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14. Remote Sensing of the Spheres +
15. High alpine remote sensing

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WSL

14. Remote Sensing of the Spheres + 15. High alpine remote sensing

Convenors 14: Stefan Wunderle, Mathias Kneubühler, Dominik Brunner, Alain Geiger +
Convenors 15: Yves Bühler, Christian Ginzler

Swiss Commission for Remote Sensing
Swiss Geodetic Commission

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14.1

Monitoring glacial, periglacial and landslide surface motion with Sentinel-1 over the Swiss Alps every 6 days.

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A large number of slopes in the Swiss Alps is in a state with active continuous movement. Different process types such as flow, glide, creep or slide can be identified. Using satellite based radar interferometry data, up to now more than 2000 active zones with movement rates ranging from several mm up to few meters per year could be identified. Most of the observed slope movements with velocities higher than 2-4 m/year are rock glaciers. A second common type is the process of slow moving continuous landslides. For both process types, there are strong needs to determine the current state by means of extension and surface velocity. Slope movement processes are seen as hazardous processes that can pose significant risk to life or result in damage to infrastructures. In addition, changes in rockglacier motion are believed to be the most indicative short- to medium-term response of rockglaciers to environmental changes and thus an indicator of mountain permafrost conditions in general. Different actively sensing SAR satellites are currently observing the earth surface and offer the possibility to quantify slope deformation by means of SAR interferometry (InSAR). The European Sentinel-1 mission became operational by the end of 2014 with the launch of the C-band satellite Sentinel-1A. In the meantime, the mission was extended with Sentinel-1B. Over the Swiss Alps Sentinel-1A/B acquisitions have been operationally acquired every 6 days since the beginning of 2017. Since interferometric radar observations are highly sensitive to changes in the state of the surface (e.g. decorrelation of the signal caused by vegetation and snow cover) and the absolute line-of-sight deformation in between two acquisitions, Sentinel-1A/B offers an unprecedented monitoring capability by means of a combination of spatial coverage, temporal resolution, data quality, timeliness of the data-availability and the open data philosophy. The short revisit time of 6 days dramatically reduces phase noise effects and decorrelation caused by slope movements drastically exceeding the wavelength of the system. An example of decorrelation of a fast rock-glacier after 12 days is given in Figure 1. The 6-day repeat cycle on the other hand still permits determining the LOS-velocity of the rock-glacier.

With the Sentinel-1 swath width of 250 km, the entire Swiss territory can be covered with two and three acquisitions in either ascending orbits (ENE-looking) or descending orbits (WNW-looking). In each of these 5 geometries the interferometric repeat cycle is 6 days. Data is available for download usually in less than 24 hours after acquisition, offering the possibility for relatively quick data availability after the satellite pass.

We are currently processing data at national level on supervised automated basis in near-real time. Since data handling with large datasets is difficult and time consuming, there is a strong need of down-scaling the processing to the local scale (e.g. watershed or mountainside) or even object scale (e.g. single landslide). With the use of an inventory of pre-existing slope movement objects, that was created by the interpretation of InSAR data, the automated data processing can be continued and refined for local area of interests. The inventory contains the spatial extent of the instability and a nearby coherent stable reference point for automated data-processing, including treatment of atmospheric disturbances to increase the quality of the observations.

We present numerous examples of current active slope instabilities over the Swiss Alps, including glacier and rock-glacier flow and continuous land- and rockslides. We will show to what level the 6-day acquisition cycle enhances the applicability of the technique even at times with frozen snow cover in the area of interest. Finally, we present the architecture and prerequisites necessary for an object based automated processing workflow.

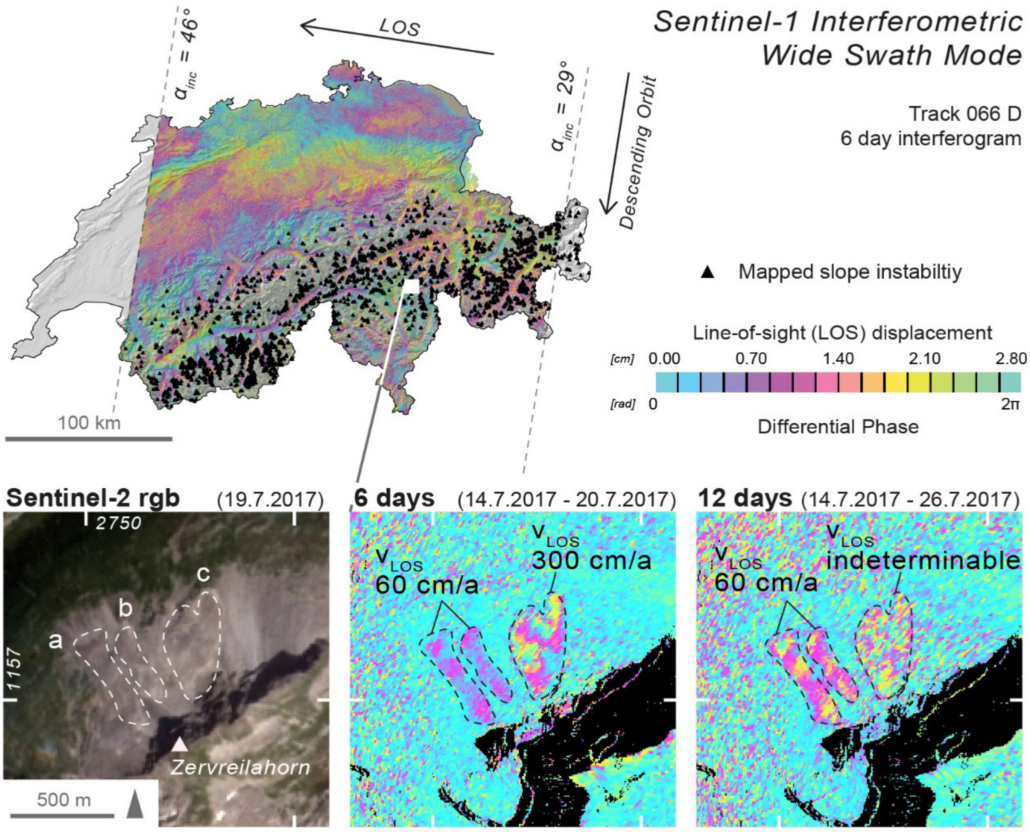

Figure 1. Full Sentinel-1 swath over Switzerland. The details of rockglaciers on the toe of the Zervreilahorn/GR demonstrate the value of 6 day repeat cycles: While in 6 days, the LOS-velocity (v_{LOS}) of area c) can be estimated as ~3 m/year, the same rate cannot be determined due to decorrelation after 12 days. Areas a) and b) are still coherent and v_{LOS} can be determined as ~60 cm/year. (S1 and S2 data source: Copernicus Sentinel data 2017)

14.2

Webcam-based snow cover monitoring in the Swiss Alps: methods and evaluation

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Hundreds of publicly available outdoor webcams are located in the Swiss Alps. Most of these webcams are provided by mountain railway operators, restaurants, hotels, and private citizens and are located at elevations ranging from 800m to 3600m a.s.l.. Its images offer the possibility to observe snow cover variability on a high spatio-temporal resolution. Derived snow cover maps could not only serve as a reference for improved validation of satellite-based approaches but also offer unique potential for complementing satellite-derived snow retrieval in steep alpine terrain and under cloudy conditions. Our procedure allows to almost automatically derive snow cover maps from webcam images by using an estimate of the webcams position and a high-resolution digital elevation model (DEM). Mountain silhouettes are used to register the webcam images with the DEM and therewith to automatically resolve webcam parameters such as camera orientation, principal point, and field of view. Combined with automatic snow classification and image alignment using SIFT features, our procedure can be applied to arbitrary webcam images to generate snow cover maps with a minimum of effort. We discuss the assets and drawbacks of our procedure and evaluate the mapping accuracy using ground control points. Furthermore, we compare our webcam-based snow cover maps to the Sentinel-2 snow cover product provided by the Theia land data services centre and show some possible applications of a webcam-based snow cover dataset.

14.3

Atmospheric CO_2 simulations to study the capability of future imaging CO_2 satellites to observe emissions from cities and power plants

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Under the Paris climate agreement, the signatory countries have set ambitious goals to reduce CO_2 emissions and limit global warming to below 2°C. The ability to implement long-term policies and manage them effectively will require consistent, reliable, and timely information on CO_2 emissions [1]. The majority of these emissions are concentrated on a tiny fraction of the globe, notably on cities and power plants. Cities, for example, have been estimated to contribute roughly two thirds of global anthropogenic CO_2 emissions [2]. A growing number of cities therefore acknowledges both the responsibility for, and the vulnerability to, climate change as indicated by several international initiatives of city governments [3,4]. Cities often take more aggressive mitigation measures to reduce CO_2 emissions compared to the country average, but are lacking reliable means to monitor the success of their policies. The European Space Agency (ESA) and the European Commission are therefore proposing a constellation of CO_2 satellites to support the quantification of anthropogenic and natural CO_2 fluxes and to assist greenhouse gas mitigation policies at the national, city and facility level. The satellites are envisioned as an essential component of a CO_2 observation system to be established under Europe's Earth observation programme Copernicus.

