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2013 Environ. Res. Lett. 8 045026

(http://iopscience.iop.org/1748-9326/8/4/045026)

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IOP PUBLISHING ENVIRONMENTAL RESEARCH LETTERS
Environ. Res. Lett. **8** (2013) 045026 (9pp) doi:10.1088/1748-9326/8/4/045026

# Assessment of spring floods and surface water extent over the Yamalo-Nenets Autonomous District

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Received 23 June 2013
Accepted for publication 28 October 2013
Published 21 November 2013
Online at stacks.iop.org/ERL/8/045026

**Abstract**
Remote sensing of Arctic water bodies is an essential method for monitoring the dynamics of frozen ground. Thaw lake change provides insight into the state of permafrost. In the vast Arctic and sub-Arctic areas capturing changes in lake extent is assisted by satellite data. In particular, active microwave sensors can be used in a straightforward manner for water body classifications.

This study uses the pan-Siberian datasets that are provided under the ESA STSE-ALANIS methane project. Surface water classifications in 10-day intervals have been produced using Envisat ASAR (Advanced Synthetic Aperture Radar) operating in wide swath mode. The high temporal frequency of these data allows an investigation of surface hydrology on an intra-annual basis.

The current study applies a post-processing algorithm to the ALANIS products in order to investigate changes in surface inundation across the Yamalo-Nenets Autonomous District over the summer period of 2007. Multiple areas are found to exhibit changes in surface inundation. Strong seasonal variations occur in areas where previous investigations determined disappearing lakes. Spring floods associated with the depletion of snow-cover and melt waters as well as floodplain dynamics can be identified. On the Yamal peninsula, these changes occur most dominantly in the west; an area subject to anthropogenic land-use change. Changes in water body extent for each hot spot of seasonal variations are quantified and discussed.

**Keywords:** permafrost, surface hydrology, wetland dynamics—remote sensing, active microwave, synthetic aperture radar

S Online supplementary data available from stacks.iop.org/ERL/8/045026/mmedia

## 1. Introduction

Wetlands play an important role in the global carbon budget. They are sources of carbon dioxide ($CO_2$) and methane ($CH_4$) emissions and hence have implications for our climate. Arctic and sub-Arctic wetlands are to be considered especially fragile ecosystems due to their location in the climate sensitive tundra and boreal biomes (Aber *et al* 2012). Rising air temperatures are resulting in landscape evolution; changes in vegetation and warming of permafrost associated with complex links to biogeochemical cycling (Callaghan *et al* 2005).

In addition, the highly dynamic surface hydrology of these high-latitudinal wetlands and surface waters may be a significant factor contributing to potential climate feedbacks through its effects on, and reciprocal interactions with, the frozen ground below (Goswami *et al* 2011). The significance of freshwater ecosystems regarding carbon exchange with the atmosphere is not to be underestimated (Downing *et al* 2006). Furthermore, understanding the seasonal variability of these surface water bodies and their inherent processes is of utmost importance. To determine the environmental and climatic impacts of lakes it is necessary to know their abundance and extent (Grosse *et al* 2008). The percentage ratio of surface water cover and land-cover, known as the limnicity, gives us some indication of this abundance (Likens 2009).

Key components of the Arctic and sub-Arctic hydrological system are the spring flood season and its runoff mechanisms. River discharge is primarily affected by snow-melt waters (Zakharova *et al* 2011). The onset of spring snow-melt leads to sudden and extreme hydrological responses associated with flashy hydrographs (Lyons and Finlay 2008). In addition, permafrost restricts water infiltration into the ground, leading to seasonal inundation and surface water flow (Woo 1990).

Remote sensing techniques are a well-established method for monitoring wetland dynamics. Information on seasonal and periodic inundation patterns can easily be retrieved from such techniques. Microwave satellites (both active and passive) provide valuable information on wetland hydrology (Prigent 2001, Prigent *et al* 2007, Schroeder *et al* 2010, Watts *et al* 2012). Active microwave sensors may be used to map open water surfaces (Bartsch *et al* 2009) and monitor their dynamics (Bartsch *et al* 2007a, 2012). Investigating wetland dynamics is a multi-scale problem; both spatial and temporal aspects need to be considered. Furthermore, the inherent trade-off between spatial and temporal resolution of remotely sensed data is cause for heed. Careful considerations on which sensors provide the optimum resolution for the investigation of wetland processes are essential. The advantages of Earth observation products are undeniable, however, their suitability as a long-term monitoring method is influenced by data availability and satellite lifetime (Bartsch *et al* 2012). The limiting factors to long-term monitoring being a matter of continuity of comparable and self-consistent data.

