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Frau, Lorenzo Joseph; Rizvi, Syed R.; Chatenoux, Bruno; Poussin, Charlotte; Richard, Jean-Philippe; Giuliani, Gregory

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SNOW OBSERVATIONS FROM SPACE: AN APPROACH TO MAP SNOW COVER FROM THREE DECADES OF LANDSAT IMAGERY ACROSS SWITZERLAND

[1]Lorenzo Frau, [2]Syed R Rizvi, [1]Bruno Chatenoux, [1]Charlotte Poussin [1]Jean-Philippe Richard, [1]Gregory Giuliani

[1]University of Geneva, Institute for Environmental Sciences, GRID-Geneva
[2]Analytical Mechanics Associates, Hampton, VA

ABSTRACT

Snow accumulation is one of the most important forms of water storage. The natural cycle of water is being increasingly influenced by climate change and will continue to change in the future. To understand the evolution of snow cover and to perfect its accurate detection UN Environment/GRID-Geneva and the University of Geneva have developed a Snow Detection tool called "Snow Observations from Space" for the Swiss Data Cube. The Snow Detection tool uses the C Function of Mask to identify snow pixels and then subsequently produces a normalized detection raster.
Through further development, this tool will reach its full potential as an accurate method of detecting snow cover change for Switzerland.

Index Terms— Landsat, Snow, Open Data Cube, Switzerland, CF Mask, Jupyter

1. INTRODUCTION

Switzerland in known internationally for its tall mountains and verdant pastures. This reputation however could never come to be without the copious amounts of water that flow from the "water castle of Europe" [1].

Although its territory is many times smaller than the rest of Europe, Switzerland is the repository for 6% of Europe's water reserves [1].

Of these water reserves, 40% of all running waters in Switzerland comes from snowmelt [2]. Snow is consequentially a critical part of the water cycle in Switzerland as well as the rest of Europe.

Unfortunately due to climate change, the portion of snow contributing to water bodies is set to diminish to 25% by 2085. This will have serious consequences on many major rivers that are born in Switzerland, such as the Rhone, Rhine and Danube [2].

To better understand the distribution of snow cover, as well as its evolution over time, the UN Environment/GRID-Geneva and the University of Geneva have developed a Snow Detection tool that uses the data present in the newly created Swiss Data Cube.

In recent years, satellite-based snow detection strongly relied on the NDSI (Normalized Difference Snow Index) to map snow cover [3]. However this method has one drawback: it cannot distinguish between water bodies and snow, making it necessary to use a mask to remove the former from calculations.

The aim of this paper is to present the preliminary results obtained with the Swiss Data Cube Snow Detection tool.

These results were obtained using Landsat imagery and are to our knowledge, the first examples of a snow detection tool used in a Data Cube environment. They illustrate the application Snow Detection on three distinct regions of Switzerland for a multitude of separate time periods.

2. THE SWISS DATA CUBE

To help monitor pressures on Swiss natural resources in support of land planning for various environmental issues such as climate change, biodiversity loss, urbanisation, or water quality, UN Environment/GRID-Geneva and the University of Geneva, supported by the Federal Office for the Environment (FOEN) are currently building the Swiss Data Cube (SDC – http://www.swissdatacube.org).

Based on the Open Data Cube (ODC – http://www.opendatacube.org) technology, an open source project initiated and developed by Geoscience Australia, the Commonwealth Scientific and Industrial Research Organization (CSIRO), the United States Geological Survey (USGS), the National Aeronautics and Space Administration (NASA) and the Committee on Earth Observations Satellites (CEOS), the "Open Data Cube" is a new way for organizing Earth Observations geospatial data (especially satellite data) by gathering all satellite images from selected sensors (e.g. Landsat, Sentinel) through space and time for a given period over a dedicated region. While a data cube is just a data storage format, the Open Data Cube also provides a common analytical framework for processing satellite data. This is a change of paradigm in the way that remote sensing data are being organized for delivering it to end-users. In the recent years, the development of Open Data Cube has involved API development, big data, cloud integration, data analysis and collection, user interface development, analytics and reporting, visualization, and verification and validation. It is a sophisticated software with multiple services designed for better satellite data collaboration, automation and governance across platforms.

