Proceedings Paper:

Lazecký, M, Hlaváčová, I and Kocich, D (2017) Czech System for Exploitation of Land Dynamics Using Copernicus Sentinel-1 Data. In: Proceedings of GIS Ostrava: Dynamics in GIscience. GIS OSTRAVA 2017, 22-24 Mar 2017, Ostrava, Czech Republic. Springer, Cham , pp. 277-287. ISBN 978-3-319-61296-6

https://doi.org/10.1007/978-3-319-61297-3_20

CZECH SYSTEM FOR EXPLOITATION OF LAND DYNAMICS USING COPERNICUS SENTINEL-1 DATA

Milan Lazecký[1], Ivana Hlaváčová[2], David Kocich[3]

[1] IT4Innovations, VSB-TU Ostrava, *E-mail:* milan.lazecky@vsb.cz

[2] GISAT Corp., Prague, *E-mail*: hlavacova@insar.cz

[3] Institute of Geoinformatics, VSB-TU Ostrava, *E-mail:* david.kocich@vsb.cz

Abstract

The topic of this work covers current implementation of satellite radar (SAR) interferometry (InSAR) techniques for routine identification of dynamic land processes such as downhill creep and landslide activity, subsidence or displacements of various objects of infrastructure. With the emerge of European Copernicus programme, the need of effectivity in satellite Big Data processing increased. There are two Sentinel-1 satellites observing the Earth with 6 days revisit time, sending daily 100 TB of data to be archived. In case of the relatively small area of Czechia, the amount of data to be archived in a Czech national mirror is around 24 GB per day.

Czech CESNET e-infrastructure has accepted the role of assessing Copernicus Ground Segment programme. A database mirroring Sentinel data over Czechia is established, however still in its early stage. A potential service based on an interferometric processing of Sentinel-1 data from this database has been prepared in Czech national supercomputing center IT4Innovations. As a basis of the system, several open-source projects were deployed, including MySQL-based burst metadatabase (TU Leeds), ISCE TOPS Processor (NASA/JPL), Doris coregistration algorithm (TU Delft) and StaMPS Small Baselines processor (Stanford University). Though more functionality can be rapidly developed, incorporating some of the own post-processing algorithms, even current early version of the system can yield interesting results by a fully automatic processing chain.

Keywords: SAR Interferometry, Copernicus, Sentinel-1, HPC, displacements monitoring

INTRODUCTION

The role of geoinformatics is to give an information about our real world in a spatial model. By adopting temporal information, a four dimension model is created, describing dynamic changes of a specific parameter. Satellite remote sensing offers appropriate input data to prepare such model. Terrain dynamics can be observed by satellite radar (SAR) interferometry (InSAR). European programme Copernicus has developed and sent to orbit a European SAR satellite Sentinel-1A in April 2014 and its twin Sentinel-1B in April 2016. These two satellites fly in a synchronized orbit and acquire InSAR-ready images of any European area every six days. The ground resolution is moderate, around 20x5 m per pixel (in comparison with e.g. TerraSAR-X satellite that offers a resolution of even 25 cm/pixel). But the frequent revisits, global coverage and especially open access makes the data very demanded in the InSAR community. Using radio waves of 5.5 cm wavelength, it has a moderate sensitivity to vegetation and a potential to identify displacements of structures or terrain in a magnitude of down to few millimeters per year.

Various works have already shown the potential of Sentinel-1 interferometry and various groups prepare national InSAR-based maps and systems nowadays (Dehls, J., 2016; Kalia, A., 2016). With the confirmation of Czech e-infrastructure CESNET about active participation and preparation of a Czech Ground Segment to support Copernicus programme, a similar goal is achievable also in Czechia. Current experiments for InSAR-based identification of landslide hazard (Lazecky et al., 2016a), bridge displacements (Lazecky et al., 2016b) or subsidence of undermined zones (Lazecký et al., 2017) demonstrate a realistic potential for Sentinel-1 applications, as well as its limits in the Czech natural conditions. A semi-automatic Sentinel-1 InSAR processing system (Sentineloshka) is already functional and hosted in the Czech national supercomputing center, IT4Innovations. The aim of this system is to generate publicly available maps of terrain displacements, based on the satellite measurements. This will help to increase knowledge of public about the situation in their own neighbourhood and potentially to avoid risks of unknown hazardous situations.

