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OCEAN EFFECTS ON WEATHER AND CLIMATE

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RESUMEN

Un modelo termodinámico se usa, para el hemisferio norte, en enero y en julio, para evaluar en el sistema Atmósfera-Océano-Continente las contribuciones, en los campos de temperatura, de la evaporación y del calor sensible dado a la atmósfera de la superficie de los océanos; así como del almacenamiento de energía en los mismos.

Se presentan cálculos de la respuesta del sistema Atmósfera-Océano-Continente a una anomalía inicial de 2°C en la temperatura de la superficie de los océanos. Los resultados muestran que importantes anomalías aparecen en la temperatura, las funciones de calentamiento y la circulación atmosférica, que dependen de la estación del año.

Se hace una estimación cuantitativa de los efectos del océano en la respuesta del sistema Atmósfera-Océano-Continente a un aumento de 2% en la constante solar, para el hemisferio norte.

ABSTRACT

A thermodynamic model is used for the Northern Hemisphere, in January and July, to evaluate in the Atmosphere-Ocean-Continent System the contributions to the temperature fields of the evaporation and the sensible heat given off to the atmosphere from the surface of the oceans; and of the storage of heat in the oceans.

Computations of the response of the Atmosphere-Ocean-Continent System to an initial anomaly in the surface ocean temperature of 2°C over the whole oceanic areas are carried out. The results show that important anomalies in the temperature fields, the heating functions and the atmospheric circulation are generated, that depend on the season of the year.

A quantitative estimate of the ocean effects in the response of the Atmosphere-Ocean-Continent System to an increase of two percent in the solar constant is carried out, for the Northern Hemisphere.

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I. INTRODUCTION

The influence of the ocean on weather and climate has been recognized for many years. However, not until the last decade have attempts been made to quantify such an influence in a systematic way.

In the Atmosphere-Ocean-Continent System there exist very complex interactions and feed-back mechanisms as shown in Figure 1.

The primary energy that feeds the system is the solar radiation that depends on the solar constant and on the declination of the sun. Part of this energy is absorbed by the atmosphere and part by the oceans and continents. There exists, furthermore, the radiation energy emitted at terrestrial and atmospheric temperatures. The atmosphere is also heated by condensation of water vapor in the clouds and by sensible heat given off by vertical turbulent transport from the surface of the oceans and continents. In the atmosphere, the energy is transported horizontally by mean winds and by horizontal mixing; and there exists storage of energy which is comparatively small.

In the upper layer of the oceans, besides the energy gained by radiation processes and the sensible heat given off to the atmosphere by vertical turbulent transport, there exists a loss of heat by evaporation and a horizontal transport of thermal energy by ocean currents and by turbulent mixing. These processes of heating and of transport of heat that exist in the atmosphere and in the ocean depend on the temperatures of the atmosphere and the ocean and, at the same time, such temperatures also have influence on the heating functions and transport mechanisms so that there exists a simultaneous multiple interaction of causes and effects.

Furthermore, the generation of the horizontal winds depends on the atmospheric temperature; and the winds in turn produce surface ocean currents, affecting the horizontal transport of heat in the oceans which, in turn, affect the field of ocean temperature. The wind affects also the evaporation and the sensible heat given off by vertical turbulent transport to the atmosphere from the ocean, which in turn affect the thermal field.

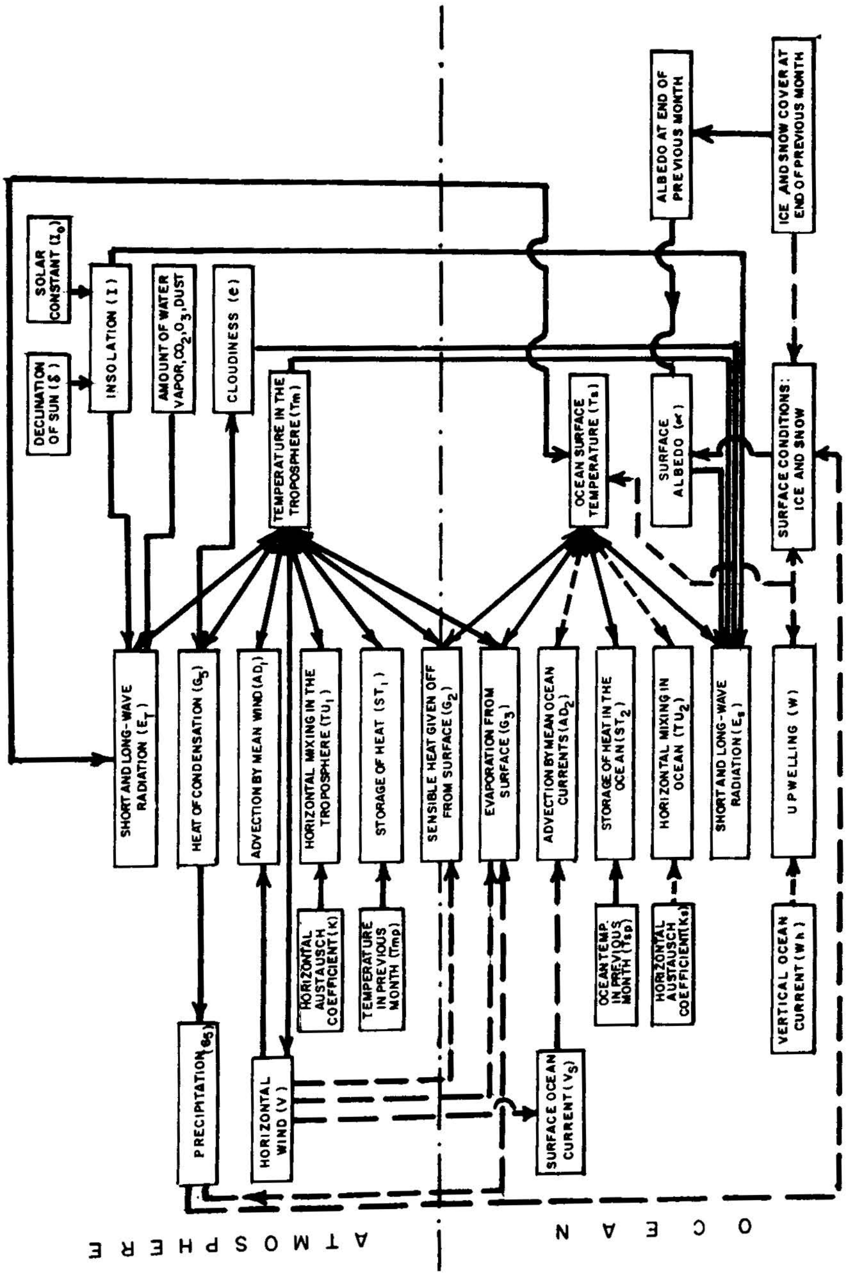


Figure 1. Schematic representation of the thermodynamic interactions of the ocean-atmosphere system.

The condensation of water vapor in the clouds adds heat to the atmosphere and, at the same time, produces precipitation, which influences the surface conditions and, therefore, the surface albedo which affects the radiation energy absorbed at the surface, and which in turn affects the thermal field.

Other factors of great importance in the energy balance in the Atmosphere-Ocean-Continent System are the quantities of water vapor, carbon dioxide, ozone and dust that are present in the atmosphere, which regulate the absorption and emission of radiation energy; and the cloudiness, which strongly affects the absorption of short-wave radiation in the surface of the earth, and affects also, in an important way, the radiation balance in the whole system.

Another important factor is the albedo of the surface of the earth, which depends on the initial conditions of the surface, and varies simultaneously with the meteorological variables of the system, especially the precipitation and the temperature; and depends critically on the distribution of snow and ice on the surface.

Important factors in the balance of thermal energy are the initial temperatures, especially in the ocean, since they determine the storage of energy which contributes in an important way to the balance of thermal energy affecting the thermal fields, both in the atmosphere and in the ocean. Other parameters that enter in the balance of energy are the turbulence exchange coefficients for the atmosphere and the oceans which allow a parameterization of a smaller scale than the one considered in this study and which, for the atmosphere, corresponds to the turbulence associated with cyclones and anticyclones of middle latitudes, having values of the order of 3×10^{10} cm^2 sec^{-1}. In the ocean, the coefficient has values 100 times smaller than in the atmosphere. Finally, the vertical component of the currents in the ocean transports the contribution due to the deep ocean currents, which in turn depends on factors such as evaporation and melting of ice. This vertical transport is a factor that has been explored very little, but which can play an important role in studies related to climatic changes as well as in long-range weather prediction, because upwelling produced by such currents brings to the surface of the ocean strong anomalies in the field of temperature that affect climate and weather.

Most of the interactions described above have been taken into account in the formulation of a thermodynamic model developed during the last 15 years. The purpose of this paper is to present numerical results of the application of this model to evaluate some of the large-scale long-term thermodynamic influence of the ocean on weather and climate.

Figure 1 shows a schematic representation of how the variables and parameters interact in the model. Variables computed internally in the model interact with the temperature fields in both directions. External parameters are related to the variables with interaction only in the direction of the variables. The dashed lines indicate interactions which may be included in future experiments, but which were not included in those reported in this paper.

The basic equations of the model can be written in the form:

$$ST_1 + AD_1 + TU_1 = E_T + G_2 + G_5 \tag{1}$$

$$ST_2 + AD_2 + TU_2 = E_S - G_2 - G_3 \tag{2}$$

where ST_1 and ST_2 are the storages of heat in the troposphere and in the ocean respectively; AD_1 and AD_2 are the horizontal transports of heat by the mean wind and the mean ocean currents respectively; TU_1 and TU_2 the horizontal turbulent transports in the atmosphere and in the oceans respectively; E_T and E_S the heats added by short and long wave radiation to the atmosphere and to the ocean respectively; G_2 is the sensible heat given off by vertical turbulent transport to the atmosphere from the surface, G_3 is the heat lost by evaporation at the surface; and G_5 the heat gained by condensation of water vapor in the clouds.

In the continents (2) reduces to:

$$0 = E_S - G_2 - G_3 \tag{3}$$

In the present investigation, it is assumed that AD_2 and TU_2 are equal to zero.

Besides these equations, other equations are used that express the terms that appear in (1), (2) and (3) as linear functions of the mean tropospheric temperature T_m and its first and second space derivatives, and of the surface temperature T_s, such that, from (2) and (3), T_s becomes a linear function of T_m, which substituted in (1) together with the linear expressions for all the terms, yields a single elliptic differential equation to compute T_m. Substituting the computed value of T_m in the equations for T_m and for all the heating components, one obtains a solution to the simultaneous system of equations.

First we compute the normal climatological values. In this case, with the parameterizations used for the different terms in (1), (2) and (3), we need to prescribe over the whole region of integration normal values of G_2 G_5, the cloud cover (ϵ), the horizontal component of the mean wind (u and v) and G_3 over the oceans only. Using the best estimates of these six scalar fields, the model allows the internal computation of T_m, T_s, ST_1, ST_2, AD_1, TU_1, E_T and E_S over the whole region of integration, and of G_3 over the continents.

When computing the cases in which there exist departures from the computed normal values, the model computes internally the 14 variables T_m, T_S, ST_1, ST_2, AD_1, TU_1 E_T, E_S, G_2, G_3, G_5, ϵ, u and v. Therefore, for G_2 G_5, ϵ, u and v, only departures from the normals are generated internally within the model.

The version of the model used in the present experiments is called Model 2, described by the author in a previous paper (Adem, 1965), except for the following changes:

1) The advection by mean wind is generated using option 3 of Adem (1970 a).

2) New estimates are used of the relation between cloudiness and precipitation, which include seasonal variations (Clapp, 1970).

To avoid repetition, for information regarding assumptions, parameterizations and data used in the model, the reader is referred to the above mentioned papers and to the pertinent references given in them.

The thermodynamic model has been used with success to reproduce the mean temperature conditions observed in the different seasons of the year and the results have been published (Adem 1964a, 1964b, 1970a), and therefore will not be shown here.

To emphasize the importance of the ocean in the maintenance of these fields of temperature, computations in which the effect of suppressing the main oceanic components that enter in the thermal energy balance are given below.

2. EFFECT OF THE SENSIBLE HEAT GIVEN OFF TO THE ATMOSPHERE BY VERTICAL TURBULENT CONDUCTION.

Figure 2 shows the normal sensible heat given off from the surface to the atmosphere by vertical turbulent transport for January and July respectively, in langleys per day, as computed by Budyko (1963). In January, the main source of energy is in the eastern side of the oceans reaching maxima of 300 langleys per day; in the continents, above latitude 40°N or 45°N, the values are small and negative, while below these latitudes, the values are positive with a maximum of 115 langleys per day at latitude 25°N in Mexico, and with a maximum belt reaching values of about 150 langleys per day at latitude 20°N in Asia.

In July, the largest values are over the continents at latitude 30°N with values of about 250 langleys per day. For this month, the values are small over the oceans with a large region of negative values at middle latitudes in the Pacific.

Figure 3 shows the resulting anomalies of temperature in tenths of degrees Celsius, at 500 mb for January and July, when the sensible heat given off to the atmosphere from the oceans by vertical turbulent transport is suppressed. In January, the effect of suppressing the sensible heat is a considerable decrease of the 500 mb temperature over the oceans and continents, with the largest values in higher latitudes, and with a minimum of -7°C over the Pacific Ocean near latitude 55°N and longitude 170°W.

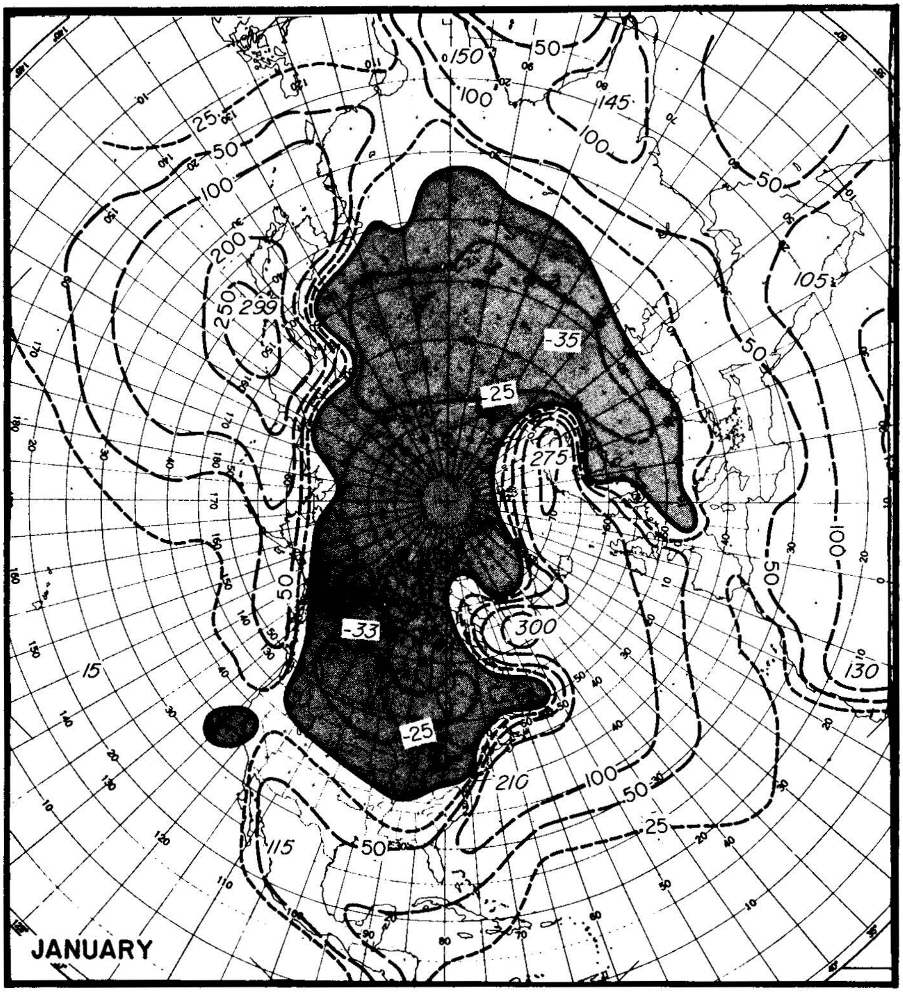
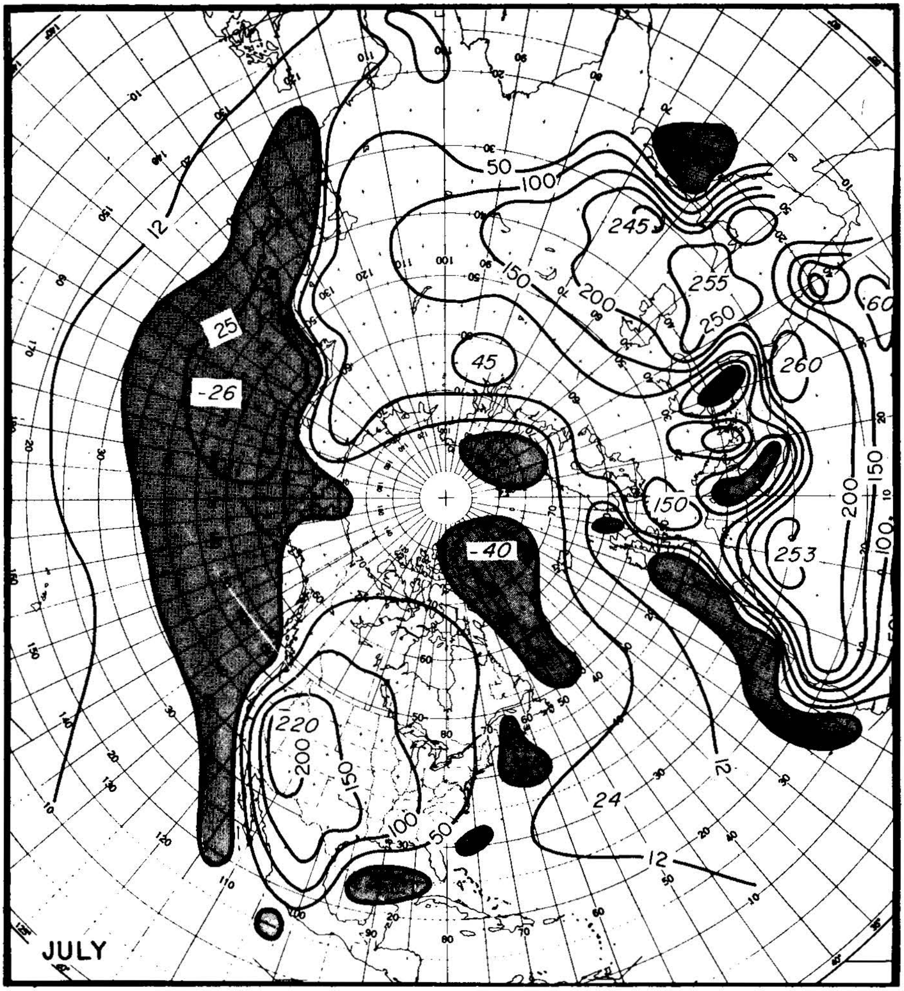


Figure 2. Normal sensible heat given off from the surface to the atmosphei



y vertical turbulent transport in langleys per day (after Budyko).

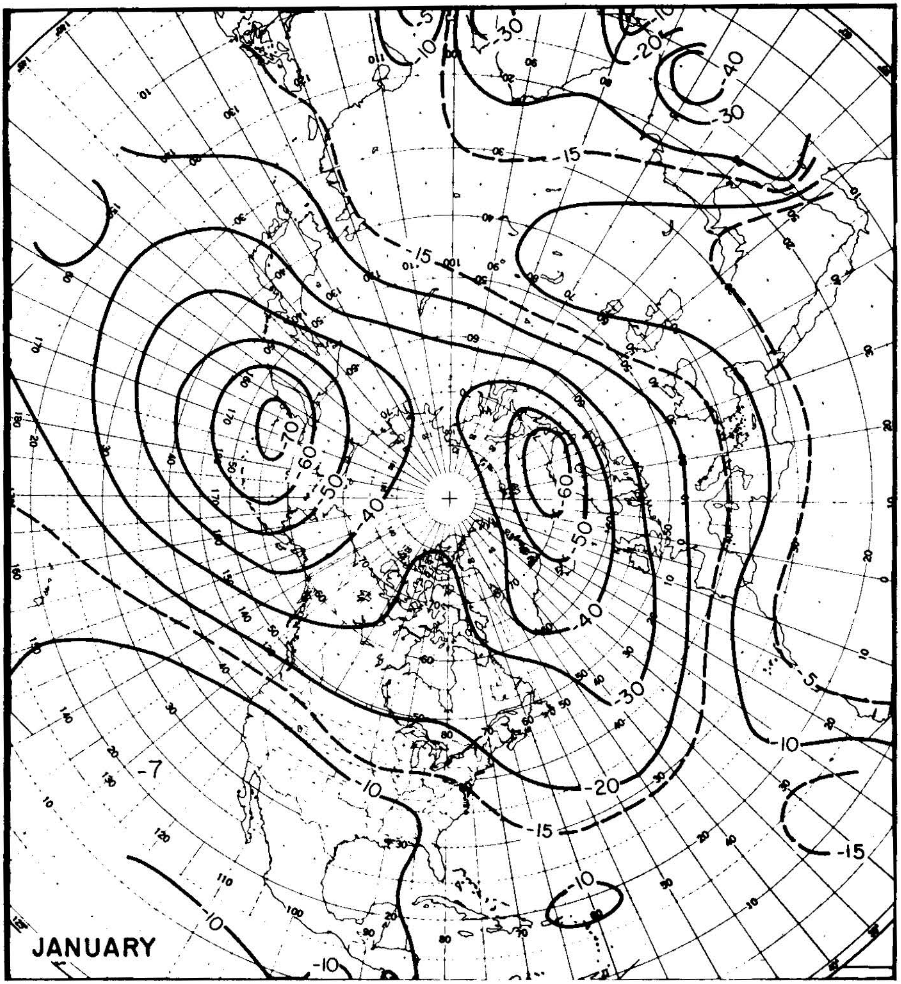
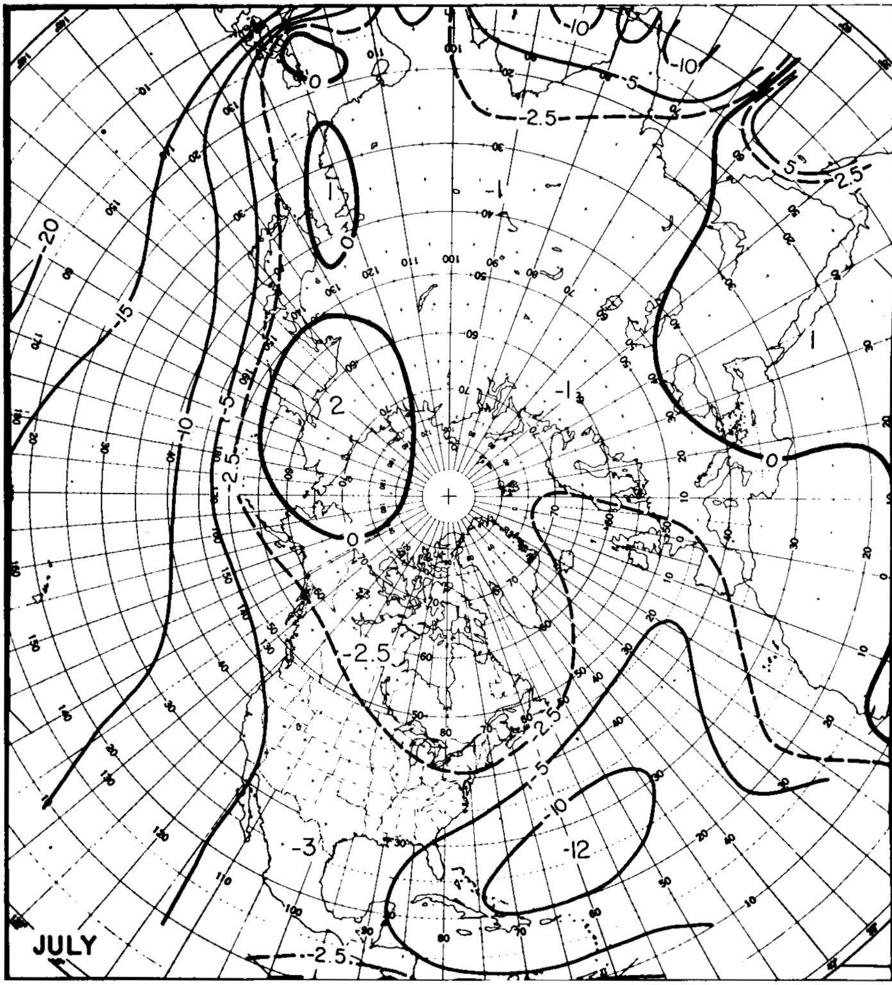


Figure 3. Increase of the 500-mb temperature, in tenths of degrees Celsius, due to the suppressio



' the sensible heat given off to the atmosphere from the oceans by vertical turbulent transport.

