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Variability of the North Pacific circulation model under the surface forcing from re-analysis data*

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The 3-D finite element North Pacific Circulation Model developed in the Novosibirsk Institute of Computational Mathematics and Mathematical Geophysics (ICMMG) is used to study the sensitivity of the North Pacific circulation to the varying boundary conditions at the sea surface. The initial conditions have been taken from the results of diagnostic numerical experiments of climatic circulation which were carried out on the basis of climatic temperature and salinity data of Levitus, 1994 and wind-stress of Hellerman, Rosenstein, 1982. The numerical experiment was concerned with the spin-up prognostic experiments for the study of the variations of the North Pacific hydrophysical characteristics to real forcing on the surface. For this purpose the ten-days mean distribution of the surface forcing was adopted from the European Center for Medium-Range Weather Forecast Ensemble Simulation, 1987. The spin-up period was chosen as a period of the pre-El-Nino and El-Nino event 1982. Satellite data for this period were used as the control data to compare the simulation results with the real processes. Simulation experiment for two-and-half year period with the climatic initial state and varying boundary conditions at the sea surface was carried out. The results show the development of the positive temperature anomaly in the eastern part of the tropical Pacific, propagating at thermohaline depth from the west to this region. The analysis of these processes and the comparison with the satellite derived distributions are done in the paper.

1. Introduction

The 3-D finite element North Pacific Circulation Model developed in the ICM&MG is used to study the response of the North Pacific circulation to the varying in time boundary conditions at the sea surface associated with the period of the EL-Nino 1982 event. The results of the short-range period spin-up experiment with the climatic and then the two-year simulation period (1981–1983) with wind-stress and heat flux at the sea surface, adopted from the re-analysis, were analyzed. The anomalies of the circulation, temperature distributions and heat fluxes are discussed in comparison with the climatic state.

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2. Structure of the ocean circulation model

A numerical Pacific Ocean Circulation Model is based on the Finite Element Method. The model grid covers the region between 30.5°S–60.5°N with the spatial resolution of 2° in longitude and 1° in latitude, with 18 levels in depth. The model includes a block of vertical mixing in the upper layer.

The basic features of the model are as follows:

- separation of the external and the internal modes;
- transformation of advective terms from the gradient form to special divergent form;
- splitting of the equations according to the physical processes;
- Finite Element Method discretization with respect to space;
- splitting of the multipoint FEM grid operators to a series of three-point operators;
- the use of implicit and semi-implicit schemes with respect to time.

3. Data sources and analysis

1. The climatological monthly mean temperature and salinity fields from the "World Ocean Atlas" (Levitus, 1994).
2. The climatological monthly mean wind-stress by Hellerman, Rosenstein, 1982.
3. Wind-stress, surface temperature and heat fluxes from the "European Centre for Medium-Range Weather Forecast Ensemble Simulation", 1997 CD-ROM (further ECMWF).
4. "Climatological surface ocean heat fluxes". J. Oberhuber. Max-Plank Institute fur Meteorology, Hamburg, 1992.
5. The weekly average satellite information on the sea surface temperature, obtained from the NOAA satellites in the JPL (Jet Propulsion Laboratory, University of Miami, Dr. O. Brown), further-satellite data,

   ftp://podaac.jpl.nasa.gov/pub/sea-surface-temperature/avhr/mcsst

The anomalies of the satellite data in comparison with climatological data were used as control values for the anomalies simulated by the model. An analysis of the ECMWF decadal-averaged wind-stress for the 1981–1983 period and Hellerman's wind-stress data has shown a significant structural difference as well as a difference in the maximum and in the mean values. The ECMWF data have more complicated structural features. It is especially visible in the tropical part of the Pacific.

