Report
Phase 2 _ 2019, 01.01 – 31.12.2019
for ERANET-RUS-PLUS-SODEEP project
"Study of the development of extreme events over permafrost areas"

Phase_2: Development of an integrated remote sensing methodology to process and interpret satellite imagery and aerial photography and establishing a permafrost dynamics database (in the frame of WP1).

Purpose ond overall objectives of the project

In this project the impact of climate change on the permafrost degradation and its impact on the occurrence and development of extreme events in the high northern latitudes will be examined. The goal is to assess the role of land-atmosphere interactions on the severity and frequency of extreme events in the arctic and sub-arctic areas, which are extremely vulnerable to climate change conditions. Data from long-term in situ observations and field studies as well as medium and high-resolution satellite images together with state of the art hierarchy of numerical models both in global and regional climate simulations as well as the permafrost standalone model will be integrated. Specific objectives of the project are: to develop semi-automated algorithms for classifying remote sensing images, in order to identify spatio-temporal patterns in the evolution of arctic landscape and quantify the changes over time; evaluate the land surface temperature dynamics in permafrost areas; establish a permafrost temperature dynamics database and high resolution (~1km) maps of permafrost temperature and active layer thickness distribution for selected regions of the Siberian permafrost domain that will provide spatial data for calibration and validation of ESMs; identify missing or misrepresented permafrost-relevant key processes in ESMs and provide adequate, potentially scale-dependent representations of these processes; identify weather regimes and the role of land-atmosphere interactions for the development of extreme events over circum-Arctic land areas; consider mechanisms responsible for future changes in extreme events over these areas on various spatial scales and estimate future change in extreme events over circum-Arctic land areas; quantify the potential impact of these changes on permafrost landscapes.

To reach the objectives and answer the scientific relevant questions high-resolution numerical models both in global and regional climate will be used as well as permafrost process-study simulations, verified with state-of-the art in situ and remote sensing observations.

Phase summary

The main activities in the frame of phase 2 interval are related to the WP1 (Development of an integrated remote sensing methodology to process and interpret satellite imagery and aerial photography and establishing a permafrost dynamics database) for the project partner PP1, as follows:

- Analysis of the parameters and indices relevant for landscape changes based on remote sensing data
- Develop and test the algorithm for detection of changes in the arctic landscape of West Siberia
- GIS database development and updating

In the frame of the WP1 for the phase 2 reporting interval, the indices and parameters related to the changes in arctic landscape have been quantified for specific points and areas in West Siberia. An algorithm for automated calculation of mean values and trend of several indices using Landsat and MODIS data has been developed using Google Earth Engine on API Java Script. The algorithm uses the images available in the archives from Landsat and MODIS and has been tested on four sites located in the main bio-climatic zones of West Siberia (Belyi Island for arctic tundra, Marre-Sale in typical tundra, Urengoy in forest tundra and Pechora delta). The results of the temporal analysis can be displayed as graph between selected years or as map of mean values of a selected index.

Activities

The Arctic is warming much faster than the global average and most of the areas in the Arctic experienced rapid changes due to permafrost degradation, these areas being particularly sensible to climate change (Karjalainen et. al, 2019). Permafrost is considered one of the reliable terrestrial indicators of climate change and has been identified as an Essential Climate Variable by the global observing community. Permafrost degradation generates irreversible ecological changes, posing serious impacts on infrastructure and sustainability of local communities, too (Hjort et al, 2018).

The study areas that cover the major bio-climaticzones from Russian arctic are located in West Siberia (fig. 1) and overlap on different permafrost zones (based on modeled permafrost zones from Obu et. Al, 2018), as follow:

- the arctic tundra from Belyi Island in continuous permafrost (>90% coverage)
- typical tundra from Marre-Sale, western Yamal in continuous-partly discontinous permafrost (50-90% coverage)
- forest tundra from Urengoy region in discontinuous permafrost (50-90% coverage)
- southern tundra from Bolvansky Cape in Pechora delta in sporadic permafrost (10-50% coverage)