Previous studies have demonstrated that an imaging CO_2 satellite with sufficient precision will have the potential to quantify emissions from strong point sources such as cities and power plants during single overpasses [5].
Here, we present the results of a high-resolution model simulation study conducted on behalf of ESA, which aims to investigate the capabilities of such a CO_2 satellite mission, to analyze the benefit of auxiliary measurements of anthropogenic tracers such as NO_2 and CO, and to specify the requirements in terms of observation strategy and measurement accuracy. For this purpose, we have set up a highly optimized version of the COSMO numerical weather prediction model [6] extended for the simulation of CO_2, CO and NO_x for a domain centered over the city of Berlin and covering a large number of power plants in Germany and neighbouring countries. The simulations were conducted at a horizontal resolution of 1 km x 1 km and sampled along the tracks of a future satellite mission expected to have a pixel size of up to 2 km x 2 km and a swath width of approximately 250 km. Different levels of unstructured and structured noise were applied to the simulated satellite observations in order to investigate the capability of observing the CO_2 plumes of Berlin and individual large power plants. In addition, several different scenarios for auxiliary measurements of NO_2 and CO on either the same or a different satellite platform (with different overpass time) were tested for their ability to support the detection of the plumes and the quantification of the CO_2 emissions.

The results emphasize the need for both high measurement precision and high observation frequency, because the detectability of the plumes is highly dependent on the meteorological situation and clouds frequently obscure the view.

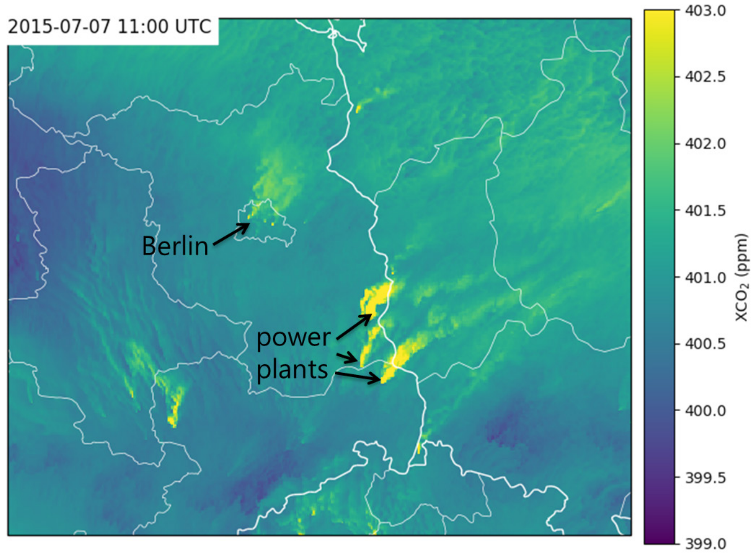

Figure 1: Column averaged dry air mixing ratios of CO_2 simulated for 7 July 2015, 11 UTC highlighting the plumes of the city of Berlin and several power plants.

REFERENCES

[1] Ciais, P., Crisp, D., Gon, H. v. d., Engelen, R., Heimann, M., Janssens-Maenhout, G., Rayner, P., and Scholze, M.: Towards a European Operational Observing System to Monitor Fossil CO2 emissions - Final Report from the expert group. European Commission, Copernicus Climate Change Service, 2015.

[2] UN-HABITAT, Cities and Climate Change: Global Report on Human Settlements, 2011. Global Report on Human Settlements. 2011: Earthscan. 300.

[3] http://www.c40.org

[4] http://www.covenantofmayors.eu

[5] Bovensmann, H., et al., A remote sensing technique for global monitoring of power plant CO2 emissions from space and related applications. Atmos. Meas. Tech., 2010. 3(4): p. 781-811.

[6] Fuhrer, O., Osuna, C., Lapillonne, X., Gysi, T., Cumming, B., Bianco, M., Arteaga, A., & Schulthess, T.: Towards a performance portable, architecture agnostic implementation strategy for weather and climate models. Supercomputing frontiers and innovations, 1(1), 5-62, doi:10.14529/jsfi140103, 2014.

14.4

The impacts of human activities and environmental variables on grassland canopy traits on the Qinghai-Tibetan Plateau

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In order to understand an ecosystem's response to global change, the relationships between plant traits, environmental variables and human factors need to be identified. This understanding is of particular importance for the Qinghai-Tibetan Plateau, where the ecosystem is highly sensitive to global changes. In this study, we analyze the impacts human activities (grazing intensity, roads and residential areas) and environmental variables (climatic variables, elevation and soil properties) on the spatial distribution of three selected canopy traits: (1) chlorophyll content, (2) specific leaf area and (3) leaf dry matter content on the Qinghai-Tibetan Plateau. We derive canopy traits based on empirical models that combine satellite data and field measurements. We perform a Multiple Linear Regression of the predicted canopy traits against the selected explanatory variables based on their relative importance. Our preliminary results indicate that precipitation, soil PH, altitude and soil nitrogen availability could explain 67% of the spatial variation in canopy traits. Canopy chlorophyll content and specific leaf area decrease towards roads and residential areas within 2 kilometers distance, indicating that human activities impact those canopy traits within certain surroundings. Such findings are important to better understand the impact of human activities and climate change on ecosystem degradation in the Qinghai-Tibetan Plateau.

14.5

Remote sensing of rock fall events in high alpine environments

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Remote sensing is referred to as the capability of retrieving information of an object without physical contact. This definition is generally used to describe methodologies leveraging active and/or passive electromagnetic radiations, and relying on space borne, airborne, and/or terrestrial sensors (optical, multispectral, LiDAR, radar, etc.). However, seismic sensors may fall also into the broader definition of remote sensing, as they are capable of detecting and accurately measure the ground shacking caused by events located hundreds of kilometers away, such as earthquakes and other mass wasting phenomena (rockslides, rock falls, debris flows, avalanches).

Several authors have recently shown how the analysis of seismic signals generated from rock falls can be very useful to investigate their physical properties (Manconi et al., 2016 and reference therein). The goal of this study is to test how low-cost seismic sensors can be used to identify and monitor rock fall activity in alpine environments, when the use of classical remote sensing methods might be hindered because of logistic problems and/or severe weather conditions. Our area of study is a large instability adjacent to the Great Aletsch glacier in the Swiss Alps, i.e. the Moosfluh slope, which is undergoing an acceleration phase since the late summer 2016. During the acceleration phases, rock fall activity also increases. Due to the limited access to the site, rock falls are identified and investigated by analyzing the data acquired with a local seismic network composed of 3 Raspberry Shake (RS) seismometers (see figure 1). RS are a low-cost, all-in-one plug-and-go solution developed by OSOP S.A., which integrate vertical velocity sensor (4.5 Hz Racotech RGI-20DX), digitizer, and micro-computer in a single box (100x120x50 mm, 0.35 kg). Installation of the RS was achieved by beginning of July 2017, when we expected to start recording a further increase of rock fall activity. Seismic data are currently collected and analyzed to identify and locate rock fall phenomena. Moreover, a webcam was installed on the opposite side of the Moosfluh slope, acquiring images every 10 minutes to map the surface deformation and to validate the occurrence of slope failure events.

Our preliminary results show that the data acquired from RS sensors allow to well discriminate between local events (i.e., rockfall phenomena) and distant events (mainly regional earthquakes and teleseisms). In particular, we show a number of examples where seismic data can be the only viable approach to retrieve information on rock fall activity in an alpine environement .