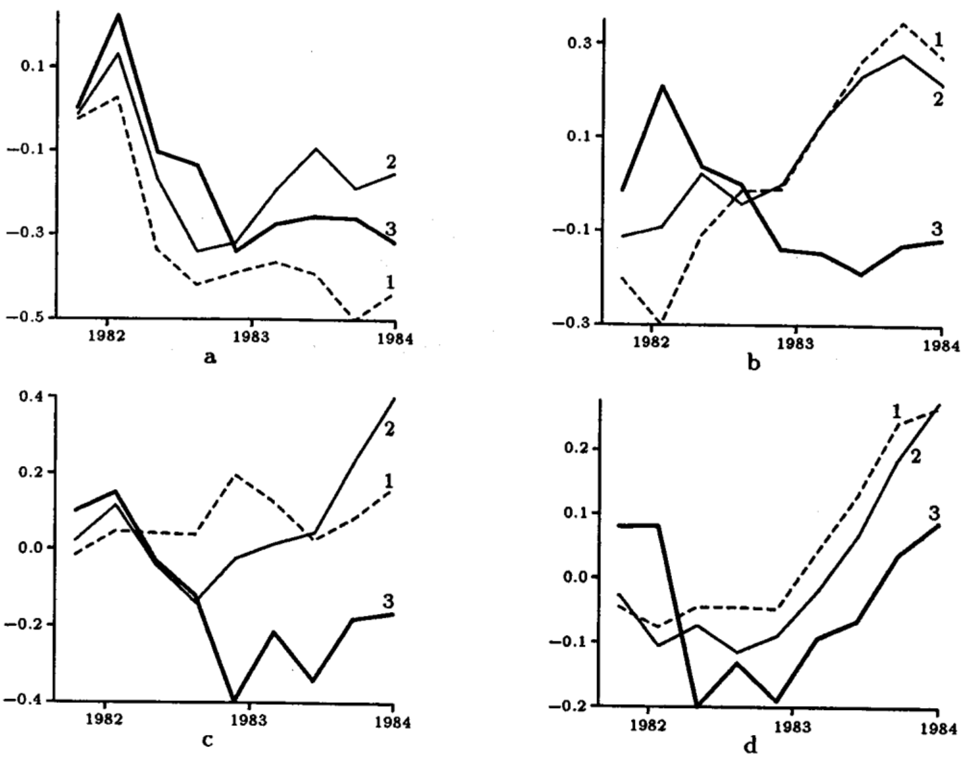

Figure 1. The anomalies ECMWF data from climatic at the equator averaged along longitudes 160–80°W and 120–180°E: a) T_x-component averaged along longitudes 160–80°W; b) T_y-component averaged along longitudes 160–80°W; c) T_x-component averaged along longitudes 120–180°E; d) T_y-component averaged along longitudes 120–180°E

Figure 1 represents a deviation of the ECMWF wind-stress data from the climatic data been averaged over the following areas: λ = 160–80°W (Figures 1 a, b), λ = 120–180°E (Figures 1 c, d) of the zonal (T_x) and meridional (T_y) wind-stress components respectively.

In Figure 1a, in the equatorial zone one can see a markable decreasing of the zonal component (T_x); which begins in February–March 1982 and continues until September–October, 1983. Let us mark that similar changes have a place in the subtropical zone (line 3), whereas in the tropics (line 2) the decrease stops by April–May, 1983. Figure 1b shows the anomalies of the wind-stress meridional component (T_y). In the tropical zone (lines 1 and 2), one can see increase of T_y, whereas in the subtropical zone (line 3) the decrease of the meridional wind-stress component is observed.

Figure 2 represents a spatial-temporal picture of the behavior of the T_x-component in the equatorial zone for the 1982–1985 period. In the western zone, in the beginning of 1982, the decreasing of the negative T_x is

