ISOCHRONES OF THE WETTEST MONTHS IN CONTINENTAL AREAS

by

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A legcsapadékosabb hónapok isochronjai kontinentális területeken. A dolgozat célja, hogy bemutassa az év legcsapadékosabb hónapjának fáziseltolódását a kontinentális területeken. Adatbázisként éghajlati csapadékadatok szolgáltak, mégpedig Európából 122, a Szovjetunióból 66, Eszak-Amerikából 70, Dél-Azsiából 72, Magyarországról 750 és kiegészítő vizsgálat céljára Ausztráliából 48 állomásról. Meglehetősen szoros *korreláció mutatkozik az év legcsapadékosabb hónapjának fázisa és a földrajzi szélesség között Európában*, a Szovjetunióban és Eszak-Amerikában. A legcsapadékosabb hónap isochronjai többé-kevésbé bonyolult képet mutatnak Dél-Azsiában és Ausztráliában, másrészt jóval nagyobb állomás sűrűség használatával mezoklimatikus hatások mutathatók ki Magyarországon.

The purpose of this paper is to demonstrate the displacement in phases of maximum precipitation in continental areas. Climatic data are used of Europe (122 stations), Soviet Union (66 stations), North America (70 stations), South Asia (72 stations), Hungary (750 stations) and for additional investigation 48 stations of Australia. Rather close correlations exist between the phases of the wettest months and latitude in continental areas of Europe, Soviet Union and North America. The isochrones of the wettest months exhibit more or less complicated distribution in South Asia, Australia, while using much greater density of stations the effect of mesoclimatic factors is demonstrated in Hungary.

Introduction

The mean annual variation of precipitation, in a geographical region, is determined by two basic factors: seasonal features of the general atmospheric circulation and annual variation of the temperature in the same region. The *former factor* produces e.g. dry summers in Mediterranean climate due to meridional shift of the subtropical high pressure belt, and rainy winters, when extratropical cyclones dominate in this area. The double maximum of annual variation in the equatorial zone is subject to the annual course of sun's declination, or the meridional shift of ITC. In this region the annual variation of temperature is negligible. Between 15-25° latitudes a single appearance of ITC results in one short rainy season.

The second factor is effective, if the annual amplitude of temperature is significant, i.e. in moderate and high latitudes and far from tempering influence of the sea. It is evident that in these areas the maximum of the rain occurs during the warmer half-year. Its simpliest explanation is that the air may contain much more water vapor in the warm season, hence the precipitable water is generally greater, than in the cold season. E.g. the specific humidity of satureted air is as much as 20 g/k at +25°C, 3,7 g/kg at 0°C, and 1,6 g/kg at -10°, respectively. The unstable sratification of the lower troposphere and the convective activity also contribute to formation of the summer rain.

The annual amplitude of temperature exceeds 20°C in most part of Europe, it varies between 25-60°C in the territory of Soviet Union, it reaches 20-40°C over a great part of North America. The purpose of this paper is to investigate the isochrones of the wettest months in these areas and to search regularities in their geographic distribution. This investigations includes only the territory of Europe, North America, Soviet Union, and South Asia; the formation of precipitation over the other part of Asia is strongly depending on the mountains resulting in complicated distribution of isochrones. The extratropical regions of South America, Africa, and Australia are too small for large scale analysis.

Amounts of annual precipitation, the wettest and driest months in Europe, Asia and America were tabulated by *ALISOV (1950)*, However, the numbers of stations in these tables are insufficient for a comprehensive analysis over these continents. Similar survey was given for various climatic regions by *KHROMOV (1968)*, but the avialable data in this worl are also insufficient. More detailed view is comprised in *World Survey of Climatology, Vol.7* about the wettest months in the Soviet Union in form maps and tables *(LYDOLPH, 1977)*. *BARRY* and *CHORLEY (1982)* give a survey of annual precipitation variation in North America. At the *Department of Climatology in Szeged University (Hungary) G. KRISTOF (1987)* is engaged in analysing isochrones of the wettest months in co-operation with the author. Her research is limited for the continental territory of Europe.

It is noteworthy that the mean wettest month may change more or less from one decade to another due to long lasting variations in the general circulation. E.g. in Budapest, according to observations from 1841 *(RETHLY, 1947)* the wettest month in decadal average varies from May to November, though most frequently it appears in May or June. In this respect there are differences in data taken from many European stations, comparing the wettest months in different series *(Linkes Meteorologisches Taschenbuch, 1.Band, 1962; Climatic Normals, WMO, No 117, T.P. 52, 1962; PECZELY, 1994)*. Nevertheless, these differences do not influence significantly the geographical distribution of relevant isochrones in territories as large as continents.

Europe

The precipitation regime of Europe is determined by three climatic effects:

1. *Atlantic ocean* with its smooth annual distribution of precipitation, and relatively small annual variation.
2. *Mediterranean climate*, here the maximum rain occurs in colder half-year, and the annual variation is rather varying.
3. *Continental climate* with maximum precipitation in warmer half-year, and the annual variations are generally greater, than in the Atlantic climate.

In this research 113 European and 9 Turkish stations were used.* The wettest month of the year was established for each station, as well as the annual amount of precipitation, and the annual variations (v) in per cent of the annual amount:

$$v = \frac{\text{max. monthly precip.(mm)} - \text{min. monthly precip.(mm)}}{\text{annual amount (mm)}} \cdot 100$$

The 123 stations were classified, as follows:

1. *Atlantic climate (A)*. Maximum monthly precipitation may occur in any season, the annual amount ranges generally between 700 and 1400 mm, the annual variations are as much as 4-8 per cent. 30 stations belong to this class.
2. *Mediterranean climate (M)*. Maximum monthly precipitation occurs in colder season, the annual amount is generally 400-900 mm, the annual variations range between 6 and 17 per cent. 24 European, and 4 Turkish stations belong to this region.

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* See in APPENDIX, Table I

3. *Continental climate (C).* The wettest month occurs in warmer half-year, the annual amount is generally 400-1100 mm, the annual variations range between 6 and 12 per cent. 60 European and 5 Turkish stations belong to this area.

