DAYLIGHT CLIMATOLOGY IN ATHENS, GREECE: TYPES OF DIURNAL VARIATION OF ILLUMINANCE LEVELS

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ABSTRACT

In the present work, the diurnal variation of illuminance levels in Athens, Greece, is studied during winter and summer. The database consists of 5-minute values of global horizontal illuminance for the period 1992-1996 (National Observatory of Athens – NOA, 37°58΄N, 23°43΄E). For each season, two sets of data are determined (sunrise-noon, noon-sunset) consisting of the semi-diurnal courses of illuminance anomalies from the mean semi-diurnal course of each day of the year. By using the multivariate statistical methods Factor Analysis and Cluster Analysis, the identification of the most characteristic modes of diurnal variation of global illuminance is attempted. It is found that, 6 types of semi-diurnal courses (sunrise-noon, noon-sunset) of global illuminance are the most characteristic for winter, while for summer, 6 types of courses are found for sunrise-noon and 5 for noon-sunset. Some of these courses present the almost smooth ascending / descending intra-daily variation of illuminance, while others show significant disturbances during various daytime periods, due to development of clouds.

DATA AND METHODOLOGY

THE DATA

1st Step: Quality Control Tests (Table 1) (CIE, 1994).

Table 1: CIE quality control tests for illuminance horizontal measurements

$E_{vg} < 1.2\ E_v$
$E_{vd} < 0.8\ E_v$
$E_{vd} < 1.1\ E_{vg}$
$P_v = E_{vg} - E_{vd} < E_v$
$E_v = E_{vext} \sin\gamma_s$
$E_{vext} = E_{ves}[1+0.034\cos[(2\pi/365)(D-2)]]$
E_{ves} = 133800 lux
E_{vg} = global horizontal illuminance, E_{vd} = diffuse horizontal illuminance, P_v = direct horizontal illuminance, E_v = horizontal extraterrestrial illuminance, E_{ves} = luminous solar constant, D = Julian day, γ_s = solar altitude

2nd Step: Each day is divided in two parts: i) from sunrise to noon and ii) from noon to sunset (True Solar Time - TST) and therefore two independent data sets are created from the available database.

3rd Step: Semi-days with at least 90% availability of the 5-min values are only used.

4th Step: Since the day length is not constant during the year, days with lengths in the range ±10% of that on the winter solstice (22 December) and summer solstice (21 June) are only selected. Thus, new "winter" (6 November – 5 February) and "summer" (20 April – 22 August) periods are formed. After the application of the above criteria and restrictions, the semi-days are reduced to a total of 346 for winter and 830 for summer (more missing data are found in the winter period).

5th Step: Each semi-diurnal variation of global horizontal illuminance is converted to a semi-diurnal variation of anomalies from the mean semi-diurnal variation of the same calendar day (by calculating the difference for each 5-min value). Because of the lack of a very long database, the mean semi-diurnal variation of each calendar day is constructed not only from the days of the same date but also from those within 10 days around it (21 days running period).

6th Step: In order to have the same day-length for all the winter and summer days, a few 5-min values after sunrise and before sunset have been omitted. Thus, in winter the day-length is defined from 9:15 to 15:55 Local Standard Time (LST) and in summer from 7:50 to 17:10 LST.

7th Step: Two matrices of semi-diurnal variations of anomalies of global horizontal illuminance (Sunrise-Noon, S-N, and Noon-Sunset, N-S) for winter, W, and summer, S, are created. The dimensions of the four matrices are: 144 rows (number of semi-days) x 34 columns (number of 5-min values) (W, S-N), 202 x 39 (W, N-S), 407 x 54 (S, S-N) and 423 x 56 (S, N-S).

THE STATISTICAL METHODS USED

The multivariate statistical methods Factor Analysis (FA) and Cluster Analysis (CA) are applied to these data matrices in order to classify the diurnal variation of illuminance levels. At first, FA is applied to the original matrices and then CA to the new matrices consisting of the factor scores derived from FA. FA is used in order to reduce the dimensionality of the data matrices and thus eliminate "noise" (5-6 Factors were retained explaining 85% of the total variance).

A short description of the two methods is given below.