The past years have shown an increased interest in studies of the Yamalo-Nenets Autonomous District, their prime concern being the ongoing land-use and land-cover changes through industrial development. Disturbances in vegetation have been investigated through standard NDVI techniques (Walker *et al* 2009) and Kumpula *et al* (2010, 2011, 2012) have discussed the impacts of hydrocarbon exploration in this area as measured by various sensors (ASTER VNIR, Quickbird-2, SPOT, Landsat TM and ETM+), each of different spatial resolution. They also take an interdisciplinary approach, using anthropological techniques to analyse these impacts on the indigenous Nenets people. Further, Bartsch *et al* (2010) used scatterometer data to analyse the effects of snow conditions on reindeer husbandry. Tundra lake studies have been presented by Kravtsova and Tarasenk (2011) and, on Yamal, Sannikov (2012).

The north of West Siberia is a region of fast development. It is, however, a region susceptible to environmental change on two accounts. On the one hand, gas exploration is leaving its mark on the environment and the stability of the frozen ground. On the other hand, a number of modelling studies have predicted a warming climate to have large impacts on this permafrost region (Anisimov and Reneva 2006). Lakes in permafrost regions are used as indicators of a changing climate (Yoshikawa and Hinzman 2003, Smith *et al* 2005, Plug and Scott 2008), however, so far short-term changes and other direct impacts have been overlooked and remain unstudied.

The objective of this study is to provide a starting point for investigating seasonal dynamics of open water bodies in the north of West Siberia, the Yamalo-Nenets Autonomous District. An algorithm that detects surface water extent and its retreat over time has been developed and is presented here. The authors choose to refer to the process of spring inundation drainage and runoff as dynamic behaviour, considering the one-directional changes in water extent as dynamics. It is anticipated that this method may be applied to future studies over consecutive years in order to appropriately investigate seasonal dynamics. Water body classifications are derived from synthetic aperture radar (SAR), an active microwave sensor. The focus lies on quantifying seasonal inundation due to spring floods from snow-melt waters and river discharge. High temporal resolution data are necessary for this task. The trade-off between spatial and temporal resolution is addressed by using the European Space Agency's Envisat Advanced Synthetic Aperture Radar (ASAR). This instrument operates at medium–low spatial resolution in ScanSAR mode (with a product resolution of 150 m in wide swath (WS) mode) with high temporal frequencies. Previous studies have investigated the feasibility of using ASAR data for this type of study and have shown that its coarse spatial resolution is able to capture dynamics in tundra regions (Bartsch *et al* 2012, Trofaier *et al* 2012). These data have been used to create a wetlands product in northern Eurasia within the framework of the ESA STSE-ALANIS methane project (Bartsch *et al* 2012, Reschke *et al* 2012, see supplement material available at stacks.iop.org/ERL/8/045026/mmedia; in the following referred to as ALANIS dataset).

The present study evaluates the applicability of these ALANIS methane local wetland datasets by developing a post-processing algorithm that identifies and quantifies spring flood extent of water bodies and discusses their nature in the context of their geographical setting.

## 2. Data, study areas and method

### *2.1. Envisat ASAR WS*

The ALANIS dataset covers the entire Yamalo-Nenets Autonomous District. The source, Envisat ASAR, is a C-band (centre wavelength $\lambda \sim 5.6$ cm) instrument. The ScanSAR resolution in ASAR's Wide Swath (WS) mode is 120 m for all sub-swaths (Closa *et al* 2003). An undersampled pixel spacing of 75 m is used.

ASAR WS data are acquired on request; this limits the archived material. However, more than 10 acquisitions per month are available over the study area in 2007 (Bartsch *et al* 2012). Data were taken in single polarization HH (horizontally emitted and horizontally received). The local incidence angle of the backscatter coefficient ($\sigma^0$) has been normalized to a reference angle of 30° (Sabel *et al* 2012). The normalization technique has been chosen to reduce the angular dependency of the radar backscattering coefficient on the local incidence angle. This step allows a comparable analysis of measurements taken at different incidence angles and has been successfully applied to SAR studies such as e.g. Bartsch *et al* (2007a, 2008) and Reschke *et al* (2012), who have investigated wetland dynamics and extensively cross-validated their datasets, including the ALANIS methane regional wetland product. Sabel *et al* (2012) discuss the pre-processing in more detail. The digital elevation model (DEM) used for geometric correction of the SAR data is taken from digitized Russian Topographic Maps at a 1:200 000 scale (Santoro and Strozzi 2012).

