Boreal Forest mid-21st Century: Disturbed or Disturbing?

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Introduction

Climate change is altering the extent and function of global forests. Eurasian boreal forests represent half of the global forested area, constitute nearly a quarter of a forested area (Anagnostou, 1990; Conard et al., 2002), and comprise a significant area for the exchange of carbon between the atmosphere and the terrestrial biosphere. The Siberian boreal forests have experienced the greatest modification in regional climate, and are experiencing increasing amounts of stress and disturbances, including wildfires and insect outbreaks, all of which facilitate short- and long-term release of carbon to the atmosphere. Modeling the effect of changing disturbance frequencies and intensities on the boreal ecosystem functioning is important for understanding how these forests may change in the future (decades to centuries). There is the possibility of southern boreal forest dying out due to stress and increased disturbance pressures in the next several decades, and that region becoming a regular source of atmospheric carbon.

We present a new disturbance module (DISTURB) developed for application with a spatially-explicit individual-based gap dynamics model SIBORK. This module simulates the effect of disturbances on a forested landscape. A disturbance, such as a fire or an insect outbreak, either kills or damages (stresses) individual trees, which alters the species composition, the albedo, the radiation budget and hydrologic properties of the forest. The forest and already observed increases in disturbances in the Siberian boreal forest could result in a feedback that further worsens the climate in the region, facilitating forest die-off. DISTURB builds on the spatially-explicit nature of the SIBORK, and increases the probability that a disturbance will occur in a given area (multiple adjacent plots) rather than on an individual plot. These nuances are generally absent from existing disturbance modules and no spatially-explicit analog exists. This presents an important improvement in the simulation of boreal forest functionality under climate change and helps us understand the potential near-future shifts in forest composition.

Disturbances in Siberia

It is vital to understand how climate change and the associated shifts in disturbance regimes may affect the structure and composition of the boreal forests and their ability to sequester and store carbon. The most prominent forest disturbances in Siberia are fires and insect outbreaks. Millions of hectares of boreal vegetation is destroyed by wildfires annually (Conard et al., 2002). The frequency, intensity and extent of disturbances has increased since 1990 (Bovza et al., 2016), and are expected to continue to increase in the near future. In recent decades, the loss of forest biomass has already exceeded biomass accumulation in these forests (Krankina and Dixon, 1994; Krankina et al., 1996, 2005). Fire and insect outbreaks change species composition due to differential susceptibility of different tree species to forest of different intensities (stress and herbivores); by various insects. These changes modify the canopy geometry, the local radiation budget and hydrology, as well as the albedo. If the disturbance is large or there are many disturbances occurring in one area, the radiation budget and albedo can be modified at the regional or even continental scale.

DISTURB Module

Figure 2. Typical disturbance module, common in non-spatially explicit, e.g. Monte Carlo, simulations. Disturbances occur on individual independent plots based on probability derived from the mean return interval for the specific disturbance.

Figure 3. Fire used as a sample disturbance. (a) Process flow for two DISTURB modules: (1) based on mean annual probability, (2) additionally based on a drought trigger fire kills all or only susceptible trees (top). A probability (c) of a fire based on probability simulated landscape - fire kills all or only susceptible tree species in plots B6, C1 and SD5 (b) fires based on drought-stress plots A3, A6, D4, and D5, designated by brown trees here and in (a). (c) all or susceptible/irresistant trees also burn.

Results: Disturbance Alters Forest Structure

Figure 4. With a combination probabilistic and environmentally- triggered disturbance, such as fire, the contribution of each species to forest composition does not change on flat terrain in middle taiga on central Siberia (a) compared to c), however, the total biomass accumulated is significantly different, with approximately 1/3 biomass accumulated under conditions that include fire, as compared to a forest without disturbance (b) compared to c).

Conclusions

When the simulation does not include disturbance, the taiga on the south-facing slopes in south-central Siberia are likely to be replaced by steppe by 2100 on mountains less than 3000m tall. The disturbing is that when disturbances, such as fire, are included in the simulation with a 60-year return interval, the boreal forest on these mountains disappears from the south-facing slopes ever sooner. However, in order to more accurately predict when the exposition forests on south slopes is likely to undergo a non-reversible shift to steppe, we need to know the fire return interval for the region, as well as the degree to which drought increases the probability of fire. Currently, different fire return intervals have been observed on north- and south-facing slopes and reported for the region. Furthermore, drought enhancement to the fire regime needs to be further investigated.