EO4ALPS: the Alps from Space

Workshop Report and Roadmap

Opportunities for EO research and development and downstream activities to support geo-information needs relevant to the Alpine Region.

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Illustration on cover page: the Lumnez valley in the canton of Grisons, Switzerland (H. Raetzo, FOEN).

Photo courtesy Nomi Baumgartl

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EO4ALPS Workshop report and roadmap

Purpose of this document:

The purpose of this document is to present the outcome of the **'Alps from Space'** or **EO4ALPS** workshop that took place on 27-29 June 2018 in Innsbruck, Austria and to suggest priorities for a roadmap concerning the EO4ALPS initiative. This workshop was organized by the European Space Agency with the aim to assess the opportunities for regionally focused EO research, development, downstream activities and ICT evolution in the European alpine region that may be the basis for future ESA investments and to address some of the key information needs of this important area.

The policy and strategic drivers associated to the Alps region are presented in Section 1. Section 2 describes the workshop and provides the link to the material presented. Section 3 (Roadmap: priority areas to be addressed in EO4ALPS) is structured taking into account three main programmatic areas that are *science* exploitation, *applications* development and processing *platforms*. The analysis is based on the presentations and posters of the seven sessions of workshop (see section 2) and the discussion with workshop participants.

1. Introduction

Background:

As described in the Alpine Convention (http://www.alpconv.org/en/convention/default.html), the Alps, with their biodiversity capital, water and wood reserves, are the natural, cultural, living and economic environment for nearly 14 million people and an attractive tourist destination for approximately 120 million guests every year. The Alps are considered to be the water tower of Europe and are known all over the world for their natural beauty, varied landscapes, rich biodiversity and cultural heritage. As explained in the EU Strategy for the Alpine Region (EUSALP) the Alpine area is composed of territories with contrasted demographic, social and economic trends and a great cultural and linguistic diversity. According to the EC report COM(2016)805 there is a growing interest in the implementation of macro-regional strategies and an Alpine macro-regional strategy would provide an opportunity to improve cooperation in the Alpine States as well as identifying common goals and implementing them more effectively through transnational collaboration.

From an ecological point of view the Alps belong to a complex parts of the "System Earth" and are particularly affected by environmental change processes. Especially, climate change more and more leaves its mark on this system and the Alps are sentinels of this evolution. To monitor and to understand these complex processes in the environment including human health related issues, economy, and transport, satellite based observations continuously deliver consistent, areal measurements and thus represent a valuable contribution.

In this context, Earth Observation (EO) represents an opportunity to support innovative science, applications and information services to face some of these issues, while at the same time acting as a potential catalyst for innovation and growth in the region. We are entering a new era for EO science and applications driven by the step change in observation capacity offered by the Sentinel missions, the opportunities for novel science offered by the Earth Explorer series and the capabilities to accurately characterise long-term processes based on existing archives spanning more than 25 years of EO data acquisition. To maximize the full exploitation of this unprecedented ability of space-borne Earth monitoring by the scientific community, industry and the public sector, dedicated research and development efforts are required, as well as data access, processing and analysis capabilities facilitating these efforts and multiplying their results.

Alpine Policy and Earth Science Priority Issues:

The Alpine Region is among the most dynamic, innovative and competitive areas in Europe with unique geographical and natural features. Better cooperation and coordination between the countries and regions concerned is needed to address shared challenges and better exploit opportunities. The region is the focus of several policy and Earth science initiatives. These include international cooperation agreements addressing the issues faced by the Alps region, technical cooperation fora to ensure long-term data collection, management and analysis of scientific and environmental information in the Alps region and multi-national strategies intended to support the sustainable development and resilience of the Alps region.

