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Topographic properties of sea ice surface in both Cryosat-2 and SAR sub-footprint scale, Preliminary results

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The mission and data set

NASA's Operation IceBridge, utilizing NASA's DC-8 flying laboratory and a Gulfstream-V owned by the National Science Foundation, flew a record 24 science flights during their six-week Antarctic 2011 campaign. The highlight was the discovery of a large crack across the Pine Island Glacier ice shelf. Additionally, IceBridge charted the continued rapid acceleration and mass loss of Pine Island Glacier and made historic flights to rarely studied regions of East Antarctica, Slessor and Recovery glaciers, where ice-penetrating radar measured the topography of the bedrock underneath the ice sheet.

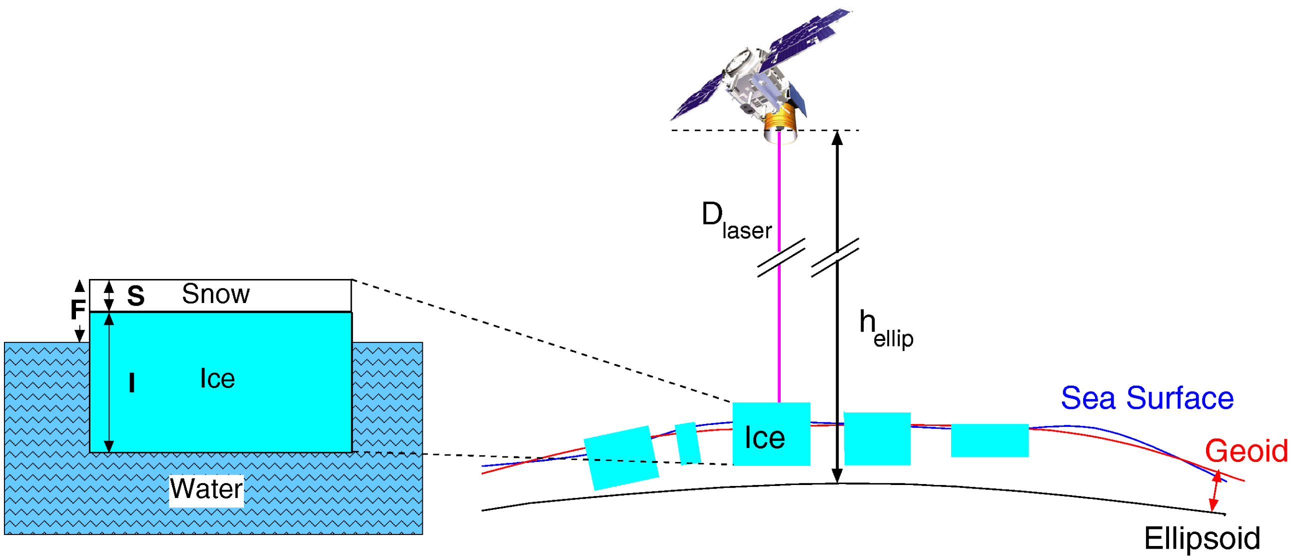
Krabill, William B. 2010, updated 2013. IceBridge ATM L1B Qfit Elevation and Return Strength. Boulder, Colorado USA: NASA DAAC at the National Snow and Ice Data Center. http://nsidc.org/data/ilatm1b.html.

Motivation and approach

Knowledge of the spatial variability or patchiness of the sea-ice roughness is rather limited. Most of the earlier studies has been based on 1D laser altimetry measurements, airborne or satellite. The main focus has been in quantifying surface topography of the sea-ice in terms of fraction, number or density of ridges and ridge height or in the statistical properties of the free board; such as correlation length, root-mean-square of elevations, empirical propability dencity functions of elevations. These studies are based mostly on a single beam laser measurements.

Majority of the studies that use 2D laser altimetry data are however using 1D statistical methods for the data analysis, the focus is still on the elevations not on the 3D structure of the ice surface. In this case study, the topographic properties of the sea ice surface are inspected in the light of some terrain analysis techniques.

Where is the zero level?



Dilemma with sea ice altimetry: we have elevations in respect to the reference ellipsoid, we need the elevations in respect to the actual sea surface.

The next four slides will be skipped; about how the dilemma can be solved and was solved.

Data processing

- The primary product given by the IceBridge ATM laser altimeter is the surface elevation referenced to the WGS84 ellipsoid, h_e. For terrain analysis, we need the elevation in respect to the sea surface, the freeboard.

- The formal equation can be written as:

$$frb = h_e - (h_{geoid} + h_{tides} + h_{pressure} + h_{dynamic}),$$

where frb is the freeboard, h_{geoid} the geoid, h_{tides} the contribution of tidal forces, $h_{pressure}$ the effect of atmospheric pressure loading and $h_{dynamic}$ the dynamic topography of the ocean surface.

Kurtz, N. T., Farrell, S. L., Studinger, M., Galin, N., Harbeck, J. P., Lindsay, R., Onana, V. D., Panzer, B., and Sonntag, J. G. 2013. Sea Ice Thickness, Freeboard, and Snow Depth Products from Operation IceBridge Airborne Data. The Cryosphere, 7:1035-1056, doi:10.5194/tc-7-1035-2013.

- The focus of the study is only on the topography of the ice field.
- The calculation of the three last terms is quite complicated (and time consuming).
- Shortcut: the effect of these terms were interpreted as fluctuations in the flight altitude of the aircraft.
- Thus, method described in Hibler, 'W.D. III 1972: Removal of aircraft altitude variation from laser profiles of the Arctic Ice Pack' was applied with some modifications.

