Vegetation modeling in Yakutia, northeastern Siberia: connecting to palaeovegetation simulation and model-data comparison

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Introduction

Vegetation model is a helpful tool to understand the impacts of climate change on ecosystems in the present, past and future. Simulation of the palaeovegetation can link the geographical pattern of vegetation in the past to pollen proxy and then test the palaeoclimate modeling. The Russian Arctic, especially the northern Siberia, has suffered climate warming, increased winter precipitation, and change in variability (Vaganov et al., 1999; ACIA, 2005; McGuire et al., 2007). The changes of vegetation pattern, structure and functions (especially the treeline) have been occurred in recent decades (Vaganov et al., 1999; ACIA, 2005; Callaghan et al., 2005; McGuire et al., 2007) and in early warm periods of the Holocene (MacDonald et al., 2000). However regional variations in palaeovegetation reconstruction and in simulated vegetation patterns existed. Here we present a study about the impact of climate change on arctic and sub-arctic vegetation in northern Yakutia, northeastern Russia, during the past 102 years based on vegetation modeling. The aim of this study is not to work on the improvement of vegetation modeling technique in the Yakutian arctic region, but to show the performance of current-existed, well- and common-used global vegetation models in regional and local specific vegetation simulations in the context of palaeovegetation modeling and model-pollen data comparison.

Methods

The study area: The target area of vegetation modeling is the Yakutia (55-75°N, 105-165°E) in eastern Siberia and the northwestern Yakutia (70-74°N, 110-115°E) where lake surface pollen and macrofossil were recently recorded.

The vegetation models: We use two global vegetation models, the equilibrium biosphere model BIOME4 (Kaplan et al., 2003) to simulate the current potential vegetation patterns, and the dynamic global vegetation model LPJ (Sitch et al., 2003; Gerten et al., 2004) to predict the dynamic changes of vegetation structure and functions.

Climate data: The dataset of mean monthly temperature, minimum temperature, precipitation and cloud cover during 1961-1990 (CRU CL 1.0) was used to drive the BIOME4 model. The modern climatology (mean monthly surface temperature, precipitation, cloud cover and wet days) to drive the LPJ model was extracted from the CRU TS 2.1 data set.

CO_2 concentration: An atmospheric CO_2 concentration of 360 ppm was used to force BIOME4 for the present-day baseline simulation. The LPJ model however needs the time-series historical global atmospheric CO_2 concentrations from 1901-2002 which was derived from a combination of ice-core measurements and atmospheric observation.

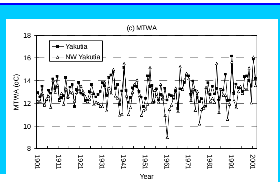
Soil property: BIOME4 uses the soil properties of water holding capacity and percolation rate at two layers (top: 0-30 cm; bottom: > 30 cm) from the FAO digital soil map of the world. In the LPJ run the soil texture data were used based on the TERRASTAT database at 5 minutes resolution of the FAO.

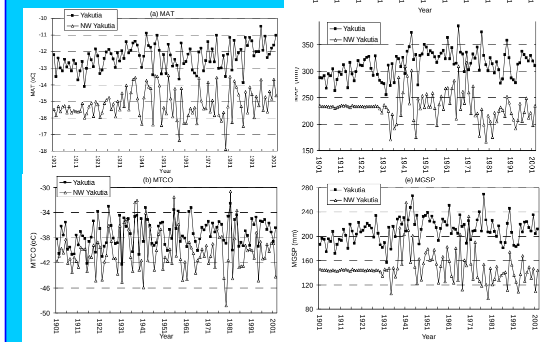
Natural vegetation: A vegetation map of Yakutia (1:1,000,000; Governmental Agro-industrial Committee of the Yakutian Republic, 1989.) and the Circumpolar Arctic vegetation map (1:7,500,000; Walker, 2000; Walker et al., 2005) are used to compare and to validate the model results.

Results

Climate changes in the Yakutia

During the past century the global warming has led to a warming trend and more precipitation in the Yakutian region, but with strong variabilities.



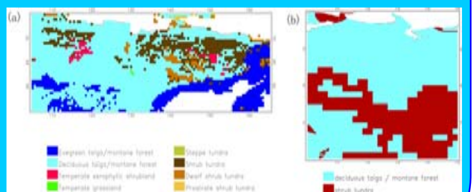


The changes of climate in the Yakutian region from 1901 to 2002. (a) MAT: mean annual temperature; (b) MTCO: mean temperature of the coldest month; (c) MTWA: mean temperature of the warmest month; (d) MAP: mean annual precipitation; and (e) MGSP: mean growing season precipitation from May to September.

