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A ROLE THAT INTERACTION BETWEEN THE CLIMATE AND ECOSYSTEMS PLAYS IN SHAPING THE CLIMATE RESPONSE TO EXTERNAL FORCING[1]

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Abstract. A review is given of the interaction between the climate and ecosystems under the external (natural and anthropogenic) forcings. In particular, the effects of the replacement of the natural vegetation by crops, of the release of greenhouse gases, and of biogeochemical cycles are considered.

The Earth system, in addition to its physical compartments (the atmosphere, the ocean, the soil, and the cryosphere), also includes ecosystems. The latter interact with each of the just listed physical compartments and affect climate variations at a large number of spatial and temporal scales. Traditionally, the processes behind the interaction between the climate and the ecosystems are subdivided into the biogeochemical and biogeophysical groups. The former group consists of the processes related to the uptake of chemical substances by the terrestrial and oceanic ecosystems, and to the further transformations of these substances within the Earth biota. Other processes contributing to the interaction between the climate and ecosystems are referred to as biogeophysical.

This presentation is focused on the review of the results related to the interaction between the climate and the ecosystems under the external (natural and anthropogenic) forcings.

In particular, if a particular ecosystem is replaced by another one (like, e.g., crops replace forest after land use deforestation), surface albedo is changed. The latter results in redistribution of the solar radiation within the Earth system. According to the simulations with global climate models, an increase of albedo due to land use in the 20th century has compensated 10–20% of the global warming during this century (Fig. 1) [Brovkin et al., 2006; Eliseev and Mokhov, 2011].

In addition, replacement of the natural vegetation by crops suppresses transpiration (i.e., moisture transport by terrestrial plants from the soil to the atmosphere). This effect may be exacerbated by the suppression of the convective precipitation because of the near-surface cooling (Fig. 2) [Eliseev and Mokhov, 2011]. However, if the existing agriculture becomes more intense, it enhances transpiration. The net effect, as well as its impact on climate change, are uncertain, however [Pitman et al., 2009].

[1] Talk presented at the Interdisciplinatory Colloquium on cosmic factors of evolution of the biosphere and geosphere, Moscow, May 21–23, 2014.

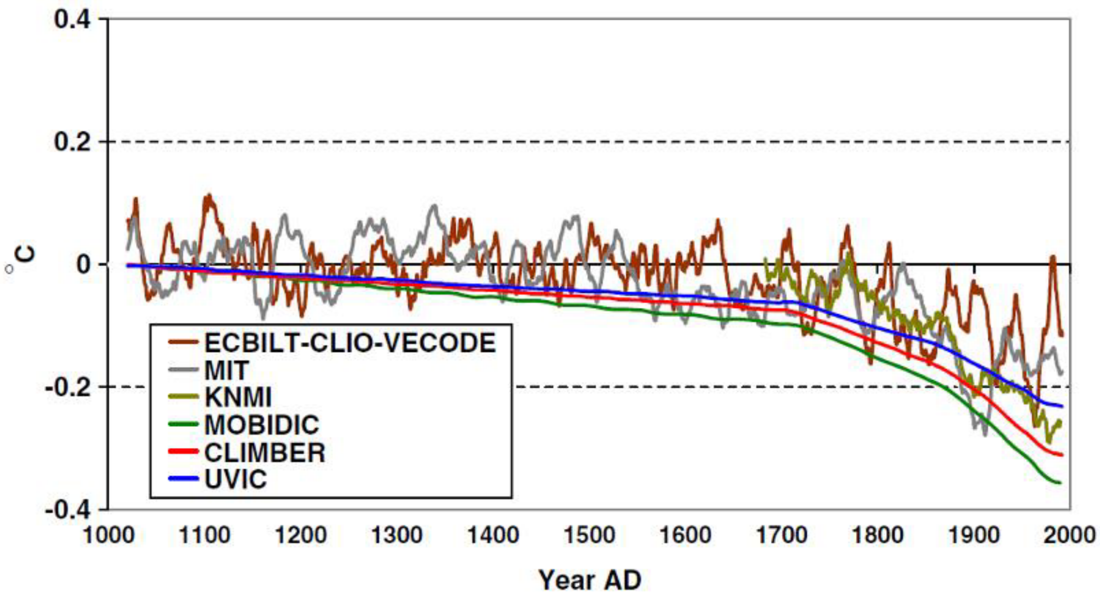

Figure 1: Changes in mean annual surface air temperature in different climate models (see legend) (°C) for the Northern Hemisphere due to historical land use, 20-year moving average [Brovkin et al., 2006].

