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# PROBABILITIES OF SUNSHINE HOURS ACCUMULATED OVER PERIODS OF $2 \leq N \leq 31$ CONSECUTIVE DAYS

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## Summary

Daily, monthly, and yearly totals or averages may give a first orientation on sunshine conditions. A survey is of course much more detailed and extensive, if the complete frequency distribution of the total amount of sunshine hours for periods of arbitrary length is available. Such data are useful with respect to many problems of planning, like energy storage, heating and air-conditioning design, recreation and tourism, water supply etc.

The present study includes about 30 Swiss stations recording sunshine with data of at least 12, many of them of 30 and more years. For each month, frequencies of 1, 5, 10, 20, ..., 90, 95, and 99 % of the 1 day total, as well as of totals summed up over $2 \leq N \leq 31$ (or 28, 29, 30) consecutive days, were computed and plotted graphically. For all N-day runs the counting-out of frequencies was equally based on 31 (or 28, 29, 30) cases per calendar year, by adding the last $(N-1)/2$ (for odd N) or $N/2$ (for even N) days belonging to the preceding month, as well as the first $(N-1)/2$ (for odd N) or $(N-2)/2$ (for even N) days belonging to the succeeding month, respectively.

Regional and seasonal differences, the dependence on altitude a.s.l., and other features of the frequency structures are examined. Limiting the computations to days having sunshine during at least 1, 2, or more hours with or without interruption respectively, further analysis of the frequency distributions are made. By successively including 5, 10, ... 70 years of records in the data processing, the effect of the length of the period of observation is studied.

## Zusammenfassung

Eine erste Orientierung über die Sonnenscheinverhältnisse lässt sich aufgrund von Tages-, Monats- und Jahressummen oder -Mittelwerten der Sonnenscheindauer gewinnen. Die volle Häufigkeitsverteilung der Sonnenscheinstunden über beliebig lange Zeitfolgen vermittelt natürlich eine wesentlich feinere Information. Solche Angaben sind bei Planungsfragen verschiedener Art wie Energiespeicherung, Heizungs- und Klimatisationsplanung, Erholung und Tourismus, Wasserwirtschaft u.a.m. von Nutzen.

Die Untersuchung umfasst etwa 30 Schweizer Stationen mit mindestens 12, in vielen Fällen 30 und mehr Jahren Sonnenscheinbeobachtungen. Es wurden für das Tagestotal, sowie die über $2 \leq N \leq 31$ (bzw. 28, 29, 30) aufeinanderfolgenden Tage aufsummierten Totale die Häufigkeiten von 1,5, 10, 20, ..., 90, 95 und 99 % monatsweise errechnet und aufgezeichnet. Indem für ungerade N die letzten (N-1)/2 Tage des Vormonats und die ersten (N-1.)2 Tage des darauffolgenden Monats, bzw. für geradzahlige N die letzten N/2 Tage des Vormonats und die ersten (N-2)/2 Tage des darauffolgenden Monats in die Berechnungen jeweils miteinbezogen wurden, konnten die Häufigkeiten für alle N-Tage-Folgen durchwegs aufgrund von 31 (28, 29, 30) Fällen pro Jahr ausgezählt werden.

Unterschiede in den Verteilungskurven für verschiedene Stationen und Jahreszeiten, die Abhängigkeit von der Meereshöhe und andere Eigenschaften der Häufigkeitsverteilungen wurden untersucht. Bei einer weiteren Analyse wurde die Häufigkeitsauszählung nur auf Tage von mindestens 1, 2 usw. Stunden Sonnenscheindauer mit, bzw. ohne Unterbruch beschränkt. Der Einfluss des Datenumfanges auf die Ergebnisse wurde durch die sukzessive Ausdehnung der Rechenprozedur auf 5, 10, ..., 70-jährige Beobachtungsreihen untersucht.



## Résumé

Les totaux quotidiens, mensuels et annuels ainsi que les moyennes effectuées sur ces périodes peuvent donner une première orientation sur les conditions d'ensoleillement. Une étude sera bien entendu beaucoup plus détaillée et extensive si l'on a à sa disposition le spectre complet des fréquences du montant total des heures d'ensoleillement pour des durées de longueur arbitraire. De telles données sont utiles quant aux nombreux problèmes de planning,

tels le stockage d'énergie, les systèmes de chauffage et d'air conditioné, les loisirs et le tourisme, les réserves d'eau etc.

L'étude ci-présente comprend les enregistrements de l'ensoleillement pour environ 30 stations suisses avec des valeurs s'étendant sur au moins 12 années et dans bien des cas sur 30 ans ou plus. Pour chaque mois, les fréquences de 1, 5, 10, 20, ..., 90, 95 et 99 % du total journalier ainsi que des totaux additionés sur $2 \leq N \leq 31$ jours consécutifs (ou 28, 29, 30 jours) ont été calculées et représentées graphiquement. Pour toutes les expériences s'étendant sur N jours, le compte des fréquences a été basé de façon égale sur 31 cas par année du calendrier (ou 28, 29, 30 cas), ceci en additionant respectivement les derniers (N-1)/2 jours (pour N impairs) ou N/2 jours (pour N pairs) appartenant au mois précédent ainsi que les premiers (N-1)/2 jours (pour N impair) ou N/2 jours (pour N pair) appartenant au mois suivant.

