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EDITORIAL

Ongoing climatic change in Northern Eurasia: justification for expedient research

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A brief overview of the ongoing climatic and environmental changes in Northern Eurasia serves as an editorial introduction to this, the second, special Northern Eurasia Earth Science Partnership Initiative (NEESPI) focus issue of *Environmental Research Letters*. Climatic changes in Northern Eurasia over the last hundred years are reflected in numerous atmospheric and terrestrial variables. Many of these are noticeably significant above the confidence level for 'weather' or other (fire regime, ecosystem change) noise and thus should be further investigated in order to adapt to their impacts. In this focus issue, we introduce assorted studies of different aspects of contemporary change in Northern Eurasia. Most of these have been presented at one of the NEESPI workshops (for more information see http://neespi.org) and/or American Geophysical Union and European Geosciences Union NEESPI open sessions during the past year. These studies are diverse, representing the diversity of climates and ecosystems across Northern Eurasia. Some of these are focused on smaller spatial scales and/or address only specific aspects of the global change implications across the subcontinent. But the feeling (and observational evidence) that these changes have already been quite rapid and can have global implications inspires us to bring this suite of papers to the readers' attention.

Climatic changes at the continental scale

Northern Eurasia is a region where contemporary warming and associated climatic and environmental change are among the most pronounced globally, where winter temperatures have increased by more than 2 °C and summer temperaturse by 1.35 °C during the period of instrumental observations since 1881 (figure 1). Summer warming is a new phenomenon, observed over the past several decades, and it is the summer temperature that largely controls vegetation growth in polar regions. In this region, the total net radiative energy into the surface

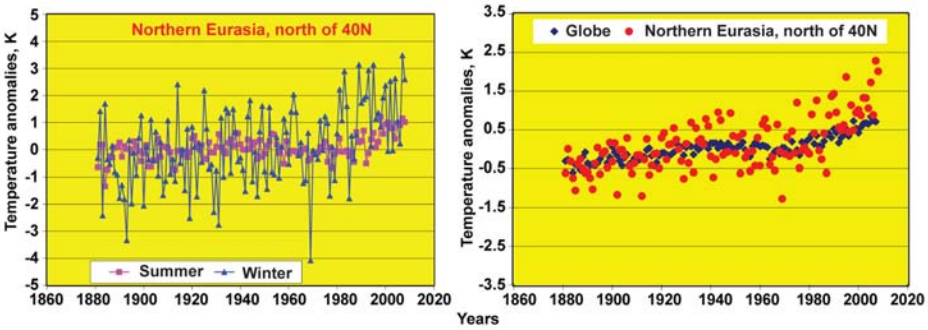

Figure 1. Left panel: summer and winter surface air temperature anomalies area-averaged over Northern Eurasia (north of 40°N, east of 15°E). Warming trends for the period of record (1881–2008) are statistically significant at 0.01 or higher level. Right panel: comparison of annual surface air temperature anomalies area-averaged over the globe (zone 60°S to 90°N) and over Northern Eurasia. Linear trends, 0.86 K/128 yr and 1.4 K/128 yr respectively, are statistically significant at the 0.001 level. Anomalies are taken from the 1951–1975 reference period. Updated time series from the archive of Lugina *et al* (2007).

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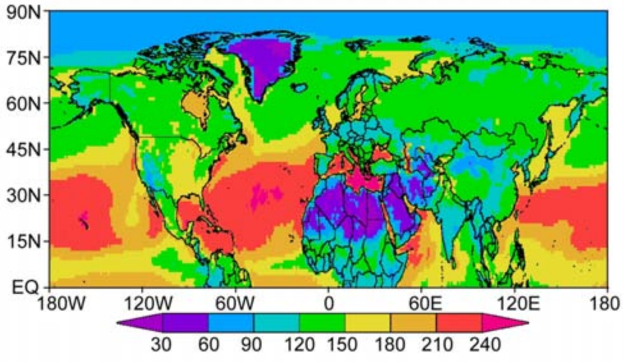

Figure 2. Total net irradiance (solar net + thermal infrared net) from the 22 year average for July from the NASA/GEWEX Surface Radiation Budget project. Courtesy of Dr Paul Stackhouse Jr and Colleen Mikovitz, NASA Langley Research Center (personal communication).

as estimated by the Surface Radiation Budget project is positive only for a short period of the year. But, in July this quantity exceeded values in the Sahara or the desert Southwest US (figure 2).

