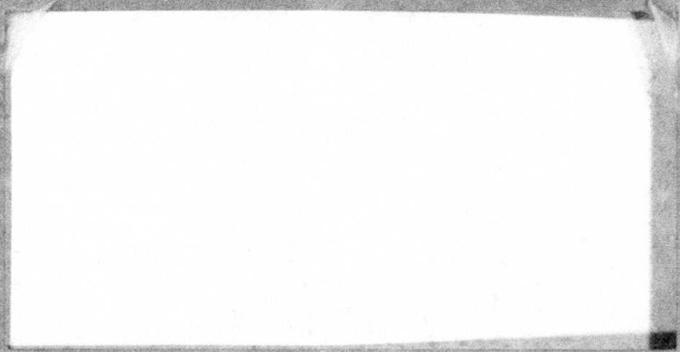


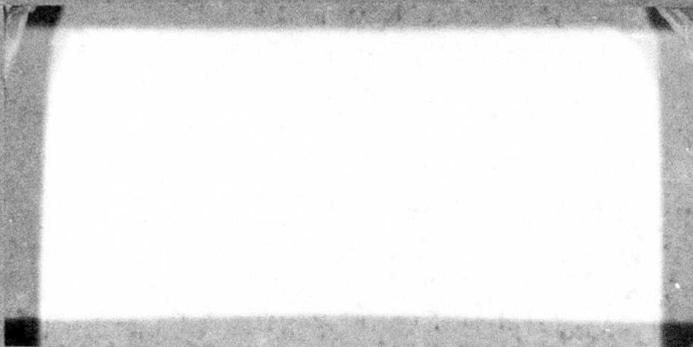
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SOVIET DEVELOPMENTS IN  
WEATHER MODIFICATION, CLIMATE  
MODIFICATION AND CLIMATOLOGY

Sponsored By  
Defense Advanced  
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Climatic Change	Laser Atmospheric Sounding	Fog Dispersal
ABSTRACT (Continue on reverse side if necessary and identify by block number) This report focuses on Soviet developments in weather modification, climate modification, and climatology during the period from late 1973 through mid-1975. Current Soviet work in solar meteorology and laser applications in atmospheric sounding are also surveyed. The source literature includes regular Soviet scientific journals, recent monographs, popular science periodicals, and the daily press.		

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## INTRODUCTION

This report focuses on Soviet developments in weather modification, climate modification, and climatology during the period from late 1973 through mid-1975. Current Soviet work in solar meteorology and laser applications in atmospheric sounding are also surveyed. The source literature includes regular Soviet scientific journals, recent monographs, popular science periodicals, and the daily press.

The vulnerability of the Soviet Union to drought, and the State's commitment to reduce this liability, are a central theme of this report. Citing the Arctic warming trend of the 1920's and 1930's which led to the intensification of drought tendencies in the south and central continental areas of the Soviet Union, Soviet climatologists now view a global warming trend as undesirable, potentially more detrimental than beneficial to agriculture.

In the first section, Planetary Climate Modification, M. I. Budyko and co-authors outline a possible method of moderating planetary warming trends by temporarily increasing the concentration of sulfate aerosol particles in the lower stratosphere and thereby reducing incoming solar radiation. Section II, Climatic Variation: a Projected Climatic Warming, illustrates Soviet concern that a man-generated global warming trend is imminent, induced in particular by the increasing atmospheric carbon dioxide build-up.

Section III, Environmental Modification in the USSR, reviews projected large-scale, long-term water diversion plans to reduce the vulnerability of the USSR to drought in the agricultural belt and to open up new territory in the southern R. S. F. S. R., Central Asia, and Siberia to stable agricultural exploitation. A sub-section, Thermal Reclamation of the Northern Latitudes: Pro and Con, is concerned with more speculative material, but, in conclusion, reflects the considerable present reservations of Soviet scientists as to the advisability of melting the Arctic ice cap.

Section IV reports on significant recent Soviet work in synoptic climatology, solar meteorology, and atmospheric laser sounding including A. A. Girs' recent fundamental work on the macro-circulation method of long-range forecasting and the experimental studies on laser atmospheric sounding being conducted by the Central Aerological Observatory and the Tomsk Institute of Atmospheric Optics.

Section V, Weather Modification, reviews recent Soviet work in cloud seeding, updraft generation (the Supermeteotron), downdraft generation (cloud dissipation), hail suppression, and fog modification.

The concluding general section offers a brief overview of major areas of Soviet concern in climate and weather modification, as presented to the general public, including Soviet views on the threat of environmental warfare.

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## I. PLANETARY CLIMATE MODIFICATION

The projected global effects of future thermal pollution and the increasing build-up of atmospheric CO<sub>2</sub> are discussed by Budyko in [1, 2, 3, 4] with reference to Syukuro Manabe's estimate\* that by the year 2000 the rising CO<sub>2</sub> concentration could cause a mean global 0.5 C surface temperature increase and a mean 1 C temperature rise in the high latitudes.

In Budyko's judgement, the present global climatic conditions should be maintained, since restructuring the Soviet national economy would require a far greater capital investment than the anticipated benefits from improving climatic conditions for certain sectors of the economy.

The detrimental agroclimatological effects are cited of the warming trend of the 1920's and 1930's, (i. e. mean surface air temperature rose 0.3 C in the Northern Hemisphere as a whole and 0.7 C in the higher latitudes). During this period in drought-prone areas of the USSR, such as southern European Russia and Kazakhstan, the number of droughts extending over broad areas was three times greater than during either preceding or subsequent decades. Precipitation in the Volga basin declined significantly, as reflected by the major drop in the level of the Caspian Sea.

In a 1972 monograph [4], Budyko proposed decreasing climatic fluctuations by regulating the density of the aerosol layer of the lower stratosphere. A climate modification program designed, for example, to counteract an Arctic warming on the scale of the trend in the 1920's and 1930's would require a 2% reduction in direct radiation, i. e. a 0.3% reduction in total radiation. Based on the author's analysis, a 0.36  $\mu\text{g}/\text{m}^3$  increase in the Northern Hemisphere stratospheric aerosol concentration will cause a 1% decrease in total radiation. (Estimating that the aerosol layer is 10 km thick, this value will correspond to a  $0.36 \times 10^{-6} \text{ g}/\text{cm}^2$  aerosol concentration

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\* SMIC, Inadvertent Climate Modification, MIT Press, 1971.

in a vertical column passing through the aerosol layer.)

A comparison is made of a number of theoretical calculations for M, or the aerosol concentration required to reduce total radiation 1%. This survey included the values for M independently obtained by Ye. P. Novoseltsev, K. Ya. Vinnikov, E. W. Barrett\*, and Yamamoto and Tanaka\*\*, which ranged from  $0.4 \times 10^{-6}$  g/cm<sup>2</sup> to  $1.3 \times 10^{-6}$  g/cm<sup>2</sup>, respectively.

In addition, the M value derived from observational data and empirical relationships was also considered. Based on actinometric data, for example, the aerosol attenuation of direct radiation flux averages about 10%. Judging from the available data, two thirds of radiation attenuation is caused by aerosol backscattering and one third by particulate absorption of radiation. If it is assumed that the mean concentration of optically active aerosols in the atmosphere is equal to  $10^{-5}$  g/cm<sup>2</sup>, and considering the above-cited relationship between the attenuation of direct radiation and total radiation during backscattering, then  $M = 1.1 \times 10^{-6}$  g/cm<sup>2</sup>.

Using Angstrom's formula linking the albedo for the Earth-atmosphere system with the optical turbidity index (and assuming the mean aerosol concentration cited above), the value obtained for M was  $0.6 \times 10^{-6}$  g/cm<sup>2</sup>.

(In regard to this survey of values obtained for M, Budyko notes that the slightly lower value obtained by direct measurements of the stratospheric aerosol concentration reflects the concentration of sulfate compounds in the lower stratosphere, rather than the actual aerosol concentration.)

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\* Barrett, E. W. Depletion of Short Wave Irradiance at the Ground by Particles Suspended in the Atmosphere, Solar Energy, Vol. 13, No. 3, 1971.

\*\* Yamamoto, G., and M. Tanaka. Radiative Transfer and Optical Properties in Turbid Atmospheres, Proc. Internat. Rad. Symp., Sendai, Japan, 1972.

Based on the evaluations cited above, the mean value for  $M$  is  $0.8 \times 10^{-6}$  g/cm<sup>2</sup>. Thus, in order to reduce total radiation 0.3%, the aerosol volume in the stratosphere of the Northern Hemisphere should be increased 600,000 tons. This level could be obtained through the combustion of 200,000 tons of sulfur, which would yield approximately 400,000 tons of sulfur dioxide, and thus the targeted 600,000 tons of H<sub>2</sub>SO<sub>4</sub> aerosol particles. Estimating an average two-year lifetime for aerosol particles in the lower stratosphere, approximately 100,000 tons of sulfur would have to be injected into the lower stratosphere annually in order to maintain the necessary concentration of pure sulfuric acid aerosol particles. However, due to the hygroscopic nature of concentrated sulfuric acid it may be possible to reduce the estimated amount of reagent significantly, depending on the value determined for the H<sub>2</sub>SO<sub>4</sub> concentration in atmospheric aerosol particles. Since the exact value for the H<sub>2</sub>SO<sub>4</sub> concentration in atmospheric aerosol particles is not known, two orientational values of 30% and 15% were adopted by Budyko [1], corresponding to the annual injection into the stratosphere and combustion of 20,000 tons of sulfur, in the first case, and 8,000 tons of sulfur in the second case. The required volume of the reagent could be delivered to the lower stratosphere by several regularly operating aircraft equipped with sulfur combustion devices.

The quantity of the reagent to be injected into the atmosphere as a result of such a climate modification effort would be insignificant compared to the volume of matter introduced into the atmosphere through human industrial activity, e. g. several orders of magnitude less than the several 100 million tons of particulates annually discharged into the atmosphere. Furthermore, the amount of the reagent which would be eventually returned to the Earth's surface would average, on the basis of these figures, about 0.2 mg of sulfur per square meter per year, or approximately 1000 times less than the natural sulfur fallout in atmospheric precipitation.

The location at which the reagents will be injected into the stratosphere is of limited importance, since, as demonstrated by the distribution of dust from volcanic eruptions, a reagent discharged at a point

outside of the equatorial zone is swiftly disseminated throughout the Northern Hemisphere. However, study of the circulation patterns in the lower stratosphere may lead to a determination of the optimal regions and time periods for the most effective dissemination of reagents.

In regard to the problem of inadvertent climate modification, Budyko refers to the 1970 SCEP\* estimate that in 1985-1990 over 500 aircraft will be flying at altitudes from 18-20 kilometers. If a low-sulfur (0.05% sulfur content) fuel is used, the emissions from these aircraft will introduce into the Earth's lower stratosphere about 63,000 tons of SO<sub>2</sub>, or the equivalent of about 100,000 tons of sulfate aerosols. Budyko estimates that the annual increase in sulfate particles in the stratosphere over the Northern Hemisphere will equal approximately 70,000 to 80,000 tons, hence a total aerosol volume of at least 200,000 tons. Estimating a mean lifetime of two years for particles in the stratospheric aerosol layer, stratospheric flights would increase the Northern Hemisphere concentration of these particles by approximately 400,000 tons, i. e. by over half the aerosol volume needed to carry out the climate modification effort described above.

In later monographs by M. I. Budyko, co-authored with L.S. Gandin, O.A. Drozdov, I.L. Karol', and Z.I. Pivovarova [2,3] and with K.Ya. Vinnikov[3] it is indicated that by increasing the aerosol concentration in the lower stratosphere according to the method described above, precipitation would be increased in a number of regions in the temperate latitudes. This conclusion is supported by the following analysis.

Using Budyko's semi-empirical model\*\* of the atmospheric thermal regime, calculation was made of the effect of variations in the stratospheric aerosol concentration, and thus in direct radiation, on the atmospheric temperature regime in the Northern Hemisphere. The estimated

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\* SCEP, Man's Impact on the Global Environment, MIT Press, 1970.

\*\* Budyko's semi-empirical model is described in [4] and M. I. Budyko, The Effect of Solar Radiation Variations on the Climate of the Earth. *Tellus*, 21: 611-619.

variations in total radiation, given a mean hemispheric variation of 2% in direct radiation, are shown in the table below.

Table 1  
Relative variations in total radiation (in %) due to a 2% variation in direct radiation.

Half Year	North Latitude, degrees										
	0	10	20	30	40	50	60	70	80	90	0-90
Warm	0.19	0.19	0.19	0.22	0.28	0.31	0.38	0.48	0.61	0.90	0.26
Cold	0.19	0.24	0.28	0.34	0.40	0.49	0.67	1.03	2.15	-	0.43

Using semi-empirical formulas for the Northern Hemisphere atmospheric thermal regime, the authors calculated that, given a 2% reduction in direct radiation in the Northern Hemisphere, the mean air temperature in the tropical and temperate latitudes during all seasons of the year will decline approximately 0.3 C. In the zone from 70° to 80° north latitude the temperature would decline 0.6 C during the warm half of the year and 1.2 C during the cold half of the year.

Using the more general thermotropic world climate model of L. S. Gandin, B. M. Il'yn, et al.\* (based on an equation for the influx of heat into the atmosphere, integrated for height and calculating for both hemispheres), the effect on global air temperature of changes in direct radiation of 2%, 6% and 18% was investigated. It was determined, as indicated in table no. 2 below, that the polar-equatorial temperature gradient changes of 0.5, 1.7, and 5.6 C correspond to increases of 1.8%, 5.7%, and 20% in the mean velocity of zonal circulation.

\* Glavnaya geofizicheskaya observatoriya, Trudy, no. 315, 1973.

Table 2

## Variations in direct radiation and global air temperature

Direct radiation variation, %	-2%	-6%	-18%
Equatorial temperature variation, °C	-0.3	-1.1	-3.7
Mean global temperature variation, °C	-0.6	-2.0	-6.6
Polar temperature variation, °C	-0.8	-2.8	-9.3
Equatorial-polar temperature gradient variation, °C	0.5	1.7	5.6

As established by Drozdov\* and others, the meridional air temperature gradient is the most significant of the factors affecting precipitation volume over periods of a month or more. In the USSR, in the course of a year, the correlation coefficients between the air temperature gradients and precipitation vary from 0.91 in December to -0.20 in July and August. Generally during a warming trend in the high latitudes, precipitation increases in the northern regions due to the increased water vapor in the atmosphere and the shifting of cyclone tracks to the high latitudes. Correspondingly, during a polar zone cooling trend the volume of precipitation in drought-prone areas of the temperate latitudes will generally increase.

Analysis of data for the last two centuries demonstrates that during the periods of reduced ice cover in the Atlantic or Barents sectors of the Arctic, severe droughts have invariably occurred in central and western Europe and in southwestern Siberia. Consequently, preservation of the Arctic glaciation should significantly improve moisture conditions in the steppe regions and promote a more even distribution of precipitation over the territory of the USSR.

\* Drozdov, O. A. Ob izmenenii osadkov severnogo polushariya pri izmenenii temperatur polyarnogo basseyna (On precipitation variations in the Northern Hemisphere due to Arctic Basin temperature variations). GGO, Trudy, no.198, 1966.

The nonuniform distribution of the ice cover leads to increased meridional circulation and a distinctly uneven distribution of moisture. Thus, an intensified temperature contrast (e. g. a warm Barents Sea and an ice-choked Kara Sea ) probably contributed to the development of the 1972 droughts in the European USSR, as well as the cold, rainy summer in Western Siberia and in Kazakhstan.

The existence of such relatively simple, inexpensive technical means for modifying global climate raises certain critical questions requiring further study. (1) An international climate control program should be developed which would insure the maintenance of the existing climate, despite the projected trend towards a global warming induced by human industrial activity. (2) A method should be adopted for preventing the natural climatic fluctuations which intensify drought tendencies in arid areas in the temperate zone. (3) Further study of the impact on the lower stratosphere of high-altitude aircraft and the effects of human industrial activity is essential.

Solution of these problems depends to a considerable extent on the development of a comprehensive quantitative theory of world climate.

Budyko concludes that adoption of an international agreement, banning unilateral climate modification is imperative. This agreement should encompass both deliberate climate modification measures as well as the inadvertent environmental consequences of large-scale human activity.

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3. Budyko, M. I., K. Ya. Vinnikov, L. S. Gandin, O. A. Drozdov, I. L. Karol', and Z. I. Pivovarova. Klimat i vozdeystviya na aerazol'nyy sloy stratosfery (Climate and modification of the stratospheric aerosol layer). Leningrad, Gidrometeoizdat, 1974, 41 p.
4. Budyko, M. I. Vliyaniye cheloveka na klimat. (Man's impact on climate). Leningrad, Gidrometeoizdat, 1972, 46 p.

## II. CLIMATIC VARIATION: A PROJECTED CLIMATIC WARNING

The case for a possible major, rapidly-accelerating global warming trend, induced by the compounding growth rates of thermal pollution and of the atmospheric CO<sub>2</sub> concentration, is set forth by M. I. Budyko in [1].

The Earth's "thermal barrier" (i. e. a 2 to 3 C increase in global air temperature) could be reached within the next century if the growth rate of world energy production, resulting in a mean 6% annual increase in energy production and a 0.2% annual increase in the atmospheric CO<sub>2</sub> concentration, continues as projected. This is illustrated in Figure 1.

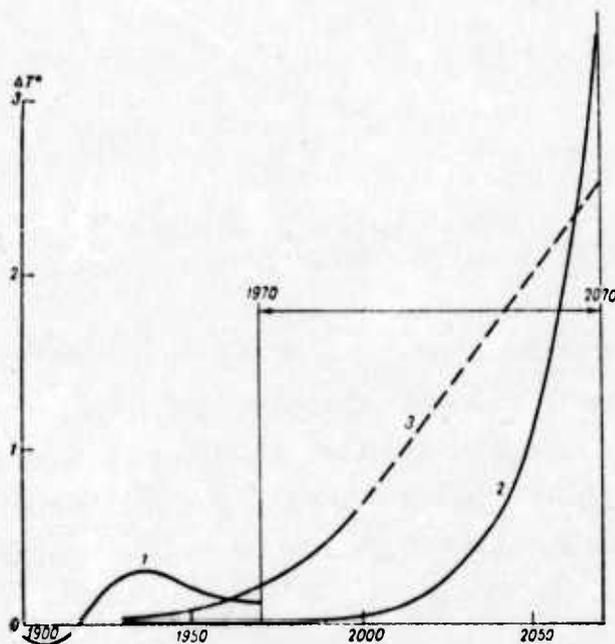


Fig. 1. Secular Trend of Surface Air Temperature Anomalies (1900-2070).

1 - observational data; 2 - changes caused by the growth of energy production (projected at 6% annually); 3 - changes caused by the growth of the atmospheric CO<sub>2</sub> concentration (projected at 0.2% annually).

According to Budyko's projections, by the year 2000 the mean boundary of the polar ice cap could retreat  $2^{\circ}$  to the north (i. e. more than 200 kilometers), thus causing a marked air temperature increase in the high latitudes, particularly during the cold period of the year. Based on the above analysis, complete thawing of the Arctic Ocean ice cap could occur within 80 years (Fig. 2). Possible consequences of the thawing of the Arctic Sea ice could include the gradual thawing of the

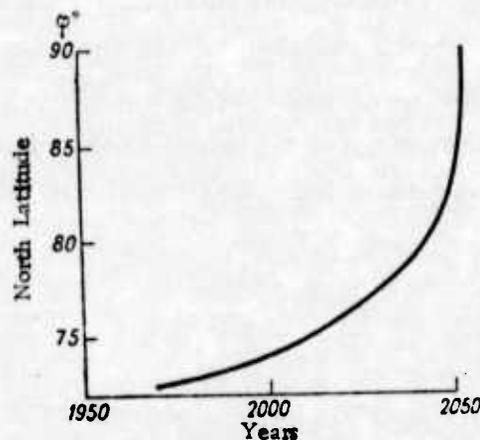


Fig. 2. Mean latitudinal changes in the boundaries of the Arctic Ocean ice cover.

Greenland and Antarctic glaciation, which would further raise the level of the world ocean as well as alter the continental hydrologic cycle. As evidence of the detrimental effects to the Soviet Union of a climatic warming trend, Budyko cites the polar warming trend of the 1920's and 1930's which aggravated drought tendencies in the arid continental areas in the USSR.