Les différences régionales ou saisonnières, la dépendance de l'altitude au dessus du niveau de la mer ainsi que d'autres caractéristiques de la structure des fréquences sont étudiées. De plus amples analyses de la distribution des fréquences sont effectuées en limitant les calculs aux jours où le soleil apparaît au moins pendant 1 heure, 2 heures ou plus, respectivement avec ou sans interruption. En ajoutant successivement 5, 10, ...,70 années d'enregistrement dans le traitement des données, l'effet de la longueur de la période d'observation est aussi pris en considération.

When considering data on the duration of sunshine and in view of problems of planning, frequencies of sunshine hours over sequences of days of different length were computed. Figure 1 shows the result of these computations in the case of two stations in Switzerland, for Lugano, on the southern side of the Alps, and for Zurich, north of the Alps.

The figure shows cumulative frequency curves of sunshine hours of 1, 5, 10, 20, ... , 90, 95 and 99 % aggregated over 1, 2, ... , 30 (28, 29 or 31) consecutive days.

The curves above are valid for July, those below for December. For example, one wants to spend a fortnight's holiday in Lugano in July. In this case, there is only 1 % probability for 160 hours of sunshine, but one may be almost completely sure, considering 99 % probability, that the sun will shine some 80 hours in total.

The meteorologist can, of course, present only frequencies, but the user of the information will interprete them as probabilities. It depends on the amount of data, whether this interpretation is permitted or not; we will come back to this question later. The curves of Fig. 1 were computed by using 70 years of records of daily sunshine totals. The period of consecutive days, measured on the horizontal scale, indicate periods lying arbitrarily within the month considered. A period of five consecutive days, for instance, may cover days between the 1st and the 5th, the 2nd and the 6th of the month, and so on. Obviously, the longer the period, the less the amount of cases available for counting out the frequencies. To avoid this and to base the computations equally on the same number of cases (= days a month), independently of the length of the N-day runs, a necessary amount of days were "stolen" both from the preceding and the succeeding months. When counting the frequencies of sunshine totals over 20 consecutive days in July, for instance, all 31 periods, starting with that between June 21th and July 10th, shifted over day by day till the last between July 21th and August 9th, were taken into account.

In comparison to this continuous information, earlier tables of conventional climatology contain usually mean monthly totals or, sometimes, also extremes, these representing only single points or perhaps a line in this diagram.

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Such frequency diagrams were plotted for each month separately for about 30 stations. In this way, several comparisons may be made between curves representing different seasons or different climatic regions.

As an example, let's consider 1 and 99 % curves for July for four stations (Fig. 2); among these, Lugáno has the most stable sunshine conditions while Säntis, lying 2500 m a.s.l. shows the highest relative variability.

The next figure (Fig. 3) is valid for December showing again 1 and 99 % frequencies; the mountain station Säntis may receive 200 hours of sunshine a month while Zurich is the poorest in sunny hours.

- - -

In the figures shown till now, the counting out of frequencies were extended over all available minutes of sunshine. In many respects, however, the user is not interested in days having sunshine only in short time-intervalls interrupted by repeated cloudy periods. On the occasion of the international comparisons of pyrheliometers, for instance, it is useful to select a period of consecutive days showing a high probability for receiving sunshine at least during three uninterrupted hours. For such and similar purposes, days were divided in seven different categories (Table 1):

| Type Number | Limits | | | | | |
|---|---|---|---|---|---|---|
| 0 | no restriction | | | | | |
| 1 | at least | | 1 hour | of sunshine a day | | |
| 2 | " | " | 2 hours | " | " | " |
| 3 | " | " | 2 continuous hours | " | " | " |
| 4 | " | " | 4 hours | " | " | " |
| 5 | " | " | 4 continuous hours | " | " | " |
| 6 | " | " | 8 hours | " | " | " |
| 7 | " | " | 12 hours | " | " | " |

Table 1. Criteria for typifing frequency distributions of sunshine hours.

Type 3, for instance, means that daily totals of sunshine were taken into account only if on the respective day the sun was shining at least during two hours without interruption. It may be seen that each type (almost always) involves cases belonging to all types of lower order.

Fig. 4 shows the frequency structure of sunshine hours for Neuchâtel, in January, fulfilling the restriction according to type 3. Characteristic are the wide range between the extreme frequencies and the irregularities in the lapse of the curves as a consequence of the small number of cases fulfilling the restriction.

Fig. 5 compares the extreme frequencies of all seven types for Lugano in June. As may be seen, 1 % curves don't differ much from each other, since high values of sunshine totals occur anyhow on beautiful days, but the more severe the restriction, the wider the range of scattering.

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The relatively wide range of scattering, as well as the irregularities in the lapse of some curves, indicate that the number of years of observation must be high anough to guarantee reliable results. This is especially valid, when considering winter months or distributions of higher type order.

Fig. 6 shows the diminution of the number of days with increasing type number, for different months in Basel. Even in July, only 20 % of all sunny days receive 12 hours or more sunshine. During winter time, until April, there are no days fulfilling the above restriction. The annual variation of cloudiness shows up clearly when considering the number of days belonging to the same type number.

Finally let's consider a check of results, when successively including 10, 20, 30, ... 70 years of records in the data processing. In doing this, the assumption is made that if the observation periods were to be infinitely long, the long range climatological law would appear and this would produce completely smooth curves in all cases. Consequently the shorter the observation period, the rougher the curves will be.

