THE MOUNTAIN COMPONENT OF THE COPERNICUS CLIMATE CHANGE SERVICES – SECTORAL INFORMATION SERVICE « EUROPEAN TOURISM » : TOWARDS PAN-EUROPEAN ANALYSIS AND PROJECTIONS OF NATURAL AND MANAGED SNOW CONDITIONS

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ABSTRACT: Ski tourism plays a major role in European mountain areas such as the Alps, Pyrenees, Scandinavia, Turkey, Eastern European Mountains etc. Meteorological conditions govern the operating conditions of ski resorts, due to their reliance on natural snow fall and favorable conditions for snowmaking. However, there is currently a major lack of assessment of past and future operating conditions of ski resorts at the pan-European scale in the context of climate change. The presented work aims at filling this gap, as part of the ongoing development of « European Tourism » Sectoral Information Service (SIS) of the Copernicus Climate Change Services (C3S). C3S is run by the European Center for Medium-range Weather Forecast (ECMWF) on behalf of the European Commission. Such an endeavor requires combining state-of-the-art meteorological reanalysis with regional climate projections, followed by the application of a snowpack model accounting for grooming and snowmaking. Emphasis will be placed on the workflow making it possible to analyze the data with various levels of aggregation (from daily data to annual scale indicators, to their statistical moments accounting for multiple climate scenarios and lead times), in order to address the needs of various stakeholders, at the European, national, regional and local scales. The data will be made available freely through the Copernicus Data Store in various ways (download of raw data, download or graphics based on post-processed information accounting for user specific needs). It is expected that the data and the tools developed within this project will not only make it possible to analyze the climate sensitivity of ski tourism in Europe as a topical yet academic research question, but would also help third-parties in developing climate services specifically targeting the ski tourism industry in Europe. This contribution introduces the scientific background and general strategy for generating the products, and delivers preliminary information relevant to this upcoming operational service, planned to open to users from 2019 onwards.

KEYWORDS: ski resorts, climate, snow management, climate service

1. INTRODUCTION

Like most human activities, tourism is heavily dependent on meteorological conditions, hence significantly impacted by climate change. One of the most often cited example for such a link between climate change and tourism is ski tourism, because of climate projections of significant reduction of seasonal snow in mid-altitude mountain areas. Ski tourism plays a major role in the socio-economic functioning of European mountain areas such as the Alps, Pyrenees, Scandinavia, Turkey, Eastern European Mountains etc. Meteorological conditions govern the operating conditions of ski resorts, due to their reliance on natural snow fall and favorable conditions for snowmaking. They are thus sensitive to interannual variability of snow conditions, and long term climate change (Steiger et al., 2017, and references therein). However, there is currently a major lack of assessment of past and future operating conditions of ski resorts

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at the pan-European scale in the context of climate change. Most pan-European climate change studies address past and future change of meteorological conditions and natural snow conditions (e.g., Gobiet et al., 2014, Beniston et al., 2018). Such information provides context for ski resorts operating conditions, and have been used to infer future ski tourism projections in many European countries (e.g. Damm et al., 2017, Tranos and Davoudi, 2014), but their relevance for ski tourism stakeholders is limited because such studies do not account for snow management, although it plays a central role for the operations of ski resorts (Steiger et al., 2017). In contrast, several studies have provided information relevant to ski resorts management at the local to regional scales, accounting for future climate conditions but also explicitly handling snow management elements, such as threshold wet-bulb temperature for snow making, impact of grooming etc. (e.g. Pons et al. 2015, Marke et al., 2015, Spandre, 2016a). Such studies, however, are based on different tools and hypotheses, which makes it difficult to provide a pan-European vision of the reliability of operating conditions for ski resorts, in the most homogeneous way. The "Mountain Component" of the "European Tourism" Sectoral Information Service (SIS) of Copernicus Climate Change Services (C3S) intends to address this knowledge gap. Note that C3S SIS European Tourism does not only have a "Mountain" component, but also components targeting "Coastal", "Urban", "Rural" and "Lakes" touristic activities.

This contribution introduces the scientific background and general strategy for generating the C3S SIS European Tourism "Mountain component" products, and delivers preliminary information relevant to this upcoming operational service, planned to open to users from 2019 onwards. Section 2 is devoted to the description of the Mountain Tourism Meteorology and Snow Indicators (MTMSI) and their geographical extent. Section 3 introduces the tools used to generate the MTMSI and deliver information to the users. Section 4 focuses on the Case Studies developed alongside the MTMSI generation, which are intended to foster their uptake by a variety of stakeholders, as such or through further post-processing. Section 5 summarizes the current achievement and the upcoming steps until the official release of the service expected by mid-2019.