The main Policy and Strategy Stakeholders to be engaged at overall regional level are as follows:

- EUSALP: the European Council of 19-20 December 2013 invited the Commission, in cooperation with the Member States and regions involved, to draw up an *EU Strategy for the Alpine Region* that concerns 80+ million people living in the 48 regions of the 7 countries involved. On 27 November 2015 the EU Strategy for the Alpine Region (EUSALP) was endorsed by the Council of the European Union and on 28 June 2016 by the European Council (https://www.alpine-region.eu). It is based on a joint initiative of Alpine states and regions to strengthen cooperation between them and to address common challenges in a more effective way. Seven countries (Austria, France, Italy, Germany, Slovenia, Liechtenstein and Switzerland) and 48 regions are involved. The EUSALP aims at addressing Alpine-specific challenges, such as the balancing of development and environmental protection, the enhancement of competitiveness, and the reduction of territorial disparities. Its objectives include: fostering sustainable growth and promoting innovation in the Alps (e.g. foster research and innovation, increase the economic potential of strategic sectors), connectivity for all (environmentally friendly mobility patterns, transport systems and communication services and infrastructures), ensuring sustainability in the Alps (e.g. preserve and develop natural resources, improve risk management, and better adapt to climate change, promote energy efficiency and renewable energy), and improving cooperation and the coordination of action in the Alpine Region. The General Assembly of the EUSALP gathers the high-level political representatives of States and Regions involved in the Strategy, the European Commission, and the Alpine Convention as observer.

As its main objective, the EU Strategy for the Alpine Region aims to ensure that this region remains one of the most attractive areas in Europe, taking better advantage of its assets and seizing its opportunities for sustainable and innovative development in a European context. This will be attained through the following 3 Thematic Policy Areas and priorities:

- Economic growth and innovation - Objective: Fair access to job opportunities, building on the high competitiveness of the Region. This is supported by three Action Groups:
  - Action Group 1: To develop an effective research and innovation ecosystem
  - Action Group 2: To increase the economic potential of strategic sectors (at present bio-economy, timber and health tourism)
  - Action Group 3: To improve the adequacy of labour market, education and training in strategic sectors
- Mobility and connectivity Objective: Sustainable internal and external accessibility to all. This is supported by two Action Groups as follows:
  - Action Group 4: To promote inter-modality and interoperability in passenger and freight transport
  - Action Group 5: To connect people electronically and promote accessibility to public services
- Environment and energy- Objective: A more inclusive environmental framework for all and renewable and reliable energy solutions for the future. This is supported by four Action Groups:
  - Action Group 6: To preserve and valorise natural resources, including water and cultural resources
  - Action Group 7: To develop ecological connectivity in the whole EUSALP territory
  - Action Group 8: To improve risk management and to better manage climate change, including major natural risks prevention
  - Action Group 9: To make the territory a model region for energy efficiency and renewable energy.

It is intended that the Priority Action Groups to be engaged by ESA are Action Group 1, Action Group 2, Action Group 6, Action Group 7 and Action Group 8.

- The Alpine Convention (http://www.alpconv.org/) is an international treaty between various countries for the protection and sustainable development of the Alpine Region. It came into force in 1995 and is an agreement within the law of nations for the overall protection and the sustainable development of the Alps. Its scope and priorities include the preservation and protection of the Alpine region (regarding population, spatial planning in natural habitats, air pollution, soil conservation, water management, nature protection and landscape conservation, mountain farming, mountain forest, tourism, transport, energy, waste, etc.). The Natural Hazards Platform of the Alpine Convention (PLANALP) was set up to develop common strategies designed to prevent natural hazards in the Alps, as well as to share knowledge about adaptation strategies. It focuses on natural hazards risk management, the integrated reduction of natural hazards, associated best practices, and cross-border exchange of experience. ALPARC, the Alpine Network of Protected Areas is a legal organization enshrined in the framework of the Alpine Convention and its accompanying implementing protocols.

The general framework convention is applied by means of the so called Protocols of Implementation. The protocols of implementation are envisaged for twelve sectors, with protocols already in place for eight of these:

- Water management
- Spatial planning, disaster risk reduction and sustainable development
- Conservation of nature and the countryside, soil conservation
- Mountain farming
- Mountain forests
- Tourism
- Energy
- Transport.

Four further protocols on Population and culture, Prevention of air pollution, Water management and Waste management have not been drafted yet. In addition to protocols, two Ministerial declarations on specific topics have also been adopted:

- Declaration on Population and Culture
- Declaration on Climate Change

It is expected that customized EO-related developments can support the implementation and monitoring of each of these protocols as well as aspects of the two declarations.

