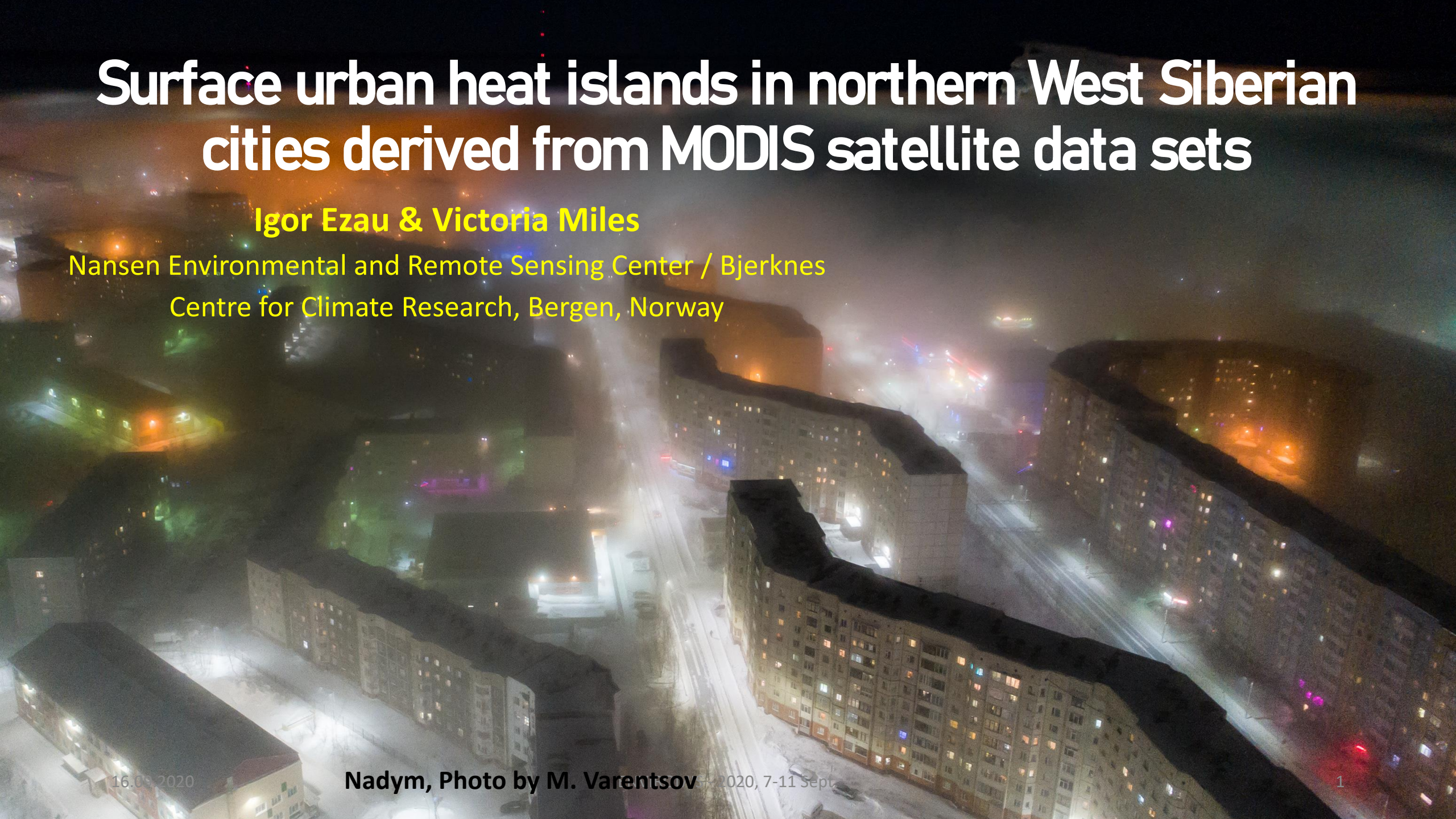
Surface urban heat islands in northern West Siberian cities derived from MODIS satellite data sets

Igor Ezau & Victoria Miles

Nansen Environmental and Remote Sensing Center / Bjerknes Centre for Climate Research, Bergen, Norway



Nadym, Photo by M. Varentsov

Overview

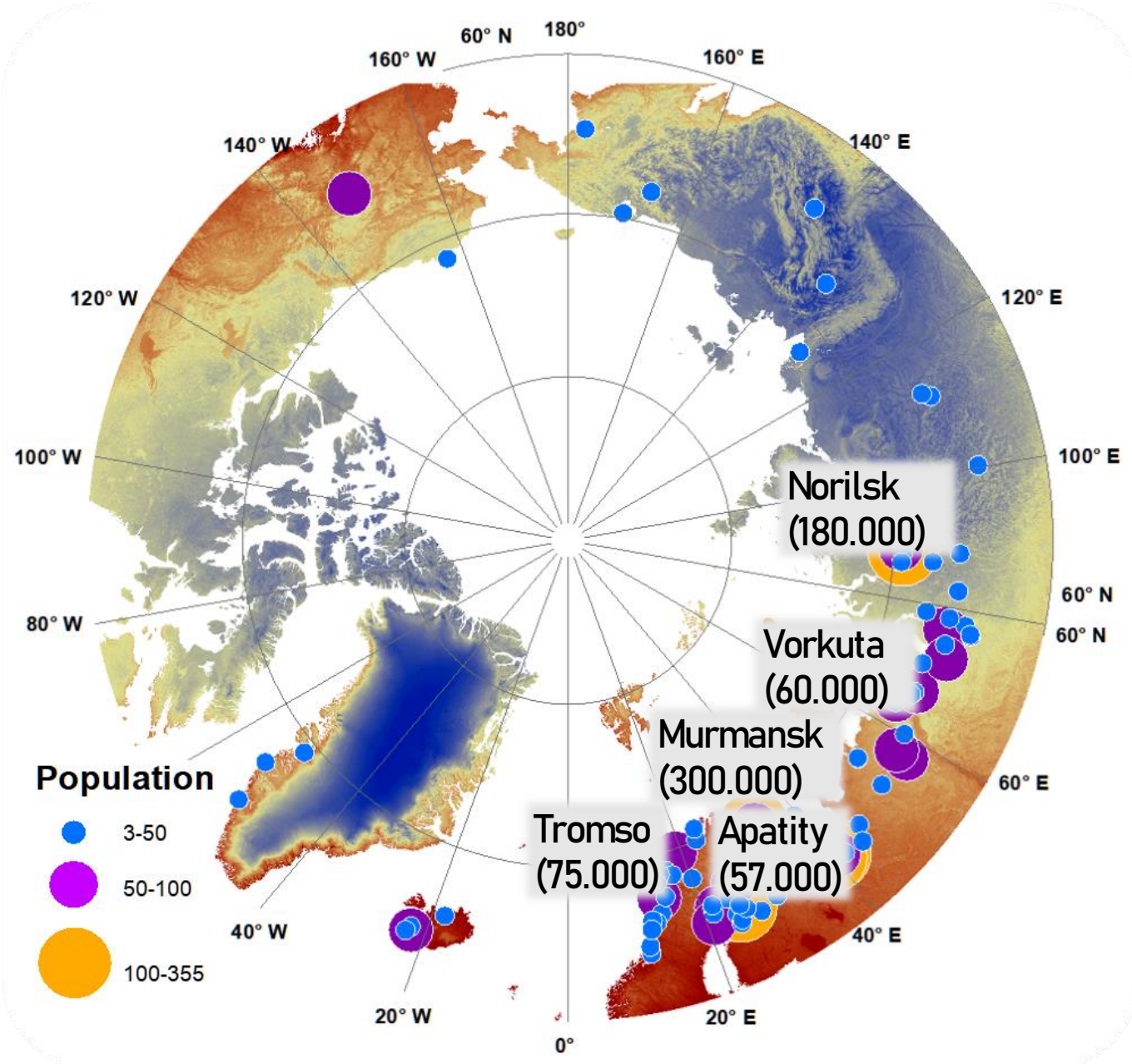
- *Urban Arctic*
- *Warmer Arctic*
- *Urban Heat Island*
- *Land use – land cover impact*
- *Green belts and vegetation*
- *Sustainability and risks – urban Arctic harbinger of future environment*

The Urban North:

