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Comparison of the atmospheric response to the sea surface temperature anomalies according to observations and numerical simulation

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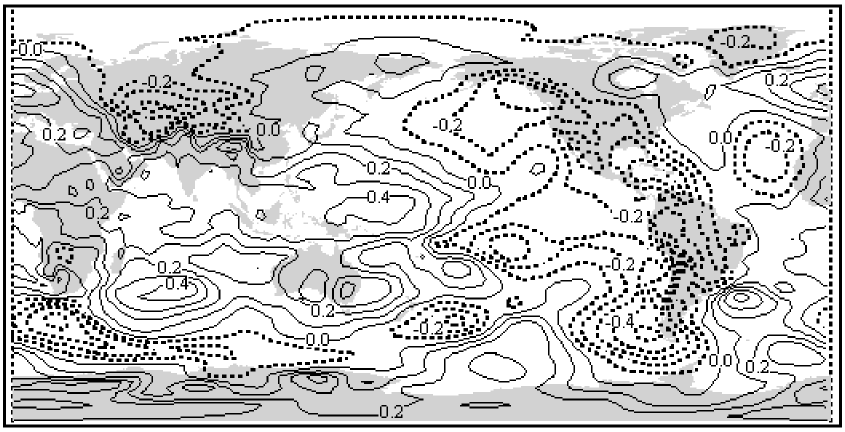
Abstract. According to the recent observations the world climatic system undergoes essential changes. Some of them are associated with the El-Nino–Southern oscillation. This paper considers the circulation and its response to the sea surface temperature anomalies with the use of the ECSib global circulation model. The model simulation and circulation anomalies are compared based on the NCEP/NCAR reanalysis supplementary datasets (the National Centers for Environmental Prediction-National Center for Atmospheric Research). It is found that the model reasonably simulates the spatial structure and variance of the sea level pressure and surface air temperature anomalies. The most distinctions between simulations and the observational data are in the middle latitudes over the midland areas of Eurasia, America and Africa. It is important that both the observations, and the numerical simulation clearly show the influence of the ENSO on the Asian monsoons, and hence, on those of the Central Asia.

At present, numerical modeling of the atmosphere and the ocean circulation is the basic tool of the research into quasi-decadal and intracentury climatic changes [1]. Much attention is being given to the influence of the sea surface temperature anomalies (SST) in the tropics on the extratropical circulation, first of all, to the influence of the phenomenon the El-Nino–Southern oscillation (ENSO), causing serious weather anomalies in large parts of the world [2, 3]. It has long been known that the Southern Oscillation has the scale of correlation much greater, than the Pacific basin, reaching the Indian ocean on the West and the Aleutian islands and Canada on the north. During the ENSO, in the mid-latitude significant anomalies of the atmospheric circulation, there occur precipitation and advection over the North and the South America. A surprising similarity between observations and model calculations for the period of 1939–1940 [4] indicates to a possibility of an essential influence of the ENSO on the atmospheric circulation in the middle and high latitudes of Eurasia. The influence of the ENSO on the Central Asia regions and on the high latitudes of the Southern hemisphere are less distinct. Meanwhile, large climatic anomalies develop in these areas, but a driver of these anomalies is not quite clear. This paper pursues two objectives: estimation of the quality of calculations by the ECSib general circulation model [5] of the atmospheric circulation response to the SST anomalies over the equatorial Pacific, and estimation of the extent of the influence of the tropical SST anomalies on the mid-latitude circulation. The model simulations were compared to the NCEP/NCAR Reanalysis data. As boundary conditions, the SST data (SST Reynolds) interpolated at regular grid points were used. Calculations have been executed for 19 years, from 1982 to 2000.

The ECSib general circulation model (GCM) represents the "European Centre for Medium-Range Weather Forecasts" (ECMWF) GCM version, which was improved in the Novosibirsk Institute of Computational Mathematics and Mathematical Geophysics, SB RAS. Parameterization of the subgrid scale processes of the model are similar to those used in the ECMWF version, while the dynamic part has been developed, mainly, in Novosibirsk. The model has 15 vertical levels, which are defined on σ-surfaces in the troposphere and low the stratosphere. The dynamic terms and physical processes are calculated on Arakawa C-grid, which yields $5{\times}4^{\circ}$ spatial resolution. A spatial-difference scheme gives the second order approximation. A special choice of approximation of the hydrostatic equation allows us to construct a vertical angular momentum conserving scheme. The possibility of the long-term integration is provided by conservation of some global invariants in the finite difference form.

