GEODAR Data Repository of Snow Avalanches from Vallée de la Sionne:

Seasons 2010/11, 2011/12, 2012/13 & 2014/15

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This data repository contains radar data from 77 snow avalanches recorded using the GEODAR (GEOphysical flow dynamics using pulsed Doppler radAR) system at the Swiss full-scale avalanche testsite Vallée de la Sionne. GEODAR is a purpose built, advanced phased-array FMCW system. The data contain range-time plots of intensities gained from moving target identification (MTI) processing. This document covers details about the different versions of the radar setup and raw data processing steps as well as a description of the repository content.

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1 GEODAR versions

From winter season 2010/11 to 2017/18 there have been five different versions of GEODAR. The avalanche data of the first three system are presented here. This document describes these three systems (Tab. 1) and the raw data processing. Details of the other two versions and a more in-depth discussion of the data processing are contained in the Ph.D. thesis of Anselm Köhler, 2018, Durham University. For information about the general radar design refer to the Ph.D. thesis of Matthew Ash, 2013, University College London.

The transmit chain was similar for all three versions. The transmit antenna had an opening angle of 30°, which illuminated approximately the full avalanche release area and track until the valley floor. The maximum transmit power of 15 W ensured that even avalanches starting at nearly 3 km distance are imaged. The chirp bandwidth was kept maximal with as total sweep frequency of 200 MHz, giving a range resolution or a rangebin size of 0.75 m. This frequency sweep of variable duration was imposed on a baseband of 5.3 GHz, which equates to the radar wavelength and approximately the minimum size of detectable reflectors of 57 mm.

1.1 GEODAR I

GEODAR I was operating from November 2010 to April 2012. The transmitted waveform consisted of 3 chirp pairs of up and down chirps with different duration. The durations were 0.001, 0.002, 0.005 seconds with short breaks (zero amplitude) in between the chirps to prevent signal leakage between them. There was no phase lock between the signal generator and the data acquisition nor any marker signal when the chirp sequence started, which results in a weak phase stability. The chirp extraction from the raw data is done with correlation of the amplitude window against the received signal. Due to the long duration of the full chirp chain (0.02 seconds inclusive breaks), the pulse repetition rate was only 50 Hz. The sampling rate of the signal generator was 400 MHz, thus only twice as the bandwidth.

1.2 GEODAR II

GEODAR II was operating from November 2012 to April 2013. All high frequency cables on the receiving side were exchanged to low loss cables, giving higher signal-to-noise ratio compared to the previous system. The waveform was not changed from the years before, so still 3 chirp pairs with 0.001, 0.002, 0.005

GEODAR system	I	II	III
Measuring season	2010/11 – 2011/12	2012/13	2013/14 – 2014/15
Chirp sequence	2x[1, 2, 5] ms	2x[1, 2, 5] ms	2x[4] ms
Pulse repetition	50 Hz	50 Hz	111 Hz
Phase-lock	no	yes	yes
Marker signal	no	no	yes
Recoding time	3 min	9 min	9 min

Table 1: Overview of GEODAR system specifications for version I, II and III.

seconds duration. The signal generator and the data acquisition system were phase-locked but no marker signal was used. If the start of one chip sequence is found with correlation, the other chirps are then extracted by translating the chirp sequence window by its length. Again the chirp repetition rate was 50 Hz. The sampling rate of the signal generator was increased to 600 MHz. The recording time was increased to 9 minutes with a larger hard drive.

1.3 GEODAR III

GEODAR III was operating from November 2013 until Mai 2015. The signal generator was setup to transmit a marker signal indicating the beginning of the chirp sequence, thus the chirp extraction is much easier and results in a stable phase. The chirp sequence was reduce to only one set of up and down chirp with a duration of 0.004 seconds, thus the chirp repetition rate could be increased to 111 Hz, which increases the MTI resolution since the flow changes between two chirps are higher sampled.

2 Data processing

The data processing leads from the recording of the time–domain chirp signal to the MTI images. This *moving target identification* (MTI) is a filtering step which cancels the static background and emphasizes the avalanche signal. The chirp extraction and the frequency estimation (fast-time processing) are rather standard FMCW processing step, but the MTI step (slow-time processing) is crucial to obtain best results in visualizing the avalanche flow. A great advantage of GEODAR is that most of the data processing is done offline with digital signal processing. Thus advances in the processing methods can be directly tested with various avalanche recordings and applied to older data sets. During the last years, many different MTI filters have employed making it complicated to compare the results. However, the MTI processing steps used to produce this repository is outlined in the following sub-sections.

This document focus on the MTI processing including filtering, normalization and averaging as part of the slow-time processing. The fast-time processing steps of the raw data is described in *Ash et al.* (2014a) and in the PhD thesis of *Ash* (2013) and *Köhler* (2018).