Let's measure this roughness of the curves. Denoting with $S_N$ the total of sunshine hours of P % probability during N consecutive days, we successively compute the means

$$\bar{S}_N = \frac{\frac{S_{N-1} + S_N}{2} + \frac{S_N + S_{N+1}}{2}}{2}$$

for all N-days runs between N=2 and $N_{max} - 1$ ($N_{max}$ indicating the total number of days a month) and sum up the deviation squares

$$\Delta S_N^2 = (S_N - \bar{S}_N)^2$$

over all values of N as well as over all P percentages between 1 and 99 %:

$$\sum_{P=1}^{P=99} \sum_{N=2}^{N_{max}-1} \Delta S_N^2$$

The smaller these sums, the smoother the curves, the more reliable the results. Obviously these totals will never reach 0, because of the linear interpolation between successive values.

Fig. 7 shows the results of these summations for December and July for the four stations Lugano, Davos, Zurich and Säntis, for the 0-type distributions. The figures are normalized to the sum of the 70-years totals of the deviation squares. As it may be seen, more than about 40 years of records don't essentially increase the reliability of the statistics.

Independently of this kind of checking however, for many practical purposes even less than 10 years of observations are sufficient, if the mean lapse of the single percentage curves, representing short and long observation periods respectively, coincide with each other with adequate accuracy.

## List of Figures


1. Cumulative frequency distribution of sunshine hours for Lugano, July and Zurich, December.

2. Comparison of 1 and 99 % July-frequency curves for different stations representing different climatic and topographic conditions.

3. Same as figure 2 for December.

4. Cumulative frequency distribution of sunshine hours for Neuchâtel, January considering only days with ≥ 2 consecutive hours of uninterrupted sunshine (Type 3, s. Table 1).

5. 1 and 99 % June-frequency curves for Lugano, for different type numbers (s. Table 1).

6. Diminution of the number of days with increasing type order, normalized to the number of days belonging to type 1 (s. Table 1), drawn for different months, based on 40 year sunshine statistics for Basel.

7. Deviation square totals related to that of the 70-years period of sunshine data, indicating the diminution of statistical reliability with decreasing volume of data involved in the computing procedure.


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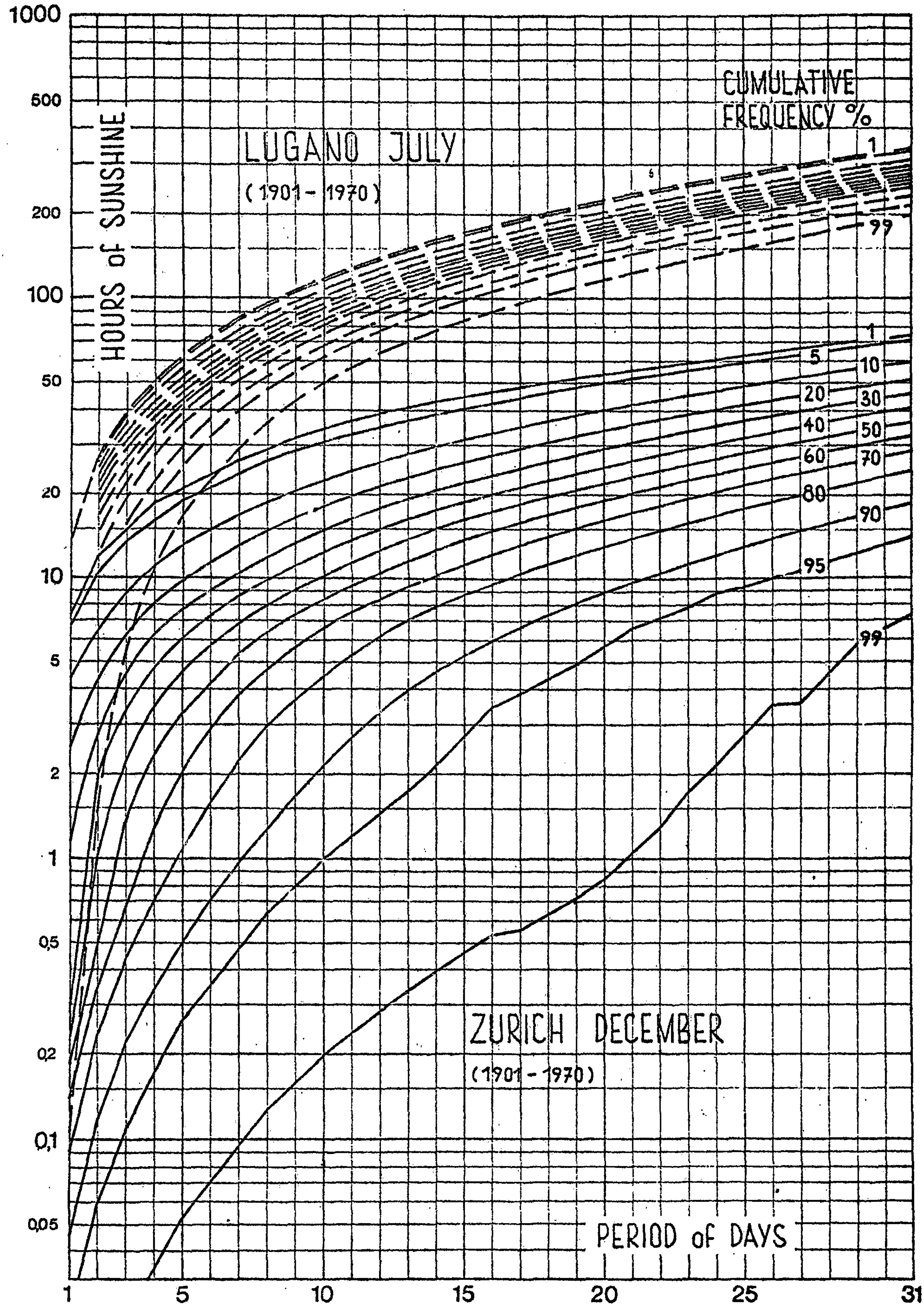
Figure 1



