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WARMER URBAN CLIMATES FOR DEVELOPMENT OF GREEN SPACES IN NORTHERN SIBERIAN CITIES

ABSTRACT. Modern human societies have accumulated considerable power to modify their environment and the earth's system climate as the whole. The most significant environmental changes are found in the urbanized areas. This study considers coherent changes in vegetation productivity and land surface temperature (LST) around four northern West Siberian cities, namely, Tazovsky, Nadym, Noyabrsk and Megion. These cities are located in tundra, forest-tundra, northern taiga and middle taiga bioclimatic zones correspondingly. Our analysis of 15 years (2000–2014) Moderate Resolution Imaging Spectroradiometer (MODIS) data revealed significantly (1.3 °C to 5.2 °C) warmer seasonally averaged LST within the urbanized territories than those of the surrounding landscapes. The magnitude of the urban LST anomaly corresponds to climates found 300–600 km to the South. In the climate change perspective, this magnitude corresponds to the expected regional warming by the middle or the end of the 21st century. Warmer urban climates, and specifically warmer upper soil layers, can support re-vegetation of the disturbed urban landscapes with more productive trees and tall shrubs. This afforestation is welcome by the migrant city population as it is more consistent with their traditional ecological knowledge. Survival of atypical, southern plant species encourages a number of initiatives and investment to introduce even broader spectrum of temperate blossoming trees and shrubs in urban landscapes. The unintended changes of the urban micro-climates in combination with knowledgeable urban planning could transform the Siberian pioneer settlements into places of belonging.

KEY WORDS: Surface urban heat island (SUHI), traditional ecological knowledge (TEK), urban green spaces, satellite data analysis, MODIS, NDVI, Siberia.

INTRODUCTION

Urbanized territories represent significantly, or even entirely, anthropogenic environment. Anthropogenic modification of some environmental features, such as landscapes, land use types and air quality, is obvious to any observer. Changes in other environmental features are less apparent. For instance, the vegetation productivity and land surface temperature (LST) changes, considered in this study, could be quantified only through statistical analysis of meteorological data and satellite images.

It is even more difficult to establish unambiguous links between socio-economic, ecologic and physical environments. A straightforward causality approach, from which natural sciences benefit, is usually not fruitful in such studies. Almost any author points to some connections between the physical environment and social aspects of the urban life [e.g. Brown and Raymond, 2007; Barthelet al., 2010; Buyantuyev and Wu, 2010; Wolfe and Mennis, 2012; Hebbert, 2014]. At the same time, the statistical support, aside from the deterministic models, for the proposed constructs remains weak. Boundaries between categories are often unclear and important nuances pertain.

Nevertheless, there is a growing understanding that the urban development should take into account interplay between the environmental and social forces. For instance, a sociological study from Svalbard [Kaltenborn, 1998] found that environmental impact assessments often do not capture a sufficient breadth of qualitative environmental meanings intrinsic to the migrants' groups. Cultural values of the urban migrants' groups are influential factor in the decision making process [Stephenson, 2008]. Those groups possess both technologic and policy strength, but the groups' cultural values may not fully account for the limiting climate and ecosystem resources. This dissonance could be particularly challenging in new pioneering settlements where people rely on their incompatible traditional ecological knowledge (TEK) in solving the environmental issues. Although rather blur and to some degree internally inconsistent [Whyte, 2013], the TEK concept has been shown useful in adaptive environmental management [Berkes et al., 2000]. McBride and Douhovnikoff [2012] study gives an example of the migrants' TEK in action. They show that high symbolic and cultural values of trees drive significant efforts for urban afforestation and creation of urban green places in polar cities with climates as harsh as in Nuuk (Greenland).

Similar dissonance in the social-environmental interactions characterizes the northern West Siberia (NWS) cities. Intensive exploration of the oil and gas reserves drives migration from the temperate climate zone to new urban centers in the cold continental climate zone. As the natural landscape in the NWS is valued rather low in the migrants' TEK, the urban development went along with significant damages to the natural vegetation cover, soils and hydrological systems. Wide use of sand in urban development modified thermal features, albedo and moisture content of artificial urban soils. As we show in this study, high albedo of urbanized territories is effectively counterweighted by other physical factors leading to elevated averaged LST in the cities. This is in dramatic contrast to the reported albedo-dominated feedbacks in the cities of lower latitudes (e.g. Jin et al., 2005]. The albedo-vegetation feedback is also contrasting in high latitudes. Li et al. (2015] found that boreal forests have strong warming effect in winter and moderate cooling effect in summer with net warming annually. Thus, the NWS cities have warmer micro-climate, which helps afforestation and survival of introduced more southern and more productive tree species (Srodnykh, 2008], and vice versa, the urban afforestation and green spaces might support warmer micro-climates in cities. We reveal that vegetation productivity in and around the cities is increasing, perhaps as a response on the warmer micro-climates.

The introduction of temperate blossoming plants is welcome by the migrants' population. Although the cold climate vegetation remains biologically inactive during the largest part of the year, it still changes the aerodynamic and thermal resistances of the lowermost atmospheric layer, surface emissivity and albedo as well as soil characteristics. Beyond the physical impact of vegetation, growing empirical evidence indicates its impact on population health and lifestyles, eventually contributing to the population psycho-physiological comfort (Zrudlo, 1988; Nikolopoulou and Steemers, 2003]. Urban green spaces serve as places of identity and belonging. They provide important social and psychological benefits enriching human life and emotions. Those benefits might be as important to urban sustainability as more recognized recreation and protective services of the green spaces (Royet al., 2012]. Indeed, sociological studies in Niznevartovsk [Vyhodzev, 2010] demonstrated that a lack of urban green spaces was an influential factor degrading the perception of sense of place and ecological perspectives among the city dwellers. Only 40 % of the respondents in this city considered it as the place of permanent residency in 2009. This is a considerable decline from almost 80 % reported in 1989.