The model ECSib, in general, was not been intended for reproducing interaction features of the tropical and the extratropical atmospheric processes, a simple correlation method for comparison of the modeling results and observations was used. We calculated the correlation coefficients of the monthly mean sea level pressure and temperature anomalies with the annual mean SST anomalies at the point (0°N; 100°W), distinctly representing the El-Nino variations. The El-Nino–La-Nino phenomena were not isolated from the time series of SST anomalies, that is, the correlation coefficients calculated for all of the temperature anomalies. It is known, that the GCM models reproduce strong circulation anomalies better, than the weak ones, therefore a comparison of simulation and observations was carried out in the most adverse conditions.

An example of the correlation distributions is shown in Figure 1. These coefficients were used for different months of 1970–2000 between the NCEP/NCAR monthly mean SLP anomalies and the annual mean SST anomalies from archive "SST Kaplan" the National Climatic Center of the USA. The data "SST Kaplan" have the long-time rows (since 1860), but low 5° spatial resolution. Since 1970-s, the tendencies of the SLP variations are homogeneous enough and, possibly, the sea level pressure response is identical for all the SST variations since that time. For comparison, in Figure 2 analogous correlation distributions of the annual tropical SST anomalies and the monthly mean SLP, simulated by means of the GCM ECSib, are presented. As boundary conditions, the data of the archive "SST Reynolds" interpolated at regular grid points were used.



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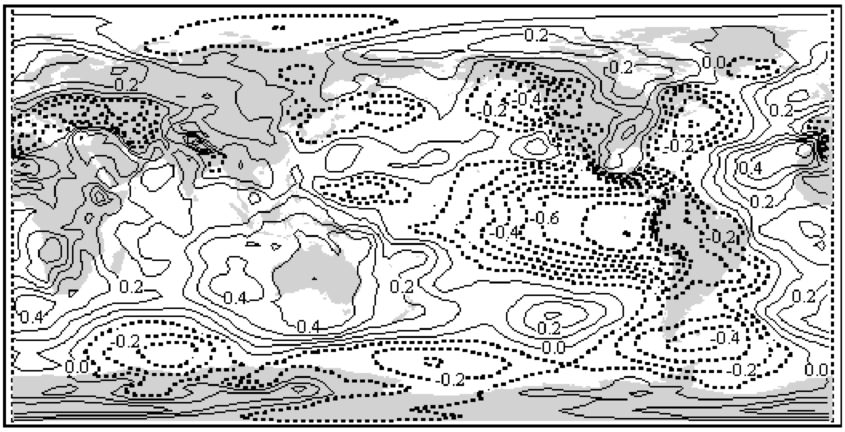

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Figure 1. Distributions of correlation coefficients of the monthly mean SLP at the nodes of 2.5×2.5° spatial grid and annual mean SST anomalies in the East Pacific point (100°W, 0°N) from the NCEP/NCAR Reanalysis data in January (a) and July (b). Solid (dashed) contour lines show positive (negative) correlations. Isobars are drawn at 0.1 intervals

The key feature of the ENSO, as is known, is a change in the Walker tropical cell. In winter and in spring, the months till April in the western hemisphere, the SLP decrease is more clearly expressed in tropics and subtropics, than on the equator. In the East hemisphere, in the same months, an increase in the SLP covers the equatorial zone, tropics and subtropics of the Southern hemisphere, shifting towards the Northern hemisphere in summer. At higher latitudes, areas of the pressure decline in the region of the Asian anticyclone are distinctly prominent in winter months. In a sense, these areas are an exception, as more often changes the SLP anomalies caused by the ENSO, avoid the persistent centers of high pressures.