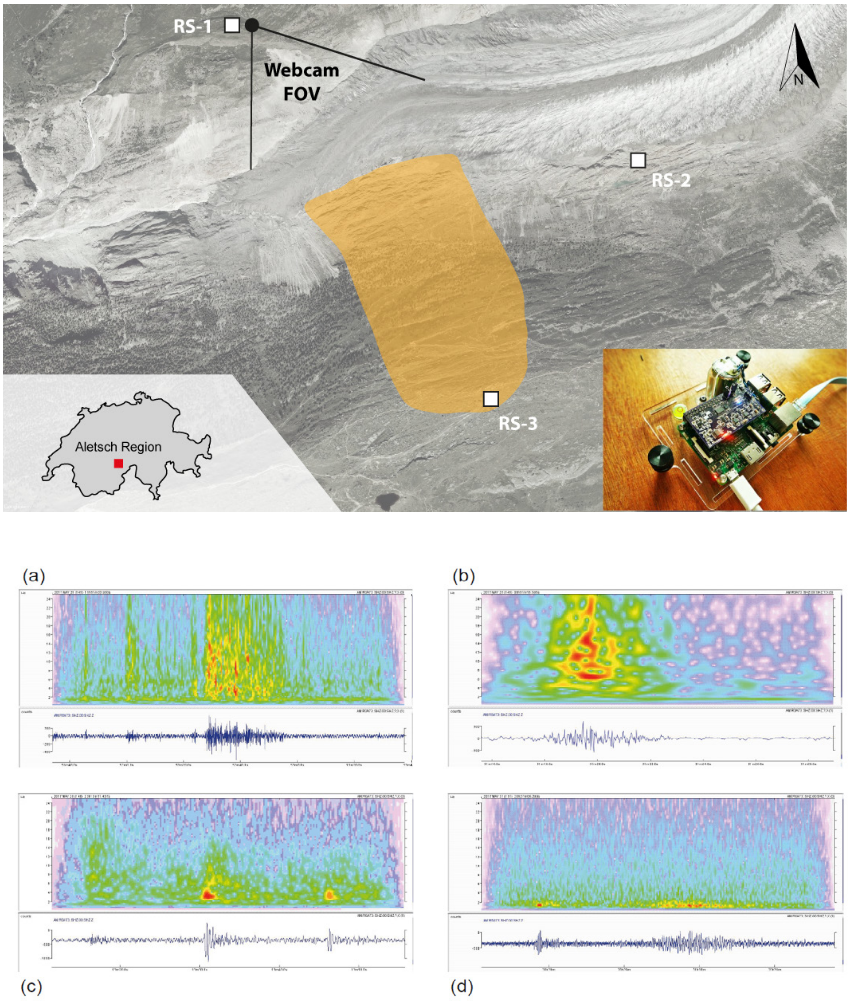

Figure 1. (top panel) Overview of the area of investigation, the Moosfluh rock slope instability, in the Aletsch region (Swiss Alps). White squares indicate the position of the Raspberry Shake sensors (RS 1-3, see picture in the inset on the bottom right, www.raspberryshake.org). (bottom panel) Examples of seismic signals measured by the RS sensors. (a) seismic signal recorded by the raspberry shake, but not visible changes are recognized in the optical imagery; (b) rockfall activity confirmed by the optical imagery; (c) Seismic signal associated to a Magnitude ML= 2 earthquake occurred in Montreaux, Switzerland, (about 80 km distance) on 29/05/2017; (d) Seismic signal associated to a Magnitude Mw= 4.5 earthquake occurred in Poland (about 800 km distance) on 31/05/2017.

REFERENCES

Manconi, A., Picozzi, M., Coviello, V., De Santis, F., Elia, L., 2016: Real-time detection, location, and characterization of rockslides using broadband regional seismic networks. Geophys. Res. Lett. 43, 2016GL069572. doi:10.1002/2016GL069572.

14.6

Mapping snow depth distribution in forested terrain using Unmanned Aerial Vehicles and Structure-from-Motion

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In forested areas, snow distribution is strongly affected by the spatial layout of canopy elements and thus exhibits strong spatial heterogeneity compared to adjacent open sites. Given the wide extent of forested areas that feature seasonal snow cover, forest snow dynamics strongly impact on the hydrological cycle from the local to the global scale. Measurement of snow depths in forests is currently limited to in-situ measurements, which are time-intensive and have limited spatial coverage, or airborne LiDAR acquisition, which is expensive and may deteriorate in denser forests. Limited knowledge of the snow distribution has hampered our abilities to accurately quantify forest snow water resources.

We present the application of unmanned aerial vehicles in combination with structure-from-motion (SfM) methods to map snow depth distribution in forests.
Two separate flights were carried out 10 days apart across a heterogeneous forested area of 900x500m. Corresponding snow depth maps were computed by subtracting DTM data from the surface elevation model derived by SfM. Manual measurements collected following each flight were used to validate the snow maps. In semi-closed forest, small-scale spatial variability of snow depth typical to forested areas was well visible. Differential snow depth maps revealed distinct spatial patterns in local ablation rates particularly around exposed trees. While these findings are promising, resolving snow depths below trees or in very narrow gaps remains challenging.

This new application of SfM demonstrates an efficient method which could be extended to more frequent observations of the forest snow cover, surveys with wider areal coverage, or in unaccessible terrain. It constitutes an encouraging tool to explore snow patterns in forests and enhance our understanding of spatial variability of snow accumulation and depletion rates; And it could contribute to improving estimates of hydrological resources stored in the forest snow pack if coupled to in-situ measurements of snow water equivalent.

14.7

Remote Monitoring of Glaciers and Landslides Using Interferometric Radar and High-Resolution Cameras

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Monitoring surface deformations is a common challenge when assessing natural hazards in the high alpine environment like glacier- or rock-instabilities or landslides. Different technologies are available and the selection depends on multiple requirements, among them:

- Which measurement precision is necessary?
- Are absolute deformation values necessary or is the relative deformation sufficient?
- Is a monitoring based on single points sufficient, or should it be area-wide?
- Are one, two or three-dimensional measurements required?
- Are measurements needed during times of bad weather or at night (data availibility)?

A large part of the glacierized northwest face of Weissmies in the Saas Valley (Switzerland) recently became unstable. The likely causes of this instability are climate-induced glacier thinning of the supporting Triftgletscher and a progressive warming from freezing to melting temperatures at the ice-bed interface.

Starting in October 2014, a ground-based interferometric radar system was installed on the roof of the cable-car station Hohsaas at 3’142 m.a.s.l. Until April 2017, the radar permanently scanned the face and surface velocities with high precision and availability could be obtained. Several small size ice falls (< 20’000 m3) could be predicted in advance with a few days warning time. In February 2017, we additionally installed a high-resolution camera with 42 megapixels to monitor this area. Every day, an image processing algorithm automatically determined the surface deformations based on a correlation analysis. The goal was to provide a more cost-effective monitoring solution. Both instruments were operated simultaneously during three months.

We compared the deformations obtained with both systems. While the radar data allows a prediction of small ice falls even during no visibility conditions (bad weather), the camera only provides data during the day and good visibility conditions. The image processing technique is sensitive to deformations of a few centimeters between two acquisitions. It relies on the existence of persistent optical surface features that vary with for example snow fall events. For the Weissmies monitoring during the summer months, the camera performance turned out to be a sufficient and cost-effective monitoring solution.

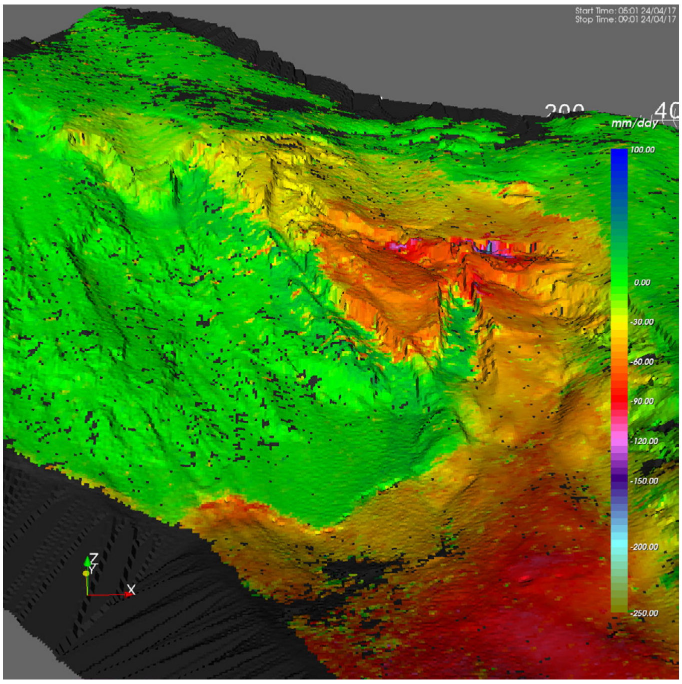

Figure 1. Surface deformations measured by the interferometric radar (line-of-sight). Units are mm per day.

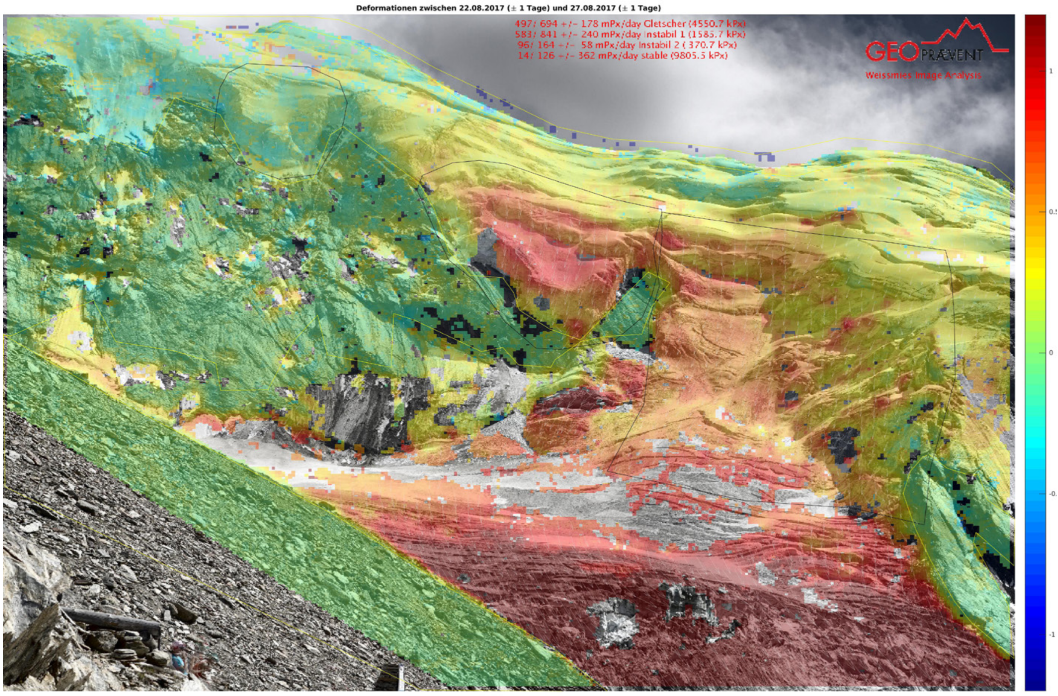

Figure 2. Surface deformations measured by the high-resolution camera (cross line-of-sight). Units are pixels per day.