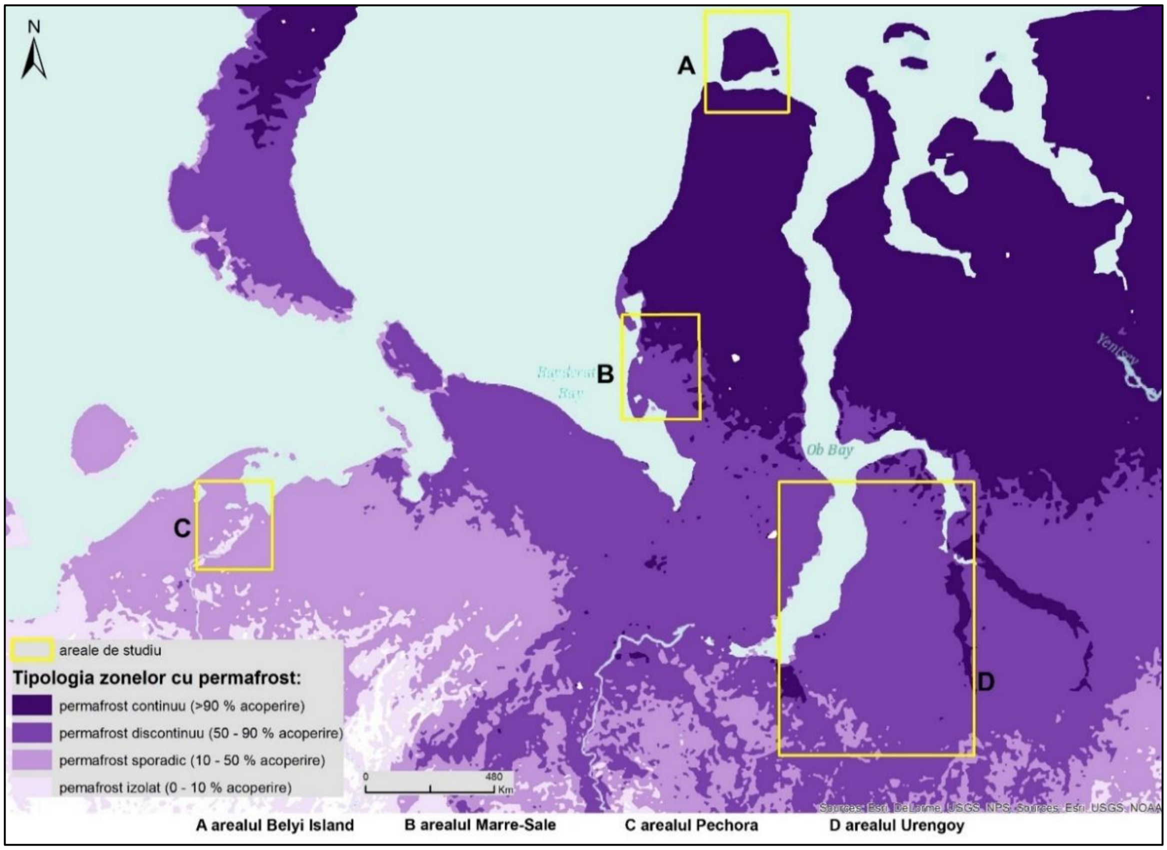


Fig. 1 Location of study areas ovellaped on the permafrost zonation based on modeling (permafrost zonation downloaded from Obu et al. 2018, https://doi.pangaea.de/10.1594/PANGAEA.888600?format=html#download)

From the measurements data for the monitoring sites from Cirmcupolar Active Layer Monitoring (CALM) network, several located in the study sites from West Siberia (fig. 2), a general increase in active layer tickness (ALT) (https://www2.gwu.edu/~calm/data/north.htm) correlated with the increase of air temperature and the temperature of permafrost has been observed (Biskaborn et al., 2019).

In the same time an increase in the rate of change of mean annual temperature of permafrost, more evident in continuous permafrost areas as compared to discontinuous permafrost has been observed (Biskaborn et al., 2019).