In contrast to the January case, in July the effect on the mid-tropospheric temperature of suppressing the sensible heat is relatively small.

At the surface of the earth, the effect on the temperature field is also a decrease in the normal values. This decrease is larger in January than in July (Figure 4); with a minimum of -4.7°C over the Asian continent in higher latitudes. It is of interest to point out that although the direct effect of the suppression of the heat lost at the surface by turbulent vertical transport in winter would be an increase of temperature, the suppression of the gain of the same amount of heat in the troposphere results in a net decrease of temperature (except in small areas). The same can be said for July over most of the whole area, except that over a large area in the Pacific, as mentioned above, the atmosphere transmits heat to the ocean, so that the heat lost in negative. Therefore the direct effect of suppressing it is to produce a negative anomaly in the surface temperature.

In conclusion, it can be stated that the suppression of the heat given off from the oceans to the atmosphere by vertical turbulent transport has an important influence on the temperature field at the surface and in the mid-troposphere in winter, especially at higher latitudes.

3. EFFECT OF EVAPORATION.

Figure 5 shows the normal heat lost by evaporation at the surface, for January and July respectively, in langleys per day, as computed by Budyko. Evaporation is larger over the oceans than over the continents, and larger in January than in July over the oceans. The maxima are reached in January over the Western part of the oceans near the continents. A maximum of 685 langleys per day occurs in the Atlantic and another of 640 langleys per day in the Pacific. It is interesting to point out that the position of these two maxima of evaporation coincide with the location of the gulf stream and Kuroshio current respectively, as well as with the two maxima of the zonal winds.

Over the continents, evaporation in winter is small. However, in summer, it reaches values as large as 200 langleys per day in Asia, at lower latitudes.

Figure 6 shows the computed anomalies in the surface temperature due to the suppression of evaporation from the oceans.

The change over the oçeans is an increase with a similar configuration to that for evaporation, with two maxima in January of 6°C, coinciding with the maxima of evaporation; and, in July, with the largest values of about 4°C in lower latitudes. The effect in the surface temperature in the continents in both cases becomes larger as the latitude decreases, with the largest values of about 2°C.

At 500 mb (Fig. 7), the effect is also strong, with maxima at lower latitudes, reaching values of 3.5 to 4.0° at a latitude of 10°N or 15°N. Over the continents, the increase of temperature is of about 1 to 1.5°C. The change is an increase of temperature that becomes larger toward the south. The change is also of importance over the continents where values as large as 1.5°C are induced at latitudes of about 20°N. The values are on the average about 0.5°C larger in January than in July.

Although evaporation does not affect directly the temperature field in the mid-troposphere, the changes are due to the interaction and feed-back of other heating and transport mechanisms in the Atmosphere-Ocean-Continent System induced by the changes of surface temperature.

4. EFFECT OF THE STORAGE OF HEAT IN THE OCEANS

Figure 8 shows the computed storage of heat in the oceans for January and July. In January, the values are negative, which means that the oceans are losing thermal energy, while in July, the values are positive at middle and higher latitudes, where the oceans are gaining energy. However, in the latter case, the values are negative in lower latitudes.

The largest absolute values occur in January, corresponding to the two maxima of evaporation and are equal to 896 langleys per day in the Atlantic and 819 langleys per day in the Pacific.

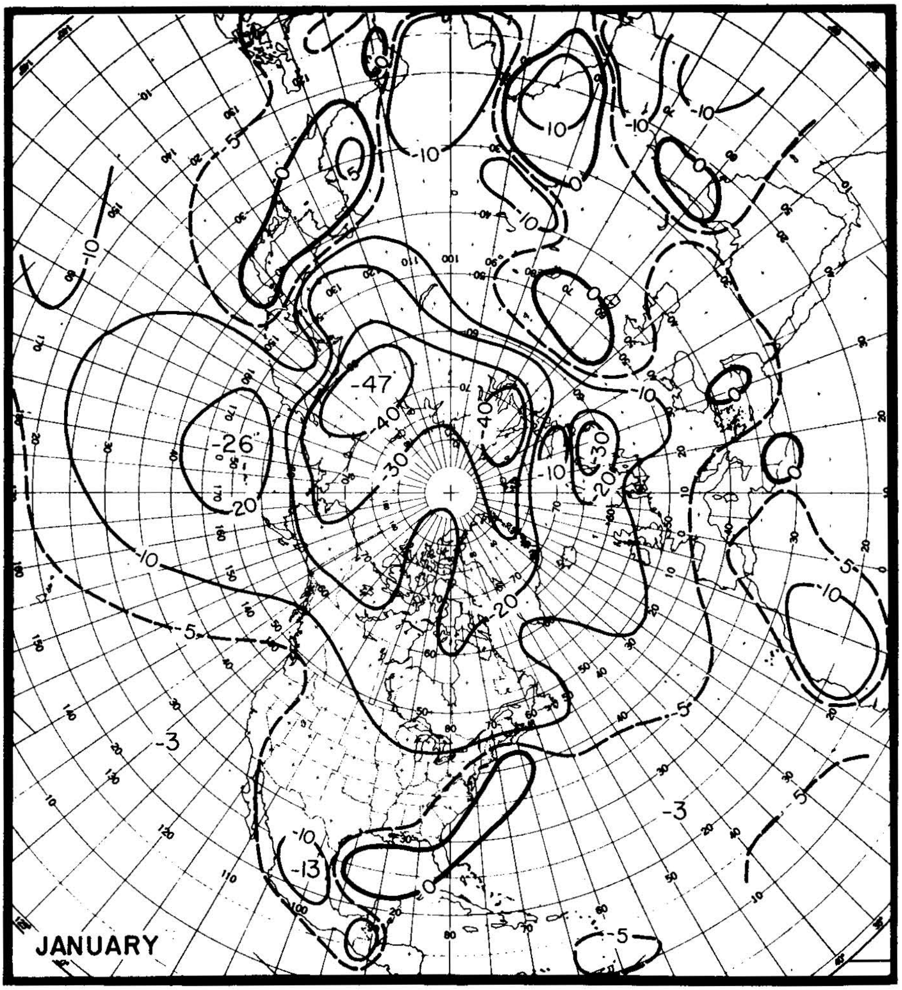
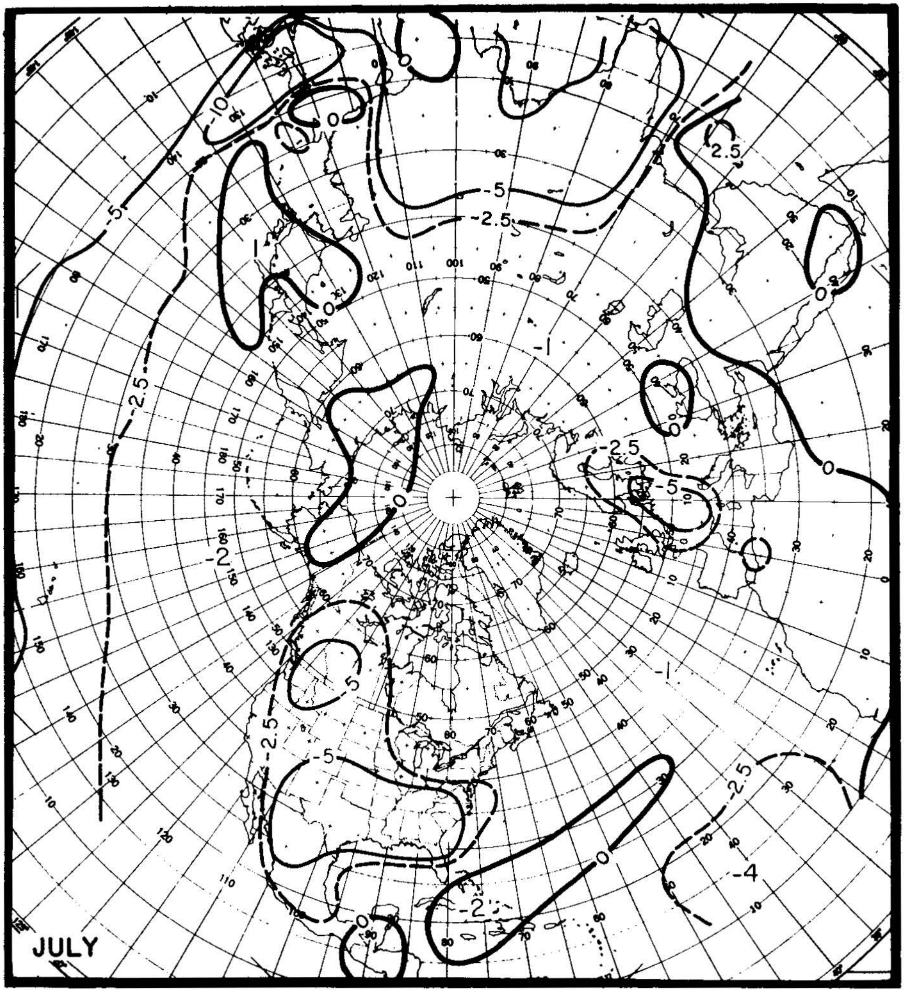


Figure 4. Increase of the surface temperature, in tenths of degrees Celsius, due to the suppressi



the sensible heat given off to the atmosphere from the oceans by vertical turbulent transport.

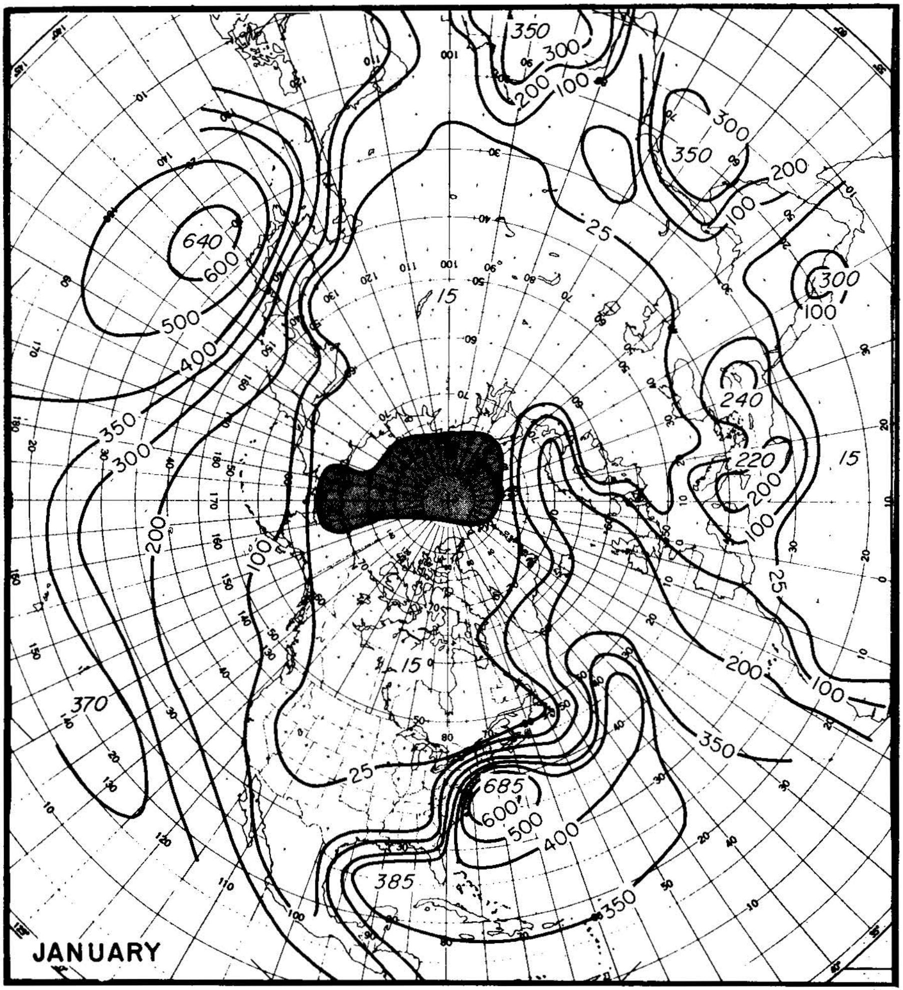
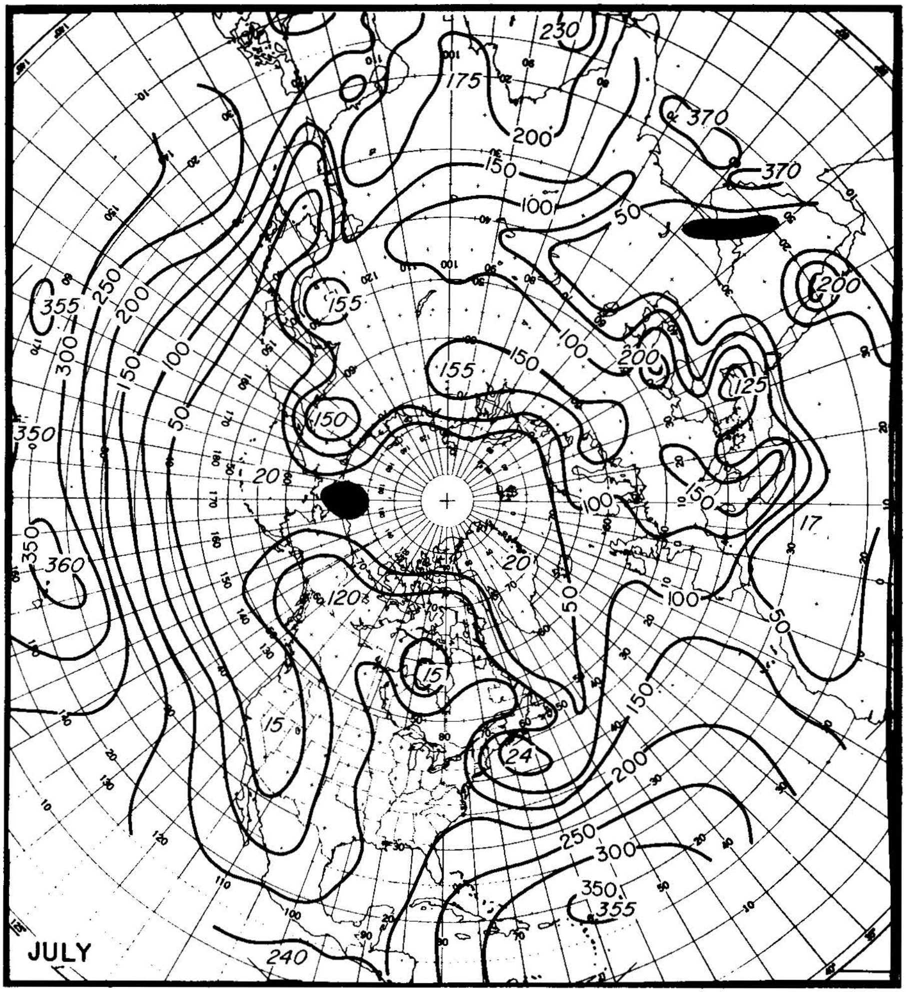


Figure 5. Heat lost by evaporation at t



surface, in langleys per day (after Budyko).

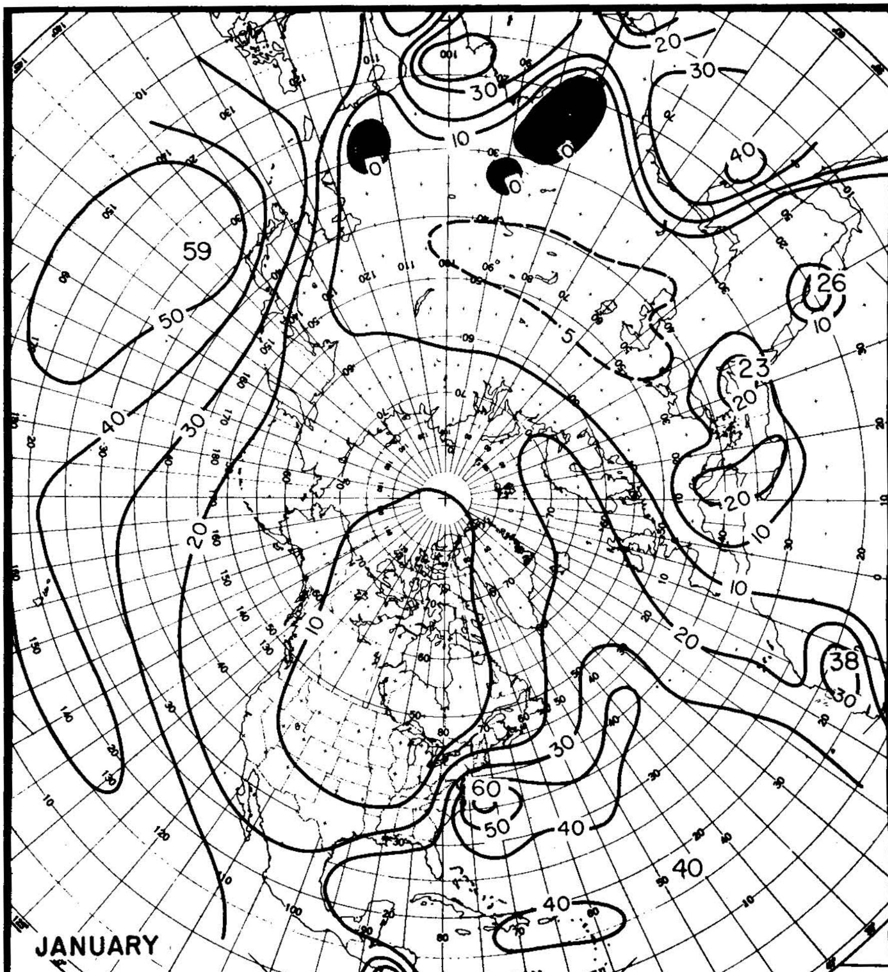
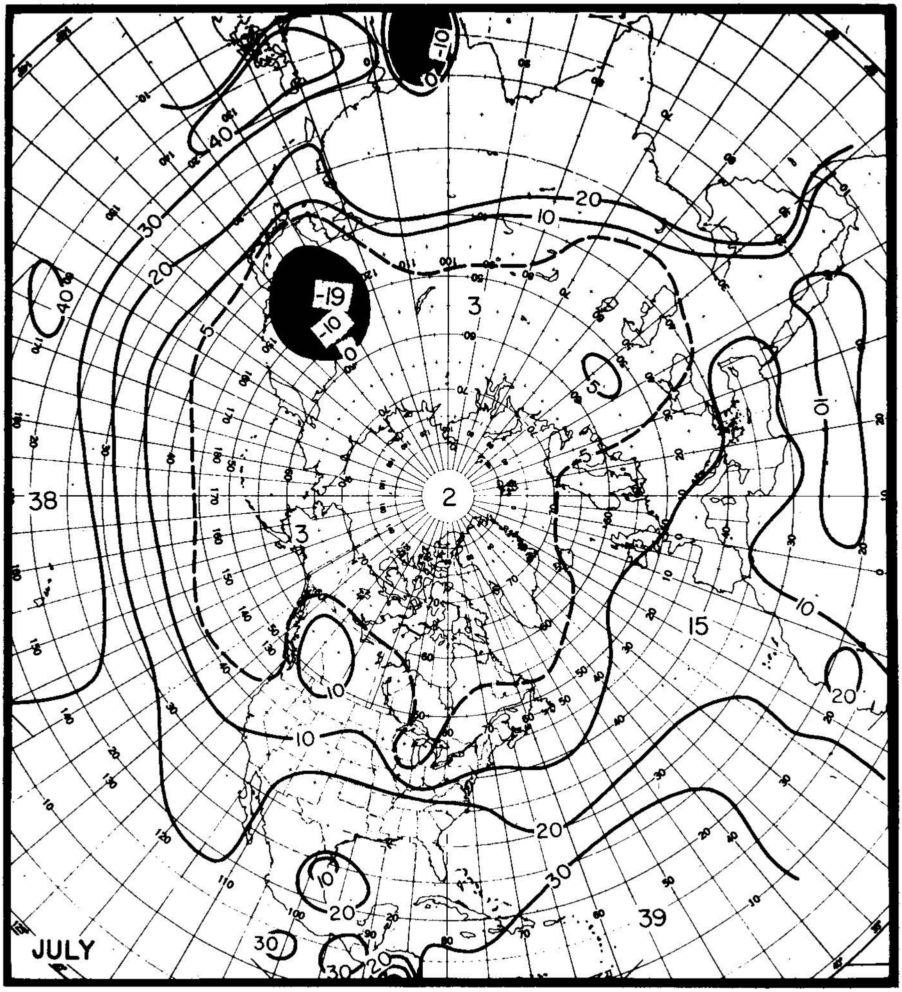


Figure 6. Increase of the surface temperature, in tenths of degree



elsius, due to the suppression of the evaporation from the oceans.