SENTINELOSHKA – THE PROCESSING SYSTEM

The name of the system introduces information that it is specialized in processing of only Sentinel-1 images. Currently, the system involves steps drafted in Fig. 1. First, a system dedicated to pre-processing (running at CESNET infrastructure) identifies Sentinel-1 images stored in a dedicated storage, based on the input of coordinates of the area of interest (AOI). These images are sorted based on their relative orbit identifier, ensuring interferometric consistence. Afterwards, the Sentinel-1 sub-images (called bursts) are exploited and pre-processed by including precise orbital data and calibrating the image intensity. Once pre-processed, the burst files of each relative orbit stack are sent to the IT4Innovations High Performance Computing (HPC) facility for the main processing.

The HPC part of the Sentineloshka system performs series of operations for each relative orbit stack. In the first stage, differential interferograms are generated for the net of temporally short connections between all images. Two temporally successive images are used in combination with each image in the stack. The short temporal baselines of interferometric connections (of maximally 24 days) ensure overall high coherence, often with as minimal influence of vegetation in non-urban areas as possible. This strategy is generally named Small Baselines Interferometry (SB InSAR). After generation of interferograms, they are precisely co-registered to a common framework and optionally filtered by a selected spatial filter (e.g. Goldstein filter). Finally, they are sent to an SB InSAR processor in order to perform advanced estimation and removal of error sources and to achieve time series information about the progress of displacements of selected points. The whole processing chain is based on specific open-source codes, such as OpenSARkit (Vollrath, A. et al., 2016), Doris (Kampes et al., 2003), ISCE (Zebker, H.A. et al., 2010), STAMPS (Hooper, 2008), TRAIN (Bekaert, D. P. S. et al., 2015) and LiCS database (Li et al., 2016).

After the basic processing, several post-processing mechanisms were implemented. The main two algorithms allow: a) landslide identification (Lazecky et al., 2016a) and b) distinguishing between vertical and horizontal components of the displacement vector (Samieie-Esfahany et al., 2009). These algorithms are based on ways of a recomputation of displacements identified in the satellite line of sight (LOS) from all the input satellite tracks. In a case of landslide identification, the displacements are recomputed into the direction of slope, while decomposition algorithm assumes the existence of objects observed from at least two opposite orbital tracks that allow distinguishing between horizontal and vertical movement. Results of using both algorithms are under validation stage.

