.163	0.155	0.153	0.00	12.09
		0.010	0.009	0.008	0.008	0.007	0.008	0.008		
19940321	9433.31	0.692	0.388	0.319	0.275	0.185	0.182	0.171	0.00	12.21
		0.015	0.013	0.013	0.012	0.011	0.011	0.010		
19940322	9434.19	0.664	0.366	0.298	0.259	0.170	0.166	0.155	0.00	18.28
		0.026	0.013	0.013	0.012	0.013	0.013	0.013		
19940323	9435.23	0.639	0.342	0.276	0.236	0.155	0.153	0.143	71.24	60.95
		0.015	0.009	0.009	0.008	0.006	0.007	0.006		
19940325	9437.22	0.640	0.345	0.279	0.241	0.162	0.158	0.149	0.00	29.23
		0.010	0.009	0.007	0.007	0.006	0.006	0.006		
19940326	9438.24	0.652	0.356	0.289	0.252	0.168	0.164	0.157	0.00	16.52
		0.014	0.010	0.009	0.010	0.006	0.007	0.008		
19940327	9439.21	0.630	0.340	0.274	0.235	0.156	0.153	0.145	0.00	26.03
		0.020	0.016	0.015	0.013	0.011	0.010	0.009		
19940331	9443.05	0.696	0.386	0.320	0.274	0.179	0.182	0.160	51.33	57.87
		0.020	0.013	0.012	0.007	0.007	0.009	0.004		

This table contains the satellite and ground-based data (16 measurements) for March 1994. The first column gives the date (year, month, day), the second column gives the date in modified Julian day minus 2,440,000 days. Columns 3 to 9 give the extinction coefficients and their standard deviations when available. Columns 10 and 11 give the Transparent Cirrus (TC) and the Upper Tropospheric Humidity (UTH).

3 DESCRIPTION OF THE FIGURES

June 1993

• For the 15 measurements in this data set, Figure 1 displays the Transparent Cirrus (TC) vs. Geneva photometric extinction coefficients. There seems to be a trend, stronger in the blue than in the red filters, showing that the extinction coefficients increase with the amount of transparent cirrus.

• No correlation is visible in Figure 2, which displays the Transparent Cirrus (TC) vs. standard deviations of the Geneva photometric extinction coefficients.

• Figure 3 displays the Upper Tropospheric Humidity (UTH) vs. Geneva photometric extinction coefficients. In a way similar to Figure 1, there seems to be a trend, stronger in the blue than in the red filters, showing that the extinction coefficients increase with the amount of Upper Tropospheric Humidity.

• No correlation is visible in Figure 4, which displays the Upper Tropospheric Humidity (UTH) vs. standard deviations of the Geneva photometric extinction coefficients.

Summary: For this data set, there are some weak correlations when the abscissa represents the extinction coefficients, but no correlation when the abscissa represents the standard deviations of the extinction coefficients.

December 1993

• For the 20 measurements in this data set, Figure 5 displays the Transparent Cirrus (TC) vs. Geneva photometric extinction coefficients. No correlation since the satellite provide only null values for the Transparent Cirrus, pointing towards what must have been a very good photometric period.

• Figure 6 displays the Upper Tropospheric Humidity (UTH) vs. Geneva photometric extinction coefficients. There seems to be a trend, similar in the blue and red filters, showing that, for large values only, the extinction coefficients increase with the amount of Upper Tropospheric Humidity. It is worth mentioning that all values of UTH and extinction coefficients are smaller the those in Figure 3, pointing towards what must have been a very good photometric period.

Summary: For this data set, there is a weak correlation between Upper Tropospheric Humidity and extinction coefficients. The standard deviations of the extinction coefficients are not available from Geneva Observatory. The UTH values of this set are smaller than in the other two sets.

March 1994

• For the 16 measurements in this data set, Figure 7 displays the Transparent Cirrus (TC) vs. Geneva photometric extinction coefficients. No clear correlation since part of the satellite values for the Transparent Cirrus are equal to zero.

• For the same reason, no correlation is visible in Figure 8, which displays the Transparent Cirrus (TC) vs. standard deviations of the Geneva photometric extinction coefficients.

• Figure 9 displays the Upper Tropospheric Humidity (UTH) vs. Geneva photometric extinction coefficients. Contrary to what is observed in Figure 3 for June 1993 and Figure 6

for December 1993, there seems to be an anticorrelation, showing that the amount of Upper Tropospheric Humidity decreases when the extinction coefficients increase. However, three points, with large UTH values, depart strongly from the rest of the population.
• No correlation is visible in Figure 10, which displays the Upper Tropospheric Humidity (UTH) vs. standard deviations of the Geneva photometric extinction coefficients.

Summary: For this data set, there is a weak anti-correlation, opposite to what is observed in Figure 3 and 6, when the abscissa represents the extinction coefficients, but no correlation when the abscissa represents the standard deviations of the extinction coefficients.

All data

• Figure 11 displays the Upper Tropospheric Humidity (UTH) vs. Geneva photometric extinction coefficients for all three periods, corresponding to the overlap of Figures 3, 6, and 9. This final figure confirms that there is a trend, stronger in the blue than in the red filters, showing that the spread of Upper Tropospheric Humidity values increases with extinction coefficients. There is no data point with small extinction coefficient and large UTH values.

4 CONCLUSION

As a conclusion of this report, we can state that, although the satellite images have proven their usefulness in the forecasts of cloud coverage, it seems not possible to use the Upper Tropospheric Humidity (UTH), i.e., the water vapor measurement derived from the earth brightness temperature at 6.7 μm, in order to determine precisely enough the extinction curve in the visible, during photometric nights. There is a trend, stronger in the blue than in the red filters, showing that the spread of Upper Tropospheric Humidity values increased with extinction coefficients, probably because UTH is only one among the many contaminants creating the atmospheric extinction at visible wavelenghts.

We recall that Geneva photometry is operating only during excellent photometric nights, when cloudiness is extremely low. Following the values of Upper Tropospheric Humidity (UTH) provided in Tables 3, 4, and 5, in which UTH is always smaller than 72 %, and applying the definitions in Table 1, we can conclude that all nights considered here were of the “clear sky” type. None of these night could be considered of the “transparent cirrus” type.

The high standard and quality Geneva photometry is restricting the present study to a very narrow range of Upper Tropospheric Humidity values, making very difficult any search for correlations. It is similar to looking for the Hubble law in restricting ourself only to the lower-left portion of the Redshift vs. Distance diagram, although with less astrophysical implications in our case...