Temperature change across Northern Eurasia has accelerated, especially in Siberia and the continental interior (figure 3). The latitudinal expanse of mountain systems across the Eurasian interior (Himalayas, Karakorum, Caucasus, Tian Shan, and others) serves to block the moisture influx from tropical oceans to Northern Eurasia (Kuznetsova 1983). This blocking terrain and the large size of Eurasia leads to a larger (compared to North America) dependence of the water budget of Northern Eurasia from the water vapor transfer that originates from the North Atlantic via the westerlies. The intensity of the latter depends strongly upon the meridional gradients of the surface air temperature field. The pattern of ongoing global warming (stronger warming in high latitudes compared to the tropics) gradually reduces these gradients and this process has accelerated in recent decades (figure 4). As a result, we have already witnessed a gradual increase in the frequency and extent of dry conditions and forest fire risk across Northern Asia (Mescherskaya and Blazhevich 1997, Zhai *et al* 2004, Soja *et al* 2007, Groisman *et al* 2007, 2009, Elizbarashvili *et al* 2009).

Changes of global concern in the Artic

North of the Eurasian coast, the Arctic Ocean is rapidly advancing towards perennial ice-free conditions and has already lost nearly half of its end-of-summer extent since the late 1970s (Serreze *et al* 2007). The sea ice thickness has also been noticeably reduced (Frolov *et al* 2009). This development changes

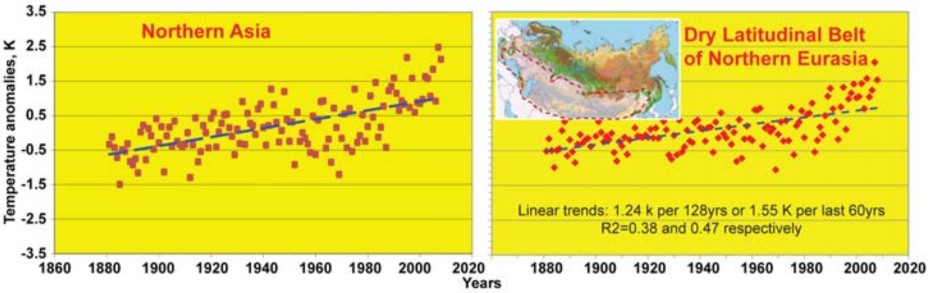

Figure 3. Annual surface air temperature anomalies and their linear trends area-averaged over Northern Asia, north of 40°N (left panel) and over the Dry Latitudinal Belt of Northern Eurasia shown in the inset (right panel). Warming trends for the period of record are statistically significant at 0.01 or higher level. Anomalies are taken from the 1951–1975 reference period. Updated time series from the archive of Lugina *et al* (2007).

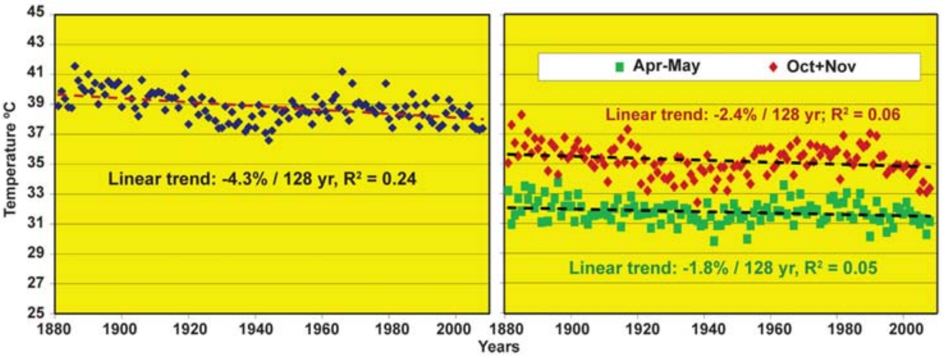

Figure 4. Decrease in surface air temperature meridional gradients over the Northern Hemisphere estimated as a difference of tropical mean zonal temperature (zone 0°–30°N) and polar mean zonal temperature (zone 60°N–90°N). Left panel: cold season (December through March). Right panel: intermediate seasons (April to May and October to November). Updated time series from the archive of Lugina *et al* (2007).