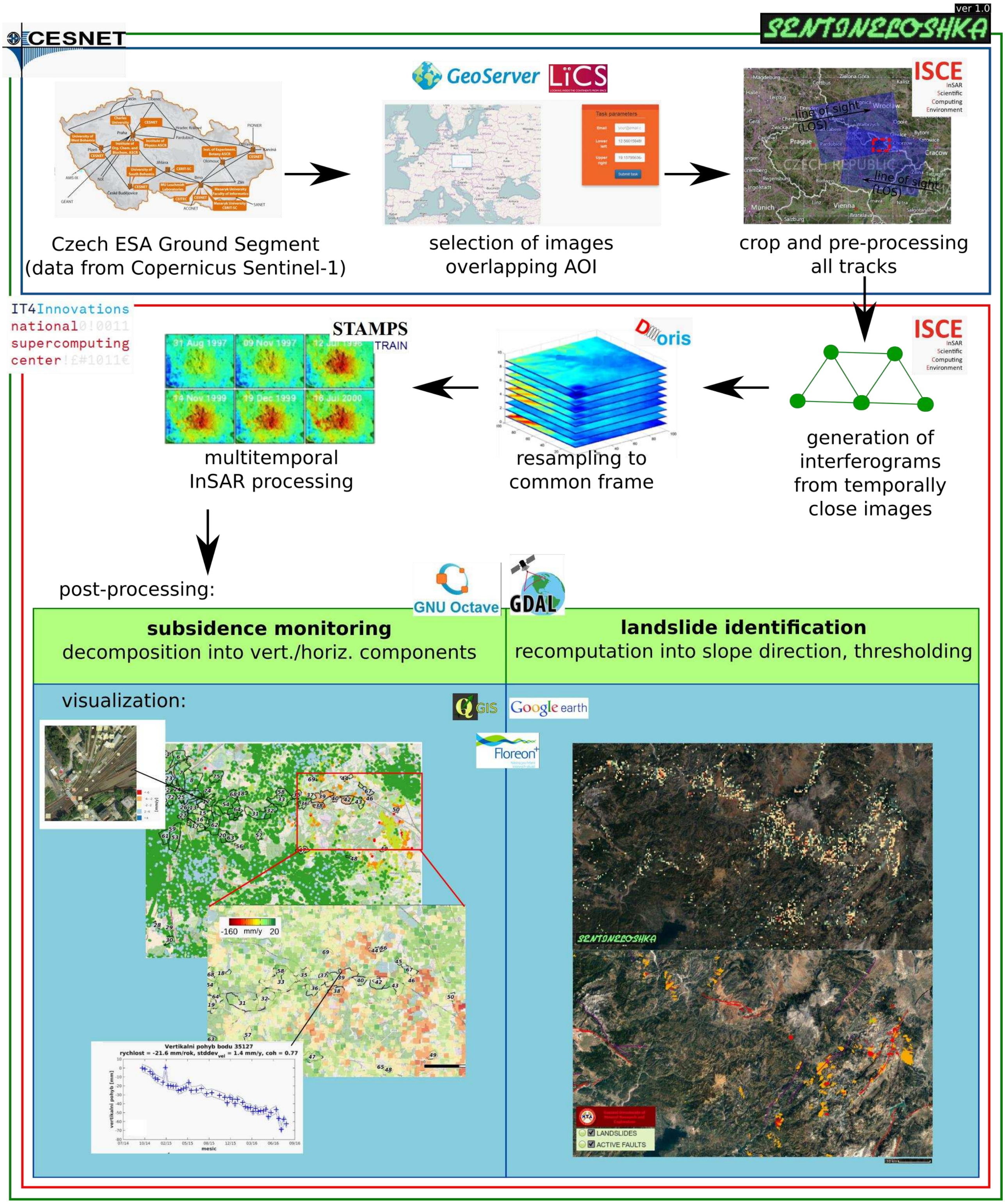

Fig. 1. Basic framework of Sentineloshka processing chain. Sentinel-1 data over selected area are cropped and pre-processed in CESNET environment (upper figure). Interferograms are generated, resampled into a common frame and used for SB processing in the IT4Innovations HPC environment (middle figure). Results from SB InSAR processing are visualized and post-processed, e.g. for subsidence monitoring or a landslide identification (lower figure).

DEEPER INSIGHT INTO PROCESSING STEPS

CESNET Preprocessing Cloud: Once latitude and longitude coordinates of AOI corners are given, the script will send an SQL query to MySQL database based on LiCS solution (Li et al., 2016). This database links existing Sentinel-1 SLC zip files there were downloaded beforehand and recognizes bursts within these files. The SQL query returns set of Sentinel-1 zip files that include bursts covering the AOI and sorts it according to relative orbit track number. If the number of images is lower than the default value of 10, this relative orbit is dropped from further processing. Afterwards, for all the relative orbits tracks, its images are pre-processed, i.e. bursts overlapping AOI are extracted. For this purposes ISCE algorithms of topsApp.py script has been adapted to allow performing first two steps of its workflow (Agram et al., 2016) for a single image only. Additionally, the latest SRTM in 1 arcsec resolution is automatically downloaded. All relative orbit folders are uploaded to the HPC server continuously with the processing.

HPC Processing: Once a relative orbit folder is uploaded, the images are combined in SB way – every image (except for first and last one) is connected with three other temporally close images. ISCE is called for each connection to perform all the steps to generate merged interferogram for all the uploaded bursts – only after successful interferogram generation, this interferogram is cropped to the AOI bounding box (including a 0.01° buffer zone around it). This processing is distributed to computing nodes by PBS scheduler since it is time and computationally extensive.

