Section 7

Global and regional climate models, sensitivity and impact experiments, response to external forcing

Methane emissions from Western Siberian wetlands: sensitivity to climate change from multi-model estimations

S.N. Denisov, M.M. Arzhanov, A.V. Eliseev, I.I. Mokhov
A.M. Obukhov Institute of Atmospheric Physics RAS, Moscow, Russia
denisov@ifaran.ru

Scheme of methane emissions from wetlands which takes into account dependence of methane flux to climate state and was used in [1,2] is combined with the model of heat and moisture transport in soil [3]. Simulations with the combined model are performed for the region of Western Siberia (55-65°N, 65-85°E) for the 21st century forced by atmospheric parameters from the ensemble of climate models: CCCMA-CGCM3, INMCM3, ECHAM5/MPI-OM, NCAR-CCSM3 and IAPRAS CM.

On average, simulated methane emissions E_{CH4} for the chosen region increase from 9.1 $MtCH_4$/yr for the early 21st century to 21.3 $MtCH_4$/yr in its end (Fig.1). Different observational estimates of methane emissions from Western Siberia give wide range for total methane flux from 1 to 20 $MtCH_4$/yr [4]. According to estimates [4,5], E_{CH4} equals to 3.1 $MtCH_4$/yr and 1.7 $MtCH_4$/yr correspondingly. In the climate model of intermediate complexity developed at the A.M. Obukhov Institute of Atmospheric Physics RAS (IAPRAS CM), methane emissions for the analized region increase from 9.9 to 22 $MtCH_4$/yr during the 21st century [2]. Estimations of methane fluxes obtained for ensemble of models show notable scatter and the difference in E_{CH4} between the models may reach 15 $MtCH_4$/yr.

To access sensitivity of simulated methane emissions to input parameters of atmospheric forcing simulations are performed for 21st century when the value of one of parameters is kept corresponding to year 2001. When the air temperature is kept on the year 2001 level, simulated average E_{CH4} increases from 8.4 to 10.5 $MtCH_4$/yr during the 21st century (Fig.2). When other parameters are fixed corresponding to their values for year 2001, the simulations results are relatively close to base results depicted at Fig.1. Thus, the combined soil-methane emission model is most sensitive to the surface air temperature. Inter-model differences in E_{CH4} may be explained by the differences in surface air temperature for the analyzed region, which may be as high as 2-3°C.

This work was supported by the Russian Foundation for Basic Research, by the programs of the Russian Academy of Sciences, and by the Russian President scientific grant.

References

[1] Mokhov I.I., Eliseev A.V., Denisov S.N. Model diagnostics of variations in methane emissions by wetlands in second half of the 20th century based on reanalysis data. *Doklady Earth Sciences, 2007, V. 417, N. 8, 1293-1297.*

[2] Eliseev A.V., Mokhov I.I., Arzhanov M.M., Demchenko P.F., Denisov S.N. Interaction of the methane cycle and processes in wetland ecosystems in a climate model of intermediate complexity. *Izvestiya, Atmos. Oceanic Phys., 2008, 44 (2), 139-152.*

[3] Arzhanov M.M., Eliseev A.V., Demchenko P.F., Mokhov I.I., and Khon V.Ch. Simulation of thermal and hydrological regimes of Siberian river watersheds under permafrost conditions from reanalysis data. *Izvestiya, Atmos. Oceanic Phys., 2008, 44 (1), 83-89.*

[4] Glagolev M.V. and Shnyrev N.A. Dynamics of methane emission from mires of Tomsk oblast in the summer and fall and the problem of spatial and temporal extrapolation of the obtained data. *Moscow University Soil Science Bulletin, 2008, 63 (2), 67-80*

[5] Matthews E., Fung I. Methane emissions from natural wetlands: Global distribution, area and environmental characteristics of sources. *Glob. Biogeochem. Cycles, 1987, 1 (1), 61-86.*