1) The basic idea of **FA** is to describe a set of p correlated variables $X_1, X_2, \ldots, X_p$ in terms of a smaller number m of new uncorrelated variables $F_1, F_2, \ldots, F_m$ (factors). Each of the p initial variables can be expressed as a linear function of those m (m<p) factors, i.e.

$$X_i = \alpha_{i1}F_1 + \alpha_{i2}F_2 + \ldots + \alpha_{im}F_m$$

where $\alpha_{i1}, \alpha_{i2}, \ldots, \alpha_{im}$, are the factor loadings that express the correlation between the initial variables and the new ones (factors).

The values of each factor are called factor scores and they are presented in a standardized form, having zero mean and unit variance (Jolliffe, 1986; Manly, 1986). The number m of the retained factors has to be decided by using various rules (Jollife, 1986; 1993; Overland and Preisendorfer, 1982) and considering the physical interpretation of the results. In this work, factors with variances (eigenvalues) greater than unity (Guttman criterion) are retained. A widely used process in FA is the rotation of axes, which creates new factors with different variances, keeping the cumulative variance of the m factors unaffected. The rotation results in a better separation among the initial variables by maximizing some factor loadings and minimizing some others, thus giving in a better interpretation of the results. There are various types of rotation. In this work the Varimax rotation is used, which keeps the factors uncorrelated (Ritchman, 1986).

2) The objective of **CA** is to group the observations into clusters as homogeneous as possible with respect to the clustering variables (Sharma, 1996). The first step in CA is to select a measure of similarity. For example, in case of m observations with p variables each, a point in a p-dimensional space can represent each observation. Thus, observations close to each other in the p-dimensional space can merge in a cluster. In the present work, the squared Euclidean distance is used as a measure of similarity, that is, the value of this measure for the i^{th} and the j^{th} observations is given by

$$D_{ij}^2 = \sum_{k=1}^{p} (x_{ik} - x_{jk})^2$$

where x_{ik} is the value of the k^{th} variable of the i^{th} observation and x_{jk} is the value of the k^{th} variable of the j^{th} observation. Next, it has to be decided which type of clustering technique shall be used (K-Means or hierarchical). In the present work, the hierarchical technique is used, in which a number of different rules or methods have been suggested for computing distances between two clusters. Here, the Ward's method is used, which does not compute distances between clusters but it forms clusters by maximizing the within-cluster homogeneity. The within-cluster sum of squares is used as the measure of homogeneity. That is, the Ward's method tries to minimize the total within-cluster sums of squares (error sums of squares) (Sharma, 1996).

RESULTS

➢ *Winter*

- ✓ *Time period*: around winter solstice (6/11-5/2)
- ✓ *Number of Clusters*: 6 for both cases (S-N and N-S)

❖ *Sunrise-Noon*

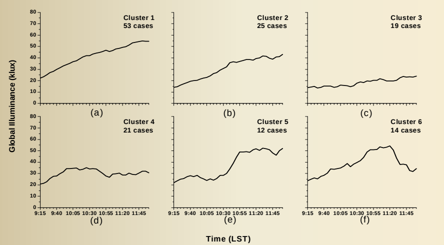

Figure 1. The Clusters of semi-diurnal (Sunrise-Noon) variation of global horizontal illuminance, in Athens, during winter (LST-Local Standard Time).

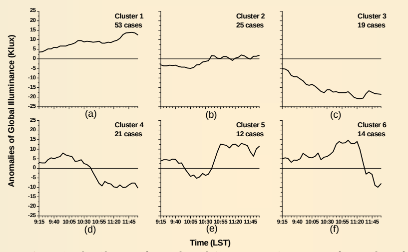

Figure 2. The Clusters of semi-diurnal (Sunrise-Noon) variation of anomalies of global horizontal illuminance, in Athens, during winter (LST-Local Standard Time).

❖ *Noon-Sunset*

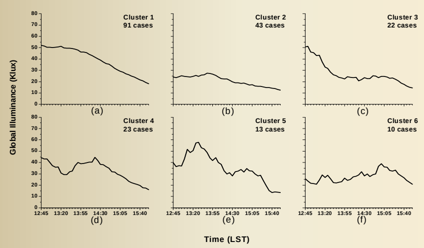

Figure 3. As in Fig. 1, but for Noon-Sunset.