Once a generation of all interferograms is finished, a check is performed, dropping unsuccessfully generated combinations, in extreme case cutting the dataset into consistent chunks. Then a master image is selected in the middle of the dataset and all other interferograms are coregistered to it using Doris – the Doris processing has been parallelized for each interferogram per processing core. Only after the coregistration, the interferograms are cropped to the final bounding box, spatially filtered using Goldstein filter and exported to the STAMPS processing structure. Finally, the STAMPS processing is performed, based on universally selected parameters. Several own scripts related to noise filtering and points pre-selection as well as TRAIN atmosphere correction toolbox (Bekaert et al., 2015) are included in order to maximally increase the processing performance. The final result (including coherence quality parameter) is exported into a CSV file, ready to be loaded into a GIS software, e.g. Quantum GIS using giSAR toolbox (Guimaraes, P. and Lazecky, M., 2016).

Optionally, a script using GDAL library is prepared to convert the output format into an ESRI Shapefile format and to interpolate mean velocity values into a raster file. For landslide identification, only points at slopes are selected and their velocity model is recomputed towards slope direction, neglecting N-S direction and layover areas due to InSAR blind zones (Lazecky et al., 2015). Once all relative orbit directories are processed, the results are merged using the decomposition algorithm.

EXAMPLE CASE STUDY: OSTRAVA-KARVINA REGION

As the case study, Ostrava-Karvina region has been selected. This region is affected by a longterm black coal mining. While mines in Ostrava disappeared after their closures in 1990s, there are still mines active in Karvina region causing subsidence and other mining-induced problems in the region (e.g. increased presence of methane in the low atmosphere). Extents and dynamics of subsidence troughs are easily identifiable from classic InSAR processing, multitemporal interferometry allows an easy identification of continuous displacement of simple structures (especially houses) (Lazecky et al., 2016). Expected results were achieved also using the Sentineloshka system, in the automatic way. Subsidence areas in the mine surroundings were detected and their rate estimated. Displacements of buildings in the edge of urbanized areas were identified.

In total, 140 Sentinel-1 images have been selected over Ostrava-Karvina region from four different orbital tracks, two from descending (N->S), two from ascending passes (S->N). The images were taken during the period of 10/2014-10/2016, the selected zone of interest contained area of around 35x35 km. Several images have been (automatically) dropped due to problems within the pre-processing stage. The SB InSAR processing has been performed separately for each data stack. Two of the data stacks showed large inconsistencies and their results were not taken into account. Applied software STAMPS is capable of fine-tuning the inter-steps of the processing. However since the experiment deals with the possibility of fully automatic processing chain, it was decided to drop the whole erroneous datasets from further consideration instead of manual attempts to correct them.

All tracks show similar results after SB processing – the estimated models are consistent, therefore the results can be considered reliable. In total, 257 interferograms were generated from the data stack. The processing took 13.5 hours, however, part of the processing time was filled by waiting in the queue for processing tasks in the HPC querying system.

For visualization purposes, a specialized toolbox was prepared as a Python extension to Quantum GIS: giSAR (Guimaraes, P. and Lazecky, M., 2016). It allows importing processing results into the GIS environment able to perform post-processing functions, such as plotting time series of a selected point or interpolation etc. The giSAR is a basic open-source tool developed as a connector between heavy processing chain system of PS/SB InSAR and the world of GIS for an effective work with geospatial data. The currently existing version offers an import of InSAR-processed data in a comma-separated text file format (CSV) and a basic setting of a graphical representation of georeferenced PS/SB points in the environment of Quantum GIS open-source software (see Fig. 2). The future version should allow an easier access to selected processing tools already available in Quantum GIS or its other toolboxes. Graphical output of this tool is visible in Fig. 3, with OpenStreetMap and FreeGeodataCZ as the background layers. Non-expert users would prefer KML file plotting the results in widespread Google Earth framework. For a centralized solution, however, the optimal dissemination of results is to be provided by a web map environment, e.g. based on Geoserver.