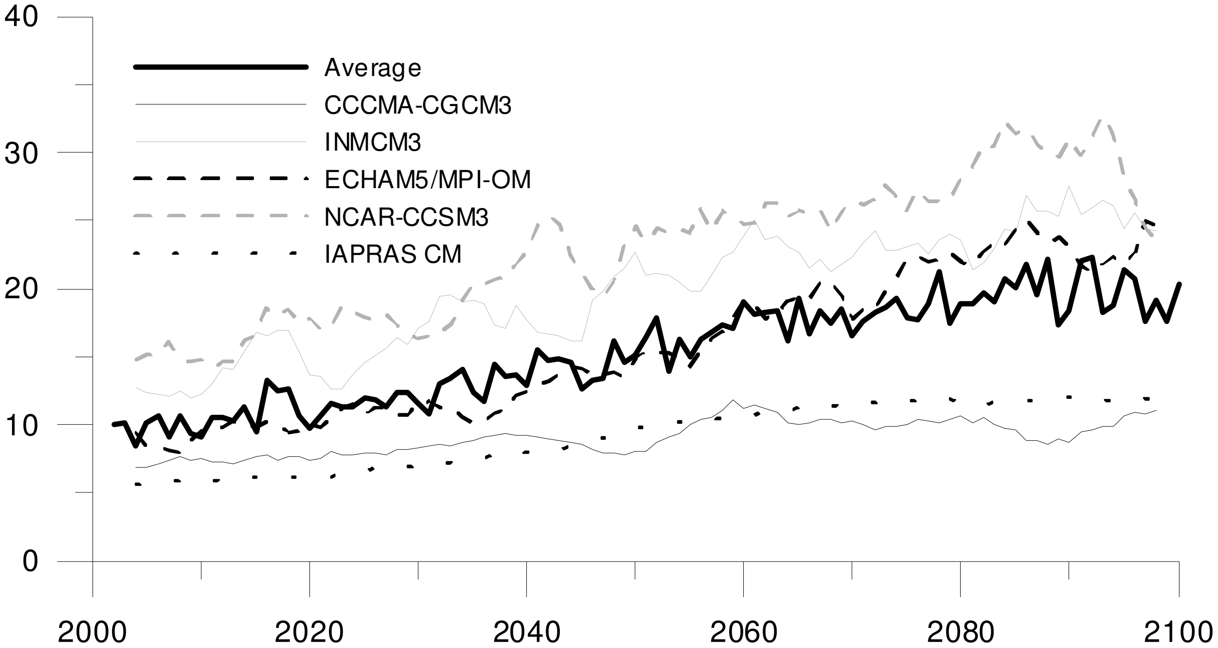

Figure 1: Average simulated methane emissions and 5-year running average emissions for each model.

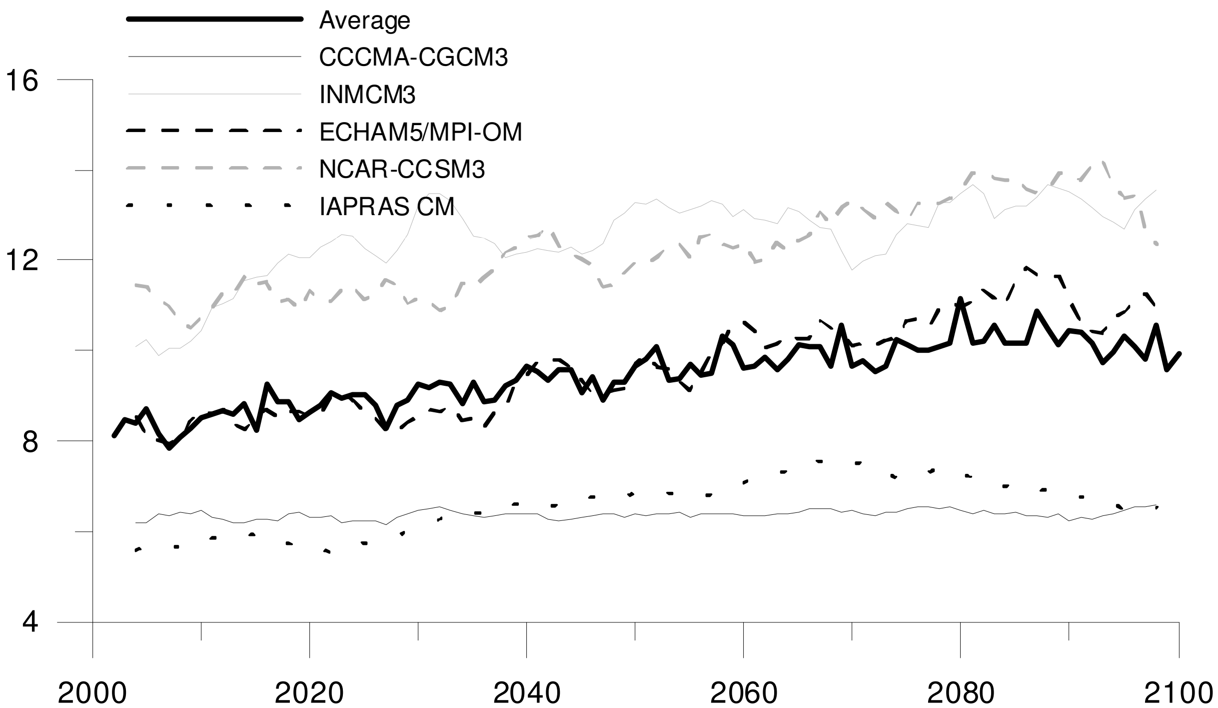

Figure 2: Average simulated methane emissions and 5-year running average emissions for each model when temperature remains on the 2001-year value.