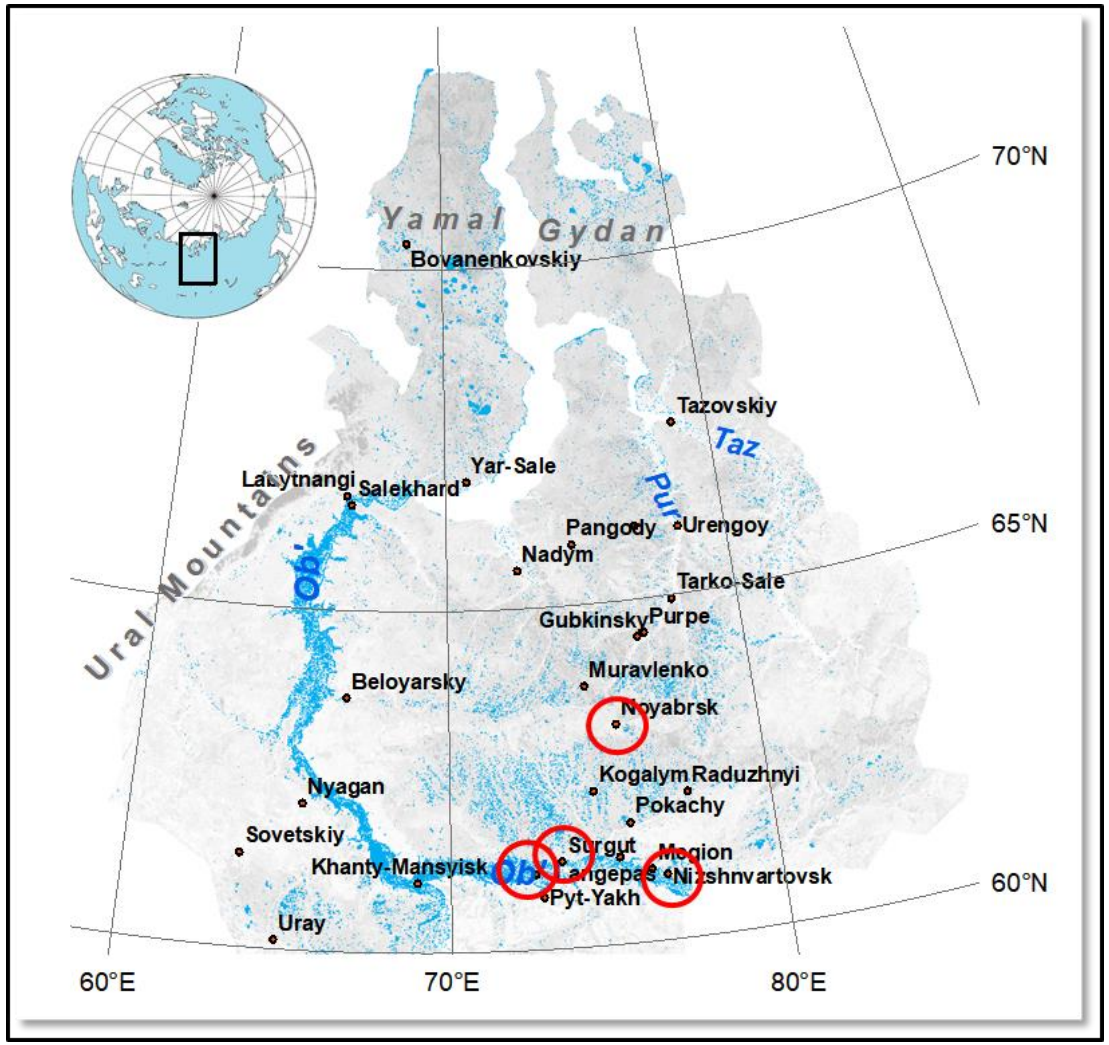
More than 100 urban settlements

Arctic population >4,000,000

85 % of Arctic population lives in a cities



Cities in the northern West Siberia NWS



We studied 28 cities in northern West Siberia located between 60°N and 73°N latitude.

Total Population nearly 1.8 million

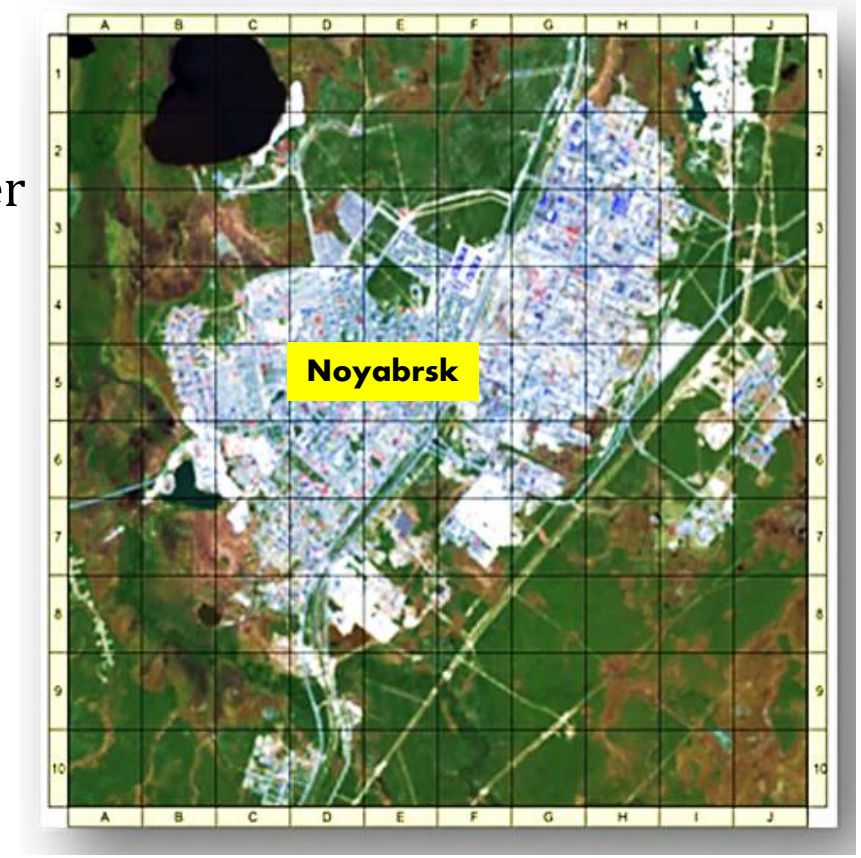
The largest cities:
Surgut (population ~332,000),
Nizhnevartovsk (266,000),
Nefteyugansk (126,000)
Noyabrsk (107,000).

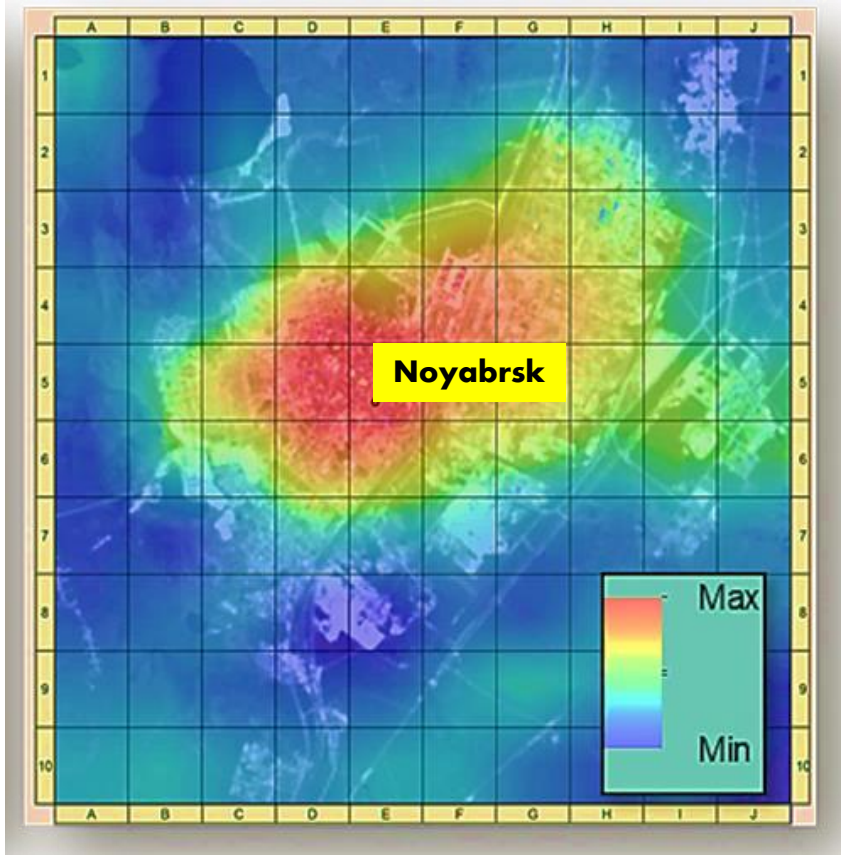
Cities – Climate change agents on local scales

Urban areas are warming significantly more rapidly than their natural background

Urban Heat Island

- Modified land use – land cover
- Anthropogenic heat release
- Modified surface structure





*Example of strong the mean **winter** urban land surface temperature anomaly in Noyabrsk, West Siberia*

Data and method:

MODerate Resolution Imaging Spectroradiometer (MODIS)