### *2.2. Study areas*

The Yamalo-Nenets Autonomous District (YNAO) is a federal subject of the Russian Federation. Its borders enclose the West Siberian Lowland, which lies between the Ural mountains and the Middle-Siberian Tableland. Both the Ob and the Yenisey rivers flow north through this territory, along its western and eastern margins respectively, into the Arctic Ocean. Continuous permafrost in the north above the Arctic circle, high ground ice content and the low relief of this area encourage poor drainage and flooding which in turn promotes peatland development. The standard deviation and inter-quartile range of the altitude of each study area are given below for each subregion.

The West Siberian Lowland is an Arctic wetland environment. Indeed, it is thought to be the world's largest Arctic wetland (Kremenetski *et al* 2003). The West Siberian Lowland embodies roughly 16% of the territory of the Russian Federation and over 50% of this lowland encloses a wetland ecosystem underlain by permafrost (Solomeshch 2005). The extent of permafrost in the district is depicted in figure 1. The developed algorithm was run for data covering the entire YNAO. The resultant classification exceeded 0.8 GB. A data volume issue arose when attempting to vectorize this raster classification, as this would have resulted in over 2 million polygons. It was therefore decided to manually inspect the classification and analyse subregions of the YNAO. The discussed subregions correspond to the areas with the highest magnitude of dynamics. They are labelled by their respective ALANIS dataset region identification number—when multiple subregions exist within one region then the identification will be of an alphanumeric type (1; see also supplement available at stacks.iop.org/ERL/8/045026/mmedia).

*2.2.1. Subregion 1—Taz river basin near Mangazeya (Мангазея).* The Taz river basin has a surface extent of about 150 000 km$^2$ (Gordeev 2006). The river flows north into the Taz river estuary (Tazovskaya Guba) approximately 250 km long running into the Ob estuary (Obskaya Guba). The study area lies in the Taz river floodplain south of the estuary, a few minutes in latitude north of the Arctic circle. The historic trade city of Mangazeya is located to the east of its borders. The size of this study area is 2345.5 km$^2$ which is an order of magnitude smaller than the other two study areas.

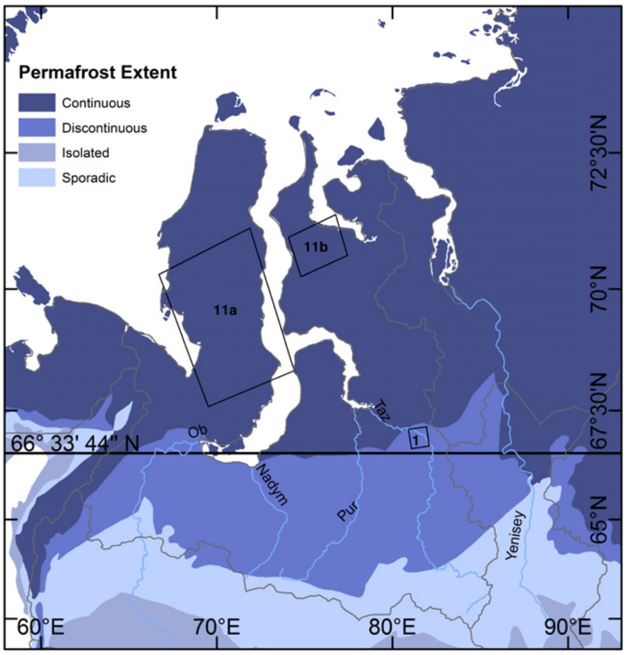


**Figure 1.** Map of the Yamalo-Nenets Autonomous District of the Russian Federation (NW Siberia) showing the location of the three study areas: subregion 1 (Taz), subregion 11a (Yamal), subregion 11b (Gydan). Permafrost extent according to Brown *et al* (1997). The borders of Russia's administrative regions are outlined in grey (Stolbovoi and McCallum 2002).

The deposits on the Taz peninsula are of marine–alluvial origin. The upper layers are alluvial sands and peat layers (Mahaney *et al* 1995, Astakhov and Nazarov 2010) This area lies in the discontinuous permafrost zone.

For the Taz study area, the standard deviation of the DEM (Santoro and Strozzi 2012) is 9.6 m, while the inter-quartile range is 12 m.

