Report no. 3
Interval 01.01.2020 – 31.10.2020
for ERANET-RUS-PLUS-SODEEP project
"Study of the development of extreme events over permafrost areas"

Phase 3: Evaluation and comparison of changes identified on satellite imagery analysis with field data

Activities

- A1.Progress meeting in Romania
- A2.Evaluation and comparison of identified changes in satellite with field data (WP 1)
- A3.Evaluation of historical extreme events and their impact on permafrost (WP 4)
- A4.Closing meeting in Germany

Phase Summary

In this phase we have analysed the changes identified on satellite imagery analysis with field data. We have also analysed the years in which extreme climatic events were recorded and we tried to understand how these climatic extreme events determined environmental changes. We have used coarse and medium resolution satellite images (e.g., MODIS, Landsat) and high-resolution satellite images (ex: WorldView, QuickBird, GeoEye, Corona). In this phase we also participated to two different workshops which took place on-line due to COVID-19 pandemic. In this phase we have published one paper in Remote Sensning and we submitted a second one to Science of the Total Environment. Another paper coordinated by HZG and AWI in which WUT was involved will be submitted in the next period.

A1. Progress meeting in Romania

Due to the pandemic situation in Europe the progress meeting scheduled to take place in Timisoara in 23 March 2020 was organized on-line using the webex platform. At this workshop organized by WUT participated all the members of the Consortium (HZG, AWI, WUT and TSU): Alexandru Onaca (WUT), Florina Ardelean (WUT), Marinela Adriana Chetan (WUT), Andrei Dornik (WUT), Philipp de Vrese (MPI), Dmitry Sein (AWI), Stefan Hagemann (HZG), Goran Georgievski (MPI/HZG/AWI) (fig. 01).

Within the workshop each partner presented the progress of the deliverables. Discussion on the disturbances identified through remote sensing analysis and comparisons with field data in CALM sites took place. The extreme climatic events which determine permafrost degradation and the calibration of the models were also discussed.

A plan for the dissemination of the scientific results was established. WUT agreed to coordinate a paper in which different indices derived from satellite images were assessed and compared with field data.
The programm of the meeting is displayed in table 1.

Tabel 1 Workshop`s progamm organized by WUT.

Agenda for SODEEP project video conference meeting

23 March 2020

09.00	Welcome, project overview and forthcoming activities/milestones (Stefan/Goran)
09.15	Introduction to WUT and their research
10.15	Coffee break
10.30	HZG & AWI – progress report and presentation of selected results
11.30	WUT – progress report and presentation of selected results
12.00	TSU & UAF – progress report and presentation of selected results
12.30	Lunch
13.30	Discussion on extreme events on selected sites (all)
14.30	Common activities: Dissemination, Publications, Administrative issues, Discussion on specific topics
15.30	Summary and plans how to continue (all)
16.00	End of meeting

The times and topics are flexible and can be adjusted.

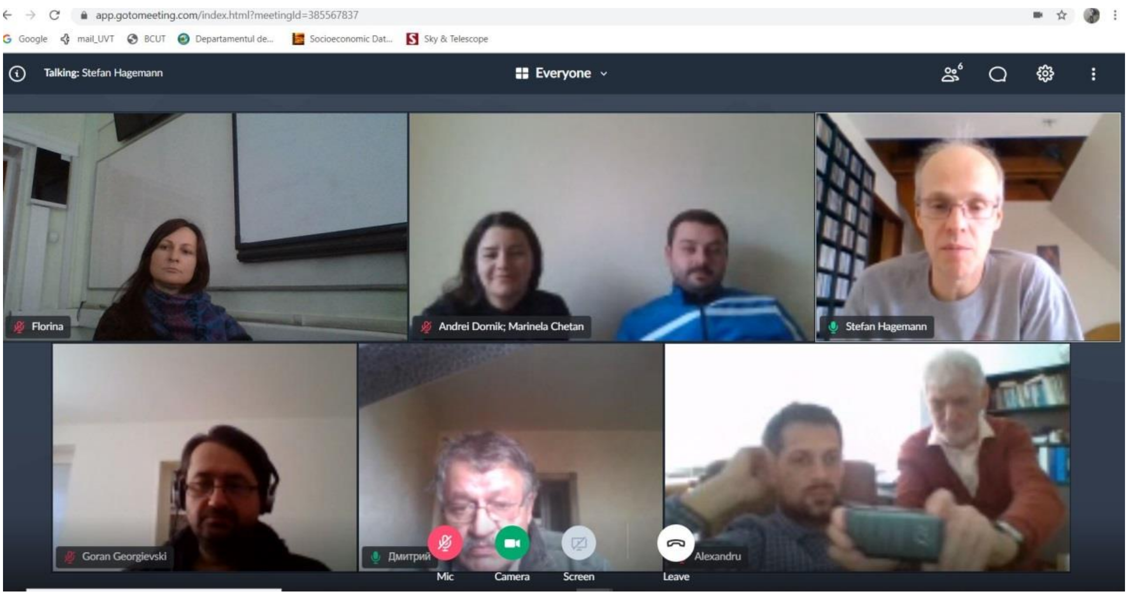

Fig. 1 Participants at the on-line workshop in 23 March 2020.