In conclusion, Budyko stresses the urgency of directing immediate attention to the "scientific, theoretical, technical, and social problems involved. . . in protecting mankind from unfavorable climatic changes."

The threat of a progressively accelerating planetary warming trend linked to the projected atmospheric CO<sub>2</sub> build-up is also discussed by T. Ayzatallin and V. Lebedev in [2], who cite Budvko's assessment that a major global warming trend could occur relatively swiftly -- roughly on the order of 100,000 times more rapidly than a pronounced planetary cooling.

As a result of the greenhouse effect an estimated 60% of the Earth's outgoing radiation is trapped by water vapor and 18% by CO<sub>2</sub>. If the present atmospheric CO<sub>2</sub> concentration doubles, global air temperature could rise 4 C. Citing the calculations of Budyko, the authors show that a 4 C annual increase in the Arctic air temperature during the three summer months alone could melt a 4-meter deep layer of ocean ice within 4 years as the amount of solar radiation absorbed by the planet progressively increases. The air temperature at the North Pole would thus rise 8 C during the warm half of the year and 22 C during the cold half of the year to a mean level of 5 C in the summer and - 5C in the winter.

Projections of the increasing global energy needs indicate that by the year 2000 the annual release of CO<sub>2</sub> into the atmosphere may grow by a factor of five. Furthermore, the atmospheric CO<sub>2</sub> buildup would be almost four times greater than at present, if the current level of excess atmospheric CO<sub>2</sub> uptake by the sea did not occur.

In regard to present climatic conditions, M. Petrosyants, Director of the USSR Hydrometeorological Center, in [3] cites statistical evidence showing a warming tendency for Moscow and possibly the western areas of the USSR. In the Moscow region during the past decade the number of positive temperature anomalies has been twice the number of negative temperature anomalies. On the other hand, in Asiatic USSR a cooling tendency has been noted. In Novosibirsk, for example, during the same period six negative monthly anomalies on the order of 3 degrees or greater have occurred, as opposed to only four positive monthly anomalies.

In Petrosyants' view, the evidence is insufficient to indicate that we are currently in an abnormal climatic period, let alone experiencing a significant climatic variation on the scale of the warming trend of the 1930's - 1950's.

The need for more sophisticated climate models capable of more accurately assessing the role of positive feedback in climatic change, e. g. the effect of the snow-ice cover on the planetary albedo-temperature coupling, is cited in a paper published in late 1974 by Budyko [4].

Comparison is made of the results obtained through Budyko's semi-empirical climate model and those obtained by independently developed U.S. climate models for the estimated effect on global air temperature of: (1) potential changes in the thermal pollution rate, (2) a doubling of the atmospheric CO<sub>2</sub> concentration, and (3) a 2% increase in the solar constant. Examination of the results shows that relatively comparable values were reached in these three cases.

For example, in assessing the effect of thermal pollution on global temperature, W. M. Washington used in a three-dimensional general circulation model (1971) the figure of 50 cal/cm<sup>2</sup>/day for the estimated rate of increase of global energy production. Budyko's application of this figure in his semi-empirical climate model gave a mean global temperature increase of 3C, as compared with Washington's results, namely increases in mean temperatures ranging from 1-2 C in the tropics to 8-10 C in the high latitudes of the Northern Hemisphere. (In both cases the planetary albedo-global temperature coupling was not considered).

In a later (1972) study Washington used a thermal pollution rate 1/6 that of the first, above-cited rate with the heat flux distributed according to global population density. Application of these data in Budyko's semi-empirical climate model yielded a global temperature alteration of 0.5 C, a value which is considerably less than the range of the natural fluctuations characteristic of Washington's three-dimensional general circulation model.

In regard to the effect on the mean latitudinal air temperature of doubling the atmospheric CO<sub>2</sub> concentration, (considering the feedback between changes in the atmospheric thermal regime and the snow-ice cover), comparison of calculations using Budyko's semi-empirical model and S. Manabe's general theory of climate yields comparable results, as shown in Fig. 3 below.

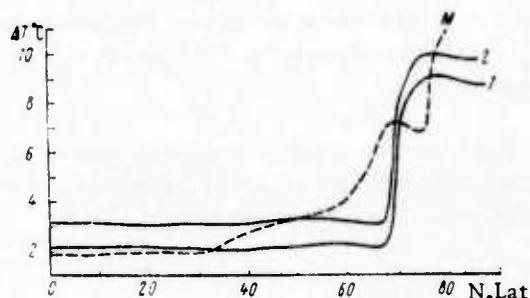


Fig. 3. Air temperature changes in the Northern Hemisphere due to an increase by a factor of two in the the atmospheric CO<sub>2</sub> concentration.

Line M indicates Manabe's results using a general theory of climate. Lines 1 and 2 demonstrate the application in the author's semi-empirical model of two different calculations for the atmospheric CO<sub>2</sub>-air temperature coupling: line 1 represents the calculations of L. R. Rakipova and O. N. Vishnyakova (1973), and line 2 the work of Manabe and Wetherald (1967).

The effect on surface air temperature of a 2% increase in the solar constant is also examined, comparing the results of Manabe's recent work (using a three-dimensional dynamical model with idealized geography)\*\* with the results from Budyko's semi-empirical climate model. See Fig. 4 below.

\* Rakipova, L. R., and O. N. Vishnyakova, *Meteorologiya i gidrologiya*, no. 5, 1973, 23-32.

\*\* Work as yet unpublished in 1974 by Manabe, as described by J. Smagorinsky in W. N. Hess, Weather and Climate Modification, New York, Wiley, 1974, p. 681-682.

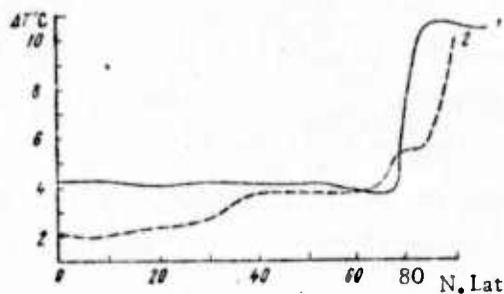


Fig. 4. Air temperature changes in the Northern Hemisphere due to a 2% increase in the solar constant.

Line 1 represents the calculations using Budyko's semi-empirical climate model; line 2 refers to Manabe's above-cited three-dimensional model.

As shown in Fig. 4 above, Manabe's general model of climate theory which considers the linkage between the thermal regime and snow-ice cover indicates a 3.1 C mean hemispheric temperature increase, given a 2% increase in the solar constant, as compared with the calculation of 4.5 C obtained by Budyko. A roughly 4% reduction in the solar constant is considered sufficient to cause complete glaciation of the Earth by both Manabe and Budyko. Budyko comments that the somewhat greater sensitivity of semi-empirical models to variations in the radiational flux as compared with Manabe's model is explained in large measure by special characteristics of the parametrization of the effect of cloud cover on outgoing radiation, rather than by differences in the calculation of large-scale atmospheric motion in the models being examined.

In regard to man's impact on climate (e. g. the estimated 6% mean annual increase in energy production, a 0.2% mean annual increase in the atmospheric CO<sub>2</sub> concentration, and an annual approximately 200-400 million ton increase in the atmospheric anthropogenic aerosol load), Budyko calls for further quantitative study of the CO<sub>2</sub> absorption mechanism and development of a comprehensive quantitative theory to assess the effect of the buffer processes in the ocean and in the biosphere on changes in the atmospheric CO<sub>2</sub> concentration.

Budyko makes a comparison, using different climate models, of the global warming which could be induced by the projected 20% increase in the atmospheric CO<sub>2</sub> concentration between 1970 and the year 2000. According to the one-dimensional (1967) climate model of Manabe and Wetherald such CO<sub>2</sub> increase would cause a 0.5 C rise in the mean global air temperature, while Manabe's recent calculations using a three-dimensional climate model\* indicate a mean 0.7 C increase. Budyko's semi-empirical atmospheric thermal regime model, applying the above-cited Rakipova-Vishnyakova linkage between air temperature and CO<sub>2</sub>, yields a mean 0.6 C temperature increase, assuming a quasi-steady state of the polar ice, and a 0.9 C increase if a steady-state ice regime is assumed. Thus a mean 0.5 -- 1.0 C global temperature increase by the end of this century is an imminent possibility.

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\* Ibid.

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### III. ENVIRONMENTAL MODIFICATION IN THE U.S.S.R. AND THE ARCTIC BASIN

#### 1) Large-scale Water Diversion Projects in the U.S.S.R.

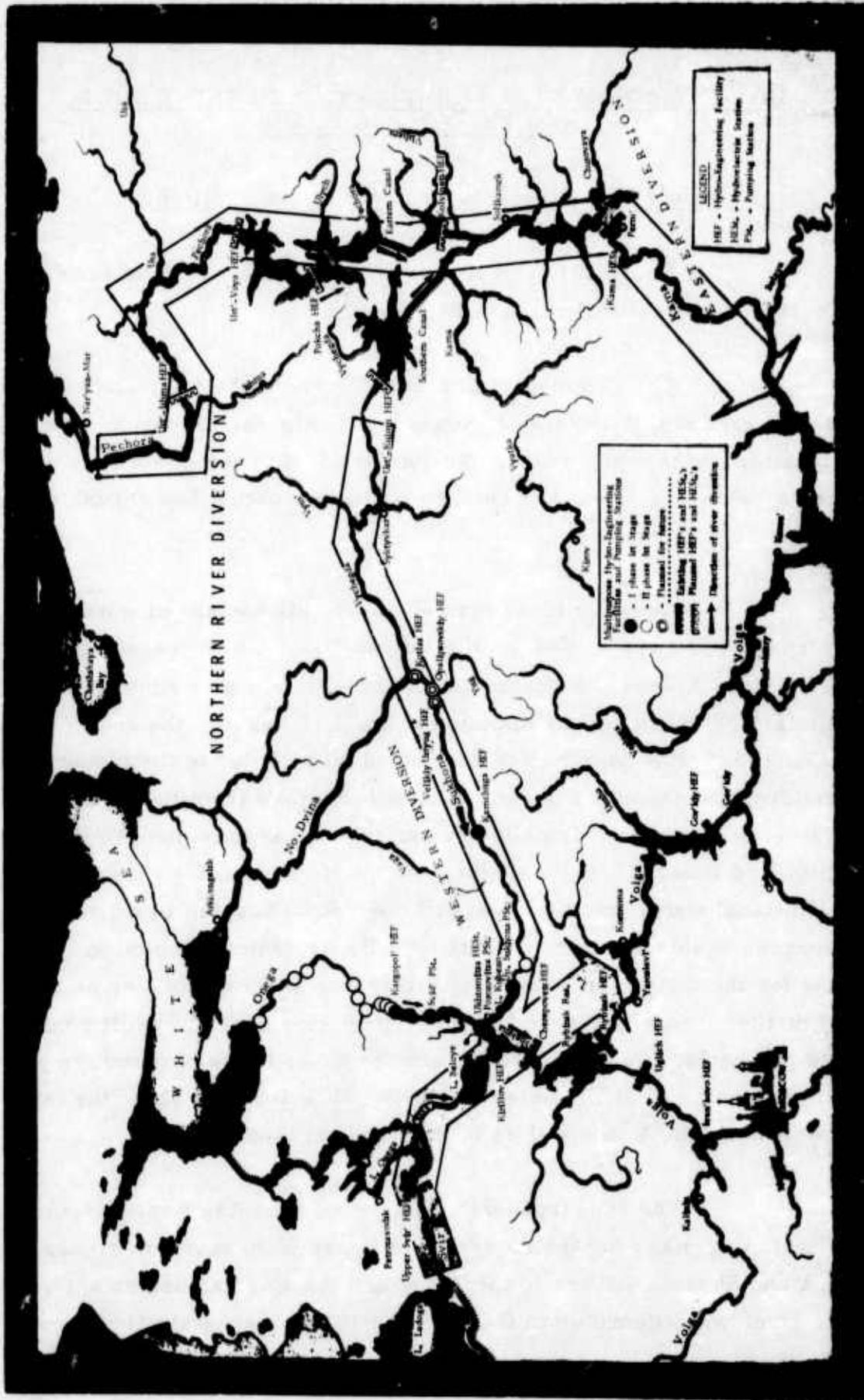
Barvinskiy and L'vov [1] review the rationale for diversion of northern rivers in the U.S.S.R.

The 2.5 meter drop in the level of the Caspian Sea which has occurred within the last 40 years is the highest recession rate of the Caspian in the last 400 years. The water level of the Caspian is now 29 meters below sea level; her shallow northern portion has shrunk almost one fourth.

Annually more than 300 cubic kilometers of water flow into the landlocked Caspian Sea via the Volga, Ural, Kura, Terek, Salur, Sulak, and Sefidrud Rivers. If precipitation and ground water runoff are considered the total volume is approximately  $400 \text{ km}^3$ . However, the annual runoff from the Volga into the Caspian has decreased  $20 \text{ km}^3$  due to the industrial and agricultural demand for water. The water intake from the Ural River is even greater: in dry years virtually her entire discharge is pumped off. The diminished Emba River no longer reaches the Caspian. Without the diversion of additional water into the rivers of the Volga-Caspian Basin, the water resources of this area are threatened with systematic depletion. The extensive plans for the irrigation of approximately 8.2 million hectares along the Volga will further intensify this problem. Estimating roughly that the minimum grain yield per hectare is about 2 tons and the expenditure of moisture per ton of grain is about 270 cubic meters, then for this program alone the total annual drawoff from the Volga will be in the neighborhood of  $5 \text{ km}^3$ .

The "Gidroproekt" Design and Planning Research Institute is developing plans for the diversion of water from northern rivers via the Kama and Sheksna Rivers to the Volga and the Caspian Sea as shown in Fig. 1 below. According to the director of the Institute's Department for

Fig. 1. Northern River Runoff Diversion Plan for European U.S.S.R.



the Diversion of Northern Rivers, G. Sarukhanov, runoff will be diverted to the southern portion of the European USSR via an eastern artery, fed by the Pechora and the Vychegda Rivers, and via a western artery which will channel water from the Northern Dvina and its tributaries in addition to intake from Lakes Kubena, Vozhe, Lacha, and Onega.

Completion of the first phase of this project, which will require 30 to 40 years, will result in the annual diversion of approximately 60 cubic kilometers of water to the Volga. The southward diversion of water from the Pechora River will be undertaken in three independent stages, the first of which could be completed within the next five-year plan (1975-'80). From an initial annual diversion rate of 5-6 cubic kilometers, the volume will be gradually increased so that by the end of the 11th five-year plan (1981-'85), approximately 20 km<sup>3</sup> of runoff will be annually diverted south into the Volga.

The projected comprehensive plans for the diversion of northern river water to the south are outlined in more detail by A. N. Kosarev [2] as measures to alleviate the serious continuing recession of the landlocked southern seas of the USSR, the Caspian and Aral Seas (Fig. 2) and the Sea of Azov.

In the course of the last 40 years the mean annual deficit in the water balance of the Caspian Sea has been 8.8 km<sup>3</sup>, while the annual deficit of the Aral Sea has averaged 2.2 km<sup>3</sup>. At present the Caspian Sea loses about 10 km<sup>3</sup> per year in runoff to the Kara-Bogaz-Gol. The annual outflow from the Sea of Azov to the Black Sea is approximately 49.2 km<sup>3</sup>, while the return flow is only 33.8 km<sup>3</sup> annually. In addition the Sea of Azov annually loses about 1 km<sup>3</sup> of runoff to the Sivash Sea, which lies to the immediate west. After the construction in 1952 of the Tsimlyansk Reservoir and the irrigation systems on the Don and the Kuban Rivers, the annual volume of water diverted from these rivers reached 15% of their long-term mean runoff.

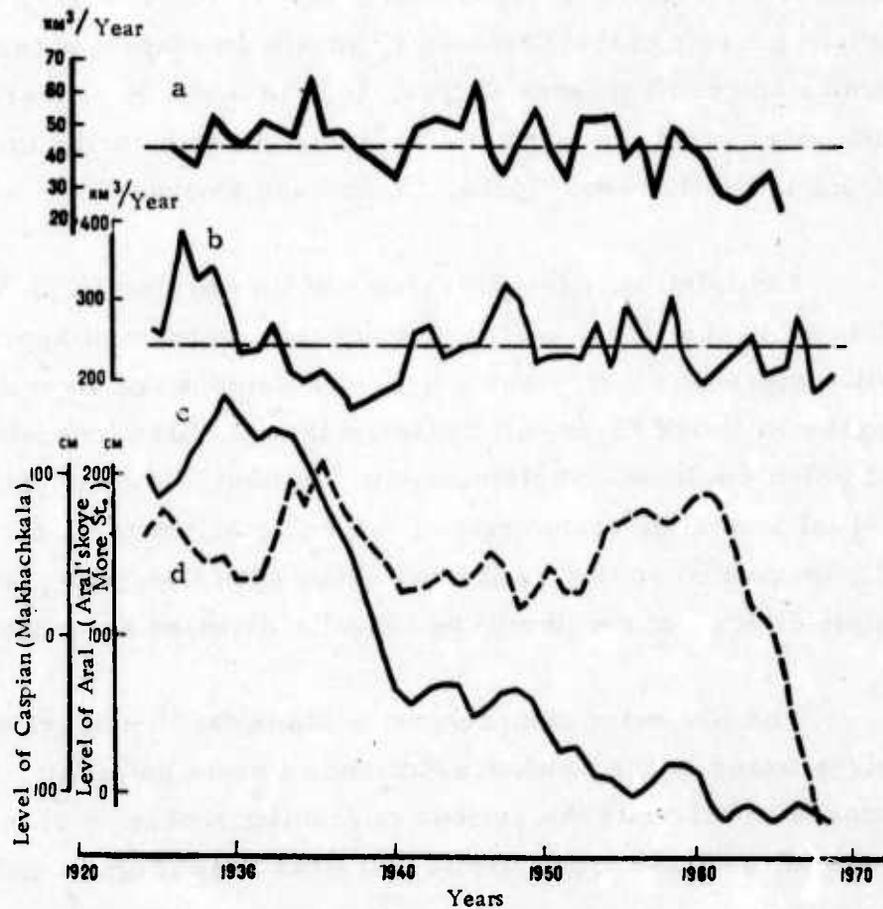


Fig. 2. Changes in the runoff of the Amu-Dar'ya (a) and Volga (b) Rivers, and in the levels of the Caspian (c) and the Aral Seas (d) in the twentieth century.

In regard to the Sea of Azov, in 1966 the Gidroyekt Institute developed a "Plan for the Complex Use and Protection of the Water Resources of the Azov Basin." The plan is to be implemented in two stages: until 1985 the water resources of the Azov Sea Basin will be exploited; by 2000 northern river runoff will be diverted to the Azov via the Volga, the Tsimlyansk Reservoir and the Volga-Don Canal. In 1972 work was begun on the Kerch Hydro-Engineering Complex, which will regulate water exchange between the Black Sea and the Sea of Azov. It is scheduled for completion by 1980.

The primary cause for the drastic recession of the Caspian Sea, in addition to recurring droughts, has been the construction of the Kuybyshev and Volgograd Hydroelectric Stations, which has significantly decreased the annual runoff from the Volga River. Year 2000 projections of the further recession of the Caspian Sea range from 4 m to 60 to 70 cm, depending on climatic conditions and the demands imposed on Volga Basin resources by water diversion projects.

The most expedient course of action for stabilizing the Caspian is the diversion into the Volga Basin of runoff from northern rivers in the European sector of the USSR. Under this plan an estimated additional  $30 \text{ km}^3$  would be annually diverted to the Caspian. At present plans are also under way to regulate the outflow of water from the Caspian to the Kara-Bogaz-Gol, as well as to reduce the loss of water by evaporation in the shallow northern portion of the Caspian. It is estimated that the construction between the Caspian and the Kara-Bogaz-Gol of a dam with locks will conserve about  $5 \text{ km}^3$  of water annually, while approximately  $10 \text{ km}^3$  of water per year could be saved by artificially closing off the shallow areas of the northern Caspian from the main body of the Sea.

