

**40 years of Noctilucent Clouds observations near Moscow :
database and simple statistics**

V.A. Romejko, and P.A. Dalin¹

Space Research Institute, Russian Academy of Sciences, Moscow, Russia

N.N. Pertsev

A.M. Oboukhov Institute of Atmospheric Physics, Russian Academy of Sciences, Moscow,
Russia

V.A. Romejko, and P.A. Dalin, Space Research Institute, Russian Academy of Sciences, ul.
Profsojuznaya 84/32, Moscow, GSP-7, 117997, Russia (vitrom@museum.ru; pdalin@iki.rssi.ru)
N.N. Pertsev, A.M.Oboukhov Institute of Atmospheric Physics, Russian Academy of Sciences,
Pyzhevsky per. 3, Moscow, 109017, Russia (meso@omega.ifaran.ru)

¹Now at Swedish Institute of Space Physics, Box 812, SE-981 28 Kiruna, Sweden
(pdalin@irf.se)

Abstract. The observation procedure and relevant database of Moscow (56° N, 37° E) Noctilucent Clouds (NLCs) systematic observations (1962-2001) are described. The long-term series of Moscow NLCs data are analyzed and compared to the observations in Western Europe. Statistical analysis of seasonally averaged parameters of the NLCs is carried out. Characteristic periods in interannual variability of the integral NLCs brightness fluctuation are extracted. Particular attention is paid to decadal (~ 10 years) periodicity in the NLCs occurrence and their brightness. A distinct difference between decadal periodicity in NLCs parameters and solar activity is found and its possible origin is discussed.

1. Introduction

Noctilucent Clouds (NLCs) were observed in Moscow (Russia) for the first time in 1885 by the astronomer W. Ceraski. Some years later many researchers [*Bronshtein and Grishin, 1970*] were engaged in this affair. However, these observations were only unsystematic, sporadic registrations of NLCs, and there was no common program of NLC observations till the middle of the 20-th century. In 1957, NLCs observations began under the programs of the International Geophysical Year and the Quiet Sun Year. A network of sites was created in several regions of the Former Soviet Union and the first catalogues of NLC data were published [*Gromova, 1963; Fast, 1972; Fast, 1980*]. It was the beginning of regular observations of NLCs in several regions of Russia. Now the accumulated data are analyzed. In this paper we describe the procedure of NLCs observations near Moscow during the period from 1962 up to now. We give a review of

the Moscow NLCs database and present some statistical results concerning the NLCs near Moscow.

2. Observations

Since the first days of NLCs discovery and up to now, the visual observations are the most effective method for NLCs systematic study. The NLCs' rather frequent appearance allows observer to be trained quickly and easily during one season. As a rule a trained observer participates in 3-5 NLC seasonal campaigns.

With the adopted technique of visual observations an observer examines the twilight sky every 15 minutes during a night, usually from 11:00 p.m. till 4:00 a.m. LT. The observations of the NLCs are carried out from the end of May to the middle of July (the most favorable period for NLCs occurrence). This technique allows us to create data sets of NLCs parameters with a high temporal resolution.

The following parameters are visually estimated in the case of the NLCs occurrence:

- Date and time of the observation of a twilight sky (local time)
- Time of appearance and disappearance of NLCs
- The brightness of a NLCs field on a five-mark scale
- Morphological forms
- The intensity of the NLCs (its definition is given below).

Besides this, the meteorological conditions for observations are estimated including the area covered by tropospheric clouds (in percentage in the twilight segment of the sky). The estimation of the NLCs' brightness and classification of morphological forms follow the procedure elaborated by *Grishin* [1957]. The intensity (dimensionless), which was introduced by V. Romejko in 1979, provides the most generalized characteristic of the NLCs' field as a whole.

This parameter is the integral value of the brightness and general area of the NLCs field in a twilight sky. Table 1 presents the value of the intensity dependence on the brightness and the NLCs' area.

Table 1.

After an observation the results are to be filled in a table of standard form containing the following parameters:

- Date;
- Maximal brightness of the NLCs during the night, marks;
- "Integral brightness", marks - the sum of all the 15 minute estimations of NLCs' brightness,

in effect it is the integral of brightness over time;

- Registered morphological forms;
- Time of the beginning and the end of NLCs visibility;
- Duration of NLCs visibility;
- Maximal value of intensity;
- Weather conditions.

For treatment of the obtained data we have chosen an integral brightness as the single parameter, best describing the level of NLCs activity during each night, because it represents both the level of brightness of NLCs and duration of their visibility.

