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The response of the climate system to small temperature perturbations in the Aral Sea region

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Abstract. This paper discusses the results of calculations of the climatic river runoff for the subarctic East Siberia region obtained by the linear reservoir model. For the verification of the model, the measurements data as well as the MERRA reanalysis data for the XXth century were used. For the XXIst century, the calculations with the data of the INM, CRNM, GFDL, HadGEM, MIROC5, MPI models of the scenario RCP 8.5 of the Project CMIP5 IPCC were carried out. The results reveal a remarkable increase of the annual runoff for all the models. The annual variability has a positive trend during the XXIst century.

Keywords: mathematical modeling, climatic river runoff, East Siberia rivers basins.

1. Introduction

This study is an attempt to assess the impact of the Aral Sea disaster on global processes in the atmosphere. Until 1960, the Aral Sea was the fourth largest inland lake in the world. Being located in the heart of the Central Asian deserts, at the altitude of 53 meters above the sea level, the Aral Sea served as a giant evaporator [1]. As the Aral Sea is located on the route of a powerful jet airstream from west to east, this moist flow has moved along the whole Central Asian region, softening the climate of the region, to the Pamir mountain ranges. There, part of the air currents surrounds the Pamir Mountains from the north and moves further to the east, and the other part is retained by the mountains and falls as precipitation. Further, the water would return to the Aral Sea through the rivers Amudarya and Syrdarya.

By today, the Aral Sea and its surrounding areas have become world-famous as a result of man-made environmental disaster. With increasing the water consumption associated with the development of new irrigated areas, an increase in population, the influx of water into the sea from the two major river systems in the basin, the Amudarya and the Syrdarya rivers has almost completely stopped. In other words, a closed cycle described above (the evaporation of the Aral Sea — the transfer of moist air masses to the mountain ranges — rainfall — moisture return to the Aral Sea through rivers) appeared to be disconnected. The table demonstrates the scales of what is happening.

A characteristic feature of the Aral Sea region climate today (the term “Aral Sea region”, or the other name “Aral region” stands for the geographic

The key features of the Aral Sea changes over years

Year	Precipitation (km^3)	Evaporation (km^3)	The volume of water mass (km^3)	The water surface area (km^2)	Salinity (gm/L)
1960	9.41	71.13	1093.0	68478	9.9
1970	7.22	62.03	971.7	60692	11.2
1980	9.73	50.24	648.7	51743	16.8
1990	0.70	1.04	354.0	35349	30.0
2000	0.13	0.96	181.0	24266	55.8
2004	0.16	0.95	169.0	22745	58.6
2008	0.17	0.97	169.0	22744	58.7

location of the Aral Sea and the surrounding area within a radius of 500 km) is its being sharp continental. In recent years, due to the process of drying the Aral Sea a drastic change in climatic conditions of Central Asia has been marked. Earlier, the Aral sea acted as a sort of regulator mitigating cold winds coming in the autumn and in the winter seasons from Siberia and reducing the heat effect in the summer months like a giant air conditioner. With a change for the worse, the summer in the region has become dryer and shorter, the winter — longer and colder. These changes are reflected in the report of the IPCC AR5 [2]. A characteristic feature of the Aral region climate is a high repeatability and a long duration of dust storms. There are often strong winds in the Aral Sea region. A maximum wind speed can reach 20–25 m/s. The drying up of the Aral Sea has brought about the double desertification. This is due to the appearance of the dried sea bottom and due to the artificial waterlogging of irrigated lands. As a result, at the center of the belt of the Karakum and the Kyzylkum deserts another new desert "Aralkum" was formed, where danger is caused by the appearance of continuous saline lands consisting of fine marine sediments and residues of mineral deposits washed from irrigated fields. This marked a new stage of the desertification impact on the ecosystem degradation of the Aral Sea area, regional and global climate. The seabed that in the former natural state served as a sort of desalination factory, is now acting as an artificial man-made volcano emitting into the atmosphere a huge mass of salt and pathological dust. The effect of pollution is amplified by the fact that the Aral Sea is located on the route of a powerful jet airstream from west to east. This facilitates the rise of aerosols in the upper layers and the rapid dissemination in the Earth's atmosphere.

Thus, the main characteristics responsible for the climate changes in the Aral region are a temperature increase and a decrease in humidity.

Using the Planet Simulator model, based on solving a complete system of hydro-thermo-dynamics equations, developed at the University of Hamburg (Germany) [3], an attempt is made to evaluate the effect of the temperature rise in the Aral Sea on a change in the global climate characteristics. The Planet Simulator model refers to a class of models of intermediate complexity. The subgrid processes: the boundary layer, radiation, humid and cloud processes are parametrically described. The vertical turbulent mixing is computed in accord with [4], and the horizontal diffusion—with [5]. Clouds in this model are described as being gray. The parameterization convection is based on the Kuo scheme [6]. When the air is over-moistened, its surplus immediately falls as precipitation. The preservation of water in the liquid phase in the clouds is not provided. The model does not take into account the phase precipitation changes and the growth of cloud droplets.