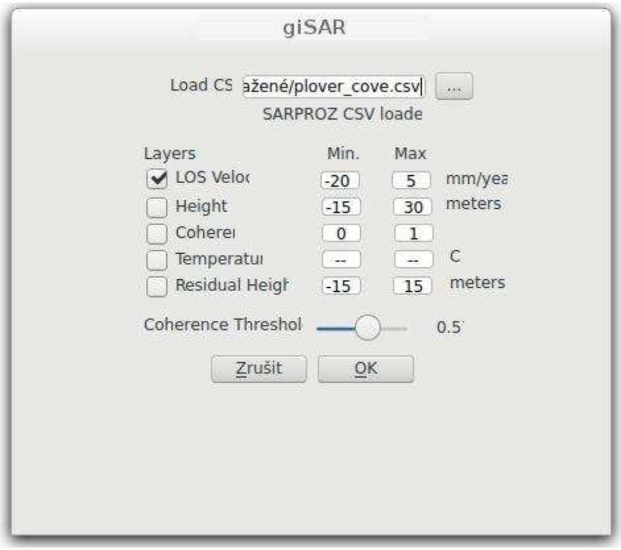

Fig. 2. Basic window of Quantum GIS: giSAR toolbox offering preliminary functionality of importing InSAR-based CSV file as GIS layers

The Fig. 3 shows the basic result – a map of a mean LOS velocity of displacements. Subsidence at undermined areas was properly identified and its rate was estimated (though the accuracy can be lower due to a less accurate SB InSAR method used here). An example of decomposition is provided in Fig. 4, based on small area processing of relative orbits 51 and 175.