Qualitative Analysis of Ice Sheets Mass Balance Variations Under Global Climate Change

A.V. Malyshkin, I.I. Mokhov
A.M. Obukhov Institute of Atmospheric Physics RAS
malyshkin@ifaran.ru

In the late decades problem of Greenland and Antarctic ice sheets' evolution has been gaining much popularity. Current experimental techniques for investigation of two major ice sheets does not provide enough input data for complex ice sheet models to be used. This is the reason complex ice sheet models should be used with a precaution. On the same time, simple models are very coarse to be trusted. But, errors due to large number of parameters in a complex model on one hand, and inaccuracies of a simple model due to rough treatment of physical processes on the other – make one incline to use a simple model for clear analytical interpretation of possible regimes in ice sheet behavior. In this work the Antarctic and Greenland ice sheets are considered.

Estimates of current mass balance for Antarctica vary from -211 Gt/yr to 156 Gt/yr [IPCC 2007], [Kotlyakov 2008]. Whereas Greenland mass balance is estimated to range from -239 Gt/yr to 23 Gt/yr [IPCC 2007] with the most likely decreasing ice sheet mass.

Components of mass balance are: precipitation, surface sublimation and condensation (and processes reverse to them – evaporation and desublimation), ice discharge and water runoff into the ocean. We suggest [Malyshkin and Mokhov 2009], [Malyshkin and Mokhov 2010] a simple model accounting for main components of the ice sheet mass balance: precipitation and ablation comprising ice discharge and water runoff into the ocean. Rate of total mass change:

$$\frac{dM}{dt} = \rho S_0 \left(h_p - h_m - h_f \right), \tag{1}$$

where h_p, h_m, h_f are responsible for precipitation, melting and ice discharge, correspondingly; S_0 is the surface area of grounded ice. Generally speaking, surface area of grounded ice may decrease as a result of melting, and the same is true for area of surface melting. We assume that precipitation over an ice sheet depends on global temperature with sensitivity parameter b $(mm/(yr\cdot{}^oC))$. Melting relates to the surface air temperature above ice and ratio of melting area to total area of grounded ice. Ice discharge is treated constant on the time scale considered.

With all above prerequisites one can obtain relation for total mass of grounded ice depending on global temperature T:

$$M(T) = M_0 + \sum_{i=1}^{4} \frac{k_i}{R_T^i} (T - T_0)^i, \tag{2}$$

where coefficients k_i are defined as follows

$$k_1 = \rho S_0 \left(h_{p0} - h_f - \beta T_{m0} \Omega_0 \right), \qquad k_2 = \frac{R_T}{2} \rho S_0 \left(b - \beta v \Omega_0 - \beta r T_{m0} \right) + \pi \rho l \beta T_{m0} \left(h_f - h_{p0} \right) ctg\varphi,$$

$$k_3 = -\frac{R_T^2}{3} \rho \beta \left[v \left(\frac{2\pi l}{R_T} \left(h_{p0} - h_f \right) ctg\varphi + r S_0 \right) + \frac{2\pi l}{R_T} b T_{m0} ctg\varphi \right], \qquad k_4 = -\frac{R_T^2}{2} \pi \rho l \beta v b ctg\varphi. \tag{3}$$

As can be seen from (2), ice sheet mass relates to temperature as fourth power polynomial. Such complex behaviour should be attributed to variations of four quantities: precipitation h_p via sensitivity b, surface air temperature above ice (sensitivity v), melting area (sensitivity r) and area of grounded ice (sensitivity with factor $ctg\varphi$).

Assume Antarctic ice sheet retains its grounded ice area, i.e. it has ice shelves almost along the whole shoreline. Hence, it is justified to neglect the effect of changing area of grounded ice, which is equivalent to ignoring all terms in (3) containing $ctg\varphi$ factor. Consequently, fourth power in $M(T)$ dependence vanishes: $k_4 = 0$.

On the contrary, Greenland ice sheet is considerably influenced by surface melting. That is why its grounded ice area reduces as global temperature rises. Since ice retreats from shoreline to regions with lower temperatures, it seems reasonable to disregard effect of changing surface air temperature in melting region $v = 0$. This allows to reduce order of $M(T)$ dependence similar to situation with Greenland: $k_4 = 0$.

