Product Guide: TerraSAR-X derived Cliff Top Retreat

Helmholtz Alliance:
Remote Sensing and Earth System Dynamics

DLR AWI PAGE21

Stettner, Samuel[1)], Bartsch, Annett [2),3)], Widhalm, Barbara[2,3)], Heim, Birgit[1)], Günther, Frank[1)], Morgenstern, Anne[1)]

[1)]Alfred-Wegener-Institut, Helmholtz-Zentrum für Polar- und Meeresforschung (AWI), DE
[2)]Zentralanstalt für Meteorologie und Geodynamik (ZAMG), AT
[3)]Technische Universität Wien (TUW), AT

Version: 1.0, 20.05.2015

Intra- and Inter-annual Monitoring of Cliff Top Retreat, Lena Delta, Siberia (2010-2014)

Thawing-induced cliff top retreat in permafrost landscapes is mainly due to thermo-erosion. Ground-ice-rich permafrost landscapes are specifically vulnerable to thermo-erosion and may show high degradation rates. Within the HGF Alliance Remote Sensing and the FP7-PAGE21 permafrost programs we investigated how SAR and optical remote sensing can contribute to the monitoring of erosion rates of ice-rich cliffs in the Lena Delta in Arctic Siberia (Russia) (Fig. 1, Fig.2).

We produced two different vector products:

i) Intra-annual cliff top retreat based on TerraSAR-X (TSX) satellite data (2012-2014):

High-temporal resolution time series of TSX satellite data allow the inter-annual and intra-annual monitoring of the upper cliff-line retreat also under bad weather conditions and continuous cloud coverage. This published SAR product contains the retreating upper cliff lines of a 1.5 km long part of eroding ice-rich coast of Kurungnakh Island in the central Lena Delta. The upper cliff line was mapped using a thresholding approach for images acquired in the years 2012, 2013 and 2014 for the months June (2013, 2014), July (2013, 2014), August (2012, 2013, 2014) and September (2013, 2014). The cliff-retreat vector-product is called 'upper_cliff_TerraSAR-X'.

ii) 4-year cliff top retreat based on optical satellite data (2010-2014):

Long-term cliff top retreat could be assessed with2 high-spatial resolution optical satellite images (GeoEye-1, 2010-08-05 and Worldview-1, 2014-08-19). The cliff-retreat vector-product is called 'upper_cliff_optical'.

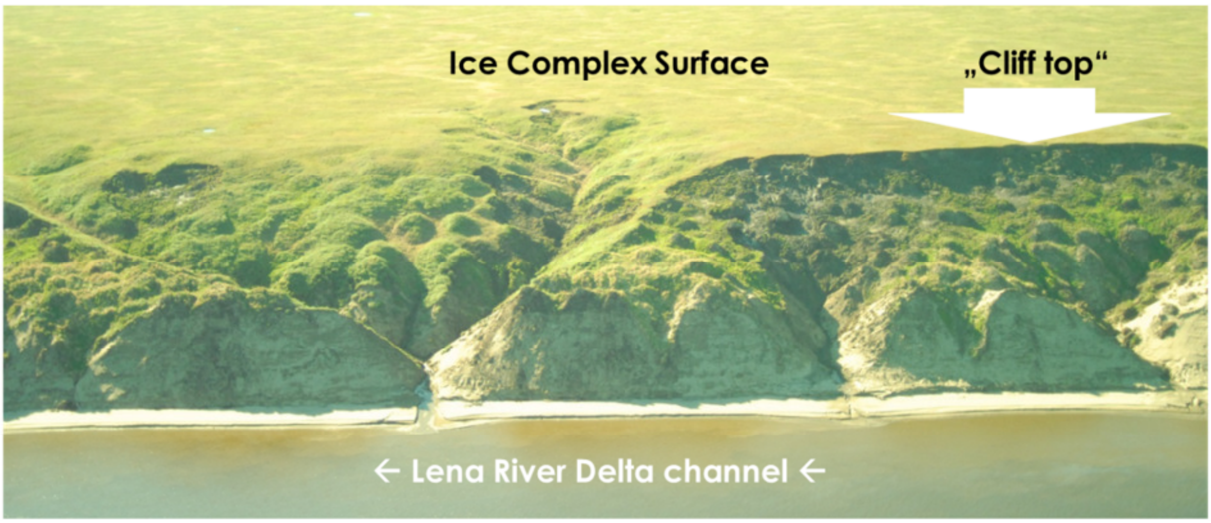

Figure 1: Eroding cliff at Kurungnakh Island at the southern end of the study area shown in Figure 3. The sharp transition from the undisturbed ice complex surface to the actively eroding cliff is referred to as cliff top. Photo: Samuel Stettner, LENA2013 expedition.

