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Simulation of meteorological field variations associated with changes in different-level cloud formation conditions*

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Numerical experiments have been performed in order that the response of the surface thermobaric fields to changes in the formation conditions of different-level clouds be investigated. On the average, a 20% increase of the coupling coefficient between the amount of low clouds and relative humidity leads to an increase in the global surface air temperature by about 1°. The temperature rise effect is more pronounced in summer and winter. The polar areas and baroclinic regions have been found to be most sensitive to changes in the cloud formation conditions.

In recent years, it has been generally agreed that the influence of cosmic rays on the atmospheric air characteristics is likely a mechanism of solar-terrestrial relationships. Cosmic rays, owing to their tremendous penetrability, are able to create in the atmosphere a large amount of additional condensation nuclei that affect cloud formation conditions. The cloud formation, in turn, is accompanied by the liberation of condensation heat and by a change in radiation balance, which could cause a change in the circulation and atmospheric characteristics of the atmosphere.

Unfortunately, simple estimates are of little use in the analysis of the significance of climate-forming factors of such a complex system as the atmosphere. This is due to the nonlinearity of atmospheric processes, and to a large number of positive and negative feedbacks involved. The production of additional condensation nuclei, for example, can differently affect on the formation of different-level clouds, the radiation balance of the underlying surface, the vaporization rate, and the air humidity, which can ultimately result in a decrease, rather than an increase, of the cloud amount. Adequately reliable estimates of the role of climate-forming factors can only be obtained by using realistic circulation models with allowance for a maximum possible number of intrinsic feedbacks of the system.

In our analysis of the influence of cloud formation conditions on the atmospheric circulation and climate we employed the finite difference atmosphere dynamics model from the Novosibirsk Institute of Computational

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Mathematics and Mathematical Geophysics SB RAS now in use to generate prompt weather forecasts at the Novosibirsk Hydrometeorology and Environmental Monitoring Administration. The model includes equations of motion in the Gromeki–Lamb form, and continuity and equations of heat and moisture transport in the spherical coordinate system. Spatial difference approximation of the equations ensures the fulfillment, in the finite difference form, of the law of conservation of mass, energy, angular momentum, specific humidity and potential entropy thus enabling integration over long time intervals.

Four numerical experiments on the simulation of the dynamics of meteorological fields for eight years were carried out using different variants of parameterization according to Smagorinsky of the total amount of lower-, middle-, and high-level clouds. form. Coupling coefficients of the total cloud amount with a relative humidity varied in the experiments by 20%. Monthly-mean distributions of the surface thermobaric field, averaged for eight years, were compared for different coupling coefficients. The spatial dispersion of the surface air pressure in different sectors of the globe was calculated in order that the circulation rate variations be estimated. This characteristic depends on the localization of a spatial region and on the season, and can, in principle, be used as atmospheric circulation index. The processes were preliminarily separated into "fast" and "slow" using a simple moving averaging. According to [1, 2], this method works rather effectively when used to identify synoptic processes and processes caused by the dynamics of the centers of forcing if the averaging interval is chosen to be about 10 days. As our prime interest was with the dynamics of large-scale fields, the averaging interval was increased up to 12 days. Analysis of the resulting fields showed that the "high-frequency" part of the variations was determined by the dynamics of cyclones and anticyclones, and the "low-frequency" part was governed by the variability of the centers of forcing.

A non-trivial problem was that of selecting a spatial region for calculation of the pressure fields dispersion. In spite of a high level of connectivity of the processes, the atmospheric circulation has a large number of specific features in different latitudinal and longitudinal zones [3, 4]. Taking these features into account would inevitably make the analysis of the common features of the dynamics of circulation processes more complicated. For that reason, we confined ourselves to estimating the dispersion in two quadrants of the northern hemisphere and in two quadrants of the southern hemisphere (North-West, North-East, South-West, South-East) in the latitude ranges from 10° to 70°.