2000 – 2018

T_{Umax} – ***maximum*** urban pixel temperature

T_r – ***mean*** rural buffer temperature

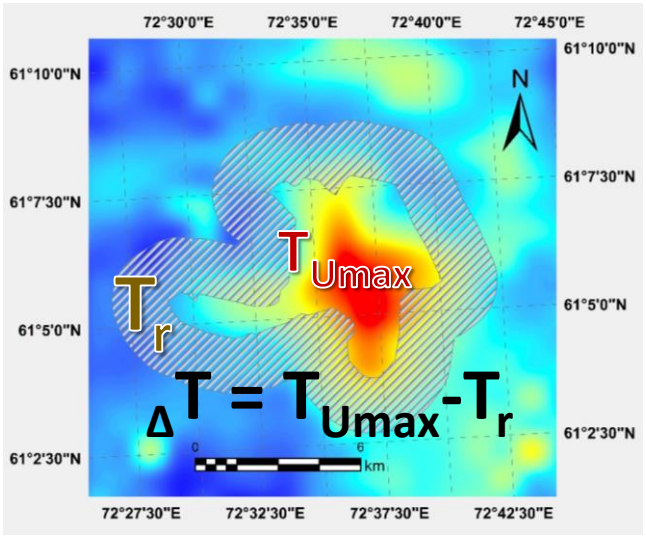
MODIS LST

- 1000 m spatial resolution,
- 8-day composites

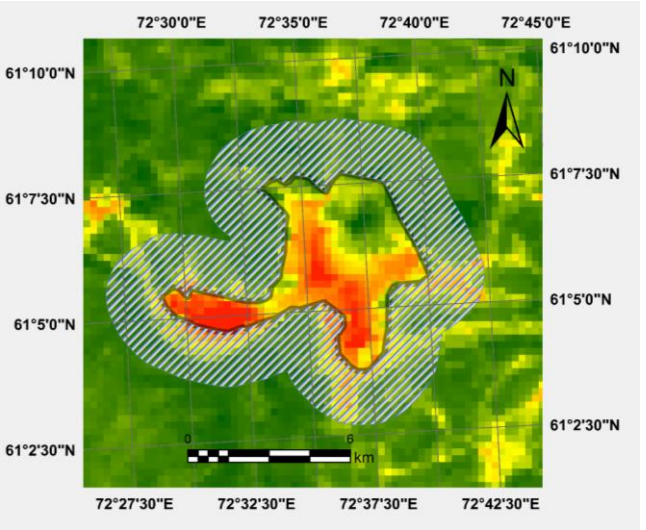
MODIS NDVI

- 250 m spatial resolution
- 16-day composites

Urban Heat Island UHI ($_{\Delta}T$)

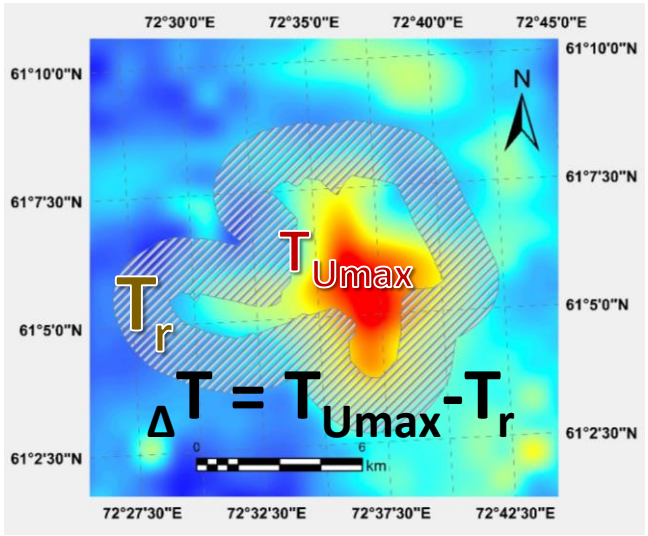


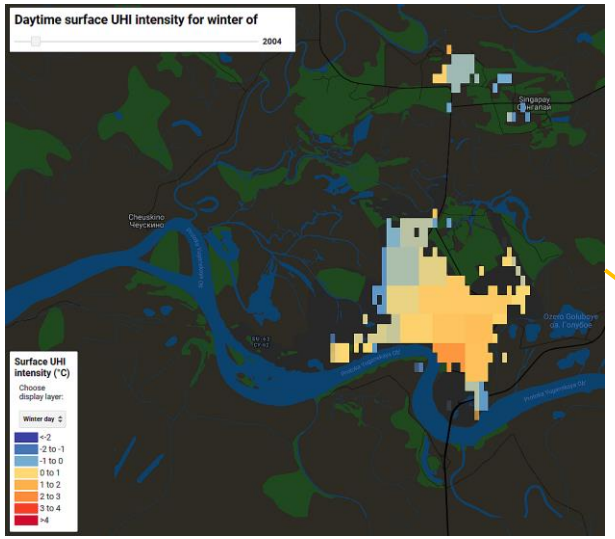
Normalized Difference Vegetation Index (NDVI)



Urban polygon and 2 km boundary buffer

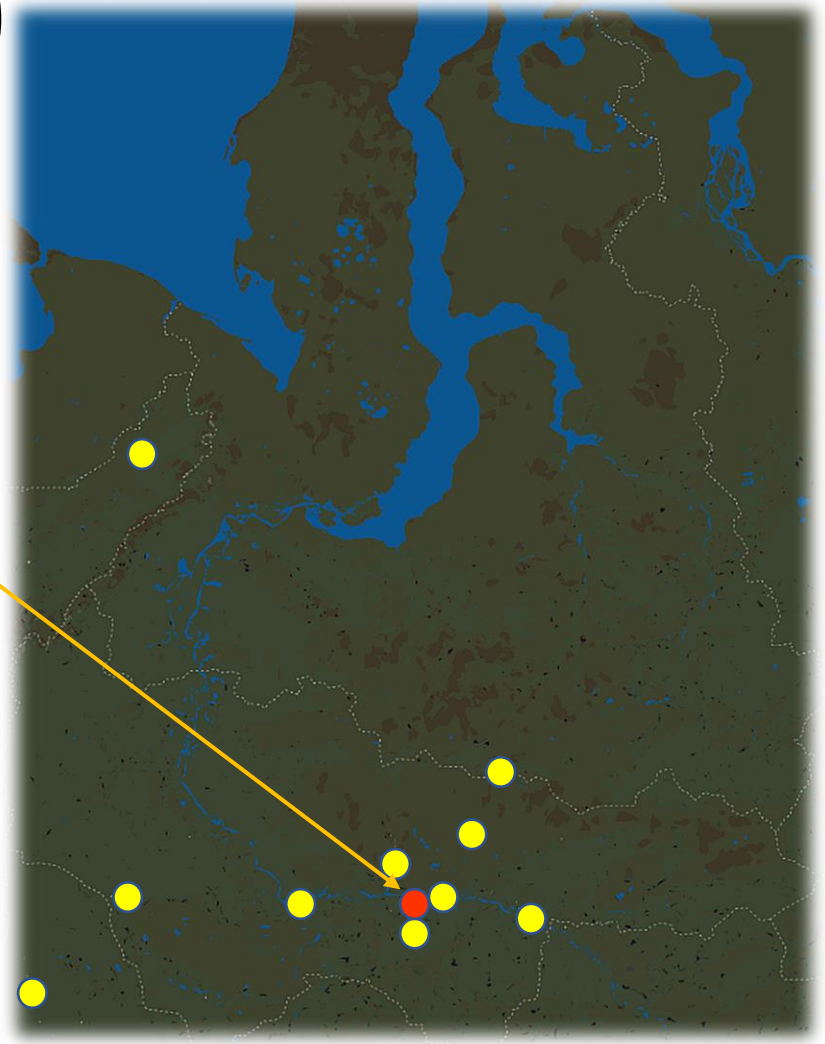
SUE-UHI: Global MODIS SUHI dataset by Chakraborty et al. (2019)





BF-UHI – buffer-zone method

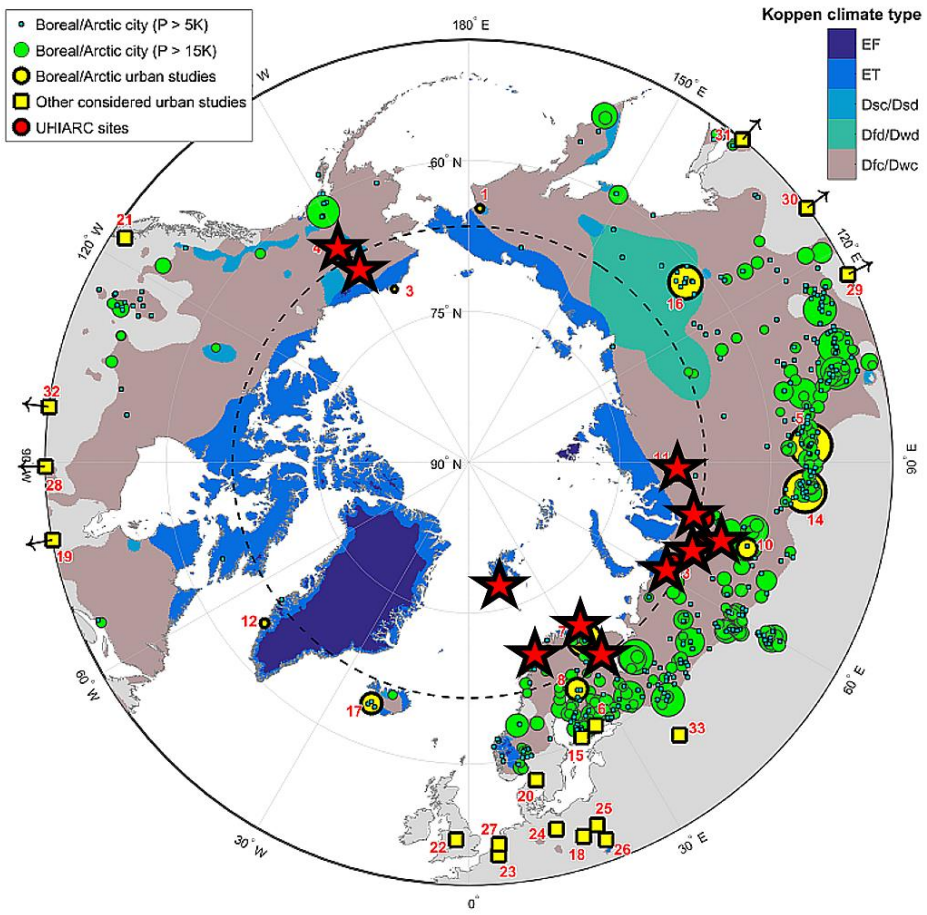
SUE-UHI – inter-urban difference method



Other drawbacks of the available global datasets:

- **No manual check** – urban areas identified based on nightlight detection
  - E.g., misrepresentation of gas flares as urban areas
- **Problematic coverage of smaller urban areas and sub-urbs** –
  - Misrepresentation of land use – land surface type
- **Poor coverage of the Arctic urban areas**

Urban Heat Island in 11 High Arctic Cities

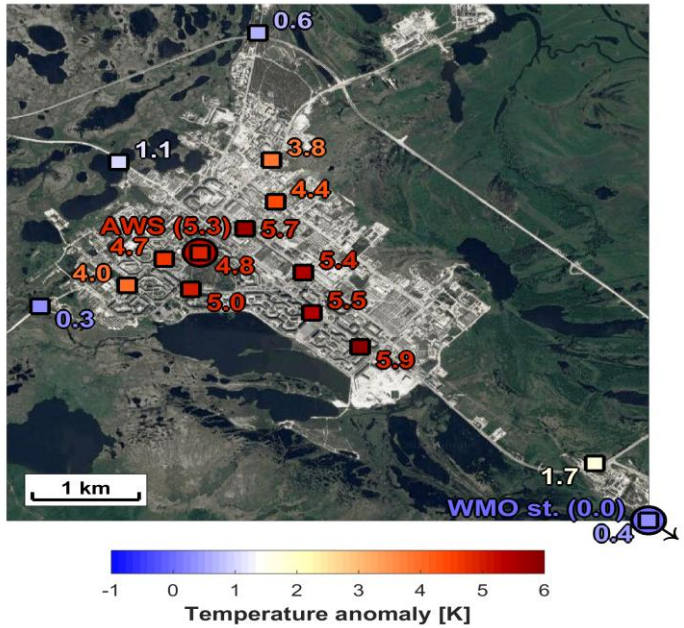


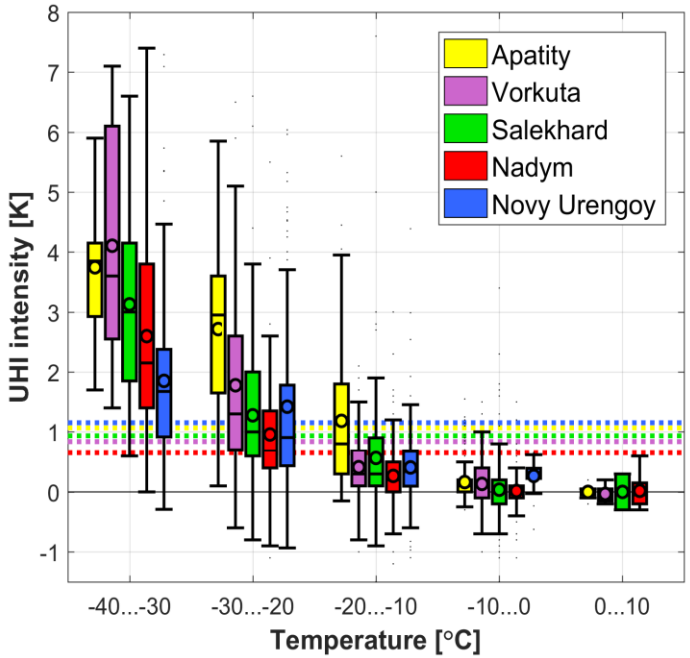
The review of 11 high Arctic Siberian cities

Esau I., Varentsov M., Laruelle M., Miles M.W., Konstantinov P., Soromotin A., Baklanov A. A. and Miles V. V., 2020: Warmer Climate of Arctic Cities, in the monography "The Arctic: Current Issues and Challenges", Pokrovsky O., et al. (Eds), NOVA Publishers, ISBN: 978-1-53617-306-2

In situ Arctic urban climate studies with UHIARC observational network:

- **In 6 cities** (Apatity, Vorkuta, Nadym, Novy Urengoy, Murmansk, Norilsk)