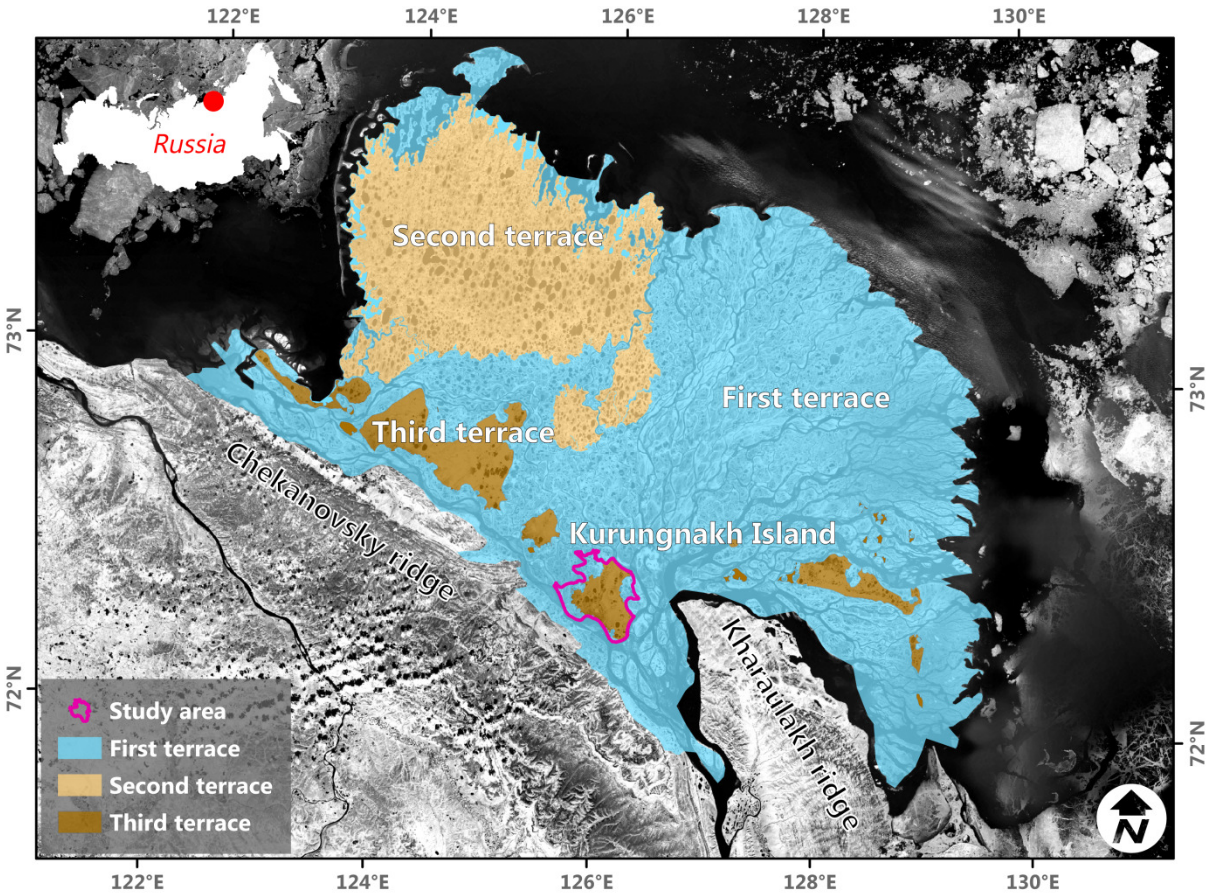

Figure 1: Geomorphological overview of the Lena Delta and location of the study area Kurungnakh Island. Three main geomorphologic units can be differentiated in the Lena Delta (Grigoriev 1993)**. The first main terrace is today's active delta with heights from 1-12 m above sea level (m.a.s.l.) and has formed since the Middle Holocene. The second terrace with heights ranging from 11-30 m was formed during the Late Pleistocene to Early Holocene. The third main terrace ranges from 30-60 m elevation and is the oldest part of the delta area. It's upper layer has not a fluvial-deltaic origin but represent erosional remnants of a Late Pleistocene sedimentary accumulation plane consisting of fine grained, organic- and ice-rich sediments derived from the Chekanovsky Ridge and the Kharaulakh Ridge located in the south** (Schirrmeister et al. 2011)**. Underneath these so called Ice Complex deposits are fluvial sands. The thickness of the active layer on the Ice Complex upland is usually in the range of 30–50 cm depth during summer months. The geodata of the main geomorphological units in the Lena Delta are data published in PANGAEA (**Morgenstern et al. (2011)**). Background image: Landsat ETM+ 2000.**

