Working Paper

ENERGETICALLY ACTIVE CLIMATE-FORMING REGIONS AS REVEALED FROM DATA ON SURFACE EVAPORATION FROM LAND AND OCEAN

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International Institute for Applied Systems Analysis
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Foreword

The design of monitoring systems is an important theme within the Environment Program. This Working Paper is a contribution to the design of climate-monitoring systems in the USSR and is based on the idea that areas of maximum variability of evaporation are climate forming.

The paper has been written by M. Antonovsky and his colleague, P.A. Kolosov from the Natural Environment and Climate Monitoring Laboratory Goskomgidromet and the USSR Academy of Sciences.

R.E. Munn
Head, Environment Program

Preface

As is well known, a considerable part of the USSR belongs to marginal climatic regions that are permafrost, tundra, desert and mountains. Bioproductivity potential in the USSR is at least two times less than, for example, in the USA. A substantial part of the agricultural activity is held on marginal agricultural regions (dry, cold and high altitude). The total agricultural production in the country fluctuates from year to year as a result of climate impact. For example, the difference of total crop production in the extremely unfavorable year 1975, when severe drought damaged vast territories of the country, and the favorable year of 1976, was approximately 40%.

Besides agriculture many other branches of the national economy - transport, sport, construction, energy demand and production - also largely depend on climatic conditions. It is now evident that technology development cannot completely remove the dependence of society on climate. It is excepted that significant climate changes may occur in various parts of the USSR. Therefore, Soviet policy makers consider climate impact analysis as a very important component in establishing, particularly long-term, state plans. A special feature of the Soviet planning system is that plans for short-term periods (5 years) and long-term (up to 20 years) are now made. Such a period, as considered by climatologists, is the period when substantial climatic changes may occur in the Northern Hemisphere.

Hence, the establishment of a climate monitoring system based on a mechanism which truly corresponds to reality is very important from many points of view.

The first author wishes to show his sincere appreciation to Professor R.E. Munn for his overall support and advice.

ENERGETICALLY ACTIVE CLIMATE-FORMING REGIONS AS REVEALED FROM DATA ON SURFACE EVAPORATION FROM LAND AND OCEAN

*M.Ya. Antonovsky and P.A. Kolosov**

A climate monitoring system must take into account the degree and character of continental influences on climate changes and fluctuations, i.e., the climate-forming role of land surfaces. The Soviet national system of land surface monitoring is of great importance for the global climate monitoring system, since the USSR occupies the largest land area in the Northern Hemisphere.

The main climate-forming factor for land areas is soil moisture content.

The moisture content of an area is defined as the total amount of moisture in liquid and solid phases which is contained in all possible accumulators within the area for a given averaging period. The term "moisture content" is introduced into the global hydrologic cycle in the ocean-continent-atmosphere system to characterize the intensity and direction of the ocean-continent water exchange. Therefore, spatial anomalies in moisture level and areas of maximum variation should be determined. Varying the size of the area under study and the averaging period yields for every space-time scale, moisture-content elements with greatest variability. They will serve as an indicator of the hydrologic cycle at a given scale.

Beginning with the monthly averaging interval and with an area that is comparable in size to a continent, indicators of climate-forming factors are, first of all, those moisture elements whose variations control the moisture transfer (and accompanying heat flux) from the continents to the atmosphere and ocean. In summer and autumn these are the water storage in the soil. In winter and spring they are the area of snow cover and frozen lakes, and the associated water storage.

The climate-forming effect of moisture content is revealed in the fact that changes (on a monthly time scale) have a dramatic effect on the heat and moisture exchanges between the atmosphere and the underlying surface over great areas. The effect of biota is also connected primarily with atmospheric moisture content, through transpiration.

To take an example, the annual variation of the main constituents LE, P and R of the land heat balance, are closely connected with moisture conditions. (Here, LE is the heat loss due to evaporation, P is the turbulent flux of sensible heat, and R is the net radiative balance of the earth's surface. For excessive soil moisture during a year, $LE \rightarrow R$, and P is small).

In dry periods when the soil becomes rather dry, P increases due to decreasing LE, the drier the soil. The beginning of the decrease of LE and increase of P somewhat lags behind the beginning of the rainless period, because usually, early in this period, the soil still retains considerable moisture (1).

Study has shown that the difference (R-LE) between the values of net radiation and the heat loss due to evaporation in the warm period of the year is larger, the greater the moisture lack for a given area (1).

