Potential effects of albedo feedbacks due to land cover change in Siberia under IPCC climate change scenarios

Tchebakova N.M,* Parfenova E.I.* and A.J. Soja**

*Institute of Forest, Siberian Branch, Russian Academy of Sciences, Email: ncheby@ksc.krasn.ru

* *National Institute of Aerospace (NIA), Email: Amber.J.Soja@nasa.gov

Fig. 1. Study area, Siberia, (60-140ºE and 48-72ºN, 12 million square km) (**Fig. 1**)

Goal Our goal was to evaluate possible effects of feedbacks of vegetation-induced albedo change to net radiation change to accelerating/mitigating vegetation shifts over Siberia (**Fig. 1**) in a warmed climate by the end of the 21st century.

Methods. First, we simulated vegetation cover change in Siberia by 2080 to insight vegetation change feedbacks on the alteration of surface albedo and energy. We applied our Siberian BioClimatic Model (SiBCliM) to the HadCM3 A2 (with the highest temperature increase) and B1 (with the lowest temperature increase) scenarios of the Hadley Centre (IPCC, 2007) to highlight possible vegetation change at 2080.

Results. Our SiBCliM predicts biomes (zonal vegetation class) from three climatic indices (growing degree-days, negative degree-days, and an annual moisture index) and permafrost. Our simulations indicate large changes in Siberian vegetation (**Fig. 2**): coverage by northern vegetation types (tundra, forest-tundra, and taiga) would decrease from 81.5 % to 30-50% depending on the climate change scenario. Southern habitats (forest-steppe, steppe and semi-desert) would expand from 18.5% to 50-70% (**Table 1**).

Biomes could shift northwards as far as 600-1000 km by substitution or complete replacement of northern ecosystems.

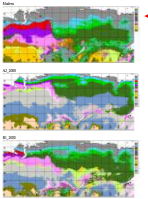

Fig. 2. Vegetation distribution in Siberia the current climate resulted from coupling our SiBCliM with maps of bioclimatic indices and permafrost driving the model under current climate (upper) and climate change scenarios A2 (middle) and B1(lower)

Vegetation key: 1 – Tundra, 2 – Subalpine dark-conifer and meadow, 3 – Subgolets light-conifer, 4 – montane dark conifer, 5 – montane light conifer, 6 – Subtaiga and forest-steppe, 7 - "chern", 8 - Steppe, 9 – Dry Steppe, 10 – Semidesert, 11 - Desert

Methods. Changes in the surface albedo would follow significant change in land cover by the end of the century. Albedo of current and the 2080 vegetation was calculated for each pixel as a sum of winter albedo (vegetation covered by snow), summer albedo (snow-free vegetation) and albedo of winter-to-summer and summer-to-winter transition periods. Albedo values for each year period were derived from Budyko (1974).

Results. According to the harsh A2 scenario albedo would increase over 45% of the area in the southern and middle latitudes in Siberia due to the forest retreat. In the northern latitudes and highlands, tundra would be replaced by the forest resulting in decreased albedo in 55% of the territory.

According to the moderate scenario B1, albedo would increase over 30% of Siberia and would decrease in 70% of the territory (**Fig.3**).

Results. Shortwave radiation and thus net radiation would change due to change in albedo. Under a greater warming (scenario A2) net radiation balance would increase by 220*10^{13} MJ/yr in a half of the area in the north and would decrease by 70*10^{13} MJ/ yr in other half of the area resulting in a net increase of 150*10^{13} MJ per year over the entire Siberian window (about 1.2 *10^{13} m^2). Compared to the annual net radiation 1000-2000 MJ*m^{-2} in current climate, this change is about 10% in the A2 climate and 6% in the B1 climate (**Fig.4**).

HadCM3 A2 **HadCM3 B1**

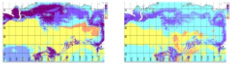

*Fig. 3. Vegetation-induced albedo change (in Siberia in the **A2** climate and **B1** by 2080.*

Albedo class key: 1.<-0.3, 2. -0.3-(-0.2), 3.-0.2 –(-0.1), 4.-0.1-0, 5.0-0.1, 6.<0.1.

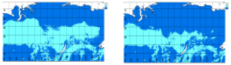

*Fig. 4. Albedo-induced net radiation change in Siberia in the **A2** climate and the **B1** climate by 2080.*

Net radiation key: 1. negative change, 2. positive change

Table1. Potential vegetation change (%) in Siberia by 2080 predicted from two IPCC climate change scenarios and its correction (Δ, %) for potential effects of albedo feedbacks due to land cover change applied to these scenarios

Vegetation	Current Climate, %	Had CM3 A2, %	Had CM3 A2, Δ, %	Had CM3 B1, %	Had CM3 B1, Δ, %
Tundra	18.3	2.0	-0.8	7.5	-1.3
Forest-tundra	8.5	2.4	-1.6	4.0	-2.5
Taiga	54.6	28.9	+0.8	37.8	+3.8
Forest-steppe	6.1	23.8	+9.4	22.5	+4.2
Steppe	10.0	30.1	-8.5	19.1	-5.8
Semidesert	2.5	12.9	+0.6	9.0	+1.7

Methods. In order to transform albedo-induced net radiation change by 2080 to growing degree-days, GDD, the climatic constrain we use in our SiBCliM, a linear regression model relating net radiation (B) and GDD was developed for Siberia from observed data (**Fig. 5**) .

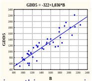

Fig.5 The relationship between net radiation and growing degree-days in Siberia (R^2= 0.83, n-45, st.er. = 193;

Using this regression, GDD corrections were calculated from the net radiation map (**Fig. 4**) and applied to IPCC A2 and B1 climate change scenarios for 2080. SiBCliM was run again based on these scenarios to insight how vegetation would shift with regard the predicted feedbacks (**Fig. 6**).

Results. Potential albedo feedbacks due to land cover change in Siberia predicted from IPCC scenarios, may result in additional warming in the tundra zone and some cooling in the enlarged forest-steppe ecotone which correspondingly promote the further forest advance northwards and the forest return into the steppe zone in the south (**Fig. 6 lower**). Thus, the forest may additionally gain back in its area about 1% of tundra and 6-8.5% of grasslands (**Table 1**).

HadCM3 A2 **HadCM3 B1**

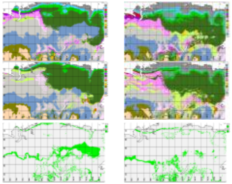

Fig. 6. Vegetation distribution in 2080 predicted from climate change scenarios HadCM3 A2 and B1 with no albedo feedbacks (upper), corrected for albedo feedback effects (middle), and corrections for the forest portion (green) increased due to albedo feedback effects (lower).

Conclusions. The pattern of land cover change predicted from IPCC climate change scenarios and followed by albedo-induced feedbacks suggests accelerating warming and the further forest advance into tundra in the north and mitigating warming and the forest return into steppe in the south resulting in the increased forest area.

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