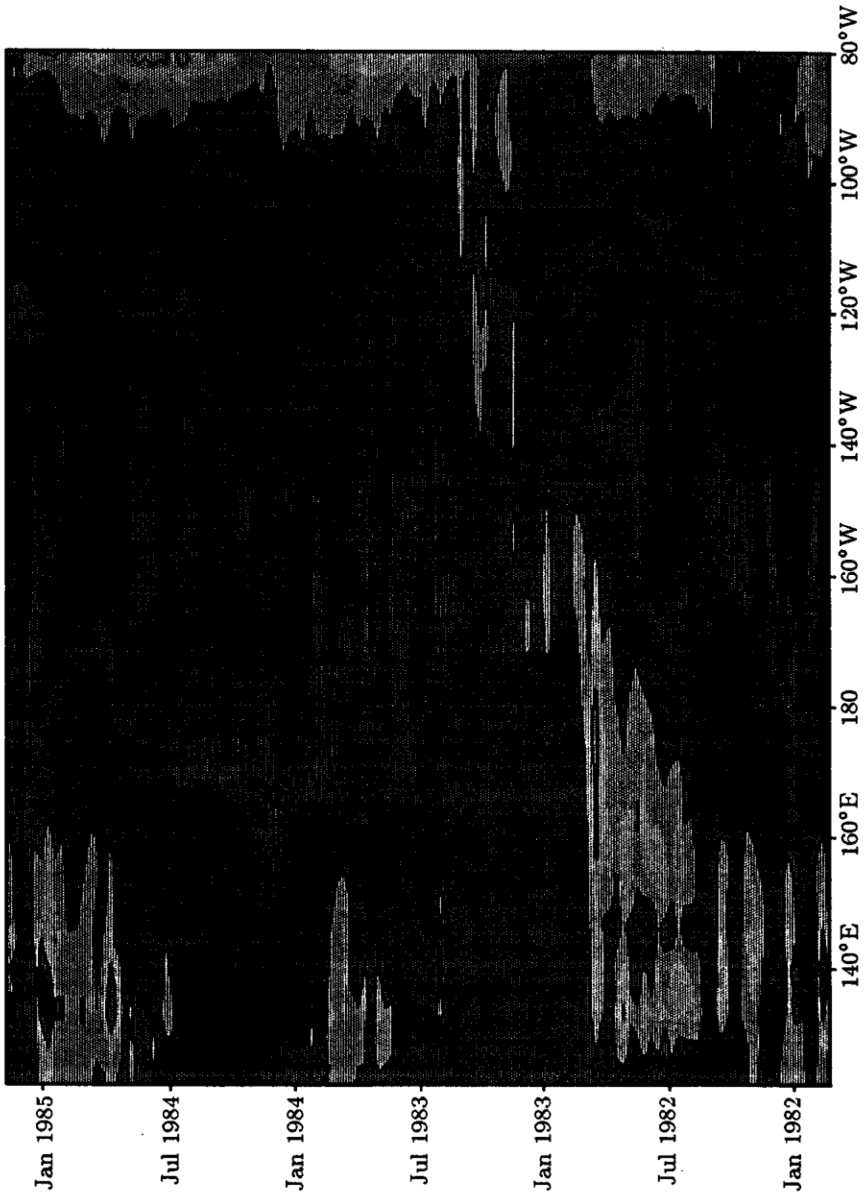

Figure 2. Hovmuller' diagramm for T_x-component (ECMWF) at the equatore: mean T_x for 5°S–5°N, min = −0.1 Pa, max = 0.1 Pa, step = 0.05 Pa

observed. This decreasing moves to the east, and by 1983 reaches the eastern boundary of the ocean. To indicate changes in the structure of the wind-stress in the period of 1981–1983, the wind-stress vorticity was analyzed. In the first half of 1982, there exist changes in the intensity of the wind-stress vorticity near the equator. The difference of the wind-stress vorticity between Februaries of 1983 and 1982 also indicates to essential intertropical weakness of the wind atmospheric forcing in 1982. This feature is only natural for the situation during the pre-El-Nino period.

Heat fluxes, adopted from the ECMWF data have also some specific features in this period. In the tropical zone by the fall of 1982 and winter of 1983, there is observed a strong decrease of the positive heat fluxes into the ocean in comparison with the previous and the next winters. In the central part, this results to the negative heat fluxes.

4. Numerical experiments and results

The diffusivity and viscosity coefficients are as follows:

- coefficient of the horizontal viscosity $A_L = 5 \cdot 10^6$ cm^2/s,
- coefficient of the vertical viscosity $A_V = 10^2$ cm^2/s,
- coefficient of the horizontal diffusivity $\mu = 2 \cdot 10^6$ cm^2/s,
- coefficient of the vertical diffusivity $\nu = 10^2$ cm^2/s,
- bottom drag coefficient R= 10^{-7} s^{-1}.

The diagnostic and the short-range prognostic experiments for the fall season were carried out to make some spin-up for the model. At the initial moment, the seasonal temperature, salinity fields are prescribed. The 3D momentum equations were calculated during the 60-day period of the model time. The value of annual mean mass transport for the subpolar and subtropical gyres are 20 and 40 sv, respectively. The Kuroshio integral mass transport has the value of 38 sv. As it is well-known, the results of the 3D velocity diagnosis are appropriate for the extra-tropical zones, however for the tropical basin the circulation, meridional circulation, integral heat fluxes and some other characteristics are rather uninformative because of the inconsistency of the density field and the diagnostic model. To avoid this problem and to make some balance of the characteristics to the simulation experiment with time varying re-analysis data the short-range prognostic calculations for the two-month periods with a primitive equation model were done. The wind-stress and surface temperature was chosen according September–October, 1981. This procedure allows us to balance hydrophysical fields and brings about some initialization of the hydrological characteristics for the further calculation.