3. Available database

This chapter is devoted to the NLCs database, which is the property of Moscow group of NLCs observers. Most of the database contains the observations near Moscow ($\varphi=56^\circ$, $\lambda=37^\circ$),

although there are also NLCs observations in some other regions of Russia [*Romejko et al.*, in press]. Only the observations near Moscow will be considered below.

Although the long-term observations began in 1950 [*Grishin*, 1952], uniformly organized data of the same value were made since 1962. For all of that period the technique of visual observations including brightness estimation and morphological classification of NLCs has been kept without change. Uniform style of observations and scripts has been ensured by the supervision of N. Grishin (before 1969) and V. Romejko (since 1969) [*Romejko*, 1989]. This database is unequalled in the world regarding total duration, quantity of the observations and volume of accompanying information. The total number of observations made every 15 minutes is more than 26,800 i.e. more than 1340 duty nights during 6700 hours. The occurrence number of NLCs for this period (1962-2001) is 426 and the total duration of the NLCs visibility is 830 hours. It is necessary to note that the technique of visual observations including the brightness estimation and also the morphological form classification did not change from 1962 until the present.

The database contains not only filled tables but also photographs, video materials and theodolite surveys, accompanied some NLCs observations. We are planning to transform them to a digital form. Photo- and videoimages are very helpful for more accurate detection of NLC morphological forms and investigations of NLCs spatial – temporal structure.

At present, the electronic version of the database contains only the information, summarized over every night: the values of maximal brightness of the NLCs, integral brightness, NLCs morphological forms, the time of the beginning and the end of twilight sky observations, the duration of NLCs visibility and the meteorological conditions. This database essentially differs from West Europe published catalogues [e.g., *McIntosh and Hallissey*, 1974], which include the

diverse notes of the observers instead of precise estimations of the morphological form classification and meteorological conditions. Particularly, the West Europe databases do not include the cases of the NLCs absence at good weather, which is extremely important for correct statistical analysis.

4. Statistical analysis and its results

In spite of the fact that many papers [e.g., *Willmann*, 1970; *Gadsden*, 1998; *Sugiyama*, 1998] were devoted to NLCs statistics and revealed the important statistical properties of NLCs occurrences, all of them have the following shortcomings:

- Rather short data sets (less than for two solar cycles) are subjected to the statistical analysis;
- Diverse data received by different techniques are treated.

Besides, many databases don't describe carefully the weather conditions and missing observations which results inevitably in the distortion of NLCs statistics due to unexplored statistics of the clear-weather nights. The Moscow database, although having a natural territorial restriction, is free from the defects mentioned above.

We provide here only the first part of a statistical analysis, examining annual variability of the seasonally averaged parameters of the NLCs. For this we calculated the seasonally averaged NLC parameters. Although the database contains 10 cases of NLCs appearance before May 24-25 or after July 24-25, we did not include such unusual observations into the statistics for better uniformity of the NLCs analysed data restricting our analysis by “the season” of bimonth duration between these two dates. In this case we have 35 duty nights per season in average with

slight variations from year to year and with the best concentration in late June and early July. For every NLCs season the following seasonally averaged parameters were calculated:

s_1 - the number of nights with NLCs occurrence;

s_2 - the integral brightness, accumulated for the whole season;

s_3 - the number of clear-weather nights;

s_4 - the number of semi-clear-weather nights.

The data sets of s_1 , s_2 , $s_3 + s_4$ are presented in Figures 1, 2. The curves of solar radioemission index $F_{10.7}$ (averaged over June and July) and the number of nights with NLC

Figure 1.

Figure 2.

occurrence in North-West Europe [Gadsden, 1998] are given too. We can see from Figure 2 that the numbers of NLCs occurrences in North-West Europe and in Moscow are correlated well.

The values of s_1 and s_2 characterize not only NLCs activity as they depend also on the weather conditions for the season; this is well manifested in Figures 1, 2. That is why two new values (influenced by weather conditions to a much lesser degree) were analyzed:

$$s_5 = \frac{s_1}{s_3 + s_4}$$

- the estimation of probability of the NLCs occurrence in clear or semi-clear night;

$$s_6 = \frac{s_2}{s_3 + s_4}$$

- the normalized integral NLCs brightness, i.e. average integral brightness during a clear or semi-clear night.

Note that average integral brightness is normalized by the number of clear and semi-clear nights, but not by the number of nights with the NLCs occurrence.