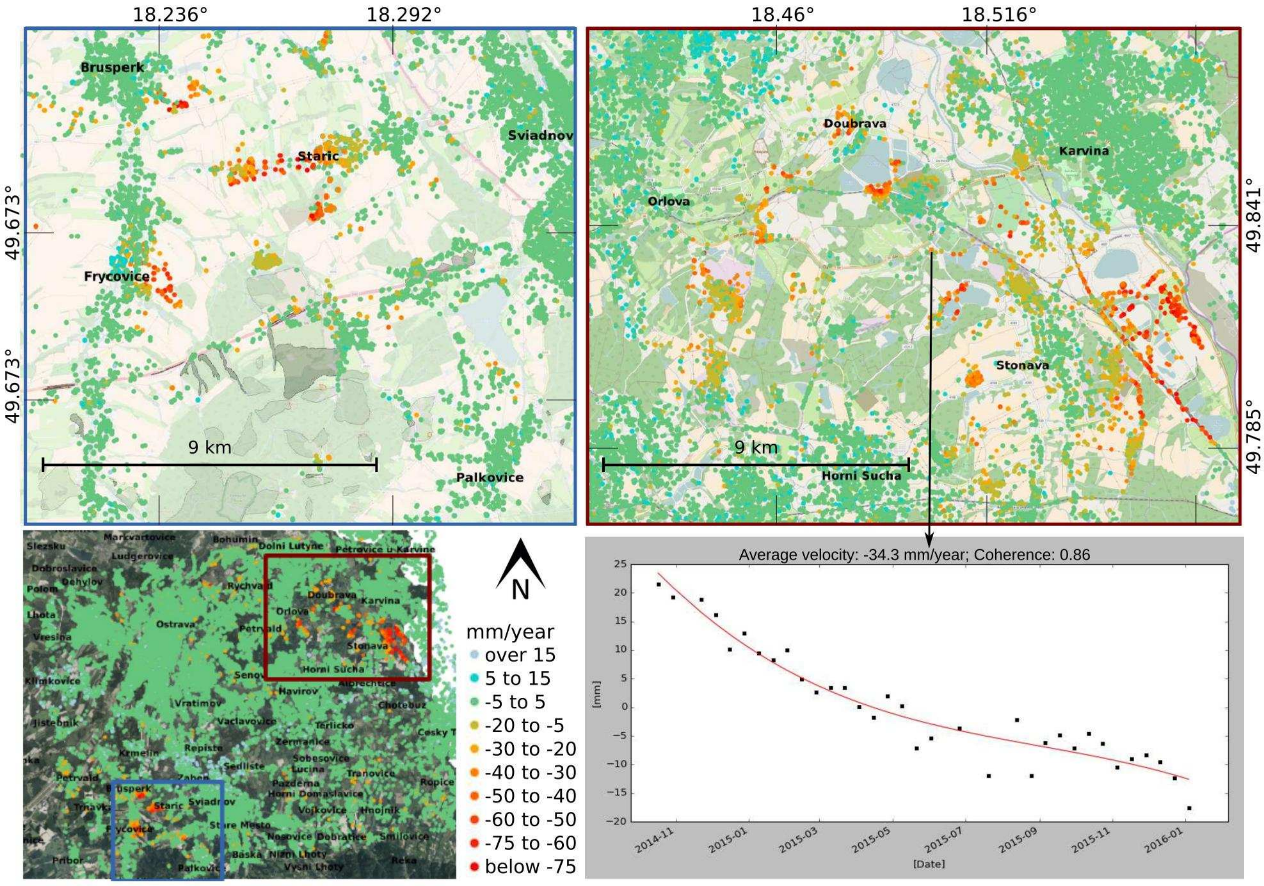

Fig. 3. Merged automatic SB InSAR result of descending relative orbits 51 and 124 showing subsidence in Karvina region (red box) and around Paskov mine (blue box); data from 10/2014-01/2016.

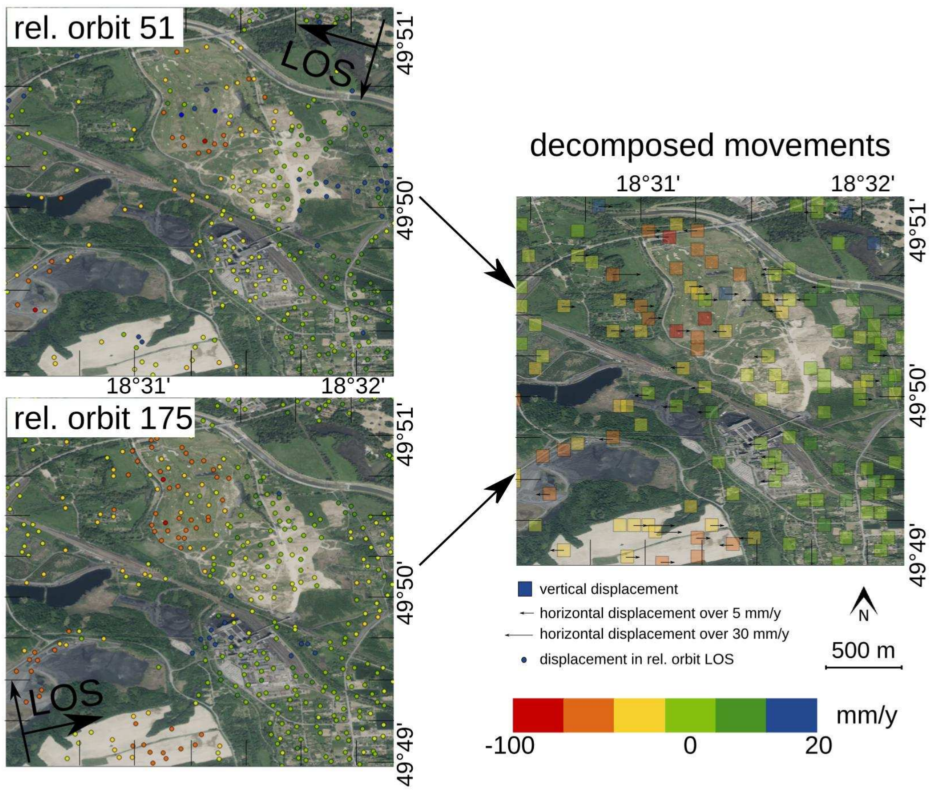

Fig. 4. Decomposition of displacement direction from data of descending and ascending tracks. Location is at the mining site of CSA Mine, Karvina