The maximum precipitation appears in colder half-year (October-March) *in 72.4 per cent of the stations* belonging to the *Atlantic climate, in 93 per cent of the stations* belonging to the *Mediterranean climate*, however it appears *in warmer half-year* (April-September) *in 97 per cent of the stations* belonging to the *continental climate.*

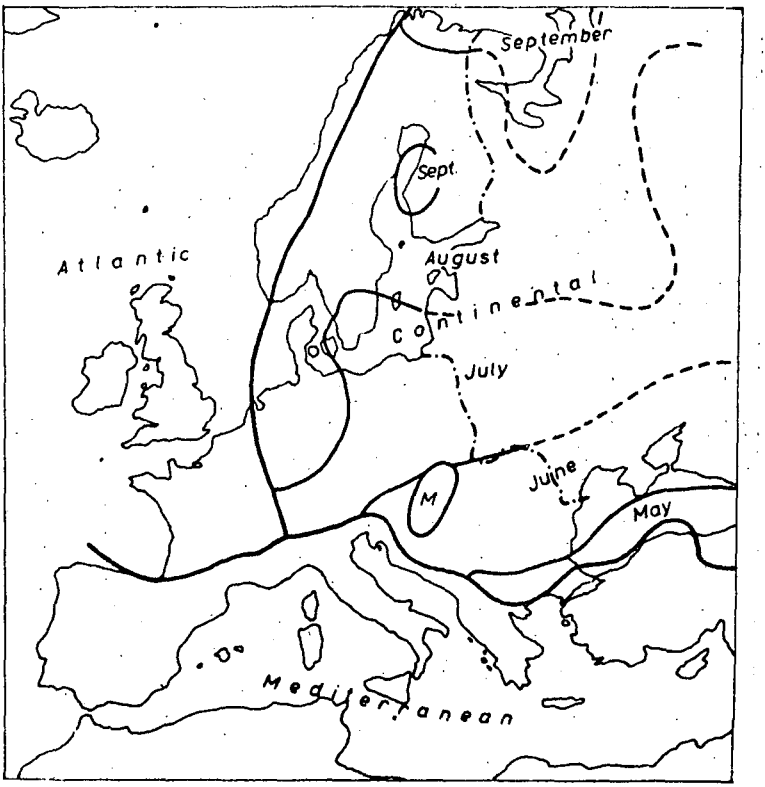


Fig.1.

In *Fig 1* thick line denotes boundary between three climatic regions. In continental area thin lines denote the isochrones of the wettest months. The isochrones are denoted by dotted lines in European part of Soviet Union, because the Soviet stations will be discussed in the next chapter of this paper. In *Fig 1* it is evident that the maximum is lagging from one month to another towards the higher latitudes: over a part of Balkan Peninsula, Turkey and Hungary the wettest month is May, in northermost region it is September.

Marking the months of the year from Jynuary to December with numbers 1-12, a linear regression was defined expressing the relationship between the wettest months and the latitude. If Y denotes the wettest month (1-12) and X the latitude (in degrees), the linear regression can be written:

$$Y = 1.714 + 0.1004\ X. \qquad /1/$$

The correlation between X an Y: $r = 0.648$.

It follows from equation /1/ that maximum rain is delaying by one month with increasing latitude by ten degrees.

KRISTOF (1987) using 140 European stations including the European part of Soviet Union obtained similar regression:

$$Y = 2.778 + 0.0803\ X,$$

and the correlation between X and Y : $r = 0.569$. According to this equation the maximum precipitation is delaying one month northwards in every 12.45 degrees (= 1/0.0803) latitude.

The interpretation of these results will be discussed later.

Soviet Union

In this analysis precipitation data of 66 stations both over the European and Asian territory of Soviet Union were used (*World Survey of Climatology, Vol.7, 1977*).* The *maximum precipitation occurs in 97 per cent of stations in warmer half-year* (April-September). This ratio correspondes to that obtained for continental area of Europe (see in previous chapter). The annual amounts range between 120 and 900 mm, the amplitude of annual variation is generally 6-20 per cent. Taken into account the total extension of this area (22 million square km), and the meridional extension from 35 to 75°N, the differences in annual amounts and in amplitudes of annual variations are not surprising.

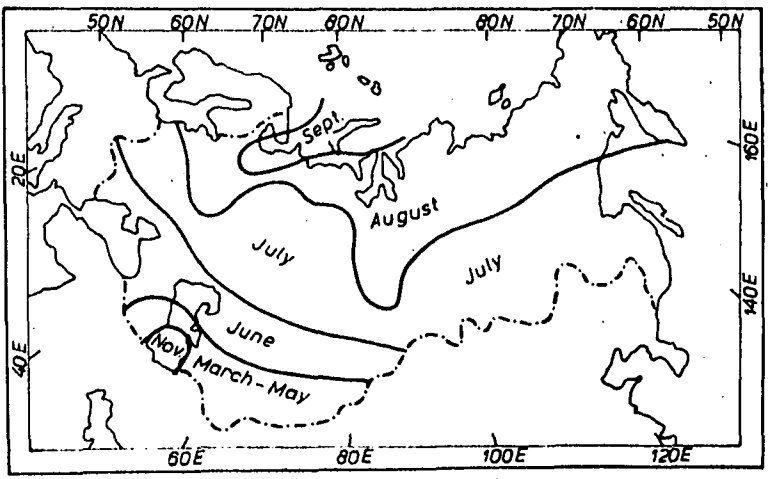


Fig. 2

Fig. 2 shows the isochrones of the wettest months over the territory of Soviet Union. South of 40°N there can be found a small area having Mediterranean character with maximum precipitation in March and November, respectively. North of this latitude the wettest month is delaying northwards: southernmost region it is May or June, in northernmost it is August or September. The relationship between wettest month and the latitudes can be expressed by a linear regression, as follows:

$$Y = 3.487 + 0.0668\ X \qquad /2/$$

* See in APPENDIX, Table II

According to equation /2/ the maximum rain is delaying by one month with increasing latitude in every 15 degrees (1/0.0668 = 15). The correlation between X and Y is r = 0.422. These results resemble those, which have been obtained for continental area of Europe, therefore their interpretation will be discussed later.

