# SETSM

# User Manual

## Version 4.2.0

(https://mjremotesensing.wordpress.com/setsm)

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August 12, 2019

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# 1. Overview

The Surface Extraction by TIN-based Search space Minimization (SETSM) software is designed to provide fully-automatic, generalized Digital Surface Model (DSM) and orthoimage extraction from high-resolution stereoscopic image pairs distributed by DigitalGlobe and Airbus. Currently, these include imagery from IKONOS, Quickbird, GeoEye, Worldview and Pleiades satellite constellations. In principle, SETSM could be applied to any set of pushbroom-mode imagery, but only DigitalGlobe Airbus/Pleiades metadata are currently supported.

SETSM consists of a series of self-contained C++ functions. The file names of images (at least 2) are passed as arguments, along with an output directory name. Other options are also passed as arguments. The images can either be in flat-binary format with an ENVI style header or can be Geotiff. SETSM produces three outputs, all Geotiff files: the DSM at the specified output resolution, an orthorectified image of the first image in the pair at the same resolution as the DSM and a “matchtag” mask, which gives ones at locations of data points and zeros for interpolated or background grid points. The Geotiff output can be converted to other formats with GDAL or other software packages.

For processing high-resolution (submeter) commercial imagery, a node with 12 or more cores is generally needed. Typical times for processing a pair of WorldView-1 images to 2 m resolution is 12 hours on a 16-core node, with 8m taking 4 hours. The processing time, however, will vary widely depending on the terrain and the area of overlap between the stereo images. SETSM is currently parallel within a node (multithreaded with OpenMP) and has limited support for multi-node (MPI) processing.

Note that SETSM is currently under active development by Myoung-Jong Noh and the Ohio Supercomputer Center (OSC) under a grant from the National Science Foundation and is expected to have many updates in the near future.

# 2. Installation

The SETSM code is currently distributed as source with a makefile and readme. Installation consists of specifying the libtiff and libgeotiff paths and then running make to build the SETSM executable.

## 2.1. Dependencies

SETSM depends on the libtiff and libgeotiff libraries. The GDAL utility is useful for manipulating/translating the output.

### 2.1.1. libtiff

SETSM uses libtiff to read input tiff images. In order to read bigTiff (> 4 GB) images, libtiff version 4.0.3 or higher is required. The following commands will install libtiff in your home directory:

wget http://download.osgeo.org/libtiff/tiff-4.0.10.tar.gz
tar -zxvf tiff-4.0.10.tar.gz
cd tiff-4.0.10
./configure --prefix=**/directory-to-install-in/**
make
make install
ldconfig
make distclean

### 2.1.2. PROJ

The coordinate transformation software PROJ is required by libgeotiff. The following commands will install PROJ into directory <proj build dir>.

wget http://download.osgeo.org/proj/proj-5.1.0.tar.gz
wget http://download.osgeo.org/proj/proj-datumgrid-1.7.zip
tar xvf proj-5.1.0.tar.gz
cd proj-5.1.0/
./configure --prefix=<proj build dir>
unzip ../proj-datumgrid-1.7.zip -d nad/
make
make install

### 2.1.3. libgeotiff

SETSM uses libgeotiff to write geotiff images. Note that libgeotiff depends on libtiff and proj. The following commands will install libgeotiff into directory <libgeotiff build dir>. If libtiff and proj are installed in standard (system) locations, the --with-proj and --with-libtiff options can be omitted. Be sure to use the same installation of libtiff that you use to build SETSM.

wget https://download.osgeo.org/geotiff/libgeotiff/libgeotiff-1.4.2.tar.gz
tar xvf libgeotiff-1.4.2.tar.gz
cd libgeotiff-1.4.2
./configure --prefix=<libgeotiff build dir> --with-proj=<proj build dir> --with-libtiff=<libtiff build dir>
make
make install

### 2.1.4. GDAL

The Geospatial Data Abstraction Library (GDAL) is an open source geospatial data manipulation package. The Polar Geospatial Center (PGC) maintains a handy install script for installing or updating GDAL and all of its dependencies at https://github.com/PolarGeospatialCenter/gdal-full

- Command for converting ntf into tif

gdal_translate -q --config GDAL_CACHEMAX 2048 -ot UInt16 -co NBITS=16 -co bigtiff=if_safer -co tiled=yes -co compress=lzw input.ntf output.tif

## 2.2. Building the SETSM Executable

Use the tiffinfo command to locate the path to the libtiff library and verify that it is version 4 or higher. If your libtiff and libtiff libraries are installed in nonstandard locations you will need to edit the SETSM Makefile to point to your libtiff library installation. Alternatively you can set the environment variables TIFFINC, TIFFLIB, GEOTIFFINC, and GEOTIFFLIB to the appropriate paths.