Then the main question arises what physical processes govern $s_5(t)$ and $s_6(t)$. To approach the answer we use cross-correlation analysis, which allowed us to estimate the mutual influence of the two processes ($x_1(t)$, $x_2(t)$). This analysis is based on the cross-correlation

$$CCF(l) = \frac{\overline{(x_1(t) - \bar{x}_1) \cdot (x_2(t+l) - \bar{x}_2)}}{(\sigma(x_1) \cdot \sigma(x_2))^{\frac{1}{2}}}$$

and on the autocorrelation

$$ACF(l) = \frac{\overline{(x_1(t) - \bar{x}_1) \cdot (x_1(t+l) - \bar{x}_1)}}{\sigma(x_1)}$$

functions where the overline means a time averaging, and σ is the variance of time series [Jenkins and Watts, 1968]. The autocorrelation functions are defined for each of two data series.

Figure 3 presents the autocorrelation function for the normalized integral brightness of the NLCs. It is clearly seen that the basic characteristic period is about 10 years. The autocorrelation function for $F_{10.7}$ is shown in this figure for the comparison. Since several papers were devoted to the correlation of NLCs occurrences with the solar activity [e.g., Gadsden, 1998], in this paper

the correlation of seasonally averaged characteristics of the NLCs with the solar activity is also studied based for the much longer data series. The phase shifts between two quasi-periodic processes are often revealed using cross-correlation functions. Figure 4 presents the cross-correlation functions for three pairs of processes: s_1 and $F_{10.7}$, $s_3 + s_4$ and $F_{10.7}$, s_5 and $F_{10.7}$. The probability of significant correlation for cross-correlation maxima of the first and third pairs is not less than 0.98 and about 0.83 for the second pairs. It is interesting that all three cross-correlation functions show similar features, namely, the correlation with periodicity of about 10 years. In particular, the phase of all three processes are 2-4 years ahead of $F_{10.7}$ (or, equivalently, 6-9 years behind of $F_{10.7}$).

Figure 3.

Figure 4.

We may also see that the correlation of s_1 and $F_{10.7}$ is a result of interference between correlations $s_3 + s_4$ and $F_{10.7}$ and s_5 and $F_{10.7}$. However, the curves for s_1 and $F_{10.7}$, s_5 and $F_{10.7}$ are obviously closer to each other, than to the third curve. So we may conclude that the weather influence on the correlation of NLCs' occurrence and $F_{10.7}$ is not so strong. It is interesting that *Gadsden* [1990,1998] found the same phase shift in the number of nights with NLCs occurrence in West Europe with respect to the solar activity. Although the West Europe data do not allow to distinguish the processes s_1 and s_5 , the coincidence between the behaviour of number of nights with NLCs in West Europe and in Moscow with respect to the solar activity makes it clear that the yearly variability of the NLC activity is governed by continental or hemisphere scale dynamic processes, but not local-geographical ones. Weather conditions surely affect the observed NLCs activity, but the correlation of this effect with the solar activity is not evident.

Thus the decadal periodicity in the number of the NLCs occurrences is determined by the same period of the probability of the NLCs' occurrence for both clear and semi-clear nights (s_5) and, less substantially, by the periodicity of the number of these nights ($s_3 + s_4$). How can we estimate statistical reliability of such conclusions? Whether a correlation of solar activity with the specified processes really exists or these processes have random amplitudes at the solar activity frequency, thereby demonstrating a correlation (with random phase shift)?

To answer this question the technique of random permutation of numbers (RPN) was used for all time series except for $F_{10.7}$. If the RPN does not reduce essentially the absolute value of the cross-correlation function it means that the correlation is random. In the opposite case, if the value of cross-correlation function is attenuated strongly after the RPN procedure it means that two processes are connected to each other by direct or indirect connection with the probability close to unity.

The patterns of a typical RPN test for the correlation of s_5 and s_6 with $F_{10.7}$ are shown in Figures 5 and 6. In the both cases the RPN transform doesn't change the order of CCF amplitude with decadal periodicity and shifts randomly (from one RPN transform to another one) the CCF phase. Very small part of RPN transforms may occasionally amplify or attenuate the CCF amplitude; in [Romejko *et al.*, in press] a pattern of essentially decreased CCF amplitude and a loss of the quasiperiodic behaviour after an RPN was given. The results based on many RPN transforms show that a contribution of the solar cycle to the decadal variability of s_5 (probability of NLCs appearance in clear or semi-clear night) and s_6 (normalized integral NLCs brightness) is negligible. However, careful examination of Figures 5, 6 and of many similar results with other RPN patterns gives one more conclusion: the cross-correlation

functions between $F_{10.7}$ and the randomly permuted values of s_5 , or of s_6 , almost always have a periodicity with slightly (but distinctly) lower frequency than those before the permutation. The corresponding period for the CCF after the RPN procedure appears to be equal to the main period for $F_{10.7}$ that is about 10.5 years, and the one for the situation before the RPN is about 1 year less. This aftermath may be proved also by the autocorrelation functions. In Figure 3 it may be clearly seen that the periodicity for $F_{10.7}$ ACF has a slightly larger period than one for s_6 ACF. The least-squares method applied to correlation functions allows us to extract the main sinusoids for $s_1 \div s_6$ ACF. Relevant periods are listed in Table 2. From the obtained results we may conclude that the series s_5

Table 2.

and s_6 for seasonally averaged NLCs parameters contain a periodicity with the main frequency slightly higher than that for the solar activity. That is why the random numbers are

Figure 5.