A2. Evaluation and comparison of identified changes in satellite with field data

I Satellite data with medium resolution

The greenness and moisture of the vegetation and lake distribution in the Pechora catchment (fig. 1) were analysed using Landsat satellite images. Changes were carefully assessed in different types of permafrost and across two major biomes: taiga and tundra. In addition climatic data from meteorologic station and obtained from different models were analysed in order to assess the relationships between disturbances and changes and climatic evolution.

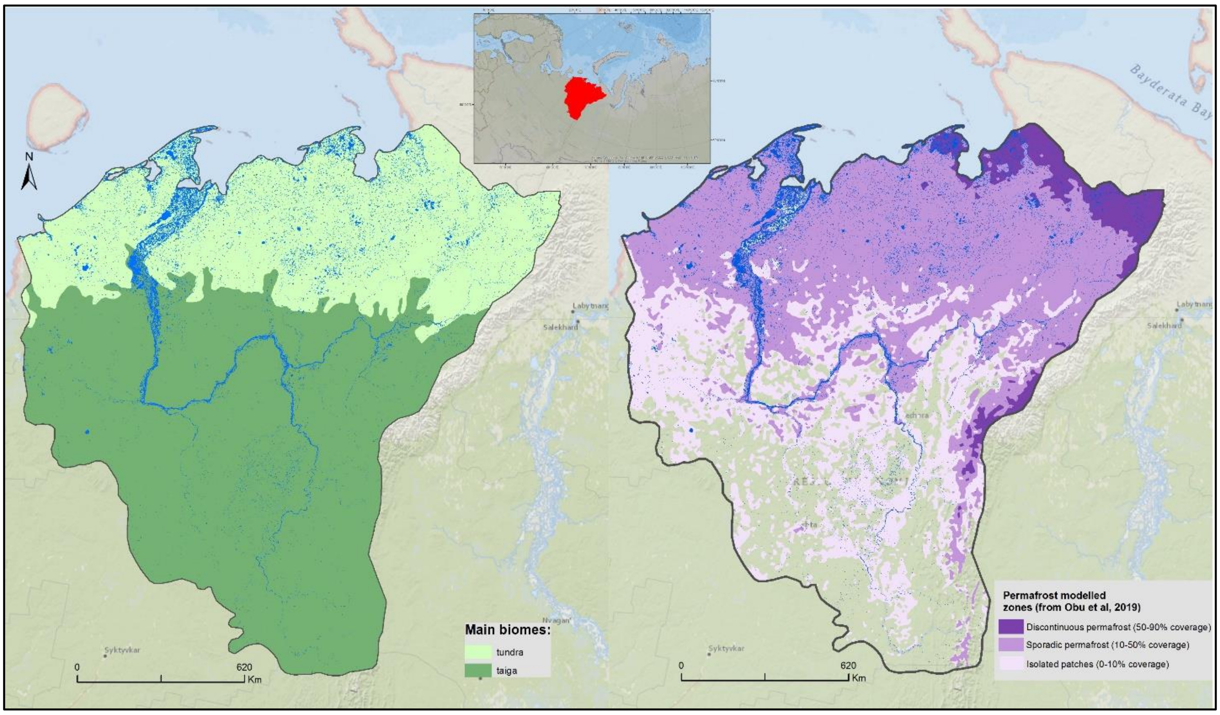

Fig 2 Main biomes and permafrost types within Pechora catchment

Analysing the Normalized Difference Vegetation Index (NDVI) (fig. 2) and Normalized Difference Moisture Index (NDMI) for the summer months we observed a greening trend and an increase of the vegetation moisture. A good correspondence between summer temperature evolution and NDVI was observed with a delay of one year. NDMI correlates better with total amounts of precipitation rather than with summer precipitation and with the snow water equivalent. For example, a warm summer is followed next year by a peak in NDVI, whereas a cold summer is followed by a next year NDVI minimum.

In the Pechora Delta the vegetation show an increase in consistency starting with 1987. In areas with discontinuous permafrost NDVI increased starting with 2007, in sporadic permafrost with 2011 and in isolated permafrost and permafrost free areas with 2002 (Chețan et al., 2020). The tendency of NDVI is to follow summer temperatures, with a delay of one year, like in Except discontinuous permafrost zone, NDVI evolution tend to be in accordance with average summer temperature across the analyzed regions, with a year delay of peaks and minimums, like 1986-1987, 1989-1990, 1993-1994, 1999-2000, 2000-2001, 2010-2011 or 2016-2017. In the discontinuous permafrost the behavior is somehow different, the vegetation response being delayed with more years (Chețan et al., 2020). There are insignificant differences between the vegetation response of tundra and taiga, however the NDVI gain is slightly greater in the taiga after 2002.