regional albedo and dramatically affects the cold season heat fluxes from the ocean to the atmosphere. Thus, Northern Eurasia and, particularly, its Arctic are being affected by global and regional factors that are contributing to these observed changes and the positive feedbacks to this forcing may further exacerbate the situation. This dramatic retreat of the Arctic sea ice is causing: (a) rampant coastal erosion of the Arctic shelf (up to 10 m yr^{-1}; Ogorodov 2003); (b) release of carbon (both methane and CO_2) stored on the frozen shelf and coast (Shakhova *et al* 2009); and (c) an additional source of heat and moisture in early winter. Figure 5 depicts the land and ocean cover composite for July–September 2008 based on Terra-MODIS RGB with 250 m resolution in the Arctic. It shows the areas of the Arctic Ocean that remain ice-free during these three months in 2008, which are substantial and much larger than just 20–25 years ago. As a result, we observe a significant increase of maximum snow depth across the northern part of Russia (Bulygina *et al* 2009), an unusual behavior of the hemispheric snow cover in October (it is not shrinking with warming against all odds due to an additional source of moisture to the Arctic atmosphere).

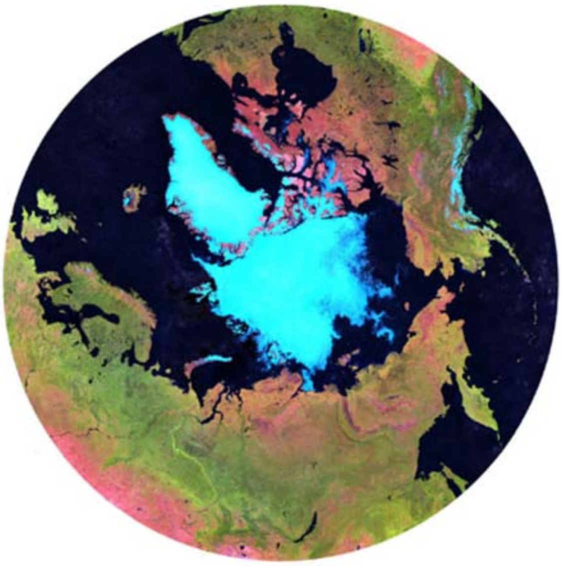

Figure 5. Terra-MODIS RGB, July–September 2008, 250 m resolution. Courtesy of Dr Alexander Trishchenko, Canada Centre for Remote Sensing, ©Her Majesty the Queen in right of Canada 2009 (Trishchenko *et al* 2009). Cloud free composite. Note the large areas of ice-free water in the Arctic during this three-month long season.

Impact on the World Ocean thermohaline circulation due to changes in the fresh water inflow into the Arctic Ocean was a concern of the Arctic Fresh Water Budget Initiative (Vörösmarty *et al* 2004) because being a small fraction of the World Ocean (less than 4%), the Arctic Ocean drainage is disproportionally high (about 10%). Furthermore, observations and pilot projections predict that the discharge and heat influx from major Siberian rivers into the Arctic Ocean has increased (Shiklomanov *et al* 2007, Lammers *et al* 2007) and will further increase (Kattsov *et al* 2007).

Ecosystem changes of global concern in Northern Eurasia

The largest reservoir of terrestrial carbon resides in the boreal forest zone, primarily in permafrost, wetlands and soil, and 3/4 of the boreal forests are in Russia (Alexeyev and Birdsey 1998, Apps *et al* 1993, Zoltai and Martikainen 1996). There is an additional carbon reservoir held on the previously frozen Arctic shelf, which is becoming increasingly threatened by warming. Continuous climate warming, coupled with associated permafrost thawing (Romanovsky *et al* 2007, Shakhova *et al* 2009) and an intensification of the processes acting on the expansive wetlands of West Siberia (Peregon *et al* 2007, 2009, Bohn *et al* 2007) could result in an additional *positive* biogeochemical feedback to the global climate caused by increased greenhouse gas (CO_2 and methane) influx to the atmosphere. Warming and drought are significantly altering climate in Kazakhstan (Akhmadieva and Groisman 2008, Wright *et al* 2009) and are the likely reason for the extremely early and intense 2008 fire season across Russia, which resulted in unexpected Arctic aerosols that could alter snow/ice/albedo feedbacks in the Arctic, exacerbating melting (see Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) at www.espo.nasa.gov/arctacs/docs/arctas_wp.pdf).