REFERENCES

Lorenz Meier, Mylène Jacquemart, Bernhard Blattmann, Sam Wyssen, Bernhard Arnold, Martin Funk 2016: Radar-based Warning and Alarm Systems for Alpine Mass Movements. Conference Proceedings INTERPRAEVENT 2016

14.8

GRACE satellite gravimetry to assess global hydrology and ice melt

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The satellites of the GRACE and the upcoming GRACE Follow-On missions are dedicated to observing the Earth's gravity field and its temporal variations. These variations are related to global mass transport caused by the water cycle, polar and mountain ice mass loss, changes in ocean surface currents and sea level rise.

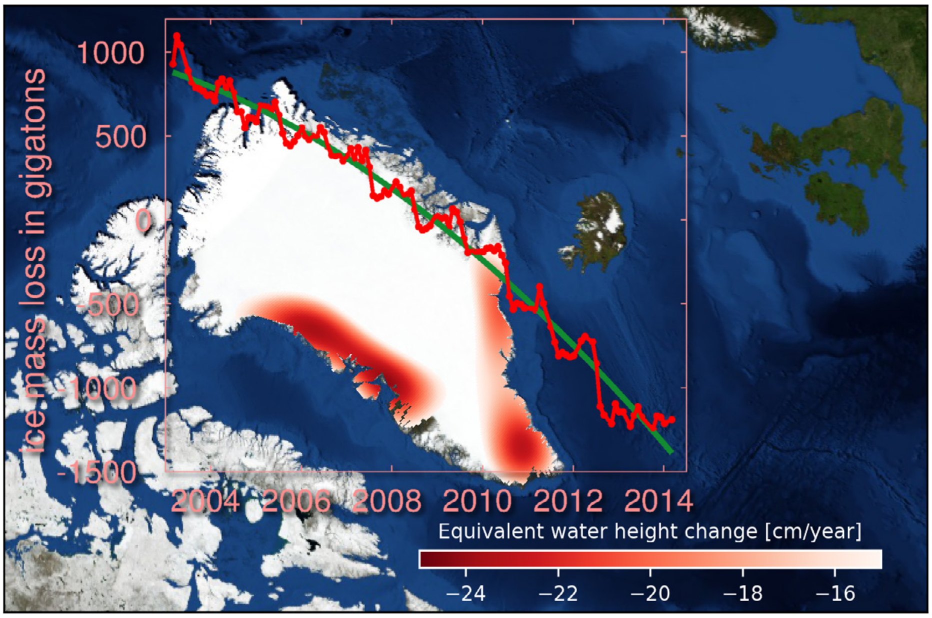

Figure 1. Mass loss (red) at the coasts of Greenland indicates ice melt associated with climate change. It amounts to 200 billion tons per year.

AIUB is leading the Horizon 2020 EGSIEM project, a European initiative to provide the best satellite derived gravity field models with a short latency for applications in Earth and environmental sciences to demonstrate their value for flood and drought monitoring services. In the frame of EGSIEM three services are beeing installed: 1) a scientific combination service, 2) a near real-time / regional service and 3) a hydrological / early warning service.

We here focus on the scientific combination service, where monthly gravity field models of different analysis centers (AC) are combined. All ACs perform independent analyses but apply consistent standards. A combination thus enhances the quality, robustness, and reliability of the monthly gravity models. The products are combined on normal equation level to correctly take into account all correlations between model parameters and the orbit parameters of the GRACE satellites. The resulting combined monthly gravity models are provided in spherical harmonic representation as well as user-friendly global grids of equivalent water hight, pre-filtered and tailored to the needs of hydrological or oceanographic applications.

The EGSIEM scientific combination service is in transition to become COST-G, a combination center under the umbrella of the International Gravity Field Service (IGFS) of the International Association of Geodesy (IAG). It is envisaged to provide a consistently reprocessed and combined time series of monthly gravity fields spanning the entire GRACE mission and, in the future, also its successor, GRACE Follow-On.

REFERENCES

Meyer, U., Jäggi, A. & Beutler, G. 2012: Monthly gravity field solutions based on GRACE observations generated with the Celestial Mechanics Approach, Earth and Planetary Science Letters, 345, 72-80.

Meyer, U., Jäggi, A., Jean, Y. & Beutler, G. 2016: AIUB-RL02: an improved time-series of monthly gravity fields from GRACE data, Geophysical Journal International, 205, 218-233.

Jean, Y., Meyer, U. & Jäggi, A. 2017: Combination of GRACE monthly gravity field solutions from different processing strategies, submitted to Journal of Geodesy.

14.9

Recent glacier changes in western Greenland and glacier mapping challenges in mountain topography

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The region to the NW of Jacobshavn Isbrae (e.g. Disko Island, Nuussuaq and Svartenhuk Peninsula) in western central Greenland is hosting >1000 glaciers and ice caps that receive comparably little attention. A previous study presented a glacier inventory for 2001 derived from Landsat ETM+ scenes and area changes since their assumed LIA maximum extent as mapped from trim-lines (Citterio et al. 2009). The region is well known for its high number of surge-type glaciers of which the largest one (Kuannersuit) had a massive surge in 1995/96 with a frontal advance of more than 10 km (Yde and Knudsen 2005). This has to be considered when interpreting length, area or volume changes in climatic terms. With the now available image data from 1985 (Landsat TM and the new orthomap) and 2015/16 (Landsat 8 OLI and Sentinel 2 MSI) it is possible to study recent glacier fluctuations in detail. Additionally, high-quality DEMs from 1985 (aerodem) and around 2012 (ArcticDEM, TanDEM-X) that are now available allow calculation of volume changes over a multi-decadal time period.

In this study we present the new glacier inventory for 2016 derived from three Landsat OLI scenes, a comparsion of the available DEMs (incl. GDEM and GIMP) and elevation changes since 1985, and how spatial resolution and time of image acquisition impacts on the visibility of glacier extents in steep mountain topography casting deep shadows in early autumn. Glaciers were automatically mapped with the band ratio method from three Landsat OLI scenes with a subsequent manual correction for misclassified debris cover, rock glaciers, water, shadow, seasonal snow, sea ice and icebergs. Hill-shades and subtraction of the DEMs (after co-registartion) revealed data voids, interpolation artefacts and outliers that restricted the analysis of elevation changes to selected glaciers. We used the new TanDEM-X DEM to derive new drainage divides and topographic attributes for all glaciers.

A first analysis reveals a general glacier retreat and down-wasting with several local exceptions. In particular on Disko Island glaciers have advanced or surged after 1985, requiring to remove them from the statistical analysis. A strong area decrease is observed for ice caps at higher elevations whereas volume loss (or gain) is strongest for glaciers that have surged. A general trend of increasingly higher snow lines at the end of the ablation period can be observed from 1985 to 2016. Despite recent conditions of mass loss, some small glaciers (<5 km^2) on Disko Island have started advancing or even surging after 2012.

REFERENCES

Citterio, M., Paul, F., Ahlstrøm, A.P., Jepsen, H.F. & Weidick, A. 2009: Remote sensing of glacier change in West Greenland: accounting for the occurrence of surge-type glaciers. Annals of Glaciology, 50 (53), 70-80.

Yde, J.C. & Knudsen, N.T. 2005: Glaciological features in the initial quiescent phase of Kuannersuit Glacier, Greenland. Geografiska Annaler, 87A, 473-485.

14.10

The GEO-GNOME Mountain Explorer - visualizing and comparing commonly applied mountain definitions

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Mountain ecosystems are globally distributed environments that provide significant societal benefits, yet their ability to provide goods and services to both highland and lowland residents is threatened by changes in climate and land use, environmental pollution, large-scale political and socio-economic transformations, unsustainable management of natural resources and serious gaps in the understanding of mountain systems.

Improving our understanding of mountain regions and sharpenening our future ability to identify context-specific opportunities for sustainable development requires an accurate definition of the world’s mountains. How to define mountains has been a topic of controversy for many years, and various definitions using different benchmarks have been proposed for different contexts of use (e.g., biogeographical research versus hydrology or climatology). To date, the three most commonly applied mountain definitions are those of Kapos et al. (2000), Körner et al. (2011), and Karagulle et al. (2017). The definition by Kapos constrains mountains to parameters that combine elevation and ruggedness. The definition by Körner and colleagues, used for the first inventory of the world’s mountains for biogeographic applications (Körner et al. 2017), constrains mountains by ruggedness only, irrespective of elevation. This appears to be the most meaninfgul approach from the biodiversity and biogeography perspective. In the work by Karagulle et al. (2017), mountains are one of the many different ecological land units (ELUs) identified while developing a high-resolution and data-derived global ecosystem map. These diverse means for the characterisation and representation of mountains result in fundamental differences in statistics for attributes such as land area size and population, most notably. For example, the approach of Kapos et al. arrives at twice the global mountain area and much higher human population numbers than the one by Körner et al. (Körner et al. 2017). These differences profoundly impact research results and the conclusions drawn on the state and prospects of mountain socio-ecological systems, ultimately affecting decisions on policy and investment.