1000
500
200
100
50
20
10
5
2
1
0,5
0,2
0,1
0,05
HOURS of SUNSHINE
LUGANO JULY
(1901- 1970)
CUMULATIVE
FREQUENCY %
1
99
1
5
10
20
30
40
50
60
70
80
90
95
99
ZURICH DECEMBER
(1901 - 1970)
PERIOD of DAYS
1
5
10
15
20
25
31

Figure 2

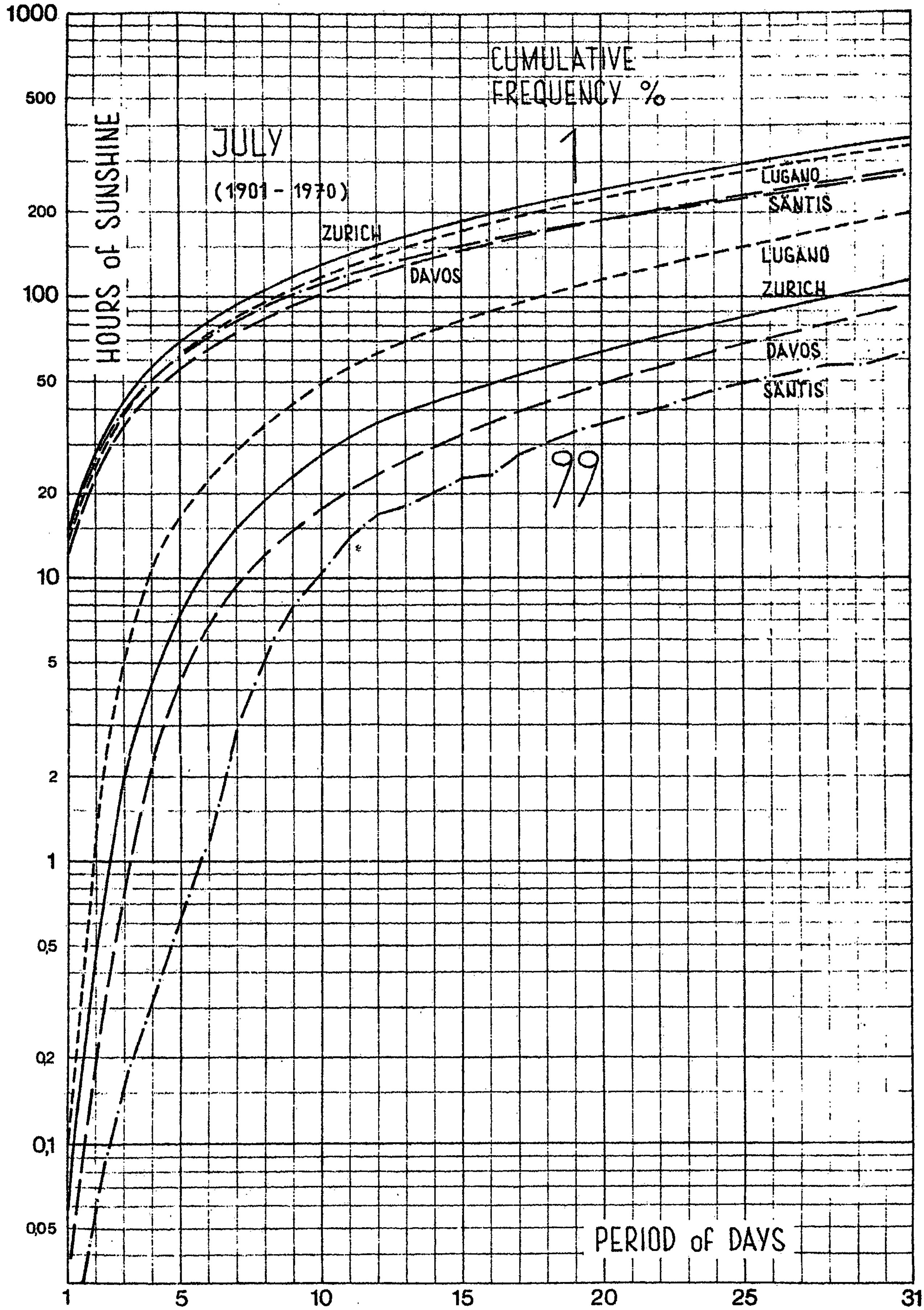
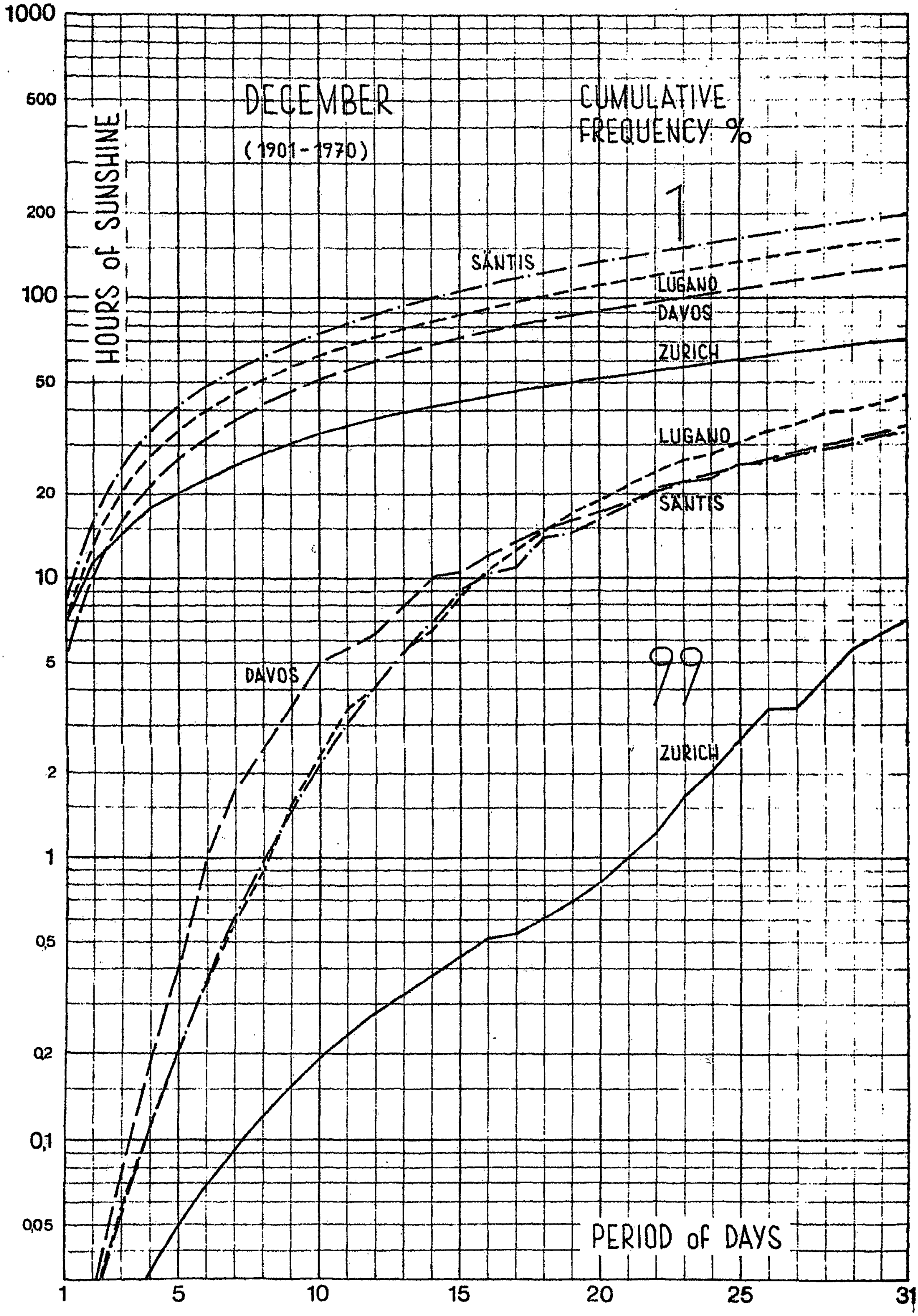