2.1 MTI filtering

Two different filters are mainly used in the last years. The first is called DIFF and is simply the difference (or absolute change) between two consecutive chirps. The other is called FIR and uses 150 chirps, giving a much smoother background signal. The choice of MTI filter depend on the application: DIFF is fast, FIR is slower but give clearer results. Each filter can be characterized by its frequency response and the normalized cut-off frequency f_c, which is approximately related to a spatial frequency of features with size d and velocity v, $f_c \approx d/v$.

The DIFF filter was employed in the early work on the GEODAR data published by *Vriend et al.* (2013) and *Ash et al.* (2011a). The filter is simply the difference between two adjacent pulses, the filter coefficients are $[1, -1]$. The normalized cut-off frequency at the -3 dB point lies at $f_c = 0.5$. This short filter

($n = 2$) has a very gentle frequency attenuation towards the low (signal drift) and static signals (background). This filter is affected highly by electric noise and processing artefacts (chirp extraction).

Köhler et al. (2016) started to use a finite impulse response filter (FIR) with length $n = 150$ and a normalized cut-off frequency $f_c = 0.12$. The filter properties were chosen manually to return the optically clearest MTI result. The filter coefficients are generated by the function `fir2.m` in the OCTAVE signal processing toolbox. This filter has a much sharper frequency response and the unwanted frequency (low frequency and static components) are attenuated stronger. Here, this FIR filter is applied to the dataset.

2.2 MTI normalization

Because of radar signal intensity decreases with increasing range by a factor of R^3, an analog filter is build into the receiver system to compensate for this geometrical attenuation prior to the analog-digital converter to use the full dynamic range. But this filter chain compensates only approximately the geometric attenuation, so the MTI intensities need normalization.

Vriend et al. (2013) and *Ash et al.* (2011a) converted the MTI intensities into dB referenced to the maximum MTI value. Depending on the displayed frame (for example only high ranges or background at close range) the normalization factor (the maximum) varies. Furthermore, this maximum value is mostly found in the deposition zone at close ranges and therefore these MTI intensities are held high, whereas the intensities higher up are attenuated. However, for small span of ranges the resulting normalized MTI shows already an exceptional fine degree of different structures.

Köhler et al. (2016) normalize the MTI of each range gate to its mean value over time. While this procedure equalizes the avalanche signal over larger range extend, the normalization factor still lacks to be a scale-invariant value as the measurement duration plays a crucial role. Especially, if the avalanche duration is large compared to the measurement duration (large wet flow avalanche), the mean value as the normalization factor is biased by the avalanche signal to higher values and results in unnecessary lower MTI values. However, if the avalanche duration is small (often true for dry flows), the normalization factor comes close to the MTI background noise level. Other sources of noise, e.g. from moving tress at ranges below 800 m or electronic noise, are suppressed so that the background looks uniform but horizontal streaks inside the avalanche may evolve. If one is interested only in the leading edge or internal surge position, this procedure gives good results even over a large span of range.

However, in here and the corresponding publication *Köhler et al.* (2018), we perform a similar normalization, but instead of normalizing to the mean intensity of each range (which include the avalanche), we normalize to the mean of the pure static background signal. This is found by calculating the normalization values from false trigger events when nothing is moving in the field of view. The normalization scheme is the same for each individual system, but differs between them. This normalization scheme allows to directly compare the MTI intensities between the different avalanches.

2.3 MTI averaging

Since all GEODAR versions acquire the moving avalanche with 8 channels (or antennae) simultaneously, the normalized MTI intensities can be averaged across the channels to increase signal to noise ration.

If this would be done with the complex MTI values and including proper phase calibration of each channel, the averaging becomes equal to the process of electronic beam steering, and thus could be used to suppress or enhance features at different lateral position by the principle of destructive interference. Here, we average the normalized and absolute MTI intensities over all channel. Afterwards, the MTI intensities are converted into decibels by taking $20 \cdot \log_{10}$ of the average MTI. Normally all 8 channels are averaged, but in some occasions single channels have been excluded. This is occasionally due to some antennas have been subjected to stronger noise or weaker signal caused by snow covering. Which channels have been averaged is indicated in the title of the preview PDF image.

3 Repository format and content

The data are stored in HDF5 format (`https://www.hdfgroup.org/hdf5/`), which is open (BSD-style license) and thus can be read with a various of programs like R, Python, Matlab/Octave even bash.

See in subsection 3.2 for examples to read the repository content.

3.1 Repository Content

For each avalanche, the data are stored in a separate sub-folder named after the GEODAR timestamp in the format `yyyy-mm-dd-HH-MM-SS`. This folder contains five files. The five files are the MTI-data, a preview image, a trajectory, the Thalweg and an info-file.