DISCUSSION

Sentinel-1 is becoming very popular as the new generation of InSAR-capable satellites, especially thanks to high revisit rate, global archived coverage and the open access to the data. It still is limited due to physical constraints, known to every C-band SAR system. The SB InSAR tries to compensate the major problem that is the total loss of signal coherence in the case of presence of vegetation. Though 6 or 12 days is relatively short time, the signal is still decorrelated by the vegetation. It was found out that an exception exists during the seasons of diminished vegetation activity, such as early spring or late autumn. Winter period is covered by another source of decorrelation that is a snow. The current version of the system is based on SB InSAR that does not distinguish seasonal coherence. The algorithm uses spatial information between selected points; including unstable points (in vegetated areas) would cause errors that may propagate into originally stable points. These and other technical issues keep Sentinel-1 and InSAR generally from the state of a reliable technique for monitoring terrain displacements, though the theoretical accuracy of measurements using this technology is around 1 mm/year using persistent scatterers (PS)-based techniques. The SB InSAR has been chosen here for the possibility of identification of movements in non-urban areas, though with lower precision, especially due to the merging of a short temporal information in order to compute a long temporal displacement value. There is a lot of further work needed into the development of a season-based InSAR processor that would indicate movements also in densely vegetation-covered areas. It is in the plan to use polarimetric footprints that would distinguish the vegetation cover (Donga et al., 2013) since Sentinel-1 is using both co-polarized and cross-polarized wave backscatter information, or at least some other public available data such as moderate-resolution land cover maps. Yet, the work demonstrates that the automatic system is currently able to evaluate displacements over solid structures (buildings, transportation structures etc.) and non-cultivated grass lands or sparsely vegetated areas.

CONCLUSIONS

We demonstrate the potential of Sentinel-1 for monitoring of land dynamics in this and previous works. Areas sparsely covered by vegetation can be evaluated using a fully automatic chain, as prepared within Sentineloshka system (Lazecky, M., 2016). The current preliminary version of the system allows to achieve only a static map describing temporal changes of a selected area. We consider it important to make such map publicly available, while it must be noted that the reliability of results is depending on local conditions and the interpretation of shown results is to be kept within the hands of an expert. However a public feedback is necessary in order to perform appropriate steps towards specific areas or structures.

Further steps of the system development include a special way to store Sentinel-1 data that would allow an effective automatic system for dynamic observations of up-to-date displacements of terrain or structures. In case of need, such dynamic implementation would allow fast assessment of deformations and could provide important information for risk identification. Based on the innovative data storage, we will be able to implement also more reliable processing techniques, such as persistent scatterers (PS) or partially coherent PS technique. Such storage will be used also for non-interferometric SAR processing, using a radar backscattering coefficient of SAR images. This will allow automatized processing leading to e.g. current flood maps, time series useful for a change detection (forest loss, agriculture monitoring), soil moisture maps etc. The current state of described system is still in a preliminary stage with the development continuously ongoing. The main target is to generate reliable maps of active land displacements over the whole Czechia and share them publicly within an appropriate framework - the Czech Collaborative Ground Segment should provide such framework and public interactive maps are being kept as a topic under ongoing discussion.

ACKNOWLEDGMENTS

This work was supported by The Ministry of Education, Youth and Sports from the National Programme of Sustainability (NPU II) project „IT4Innovations excellence in science - LQ1602“ and from the Large Infrastructures for Research, Experimental Development and Innovations project „IT4Innovations National

Supercomputing Center – LM2015070". Access to computing and storage facilities owned by parties and projects contributing to the National Grid Infrastructure MetaCentrum, provided under the programme "Projects of Large Infrastructure for Research, Development, and Innovations" (LM2010005), is greatly appreciated. Authors are grateful to researchers sharing their development work, especially team of Leeds University led by Prof. Andrew Hooper that offered codes of the LiCS database and UNAVCO WInSAR for opening codes of ISCE software. The research is supported by the VŠB - Technical University of Ostrava, the Faculty of Mining and Geology, grant project Crowdsourced geodata, No. SP2016/41.