2. MOUNTAIN TOURISM METEOROLOGY AND SNOW INDICATORS

2.1 Definition of the indicators

Mountain tourism climate indicators are linked to the state of the atmosphere, which is described by several relevant variables such as air temperature, relative humidity, wet-bulb temperature – critical for snowmaking, snow and rain precipitation, wind speed, and snow conditions, characterized by snow depth and snow water equivalent (SWE), accounting, or not, for snow grooming and snowmaking. Such variables are typically defined for each point of interest and at the diurnal or subdiurnal time scale. Relevant indicators can be computed based on these variables, for flat and sloped terrain. Different users will require different indicators, depending on their management strategies and climate/meteorological sensitivity. The number of indicators, which could be computed, is virtually infinite but general principles can help streamlining the type of indicators which will be generated.

- Value on one day, for example, snow depth, accounting for grooming and snowmaking, on December 25
- Minimum or maximum value over a given time period, for example maximum daily SWE from 1 November to 30 April.
- Number of days with one variable under/above a given threshold within a given time period, for example number of days with snow depth above 5 cm from 1 November to 30 April or the number of days with wet bulb temperature lower than -2°C from 1 November to 31 December.
- Average values over a given time period, for examples average temperature from 1 November to 30 April, or the average snow depth from 1 November to 30 April.
- Cumulative value over a given time period, for example total snow precipitation from 1 November to 30 April, or total precipitation (rain + snow) from 1 August to 31 July.

Although most examples dealt with in this contribution relate to snow conditions in relationship to the ski industry, it is worth noting that the indicators can also address other wintertime activities, and non-winter conditions too, making it applicable to assess future tourism comfort indices in mountainous areas year-round.

2.2 Geographical resolution of the pan-European products

Horizontal: Due to the need to provide European-wide information, and the need expressed by some interviewed stakeholders to be able to link climate information with other socio-economic information, the indicators will be computed at the geographical scale of NUTS-3 regions (see Figure 1), consistent with previous studies (e.g. Damm et al., 2017, Tranos and Davoudi, 2014). Higher resolution capabilities may be available in some European countries, making it possible to compute indicators at a higher spatial scale (e.g. Steiger et al., 2017), but such approaches can not be generalized within the scope of the current project to upscale to the European-wide level, mostly due to the lack of adequate high resolution observation or reanalysis data sets.

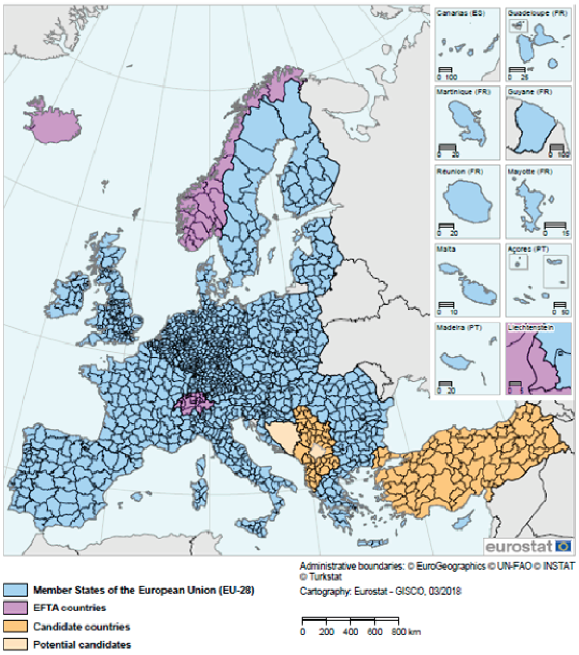

Figure 1: Overview of the NUTS-3 regions.

Vertical: Based on interview with stakeholders (and consistent with literature), the altitude range attracting most attention and critical challenges lies between 1000 and 2000 m altitude in alpine areas (Alps, Pyrenees), within which indicators should be computed every 100 m altitude. It is further suggested to add altitude levels of 2500 m, 3000 m and 3500 m altitude, relevant for some alpine locations and in Turkey, and add altitude levels below 300 m and 1000 m (every 200 or 300 m altitude) for lower-lying mountain areas (e.g., Scandinavia). Not only information on flat terrain but also on representative slopes can be useful (typically, 20° slope, N-E-S-W aspect). The exact altitude levels and slope conditions to be covered may be adjusted during the production phase.