The Makefile supports building SETSM with the Intel, GNU and Cray compilers. Use one of the following commands as appropriate. If no compiler is specified it defaults to gcc/g++.

```
COMPILER=intel make
COMPILER=cray make
make
```

The Makefile sets optimization options for each compiler that are generally recommended. You can also set the OPTFLAGS variable to override the default optimization flags, for example,

```
COMPILER=intel OPTFLAGS='-O3 -fp-model precise' make
```

To build SETSM as an MPI application, follow the above instructions but specify setsm_mpi as the target of make, for example,

```
COMPILER=intel make setsm_mpi
```

# Please refer to the README.md file in the SETSM github (https://github.com/setsmdeveloper/SETSM) for details.

# 3. SETSM Basic Usage

The basic SETSM syntax is:

```
./setsm  -image [image1(*.raw|*.tif)]   -image [image2(*.raw|*.tif)]
-outpath [outputpath/name]  [-options]
```

where “-image” argument defines input imagefile and it have to be at least two for stereo matching. Multiple images are available, but current SETSM version does not apply any multiple matching algorithm. We do not recommend to use multiple images more than two. “-outpath” argument defines output path. image1 and image2 are paths/names of the stereo images and outputpath specifies the directory to which the output will be saved. SETSM automatically loads header information from the image filename (image1 and image2), so the header file(*.xml) should have the same filename(*) of image (*.raw|*.tif). Stereo images can be in one of two formats specified by their extension: *.raw are read as flat binary rasters with ENVI-format ascii header files (*.hdr) and *.tif are read as geoTiff.
The following output will be written to the outputpath:

- outputpath/name_dem.tif : the final DEM in float 32 bits geotiff format
- outputpath/image1_[outres]_ortho.tif : the integer 16 bits geotiff orthoimage on the same grid as the DEM made from image 1
- outputpath/name_matchtag.tif : the BYTE geotiff matchtag mask with 1’s for grid points with match solutions
- outputpath/name/tmp/ : contains temporary files and is deleted after completing the process.
- outputpath/name/txt/: contains ascii intermediate files currently used and saved mainly for debugging purposes.
- outputpath/name_meta.txt : DEM metadata including output size and boundary coordinates, etc.

Options can be either be passed as input arguments or can be edited in the default.txt file. Input arguments take precedence over default.txt statements. We strongly suggest keeping an original copy of the default.txt file. Common options are:

**-mem [**value**] :**specifies an amount of available system physical memory size, unit is Gigabyte. If it is not enough to support a minimum required memory size with a defined tilesize at each level processing, there is an error message to reduce the tilesize (default 4 by 4 km). In addition, it determines output DEM and orthoimage file size. When it is not enough to generate single output, SETSM automatically divides the entire output into several parts. Version 3.4.2 has a speed-up module to reduce processing time with large amount of physical memory usage. Default is 50 which is enough memory size to process 2m DEMs. (depends on DEM coverage). When DEM less than 2m grid with the default is processed, SETSM ignores the speed-up module at fine level processing and generates subparted outputs.

**-provider [**DG (default) | Pleiades**] :**specifies a provider of input image: For Pleiades, users need to first convert the original IMG_*.JP2 image into *.tif or *.raw format (using e.g. GDAL) and change the filenames of the RPC_*.xml to match the image filenames prior to running SETSM.

**-GSD [value] :**specifies GSD(ground sample distance) of input image in meters. For DG imagery, GSD is automatically calculated with xml header file. For Pleiades, the default in 0.5 m.

**-outres [**8 (default)**] :** specifies output grid resolution in meters.

**-tilesize [value]** : specifies the size of the processing subset tile, in meters. The software breaks the stereo overlap into square tiles with an edge buffer, processes each individually, and merges them back together. The tiles are used to reduce physical memory usage and/or provide process checkpointing. Smaller tiles reduce memory usage but result in more redundant processing (at the tile boundaries) and therefore increase computation. The default is 4000. To process without tiling, insert a number larger than the width of the image, such as 100000. However, insufficient system memory will result in failure and file corruption. Also, tiles provide checkpointing because an interrupted job can be restarted, beginning at the last complete tile. Therefore, it is recommended that tiling be used for output resolutions greater than 8m.

