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Abstract

Time series of ground deformation are used to describe motion produced by various natural and anthropocentric processes, such as earthquakes, volcanic eruptions, landslides, subsidence due to resource exploitation and uplift due to fluid injection. The Multidimensional Small Baseline Subset version 3 (MSBASv3) software simultaneously processes multiple ascending and descending Differential Interferometric Synthetic Aperture Radar (DInSAR) data sets and produces either one-dimensional, line-of-sight, or two-dimensional, horizontal east-west and vertical, deformation time series with combined temporal resolution. The set of linear equations solved by MSBASv3 is usually rank deficient and is solved in the least-square sense by applying the Singular Value Decomposition (SVD) and the zero, first, or second order Tikhonov regularization. The MSBASv3 source code is written in C++ and is parallelized using OpenMP. It is linked to the Linear Algebra PACKage (LAPACK) library that provides SVD support and to the Geospatial Data Abstraction Library (GDAL) that provides GeoTiff support. To demonstrate the capabilities of the MSBASv3 a test set of ascending and descending RADASAT-2 data over the Barnes Ice Cap (Baffin Island, Nunavut, Canada) during December 2014 - May 2015 is included and is used throughout this user manual to illustrate the processing sequence.

Introduction

The Multidimensional Small Baseline Subset version 3 (MSBASv3) software computes either one-dimensional, line-of-sight, or two-dimensional, horizontal east-west and vertical, time series of ground deformation from ascending and descending Differential Interferometric Synthetic Aperture Radar (DInSAR) data. DInSAR data can be acquired by various SAR sensors with different acquisition parameters, such as azimuth and incidence angles, spatial resolution, and wavelength. MSBASv3 has the facility to combine discrete time series to give temporally dense coverage. A near daily temporal resolution can be achieved by simultaneous processing data from multiple SAR sensors. For the implicit set of equations, solved by MSBASv3, refer to Samsonov and d'Oreye, 2017. Version 3 and the previous versions of MSBAS have already been used for measuring various ground deformation, including:

- mining (Samsonov et al., 2013a,b, 2014b);
- urban development (Samsonov et al., 2014a, 2016c; Samsonov and d'Oreye, 2017);
- carbon sequestration (Samsonov et al., 2015; Czarnogorska et al., 2016);
- permafrost aggradation and pingo growth (Samsonov et al., 2016b);
- volcanic activities (Samsonov and d'Oreye, 2012; Smets et al., 2014; Samsonov et al., 2014d,c, 2016a).

This document demonstrates the capabilities of MSBASv3 and its correct use by computing two-dimensional deformation time series from seven ascending and descending fine resolution RADARSAT-2 interferograms acquired over the Barnes Ice Cap (Baffin Island, Nunavut, Canada) during December 2014 - May 2015.

Installation

MSBASv3 is written in C++ using the NetBeans integrated development environment (https://netbeans.org/). It is linked to the Linear Algebra PACKage (LAPACK) library that provides SVD support and to the Geospatial Data Abstraction Library (GDAL) that provides GeoTiff support. Developer versions of these libraries must be installed prior to compilation. MSBASv3 is parallelized with OpenMP so compilation needs to be performed using a compiler that supports OpenMP technology. The easiest way to compile the software is to run the ***make all*** command in terminal mode. The compiled binary file ***msbasv3*** is created in ***dist*** directory. The MSBASv3 source code can also be openned and compiled from within NetBeans.

Supplementary scripts, provided with the MSBASv3 software require the installation of the GNUPLOT (*http://www.gnuplot.info*) and the Generic Mapping Tools (GMT, *http://gmt.soest.hawaii.edu/projects/gmt*) software.

Input Data and Parameters

The input data to the MSBASv3 software consists of one or more sets of ascending and/or descending Differential Interferometric Synthetic Aperture Radar (DInSAR) interferograms, unwrapped and geocoded to a common grid. Interferograms can be stored either in standard binary (4-byte float, small or big endian) or GeoTiff formats. The example provided consists of two sets of interferograms acquire over the Barnes Ice Cap (Baffin Island, Nunavut, Canada) during December 2014 - May 2015 (Fig 1): one set comprising four ascending (Listing 1, set header file ***asc.txt***) and a second set of three descending (Listing 2, set header file ***dsc.txt***) interferograms. Each set header file contains space-delimited interferogram names (with a path), perpendicular baselines (in meters), and master and slave acquisition