A clear increasing trend of vegetation moisture was also observed in the Pechora catchment in the last 35 years. The increase was more significant in the Pechora Delta. NDMI is strongly controlled by yearly total precipitation, revealing an increasing trend between 1985 and 2005/2007. From 2005 to 2016 both annual precipitation and vegetation moisture decreased, whereas after 2016 NDMI and precipitation increased again (fig. 4) (Chețan et al., 2020).

An evident general greening trend was observed for the entire Pechora catchment, with small areas showing decreasing NDVI values distributed mainly at high altitudes (fig. 5)

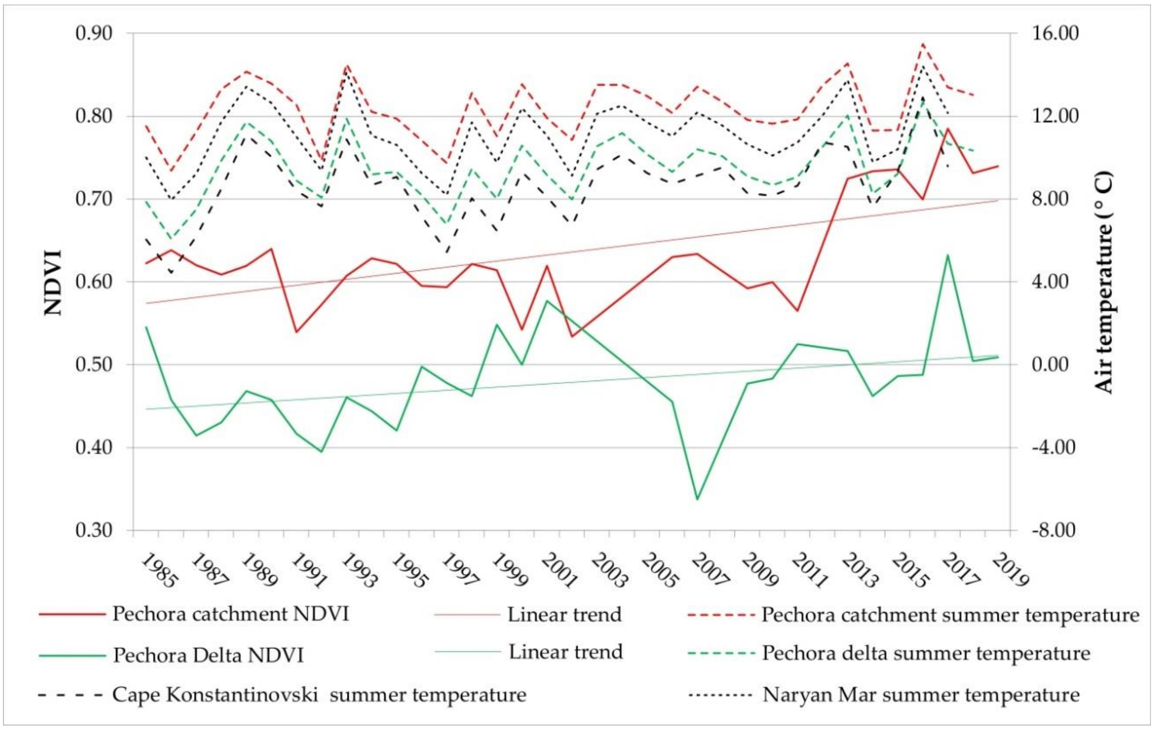

Fig. 3 Vegetation consistency (NDVI) dynamics over the last 35 years in comparison with climatic data (ERA-Interim for Pechora catchment and metorological data from Naryan Mar and Cape Konstantinovski) (from Chetan et al., 2020).