Although far from being exhaustive, the reviewed literature highlights the high cultural value and psychological benefits of urban green spaces. Creation of "sense of place" and green spaces in the NWS cities is more difficult and requires more resources than similar development in lower latitudes. The major vegetation limiting factor here is the cold climate with its low winter temperatures and a short growing season [Barichivich et al., 2014]. Another frequently cited limiting factor – soil moisture – may have an impact on the vegetation surrounding the cities, but the tended urban vegetation is likely to be insensitive to it.

The warmer urban soils and the warmer surface air layers could significantly alleviate constraints imposed by the low temperatures. The systematic temperature difference between the urban and the surrounding rural locations are known in literature as the urban heat island (UHI). UHI is usually related to the air temperature. Therefore, we distinguish the surface urban heat island (SUHI) in the study of the LST contrasts. There are several publications reporting warmer UHI in the polar cities [Magee et al., 1999; Hinkel and Nelson, 2007; Klene et al., 2013; Konstantinov et al., 2015]. Wienert and Kuttler [2005] found that the UHI amplitudes increase towards high latitudes. The dependence could be explained by trapping and accumulating the additional anthropogenic urban heat in shallow stably stratified atmospheric boundary layer [Davy and Esau, 2016]. Neither UHI nor SUHI were studied in the NWS cities. Sparse in situ observational networks do not allow UHI identification. Moreover, many existing stations of the WMO network are located at airports, thus making the data unsuitable, as we will show here.

The subsequent presentation consists of three parts. The next section describes the data and methods followed by the section reporting the results. These sections comply with the quantitative rigor of the natural earth's system science. The last section presents discussion and conclusions. Here we attempt to bridge with the Stedman's [2003] interpretation of the physical environment as a key element of the social "sense of place" construct.

DATA AND METHOD

The UHI amplitudes are usually calculated from in situ meteorological observations both at regular certified stations and increasingly at irregular networks of citizens' observations [Meier et al., 2015]. Nevertheless, even dense citizens' observation networks do not cover the diversity of urban micro-climates as they tend to concentrate in residential areas leaving urban green spaces without coverage [e.g. Moelders and Olson, 2004].The regular networks are sparse so that pairing of urban and rural stations is difficult [e.g. Mishra et al., 2015]. In the considered NWS cities, such pairing was impossible. There were no self-identified urban stations and only three airport stations are included in the regular WMO network in the NWS.

A new perspective on the urban heat islands is provided by the hyperspectral Moderate Resolution Imaging Spectroradiometer (MODIS) system, channels 31 and 32 (10.78–11.28 and 11.77–12.27 micrometers, respectively) onboard of Terra and Aqua satellites. We used two MODIS data products. The level-3 MODIS global LST 8-day data (MOD11A2) are composed from the daily 1-kilometer LST product (MOD11A1) and stored on a 1-kilometer Sinusoidal grid (SIN) as the average values of clear-sky LSTs during an 8-day period. The further processing of these data products was similar to the processing of a Normalized Difference Vegetation Index (NDVI) data. Therefore, we describe below only the NDVI data processing from Esau et al. [2016] and Miles and Esau [2016].

LST data characterize SUHI. The LST is related to the surface air temperatures but may have considerable deviations in the seasonal and diurnal cycles, since they are more sensitive to the surface energy balance and less to the turbulent exchange in the overlying atmosphere [Gentine et al., 2010].

Schwartz et al. [2011] used MODIS LST products for 2002–2003 to study the SUHI and its relations with other eleven urban heat island indicators in 263 European cities. They found that time series of SUHI and other indicators individually reveal diurnal and seasonal patterns but show rather low correlations over time, although they were constructed to quantify the same phenomenon. Recently, Konstantinov et al. [2015] compared the MODIS LST and the spatially distributed direct observations of the surface air temperatures in the city of Apatity. They concluded that the air temperature calculated according to the MODIS data is systematically higher under winter conditions than the air temperature from direct measurement data.

To identify permanent thermal anomalies associated with urban areas we used the Terra/MODIS Land surface temperature (LST) data from 2001 to 2015. Land surface temperature and emissivity product, MOD11A2 of Terra-MODIS has been used in the study. MOD11A2 is an eight-day LST product by averaging from two to eight days of the clear sky MOD11A1 daily product of Terra-MODIS and has 12 Science Data Sets (SDS) layers [Li, 2013]. It has high calibration accuracy in multiple thermal infrared bands designed for retrievals of LST and atmospheric properties [Wang, 2008]. A split-window algorithm is used for calculating LSTs. The day/night LST method retrieves land-surface temperature and band emissivity simultaneously from pairs of daytime and nighttime MODIS data in seven TIR bands.

LST composites were downloaded from http://reverb.echo.nasa.gov/. The downloaded data is in HDF-EOS format and in SIN Projection System. The data were re-projected to UTM Zone 42N projection system with WGS84 datum and were reformatted from HDF-EOS to GeoTIFF format and converted from Kelvin to degree centigrade. According to the product quality control flag, the data we used have an average LST error less than or equal to 2 °C. We process day and night LST data. For Terra/MODIS the satellite overpass time is approximately 10:30 and 22:30 local time.

For each city, we compute annual mean LST per pixel by aggregating the available 8-days-mean composite separately for winter and summer. The mean values were calculated based on the 14 year time series. As a result we produced temporally average summer and winter LST map for each city. To compute SUHI magnitudes, we identified urban and rural pixels. Urban pixels were allocated by the city polygon; the surrounding, non-urban land, was considered as rural. Rural pixels are classified as natural surfaces such as different type of forest and non-forested areas.