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If soil moisture has a potential climate-forming role, evapotranspiration represents the process of interaction between the underlying surface and the atmosphere, combining both the properties of the underlying surface and atmospheric conditions.

Thus, the regions of most intensive change in the heat and moisture exchange between the atmosphere and the underlying surface coincide with regions of maximum variability of evaporation and are climate-forming. Therefore, they are preferable for locating climate and land surface monitoring stations.

To reveal such regions on the USSR territory and in the North Atlantic, a method suggested previously for estimating the time-space variability of climatic quantities (2) is applied to a long data series on evaporation from land surface and on mean-square deviations of monthly evaporation values (3), and to a long data series on evaporation and sensible heat loss from the North Atlantic surface averaged over $5^{o} \times 5^{o}$ squares of the geographic grid (4).

L.I. Zubenok (3) calculated for 1700 points the mean many-year values of evaporation from the land surface using a method based on a simultaneous solution of the equations of heat and water balance and on the experimentally determined evaporation rate as a function of soil moisture (3). L.I. Zubenok compiled maps of monthly mean evaporation from land based on many-year data on precipitation, drainage, radiation balance of the underlying surface, air temperature, etc.

The variability of evaporation was estimated from 28 sites within the USSR grouped according to landscape zones: forest, forest-steppe, and steppe, for a decade (3) (Table 1).

Table 1. Mean Square Deviations of Land Evaporation (δ_E) for Various Landscape Zones

Territory	Landscape zones	δ_E cm/month		
		June	July	August
European USSR	Forest	1.7	1.7	1.6
	Forest-steppe	2.4	2.5	1.9
	Steppe	2.7	2.7	2.5
Asian USSR	Forest	1.0	0.75	0.75
	Forest-steppe	2.1	2.4	1.9
	Steppe	2.5	2.6	2.3

We based our calculations on the assumption that land evaporation time series obey the Pearson probability distribution of type III for $C_s = 2C_v$. This assumption made it possible to relate information on mean many-year values of monthly evaporation to their variability over landscape zones and to calculate, on this basis, all characteristics of time-space variability (2).

As a result of these calculations, charts were compiled for the following characteristics of time-space variability at the points of a $2^{\circ} \times 2^{\circ}$ geographic grid:

1. $\delta E_p = E_p - E_{100-p}$, an index of absolute time variability (p is the percent probability of the variable E exceeding some fixed value); E_p is taken from the Pearson curve of type III which approximates empirical data);

2. $|\mathrm{grad}\,(E_p - E_{100-p})|$, the space gradient δE_p, from which maximum values of the boundaries of zones and regions that are homogeneous with respect to absolute time variability are determined;

3. $$C_{E_p} = \frac{(E_p - E_{100-p}) + 1}{(\bar{E}_{\max} - \bar{E}_{\min})_{zone} + 1} = \frac{\delta E_p + 1}{\Delta \bar{E}_{zone} + 1}$$

an index of time-space variability showing the correlation of amplitudes of spatial fluctuations E in a homogenous zone with time fluctuations $\bar{E}$ at a given probability; here, $\bar{E}_{\max}$ and $\bar{E}_{\min}$ are, respectively, maximum and minimum values of mean many-year evaporation at the boundaries of a zone that is homogenous with respect to δE_p;

4. $\eta_{E_p} = (E_p - \bar{E}_{\max_{zone}};\ E_{100-p} - \bar{E}_{\min_{zone}})$, a parameter characterizing the presence and prevalence, for the observation period, of peaks in E occurring outside the upper and/or lower limits of the space interval of mean values in a homogenous zone.

The resulting boundaries reveal regions that are homogenous with respect to land and ocean evaporation characteristics. The indices C_{E_p} and η_{E_p} describe the inner structure of these regions, which is determined by the interaction of specific zonal landscape features with specific stable features of the atmospheric circulation.

Depending on various combinations of these statistical characteristics, natural regions and areas are identified which play particular roles in the climatic system, i.e., have different functional importance.

The regions where both the average amount and variability of evaporation are large, ($\bar{E} = \bar{E}_{\max}$, $\delta E_p = max$, $C_{E_p} > 1$, $\eta_{E_p} > 0$, $\eta_{E_{100-p}} < 0$) have the greatest effect on the climate system. Such regions may be characterized as energetically active (Figure 1).

Similar energetically active regions were revealed in the North Atlantic from the data on the distribution of latent and sensible heat (LE and P) fluxes over the area in January (4) (Figure 2).

