Product documentation: Subsidence

Contract:	4000116196/15/I-NB
Code:	DUE-GlobPermafrost
Organisation:	Central Institute for Meteorology and Geodynamics
Version:	3.0
Date:	20 February 2019

Consortium:

Signatures

	Name	Organisation	Signature
Edited by	Tazio Strozzi	GAMMA	
Contributions from	Annett Bartsch, ZAMG; Sina Muster, AWI		

Distribution

Version	People and/or Organisation	Publicly available on website
1.0	Users	No, ftp only
2.0	Users	No, ftp only
3.0	Users	No, ftp only

Change Log

Version	Date	Details	Editor
0.1	12 Sep. 2017	Initial document	TS
1.0	17 Sep. 2017	Minor amendments	AB, TS
2.0	15 Feb. 2018	Additional information on processing	SM, TS
3.0	24 Jan. 2019	Final amendments	TS

Table of Contents

List of Tables

1. Product overview

The GlobPermafrost project developed, validatee and implemented Earth Observation (EO) products to support research communities and international organisations in their work on better understanding permafrost.

Low-land permafrost areas, with large amounts of ground ice, are subject to intense seasonal freezing and thawing cycles and, due to phase changes from ground ice to liquid water, are exposed to surface deformation processes (French, 2007; Günther et al., 2015). Annually, downward movement of the land surface associated with seasonal thaw in summer is compensated by upward movement associated with frost heave in fall (Shiklomanov et al., 2013). Seasonal changes in elevation can reach decimetres every year. If seasonal thaw in summer dominates in the long term over upward movement associated with frost heave in fall, an effective subsidence of the surface is observed. The position of the Earths surface over multi-annual scales can thus be a direct measure of permafrost change.Satellite SAR interferometry (InSAR) has been applied in the past to measure surface deformation over permafrost during thawing seasons (Rykhus and Lu, 2008; Liu et al., 2010; Short et al., 2011; Short et al., 2014; Wang et al., 2017; Beck et al., 2015; Antonova et al., 2018) and to derive remotely sensed active layer thickness (Schaefer et al., 2015). Seasonal as well as year to year developments in the freeze-thaw cycle and subsequent subsidence have been identified using in most cases satellite SAR data of the ERS-1/2 SAR, ALOS-1 PALSAR-1, TerraSAR-X and Radarsat-2 sensors. The records have been rather sparse, because the acquisitions have been irregular between the years, but the results could be identified as reasonable using models re-sampling the cyclic behaviour of subsidence.Withing GlobPermafrost, an approach to monitor summer subsidence in several cold spot regions has been developed based on Sentinel-1a/b C-band SAR data (Strozzi et al., 2018). The subsidence product is generated using the multi-baseline interferometric algorithm implemented in the GAMMA software (Berardino et al., 2002; Werner et al., 2012).

2. Processing Chain

The InSAR processing sequence includes the co-registration of the single-look complex Sentinel-1 image, the computation of interferograms acquired in series during the summer season with 6 or 12 days time intervals and over one year at the end of the summer season with a multi-looking factor of 5 pixels in slant-range and of 1 pixel in azimuth, the removal of the topographic-related phase with use of the external DEM, adaptive phase filtering, phase unwrapping using a minimum cost-flow algorithm, low-pass phase filter, computation of summer cumulative displacement maps and time series of movement via multi-baseline InSAR, and terrain-corrected geocoding. For the precise co-registration of the Sentinel-1 IWS a refinement based on the spectral diversity within bursts and swaths was included. Occasional ionospheric disturbances were mitigated using a low-pass filter but without applying a procedure based on split-beam (Wegmüller et al., 2012) or split-spectrum interferometry (Gomba et al., 2016).

The main results of the SAR interferometric analysis are maps of the averaged displacement rates on coherent targets in the satellite line-of-sight direction and temporal series of displacements on points of particular relevance.

3. Product Specification

Table 1: Specifications of the file naming nomenclature for the subsidence product.

Subject	*Code*	*Specification*
Organization	GRS	Gamma Remote Sensing
Product	CSP	Cold spot
Algorithm	SBASI	Short Baseline Interferometric Analysis
Satellite sensor and mode used to create product **	SENT1	Sentinel-1
Product version	VVV	E.g. V01
Start date and time	YYYYMMDD	E.g. 20150815
End date and time	YYYYMMDD	E.g. 20160815
Region of interest*	CS3 CS7 CS8 CS9 C10	Teshekpuk, Alaska Lena Delta, Russia Yamal, Russia Illulisat, Greenland South Shetland Islands, Antarctica
File Extension	TIF	Geotiff

* The value of the “Region of Interest” field is defined according to the Observation Strategy document.

** The identifier will be renamed accordingly depending on satellite sensor and mode.

Table 2: Specifications of the subsidence product.