The changes in vegetation productivity are characterized using the maximum annual NDVI (NDVImax). NDVI is defined as a normalized ratio of reflectance factors in the near infrared and red spectral radiation bands. NDVI is based on the contrast between red and near infrared reflectance of vegetation, as chlorophyll is a strong absorber of red light, whereas the internal structure of leaves reflects highly in the near infrared. Vegetation produces positive NDVI and approaches + 1 with increasing plant chlorophyll content or green biomass. The tiles of the original data products were downloaded and imported into the ArcGIS geographic information system (GIS). Images were reprojected to the universal Transverse Mercator projection (UTM Zone 42N, WGS84 ellipsoid). The data were quality-filtered by the MODIS reliability data provided together with the products, to retain only data of the highest quality. The gaps in the raster pixels were filled with information using the nearest neighbor statistical interpolation from the surrounding pixels with data. The percentage of excluded pixels is variable, ranging from 10 %–30 %. The NDVI values below 0.2 are generally non-vegetated surfaces and green vegetation canopies are generally greater than 0.3. A 0.3–1 NDVI threshold was used to exclude water, bare soil and other non-vegetated pixel from the analysis.

We use annual maximum NDVI (NDVImax) in this study. NDVImax values characterize the maximum development and represent the peak greenness achieved by vegetation during the growing season. Summarizing

NDVI into NDVImax composites eliminates any seasonal variation in NDVI and reduces the errors in beginning of phenological phases between different vegetation zones. An NDVImax map for each year (summer, JJA) was compiled by selecting the maximum NDVI value from each 16-day composite for each pixel. This results in a 250 m resolution, 15-year dataset of NDVImax and generated an up-to-date 15-year mean NDVImax map throughout NWS. We do not analyze here the NDVI data for the winter period.

The MODIS NDVImax and LST data for the 2000–2014 summers (June–July–August, JJA) and winters (December–January–February, DJF) were computed across the entire NWS area. For the specific purpose of this study, the data were clipped in 40 x 40 km squares centered at the four cities. The cities are Tazovskiy, Nadym, Noyabrsk and Megion.

Statistical methods were applied to the time series in order to provide metrics and to identify and test for changes. Time series characteristics of interest are the seasonal means for the LST and trends for the NDVImax. The linear trends in NDVImax were obtained for the period 2000–2014 through the Ordinary Least Squares (OLS) regression for each pixel stack, with year as the independent variable and NDVImax as the response variable. The purpose is to do a pixel-wise trend analysis and extract only significant trends over a certain period of time for rejecting the null hypotheses. To identify pixels with statistically significant trends, we masked out all pixels with an estimate p-value >0.05.

RESULTS

This study considers four NWS cities (Tazovskiy, Nadym, Noyabrsk, and Megion) located in four bioclimatic zones such as tundra, forest-tundra, northern and middle taiga, correspondingly. Table 1 summarizes the city characteristics. The MODIS-based climatology reveals that all four cities have significantly modified LST and vegetation cover. Figure 1 shows that warmer mean seasonal temperatures are found in the urbanized areas. The strongest and the most localized SUHI is found in Noyabrsk. The LST maps need some comments. All four cities are surrounded by very sparsely populated areas. There are no sub-urban or rural settlements there. Nevertheless, one can observe that the spots of warmer LST are found not only within the cities but also around them. Most of those spots are identified as lakes, large rivers and, in summertime, patches of drier sandy soils. There are also many industrial installations and locations of drilling platforms, particularly around Megion. The detailed analysis of these warmer spots is beyond the scope of this study.

Urban development destroys the natural vegetation cover. In addition, many northern cities are built on the artificial sandy ground that is higher than the surrounding landscape and therefore better drained. Distortions of the established cold-conserving ecosystems [Archegova, 2007], better drainage and anthropogenic heating (up to 50 $W \cdot m^{-2}$) create favorable conditions for reclaiming the urban land disturbances by broad-leaf and dark-needle trees and other more southern plant species [Lloyd et al., 2003; Koronatova and Milyaeva, 2011]. However, except for the northernmost city of Tazovskiy, no significant correlation between the NDVImax and LST was found. Perhaps, we observe here the effect of lacking nutrients in the sandy soils as it has been pointed to in [Srodnykh, 2008]. More detailed analysis revealed that there is a productivity decline in all types of forests except that in larch forest in the tundra-forest zone (Nadym). The patches of unforested area do demonstrate statistically significant greening, i.e., increase of vegetation productivity. This urban greening is particularly interesting to observe in the southernmost city of Megion where the surrounding vegetation shows no NDVImax changes or even widespread significantly negative trends.

The city of Nadym is of specific interest here. Figure 1 shows the mean seasonal LST patterns

Table 1. Four cities in Western Siberia included in the study. The city population (pop. in thousands inhabitants) is given from the Russian national census, 2010. The mean background *NDVImax* (nature) is shown for the most distant 40-km ring. The relative trends are given for the time series without the years with the minimum and maximum *NDVImax*. Statistically significant trends at 95 % level are underlined. The biomes are abbreviated as: tundra (T); forest-tundra (FT); northern taiga forest (NTF); and middle taiga forest (MTF). The analysis is based on 2000–2014 (15 years) climatology

N	City Name	Lat. Long.	Pop. (×1000)	Biome	UHI [K] Summer	UHI [K] Winter	Mean NDVImax (nature)	NDVImax trend (nature) [% dec^{-1}]	Mean NDVImax (city core)	NDVImax trend (city core) [% dec^{-1}]
1	Tazovskiy	67°28′N 78°42′E	↓7	NTF	0.3	0.8	0.73	+1.5 %	0.63	**+7.6 %**
2	Nadym	65°32′N 72°31′E	↓46	NTF	1.3	1.8	0.71	+1.2 %	0.55	–1.8 %
3	Noyabrsk	63°11′N 75°27′E	↓107	MTF	3.2	2.7	0.69	No change	0.60	+0.6 %
4	Megion	61°22′N 76°06′E	↓49	MTF	1.3	1.6	0.77	+0.8 %	0.52	**+6.9 %**