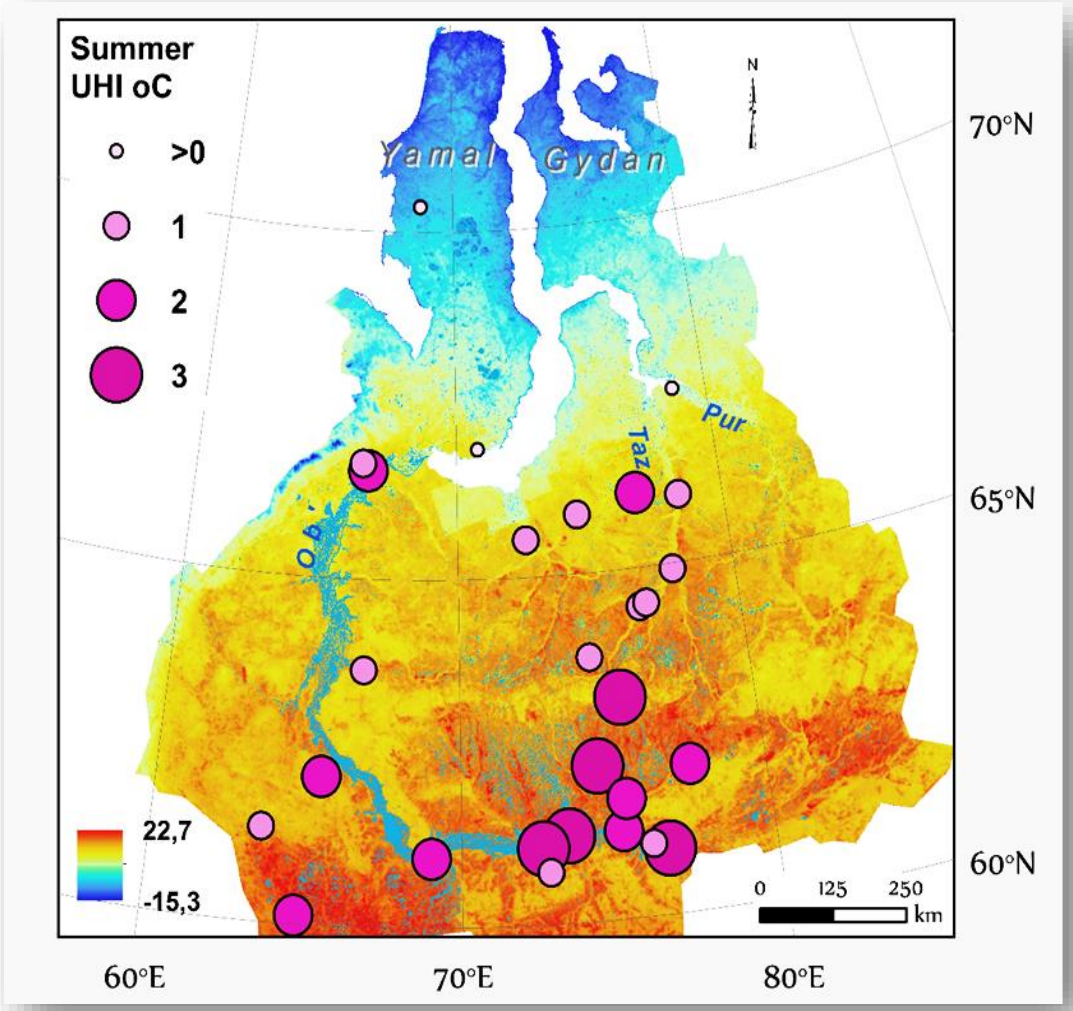


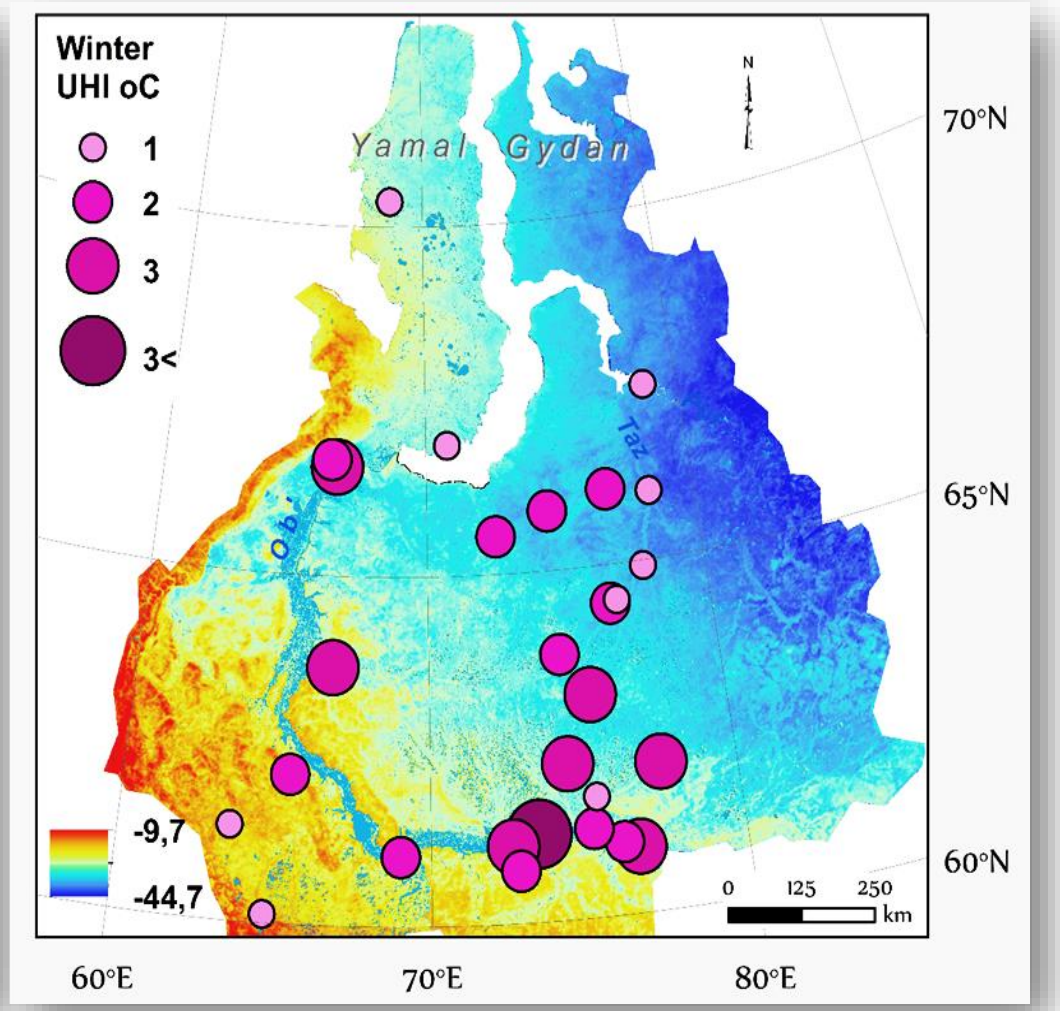


A review of 4 cities is published in Konstantinov P., Varentsov M., Esau I., 2018, *Environmental Research Letters*, **13**, doi: 10.1088/1748-9326/aacb84

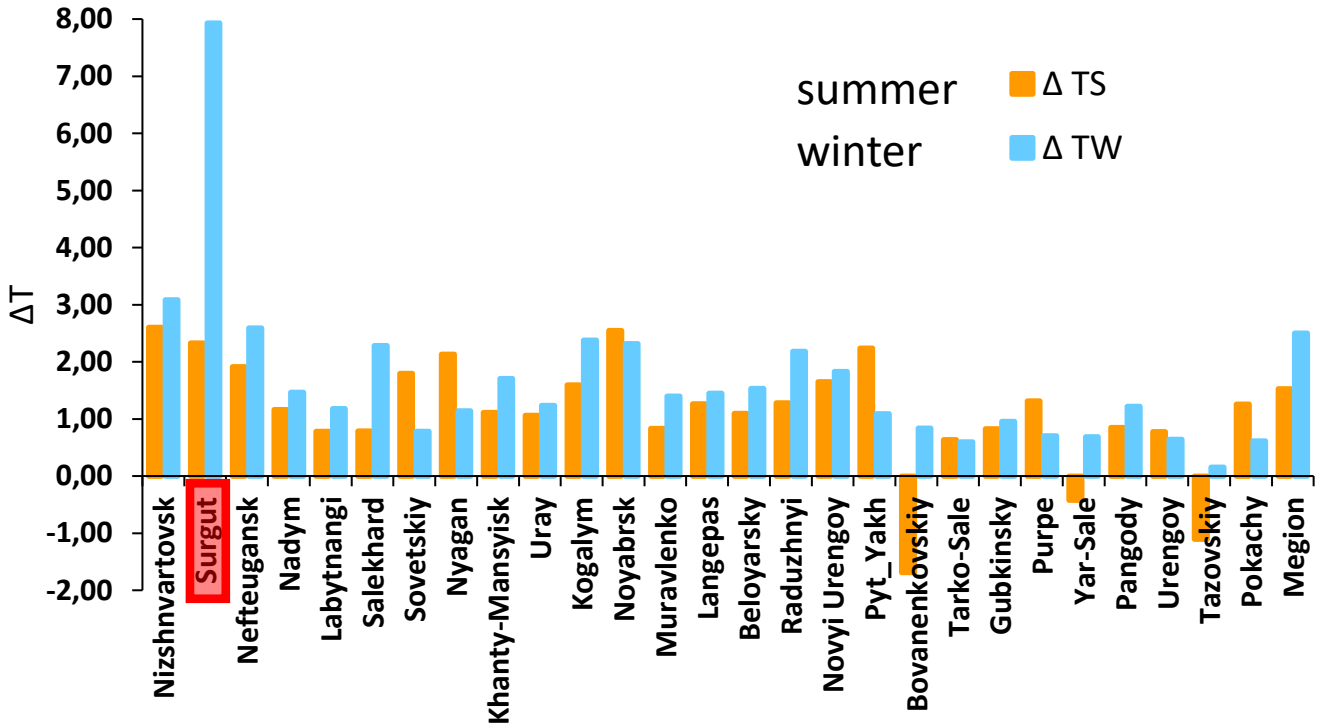
Urban Heat Island in 28 Siberian Cities

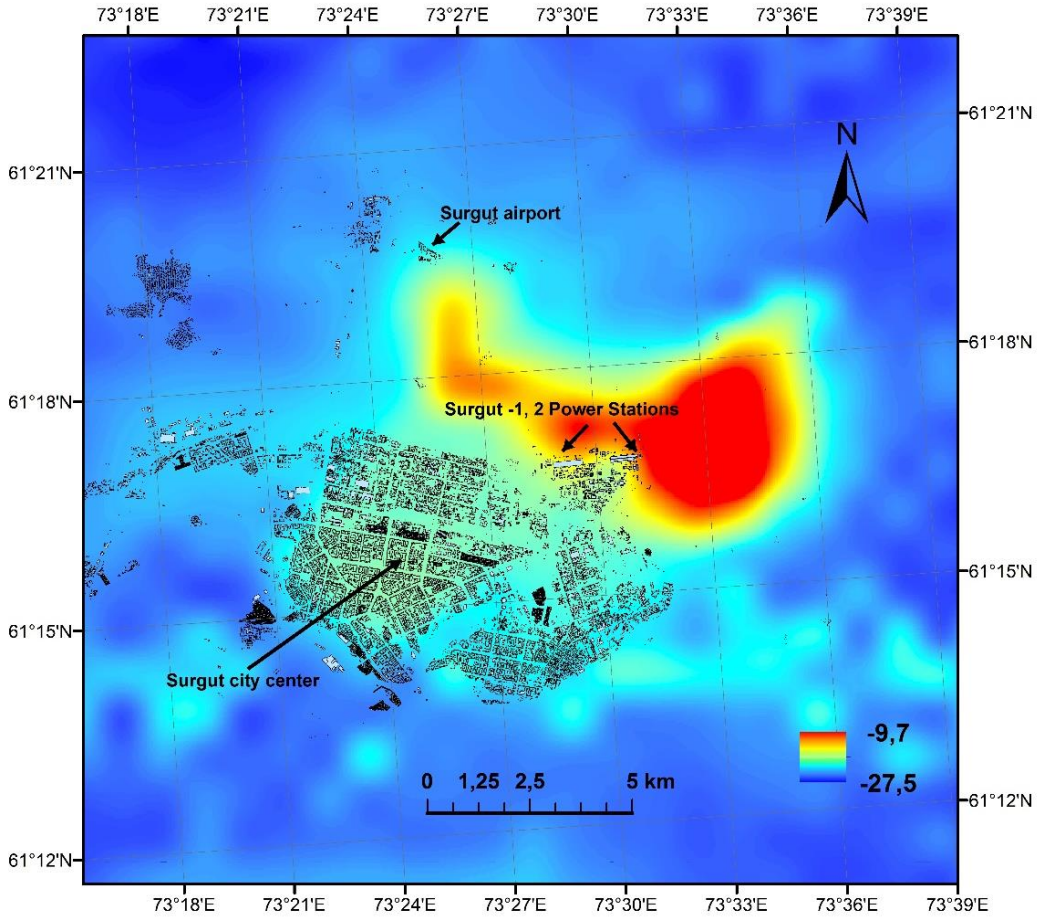
Miles V. and I. Esau, 2017, *Remote Sensing*, **9**(10), 989, doi:10.3390/rs9100989