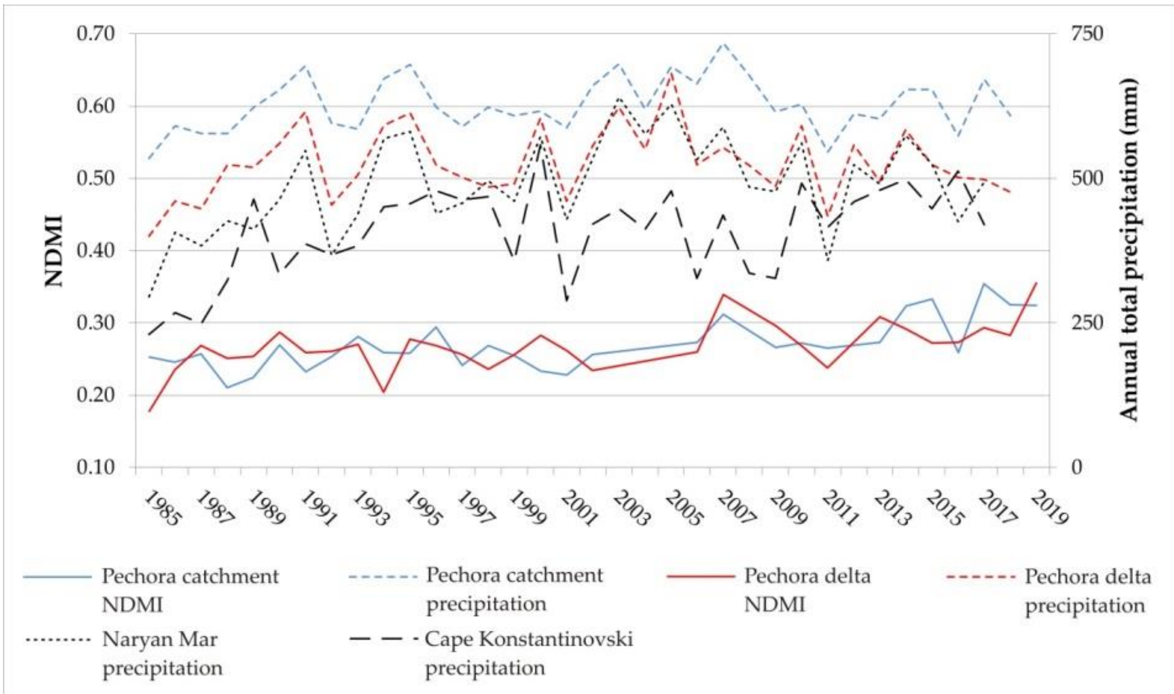

Fig. 4 Vegetation moisture (NDMI) dynamics within study areas over the last 35 years in comparison with climatic data (ERA-Interim for Pechora catchment and metorological data from Naryan Mar and Cape Konstantinovski) (from Chetan et al., 2020).

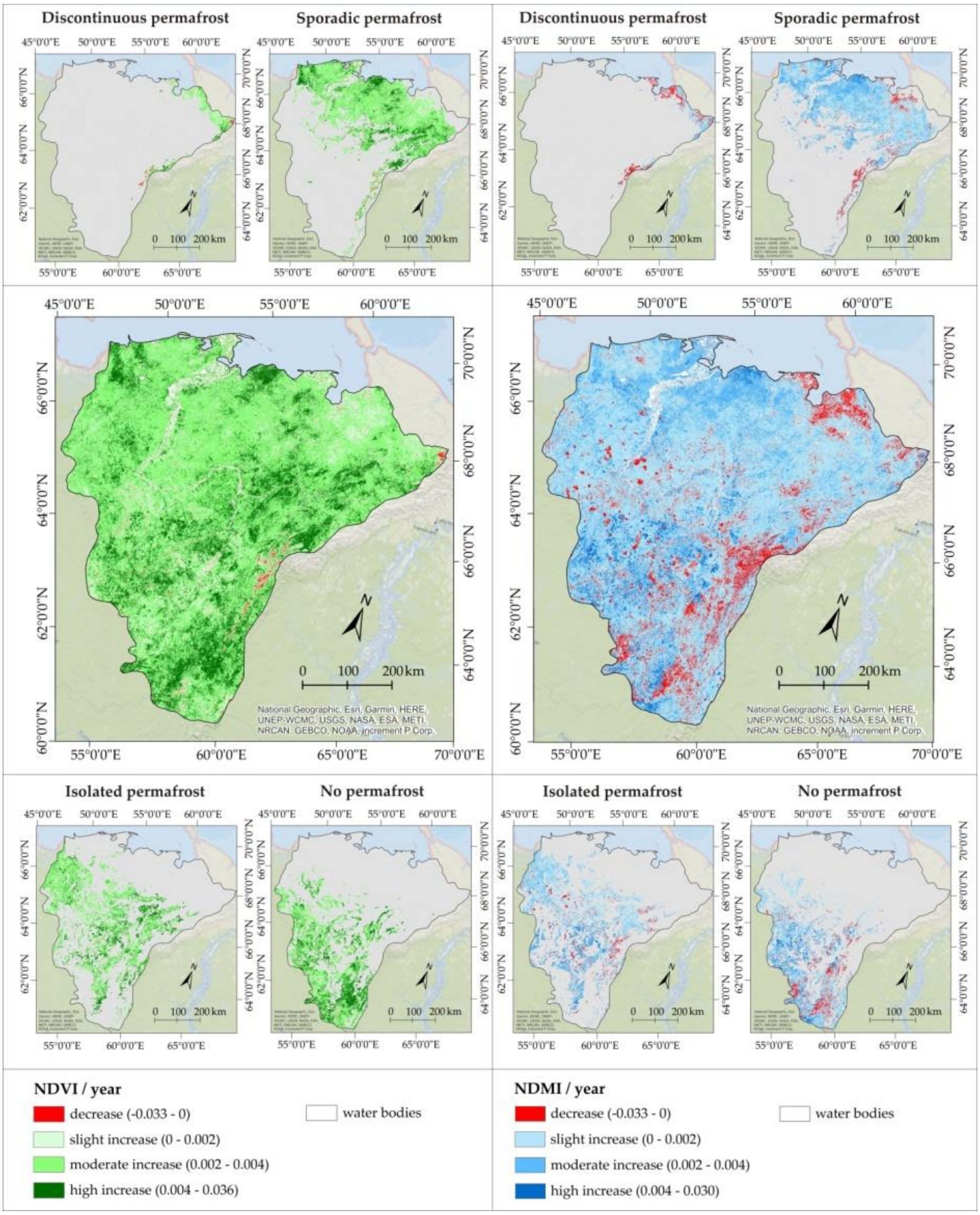

Fig. 5. Annual trend slope of vegetation multi-spectral indices within Pechora catchment (from Chetan et al., 2020).