**-projection [** utm | ps **]** : specifies the output projection. Options are “utm” , for Universal Trans Mercator projection, or “ps” for polar stereographic with standard parallels of -45°E and -71°E (the Polar Geospatial Center standard projections) for the northern and southern hemispheres, respectively. By default, will set the projection to "ps" for scene center latitudes greater than 60°, and "utm" otherwise. The UTM zone is also determined automatically from the scene center coordinates.

**-utm_zone [value]** : specifies the user defined utm zone from 1 to 60. If not, the utm zone is automatically determined from the scene center coordinates.

**-boundary_min_X [value]** : Lower-left X coordinate in meters of the selected output projection
**-boundary_min_Y [value]** : Lower-left Y coordinate " " " "
**-boundary_max_X [value]** : Upper-right X coordinate " " " "
**-boundary_max_Y [value] :** Upper-Right Y coordinate " " " "
: defines a subset within the stereo pair overlap area to process. This is useful for reducing processing time when only part of a pair is of interest or when processing to very high resolutions (e.g. 0.5 m).

**-tilesSR [value]** : Starting row number of tiles
**-tilesER [value]** : Ending row number of tiles ( > tilesSR )
**-tilesSC [value]** : Starting column number of tiles
**-tilesEC [value]** : Ending column number of tiles ( > tilesSC )
: defines a subset of tiles within the stereo pair overlap area to process. The tile number starts from lower-left corner (1, 1) [row, column] to Upper-right corner ($r_{max}$, $c_{max}$).

**-seed [**path/name heightRange**]** : SETSM can use a seed DEM to reduce processing time. The seed DEM can be used as binary (*.raw) format with envi header file format (*.hdr), or lower resolution of SETSM DEM (*.raw or *.tif) with meta file(*meta.txt) to generate a higher resolution DEM. The first argument is the path/name of the seed dem and the second argument is an +/- height range in meters from the seed DEM height to limit the search-heights at initial computation. The chosen height range should depend on the resolution and confidence of the seed DEM, such as 1.5 to $2\sigma$ uncertainty. We caution that it is better to not use a seed DEM if possible, as it can only negatively impact the quality of the SETSM DEM. For example, errors in the seed DEM with too low a range will result in data loss in SETSM.

**-minH [value] :** minimum terrain height of the stereo pair overlap area [m]

**-maxH [value] :** maximum terrain height of the stereo pair overlap area [m]

: defines minimum and maximum terrain height information if known, which helps SETSM set initial search heights if the provided heights from RPCs are significantly incorrect in order to reduce processing time. We have found large (> 10 m) sensor model errors in a small percentage (< 5%) of DG and Airbus imagery.

**-RAline [value]** : relative RPC line bias

**-RAsample [value]** : relative RPC sample bias

: defines relative bias in RPC sensor models between stereo images. If known, this will reduce overall processing time. After generating any lower resolution SETSM DEM, resulted metafile (*meta.txt) includes the bias information that can be input to generate higher resolution SETSM DEM. If the **-seed** option is used, the bias information is automatically loaded from the metafile.

**-gridonly [** path **]** : where path contains the /txt directory from a previous SETSM run for which the output DEM is deleted or missing. This option will rebuild the DEM more quickly using the results in txt folder to bypass the matching processes.

**-LOO [** 50 (default) **]** : Maximum length [km] of overlapped area for calculating relative RPC bias : SETSM uses a zero-order polynomial bias compensation model with row and column shifts under the assumption that the overlapped area is less than 50 km.(Grodecki and Dial, 2003; Fraser and Hanley, 2003). If the stereo pair has over 50 km length, SETSM is terminated with following messages:

"Overlapped area between stereo pair is very long along the strip(height=#(km), width=#(km)), so that the assumption of RPC bias computation (less than 50km) is not satisfied,
so relative RPC bias can be not accurately compensated.
Please process after split the overlapped area in strip direction into several small area less than 30 km
Boundary(minX, minY, maxX, maxY[m = # # # #]"

**-LSF [** 0 (default) **]** : This option allows to apply Local Surface Filtering(LSF) for smoothing height variation depending on stereo viewing geometry. Value can be '1' for applying the LSF smoothing for DEM results, and additional smoothed DEM is created as 'outputpath_dem_smooth.tif'. Value can be '2' for only generating LSF smoothed DEM.