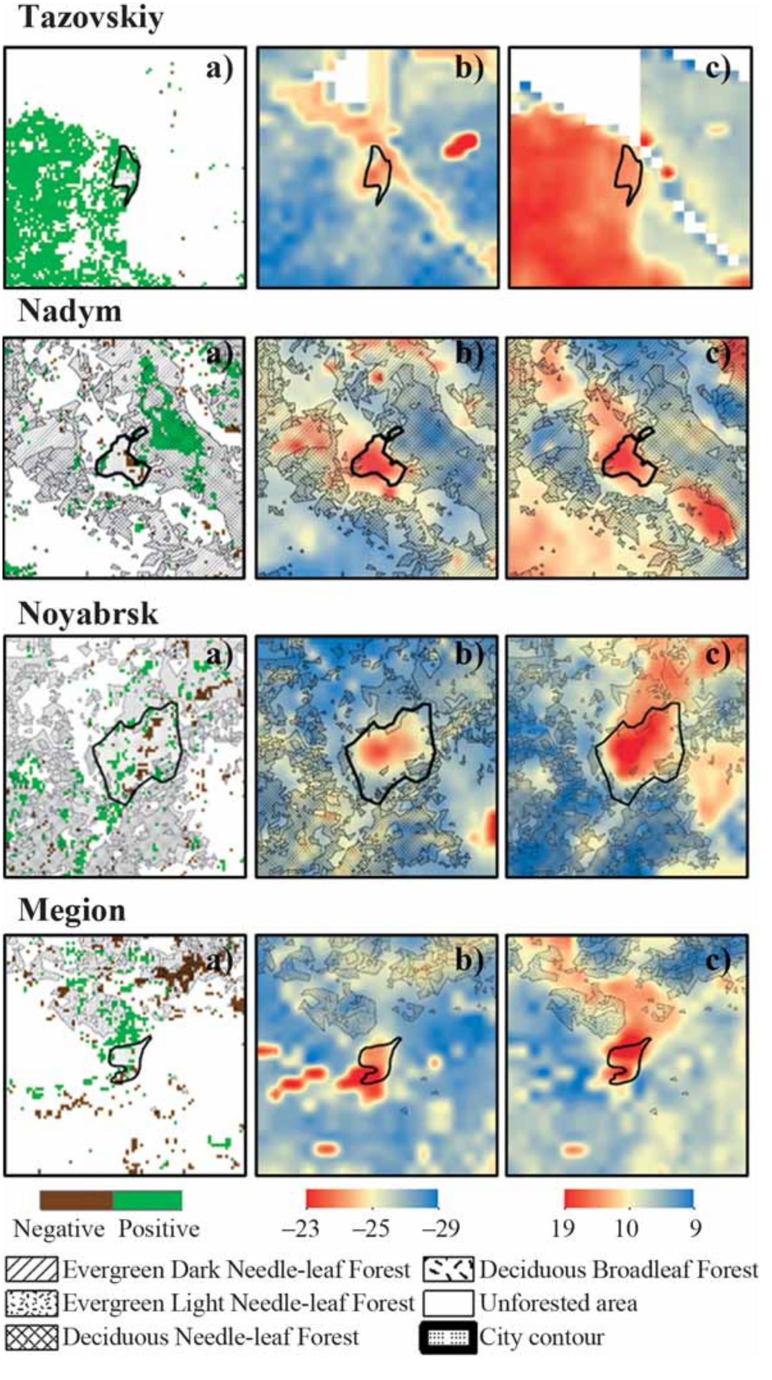

Fig. 1. Maps of four cities situated in different bioclimatic zones of the northern West Siberia: tundra (Tazovskiy); forest-tundra (Nadym); northern taiga (Noyabrsk); and middle taiga (Megion).

The panels (a) show the statistically significant NDVImax trends. The panels (b) and (c) show the seasonally averaged LST for the winter (DJF) and summer (JJA) seasons, correspondingly. The bold black contours identify the city boundaries. The different vegetation types [Bartalev et al. 2014] are shown with hatching.

around Nadym. The winter warmer spots are mostly localized within the city boundary. This is consistent with active anthropogenic heat release in the city. The summer warmer spots are more widely distributed. A strong warmer spot emerges to the southeast from the city. Figure 2 details the mean summer LST pattern around Nadym. The reader can observe that a summer seasonal warmer spot is associated with the Nadym airport. The airport area is a vast barren soil and sand area as the Google Earth image in the collage shows. One can observe that the meteorological station Nadym (WMO code 23445) is found within the warmer spot in summertime. The airport warmer spot disappears in wintertime. It helps to distinguish between the direct anthropogenic urban heating, which creates the Nadym SUHI, and the indirect heating induced by the surface energy balance changes due to drier barren and sandy soil, which creates the airport SUHI due to reduced heat consumption on evapotranspiration. Longer field studies summarized by Moskalenko [2009] reveal the permafrost and vegetation changes in Nadym in 1970–2008. The human-induced terrain disturbances were reclaimed by plant communities of birch (*Betula nana*), pines (*Pinus silvestris, P. sibirica*) and tall shrubs, which are more typical of northern taiga ecosystems further south from this area. The statistically significant increase of the NDVImax (greening) is found for all vegetation cover types around the city. Although the most pronounced greening in the larch (*Larix sibirica*) forest is likely unaffected by the SUHI, the greening of the urban green spaces is found in the areas where the annual mean SUHI reaches 4–5 K.