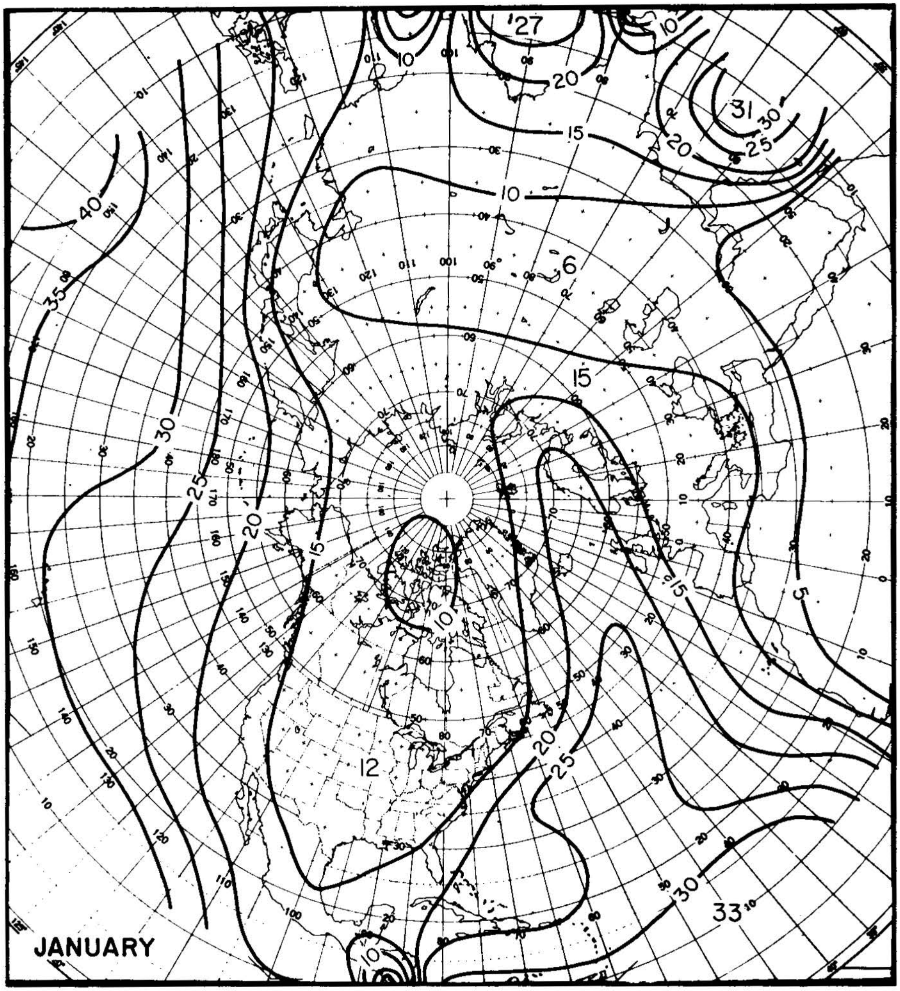
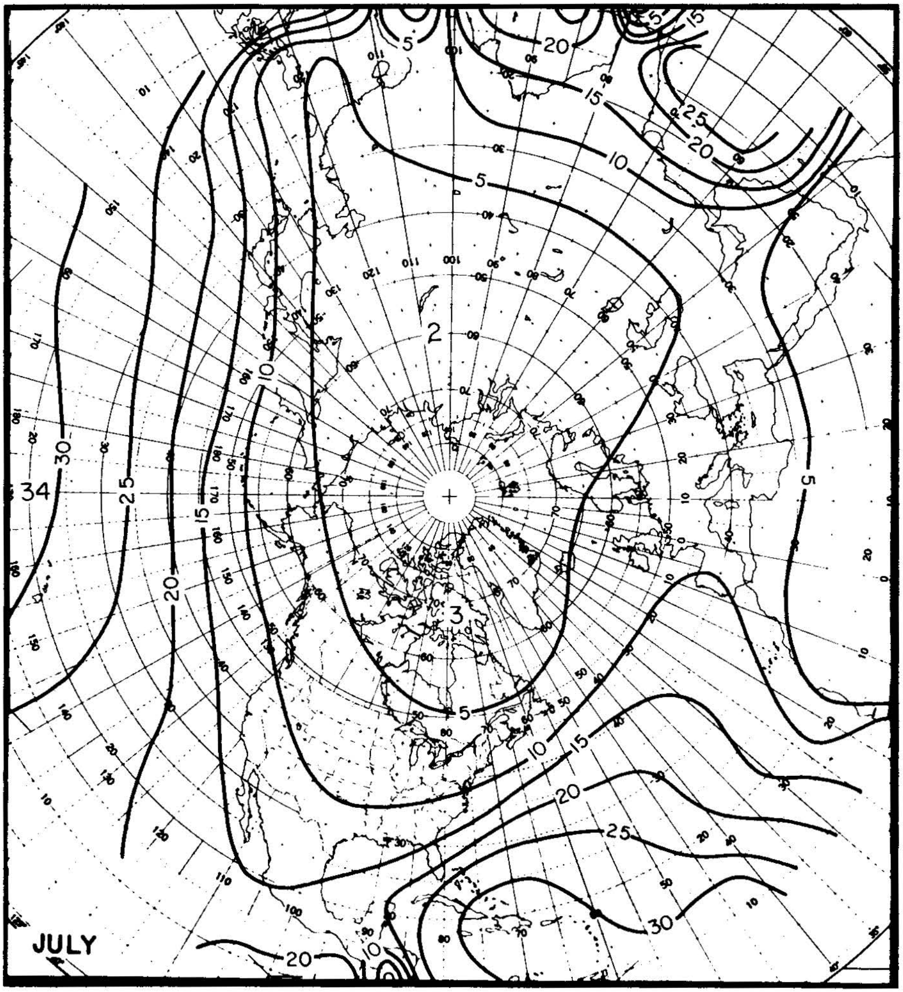


Figure 7. Increase in the normal mid-tropospheric temperature, in tenths c



ɛgrees Celsius, due to the suppression of the evaporation from the oceans.

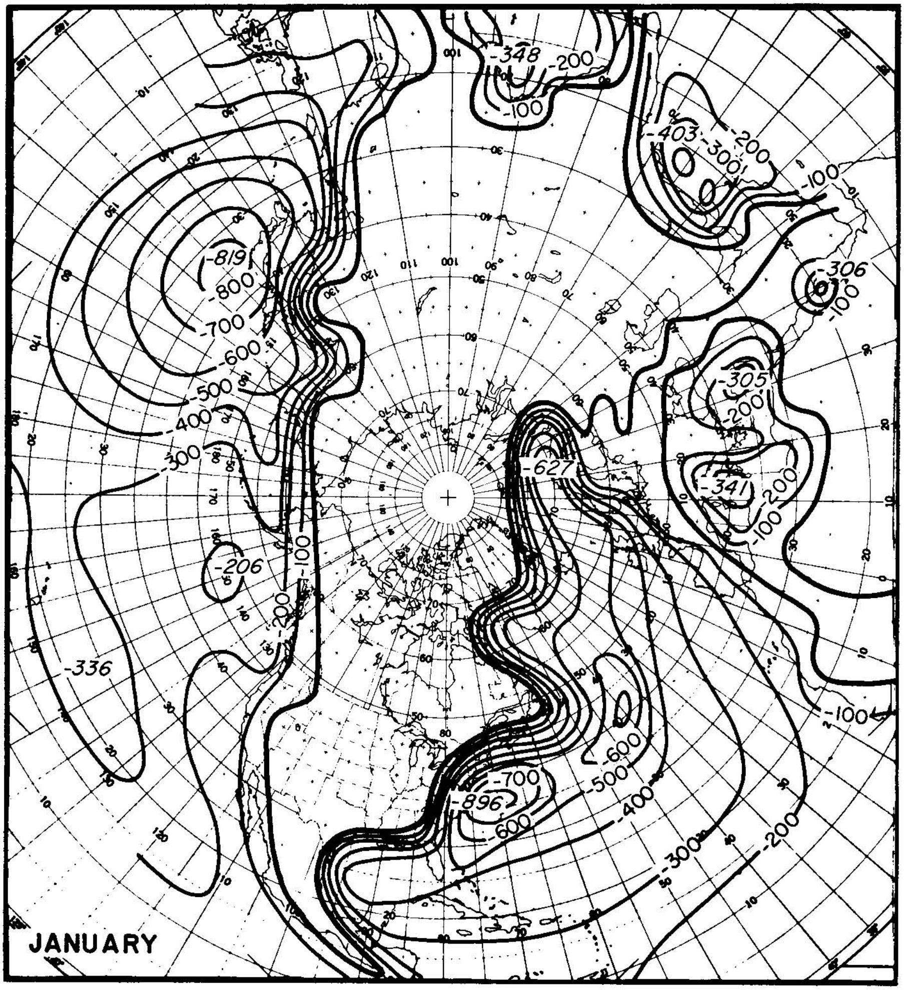
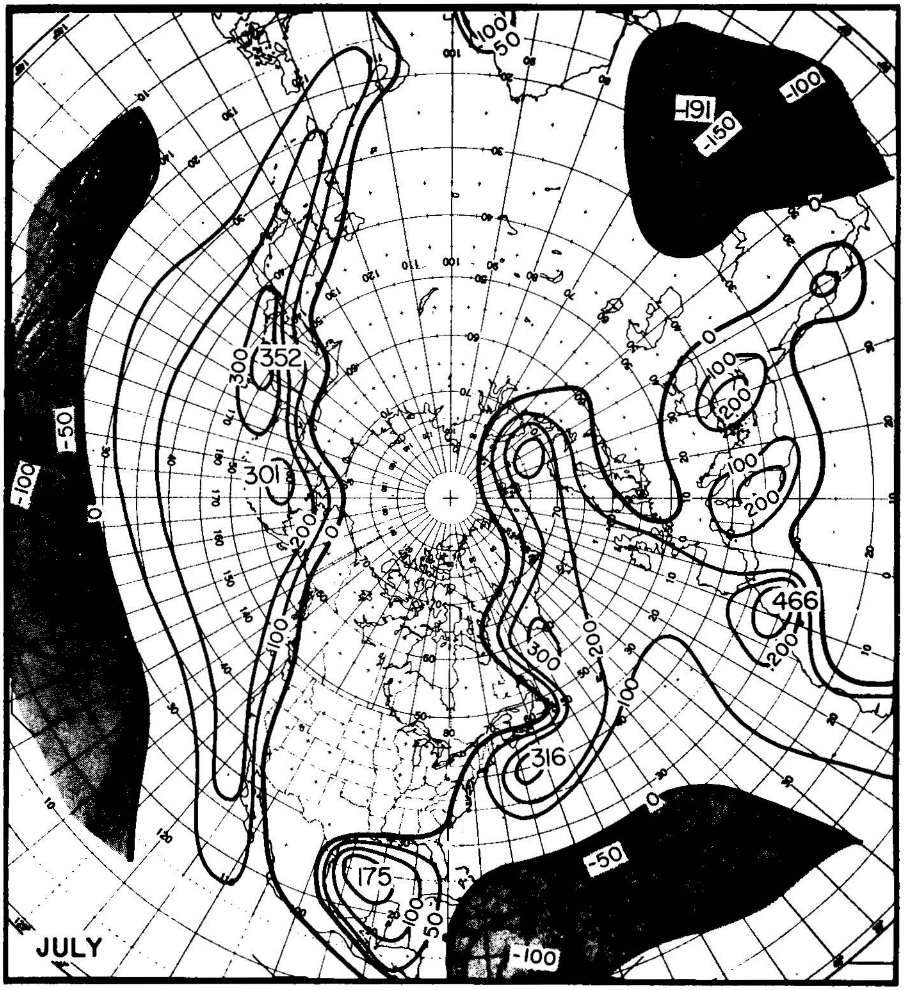


Figure 8. Normal storage of heat



he oceans, in langleys per day.

The computation for all the months of the year shows that the average over the entire year yields a storage of heat equal to zero.

To estimate the effect of the storage of heat in the oceans on the Atmosphere-Ocean-Continent System, we have computed the increase in the thermal field due to the suppression of such storage. Figure 9 shows the resulting increase in the surface temperature in tenths of degrees Celsius. The January values are negative, which means that the effect is a decrease in the normal temperature field, with an average absolute value of the order of 10°C in the Pacific and of 7.5°C in the Atlantic. The largest absolute values are equal to about 15°C. In the continents, the values vary from 5 to 2.5°C.

In July, over the oceans, the increase in temperature is positive except in lower latitudes. The largest values are in higher latitudes with a maximum of 14°C; and there exists a strong latitudinal temperature gradient in the increase, so that it becomes rapidly smaller toward the lower latitudes, and even becomes negative.

The effect on the continents is very important, with a maximum of 10°C in the west coast of Africa.

Figure 10 shows the corresponding increases at the mid-tropospheric temperature. The sign of the temperature anomalies is the same as that at the surface. The January values are negative, with absolute values varying from 5 to 10°C in the Pacific and with the largest values in lower latitudes. In the Atlantic, the approximate absolute value is of about 6°C. Over the continents, the largest values are of about 6°C, in the higher latitudes.

For July, the largest values of increases of the mid-tropospheric temperature are at higher latitudes, with a maximum of 6°C, and as at the surface, there exists a strong latitudinal temperature gradient, so that the values in lower latitudes become negative. In the continents, the values are from 2°in lower latitudes to 4°C in higher latitudes. In Asia, over India, there are negative values, with a maximum absolute value of 3°C at latitude 10°N.

These numerical experiments show the very important role that the oceans play as regulators of the temperature of the Earth, by storing part of the energy received in the hot season and using it as a heat source in the cold season, creating a milder winter and a cooler summer.

In the above experiments, we have assumed that in the upper layer of the oceans the temperature is independent of depth, and that the normal depth of the considered ocean layer is equal to 25 meters. To eliminate the effect of storage we have computed the anomaly of temperature corresponding to an anomaly of the depth equal to −25 meters, i.e. when the depth of the layer is equal to zero. Therefore there exists no storage of energy in the ocean. To determine the dependence of the temperature fields on the depth of the layer, we shall in addition compute the anomalies due to an increase of the depth of the considered layer.

A computation with an anomaly of +25 meters (total depth of the layer equal to 50 meters) shows anomalies of temperature with similar patterns to the case of the layer depth anomaly equal to −25 meters (case of depth of layer equal to zero) but with opposite sign, and with the absolute values of the anomalies about 5 times smaller.

From these results, it is evident that the temperature is very sensitive to variations in the depth of the layer. After the first 25 meters, as the depth is increased, the storage of heat increases in such a way that the temperature becomes less and less sensitive to such changes, and approaches asymptotically the case of infinite heat capacity, in which the solution is simply the initial ocean temperature.

5. EFFECT OF UPWELLING

In a previous paper (Adem 1970b), the author has shown that vertical velocities of the order of 4×10^{-3} cm sec^{-1} could yield non-negligible changes of ocean temperature. Recently Roden (1972) has shown that such velocities exist off the coast of California. As will be shown in section 7, the corresponding anomalies in the ocean temperature produce anomalies in the atmospheric temperature and associated circulation which could affect the weather in the coastal zone.

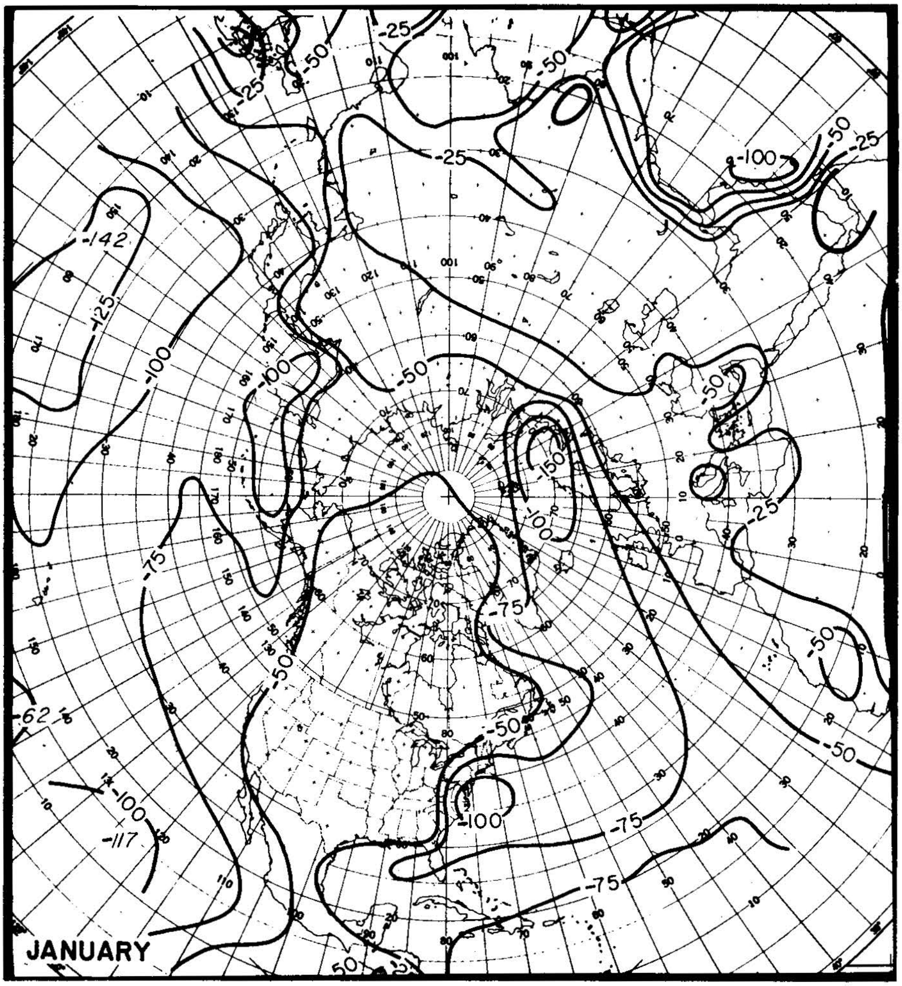
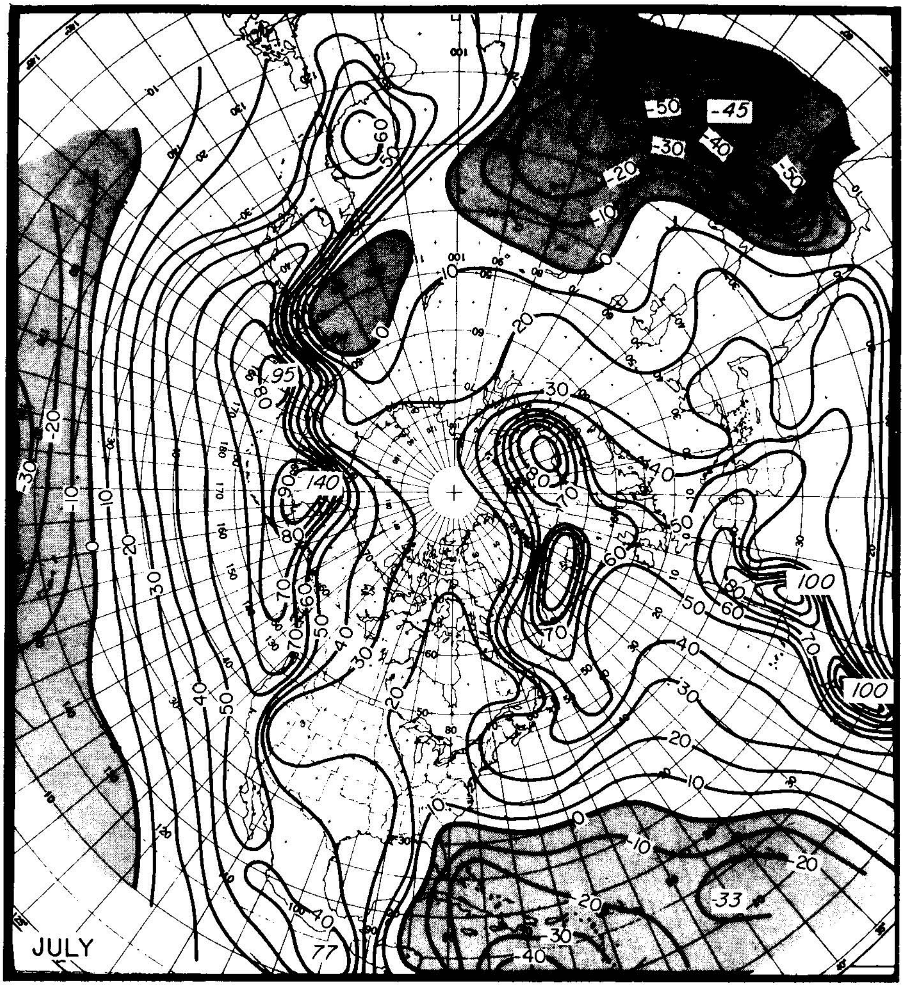


Figure 9. Increase of the surface temperature, in tenths of degr



ılsius, due to the suppression of the storage of heat in the oceans.