An integral effect of the influence of the cloud formation conditions on climate is illustrated by Figure 1, showing the average seasonal behavior of a difference of global ground air temperatures in the experiments, differing by 20 percent in the coupling coefficients of the low-level clouds and relative

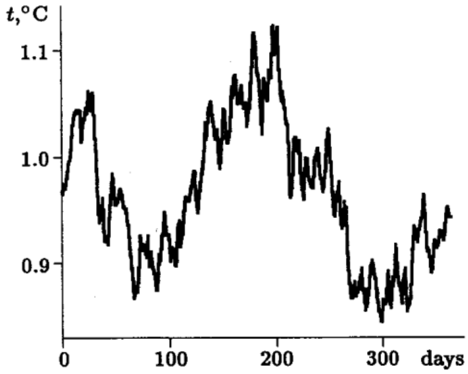

Figure 1. Average seasonal behavior of the difference of global surface air temperatures resulting from experiments with different coupling coefficients of low-level clouds and relative humidity

humidity. On the average, an increase in cloudiness brings about a rise in the global temperature by about 1°. In summer and winter, the effect of the temperature rise is more pronounced. In winter and summer, respectively, the enhancement of the response is associated with the response of the Southern and Northern hemispheres. Unfortunately, the insufficiently high spatial resolution of the model does not ensure accurate numerical estimates, although a general tendency is conserved. Furthermore, the response in the thermobaric field crucially depends on geographic coordinates. This is because studying the spatial structure of responses was thought of as more important for this stage of investigation. Comparison of model distributions with atmospheric responses to particular helio-geophysical events would provide a more penetrating insight into the mechanism of forcing.

It was found that the variation in the low-level cloud formation conditions shows up most conspicuously in the change of the temperature conditions. Figure 2 shows the difference of monthly mean temperature distributions averaged for 8 model years. Isotherms are drawn at intervals of 0.5°. The differences of temperature distributions are constructed for the central months of the seasons: January, April, July, and October. Differences in the surface pressure are plotted in Figure 3 for the same months. Isobars are drawn at 0.25 gPa intervals.

The polar areas and baroclinic regions were found to be most sensitive to variations in the cloud formation conditions, which is in agreement with the findings reported by Mustel [5]. A rise in temperature is characteristic of all regions with increased cloudiness, and the greatest decrease is typical of the areas with little cloudiness. Furthermore, the background of the atmospheric pressure variation and the thermal conditions, respectively, were found to be most sensitive to changes in the lower-level cloud formation conditions during transition seasons and in the warm seasons when processes of radiational heating and underlying surface evaporation are intense. The amount of low clouds at this period is the largest (in the Arctic – from May to September, and in Antarctica – from October to April). Tempera-