The hydrologic regime of the Aral Sea had been relatively stable until 1960. However since 1960 the intensified tempo of irrigation in the Amu-Dar'ya and the Syr-Dar'ya basins has led to hard estimates of a potential 75% reduction in the size of the Aral Sea by 2000, if the present hydrologic conditions continue. Hence plans are being drafted to divert a portion of the Siberian river runoff into the basins of the Amu-Dar'ya and the Syr-Dar'ya. One of the most interesting draft versions under consideration envisages the diversion of runoff from the Irtysh and the Upper Ob' into the basins of the Aral and Caspian Seas. The water intake into the diversion system will take place at the confluence of the Tobol and Irtysh Rivers. A system of seven canals will feed water into the Amu-Dar'ya and the Syr-Dar'ya, as well as into the southern irrigation systems (Fig. 3). During the first of the three to four stages of the comprehensive diversion plan an estimated  $25 \text{ km}^3$  of Siberian water will be diverted to the south.

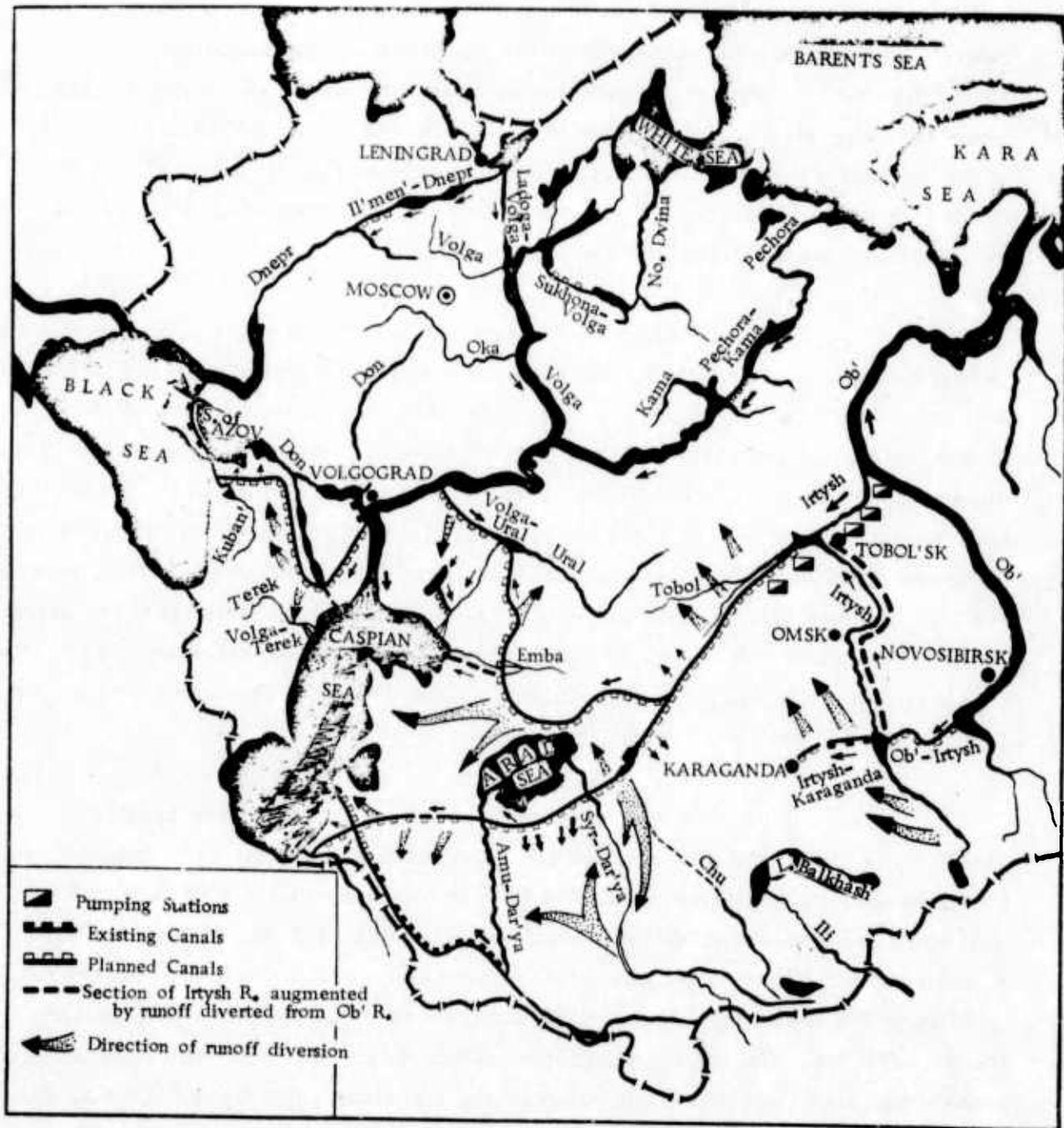


Fig. 3. Projected water diversion systems in the region of the Sea of Azov, the Caspian Sea and the Aral Sea.

During the second stage the volume of water diverted will be doubled, either by increasing the intake from the Lower Irtysh or by diverting water from the Upper Ob' into the middle course of the Irtysh via a special canal which will carry water from a reservoir to be constructed on the Ob' River near Kamen'-na-Obi (53° 47' N, 81° 20' E) or near Biysk (52° 34' N, 85° 15' E). This canal will simultaneously serve as the main artery for the irrigation of the Kulunda Steppe (between the Irtysh and the Ob', approximately between the 52nd and 54th parallels) and the Barabinsk Steppe (extending between Omsk and Novosibirsk, approximately between the 54th and 56th parallels). During the third and fourth stages the Ob' River will be further tapped. A portion of her runoff will be diverted to the south via two arteries: one artery will divert Ob' water up the Middle Irtysh, from Khanty-Mansiysk at the confluence of the Ob' and the Irtysh, while the second artery will channel Ob' runoff from Kamen-na-Obi or Biysk through the Ob'-Irtysh Canal to the Irtysh, as shown in Fig. 3.

Based on estimates of future agricultural, industrial and civilian water consumption in southwestern and south central Siberia, the Soyuzvodproyekt (All-Union Water Management Planning) Institute has proposed a three stage southward diversion of runoff from the Ob'-Irtysh basin. During the first stage, by 1985, 25 km<sup>3</sup> of runoff would be annually diverted to the south, during a second stage 50 km<sup>3</sup> per year. During the third stage, to be initiated after the year 2000, the volume would reach 100 km<sup>3</sup> annually, including the runoff diverted from the Yenisey basin.

In assessing the impact of this massive diversion, Yu. D. Mikhaylov [3] notes that one of the most crucial environmental problems is establishing the permissible limits for the diversion of water from the Ob' basin. Preserving the basic features of the present hydrologic regime in the Ob' flood plain is viewed as essential to preventing a significant cooling of the southern portions of the mouths of the Ob' River (69° N, 73° E) and the Taz River (69° 05' N, 76° E) and a substantial increase in their salinity. Therefore it may be necessary to limit the diversion of annual runoff from the

Ob' to  $40 \text{ km}^3$ , or to no more than 10% of her annual runoff (although the Soyuzvodproyekt proposal calls for the annual diversion of  $50 \text{ km}^3$  by the second stage). Moreover, in the northern Ob' basin the projected growing industrial demand for water also militates against diverting annually more than  $40 \text{ km}^3$  to the south.

The environmental impact of the Kara-Kum canal has been discussed by Grave [4] and by Kornilov et al [5].

The Kara-Kum canal extends approximately 800 km, from the settlement of Bassag on the left bank of the Amu-Dar'ya River, across the southeastern Kara-Kum desert, through the deltas of the Tedzhen and Murgab Rivers to the Kopet-Dag uplands in the extreme southern portion of the Turkmen SSR. By 1972 nearly 500,000 hectares were under irrigation in the canal zone, as opposed to 186,000 hectares in 1958 before the canal's opening. In 1964 the construction costs for the canal, including the outlay for developing new agricultural territory, construction of state farms, etc., had been completely recovered by the State. By 1971 the canal had returned a clear profit of 2.5 billion rubles to the State.

The width of the Kara-Kum canal for the first 400 kilometers is 100 meters, the filled depth is approximately 5 meters, and the maximum velocity of the flow is 0.5 to 1.0 meters per second. In 1971 the actual intake into the canal at the head installation exceeded  $350 \text{ m}^3/\text{sec}$ .

In 1971 the canal supported the irrigation of over 300,000 hectares, if the land in the Amu-Dar'ya flood plain and the territory generally irrigated by Murgab and Tedzhen Rivers (c. 40,000 hectares) is included.

By 1980-'85 completion of the canal's fifth section will extend the canal to the Atrek River valley ( $37^{\circ}28'N$ ,  $54^{\circ}03'E$ ) in the extreme southwest of the Turkmen SSR. The canal will then extend over 1400 km. Completion of this link will allow the cultivation of 750,000 - 1,000,000 additional hectares in fine-fibered cotton and other subtropical crops [5].

In another diversion project reported recently by A. Merkulov [6], Kirgiz water management specialists and "Soyuzvzvyvprom" (All-Union Blasting Operations Trust) have begun work on a joint effort to divert water from a tributary of the Naryn River, the Arabel'-Suu, into the Dzhuuku River, which empties into Lake Issyk-Kul'. Although the Arabel'-Suu originates on a southern slope of the Terskey-Alatau, one of the highest mountain ranges in the Tyan'-Shan' chain while the Dzhuuku originates on its northern flank, at the proposed diversion point they flow within relatively close range of one another.

The diversion plans call for the creation of an 800 m new river bed linking the Arabel'-Suu with the Dzhuuku through a cratering explosion which will displace approximately 4 million cubic meters of earth. The goal is to divert additional water into Lake Issyk-Kul' so that it can support the irrigation of 12,000 hectares of new cropland in the Dzhety-Oguz district (42°00'N, 78°30'E). A 30 million m<sup>3</sup> reservoir may also be constructed in the bed of the Dzhuuku River to store water during the winter for spring and summer irrigation needs.

## 2) Thermal Reclamation of the Northern Latitudes: Pro and Con

A USSR Academy of Sciences working conference on Thermal Reclamation of the Northern Latitudes, sponsored by the Institute of Geography, is the primary source of the papers in a collection edited by G. A. Avsyuk [7]. Among the topics examined are climatic changes and the prospects for climate modification (M. I. Budyko); the role of the Gulf Stream and the Kuroshio in forming the climate of the Arctic Ocean (A. O. Shpaykher); the reversible nature of the ice cover of the Arctic Seas (M. I. Budyko, P. M. Borisov); the probable changes in Northern Hemisphere atmospheric processes in connection with a warming of the Arctic (Kh. P. Pogosyan); a model of the mean annual temperature distribution in the surface boundary layer and its use in evaluating possible means of modifying climate (A. M. Gusev); the problem of forecasting natural changes in the northern latitudes in light of paleogeographic evidence (A. A. Velichko); changes in the glaciation of the European Arctic during the second half of the Quaternary (M. G. Grosval'd); and the absolute chronology of the paleoclimatic boundaries

of the late Quaternary in Siberia (N. V. Kind).

Substantial differences in both approach as well as assessment of the effects and the feasibility of altering the climate of the northern latitudes are reflected in the papers. The paper by the late P. M. Borisov, a long-time proponent of a polar Gulf Stream, postulates that the diversion of warm Atlantic water through the Arctic Basin to the Pacific could be controlled to allow a gradual return to the milder, "beneficial" climatic conditions of the Upper Cretaceous-Paleocene optimum. On the other hand, a considerable number of scientists (including Academician Fedorov in the interview cited in the concluding section of this report [15]) now caution against massive environmental "tampering". Although in the mid-sixties Budyko discussed artificially thawing the Arctic ice cap, his current works now warn of the complex potentially harmful (i. e. drought-inducing) effects of a warmer Arctic Basin, and emphasize the prohibitive cost of restructuring the national economy if the climatic zones were to shift. Budyko's recent works, including his lead paper in this collection, now stress the impending threat of planetary overheating due to thermal pollution coupled with the increasing atmospheric CO<sub>2</sub> build-up.

The editor, G. A. Avsyuk, a corresponding member of the Academy of Sciences, concludes that despite the contributors' differing views on the effects as well as the desirability of modifying the climate of the Arctic Basin, substantial agreement is demonstrated in the analyses of the laws of climate change in the late Quaternary.

The papers of five of the contributing authors to [7] are reviewed herewith in greater detail.

a) Projections - Pro Thermal Reclamation

The planetary cooling and progressive thermal isolation of the Arctic latitudes which began during the Tertiary period are linked by Borisov [8] to the rising of portions of the ocean floor and the resulting major deterioration in water exchange between the Arctic Basin and the tropical ocean basins occurring during the Upper Cretaceous-Paleocene period. This is shown in Figure 4 below, Paleogeography of the Upper Cretaceous period.

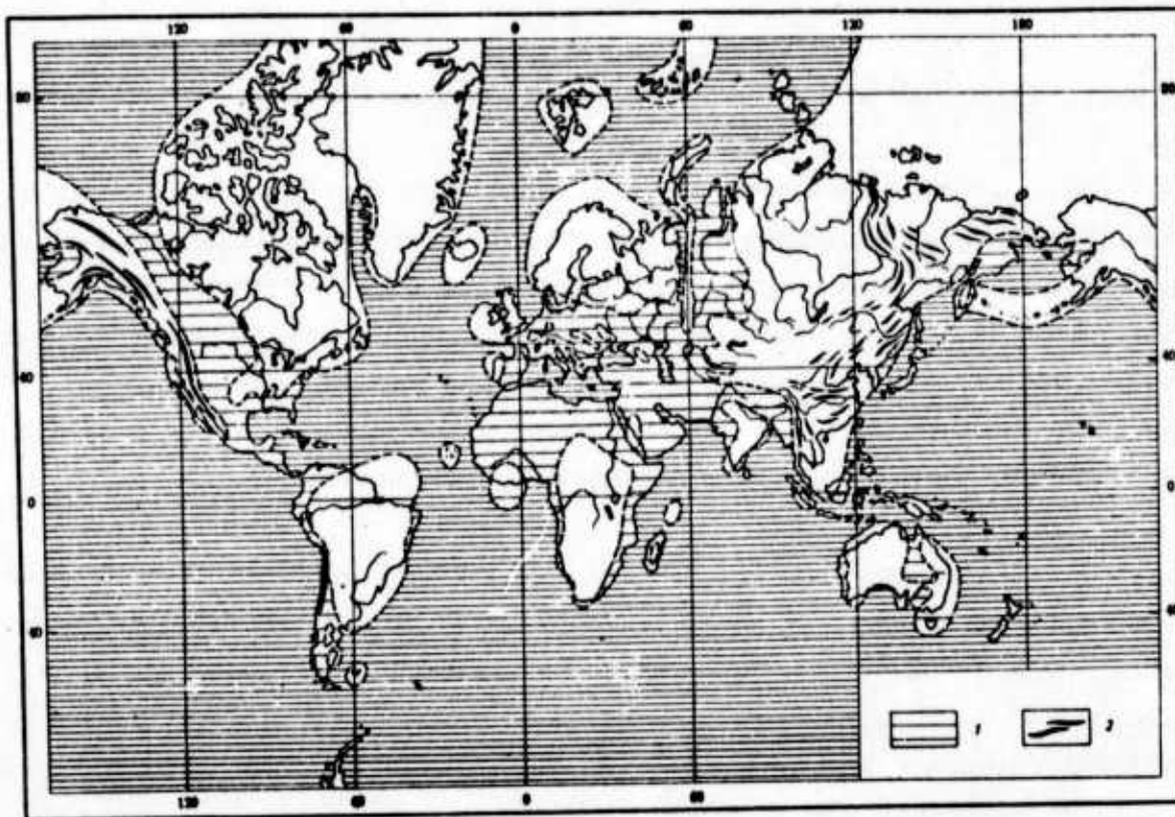


Fig. 4. Paleogeography of the Upper Cretaceous period (after N. M. Strakhov).

1 - present mainland, covered by seas in the Upper Cretaceous period, 2 - mountain ranges.

Before the rising of the continents, the surface water temperature in the Arctic Basin off the coasts of Alaska and Siberia was an estimated 14 C, while the climate of the sub-polar latitudes resembled that of the subtropics. (At present only an estimated 13% of the world ocean surface temperature is 4 C or lower, while the present mean ocean surface temperature is 17.4 C.)

Borisov's thesis is that, given a sufficiently intensive latitudinal water exchange, the surface temperature of the ocean along the Alaskan and Siberian coast line could be even higher than 14 C. This could be achieved through the creation of a direct flow of warm Atlantic water through the Arctic Basin to the Pacific Ocean, using pumping facilities to be installed

at the Bering Straits or further south at the Shpanberg and Chirikov Straits (roughly  $65^{\circ}$  N,  $175^{\circ}$  W), slightly west and north of St. Lawrence Island.

Borisov maintained that the energy required for the creation of such an Arctic "Gulf Stream" is less than is frequently cited and would be recoverable at all stages of the project. The energy could be obtained, at least partially, through the warming of the Arctic Basin: a rise in the ocean surface temperature will increase evaporation, and thus continental precipitation; this would, in turn, increase river runoff, thereby boosting hydroelectric power production at existing river power plants.

In Pogosyan's paper [9], the probable changes in the intensity of atmospheric circulation which could result from a warming of the Arctic surface water to a mean temperature of  $0^{\circ}$  C were calculated for the zone north of  $65^{\circ}$  -  $70^{\circ}$  north latitude, and (assuming no alterations in present air temperatures at 6-9 km), charts of relative and absolute topography for the 300 mb surface were constructed (Figs. 6, 7 below).

The author concludes that such projected changes in the Arctic atmospheric pressure distribution (an estimated maximum winter atmospheric pressure increase at the 300 mb level from 840 decameters to approximately 860 decameters) would only significantly affect the climate of northern Europe; the isohypses for the continental zone south of  $55^{\circ}$  north latitude would remain virtually unchanged. As the surface atmospheric pressure rises slightly in the western Arctic it will decrease somewhat in northern Europe. (Estimating that the present mean temperature difference in winter between the temperatures of the Arctic and the Equator for the 300 - 1000 mb layer is  $37 - 38^{\circ}$  C, after a warming of the northern latitudes on the scale described above the reduction in the temperature difference in winter between continental cold centers and the equatorial zones should be  $1 - 2^{\circ}$  C.) Although these changes should have virtually no effect on the intensity of global circulation, meridional circulation processes from the Arctic should distribute warmer, more humid air to the continental areas of the USSR, in particular improving the climate in the fall and in the spring, according to Pogosyan.

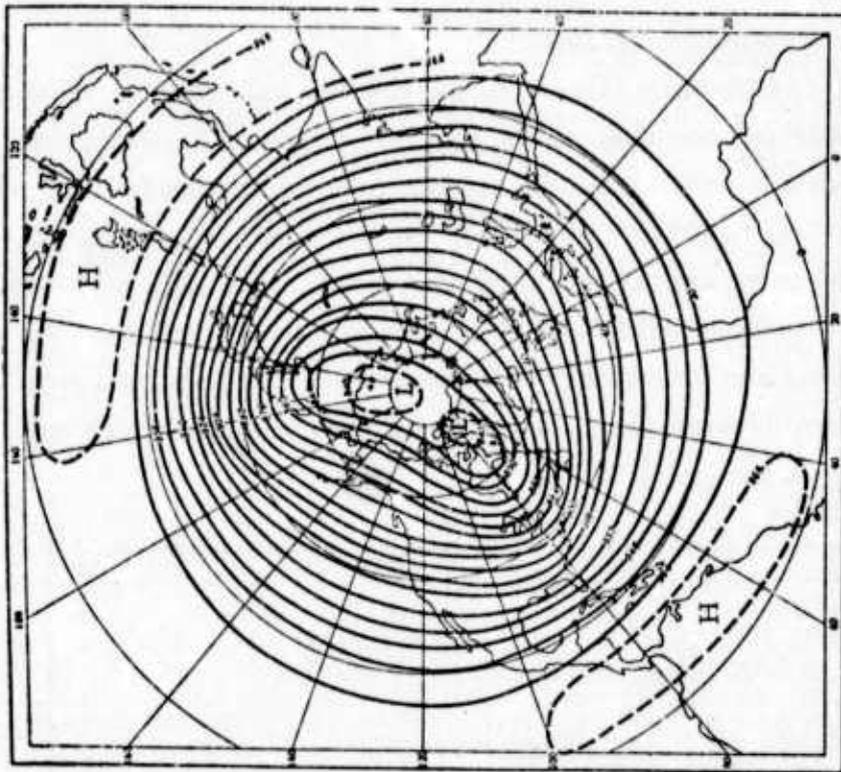


Fig. 7. Long-term mean winter topography of isobaric surface at 300 mb, [9].