Figure 6.

slightly correlated with $F_{10.7}$ at the solar activity frequency and random phase; and the small correlation is also observed between s_5 or s_6 with $F_{10.7}$ at some intermediate frequency for these two processes, caused by weak mutual resonance at the wings of the relevant spectral lines. The values of period, listed in Table 2, slightly differ from those found in [Romejko *et al.*, in press]. This arises because of a slight change in time series $s_1 \div s_6$: in this paper the 2001 year values have been added, and the limits for NLCs seasons, as described above, have been established. The comparison shows that these changes are not substantial.

The s_6 series reveals the most distinct decadal periodicity among all the considered series $s_1 \div s_6$. Not only the frequency difference but also a lag of s_6 behind $F_{10.7}$ leads to some doubts on the existence of a direct solar activity effect on the NLCs. Figures 4-6 demonstrate that the minima of s_5 and s_6 delay after the maxima of $F_{10.7}$ by about 1 year, and that for s_1 the delay is even greater.

Now we consider the temporal dynamics for the number of NLCs occurrences (s_1). The least squares method gives a period of 10.8 ± 0.2 years for the s_1 time series (see Table 2); although this period is very close to the solar activity period, it may be the result of poor frequency sensitivity when a wave of 9.4 years period for s_5 is superposed on a 12.5 years wave for $s_3 + s_4$, since $s_1 = s_5 \cdot (s_3 + s_4)$.

Very similar expression may be written for seasonally accumulated brightness. We do not deny a possibility of beats in the system NLCs – solar activity, however, much longer time series are required for their extraction.

Another interesting feature of interannual variability of NLCs parameters is an existence of strong harmonics with periods of 2-5 years, contrasting to the absence of these in solar activity indices. It is well seen for s_6 and $F_{10.7}$ ACF, see Figure 3. These oscillations may be caused either by combined oscillations, arising from quasi-decadal oscillations, or by generation of higher harmonics in the decadal variations. However it is more natural to expect some other influences, not connected with the decadal variations.

As to the oscillations with 9-9.5 years period in NLCs parameters, they may be caused by some indirect influence of solar activity with periodicity, distorted or masked by other processes. Besides, such periods may arise, from our opinion, on the one hand, in the auto-oscillations in the

atmosphere-ocean system [*Handorf et al.*, 1999], and on the other hand, in the periodic variations in the Earth-Moon gravitational system [*Kropotkina and Shefov*, 1976]. In future we will analyze the correlation between various NLCs parameters and parameters of the Moon's motion.

5. Conclusions

NLCs near Moscow (56° N, 37° E) have been observed by stable techniques almost every summer season for 40 years (1962-2001). Some conclusions, obtained from the analysis of these observations are summarized as follows:

1. The number of nights with NLC occurrence was a basic value used in previous statistical investigations. It has some shortcomings, which do not allow to extract the correct geophysical information from the time series of this parameter. In this paper some more important parameters for NLCs were introduced and their time series were analyzed.

2. The main seasonally accumulated parameters of NLC activity vary quasiperiodically with a period of about 10 years. Besides, NLCs time series contain also distinct quasiperiodic variations with periods of 2-5 years, unlike the interannual variations of solar index $F_{10.7}$.

3. The correlation analysis between the seasonally averaged characteristics of NLCs and the solar activity index $F_{10.7}$ is carried out. The strongest correlation is observed between the normalized integral NLCs brightness for a season and the solar activity index $F_{10.7}$ averaged for June and July. The corresponding cross-correlation function has a decadal periodicity and the analyzed processes are almost in antiphase (minimum of the brightness lags behind about 1 year after the maximum of the solar activity).

4. However, tests for statistical reliability do not allow to distinguish unambiguously the found correlation from a random one. Besides, careful analysis shows that periods for NLCs

characteristics are 1-1.5 years less than the period of 10.5 years for $F_{10.7}$. Thus, the decadal periodicity in NLCs parameters appears to be of another origin than direct influence of solar activity. The antiphase behavior of normalized integral NLCs seasonal brightness and $F_{10.7}$ value can change in other epochs.