Data and Methods

Software used:

- Next ESA SAR Toolbox (NEST) 5.1 for pre-processing of SAR data
- ENVI + IDL for scale conversion of backscatter intensities
- ArcGIS 10.3 for raster analysis and mapping of the cliff top
- PCI Ortho Engine 2014 for orthorectification of optical satellite data

Data source

- TSX data were made available through DLR EOS Land Surface (LAN1747 und LAN2666). Overview on image acquisitions see Fig. 3

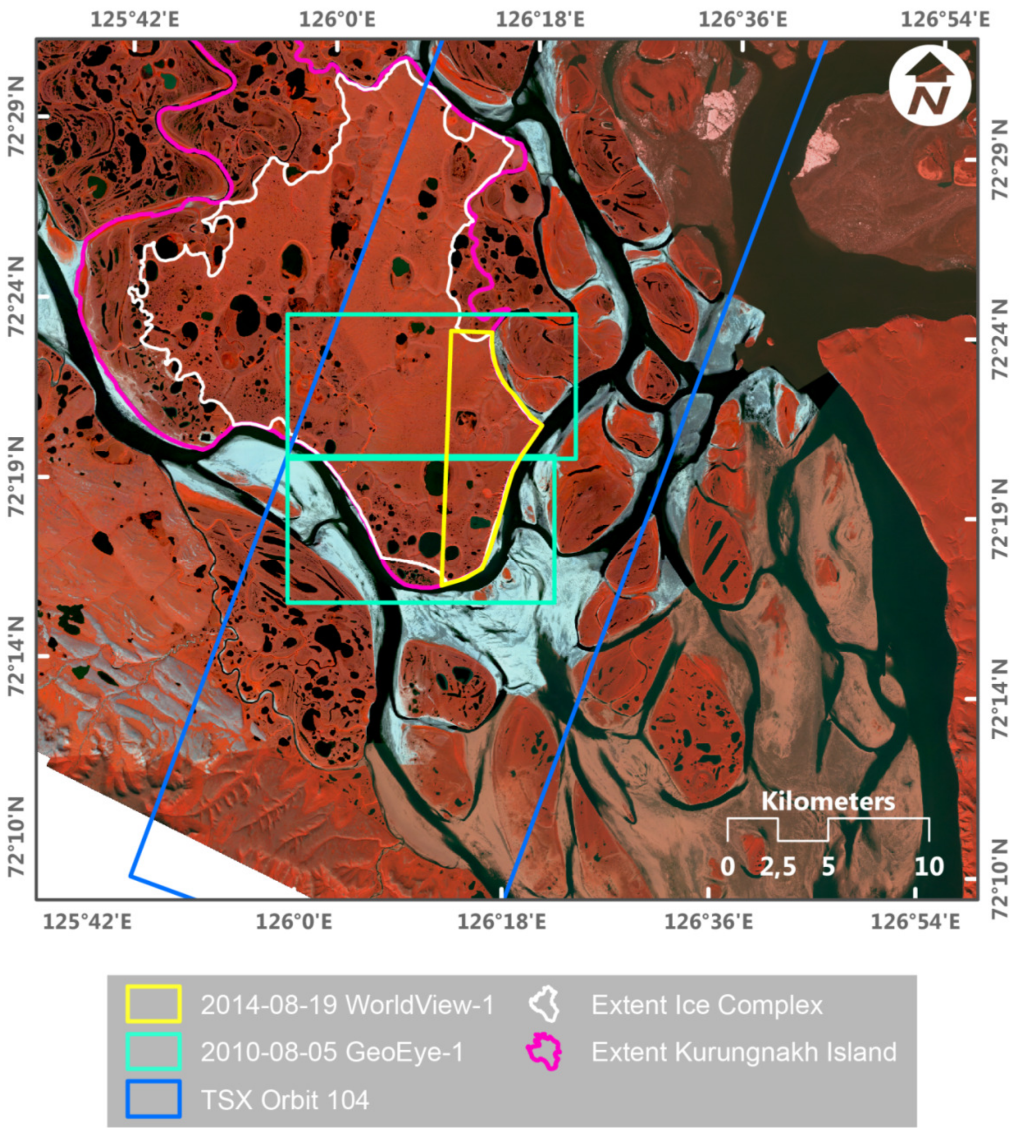

Figure 2: Study area and image frames of datasets used. The TSX acquisition dates are shown in Figure 4. Background image: RapidEye acquisition 2010-08-04, RGB composite 521 (copyright RapidEye).