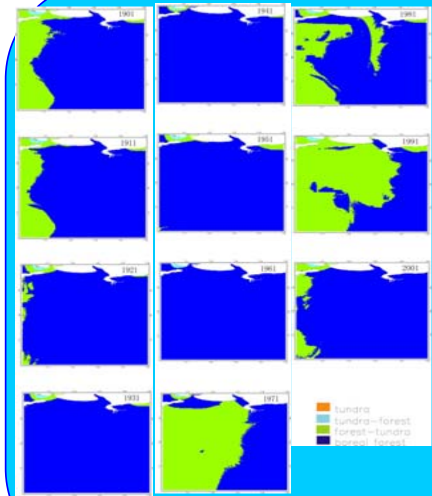
Potential natural vegetation

The BIOME4 simulated a reasonable pattern of present biome distribution compared to the regional vegetation maps: the deciduous taiga–montane forests in the southern and central Yakutia, evergreen taiga–montane forests in the southwestern mountainous region and in the eastern coast, shrub tundra and dwarf shrub tundra in the northwest and northeast mixed with temperate xerophytic shrubland.

In the north-westernmost Yakutia the model only simulated two biomes, the deciduous taiga / montane forest in the north and southwest, and shrub tundra in the middle to south. Compare to the local vegetation this pattern is somehow questionable, because the shrub tundra occupies most of the area in the natural vegetation.



Biome distribution map in Yakutia (a) and in NW Yakutia (b) simulated by the BIOME4 equilibrium vegetation model.

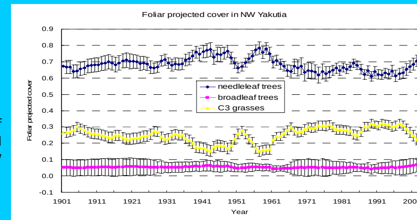


The dynamic changes of vegetation in NW Yakutia predicted by the LPJ dynamic vegetation model.

Vegetation changes

The LPJ model basically obtained the general pattern of vegetation in the NW Yakutia, and demonstrated a dynamic change through time responding to the changed climates.

Forest and shrub covered the large area of the NW Yakutia from the beginning to the 1950s of the 20th century. Tundra (grass-dominated vegetation) extended from the west to the east during 1960s to 1970s. In 1980s woody plants extended and in 1990s grasses extended again. In late 1990s to early 21st century woody plant extended their area again. From the mean coverage point of view the boreal needleleaved summergreen woody plants and C_3 herbs dominate and the broadleaved summergreen woody plants only occupy a small proportion. During the first half of the 20th century the needleleaved woody plants slowly increased their coverage and grasses decreased. In late 1940s to year 1950 the woody plants suddenly declined and grasses significantly increased, then from 1950 to late 1950s the woody plants increased to their highest coverage together with the big decrease of grasses. Then the needleleaved woody plants decreased and the grasses increased till the middle of 1990s, except for an opposite trends in early 1970s to early 1980s. From middle of 1990s the needleleaved woody plants increased again and the grasses decreased.



The changes of foliar projected cover (FPC) in NW Yakutia.

Discussion and Conclusions

The equilibrium vegetation model (BIOME4) and the dynamic vegetation model (LPJ) can both characterize the basic features of the regional vegetation patterns, functions and changes through time in the Yakutia. This means that both the global vegetation models could be well used in the regional vegetation simulations. However problems still existed in the regional vegetation modeling using the global vegetation models.

The BIOME4 model over-simulated the forest biome in the arctic region, because: 1) The BIOME only has a shrubby plant functional type (PFT), which does not sufficiently characterize various shrub vegetation in this region. 2) The BIOME4 used a broad climate constraint to different PFTs, which is not enough to distinguish and constraint different regional vegetation types. 3) Permafrost, snow, groundwater and fire in the Arctic have very important impacts on vegetation. However the BIOME4 did not consider much about these environmental factors, only the soil texture-related water holding capacity and water percolation index were used. It seems that the simulated biome distribution is more related to the soil water condition rather than the climates in regional scale. 4) The climate data and soil properties derived from the global data sets are relatively coarse and have less accuracy.

The LPJ model has the similar principles with BIOME4 so that it has the similar problems. The model doesn't have the shrub PFTs. The simulated woody plants actually included the shrubs but the model couldn't separate them with the trees. On the other hand, the classification of other tree and grass PFTs in LPJ are still very coarse. The LPJ includes permafrost, snow and fire modules but they are rather simple or problematic (Sitch et al., 2003; Gerten et al, 2004). Soil texture classification (derived from the global soil map) is very coarse in the arctic region, only medium and organic soil.

In general both the vegetation models and the input data need improvements. We need to re-write the models taking these points into account: adding more PFTs especially the shrubs and grasses; redefining the climatic constraints to PFTs; redefining the soil water-related parameters; and adding or modifying the modules of permafrost, snow, and fire. Regional input data of climates, vegetation and soils at finer resolutions will be obtained from the Russian local organizations.

The accurate vegetation modeling under present-day climate condition is the basis of palaeovegetation simulation driven by past climates. The palaeovegetation simulation is furthermore validated by the pollen records. Both the pollen- and model-based palaeovegetation, especially their dynamic changes, can be used to test the palaeoclimate models which usually did not change the land surface – thus omitting the important interaction and feedback between vegetation and climate (Prentice et al., 2000; Braconnot et al., 2007a, b).

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