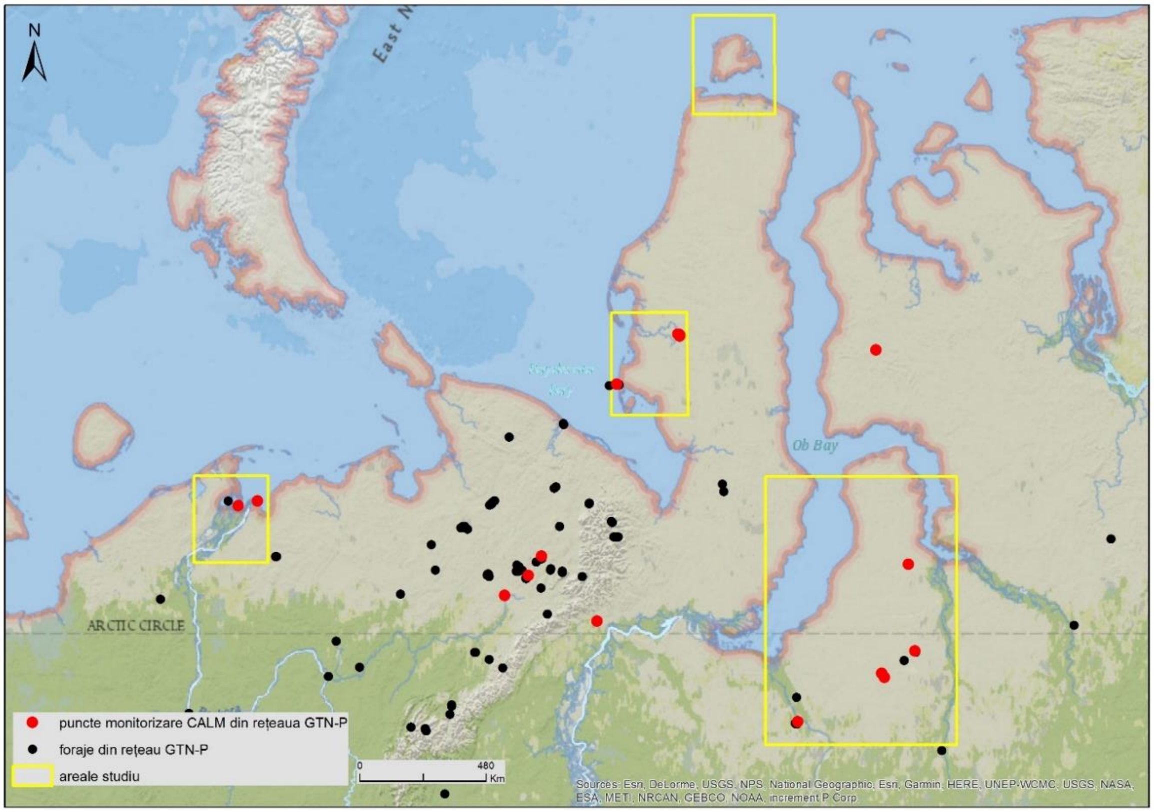


Fig. 2 Distribution of the CALM monitoring sites and boreholes from GTN-P in West Siberia (points downloaded from https://gtnp.arcticportal.org/resources/maps/12-resources)

In the frame of phase 2 , activitites of the PP1 partner include spatio-temporal analysis of the parameters and indices relevant for landscape changes based on remote sensing data, develop and test the algorithm for detection of changes in the arctic landscape of West Siberia, GIS database development and updating.

For each parameter, satellite images from Landsat, MODIS and Sentinel 1 and 2 have been used, starting with the oldest image in each archive. For the changes at a more detailed scale, very high resolution multispectral images from Quickbird, WorldView și GeoEye (digitalglobe.com) at 12-14 years interval for 3 sites have been used.

1. ***Establish the parameters and indices relevant for landscape changes based on multipectral remote sensing images***

For the analysis of landscape changes in different permafrost based on satellite images, we selected Landsat, MODIS, Sentinel 2 and Global Surface Water archives, these being the most used data with free access for applications. These archives have also a good temporal resolution and extent, starting with

1985 for Landsat and 2000 for MODIS, and more recent for Sentinel for the last 5 years. The spatial resolution varies from 20 m at Sentinel, 30 m at Landsat and GSW datasets, 250/500/1000 for MODIS.

Based on the spectral bands from different sensors, several indices that capture different aspects of landscape such as vegetation, humidity, water bodies, wildfire risk, snow cover, land surface temperature have been calculated. We have chosen 8 multipectral indices, relevant for landscape changes in the study areas, mostly using Landsat and MODIS, archive that cover longer time interval. For the water spatio-temporal dynamics the GSW dataset was used to identify the temporal variation of different classes of surface water (Pekel et al., 2016).

From Landsat available scenes, indices as Normalized Difference Vegetation Index (NDVI), Tasseled Cap Greenness (TCG), Tasseled Cap Angle (TCA), Normalized Difference Moisture Index (NDMI), Tasseled Cap Wetness (TCW), Normalized Difference Water Index (NDWI), Tasseled Cap Brightness (TCB) have been calculated for the interval 1985-2019. From MODIS archive indices as Normalized Difference Vegetation Index (NDVI), *Enhanced Vegetation Index* (EVI), Leaf Area Index (LAI) and Land Surface Temperature (LST) have been calculated for the 2000-2019 interval.

From the GSW datasets the transition between different classes and the evolution of permanent and seasonal water between 1984 - 2018 have been analyzed (https://developers.google.com/earthengine/datasets/catalog/JRC_GSW1_1_GlobalSurfaceWater).

2. Develop and test the algorithm using the available archives of satellite images

The algorithm has been developed using the code editor Google Earth Engine (GEE) (code.earthengine.google.com), a cloud-based geospatial processing platform with APIs for JavaScript and Python. The GEE has capabilities of using a petabyte-scale archive of publicly available remote sensing images and is optimized for parallel processing of geospatial data (Gorelick et al., 2017)
The functions of the editor are adapted for interactive algorithm development, with instant access to a large volume of data and for complex geospatial work fluxes.

The algorithm uses data publicly available through GEE, as spectral bands in Landsat / MODIS, normalized indices, biophysical indices –land surface temperature, annually global surface water datasets. For the calculation of multispectral indices, only the images from the summer season (July and August have been used). Main processing steps from the analysis consist of: defining area of interest (or the point of interest) as a vector (polygon or point) interactively or imported, defining variables, starting year, ending year for the temporal evolution analysis¸ defining the monthly interval, defining overlapping area in mosaicked images (threshold of 0,8 or to cover 80% from the analyzed areas), function for cloud removal, generating the collection of satellite images from Landsat 5, 7, 8, filtered with the area of interest, filtering of images after 2003 from Landsat 7, merging the collections and clip after area of interest, creating the list with the selected years for analysis, functions for calculating the indices applied on the entire collection, generating Tasseled Cap indices with coefficients from DeVries et al. (2016), creating the graphs with the evolution of mean values and trend of selected index.

For the calculation of areas for different type of surface waters, the code from the application *https://developers.google.com/earth-engine/tutorial_global_surface_water_04* has been used (Pekel et al., 2016).

The algorithm generates several types of results:

- temporal trend in mean values in areas defined by user for all multispectral indices mentioned above
- temporal trend of all multispectral indices in points defined by the user (i.e. in-situ measurement points or points with extreme climatic events)
- surface water dynamics and temporal evolution of different classes

The results of the analysis can be displayed/exported as graphs or maps.