Processing of Optical Image Data

Orthorectification of the Worldview-1 and GeoEye-1 acquisitions was performed using the software module OrthoEngine of PCI Geomatica 2014. In total 7 ground control points (GCPs) and 13 Tie Points were set with an overall GCP RMS of 0.33 meters using the rational functions model. GCPs were collected during the LENA2013 expedition in summer 2013 with a Leica Viva GNSS in real-time kinematic-GPS mode. The two cliff top lines from the optical images were digitized in 1:500 scale.

Processing of SAR Data

The TSX data were delivered in Level 1 B. For preprocessing of the TSX data the open source software NEST from ESA was used. To improve image quality, multi-looking with two looks was performed for every image of the time series. The eroding coast is observed over a three year time span and there are no successive DEMs available that reflect the terrain for each of the acquisition dates. Therefore an ellipsoid correction was performed with a geolocation grid and nearest neighbor resampling with full spatial resolution of 2.5 m in the UTM Map projection WGS84 Zone 52 North. This allows relative comparison of the processed TSX images. However, the absolute geolocation has a shift compared to the ortho-rectified optical satellite images. Finally, the backscatter intensities were scaled for better interpretation.

A thresholding of the scaled backscatter images (> 46 scaled backscatter) was applied within the ArcGIS 10.3 environment to extract areas with disturbed surface (see Figure 3). Finally, 10 cliff top lines were digitized in 1:1000 scale. A lateral shift of the TSX-derived cliff top lines of about 57 meters occurs compared to the cliff top lines derived from the ortho-rectified optical satellite data. This lateral shift is due to the only ellipsoid-based correction of the TSX dataset in comparison to the very accurate ortho-rectification of the optical satellite images.

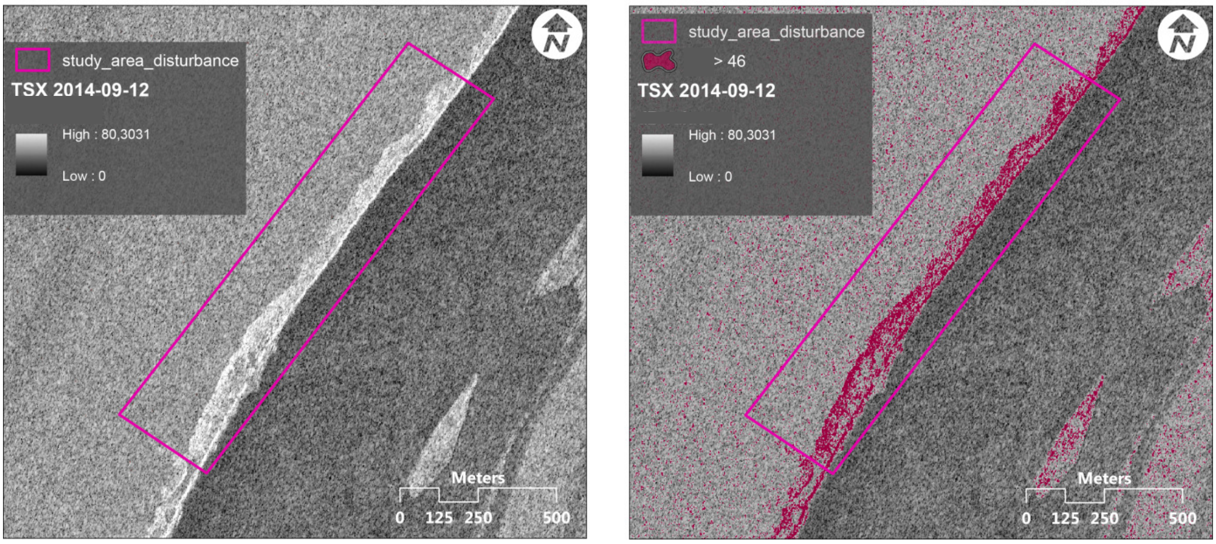

Figure 3: The figure shows the most recent TSX acquisition (2014-09-12). Dark areas are characteristic for the water in the Lena River Delta, while the light grey areas show the Ice Complex upland tundra surface. Very bright areas show the disturbed exposed areas of cliff erosion. The box indicates the 1500 meter long study area. TSX data are copyright DLR.

4 Results

The overall cliff top retreat-rate extracted from TSX of about 18 m in 2 years matches the one from the optical satellite images of about 35 m in 4 years (when looking at the complete time span of the time series) (Figure 4). The Intra-seasonal cliff top retreat lines from 2014 show a rate of 2 to 3 m per month. The lines from 2012 and 2013 are not always chronological ordered, probably because of differing image quality. However, cliff top lines from the end of the season of a year are close to the lines from the beginning of the next summer season, reflecting the low cliff retreat in winter.