*2.2.2. Subregion 11a—Yamal peninsula.* The study area on the Yamal peninsula is the largest of the three chosen subregions of the YNAO. It covers an area of approximately 60 929 km$^2$, which is roughly 36% of the 700 km long and 240 km wide peninsula. This area is subject to ongoing anthropogenic stressors due to past and current gas exploration. The development of the gas fields, the largest of which is the Bovanenkovo gas field in the northwest of the study area, are leading to land-use and land-cover changes on the entire peninsula (Kumpula *et al* 2012). Analyses of aerial photographs in the surroundings of the gas field have shown small scale long-term expansion and decrease of thaw lakes (Sannikov 2012). Previous investigations of ASAR WS have demonstrated seasonally reoccurring variations (Bartsch *et al*

2012, Trofaier *et al* 2012). Indeed, Trofaier *et al* (2012) noted extensive open surface water, located at 70°N 68°E, to drain each year after the first two weeks of July in 2007, 2008 and 2009.

The surficial deposits are slope aeolian, alluvial, lacustrine and marine sandy to clayey deposits washed out within the active layer and of high salinity within the permafrost. Some of these deposits are also saline in the active layer (Walker *et al* 2009) resulting from active slope processes removing active layer deposits and exposing permafrost (Leibman and Streletskaya 1997).

The Circumpolar Active Layer Monitoring (CALM) site at research station Vaskiny Dachi (70° 17′N 68° 54′E) is situated in the proximity of the Bovanenkovo gas field, within the watershed of the Se-Yakha (Сёяха) and Mordy-Yakha (Мордыяха) rivers. This site is on the third alluvial–marine terrace of the Yamal peninsula which is at a maximum height of 36 m asl. Active layer depth and temperature monitoring is ongoing and records date back to 1993. In 2007, the maximum active layer depth at this site (i.e. summer thaw depth) was 135 cm (Leibman *et al* 2012).

For the Yamal study area, the standard deviation and inter-quartile range of the DEM are 19.7 m and 30 m, respectively.

*2.2.3. Subregion 11b—Gydan peninsula.* The Gydan peninsula is, similarly to the Yamal peninsula, a hydrocarbon rich environment. The study area is approximately 11 274 km$^2$ large, encompassing the untapped Salmanovskoye gas field. In the immediate south of this region lies the CALM site Parisento (70° 07′N 75° 35′E). Here, we find sands and loamy sands. In some places these are enriched by peat (Pavlov 1998). This site is less than 30 km south of the study area, lying on the same lacustrine–alluvial terraces and within the floodplain of the river Yuribei (Юрибей)—note, same name but different river to that on the Yamal peninsula over which the Yuribei Bridge was built by the gas industry, renowned for being the Arctic's longest bridge to date.

Active layer depth measurement via CALM are scarce, and last measurements are from 1995 when maximum thaw depth was 185 cm.

For the Gydan study area, the standard deviation and inter-quartile range of the DEM are 18.4 m and 31 m, respectively.

### *2.3. Mapping inundation, monitoring surface water dynamics*

Issues for mapping inundation with C-band SAR are related to the effects of waves on the water surface and emerging vegetation, as discussed in Bartsch *et al* (2012, 2009). Emerging vegetation is common for Arctic and particularly sub-Arctic water bodies. The aquatic and waterborne vegetation in wetlands and those at the margins of lakes will affect the classification method by establishing a point of difference from a smooth water surface. Figure 2 shows a photograph of an Arctic lake on the Yamal peninsula with reeds, such as arctophila grasses, growing in the water and emerging from the lake surface. It is important that change

**Figure 2.** Lake on the Yamal peninsula with arctophila emerging from the water surface and growing at its margins. (Photo taken on 3 July 2012 by Trofaier.)

analysis also considers the effects of waterborne and marginal vegetation as the classification method can only be used for identifying the drainage and runoff dynamics of open surface waters.

The ALANIS dataset is a thematic map consisting of five classes (see supplementary file for more information available at stacks.iop.org/ERL/8/045026/mmedia). Mapping of water bodies is done using the procedure first put forward by Bartsch *et al* (2007a) and which has subsequently been used for this type of investigation (Bartsch *et al* 2012, Trofaier *et al* 2012). An algorithm that uses the ALANIS dataset for identifying surface water dynamics was established. The authors shall henceforth refer to this algorithm as the surface water dynamics algorithm (SWDA). As a first step the SWDA transforms the product into a binary classification; water bodies are set to the class value 1, the surroundings to 0. This enables a straightforward calculation for determining any changes in surface water extent. In a further step, the SWDA sums each binary classification for each study area over a given time period (see equation (1)), resulting in a single classification of changes in surface water extent $X_{ij}$.

$$X_{ij} = \sum_{k=1}^{n} (x_{ij})_k \tag{1}$$

where $(x_{ij})_k$ is the $k$th classification for the region within the given time period, $i$ and $j$ are respective raster rows and columns and $n$ is six for a two-monthly period—there are three 10-day ALANIS methane water body classifications per month. The current study's time period is chosen to be July–August 2007. Previous research has shown that water bodies are still subject to a late-spring ice cover at the end of June (Trofaier *et al* 2012). It was also chosen to limit the analysis time period to two months in order to facilitate computational efficiency.