Similar SUHI and NDVImax trends patterns are found around Noyabrsk. The urban greening is widespread in this city and around the airport. The airport SUHI has smaller magnitude, presumably because it occupies smaller area and does not have such a strong soil moisture contrast with the surrounding territory.

We further studied the mean NDVImax and its trends in eight 5-km wide rings around the city cores. Figure 3 shows that the ring closest to the city, and therefore the most affected by the SUHI but only insignificantly disturbed by the direct human activity, has higher NDVImax than the more distant rings. This NDVImax difference is statistically significant

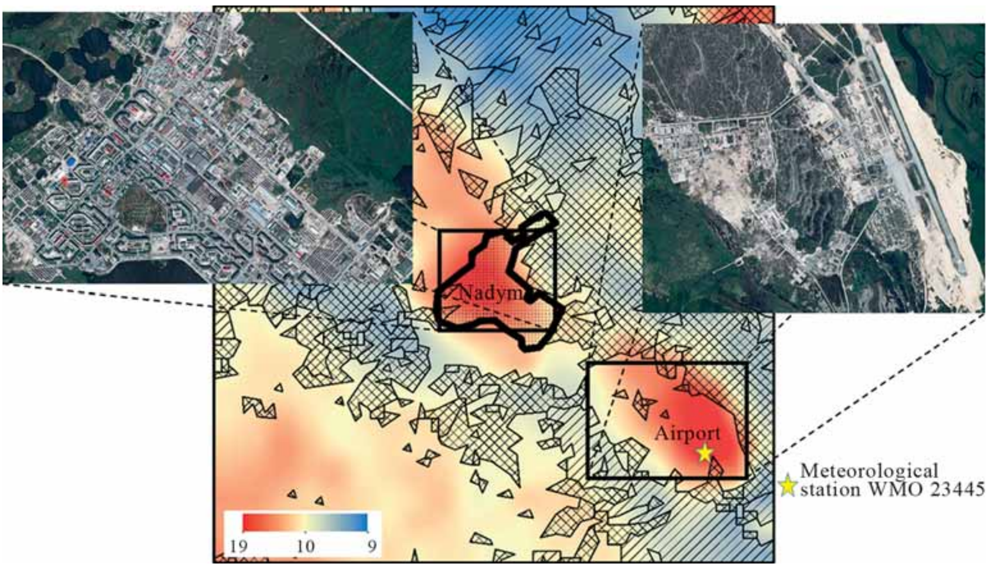

Fig. 2. The mean summer LST (color scale) and the vegetation cover types (the same as in Fig. 1) around Nadym and the Google Earth© images of the two selected warmer spots.

The meteorological station Nadym (WMO nr. 23445) is located within the summer seasonal warm spot at the airport.

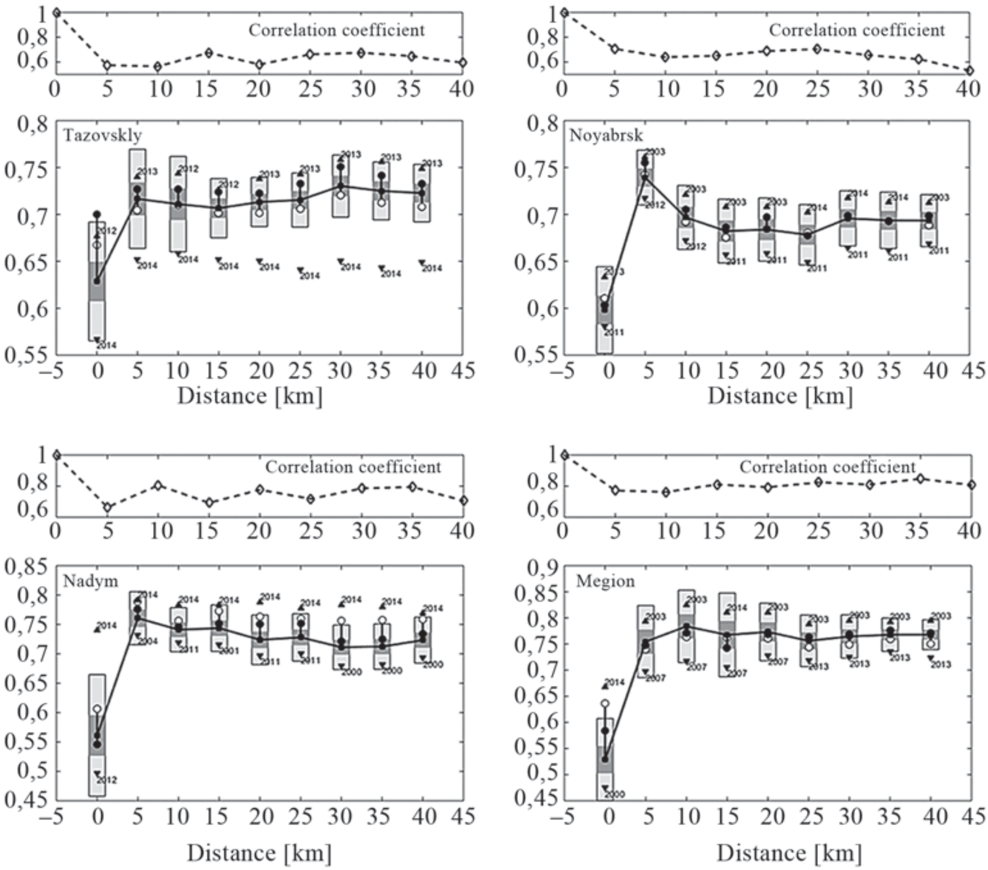

Fig. 3. The statistical structure of NDVImax, correlations and trends at the city-core and the eight 5-km wide rings around Tazovskiy (tundra), Nadym (tundra-forest), Noyabrsk (northern taiga) and Megion (middle taiga).