Now let us dwell briefly on some features of the hydrological characteristics and their peculiarities. Analysis of the obtained results has shown that the general circulation of the Pacific Ocean did not essentially change depending on different data used. Nevertheless, a more detailed current structure has been obtained. At the same time the main boundary currents are more intensive, and the volume transport estimates have shown in some periods slightly higher values when climatological data applied. The common features of circulation in the results are the presence of the subpolar, subtropical, and tropical systems of circulation with strong intra-tropical countercurrents and the equatorial undercurrent which begins to form. The Oyashio and the Kuroshio with the re-circulation zones are well expressed, although are not so intensive and narrow. At the layers deeper than 1200 m there arises a system of undercurrents shifted relatively the main current with respect to the latitude. At the next stage, numerical experiments have been carried out with application of the ECMWF time dependent data on heat fluxes and wind-stress for the period of October, 1981 – July, 1983 to estimate the role of the wind-stress anomalies and thermoline factors during El-Nino event on the Pacific Ocean circulation and to compare the results of simulation with observational data. Analysis of the obtained results has shown that the general circulation of the Pacific Ocean did not essentially change when it is forced by time dependent data used. The main changes arise in the tropical zone and are connected with the transport of temperature anomaly from west to east. It was a special interest to examine the surface and subsurface temperature variations during the simulation period. At the first stage (fall 1981 – winter 1982) the SST anomalies are in poor correspondence with the satellite observational data. However under the influence of the surface forcing in the equatorial zone during this period, the temperature anomaly in the central part begins to form. Warm water arises at the thermocline level and propagate to the east. In this period there exist a weak enough signal (Figure 3a) at the surface. This is in agreement with the satellite observational data (Figure 4a). Propagating to the east the anomaly comes up along the thermocline that becomes shallower to the east. This can be observed in Figures 5 and 6 representing the vertical cross-sections of the temperature anomaly field (simulated SST – Levitus SST values) for June and December respectively. When a temperature anomaly reaches the eastern coast in November–December 1982, it comes to the surface (see Figure 6). The amplitude of the anomaly in the simulation is about 3–4 degrees (Figure 3b). In the western part of the basin, the negative temperature anomaly is formed (see Figure 6). This is in agreement with the (satellite SST – Levitus SST) anomalies presented in Figure 4b.

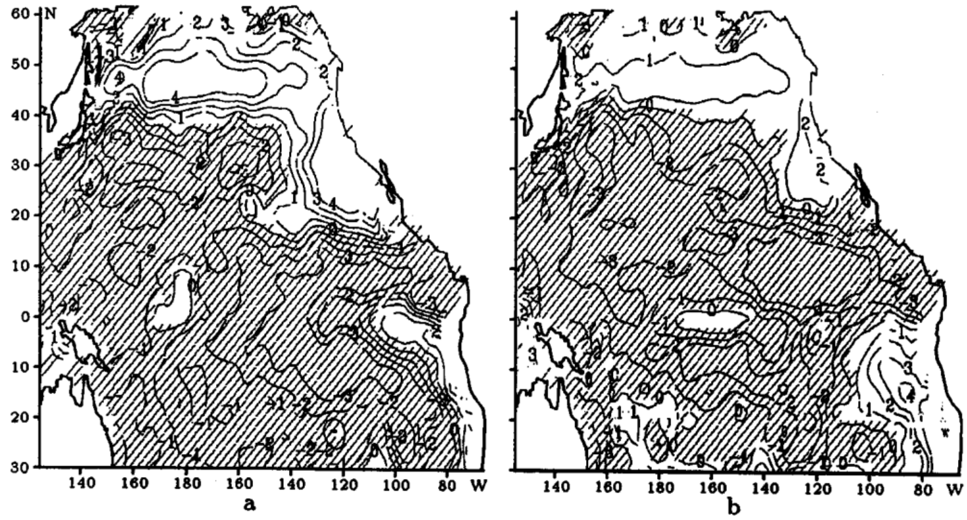

Figure 3. The SST anomalies (model–climate): a) in July 1982, b) in December 1982