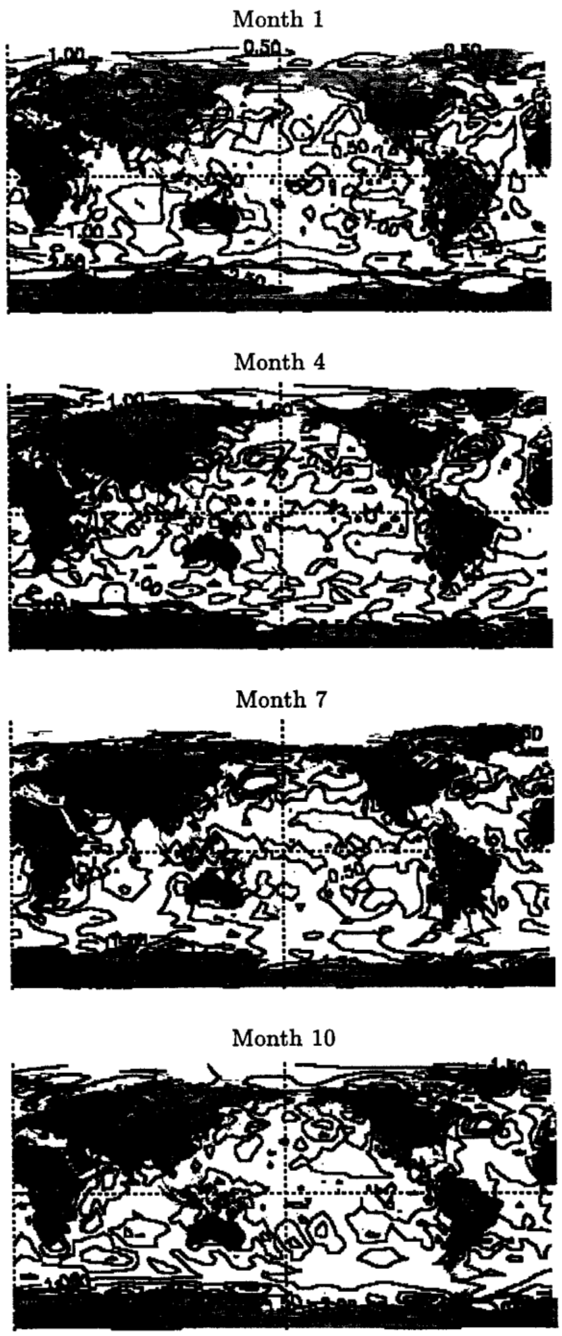

Figure 2. Distributions of the difference of monthly mean surface air temperatures resulting from experiments with different coupling coefficients of low-level clouds and relative humidity. Solid line marks positive areas of temperature anomaly, and dotted line marks negative id

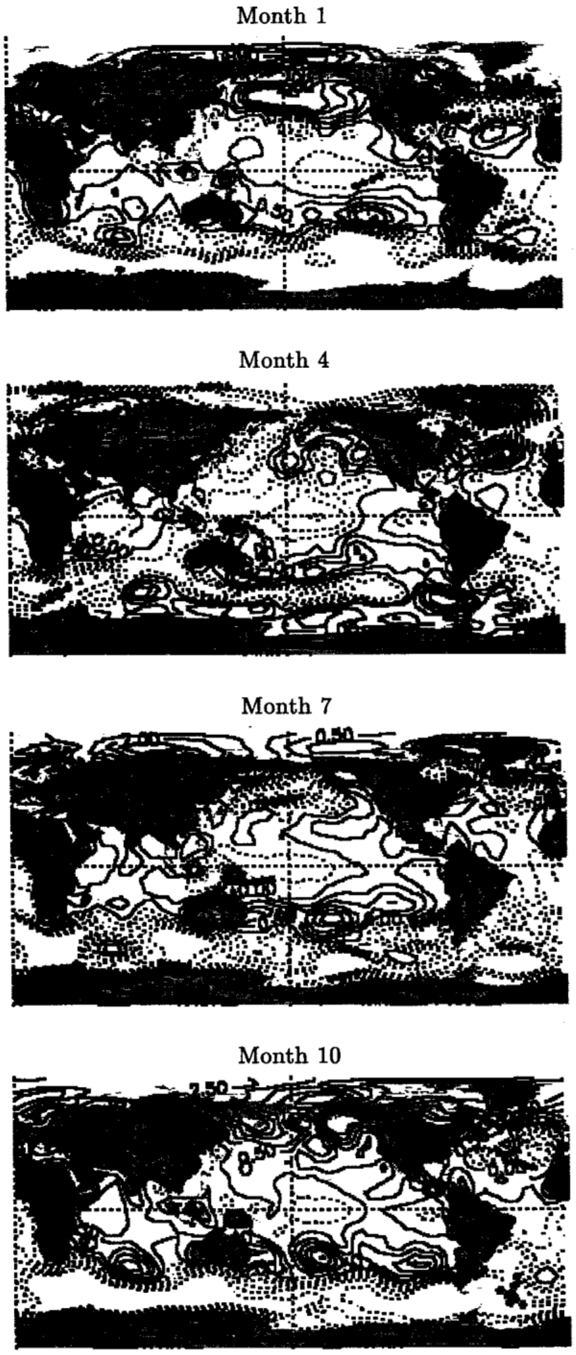

Figure 3. Distributions of the difference of monthly mean surface-pressure fields resulting from numerical experiments. Solid line marks positive areas of pressure anomaly and dotted line marks negative id