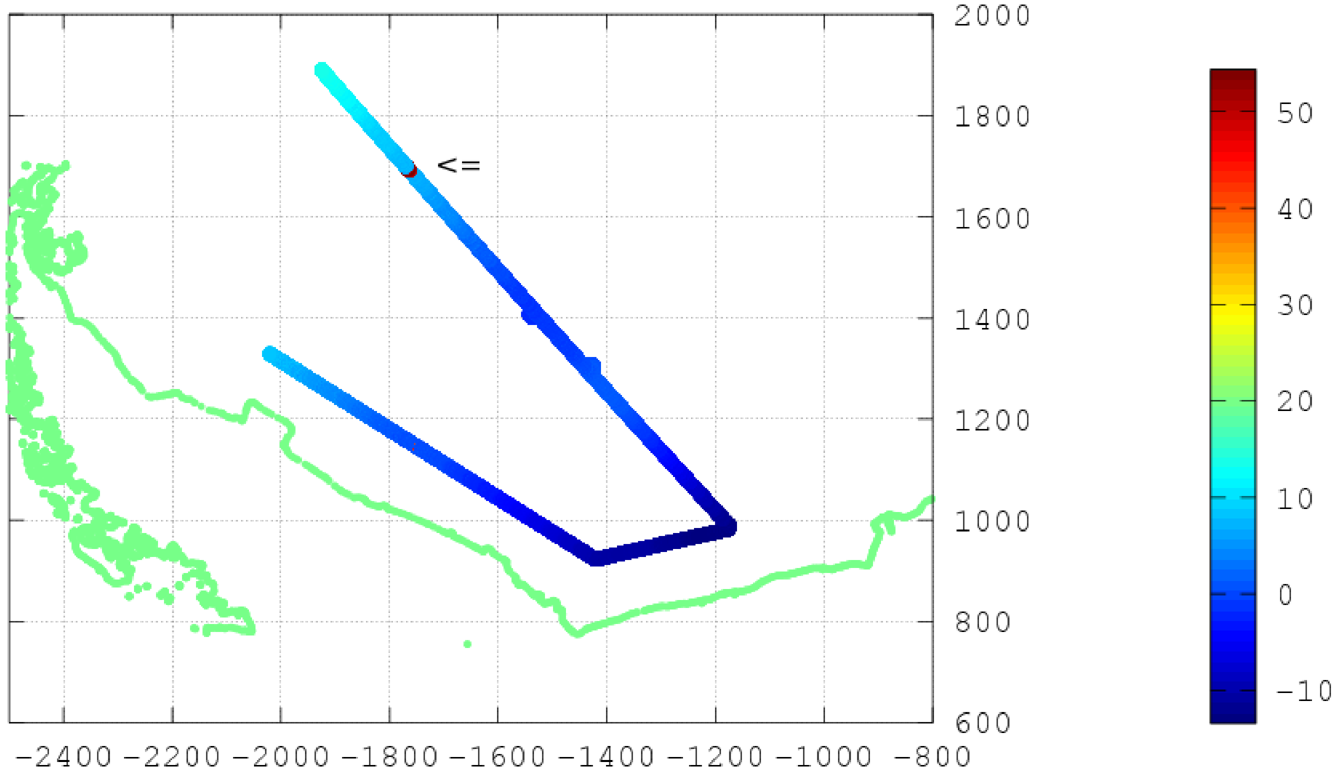


Figure 1: The original elevations, h_e, in metres. The red section might be iceberg B151, (see the next page)