In contrast to this, one also identifies regions of comparatively stable and small evaporation $\bar{E} = \bar{E}_{\min}$, $\delta E_p = \min$, $C_{E_p} < 1$, $\eta_{E_p} < 0$, $\eta_{E_{100-p}} > 0$). These regions are stable under short-period climate fluctuations and are, therefore, indicators of long-period climate change.

Note that only those regions for which deviations are typical, i.e., $\eta_{E_p} > 0$, $\eta_{E_{100-p}} < 0$), can be truly climate-forming. Regions where even for large values of the mean and the mean-square deviations over a many-year period, positive ($\eta_{E_p} > 0$, $\eta_{E_{100-p}} > 0$) or negative ($\eta_{E_p} < 0$, $\eta_{E_{100-p}} < 0$) deviations prevail, are not climate-forming.

The 5%-probability charts have revealed, for the quasi-twenty-year period oscillations, that the climate-forming regions move over the continent from south-west to north-east of the USSR plain area during the warm season.

Thus, in June the main climate-forming region is situated on the south and east of the European USSR, occupying the whole zone of broad-leaved forests, forest-steppes and a part of the steppe zone, and in West Siberia it covers only a narrow band, again in the forest-steppe zone (Figure 1a). Note that the June climate-forming regions agree well with the intersections of regions of maximum average evaporation ($\bar{E}_{max}$) and those of maximum variability ($\max \delta E_{5\%}$)

In July a climate-forming region with intense and unstable evaporation forms in the wide swamp areas of the taiga zone of the West Siberian Plain. At the same time, although evaporation variability in the European USSR remains high, the amount of evaporation decreases. The area of the energetically active region substantially decreases compared with June (Figure 1b). The intersections of regions of $\bar{E}_{max}$ and $\max \delta E_{5\%}$ do not agree well, especially in West Siberia; neither do the above mentioned energetically active regions of July agree with the indicator regions on the charts of moisture coefficient $K = {}^{x}/E$ of 5% probability. This fact is due to different (in time and space) amounts of precipitation, together with soil moisture storage.

In August, both the amount of evaporation and its variability are substantially less because of the slight soil moisture storage and lower precipitation. The evaporation from land can no longer have a strong climate-forming effect. In August the primary climate-forming role of evaporation is again in the south of the European USSR, though the evaporation intensity decreases. In West Siberia, only the Barabinskaya steppe region stands out as a climate-forming unit (Figure 1c). The climate-forming regions again agree better with the regions of $\bar{E}_{max}$ and $\max \delta E_{5\%}$.

To sum up, the climate forming region of the European USSR is much more stable and functionally continuous compared with the West Siberian one. The latter is not apparent in the 20% probability charts, i.e., it occurs only under conditions of anomalously high moisture or dessication.

The significance of the climate-forming role of the energetically active regions is shown by comparing average values and between-year fluctuations of heat flux into the atmosphere from the underlying continental and ocean surface over summer and winter months (Tables 2 and 3).

Table 2 shows that the climate-forming role passes from ocean to continent in summer. The same is true as regards the oscillation range of fluxes of sensible heat P or R-LE. Also substantially higher in summer is the average heat-exchange level in the continental climate-forming regions compared with the oceanic ones. However, in value and intensity, the climate-forming role of the heat flux from the winter ocean is much greater than the summer contribution of the continent.

An analysis of Tables 2 and 3 shows that energetically active regions of the continent in summer and the ocean in winter are comparable in evaporation intensity with a substantially larger (by about a factor of 5) area of energetically active regions of the North Atlantic. The value of absolute time variability of evaporation in continental energetically active regions for 20% probability is 2.5 times as small as that in winter in the active north-west Atlantic source and approaches the latter for 5% probability.

The West Siberian energetically active region is weaker than that in the European USSR because, covering a wider area, it is less favorable than the European USSR energetically active region in all statistical characteristics: the mean, variability indices, and extreme values. This fact is confirmed by comparing the energetically active (climate-forming) regions to the regions of coincidence of maximum evaporation values and its maximum absolute time variability. In West Siberia such a coincidence is absent, but takes place in the European USSR.