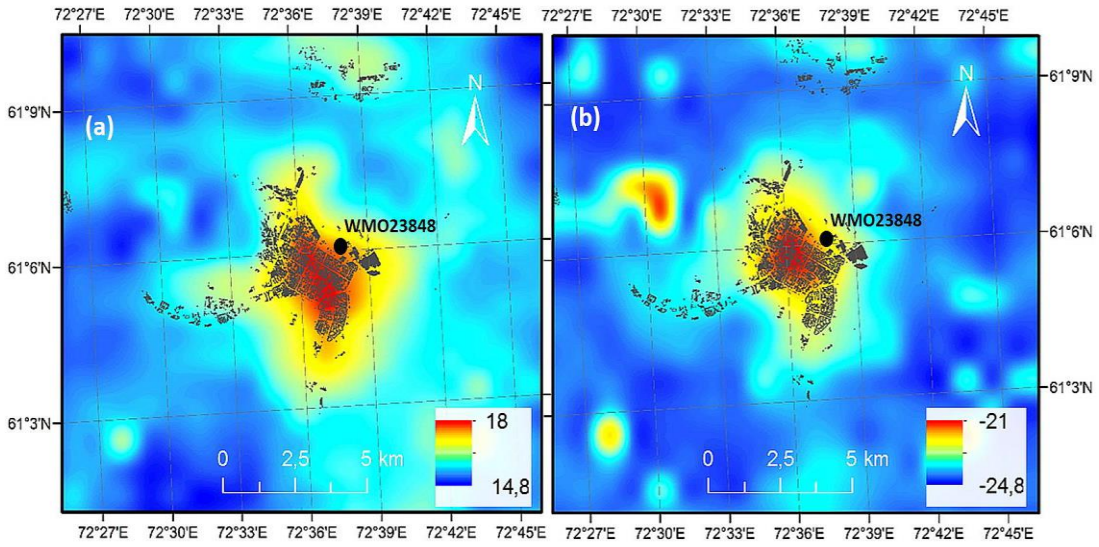
Urban Heat Island in 28 Siberian Cities



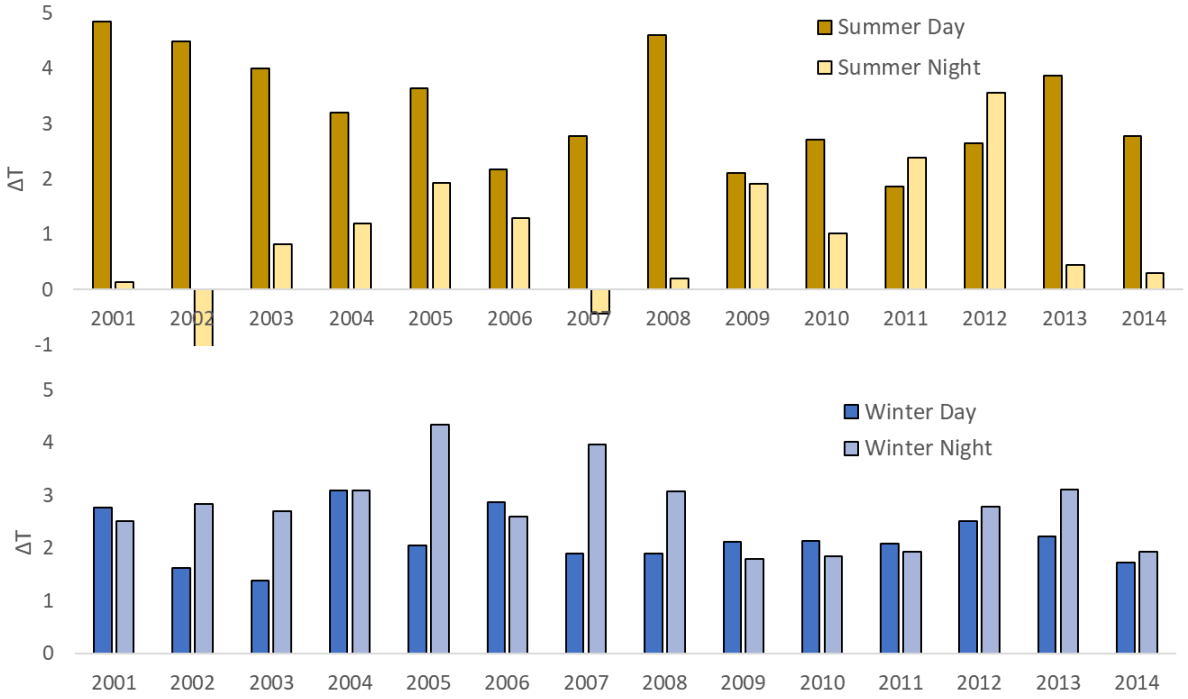


Miles & Esau, 2017

Surface UHI: Variations in the Nefteyugansk case study



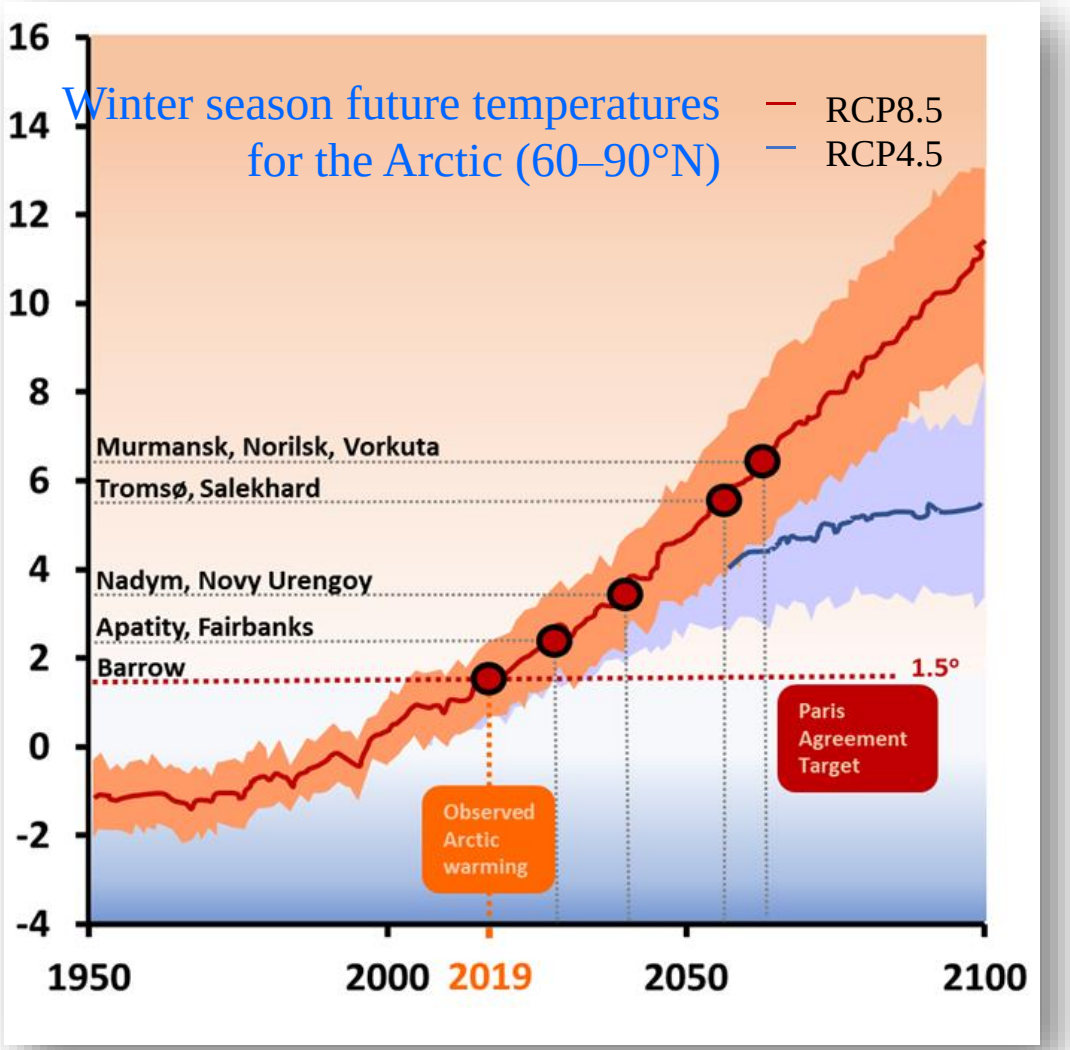
The 14 years (2001-2014) climatology of the MODIS LST in Nefteyugansk for (a) summer and (b) winter seasons. A black dot -the location of the WMO station.



Nefteugansk , Summer & Winter SUHI (ΔT Day, ΔTNight)

Connecting Local and Global Scales:

Urban Arctic climate is a harbinger of future Arctic warming

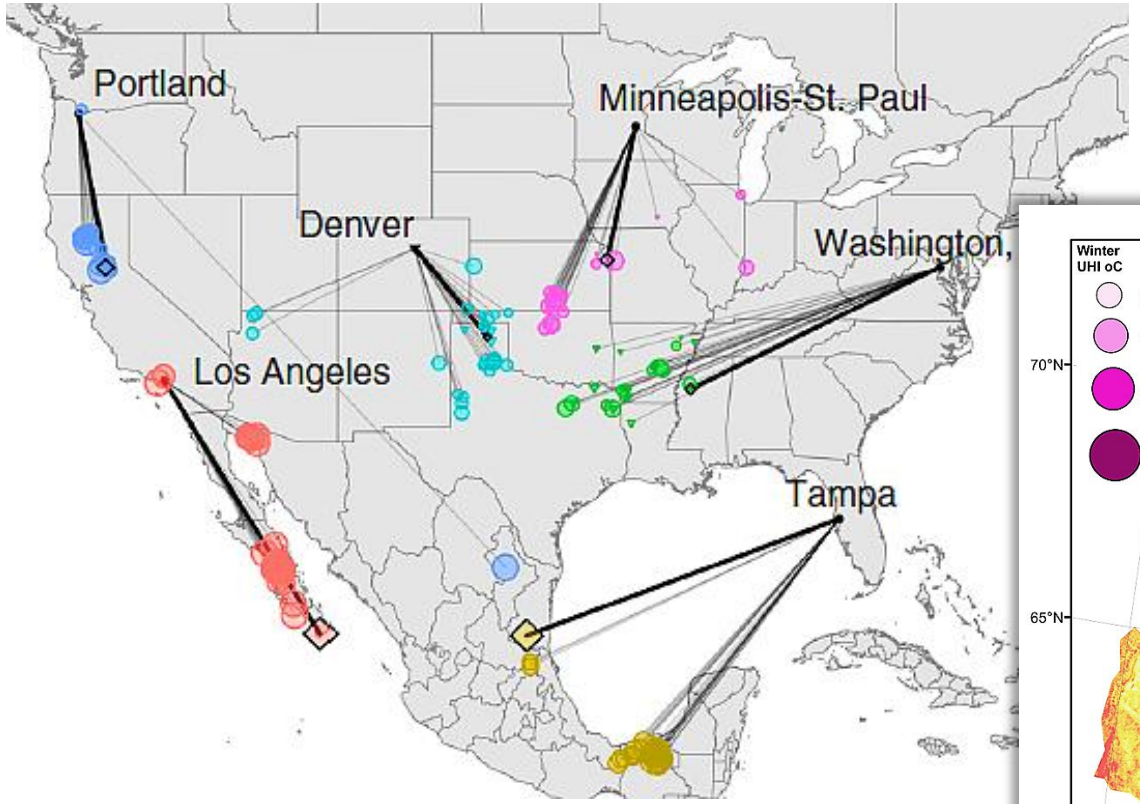


«Swimming resort» in Norilsk – world`s northernmost large city
69°20'N 88°13'E

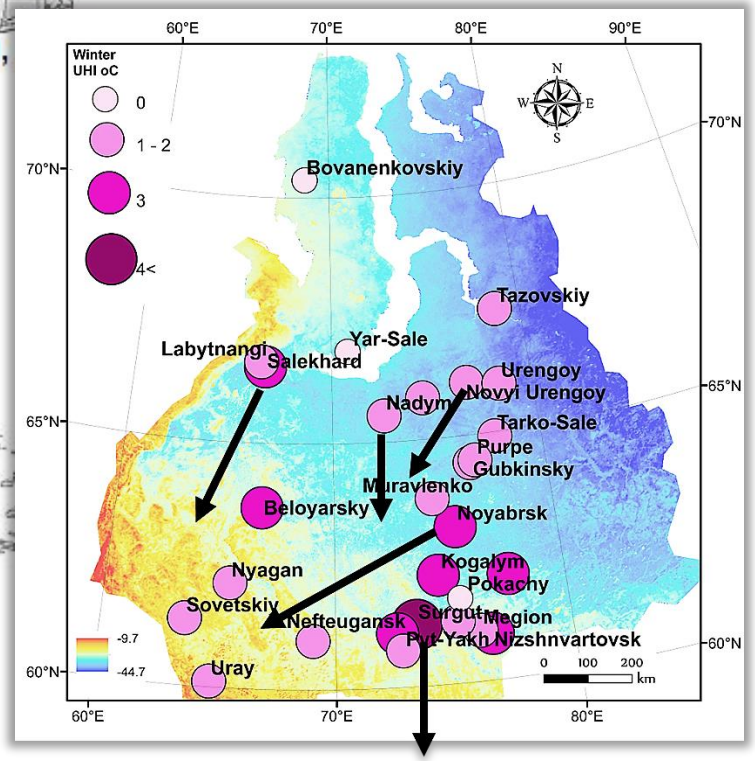
- 40% to 80% of infrastructure in the Arctic cities has been already damaged
- Soil bearing capacity has decreased by 30%

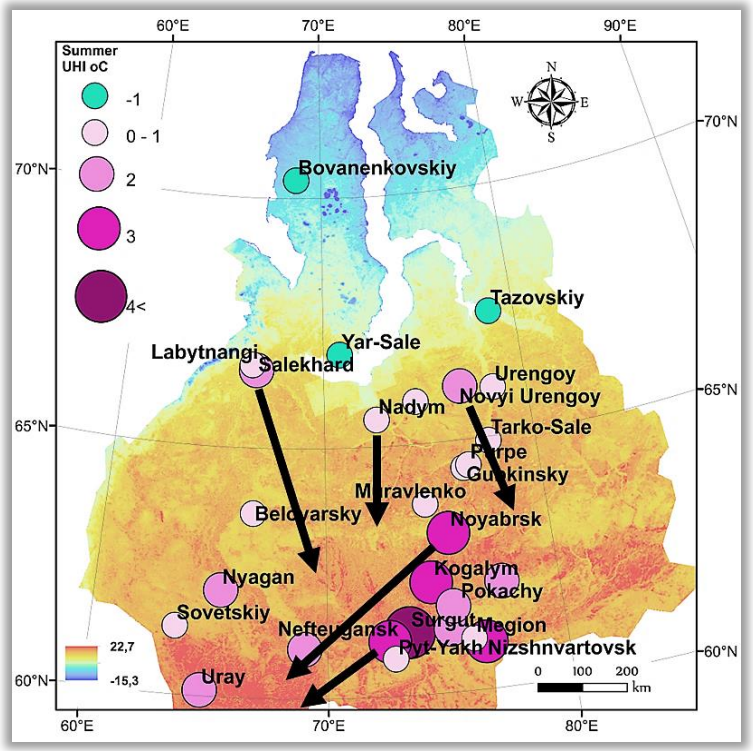
D. Streletsky and N. Shiklomanov (2016) in Earth's Cryosphere

Connecting Local and Global Scales:
Climate Analogues



North West Siberian cities already have climate found ~600 km south



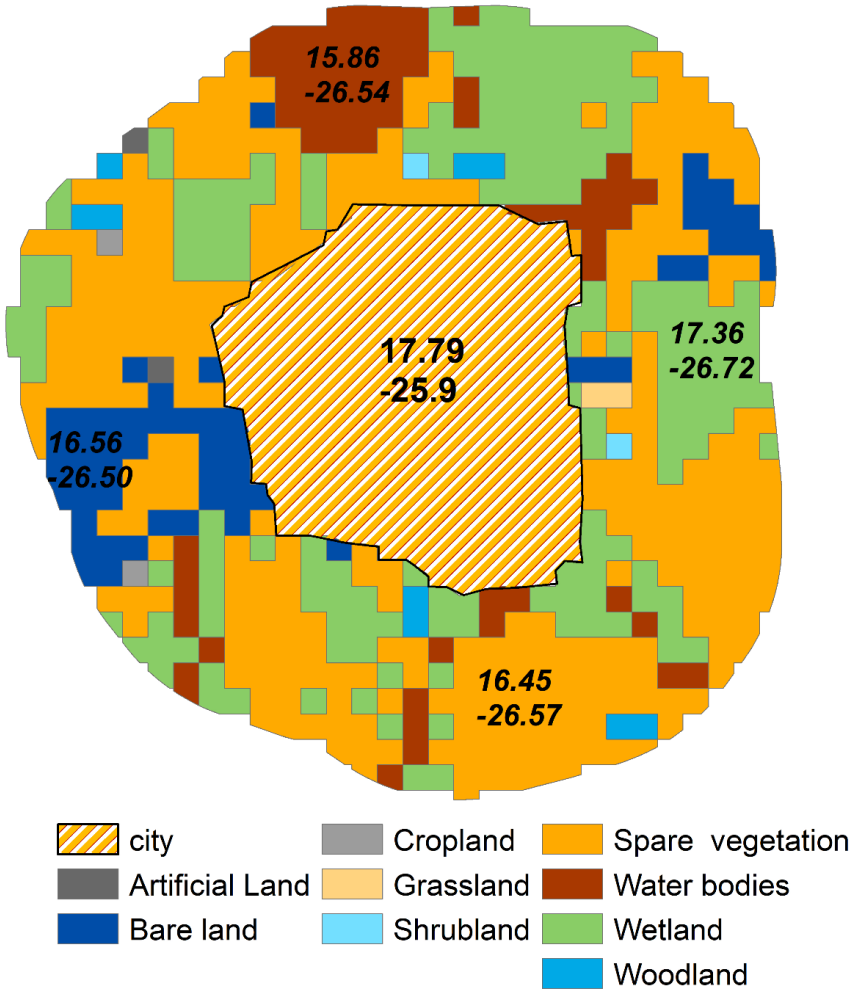


Fitzpatrick, M. C., & Dunn, R. R. (n.d.). American urban areas in the late 21st century. *Nature Communications*, (2019), 1–7. https://doi.org/10.1038/s41467-019-08540-3

Potential drivers for the surface UHI

- Meteorological drivers:
  - Background temperature
  - Atmospheric stability
  - Continentality of climate
  - Cloudiness
- Land use – land cover (LULC) factors – exogenous
  - LULC type features: NDVI, albedo, soil moisture etc.
  - LULC type relative abundance and diversity (the Shannon index)
- Socio-economic factors – endogenous
  - Urban area extent
  - Urban LULC type features
  - Urban metabolism: Population density, AHF per capita