5 ACKNOWLEGEMENT

We would like to thank Dr. A. Erasmus for providing us the files containing the satellite data.

6 BIBLIOGRAPHY

1. Budding E., 1993, it An Introduction to Astronomical Photometry, Cambridge: Cambridge University Press

2. Burki G., 1995, A&AS, 112, 383

3. Erasmus A., Stanko P.R., 1997, Feasibility Study and Development of Software Computer Code for Cloud Cover and Water Vapor Forecasts, ESO Report # VLT-TRE-ERA-17440-1039

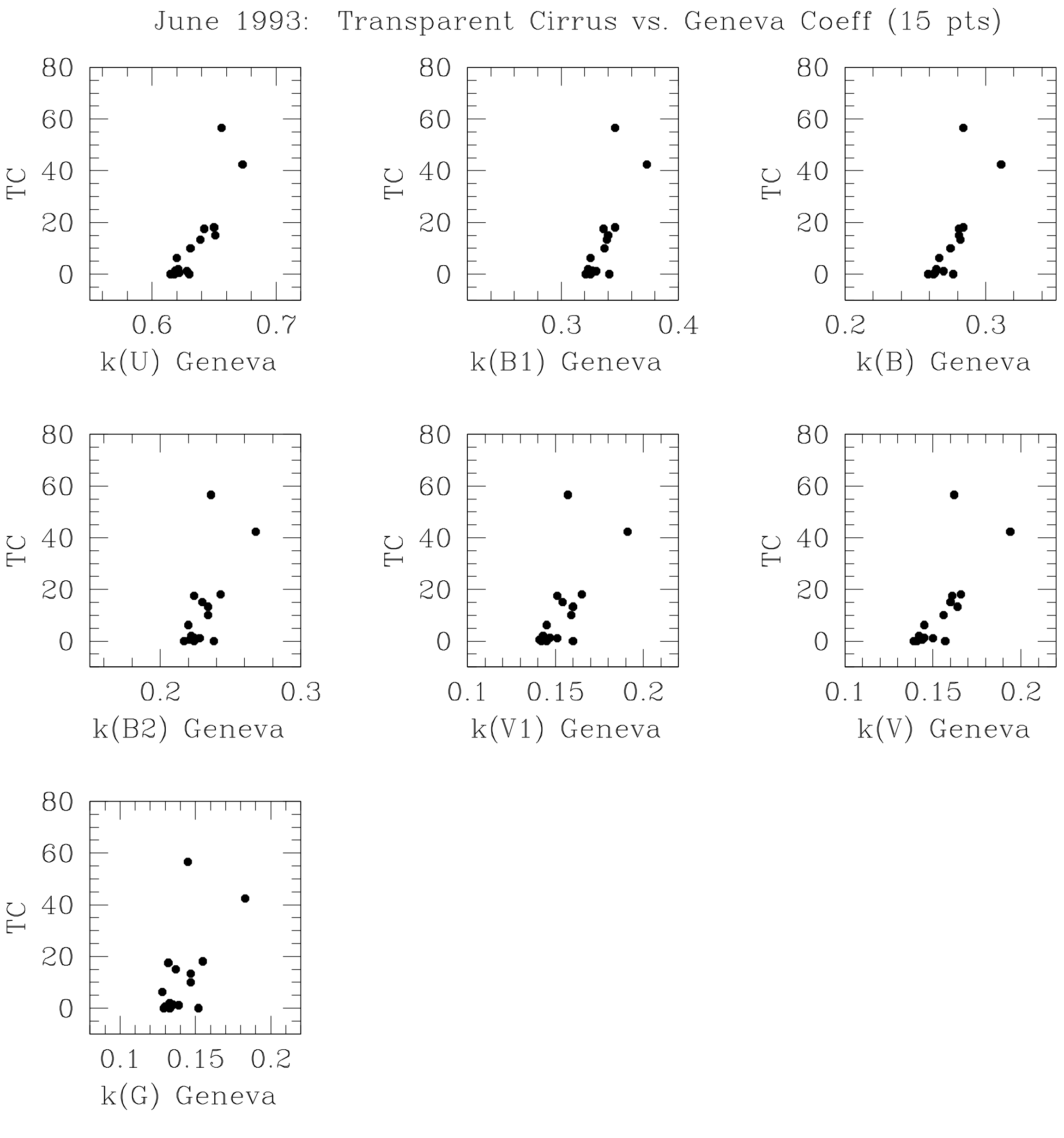

Figure 1: Transparent Cirrus (TC) vs. Geneva photometric extinction coefficients for the 15 measurements obtained in June 1993.