North America

From territory of North America (Alaska, Canada, U.S.A.) 70 stations were used (PECZELY, 1984).* As in case of Europe, three climatic regions were defined:

1. *Continental region* (43 stations). All stations of this area has a maximum precipitation in warmer half-year (April-September). The annual amount varies generally between 100 and 800 mm, the amplitude of annual variation ranges from 5 to 23 per cent. The differences can be understood taking into account that the locations ofthe stations vary from 33 to 74°N.

2. *Pacific region* (12 stations). The maximum precipitation occurs in 91.7 per cent of stations in the colder half-year (October-March). The annual amount ranges 300-1900 mm, the annual variations vary mostly from 6 to 10 per cent North of 41°N, and 16 to 22 per cent South of 41° latitude, respectively.

3. *Atlantic-Gulf region* (15 stations) is located along the coast of Atlantic ocean and Gulf of Mexico. The wettest month appears in 53 per cent of stations during the warmer half-year, in other words there is no characteristic annual course in precipitation.

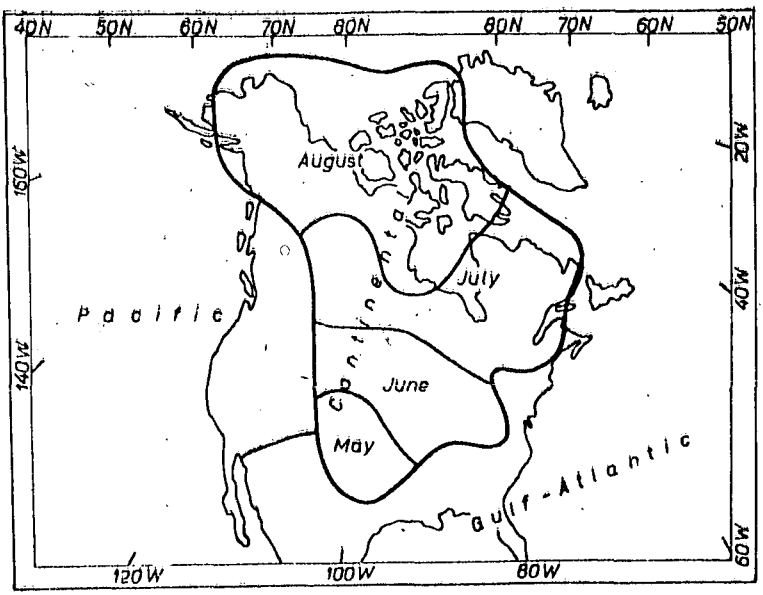


Fig. 3

Fig. 3 demonstrates the isochrones of maximum precipitation in continental region. In the southernmost zone, near 30°N latitude the wettest month is May, in Alaska and in great part of Canada, it is August.

* See in APPENDIX, Table III

The relationship between the annual phase of maximum rain and latitude is expressed by linear regression, as follows:

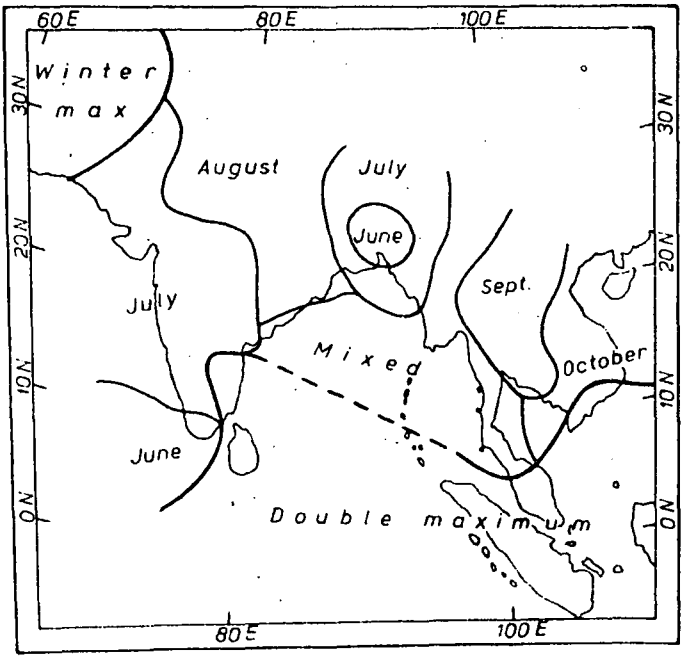
$$Y = 2.981 + 0.0749\ X. \qquad /3/$$

According to equation /3/ the maximum precipitation is delaying by one month northwards approximately in every 13 degrees (1/0.0749). The value of correlation (r) between X and Y is rather high: $r = 0.829$.

Additional investigations

The analysis of isochrones of maximum precipitation was performed for South Asian territory extending from Afghanistan to Vietnam, as well as for Australia. From South Asia 73*, from Australia 48 stations were used.

The precipitation regime of South Asia is rather complicated. In Afghanistan and in some stations of Pakistan the maximum precipitation occurs during the colder half-year, the annual variation ranges between 20 and 46 per cent, so it is rather significant. Approximately south of 10°N the annual variation is characterized by double wave with maximum in spring and autumn, respectively. Those correspond to the vernal and autumnal equinoxes. In some areas of monsoon rains the annual variation is characterized also by double maximum, but in rather irregular distribution. E.g. in North Pakistan the maximum rain occurs in March and August, in South Pakistan in January and July, in Bangladesh in June and August, in Burma in May and September. Nevertheless the isochrones of maximum monsoon rains shows significant regularity, the maximum is delaying northwards in great part of Pakistan and India, but east of 90°E it is delaying eastwards. While in southern India the maximum rain is observed in June, towards northeast it appears in July and August. Near Bay of Bengal maximum rain occurs in June or July, eastwards a phase displayment can be recognized, and the maximum rain shifts to September or October (*Fig. 4*).