5. The similar properties of decadal variability for the number of NLC occurrences in Moscow and in North-West Europe suggest that NLCs decadal variability is controlled by continental or hemisphere scale dynamic processes but not by local-geographical ones.

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References

- Bronshtein, V. A., and N. I. Grishin, *Noctilucent Clouds* (in Russian), 359 pp., Nauka. Moscow. 1970.
- Fast, N. P., *The catalogue of observations of noctilucent clouds by world data*, (in Russian), 194 pp., Tomskiy Universitet, Tomsk, 1972.
- Fast, N. P., *The catalogue of observations of noctilucent clouds by world data*, (in Russian), 101 pp., Tomskiy Universitet, Tomsk, 1980.
- Gadsden, M., A secular change in Noctilucent clouds occurrence, *J. Atmos. Terr. Physics*, 52, 247-251, 1990.
- Gadsden, M., The North-West Europe data on Noctilucent clouds: a survey, *J. Atmos. Solar-Terr. Physics*, 60, 1163-1174, 1998.
- Grishin, N. I., Noctilucent clouds in 1950-1951, (in Russian), *Meteorologiya i Gidrologiya*, 6, 22-26, 1952.
- Grishin, N. I., *Instructions for noctilucent cloud observations*, (in Russian), 23 pp., Izdatelstvo Akad. Nauk SSSR, Moscow, 1957.
- Gromova, L. F., Catalogue of observations of noctilucent clouds on the territory of our country for 1889 – 1956, (in Russian), *Issledovaniya po klimatologii serebristyh oblakov. Meteorologiya*, 6, 64-83, Izdatelstvo Akad. Nauk SSSR, Moscow, 1963.
- Handorf, D., V. K. Petoukhov, K. Dethloff, A. V. Eliseev, A. Weisheimer, and I. I. Mokhov, Decadal climate variability in a coupled atmosphere-ocean climate model of moderate complexity, *J. Geophys. Res.*, 104, 27253-27275, 1999.
- Jenkins, G. M., and D. G. Watts, *Spectral analysis and its applications*, 604 pp., Holden-Day, San Francisco, 1968.

- Kropotkina, Ye. P., and N. N. Shefov, Influence of lunar tides on the probability of appearance of noctilucent clouds, *Izv. Acad. Sci. USSR Atmos. Oceanic Phys.*, Engl Transl., *11*, 741-742, 1976.
- McIntosh, D. H., and M. Hallissey, Noctilucent clouds over Western Europe during 1973, *Meteorol. Mag.*, *103*, 157-160, 1974 .
- Romejko, V. A., Noctilucent cloud observations in USSR, (in Russian), *Katalog dannyh*, 9-25, Mezhdoved. Geofiz. Komitet, Moscow, 1989.
- Romejko, V. A., N. N. Pertsev, and P.A. Dalin, Long-term observations of Noctilucent clouds in Moscow: the database and statistical analysis, (in Russian), *Geomagnetizm i Aeronomiya*, *42*, in press.
- Sugiyama, T., Statistical study of Noctilucent cloud occurrence in Western Europe, *Proc. NIPR Symp. Upper Atmos. Phys.*, *11*, 81-87, 1998.
- Willmann, Ch. I., On the spatial-temporal characteristic of the noctilucent cloud occurrence, (in Russian), *Fizika mezosfernyh (serebristyh) oblakov. Trudy soveshchaniya po mezosfernym oblakam (Riga, 1968)*. 103-113, Riga, Zinatne, 1970.

Figure captions

Figure 1. Time series: s_2 – seasonally accumulated NLC integral brightness, marks (solid line with black circles), and $F_{10.7}$ – solar radioflux index, $10^{-22} \text{ Wm}^{-2} \text{ Hz}^{-1}$, averaged over June + July (dotted line with open circles).

Figure 2. Total number of nights within a season : with NLC in North-West Europe [Gadsden, 1998] (triangles), s_1 - with NLC near Moscow (black circles), $s_3 + s_4$ - with clear or semi-clear sky near Moscow (open circles).

Figure 3. Autocorrelation functions for s_6 (normed integral brightness, solid) and $F_{10.7}$ (averaged solar radioflux index, dotted).

Figure 4. Cross-correlation functions for the three pairs of processes: $F_{10.7}$ & s_1 (solid thick line), $F_{10.7}$ & $s_3 + s_4$ (solid thin line), $F_{10.7}$ & s_5 (dotted line).

Figure 5. Cross-correlation function for solar activity index $F_{10.7}$ and probability of NLCs appearance in clear or semi-clear night s_5 (solid line); a typical pattern of RPN test for $F_{10.7}$ and randomly permuted s_5 (dotted line).

Figure 6. As in Figure 5 but for s_6 instead of s_5 .