Listing 1: Example of MSBASv3 ascending set header file ***asc.txt***

```
asc/20141216_HH_20150109_HH.disp.geo.bin -134.814700 20141216 20150109
asc/20150109_HH_20150202_HH.disp.geo.bin 140.286400 20150109 20150202
asc/20150202_HH_20150226_HH.disp.geo.bin -98.237100 20150202 20150226
asc/20150226_HH_20150322_HH.disp.geo.bin 81.508800 20150226 20150322
```

Listing 2: Example of MSBASv3 descending set header file ***dsc.txt***

```
dsc/20150106_HH_20150130_HH.disp.geo.bin -204.596500 20150106 20150130
dsc/20150130_HH_20150223_HH.disp.geo.bin -94.849500 20150130 20150223
dsc/20150223_HH_20150319_HH.disp.geo.bin 109.509600 20150223 20150319
```

dates (in YYYYMMDD format). For all interferograms the master date must be earlier than the slave date.

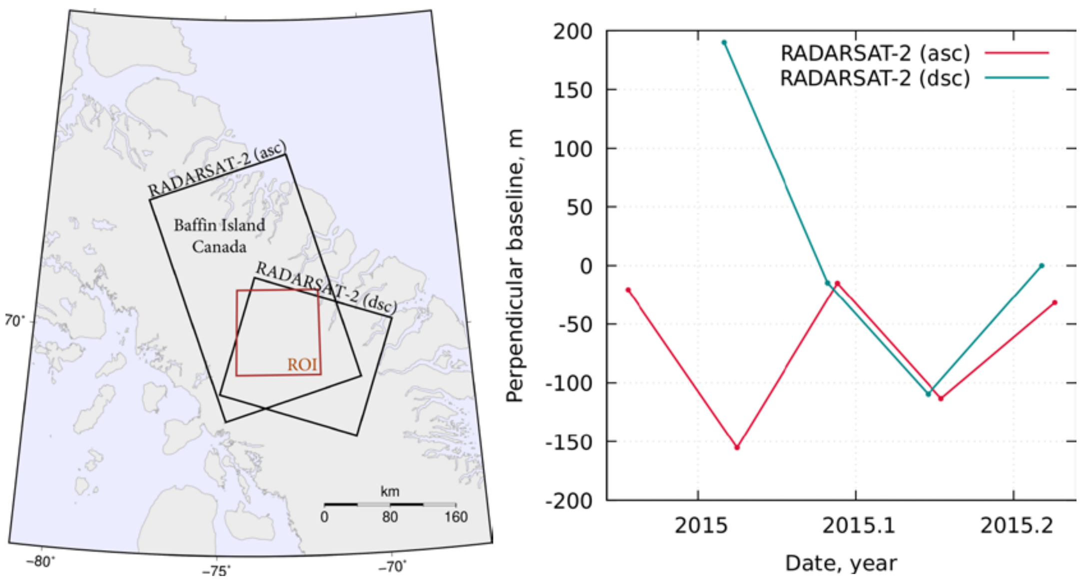

Figure 1: Region of interest - the Barnes Ice Cap, Baffin Island, Nunavut, Canada (left). Temporal and spatial baselines of RADARSAT-2 data used in this study (right).

By default, MSBASv3 saves deformation time series for each acquisition epoch in binary files of the format identical to the input format. It is possible to save deformation time series for a selected number of small region(s) to text file(s) by supplying an additional file (here called ***par.txt***) with coordinates and half-width/length of regions, for which time series are to be extracted. For example, the following information should be provided in the parameter file (Listing 3, file ***par.txt***) in order to extract time series in a text format for two regions centered at column/row **220/510** and **290/210**, with half-width/length of 5/5 pixels. Alternatively, the ***msbas_extract*** command (described below) can be used in post processing.

Listing 3: Example of MSBASv3 ***par.txt*** file

```
220 510 5 5
290 210 5 5
```

An example of a main processing file ***header.txt*** is shown in Listing 4 (file ***header.txt***). Supported parametrs with options are summarized in Table 1. To execute MSBASv3 run ***msbasv3 header.txt*** in terminal mode.