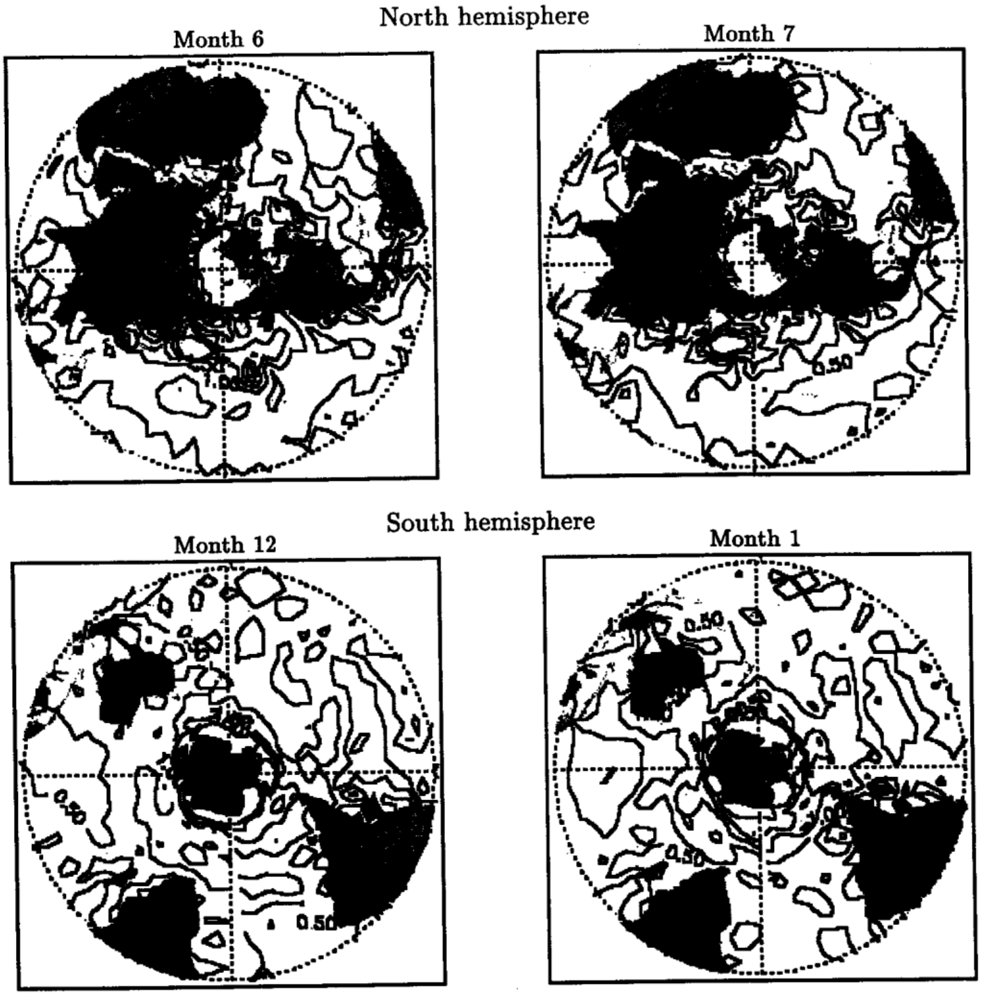

Figure 4. Distributions of the difference of monthly mean surface air temperatures in the northern and southern hemispheres using the stereographic projection

ture variations in the polar regions are illustrated by Figure 4, in which the temperature differences are constructed using the stereographic projection.