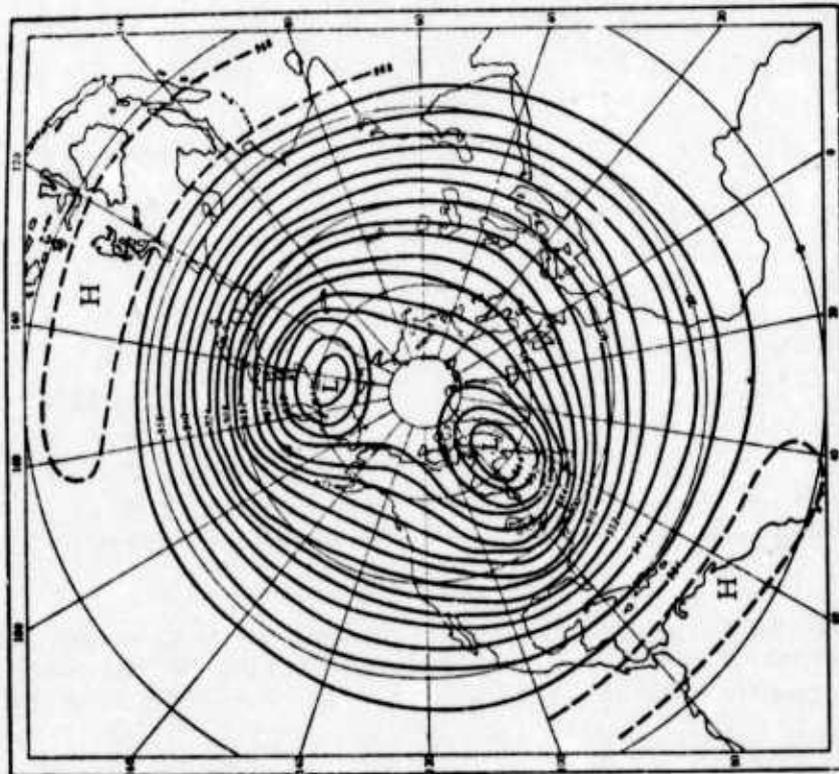


Fig. 6. Prognostic mean winter topography of isobaric surface at 300 mb, assuming the elimination of the Arctic sea ice and a warming of the Central Arctic surface water to a mean temperature of 0 C.

b) General Paleoclimatic Evidence

Based on the analysis of paleobotanical material collected by Western and Soviet scientists at 22 sites throughout the Northern Hemisphere above  $29^{\circ}$  north latitude, comparative quantitative values were established by Grichuk [10] for five basic climatic indices (mean winter and summer temperatures, annual temperature range, annual precipitation, duration of frost-free period) for the Atlantic period or Middle Holocene climatic maximum occurring approximately 5500 years ago. Figure 8 below illustrates the deviations from present January temperatures, based on the paleoclimatic data for the Atlantic period.

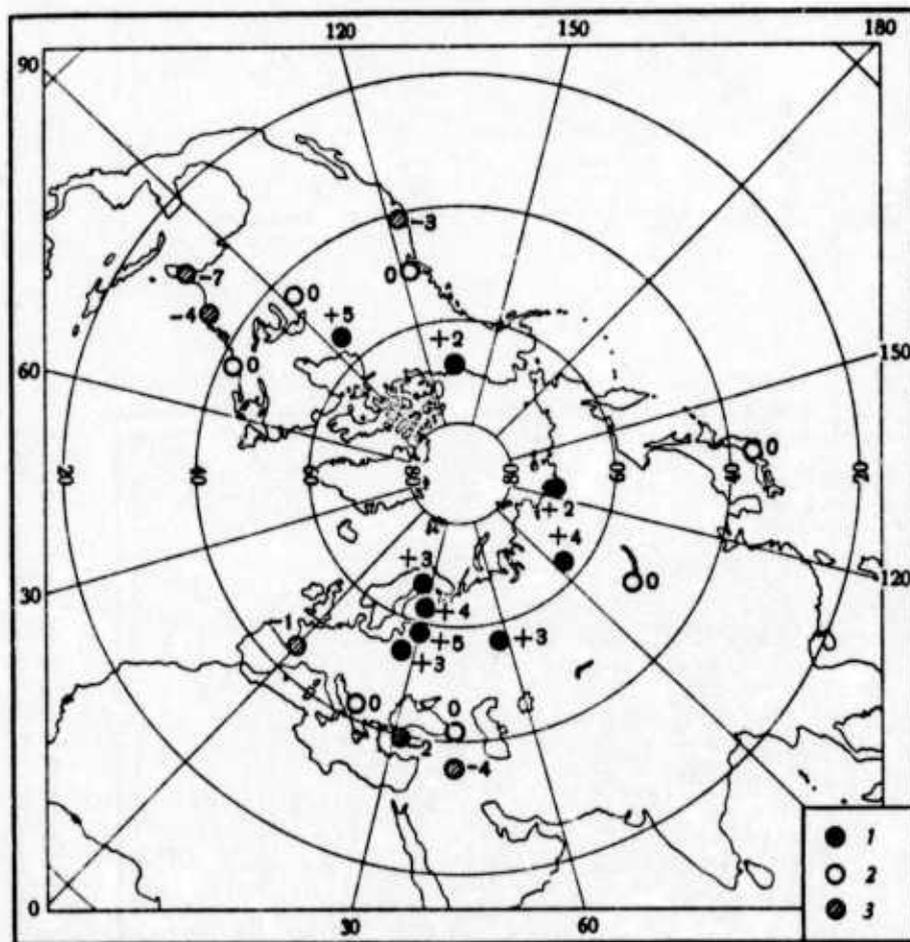


Fig. 8. Reconstruction of deviations from present January temperatures,  $^{\circ}\text{C}$  during Atlantic period of Holocene.  
1- positive; 2- non-existent or less than  $1^{\circ}\text{C}$ ; 3- negative.

The climatic changes which occurred in the continental areas surrounding the Arctic Basin cannot be explained solely by an intensified influx of warm Atlantic water into the Arctic Basin, Grichuk concludes. For example, the distribution of July temperature deviations shows the same value, a 2 C temperature rise for locations which would be affected differently by a warming of the Atlantic Ocean, e. g. sites in the north of the Scandinavian peninsula, at the Lena River delta and near the Mackenzie River delta in Canada (Fig. 9).

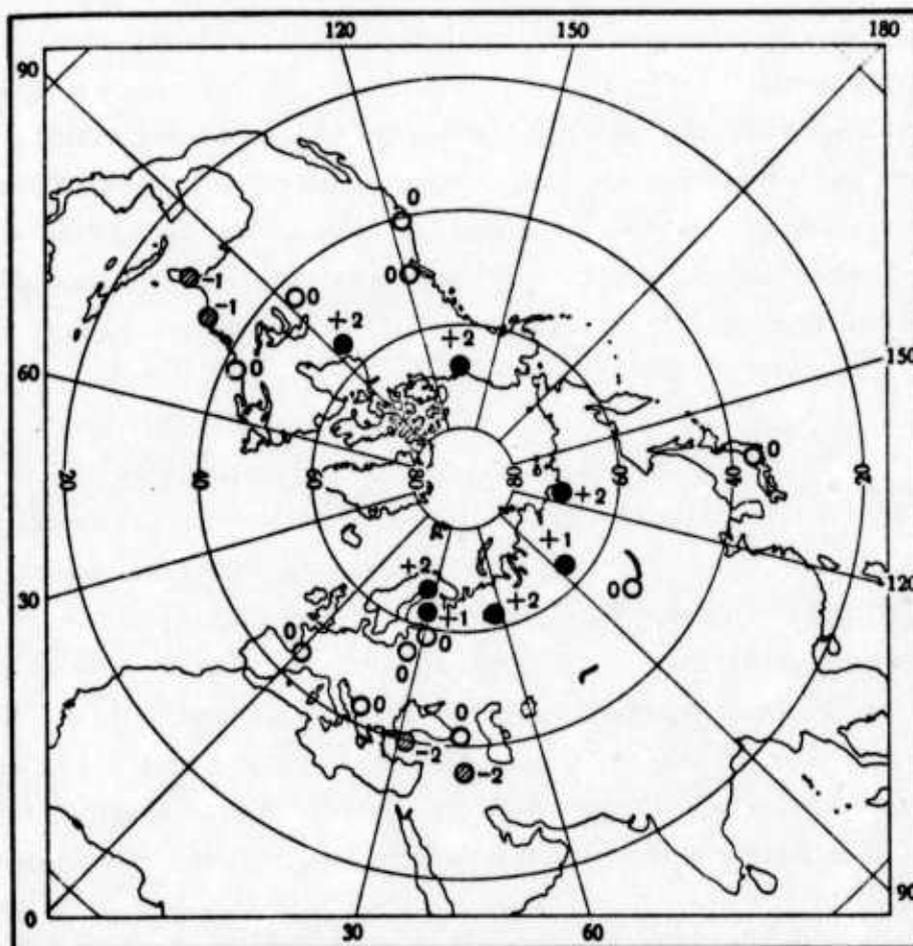


Fig. 9. Reconstruction of deviations from present July temperature values, C during Atlantic period of Holocene (same symbols as in Fig. 8) [10].

On the basis of the available evidence, Grichuk concludes that the polar ice cap apparently remained intact north of the 75 - 80° north latitude during the mid-Holocene interglacial. Hence this period could not serve as a model for the conditions which could occur due to a substantial reduction or full elimination of the Arctic ice cover.

The climatological effects of the oceanization of climate which would result from a reduction in the size of the polar ice sheet are further discussed by Velichko [11]. Examining the interglacial oceanization of climate, he draws a comparison between the Mikulino interglacial (or Riss-Würm stage of the Pleistocene, 100,000 - 70,000 years ago) and the cooler, drier present interglacial. Analysis of the paleoclimatic data on soil profile characteristics and vegetation composition indicates that during the mild, humid Mikulino epoch, ocean ice either disappeared or was considerably less extensive than now, whereas the present climate is significantly influenced by the large areas of ocean ice inherited from the glacial third stage of the Pleistocene.

The present radiation balance in the Arctic is discussed, citing M. K. Gavrilova's calculations that the total annual absorption of radiation in the ice-bound Central Arctic equals 20 kcal/cm<sup>2</sup> as opposed to 50 - 60 kcal/cm<sup>2</sup> in the ice-free portions of the Bering, Kara, Laptev, Barents Seas, etc. Gavrilova concluded that the annual radiation balance in the Central Polar Basin is essentially neutral: in the Siberian-Alaskan sector it is 2 kcal/cm<sup>2</sup>, while in the European and Greenland sectors it is close to 0 kcal/cm<sup>2</sup>. Thus while the ice cover may begin to melt during the short Arctic summer, it will be regenerated in the winter.

In regard to the problem of the regeneration of the ice sheet, V. S. Samoylenko (1964) concluded that advection must be greater than 0.025 cal/cm<sup>2</sup>/min. for the ice not to reform. M. I. Budyko, citing evidence for the instability of the Arctic ice regime, maintains that present Arctic ocean ice is an ice age relic; in order to transform such perennial Arctic ice into annual ice a summer Arctic Basin temperature increase of 4 C is necessary. After the polar ice cover has been eliminated, radiational

cooling on the open sea will increase by a factor of three, as opposed to the cooling rate for an ice-covered surface, according to Cavrilova's calculations. Thus, if the ice cover is not to regenerate, the water diverted into the Polar Basin must be warm enough to offset the sharply intensified radiational cooling which will occur on ice-free water surfaces.

c) Conclusion - Planetary Warming Viewed as a Future Threat

The dependence of planetary climate on fluctuations in atmospheric transparency is examined by Budyko [12], in particular linking global climatic cooling trends to the atmospheric turbidity caused by intensive volcanic activity.

In regard to the problem of an ice-free Arctic, the crucial question is the extent to which the heat exchange with the sub-polar zones of the Earth will be altered. Budyko postulates that if the polar ice cap were eliminated, the effect of decreased atmospheric advection would be greater than the effects of the increased heat flux in the hydrosphere.

Although man's impact on the macroclimate through thermal and particulate pollution is still relatively insignificant, projections of the global thermal pollution rate indicate that planetary overheating will become a serious threat within the next 100 to 200 years. Moreover, planetary overheating will be exerting a significant effect on polar glaciation long before its effects are evident, Budyko warns.

Writing in another collection of articles on climatic change, V. P. P'yankov [13] asserts however that a global climatic warming trend which would raise the water temperature of the North Cape branch of the Gulf Stream could have a "catastrophic" effect on Soviet agriculture, increasing the frequency of droughts, (black earth) dust storms, and severe winter weather in the vital agricultural belt of the southern USSR.

Citing the correlation between a warming of the North Cape Current and the development in the southern European territory of the USSR of severe droughts during the summer and exceptionally bitter cold weather during the winter, the author notes, that during the severe drought year of 1969 the Archangelsk navigational season was unusually long, continuing

virtually until Feb. 19th. In the south, on the other hand, by early January 1969 an intensive ice cover had already formed on the Caspian Sea, threatening the oil drilling installations there; the Sea of Azov was frozen over, and the port of Odessa on the Black Sea was ice-bound.

P'yankov posits a four-year cycle in the temperature and velocity of the Gulf Stream, which is reflected in the periodic droughts afflicting the southern USSR. For example, 1966, a very favorable year for agriculture, was followed in 1967 by a dry year, in 1968 by a year of severe drought, and in 1969, by a year of still more intense drought with severe winter dust storms in the Ukraine and the Kuban. Paralleling the 1966-1969 pattern, 1970 was a favorable year for agriculture, 1971, less favorable, and 1972 a drought year.

On the basis of the correlations between a warming of the Gulf Stream and droughts in the southern USSR, P'yankov opposes the elimination of the polar ice cap as proposed by P. M. Borisov. (Borisov's plan was to create a direct flow of warm Gulf Stream water through the Arctic Basin. It called for the installation of pumping facilities having a 20 million kw capacity at the Bering Straits). As an alternative P'yankov suggests some redirection of the Gulf Stream, as indicated by Figs. 10 and 11.

Fig. 10 shows present ocean currents in the Barents Sea - Kara Sea. Fig. 11 indicates the author's proposed plan for warming the Kara Sea by redirecting the flow of the Gulf Stream through the Kara Straits. The first map indicates that the Gulf Stream actually does not flow further east than the Barents Sea: by Cape Kanin Nos ( $68^{\circ}39'N$ ,  $43^{\circ}16'E$ ) it is veering northward to merge eventually with the cold East Greenland Current. Moreover, when both the water temperature and speed of the Gulf Stream are low, the Gulf Stream will cool significantly in the Barents Sea even before turning northward. As shown in the second map, the author proposes directing the Gulf Stream through the Kara Straits into the Kara Sea through the construction of current-directing moles along Cape Kanin Nos and the restoration of the ancient Cheshkiy Strait.

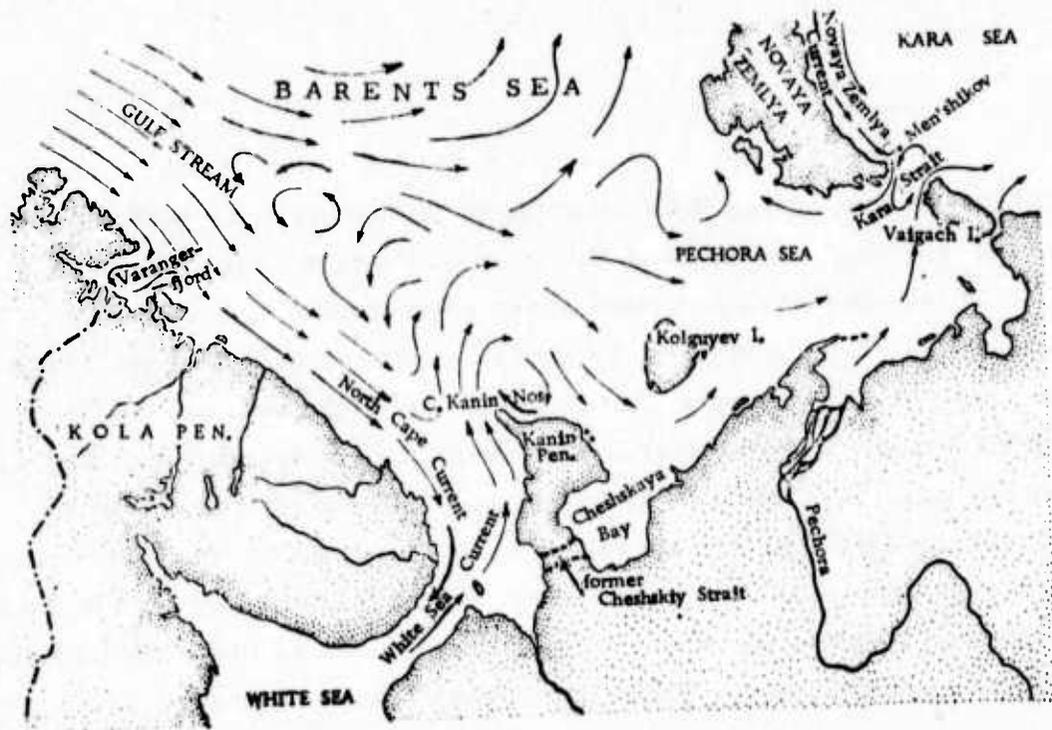


Fig. 10. Present hydrologic conditions in the southern portion of the Barents Sea.

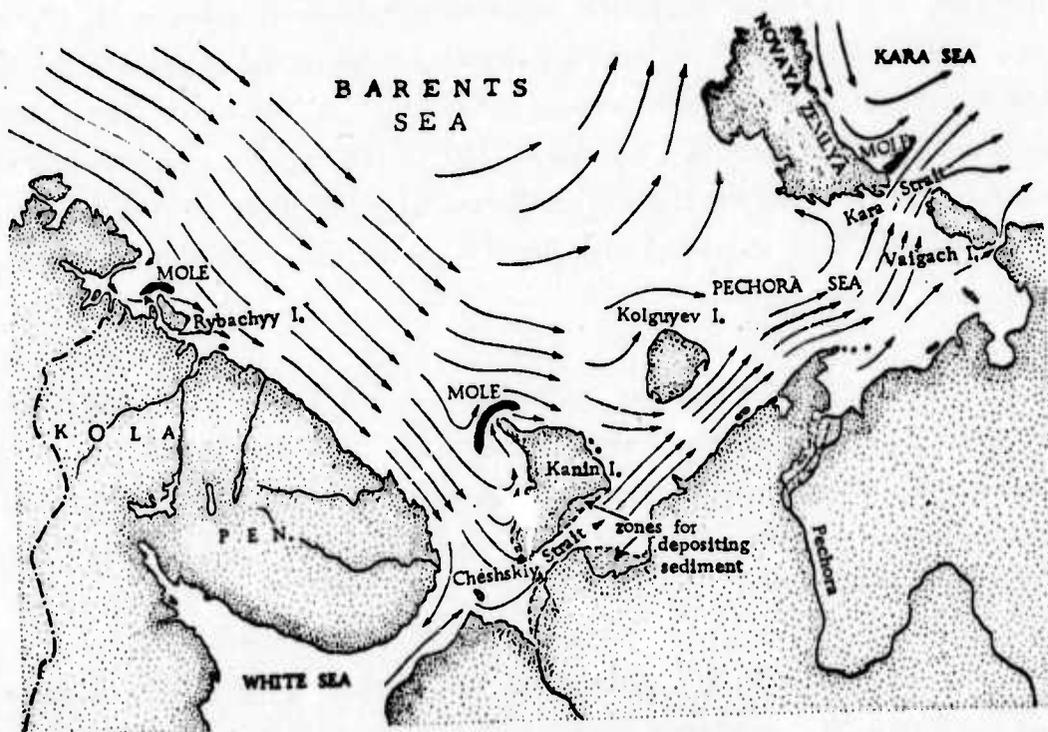


Fig. 11. Restoration of the former Cheslavskiy Strait and/or installation of a current-directing mole along Cape Kanin Nos. [13].