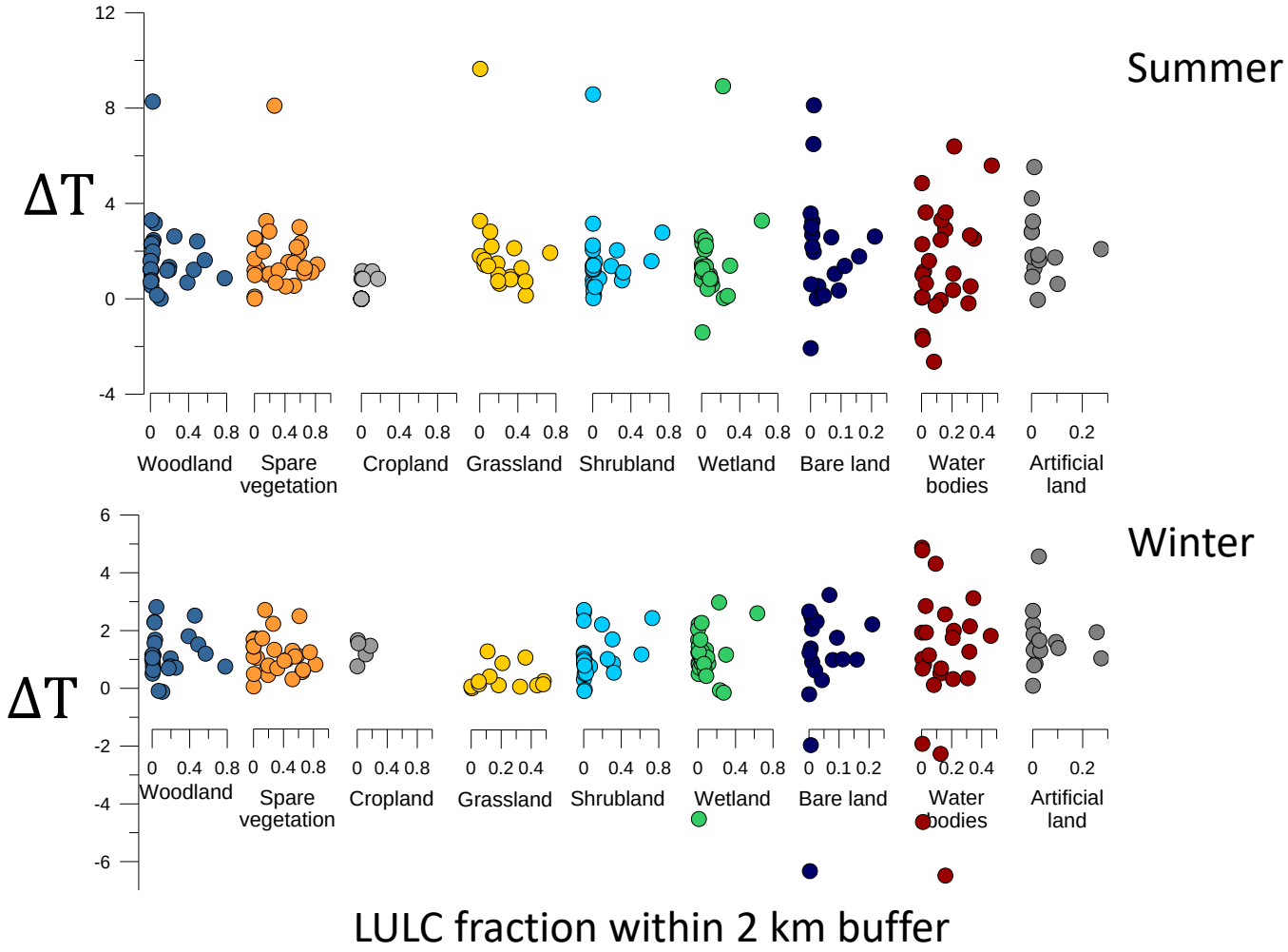
Exogenous LULC drivers: Example of Pokachy



Example of the Pokachy city polygon and 2-km buffer polygon.

Urban pixels were allocated to the city polygon and surrounding land in a 2-km buffer was considered as rural. The buffer polygon combined different land cover (LC) polygons. The land cover was extracted from LC CCI raster and converted to polygons. LC CCI original classes were joined into 9 new classes. The numbers represent mean LST for different LC classes in the buffer. The upper numbers are summer LST and the lower numbers are winter LST.

Exogenous LULC drivers: All 28 Siberian cities



LULC fraction within 2 km buffer

Endogenous drivers: All 28 Siberian cities

(a) Summer

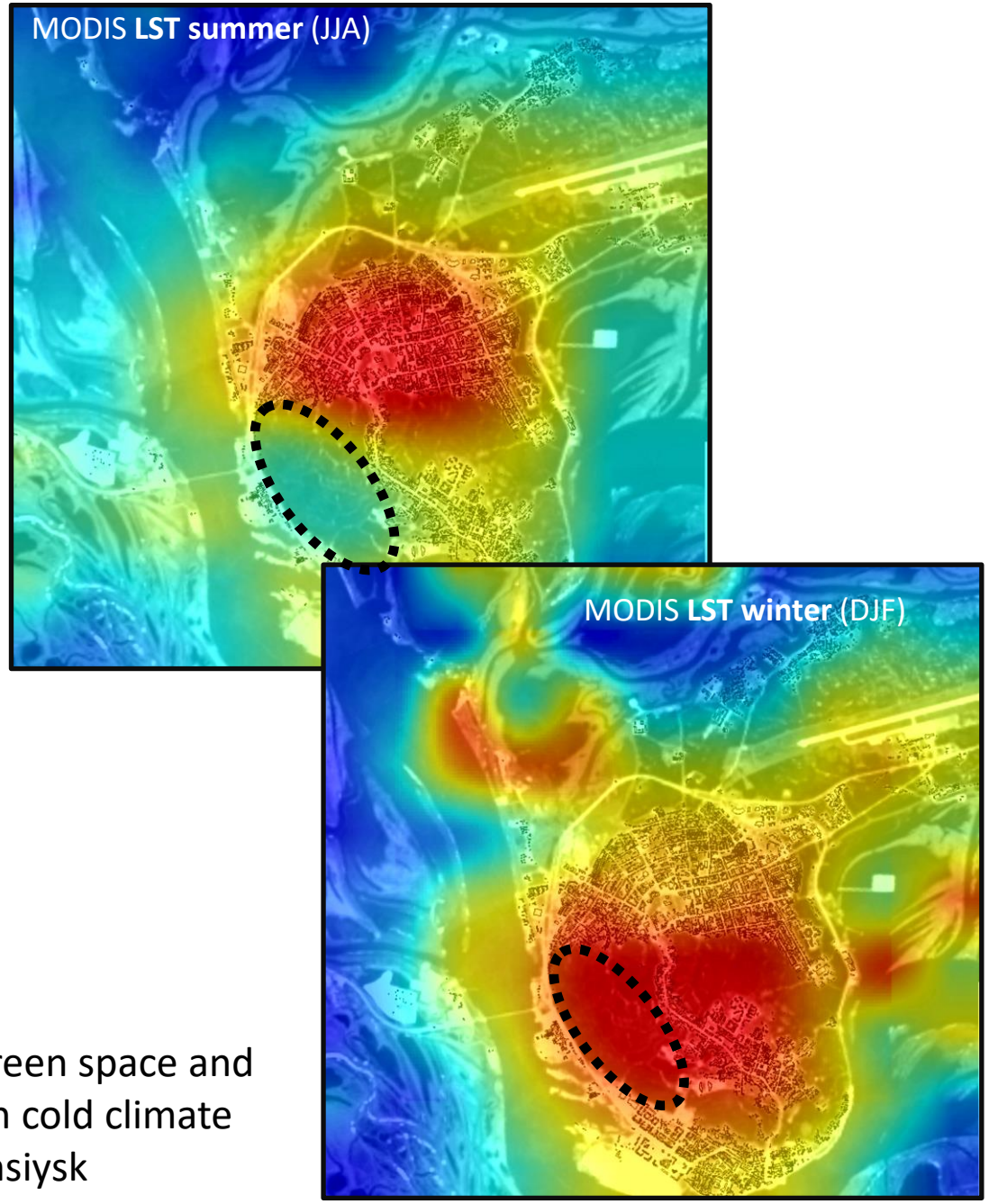
	T*rs*	ΔT*s*	SHEI	log(P)	Area km²
|ϕ|	**–0,93**	**–0,77**	0,44	**–0,63**	–0,38
T*rs*		**0,73**	–0,44	**0,67**	0,40
ΔT*s*			–0.25	**0,81**	**0,50**
SEI				–0.36	–0.30
log(P)					**0,61**

(b) Winter

	T*rw*	ΔT*w*	SHEI	log(P)	Area km²
|ϕ|	**–0,63**	–0,39	0,47	**–0,62**	–0.36
T*rw*		0.15	–0.28	0.35	0.01
ΔT*w*			**–0,52**	**0,82**	**0,64**
SHEI				–0,45	–0.32
log(P)					**0,60**

Conclusions

- Northern cities reveal large UHI (SUHI)
  - Related to the heat trapping in stably-stratified PBL
- Temporal and spatial patterns are diverse
- Northern UHIs might have a pronounced socio-environmental impact
- Driving/scalng factors:
  - Population is the most important
  - City area and density are less influential
  - Counterintuitive – Urban green spaces induce warming (not cooling) effects – subject of studies in the Belmont Forum project SERUS (Nansen Center in Norway, George Washington University in USA, Tyumen State University in Russia)



The role of local green space and small-scale relief in cold climate cities: Khanty-Mansiysk