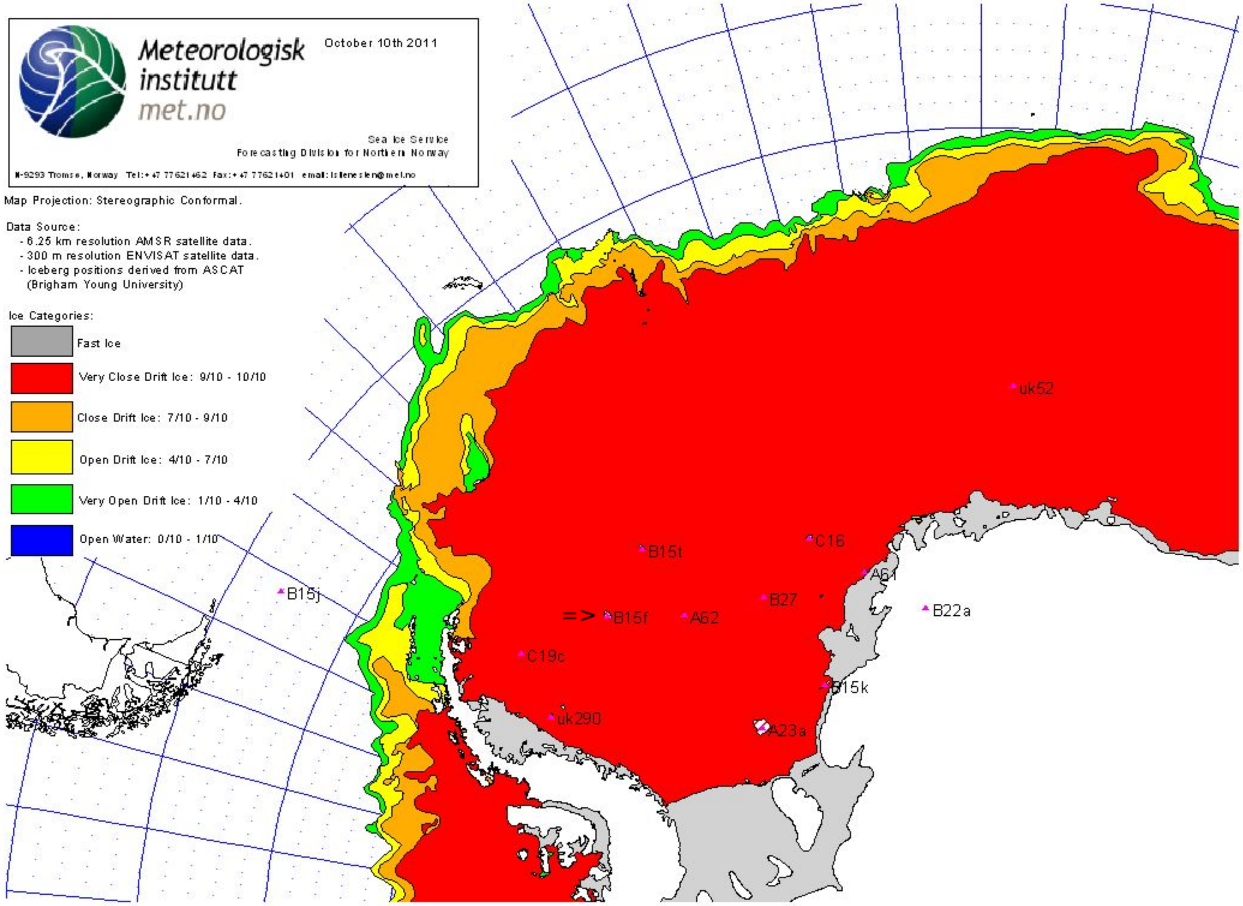


Figure 2: MetNo ice map 10.10.2013 (in different map projection).

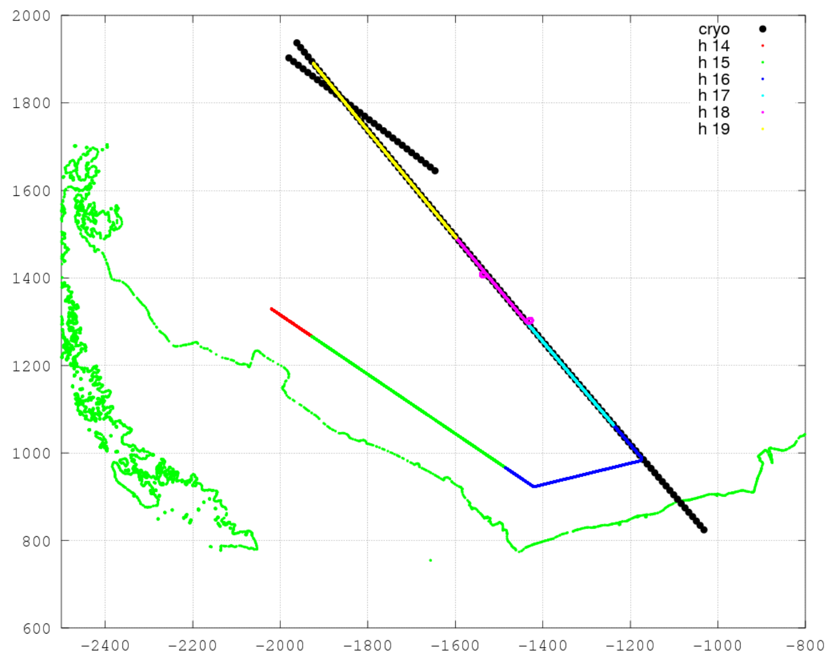


Figure 3: Sections of the 13.10.2013 flight tracks. The colours indicates the flight line during one hour. Black indicates the co-incident CryoSat-2 ground track. The axis values are coordinates of the map projection, in kilometres.

Resolutions

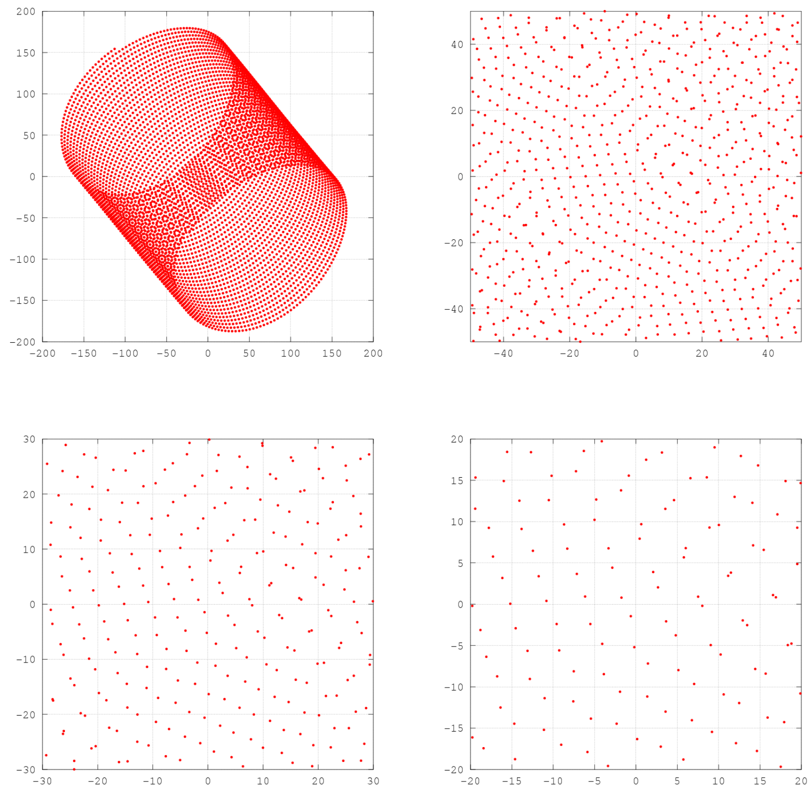


Figure 4: Examples of spatial distribution of ATM point measurements at different spatial scales at randomly selected location. The axis valueas are in metres.