Six regimes can be distinguished for the described particular cases of Antarctic and Greenland ice sheets. If initial mass balance is negative, i.e. the ice sheet thickness is decreasing, then regimes I, IV, V and VI are possible for realization. And if at current temperature T_0 the ice sheet is growing, then regimes II and III are realizable.

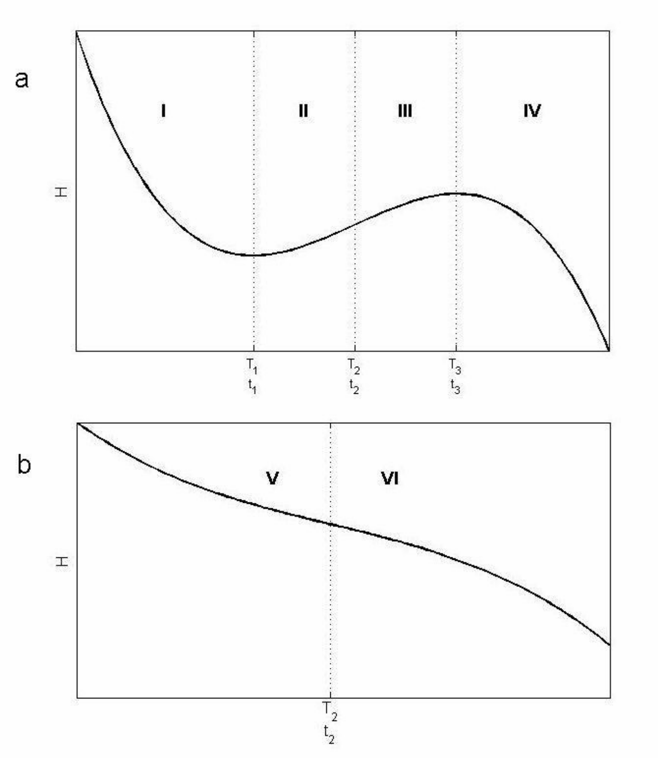

Fig. 1. Patterns of ice thickness change depending on model parameters, a) with extrema and b) without them.

In regime I ablation initially prevails over precipitation, this stays true up to temperature T_1. Subsequent growth of the ice sheet is explained by amplification of precipitation under global warming. Melting also increases at elevating temperatures, however, due to large precipitation sensitivity b, precipitation rises at a greater rate in the temperature interval $\left(T_0, T_2\right)$. At temperature T_3 melting reaches the value sufficient, altogether with ice discharge, to equilibrate precipitation. Regime IV is realized when precipitation sensitivity is small enough. Here minimum and maximum in temperature dependence of ice thickness lie in the region of lesser temperatures with respect to current temperature: $T_0 > T_3$, and, accelerating with warming, melting leads to further reduction of the ice sheet. Regime V is encountered in case of intermediate values of precipitation sensitivity (Fig. 2a). In that case precipitation sensitivity is large enough for precipitation to grow faster than melting under global warming, however not enough for the ice sheet to start growing ($T_0 < T_2$). In regime VI precipitation is not sufficiently sensitive and increases slower than melting under elevating temperatures ($T_0 > T_2$). In regimes V, VI ice thickness decreases for any temperature value.

For positive current mass balance regimes II, III of ice sheet dynamics are possible. Regime II exhibits sufficiently large precipitation sensitivity, and under warming precipitation increases faster than melting does, which leads to acceleration of ice sheet growth ($T_1 < T_0 < T_2$). Regime III is realizable at sufficiently small b, and at elevating temperatures precipitation increases slower than melting does, consequently ice sheet growth decelerates ($T_2 < T_0 < T_3$). In regimes II, III ice sheet grows up to the temperature T_3, and under further warming it shrinks.

References

[Kotlyakov 2008] Kotlyakov V.M., Vasilyev L.N., Moskalevsky M.Yu., Hromova T.E. (2008) Continental ice discharge and mass balance of the Antarctic ice sheet. Environmental and Climate Change. Environmental and Relevant Man-caused Catastrophes, v. 8, part 2: Environmental Processes in Polar Regions of the Earth, p. 97-106 (in Russian).

[Malyshkin and Mokhov 2009] Malyshkin A.V., Mokhov I.I. (2009) Mass balance of the Antarctic ice sheet: conceptual model interpretation. Reasearch Activities in Atmospheric and Oceanic Modeling, Section 7: Global and regional climate models, sensitivity and impact experiments, response to external forcing. P. 7-8.

[Malyshkin and Mokhov 2010] Malyshkin A.V., Mokhov I.I. (2010) Conceptual ice sheet model: analysis of possible Antarctic regimes under global climate change. Meteorology and Hydrology (submitted, in Russian).