3. GIS database development and updating

The GIS database refer to several types of geospatial data, including vector files, raster formats, .csv files, etc. for the study areas in West Siberia.

The former database related to the four study areas (Belyi Island, Marre-Sale, Pechora și Urengoy) containing in-situ measurement points, CALM sites and boreholes location (downloaded through GTN-P portal https://gtnp.arcticportal.org/index.php/resources/maps), permafrost zonation (based on permafrost modeled zones from Obu et al., 2018, downloaded, https://doi.pangaea.de/10.1594/PANGAEA.888600?format=html#download),settlements, hydrography, land cover maps, has been updated and the results exported from GEE have been added. In this phase, the database has been enriched with several very high resolution images (courtesy of digitalglobe.com) acquired at 12 to 14 years interval for three different sites located in different permafrost zones, i.e. Quickbird from July 2004 and GeoEye from July 2016 in Yamal Peninsula (fig. 3).

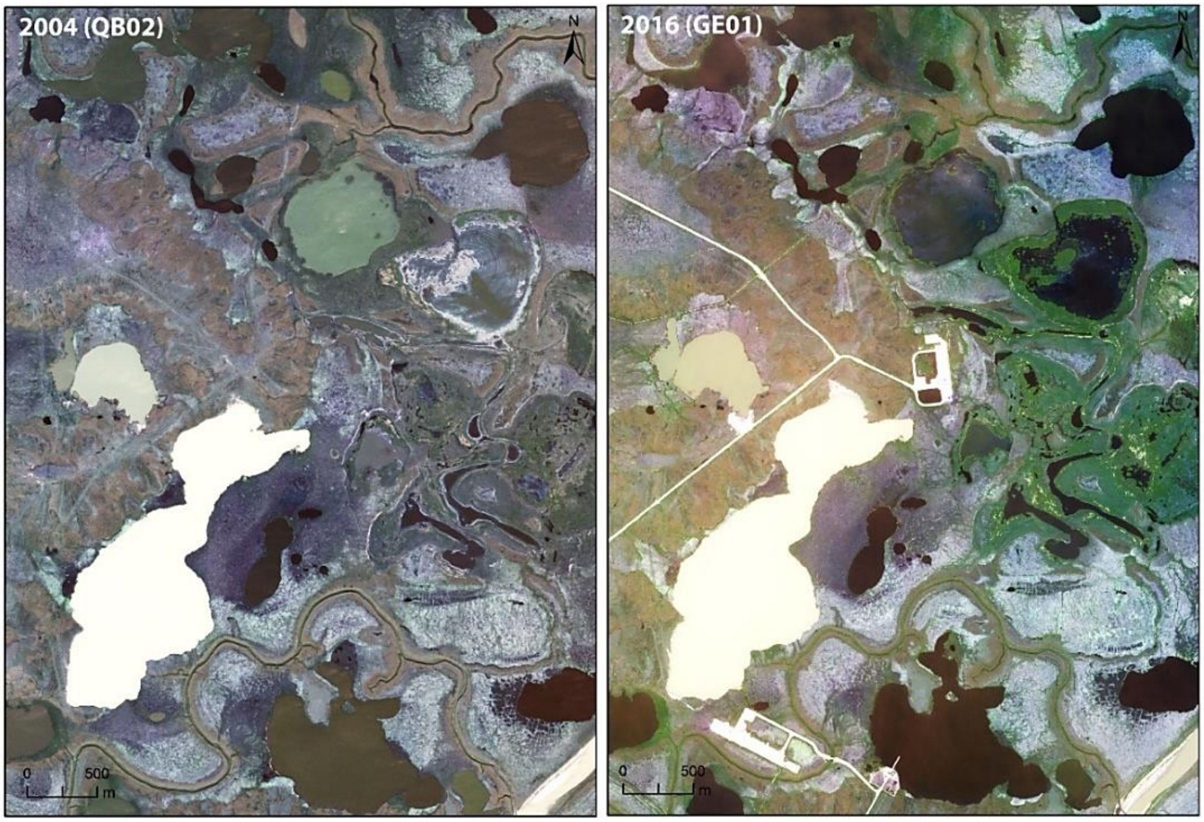


Fig. 3 Example of composite multispectral images from Quickbird, July 2004 (left) and GeoEye, July 2016 located in western Yamal (in Bovanenkovo gas field)

The results generated in GEE for all calculated indices and the surface water changes have been added as maps and graphs and also as .csv files for further statistic analysis. The raster data representing the spatial variation of a sellected index for different years were exported in GeoTiff format.

Several results generated within GEE have been selected as examples for every site from West Siberia.

Belyi Island area

From the analysis of multispectral indices evolution, an increase in the mean values of NDVI and TCG have been observed (fig. 4 and 5). The same increasing trend can be identified also on the evolution of mean LST for July between 2000-2019, with unusual high temperatures in summer of 2013 and 2016 (fig. 6), these events being correlated with data from in-situ measurements.

The evolution of air temperature and land surface temperature influence the dynamic of active layer thickness and further determine the degradation of permafrost. As for the surface water dynamics, a slight increase in surface water in summer season have been observed after the year 2000.