Subject	*Specification*
Variable	Line-of-sight displacement ("surface subsidence")
Units	m
Coverage	Cold spots case regions
Time period	Starting in 2015
Temporal frequency	6/12 days during snow-free season, subject to satellite data availability
Coordinate system	UTM, WGS84
Spatial resolution (grid spacing)	10 m
Geometric accuracy	10 m
Thematic accuracy	±6/7 mm for single measurements, 1 cm over one summer season
Data (file) format	Geotiff
Other data codes	-

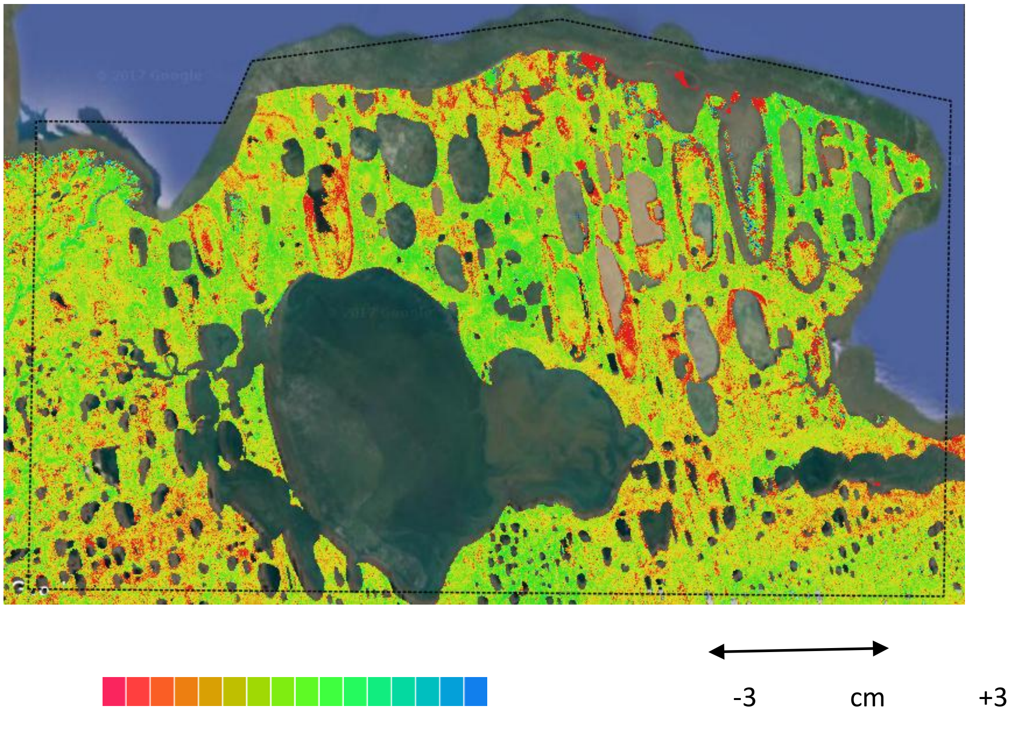

Figure 1: Surface subsidence map over CS3 (Teshekpuk Lake, North Slope Alaska) from Sentinel-1 data from 07.07 to 05.09 2016. Displacement is in the line-of-sight direction.

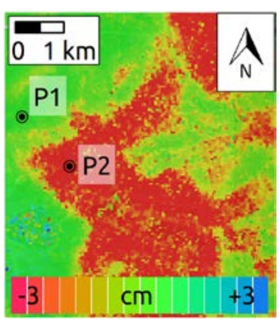

Figure 2: Surface subsidence map over part of CS9 (Ilulissat, Greenland) from Sentinel-1 data from 02.06 to 18.09 2016 and time series of displacement over an outcrop area (P1) and on peat terrain underlain by fine-grained marine sediments (P2). Displacement is in the line-of-sight direction.

4. Known issues

Assuming an error of 6 to 7 mm for single measurements at C-band (Crosetto et al., 2009), stacking of about 10 Sentinel-1 12-days interferograms over one summer season would result in an expected error of the summer surface subsidence Sentinel-1 products on the order of 1 cm (Strozzi et al., 2018). For low-land permafrost we should however also take into account possible effects on the InSAR phase of varying ionospheric, soil moisture, snow-cover, and vegetation conditions further to tropospheric disturbances and phase noise. In addition, on local areas undersampling of the SAR data in relationship to the large rates of movements can cause phase unwrapping errors and the thawing might have already started when interferograms are coherent at the beginning of the season. Thus, the amount of detected surface subsidence with Sentinel-1 data in our study might be underestimated.

5. Data access and contact information

Data are available for download via the Permafrost Information System “PerSys”. They follow the structure described in section 3.

PerSys: http://apgc.awi.de/group/about/globpermafrost

Samples of these products are also available on the PerSys-WebGIS for visualization and browsing.