To support the mountain research and policy community with the layers of information required for a pertinent choice of mountain definition, the Group on Earth Observations Initiative – Global Network for Observations and Information in Mountain Environments (GEO-GNOME) has initiated the creation of a web-based application for the visualization and comparision of existing mountain definitions. The Global Mountain Explorer (GME), developed by the U.S. Geological Survey (USGS), in partnership with Esri, the Center for Development and Environment of the University of Bern (CDE), the Global Mountain Biodiversity Assessment (GMBA), and the Mountain Research Initiative (MRI) allows for visualization and query of all definitions either separately or in pairwise comparisons. The resources are accessible as either mountains only, or as mountain classes (Kapos et al., Karagulle et al.) and bioclimatic belts (Körner et al.). Pan, zoom, and query functionality are included, and a query anywhere on the map returns the binary values for all three definitions in a pop-up query results box.

The GME is the first of a series of initiatives led by GEO-GNOME to address the paucity of observations of- and information on mountains, improve our understanding of mountain regions and sharpen our future ability to provide policy and investment relevant advice, and to create a capacity to combine data and information to meet emerging, often as-yet unarticulated policy needs.

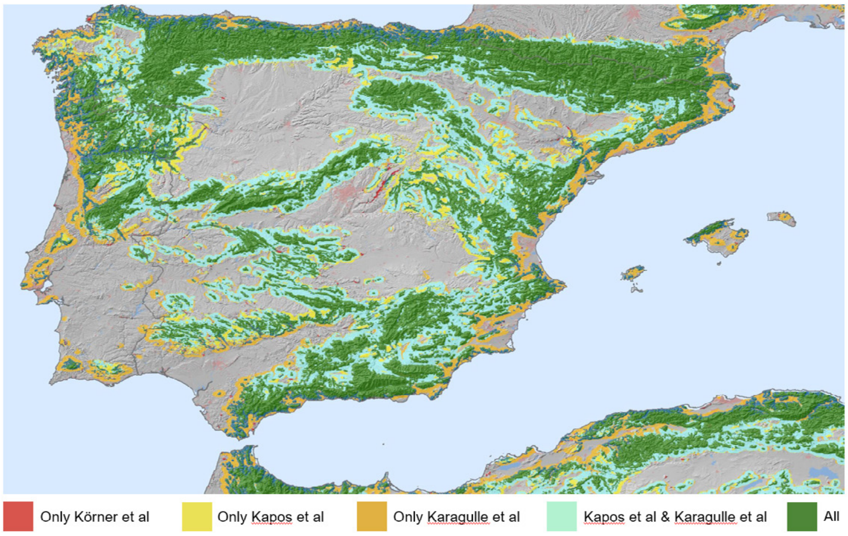

Figure 1. Overlaps and divergences between the three mountain definitions

REFERENCES

Kapos, V., Rhind, J., Edwards, M., Price, M.F. & Ravilious, C. 2000: Developing a map of the world's mountain forests. In: Price MF, Butt N (eds) Forests in sustainable mountain development: a report for 2000. CAB International, Wallingford, pp 4–9.

Körner, C., Paulsen, J. & Spehn, E.M. 2011: A definition of mountains and their bioclimatic belts for global comparisons of biodiversity data. Alpine Botany 121, 73-78.

Körner, C., Jetz, W., Paulsen, J., Payne, D., Rudmann-Maurer, K. & Sephn, E.M. 2017: A global inventory of the worlds mountains for bio-geographic applications. Alpine Botany, 127, 1-15.

Karagulle, D., Frye, C., Sayre, R., Breyer, S., Aniello, P., Vaughan, R. & Wright, D. 2017. Modeling global Hammond landform regions from 250-m elevation data. Transactions in GIS.

14.11

Seasonal dynamics and spatial patterns of the cover management factor for Swiss grassland

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According to the revised soil erosion equation (RUSLE), soil erosion is controlled by the factors rainfall erosivity R, soil erodibility K, cover management C, slope length and steepness LS, and support practices P. The C-factor represents the effect of cropping and management practices on erosion rates by water (Renard et al. 1997) and is the factor most easily to alter by a change of management and therefore a parameter of high relevance for soil erosion control. Furthermore, it has the highest amplitude of variation among all the RUSLE factors (Zhang et al. 2011). The C-factor of grassland is rather controlled by surface cover then by grassland type and crop rotation like it is common for agricultural land. To derive a Swiss national C-factor map of grassland, we used remote sensing techniques to map fractional vegetation cover (FCV) which enabled both, an assessment of the spatial and temporal variability.

The orthophoto Swissimage FCIR with a high spatial resolution of 0.25 m and the satellite derived product FCover300m with a high temporal resolution (10-day) were used for fractional vegetation cover mapping.
Swissimage FCIR was undergone a linear spectral unmixing (LSU) to estimate the fractional abundance of green vegetation and bedrock/soils with a very high spatial resolution. The FCover300m datasets were averaged over three years to a time-series of 36 mean long-term fractions of green vegetation. The resulting temporal FVC is used for normalizing the spatial results to the day of the year 181 (30th of June) since tiles of Swissimage FCIR were recorded at different periods of the year. The normalized abundances of vegetation are transformed to C-factors according to USDA (1977).

The spatio-temporal maps of the C-factor of Swiss grassland (Fig. 1) show distinct dynamics with very high C-factors in alpine areas in the winter and decreasing values from spring according to increasing vegetation coverage to a maximum soil cover in July/August. Spatially, the alpine grassland indicates a temporal delay in decreasing C-factors in summer with a shorter period of low C-factors (high vegetation cover) in elevated alpine grasslands. In combination with the spatio-temporal dynamics of the Swiss R-factor (Schmidt et al. 2016), the months June and September are the most erosion prone regions with high rainfall erosivity and low vegetation cover (high C-factor) in the alpine grasslands. Lowland grasslands have a higher FCV earlier in the summer season which better protects soils at times of high rainfall erosivity.

A combination of the monthly factors R and C enables a dynamic soil erosion risk assessment which simultaneously allows the identification of susceptible seasons and regions. Based on the results, agronomists can introduce selective erosion control measures for erosion prone regions and seasons and thereby reduce the direct costs of erosion and mitigation measures.