Tables

Table 1. The definition of “intensity” depending on the brightness (rows) and area (columns) of the NLCs.

A	S	1/4	1/3	1/2	2/3	3/4	1	M
B								
0.5	1	1	2	3	3	4	-	-
1.0	1	2	2	3	3	4	5	-
2.0	2	3	3	4	4	5	6	6
2.5	2	3	4	5	5	6	7	7
3.0	3	4	4	5	6	6	8	8
3.5	3	4	5	6	7	7	8	9
4.0	4	5	5	6	7	7	9	10
5.0	4	5	6	7	8	8	10	10

B - The NLCs brightness by the five-mark scale

A - The area ratio (NLCs field) / (twilight part of sky)

S – to be applied if only fragments of the NLCs are seen

M – to be applied if multilayered NLCs are seen

Table 2. The periods, found through the extracting of main sinusoids from the autocorrelation functions for different time series by least square method.

Time	$F_{10.7}$	s_1	s_2	$s_3 + s_4$	s_5	s_6
Series						
Period,	10.4	10.8	11.3	12.5	9.4	9.0
Years	± 0.2	± 0.2	± 0.4	± 0.5	± 0.2	± 0.1

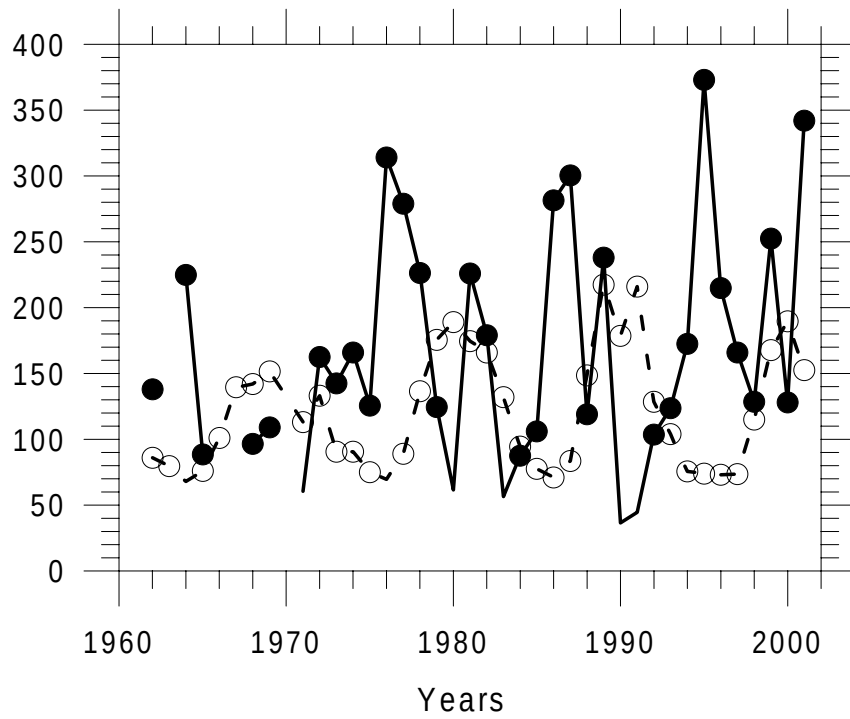


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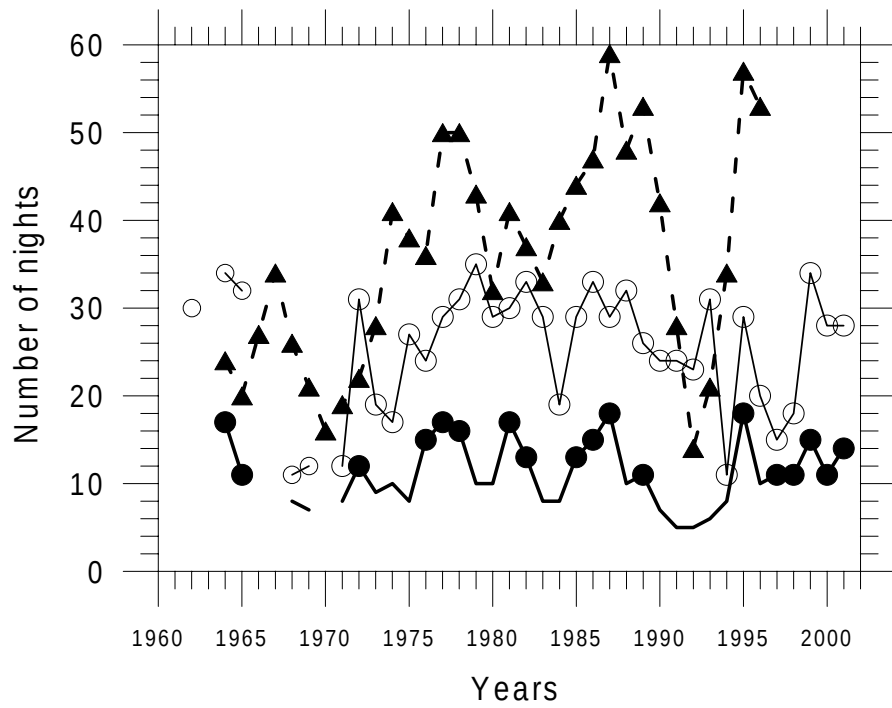