The SWDA results in a classification of changes in surface water extent: high class values represent permanent inundation, low class values identify change. Therefore we find that changes in inundation occur within the range 0 <

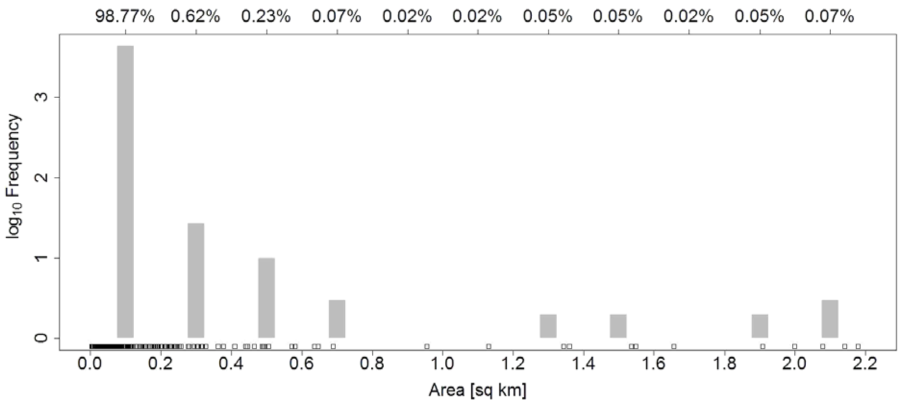


**Figure 3.** Histogram of changes in water area in subregion 1. Frequency given on a base 10 logarithmic scale. A strip chart of each change is given just above the *x*-axis.

$X_{ij} < n$. This states that grid cells equal to $n$ are determined to be permanent inundation and those equal to zero are the surroundings with no surface inundation. However, the exact value for seasonal inundation needs to be determined by inspection of both the SWDA classification and the radar data, since applying the SWDA as a stand-alone, fully automated procedure, would lead to misclassification due to wind biases. Trofaier *et al* (2012) have discussed this issue in more detail and note that availability of ample data is essential for this method. They use 14-day temporal composites to examine changes in water body extent, noting that the maximum of images used to create a composite is one per day. This, of course, is an idealized scenario which is not always achievable due to strong wind conditions. On average, Trofaier *et al* (2012) find that 10 image scenes for every 14 days are available. Therefore, it is found that over a classification time period of a number of $t$ days, the number of scenes needed to create a temporal composite is about $N > \frac{2}{3}t$. To exclude the possibility of misclassification of changes due to weather-affected imagery and lack of data, the number of useable images available for the given region was inspected. The number of radar scenes used for classifying each pixel has been determined from metafiles of the ALANIS dataset; the post-processed water body product is analysed in combination with the radar images and auxiliary data on the number of radar images that were available for each pixel in the given time period (see supplement available at stacks.iop.org/ERL/8/045026/mmedia).

The time period of investigation was cautiously chosen to cover the mid-Arctic summer period to avoid misclassification due to lake ice cover. A QuikSCAT snow-melt product (Bartsch *et al* 2007b, Bartsch 2010) was used to support this choice (see supplement available at stacks.iop.org/ERL/8/045026/mmedia).

## 3. Results

The YNAO of the Russian Federation was investigated for changes in surface inundation over the summer period July–August 2007. Surface hydrological activity, in the form of spring runoff and drainage after flooding, is quantified by applying the SWDA.

An accuracy test of lake change detection was done for the Yamal peninsula (subregion 11a) by choosing 45 random lake change polygons and inspecting a timeseries of five original Envisat ASAR WS images. 36 of these polygons corresponded to lake change; the remainder did not. The user's accuracy of the SWDA polygons against a manual interpretation of lake change, done by inspection of a radar timeseries, is determined to be 86%. In certain cases wind action played a role. The error of commission of this simple accuracy test is 27%. Unfortunately, no ground validation data are available for the present study. Previous studies on monitoring open water bodies have assessed the accuracy of the water body classification method. Bartsch *et al* (2008) found the Kappa coefficient to be 0.82 with an overall classification accuracy of 95%. An optimum threshold sensitivity analysis, examining the mean water body perimeter and area as a function of backscatter threshold, was undertaken by Trofaier *et al* (2012). Reschke *et al* (2012) assessed Envisat ASAR WS's capabilities for mapping inundation through validation with multiple datasets.