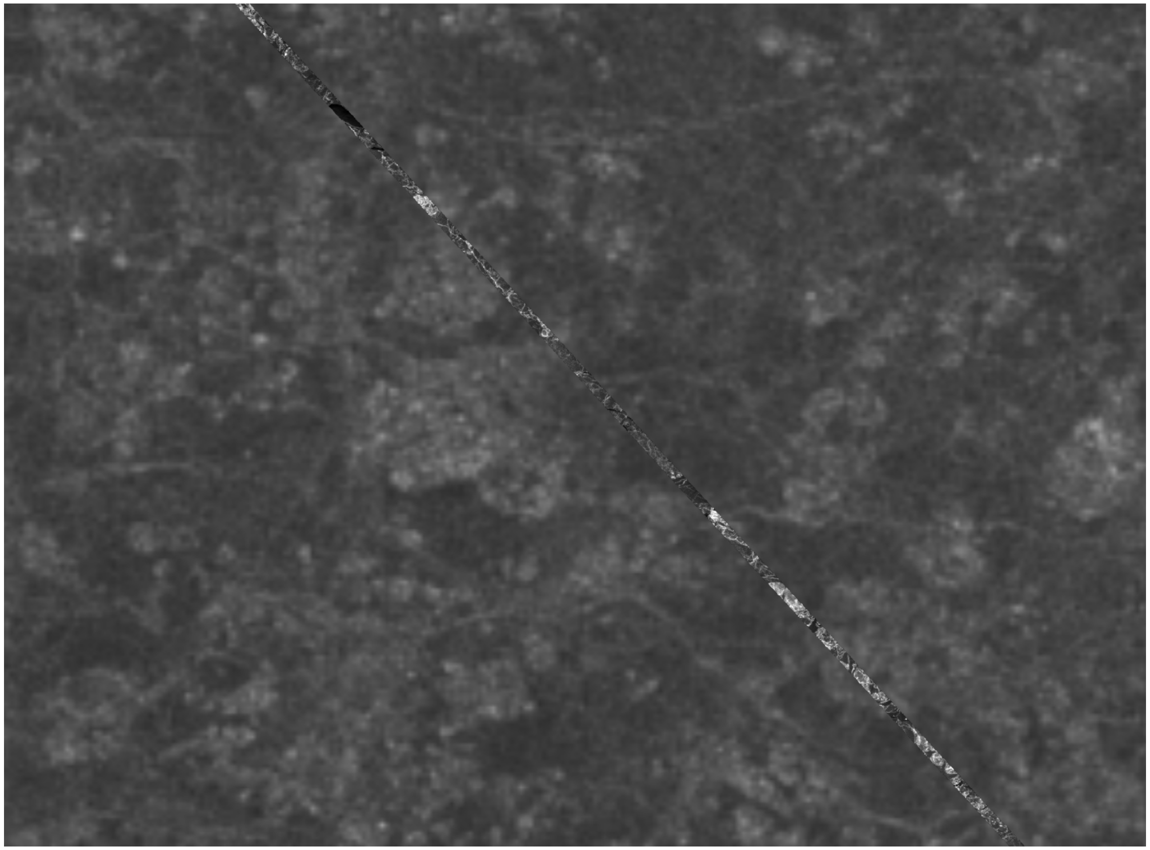


Figure 5: ATM-DEM superimposed to the 13.10.2013 Envisat ASAR WSM image. The resolution difference is allready visible.