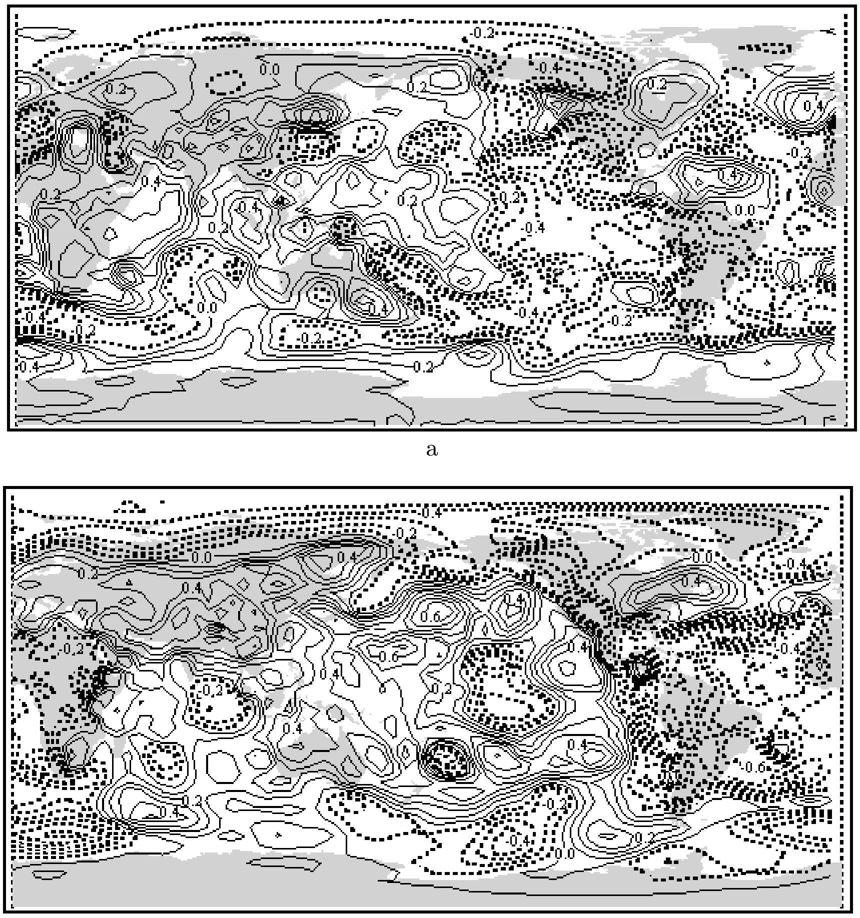

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Figure 2. Distributions of correlation coefficients from the data of model simulation in January (a) and July (b)

In May, the negative SLP anomalies in the equatorial East Pacific are considerably amplified. In June, July, September the areas decreasing the SLP amplify over the North and the South America. By the end of the year, pressure anomalies over the North and the South America are weakening and displaced to the north. In the East hemisphere, in April, May, June the region of the greatest positive anomalies moves towards the southern border of Eurasia following the intertropical convergence zone (ITCZ). Since October, the positive SLP anomaly after formation of the Asian anticyclone shifts to the west Pacific. Thus, the influence of the ENSO on the Asian monsoon and, possibly, with its help on the Central Asia was definitely traced. This influence is such, that an increase in the El-Nino intensity or frequency can lead to a stronger Asian anticyclone in winter, and in summer — to filling in the summer Asian depression.

The situation in the Southern hemisphere is rather complicated. In the subtropical anticyclones zone more often the positive SLP anomalies are observed in the area from Indian Ocean to Australia, and the negative anomalies— in the area of the Pacific Ocean. The negative anomalies are observed more often still further to the South, in the circum-Antarctic depression.

During the winter time, the model calculations successfully simulate the spatial structure and variance of the sea level pressure associated with the ENSO. First of all, this is the SLP decrease in subtropics and in the middle latitudes of the East Pacific, over America and the Central Asia. According to observations, areas of an elevated pressure include the equatorial zone and tropics in the West Pacific, Africa, the Indian Ocean down to temperate latitudes, the North of Australia. The situation in Atlantic is less certain. Calculations show the SLP lowering of the prevalence in the Central Atlantic and over the east coast of America. Reanalysis data are not so conclusive.