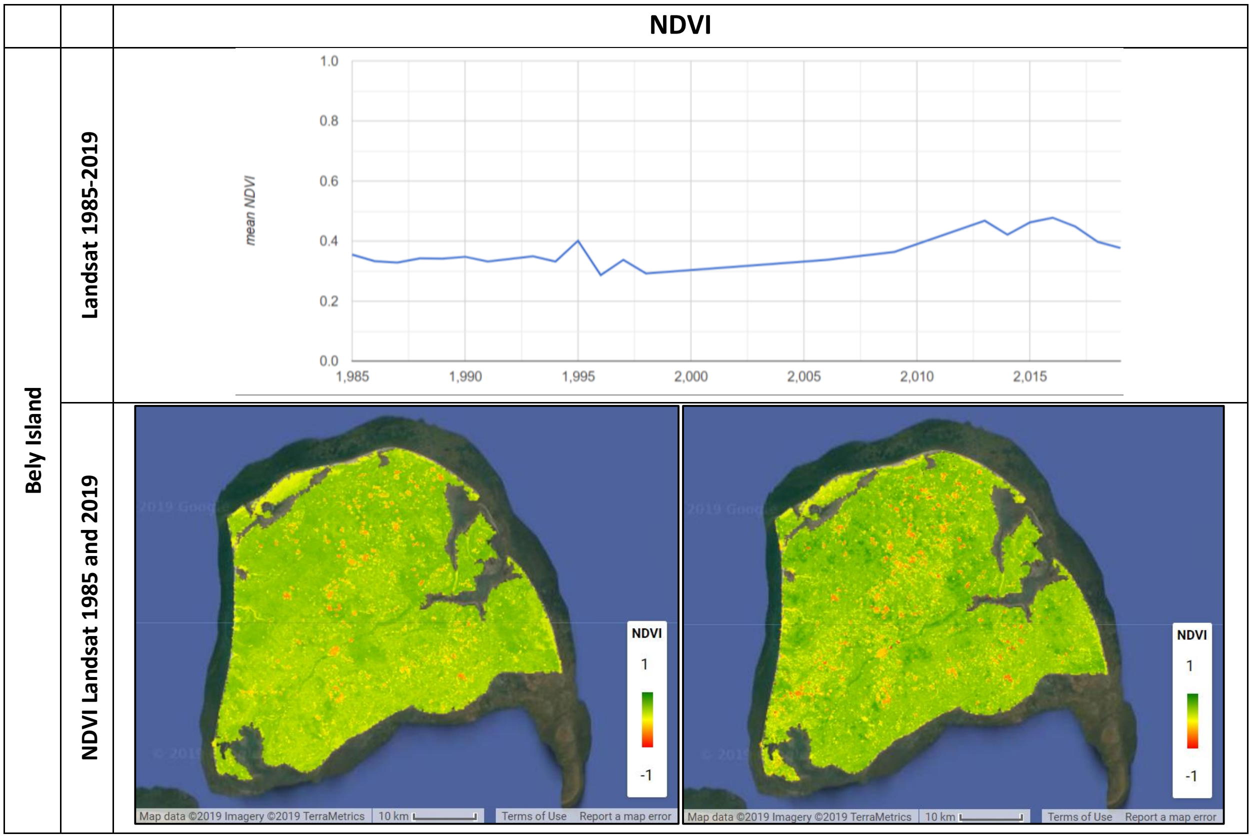


Fig. 4 Mean NDVI evolution and distribution of NDVI for 1985 and 2019 in Belyi Island site