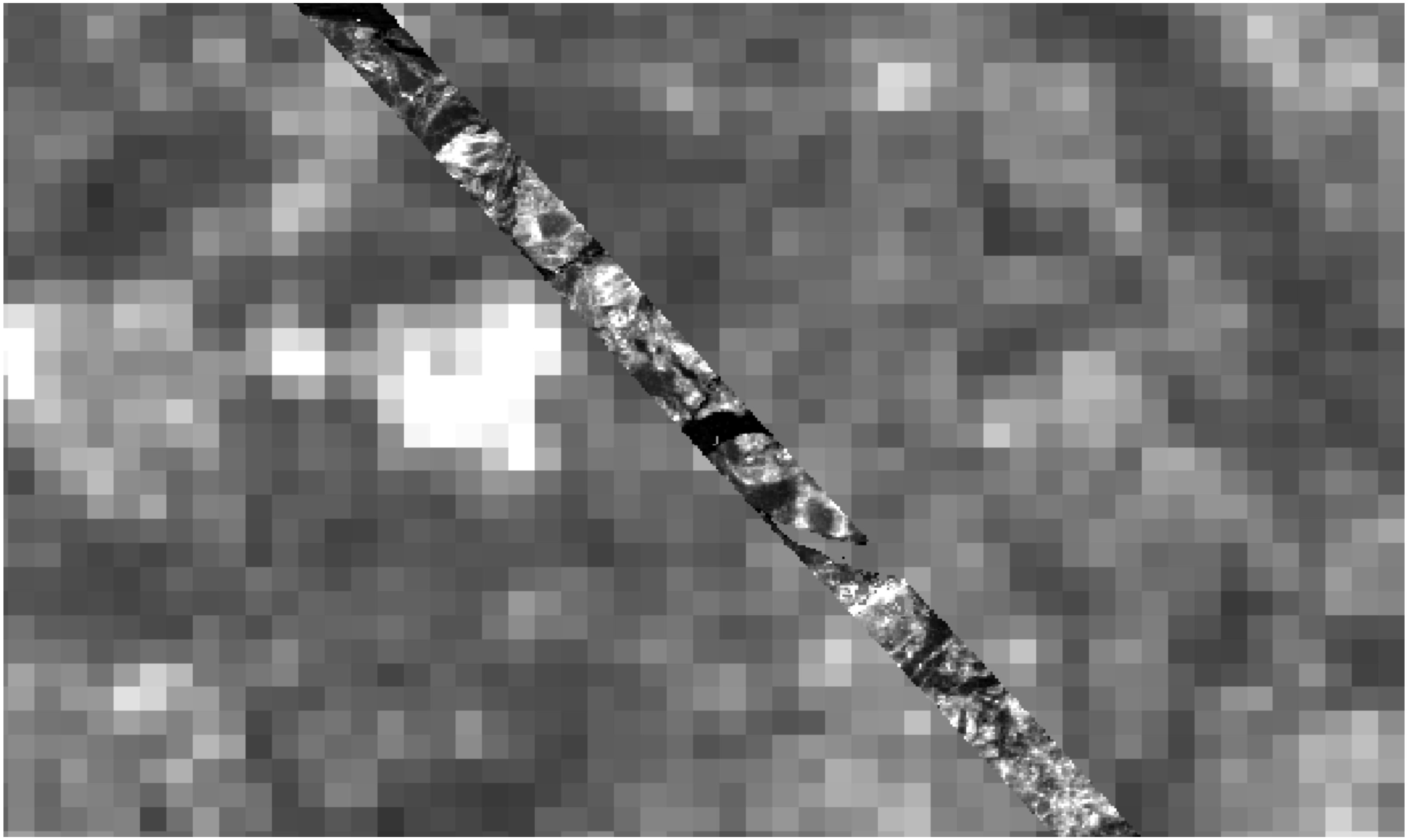
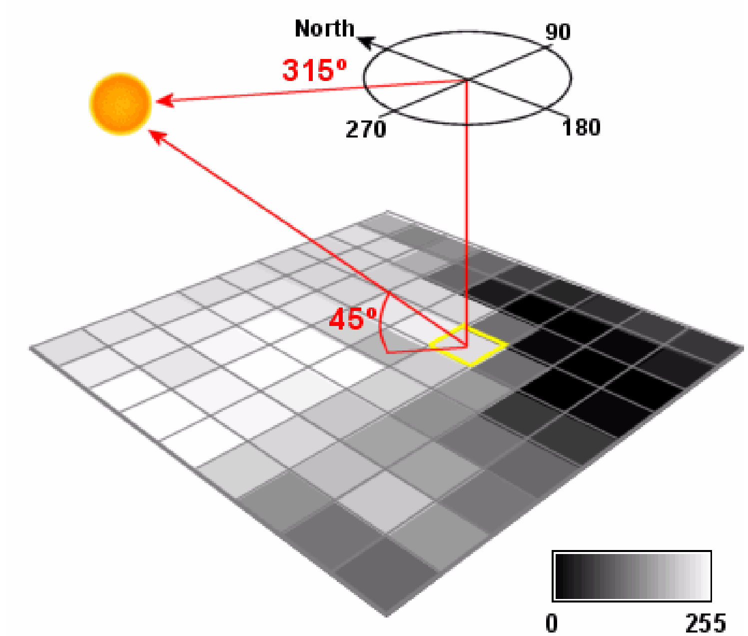


Figure 6: And at sub-pixel scale clearly visible.

Hillshading is a technique used to create a realistic view of terrain by creating a three-dimensional surface from a two-dimensional display of it. Hillshading creates a hypothetical illumination of a surface by setting a position for a light source and calculating an illumination value for each cell based on the cell's relative orientation to the light.