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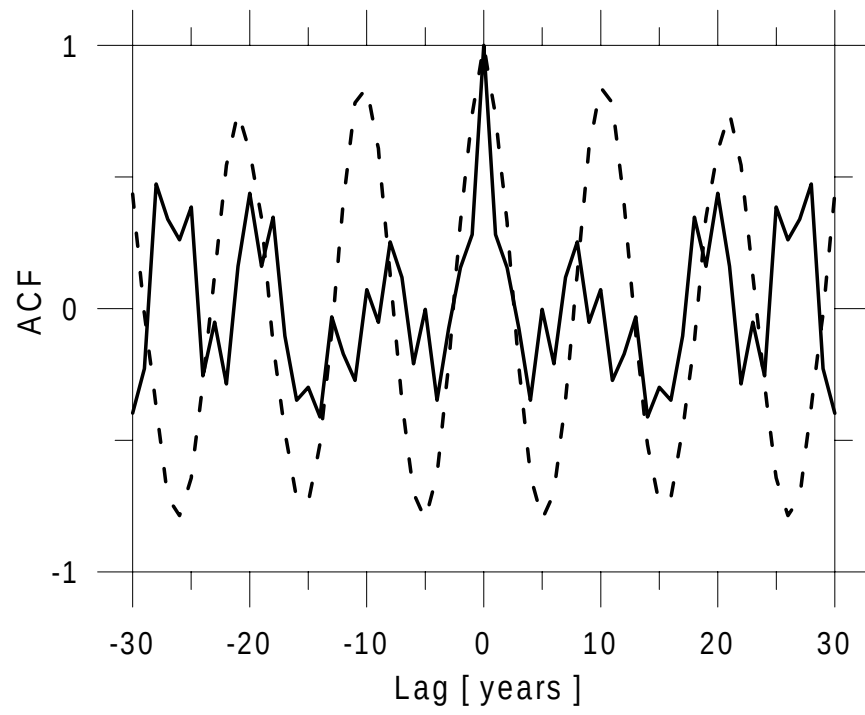


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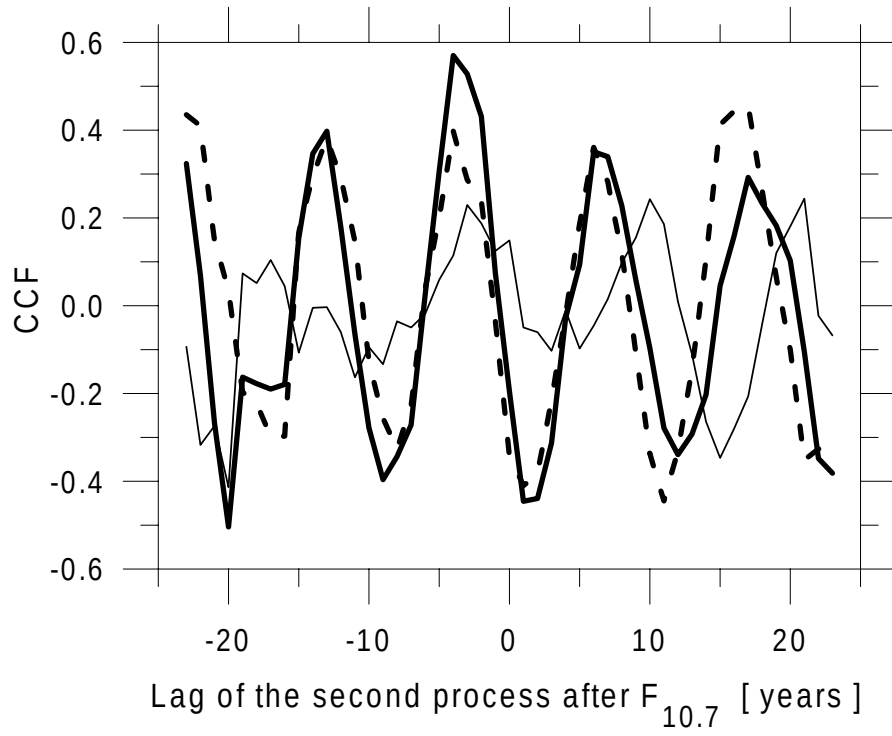