The SDC makes use of a number of freely and openly accessible data repositories. Currently, the SDC contains 33 years of Landsat 5,7,8 Analysis Ready Data (1984-2017) corresponding to approximately 4000 scenes for a total volume of 1TB and more than 35 billion observations over the entire country [4], [5]. A prototype platform is running and allows testing and applying several algorithms to extract useful information country-wide. Sentinel-2 data have been recently ingested in the SDC adding more than 2300 scenes for a total size of 3.5TB over the period 2015-2017. Soon Sentinel-1 will be also added.

This is constituting a unique collection of data which are analysis ready, meaning all corrections (spatial, atmospheric corrections) are already applied.

The Swiss Data Cube is a new paradigm aiming to realise the full potential of EO data by lowering the barriers caused by Big data challenges (e.g., Volume, Velocity, Variety) and providing access to large spatio-temporal data in an analysis ready format making it faster and easier to provide information on issues that can affect the country.

The main objectives of the Swiss Data Cube (SDC) are to support the Swiss government and the Cantons for environmental monitoring and reporting and enable Swiss scientific institutions (e.g., Universities) to facilitate new insights and research using the SDC and to improve the knowledge on the Swiss environment using EO data.

3. SNOW DETECTION ALGORITHM: THE METHOD AND TOOLS

Among the objectives set for the Swiss Data Cube (SDC), is the development of tools to facilitate the analysis and understanding of the great wealth of data available. The Python programming language is greatly suited for research in scientific computing, remote sensing, Earth science, and machine learning due to its extensive standard library and selection of add-on packages, its readability, and its ease of programming compared to other languages, and the great quantity of help resources easily found online. It has been widely adopted by the scientific community both for internal analysis and for published material. The tools in question are initially constructed in Jupyter Notebooks (.ipynb format) and subsequently implemented in the online interface. These notebooks act as interactive Python development environments which allow developers to divide their code into blocks which can be run independently of each other, with variables stored in the background and the environment persisted between blocks.

All the tools are constructed in approximately the same manner: initially, the program is instructed to connect to the Data Cube. Subsequently the desired extent values are chosen (according to the area considered for analysis) and the Data Cube is queried. At this point, the tools differ, as each distinct analysis requires a specific algorithm.

As stated in the introduction, this paper regards the development of a Snow Detection algorithm.

This tool uses the C Function of Mask to run its analysis, an algorithm applied to Landsat data, initially developed by Boston University as Function of Mask and the translated to C by USGS EROS [6]. This algorithm executes multiple runs through a decision tree system that labels pixels according to different categories. It then validates this choice by comparing the labels to the general statistics of the considered scene [6].

The CF Mask values the Swiss Data Cube uses were obtained from the Second Simulation of the Satellite Signal in the Solar Spectrum (6S) algorithm available in the Atmospheric and Radiometric Correction of Satellite Imagery (ARCSI -http://rsgislib.org/arcsi/) software and take into consideration five main classifications for pixels: clear pixels, water, cloud shadow, snow and cloud [7].

The idea behind the Snow Detection algorithm was to use the CF Mask snow pixels to obtain the snow cover for a given time period and spatial extent. Through close collaboration with CEOS, it was possible to extract the relevant pixels and perform a time series analysis on them.

To test the Snow Detection algorithm, the tool was applied to two different alpine regions of Switzerland:

- The Grimselsee Region, that presents a wide variety of terrain types (a lake, glacier, forests and urban areas) as well as a wide variation in altitude (it is a very mountainous region)
- The Bernese Alps.

4. RESULTS AND DISCUSSION

The tool was applied to the region of the Grimselsee for two separate time periods (1985 to 1995 and 2005 to 2015) to facilitate comparison.