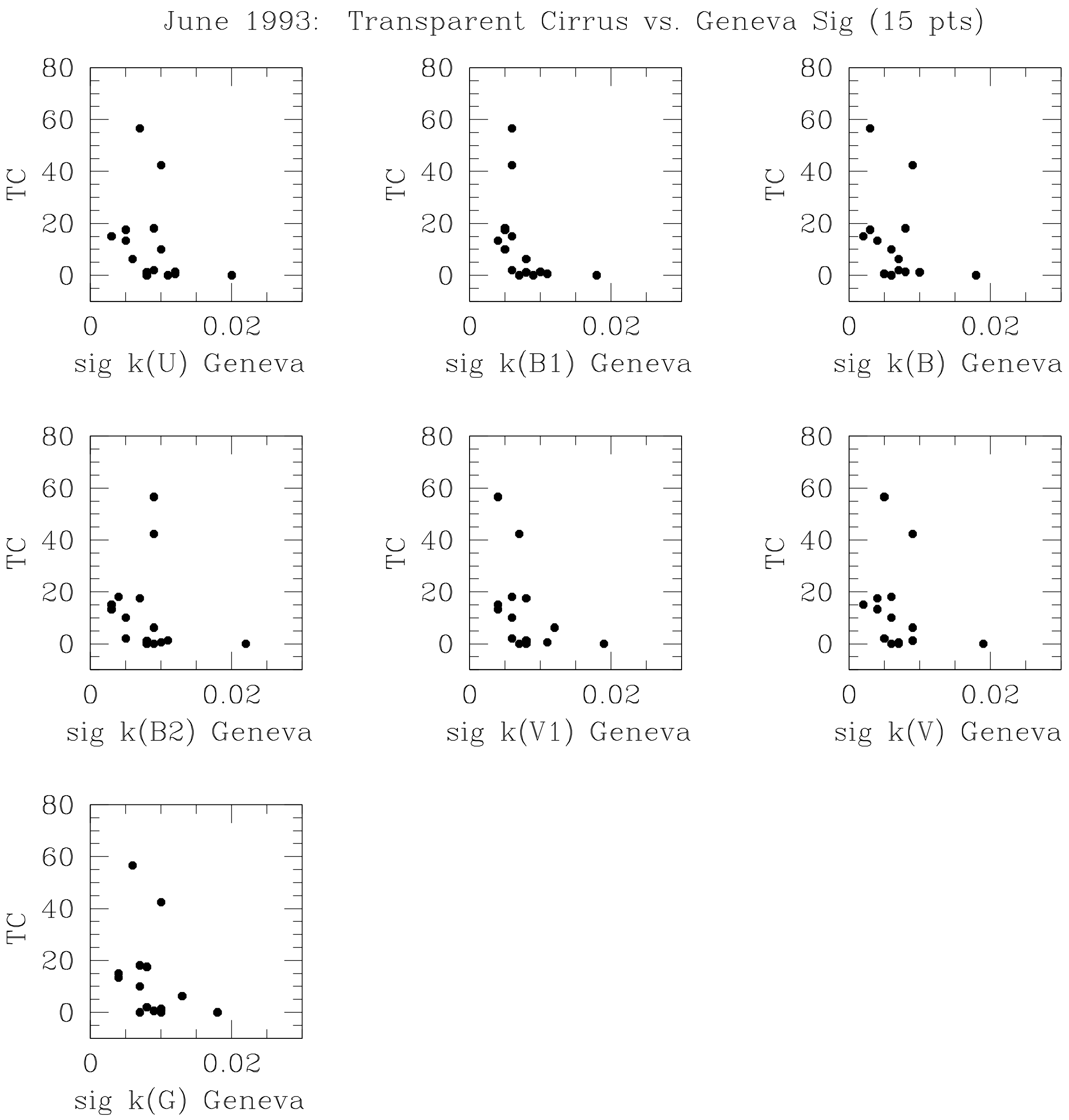

Figure 2: Transparent Cirrus (TC) vs. standard deviations of the Geneva photometric extinction coefficients for the 15 measurements obtained in June 1993.

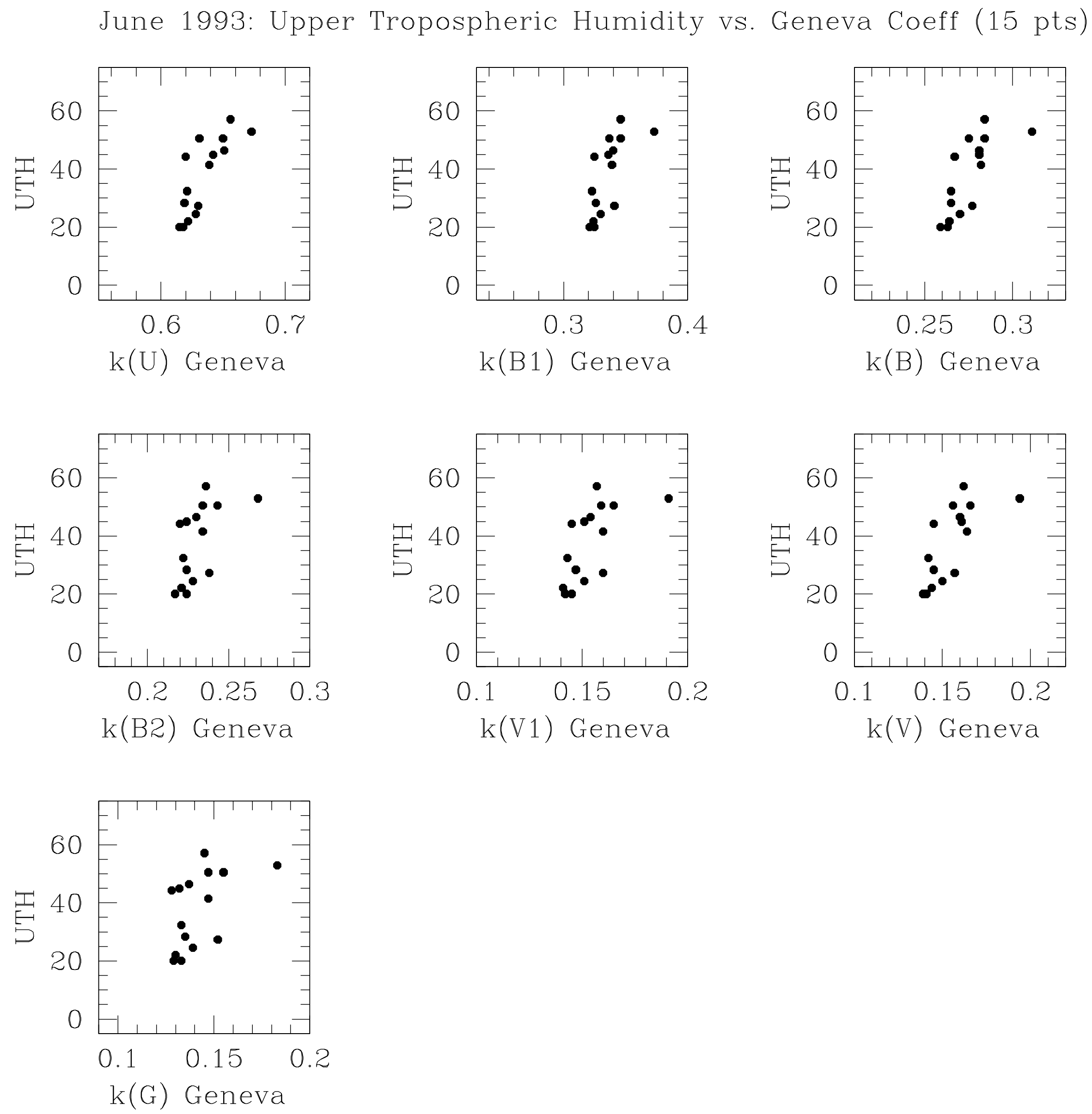

Figure 3: Upper Tropospheric Humidity (UTH) vs. Geneva photometric extinction coefficients for the 15 measurements obtained in June 1993.