1000
500
200
100
50
20
10
5
2
1
0,5
0,2
0,1
0,05
HOURS of SUNSHINE
CUMULATIVE FREQUENCY %
JULY
(1901 - 1970)
1
ZURICH
DAVOS
LUGANO
SÄNTIS
LUGANO
ZURICH
DAVOS
SÄNTIS
99
PERIOD of DAYS
1
5
10
15
20
25
31

Figure 3



DECEMBER
(1901-1970)
CUMULATIVE FREQUENCY %
1
99
HOURS of SUNSHINE
PERIOD of DAYS
SÄNTIS
LUGANO
DAVOS
ZURICH
LUGANO
SÄNTIS
DAVOS
ZURICH
1000
500
200
100
50
20
10
5
2
1
0,5
0,2
0,1
0,05
1
5
10
15
20
25
31

Figure 4

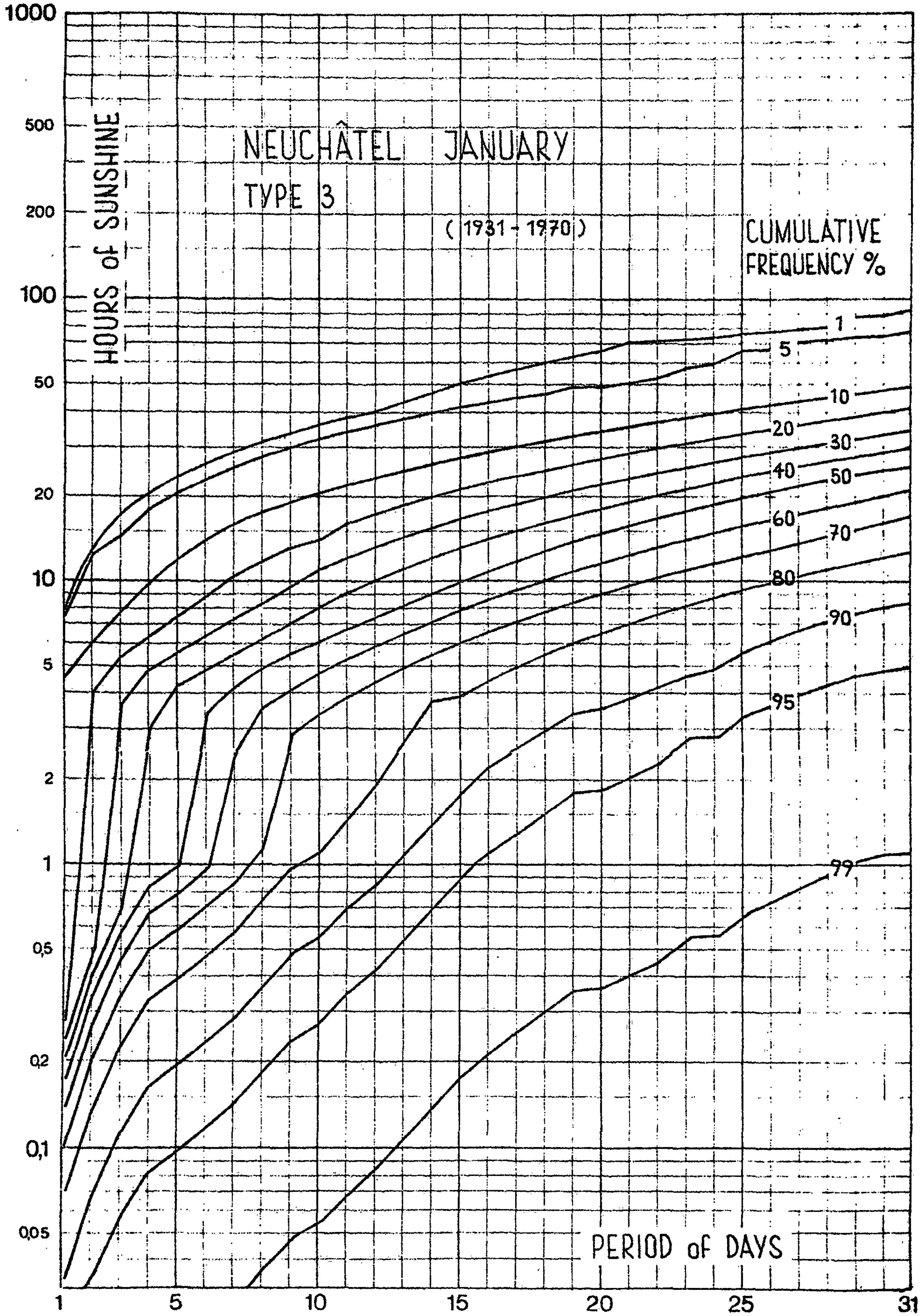
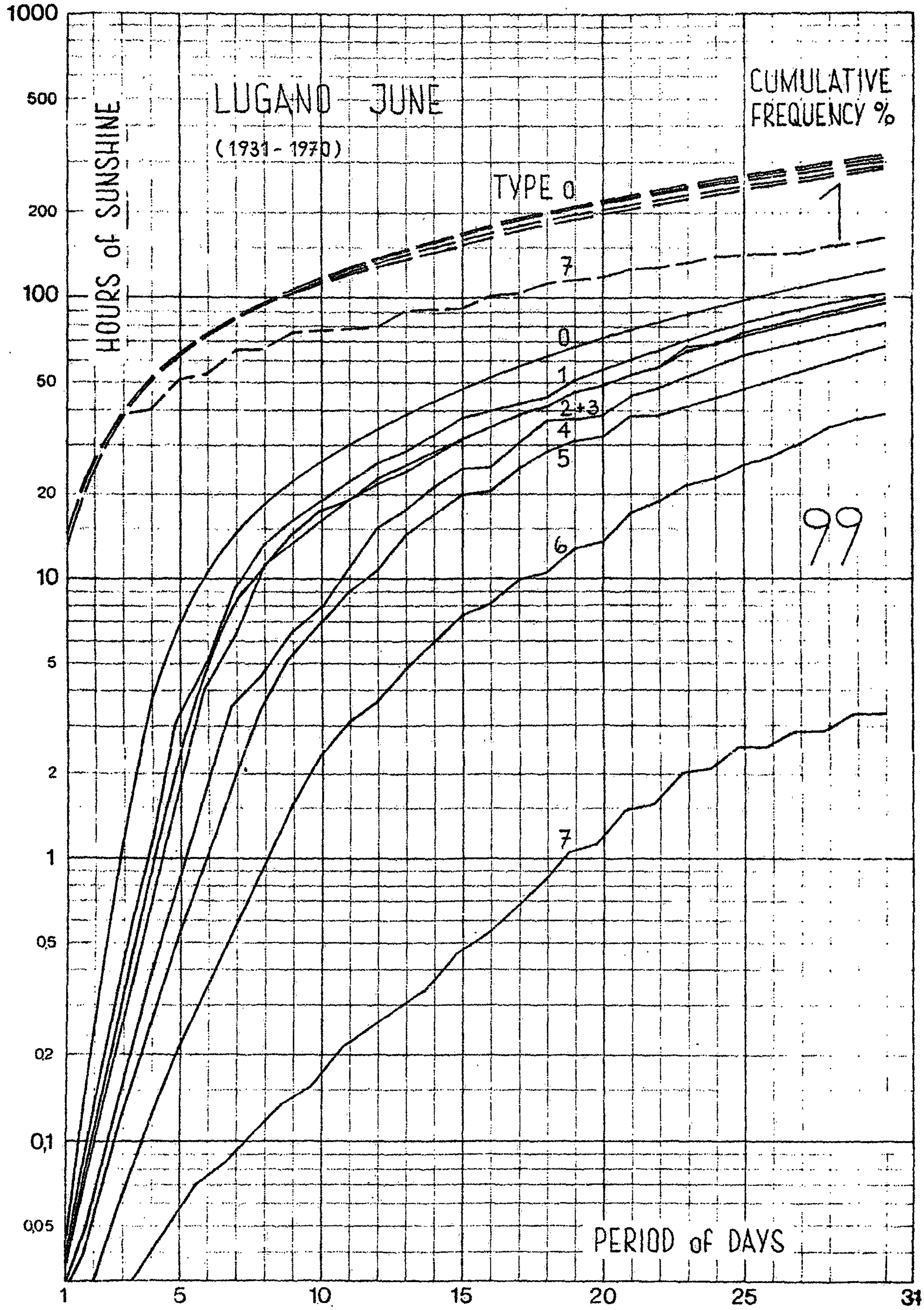
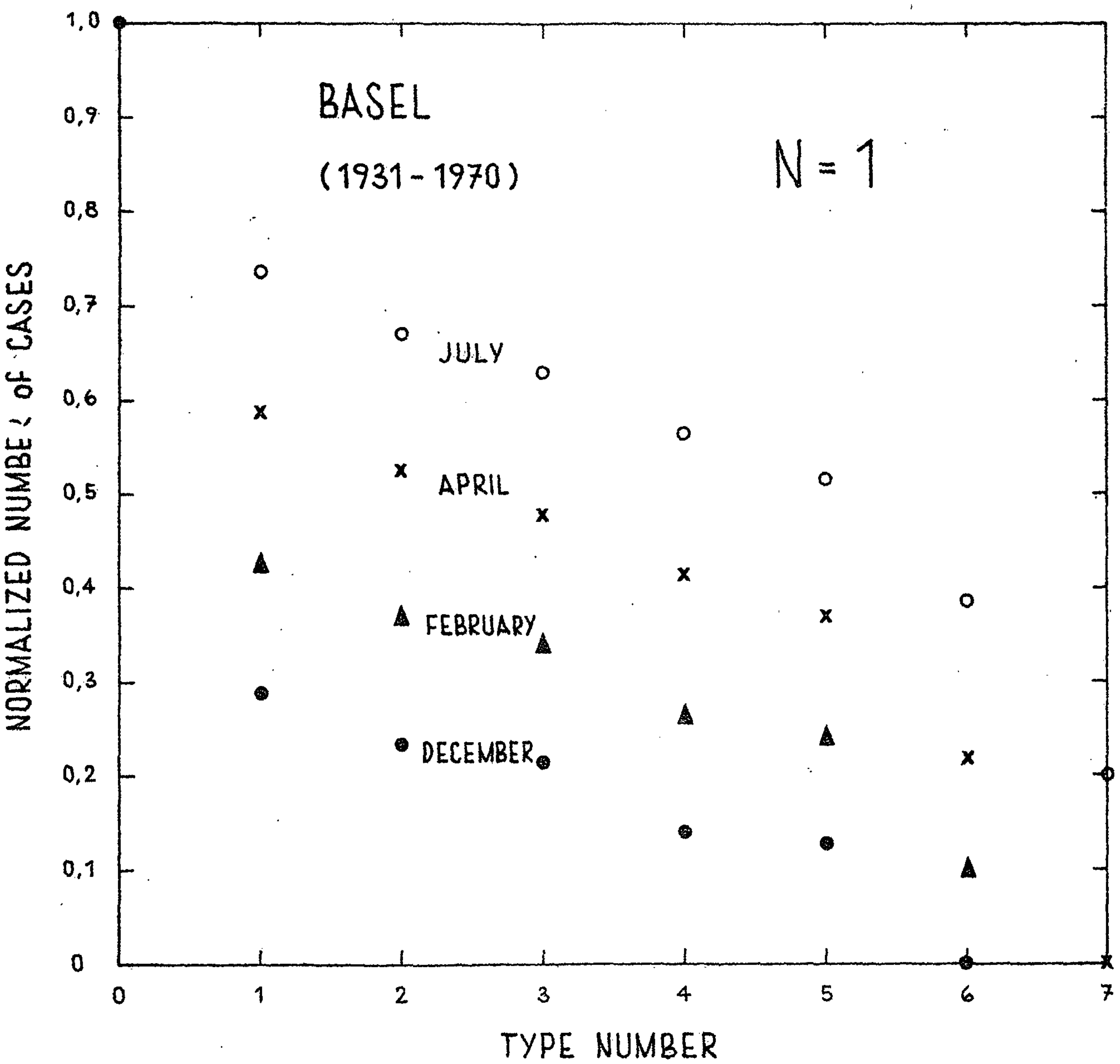