It is suggested that the distribution of the wettest months in South Asia differs more or less from that in three areas discussed above. While west of Bay of Bengal the maximum rain delays towards

* See in APPENDIX, Table III and IV, respectively.

north, on the other hand east of Bay of Bengal the maximum delays eastwards and it appears in October over eastern part of Vietnam.

The precipitation regime of Australia can be devided essentially into two types: approximately between 10 and 30°S the wettest months are January, February or March. South of this zone the amximum precipitation occurs in June or July, i.e. in winter. The isochrones of summer maximum exhibit more or less regularity, but their interpretation is outside of our goal.

Finally, in order to explore mesoclimatic effects, it seems to be reasonable to examine the precipitation regime of Hungary using data of 750 stations (*HAJOSY, 1952*). Figures characterizing the density of stations in this area are: 124 square km/station and 11 km/station. Though all the wettest months appear in warmer half-year, from west to east one can recognize an interesting dichotony. From the eastern slopes of Alps to the Transdanubian Hills the maximum rain slides from July to August, while east of lake Balaton it alternates from May to June (*Fig. 5*).

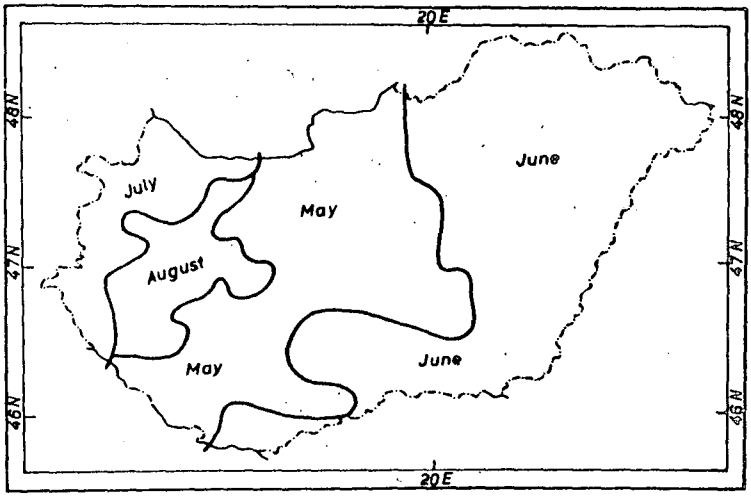


Fig. 5

This picture suggest that even by using a sufficiently high density of observations the isochrones of the wettest months provide regularity, and at the same time the mesoclimatic effects contribute in formation of precipitation regime.

Interpretations of results

The investigation of large scale precipitation regime in Europe, Soviet Union and North America proves convincingly that far enough from the oceans the wettest months are delaying northwards. The correlation coefficients between the phases of wettest months and latitudes are significant at 1 per cent level.

This property of the precipitation climate may be explained by the fact that the principal sources of atmospheric water vapor are provided by seas or oceans lying south of continents. Over a great part of Europe the primary source of moisture is Mediterranean- and Black-sea, respectively. For instance for observations in Hungary it has been pointed out that the largest amount of precipitation occurs at winds from *SW*, *WSW*, *SSW* and *SE*, while driest weather is expected at winds from *NE* and *ENE* (*KOPPANY, 1982*). In late spring or early summer abundant rain is falling in regions lying close

to the *primary source of moisture*. After that the soaked soil serves as *secondary source of moisture*. It is probable that increasing transpiration of growing vegetation in late sping and in summer contributes to formation of secondary source of atmospheric moisture. The phenological phases of plants are delaying towards the higher latitudes during the warm season, and this fact, at least partly, may explain the delay of wettest months in higher latitudes over continental areas. Naturally other factors may be important too in formation of isochrones of the wettest months, e.g. the seasonal change of circulation, however the analysis pf possible factors is beyond our goal.

In Soviet Union numerous investigations have been made dealing with methodology of rain prediction. *PED' (1966)* assumed that the prediction of the next decade or month is derived from two sources: from external one, i.e. from advection of moisture, and from local source, i.e. from evaporation of soaked soil or evapotranspiration. According to several researches *(ZVEREV, 1960; YESAKOVA, 1963; FEDULOVA, 1964)* the advection of moisture depends on the intensity of meridional or zonal circulation. *ZVEREV (1960)* after having analysed the circulation at 850 hPa level concluded that abundant rain is expected when S wind is blowing. It is noteworthy that south of Soviet Union there are only two limited primary sources of moisture: Black-sea and Caspian-sea, at least in western partof the country, butin eastern part of its Asian territory the primary source of moisture is Pacific ocean. After all the effect of secondary source is evident over whole territory of Soviet Union.

In North America *H.H. KLEIN (1965)* made a profound research relating to the synoptic climatology of precipitation. He pointed out that different regions of the U.S.A. obtain the largest amount of moisture from different directions. The principal source of moisture is Pacific ocean on western coast, that of the largest central region is Gulf of Mexico, in eastern coast it is Atlantic ocean. The main portion of precipitation falling over North America originates probably from evaporation of ocean in low latitudes. Therefore it is very plausible assumption that at the beginning of warmer half-year the southernmost region obtain abundant rain, then the soaked soil serves as secondary source of moisture, and the maximum precipitation shifts gradually northwards as it has been described above.