According to P'yankov's analysis, a warming of the northern Gulf Stream now causes the formation of an extensive barometric trough over the Barents Sea, while to the immediate east a high pressure ridge will hold over the Kara Sea, one of the coldest seas of the Arctic. The strong southerly wind flow to the central Arctic which develops between these two pressure centers causes a shifting to the north of the zone of western transport, thus contributing to the formation of droughts in the southern grain belt, as well as to the development of compensatory intrusions of frigid Arctic air masses into Siberia and North America. In Siberia this leads in the pre-winter period to an earlier development of the Siberian blocking-type anti-cyclone, inasmuch as the winter cooling then occurs against much colder background temperatures.

Thus the author holds that the warming of the Kara Sea would eliminate the basic cause for the northward shifting of the zone of western transport, and thereby lead to a moistening of the climate in the "breadbasket" of the USSR. Furthermore, as a result of these measures, the Northern Sea route should be navigable throughout the summer, while in the winter the Barents Sea and Kara Sea sections of the Northern Sea route would not freeze over. The estuaries of the Ob' and the Yenisey Rivers and Port Dikson would be ice-free throughout the year, as would the Caspian, Aral, Black, and Baltic Seas.

The changes which could occur in the Arctic Basin through a possible damming of the Bering Strait have been a major subject of investigation of the three-month long Arctic research expedition "North-27", conducted in early 1975, as reported in an interview with N. I. Blinov [14], the expedition director.

Blinov, a senior staff scientist of the Arctic and Antarctic Research Institute, confirms that a number of the existing proposals for melting the Arctic ice are now technically feasible. One plan, for example, proposes using explosives to eliminate a portion of the sill basins which extend from the coast of Scotland to Greenland, thus strengthening the Gulf Stream

flow into the Arctic Ocean. However, the most effective plan for eliminating the Arctic ice remains the installation of a dam and electric power facility at the Bering Strait.

The negative consequences of thawing the Arctic ice now appear to outweigh possible benefits. A major rise in the level of the world ocean would cause the inundation of millions of hectares of fertile coastal and river valley farm land, and necessitate the relocation of thousands of towns plus a considerable outlay for new construction in the Arctic zone. Furthermore, as the Arctic soil warms, mud slides will begin to occur on sloping terrain. In general, farming would not be practical in the Arctic territory due to the low insolation level in the high latitudes.

Citing the growing threat of planetary overheating due to industrial thermal pollution, Blinov concludes that the Arctic ice cap now has an essential positive, compensatory function in reducing the mean annual temperature in the upper latitudes by an estimated 13 C.

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correlations between the distribution of geomagnetic disturbances and the phases of both the 27-day solar cycle and the 11-year sunspot cycle (1968).

Vorob'yeva has studied the displacements of the jet stream in the north temperate latitudes as they correlate with the first and second halves of the 27-day solar cycle (1968). Considerable attention has been devoted by Vorob'yeva and others to the quasi-biennial cycle (or mean 2.4 year cycle) of variations in the intensity of zonal circulation in the mid-troposphere (1967).

In regard to the classic 11-year solar cycle, both Drozdov and Grigor'yeva in their 1971 monograph on long-term cyclical fluctuations of atmospheric precipitation in the USSR, and later Vitel's (1973), have concluded that there is a low general correlation between this basic solar cycle and precipitation.

On the other hand, quite distinct statistical relationships have been demonstrated between the ascending and descending phases of solar activity and droughts in specific areas of the USSR. In 1969 Pokrovskaya established that severe droughts in the European section of the USSR correlated with the ascending phase of the 11-year solar cycle ( $K_p$ ), while the droughts in Kazakhstan have correlated with the descending phase of the cycle. The extremely clear correlation between the cases of drought in the European USSR and phases of solar geomagnetic activity was successfully used by Pokrovskaya and D. G. Mandel' (1973) in predicting the April-June phase of the 1972 drought.

In 1973 a special department for solar geophysical research was established within the Main Geophysical Observatory.

A more recent issue from MGO [3] contains papers by Drozdov, Vitel's, Pokrovskaya, and others on solar-terrestrial relationships

#### IV. DEVELOPMENTS IN SYNOPTIC CLIMATOLOGY, SOLAR METEOROLOGY AND ATMOSPHERIC LASER SOUNDING

A publication commemorating the 125th anniversary of the Main Geophysical Observatory [1] is composed of papers by leading staff scientists surveying the history and present status of work at the MGO in their area of specialization. Contributors include: K. Ya. Kondrat'yev and L. R. Rakipova on solar radiation and atmospheric dynamics: the radiational effects of aerosols; M. I. Yudin and L. S. Gandin on quantitative analysis and weather forecasting; T. V. Pokrovskaya on research in synoptic climatology and solar geophysics and its applications in weather forecasting; M. I. Budyko and O. A. Drozdov on general and physical climatology; V. Ya. Nikandrov and N. S. Shishkin on cloud physics research at the MGO, including theoretical research on thunderstorm mitigation; I. M. Imyanitov and V. P. Kolokov, research on the atmospheric electric field; Academician F. F. Davitaya on the role of the MGO in the development of regional meteorological centers in the USSR; and Director Ye. P. Borisenkov, K. Ya. Kondrat'yev, and M. Ye. Berlyand on the Observatory's participation in international scientific exchange.

##### 1) Synoptic Climatology/Solar Meteorology

Pokrovskaya's article in the foregoing survey [2] gives an historical survey of the scientific contributions of leading synoptic climatologists and solar geophysicists who have been affiliated with the Main Geophysical Observatory: B. P. Mul'tanovskiy, Ye. Ye. Fedorov, V. Yu. Vize, G. Ya. Vangengeym, and, more recently, L. A. Vitel's, O. A. Drozdov, Ye. V. Vorob'yeva, L. R. Rakipova, B. I. Sazonov, and the author.

In the MGO section for synoptic-climatological and solar geophysical research a number of studies have dealt with the 27-day rotational cycle of the sun and its terrestrial climatological effects. Vitel's 27-day solar calendar of geomagnetic disturbances has been used to establish

and the problems of precipitation distribution and long-range forecasting.

The papers include:

- O. A. Drozdov: Cyclical, possibly solar-induced fluctuations of precipitation and temperature, used in long-range forecasts:  
Some criteria for the statistical structure of long-term meteorological series;
- O. A. Drozdov and A. S. Grigor'yeva: On the problem of the effect of volcanic eruptions on precipitation in the Northern Hemisphere;
- O. A. Drozdov, A. S. Grigor'yeva, K. V. Yeremenko, and I. V. Malkova: Principal characteristics of the secular precipitation trend in America and Africa (Northern Hemisphere);
- O. A. Drozdov and L. A. Vitel's: The secular precipitation trend in the USA as evidenced in the frequency of major precipitation deficits and a comparison with analogous conditions in arid regions of the USSR;
- L. A. Vitel's: The use of phase analogues of the 11-year solar cycle in long-range forecasts;
- T. V. Pokrovskaya: On the problem of the joint analysis of circulation and solar-geophysical factors in the formation of droughts.

a) Solar Activity and Runoff Fluctuations

Throughout the Northern Hemisphere a distinct, inverse 11-year cyclical relationship exists between runoff fluctuations and the atmospheric pressure trend, according to recent studies by N. P. Smirnov [4], E. I. Sarukhanyan, O. F. Kondratsova, and others. The runoff fluctuations are related to disruptions in zonal atmospheric circulation and the intensification of meridional processes occurring during periods of heightened solar activity.

On the basis of spectral analysis, a statistically significant variation in runoff fluctuations with a period of 10-11 years is demonstrated for northwestern Europe, Central Asia, western Siberia and for certain southwest Siberian rivers. However this cyclical variation is only weakly expressed in many rivers in the European USSR: the predominant interval for the rivers of the Kama, Pechora, and Ural basins is approximately 15 years, as shown in Fig. 1 below.

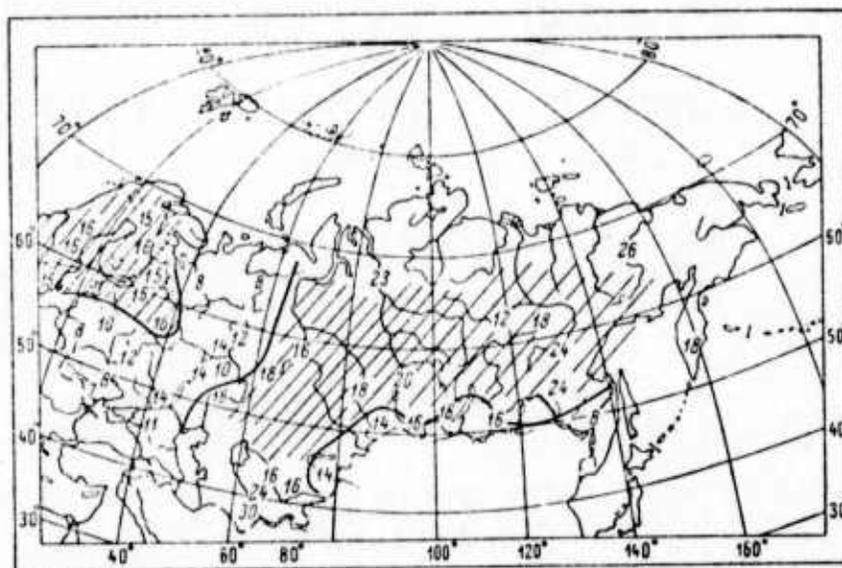


Fig. 1. Amplitudinal distribution of solar-induced fluctuations in river runoff in the USSR [4].

The correlation functions obtained for Wolf (sunspot) numbers and the runoff series for rivers with distinctly expressed 11-year cyclical fluctuations are shown in Fig. 2.

As shown in Fig. 2, the nature of the relationship between solar activity and runoff fluctuations varies according to region. In the northwestern portion of the European territory of the USSR, the runoff maximum occurs two to four years before the solar activity maximum. For rivers in western and southeastern Siberia the runoff maxima occur before the solar activity maximum or in the very year of the maximum. In

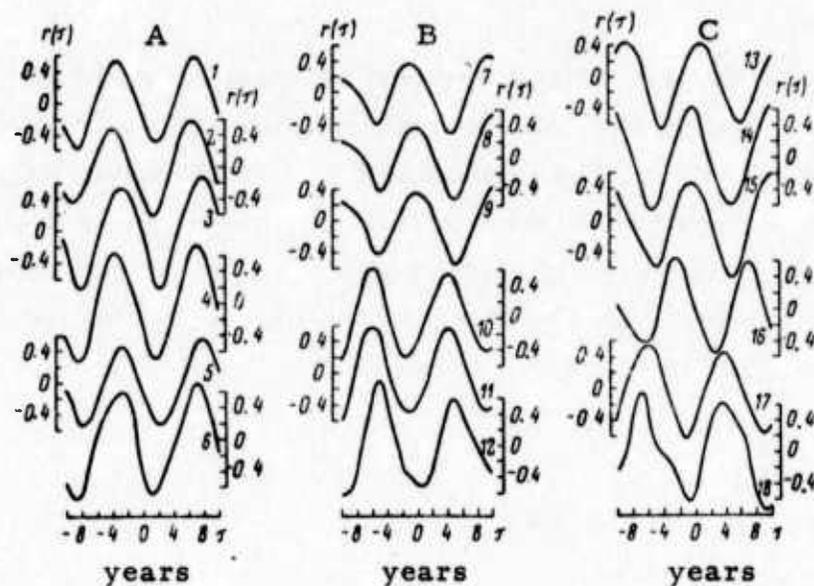


Fig. 2. Correlation functions for Wolf numbers and anomalies in mean annual river discharge. (values obtained using a "7 minus 11 filter") [4].

A. 1- Indals (Sweden); 2- Kumijoki (Finland);  
3- Neva; 4-  $\Sigma$  runoff (Volkhov, Vuoksa,  
Svir'); 5- Volga (Yaroslavl'); 6- Onega;

B. 7- Tobol; 8- Irtysh; 9- Ob'; 10- Chirchik;  
11- Zeravshan; 12- Amu-Dar'ya;

C. 13- Shika; 14- Zeya; 15- Vitim; 16- Aldan;  
17- Kolyma; 18- Kamchatka.

contrast, the runoff maximum of rivers in Central Asia and in northeastern Siberia correlates with a decline in the frequency of zonal circulation processes and the intensification of (Vangengeym-Girs) type E atmospheric macro-circulation processes, occurring three to five years after the solar activity maximum.

#### b) Macro-Circulation Method of Long-Range Forecasting

The first major sourcebook on the macro-circulation method, G. Ya. Vangengeym's "Fundamentals of the macro-circulation method of long-range meteorological forecasting for the Arctic" (Trudy Arkticheskiy n. -i. inst., vol. 34, 314 p.), was published in 1952. A recent work by A. A. Girs [5] is an updating and further development of the macro-circulation method, incorporating the advances in the theoretical and applied

long-range forecasting realized in the last 20 years by the Department of Long-Range Meteorological Forecasting of the Arctic and Antarctic Research Institute (which Vangengeym directed until 1961 and Girs has thereafter directed). Significantly, the Department has responsibilities in both theoretical and applied long-term forecasting. Annually in late December/January the Department issues long-range forecasts in the form of mean monthly characteristics for the period from January through October for both the Arctic Seas and the entire Northern Hemisphere. Upwards of 60 institutional clients employ these forecasts, including the Merchant Marine in drawing up shipping plans for the June-October navigational period in the Arctic Basin.

Girs' monograph consists of 15 chapters and a 50-page appendix, "A Catalogue of the Frequency and Deviations from the Norm of Atmospheric Circulation Types W, E, C, and their Northern Hemisphere Variants from 1900-1972".

Chapter 1 surveys the principal schools of long-range forecasting, including the synoptic method of the Mul'tanovskiy-Pagava school, the macro-circulation method of the Vangengeym-Girs school, the American school of J. Namias, and the (variously titled) synoptical-statistical, dynamical-statistical, or physical-statistical approach. The author points out that the macro-circulation school devotes primary attention to the long thermobaric waves of the troposphere, thus deriving calculations of type W, C, E, Z,  $M_1$ , and  $M_2$  macro-circulation processes from daily, hemispheric upper-air charts, while the American (Namias) school focuses on the variants of these waves occurring on the mean 30-day 700 mb charts. In general, the Rossby high index (zonal circulation) corresponds to the Vangengeym type W macro-processes, while the Rossby low index (or meridional circulation) can be equated with type E and type C circulation processes.

Chapters 2 through 13 describe the principal laws of general atmospheric circulation underlying the macro-circulation method. Chapters 8 and 9 in particular examine long-term tendencies and changes in the

character of the atmosphere and the hydrosphere, caused by macro-circulation 'epochs'. The results of these analyses have been applied in formulating basic long-range forecasts. Chapter 15 reviews the Soviet data on the effectiveness of the macro-circulation method. The conclusion details the major scientific advances in the macro-circulation method realized in the last 20 years, and indicates problem areas which will be the focus of future research.

The three basic patterns of atmospheric macro-circulation distinguished by the Vangengeym classification are illustrated in Fig. 3 below.

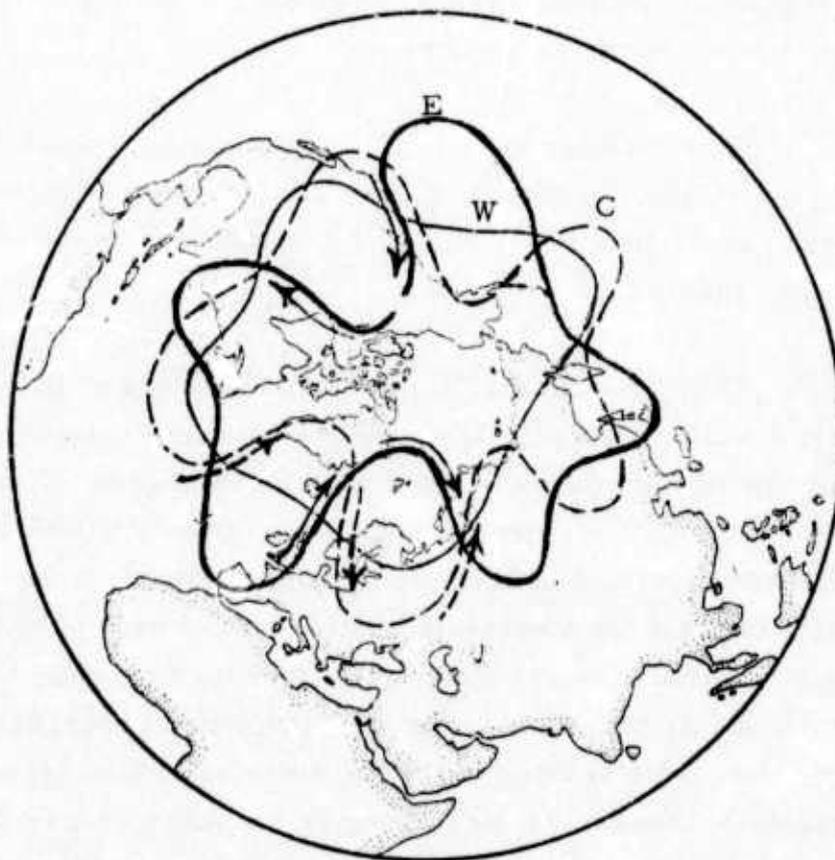


Fig. 3. Upper-air (c. 5 km) trough and ridge positions for W, E, and C macro-synoptic processes [5].

W - (narrow, solid line) = westerly, small-amplitude waves moving swiftly, essentially in a zonal circulation pattern. E - (heavy, solid line) and C - (dashed line) = large-amplitude stationary waves, reflecting meridional atmospheric conditions. [type E - easterly with well-developed subpolar lows and stationary highs over Europe and western North America; type C - meridional with shallow subpolar lows, pressure over Europe and western North American is low.] The solid arrows indicate the direction of warm air movement, the dashed arrows - cold air movement at the 500 mb level.

During prolonged periods of heightened solar activity the meridional (E /easterly/ or C /meridional/) types of circulation intensify in the troposphere. Conversely, type W (westerly) zonal circulation processes intensify in years with decreased solar activity. As the polar stratospheric heat sources associated with the increased ozone absorption weaken, the stratospheric anticyclone and the east-west air transport in the stratosphere weaken, thereby reducing the braking effect of the stratosphere on the troposphere. Thus the annual number of days with types E and C macro-circulation processes will systematically decrease, while type W processes will increase.

Girs determined through frequency analysis of macro-circulation types W, C, and E during the 80-year period from 1891-1972 that during the 29 year period from 1900-1928 type W processes predominated, type E processes, predominated from 1929-1939, and type C from 1940-1948; while from 1949 to the present a combined type E and C circulation epoch has been dominant. Figure 4 below juxtaposes the long-term fluctuations in the frequency of type W, E, and C atmospheric processes against the variations in solar activity as represented by Wolfe numbers.

A downturn in the secular solar activity cycle is anticipated by solar geophysicists. If this prediction is correct, a prolonged increase in type W macro-processes should start occurring in the 1970's.

As illustrated in Fig. 5 below during the post-1972 period a prolonged development of type W (westerly) atmospheric circulation processes is anticipated. By 1986 type W synoptic processes should merge with and be superseded in the North American-Pacific Ocean section of the hemisphere first by  $M_1$  and  $M_2$  processes, and then by type Z (zonal) processes. ( $M_1$  and  $M_2$  represent meridional circulation patterns:  $M_1$  = surface anticyclone near the Aleutian Islands, lows to the north;  $M_2$  = ridge from the Pacific high extending to western North America; Z = zonal in the North Pacific sector).