**-LSFDEM [** 0 (default) **]** : This option allows to apply LSF smoothing for existing DEM (*.tif or *.raw) with additional arguments. If '*.tif' DEM is used for LSF, SETSM requires tiff world file (*.tfw) for providing image size and map information. Value can be '1' for applying the LSF smoothing, and additional smoothed DEM is created as 'path_smooth.raw'.
Following additional arguments have to be placed with '-LSFDEM 1' argument.

**-LSFDEM_path [** path **]** : path of existing DEM

**-outres [** # **]** : specifies output grid resolution in meters as same as existing DEM

**-projection [** utm | ps **]** : specifies the output projection as same as existing DEM.

**-North [** # **]** : specifies the latitude position of DEM. '1' for North, and '2' for South.

- '*.tfw' format :

  For polar stereographic projection, 'tfw' is standard format.

  For UTM projection, three more values are required for specifying utm zone and latitude position right after standard format.

  Example of tfw of utm projected 2m DEM,

  ```
  2.000000000000000
  0
  0
  -2.000000000000000
  384933.000000000000000
  6098561.000000000000000
  UTM
  15
  N
  ```

**-MT [** 0 (default) **]** : This option allows to generate only new matchtag information by new version of SETSM from existing DEM result ( < version 3.3.1), with '-seed ' option indicating the existing DEM path. Second argument (height range) of seed option is recommended as '3' meter which is a normal range of DG stereo scene. The existing DEM must have '*_meta.txt' file. Value can be '1' for applying new version of SETSM matchtag.

**-help** : shows SETSM common options. example) `./setsm -help`

**SETSM Command Examples:**

1. Process an entire image pair to 8m resolution with tiling (basic command):

```
./setsm -image /image/path/image1.tif -image /image/path/image2.tif
-outpath /results/path -outres 8
```

2. Process an entire image pair to 8m resolution with no tiling:

```
./setsm -image /image/path/image1.tif -image /image/path/image2.tif
-outpath /results/path -outres 8 -tilesize 100000
```

3. Process an entire image pair to 8m resolution with tiling and utm projection:

```
./setsm -image /image/path/image1.tif -image /image/path/image2.tif
-outpath /results/path -outres 8 -projection utm
```

4. Process a 4km by 4km subset region of a pair to 2 m with tiling:

```
./setsm -image /image/path/image1.tif -image /image/path/image2.tif
-outpath /results/path -outres 2 -boundary_min_X -2000
-boundary_min_Y 4000  -boundary_max_X 2000 -boundary_max_Y 2000
```

5. Process a tiled subset region (2~3, 5~8) of a pair to 2 m with tiling:

```
./setsm -image /image/path/image1.tif -image /image/path/image2.tif
-outpath /results/path -outres 2 -tilesSR 2 -tilesER 4 -tilesSC 5
-tilesEC 9
```

6. Process an entire image pair to 2m resolution with 8m seed SETSM DEM (20m uncertainty), tiling and ps projection:

```
./setsm -image /image/path/image1.tif -image /image/path/image2.tif
-outpath /results/path -outres 2 -seed /8mseedpath/DEM.raw 20
-projection ps
```

7. Process an entire image pair to 8m resolution with known RPC bias (1.253, 2.365) , tiling, and ps projection;

```
./setsm -image /image/path/image1.tif -image /image/path/image2.tif
-outpath /results/path -outres 2 -RAline 1.253 -RAsample 2.365
-projection ps
```

8. Process an entire image pair to 8m resolution without tiling and min, max height (100, 1000)

```
./setsm -image /image/path/image1.tif -image /image/path/image2.tif
-outpath /results/path -outres 8 -tilesize 100000 -minH 100 -maxH
1000
```

9. Process an entire image pair to 8m resolution with LSF option

```
./setsm -image /image/path/image1.tif -image /image/path/image2.tif
-outpath /results/path -outres 8 -LSF 1
```