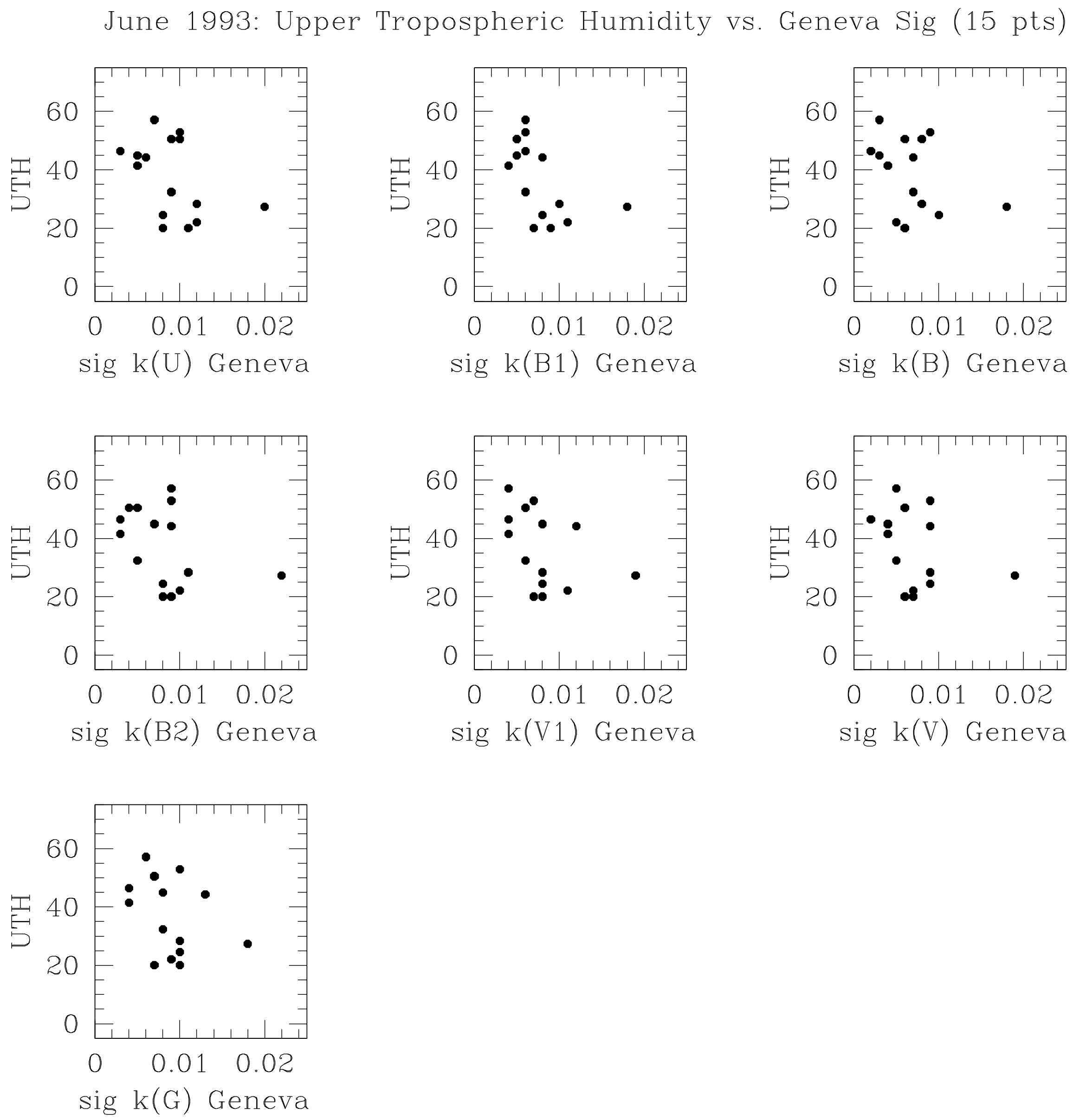

Figure 4: Upper Tropospheric Humidity (UTH) vs. standard deviations of the Geneva photometric extinction coefficients for the 15 measurements obtained in June 1993.