Listing 4: Example of MSBASv3 header file ***header.txt***

```
FORMAT=1                                      #big endian, 4 bytes float binary format
FILE_SIZE=789, 812                            #each file contains 789/812 columns/rows
WINDOW_SIZE=0,788, 0, 811                     #process entire file (optional)
C_FLAG=1, 670, 370, 32, 32                    #reference region is at 670/370 with half-sizes of 32/32
R_FLAG=2, 0.1                                 #first order regularization with λ=0.1
I_FLAG=1                                      #upon completion enter interactive mode
SET=215500, 339.099991, 26.112200, asc.txt  #time 215500, azimuth 339, incidence 26, file asc.txt
SET=114852, -163.561597, 26.151000, dsc.txt #time 114852, azimuth -163, incidence 26, file dsc.txt
```

Output Data

The output data of MSBASv3 processing consists of binary files for each acquisition epoch and several supplementary binary and text files. The output binary format and units are identical to the input binary format and units. The units for input data are normally either radians, centimeters (cm) or meters (m); below it is assumed that input data is in meters. In order to distinguish NaN values (equal to zero) deformation at the initial epoch is set to 0.000001.

The following files are produced by MSBASv3:

- ***MSBAS_YYYYMMDDTHHMMSS_LOS*** - one-dimensional, line-of-sight, deformation time series for epoch YYYYMMDDTHHMMSS (m);
- ***MSBAS_YYYYMMDDTHHMMSS_EW(UD)*** - two-dimensional, horizontal east-west (vertical), deformation time series for epoch YYYYMMDDTHHMMSS (m);
- ***MSBAS_LINEAR_RATE*** - linear deformation rate (m/year). Example of these files for the Barnes Ice Cap is shown in Fig 2;
- ***MSBAS_LINEAR_RATE_ERROR*** - standard deviation of the linear deformation rate (m/year);
- ***MSBAS_NORM_X*** - solution norm (m/year);
- ***MSBAS_NORM_AXY*** - residual norm (m);

- ***MSBAS_TOPOGRAPHIC_CORRECTION*** - topographic correction file (m/m);
- ***MSBAS_ZSCORE_MASK*** - average of absolute values of ZSCORE (i.e. (x-xmean)/st.div) with incoherent pixels marked as zeros;
- ***MSBAS_TIME_MATRIX.txt*** - text file with time matrix; this file can be analysed, for example, with R;
- ***MSBAS_TSOUT.txt*** - text file that lists binary output files, it serves as input for ***MSBAS_extract***;
- ***MSBAS_LOG.txt*** - text file with the copy of a screen output;
- ***MSBAS_x_y_dx_dy.txt*** - text file with time series for a region centered at column/row x/y with half-width/length of dx/dy;

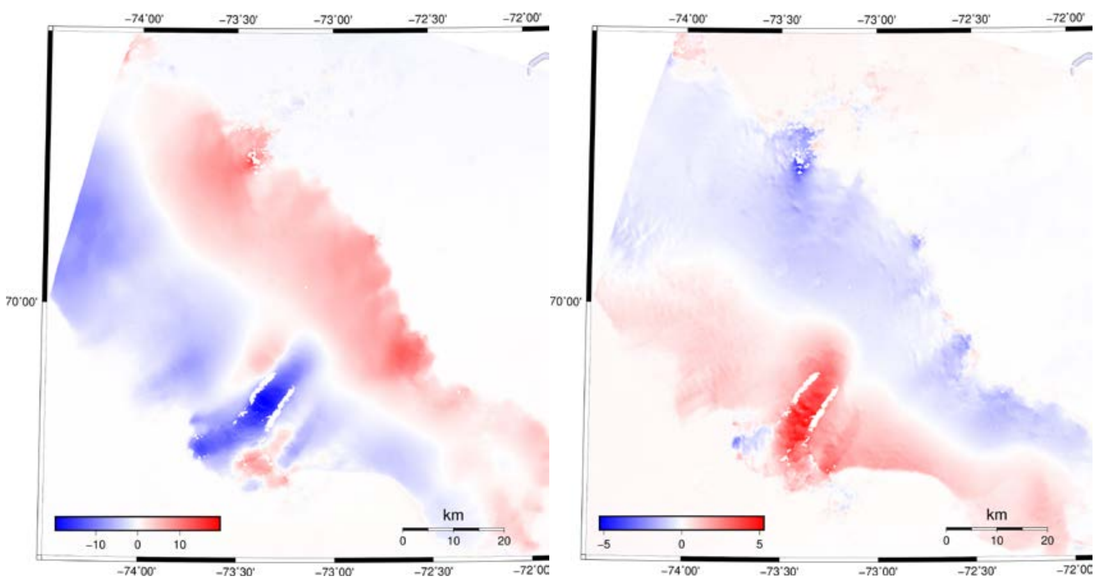

Figure 2: Output produced by MSBASv3 for the Barnes Ice Cap example - horizontal east-west (left) and vertical (right) linear deformation rates measured in m/year.