It is found that many changes registered by the SWDA occur around the margins of lakes. These are not attributed to seasonal changes in hydrology but are associated with the higher backscatter response caused by vegetation that emerges over the growing season along the shorelines and in the shallows of the lakes. An extremely high percentage of these changes are smaller than 0.2 $km^2$ (see figure 3). These changes are mostly related to the lake shorelines. Given that the spatial resolution of the sensor is only a magnitude smaller than 0.2 $km^2$ this study focuses on the statistical outliers. Therefore, a change of a minimum of 36 pixels (pixel size 74.5 m × 74.5 m) is deemed acceptable for the successful detection of seasonal inundation. This relates to all changes in water extent that are greater than 0.2 $km^2$. Any changes below this value are neglected from further analysis. The detected changes in water extent are given in table 1. The resultant SWDA changes for subregion 1 are shown in figure 4(b). This study area is 2345.5 $km^2$ large and was covered by 268.6 $km^2$ of water at the beginning of July 2007. We can also see from figure 4(b) that the main changes occur around the grid locations B2, C2-3 and D4. The calculated water body extent

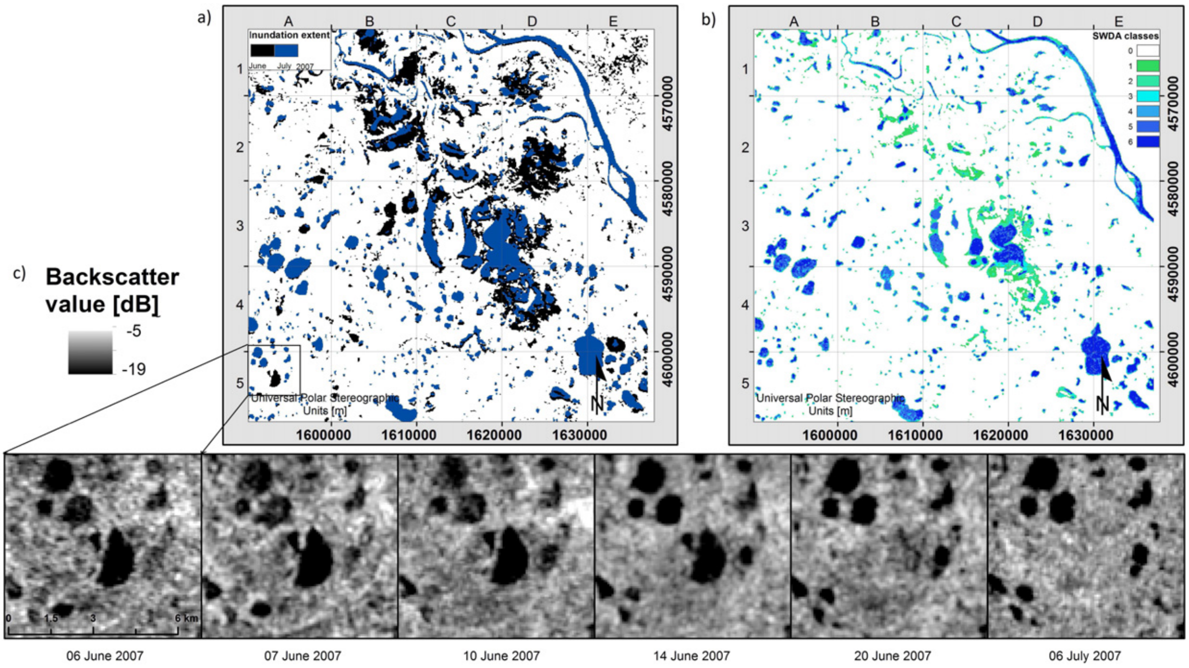


**Figure 4.** (a) Comparison of classifications of water body extent for subregion 1 for June and July 2007. (b) SWDA classification for July–August 2007. (c) Radar timeseries of disappearing open water body June–July 2007.