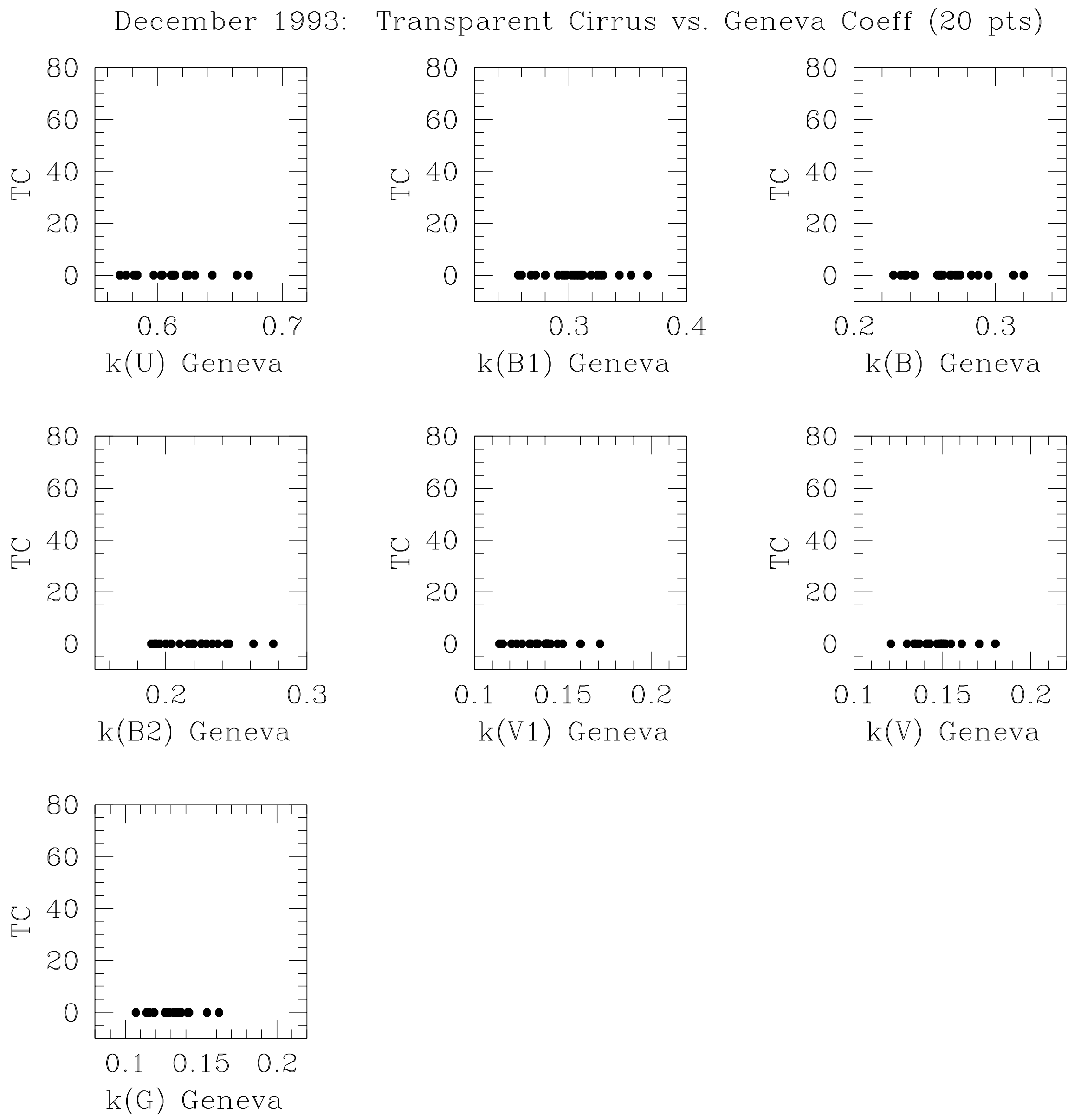

Figure 5: Transparent Cirrus (TC) vs. Geneva photometric extinction coefficients for the 20 measurements obtained in December 1993.

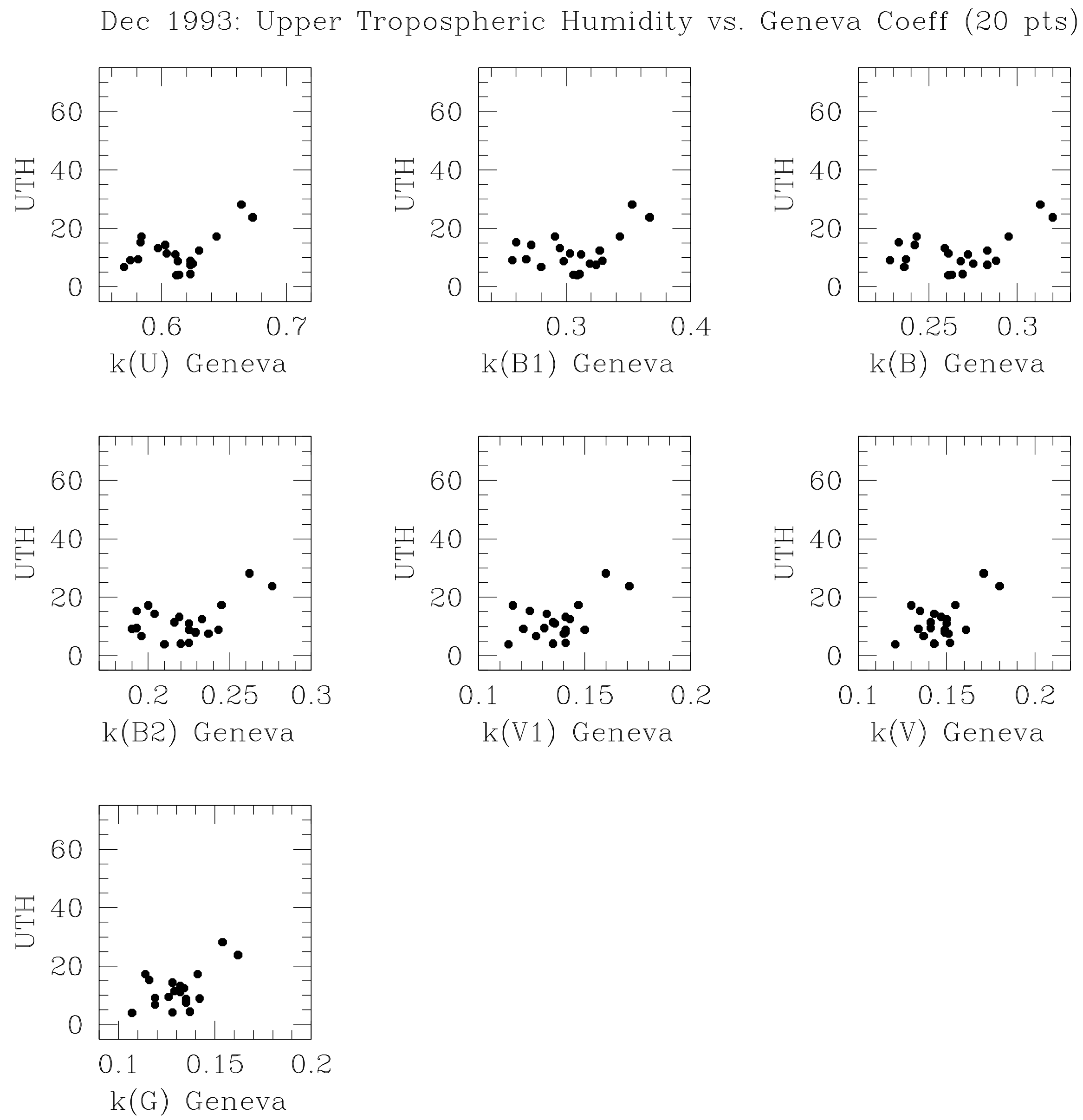

Figure 6: Upper Tropospheric Humidity (UTH) vs. Geneva photometric extinction coefficients for the 20 measurements obtained in December 1993.