The MTI-data are the processed radar data as numerical array and a .pdf-file serves as preview. A trajectory in range and time of the runout-defining flow feature (mostly front, but sometime a major surge) is stored in the trajectory file. And the thalweg gives the path of steepest descent from the release area as 1D profile. We encourage the user to extract further trajectories of flow features (manually or even automatically), which then can be matched on the given thalweg for terrain registration. The info-file contains all the settings and parameters which have been used to process the raw data into the MTI data.

MTI data

filename	`GEODAR-<timestamp>-MTI.h5`
`/mti`	Radar MTI data array in size $[t, r]$. The MTI is averaged over channels stated below.
`/r`	radar range, corrected for the cable-length.
`/t`	time
`/nm`	GEODAR timestamp of dataset
`/slf_nr`	SLF internal number for reference with other measurements

`/commit_hash`	Processing code version as GIT identification

MTI preview

filename	`GEODAR-<timestamp>-MTI.pdf`
`color scale`	between background at 0 in yellow and 35 in red
`blue line`	Trajectory `001` in range and time

Trajectory

filename	`GEODAR-<timestamp>-TRAJ-#nr.h5` with `#nr` running number for further trajectories
`/T`	radar time of picked and smoothed trajectory [s]
`/R`	radar range of picked and smoothed trajectory [m]
`/S`	arc length of picked and smoothed trajectory [m] (measured from along thalweg `#nr`)
`/V`	velocity of trajectory projected onto thalweg [m/s]
`/Theta`	slope angle along thalweg [degrees]
`/thalweg`	`#nr` of corresponding thalweg file

Thalweg

filename	`GEODAR-<timestamp>-THALWEG-#nr.h5` with `#nr` running number for other thalwegs
`/X`	easting [m] of path in CH03/LV03 (SRID 21781)
`/Y`	northing [m] of path in CH03/LV03 (SRID 21781)
`/Z`	elevation ([m] a.s.l.) of path in CH03/LV03 (SRID 21781)
`/R`	Radar range of path points [m]
`/Theta`	slope angle of path [degrees]

Metadata and processing info

filename	`GEODAR-<timestamp>-info.mat`, MATLAB `.mat`-file containing a struct
`nm`	GEODAR time stamp and identification of dataset
`slf_nr`	SLF internal number as reference to other measurements
`channels`	Array numbers `#nr` from antenna averaged in MTI
`mti_pp_#nr/*`	MTI processing info for each used antenna `#nr`
`raw_process/*`	Raw processing info for the dataset
`commit_hash`	Processing code version as GIT identification
`process_date`	Processing date

3.2 Preview

A good preview tool for HDF5 format is supplied by the HDF Group as command-line tools[1] and a Java based viewer[2]. Some useful short example commands for these bash tools are given below:

Display the content of the `<H5-File>`:

```
h5dump -n <H5-File> | grep -v /#
```

Dump a dataset `<dataset>` (e.g. `'/nm'`) from `<H5-File>` to text-file `<txt-File>`:

```
h5dump -d <dataset> -o <txt-File> <H5-File>
```

Furthermore, a Python script and a MATLAB script are added to the root of the data repository and give an example of how to read and display the MTI data from the HDF5 files.

Python script to plot MTI image (run from bash):

```
geodar_read.py GEODAR-<dataset>-MTI.h5
```

Matlab script to plot MTI image:

```
geodar_read(GEODAR-<dataset>-MTI.h5)
```

4 Data usage policy

All the data is released open access, but we encourage to get in contact with the Authors in case you use the data from the repository (GEODAR mailing list `geodar@slf.ch`). This will help to interpret the data on a common understanding. Please make sure to cite also the corresponding publication in case you use data:

> Köhler, A., J. N. McElwaine, and B. Sovilla (2018), GEODAR Data and the Flow Regimes of Snow Avalanches, *J. Geophys. Res.*, doi: 10.1002/2017JF004375

This paper is about the GEODAR signature of snow avalanches, and should be taken as reference together with the data. The publication gives an overview on how the data can be read.

The data repository should be cited as well, please make sure to include the note for shared first-author ship:

> McElwaine*, J. N., A. Köhler*, B. Sovilla, M. Ash, and P. V. Brennan (2017), GEODAR data of snow avalanches at Vallée de la Sionne: Seasons 2010/11, 2011/12, 2012/13 & 2014/15 [Data set], Zenodo, doi: 10.5281/zenodo.1042108, *equally contributing authors

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[1] `https://support.hdfgroup.org/HDF5/release/obtain5.html`
or ubuntu: `sudo apt-get install hdf5-tools`

[2] `https://www.hdfgroup.org/downloads/hdfview/`
or ubuntu: `sudo apt-get install hdfview`

5 GEODAR bibliography

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