In Fig 2 (right) the vertical linear deformation rate contains unremoved horizontal north-south component that manifests as an uplift at the slope facing south-west. For discussion of this issue see Samsonov et al., 2016a. The solution to this problem, the constrained three-dimensional solver, will be presented in a future version of MSBAS.

Supplementary tools

MSBASv3 time series extractor

msbas_extract is a postprocessing tool for extracting deformation time series for a small region(s) (or a single pixel) from the binary output produced by MSBASv3 and for saving it to a text file. It uses ***MSBAS_TSOUT.txt*** file produced by MSBASv3 shown in Listing 5 (file ***MSBAS_TSOUT.txt***).

Listing 5: Example of ***MSBAS_TSOUT.txt*** file

```
FORMAT=1
FILE_SIZE=789,812
C_FLAG=1,670,370,32,32
20150106T114852 2015.015047 MSBAS_20150106T114852_EW.bin MSBAS_20150106T114852_UD.bin
20150109T215500 2015.024420 MSBAS_20150109T215500_EW.bin MSBAS_20150109T215500_UD.bin
20150130T114852 2015.080801 MSBAS_20150130T114852_EW.bin MSBAS_20150130T114852_UD.bin
20150202T215500 2015.090173 MSBAS_20150202T215500_EW.bin MSBAS_20150202T215500_UD.bin
20150223T114852 2015.146554 MSBAS_20150223T114852_EW.bin MSBAS_20150223T114852_UD.bin
20150226T215500 2015.155927 MSBAS_20150226T215500_EW.bin MSBAS_20150226T215500_UD.bin
20150319T114852 2015.212308 MSBAS_20150319T114852_EW.bin MSBAS_20150319T114852_UD.bin
```

For example, Listing 6 shows a command to extract time series for a small region centered at column/row **220/510** with half-width/length of **5/5**:

Listing 6: Execution of ***msbas_extract***

```
msbas_extract MSBAS_TSOUT.txt 220 510 5 5
```

The output file ***MSBAS_EXTRACT_220_510_5_5.txt*** is identical to the output file ***MSBAS_220_510_5_5.txt*** produced by MSBASv3. It contains the following fields:

- Date of each acqusition (in YYYYMMDDTHHMMSS format);
- Date of each acqusition (in YYYY.YYYYYY format);
- Horizontal east-west component of deformation (m);
- Standard deviation of the horizontal component (m);
- Vertical component of deformation (m);

- Standard deviation of the vertical component (m).

Standard deviation is computed over a set of pixels in the region of a size 2dx+1/2dy+1. Standard deviation is equal to zero if both half-width/length values are equal to zero (i.e. deformation computed for a single pixel).

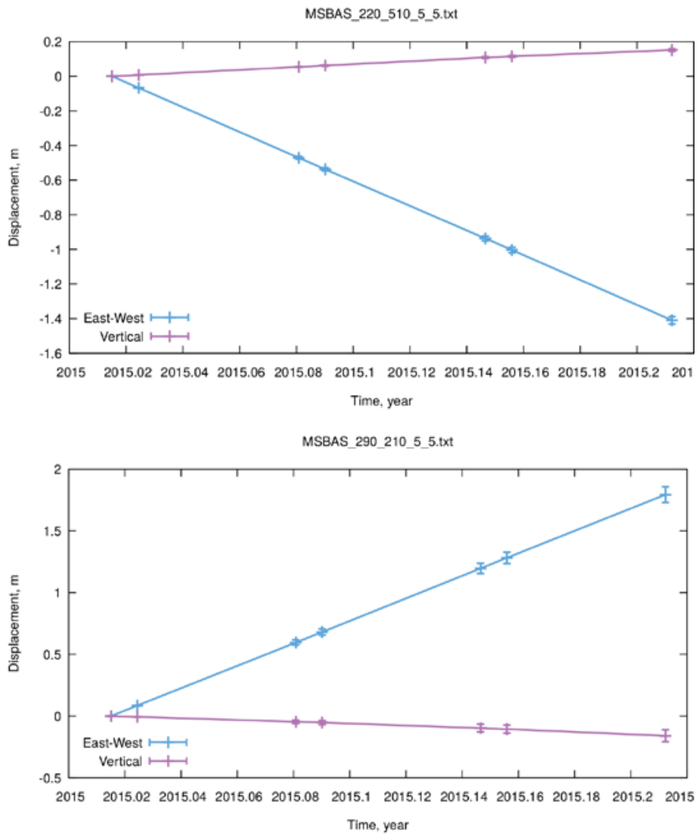

Figure 3: Time series the Barnes Ice Cap example for regions located at column/row 220/510 and 290/10 with half-width/length of 5/5 pixels.