WebGIS-Link: http://maps.awi.de/map/map.html?cu=Globpermafrost_Overview#layers

For data access and more information about the datasets please contact strozzi@gamma-rs.ch

6. References

Antonova, S.; Sudhaus, H.; Strozzi, T.; Zwieback, S.; Kääb, A.; Heim, B.; Langer, M.; Bornemann, N.; Boike, J. Thaw Subsidence of a Yedoma Landscape in Northern Siberia, Measured In Situ and Estimated from TerraSAR-X Interferometry. Remote Sens. 2018, 10, 494.

Beck, I.; Ludwig, R.; Bernier, M.; Strozzi, T.; Boike, J. Vertical movements of frost mounds in subarctic permafrost regions analyzed using geodetic survey and satellite interferometry. Earth Surf. Dyn. 2015, 3, 409–421.

Berardino, P., G. Fornaro, R. Lanari and E. Sansosti, E., 2002: A new algorithm for surface deformation monitoring based on Small Baseline Differential SAR interferograms, IEEE Trans. Geosci. Remote Sens, 40, 2375–2383.

Crosetto, M.; Monserrat, O.; Bremmer, C.; Hanssen, R.; Capes, R.; Marsh, S. Ground motion monitoring using SAR interferometry: Quality assessment. Eur. Geol. 2009, 26, 12-15.

French, H.M. The Periglacial Environment, 3rd ed.; John Wiley & Sons, Ltd.: West Sussex, UK, 2007.

Gomba, G.; Parizzi, A.; De Zan, F.; Eineder, M.; Bamler, R. Toward Operational Compensation of Ionospheric Effects in SAR Interferograms: The Split-Spectrum Method. IEEE Trans. Geosci. Remote Sens. 2016, 54(3), 1446-1461, doi:10.1109/TGRS.2015.2481079.

Günther, F.; Overduin, P.P.; Yakshina, I.A.; Opel, T.; Baranskaya, A.V.; Grigoriev, M.N. Observing Muostakh disappear: Permafrost thaw subsidence and erosion of a ground-ice-rich island in response to arctic summer warming and sea ice reduction. Cryosphere 2015, 9, 151–178.

Liu, L., T. Zhang, and J. Wahr, 2010: InSAR measurements of surface deformation over permafrost on the North Slope of Alaska. Journal of Geophysical Research, 115, F03023.

Rykhus, R.P.; Lu, Z. InSAR detects possible thaw settlement in the Alaskan Arctic Coastal Plain. Can. J. Remote Sens. 2008, 34, 100–112.

Schaefer, K., L. Liu, A. Parsekian, E. Jafarov, A. Chen, T. J. Zhang, A. Gusmeroli, S. Panda, H. A. Zebker, and T. Schaefer, 2015: Remotely sensed active layer thickness (ReSALT) at Barrow, Alaska using interferometric synthetic aperture radar. Remote Sensing, 7(4), 3,735-3,759, doi:10.3390/rs70403735.

Shiklomanov, N.I.; Streletskiy, D.A.; Little, J.D.; Nelson, F.E. Isotropic thaw subsidence in undisturbed permafrost landscapes. Geophys. Res. Lett. 2013, 40, 6356–6361.

Short, N.; Brisco, B.; Couture, N.; Pollard, W.; Murnaghan, K.; Budkewitsch, P. A comparison of TerraSAR-X, RADARSAT-2 and ALOS-PALSAR interferometry for monitoring permafrost environments, case study from Herschel Island, Canada. Remote Sens. Environ. 2011, 115, 3491–3506.

Short, N.; LeBlanc, A.-M.; Sladen, W.; Oldenborger, G.; Mathon-Dufour, V.; Brisco, B. RADARSAT-2 D-InSAR for ground displacement in permafrost terrain, validation from Iqaluit Airport, Baffin Island, Canada. Remote Sens. Environ. 2014, 141, 40–51.

Strozzi, T., S. Antonova, F. Günther, E. Mätzler, G. Vieira, U. Wegmüller, S. Westermann, and A. Bartsch, 2018: Sentinel-1 SAR Interferometry for Surface Deformation Monitoring in Low-Land Permafrost Areas, Remote Sensing, 10(9): 1360, doi: 10.3390/rs10091360.

Wegmüller, U.; Strozzi, T.; Werner, C. Ionespheric Path Delay Estimation using Split-Beam Interferometry. In Proc. IGARSS 2012, Munich (Germany), 22-27 July 2012.

Werner, C., U. Wegmüller and T. Strozzi, 2012: Deformation time-series of the Lost-Hills oil field using a multi-baseline interferometric SAR inversion algorithm with finite difference smoothing constraints. In Proc. AGU Fall Meeting San Francisco (USA), 3-7 December 2012.

Wang, L.; Marzahn, P.; Bernier, M.; Jacome, A.; Poulin, J.; Ludwig, R. Comparison of TerraSAR-X and ALOS PALSAR Differential Interferometry With Multisource DEMs for Monitoring Ground Displacement in a Discontinuous Permafrost Region. IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens. 2017, 10, 4074–4093.