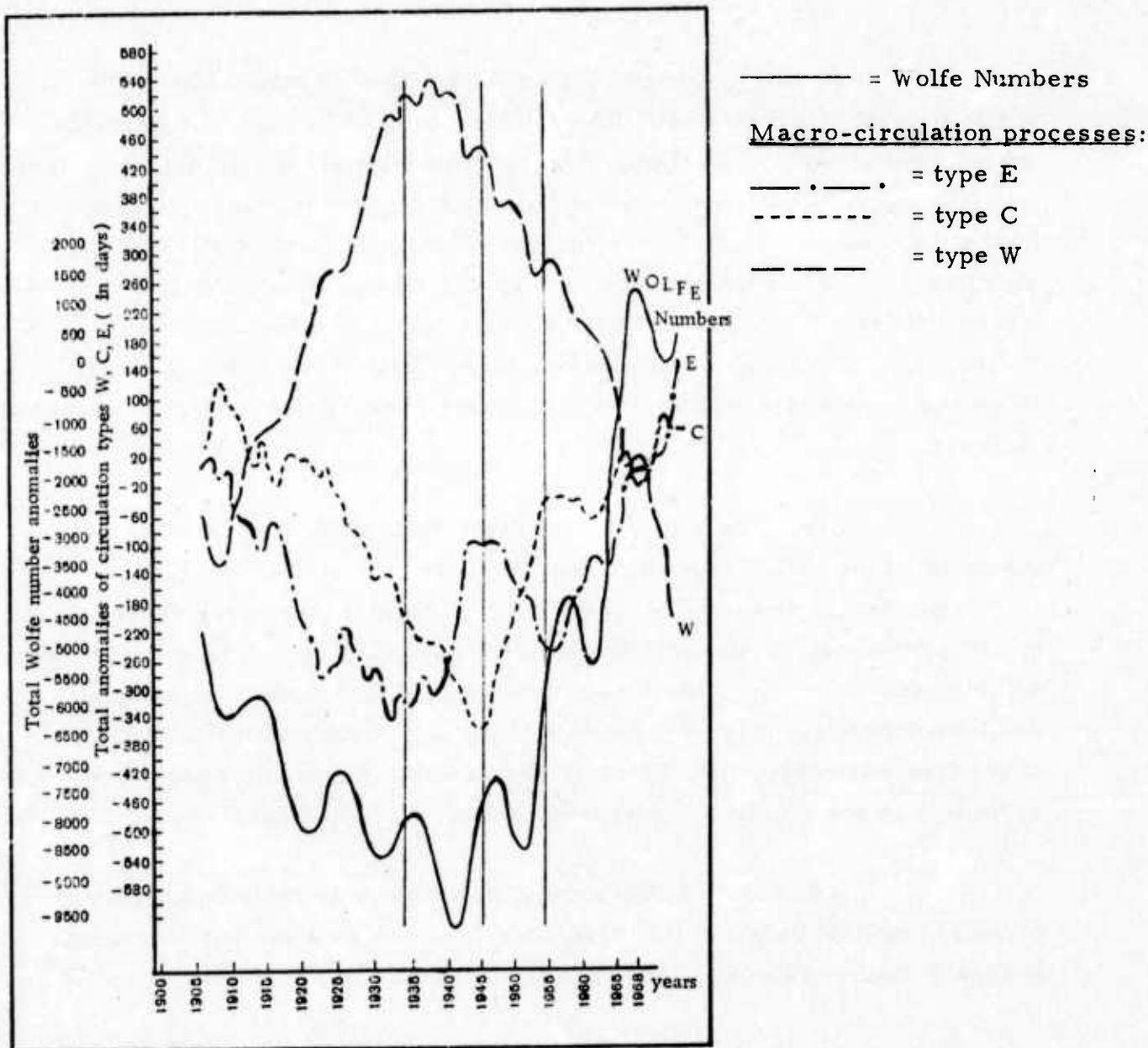


Fig. 4. Long-term fluctuations in the frequency of macro-circulation types W, E, C and variations in solar activity (Wolfe Numbers) [5].

The vertical lines indicate extended periods of curve growth, representing macro-circulation epochs: type W (1900-1928), type E (1929-1939), type C (1940-1948), combined type E and C (1949-1968...). Type W circulation epoch occurs during the descending phase of the secular solar activity cycle, types E and C during the ascendant phase of the secular solar activity cycle.

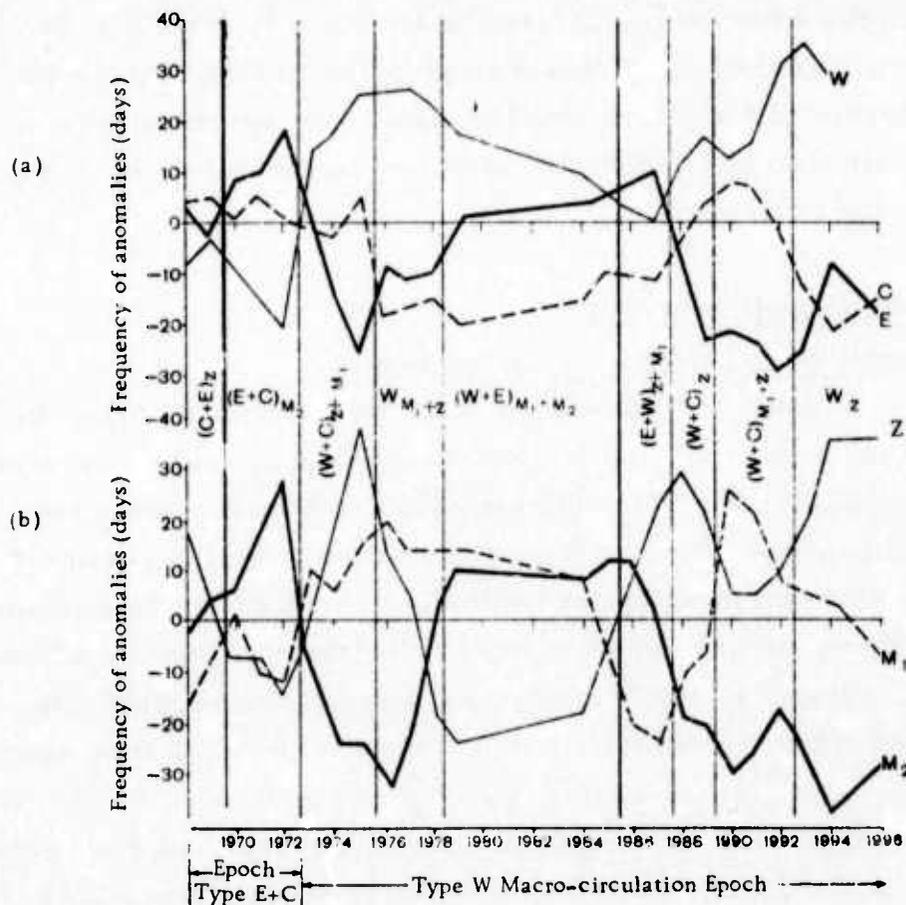


Fig. 5. Predicted anomalies in the annual frequency of W, E, C, Z, M<sub>1</sub> and M<sub>2</sub> macro-synoptic processes from 1969 - 1996, based on projections of probable variations in solar activity [5].

a) Epochs types W, E, and C, b) Epochs types Z, M<sub>1</sub> and M<sub>2</sub>

In a review of Girs' monograph [5], Vorob'yev et al. [6] conclude that the macro-circulation method enables fairly successful forecasting of the sign of the mean monthly atmospheric pressure anomalies, air temperature anomalies, and the mean pressure distribution in the Northern Hemisphere, particularly in the Arctic area. In regard to prediction of the magnitude of the variations, forecast reliability is high, if errors of the order of  $\pm 3-4$  C and  $\pm 5-6$  mb are acceptable.

The present range of long-term forecasts by the macro-circulation method has been increased by almost a factor of two (to ten months) as compared to the forecast range prior to 1964. At the same time forecast accuracy has also continued to rise. The accuracy level of the forecasts of air flow and shore wind direction in the Arctic is 70-80%, according to the reviewers.

## 2) Laser Atmospheric Sounding

### a) Tomsk Institute for Optics of the Atmosphere

Scientists at the Tomsk Institute for Optics of the Atmosphere report progress toward the application of lasers in upgrading the accuracy of weather forecasts [7]. It is anticipated that within 2-3 years the mathematical principles for deducing information from the results of the laser probes will have been refined sufficiently so that the data obtained by laser atmospheric probes can be used to calculate atmospheric density, temperature, pressure, and humidity, the size of aerosol particles, cloud thickness, and other atmospheric data essential to weather forecasting.

Currently, the laser atmospheric sounding systems under development at the Tomsk Institute are being used experimentally to measure atmospheric density, temperature and pressure at 30-100 km altitudes and to determine the lower boundary of cloud strata, water content of the lower clouds, and vertical humidity profiles up to 3-4 km. The same scientists also report the successful application of laser atmospheric sounding in monitoring air pollution above Soviet industrial centers, in natural gas prospecting, and in rupture detection in petroleum pipelines.

An examination has also been made by Zuyev [8] of the possibilities and limitations of laser methods in meteorological research, specifically weather and climate formation and atmospheric pollution processes. The physical principles of the interaction between laser emission and atmospheric phenomena are discussed, and the type of information which can be obtained by the laser method of atmospheric probing is considered.

Future progress in this area will depend on the development of mathematical algorithms for the unambiguous extraction of information on atmospheric parameters from laser probe data, and on the development of lasers having predetermined properties, Zuyev affirms.

Laser requirements are particularly stringent, as set forth by Zuyev. These would ideally include pulse energies to several tens of joules; pulse widths from the nanosecond through microsecond ranges, pulse rates up to a thousand hertz, and wavelengths in the UV, visible and IR bands.

b) Central Aerological Observatory

Simultaneous atmospheric soundings were recently conducted in a joint experiment by scientists from the Central Aerological Observatory, using laser instruments mounted aboard an IL-18 research aircraft, and by personnel on the SP-22 Arctic drift station [9]. Highly sensitive detectors on board the IL-18 registered the traces in the atmosphere of transmitted laser pulses, and the readings were translated into figures by means of a special calibrated table. Simultaneously the data from radiosondes launched by the station were radioed to the airborne TsAO (Central Aerological Observatory) laser team by the SP-22 meteorologists.

V. Torgovichev, director of the TsAO laser research team, noted that this laser sounding equipment, which is undergoing its first airborne tests, is capable of isolating individual components of atmospheric gases and determining major environmental pollutants.

The experimental results of laser atmospheric sounding at 530, 694.3 and 1060 nm wavelengths have been examined and the profiles for total and molecular backscattering derived, by V. M. Zakharov et al. [10]. Atmospheric density was extrapolated from the profile for molecular scattering of laser radar, and the results compared with simultaneous atmospheric data from radiosondes.

Two methods of processing data from laser atmospheric soundings are examined: the approximation method and the two-phase method. The data obtained on the spectral dependence of the coefficient for aerosol scattering is discussed. This research was also carried out under the auspices of the Central Aerological Observatory.

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## V. WEATHER MODIFICATION

Yu. Sedunov, Chairman of the Council on the Problems of Weather Modification and Director of the Institute of Experimental Meteorology, has reviewed Soviet weather modification efforts in [1].

Although effective techniques for supercooled fog dispersal have been developed, warm fog suppression remains a problem. The warm fog dispersal methods being investigated include applications of hygroscopic particles, surface-active substances, and electrical charges to mix dry, overlying air layer with humid, surface air. It has been found that the most efficient method, despite the expense, is to heat the air along airport runways by 0.5 - 2 C, using surplus turbojet engines. According to Sedunov, this Soviet solution is similar to the turbojet fog suppression system recently installed at Orly Airport in France. (In the U.S., according to Sedunov, such a system will not become operational until 1979). Eventually, judging by the material being published in the international scientific literature, high power CO<sub>2</sub> lasers will be used to create transparent zones over landing strips.

In regard to precipitation augmentation, Sedunov singles out the work of the Ukrainian Hydrometeorological Research Institute. The Institute's experimental work indicates that precipitation from winter frontal clouds can be increased up to 25%, while the yield from summer cumulonimbus could be even higher.

At Lake Sevan in Armenia a comprehensive experimental program is underway to increase area rainfall and thus counteract the lake's recession. However it is still too early to make an assessment of the effectiveness of the "Supermetatron", the turbojet thermal generator used in stimulating cumulonimbus development.

Hail suppression research centers include the High Altitude Geophysical Institute (Nal'chik, Kabardino-Balkhar ASSR), the Central

Aerological Observatory, the Geophysics Institute of the Georgian Academy of Sciences, and more recently, the Transcaucasian Hydrometeorological Research Institute, and the Central Asian Regional Hydrometeorological Research Institute. Currently over four million hectares of croplands are protected by hail detection radar networks, which employ either reagent-loaded artillery shells or plastic rockets for hail suppression. A 70 - 95% reduction in hail damage is reported for the areas under surveillance.

In addition, research is in progress on cloud destruction and thunderstorm mitigation. "Promising" American research in thunderstorm chaff seeding with metallized nylon fibers is cited as utilizing one kilogram of needles to compensate for one lightning stroke per second.

Scoring "American imperialism" for the deployment of weather warfare techniques during the Vietnamese conflict, Sedunov emphasizes that growing international capabilities in weather modification mandate the establishment of an international regulatory framework to insure that advances in weather modification will serve only peaceful purposes.

#### 1) Cloud Seeding

Soviet and Western precipitation augmentation research from the 1960's to the present is surveyed by V. P. Lominadze et al.[2] as background for a discussion of measures applicable to conditions in the Lake Sevan (Armenia) region.

Studies by the Transcaucasus Hydrometeorological Research Institute on the nature of the continental convective clouds in the Lake Sevan basin have indicated that the most effective method of rainfall augmentation in that area would involve a simultaneous, twofold seeding procedure: the warm base portion of Cu cong. clouds should be seeded with a hygroscopic reagent, while the supercooled Cu cong. cloud tops, (which in the Lake Sevan area often remain uncrystallized at temperatures between -20 and -30 C), are seeded with crystallizing reagents. Recently published theoretical studies by I. M. Yenukashvili et al., e.g. "Quantitative modelling, using

the Monte Carlo method, of the modification of the kinetics of precipitation formation in convective clouds' [3], support this twofold seeding approach.

Based on their analysis of the observational data on cloud and precipitation conditions in the Lake Sevan basin, A. P. Chuvayev et al [4] concluded that convective cloud modification could potentially increase precipitation over 30% in this upland region.

Three basic factors influencing the effectiveness of CuS as a cloud seeding agent are discussed by Stalevich et al. [5]: (1) factory variations in the quality of the CuS manufactured; (2) the shelf life of the reagent; (3) the dispersion method.

Improvements in 1970 in the quality of the manufactured CuS allowed approximately a two-fold reduction in the optimal dosage of CuS. In regard to the storage life of CuS, it was found that within a one year period, the effectiveness of the optimal dosage of CuS declines by nearly a factor of four.

However, the basic variations in CuS effectiveness are caused by the method of dispersion. The lowest optimal dosage is obtained with CuS in finely ground powder form. Nonground CuS powder requires a tenfold greater expenditure than ground powder. Low temperature ( $T < -10$  C) dispersion of CuS particles is more effective than using nonground powder, but less effective than finely ground CuS powder. The explosive dispersion of CuS particles at a higher temperature, in particular near the CuS threshold temperature  $T \approx -6, -7$  C), significantly reduces the reagent's effectiveness: at  $T = -6$  C the optimal dosage for (explosively dispersed) CuS particles increases to 1-3 kg., as opposed to the 500 gr. dosage for finely ground CuS powder.

P. A. Gubin [6] examines the results of cloud-seeding fire fighting pilot programs conducted in 1968 - 1972 by the Main Geophysical Observatory and the Leningrad Forestry Research Institute. According to the combined data, due to the cloud seeding operations in 1970 - 1972 in the Krasnoyarsk and Khabarovsk krays, Irkutsk oblast, and the Yakutsk and Tuva Autonomous Socialist Republics, 85 forest fires were localized and 122 fires, covering a total area of 175,000 hectares, were extinguished. Li-2, Il-14 and An-24 aircraft were used to seed Cu cong. clouds with either lead iodide, silver iodide, or copper sulfide.

An assessment of the effectiveness of the seeding agents cited is given in the table below. According to the mean orientational figures, 1.5 (26-caliber) pyrotechnic devices, or 100 - 120 grams of CuS, were fired into an average cloud having an approximate volume of 10 km<sup>3</sup>.

Quantity and effectiveness of seeding agents used to extinguish forest fires in 1969 - 1971				
Seeding agent	Form of seeding agent, type of pyrotechnic compound	Quantity of agent expended	Number of clouds treated	
			Total	Precipitation obtained
Lead iodide	S-55 pyrotechnic device	630 units	456	365
Lead iodide	S-50 pyrotechnic device	526 units	338	211
Silver iodide	I-1, I-16 pyrotechnic device	19 units	10	9
Silver iodide	A-2	380 units	224	156
Copper sulfide	powder	23 kg.	190	172
Copper sulfide	SM-2 powder	8 units	2	2
Copper sulfide	K-55 canister	119 units	110	74
			1130	989

The best cloud seeding results were obtained using copper sulfide. The low efficiency coefficient for the K-55 canister delivery of CuS was due to malfunctioning of the canister's explosive mechanism. The extensive application of CuS in combatting large-scale forest fires has been hindered by technical deficiencies in the design and functioning of CuS cloud seeding delivery systems. A drawback of seeding with CuS in powder form is that the delivery plane must penetrate into the "target" Cu cong. cloud.

According to laboratory studies by the Central Aerological Observatory on the cloud ice nucleating properties of the A-2 and S-50 pyrotechnic compounds, the A-2 compound, containing 2% AgI, was found to be somewhat less effective than the S-50 PbI<sub>2</sub> compound and to have a lower ice-formation threshold.

The effectiveness of PbI<sub>2</sub> in S-55 and S-50 pyrotechnic compounds is reflected in the table below.

Results of modifying super-cooled Cu cong. clouds with a vertical thickness of 2500-4000 m, using 26 mm pyrotechnic devices with S-55 and S-50 pyrotechnic compounds (for fire-prone periods of the year in Krasnoyarsk kray, Irkutsk oblast and in southern areas of the Yakutsk ASSR, 1969 - 1972).

Vertical Extent of Clouds, m	Temperature at Modification Level, °C											Total	Probability of Precipitation
	-6	-7	-8	-9	-10	-11	-12	-13	-14	-15	-16 and lower		
2500-3000	19/4	61/39	35/26	21/18	24/22	11/11	7/7	—	2/2	—	—	180/129	0,66
3001-3500	14/7	18/14	47/39	41/38	30/27	23/22	17/17	11/11	8/8	3/3	—	212/186	
3501-4000	8/5	17/15	29/23	14/12	16/16	17/17	15/15	9/9	7/7	6/6	2/2	140/127	0,92
Total	41/16	96/68	111/88	76/68	70/65	51/50	39/39	20/20	17/17	9/9	2/2	532/442	

Note: Numerator indicates total number of Cu cong. seeded with PbI<sub>2</sub>, denominator -- the number of seeded clouds yielding precipitation.

Approximately 1/3 of the clouds having a vertical thickness of 2500 - 3000 m. did not yield precipitation. However this figure drops to only 8% for Cu cong. with a 3501 - 4000 m vertical thickness. In regard to the cloud temperature at the point of cloud seeding, pyrotechnic devices carrying lead iodide were effective in 100% of the cases at a temperature of  $-11^{\circ}$  C or lower.

Under a new firefighting program as reported in the Soviet press [7], specially adapted aircraft, (in this instance an AN-24 equipped with 32-rocket wing pods,) are being utilized to precision-seed cumulus formations over forest fires, and over major fires at oil and gas refineries, or at major construction sites. The program is now operational in the 'Irkutsk Oblast', the Yakutsk ASSR, the Komi ASSR, the Krasnoyarsk Kray, and in the Far East, as well as in other, unspecified areas.

## 2) Updraft Generation

The "Supermetatron", an extremely powerful thermal generator designed to stimulate cumulonimbus buildup in arid regions, is now undergoing on-site testing at the Lake Sevan reclamation project in Armenia, as reported by Yu. Kovaleva [8].

Significantly more powerful than the earlier gas turbine meteatrons, the "Supermetatron" utilizes six rebuilt turbojet aircraft engines which are joined in a single assembly. The diameter of its combined intake area is 18 meters. In contrast to earlier meteatrons, in the "Supermetatron" the gas flow from the individual engines is fed into a single receiver and then reignited with additional fuel in the afterburner at temperatures in excess of 1000 C. Brilliant dyes are injected into the intense updrafts generated by the "Supermetatron" in order to track cumulonimbus development.