NEUCHÂTEL JANUARY
TYPE 3
(1931 - 1970)
HOURS of SUNSHINE
CUMULATIVE FREQUENCY %
PERIOD of DAYS
1000
500
200
100
50
20
10
5
2
1
0,5
0,2
0,1
0,05
1
5
10
15
20
25
31
1
5
10
20
30
40
50
60
70
80
90
95
99

Figure 5

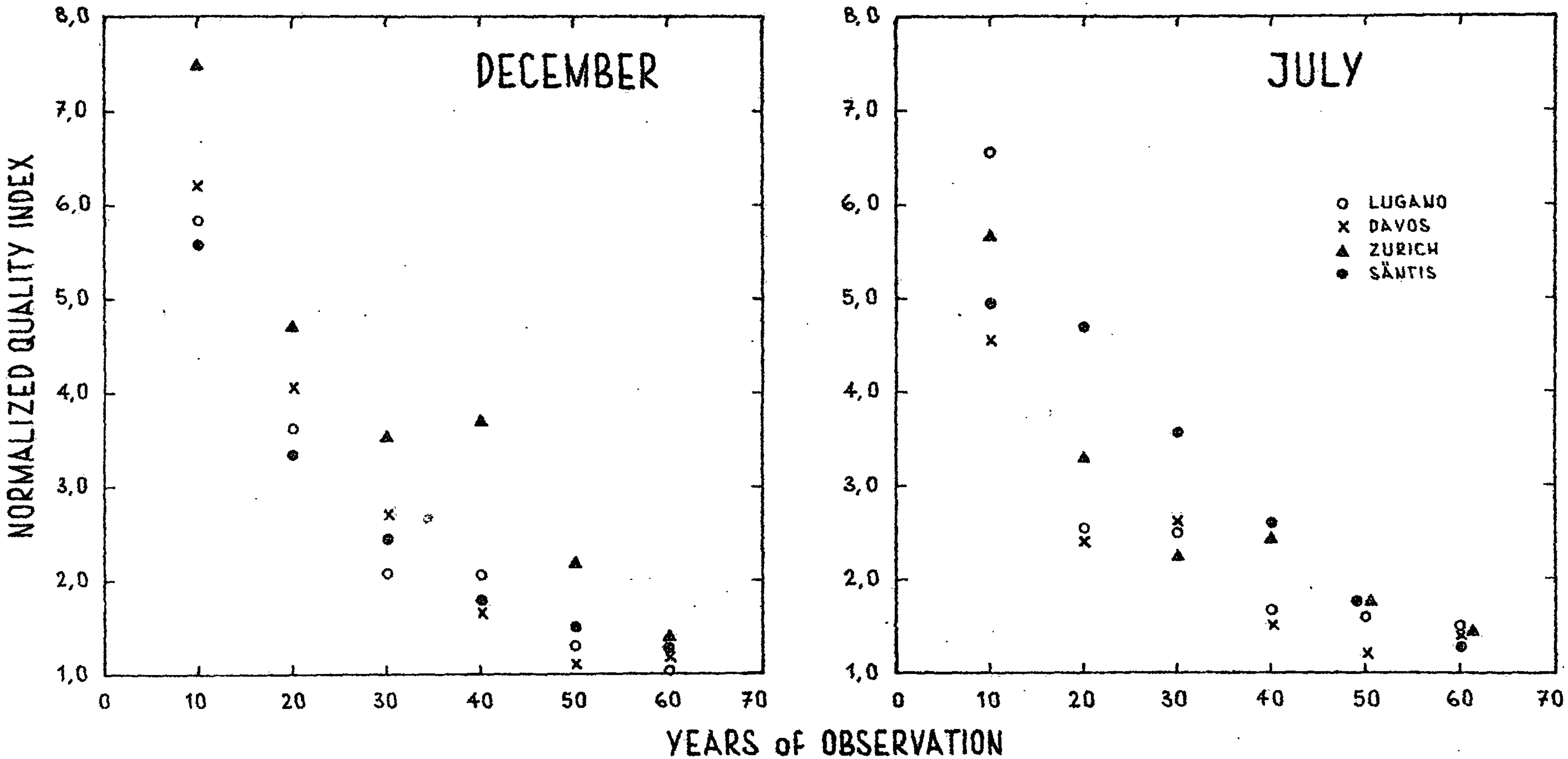


LUGANO JUNE
(1931 - 1970)
CUMULATIVE FREQUENCY %
TYPE 0
7
0
1
2+3
4
5
6
7
99
HOURS of SUNSHINE
PERIOD of DAYS
1000
500
200
100
50
20
10
5
2
1
0,5
0,2
0,1
0,05
1
5
10
15
20
25
31

Figure 6



BASEL
(1931 - 1970)
N = 1
JULY
APRIL
FEBRUARY
DECEMBER
NORMALIZED NUMBER of CASES
TYPE NUMBER
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
1
2
3
4
5
6
7



DECEMBER
JULY
NORMALIZED QUALITY INDEX
YEARS of OBSERVATION
LUGANO
DAVOS
ZURICH
SÄNTIS
8,0
7,0
6,0
5,0
4,0
3,0
2,0
1,0
0
10
20
30
40
50
60
70


Figure 7