Table 2: Comparison of Energetically Active Regions of Continent and Ocean

Value	Climate-forming regions of continent						North Atlantic					
	European USSR, June			West Siberia, July			June*			December**		
	LE	R-LE	B	LE	R-LE	B	LE	P	B	LE	P	B
The mean long-term value kkal/cm^2	7.16	1.12	0.63	6.56	0.81	0.53	3.8	0	7.2	9.8	2.9	10
The maximum range between years oscillations, kkal/cm^2	4.90	4.67	1	3.86	3.23	0.63	1.8	0.8	7	6.4	4.5	

Key: LE - heat loss due to evaporation;
P - turbulent flux of real (explicit) heat;
R - radiative balance of the earth's surface.

* Kolosov and Nuriakhmetova (1982).
** Budyko (1971).

Table 3: Statistical Characteristics of Land Evaporation in Energetically Active Regions of Continent and Ocean

Statistical characteristics of evaporation	European USSR, June	West Siberia, July	North Atlantic, January*
Mean, mm	110-120	100	123
Mean square deviation, mm	24-27	7.5-2.4	-
Absolute time variability, mm δE_p			
$p = 5\%$	87-95	51-113	-
$p = 20\%$	47-48	24-56	115
Standard time-space variability, C_{E_p}			
$p = 5\%$	4.30-4.75	1.70-1.80	-
$p = 20\%$	2.15-2.40	0.80	0.44-0.87
Extreme evaporation values, E_p mm			
$p = 5\%$	-	127-140	-
$p = 20\%$	122-140		247
$p = 80\%$	87-96		-
$p = 95\%$	67-77	76-84	-

*Kolosov and Nuriakhmetova (1982).

The comparison of the areas of energetically active regions is given in Table 4.

As far as monitoring the climate-forming role of the continent is concerned, one should suggest, as the key USSR territory, the region between 48°S and 56°S and 30°E and 56°E in the zones of broad-leaved forests, forest-steppes and steppes of the European USSR which coincides with the zone of intensive farming.

As a region of secondary priority, one should recognize the wide plain areas of West Siberia between 56°S and 68°S and 60°E and 86°-94°E.

Now we discuss the estimate of the existing (up to 1972) weather ship network from the point of view of its coverage of the climate-forming regions and intervening areas.

Weather ships B and D observe the north-west active region of heat-moisture exchange; for a heat exchange zone with $C_p > 1$, i.e., where the temporal variations are greater than spatial ones, this number of stations can be sufficient to characterize this zone and to monitor it. Note that in the south-east North Atlantic where an active unstable moisture exchange zone is situated there is no weather ship.

Table 4: Comparison of Areas of Energetically Active Regions of Continent and Ocean

Months	European USSR			West Siberia			North Atlantic	
	Area ths km^2	Mean evaporation	Mean square deviation	Area, ths km^2	Mean evaporation,	Mean square deviation	Area, ths km^2	Mean Evaporation
	F	$\bar{E}$	δ_E	F	$\bar{E}$	δ_e	F	$\bar{E}$
June	320	115	25	150	110	24	-	63
July	70	-	-	520	100	7.5	-	-
August	90	-	-	50	-	-	-	-
December	-	-	-	-	-	-	2500	164*
January	-	-	-	-	-	-	2500	98-123**

* Budyko (1971).

** Kolosov and Nuriakhmetova (1982).

The Gulf Stream system is covered in its various parts: near the source (H) where heat and moisture transfer are active, in the stable parts (D and F) with a weak prevailing fluxes; in the unstable zone, at the end of the Irminger's North Atlantic current where stable heat transfer is localized. Three weather ships, A, C and K are also related to the conditions of stable cold currents with weak turbulent heat flow from the ocean.

Thus, the majority of stations-weather ships were located in the stable zones and boundary regions rather than in the active sources of heat and moisture exchange.

After considerable cuts in the weather ship network in 1972, four stations (C,K,J,M) remain, none of which characterizes the active sources of heat and moisture exchange and, therefore do not provide information on absolute values of their energetic contributions.

However, these stations can serve as indicators of climatic changes, since they are located at the ends of current (C to the Labrador stream, J to the North Atlantic stream, M to the Norwegian stream) which reflect especially well the between-year oscillations in heat transfer. Ship K is located in the cold Canary current.