The model is defined on the longitude-latitude grid, vertically using σ-system with allowance for irregularities of the underlying surface.

A numerical method for solving the system [3] is based on spectral representation of desired functions in latitude and longitude with a resolution of T41. In vertical, 10 σ-levels with non-uniform steps are set. A semi-implicit integration scheme is used with respect to time.

The following describes the results of the two possible scenarios of the 10-year-old integration model.

Scenario 1: Starting temperature fields correspond to the average long-term values (T_1).

Scenario 2: Considering a steady increase in the temperature in the Aral Sea region, "noise" making up 10 % of the long-term values was added on the two lower levels in vertical. Thus, the second experiment T_2 differs from the first T_1 only in the superimposed noise at the Aral region points ($40N$, $29N$).

Since the initial fields correspond to the winter period, a maximum change in temperature corresponds to 1°.

Despite the fact that the model reproduces all the main climatic characteristics (wind fields, surface pressure, temperature and humidity) this paper demonstrates a preliminary analysis of the temperature and humidity fields. The analysis was performed only for the month of January of each model year. Figure 1 shows the results of the total absolute difference across the whole field of the main characteristics being reproduced from the model, for example, ΔT is a difference of temperature between the two scenarios at the same points in the same period:

$$\Delta T = \frac{1}{KL} \sum_{k=1}^{K} \sum_{l=1}^{L} |(T_1 - T_2)_{k,l}|,$$

where K is the number of levels in height, L is the number of the Gaussian nodes from pole to pole. A similar formula is used to calculate the absolute difference for the Aral Sea region. In this case, only 4 points ($40N$, $29N$) and two lower levels in height are taken into account.

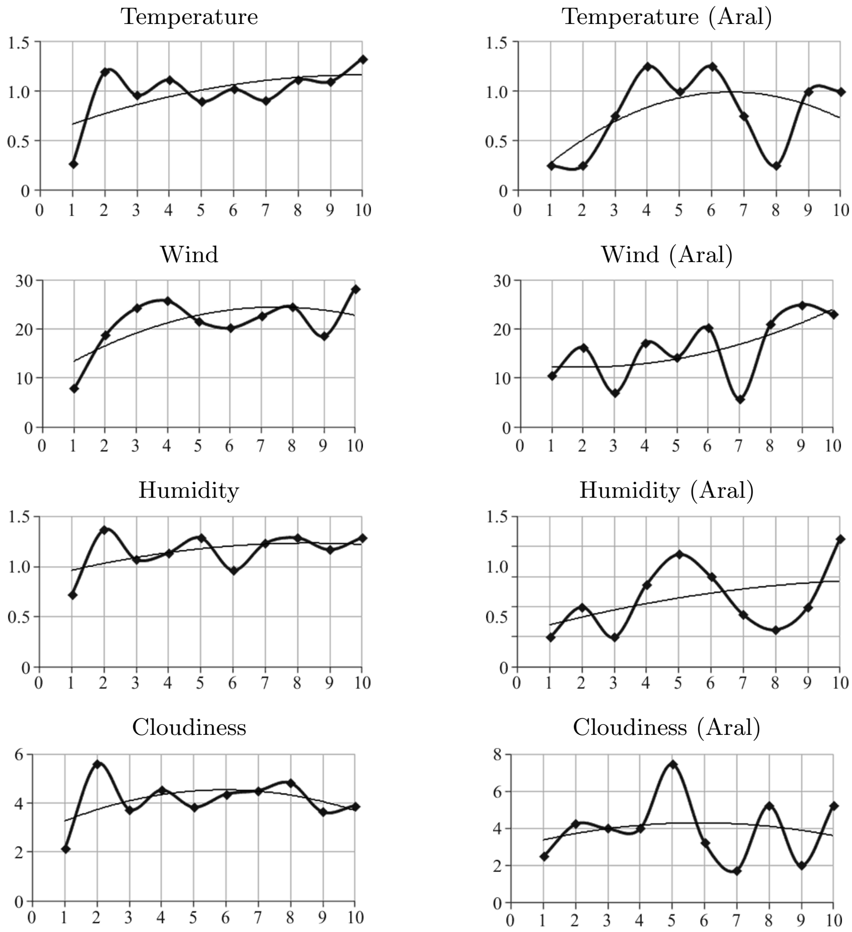

Figure 1. Differences of temperature, wind, humidity, and cloudiness over 10 model years in January. The left diagrams present the values averaged in latitude and altitude. The right diagrams are the same, but above the Aral region

The total ΔT difference averaged in height and in width shows an intensive error growth in the first year of integration and then the oscillation mode for the remaining nine years. In other words, global rearrangement of the field T is made in the first 2 years. The line of the trend shows a tendency of a slow temperature rise.