REFERENCES

Agram, P. et al. (2016). ISCE topsApp. https://winsar.unavco.org/isce.html

Bekaert, D. P. S., Walters, R. J., Wright, T. J., Hooper, A. J., and Parker, D. J. (2015). Statistical comparison of InSAR tropospheric correction techniques. Remote Sensing of Environment. ekaert, D.P.S., Walters, R.J., Wright, T.J., Hooper, A.J., and Parker, D.J. (2015), doi: 10.1016/j.rse.2015.08.035

Dehls, J. (2016). The Norwegian national ground motion service - experience from first year(s) of operation. Hannover: BGR, 3-4 Nov 2016

Donga J., Xiao X., Chen B., Torbick N., Jin C., Zhang G., Biradar C. (2013). Mapping deciduous rubber plantations through integration of PALSAR and multi-temporal Landsat imagery. Remote Sensing of Environment *134*, pp. 392–402.

Guimaraes, P., and Lazecky, M. (2016). giSAR (Quantum GIS toolbox). https://github.com/espiritocz/giSAR

Hooper, A. (2008). A multi-temporal InSAR method incorporating both persistent scatterer and small baseline approaches. Geophysical Research Letters *35*.

Kalia, A. (2016). Ground Motion Service Germany. Hannover: BGR, 3-4 Nov 2016

Kampes, B.M., Hanssen, R.F., and Perski, Z. (2003). Radar interferometry with public domain tools. In Proceedings of FRINGE, (Frascati), pp. 1–5.

Lazecky, M., Comut, F.C., Hlavacova, I., and Gurboga, S. (2015). Practical Application of Satellite-Based SAR Interferometry for the Detection of Landslide Activity. In WMESS 2015, pp. 613–618.

Lazecky, M., Canaslan Comut, F., Nikolaeva, E., Bakon, M., Papco, J., Ruiz-Armenteros, A.M., Qin, Y., de Sousa, J.J.M., and Ondrejka, P. (2016a). POTENTIAL OF SENTINEL-1A FOR NATION-WIDE ROUTINE UPDATES OF ACTIVE LANDSLIDE MAPS. ISPRS 2016, *XLI-B7*, 775–781.

Lazecky, M., Hlavacova, I., Bakon, M., Sousa, J.J., Perissin, D., and Patricio, G. (2016b). Bridge Displacements Monitoring Using Space-Borne X-Band SAR Interferometry. IEEE JSTARS *PP (99)*, 6 p.

Lazecky, M. (2016). Sentineloshka. https://github.com/espiritocz/sentineloshka

Lazecký M., Jiránková E., and Kadlečík P. (2017). Multitemporal monitoring of Karvina subsidence trough using Sentinel-1 and TerraSar-X interferometry.

Acta Geodyn. Geomater., *14*, No. 1 (185), pp. 53–59. DOI: 10.13168/AGG.2016.0027

Li, Z., Wright, T., Hooper, A., Crippa, P., Gonzalez, P., Walters, R., Elliott, J., Ebmeier, S., Hatton, E., and Parsons, B. (2016). Towards InSAR everywhere, all the time, with Sentinel-1. In International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, pp. 763–766.

Samieie-Esfahany, S., Hanssen, R., van Thienen-Visser, K., and Muntendam-Bos, A. (2009). On the effect of horizontal deformation on InSAR subsidence estimates. In Proceedings of the Fringe 2009 Workshop, ESA SP, p.

Vollrath, A., Lindquist, E., Jonckheere, I., and Pekkarinen, A. (2016). Open Foris SAR Toolkit – free and open source command line utilities for automatized SAR data pre-processing. In: ESA LPS 2016, Prague

Zebker, H.A., Hensley, S., Shanker, P., and Wortham, C. (2010). Geodetically accurate InSAR data processor. IEEE Transactions on Geoscience and Remote Sensing *48*, 4309–4321.