The influence of the ocean currents parameterization on changes in tropical circulation at CO_2 concentration doubling

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Abstract. In a number of papers, it is shown that the ocean currents velocity considerably affects the interaction between the atmosphere and the ocean in the regions where currents are sufficiently strong. In this paper, the influence of the ocean currents on its response of the atmosphere to changes in CO_2 concentration with the use of an intermediate complexity model is investigated.

1. Introduction

The response of the Earth's surface temperature to changes in the radiation balance of the atmosphere depends both on the feedback of the climate system, and the rate of the energy absorption by the deep ocean. Radiative forcing in the atmosphere initially affects the temperature in the troposphere and the mixed layer, and then the deep ocean [1]. In some studies, the response of the climate fields to increasing the CO_2 concentration is decomposed into two components — "fast" and "slow" [2]. The time of relaxation of the dynamic fields to a basic state is determined by the interaction of the atmosphere and ocean.

The ocean/atmosphere interaction is primarily determined by the sensible and latent fluxes that can be presented as

$$Q_s = \rho_a c_p C_h |\vec{u_a}|(\theta_a - \theta_s), \quad Q_l = \rho_a C_e |\vec{u_a}|(q_a - q_s), \tag{1}$$

where $\vec{u_a} = (u_a, v_a)$, u_a and v_a are zonal and meridional components of the wind speed, $\rho_a = 1.29$ kg/m^3 is the air density, θ_a and θ_s are potential temperature in the atmosphere and at the surface, q_a and q_s are specific in the atmosphere and at the surface, c_p is the specific heat for moist air at constant pressure, C_h and C_e are the transfer coefficients.

In addition to the explicit and the latent heat fluxes, one of the mechanisms determining energy exchange between the atmosphere and underlying surface is the wind friction:

$$\tau_x = \rho_a C_D |\vec{u}_a| u_a, \quad \tau_y = \rho_a C_D |\vec{u}_a| v_a, \tag{2}$$

where $C_D = 10^{-3}$ is the friction coefficient.

In [3], it was shown that the wind power input is determined by the ocean currents velocity. In this work, the currents were decomposed into

geostrophic and ageostrophic components. In extratropical latitudes, the geostrophic component dominates, and in the tropics there dominates the ageostrophic one, which can be estimated using the Ekman parametrization.

Typically, when modeling the interaction of the atmosphere and the ocean, the influence of the ocean currents on the heat flux from the surface is considered negligible. However, in some studies it is shown that the currents velocity significantly affect the climate system. In this paper, we investigate the dependence of the climate response to increasing carbon dioxide concentration on the ocean currents velocity. For the numerical experiment, a model of intermediate complexity "Planet Simulator" developed in the Meteorological Institute of Hamburg University was used.

2. Numerical experiments

The model "Planet Simulator" consists of several processing modules: atmospheric, ocean, biosphere, land surface and sea ice. The model dynamic core is based on dimensionless equations of the atmospheric dynamics written in the variables "vortex-divergence".

When calculating the linear terms, a spectral approach with the method of spectral transformation is used. For the vertical approximation, a semi-implicit scheme is used. The impact of subgrid processes is taken into account using parameterizations. In the model used, parameterizations are set for humidity processes.

Two numerical experiments were conducted. The dynamic fields in the case when currents were estimated with the Ekman parameterization were compared with a control experiment in which the wind stress and fluxes of heat and humidity did not depend on the velocities. Calculations were carried out for twenty years of the model time before reaching the stationary regime. In both cases, the CO_2 concentration abruptly increases at a two fold rate and the response of the global mean surface temperature is evaluated. Ekman's velocities are defined as $\vec{u}_s = -\vec{k} \times \vec{\tau}/(f\rho_w H_0)$, where $\vec{\tau} = (\tau_x, \tau_y)$ is the wind stress, $H_0 = 20$ m is the mixed depth, $\rho_w = 10^3$ kg/m^3 is the water density, $f = 2\omega \sin\varphi$ anywhere except the region around the equator, where $1/f$ is approximated by the linear function.