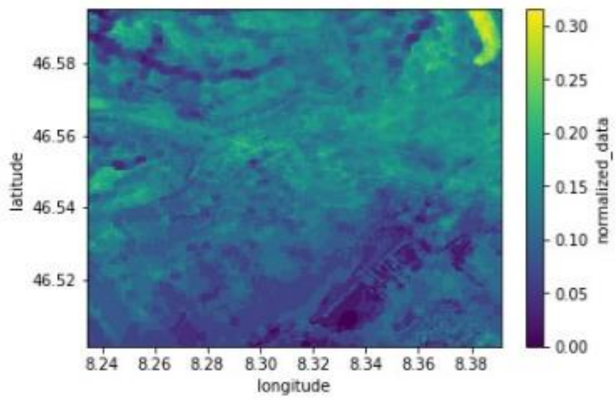

Figure 1: Grimselsee normalized Snow Detection for 1985 to 1995

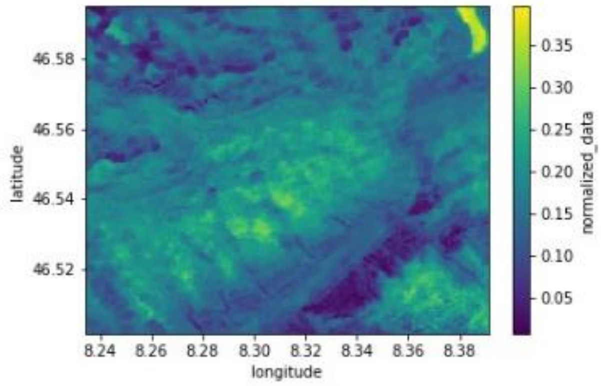

Figure 2: Grimselsee normalized Snow Detection for 2005 to 2015

The figures above (Figure 1-2) represent the normalized snow detection (that is to say the total snow observations divided by the number of clear observations) for the considered area. The images show clear differences between each other, although it would currently be difficult to establish a relationship between the two time periods.

We can observe however that the small glacier in the higher right corner from Figure 1 to 2 appears to have become somewhat smaller between the two considered time periods.

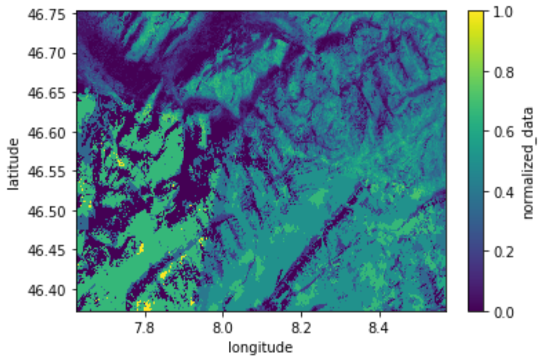

Figure 3: Bernese Alps normalized Snow Detection for 1985 to 1995 (winter months)

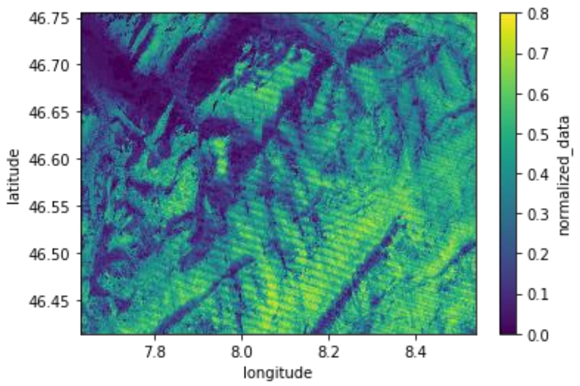

Figure 4: Bernese Alps normalized Snow Detection for 2005 to 2015 (winter months)

Figures 3 and 4 represent normalized snow detection that only takes into consideration winter months (December to February). This filter was added to the Snow Detection tool to avoid smoothing of final results. We can observe that although there may not be a very large difference visually, scale-wise there are regions in Figure 3 that present a higher number of snow observations than in Figure 4.

This new tool is the first step in the accurate detection of snow cover and potentially, glacier evolution. This tool is the first of its kind which can detect snow independently from water. This is great step ahead both for future snow detection tools as well as for more accurate water detection. By detecting the change in snow cover for different time periods, it will become possible to better understand the effects of climate change on both a national scale, as well as a local one. Also, the possibility of using this tool for developing a more accurate ice detection algorithm could prove invaluable to accurately detailing glacier evolution through the use of satellite data.