An enhancement of the low-level cloud formation processes led to an increase in the pressure over Europe, Greenland, and the Western coasts of North and South America (see Figure 3). The pressure in the near-Antarctic zone was steadily decreasing, although over Antarctica, the pressure variations had a seasonal character – pressure was increasing during the warm season and was decreasing during the cold season. A similar situation occurred in the northern part of the Pacific: an increase in the pressure during the cold season was compensated by its decrease during the warm season. The smallest pressure variations were characteristic, mainly, of the areas of

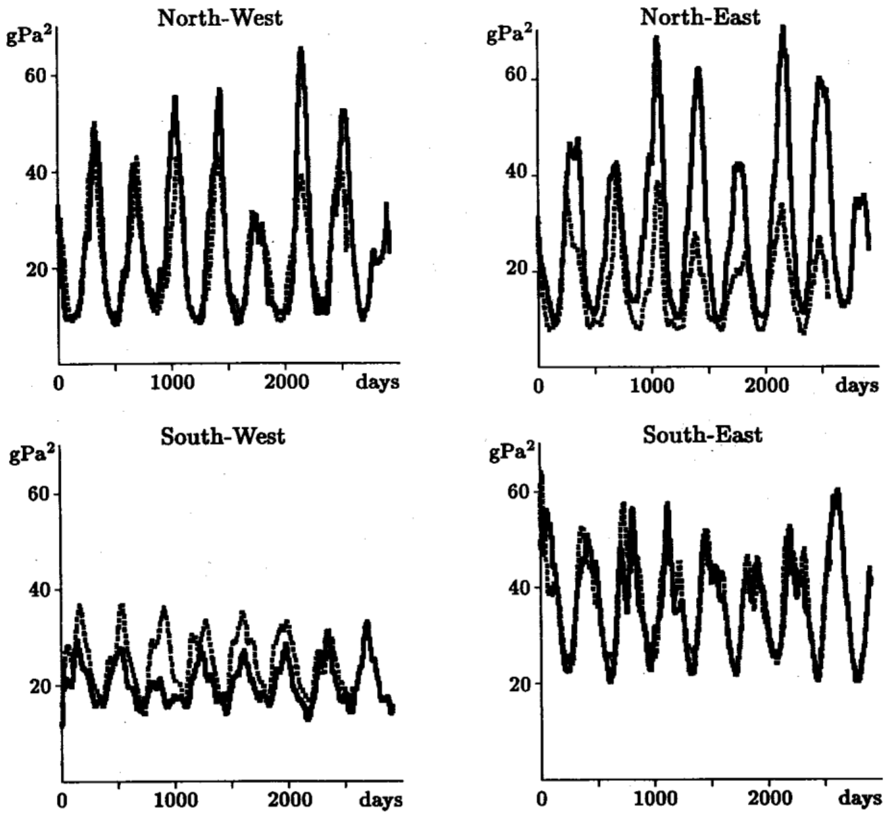

Figure 5. Time variation of the surface-pressure field dispersion in different quadrants of the globe. Solid line – connection coefficient of low cloudiness with relative humidity is equal 1, dot line – coefficient is equal 0.8.

the globe with a small amount of clouds where temperature variations were also the smallest.

The change in the lower-level cloud formation conditions led to characteristic changes in the circulation in both the northern and southern hemispheres. Figure 5 shows the smoothed plots of circulation indices of the simulated slow processes. It can be seen that the strongest changes occurred in the eastern hemisphere in the northern part, and in the western hemisphere in the southern part, while in the Northern hemisphere the circulation rate generally decreased, and in the Southern hemisphere it increased, with an increase of the amount of clouds. Changes in the circulation rate occurred in all seasons of the year but were more pronounced in the periods of a maximum synoptic activity, in winter, in the northern hemisphere, and, in summer, in the southern hemisphere.