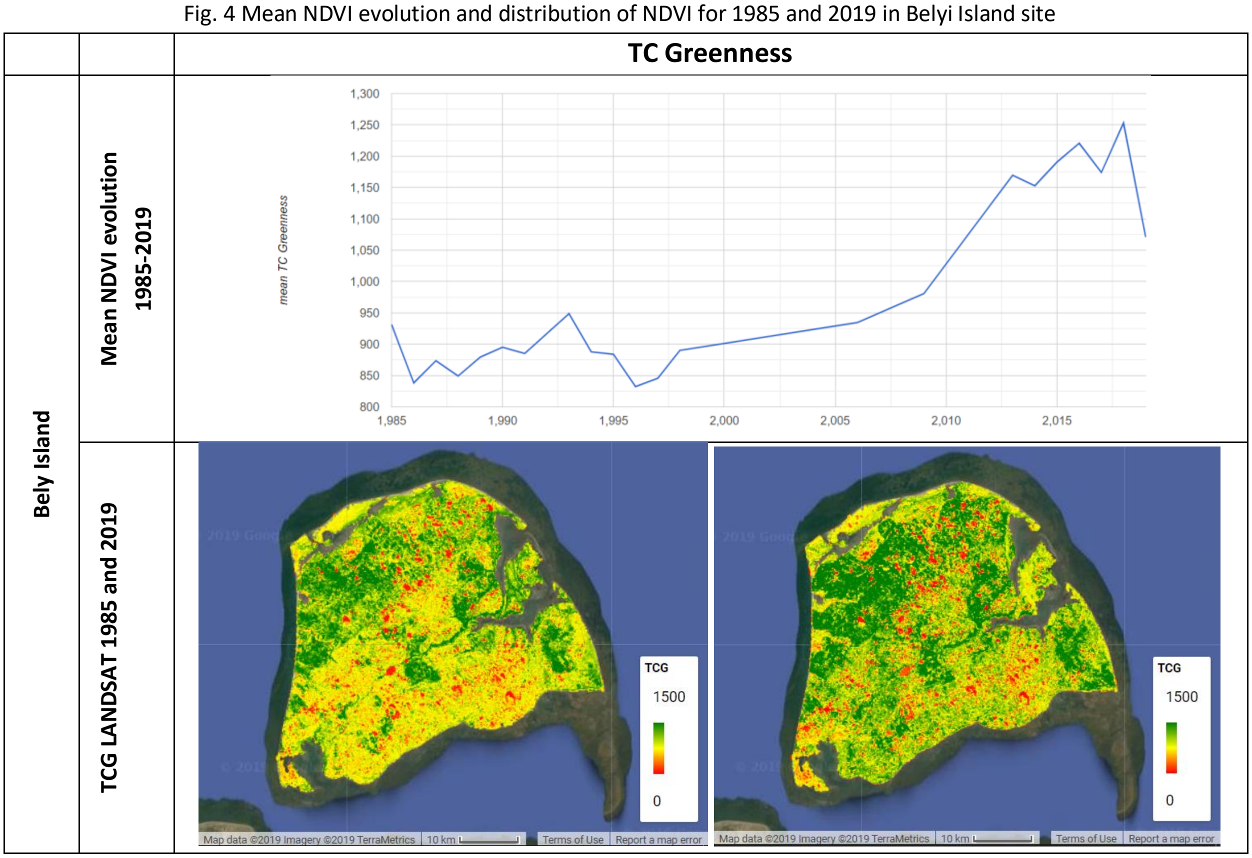


Fig. 5 Mean TC Greenness and distribution of TCG for 1985 and 2019 in Belyi Island site

MODIS LST evolution 2000-2019

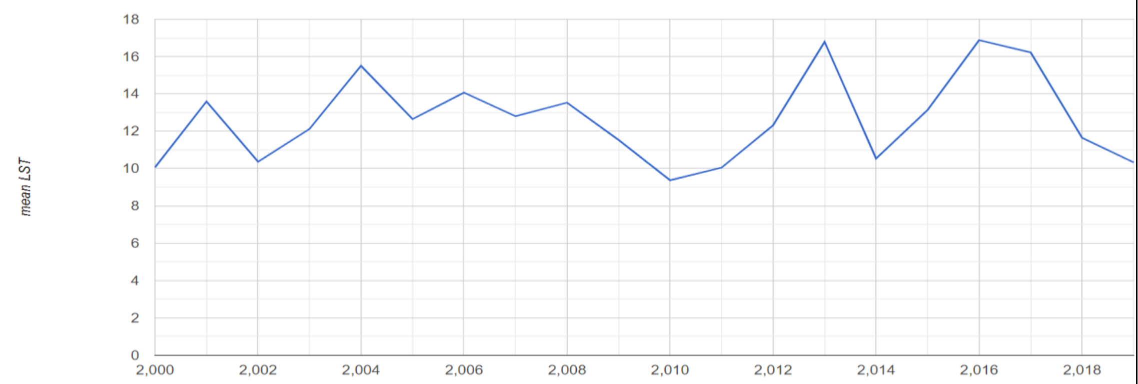


Fig. 6 Evolution of mean LST in July between 2000 - 2019 in Belyi Island area

Marre-Sale area, western Yamal Peninsula

For the Marre-Sale area, a typical tundra landscape, the same increase in the mean values of TCG and NDVI has been observed from the analysis of images between 1985 and 2019 and also on the maps of mean NDVI at the beginning and end of the interval (fig. 7 and 8). LST evolution shows an increase in mean temperatures with high summer temperatures in 2004, 2013 and 2016. In the same time a slight decrease in mean NDWI values

TC Greenness

Marre-Sale

LANDSAT 1985-2019

TCG LANDSAT 1985 și 2019

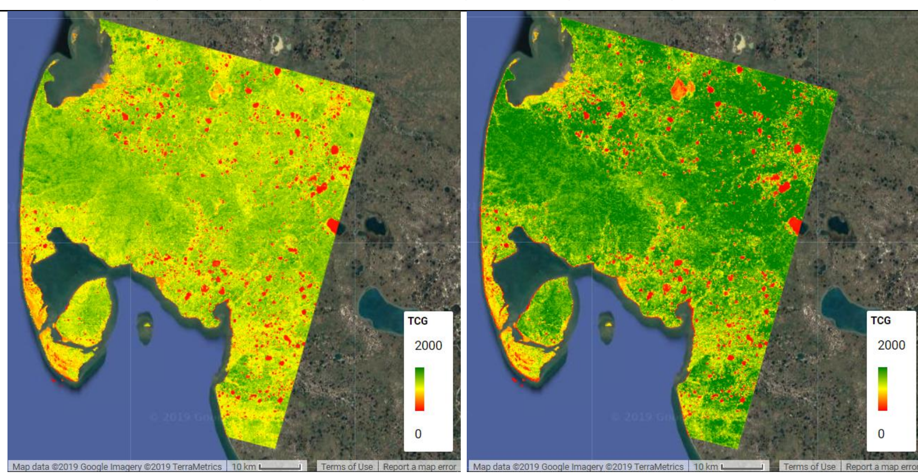


Fig. 7 Mean TC Greenness and distribution of TCG for 1985 and 2019 in Marre-Sale site