Since the initial development of the tool in January 2018, the snow detection algorithm has undergone further testing. Shortly after its application to Landsat data, the algorithm was adapted for Sentinel 2.

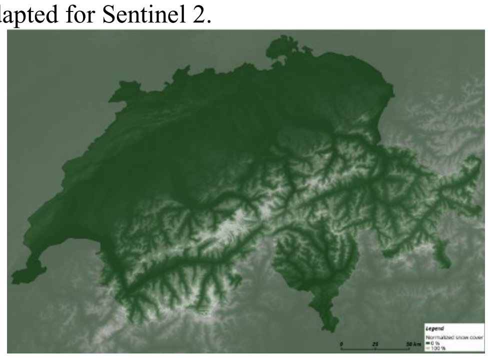

Figure 5: Normalized Snow Cover in Switzerland from April to August 2017, Sentinel 2 data

Figure 5 illustrates the successful application of the algorithm to the totality of the Swiss Territory using Sentinel 2 data. This proves that the Snow Observations from Space algorithm has the potential to detect snow cover for large portions of territory with relative ease.

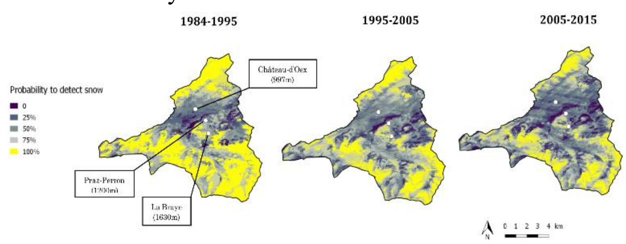

Figure 6: Snow Cover evolution for the ski season (December to April in Château-d'Oex for three time periods obtained with the SOfS

Another development concerning this algorithm is its application to a study revolving around the decrease in snow cover due to climate change and its potential impact on society.

Figure 6 represents the perfect example of the application of the SOfS to a changing situation regarding snow cover. The decrease in snow cover in Figure 6 between 1984 and 2015 may put the economic stability of Château-d'Oex (a mid-altitude ski location) in serious jeopardy. Examples such as these prove the capability of the SOfS algorithm to be an invaluable asset in the evaluation of snow cover trends through time, as well as its potential for application to real-world problems.

The tool presents a series of limitations. Some of them have been overcome, such as the application of a unique scale tied to a color scheme (see Figure 6).

Another limitation which still needs to be overcome is that the tool does not currently take into consideration the variation in altitude. At the current stage of testing, this appears to cause only minor distortions in snow detection, but it remains an issue to be solved. A possible solution could be to implement a stage in the algorithm that corrects the total snow observations according to a digital elevation model. The code for this solution is currently partially developed and will soon be tested.

As stated previously, the tool is still in the process of being developed and will undergo a series of modifications before it can be considered to accurately detect snow. Initially, the tool should correct for altitude distortion. After this has been implemented the tool can be implemented in the Swiss Data Cube Interface and tested to verify its effectiveness and accuracy.

5. CONCLUSIONS

In this article, we have illustrated the development and application of a Snow Detection algorithm called "Snow Observations from Space" to the Swiss Data Cube.

If we consider the future projections concerning climate change [8] and water availability [2], we can conclude that snow detection can be an invaluable asset to water management practices.

In "Europe's Water Castle" [1], snow is and will remain an important water source; how it changes and is managed will affect the future of Switzerland as well as its neighboring countries.

Satellite data can greatly contribute to the accurate detection of snow. By using the data provided by the Landsat and Sentinel programs ingested in the Swiss Data Cube, it is now possible to run a variety of algorithms for the whole of Switzerland as well as monitor the evolution of certain environmental factors (such as Forest Cover or Water Detection).

The Swiss Data Cube's Snow Detection algorithm is the latest step towards a better understanding of snow cover and its evolution through time in Switzerland. Thanks to its application to the Data Cube's unique format, it is now possible to uncover the trends and changes in snow cover of our territory.

There is still much to do to fully exploit the available data's potential, but the preliminary results demonstrate that this algorithm can prove to be a powerful asset for past, present and future snow detection.

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