Zonobiomes, forests, and major forest-forming conifers across Russia in the altered climate of the 21st century

Tchebakova N.M,* Parfenova E.I.*, Luke Oman**, Soja A.J.***, and Conard S.G.****
Institute of Forest, Siberian Branch, Russian Academy of Sciences, Email: ncheby@ksc.krasn.ru
* *NASA, Email:luke.d.oman@nasa.gov
***National Institute of Aerospace (NIA), Email: Amber.J.Soja@nasa.gov
**** US Forest Service, Email: sgconard@aol.com

Fig. 1. *Study area, Russia* (20-140ºE and 48-72ºN)

Goal. Develop bioclimatic (biogeographic) models of Russia and Northern Eurasia and produce current and future zonal vegetation distributions in Russia by the mid-century using the Goddard Earth Observing System (GEOS) Chemistry-Climate Model (CCM)

Methods. We expanded our Siberian vegetation bioclimatic model (SiBCliM) to a North-Eurasian bioclimatic model (NEBCliM);

• NEBCliM predicts zonobiomes (zonal vegetation classes) from three climatic indices (growing degree-days, negative degree-days, and an annual moisture index) and permafrost;

•NEBCliM includes 13 zonobiomes, of which 10 are boreal and 3 are temperate; steppe and forest-steppe are sums of both zones correspondingly;

•To verify the ability of NEBCliM to model vegetation, modeled vegetation was compared to the actual vegetation map of Isachenko (1989) using kappa statistics;

•NEBCliM was applied to both climate indices and permafrost in the current climate and in the A1B GEOS climate to highlight possible vegetation change by the mid-century;

•GEOSCCM used the A1B (mid-range) greenhouse gas scenario which produces temperature warming of 1.5 to 3.5C across Northern Eurasia by 2050. Precipitation changes are more variable with 10% less precipitation in the central and 10-20% more precipitation in the western and eastern regions

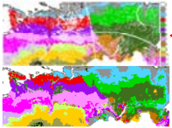


Fig. 2. Map comparison between actual (upper) and modeled (Lower) vegetation over Russia in modern climate

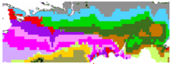


Fig. 3. Modeled vegetation distribution in Russia for modern climate (left) and the GEOS A1B climate scenario for 2050 (above)
Vegetation: *1. tundra, 2. Forest-tundra; Northern taiga: 3. dark, 4. light; Middle taiga: 5. dark, 6. light; Southern taiga: 7. dark, 8. light; 9. Forest-steppe; 10. Steppe; 11. Mixed; 12. Broadleaved; 13. Semidesert*

Table 1. Map comparison of real and modeled vegetation

BIOME	Kappa
1. Tundra	0.56 good
2.Forest-tundra	0.17 poor
3.North dark taiga	0.27 poor
4. North light taiga	0.25 poor
5. Mid. dark taiga	0.30 poor
6. Mid. light taiga	0.56 good
7. South dark taiga	0.40 fair
8. South light taiga	0.24 poor
9. Forest-steppe	0.41 fair
10. Steppe	0.69 v. good
11. Mixed	0.46 fair
12. Broadleaf	0.45 fair
13 Semides/Desert	0.73 v. good
OVERALL	**0.40 FAIR**

Results. The comparison between our modeled and the real (Isachenko 1988) vegetation maps showed that the overall agreement was "fair" (K=0.40) and agreements by separate zonobiomes ranged from "very good" to "fair" (yellow) to poor (K<0.4) (Table 1, Fig. 2). Overall we concluded that NEBCliM does a reasonable job of modeling Russian vegetation distribution at a broad scale.

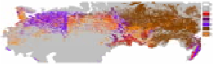
Biome simulations resulting from coupling NEBCliM with the conservative A1B climate scenario indicated that "potential" vegetation in Russia would be moderately altered by 2050 (Fig. 3; Table 2). Northern tundra and forest-tundra areas would remain about the same. Northern taiga would decrease about 10% and light taiga would increase about 5% in a dryer climate at higher latitudes. Southern steppe would decrease 50% and be replaced by mixed and broadleaved forests due to increased precipitation in the south. Forest-steppe and semidesert areas would remain relatively unchanged. According to this mild scenario, forest vegetation would remain dominant over Russia.

Modeled and actual **conifer species** distributions across Russia are shown in Fig.4 (left). Comparison showed a fair agreement between them: 78% of the real *Larix spp.* range, 75% of the real *Picea spp.* range, 71% of the real *Pinus sylvestris* range, 46% of the real *Pinus sibirica* range and 41% of the real *Abies sibirica* range were within their climatic potential ranges. Those matches might be higher because part of primary conifer forests were replaced by secondary birch and aspen forests after large disturbances.

Table 2. Biome distribution (%) in modern and GEOS A1B climate at 2050

BIOME	CURRENT CLIMATE	GEOS A1B 2050
Tundra	4.7	7.8
Forest-tundra	11.3	10.1
Northern darkl. taiga	5.5	3.1
Northern lightl. taiga	10.1	10.3
Middle darkl. taiga	8.8	6.8
Middle lightl. taiga	12.8	12.9
Southern darkl. taiga	12.7	8.2
Southern lightl. taiga	3.0	6.7
Forest-steppe	6.2	5.6
Steppe	11.0	4.8
Mixed Broadl.&Conifer	6.9	11.0
Broadleaved	3.2	7.7
Semidesert/ Desert	3.7	4.8

Map of Forests of the USSR Real range across Russia (1990)



Potential species range across Russia

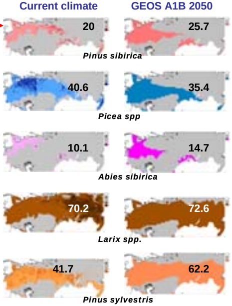


Fig. 4. Major conifer distributions in Russia. Actual distributions from Isaev's map (top) are shown as dots on maps of modeled distributions of individual species for current climate (left). Modeled distributions for the GEOS A1B 2050 climate are on the right. Percent of Russian territory with mapped potential habitat is shown on each species map.

Conclusions

• Kappa statistics rated NEBCliM as "fair" in modeling current Russian vegetation;

•According to the GEOS A1B climate change scenario, impacts of global warming on the site potential for most major Russian ecosystems will be quite moderate by the mid- 21st century;

•Decreased precipitation in the high latitudes would favor increased distribution of light-needled taiga (*Larix sibirica* and *Pinus sylvestris*) in West Siberia, which is currently dominated by dark-needled taiga (*Picea obovata, P. sibirica, Abies sibirica*);

•Increased precipitation in lower latitudes would favor expansion of temperate mixed and broadleaf forests into areas currently dominated by forest-steppe and steppe;

•Climate change effects are not projected to shift zonobiomes substantially, but would change their area: boreal dark-needled forests would decrease and light-needled forests would expand due to increased dryness across the taiga zone;

•The dryer climate would favor light conifers pine and Siberian larch in West Siberia and *Dahurian* larch within the permafrost zone in East Siberia;

• All light conifers, especially pine, may also develop because they have an advantage over dark conifers due to their stronger resistance to water stress and wildfire.

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