Tools for plotting MSBASv3 results

Two *bash* scripts are provided for plotting time series in text format and for plotting binary GeoTiff files:

- ***msbas_plot_ts.sh*** – based on the GNUPLOT software that must be pre-installed. To run the the script, provide the file to be plotted in terminal mode as shown in Listing 7.

Listing 7: Execution of ***msbas_plot_ts.sh***

```
msbas_plot_ts.sh MSBAS_EXTRACT_220_510_5_5.txt
```

- ***msbas_plot_tif.sh*** – *based on the GMT software that* must be pre-installed. To run the the script, provide a file to be plotted in the terminal mode as shown in Listing 8.

Listing 8: Execution of ***msbas_plot_tif.sh***

```
msbas_plot_tif.sh MSBAS_LINEAR_RATE.tif
```

GeoTiff files can be converted to binary format using the ***gdalwarp -of ENVI*** command.

Table 1: MSBAS parameters and supported processing options.

Parameter	Type	Value(s)	Description
Parameter=Value(s), values are comma-dellimited, # comments lines			
FORMAT	int	0	4 bytes float, small endian
FORMAT	int	1	4 bytes float, big endian
FORMAT	int(s)	2, r	GeoTiff, interpolation radius in pixels, e.g. 2,3
FILE_SIZE	int(s)	x, y	e.g. columns 1000, rows 1000
WINDOW_SIZE	int(s)	xa, xb, ya, yb	default: 0, x-1, 0, y-1
C_FLAG	int	0	no callibration
C_FLAG	int(s)	1, x1, y1, dx, dy	one reference region at x1,y1 of size 2dx+1, 2dy+1
C_FLAG	int(s)	2, x1, y1, x2, y2, dx, dy	two reference regions of size 2dx+1, 2dy+1
C_FLAG	int	10	interferogram average set to zero
C_FLAG	int(s)	100, dx, dy	one reference region auto selected (ZSCORE)
R_FLAG	int	0	no regularization
R_FLAG	int, float	1, λ	zero order regularization
R_FLAG	int, float	2, λ	first order regularization
R_FLAG	int, float	3, λ	second order regularization
T_FLAG	int	0	no topographic correction
T_FLAG	int	1	topographic correction
I_FLAG	int	0	no interactive mode
I_FLAG	int	1	interactive mode
I_FLAG	int, string	2, par.txt	process par.txt file
I_FLAG	int	3	save output in a text file
SET	int (6), float, float, string	hhmmss, θ, ϕ, set.txt	122435, -189.0, 34.0, dsc.txt

Legend

- ***r*** is non-negative interpolation radius in pixels; interpolation is performed by GDAL function ***GDALFillNodata*** and supported only for data supplied in GeoTiff format.
- ***x, y*** are width and length of interferograms; i.e. number of columns and rows.
- ***xa, xb, ya, yb*** are first and last columns and rows of sub-region to be processed; the objective is to limit processing to sub-region when computer RAM memory is insufficient for processing the entire region.
- ***x1, y1 (x2, y2)*** are column and row numbers of a reference region(s); up to nine regions of similar size are supported.
- ***dx, dy*** are half-width/length of a reference region(s).
- ***λ*** is regularization parameter, usually in range 0.01-0.50; value of 0.1 is a good initial guess;
- ***θ, φ*** are azimuth and incidence angles, measured in degrees.
- Lines can be commented with symbol ***#.***

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References

M. Czarnogorska, S. Samsonov, and D. White. Airborne and spaceborne remote sensing characterization for Aquistore carbon capture and storage site. Canadian Journal of Remote Sensing, 2016. https://doi.org/10.1080/07038992.2016.1171131

S. Samsonov and N. d'Oreye. Multidimensional time series analysis of ground deformation from multiple InSAR data sets applied to Virunga Volcanic Province. Geophysical Journal International, 191(3):1095-1108, 2012. https://doi.org/10.1111/j.1365-246x.2012.05669.x