APPENDIX

Table I

List of stations used in Fig 1

Europe

Stations	φ	λ	Max.	v (%)	Class.
1. Vardo	70°23'N	31°06'E	IX	6.7	C
2. Tromso	69°39'N	18°57'E	X	6.7	A
3. Bodo	67°17'N	14°25'E	X	7.5	A
4. Trondheim	63°25'N	10°27'E	X	5.8	A
5. Bergen	60°24'N	5°19'E	X	7.8	A
6. Oslo	59°56'N	10°44'E	VIII	9.4	C
7. Haparanda	68°50'N	24°09'E	VIII	12.4	C
8. Östersund	63°10'N	14°40'E	VIII	14.0	C
9. Härnösand	62°28'N	15°57'E	XI	7.9	A
10. Karlstad	59°22'N	13°28'E	VIII	8.9	C
11. Stockholm	59°21'N	18°04'E	VIII	9.0	C
12. Jönköping	57°46'N	14°11'E	VII	8.8	C
13. Göteborg	57°42'N	11°58'E	VIII	8.5	C
14. Sodenkylä	67°22'N	26°34'E	VII	10.6	C
15. Kajaani	64°17'N	27°41'E	VII	9.4	C
16. Vaasa	63°03'N	21°46'E	IX	9.1	C
17. Luonetjärvi	62°24'N	25°40'E	VIII	9.5	C
18. Turku	60°31'N	22°16'E	VIII	9.2	C
19. Helsinki	60°12'N	24°55'E	VIII	5.2	C
20. Thorshavn	62°03'N	6°45'W	XII	6.5	A
21. Kobenhavn	55°41'N	12°33'E	VII	6.5	C
22. Lerwick	60°08'N	1°11'W	XII	6.6	A
23. Stornoway	58°13'N	6°20'W	X	6.3	A
24. Aberdeen	57°12'N	2°12'W	XI	4.9	A
25. Aldergrove	54°39'N	6°13'W	VII;XII	5.4	A
26. Manchester	53°21'N	2°16'W	VIII	4.5	A
27. London	51°28'N	0°19'W	XI	4.4	A
28. Plymouth	50°21'N	4°07'W	XI-XII	6.0	A
29. Gorleston	52°35'N	1°43'W	XI	5.3	A
30. Belmullet	54°14'N	10°00'W	XII	6.7	A
31. Dublin	53°22'N	6°21'W	IX	3.7	A
32. Valencia	51°56'N	10°15'W	XII	6.2	A
33. De Bilt	52°06'N	5°11'E	VIII	5.6	A
34. Bruxelles	50°48'N	4°21'E	X	5.9	A
35. Le Havre	49°31'N	0°04'E	XI	5.8	A
36. Brest	48°27'N	4°25'W	XII	8.3	A
37. Paris	48°58'N	2°27'E	VIII	5.1	A
38. Nantes	47°10'N	1°37'W	XII	5.8	A
39. Bordeaux	44°50'N	0°42'E	XII	6.7	A
40. Lyon	45°43'N	4°57'E	IX	5.9	A
41. Toulouse	43°37'N	1°22'E	V	4.7	A
42. Nice	43°40'N	7°12'E	XI	12.6	M

Table I

Europe

Stations	φ	λ	Max.	v (%)	Class.
43. Bastia	42°33'N	9°29'E	X	13.6	M
44. Ajaccio	41°55'N	8°48'E	XII	13.1	M
45. La Coruna	43°22'N	8°22'W	XII	11.3	A
46. Zaragoza	41°39'N	0°53'W	X	5.3	M
47. Madrid	40°25'N	3°41'W	X	9.6	M
48. Barcelona	41°24'N	2°09'E	IX	8.2	M
49. Mallorca	39°36'N	2°42'E	X	15.4	M
50. Sevilla	37°24'N	6°00'W	III	15.9	A-M
51. Gibraltar	36°09'N	5°21'W	I	18.8	A
52. Lisboa	38°46'N	9°08'W	III	15.2	A
53. Lübeck	53°54'N	10°42'E	VII-VIII	6.6	C
54. Hamburg	53°38'N	10°00'E	VIII	6.4	C
55. Marburg	50°49'N	8°46'E	VIII	5.6	C
56. Karlsruhe	49°00'N	8°23'E	VIII	4.9	C
57. Augsburg	48°22'N	10°54'E	VII	8.8	C
58. Partenkirchen	47°30'N	11°06'E	VII	9.4	C
59. Greifswald	54°06'N	12°07'E	VII	6.5	C
60. Potsdam	52°23'N	13°04'E	VII	6.6	C
61. Dresden	51°07'N	13°41'E	VII	11.3	C
62. Zürich	47°23'N	8°34'E	VII	6.9	C
63. Genève	46°12'N	6°09'E	IX	5.6	A
64. Wien	48°15'N	16°22'E	VII	6.5	C
65. Salzburg	47°48'N	13°00'E	VII	9.5	C
66. Graz	46°59'N	15°27'E	VI	11.3	C
67. Mar. Lazne	49°58'N	12°42'E	VII	5.4	C
68. Praha	50°05'N	14°25'E	VII	11.6	C
69. Brno	49°12'N	16°34'E	VI	11.3	C
70. Oravsky Podzamok	49°15'N	19°20'E	VII	8.3	C
71. Presov	49°00'N	21°15'E	VII	10.1	C
72. Gdynia	54°31'N	18°33'E	VIII	8.5	C
73. Poznan	52°25'N	16°50'E	VII	8.3	C
74. Warszava	52°09'N	20°59'E	VII	11.2	C
75. Wroclaw	51°08'N	16°59'E	VII	8.9	C
76. Kielce	50°51'N	20°37'E	VII	9.8	C
77. Krakow	50°05'N	20°01'E	VII	9.5	C
78. Szombathely	47°15'N	16°36'E	VII	7.8	C
79. Pécs	46°05'N	18°15'E	V	4.4	C
80. Budapest	47°31'N	19°02'E	V	4.9	C
81. Szeged	46°15'N	20°09'E	VI	6.3	C
82. Nyiregyháza	47°58'N	21°43'E	VI	7.0	C
83. Baia Mare	47°40'N	23°35'E	VI	5.0	C
84. Timisoara	45°46'N	21°15'E	VI	6.5	C
85. Cluj	46°46'N	23°36'E	VI	11.9	C
86. Sibiu	45°48'N	24°09'E	VI	13.0	C