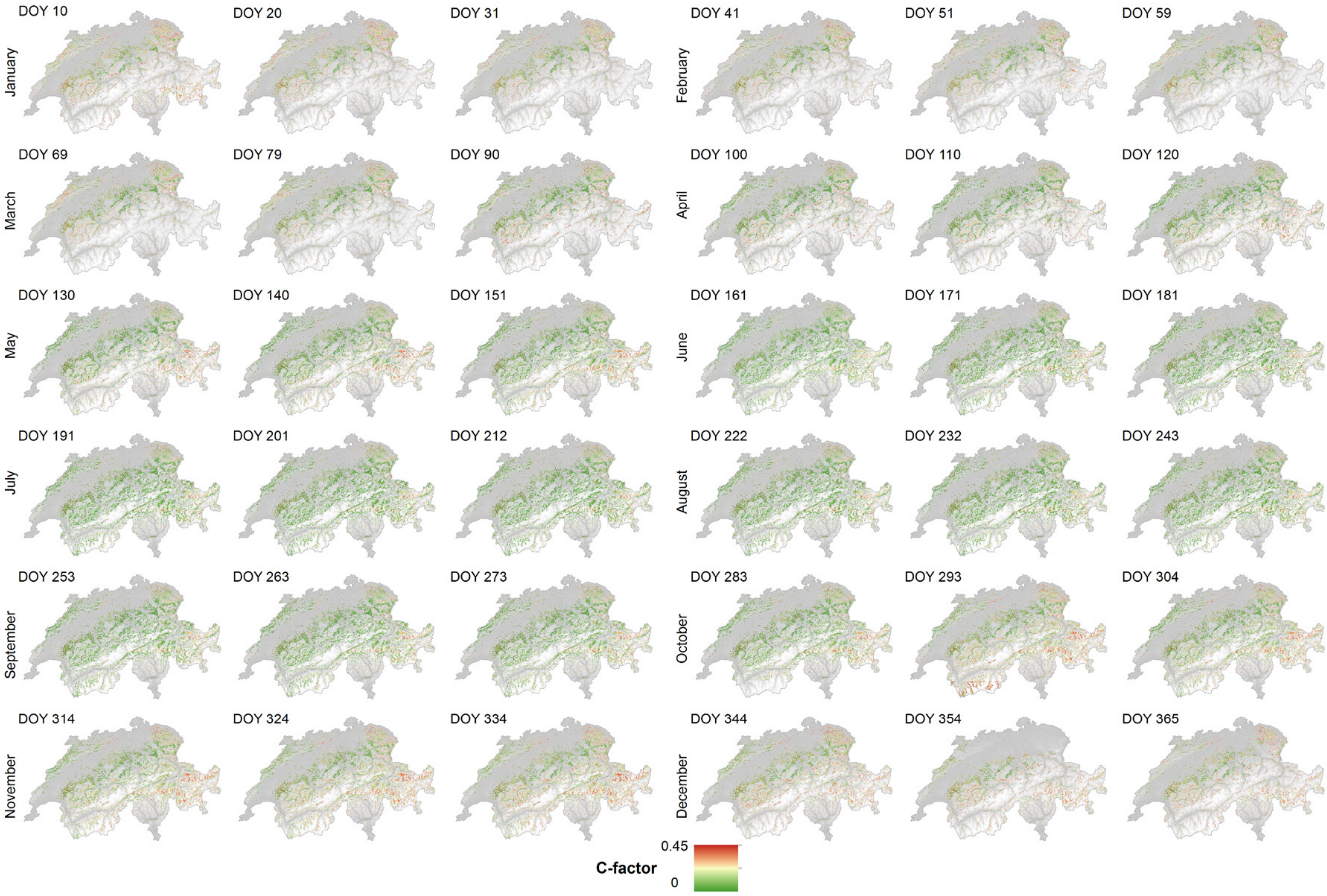

Figure 1. Spatio-temporal dynamics of the C-factor on Swiss grasslands (DOY day of the year; spatial resolution 100 m)

REFERENCES

Renard, K. G.; Foster, G.; Weesies, G.; McCool, D. K.; Yoder, D. C. 1997: Prediction Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). Agriculture Handbook (703).

Schmidt, S.; Alewell, C.; Panagos, P.; Meusburger, K. 2016: Regionalization of monthly rainfall erosivity patterns in Switzerland. Hydrol. Earth Syst. Sci. 20 (10), 4359–4373.

USDA US Department of Agriculture S.C.S. 1977: Procedure for computing sheet and rill erosion on project areas. Technical Release (51).

Zhang, W.; Zhang, Z.; Liu, F.; Qiao, Z.; Hu, S. 2011: Estimation of the USLE cover and management factor C using satellite remote sensing. A review. 19th International Conference on Geoinformatics. Shanghai, China, 24.06.-26.06.2011, 1–5.

14.12

Inventory and state of activity of rockglaciers and periglacial slope instabilities from satellite SAR interferometry (InSAR)

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Past investigations conducted in the Swiss Alps demonstrated that the visual analysis of satellite differential Synthetic Aperture Radar (SAR) interferograms can be employed for the estimation of the surface deformation rates of rockglaciers and other periglacial slope instabilities (Strozzi et al., 2004; Barboux et al., 2014; Barboux et al., 2015). Within the GlobPermafrost project funded by the European Space Agency (ESA) we are building up a worldwide long-term monitoring network of active rockglacier motion investigated using remote sensing techniques. Five sites in the European Alps, the Brooks Range of Alaska, the Andes in South America and the Tien Shan and Karakoram regions in the Himalaya Range are analysed through a uniform set of data and methods. Our analysis is divided in two major steps. InSAR data are first considered as a base for an inventory of periglacial slope instabilities, including rock glaciers. Deformation rates are expressed using different classes (e.g. 0-2 cm/a, 2-10 cm/a, 10-50 cm/a, 50-100 cm/a, > 100 cm/a). Classification of the process types and validation of the spatial extent is done using optical imagery. In a second step, matching of repeat optical data and SAR interferometry are considered to quantify the rate of surface movement and the relative changes over time of a few significant active rockglaciers. Changes in rockglacier motion are indeed believed to be the most indicative short- to medium-term response of rockglaciers to environmental changes and thus an indicator of mountain permafrost conditions in general.

In this contribution, we focus on the potential of recent high spatial and temporal resolution SAR data for the analysis of periglacial processes in mountain environments with special attention to the Arolla Valley (Valais), an area which we are actively studying since many years using SAR interferometry along with other in-situ and remote sensing methods. Our area of interest encompasses active rockglaciers with deformation rates ranging typically between 0.1 and 2.0 m/yr, a recently destabilized (or "surging") rockglacier with rate of motion above 5.0 m/yr, and many other much more slowly moving landforms in which permafrost is likely to occur. We first applied InSAR with the high-resolution satellite radar data (spatial resolution on the order of 20 m) of the ERS-1/2 SAR and JERS-1 sensors during the 1990's with acquisition time intervals from 1 day to several years to compile a first inventory of slope movements. Results from this inventory were then considered in the set-up of in-situ monitoring sites, showing increased velocity of rock glaciers in recent years. In recent years, new SAR sensors, advanced processing techniques, and very-high resolution Digital Elevation Models (DEM) to more accurately compensate for the topography related phase have become available recently. Very-high resolution SAR data with spatial resolution on the order of 3 m from the TerraSAR-X and Cosmo-SkyMed missions were for instance considered to better spatially characterize the rate of movement of the inventoried landforms. In addition, nowadays the Sentinel-1 mission represents the newest approach to SAR mission design with acquisitions regularly available over nearly all mountainous areas worldwide every 6 to 24 days allowing to better characterize changes of surface motion over time (Caduff et al., 2017). Apart from SAR interferograms, more sophisticated processing approaches, like Persistent Scatterer Interferometry (PSI), Short Baseline Interferometry (SBAS) or Offset-Tracking (OT) (Strozzi et al., 2002; Barboux et al., 2015), are used to quantitatively detect points moving with velocities below a few cm/yr, below several dm/yr and more than 1 m/yr, respectively, with different levels of accuracy and resolution. Finally, besides satellite sensors, a terrestrial radar instrument was used to complement satellite SAR data in time and space (Werner et al., 2012), allowing the measurement of additional displacement vectors and velocity classes. Recent InSAR data processed with up-to-date technologies are considered to update the inventory of slope movements and to quantify over time the rate of motion of the most active rockglaciers.

REFERENCES

Barboux C., Delaloye R. & Lambiel, C., Inventorying Slope Movements in an Alpine Environment Using Dinsar, Earth Surface Processes and Landforms, 39(15): 2087-2099, 2014.
Barboux C., Strozzi T. Delaloye R., Wegmüller U. & Collet C., Mapping slope movements in Alpine environments using TerraSAR-X interferometric methods, Journal of Photogrammetry and Remote Sensing, 109: 178-192, 2015.
Caduff R., Strozzi T., Wiesmann A. & Wegmüller U., Monitoring glacial, periglacial and landslide surface motion with Sentinel-1 for the entire Swiss Alps every 6 days. 15th Swiss Geoscience Meeting, Davos, 2017.
Strozzi T., Luckman A., Murray T., Wegmüller U. & Werner C., Glacier motion estimation using SAR offset-tracking procedures, IEEE Transactions on Geoscience and Remote Sensing, 40(11): 2384-2391, 2002.
Strozzi T., Kääb A. & Frauenfelder R., Detecting and quantifying mountain permafrost creep from in situ inventory, space-borne radar interferometry and airborne digital photogrammetry, Int. J. Remote Sensing, 25(15): 2919-2931, 2004.
Werner C., Wiesmann A., Strozzi T., Kos A. & Wegmüller U., The GPRI Multi-mode Differential Interferometric Radar for Ground-based Observations, Proceedings of EUSAR 2012, Nuremberg, Germany, 24-26 April 2012.

14.13

UAV-photogrammetry for rock glacier monitoring: Examples from the Swiss Alps

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The use of Unmanned Aerial Vehicles (UAV) and digital optical cameras for aerial surveying has become a standard practice in the fields of geoscience. Images acquired by UAV platforms are usually employed for generating high-density point clouds, Digital Elevation Models (DEMs) and high-resolution orthorectified images of different landforms. This study focuses on the applications of UAV surveys and Structure-for-Motion (SfM) photogrammetric methods for rock glaciers research. Rock glaciers constitute a significant component of the cryosphere in many mountain regions, where favourable geomorphological and climatic factors allow their development. Rock glacier movement represents the manifestation of creeping mountain permafrost, which has received considerable attention about their current velocity changes in the European Alps. Given the rapid change and hazardous terrain of our study areas, the potential to carry out detailed field observations is demanding and troublesome. To overcome this, we have been employing different UAV configurations to monitor permafrost creep and their environs. We provide the first results after 2-years of UAV surveys from “fast” and “slow” rock glaciers in the Valais Alps. High-resolution images in combination with image classification algorithmic permitted to derive superficial boulder sizes; surface displacement vectors and to improve morphological parameters such as slope and aspect.

14.14

High-resolution troposphere models based on numerical weather prediction and Global Navigation Satellite Systems data

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The microwave signal propagating through the atmosphere is delayed due to the free electron content in the ionosphere and due to the air molecules and the water vapor in the troposphere. The tropospheric delay can be expressed in terms of zenith tropospheric delay (ZTD) or total refractivity depending on the meteorological parameters: air pressure, temperature and humidity (water vapor).