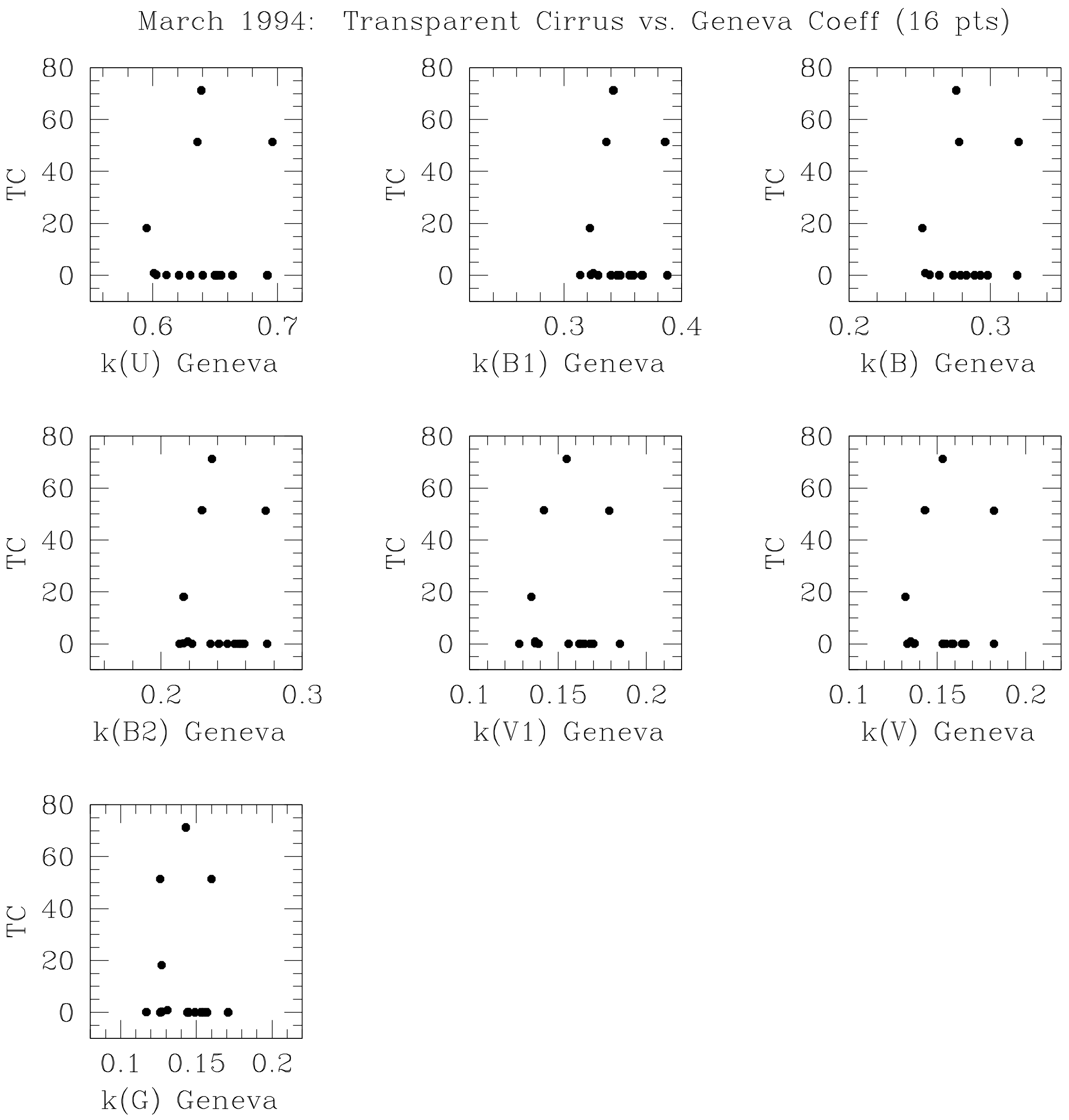

Figure 7: Transparent Cirrus (TC) vs. Geneva photometric extinction coefficients for the 16 measurements obtained in March 1994.

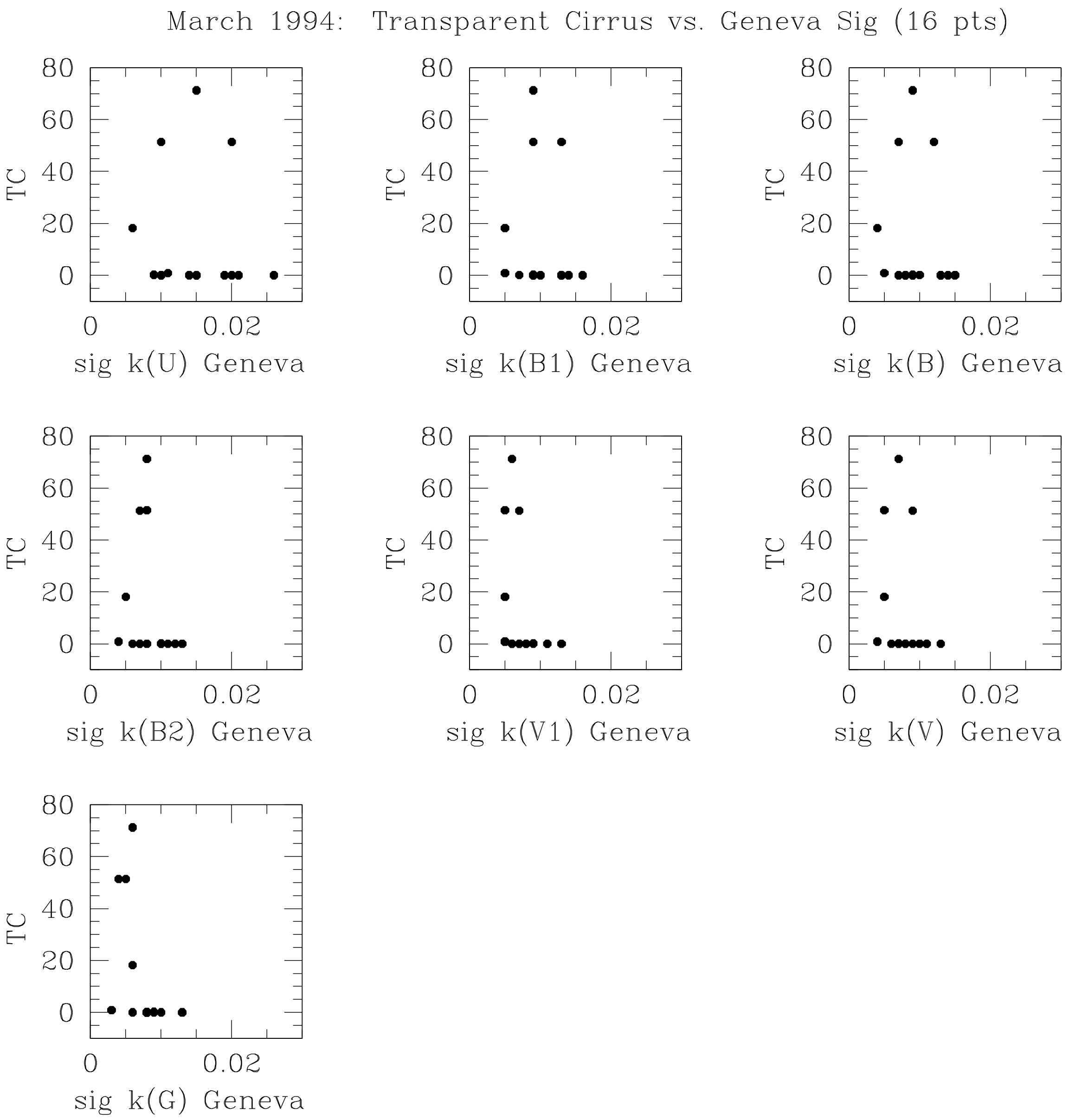

Figure 8: Transparent Cirrus (TC) vs. standard deviations of the Geneva photometric extinction coefficients for the 16 measurements obtained in March 1994.