Table I

Europe

Stations	φ	λ	Max.	v (%)	Class.
87. Iasi	47°10'N	27°36'E	VI	9.3	C
88. Braila	45°17'N	27°59'E	VI	8.6	C
89. Bucuresti	44°25'N	26°06'E	VI	10.3	C
90. Constanta	44°11'N	28°40'E	VI	5.3	C
91. Pleven	43°46'N	24°35'E	VI	8.8	C
92. Varna	43°12'N	27°55'E	VI	7.4	C
93. Sofia	42°42'N	23°20'E	VI	8.6	C
94. Sandanski	41°34'N	23°17'E	XI	8.2	C
95. Udine	46°02'N	13°11'E	VI	6.4	M
96. Milano	45°28'N	9°11'E	X	6.0	M
97. Ancona	43°37'N	13°31'E	X	7.7	M
98. Roma	41°54'N	12°29'E	X	12.9	M
99. Napoli	40°51'N	14°15'E	XII	13.5	M
100. Palermo	38°07'N	13°21'E	XII	15.2	M
101. Cagliari	39°13'N	9°06'E	X	13.9	M
102. Thessaloniki	40°34'N	23°00'E	XI	9.4	M
103. Larisa	39°37'N	22°15'E	XI	10.2	M
104. Athens	37°58'N	23°43'E	XII	17.0	M
105. Ljubljana	46°04'N	14°34'E	X	7.8	M
106. Zagreb	45°49'N	15°58'E	VI	5.6	C
107. Beograd	44°48'N	20°27'E	VI	7.1	C
108. Sarajevo	43°52'N	18°26'E	VI	4.0	C
109. Nis	43°20'N	21°45'E	V	8.4	C
110. Titograd	42°26'N	19°16'E	XII	11.6	M
111. Skopje	42°00'N	21°06'E	XI	6.8	M
112. Dubrovnik	42°39'N	18°06'E	XII	14.4	M
113. Luga (Malta)	35°51'N	14°29'E	X	24.2	M
114. Tirana	41°18'N	19°48'E	X	10.8	M
115. Istambul	40°58'N	29°05'E	XII	11.5	M
116. Sinop	42°02'N	35°10'E	XI	9.6	M
117. Samsun	41°17'N	36°20'E	XI	7.4	M
118. Trabzon	41°00'N	39°43'E	XI	8.8	M
119. Ankara	39°57'N	32°53'E	V	11.5	C
120. Kars	40°36'N	43°05'E	V	12.4	C
121. Sivas	39°45'N	37°01'E	V	14.2	C
122. Kastamonu	41°22'N	33°47'E	V	12.2	C
123. Erzurum	39°55'N	41°16'E	V	12.1	C

Table II

List of stations used in Fig 2

Soviet Union

Stations	φ	λ	Max.	v (%)	Class.
1. Aldan	58°37'N	125°22'E	VII	13.25	C
2. Alma Ata	43°12'N	76°56'E	V	12.56	C
3. Anadyr	64°47'N	177°34'E	VIII	14.23	C
4. Apuka	60°26'N	169°40'E	VIII	10.21	C
5. Archangel	64°30'N	40°30'E	IX	7.05	C
6. Ashkhabad	37°58'N	58°20'E	III	20.48	M
7. Astrakhan	46°16'N	48°02'E	V	6.84	C
8. Baku	40°21'N	49°50'E	VIII	10.92	M
9. Balkhash	46°54'N	75°00'E	VI	13.04	C
10. Barnaul	53°20'N	83°48'E	VII	13.15	C
11. Batumi	41°45'N	41°40'E	IX	9.30	M
12. Blagoveshchensk	50°16'N	127°30'E	VII	19.66	C
13. Chita	52°01'N	113°20'E	VII	26.53	C
14. Chokurdakh	70°37'N	147°53'E	VIII	11.72	C
15. Dudinka	69°24'N	86°10'E	VIII	14.98	C
16. Yerbogachen	61°16'N	108°01'E	VII	16.10	C
17. Fergana	40°23'N	71°45'E	III	14.79	M
18. Shevchenko	44°33'N	50°17'E	VI	7.69	C
19. Gur'yev	47°01'N	51°51'E	VII	7.32	C
20. Ilirney	67°20'N	168°11'E	VII	20.39	C
21. Irkutsk	52°16'N	104°19'E	VII	20.52	C
22. Kaliningrad	54°42'N	20°37'E	VII	9.02	C
23. Karaganda	49°48'N	73°08'E	VII	11.72	C
24. Kaunas	54°53'N	25°53'E	VII	7.10	C
25. Kazan	55°47'N	49°11'E	VII	10.80	C
26. Kem	65°00'N	34°48'E	VIII	9.88	C
27. Kemerovo	55°23'N	86°04'E	VII	17.05	C
28. Kharkov	49°56'N	36°17'E	VII	8.28	C
29. Khatanga	71°50'N	102°28'E	VIII	12.16	C
30. Kiew	50°24'N	30°27'E	VII	5.69	C
31. Kirensk	57°46'N	108°07'E	VII	15.75	C
32. Kirov	58°39'N	49°37'E	VIII	8.92	C
33. Kishinev	47°01'N	28°52'E	VI	12.76	C
34. Klyuchu	56°19'N	160°50'E	XII	6.58	C
35. Kolpashevo	58°18'N	82°54'E	VIII	14.10	C
36. Krasnodar	45°02'N	39°09'E	VI	4.38	C
37. Krasnoyarsk	56°00'N	92°53'E	VII	17.66	C
38. Leningrad	59°58'N	30°18'E	VIII	9.30	C
39. Loukhy	66°05'N	32°59'E	VIII	10.27	C
40. Lvov	49°49'N	23°54'E	VII	10.08	C
41. Novaya Zemlya	72°23'N	52°44'E	IX	7.25	C
42. Minsk	53°52'N	27°32'E	VII	9.40	C
43. Minusinsk	53°42'N	91°42'E	VII	18.04	C
44. Moscow	55°45'N	37°34'E	VII-VIII	8.00	C
45. Murmansk	68°58'N	33°03'E	VIII	11.70	C
46. Mis Chelyuskin	77°43'N	104°17'E	VIII	4.76	C
47. Mis Smidta	68°55'N	179°28'E	VIII	8.44	C
48. Nar'yan Mar	67°39'N	53°01'E	VIII	11.90	C
49. Novgorod	58°21'N	31°15'E	VIII	10.67	C
50. Novorossiysk	44°42'N	37°48'E	XII	6.54	M