Additionally, as regards the function of human interaction with ecosystems, the value that is placed on the environment and government management of resources can exert a strong influence in determining ecosystem health, structure and function (Zhen *et al* 2009). Walker *et al* (2009) investigated reasons for greening on the Yamal Peninsula and found a positive feedback between climate and permafrost degradation and attributed these to a complicated interaction between warming, reindeer herding, gas-field infrastructure and sea ice melt. The accurate quantification of these feedbacks directly affects our ability to project the rate of future global change, and in some cases, the magnitude and even the sign of these feedbacks are associated with significant uncertainties, while some feedbacks are likely still unidentified. At the same time, we must carefully consider the data products that are available for research, as highlighted by Wright *et al* (2009) and Soja *et al* (2009).

Biospheric models project that further changes in Northern Eurasian energy and water budgets coupled with permafrost thaw will result in substantial northward and altitudinal shifts in major ecozones, particularly in continental Siberia. In various climate change scenarios, significant decreases in taiga, tundra, and forest-tundra and increases in steppe, forest-steppe, and temperate forests are predicted (Vygodskaya *et al* 2007, Tchebakova *et al* 2009b, 2009c). This shift will affect the surface albedo (i.e. low in dark coniferous forest, high in snow-covered steppe) and moisture balance of these ecosystems in ways that are largely undefined, and these interactions will feedback to the climate system by altering patterns of precipitation, cloud cover, solar radiation and hydrologic balances.

The role of forest fires

Randerson *et al* (2006) investigated the cumulative impact of future boreal forest fires on climate warming. They concluded a net negative climate forcing, but highlighted the uncertainty in fire severity (directly related to fire weather) and the unresolved question of the impact of changes in extensive Siberian larch forests (distinct, light, needle-leafed deciduous species underlain with permafrost).

Figure 6. Thawing of ice-rich permafrost, triggered by forest fire in Central Yakutia, transforms boreal forest into steppe-like habitats (photo by Vladimir Romanovsky) as predicted by Tchebakova and colleagues (Soja *et al* 2007, Tchebakova *et al* 2009a, 2009b).

Figure 7. Intense fire in a *Pinus sylvestris* forest in the Republic of Tyva, resulting in a likely conversion to steppe (left, no regeneration after several years; right, no regeneration after 20 years).

While the northward advance of forest into the tundra can be slow and is additionally restricted by soil properties, the advance of steppe into the forest zone can be quite swift, and there is already evidence of the advance of steppe regions in Yakutia (northern boundary; figure 6) and Republic of Tyva (southern boundary; figure 7) (cf Ivanova *et al* 2009, Kharuk *et al* 2005, Soja *et al* 2007, Tchebakova *et al* 2009b). Climate-induced increases in fire regimes (frequency, area burned and severity) can act as a catalyst by which ecosystems move quickly towards a new equilibrium with the climate system (i.e. forest to steppe).

Conclusion

The need for expedient research in Northern Eurasia in response to recent climatic and environmental change is compelling for the following reasons.

- The changes in this part of the Earth are already among the largest, and are accelerating.
- We are facing a non-linearity in environmental and climatic change in Northern Eurasia due to: (a) a dramatic retreat in Arctic sea ice; (b) the impact on the World Ocean thermohaline circulation due to changes inthe fresh water inflow into the Arctic Ocean; (c) feedbacks to the global carbon and hydrological cycles due to permafrost thaw, wetland transformation, land cover change and ecosystem shifts; and (d) identified and unidentified feedbacks to the climate system through alterations in the solar energy balance (i.e. aerosols on snow/ice, albedo change due to changes in vegetation, cloud cover, latent and sensible heat fluxes), in the distribution of aerosols and trace gases (biogenic and biomass burning) and in cloud cover and patterns of precipitation.
- This region is large enough and has the carbon store necessary to feedback to regional and global climate.

The text and figures provided in this focus issue and editorial serve to illustrate and provide support for this argument.

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