Additional applications of the "Supermetatron" include fog dispersal at airports and ventilation of the surface air layer in quarries and smog-prone areas.

Upon the initiative of the Institute of Applied Geophysics, work on the "Supermetatron" began in December 1970 at the Riga Red Banner Institute of Civil Aviation Engineers. A model of the "Supermetatron" was placed on display in 1974 at the Moscow Permanent Exhibition of the Economic Achievements of the USSR.

Supplementary data on the "Supermetatron" designed by the Riga Institute is furnished in an article by R. Goncharov [9].

In the 10-meter long afterburner tube of the "Supermetatron", air is heated to a temperature of 1,100 C. The intense updraft produced has an initial velocity of 570 meters/sec., which is sufficient to generate cumulus clouds at an altitude of two kilometers. Reportedly, two hours of operation can trigger a heavy downpour of rain. (There is, however, no discussion of the atmospheric conditions necessary to ensure rainfall).

A theoretical discussion of metatron capabilities in updraft generation is given in the recent textbook on weather modification by L. G. Kachurin [10]. Two diagrams of the thermal fluxes generated by variations in the design and output of the metatron are presented below. The theoretical metatron output ranges from  $8 \cdot 10^5$  to  $8 \cdot 10^7$  kw in these calculations. Figure 1 below illustrates the effect of the temperature stratification of the atmosphere and of the initial radius of the metatron flux on the vertical velocity profiles, where  $w_0$  = vertical velocity,

$\Delta T_0$  = superheating relative to the ambient air,

$R_0$  = initial radius of flux.



Fig. 1. Calculation of metatron thermal flux. Effect of temperature stratification of the atmosphere  $t(z)$  and the initial flux radius  $R_0$  on vertical velocity profiles in the flux  $w(z)$ . Atmospheric temperature is shown by lines  $t_1$  (example 1),  $t_2$  (example 2). The initial radius of the flux  $R_0$  and its power  $\rho$  are shown on the corresponding curves, the remaining flux parameters are the same in all the examples:  $w_0 = 1$  m/sec.,  $\Delta T_0 = 100^\circ$ ,  $f'_0 = 0.7 \times 10^{-2}$ ,  $e'_0 = 25.5$  mb.

The significance of the flux radius  $R_0$  is demonstrated by progressively increasing  $R_0$ , while retaining all other parameters at the same level. At  $R_0 = 50$  meters only a fair-weather cumulus is generated. By doubling  $R_0$  to 100 meters a cumulonimbus is formed (curve 1'). If  $R_0$  is increased to 200 meters (curve 1''), there is considerably less loss of flux velocity during passage through the isothermic layer, and a cumulonimbus with extremely high vertical velocities is formed. At  $R_0 = 500$  m. (curve 1'''), the updraft passes through the isothermic layer with virtually no loss of velocity. However, the author notes, at this point the metatron power level required is greater than would be feasible.

In Figure 2 below an inversion exists up to the 300 meter level, after which the temperature decreases at the rate of 0.8 C/100 m up to 4 km, and thereafter at the rate of 0.6 C/100 m from 4 km to 7 km.

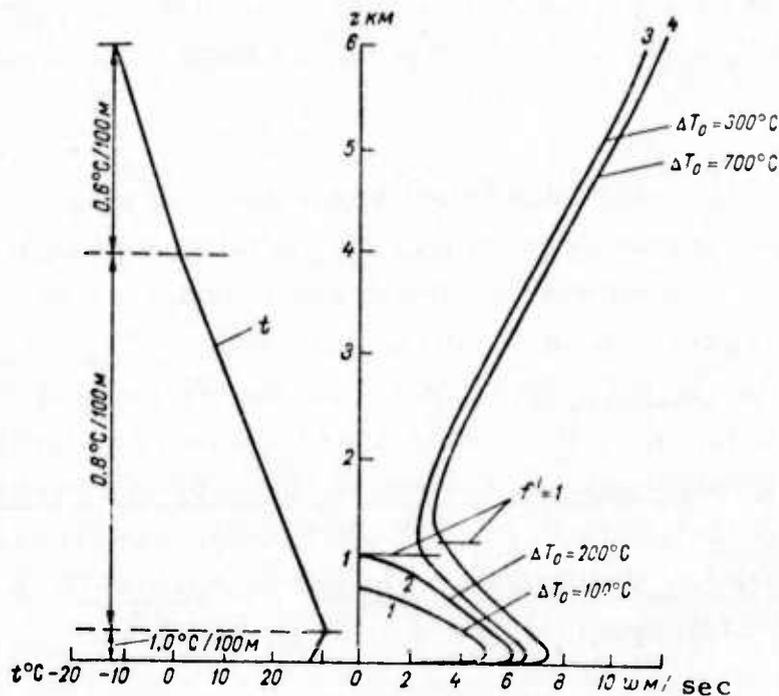


Fig. 2. Calculation of meteoron flux. Effect of the initial superheating  $\Delta T_0$  on the vertical velocity profile in flux,  $w(z)$  [10].

$$R_0 = 50 \text{ m.}, w_0 = 1 \text{ m/sec.}, \rho = 8 \cdot 10^5 \text{ kw,}$$

$$e_0 = 28 \text{ mb.}$$

The thermal fluxes generated by an initial heating to 100 C and 200 C are insufficient for cloud formation. However by boosting the initial heating to 300 C, the updraft penetrates through the inversion layer, generating a substantial cumulonimbus cloud. Further initial heating is of minimal benefit since the vertical velocity gain will be relatively insignificant.

### 3) Downdraft Generation

A patent on an atmospheric modification method was recently issued to N. I. Vul'fson et al. [11] for the purpose of convective cloud break-up or ventilation of ground surface areas. Downdrafts are initiated by

exploding shaped charges in the upper portion of a developing convective cloud or above the atmospheric zone to be aerated. A special downward-directed, shaped charge is employed to generate the descending blast effect.

(Although this patent application was submitted on 22 January 1970, the patent announcement was not published until early 1975. Additional information on the authors' studies of cloud dissipation by downdraft generation is presented in: Vul'fson and Levin. Destruction of developing cumulus clouds by explosions. *Izvestiya Akademii nauk SSSR, Fiz. Atmos. i Okeana*, vol. 8, no. 2, 1972, 156-166; and Vul'fson and Levin, The physical basis for the modification of convective clouds by downdrafts. *Institut prikladnoy geofiziki, Trudy*, no. 12, 1970, 5-16. See also L. J. Battan, Survey of Weather Modification in the Soviet Union: 1973, *Bulletin American Meteorological Society*, vol. 54, no. 10, 1024-1025.)

N. Sh. Bibilashvili et al. [12] note that the Vul'fson-Levin method of cloud dissipation has been demonstrated to be effective for Cb clouds with a vertical extent to 5-6 km. Hence the focus of a recent experimental study conducted at the Krasnodar testing grounds of the High Altitude Geophysics Institute by Bibilashvili et al. was Cb clouds with a vertical extent in excess of 7 km. "El'brus-2" anti-hail shells were exploded in the rear, pre-summit zone of mature or building Cb clouds, having a vertical extent to 10.7 km, at a distance of no more than 1 - 1.5 km from the cloud boundary, i.e. in the zone near the upper boundary of the area of natural downdraft generation in a cloud. (See Fig. 3 below.)

After shelling with 1 to 5 artillery rounds, the subsidence rate for the Cb summits ranged up to 22 m/sec. Two Cb dissipation experiments are reported in detail and their cloud summit radio echoes are indicated below in Figure 4.

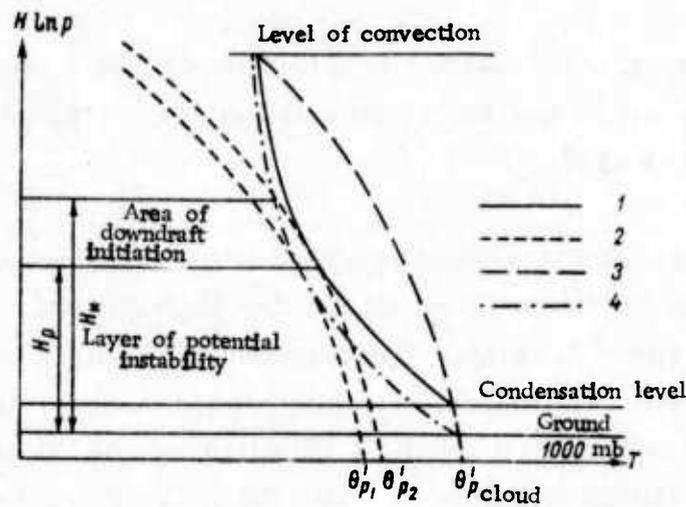


Fig. 3. Determining the level of downdraft initiation.

1- stratification curve; 2- moist adiabats;  
3- cloud (moist) adiabat; 4- temperature curve  
of wet-bulb thermometer.

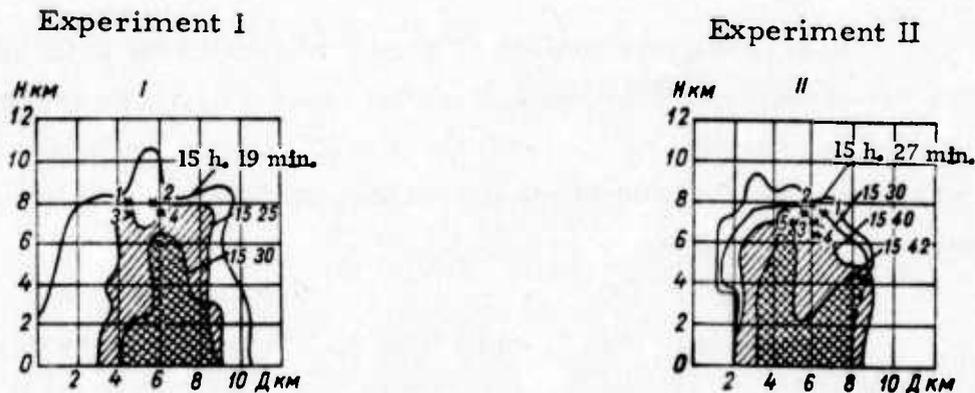


Fig. 4. Changes in radioechoes on a vertical scan screen after cloud modification ( $\lambda = 3.2$  cm).  
\* - point of shell explosion. [12].

#### 4) Hail Suppression

A review paper by I. I. Burtsev [13] assesses hail suppression work in the USSR from 1968-1972. The Soviet statistics indicate a decrease in the incidence of hailfalls by a factor of 3 to 4 within the five year period from 1968-1972. In 1972 over a total protected area of approximately

3,910,000 hectares, the calculated coefficient of effectiveness was 87%, as shown below (p.67) in the table, Results of Hail Suppression Programs in the U.S.S.R. 1968-1972.

Five of the nine major hail suppression programs, the program in the northern Caucasus of the High Altitude Geophysics Institute (VGI), as well as the Armenian, Azerbayzhan, Tadzhik, and Uzbek programs, employ anti-hail artillery shells, following procedures developed by the VGI. The Georgian program no. 6, which is directed by the Transcaucasian Hydro-meteorological Research Institute (ZakNIGMI) under V.P. Lominadze, also uses anti-hail artillery shells, but has pioneered a "combined", two-fold seeding technique whereby ice nuclei (AgI) are injected into the supercooled portion of a cloud at the same time that the warm level of the cloud is being seeded with large NaCl nuclei. Rockets are used in programs nos. 7, 8, and 9: the Moldavian program, the Ukrainian program, and the Georgian hail suppression program of the Geophysics Institute of the Georgian Academy of Sciences (IGAN), directed by A.I. Kartsivadze.

In 1972 the total territory under protection by artillery shell hail suppression programs nos. 1-5 was 2.6 million hectares. The territory protected by the ZakNIGMI combined method was about 0.25 million hectares. Rocket systems were employed in protecting one million hectares, the total area covered by programs no. 7, 8, and 9.

According to the figures of the U.S.S.R. Ministry of Agriculture, the annual value of the crops successfully protected from hail damage was approximately 40 million rubles in 1972.

Burtsev notes, in regard to the sizeable agricultural territory still vulnerable to hail damage (as indicated in the table below), that among the technical causes for hail damage in protected areas are: the increased hailfall during years having particularly intensive hail processes, cases of the lack of, or inadequate, hail modification efforts, or equipment problems such as the disruption of radio communications between the control post and the seeding unit during intense electrical storms or severe downpours, and other technical deficiencies in methodology.

Results of Hail Suppression Programs in the U. S. S. R. 1968-1972

No.	Program	1968				1969				1970				1971				1972			
		Total PT		Hail Damage		Ceff	Total PT		Hail Damage		Ceff	Total PT		Hail Damage		Ceff	Total PT		Hail Damage		Ceff
		1,000's of ha	hectares	PT	CT		hectares	PT	CT	hectares		PT	CT	hectares	PT		CT	hectares	PT	CT	
1	KPE VGI (Northern Caucasus)	785	12.8	56.5	77	890	1.7	69.2	98	960	28.6	95.9	70	1107	22.5	61.9	64	986	28.3	77.5	63
2	Armenian	500	14.1	-	-	520	1.1	4.9	77	520	7.2	35.5	80	700	6.7	-	70	721	20.1	-	70
3	Azerbaijhan	86	4.3	24.0	82	300	3.7	-	-	240	3.2	6.5	51	254	0	-	100	320	0	10.0	100
4	Tadzhik	160	4.7	-	-	200	2.9	-	-	220	3.3	-	76	300	0.2	-	83	320	0.7	-	94
5	Uzbek	-	-	-	-	150	2.0	-	-	152	1.8	12.9	81	243	0	-	100	243	2.4	-	92
6	Georgian	110	0.3	3.7	92	150	0.3	5.0	93	170	0.8	6.2	87	210	0	4.2	100	250	0.3	6.0	95
7	Moldavian	140	1.6	15.1	89	210	0.3	13.3	97	230	0	16.0	100	300	1.0	18.5	93	360	1.6	36.6	96
8	Ukrainian	47	0.3	0.9	67	70	0	3.9	100	100	0.4	5.6	93	100	0	-	100	110	0	4.6	100
9	SBG MSKh (Georgian SSR)	460	7.2	21.6	67	460	6.8	21.6	69	460	2.5	21.6	88	460	3.9	21.6	82	600	6.1	25.3	76
	Total	2288			78	2950			89	3052			81	3674			88	3910			87

Legend: PT = protected territory  
 CT = control territory  
 Ceff = coefficient of effectiveness

KPE VGI = Caucasus Hail Suppression Project  
 of High Altitude Geophysics Institute  
 SBG MSKh = Anti-Hail Service of the Ministry of Agriculture

Of prime importance in improving hail suppression efforts is the development of more comprehensive and realistic three-dimensional hail models, based on thoroughgoing theoretical and experimental studies of hail processes. Existing hail models are either too simplified or too unwieldy, and the input parameters are still too empirical, Burtsev concludes.

Descriptions of the basic types of Soviet anti-hail rockets and shells including the "Oblako" and "Alazan" rockets and the "El'brus-2" and "El'brus-3" shells are provided in Kachurin's recent textbook on weather modification [14].

The 125 mm "Oblako" anti-hail rocket, which was developed in 1964, has a length of 2070 mm, its total weight is 33.5 kg, maximum ascent 8.2 km, maximum range 12 km; the active smoke path ranges up to 8 km. The seeding reagent is either an aerosol such as AgI, or dry ice. If AgI is used, a 5.2 kg pyrotechnic payload will form  $10^{16}$  ice nuclei at a cloud temperature of -10 C. (See Fig. 5 below.)

The more recently developed "Alazan" anti-hail rocket is described as being smaller than the "Oblako", but having better ballistic properties and greater reliability, as well as a more rapid reload capability and higher reagent dispersion capacity. (See Fig. 6 below.)

Sulakvelidze et al in [15] note that the "Alazan" lofts a one kg pyrotechnic payload as compared to the approximately 5 kg payload of the "Oblako". The triggering devices for the "Oblako" have 4 directional bodies. In contrast the "Alazan" devices have 12 directed individual lines-of-fire which considerably increase operational effectiveness by allowing the dispersion of up to 12 kg of pyrotechnic material along different paths simultaneously.

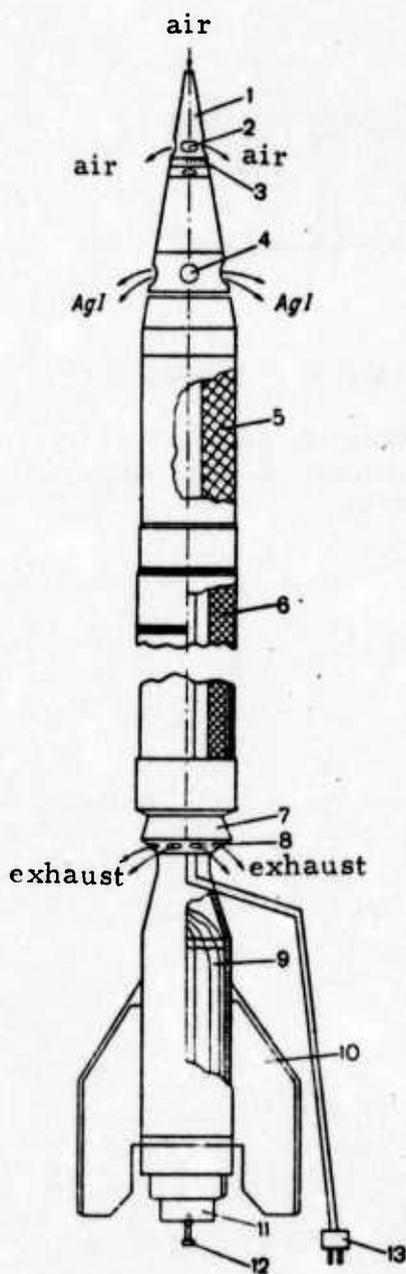


Fig. 5. Diagram of "Oblako" rocket.

1- impeller-type arming mechanism;  
 2- air outlets; 3- nose fuse; 4- openings  
 for seeding agent dispersal; 5- smoke  
 charge; 6- propellant; 7- exhaust nozzle;  
 8- nozzle ports; 9- parachutes; 10- stabilizers;  
 11- parachute release fuse; 12- back-up  
 fuse; 13- electrical firing squib.

Instead of employing a parachute system as the "Oblako", the "Alazan" self-destructs upon expulsion of the reagent. The new two-stage "Alazan" has a range of 9 km [16], however a second long-range version of the "Alazan" is planned, according to Kachurin.

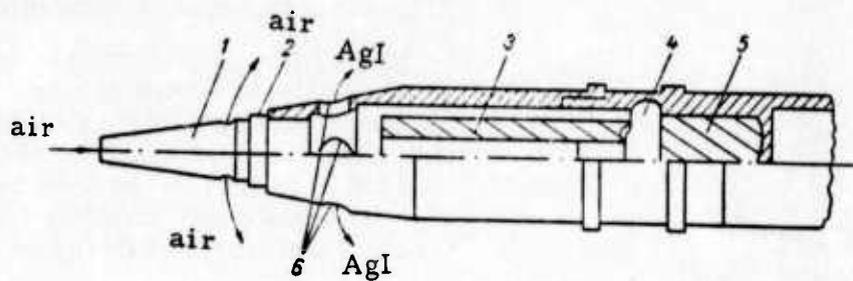


Fig. 6. Cross-section of payload of "Alazan" rocket.

1- air-driven arming mechanism; 2- fuse; 3- smoke charge; 4- spent rocket destruct mechanism; 5- explosive charge; 6- opening for reagent discharge.

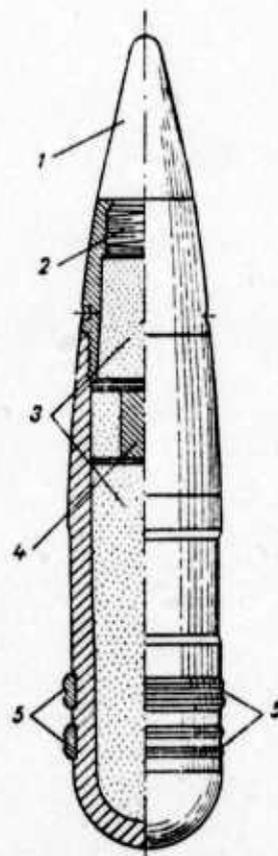


Fig. 7. 100-mm "El'brus-2" anti-hail shell.