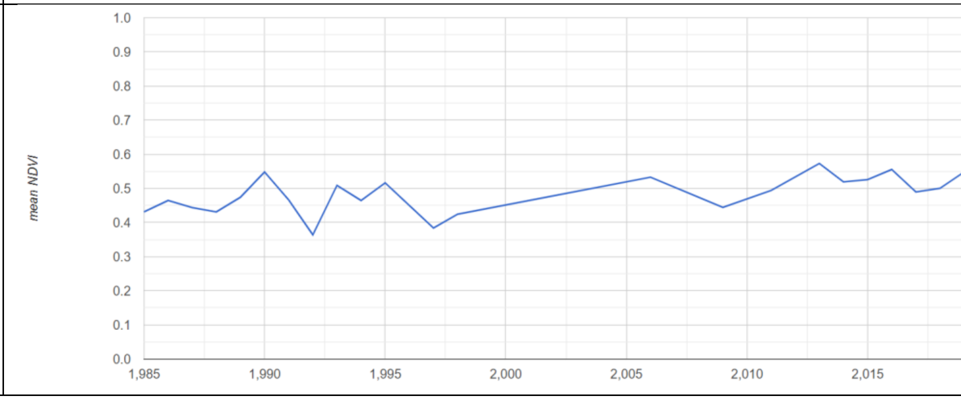
		NDVI
Marre-Sale	Landsat 1985-2019	

Fig. 8 Mean NDVI for 1985 – 2019 in Marre-Sale area

Pechora delta area

The analysis of the evolution of vegetation indices for this area of southern tundra shows the same increase as in the other analyzed sites, this pattern of tundra "greening" (fig. 9) being mentioned also in other studies (Daan et al., 2011, Yu et al, 2011, Nitze and Grosse, 2016), and is correlated with the increase o summer temperatures that influence the development of shrubs.

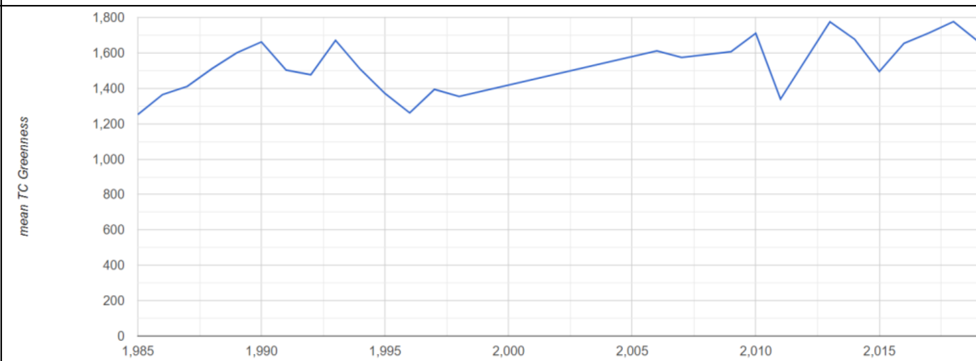
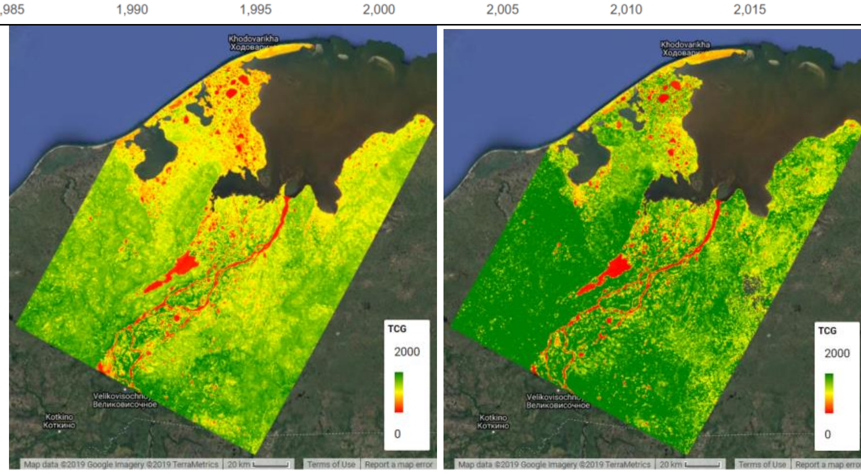
		TC Greenness
Pechora Delta	LANDSAT 1985-2019	
	TCG LANDSAT 1985 și 2019	

Fig. 9 Evolution of mean TCG and distribution of TCG values in 1985 and 2019 in Pechora delta area

Also a slight increase in NDBR mean values in the analyzed interval has been observed and also an increase of area covered by seasonal water after 2012.