The distance is given in kilometers from the central pixel of each city. The upper panels for each city show the decay of time series correlations (extreme years were excluded from the calculation to improve robustness of the parameter estimation) between the NDVImax at the city core and at the given distance. The lower panels show: bold line with squares – the mean NDVImax; dark gray rectangle – 1 standard deviation of NDVImax for each ring; light gray rectangles – 3 standard deviations; triangles – the years with the maximum (upward-looking triangle) and the minimum (downward-looking triangle) of NDVImax; vertical black line with white circle – the magnitude of the NDVImax change obtained as the trend multiplied by 15 years; black circle – the same as the white circle but for the trends obtained when the maximum and the minimum NDVImax were excluded.

($p < 0.05$) in Noyabrsk. Both the cities and the first rings around them exhibit larger positive NDVImax trends than the surrounding natural vegetation. This difference is however statistically insignificant as the sample size (15 years) is too small. Figure 3 also includes the outliers in the years of maximum and minimum biological production. It is interesting that the anomalously cold summer in 2014 resulted in the maximum NDVImax in Nadym, but in the record minimum NDVImax further east in Tazovskiy.

DISCUSSION

One of the aims of the physical environment studies is to gain robust and quantitative knowledge for sustainable development of the human societies. Arguably, such knowledge is in particularly large demand in migrant societies where the intuitive TEK of the members becomes unreliable or at least insufficient. If the industrial development and resource extraction are purely driven by technologically optimized solutions, the created living environment becomes destructive to the human aspects of life such as those collectively described as sense of place. Sense of place interlinks the physical environment, human behaviors, preconditioned by the groups' TEK, and social/psychological processes [Stedman, 2003).

In majority of publications the physical and human environments are still considered independently. As a relevant example, one can use the studies of urban forest, urban air pollution and urban green spaces in general. It was argued that the main service of the urban green spaces is to provide protection from the physical (wind, direct solar radiation) and chemical factors. However, the polar vegetation is inactive during the largest part of the year; its growth is limited by the cold climate, and therefore, its environmental services are inefficient. Moreover, the LST – vegetation feedbacks, particularly on climatic time scales, are not firmly established. Li et al. [2014] study suggested that the boreal forest effect leads to strong winter (and the annual mean) warming and moderate summer cooling. Contrary, our results show that the larch forest remains significantly colder than the open green spaces even in wintertime (see Fig. 2).

There are a growing number of publications (see Introduction) where the accents are shifted onto social services of the green spaces. For instance, it has been shown that the green spaces improve the health perception much more than they actually can improve the air quality [Kardan et al., 2015]. One of the first policy moves in the NWS cities when they were converted into the permanent settlements was to establish the green planning and nature conservation initiatives [Srodnykh, 2006]. The migrants' TEK connects the green spaces and the living comfort and encourages different forms of green planning even those involving significant time, administrative and financial resources[1]. More recently, municipal administrations have raised investment into experiments with more southern plant species and even fruit trees[2]. The population attitudes towards the permanent residency dramatically degrade in the cities where such initiatives were delayed [Vyhodzev, 2010].

It has been shown that the urban migrants' groups have intrinsic cultural and TEK attachments to trees [McBride and Duhovnikoff, 2013]. The vegetation communities in the cold Siberian climate are limited both in number of tree species and in their biologic productivity. Recently, Miles and Esau [2016] demonstrated that the forest in the NWS reveals widespread negative biological production trends. But those trends are found to be reduced or even reverted around 28 cities in this region [Esau et al., 2016]. We put forward a hypothesis that the urban-background differences in the forest productivity could be linked with the higher LST and drier soils in the NWS cities as well as with denser stand and different composition of species of the urban forested patches.

This study considered the remotely sensed mean seasonal LST and NDVImax climatology (2000–2014) in and around four cities. We found that all four cities are associated with the warmer LST spots in both winter and summer seasons. The summertime SUHIs vary from +1.7 °C in the smallest and the northernmost city of Tazovskiy to +5.2 °C in the largest city of Noyabrsk. The wintertime SUHIs vary from +1.3 °C in Tazovskiy to +3.9 °C in Noyabrsk. Thus, this sub-sample of the NWS cities suggests that the SUHI strongly depends on the city size.

The vegetation productivity is modulated by the city policy towards the green spaces or, by the other words, by the human factor. Nevertheless, Noyabrsk still demonstrates the largest urban greening trend (+ 0.6 %) when the trends in the natural vegetation cover have been subtracted. At the same time the NDVImax trend in Nadym is negative. The

[1] http://nadymregion.ru/news/11166-priglashaem-zhiteley-prinyat-uchastie-v-konkurse-nadym-cvetuschiy-gorod-kray-nego-severa.html

[2] http://neelov.ru/1830-v-nadyme-vysadili-ekzoticheskie-dlya-yamala-sorta-derevev.html http://newurengoy.rusplt.ru/index/Uchenye_pytajutsja_zasadit_Novyj_Urengoj_derev-jami-9412.html

reduction of productivity has been associated with the larch forest on the eastern rim of the city. It has been established that *Larix sibirica* forest negatively responses to the raising LST and air temperatures. The greening of the larch forest around Nadym is associated with the coldest spots of the LST map. Figure 3 shows that when the year of extremely high NDVImax (2014) is included in the analysis, the trends become positive in Nadym as well. Development of urban green spaces in Nadym consistently demonstrated implementation of the migrant's TEK. The city not only conserves the existing relict forest patches, such as dark-needle *Pinus sibirica* forest in the city park, but also actively introduces exotic southern plant species. It is interesting, that the ecological behavior is not considered as efforts to conserve patches of the natural vegetation types but as introduction of even larger areas of temperate vegetation[3]. The ultimate expression of such cultural attitude is given by the municipal program "Nadym – the blossoming city of the North" fostering the participation of city dwellers in the tree and flower planting work. Increasing psychological comfort might explain such a cherished attitude to the flowers and temperate trees (e.g. *Malus sylvestris*) in contrast to the widely presented neglecting of the natural vegetation systems.