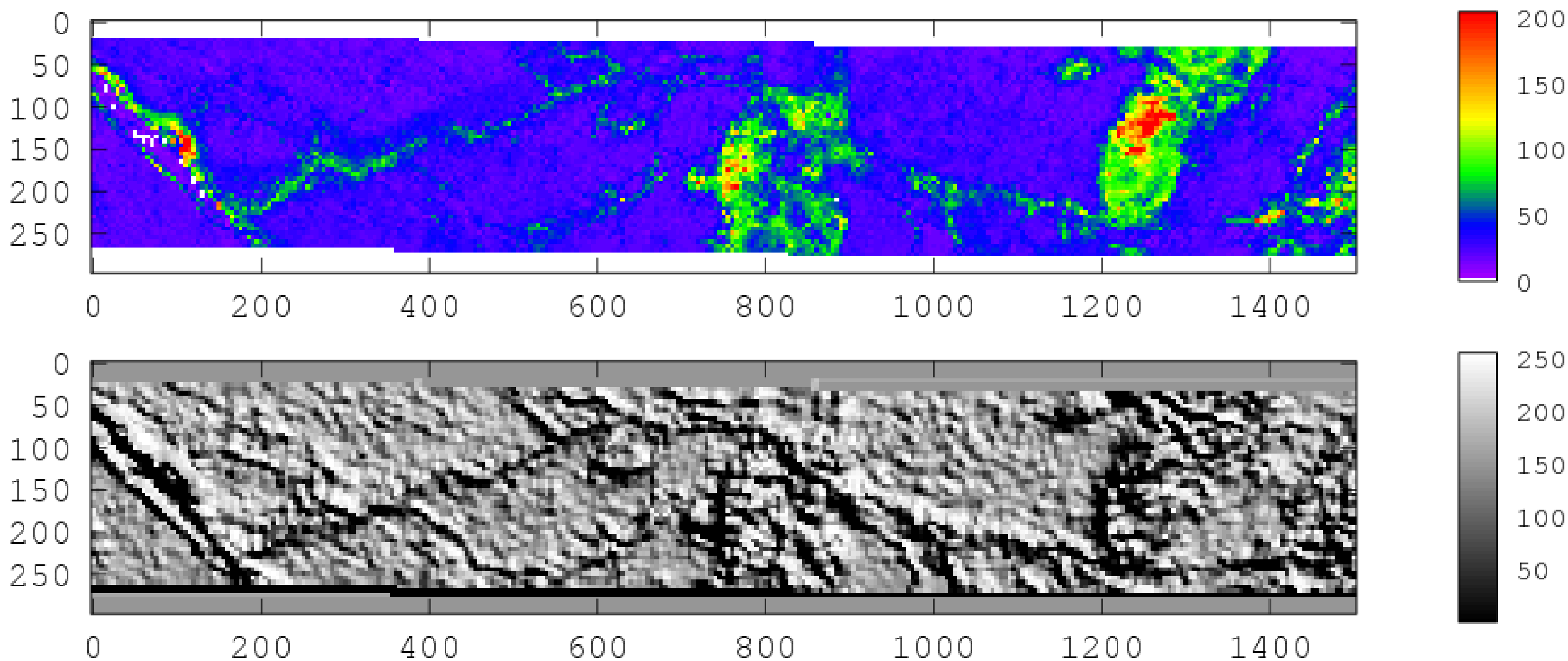


Figure 7: Example of color coded DEM and corresponding hillshde image. The coordinate axis values are in metres. DEM colorbar values are in centimetres. The grayscale bar is only to keep the same image size, values dont have any meaning.

Terrain ruggedness index, TRI

- The process essentially calculates the difference in elevation values from a center cell and the eight cells immediately surrounding it. Then it squares each of the eight elevation difference values to make them all positive and averages the squares. TRI is then derived by taking the square root of this average, and corresponds to average elevation change between any point on a grid and its surrounding area.

- DEM pixels were classified into four ice deformation categories by using TRI values. Finally a median filtering was applied to remove one pixel segments. The used threshold values were selected by visual comparison between DEM, hillshade image and the segmentation result.

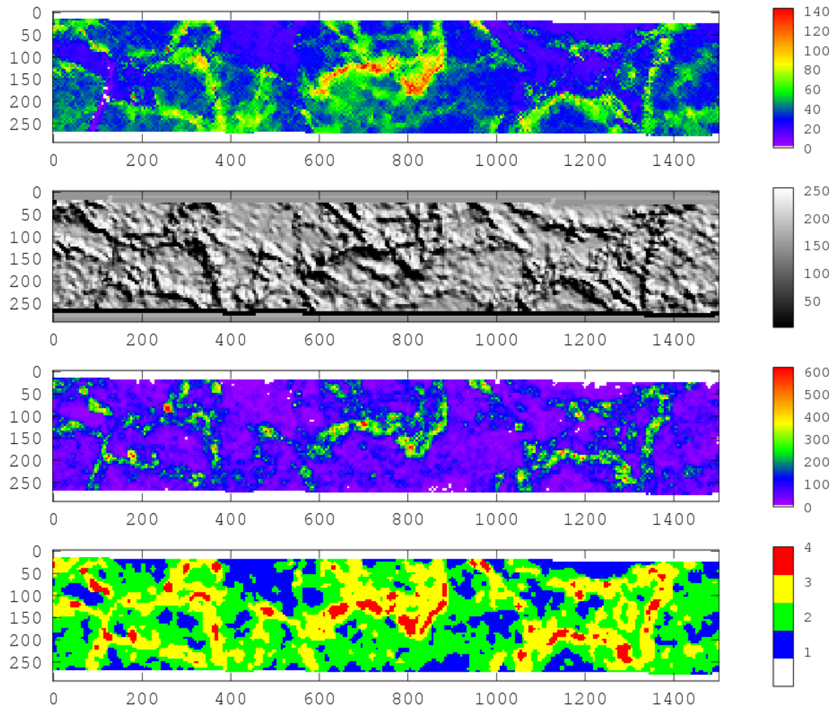


Figure 8: DEM, hillshade image, TRI and the four TRI classes. The coordinate axis values are in metres. -The grayscale bar is only to keep the same image size, values dont have any meaning.

Landscape divercity

DEM was divided into concecutive 250m wide windows and within each window

- The dominant TRI class was selected and its relative fraction in respect to the whole surface area of the window (resolution^2 x pixel count) was calculated.