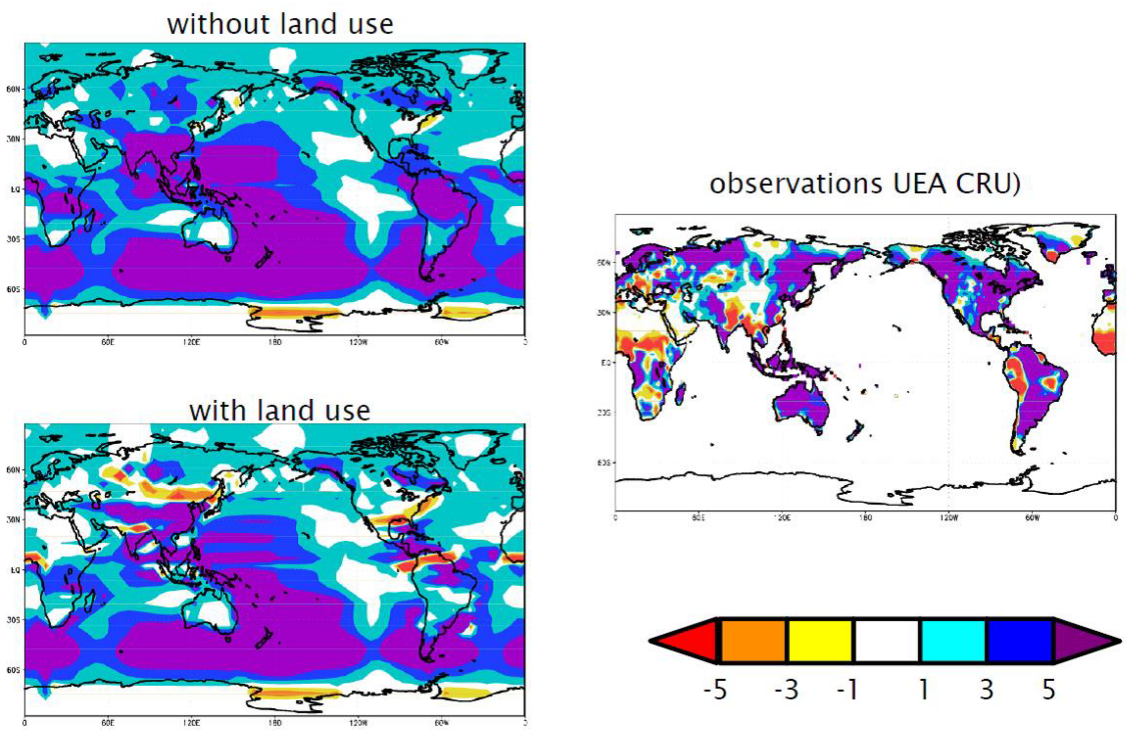

Figure 2: Change of annual precipitation (cm/yr) during the 20th century in the IAPRAS CM simulations, which are forced by anthropogenic and natural forcings [Eliseev and Mokhov, 2011].

All these results are obtained for the historic period (i.e., for the last several centuries). The impact of biogeophysical processes on climate change during next few centuries (currently, most climate models are integrated until either the year 2100 or the year 2300) is expected to be small. At least partly, the latter arises from the reasoning that, currently, the most land area suitable for the agriculture is already in use [Monfreda et al., 2000].

Among the biogeochemical processes, important role for climate is played by the carbon cycle which consists of geochemical and biogeochemical transformations of carbon dioxide CO_2 and methane CH_4. Both those are powerful greenhouse gases.

Carbon dioxide emitted due to burning of fossil fuels and due to land use is partially taken up by the ocean and by the terrestrial ecosystems. This markedly diminishes its build up in the atmosphere. In turn, such uptake depends on the climate state in a complex way. The latter dependence results in a feedback between the climate and the carbon cycle. From the simulations with global climate models it is found that this feedback is related basically to the terrestrial branch of the carbon cycle, and the respective oceanic branch plays a relatively minor role. In addition, it is found that this feedback is positive: it suppresses the just mentioned uptakes and enhances the build up of the CO2 in the atmosphere [Friedlingstein et al., 2006]. Hence, this feedback has a potential to amplify the greenhouse-gases-induced warming, by about 10% in the 21st century (Fig. 3) [Eliseev et al., 2007].