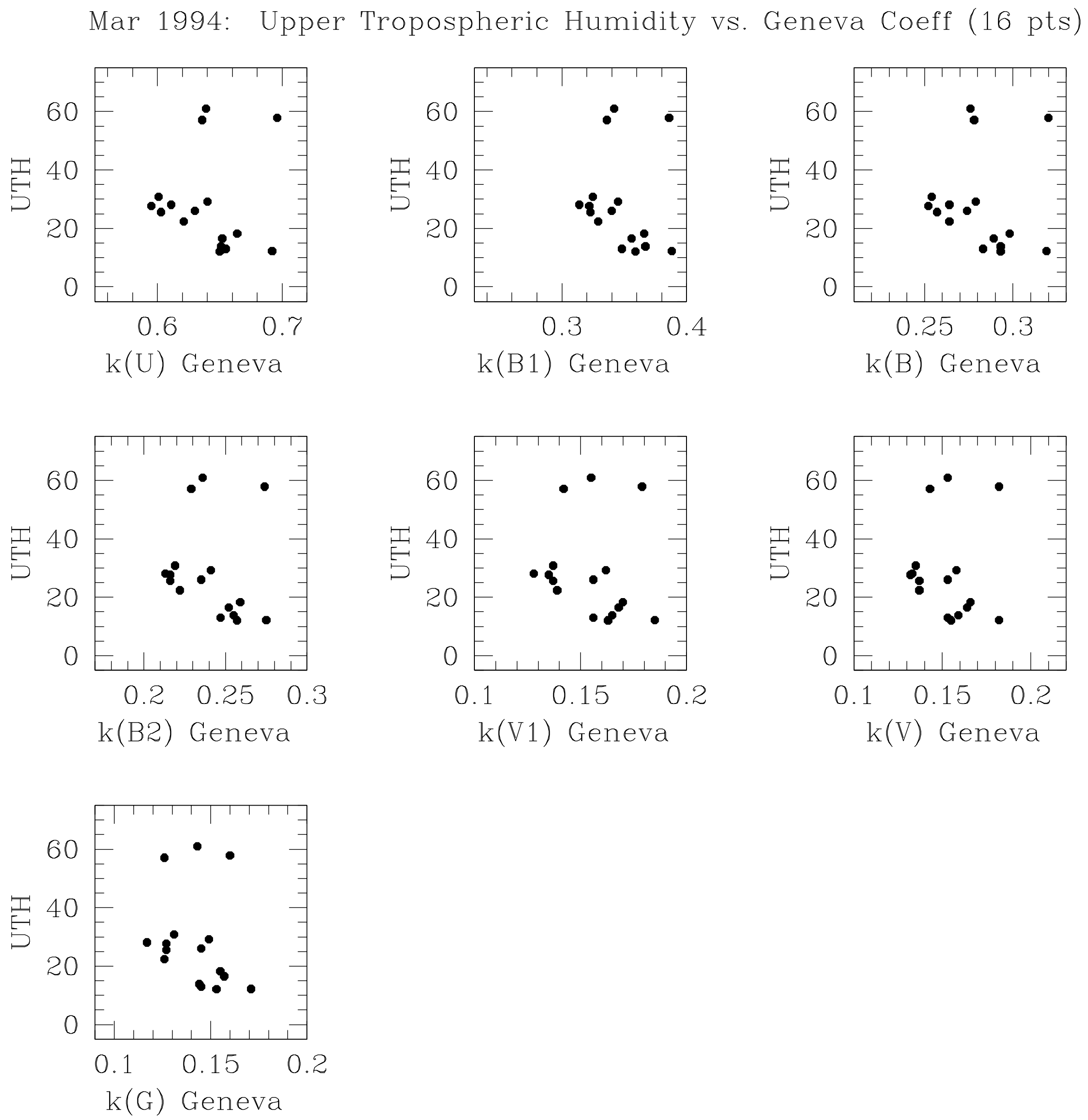

Figure 9: Upper Tropospheric Humidity (UTH) vs. Geneva photometric extinction coefficients for the 16 measurements obtained in March 1994.