**Table 1.** Main parameters of study areas and their lakes in 2007.

| Parameter | 1 | 11a | 11b |
|---|---|---|---|
| Area (km$^2$) | 2345.5 | 60 929.4 | 11 273.7 |
| Water body extent[a] (km$^2$) | 268.6 | 7550.6 | 972.2 |
| Change in water body extent[b] (km$^2$) | 42 | 302 | 61 |
| Limnicity[a] (%) | 11.45 | 12.39 | 8.62 |
| Limnicity change (%) | 1.79 | 0.49 | 0.54 |

[a] At the beginning of July.
[b] Above 0.2 km$^2$ during July–August.

further shows that subregion 1 exhibits the highest change in limnicity (1.79%) over the two summer months July–August, despite being the smallest of the three study areas. This is not surprising, as most of the study area lies within the Taz river floodplain. Lake change and seasonal inundation are primarily related to spring floods from the Taz river itself.

## 4. Discussion

The Envisat ASAR WS data and the associated ALANIS methane local wetlands product clearly identify inundation changes within the YNAO in the summer of 2007. The three study areas vary greatly in size, however in spite of this, limnicity does not (see table 1). The two northerly study areas lie within the continuous permafrost zone; similar sedimentary deposits (marine–alluvial sands and clay, as well as peat) are found in these ground ice rich regions of the West Siberian North. According to Brown *et al* (1997), subregion 1 lies in the discontinuous permafrost zone at the borders to the continuous zone, its sedimentary deposits are, however, not dissimilar to the former two subregions.

The changes in surface inundation in subregion 11b mostly occur along small branches of the Yuribei river and are also to be associated with its floodplain and the respective river spring floods. One particular lake, located a few kilometres northwest of the river, shows a change of approximately 13.4 km$^2$ in surface water extent. Closer inspection of optical data clearly shows the lake's location within a flood basin through which a stream flows that connects to the Yuribei river.

The situation in subregion 11a is of a different nature. Myriad meandering rivers and streams can indeed be found throughout the entire Yamal peninsula. However, Vaskiny Dachi, in the northwest of the study area, also lies just a few kilometres south of the Bovanenkovo gas field. Closer inspection of the seasonal changes in inundation seem to show a trend towards areas where anthropogenic land-use change is underway. Kumpula *et al* (2012) have discussed changes in land-cover caused by the gas industry. Although, these impacts are detectable with medium resolution satellite imagery, finer resolution data from the commercial Quickbird-2 and GeoEye satellites provide the best evidence of anthropogenic change. Their study showed the expansion of a visibly affected area over nearly 30 years of gas field development, and discussed the negative effects on the freshwater system and drainage networks. Moreover, Zakharova *et al* (2011) have discussed how human activities have been identified to result in changes to the primary hydrological system in the Poluy–Nadym–Pur–Taz (PNPT) region, south of Yamal, to the west of subregion 1. Thermoerosion is the main process by which surface drains are created, being related to a disturbance in ground covers, exposing easily washed out sandy deposits. The melting of ground ice on flat surfaces leads to ground subsidence

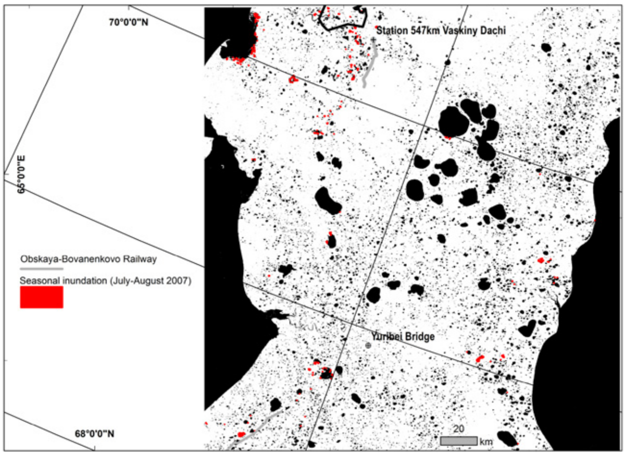


**Figure 5.** Surface hydrology classification of study area 11a. Seasonal changes in water extent for July–August 2007 are shown in red. The Obskaya–Bovanenkovo Railway was partially traced from GoogleEarth (gaps were left where the spatial resolution did not allow the identification of the railway tracks). In the north, the southern part of the Sannikov (2012) region is outlined.

and thermokarst depressions (French 2007). Processes of thermoerosion and thermokarst are promoted by human activity and infrastructure; from dirt tracks of all-terrain vehicles via gas pipelines to railway tracks and container settlements, they all contribute to land-cover changes which may result in the development of new primary drainage networks (Zakharova *et al* 2011). The present study has identified summer changes in inundation. On Yamal, these occur most dominantly in the west of the peninsula, following the route of the Obskaya–Bovanenkovo railway (see figure 5). Further analysis is beyond the scope of the present study but it demonstrates the potential of the SWDA to studies of inter-annual changes in open water bodies.