The analysis also revealed a decrease of permanent lakes and an increase of temporary lakes. 116 119 permanent lakes were identified with a total surface area of 592 289 ha, which represent 1,47% from the total area of the river basin. Permanent lakes density is 0,4 lakes/km^2, with an average area of 3,7 ha. The loss of water area of permanent lakes was 2685,1 ha. The overall lakes evolution is displayed in fig. 6. The highest number of lakes is in sporadic permafrost, whereas in discontinuous and isolated permafrost the number of lakes is relatively similar. The highest lakes density is in discontinuous permafrost, but here are the smallest lakes (Chețan et al., 2020).

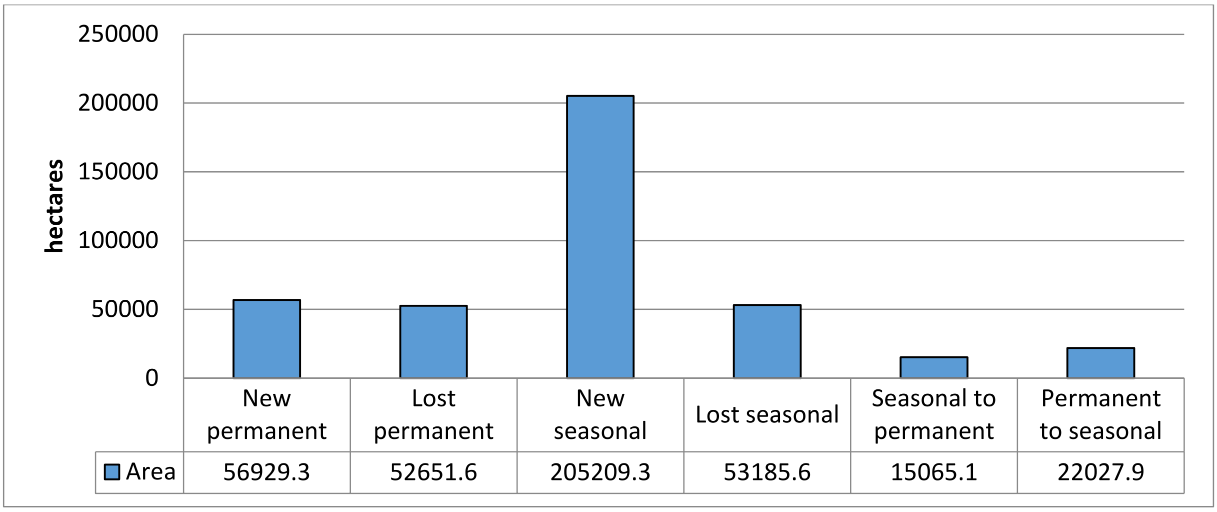

Fig. 6. Changes of permanent and seasonal lakes in the Pechora catchment (from Chetan et al., 2020).

Similar NDVI tendencies were captured elsewhere in the arctic regions (Nitze and Grosse, 2016; Ju and Masek, 2016; Fraser et al., 2014). The greening of Arctic tundra is generally associated with a recent increase of June-July air temperature (Miles et al., 2019; Walker et al., 2012; Verbyla and Kurowski, 2019). An overall slight decreasing of permanent lakes was observed in the Pechora catchment as elsewhere in the circumpolar region (Smith et al., 2005; Carroll et al., 2011; Andersen and Lougheed, 2015).

II Satellite data with high resolution

We used very high resolution optical satellite images (WorldView, QuickBird, GeoEye, Corona) to quantify various types of disturbances in the Western Arctic Russia. We focused on land use land cover changes (LULC), thermokarstic lakes, rivers courses, retrogressive thaw slumps and infrastructure. Three sites were analyzed in the Arctic Russia, one in continuous permafrost (Yamal), one in discontinuous permafrost (Urengoy) and one in sporadic permafrost (Pechora). Each site cover around 100 km^2. In the vicinity of these areas there are CALM monitoring sites (Vaskiny Dachi, Urengoy Gas Field GP15 și Bolvansky Cape).

The landcover analysis revealed a significant increase of shrubs area in all the sites and a slight increase of water class. The grassland and sparse vegetation class recorded a decrease in all the sites. The number of lakes and their corresponding total area increased in all cases. In Urengoy 317 new lakes occurred between 2003 and 2017. The investigated rivers increased in length and width and the erosion was much higher than the accumulation in the last two decades. The sinuosity of both analyzed rivers increased. The number of retrogressive thaw slumps and their corresponding area also increased in Yamal Peninsula between 2004 and 2016. The calculated headwall retreat rates were similar with others reported in arctic regions (Lantz and Kokelj, 2008; Séjourné et al., 2015). In the Yamal Peninsula the infrastructure extended between 2004 and 2016 affecting the hydrological features.