- Shannons normalized Diversity Index (H) was calculated by using the four TRI classes. Interpretation modified for TRI classes: The value of the index tends to 1 when the TRI classes have roughly equal proportion or a high number of classes being present. A low value means that the window area is dominated by one TRI class. In other words, the ice topography has less diversity.

Relative distributions of these two quantities were calculated.

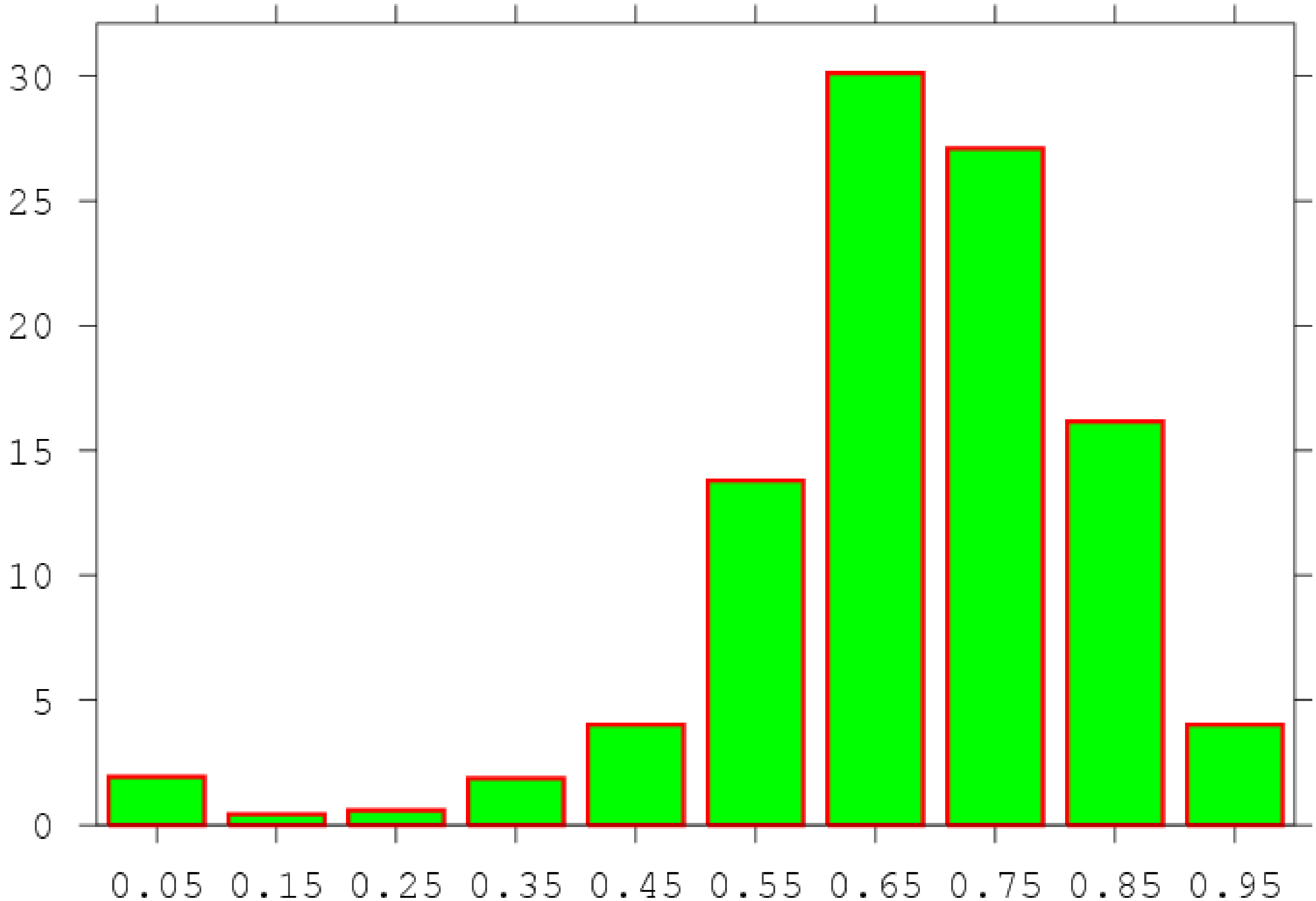


Figure 9: Distribution of H within the windows.