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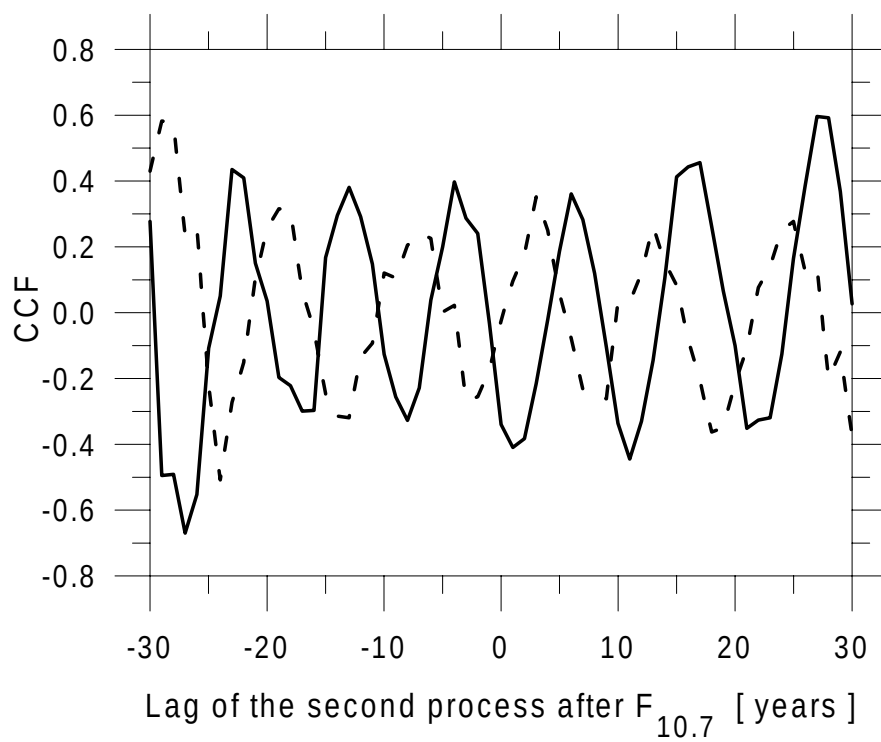


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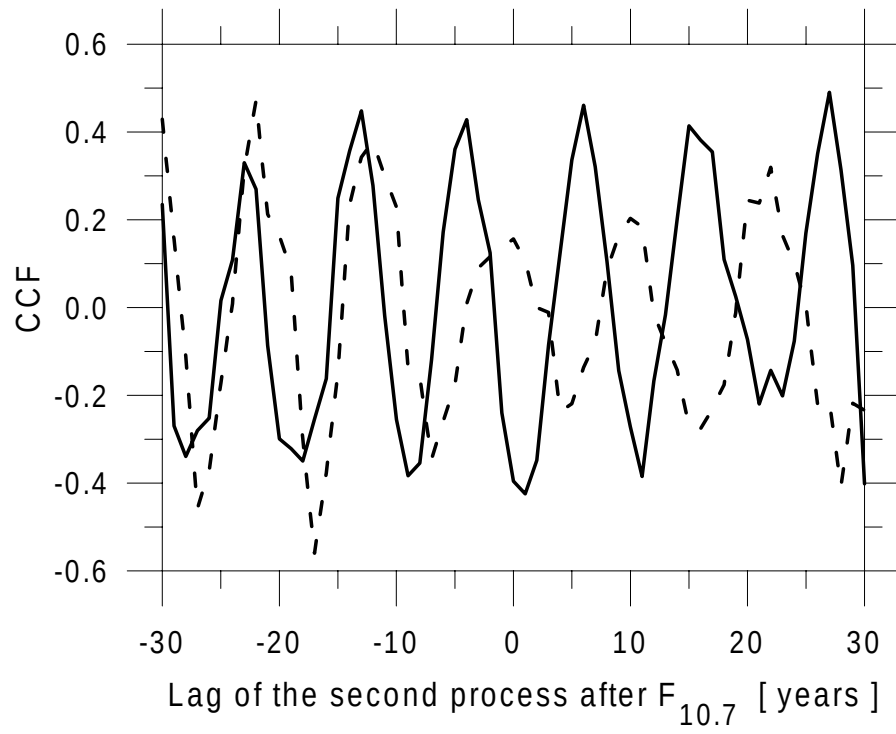


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