In April, May, June, and July, the dynamics of observational and model circulation anomalies appears to be different. According to the Reanalysis data, the ascending branch of the Walker circulation over Pacific shifts to the West up to the line of a change of dates, the area of the positive SLP anomalies keeps its position in the east hemisphere, which is a little shifted in the North-south direction following the ITCZ. According to the results of modeling of a distribution of the SLP anomalies in temperate latitudes keeps its position, but in the equatorial zone and in tropics is displaced to the east, so the basic area of the SLP lowering includes almost the whole of the South America and Atlantic, and the SLP elevation area occupies all the Pacific. The simulated SLP lowering, unlike the Reanalysis data, is observed, also, over the Indian Ocean and the Central Asia, although occupying a small area there. In autumn, a distribution of the SLP anomalies typical of the cold period of a year, is restored. At the same time, the resemblance between simulation and observations is re-established as well. The most appreciable at this time are distinctions in the South Atlantic.

As a whole, the model adequately simulates the circulation changes, caused by the El-Nino. The observations and modeling clearly show the influence of the ENSO on the Asian monsoon, Central Asia and, also, on the temperate and high latitudes of the Southern hemisphere. Possibly, in the latter case, the area from the east coast of Australia up to the line of a change of dates plays a leading role. Via this zone, an ascending branch of the equatorial Walker cell and the circum-Antarctic depression appear the ones more often connected.

Let us call attention to one feature of the SLP response to the El-Nino phenomenon. A comparison of correlation maps and climatic SLP distributions, except for several cases, does not show a high level of resemblance. This means that redistribution of atmosphere masses and pressure during the ENSO is weakly connected with the position of the basic centers of action

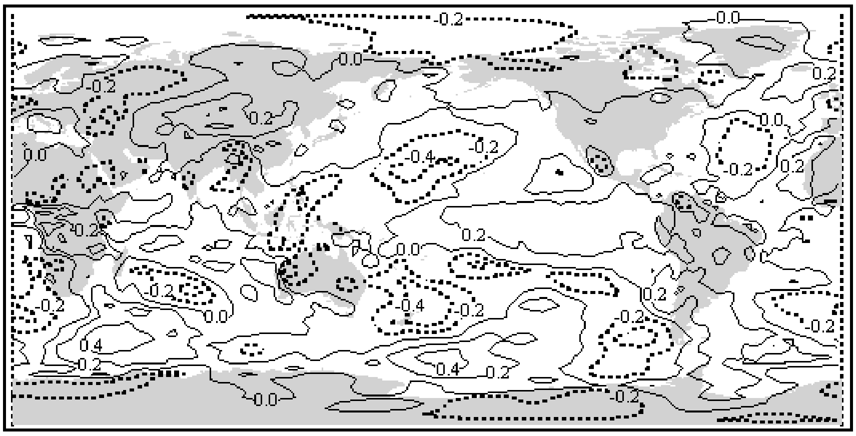

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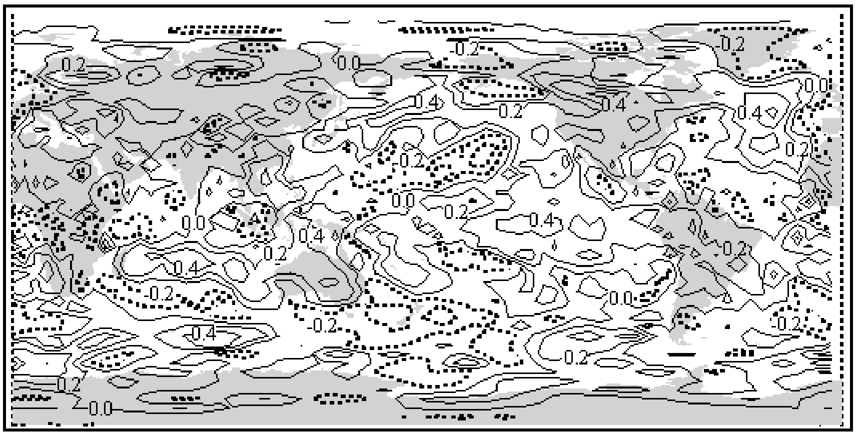
Figure 3. Distributions of correlation coefficients of surface air temperature at the nodes of 2.5×2.5° spatial grid and annual mean SST anomalies in the East Pacific point (100°W, 0°N) from the NCEP/NCAR Reanalysis data in January (a) and July (b). Solid (dashed) contour lines show positive (negative) correlations. Isotherms are drawn at 0.2 intervals

of the atmosphere. Different is a situation with the surface air temperature changes in the atmosphere during the ENSO.