Previous studies have discussed decadal lake change in the region of the Yamalo-Nenets Autonomous District (Smith *et al* 2005, Karlsson *et al* 2012). In connection with these studies it is important to point out that seasonal lake change also needs to be considered. In order to investigate lake change using high–medium resolution satellite imagery, the date for scene comparison needs to be around the same time. If the temporal frames are not similar, the changes that are identified may be due to seasonal dynamics. Karlsson *et al* (2012) compare thermokarst lake change in the years 1973, 1987–1988 and 2007–2009 in the Nadym and Pur catchments. Many images in 1973 were taken in June, whereas the images of later years were primarily taken in July–September. They supplement their analysis with hydrological data and compare their results to a study by Smith *et al* (2005). They find that their results differ from the latter study. One of the reasons for these findings, which they put forward in their discussion, is the selection of time slices. This underlines the point that inter-annual comparisons of remotely sensed imagery may need to pay greater heed to temporal frame selections. High temporal resolution imagery may be a useful tool for such an investigation. Figure 4(c) shows a radar timeseries of an open water body that disappears over a couple of days in the Taz region in June 2007. Incidentally, subregion 1 overlaps with an area where a disappearing lake was found in the Smith *et al* (2005) study which was a survey of lake change, creating a lake inventory using Landsat-1 MSS data (spatial resolution 80 m) as well as multispectral data from the RESURS-1 satellite (spatial resolution 150 m). They state in their supplementary data (available at stacks.iop.org/ERL/8/045026/mmedia) that they classify lakes larger than 40 ha to be stable since, to their knowledge and findings, these did not exhibit any seasonal variations. Floodplain areas were excluded from this analysis to avoid seasonal affects. The SWDA has detected most spring floods to happen in the floodplain areas, as is to be expected, which would be in agreement with the premises put forward by Smith *et al* (2005). However, after manual inspection of the original data, we also find that certain open water bodies, which do not lie within floodplains, also disappears within the 2 monthly period. The lake shown in figure 4(c) is one of those water bodies lying outside a floodplain. This lake is about 1.8 $km^2$ (180 ha) large. On Yamal and Gydan we also find water bodies that are larger than the 40 ha criterion and disappear over the two summer months. Future analysis of consecutive years is needed to investigate whether these are indeed of ephemeral nature. However, given the results of this study, it does seem categorization of water bodies into stable/unstable landscape features according to size may not be that straightforward. It also underpins the need for investigating seasonal dynamics using high temporal resolution data. It is proposed that future work should apply the SWDA to analyse possible seasonality of these lakes by investigating additional years.

## 5. Conclusion

This study tests the application of a change detection algorithm for analysing spring surface water dynamics in the Yamalo-Nenets Autonomous District in the north of West Siberia. Envisat ASAR WS active microwave data and water body classifications provided under the ESA STSE-ALANIS methane project were used for this analysis. These high temporal resolution radar data and classifications are ideally suited to illustrate seasonal open water body dynamics. The results indicate changes due to melt waters from a thawing landscape and spring floods from river systems. The limnicities of the study areas are of similar magnitude (lowest for Gydan), however, the highest change in limnicity is recorded for the Taz study area. The seasonal inundation in the Taz area is almost certainly associated with the Taz river floodplain and increased river discharge after snow-melt. Similar characteristics, albeit to a lesser extent, are found on Gydan where the Yuribei river plays an important role as a source of spring floods. Whereas these summer changes in water body extent appear to be natural phenomena, major anthropogenic stressors may contribute to these changes on Yamal. Changes to the drainage network through human-induced thermokarst processes have been discussed by e.g. Zakharova *et al* (2011). Further examination of these open water body dynamics on an inter-annual basis is needed, providing more comprehensive results on spring inundation and whether these flooded areas are of seasonal nature. The information will be of value to permafrost researchers and modellers in the light of global warming trends and Arctic wetlands' increased carbon contribution to the atmosphere.

## Acknowledgments

The ALANIS project was funded by the European Space Agency (ESA) Support to Science Element (STSE) programme (ESRIN Contr. No. 4000100647/10/I-LG). A M Trofaier is a recipient of a DOC-fFORTE (Women in Research and Technology) fellowship of the Austrian Academy of Sciences at the Scott Polar Research Institute. The authors acknowledge the financial support by the European Union FP7-ENV project PAGE21 under contract number GA282700 and the Austrian Science Fund (I 1401-N29) as well as the RFBR grant number13-05-91001-АНФ_a to the Earth Cryosphere Institute SB RAS.

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