3. METHODS AND TOOLS USED TO GENERATE AND HANDLE THE INDICATORS

3.1 Climate data

The calculation of the MTMSI needs to combine pan-European atmospheric reanalysis at the highest possible resolution, with pan-European climate projections, feeding a model capable of simulating natural and managed snow conditions. Based on existing data sets and in line with the future development of C3S European reanalyses and European climate projections, we selected the following climate information.

The European reanalysis generated through the project UERRA, spanning the time period from 1960 to 2010, will be used as an observation data set for the past conditions in European mountain areas. The grid spacing of this reanalysis is 5.5 km (Soci et al., 2016), and grid points from the entire reanalysis will be selected according to their geographical location and altitude to match the geographical scope of the MTMSI (see Section 2.2, and Figure 2).

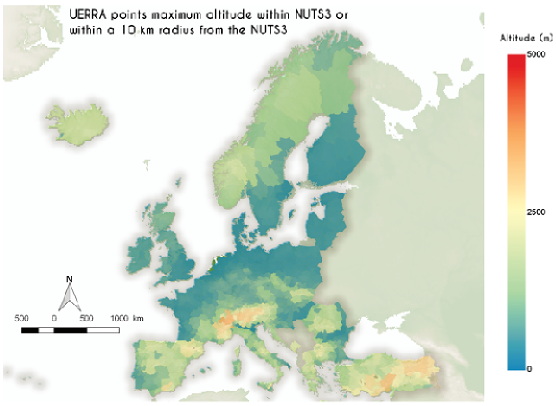

Figure 2: Map of NUT-S areas, with a color coding corresponding to the maximum altitude of the UERRA 5.5 km reanalysis grid points within 10 km around the NUTS-3 area. ©EuroGeographics for the administrative boundaries, DEM SRTM-ASTER (EU-DEM v1.1), cartography Irstea-LESSEM.

Figure 3 shows the comparison of the maximum altitude of each NUTS-3 (from a high resolution digital elevation model), and the maximum altitude of the UERRA grid within each of the NUTS-3.

Within the elevation domain concerned by the MTMSI, it will be possible to find grid points appropriate for the calculations. This reanalysis product has two additional interests, first of all it contains all the necessary data to drive a detailed snowpack model (see below), and it is also consistent with the future European reanalysis product within C3S.

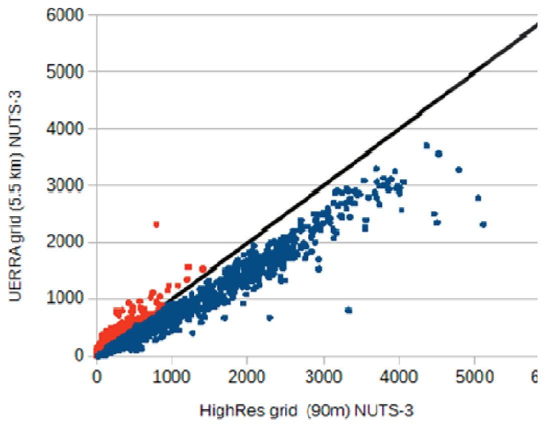

Figure 3: Comparison of the maximum altitude within all European NUTS-3 regions (x-axis) and the maximum altitude of the grid points of the UERRA 5.5 km reanalysis within 10 km around the NUTS-3. Red dots refer to situations above the 1:1 line.

The ensemble of global/regional climate model pairs EUROCORDEX (Jacob et al. 2014) will be used to provide state-of-the-art European-wide climate projections spanning the entire 21st century (2006-2100), along with historical model runs from 1950 to 2005. An appropriate number of GCM/RCM pairs will be selected from the full EUROCORDEX ensemble in order to ensure that uncertainty components are adequately sampled, while the number of simulations to be performed remains reasonable. Several Representative Concentration Pathways (RCP) will be considered, spanning a range of global scale climate policies in the 21st century (RCP2.6, RCP4.5, RCP8.5). EUROCORDEX RCM data will be statistically adjusted and downscaled to the grid points selected from the UERRA 5.5 km reanalysis, using the ADAMONT method (Verfaillie et al., 2017). This method makes it possible to generate climate projections at subdiurnal time resolution, applicable to drive detailed snowpack models, based on a quantile-mapping approach accounting for weather types and seasonal patterns. This method has been applied successfully to EUROCORDEX data in the French Alps, using the SAFRAN reanalysis has an observational reference (Verfaillie et al., 2018).

3.2 Snow modelling

The MTMSI will be computed based on daily meteorological and snow time series, for each NUTS-3 domain and each point of interest in the domain. These time series will directly originate from the UERRA 5.5 km reanalysis or the adjusted/downscaled EUROCORDEX data in the case of meteorological variables, or, in the case of snow variables, result from the application of the detailed snowpack model Crocus driven by the meteorological time series. Crocus is a multi-layer energy balance snowpack model, which has recently been equipped with a module capable of simulating the effect of grooming and snowmaking (Spandre et al., 2016c). To do so, not only physical processes but also snow management practices are taken into account, based on interviews with stakeholders and literature data (Spandre et al., 2016b).