S. Samsonov, N. d'Oreye, and B. Smets. Ground deformation associated with post-mining activity at the French-German border revealed by novel InSAR time series method. International Journal of Applied Earth Observation and Geoinformation, 23:142-154, 2013a. https://doi.org/10.1016/j.jag.2012.12.008

S. Samsonov, P. Gonzalez, K. Tiampo, and N. d'Oreye. Methodology for spatio-temporal analysis of ground deformation occurring near Rice Lake (Saskatchewan) observed by RADARSAT-2 DInSAR during 2008-2011. Canadian Journal of Remote Sensing, 39(1):27-33, 2013b. https://doi.org/10.5589/m13-005

S. Samsonov, N. d'Oreye, P. González, K. Tiampo, L. Ertolahti, and J. Clague. Rapidly accelerating subsidence in the Greater Vancouver region from two decades of ERS-ENVISAT-RADARSAT-2 DInSAR measurements. Remote Sensing of Environment, 143(5):180-191, 2014a. https://doi.org/10.1016/j.rse.2013.12.017

S. Samsonov, P. Gonzalez, K. Tiampo, and d'Oreye N. Modeling of fast ground subsidence observed in southern Saskatchewan (Canada) during 2008-2011. Natural Hazards and Earth System Sciences, 14: 247-257, 2014b. https://doi.org/10.5194/nhess-14-247-2014

S. Samsonov, M. Czarnogorska, and D. White. Satellite interferometry for high-precision detection of ground deformation at a carbon dioxide storage site. International Journal of Greenhouse Gas Control, 42:188-199, 2015. https://doi.org/10.1016/j.ijggc.2015.07.034

S. Samsonov, W. Feng, P. Peltier, H. Geirsson, N. d'Oreye, and K. Tiampo. Multidimensional small baseline subset (MSBAS) for volcano monitoring in two dimensions: opportunities and challenges. Case study Piton de la Fournaise volcano. Journal of Volcanology and Geothermal Research, 344, 121-138, 2016a. https://doi.org/10.1016/j.jvolgeores.2017.04.017

S. V. Samsonov, K. F. Tiampo, A. G. Camacho, J. Fernández, and P. J. González. Spatiotemporal analysis and interpretation of 1993-2013 ground deformation at Campi Flegrei, Italy, observed by

advanced DInSAR. Geophysical Research Letters, 41(17):6101-6108, 2014c.
https://doi.org/10.1002/2014gl060595

S. V. Samsonov, A. P. Trishchenko, K. Tiampo, P. J. González, Y. Zhang, and J. Fernández. Removal of systematic seasonal atmospheric signal from interferometric synthetic aperture radar ground deformation time series. Geophysical Research Letters, 41(17):6123-6130, 2014d.
https://doi.org/10.1002/2014gl061307

S. V. Samsonov, T. C. Lantz, S. V. Kokelj, and Y. Zhang. Growth of a young pingo in the Canadian Arctic observed by RADARSAT-2 interferometric satellite radar. The Cryosphere, 10(2):799-810, 2016b. https://doi.org/10.5194/tc-10-799-2016

S.V. Samsonov and N. d'Oreye. Multidimensional Small Baseline Subset (MSBAS) for Two-Dimensional Deformation Analysis: Case Study Mexico City. Canadian Journal of Remote Sensing, (43), 2017. http://dx.doi.org/10.1080/07038992.2017.1344926

S.V. Samsonov, K.F. Tiampo, and W. Feng. Fast subsidence in downtown of Seattle observed with satellite radar. Remote Sensing Applications: Society and Environment, 4:179-187, October 2016c.
https://doi.org/10.1016/j.rsase.2016.10.001

B. Smets, N. d'Oreye, F. Kervyn, M. Kervyn, F. Albino, S. Arellano, M. Bagalwa, C. Balagizi, S. Carn, T. Darrah, J. Fernandez, B. Galle, P. Gonzalez, E. Head, K. Karume, D. Kavotha, F. Lukaya, N. Mashagiro, G. Mavonga, P. Norman, E. Osodundu, J. Pallero, J. Prieto, S. Samsonov, M. Syauswa, D. Tedesco, K. Tiampo, C.. Wauthier, and M. Yalire. Detailed multidisciplinary monitoring reveals pre- and co-eruptive signals at Nyamulagira volcano (North Kivu, Democratic Republic of Congo). Bulletin of Volcanology, 76:787:1-35, 2014. https://doi.org/10.1007/s00445-013-0787-1