There are two popular strategies in the NWS to reclaim the disturbed natural vegetation cover. The conservation strategy emphasizes the minimum human interference with the natural processes, whereas the tending strategy focuses on green development and urban afforestation. As applied to the NWS cities, both strategies seem to be rather idealized social constructs with little reference to the real physical environment of the territory. Many studies [e.g. Moskalenko, 2009; Koronatova and Milyaeva, 2011] demonstrated that the disturbed landscapes are reclaimed by essentially different vegetation communities. This study suggests that such a shift to alternative ecosystems is driven by the warmer LST among other factors which are more difficult to quantify.

[3] A good illustration of this controversial perception of the conservation issues is given by a new 'Ecopark" project, see http://www.gazprom.ru/about/subsidiaries/news/2013/july/article166464/

CONCLUSION

In summary, this study shows that, at present, the physical climate change due to the surface urban heat island effect and the culturally motivated landscape modifications are broadly aligned. The NWS cities are associated with the warmer LST and embrace the more productive vegetation. The reviewed literature indicates that the urban vegetation communities are increasingly composed of more southern plant species. The specific efforts in the urban afforestation are directed towards planting temperate broad-leaf blossoming trees and tall shrubs. The warmer urban LST and creation of "urbanizems" [Srodnykh, 2008] support these efforts, and vice versa, the urban afforestation taken at large could maintain the urban heat islands. The SUHI may have also an unexpected implication for the climate change analysis in the region as the majority of meteorological stations are located within the SUHI (primarily at the airports).

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REFERENCES

1. Archegova I.B. (2007). Thermal Regime of Tundra Soils under Reclamation and Restoration of Natural Vegetation, Eurasian Soil Science, Vol. 40, pp. 854–859.

2. Barichivich J.,Briffa K.R.,Myneni R., van der Schrier G., Dorigo W., Tucker C.J., Osborn T.J., Melvin T.M. (2014). Temperature and Snow-Mediated Moisture Controls of Summer Photosynthetic Activity in Northern Terrestrial Ecosystems between 1982 and 2011, Remote Sensing, Vol. 6, pp. 1390–1431.

3. Bartalev S.S., Kissiyar O., Achard F., Bartalev S.A., Simonetti D. (2014). Assessment of forest cover in Russia by combining a wall-to-wall coarse resolution land-cover map with a sample of 30 m resolution forest maps, International Journal of Remote Sensing, Vol. 35, pp. 2671–2692.

4. Barthel S., Folke C., Colding J. (2010). Social-ecological memory in urban gardens – Retaining the capacity for management of ecosystem services, Global Environmental Change, Vol. 20, pp. 255–265.

5. Berkes F., Colding J., Folke C. (2000). Rediscovery of Traditional Ecological Knowledge as Adaptive Management, Ecological Applications, Vol. 10, pp. 1251–1262.

6. Brown G., Raymond C. (2007). The relationship between place attachment and landscape values: Toward mapping place attachment, Applied Geography, Vol. 27, pp. 89–111.

7. Buyantuyev A., Wu J. (2010). Urban heat islands and landscape heterogeneity: linking spatiotemporal variations in surface temperatures to land-cover and socioeconomic patterns, Landscape Ecology, Vol. 25, pp. 17–33.

8. Davy R., Esau I. (2016). Differences in the efficacy of climate forcings explained by variations in atmospheric boundary layer depth, Nature Communications, Vol. 7, 11690, doi: 10.1038/ncomms11690

9. Esau I., Miles V., Miles M., Davy R., Kurchatova A. (2016). Trends in the normalized difference vegetation index (NDVI) associated with urban development of Northern West Siberia, Atmospheric Chemistry and Physics, doi: 10.5194/acp-2016-51

10. Hebbert M. (2014). Climatology for city planning in historical perspective, Urban Climate, Vol. 10, pp. 204–215.

11. Gentine P., Entekhabi D., Polcher J. (2010). Spectral Behavior of a Coupled Land-Surface and Boundary-Layer System, Boundary-Layer Meteorology, Vol. 134, pp. 157–180.

12. Jin M., Dickinson R.E., Zhang D. (2005). The Footprint of Urban Areas on Global Climate as Characterized by MODIS, Journal of Climate, Vol. 18, pp. 1551–1565.

13. Kaltenborn B.P. (1998). Effects of sense of place on responses to environmental impacts. A study among residents in Svalbard in the Norwegian high Arctic, Applied Geography, Vol. 18, pp. 169–189.

14. Kardan O., Gozdyra P., Misic B., Moola F., Palmer L.J., Paus T., Berman M.G. (2015). Neighborhood green space and health in a large urban center, Scientific Reports, Vol. 5, doi: 10.1038/srep11610

15. Klene A.E., Nelson F.E., Hinkel K.M. (2013). Urban–rural contrasts in summer soil-surface temperature and active-layer thickness, Barrow, Alaska, USA, Polar Geography, Vol. 36, pp. 183–201.

16. Konstantinov P.I., Grishchenko M.Y., Varentsov M.I. (2015). Mapping Urban Heat Islands of Arctic Cities Using Combined Data on Field Measurements and Satellite Images Based on the Example of the City of Apatity (Murmansk Oblast), Izvestiya of the Russian Academy of Science, Atmospheric and Oceanic Physics, Vol. 51, pp. 992–998.