3.3 Data post-processing

The daily time series generated as indicated above (section 3.1 and 3.2), will be used to compute the MTMSI (section 2.1). Because of the multi-RCP and multi-model approach, and the fact that continuous simulations will be generated from 1950 to 2100, it is necessary to implement a framework to exploit the generated indicators. This depends, similarly to the definition of the MTMSI, on the climate sensitivity of the stakeholders, their operational time scales and the period of time over which they need to base their decision-making process. For example, within moving time windows, it is possible to compute for each RCP, multi-model multi-annual averages and standard deviations, making it possible to focus on the long term change signal only, thereby reducing the impact of interannual variability. Otherwise, it is also possible to compute quantile of threshold exceedance statistics of annual indicator values, over moving time windows, which combines model uncertainties and interannual variability. Indicators can be aggregated and processed as a function of global warming level (from the driving GCM), in order to provide indicator values for 1.5°C, 2°C, 3°C etc. global warming, to be placed within the scope of the 2015 Paris Agreement. Verfaillie et al. (2018) provides an overview of statistical methods to be employed to synthesize and analyze mountain meteorological and snow-relevant indicators.

3.4 *Visualization and data access*

The ultimate goal of C3S is that all computations mentioned above, as well as access to raw data and plotting applications, are handled directly on C3S servers and accessible through the Climate Data Store (CDS) free of charge for all users. In order to advance the development of user facing interfaces and foster feedback from the User Advisory Board attached to the service, mock-ups of the visualization have been generated, drawing on simulations generated in French mountain areas similarly to what Verfaillie et al. (2018) have reported for one altitude level in the Chartreuse massif. Figure 4 shows an example of the preliminary user facing interface, guiding users to access several types of plots depending of the question of interest.

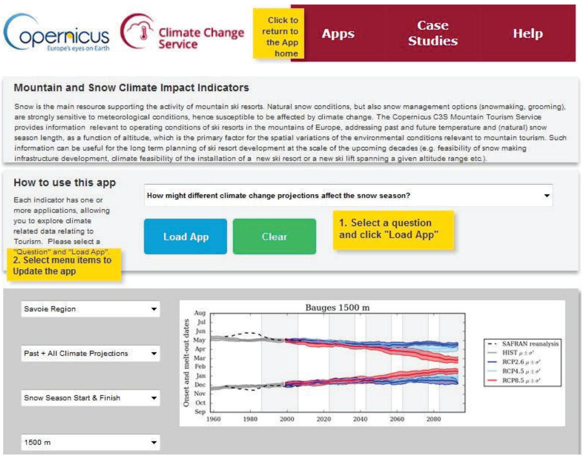

Figure 4: Overview of the mock-up for the user facing application developed to access the data in an interactive way. The user selects a question of interest, and is guided through different visualization options.

4. CASE STUDIES

Four case studies are developed to foster the use of the pan-European products described above, for a range of stakeholders and geographical areas.

- Turkey: This case study will involve a consulting company into exploring how data from the CDS can support the master planning for the restructuring of the Uludag ski resort in Western Turkey into a year-round mountain resort. The study will be developed to illustrate how the plan could benefit from site-specific climate projections.
- Switzerland: The Swiss Cable Car Association will be involved in a case study looking at possibilities to improve stakeholder information and communication with regard to climate data. The case study will be developed to show how the "daily work" of the user (i.e. information/knowledge provision and communication) can be facilitated and improved with the use of the data provided by the CDS. Examples include market/competition analysis (current and future) and strategic planning on industry level (future).
- Andorra: This case study will investigate, in cooperation with the Energy and Climate Change Office of the Andorra Government, how CDS data can support the National Climate Change Adaptation Strategy of Andorra.
- France: This case study will liaise with the ongoing H2020 PROSNOW project, and assess how the CDS data can provide framing in the context of operational decision making at the seasonal scale. Work will involve one of the pilot ski resorts of the PROSNOW project.

5. FUTURE STEPS

While the scientific, functional and technical specifications of the C3S SIS European Tourism "Mountain" are well established and described above, the production of the indicators is starting at the time of writing this contribution, some of whom may be showcased during the ISSW 2018 if the preliminary results are satisfying. The timing is tight, with an expected release to the public in mid-2019.

6. ACKNOWLEDGEMENTS

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