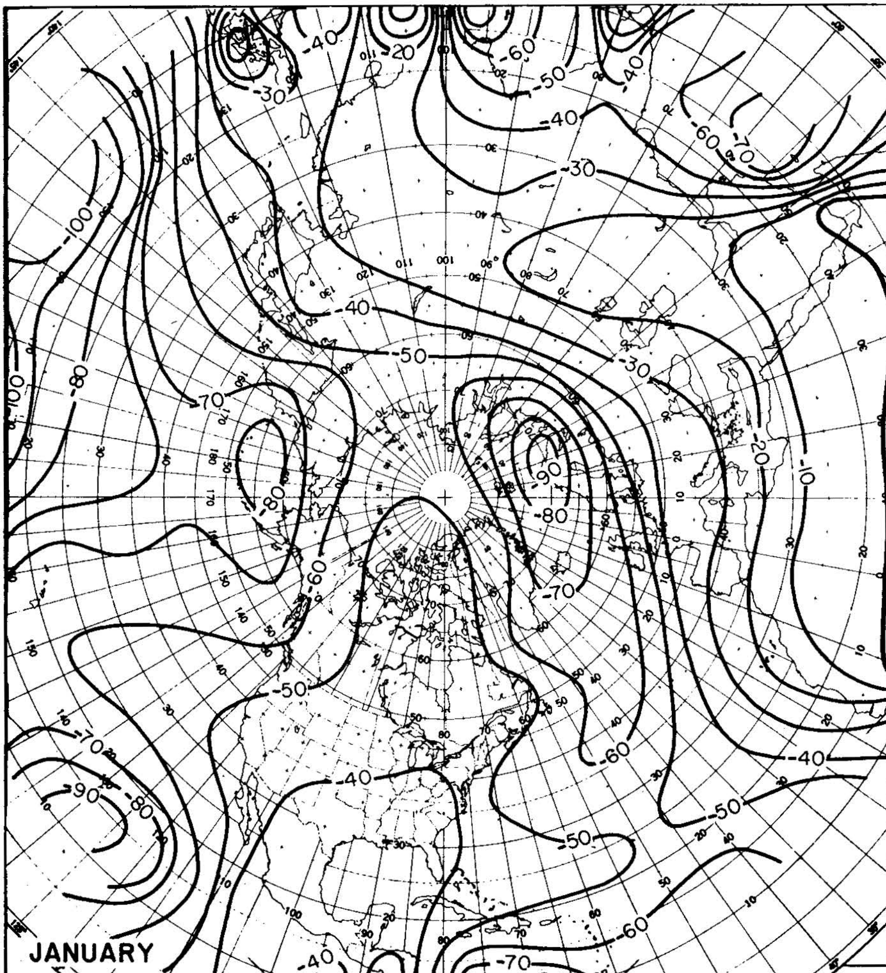
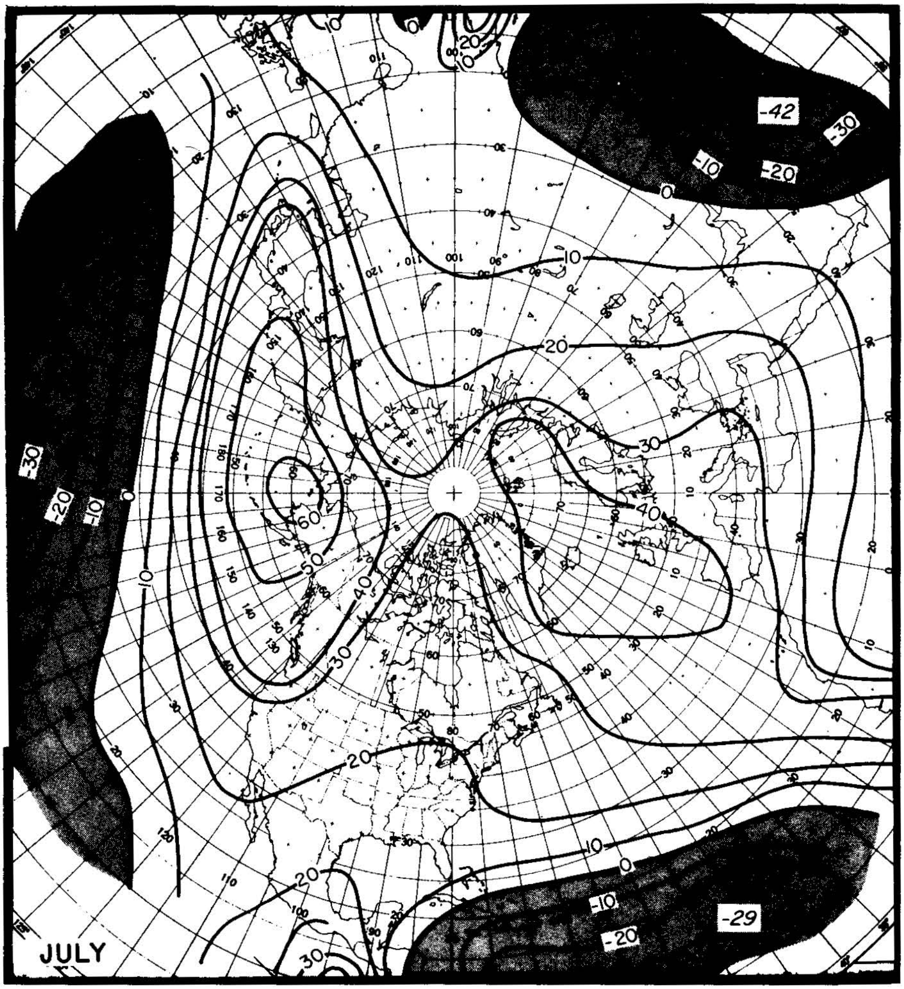


Figure 10. Increase of the mid-tropospheric temperature, in tenths of degre



:sius, due to the suppression of the storage of heat in the oceans.

On this evidence, one can anticipate that upwelling is a factor that can have important effects on weather and climate. Therefore, research on this direction seems to be of importance.

6. OCEAN EFFECTS IN THE RESPONSE OF THE ATMOSPHERE-OCEAN-CONTINENT SYSTEM TO FLUCTUATIONS OF THE SOLAR CONSTANT.

In previous papers (Adem 1964a, 1964b; 1970a), we have shown that the distribution of oceans and continents plays an important role in the maintenance of the seasonal normal patterns of the temperature fields and the associated atmospheric circulation.

In this section, we will consider the response of the Atmosphere-Ocean-Continent System to fluctuations of an external factor, the solar constant.

The effect of an increase of 2 percent in the solar constant was presented by the author in the WMO/IAMAP Symposium on Physical and Dynamic Climatology, held in Leningrad, in August 1971, and will appear in the corresponding proceedings. Using the results of this study, we have computed the latitudinal averages over oceans and continentes, and over the whole latitudinal circles.

Figure 11 shows the increases in the surface temperature for January and July, in tenths of Celsius degrees.

These results show that the increase in the continents is larger than in the oceans and larger in July than in January. In July, the average increase in the Pacific Ocean is of about 0.1°C, and in the Atlantic of about 0.2°C. In the continents, the values vary in Eurasia almost linealy from about 0.5°C in latitude 65°N to about 1°C at latitude 35°N and then decreases to 0.7°C at 20°N; in America the values are about 0.1°C or 0.15°C smaller than in Eurasia, except in latitudes lower than 35°N, where the values become larger in America, reaching values as large as 1.2°C in latitude 20°N. The latitudinal average over the whole hemispheric circles shows an increase of about 0.45°C reaching the maximum at latitude 30°N with a value of about 0.55°C.

In January, the increase over the oceans is smaller than 0.1°C. In Eurasia it varies from about 0.1°C in latitude 70°N to 0.45 in 20°N, while in America it is about 0.1 to .05° smaller, except in the neighbourhood of 25°N where the value in America is larger with a maximum of about 0.47°C. The average over the whole latitudinal circle varies from less than 0.1°C at 70°N to about 0.2°C at latitudes 30°N where the maximum increase is located. Below 30°N, the values remain smaller but close to 0.2°C.

Figure 12 shows the corresponding increase in the mid-troposphere, which is also larger over the continents than over the oceans. The average hemispheric increase is about 0.3°C in July and about 0.1°C in January.

Figure 13 shows the corresponding increase in the heat of condensation of water vapor in the clouds. In July, over the oceans, it is positive, except in the latitude zone from 60° to 70°N, where it has a negative minimum over the Atlantic and the Pacific.

The maximum value in the Pacific is about 3 langleys per day near latitude 45°N, and in the Atlantic about 5 langleys per day at latitude 25°N.

In the continents, the values are negative except in latitudes higher than 70°N. The absolute values are larger in Eurasia than in America with the minima values at 25°N of -10 ly per day in America. The average over the hemisphere is negative, except above latitude 70°N and in the neighbourhood of 35°N, where it has a maximum of about 0.5 ly per day. The minima are about -1.5 ly per day at latitudes 57°N, 30°N and 25°N.

In January, the effect of the distribution of oceans and continents is not so pronounced, and the hemispheric value is negative below latitude 45°N, the minimum is -2 ly per day in lower latitudes, and the maximum about 0.5 ly per day at latitudes 65°N.

These results show the importance of the effect of the distribution of oceans and continents in determining the response of the Atmcsphere-Ocean-Continent System to possible fluctuations of the solar constant.

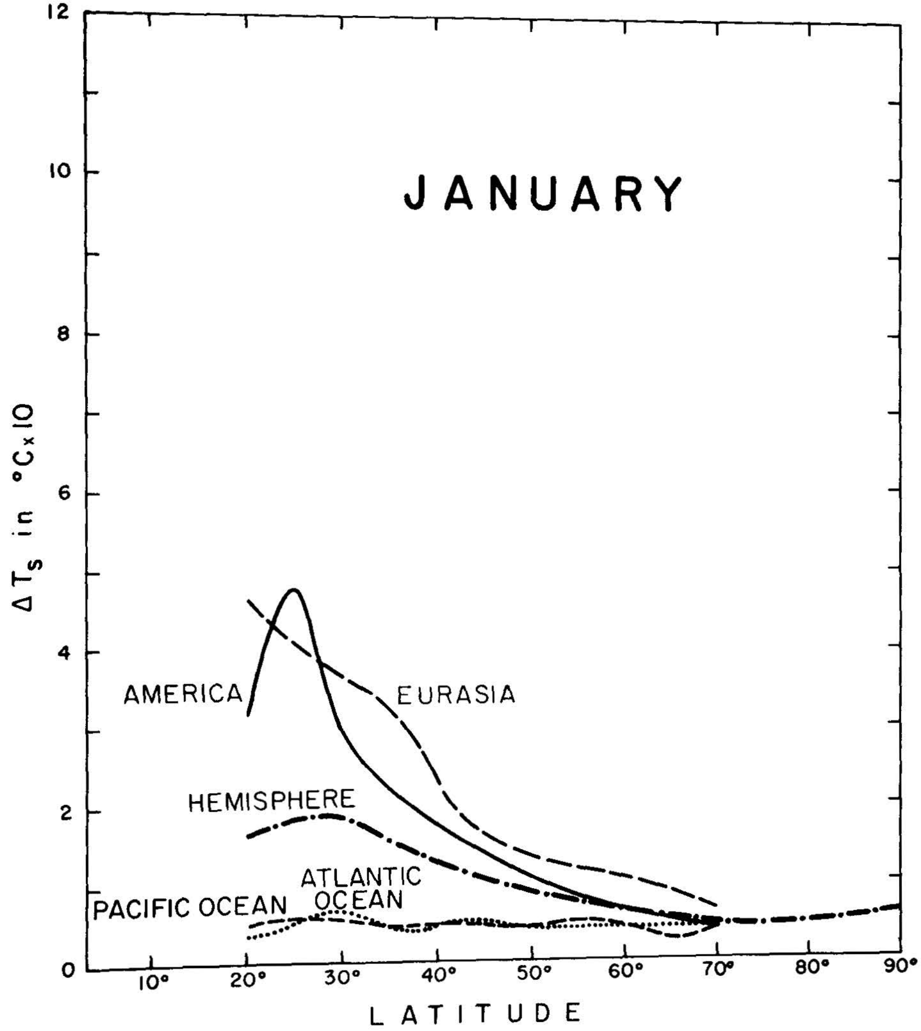
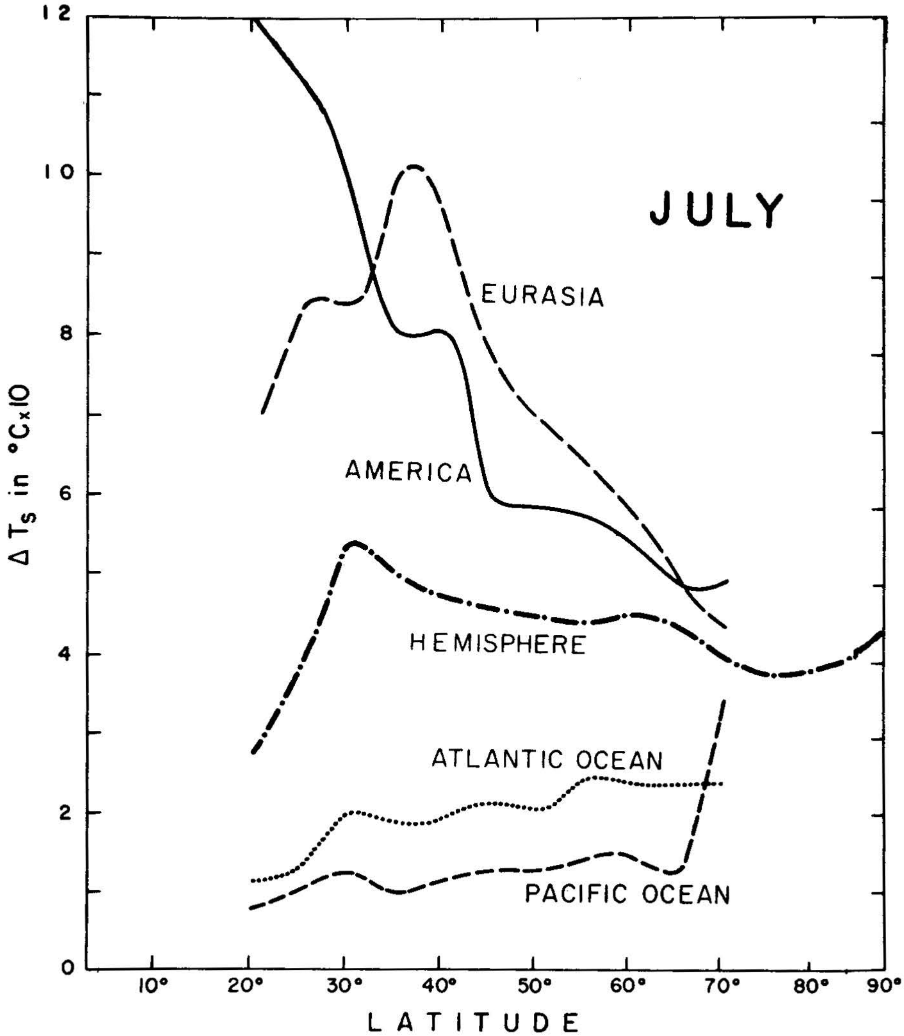


Figure 11. Zonally averaged increase of the surface temperature due to an increase of 2 percent in Celsius and the abscissa is the latitude in degrees north. The continuous line is the average for America line for the Pacific Ocean, and the dashed dotted line is the average for the whole hemisphere.



›lar constant, for the northern hemisphere. The ordinate is the temperature increase in tenths of degrees ashed line is average for Eurasia, the dotted line is the average for the Atlantic Ocean, the thinner dashed

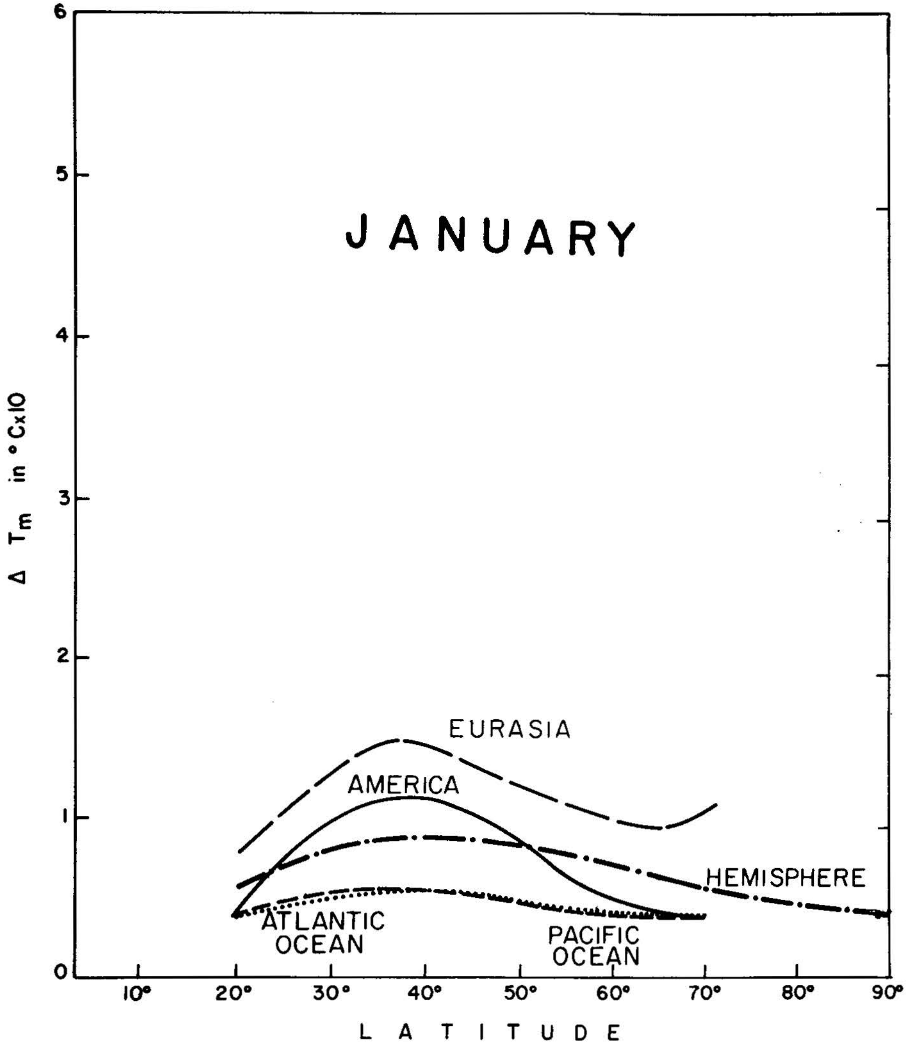
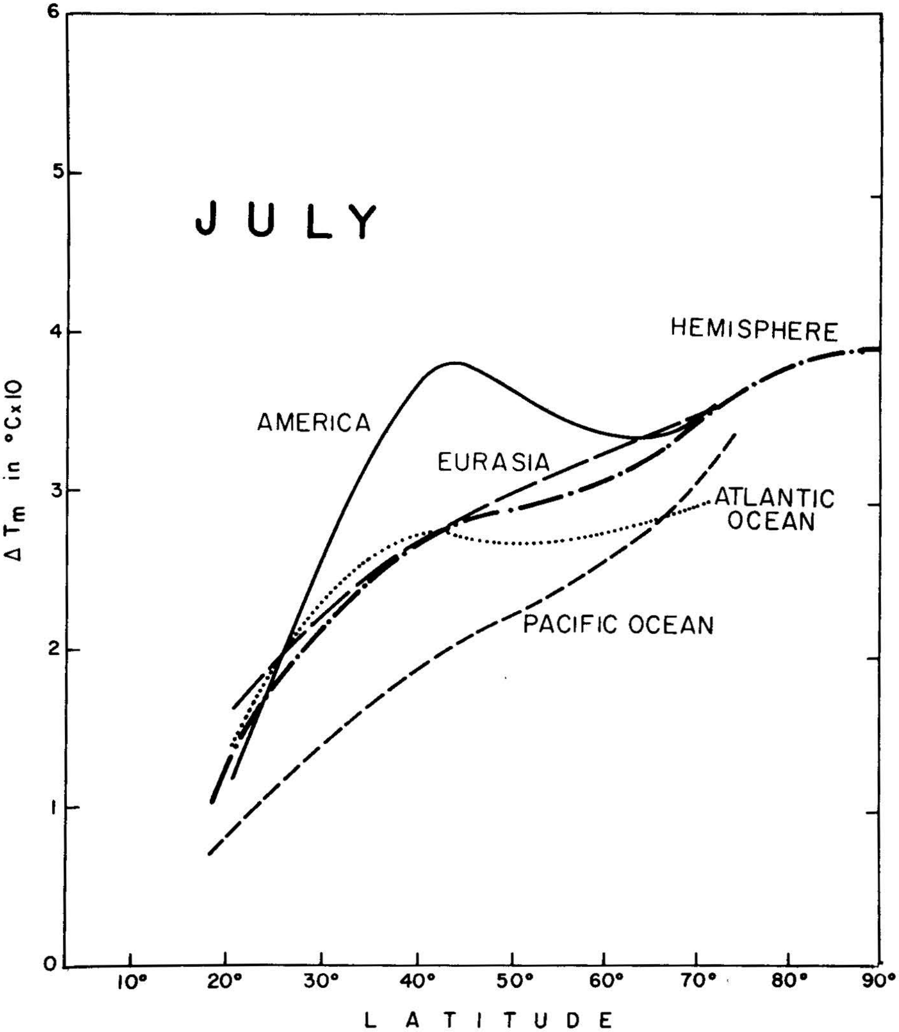


Figure 12. Zonally averaged increase of the 500-mb temperature due to an increase of 2 percent in tl
Celsius and the abscissa is the latitude in degrees north. The continuous line is the average for Americ
ner dashed line for the Pacific and the dashed dotted line is the average for the whole hemisphere.