Let us consider two case:

1. The wind stress is expressed by formula (2) and the sensible and latent fluxes are calculated by formula (1);

2. The wind stress and the above fluxes depend on the currents velocity specified by the Ekman parametrization:

$$\vec{\tau} = \rho_a C_D |\vec{u}_a - \vec{u}_s|(\vec{u}_a - \vec{u}_s),$$

$$Q_s = \rho_a c_p C_h |\vec{u}_a - \vec{u}_s|(\theta_a - \theta_s), \quad Q_l = \rho_a C_e |\vec{u}_a - \vec{u}_s|(q_a - q_s).$$

The Ekman currents are perpendicular to the wind speed, so it is possible to estimate changes in the fluxes and in the wind power input.

The module of currents velocity is given by the formula $u_s = \frac{C_D \rho_a}{f \rho_w H_0} u_a^2 = \alpha u_a^2$. The coefficient α is of order of $0.5 \cdot 10^{-2}$ m^{-1}s in the tropics, the root square mean of the wind speed is of order 5 m/s.

If the of temperature and wind speed in Cases 1 and 2 are the same, the sensible and latent fluxes and the wind stress in Case 2 will be 0.1 % greater.

3. Results

The result of doubling CO_2 concentration is a warming of the global Earth's surface increasing toward the poles. The increase of the global mean surface temperature is about 3 K.

The heat flux in the sub-equatorial zone decreases in the North hemisphere and increases the South one. In Figure 1, there is shown a change in time of the temperature averaged over the latitude for the case of constant concentration of CO_2 and when the CO_2 concentration abruptly changes. The stationary regime is obtained after about seven years.