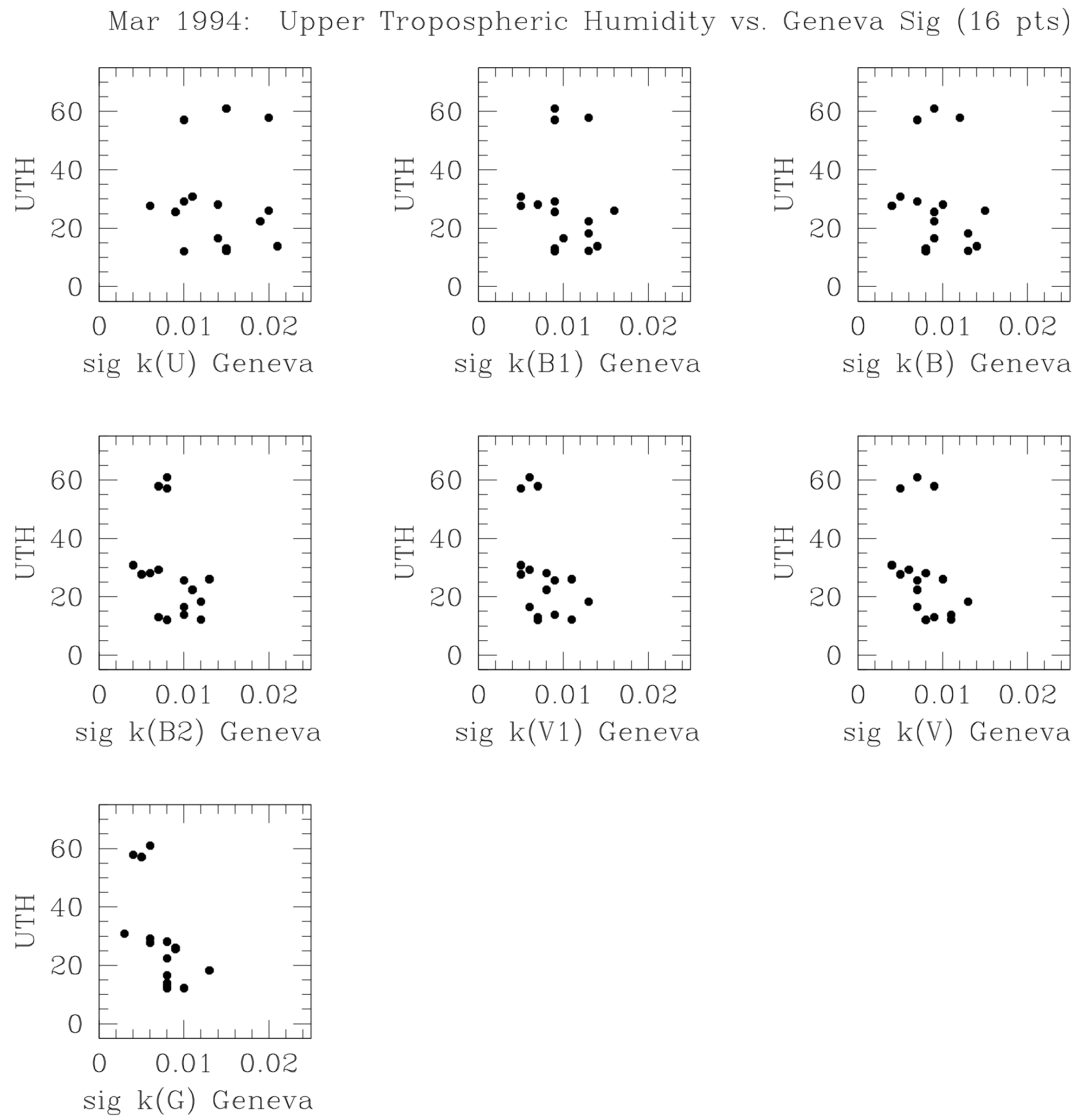

Figure 10: Upper Tropospheric Humidity (UTH) vs. standard deviations of the Geneva photometric extinction coefficients for the 16 measurements obtained in March 1994.

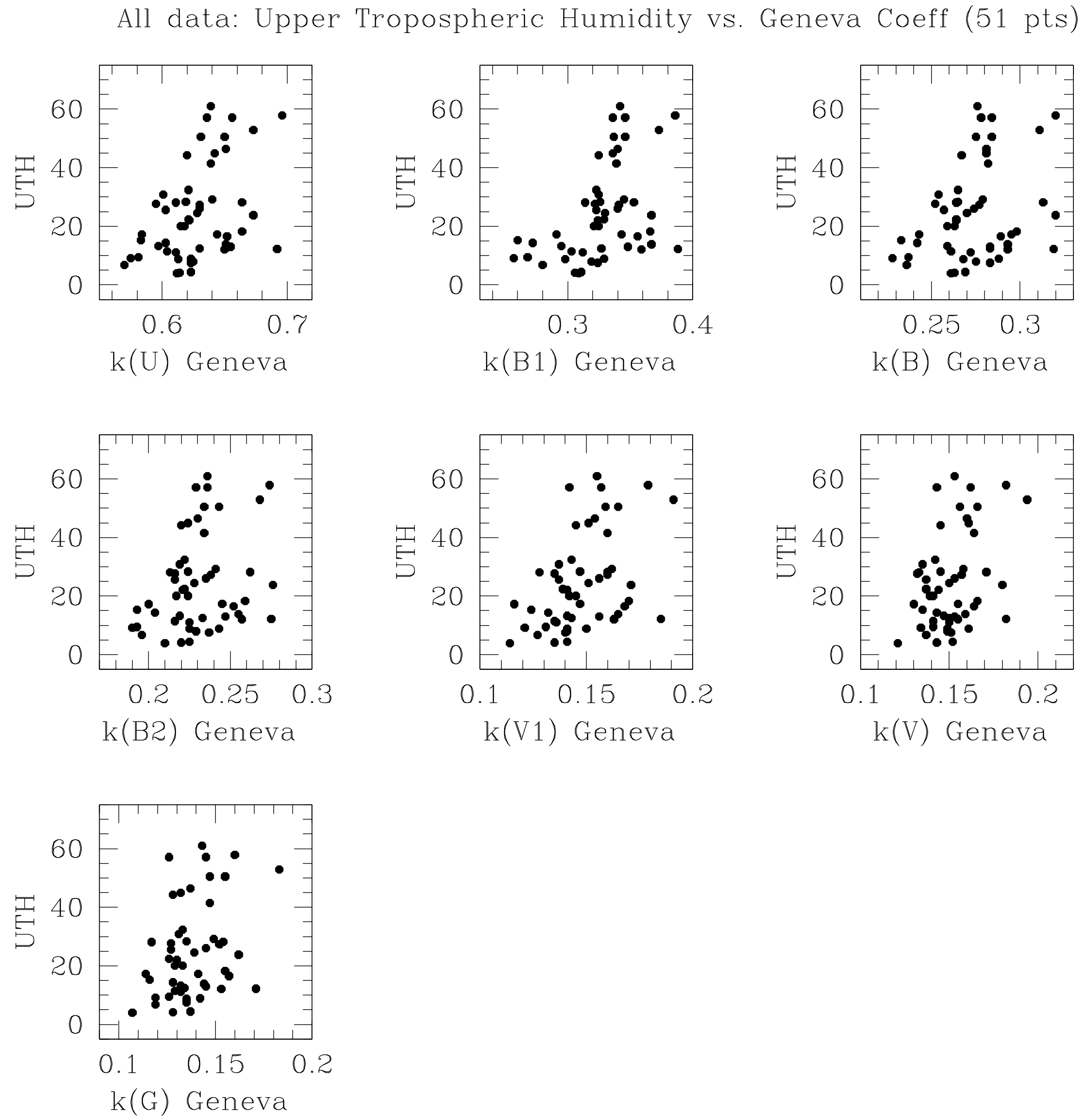

Figure 11: Upper Tropospheric Humidity (UTH) vs. standard deviations of the Geneva photometric extinction coefficients for 51 measurements corresponding to the three periods (June 1993, December 1993, and MArch 1994).