ılar constant, for the northerm hemisphere. The ordinate is the temperature increase in tenths of degrees he dashed line is the average for Eurasia, the dotted line is the average for the Atlantic Ocean, the thin-

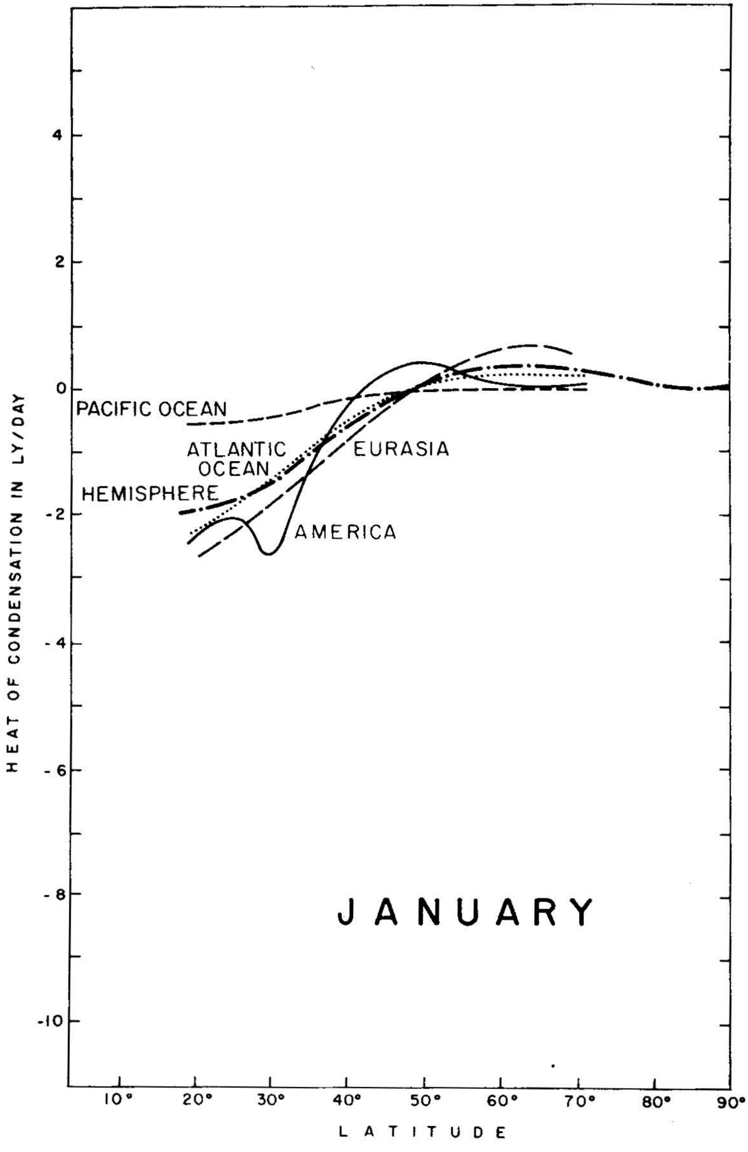
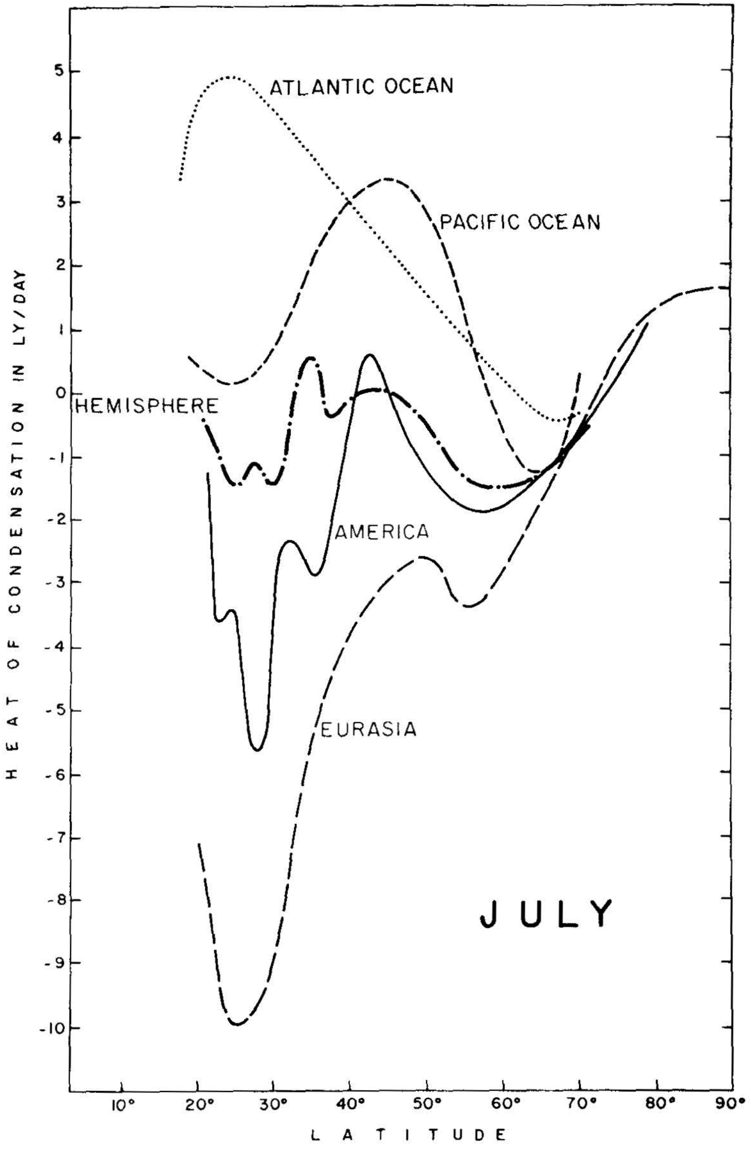


Figure 13. Zonally averaged increase of the heat of condensation of water vapor in the clouds, due t ture increase in langleys per day and the abscissa is the latitude in degrees north. The continuous line is tl the thinner dashed line for the Pacific Ocean, and the dashed dotted line is the average for the who



n increase of 2 percent in the solar constant, for the northern hemisphere. The ordinate is the tempera- ıverage for America, the dashed line is the average for Eurasia; the dotted line for the Atlantic Ocean, ıemisphere.

7. EFFECT OF THE SURFACE OCEAN TEMPERATURE ANOMALIES IN THE ATMOSPHERE-OCEAN-CONTINENT SYSTEM.

To illustrate how weather and climate are related to the ocean temperature, we have assumed that during December and June in all the ocean areas the surface waters are 2°C warmer than normal, and have computed the anomalies that are generated with this single initial anomaly in the subsequent months of January and July respectively.

Figure 14 shows the anomalies in the surface temperature, in tenths of degrees Celsius.

The initial anomaly of 2°C has decreased to values over the oceans of about 1.5°C in July and of 1.25°C to 1.5°C in January, with the largest values in the lower latitudes. Anomalies are also generated over the continents that decrease from the coasts to the central regions of the continents, in July, from 1.5°C to 0.5°C, and in January, from 1.25°C to 0.7°C in America; and from 1.0°C to 0.25°C in Eurasia.

Figure 15 shows the corresponding anomalies of temperature at the 500 mb level.

Over the ocean, in January the values are of about 1°C and in July vary from 1.25°C to 1.6°C in the Pacific and from 1.0°C to 1.8°C in the Atlantic.

Over the continents, in January, the anomalies vary from 1°C to .75°C in America and from 1.0°C to 0.25°C in Afro-Eurasia; and in July from 1.25°C to 0.6°C in America, and from 1.0°C to 0.25°C in Afro-Eurasia.

The anomalies of temperature are generated simultaneously with anomalies of the heating functions and other meteorological fields which are shown in the next figures, as follows:

Sensible heat given off to the atmosphere by turbulent vertical transport from the surface (Figure 16), heat lost by evaporation at the surface (Figure 17), radiation energy absorbed at the surface (Figure 18), storage of heat in the oceans (Figure 19), heat of condensation of water vapor in the clouds (Figure 20), radiation energy absorbed in the atmosphere (Figure 21), total heating absorbed in the atmosphere (due to radiation, sensible heat given off from the surface and heat of condensation of water vapor) (Figure 22), advection of heat by the mean wind (Figure 23), advection by turbulent eddies (Figure 24), zonal wind (Figure 25), meridional wind (Figure 26) and cloudiness (Figure 27).

The increase in the sensible heat given off from the surface to the atmosphere by vertical turbulent transport is positive over the whole region and of about 15 langleys per day over large areas of the Pacific and Atlantic Oceans. In summer, in lower latitudes, there are values as large as 20 langleys per day; however, in general, the values are smaller than in January, and in some areas the values are negative, reaching a value of -19 ly per day in the Atlantic Ocean. These negative values are due to the fact that the turbulent vertical transport of sensible heat depends on the difference of the surface temperature and the atmospheric temperature and to the fact that the increase of atmospheric temperature in this case is larger than the increase in surface temperature; this, in turn, is associated with the increase in the heat gained by condensation of water vapor (see Figure 20).

The increase in the heat lost by evaporation in January varies from 30 to 50 ly per day; and for the same reason as in the case of the sensible heat given off to the atmosphere, in July it is smaller than in January, and in the same area of the Atlantic it becomes negative.

Over the continents, the increase of sensible heat given off from the surface to the atmosphere as well as the increase of the heat lost by evaporation at the surface are small.

The increase in the radiation energy absorbed at the surface (Figure 18) is predominantly negative and considerably stronger in July than in January.

Figure 19 shows that there is a decrease in the heat stored in the oceans in both cases with values of decrease from about 40 to 70 langleys per day.

The changes in the heat of condensation of water vapor (Figure

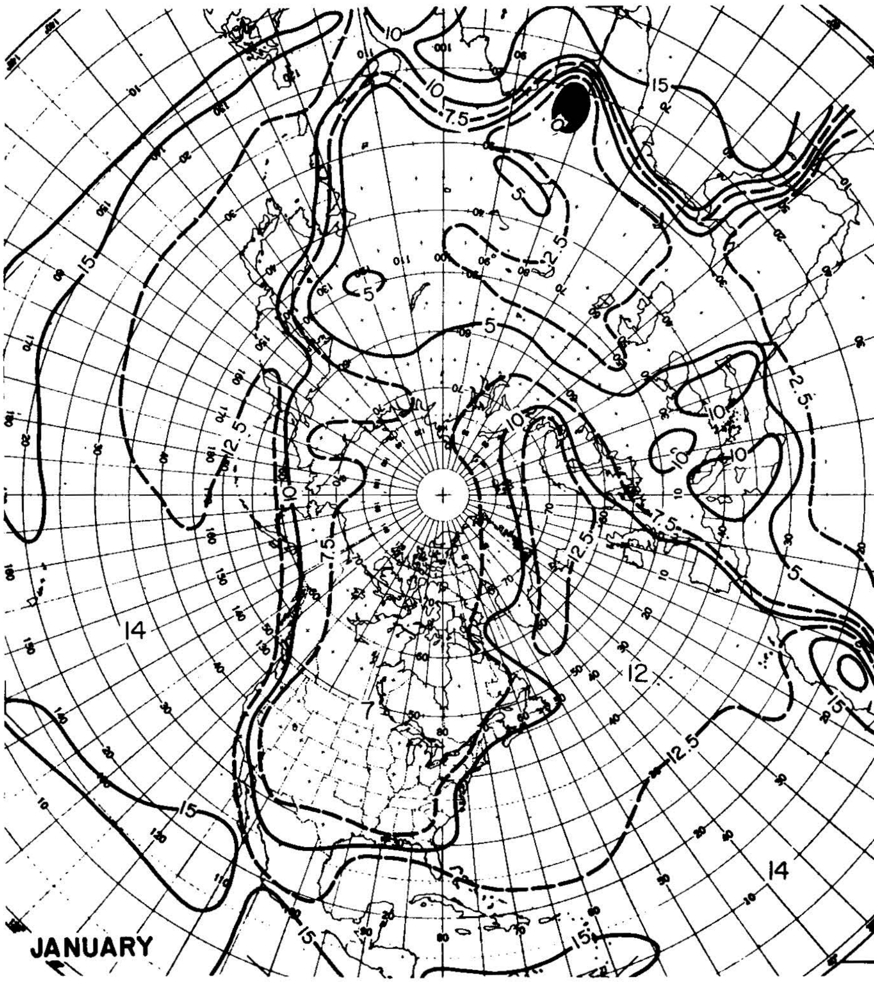
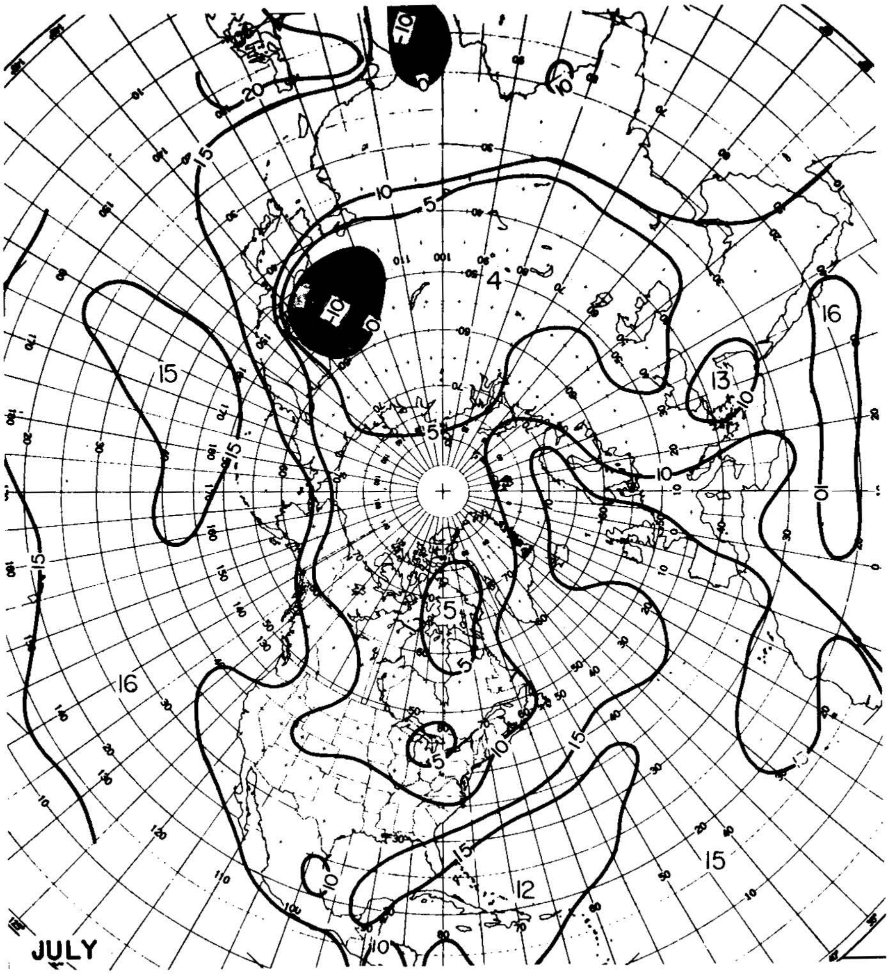


Figure 14. Increase in the surface temperature, in tenths of degrees Celsius, du



an increase of 2°C in the surface ocean temperatures in the previous month.

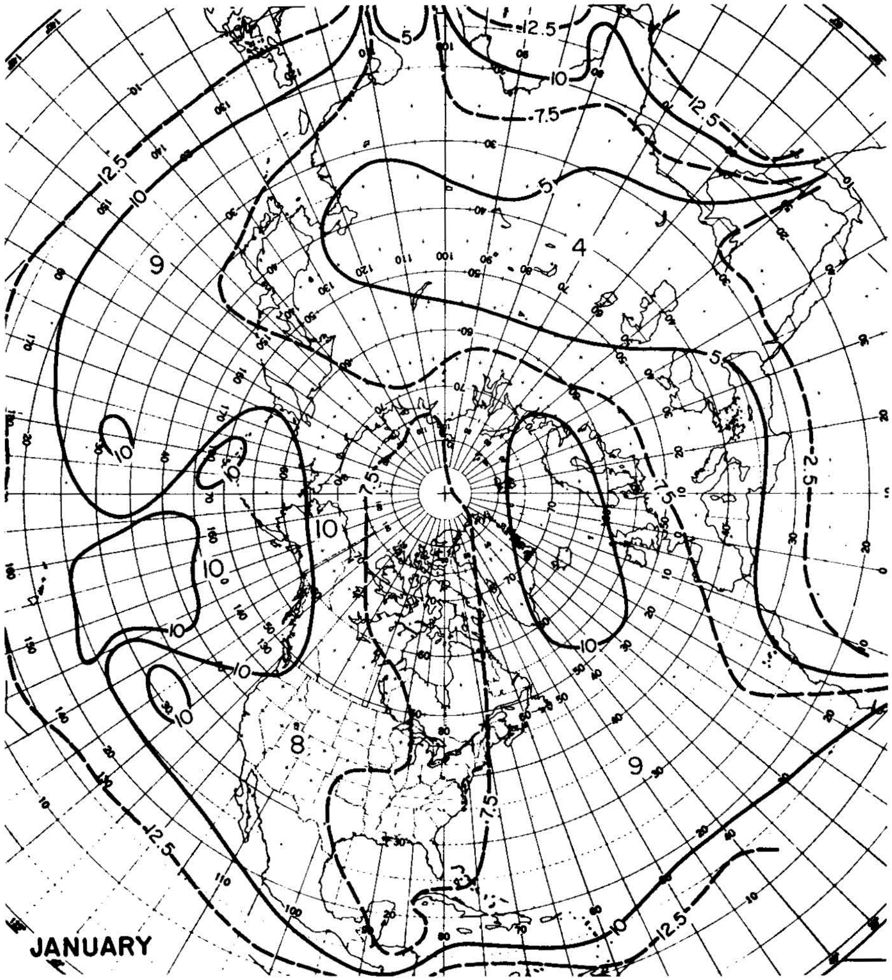
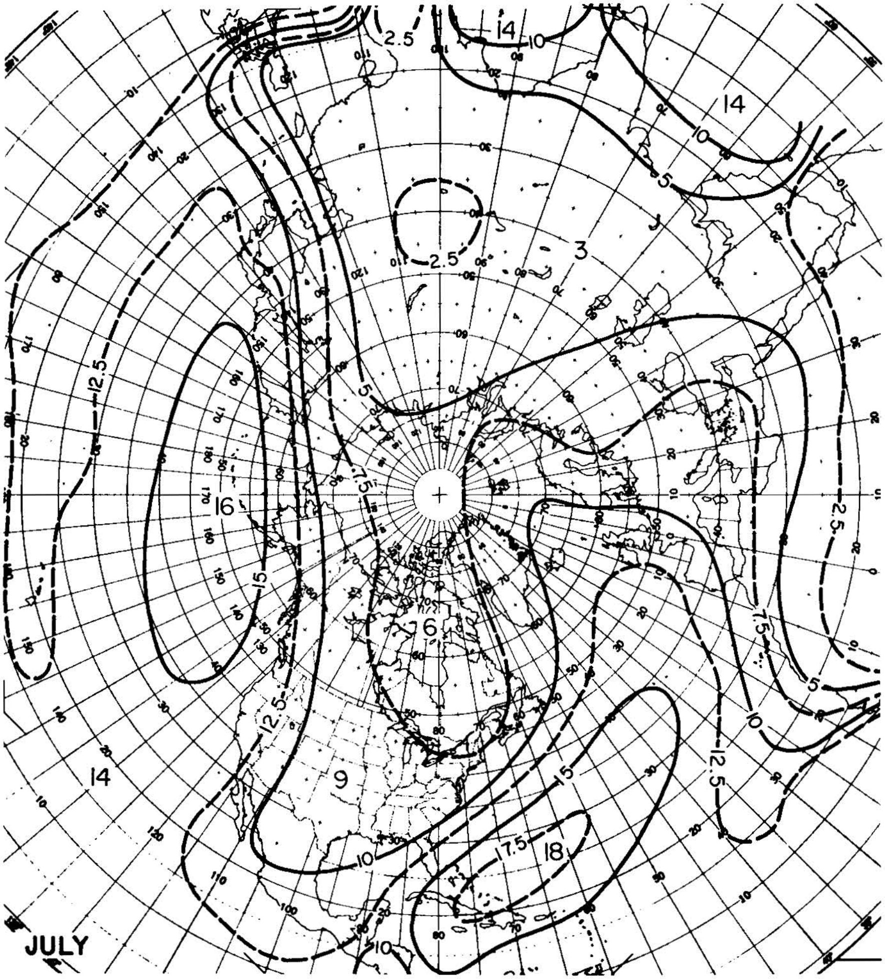


Figure 15. Increase in the mid-tropospheric temperature, in tenths of degrees Celsiu



ıe to an increase of 2°C in the surface ocean temperatures in the previous month.

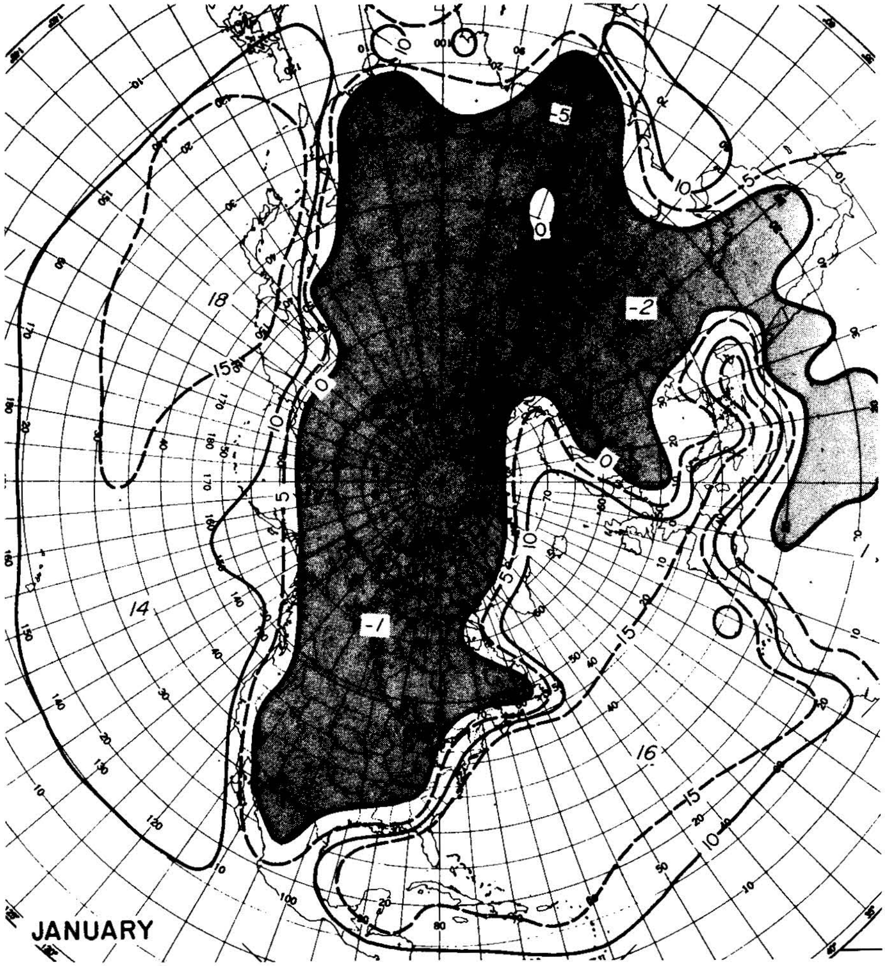
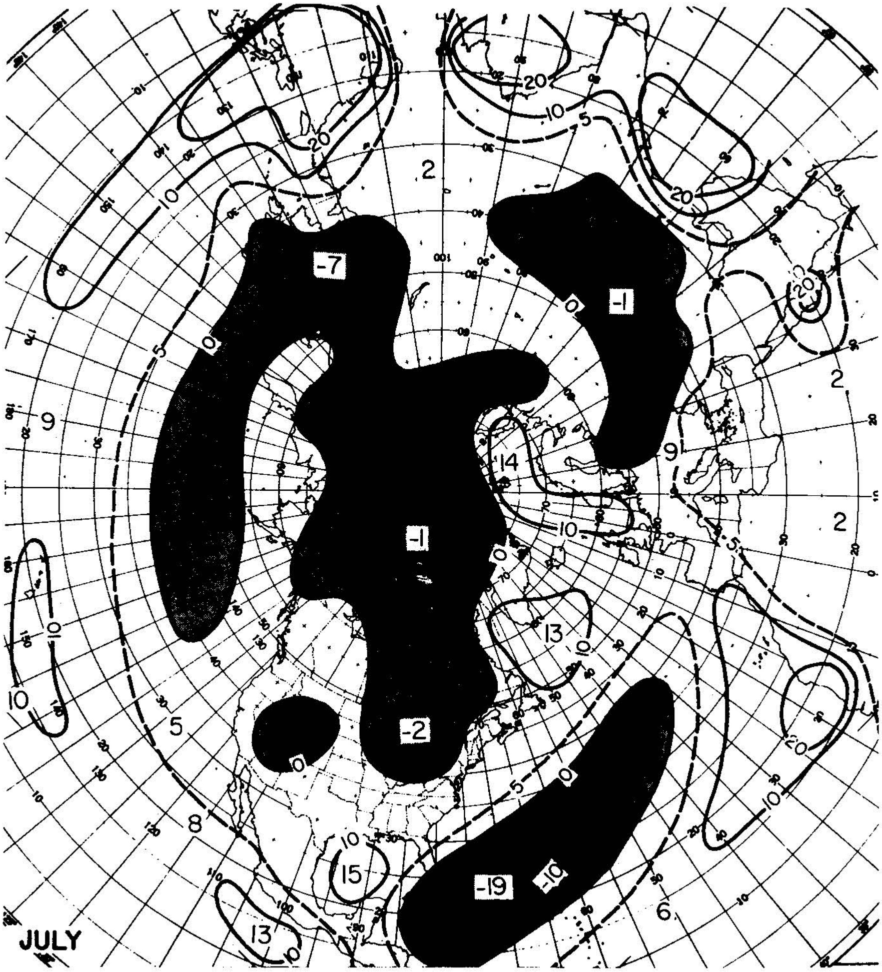