Table II

Soviet Union

Stations	φ	λ	Max.	v (%)	Class
51. Odessa	46°29'N	30°38'E	VI	6.43	C
52. Okhotsk	59°22'N	143°12'E	VII	15.61	C
53. Olenek	68°30'N	112°36'E	VIII	17.45	C
54. Omsk	54°56'N	73°24'E	VII	20.31	C
55. O. Dickson	73°30'N	80°14'E	VIII	13.91	C
56. Petrozavodsk	61°49'N	34°16'E	VII	10.73	C
57. Podk. Tunguska	61°36'N	90°00'E	VIII	10.62	C
58. Pyatigorsk	44°03'N	43°02'E	VI	13.28	C
59. Rostov-n.Donu	47°15'N	39°49'E	VI	5.38	C
60. Simferopol	45°01'N	33°59'E	VI	8.33	C
61. Surgut	61°15'N	73°30'E	VII	9.96	C
62. Sverdlovsk	56°44'N	61°04'E	VII-VIII	14.07	C
63. Syktyvkar	61°40'N	50°51'E	VII;IX	9.96	C
64. Tbilisi	41°41'N	44°57'E	V	10.92	C
65. Uzhgorod	48°38'N	22°16'E	VI	9.50	C
66. Volgograd	48°42'N	44°31'E	VI	6.92	C

Table III

List of stations used in Fig 3

North America

Stations	φ	λ	Max.	v (%)	Class.
1. Barrow	71°18'N	156°47'W	VIII	18.2	C
2. Barter (Is.)	70°08'N	143°38'W	VIII	14.4	C
3. Kotzebue	66°52'N	160°38'W	VIII	23.1	C
4. Fort Yukon	66°35'N	145°18'W	VIII	10.9	C
5. Fairbanks	64°49'N	147°57'W	VIII	17.4	C
6. Nome	64°30'N	165°20'W	VIII	17.4	C
7. Kodiak	57°30'N	152°45'W	XI	5.6	P
8. Anchorage	61°10'N	149°59'W	VIII	14.4	C
9. Juneau	58°22'N	134°35'W	X	10.0	P
10. Anette (Is.)	55°02'N	131°34'W	X	9.5	P
11. Alert	82°30'N	62°20'W	IX	16.2	C
12. Isachsen	78°47'N	103°32'W	VII	20.3	C
13. Resolute	74°43'N	94°59'W	VIII	23.6	C
14. Arctic Bay	73°00'N	85°18'W	VIII	13.8	C
15. Coppermine	67°49'N	115°05'W	VIII	14.6	C
16. Coral Harbour	64°12'N	83°22'W	VIII	11.7	C
17. Forth Smith	60°01'N	111°58'W	VII	10.9	C
18. Churchill	58°45'N	94°04'W	VIII	9.7	C
19. Trout Lake	53°50'N	89°52'W	VII	13.6	C
20. Winnipeg	49°54'N	97°15'W	VI	11.6	C
21. Vancouver	49°11'N	123°10'W	XII	10.3	P
22. North Bay	46°22'N	79°25'W	IX	5.4	A-G
23. Montreal	45°30'N	73°35'W	VII	2.5	C-A
24. Halifax	44°39'N	63°64'W	XI	3.5	A-G
25. Tatoosh (Is.)	48°23'N	124°44'W	XII	12.0	P

Table III

North America

Stations	φ	λ	Max.	v (%)	Class.
26. Portland	45°32'N	122°40'W	XII	16.5	P
27. Eureka	40°48'N	124°10'W	I-XII	16.7	P
28. San Francisco	37°47'N	122°45'W	I	21.9	P
29. Los Angeles	34°03'N	118°14'W	I	21.2	P
30. Salt Lake City	40°46'N	111°58'W	IV	9.0	P
31. Denver	39°46'N	104°53'W	V	15.0	C
32. Reno	39°30'N	119°47'W	I	14.4	P
33. Phoenix	33°26'N	112°01'W	VIII	14.1	A-G
34. El Paso	31°48'N	106°24'W	VII	12.9	A-G
35. Duluth	46°50'N	92°11'W	VI	11.4	C
36. Bismarck	46°46'N	100°45'W	VI	20.0	C
37. Kansas City	39°07'N	94°35'W	VI	9.7	C
38. Havre	48°34'N	109°40'W	VI	19.2	C
39. Amarillo	35°14'N	101°42'W	V	13.9	C
40. Buffalo	42°56'N	78°44'W	XI	2.9	A-G
41. Detroit	42°24'N	83°00'W	V	4.8	C
42. Chicago	41°47'N	87°47'W	VI	7.4	C
43. Indianopolis	39°44'N	86°17'W	VI	5.0	C
44. St. Louis	38°48'N	92°12'W	VI	7.7	C
45. Caribou	46°52'N	68°01'W	VII	5.6	C
46. Mt. Washington	44°16'N	71°18'W	IX	2.4	A-G
47. Parkersburg	39°16'N	81°34'W	VI	5.7	C
48. Nashville	36°07'N	86°41'W	I	7.0	A-G
49. Atlanta	33°39'N	84°25'W	III	6.2	A-G
50. Boston	42°13'N	71°07'W	XI	2.6	A-G
51. New York	40°47'N	75°58'W	VIII	3.8	A-G
52. Washington	38°31'N	77°03'W	VIII	5.9	A-G
53. Memphis	35°03'N	89°58'W	I	5.7	A-G
54. Little Rock	34°44'N	92°14'W	V	5.0	C
55. Dallas	32°51'N	96°51'W	V	8.4	C
56. New Orleans	29°57'N	90°04'W	VII	5.4	A-G
57. Houston	29°46'N	95°22'W	VII	6.1	A-G
58. Miami	25°48'N	80°16'W	X	10.9	A-G
59. Clyde	70°27'N	68°33'W	IX	18.4	C
60. Cambridge	69°07'N	105°01'W	VIII	14.8	C
61. Frobisher	63°45'N	68°33'W	VII	10.7	C
62. The Pas	53°58'N	101°06'W	VII	11.2	C
63. Edmonton	53°34'N	113°31'W	VII	13.7	C
64. Saskatoon	52°08'N	106°38'W	VII	12.8	C
65. Goose	53°12'N	70°54'W	VIII	4.2	C
66. Nitchequon	51°16'N	80°39'W	VII-VIII	10.2	C
67. F. Chimo	50°06'N	60°26'W	VIII	10.5	C
68. Dawson	64°04'N	139°26'W	VII	13.0	C
69. Boise	43°34'N	116°13'W	I	10.3	P
70. Lander	42°49'N	108°44'W	V	16.2	C