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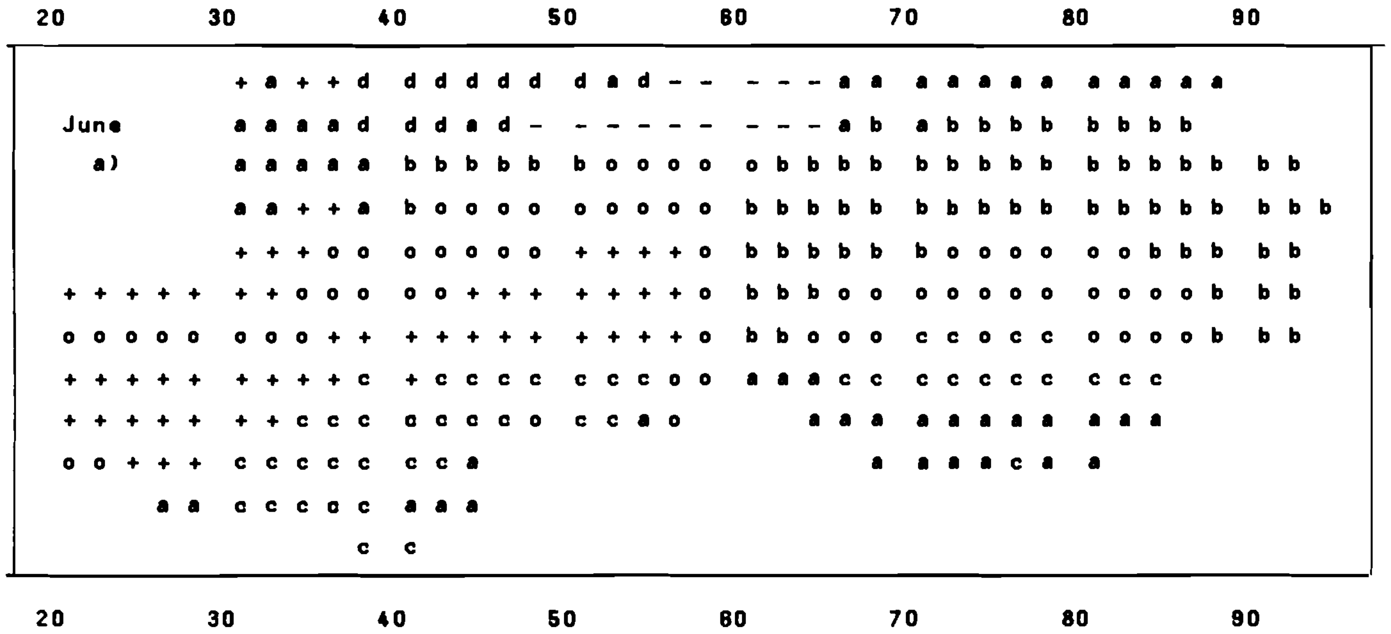
June
a)
20
30
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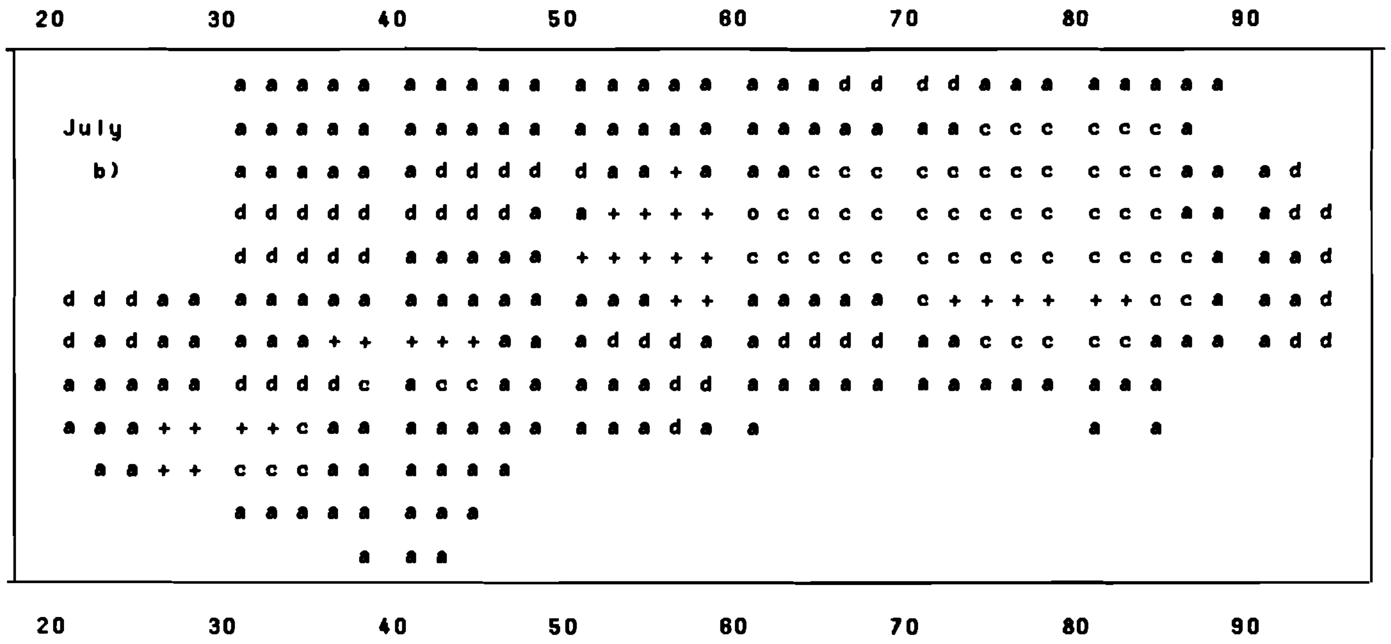
80
90