Figure 16. Increase in the sensible heat given off to the atmosphere by turbulent vertical transport fro
vious month.



e surface, in langleys per day, due to an increase of 2°C in the surface ocean temperature in the pre-

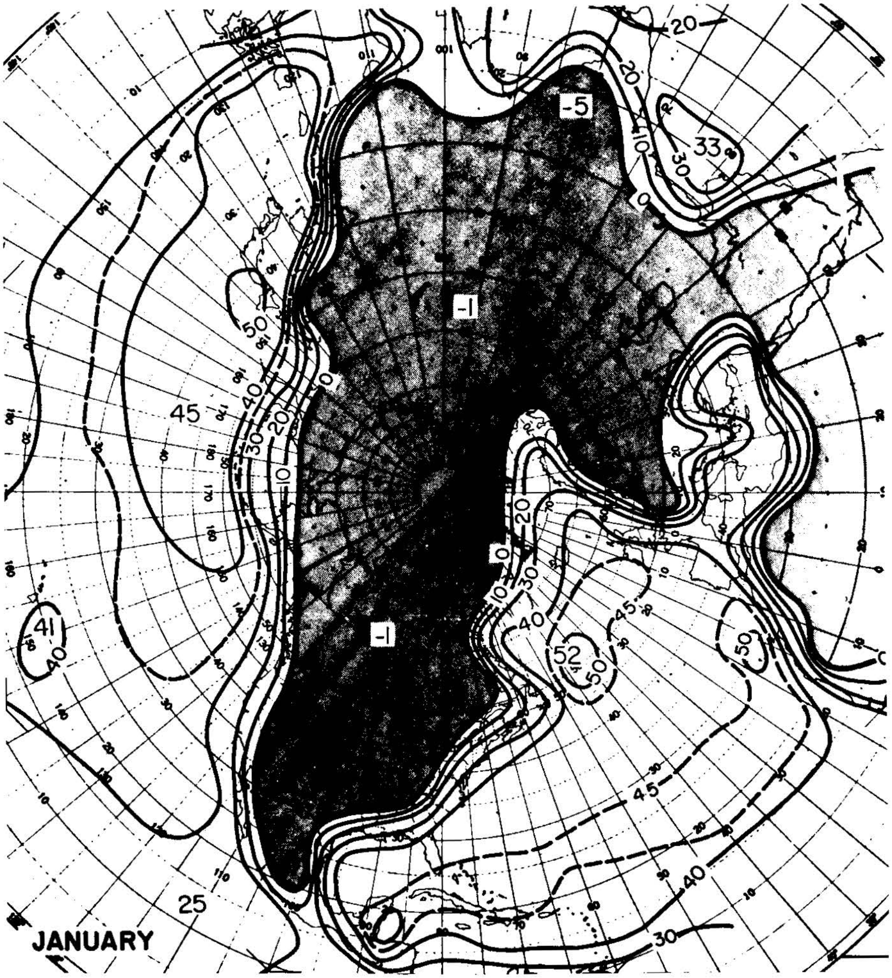
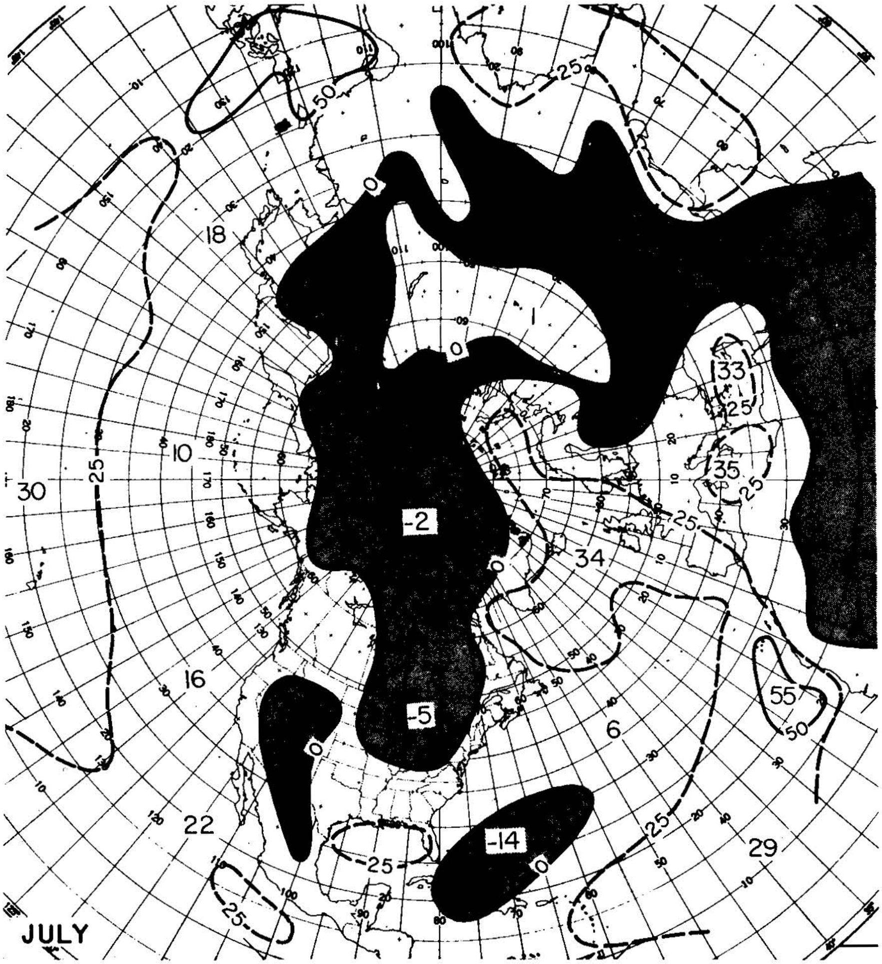


Figure 17. Increase in the heat lost by evaporation at the surface, in langleys per da



e to an increase of 2°C in the surface ocean temperature in the previous month.

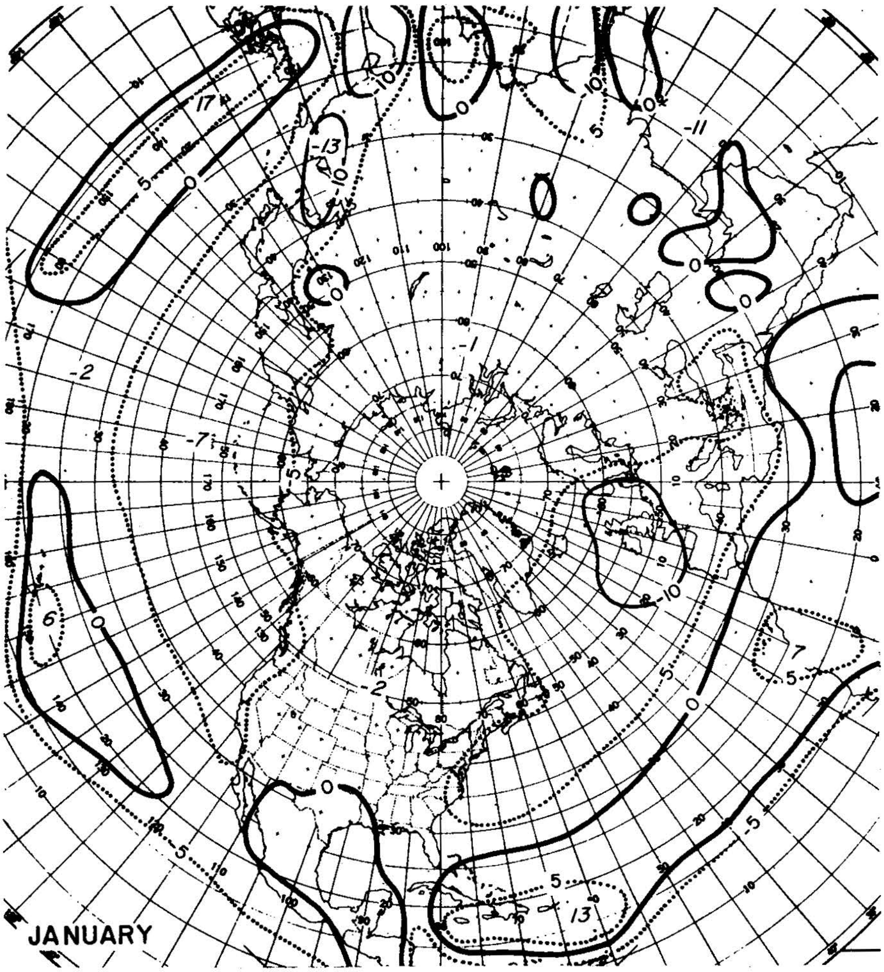
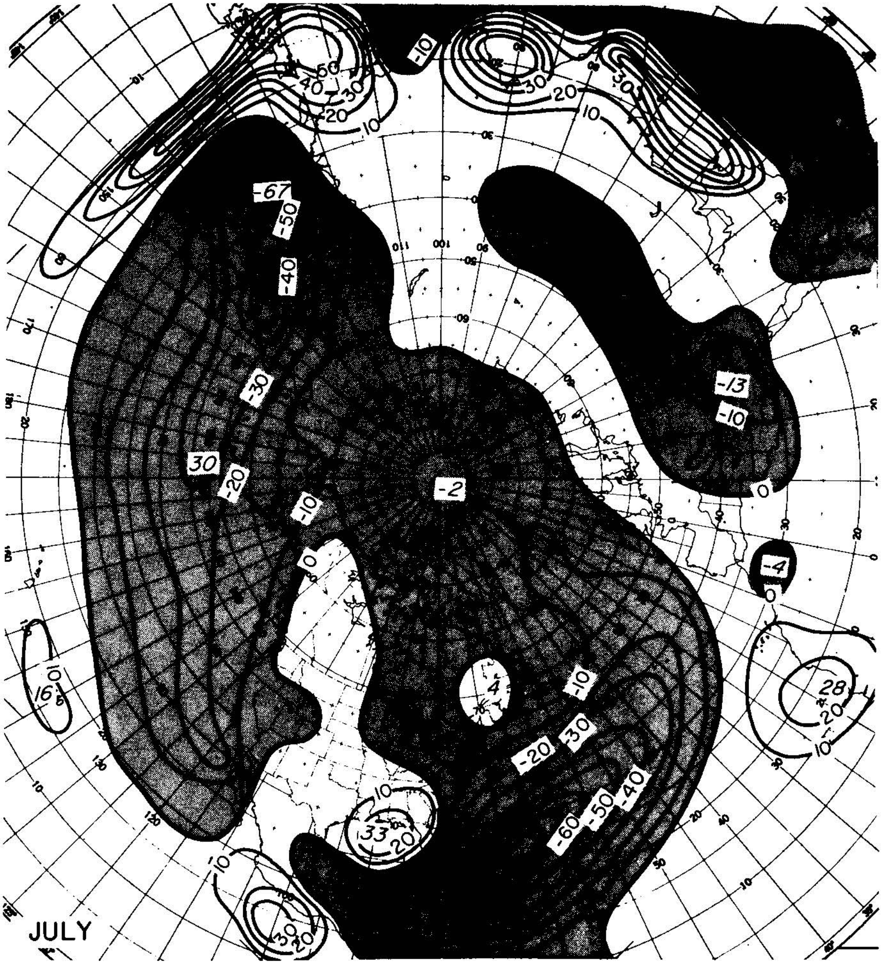


Figure 18. Increase in the radiation energy absorbed at the surface, in langleys per d



ue to an increase of 2°C in the surface ocean temperature in the previous month.

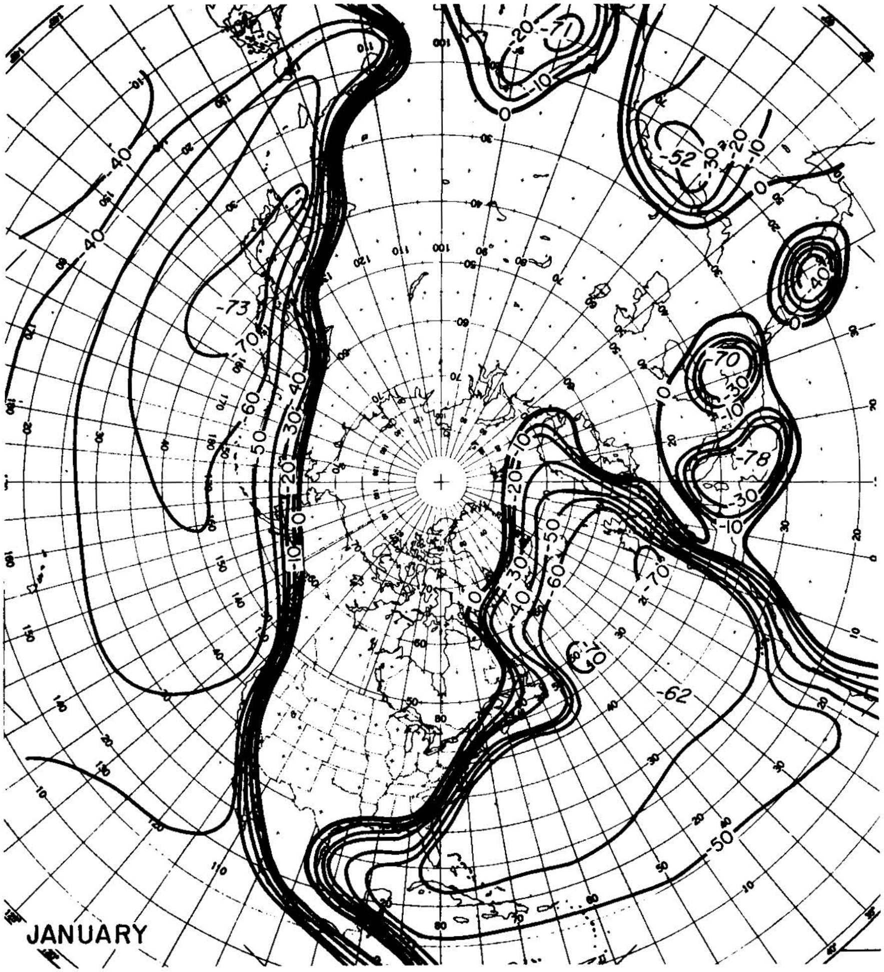
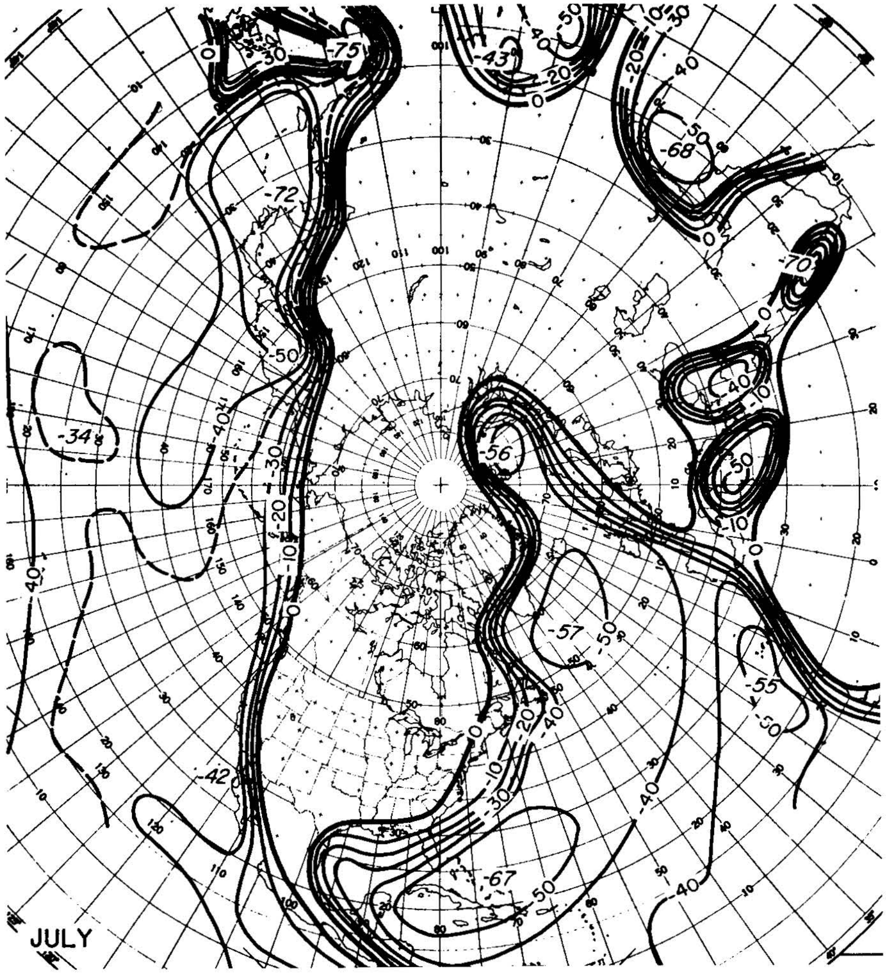


Figure 19. Increase in the storage of heat in the oceans, in langleys per day



due to an increase of 2°C in the surface ocean temperature in the previous month.

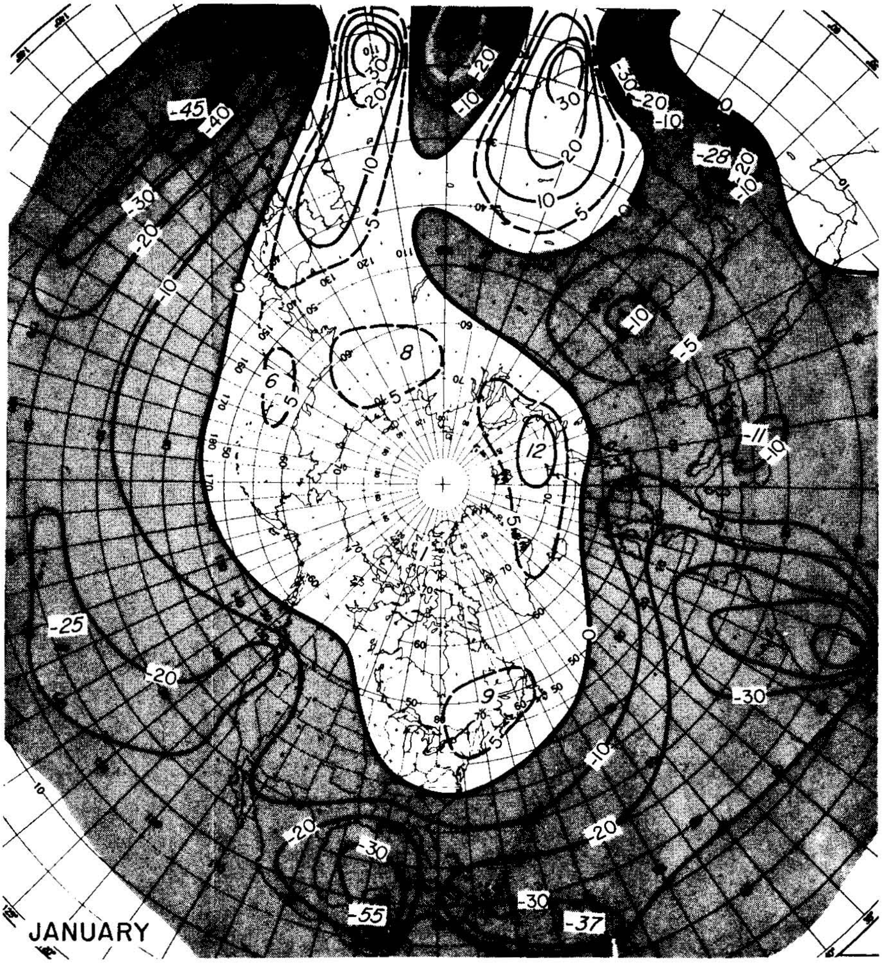
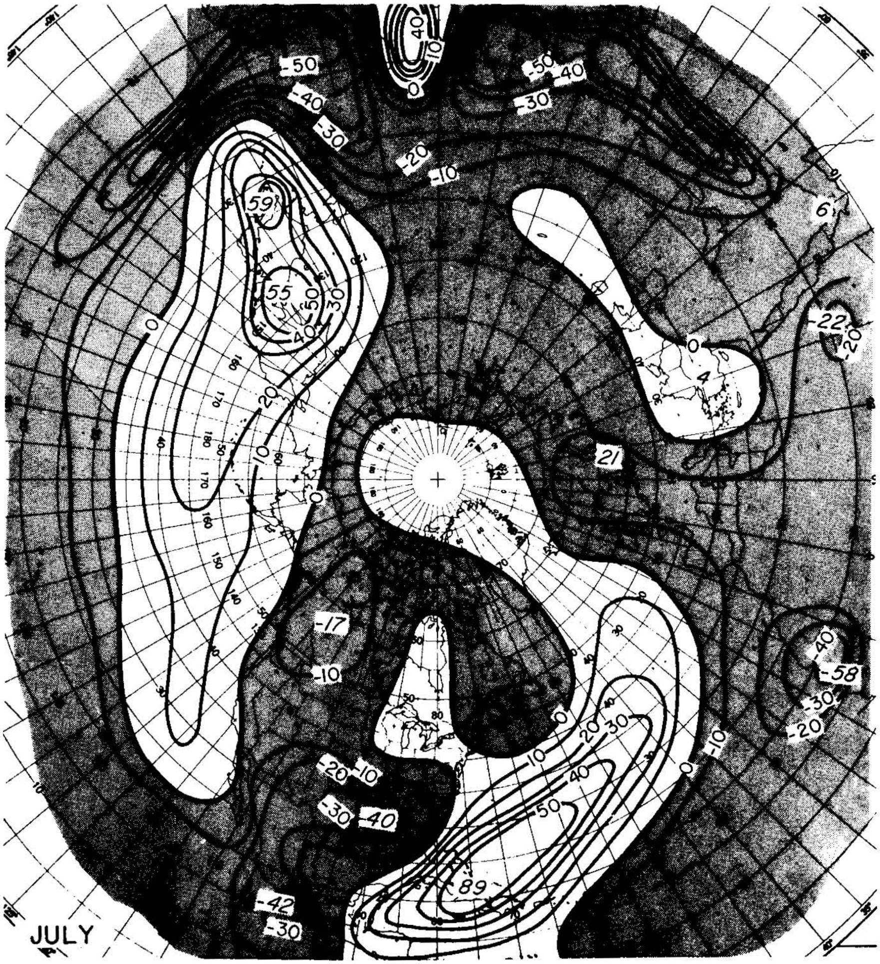


Figure 20. Increase in the heat of condensation of water vapor in the clouds, in langleys



ɔer day, due to an increase of 2°C in the surface ocean temperature in the previous month.