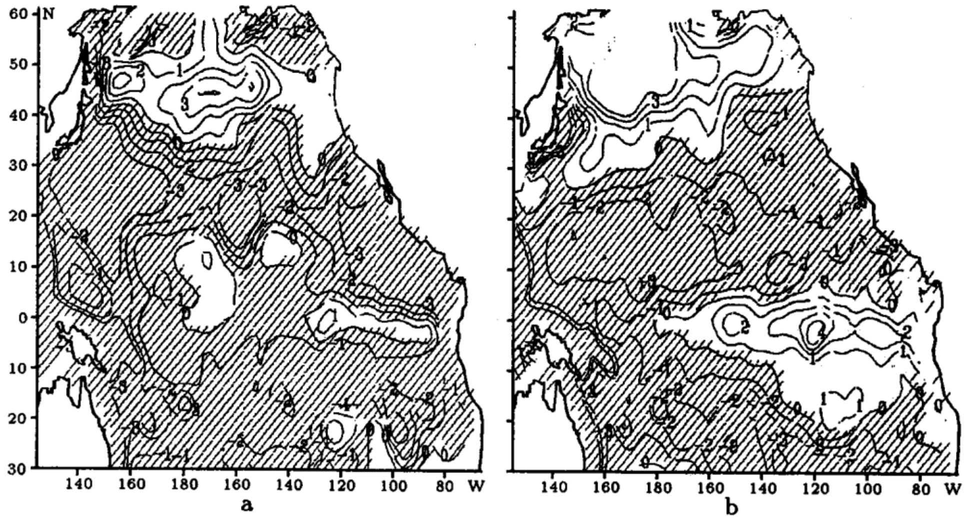

Figure 4. The SST anomalies (satellite–climate): a) in July 1982, b) in December 1982

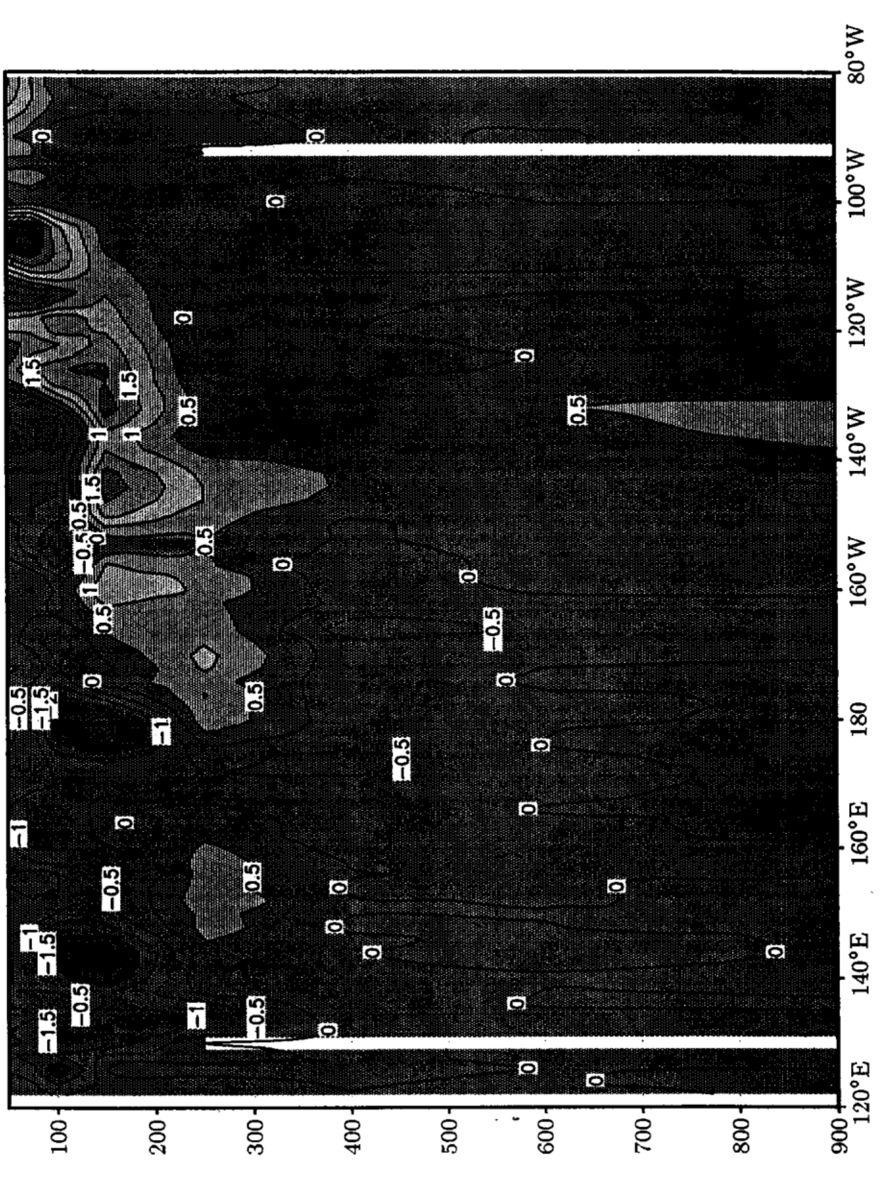

Figure 5. The meridional section of the SST anomalies along equator (model–climate) in July 1982