A somewhat different picture of the total temperature difference is observed in the Aral region. In the first two years, a relative difference is almost not growing. The growth of the relative error of ΔT is observed from the second through the sixth year of integration, and then its slow decrease is observed. In contrast to the global wind, the wind above the Aral region tends to a constant increase. Specific humidity in the Aral Sea region, as opposed to specific humidity averaged over the entire field, shows its constant

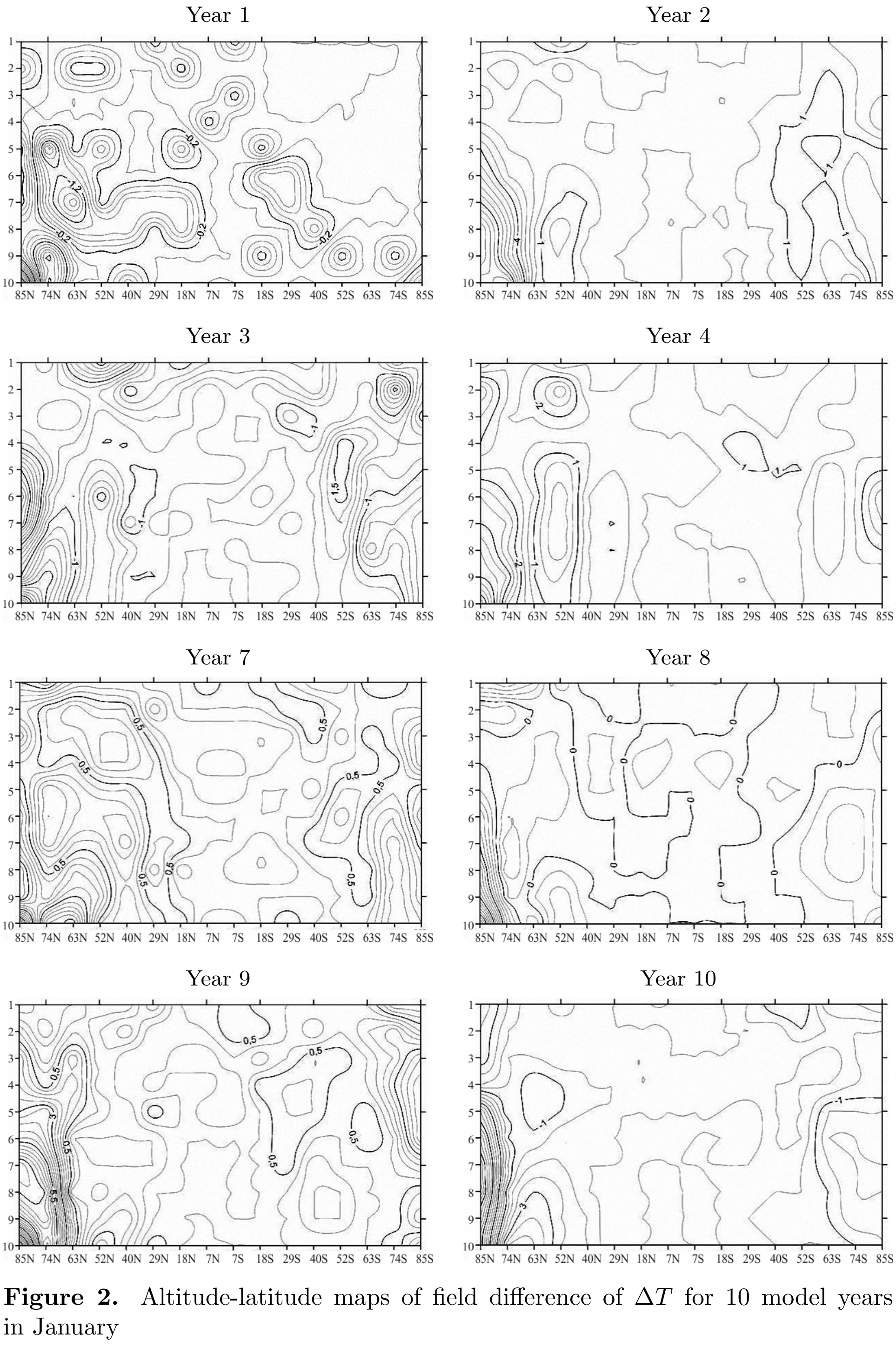

Figure 2. Altitude-latitude maps of field difference of ΔT for 10 model years in January

growth during the whole integration period. The cloud formation processes show almost the same trend above the Aral Sea and over the entire sphere. The only difference is that the variability of clouds above the Aral Sea is 1.5 times higher.

Figure 2 presents maps of the temperature differences for the month of January in 10 years. Analysis of the maps shows that the most sensitive to small perturbations in the Aral Sea are the areas of the north and the south poles. Thus, for already the second year, the model generates regions of sharp temperature gradients in the north latitudes and weaker in the south ones. The model integration in 5–8 years are characterized by small and rather chaotic distributions of ΔT. And by the 9th and 10th years, the region of sharp gradients in the north latitudes becomes strongly pronounced and, in addition, this region extends to higher atmospheric layers.

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