A3. Evaluation of historical extreme events and their impact on permafrost (WP 4)

We applied the algorithm to assess landscape feature dynamics (vegetation greenness/density/moisture, land surface temperature, seasonal and permanent water area), on CALM sites and selected cases of extreme events.

I. Analysis of CALM sites

Bely Island (73°19'37" N; 70°05'07" E)

Vegetation greenness/density

- All 5 vegetation indices suggest that vegetation greenness/density slightly increased (1985-2019)
- Some peaks (probably warmer or longer summer): 1995, 2000, 2012-2013, 2016
- Some minimums (probably colder or shorter summer): 1994, 2002, 2006, 2008, 2014

Vegetation moisture

- A slight decrease of vegetation moisture (1985-2019)
- Significant increase between 1985-2009, and decrease after 2009
- Peaks (probably higher precipitation): 1990, 1999, 2015
- Minimums: 1988, 1991, 2001, 2017

Land surface temperature (July)

- Constant between 2000-2019
- Significant increase between 2000-2016 (+6.5 degrees C), and decrease after 2016
- Peaks: 2001, 2004, 2013, 2016
- Minimums: 2000, 2002, 2010, 2011, 2014, 2018, 2019

Seasonal and permanent water

- 3 times increase in seasonal water, and a slight decrease in permanent water (possibly lake drain) between 1985-2018
- Increase trend in seasonal water after 2000
- Peaks in seasonal water: 1988, 1994, 1998
- Minimums in seasonal water: 1985, 1986, 1989, 2000, 2001, 2004, 2010, 2012
- Significant decrease of permanent water between 1985-2005 (-50 sq km)
- Minimums in permanent water: 2005, 2010

Marre Sale, Yamal Peninsula (69° 43' N; 66° 45' E)

Vegetation greenness/density

- All vegetation indices show that vegetation greenness/density increased significantly between 1985-2019
- Some peaks: 1995, 2002, 2006, 2012, 2013, 2016, 2019
- Some minimums: 1988, 1989, 1992, 1998

Vegetation moisture

- An increase of vegetation moisture (1985-2019)
- Peaks: 1986, 1990, 1995, 2001, 2019
- Minimums: 1985, 1988, 1991, 2000, 2017

Land surface temperature (July)

- Constant between 2000-2019
- Significant increase between 2000-2016 (+6.4 degrees C), and decrease after 2016
- Peaks: 2004, 2013, 2016
- Minimums: 2002, 2005, 2010, 2011, 2014, 2018

Seasonal and permanent water

- Slight increase in seasonal water, and no change in permanent water between 1985-2018
- Decrease trend in seasonal water to 1999, and increase trend after 1999
- Peaks in seasonal water: 1987, 1989, 1990, 2017, 2018
- Minimums in seasonal water: 1999, 2002, 2003, 2010, 2012
- Significant decrease of permanent water in 1999 and 2002 (-20-30 sq km)

Bolvansky (68° 18' N; 54° 30' E)

Vegetation greenness/density

- All vegetation indices show that vegetation greenness/density increased significantly between 1985-2018
- Some peaks: 2003, 2004, 2005, 2007, 2013, 2018
- Some minimums: 1985, 1996, 2001, 2006, 2015, 2016

Vegetation moisture

- Significant increase of vegetation moisture (1985-2019)
- Peaks: 1989, 1990, 2000, 2007, 2013, 2019
- Minimums: 1985, 1994, 1996, 1998, 2001, 2017

Land surface temperature (July)

- Decrease between 2000-2019
- Slight increase between 2000-2016, and decrease after 2016
- Peaks: 2004, 2013, 2016
- Minimums: 2001, 2002, 2005, 2010, 2011, 2015, 2019

Seasonal and permanent water

- Huge increase in seasonal water, and slight increase in permanent water between 1985-2018
- Decrease trend in seasonal water to 1999, and increase trend after 1999
- Peaks in seasonal water: 1987, 1994, 2007, 2017, 2018
- Minimums in seasonal water: 1990, 1999, 2003, 2004, 2012
- Significant decrease of permanent water in 1999, 2002, 2003, 2008, 2012 (-15-70 sq km)

Urengoy region
(Urengoy Gas Field GP5 - 66.31537 N, 76.90772 E;
Urengoy Gas Field GP15 67.4779100 N, 76.6952900 E;
Nadym West Siberia - 65° 20' N, 72° 55' E)

Vegetation greenness/density

- All vegetation indices show that vegetation greenness/density increased between 1985-2019
- Some peaks: 1998, 2006, 2007, 2013, 2016, 2019
- Some minimums: 2000, 2011, 2015, 2018