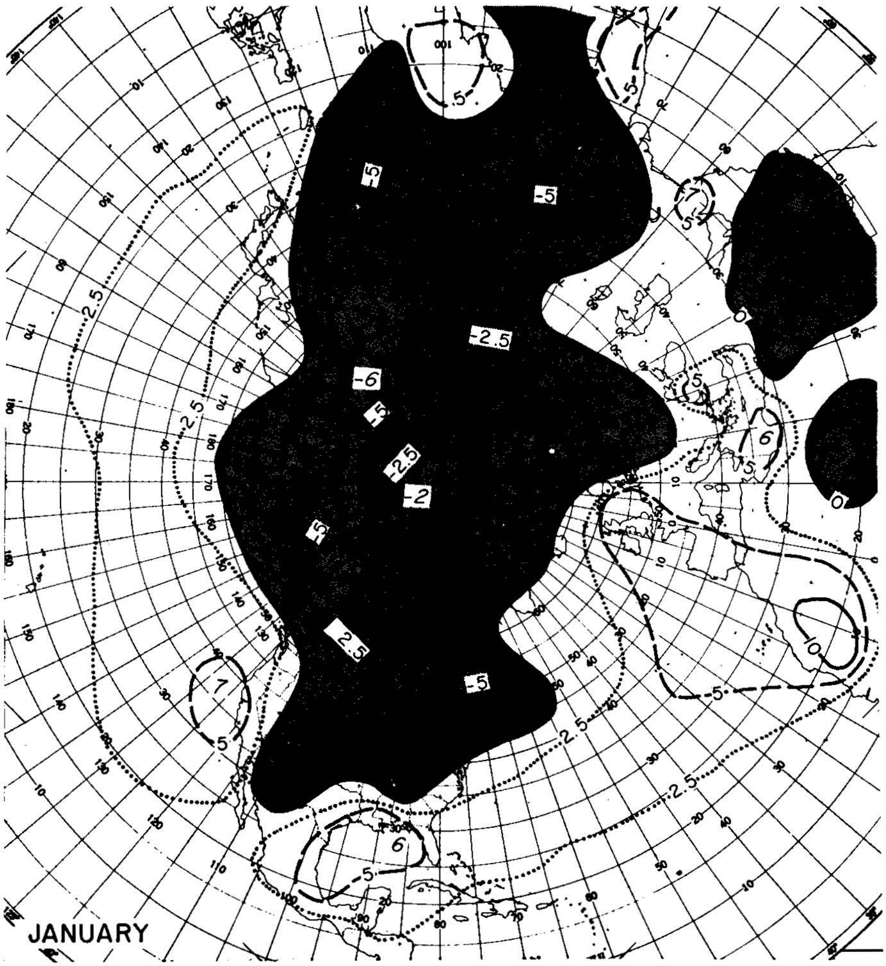
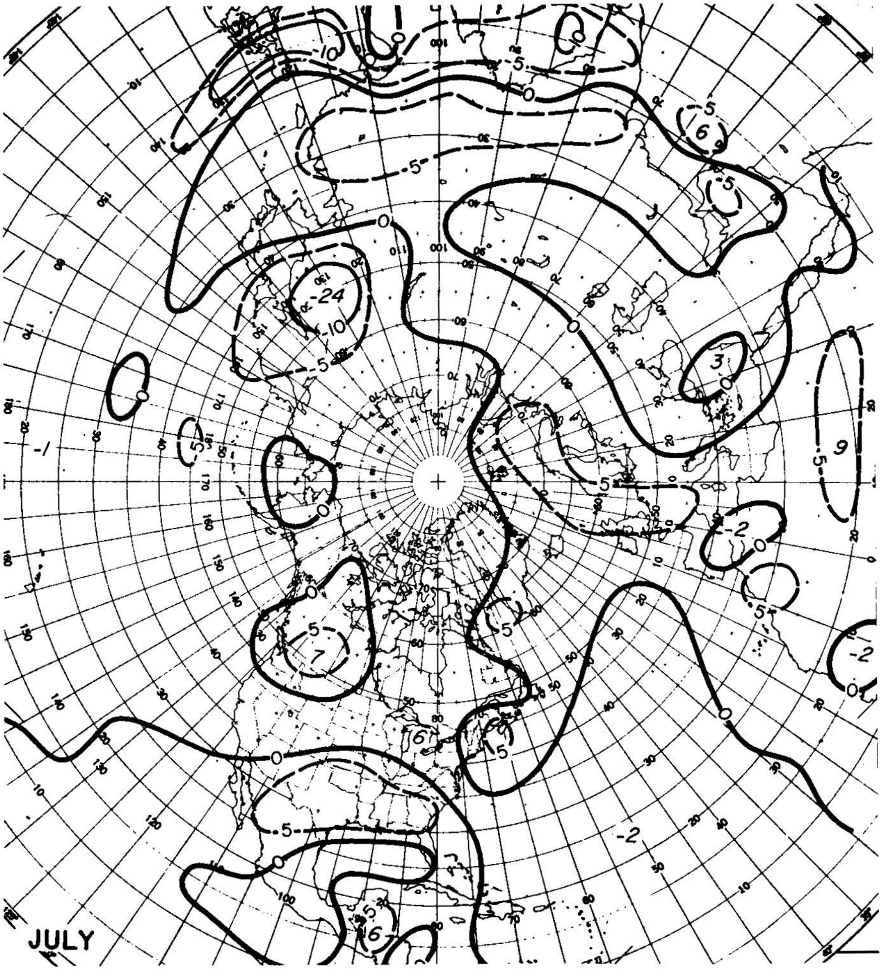


Figure 21. Increase in the radiation energy absorbed in the atmosphere, in langleys pe



ay, due to an increase of 2°C in the surface ocean temperature in the previous month.

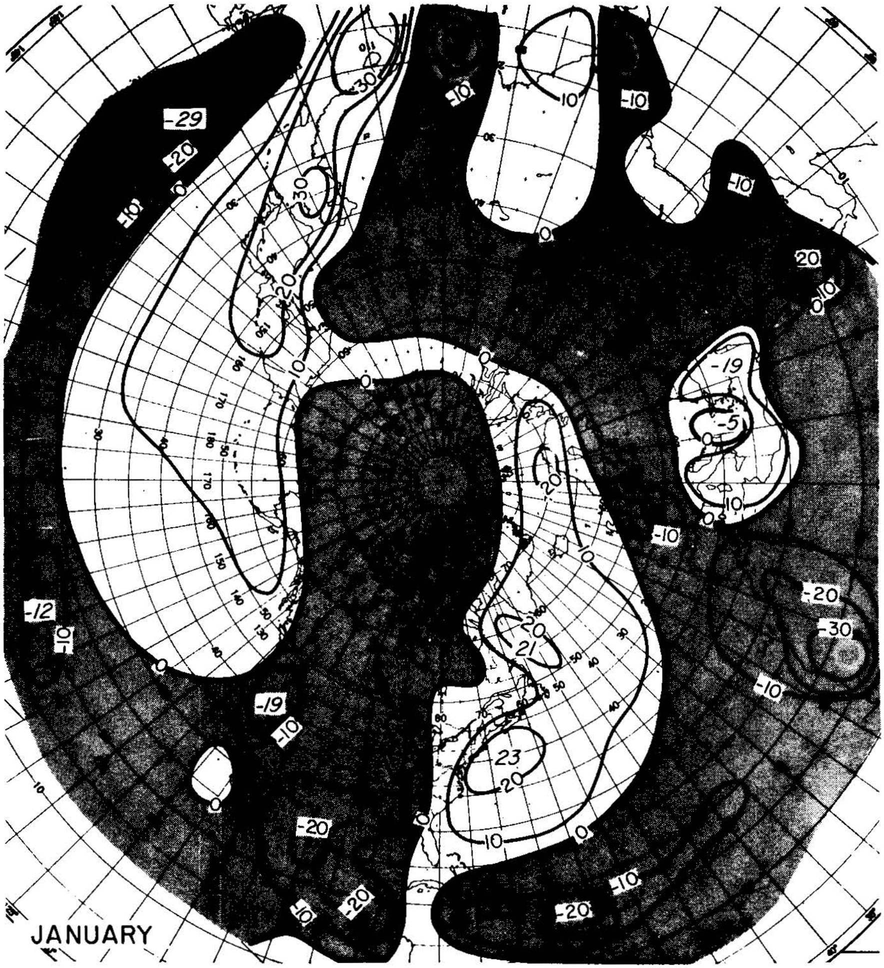
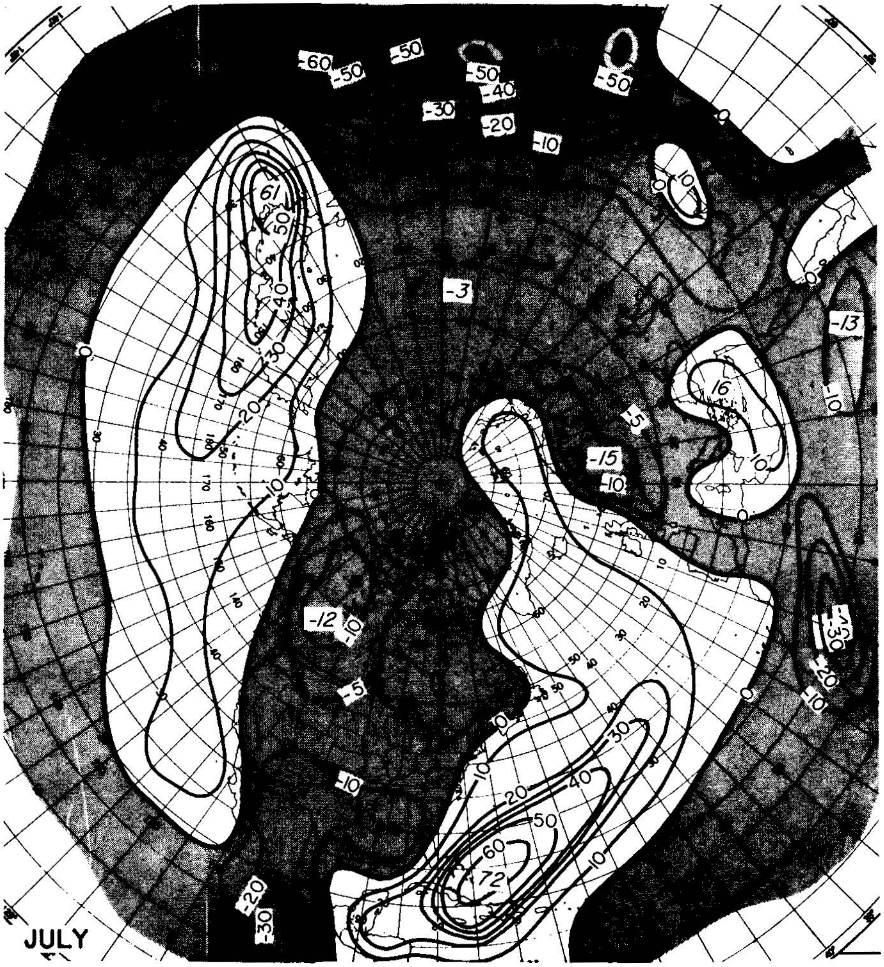


Figure 22. Increase in the total heating absorbed in the atmosphere (due to radiation, sensible he: due to an increase of 2°C in the surface ocean temperature in the previous month.



iven off from the surface and heat of condensation of water vapor in the clouds), in langleys per day,

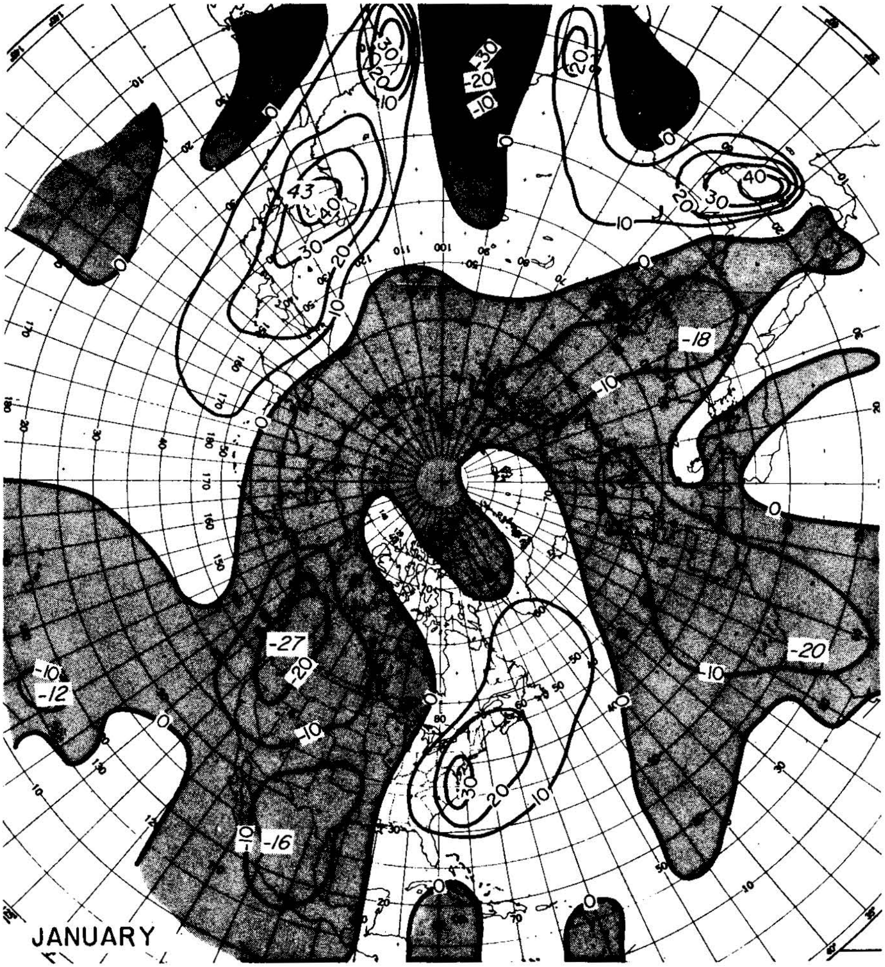
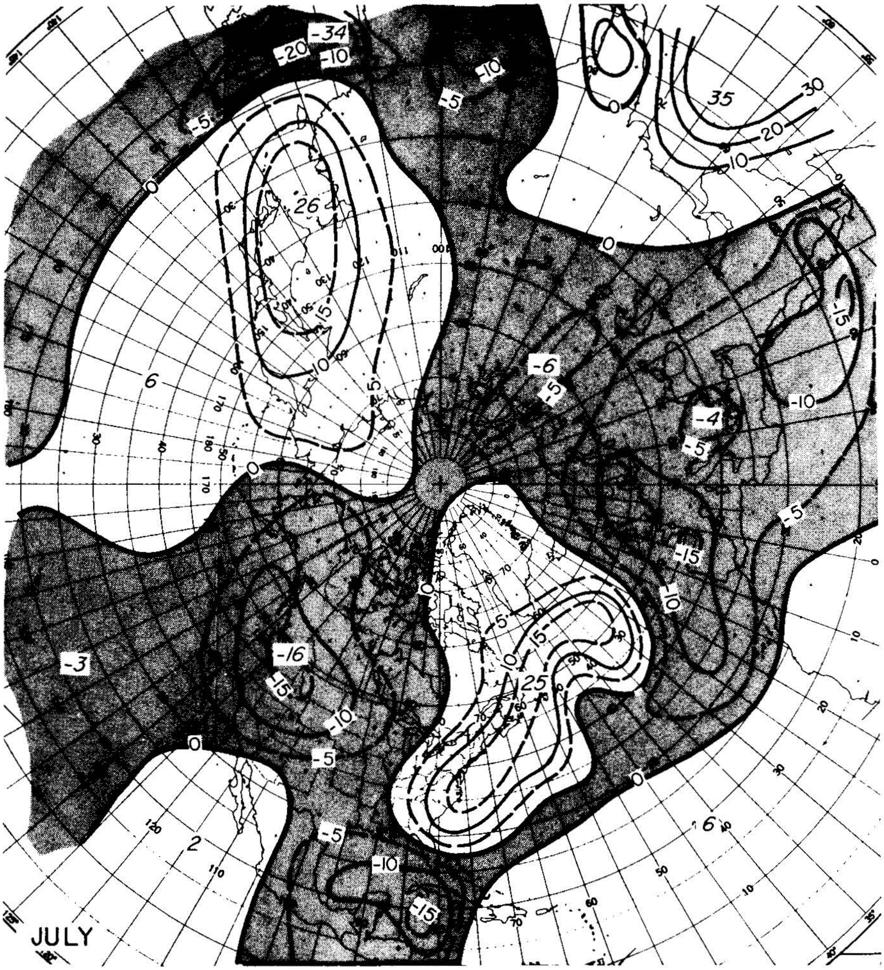


Figure 23. Increase in the advection of heat by the mean wind, in langleys per day



e to an increase of 2°C in the surface ocean temperature in the previous month.

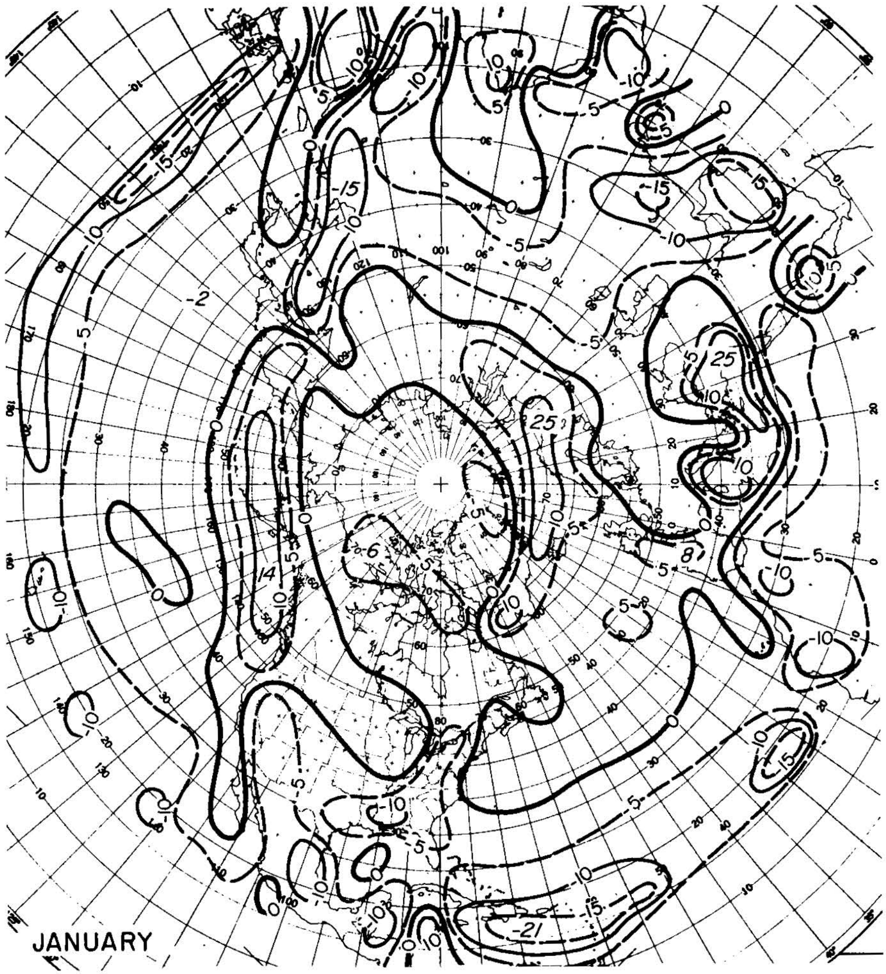
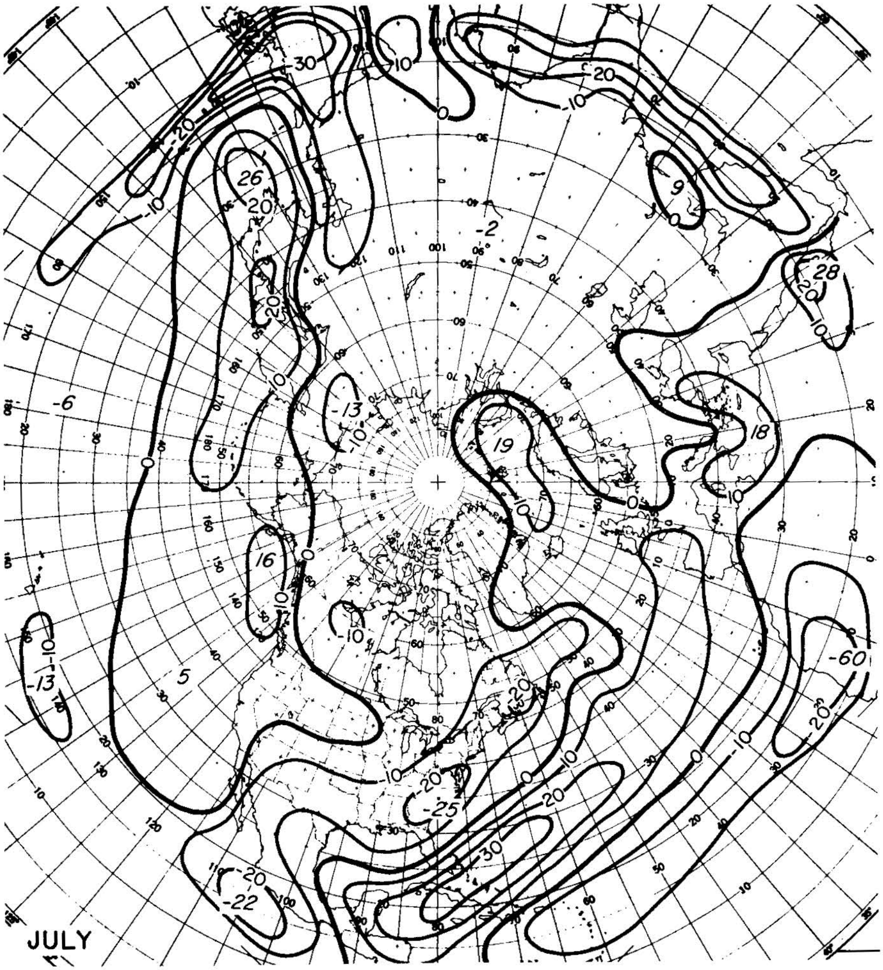


Figura 24. Increase in the advection by turbulent eddies, in langleys per da



to an increase of 2°C in the surface ocean temperature in the previous month.