17. Koronatova N.G., Milyaeva E.V. (2011). Plant Community Succession in Post-Mined Quarries in the Northern-Taiga Zone of West Siberia, Contemporary Problems of Ecology, No. 4, pp. 513–518.

18. Li Y., Zhao M., Motesharrei S., Mu Q., Kalnay E., Li S. (2015). Local cooling and warming effects of forests based on satellite observations, Nature Communications, Vol. 6, 6603.

19. Li Z.-L., Tang B.-H., Wu H., Ren H., Yan G., Wan Z., TrigoI.F.,Sobrino J.A. (2013). Satellite-derived land surface temperature: Current status and perspectives, Remote Sensing of Environment, Vol. 131, pp. 14–37.

20. Lloyd A.H., Yoshikawa K., Fastie C.L., Hinzman L., Fraver M. (2003). Effects of Permafrost Degradation on Woody Vegetation at Arctic Treeline on the Seward Peninsula, Alaska, Permafrost Periglacial Processes, Vol. 14, pp. 93–101.

21. Magee N., Curtis J., Wendler G. (1999). The Urban Heat Island Effect at Fairbanks, Alaska, Theoretical and Applied Climatology, Vol. 64, pp. 39–47.

22. McBride J., Douhovnikoff V. (2012). Characteristics of the urban forests in arctic and near-arctic cities, Urban Forestry and Urban Greening, No. 11, pp. 113–119.

23. Meier F., Fenner D., Grassmann T., Jänicke B., Otto M., Scherer D. (2015). Challenges and benefits from crowd sourced atmospheric data for urban climate research using Berlin, Germany, as testbed. ICUC9 – 9th International Conference on Urban Climate jointly with 12th Symposium on the Urban Environment, 2015, Berlin.

24. Mishra V., Ganguly A., Nijssen B., Lettenmaier D. (2015). Changes in observed climate extremes in global urban areas, Enviromental Research Letters, Vol. 10, 024005.

25. Miles V., Esau I. (2016). Satellite record of normalized difference vegetation index (NDVI) reveals contrasting trends in northern West Siberia, Environmental Research Letters, submitted.

26. Moelders N., Olson M.A. (2004). Impact of Urban Effects on Precipitation in High Latitudes, Journal of Hydrometeorology, Vol. 5, pp. 409–429.

27. Moskalenko N. (2009). Permafrost and vegetation changes in the Nadym region of West Siberian northern taiga due to the climate change and technogenesis, Earth Cryosphere, Vol. 13, pp. 18–23.

28. Nikolopoulou M., K. Steemers (2003). Thermal comfort and psychological adaptation as a guide for designing urban spaces, Energy and Buildings, Vol. 35, pp. 95–101.

29. Hinkel K.M., Nelson F.E. (2007).Anthropogenic heat island at Barrow, Alaska, during winter: 2001–2005, Journal of Geophysical Research, Vol. 112, D06118.

30. Roy S., Byrne J., Pickering C. (2012). A systematic quantitative review of urban tree benefits, costs, and assessment methods across cities in different climatic zones, Urban Forestry and Urban Greening, Vol. 11, No. 4, pp. 351–363.

31. Schwarz N., Lautenbach S., Seppelt R. (2011). Exploring indicators for quantifying surface urban heat islands of European cities with MODIS land surface temperatures, Remote Sensing of Environment, Vol. 115, pp. 3175–3186.

32. Srodnykh T.B. (2006) Ozeleneniye gorodov Tyumenskogo severa (Greening of the Tyumen northern cities) Ekaterinburg, Ural State Forest Engineering University, 139 p. (in Russian).

33. Srodnykh T.B. (2008) Rost i razvitiye pod vliyaniyem zonalnykh i intrazonalnykh faktorov drevesnykh vidov, preobladayushchikh v ozelenenii severnykh gorodov Zapadnoi Sibiri (Growth and development under the influence of zonal and intrazonal factors of woody species prevailing in urban greening of the northern cities of West Siberia). Agrarian Herald of Urals, Vol. 8, Np. 50, pp. 79–83. in Russian.

34. Stedman R.C. (2003). Is It Really Just a Social Construction?: The Contribution of the Physical Environment to Sense of Place, Society and Natural Resources, Vol. 16, pp. 671–685.

35. Stephenson J. (2008). The Cultural Values Model: An integrated approach to values in landscapes, Landscape and Urban Planning, Vol. 84, pp. 127–139.

36. Wang W., Liang S., Meyers T. (2008). Validating MODIS land surface temperature products using long-term nighttime ground measurements, Remote Sensing of Environment, Vol. 112, pp. 623–635.

37. Whyte K.P. (2013). On the role of traditional ecological knowledge as a collaborative concept: a philosophical study, Ecological Processes, Vol. 2, 7.

38. Wienert U., Kuttler W. (2005). The dependence of the urban heat island intensity on latitude – A statistical approach, Meteorologische Zeitschrift, Vol. 14, pp. 677–686.

39. Wolfe M.K., Mennis J. (2012). Does vegetation encourage or suppress urban crime? Evidence from Philadelphia, PA, Landscape and Urban Planning, Vol. 108, pp. 112–122.

40. Zrudlo L. (1988). The design of climate-adapted arctic settlements, in: J. Manty, N. Pressman (Eds.), Cities Designed for Winter, Building Book Ltd., Helsinki.

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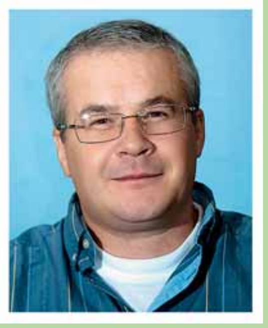

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