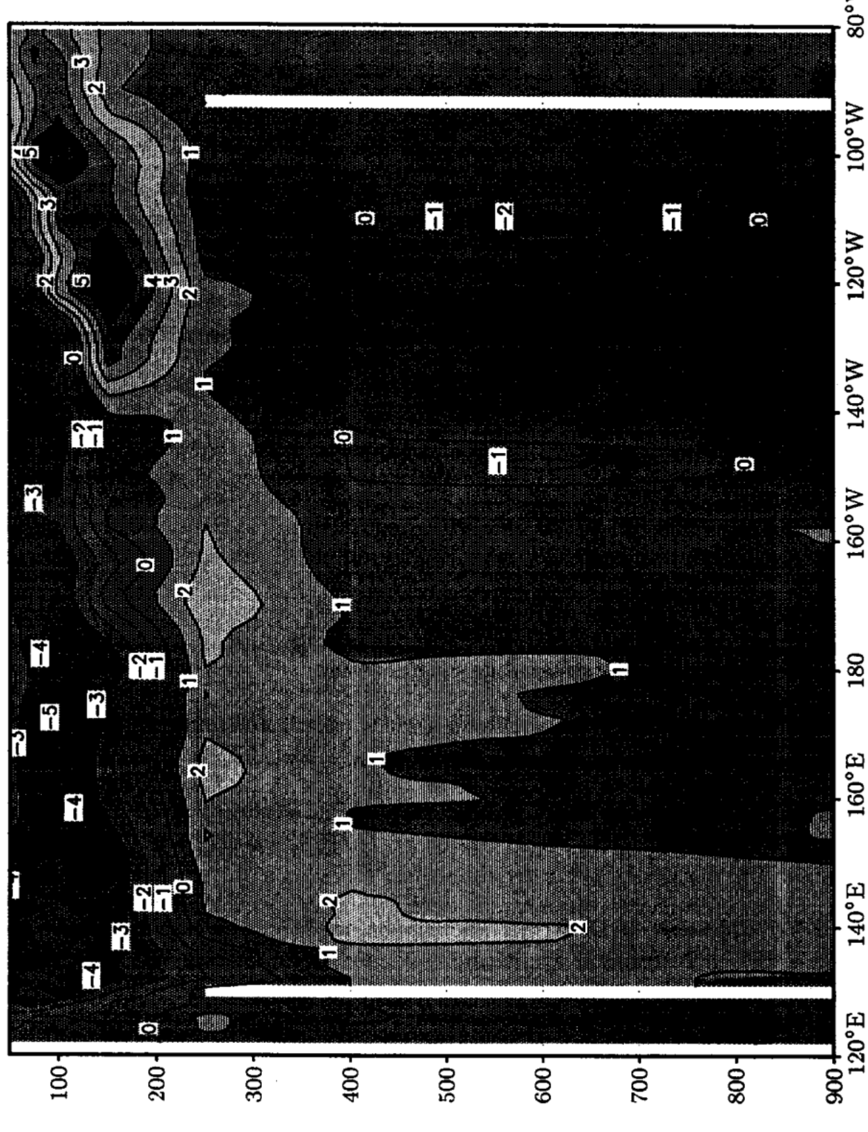

Figure 5. The meridional section of the SST anomalies along equator (model–climate) in December 1982

5. Conclusions

The major features of the general North Pacific circulation have been revealed in the simulation. A comparison of the results obtained with the use of the ECMWF data and the satellite data for the period of the 1982 El-Nino event permits us to make the following conclusions:

(a) during 1981–1982 period, the forcing at the surface of the Pacific ocean has changed: there are an essential anomalies in the wind-stress and heat flux in the tropical zone;

(b) the simulation results obtained by the model with the use of the ECMWF data keep the main features of circulation with more detailed peculiarities in some regions, and show the temperature anomaly formation in the tropical zone;

(c) the above mentioned temperature anomaly have formed in the central part of the tropical zone, that is in correspondence with the observations;

(d) the temperature anomaly propagates from west to east at the thermocline level and comes up near the eastern coast, forming the surface anomaly in the eastern part of the tropical Pacific, which is in correspondence with the observations.

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