In Figure 3, a distribution of correlation coefficients between the annual mean SST anomalies and the NCEP/NCAR monthly mean surface air temperature (SAT) anomalies is shown. For comparison, in Figure 4, analogous correlation distributions of the annual mean tropical SST anomalies and monthly mean SAT, calculated by means of the GCM ECSib, are presented.

A specific feature of the correlation maps in Figure 3 is a local structure over the Hindustan peninsula. In winter, in the course of El-Nino, the air temperature over the whole of peninsula is lowered. In spring, an area of the



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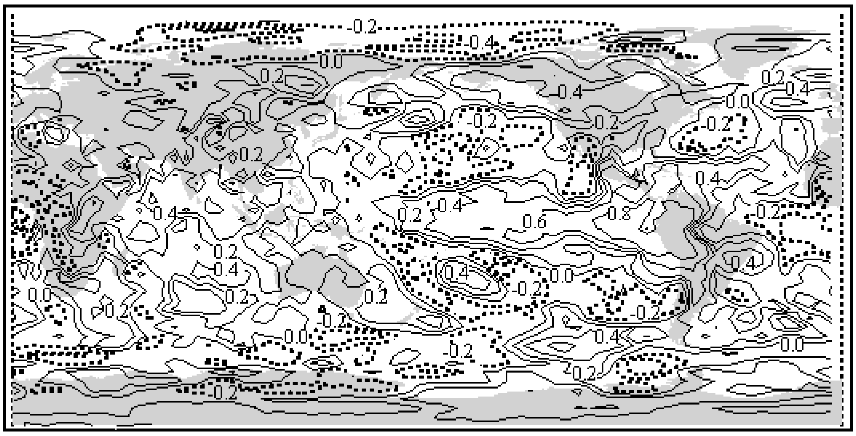

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Figure 4. Distributions of correlation coefficients from the data of model simulation in January (a) and July (b)

positive correlation appears in the south of peninsula, which by the moment of establishing a summer Indian monsoon increases in the area and moves to the north area of the SAT lowering.

In the cold months, the area of positive correlation further away to the North over the continent is dominating. In the warm months, in the East and in the Central Asia areas of the negative correlation prevail, i.e., the areas of the surface air temperature lowering during the warm phase of the ENSO. It is possible to conclude, that in the coarse of El-Nino, thermal contrasts over the continent between the warm and the cold periods decrease a little, which corresponds to the general tendency of climatic changes in Asia.

The model simulation of the surface air temperature compares is in good agreement with observations during the El-Nino event in the southern hemisphere and is somewhat worse in the northern one. As a whole, according to the results of modeling the correlation fields are more mosaic, than the fields constructed by means of the NCEP/NCAR Reanalysis, and, hence, are less reliable for interpretation. Possibly, it is caused by features of the precipitation parameterization or parameterization of processes of the latent heat transfer.

Summarizing the results of the analysis, it is possible to conclude that the ECSib model most completely reproduces the temperature response to El-Nino in tropics, over the Pacific ocean, and most distinctions between the simulation and the observational data are revealed in the temperature latitudes over the midland areas of Eurasia, America and Africa. It is possible to note, also, that the areas of SAT elevation are reproduced by the simulated model better, than the areas of SAT lowering.

Conclusion. Thus, as a whole, the model calculations during some months reasonably simulate a spatial structure of the sea level pressure, surface air temperature anomalies associated with the ENSO. According to the results of modeling the picture appears to be as global, as according to observations. Many details of this picture still remain not clear. It is important that both observations, and simulations clearly enough show the influence of ENSO on the Asian monsoon, hence, on the Central Asia, and, also, on the mid- and high latitudes of the Southern hemisphere. Possibly, in the latter case, the leading role is played by the area from the east coast of Australia up to the line of a change of dates. Through this zone, an ascending branch of the equatorial Walker cell and circum-Antarctic depression appear to be connected more often.

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