In the case, where the currents velocity is set by the Ekman parametrization, the temperature gradient reduces in the tropics and the Hadley cell slows. A possible cause of decreasing the wind speed is the wind stress increase. In Figure 2, there is a vertical cross-section of the mean annual temperature and of the difference between temperature fields in the tropical latitudes with currents and without them.
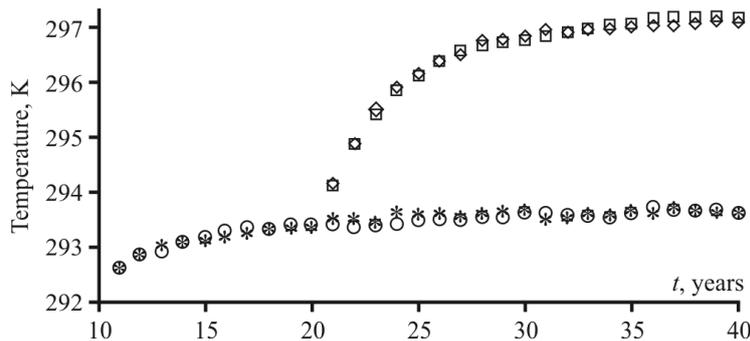
Figure 1. The global mean surface temperature depending on time. Asterisks mark the experiment not taking into account the currents velocity, circles mark the experiment with allowance for the currents velocity; the squares show the average annual temperature after a doubling of CO_2 concentration in the experiment with trends, and the diamonds indicate the control experiment
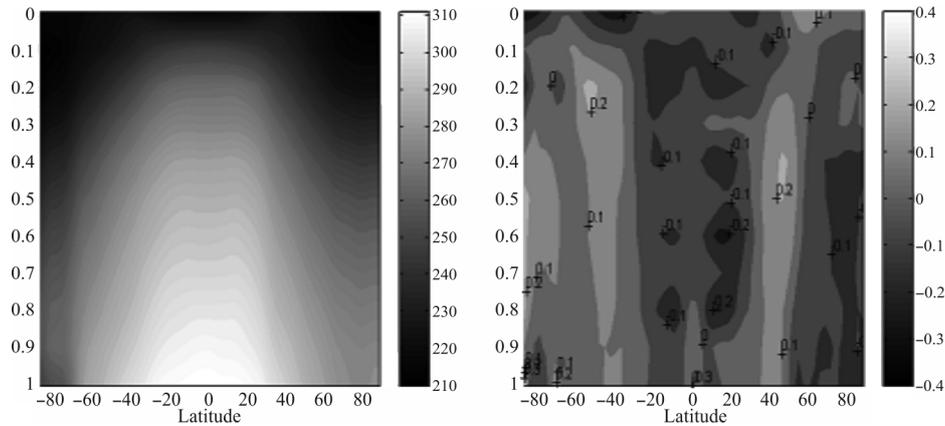
Figure 2. A cross section of the average annual temperature in the experiment with doubling of CO_2 concentration. The left picture presents the temperature for the experiment without currents, the right one is the difference between temperatures in cases with currents and without them. All data are averaged for twenty years of calculation
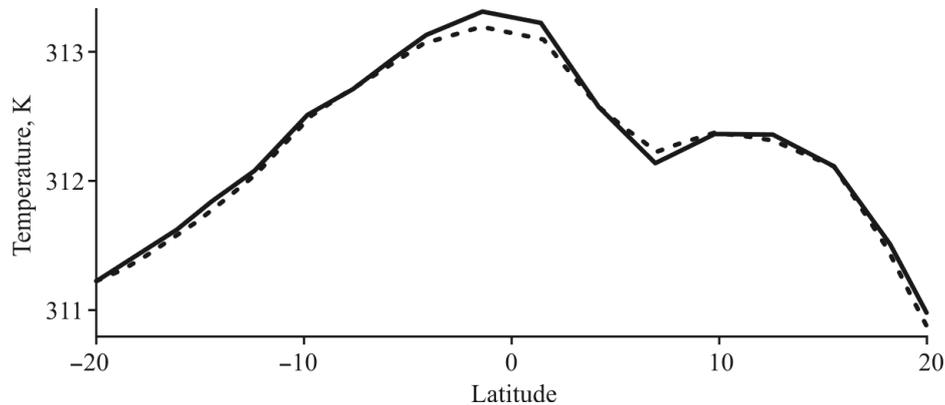
Figure 3. The case of doubling of CO_2 concentration with averaging over 5 years (36–40th years). The average annual temperature on the latitude dependency — the experiments with currents (solid line) and without currents (dashed line)

In Figure 3, the mean annual temperature depending on the latitude in the experiment with the doubling of CO_2 is shown. In the case when the current field is taken into account, the mean annual temperature at the equator is higher than in the case without currents. This is due to the Hadley cell weakening and the reduction of the heat transport from the equator to the tropics. A decrease in the time of relaxation of the motion to the basic state is observed.

4. Conclusion

In this research, we made use of the Ekman parametrization because it describes the mean climatic distribution of ocean currents in the tropics with sufficient accuracy.The numerical experiment has shown that the enhancement of the sensible and latent fluxes and wind stress causes considerable changes in dynamic fields: the reduction of temperature gradients in the tropics and weakening the Hadley cell. In the parametrization, taking into account the currents velocity, the heat fluxes in the Eastern part of the ocean are weaker, and in the West they are stronger than in the case where the currents velocity is not taken into account. This leads to an increase in temperature in the Western part of the oceans and to a decrease in the East, and, as a consequence, to the weakening of the Walker circulation. The weakening of the tropical circulation can be explained by an increase in the wind stress.

The climatic regime in the models depends on how the response of the deep ocean is parametrized. Global and regional warming is dependent on local ocean processes determining heat fluxes. Since the atmospheric circulation has significant sensitivity to ocean dynamic fields,a coupled model of the dynamics of ocean and atmosphere should be used to evaluate climate changes.

References

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