July
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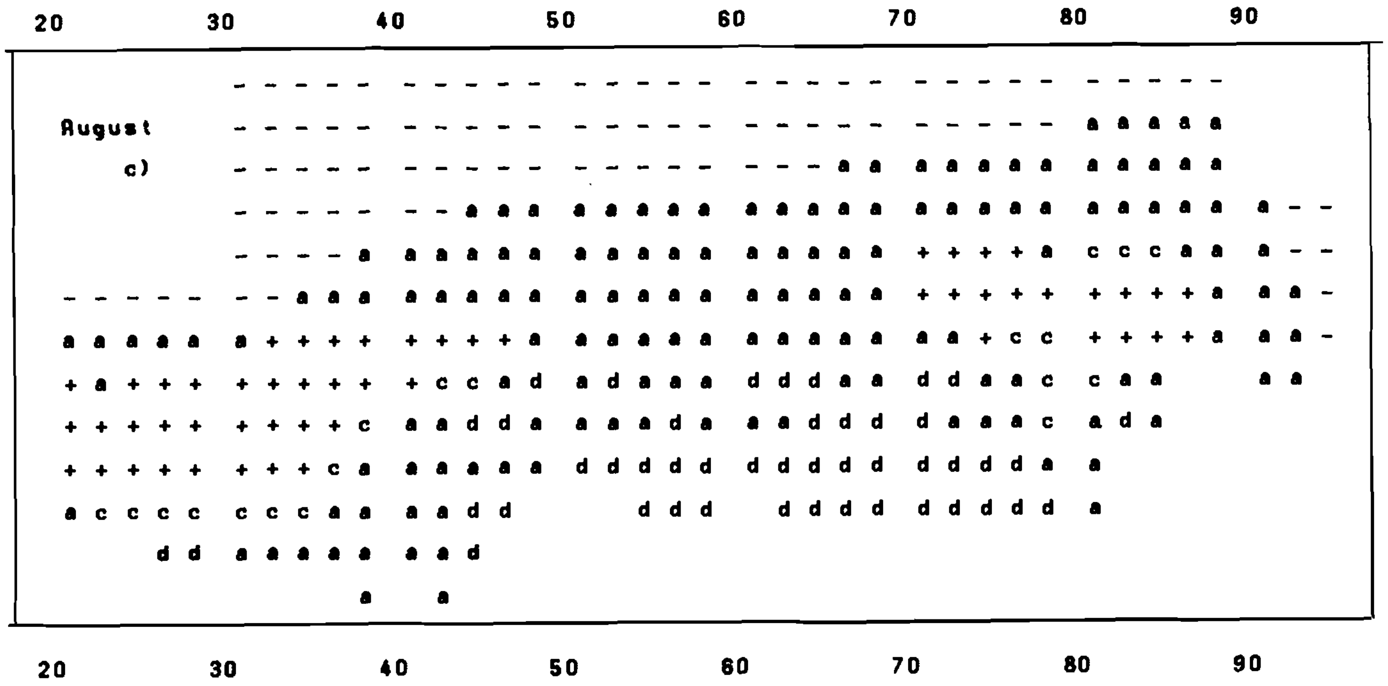

Key:

a = indicators ($\eta_{E5\%}>0, \eta_{E95\%}<0$);

b = background ($\bar{E}=\bar{E}\min$, $\delta_{E5\%}\min$, $c_{E5\%}<1$, $\eta_{E5\%}<0$, $\eta_{E95\%}>0$);

c = climate forming ($\bar{E}=\bar{E}\min$, $\delta_{E5\%}=\max$, $C_{E5\%}\geq 1$, $\eta_{E95\%}>0$, $\eta_{E5\%}<0$).