The application of external high-resolution troposphere models in Global Navigation Satellite Systems (GNSS) processing, especially in the Precise Point Positioning (PPP) technique has been proven to enhance the coordinates' accuracy and to shorten the convergence time of the position solution (e.g. Wilgan et al., 2017). The tropospheric models can also be applied to other techniques, where the microwave signal is delayed in the atmosphere, such as space-borne Synthetic Aperture Radar interferometry (InSAR). One of the limitations of InSAR technique are atmospheric effects, especially due to the different values of water vapor during two acquisitions.

In this study, we have reconstructed the total refractivity profiles and ZTD values for Switzerland with main focus on the Valais region. The tropospheric parameters are obtained by the least-squares collocation method using the in-house developed software package COMEDIE (Collocation of Meteorological Data for Interpretation and Estimation of Tropospheric Pathdelays). The troposphere models are based on different combinations of data sources, including GNSS data and numerical weather prediction model COSMO-1 with high spatial resolution of 1.1 km x 1.1 km.

The GNSS-based ZTD model shows the highest agreement with the reference data, with an average bias close to zero and standard deviations of 4 mm. The ZTD models based on COSMO-1 exhibit worse, but still acceptable accuracies, with average biases also close to zero and standard deviations of about 9 mm. Figure 1 shows the average biases and standard deviations for the particular stations in the Valais region. In case of the total refractivity, the profiles reconstructed from COSMO-1 model show the best agreement with the reference radiosonde data in Payerne, with the average bias of 1 ppm and mean standard deviations of 2.6 ppm averaged from the whole profile.

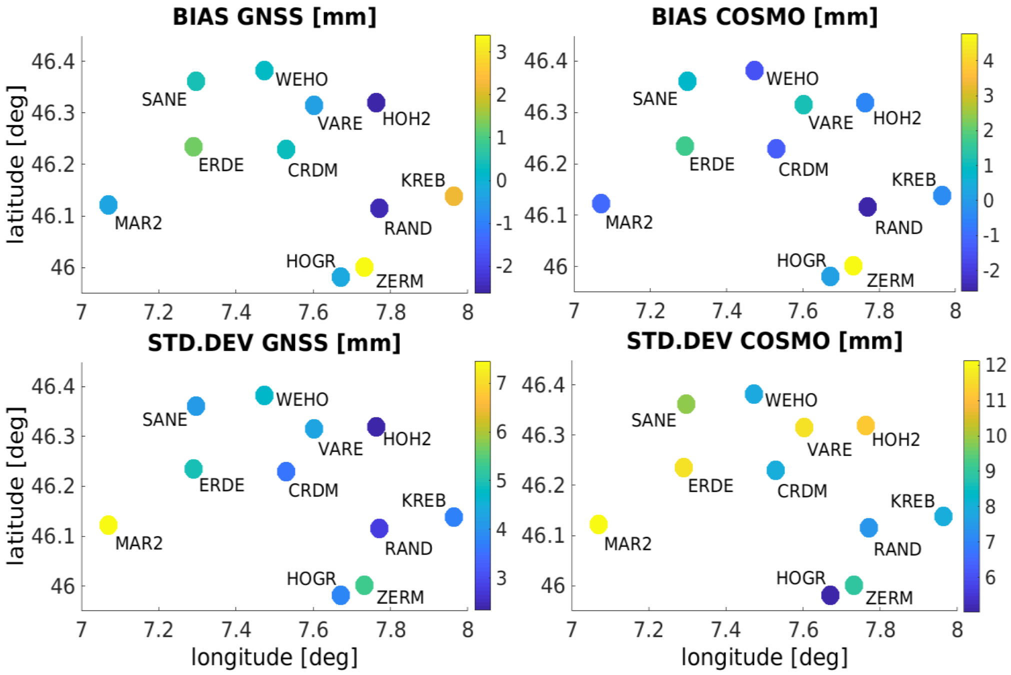

Figure 1. Average biases and standard deviations of residuals ZTD_{ref}-ZTD_{model}, where 'model' is either based on GNSS or COSMO data, 'ref' is a reference GNSS solution for particular station for which the model is calculated; this station is always excluded from building the model. Data is averaged over a period 1.08.-30.09.2016.

REFERENCES

Wilgan, K., Hadas, T., Hordyniec, P., & Bosy, J. 2017: Real-time precise point positioning augmented with high-resolution numerical weather prediction model, GPS Solutions, 21(3), 1341–1353

14.15

Influence of meteorological factors on the autumn land surface phenology in alpine grasslands

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Meteorological conditions impact the autumn phenology of alpine grasslands in various ways. However, in comparison to spring phenology our knowledge about the characteristic and magnitude of these effects is still limited and needs further investigation.

We examined the relationships between a number of meteorological factors and phenology in the alpine grasslands of the Swiss Alps using satellite-derived and gridded metrics for the period of 2003–2014. We tested the correlation of interannual differences (Δ) in the timing of the end of season (EOS) with meteorological factors (monthly maximum, mean and minimum temperatures, monthly mean relative sunshine duration and mean precipitation) across elevations (from 1000 up to 3000 meters above sea level (m a.s.l.)) and for four climatic subregions of the Alps.

We found a significant ($p < 0.05$) positive correlation between ΔEOS and interannual differences in autumn temperature (with mean R>0.69) for 31.9% of all pixels. ΔEOS showed the strongest correlation with interannual differences of minimum autumn temperature, except for the eastern Swiss Alps where precipitation showed the strongest relationship with ΔEOS. The areas sensitive to the investigated meteorological metrics were more pronounced in northern and eastern regions and at elevations below 2000 m a.s.l. across the Swiss Alps.

We conclude that a positive linear relationship exists between autumn temperature and autumn phenology of grasslands at elevations below 2000 m a.s.l. in our study area. Besides, autumn precipitation has a slightly higher impact than autumn relative sunshine duration on autumn phenology. Warmer autumn temperatures delay the end of the growing season, thus may indicate easing of growth constraints in alpine grasslands. This may suggest that alpine grassland ecosystems are therefore particularly sensitive to future climate warming scenarios.

P 14.1

UAV-based thermal remote sensing to highlight groundwater inputs in rivers

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Measuring lateral temperature fluctuations can give precious indications on river-groundwater exchanges. However, riverstream temperatures in-situ measurements are challenging to carry out and hardly representative due to the typical heterogeinity in rivers temperatures. Remote sensing methods can provide spatially continuous measurements of the surface of a river and show some of the complexity of its thermal rate. Using UAVs (drones) allows for frequent and inexpensive acquisitions covering a relatively large zone in a limited time (Handcock et al, 2012)

When interpreting such thermal data, it is critical to account for environmental conditions. For example, remotely sensed data are only representative of the stream surface, thus only the water contrasts reaching the surface are visible. Also, in high energy, turbulent rivers, temperatures are uniformized and can be supposed similar at any depth of the water column. Aerial points of views and time of day, such as before sunrise, and at nadir, allow minimizing the influence of day surface warming, reflexions and shadows (Dugdale, 2016). To determine optimal conditions, different data acquisitions settings have been tested, and some influences of hydrological and atmospheric conditions for remote sensed temperatures by UAV have been determined. The use of existing instruments and sofwares has allowed to concentrate the analysis on data acquisition conditions, comparisons to in-situ measurements, image interpretations and the identification of artefacts.

The drone used is a fixed wing Sensefly eBee equiped with ThermoMap and Multispec4 sensors. Two study sites have been monitored: the Avançon de Nant river in Vallon de Nant (VD), with acquisitions of about 1.3 km^2 and the Emme river in Aeschau (BE), with 0.5 km^2 acquisitions. The first site is a natural catchement, with multiple arms and clear groundwater inputs mainly detectable during low melt-water discharge. On the second site, multiple local hot spots have been detected in winter (fig. 1), which partially match cold spots identified in summer, indicating exfiltration zones. Along-stream temperature gradients could indicate zones of more intense groundwater inputs, giving clues of diffuse discharge.

In addition to the thermal band, multispectral datasets (R, G, NIR, R-edge) have been acquired to discriminate water bodies from other surfaces. These additional bands also allow assessing the artefacts in the TIR band and their potential origins (trees, angle, image correlation problems). Flight planning has showed that a unique water stream 2.5 km long and ~20 m wide can be mapped in under 1h at a 0.2 m resolution in the TIR band. Flight planning requires to cover enough non water surfaces (>65%) and high overlap between images (80-90%), however trees and high objects have a negative impact on the mosaicking results. Raw images can be useful to assess individual zones, that allows limiting artifacts resulting from the difficulty of performing image correlation on thermal images.

It was found that the optimal environnemental conditions for thermal UAV-based river monitoring are:
- low water discharge which maximize thermal gradients,
- no rainfall, during and and the day(s) before the flights,
- a stable discharge level and minimal TIR radiation variations during acquisition.

Two main scales of gradients have been analysed: (1) local hotspots reprensenting concentrated inputs of GW and (2) temperature variation along the stream, potentially indicating zones of infiltration and exfiltration. In conclusion, it can be said that thermal maps can contribute to a better understanding of the surface/subsurface water exchanges, and that recent advances in UAVs allow studying a large number of sites with high regularity.