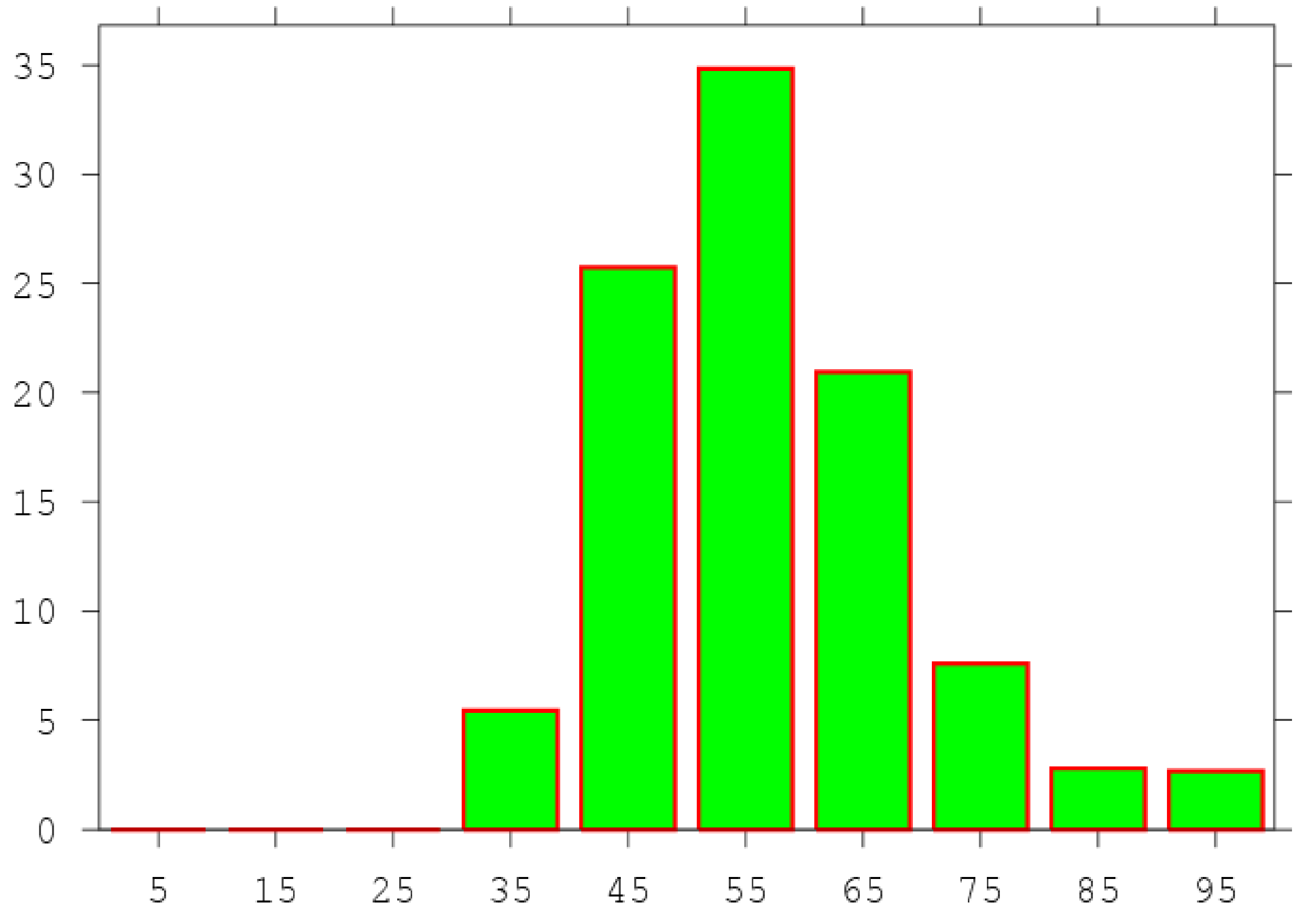


Figure 10: Distribution of the relative fractions of the dominant TRI classes within the windows.

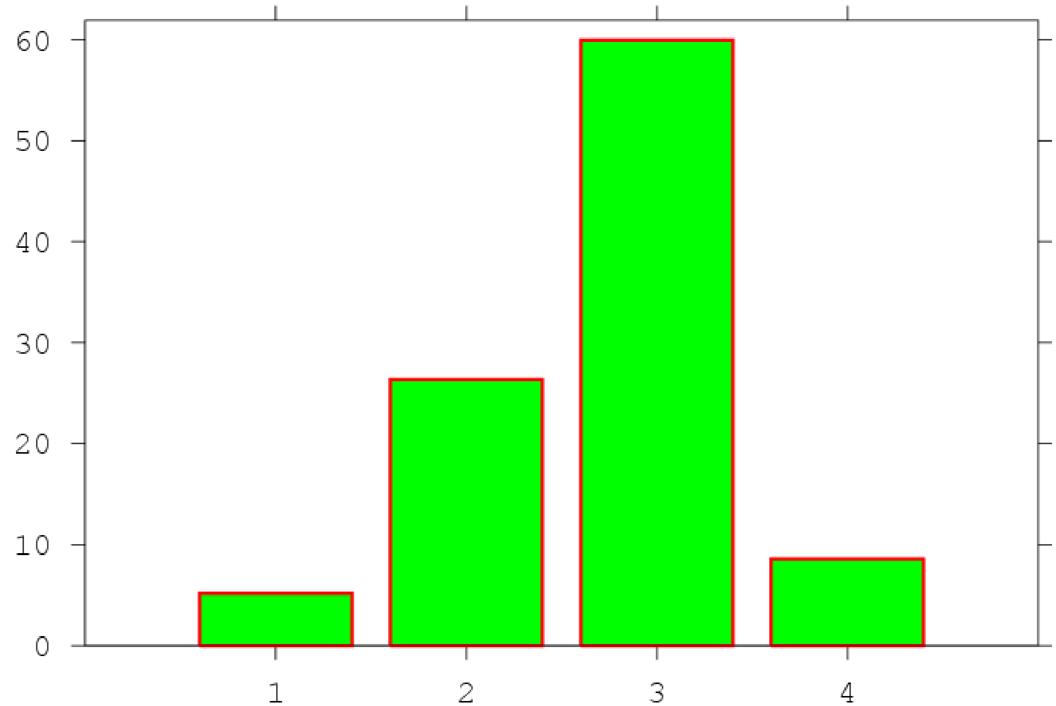


Figure 11: Distribution of the dominant TRI classes within the windows.

Under construction, lot of work to do...

- More detailed statistics and different DEM resolutions
- How to interpret the results
- Other spatial analysis indeces
- Comparison of SAR statistics and the topographic properties