+ = $\eta_{E5\%}>0$, $\eta_{E95\%}>0$, $C_{E5\%}>1$;

o = $\eta_{E5\%}>0$, $\eta_{E95\%}>0$, $C_{E5\%}<1$;

d = $\eta_{E5\%}<0$, $\eta_{E95\%}<0$, $C_{E5\%}>1$;

- = $\eta_{E5\%}<0$, $\eta_{E95\%}<0$, $C_{E5\%}<1$.

Figure 1: Charts of functional significance of the plain USSR area for evaporation from land surface.

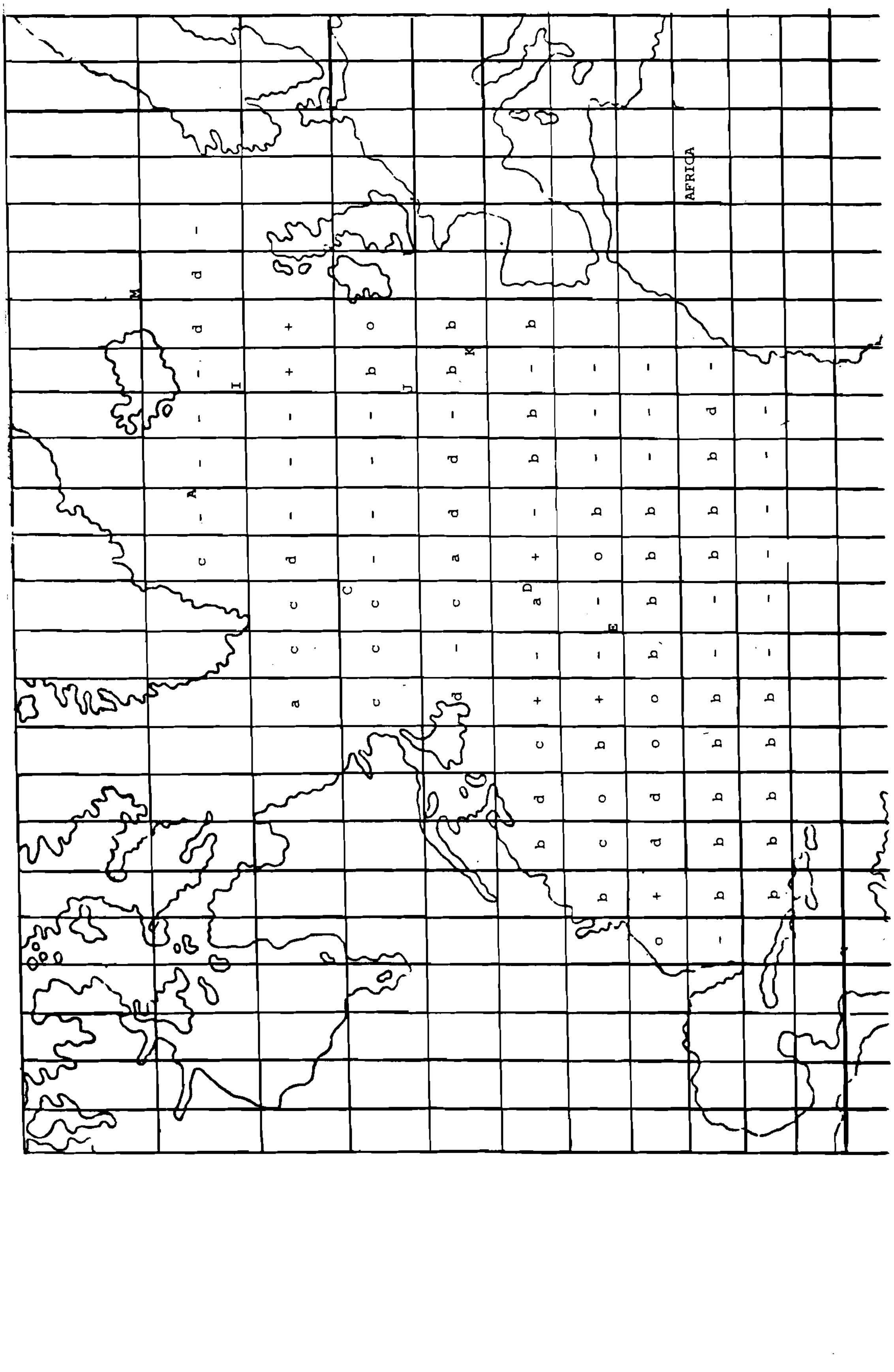

Figure 2a: Chart of functional significance of the North Atlantic water surface for the flux of explicit heat in January. Designations are as in Figure 1.