Urengoy area

This site is located in forest tundra of discontinuous permafrost. From the analysis of vegetation indices, the same increase in mean values of all indices has been identified, this being correlated with the increase in mean LST values for July (example of mean LST distribution for 2000 and 2019 can be observed in fig. 10).

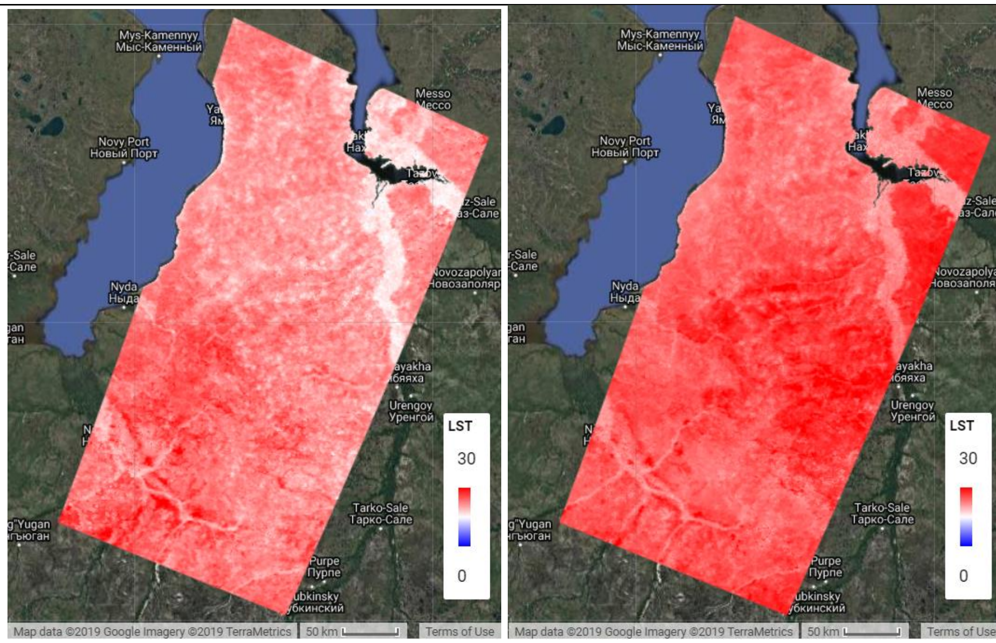
Urengoy area	**LST MODIS 2000 și 2019**	

Fig. 10 Mean LST for July in 2000 and 2019 in Urengoy area

An increase in the frequency of wildfire events has been documented in recent years in southern Siberia (Kukavskaya et al., 2016), as a consequence of summer temperatures increase. In the case of Urengoy site an increase in NDBR values was identified.

Conclusions

In the phase 2 reporting interval related to the WP1 od the project, the indices and parameters related to the changes in arctic landscape have been quantified for specific points and areas in West Siberia. An algorithm for automated calculation of mean values and trend of several indices using Landsat and MODIS data has been developed using Google Earth Engine. The algorithm uses the images available in the archives from Landsat and MODIS and has been tested on four sites located in the main bio-climatic zones of West Siberia (Belyi Island for arctic tundra, Marre-Sale in typical tundra, Urengoy in forest tundra and Pechora delta). The results of the temporal analysis can be displayed as graphs between selected years or as map of mean values of a selected index.

Most of the vegetation indices show an increase in mean values during the analyzed intervals. The surface water distribution shows high variability depending of the permafrost zone where the site is located.

In the nest steps changes at a detailed spatial scale using very high resolution images will be analyzed. Furthermore, several extreme climatic events (i.e. twice monthly precipitation 5 year warming trend) will be analyzed in correlation with changes observed in satellite images.

Dissemination

The main information about the SODEEP project can be found at the webpage: https://sodeep.projects.uvt.ro/.

The activities and results within this phase of the project have been discussed during montly telecon and within two project meetings in Hamburg (February 2019) and Moscow (September 2019), and also at four conferences as follows:

- Georgievski, G., Hagemann, S., Sein, D., Nicolsky, D., Romanovsky, D., Onaca, A., Chetan, M., Urdea, P., Drozdov, D., Gravis, A., Study Of the Development of Extreme Events over Permafrost areas - SODEEP, *EGU, Viena, Austria*, 7-12.04.2019;
- Onaca, A., Ardelean, F., Chețan, M., Dornik, A., Hegyi, A., Urdea, P., 2019, Quantifying recent landscape changes using multi-temporal satellite images in permafrost areas from Western Siberia, *17th International Symposium on Geo-Disaster Reduction*, 19-23.08.2019, Issyk Kul, Kyrgyzstan;
- Chețan, M., Ardelean, F., Dornik, A., Onaca, A., Berzescu, O., Hegyi, A., 2019, Assessing landscape changes using Google Earth Engine in different permafrost areas from West Siberia, *21st International Symposium on Symbolic and Numerical Algorithms for Scientific Computing – SYNASC*, 04-07.09.2019, Timișoara, Romania
- Ardelean, F., Dornik, A., Chețan, M., Onaca, A., Assessment of recent vegetation changes in permafrost areas from West Siberia using Google Earth Engine, "*Geographia Napocensis" Conference*, 03-06.10.2019, Cluj-Napoca, Romania.

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