10. Process LSF smoothing from existing 8m DEM (utm, north)

```
./setsm -LSFDEM 1 -LSFDEM_path /data/WV02_20150211_dem.tif -outres 8
-projection utm -North 1
```

11. Process new version of matchtag information from existing 8m DEM( < version 3.3.1)

```
./setsm -image /image/path/image1.tif -image /image/path/image2.tif
-outpath /results/path -seed /data/existing_dem.tif[raw] 3 -outres 8
-MT 1
```

12. Process an entire image pair to 1m resolution with system physical memory of 100GB:

```
./setsm -image /image/path/image1.tif -image /image/path/image2.tif
-outpath /results/path -outres 1 -mem 100
```

# 4. Additional tools in SETSM

## 4.1. Ortho rectification

Digital Globe and Pleiades images with RPCs information (xml format) can be ortho-rectified with existing overlapped DEM  by following command :

```
./setsm -ortho -image [image1(*.raw|*.tif)]   -image
[image2(*.raw|*.tif)] -seed [input_dem_path] -outpath
[outputpath/name]  -outres [image resolution]
```

**-image [**input image **]** : Maximum number of multiple input images is 10.

**-outres [**grid**] :** specifies orthoimage grid resolution in meters.

The following output will be written to the outputpath

- outputpath/[input_imagefile]_ortho_[outres].tif : the integer 16 bits geotiff orthoimage

## 4.2. Geocoded image coregistration

Geocoded image (geotiff) coregistration module is developed from relative RPCs bias compensation algorithm (related paper (2)) in SETSM software, and geocoded images can be automatically coregistered by following command :

```
./setsm -coreg [1] -image [geocoded image1(*.tif)]   -image [geocoded
image2(*.tif)] -outpath [outputpath/name]
```

**-coreg [**1(default) | 2 **]** : ‘1’ is for image coregistration, and ‘2’ and ‘3’ is for DEM coregistration

**-image [**input image **]** : Input image should be unsigned integer 16 bits as original DG tif format. First input image is a reference image for coregistration, and rest of input images are target images.

The following output will be written to the outputpath

- outputpath/[input_imagefile]_coreg.tif : the integer 16 bits geotiff coregistered image
- outputpath/GCPs_#.tif : the byte 8bits ground control points for coregistration
- outputpath/coreg_result.txt : statistics and coregistration parameters

## 4.3. Surface Displacement Map(SDM) generation

New Directional Weighted Filtering(DWF) based on coarse-to-fine strategy (related paper (4)) is developed for generating Surface Displacement Map (SDM) from high resolution orthoimages. SDM is extracted from two overlapped orthoimages by following command :

```
./setsm -sdm [1 | 2] -image [geocoded image1(*.tif)]   -image
[geocoded image2(*.tif)] -outpath [outputpath/name] -outres [sdm grid
size] -pl [pyramid level] -sdm_as [value] -sdm_days [value]
```

**-sdm [**1 | 2 **]** : ‘1’ is for without image coregistration, and ‘2’ is for with image coregistration

**-image [**input image **]** : Input image should be unsigned integer 16 bits as original DG tif format. First input image is a reference image, and second input image is target image  for SDM.

**-outres [**grid**] :** specifies sdm grid resolution in meters.

**-pl [**4(default)**] :** specifies the coarsest pyramid level depending on surface displacement between orthoimages. ‘8’ is recommended in case of 400 ~ 500 m (800 ~ 1000 pixels) displacement with 50cm orthoimages.

**-sdm_as [**20(default)**] :** specifies the maximum surface displacement amount [meter/day]

**-sdm_days [**1(default)**] :** specifies the time separation between image1 and image 2 such as temporal baseline [days]

The following output will be written to the outputpath

- outputpath/name_dx.tif : the float 32 bits geotiff x-direction displacement map (unit : meter)
- outputpath/name_dy.tif : the float 32 bits geotiff y-direction displacement map (unit : meter)
- outputpath/name_dmag.tif : the float 32 bits geotiff displacement magnitude map (unit : meter)
- outputpath/name_roh.tif : the float 32 bits geotiff correlation map applied the displacement