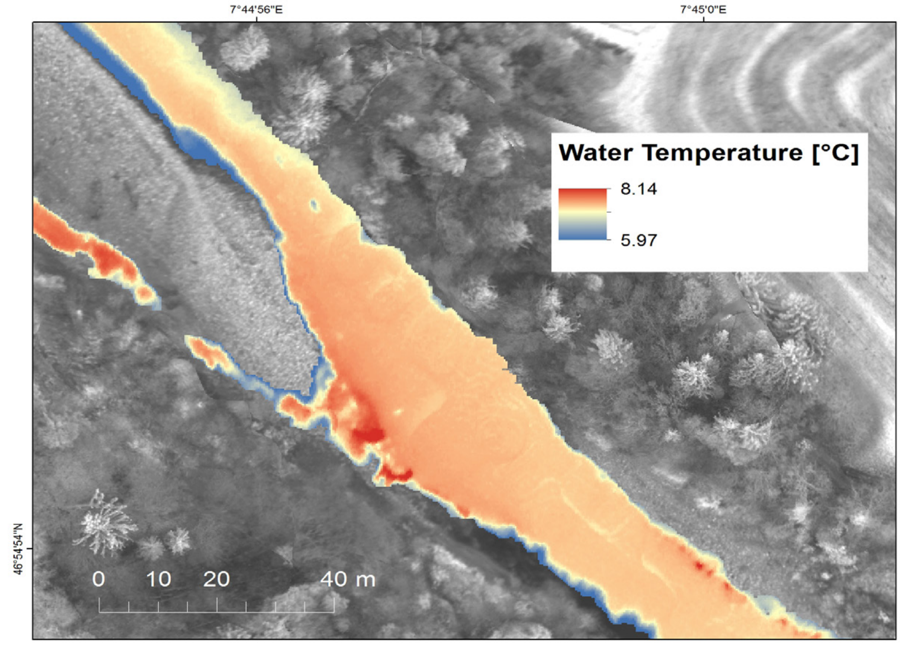

Figure 1 Water temperature on the 15.11.2016 on the Emme river, near Aeschau. Background: red-edge band.

REFERENCES

Dugdale, S. 2016. A practitioner's guide to thermal infrared remote sensing of rivers and streams: Recent advances, precautions and considerations. WIREs Water. 3, 251–268.

Handcock, R., Torgersen, C., Cherkauer, K., Gillespie, A., Tockner, K.,Faux, R., Tan, J. 2012. Thermal Infrared Remote Sensing of Water Temperature in Riverine Landscapes. In: Carbonneau PE, Piégay H, eds. Fluvial Remote Sensing for Science and Management. Chichester: Wiley-Blackwell; 2012, 85–113.

P 14.2

High alpine remote sensing test site Davos: validating remote sensing technology in complex terrain

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Satellite and airborne remote sensing has proven its value for a wide range of scientifically and socially relevant applications over many years now. However most sensors and data processing algorithms are developed and tested in relatively flat and wide regions. About 20% of the earth surface consists of rugged terrain such as mountains and hills, of which a big part is covered by seasonal or permanent snow and ice. These components of the cryosphere form temporary water storage and – during the summer – provide a crucial source of water for the human population. There is a lack of research on the performance of remote sensing technology over mountainous terrain, as it is particularly difficult to get sound reference datasets.

To close this gap, we are currently developing a well-documented alpine test site in Davos, Graubünden, Switzerland. It is part of the Global Cryosphere Watch (GCW) Cryonet site Weissfluhjoch-Davos and further encompasses the Dischma Valley catchment that is part of the International Network for Alpine Research Catchment Hydrology (INARCH). This high alpine region (elevation range 1400 – 3200 m a.s.l.) is home to the WSL Institute for Snow and Avalanche Research SLF and houses many different long-term observations. SLF operates 10 active automated weather stations measuring snow and weather data, as well as several manned stations for snow observations on the ground, one of them having continuous records for more than 80 years (Marty and Meister, 2012). Measurements include specific observational fields at Weissfluhjoch (2650 m a.s.l.) and Laret (1500 m a.s.l.), where a large variety of snow parameters are recorded. The focus of the intensive observation area (IOA) Laret is on ground-based microwave measurements accompanied by the acquisition of in-situ data relevant to foster the understanding of interactions between microwaves and snow-covered grounds.

Research at this site is conducted in close collaboration with the European Space Agency (ESA) and industry partners (GAMMA) and aims at the development of novel retrieval schemes and their validation. Ground based measurements are complemented by measurement campaigns with airborne remote sensing instruments (UAS and airplanes) to regularly map the distribution of alpine snow depth at high spatial resolution over entire catchments (Bühler et al. 2015, Grünewald et al. 2014) and at selected sites (Bühler et al. 2016). These measurements are already changing paradigms of hydrological modeling in Alpine catchments and lead to improved understanding of snow precipitation (Vögeli et al., 2016). Furthermore, many different ground based measurements performed for different projects at SLF are available. This collection of alpine datasets as well as the good accessibility of the alpine terrain and the availability of skilled field personnel through SLF provides unique opportunities to develop and validate remote sensing technology specifically for high alpine terrain. We aim at consolidating this test site by starting optical, microwave and LiDAR remote sensing validation projects financed by different national and international funding sources.

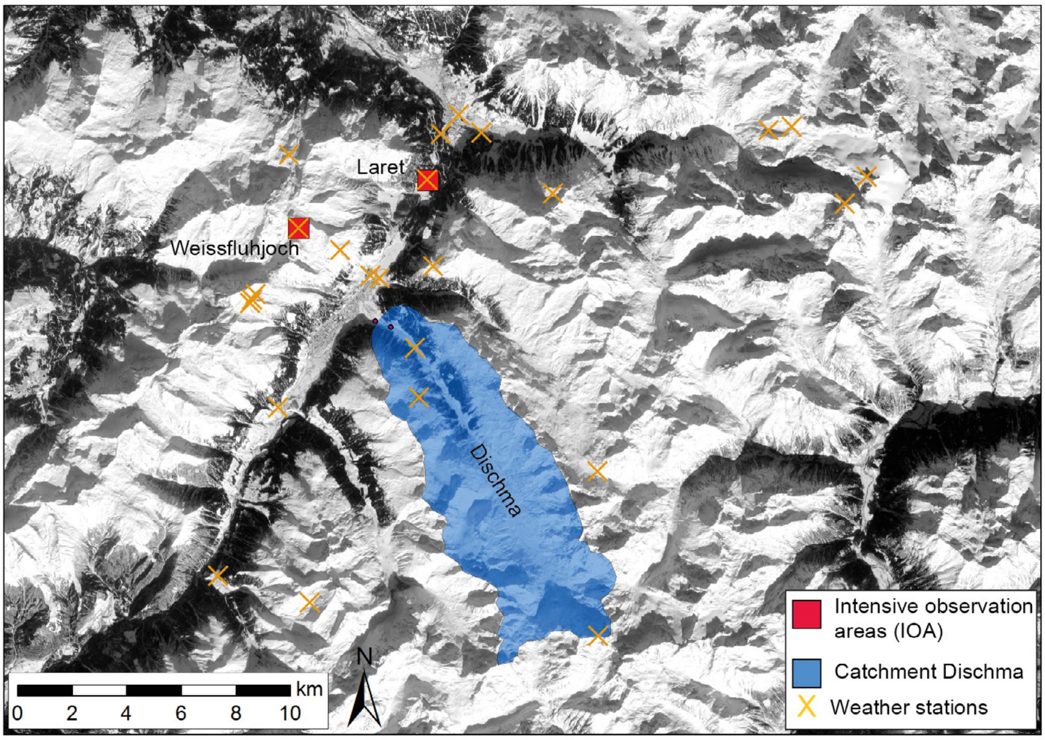

Figure 1. Sentinel-2 satellite image of the high alpine test site Davos acquired on January 27 2017 showing the already available infrastructure and intensive observation areas (IOA).

REFERENCES:

Bühler, Y., M. Marty, L. Egli, J. Veitinger, T. Jonas, P. Thee, and C. Ginzler 2015: Snow depth mapping in high-alpine catchments using digital photogrammetry, The Cryosphere, 9(1), 229-243, doi:10.5194/tc-9-229-2015.

Bühler, Y., M. S. Adams, R. Bösch, and A. Stoffel 2016: Mapping snow depth in alpine terrain with unmanned aerial systems (UASs): potential and limitations, *The Cryosphere*, *10*(3), 1075-1088, doi:10.5194/tc-10-1075-2016.

Grünewald, T., Y. Bühler, and M. Lehning 2014: Elevation dependency of mountain snow depth, *The Cryosphere*, *8*(6), 2381-2394, doi:10.5194/tc-8-2381-2014.

Marty, C. and R. Meister. 2012: Long-term snow and weather observations at Weissfluhjoch and its relation to other high-altitude observatories in the Alps, Theoretical and Applied Climatology, 110(4), 573–583, doi:10.1007/s00704-012-0584-3.

Vögeli, C., Lehning, M., Wever, N., Bavay M., 2016: Scaling Precipitation Input to Spatially Distributed Hydrological Models by Measured Snow Distribution. Front. Earth Sci. 4: 108. doi: 10.3389/feart.2016.00108.