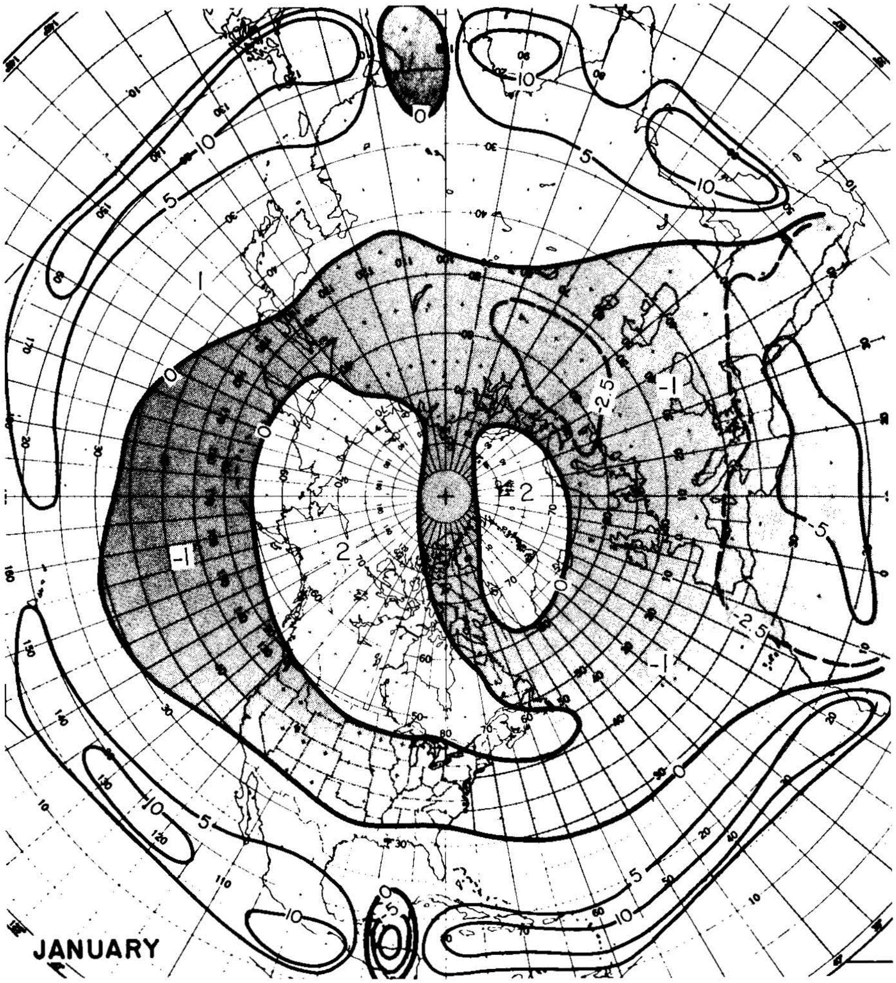
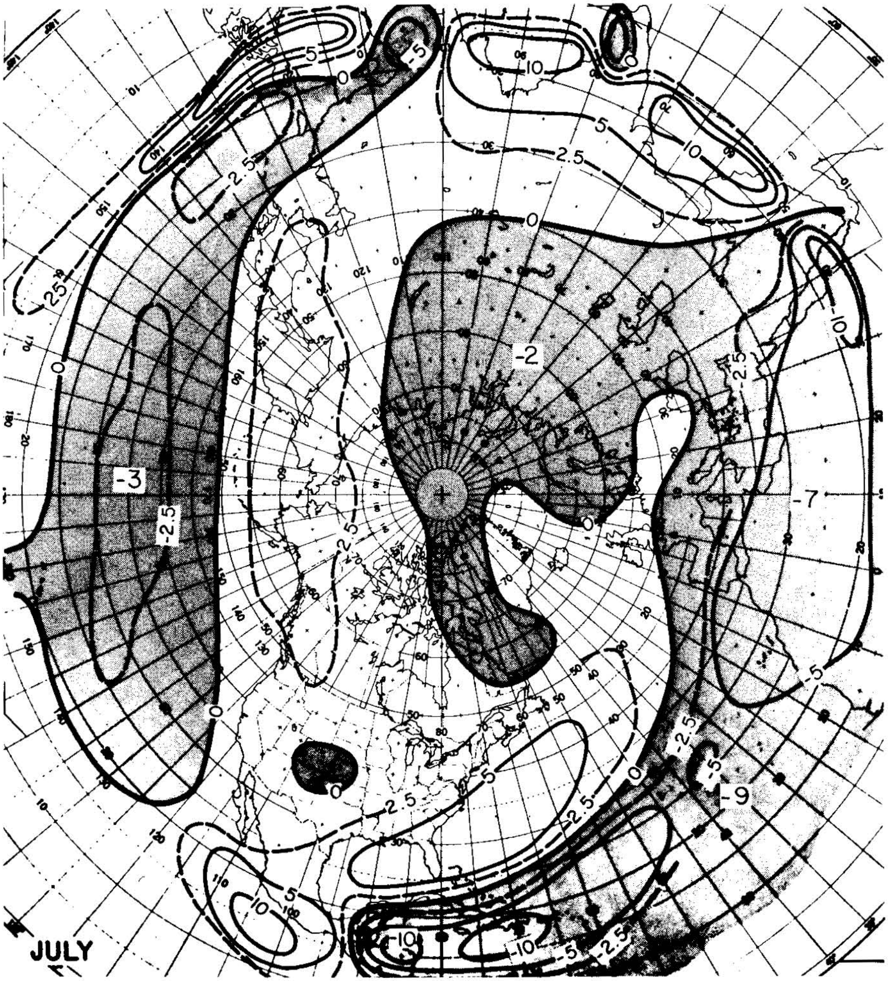


Figure 25. Increase in the zonal wind, in decimeters per second, due t



:rease of 2°C in the surface ocean temperature in the previous month.

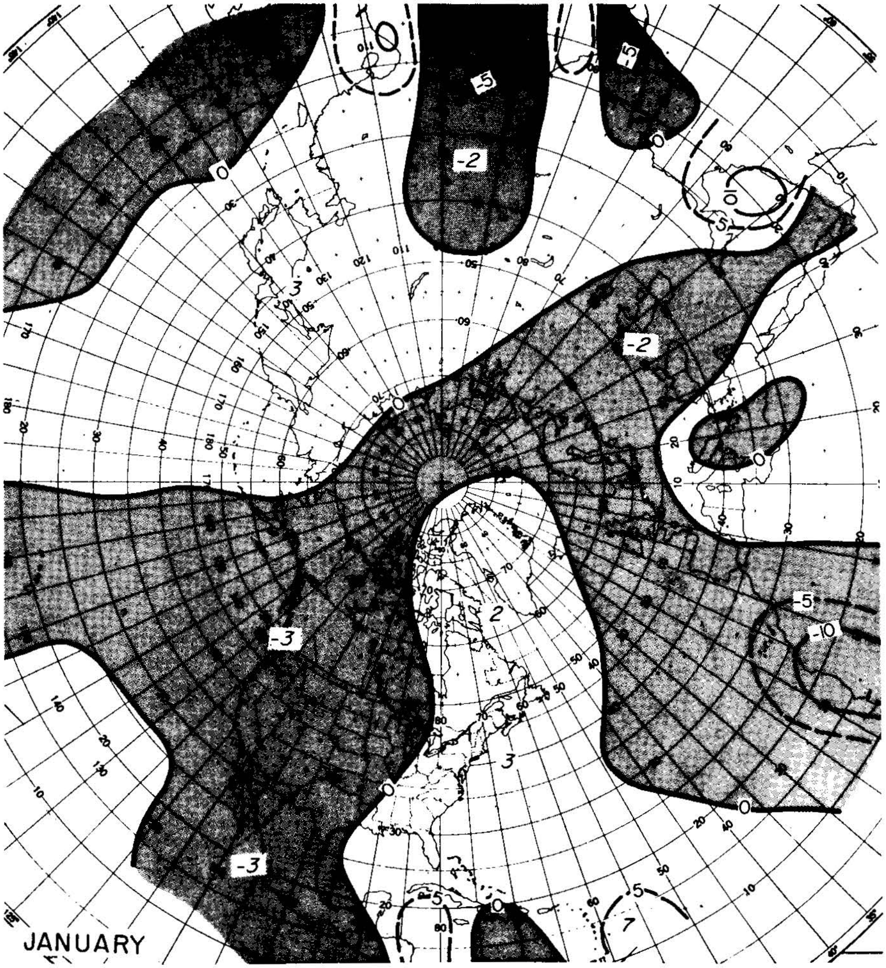
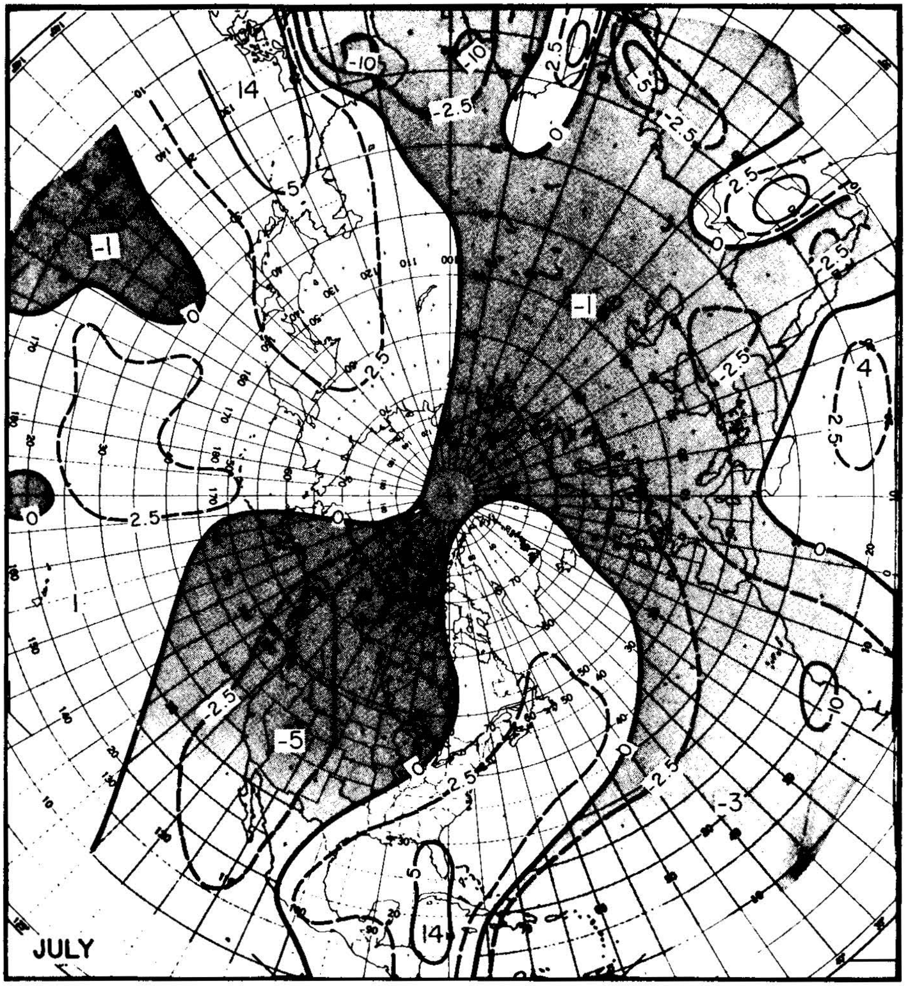


Figure 26. Increase in the meridional wind, in decimeters per second, due



ı increase of 2°C in the surface ocean temperature in the previous month.

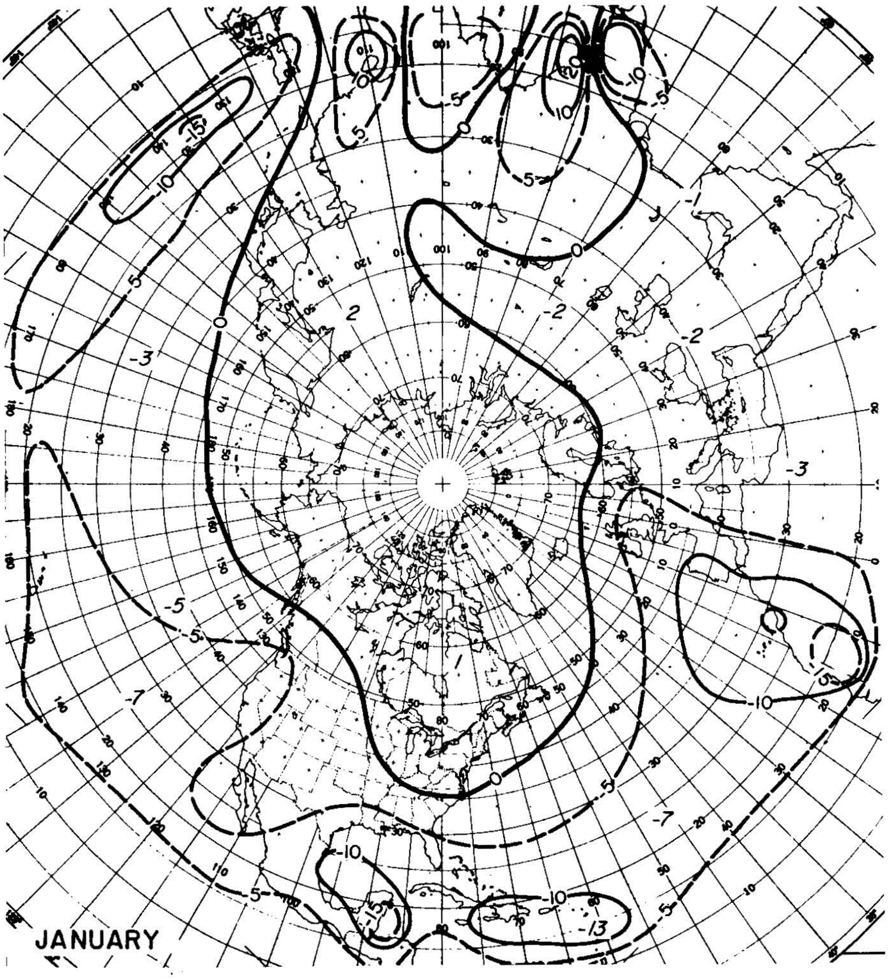
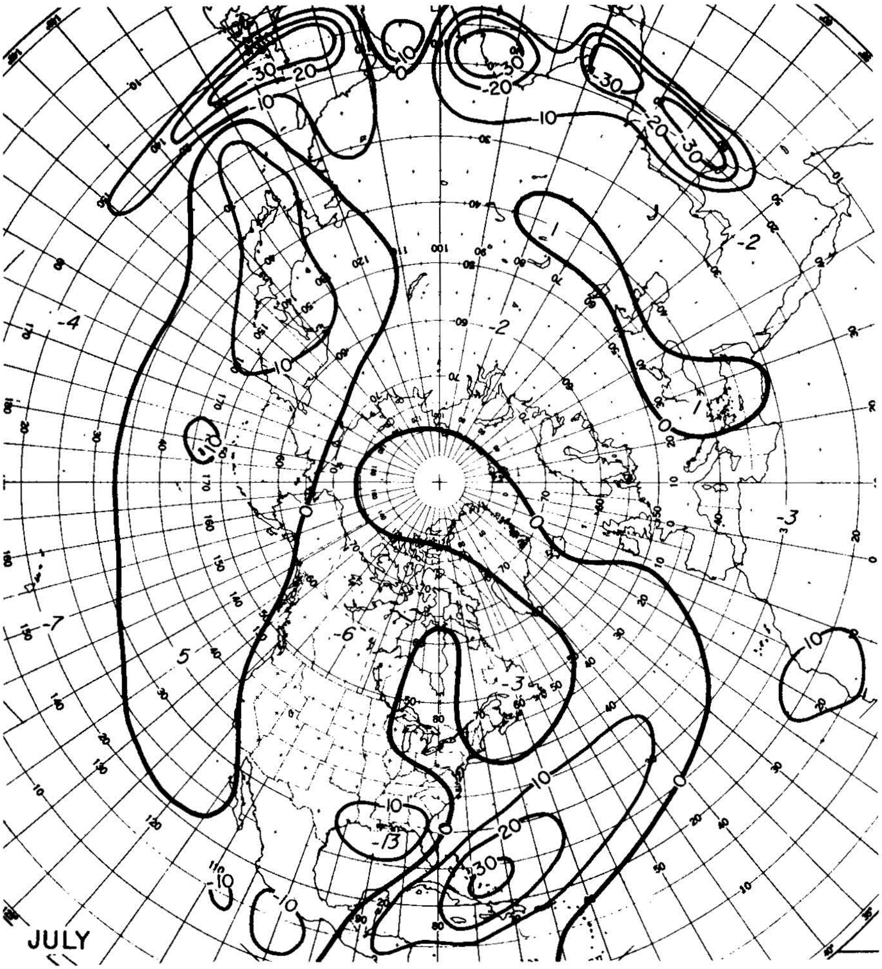


Figure 27. Increase in the cloud amount, in percent of sky covered, due



ı increase of 2°C in the surface ocean temperature in the previous month.

20) are relatively large in the oceans and in the continents. The largest values occur in July southeast of the Peninsula of Florida and are of the order of 90 langleys per day. Their effect is also important in the continents, especially in lower latitudes.

The increase of radiation energy (short and long wave) absorbed by the atmosphere (Figure 21) is relatively small. However, the increase of the total atmospheric heating (Figure 22) which is the sum of the increases in energy added by radiation, by sensible heat given off by turbulent transport from the surface and by condensation of water vapor in the clouds is relatively large, specially in July, due to the large contribution of the heat released by condensation of water vapor in the clouds.

The increase in the advection of heat by the mean wind (Figure 23) is relatively large, especially in the eastern coast of the continents, with values as large as 40 to 50 langleys per day in January and 20 to 30 in July.

The increase in the transport by turbulent eddies (of the size of the cyclones and anticyclones of middle latitudes) (Figure 24) is also important.

Since the increase in the storage of heat in the atmosphere is negligibly small (not shown); the sum of increases of the transports by mean wind and by turbulent eddies is equal to the increase of the atmospheric heating (Figure 22).

The increases in the zonal wind are shown in Figure 25, and the increases in meridional wind in Figure 26, in decimeters per second.

Finally, Figure 27 is the increase of cloud amount in percent of sky covered, which contributes in an important way in the formation of the anomalies of the temperature fields, the heating functions and the associated atmospheric circulation.

These results show that the ocean surface temperature has a profound influence in weather and climate, and that the response of the atmosphere to the ocean temperature conditions varies with the seasons of the year, and depends on the distribution of oceans and continents.

8. LONG-RANGE WEATHER PREDICTION AND OCEAN TEMPERATURE PREDICTION.

The main storage of energy in the Atmosphere-Ocean-Continent System is in the oceans, and since such storage is proportional to the temperature, it follows that the surface ocean temperature is one of the most important factors for any physical approach to long-range weather prediction.

The thermodynamic model for mean monthly prediction was discussed by the author in a series of papers (Adem 1962, 1963, 1964b). A more sophisticated version of this model (Adem 1965,1970 a) has been used operationally, and evaluated along with some of the other forecast methods, in the U.S. Weather Service since 1966. This contains the surface ocean temperature as one of the main initial data fields, as well as one of the main predicted variables computed in the model simultaneously with the heating functions and the meteorological variables. Several reports on the skill of the predictions have been published (Adem and Jacob, 1968; Adem, Bostelman and Polger, 1970; Adem 1970a).

It is interesting to point out that the resultant ocean temperature prediction shows an encouraging skill (Adem 1970b).

It is expected that these predictions can be improved with the use of improved ocean temperature data.

Improvements are also expected due to a more realistic incorporation of the mechanisms that enter in the ocean-atmosphere interaction and of the heating functions.

9. FINAL REMARKS AND CONCLUSIONS.

The computations of the normal climatological fields, as well as those of the fluctuations due to changes in the solar constant and in other factors, show that the results depend, in an important way, on the realistic distribution of continents and oceans; therefore, any theory of the climate that ignores such distribution is very restricted in its scope.

The effect of the ocean on weather and climate also depends on the seasons of the year.

The long-term variations of weather and climate depend on the conditions of the underlying surface. Therefore, in a physical model for climatic studies and for long-range prediction, the meteorological variables must be computed simultaneously with the variables and parameters that describe the conditions at the surface, such as the ocean temperature, the albedo of the surface of the earth, the wetness of the soil, the vegetation, etc.

The atmosphere has relatively little memory, its capacity to remember is obtained through the interaction with the ocean that has a large capacity to store energy and that evolves slowly, keeps its energy in the summer, and later uses it in winter, thus regulating the variation of temperature during the year.

As the atmosphere, the continents have a small capacity to store energy, but through the horizontal transport of energy, the energy stored in the oceans modifies the climate and the weather of the continents.

The energy that is stored in the oceans has normally large regional anomalies, that appear as large anomalies in the temperature of the surface of the oceans and that affect the present and future conditions of the temperature and circulation of the atmosphere, as well as the heating functions. Therefore, the ocean temperature is an essential variable for long-range prediction and for studies of climatic fluctuations.

Since upwelling is a mechanism that brings to the surface important anomalies of temperature, it has effects on weather and climate, which up till now, are not well understood. Research in this direction seems therefore to be essential for a complete understanding of the effect of the ocean on weather and climate.

ACKNOWLEDGMENT

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