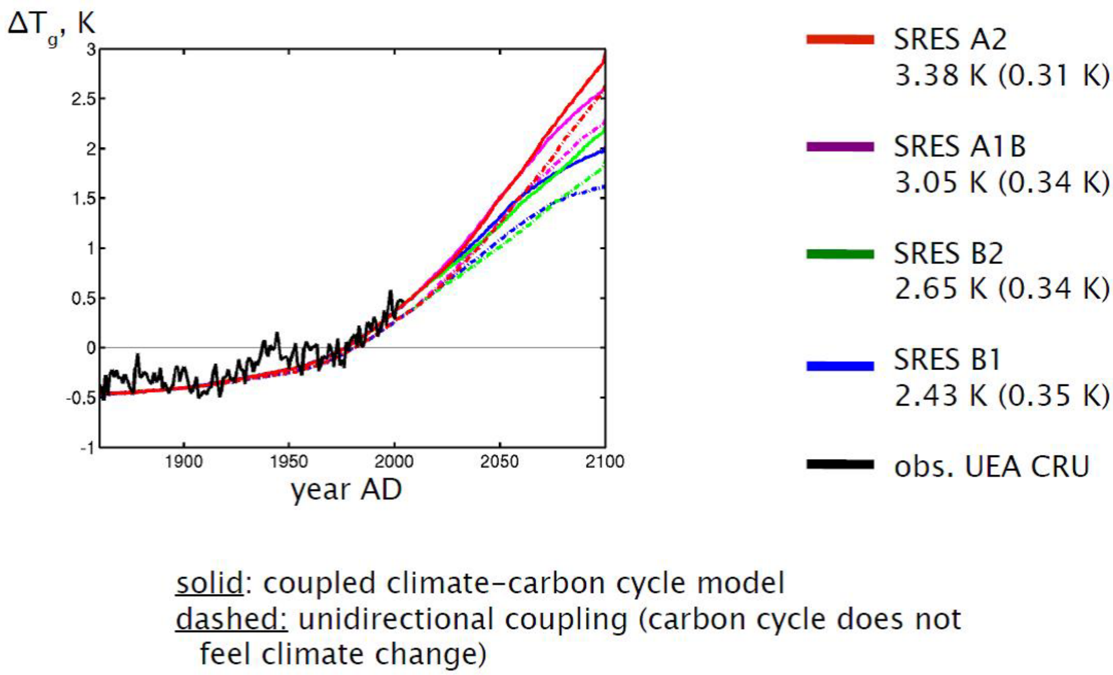

Figure 3: Change of the globally and annually averaged surface air temperature in the IAP RAS CM simulations which are forced by anthropogenic CO_2 emissions (see legend). The numbers in the legend show change of T_g during 1860–2100 AD, and the additional warming due to coupling between climate and carbon cycle (the latter are in brackets) [Eliseev et al., 2007].

The climate–carbon cycle feedback may be modified by interaction between the carbon cycle and other biogeochemical cycles. Among those, the most important is the nitrogen cycle [Sokolov et al., 2008]. Additional such modifications might be expected from interactions between the carbon and the phosphorous cycles.

Climate changes may also change the emission of methane from natural sources, e.g., from wetlands. This is a heartstone of the climate-methane cycle feedback, which is also positive, and, therefore, may enhance the ongoing warming. However, it is found that this feedback, despite markedly amplifying the CH4 build up in the atmosphere, change the climate response to external forcing very insignificantly (Fig. 4) [Eliseev et al., 2008; this paper is extended by Denisov et al., in preparation].

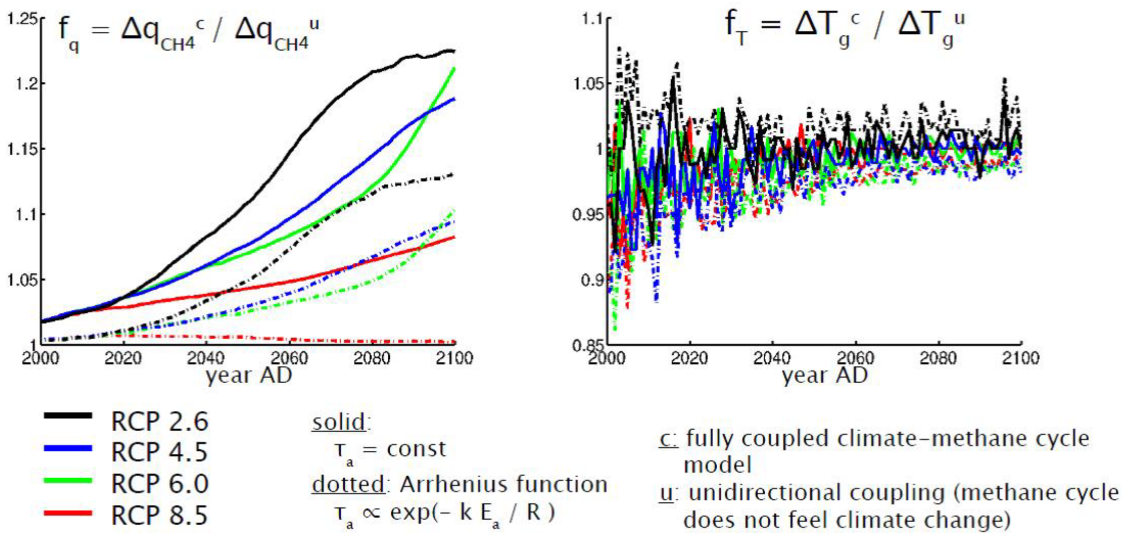

Figure 4: Climate-methane cycle feedback strength in the IAP RAS CM simulations which are forced forced by the scenarios anthropogenic and natural forcings (see legend). The feedback strength is defined as a ratio of change either atmospheric CH_4 content (left) or globally averaged surface air temperature (right) between the simulations with a fully coupled climate-methane cycle methane and with a model employing an unidirectional coupling between the climate and the methane cycle. Two versions of the model are used, one is with a constant CH_4 lifetime in the atmosphere, τ_a, and another with an Arrhenius-type dependence of τ_a on surface air temperature [Denisov et al., in preparation].

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Роль взаимодействия климата и экосистем в климатическом отклике на внешние воздействия

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Резюме. Проводится обзор сведений, касающихся влияния взаимодействия климата и экосистем на климатический отклик при внешнем (естественном или антропогенном) воздействии. В частности, рассмотрено влияние замены природной растительности зерновыми культурами, выделения парниковых газов и биогеохимических циклов.