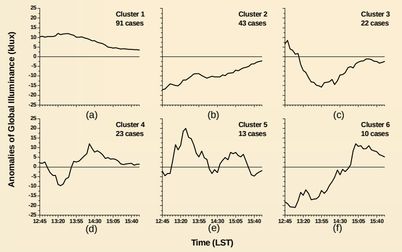

Figure 4. As in Fig. 2, but for Noon-Sunset.

➢ *Summer*

- ✓ *Time period*: around summer solstice (20/4-22/8)
- ✓ *Number of Clusters*: 6 for S-N and 5 for N-S

❖ *Sunrise-Noon*

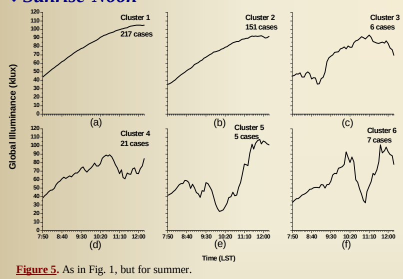

Figure 5. As in Fig. 1, but for summer.

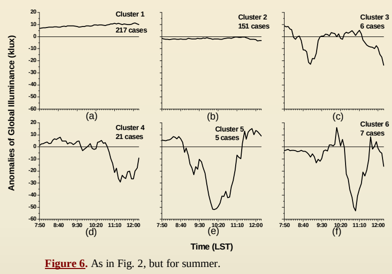

Figure 6. As in Fig. 2, but for summer.

❖ *Noon-Sunset*

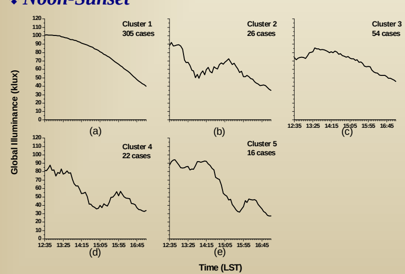

Figure 7. As in Fig. 1, but for summer and Noon-Sunset.

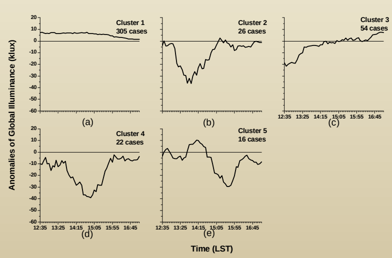

Figure 8. As in Fig. 2, but for summer and Noon-Sunset.

CONCLUSIONS

➢ For both seasons (winter and summer) and both types of semi-days, Sunrise-Noon (S-N) and Noon-Sunset (N-S), the strongest cluster (Cluster 1) comprised the majority of cases characterized by the familiar, almost smooth, ascending or descending course of global illuminance, which corresponded to clear sky conditions (positive anomalies). Moreover, for both types of semi-days (S-N, N-S) of winter and for S-N of summer, other Clusters (Cluster 3, for S-N of winter (Fig. 1c, 2c), Cluster 2, N-S of winter (Fig. 3b, 4b) and S-N of summer (Fig. 5b, 6b)) were also characterized by the same semi-diurnal variation of illuminance but with lower values, corresponding to overcast sky conditions (negative anomalies).

➢ The other four clusters (for both seasons and both types of semi-days) were characterized by fluctuations of the illuminance and an interchange of positive and negative anomalies, in different periods of the day, due to the formation and breakup of clouds. Four Clusters (Clusters 5 & 6 (Fig. 6e, 6f), for S-N and Clusters 2 & 4 (Fig. 8b, 8d), for N-S) of semi-days for summer were noteworthy for their strong negative anomalies. A consultation of the Climatological Bulletin of the National Observatory of Athens during the days classified in these Clusters, revealed that Cu, Ac, Sc, As, Ci clouds were observed and recorded. Thus, it can be argued that the deep minimum observed in the semi-diurnal variations of illuminance around 10:10 LST (Cluster 5, S-N), 11:00 LST (Cluster 6, S-N), 13:50 LST (Cluster 2, N-S) and 14:55 LST (Cluster 4, N-S) was due to cloud formation including clouds of vertical development.

➢ It is important to note that for a more accurate study of the diurnal variation of illuminance, a longer database is necessary so that the anomalies of illuminance are calculated from the mean values of the corresponding calendar day only and not from a running period around it. Furthermore, the records of all the hourly observations of clouds, precipitation and even atmospheric turbidity are required in order to result in more accurate conclusions.

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