Surface thermobaric fields and the atmospheric circulation rate are to a lesser extent influenced by changes in high- and medium-level cloud forma-

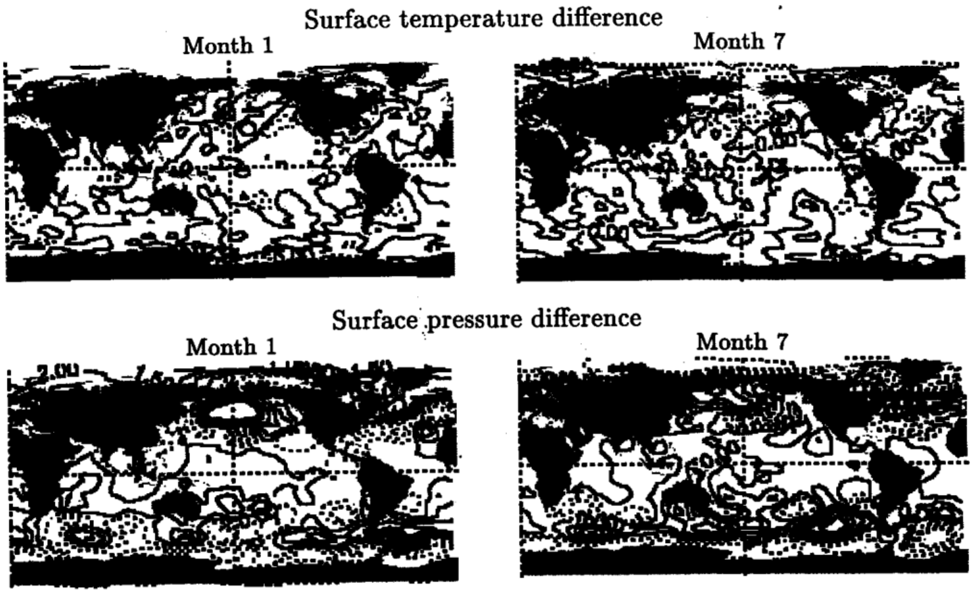

Figure 6. Distributions of the differences of monthly mean surface air temperatures and monthly mean surface-pressure fields resulting from experiments with different coupling coefficients of high-level clouds and relative humidity

tion conditions (Figure 6). The greatest rise of temperature is observed in the winter and summer seasons, on the eastern mainland coasts, and in the polar regions, respectively. With an enhancement of the formation processes of clouds of these levels, the greatest changes in the atmospheric pressure are observed in the first half of the year in the near-polar regions and on the eastern mainland coasts. In all the experiments, pressure variations in the polar regions occur synchronously, with periods of pressure increase corresponding to periods of pressure decrease in Antarctica, and vice versa, which is especially conspicuous in the case of changes in medium- and high-level cloud formation conditions. The behavior of the circulation indices suggests a certain enhancement of activity of the centers of forcing in the western part of the Northern hemisphere, with relatively small variations in the other parts of the globe.

References

[1] Blackmon M.L., Lee Y.-H., Wallace J.M. Horizontal structure of 500 mb height fluctuations with long, intermediate and short time scales // J. Atmos. Sci. – 1984. – Vol. 41. – P. 961–979.

[2] Blackmon M.L., Lee Y.-H., Wallace J.M., Hsu H.-H. Time variation of 500 mb height fluctuations with long, intermediate and short time scales as deduced from lag correlation statistics // J. Atmos. Sci. – 1984. – Vol. 41. – P. 981–991.

[3] Katz A.L. Seasonal Variations in General Atmospheric Circulation, and Long-Term Weather Forecasts. – Leningrad: Gidrometeoizdat, 1960 (in Russian).

[4] Large-Scale Dynamic Processes in the Atmosphere / Ed. by B. Hoskins and P. Pierce. – Moscow: Mir, 1988 (in Russian).

[5] Mustel E.R., Mulyukova N.B., Chertoprud V.E. On the solar-tropospheric effect in the Earth's northern and southern hemispheres // Nauchnye Informatsii Astrosoveta AN SSSR. – Riga: Izd-vo Zinantne, 1990. – Vol. 68. – P. 99–117 (in Russian).