Table IV

List of stations used in Fig 4

South Asia

Stations	φ	λ	Max.	Class.
1. Salang	35°21'N	69°07'E	IV	W
2. Kabul	34°33'N	59°12'E	III	W
3. Herat	34°20'N	62°10'E	III	W
4. Kandahar	31°30'N	65°45'E	I	W
5. Ravalpindi	33°35'N	73°03'E	VIII	M
6. Quetta	30°11'N	67°00'E	II	W
7. Dalbandin	28°53'N	64°34'E	I	W
8. Peshawar	34°01'N	71°35'E	VIII	M
9. Lahore	31°33'N	74°20'E	VIII	M
10. Multan	30°12'N	71°26'E	VII	M
11. Jacobabad	28°18'N	68°28'E	VII	M
12. Hyderabad	25°23'N	68°25'E	VII	M
13. Pasni	25°16'N	63°29'E	VII	M
14. Karachi	24°48'N	66°59'E	VII	M
15. Gilgit	35°48'N	74°00'E	VIII	M
16. Leh	34°09'N	77°34'E	VIII	M
17. Simla	31°06'N	77°10'E	VIII	M
18. Darjeeling	27°03'N	88°10'E	VII	M
19. New Delhi	28°35'N	77°12'E	VII	M
20. Jaipur	26°55'N	75°52'E	VIII	M
21. Jodhpur	26°18'N	73°01'E	VIII	M
22. Bhuj	23°15'N	69°40'E	VII	M
23. Ahmadabad	23°04'N	72°38'E	VII	M
24. Veraval	20°54'N	70°22'E	VII	M
25. Patna	25°37'N	85°10'E	VIII	M
26. Allahabad	25°27'N	81°44'E	VIII	M
27. Calcutta	22°32'N	88°20'E	VII	M
28. Bombay	18°54'N	72°49'E	VII	M
29. Mangalore	12°54'N	74°51'E	VII	M
30. Kozhikode (Calicut)	11°15'N	75°47'E	VII	M
31. Indore	22°43'N	75°48'E	VII	M
32. Nagpur	21°06'N	79°03'E	VII	M
33. Jagdalpur	19°05'N	82°02'E	VIII	M
34. Hyderabad	17°27'N	78°28'E	VII	M
35. Belgaum	15°51'N	74°37'E	VII	M
36. Bangalore	12°58'N	77°35'E	IX	mixed
37. Cuttack	20°47'N	85°56'E	VIII	M
38. Vishakhapatnam	17°42'N	83°18'E	X	mixed
39. Madras	13°00'N	80°11'E	XI	mixed
40. Trivandrum	8°29'N	76°57'E	VI	M
41. Dibrugarh	27°29'N	95°01'E	VII	M
42. Gauhati	26°05'N	91°43'E	VI	M
43. Cherrapunji	25°15'N	91°44'E	VI	M
44. Port Blair	11°40'N	93°43'E	VI	M
45. Minicoy	8°18'N	73°00'E	VI	M
46. Trincomalee	8°35'N	81°15'E	V-XI	double
47. Colombo	6°54'N	79°52'E	V-X	double
48. Bogra	24°51'N	89°23'E	VIII	M
49. Dacca	23°46'N	90°23'E	VIII	M
50. Chittagong	22°21'N	91°50'E	VII	M

Table IV

South Asia

Stations	φ	λ	Max.	Class
51. Bhamo	24°16'N	97°12'E	VII-VIII	M
52. Mandalay	21°59'N	96°06'E	V-IX	M
53. Akyab	20°08'N	92°53'E	VII	M
54. Rangoon	16°46'N	96°10'E	VII	M
55. Tavoy	14°06'N	98°13'E	VI	M
56. Mergui	12°26'N	98°36'E	VII	M
57. Chiang Mai	18°47'N	98°59'E	IX	M
58. Phitsanulok	16°50'N	100°16'E	IX	M
59. Nakhon Rathchasima	14°58'N	102°07'E	IX	M
60. Bangkok	13°45'N	100°30'E	IX	M
61. Chumphon	10°27'N	99°15'E	XI	mixed
62. Songkhla	7°11'N	100°37'E	XI	mixed
63. Kuala Trengganu	5°20'N	103°08'E	III-XI	mixed
64. Pinang	5°18'N	100°16'E	V-X	mixed
65. Ipoh	4°34'N	101°06'E	IV-XI	mixed
66. Battambang	13°06'N	103°12'E	IX	M
67. Phnom Penh	11°33'N	104°51'E	X	M
68. Lao Kay	22°30'N	103°57'E	IX	M
69. Hanoi	21°02'N	105°50'E	VIII	M
70. Dong Hoi	17°29'N	106°56'E	X	M
71. Patl-Isles	16°33'N	111°37'E	X	M
72. Quang Ngai	15°08'N	108°50'E	XI	M
73. Ho-si-Minh	10°49'N	106°42'E	VI-X	double

Legend: W = Winter max.
M = Monsoon

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