## 4.4. DEM coregistration

DEM coregistration algorithm based on 3D distance with geometric constraints is implemented with only translational parameters (Tx, Ty, Tz) in SETSM software (related paper (5)), and it is a 3D distance method. Another DEM coregistration method separately estimates horizontal and vertical shifts and it is a vertical method. Horizontal shifts are estimated through 2D image coregistration method with DEM hillshade image. Then, vertical shift is determined by averaging height differences among control points. Both module can extract translational parameters from multiple overlapped DEMs by following command :

```
./setsm -coreg [2 | 3] -coreg_output [1 | 2] -pl [pyramid_level]
-image [dem1(*.tif)]   -image [dem2(*.tif)] -image [dem3(*.tif)]
-outpath [outputpath/name]

Or
```

```
./setsm -coreg [2 | 3] -coreg_output [1 | 2] -pl [pyramid_level]
-image [dem1(*.tif)]  -txt_input [demfiles(*.txt)] -outpath
[outputpath/name]
```

**-coreg [**2 | 3 **]** : specifies DEM coregistration method. ‘2’ is for the 3D distance method, and ‘3’ is for the vertical method

**-coreg_output [**0 | 1 |2 **]** : The DEM coregistration modules create ‘DEM_coreg_result.txt’ file including results of statistics. This option specifies statistics and output file. ‘0’ is for resulting only translation parameters and its precisions computed by control points (default, and fastest option). ‘1’ is for resulting statistics over entire overlapped area with option ‘0’ results. ‘2’ generates coregistered DEMs and difference map with option ‘1’ and ‘2’ results (slowest option due to tif writing file time). The vertical method estimates average and median for vertical shifts from the control points, and its coregistered DEMs and difference maps.

**-image [**input image **]** : Input image should be float 32 bits as geotiff format. First input image is a reference image for coregistration, and rest of input images are target images. All input images have to have same grid size.

**-txt_input [**input image file **]** : this option is for using a list of input image txt file. DEM of first line is the reference DEM, and others are target DEMs as ‘-image’ option. Each line of the txt file should have a dem path/name.

**-pl [**4(default)**] :** specifies the coarsest pyramid level depending on horizontal translation parameters between DEMs for the vertical method. ‘2’ is recommended in case of 2m grid SETSM DEM generated from DG imagery. The 3D distance method does not use the coarse-fine strategy, so this option is not required.

The following output will be written to the outputpath

- outputpath/DEM_coreg_result.txt : DEM coregistion parameters and its statistics (unit : meter)
- outputpath/DEM_gcps_#.txt : extracted control points 3D coordinates on reference DEM (dem1) (unit : meter)

- outputpath/name_coreg.tif : the float 32 bits geotiff coregistered DEM
- outputpath/name_coreg_diff.tif : the float 32 bits geotiff difference map applied the translational parameters

# 5. Contacts

If you have any questions and problems, please contact one of following persons.

1. Myoung-Jong Noh, Senior Research Associate, BPCRC, OSU, ngnmj77@gmail.com
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3. Karen Tomko, Director of Research Software Applications, OSC, OSU, ktomko@osc.edu

# 6. Related Papers

(1) Noh, M.J., I.M. Howat, 2015, Automated stereo-photogrammetric DEM generation at high latitudes: Surface Extraction from TIN-Based Search Minimization (SETSM) validation and demonstration over glaciated regions, GIScience and Remote Sensing, doi:10.1080/15481603.2015.1008621.

(2) Noh, M. J., I. M. Howat, 2018, Automatic relative RPC image model bias compensation through hierarchical image matching for improving DEM quality, International Society for Photogrammetry and Remote Sensing (ISPRS) Journal of Photogrammetry and Remote Sensing, Vol. 136, PP. 120-133.

(3) Noh, M. J., I.M. Howat, 2017. Surface Extraction from TIN based Search-space Minimization (SETSM) algorithm, International Society for Photogrammetry and Remote Sensing (ISPRS) Journal of Photogrammetry and Remote Sensing, Vol. 129, pp. 55-76.

(4) Noh, M. J., I.M. Howat, 2019. Applications of high resolution, cross-track, pushbroom satellite images with the SETSM algorithm, Journal of Selected Topics in Applied Earth Observations and Remote Sensing, doi: 10.1109/JSTARS.2019.2938146

(5) Noh, M.J., I.M. Howat, 2014. Automated co-registration of repeat Digital Elevation Models for surface elevation change measurement using geometric constraints, IEEE Transactions in Geoscience and Remote Sensing, doi:10.1109/TGRS.2013.2258928