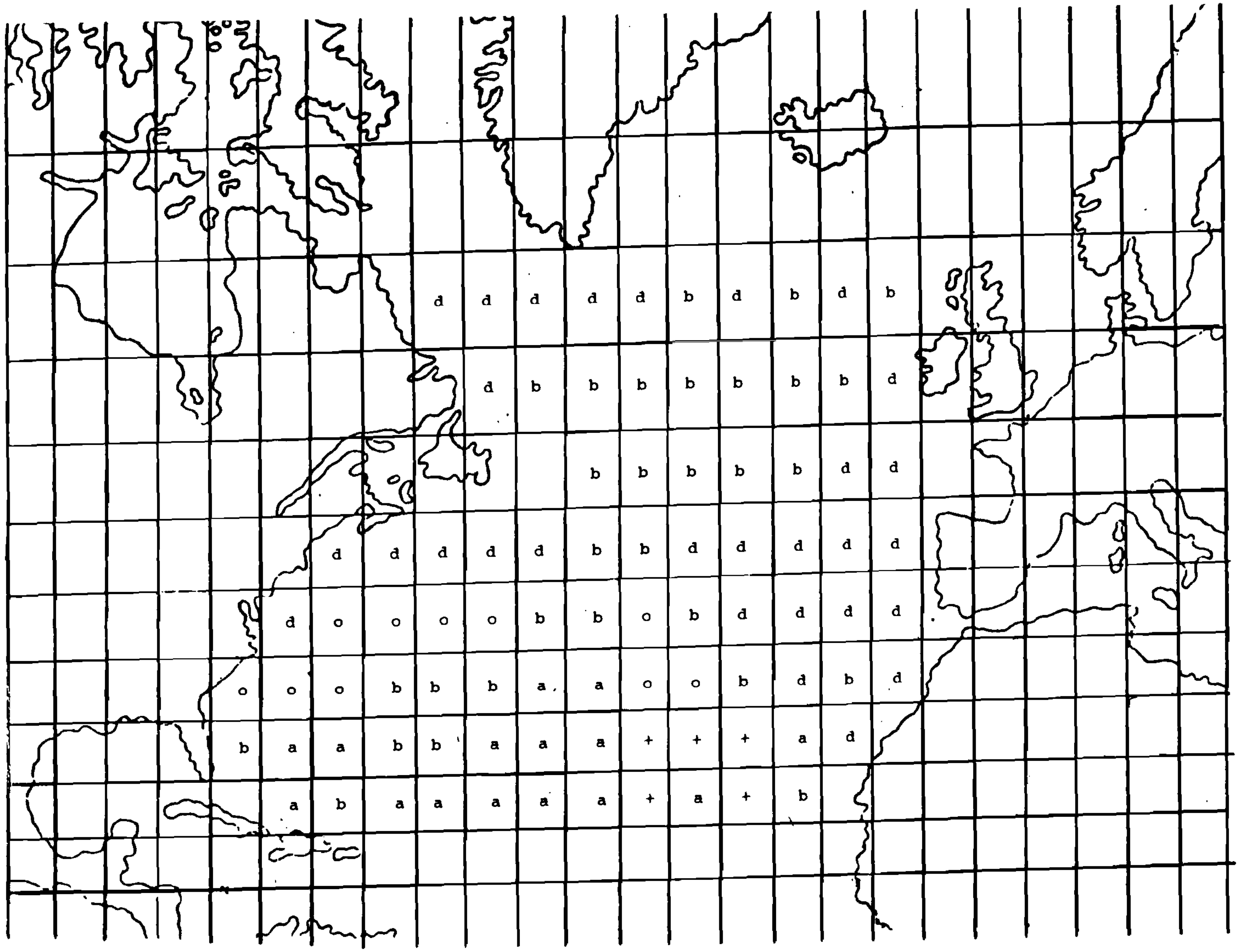

Figure 2b: The chart of functional significance of the North Atlantic water surface for the flux of latent heat in January. Designations are as in Figure 1.