Vegetation moisture

- Constant / slight decrease of vegetation moisture (1985-2019)
- Peaks: 1986, 1992, 1998, 2010
- Minimums: 1988, 1990, 1995, 2007, 2016

Land surface temperature (July)

- Significant increase between 2000-2019 (+3 degrees C)
- Slight decrease after 2016
- Peaks: 2004, 2007, 2013, 2016
- Minimums: 2003, 2011, 2014

Seasonal and permanent water

- Slight increase in seasonal water, and slight decrease in permanent water between 1985-2018
- Decrease trend in seasonal water to 1999, and increase trend after 1999
- Peaks in seasonal water: 1985, 1990, 1994, 2007, 2009, 2013, 2014, 2015, 2016, 2017, 2018
- Minimums in seasonal water: 1999, 2001, 2003, 2008, 2010
- Significant decrease of permanent water in 1999, 2002, 2004 (maximum of -2500 sq km)

II. Analysis of extreme events locations

▯ 2 events with no observable signature on landscape dynamics

Early autumn deep snow

- no effect on vegetation greenness/density or moisture
- slight decrease of permanent water after event
- decrease of seasonal water after event

Twice as much monthly precipitation

- no observable signs on vegetation greenness density, moisture after events
- an increase in seasonal water area in the next year after event (expected)

▯ 2 events with some observable signature on landscape dynamics

Late spring deep snow

- Slight vegetation decline/loss in the year of event
- In the next year after event it was observed contradictory trends, between locations
  - 2017-2018 vegetation decline (for 2017 event)
  - 2018-2019 vegetation denser (for 2018 event)
- No effect on vegetation moisture
- Slight increase of seasonal water in the year of event (expected)

5 year warming trend

- 1993 and 2011 events - significant vegetation development, greening after event (8 locations out of 9)
- 1995 and 2005 events – no vegetation change or even decline after event

A4. Closing meeting in Germany

Such as the progress meeting organized in March 2020 by WUT, the closing meeting was also on-line and was organized by HZG in 28.09.2020 on GoToMeeting platform. The programm of the workshop is displayed in Table 2.

Table 2. Agenda for on-line closing meeting

Agenda for SODEEP final project meeting using GoTo Meeting

28 September 2020

09.00	Welcome and project overview (Stefan/Goran)
09:15	TSU/UAF contributions
09.45	WUT – progress report and presentation of selected results
10.45	Coffee break
11.00	HZG & AWI – progress report and presentation of selected results
12.00	Lunch
13.00	Common activities: Dissemination, Publications, Administrative issues, Discussion on specific topics
14:00	P. de Vrese (MPI-M): Multistability and adjustment-timescales of the permafrost carbon cycle at the 1.5°C target
14.15	Summary and plans how to continue
15.00	End of meeting

The times and topics are flexible and can be adjusted.

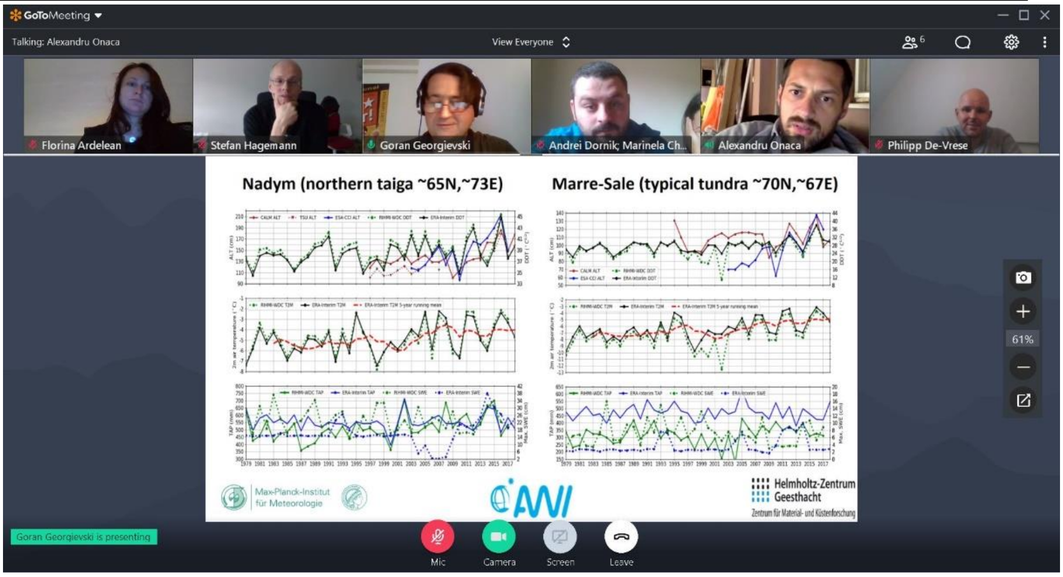

Fig. 7. Participants at the on-line workshop in 28 September 2020.

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 monthly teleconferences and within two on-line meetings in March 2020 and September 2020.