1- fuse; 2- spacer; 3- explosive; 4- reagent; and 5- gas seal.

The "El'brus-2", a 100 mm, 12.25 kg artillery shell, (Fig. 7 above), reaches an initial velocity of 850 m/sec, carrying a reagent payload capable of creating  $10^{13}$  -  $10^{14}$  ice-forming particles at a cloud temperature of -10 C. Its maximum (approximately 15 km) range and altitude are compared with the data for the "Oblako" rocket in Fig. 8 below.

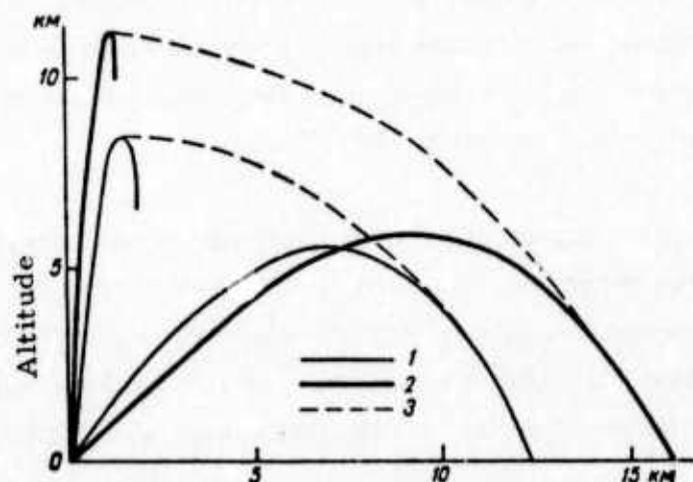


Fig. 8. Comparative range of the "Oblako" rocket and the "El'brus-2" shell.

1- "Oblako" rocket trajectory; 2- "El'brus-2" shell trajectory; 3- trajectory envelopes corresponding to different firing elevation angles.

The more recently developed "El'brus-3" is similar in construction, but designed for 130 mm caliber artillery. The "El'brus-2" and the "El'brus-3" can be used up to distances of 13 and 18 km respectively, according to N. Sh. Bibilashvili [17]. The eventual use of recoverable, guided rockets is anticipated.

An article by Bibilashvili et al. [18] contains recommendations for increasing the efficiency of VGI/High Altitude Geophysics Institute/hail modification work. These include, on the organization level, improved coordination between the anti-hail projects and the local air traffic control organizations, and better training of personnel in the field units. On the technical level goals include: maintenance of stable communications between the command post and the firing units under all meteorological conditions, and a distinct improvement in the inflight detonation reliability of anti-hail

shells so that modification could be conducted in any direction and 'danger zones' could be eliminated; an increase in the ice crystal generation from a single artillery round through improved design of anti-hail shells; automatization of operations from radar surveillance to hail modification and analysis of the results; the adoption of longer-range artillery such as the "El'brus-3" shell, and organization of the hail suppression network on the basis of one command post (radar station) per three to four 130 mm artillery guns; the development of an easy-to-operate, economical radar set capable of reliably detecting hail-producing cloud zones.

Improvement of present methods of hail suppression requires further applied research on: the velocity of air currents in and around a given cloud; the formation of hail embryos and the kinetics of their growth during artificial changes in phases and in the concentration of precipitation nuclei; the ice-forming activity of reagents which are directly sublimable in clouds.

#### 5) Fog Dispersal

##### a) Fog Dispersal/Stabilization by Hygroscopic Aerosols

The effect of hygroscopic aerosols on water fog stability has been studied in the 110 m<sup>3</sup> fog chamber of the Main Geophysical Observatory, as reported by T. N. Gromova et al. [19], using the 7 pyrotechnic mixtures described in the table below.

Reagent	Proportion of reagent in aerosol, in % by weight	Mean cubic diameter of aerosol particles in $\mu$ .
Phosphorus	40	~ 10
"	60	~ 10
"	70	~ 10
Aluminum chloride	56	0.8
Potassium chloride	53	0.3
Sodium chloride	38	0.3
" "	33	0.2

It was shown that fog dispersal can be accelerated by a factor of 2 to 2.5, using pyrotechnic compounds having phosphorus or  $\text{AlCl}_3$  as the active seeding agent. Application of the reagents in aerosol concentrations ranging from  $2 \times 10^{-3}$  to  $5 \times 10^{-4} \text{ g/m}^3$  reduced the optimal reagent dosage by a factor of 50 - 200 in relation to the required dosage in powder form.

The most effective pyrotechnic fog dispersal agent, the 40% phosphorus aerosol in a concentration of  $3.5 \times 10^{-4} \text{ g/m}^3$ , accelerated fog dispersal up to 65%, clearing the fog in approximately 10 minutes. On the other hand, KCl in the  $2 \times 10^{-3} \text{ g/m}^3$  aerosol concentration slowed fog dispersal, increasing the time required for fog clearing to 50 minutes or more.

The authors concluded that the pyrotechnic compounds tested have applications in field experiments on cloud dispersal or precipitation stimulation as well as in exploratory work on the modification of thunderstorm processes.

The dispersal rate for simulated steam fog and atomized warm fog, as modified by progressively increased dosages of the aerosol seeding reagent, NaCl, was studied by Lominadze et al. [20] in two cloud chambers: the smaller having a volume of 1 cubic meter and the larger a volume of  $50 \text{ m}^3$ .

The polydisperse reagent dosages were increased from 2 grams, to 4 g, and to 10 g for the large chamber and from 100 mg to 500 mg, then to 1 gram for the small chamber. It was shown that as the number of active nuclei increase, the rate of change in visibility increases. However, above a certain seeding threshold, corresponding to 10 g for the large chamber and to 1 g for the small chamber, visibility deteriorated due to the increasing number of inactive nuclei.

I. R. Preys [21] describes the introduction of an aerosol spectrum of diluted NaCl solution which is finer than the particles precipitated in a  $1 \text{ m}^3$  water fog chamber, causing a decrease in the light attenuation rate and prolonging the lifetime of the fog. In view of the fact that fog lifetime can also be increased by the introduction fine-grained aluminum chloride powder, the results of this preliminary experiment point to the possibility of stabilizing fog by introducing soluble particles with spectra smaller than those used for fog dispersal.

b) Fog Dispersal by  $\text{CO}_2$  Laser Radiation.

The results of the first theoretical and experimental studies of  $\text{CO}_2$  laser dispersal of cloud particles and particle aggregates, conducted at the USSR Institute of Experimental Meteorology toward the development of operational laser cloud and fog modification systems, are published in volume 5(43) of the Institute's Trudy. In addition to the two papers abstracted below (Experimental study of the process of dispersing fog by  $\text{CO}_2$  laser radiation by L. G. Akul'shina, et al., and Experimental study on the effect of the motion of a medium on the formation of a cleared zone in an artificial fog under the effect of  $10.6 \mu$  laser radiation by V. P. Belyayev, et al.), other studies on  $\text{CO}_2$  laser dispersal of fog, published in this volume, include: Experimental study of the stationary "wind deflection" effect of  $10.6 \mu$  laser radiation propagating in artificial fog by V. A. Bel'ts, B. S. Vinevich, O. M. Matveyev, V. P. Nikolayev, Yu. V. Pechenin, and S. D. Pinchuk; Experimental study of the thermal characteristics of a cloud medium in a zone of  $\text{CO}_2$  laser activity by N. K. Didenko, N. K. Krashkovskiy, and L. P. Semenov; Experimental study of the interaction between  $10.6 \mu$  laser radiation and ice platelets by Ye. V. Ivanov and V. Ya. Korovin; Fluctuations of the boundary of a cleared zone in clouds and fogs by N. P. Svirkunov and L. P. Semenov; Data on the effect of  $\text{CO}_2$  laser radiation on supercooled droplet fog and crystalline fog by O. A. Volkovitskiy, A. F. Dobrovol'skiy, Ye. V. Ivanov, and V. P. Kolomeyev.

The Director of the Institute of Experimental Meteorology, Yu. Sedunov, in a lecture delivered at the 6th session of the WMO Commission for Atmospheric Sciences in November 1973 [22], stated that the present lack of lasers with a  $10^6 - 10^7$  w power capacity is holding back the development of operational CO<sub>2</sub> laser fog suppression systems which promise to be relatively economical and effective.

Employing 10.6  $\mu$  laser radiation with 140 w output over paths up to 14 m in the large aerosol chamber of the Institute of Experimental Meteorology, Akul'shina et al. [23] studied fog dissipation effect in relation to the initial optical thickness, the lifetime and the washing-out of the cleared zone, as well as the changes in the fog microstructure from the effect of the CO<sub>2</sub> laser radiation.

The fog dispersal process on paths up to 14 m was accompanied by a considerable deformation in the size distribution spectrum of the fog droplets. The time spans observed for the development of a cleared zone ranged from 0.1 - 0.6 sec, while the washing-out time varied from 0.1 - 1.0 sec, depending on the initial optical thickness and length of the path cleared.

The diagram below shows the dependence of the transmission function  $T_{0.63}$  (1, 2) and the relative value of the attenuation coefficient  $\alpha/\alpha_0$  (4-6) on the length  $x$  for  $\alpha_0 = 0.5 \text{ M}^{-1}$  and  $\bar{V} = 5 \text{ cm/sec}$ .

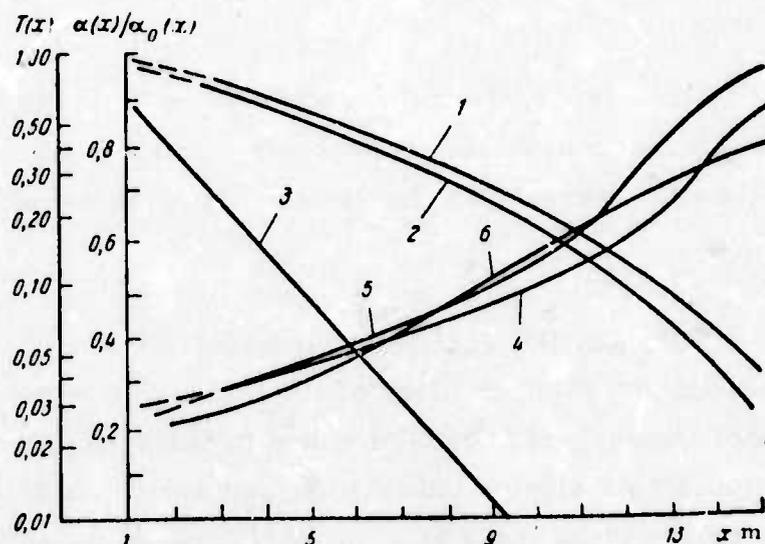


Fig. 9. Transmission and attenuation functions vs. path length.

1, 4-  $P_0 = 140 \text{ W}$ ; 2, 5-  $P_0 = 350$ ; 6- calculation for  $P_0 = 140 \text{ W}$ ; 3- Bouguer's law [23].

V. P. Belyayev et al. [24] studied the effect of continuous  $10.6 \mu$   $\text{CO}_2$  laser radiation with output to 800 w on a constant wind flow with a velocity to 80 cm/sec, and on the nature of convective movements in a stationary cleared zone created in a liquid-aerosol cloud chamber medium. The experiments were conducted using different values for the diameter of the transmitted beam ( $d \approx 1.8$ ; 2.3; 4.6; and 9.2 cm) and with lateral wind velocities ranging from several centimeters per second to approximately 50 cm/sec.

Comparison of the experimental results with the theoretical calculations for a fog dispersal model having an approximation of the fog water content indicated that the model satisfactorily described the dependence of the dispersal effect on the parameters of the source of effective radiation, wind velocity, and the characteristics of the cleared medium.

#### 6. Weather Modification

The monograph by L. G. Kachurin, referred to earlier, on modification of atmospheric processes [25], is organized as follows:

Chapter I, Phase Transitions of Water in the Atmosphere, devotes particular attention to crystallizing aerosols, and hygroscopic and surface-active substances as regulators of evaporation and of condensation processes.

Chapter II, Transformation of the Internal Structure of Clouds, discusses condensation, coagulation, and crystallization processes as reversible and irreversible phenomena, drawing considerably on the author's work.

Chapter III, Artificial Turbulent Fluxes in the Atmosphere, describes the potential capabilities of the meteotron in the artificial stimulation of atmospheric convection and presents theoretical diagrams of meteotron updraft generation under different atmospheric conditions. (This material is reviewed on pages 61-63 of this report). A sub-chapter is devoted to meteotron applications in ventilating smog-prone local air basins and dispersing atmospheric pollutants, including radioactive contaminants.

Chapter IV, The Management of Cloud Processes, gives an overview of Soviet rocket and artillery hail suppression techniques; (this material is reviewed on pages 68 -71 of this report).

Chapter V, Artificial Dispersal and Creation of Fogs, gives brief, primarily theoretical descriptions of basic fog dispersal techniques: artificial heat sources, dynamic means (surface ventilation using air compressors to draw off fog from landing strip), changing the radiation absorptive properties of fog (using carbon black), hygroscopic particle seeding, acoustic and electrical methods, CO<sub>2</sub> laser radiation, fog inhibition through evaporation control, and passivation of condensation nuclei.

Chapter VI, Modification of Electrical Processes in the Atmosphere, briefly examines cumulonimbus seeding with chaff and with crystallizing agents such as CO<sub>2</sub>, and thunderstorm mitigation by altering the crystallization potential of cloud water. Chapter VII, Hurricane Modification, reviews theoretical aspects of hurricane taming.

Chapter VIII, Climate Transformation, written by M. I. Budyko, examines the radiation balance, man's possible advertent and inadvertent modification of climate, and warns of the threat of planetary overheating in the 21st century.

A. I. Kartsivadze (head of the Department of Cloud Physics and director of the hail suppression program at the Geophysics Institute of the Georgian Academy of Sciences) reviews Kachurin's work in [26]. He notes in his review of this first major Soviet university-level textbook on weather and climate modification that virtually all the leading Soviet specialists in atmospheric modification, including the Council on the Problems of Atmospheric Modification, participated in the manuscript review. The final chapter, Climate Transformation, was especially written for this work by the distinguished Soviet climatologist, M. I. Budyko.

Kartsivadze cites the new analytical material on the modification of convective clouds in Chapter IV, The Management of Cloud Processes, and in particular commends the author's new numerical convective model of hail formation processes. (Shortly after its publication in this work, the author's cumulonimbus convective model was presented at the 1973 First International Conference on Weather Modification).

Particular attention is also drawn by Kartsivadze to the material on the calculation of artificial convection in Chapter III, Artificial Turbulent Flux in the Atmosphere, which includes diagrams of metotron processes in cumulus cloud generation and in the artificial ventilation of local air basins.

The reviewer recommends that Chapter VI, The Modification of Electrical Processes in the Atmosphere, be expanded in the next edition, particularly in light of Professor Kachurin's expertise in this area. Kachurin's earlier publications include the monographs, "Electrical measurements of aero-physical values," (1967) and with Professor V. G. Morachevskiy, "The kinetics of the phase transitions of water in the atmosphere", (1965).

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## VI. GENERAL: Weather Modification--Environmental Warfare

The focus of this concluding general section, in contrast to the preceding more strictly scientific portion of this report, is on areas of major State concern in the Soviet climate and weather modification effort, as presented to the Soviet general public. As such this section reflects commentary which appeared in the daily press and in the authoritative foreign affairs journal Mezhdunarodnaya zhizn', describing the potential threat of environmental warfare.

### 1. Weather and Climate Modification

Academician Ye. K. Fedorov, Director of the Main Administration of the Hydrometeorological Service, reviews major areas of Soviet concern in climate and weather research in a recent newspaper interview [1].

Discussing recent climatic changes (e. g. the warming trend of the 1930's, followed by the cooling tendency initiated in the 1940's), Fedorov emphasizes that the lack of a comprehensive quantitative theory of climate prevents a sufficient understanding of the causes for climatic change.

In regard to proposed large-scale climate modification projects (such as melting the Arctic ice cap by damming the Bering Straits and pumping warm Gulf Stream water through the Arctic Basin, etc.) Fedorov states that although the engineering problems have generally been well worked out (i. e. the necessary dimensions and capacity of the dams and hydraulic installations), the cardinal problem is assessing the possible effects on atmospheric circulation and the ocean currents.

The projected increases in fossil fuel combustion, thermal pollution, and particulate pollution are cause for serious concern. If the present 5-6% annual growth rate of energy production continues, within a few decades world heat production could rise from the present level of 0.2% of the received power from the Sun to a level of 2%, thus causing a 1-1.5 C

mean global temperature increase. Such a potentially harmful warming trend could, in principle, be checked by artificially increasing the planetary cloud cover.

Considering that during natural rainfall 15-20 times more water is precipitated to the earth than is contained in a given cloud, at a given moment, Fedorov holds that the effective yield from artificial rain- and snow-making is still insufficient: for artificial rainmaking to be economically viable, regular precipitation should be increased approximately one third. The problem lies in finding mechanisms for the release of additional moisture from the air. An approximately 10-15% annual precipitation increase in a low-precipitation area can only be considered economically justifiable in a few special cases, such as in the relatively small basin of Lake Sevan (Armenia), where the Hydrometeorological Service is now conducting a special experimental program to increase precipitation 10-15% and thus prevent the further recession of the lake.

Fedorov cites Soviet world leadership in hail suppression. Approximately 4 million hectares of cropland in Soviet Moldavia, the Ukraine, Central Asia, the Caucasus and the Transcaucasus are currently under hail control programs. According to Fedorov, an annual outlay of 5-6 million rubles on hail suppression measures saves the State approximately 50-60 million rubles worth of crops per year. In the future this program will be expanded to cover virtually all vulnerable crops in the USSR.

## 2. Environmental Warfare

The U.N. General Assembly at the recent XXIXth session in December 1974 approved the Soviet draft resolution calling for an international convention banning environmental warfare.

Scorning the U.S. deployment of "weather warfare" in Indochina, a Soviet commentator [2] cites the large-scale destruction of roads and communications and the severe erosion of large areas of arable land during

the Vietnamese conflict. Reportedly the U.S. military deployment of herbicides and "fire storm" defoliants destroyed the natural vegetative cover of 58,000 square kilometers of land.

According to this source, the U.S. has seven environmental warfare centers (not identified in the article) which are engaged in research on potential tactical measures such as the triggering of major earthquakes by the deep injection of "lubricants" into vulnerable geologic faults or the generation of destructive seismic tidal waves by underwater explosions. In the same vein, the Soviet commentator alludes to the potential specter of "guided" tornadoes.

In a similar vein, V. Israelyan [3] cites the Soviet draft resolution to the U.N. as the latest example of Soviet disarmament efforts. The scope of the U.S. weather warfare effort in Indochina is again discussed, referring in detail to material presented at the hearings of the Subcommittee on Oceans and the International Environment of the U.S. Senate Foreign Relations Committee in March 1974.

In characterizing the threat of environmental war, Israelyan cites the following potential geophysical warfare techniques: the creation of "windows" in the atmospheric ozone layer; the hostile deployment of ultra- and infra-acoustic fields; the manipulation of atmospheric electricity to depress the mental activity of large groups of people; the tactical deployment of "guided" lightning; the thawing of the Arctic or Antarctic ice caps through nuclear explosions; the triggering of destructive tidal waves by artificial underwater earthquakes or by dumping massive blocks of bedrock from the continental shelf into deeper portions of the ocean.

In regard to U.S. weather warfare R and D, the author refers to U.S. work in progress on methods of changing the nature of lightning in order to increase its power and to direct high-energy lightning bolts at specific targets (sic). The Institute for the Study of the Brain (sic) of the

University of California is cited as engaged in research on the debilitating effect of weak vibrational fields on human behavior.

Experiments on the stimulation of earthquakes by underground nuclear explosions are reportedly under way at the Nevada nuclear test site, while other methods of triggering artificial earthquakes are being tested near Denver, Colorado.

Israelyan concludes that the particular danger of environmental warfare lies in the possibility that the aggressor nation may be secretly, over the course of many years, employing any of a whole arsenal of hostile geophysical techniques against another nation which would be unaware of the origin of the "natural" disasters afflicting her and thus incapable of initiating any counteraction.

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