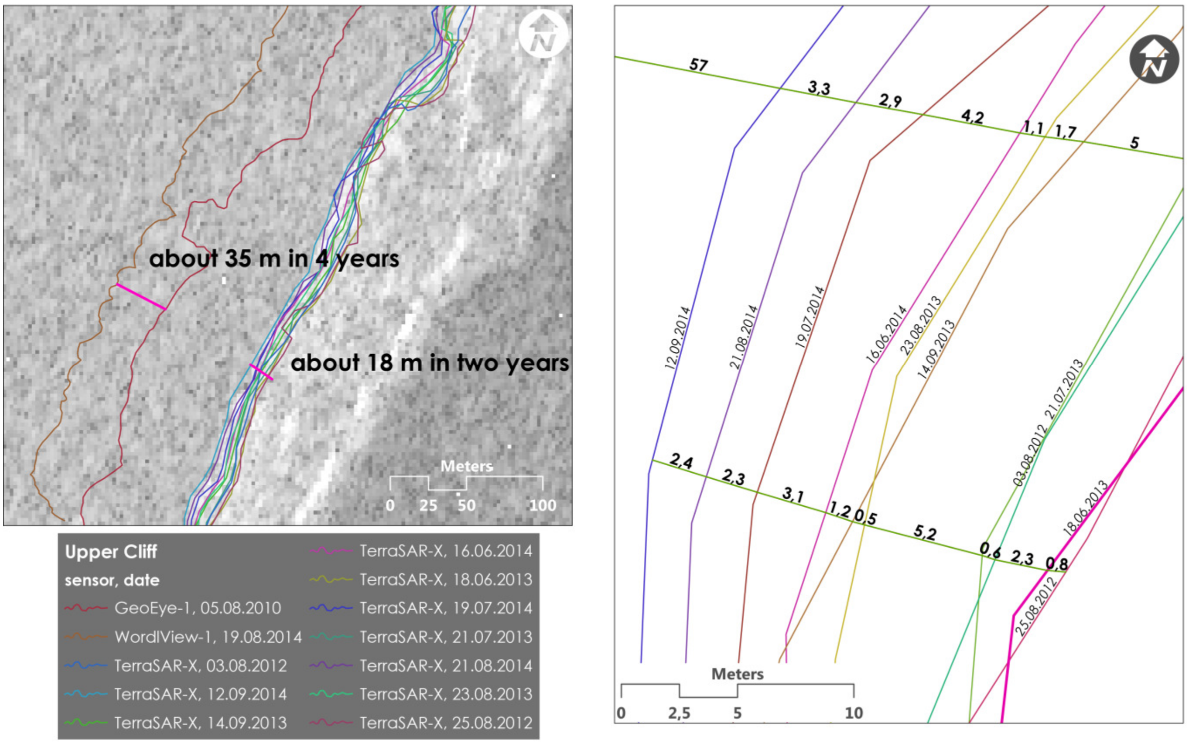

Figure 4: Left: cliff retreat lines extracted from a GeoEye-1 acquisition with acquisition date 05th of August 2010 and a Worldview-1 acquisition of 19th of August 2014 and cliff retreat lines from the TSX time-series ranging from 3rd of August 2012 to 12th of September 2014. The shift of the lines of about 57 meters occurs because of the ellipsoid-based correction of the TSX dataset in comparison to the very accurate ortho-rectification of the optical satellite images. Right: Zoom onto the cliff top retreat-rates extracted from TSX data. TSX data are copyright DLR.

References

Grigoriev, M.N. 1993. Cryomorphogenesis of the Lena River mouth area, Siberian Branch. *USSR Academy of Sciences* 176.

Morgenstern, A., Röhr, C., Grosse, G. & Grigoriev, M.N. 2011. The Lena River Delta - inventory of lakes and geomorphological terraces. doi:10.1594/PANGAEA.758728. http://dx.doi.org/10.1594/PANGAEA.758728

Schirrmeister, L., Kunitsky, V., Grosse, G., Wetterich, S., Meyer, H., Schwamborn, G., Babiy, O., Derevyagin, A. & Siegert, C. 2011. Sedimentary characteristics and origin of the Late Pleistocene Ice Complex on north-east Siberian Arctic coastal lowlands and islands – A review. *Quaternary international* 241: 3–25. doi:10.1016/j.quaint.2010.04.004 http://dx.doi.org/10.1016/j.quaint.2010.04.004