Conferences

- Ardelean, F., Chețan, M., Dornik, A., Onaca, A., Georgievski, G., Drozdov, D., Romanovsky, V., Hagemann, S., Nicolsky, D., and Sein, D., 2020, Recent landscape changes assessed by remotely sensed data in Pechora Region, EGU General Assembly, Online, 4–8 May 2020, EGU2020-17819, https://doi.org/10.5194/egusphere-egu2020-17819
- Georgievski, G., Hagemann, S., Sein, D., Drozdov, D., Gravis, A., Romanovsky, V., Nicolsky, D., Onaca, A., Ardelean, F., Chețan, M., and Dornik, A., 2020, Climate extremes relevant for

permafrost degradation, EGU General Assembly, Online, 4–8 May 2020, EGU2020-16115, https://doi.org/10.5194/egusphere-egu2020-16115

- Ardelean, F., Onaca, A., Dornik, A., Chețan, M., 2020, Assessment of spatio-temporal landscape changes from VHR satellite images in three different permafrost areas from West Siberia, 22nd International Symposium on Symbolic and Numerical Algorithms for Scientific Computing – SYNASC, Timișoara, 01-04.09.2020, https://easychair.org/smart-program/SYNASC2020/2020-09-02.html

Articles

- Chețan, M., Dornik, A., Ardelean, F., Georgievski, G., Hagemann, S., Romanovsky, V., Onaca, A., Drozdov, D., 2020, 35 Years of Vegetation and Lake Dynamics in the Pechora Catchment, Russian European Arctic, *Remote Sensing,* 12 (11), 1863, https://doi.org/10.3390/rs12111863
- Ardelean, F., Onaca, A., Chețan, M., Dornik, A., Georgievski, G., Hagemann, S., Timofte, F., Berzescu, O., Assessment of spatio-temporal landscape changes from VHR images in three different permafrost areas from West Russian Arctic, *submitted to Science of the Total Environments*

References

Andresen, C.G.; Lougheed, V.L., 2015, Disappearing Arctic tundra ponds: Fine-scale analysis of surface hydrology in drained thaw lake basins over a 65 year period (1948–2013). J. Geophys. Res. Biogeosciences, 120,466–479.

Carroll, M.L.; Townshend, J.R.G.; DiMiceli, C.M.; Loboda, T.; Sohlberg, R.A., **2011**, Shrinking lakes of the Arctic: Spatial relationships and trajectory of change. Geophys. Res. Lett. 38.

Chețan, M., Dornik, A., Ardelean, F., Georgievski, G., Hagemann, S., Romanovsky, V., Onaca, A., Drozdov, D., 2020, 35 Years of Vegetation and Lake Dynamics in the Pechora Catchment, Russian European Arctic, *Remote Sensing,* 12 (11), 1863, https://doi.org/10.3390/rs12111863

Fraser, R.H.; Olthof, I.; Kokelj, S.V.; Lantz, T.C.; Lacelle, D.; Brooker, A.; Wolfe, S.; Schwarz, S., **2014**, Detecting landscape changes in high latitude environments using landsat trend analysis: 1. Visualization. Remote Sens., 6, 11533–11557.

Ju, J.; Masek, J.G., **2016**, The vegetation greenness trend in Canada and US Alaska from 1984–2012 Landsat data. Remote Sens. Environ., 176, 1–16.

Lantz, T.C., Kokelj, S. V, 2008, Increasing rates of retrogressive thaw slump activity in the Mackenzie Delta region, N.W.T., Canada. Geophys. Res. Lett. 35. https://doi.org/10.1029/2007GL032433

Miles, M.W.; Miles, V.V.; Esau, I., **2019**, Varying climate response across the tundra, forest-tundra and boreal forest biomes in northern West Siberia. Environ. Res. Lett., 14, 075008.

Nitze, I.; Grosse, G., **2016**, Detection of landscape dynamics in the Arctic Lena Delta with temporally dense Landsat time-series stacks. Remote Sens. Environ., 181, 27–41.

Séjourné, A., Costard, F., Fedorov, A., Gargani, J., Skorve, J., Massé, M., Mège, D., 2015, Evolution of the banks of thermokarst lakes in Central Yakutia (Central Siberia) due to retrogressive thaw slump activity controlled by insolation. Geomorphology 241, 31–40.

Smith, L.C.; Sheng, Y.; MacDonald, G.; Hinzman, L., 2005, Disappearing arctic lakes. Science, 308, 1429.

Verbyla, D.; Kurkowski, T.A., **2019**, NDVI–Climate relationships in high-latitude mountains of Alaska and Yukon Territory. Arct. Antarct. Alp. Res., 51, 397–411.

Walker, D.; Epstein, H.; Raynolds, M.; Kuss, P.; Kopecky, M.; Frost, G.; Daniëls, F.; Leibman, M.; Moskalenko, N.; Matyshak, G., **2012**, Environment, vegetation and greenness (NDVI) along the North America and Eurasia Arctic transects. Environ. Res. Lett. 7, 015504.