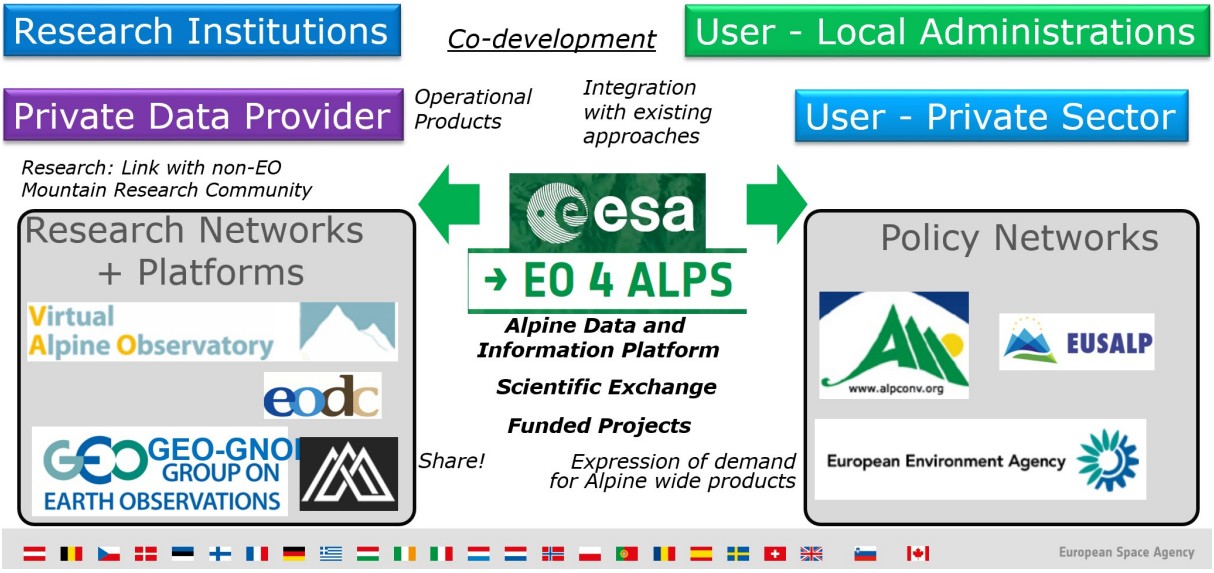
- The EUROMONTANA association (https://www.euromontana.org) founded in 1996 as a non-profit and scientific organization, with international vocation, neutral in terms of religion and politics, registered under the French law of 1st July 1901. The association forms a permanent working group looking at "socio-economic issues in mountain regions" with representatives from the agricultural sector from countries of the Alps and Pyrenees. Its priority themes are described in the position paper named Mountains 2020 (https://www.euromontana.org/en/working-themes/mountains-2020/).

- The Mountain Research Initiative (http://www.mountainresearchinitiative.org) is a non-profit organization that promotes global change research in mountain regions across borders and disciplines through connection, communication, and collaboration – with a view to supporting pathways towards sustainable mountain development.

2. EO4ALPS Workshop Objectives and Sessions

The main objectives of the Workshop were to:

1. Assess the status and priority interests in the European Alpine Region for Earth Science, geo-information and operational monitoring
2. Review the main activities, projects and initiatives taking place in the different Alpine application areas, where Earth observation from space can contribute
3. Evaluate the potential of the increasing observation capacity by satellites to address needs for science, applications and information services in the European Alpine region
4. Characterise and address data collection and analysis gaps and define high-level requirements for supporting ICT solutions to advance EO data infrastructure capabilities in the Alpine region.



The workshop was structured with seven sessions, each focusing on different domains of direct relevance to the Alps region:

1. Alpine Processes in Response to Climate and Environmental Change
2. Combination of Satellite- and Ground-Based Measurements
3. Natural Resources – Availability and Exploitation
4. Atmospheric Processes, Pollutants and Meteorological Stress
5. Natural Hazards
6. Economic Development and Ecological Networks
7. Infrastructure and Data Analytics.

Presentations are available on the event portal:
https://nikal.eventsair.com/QuickEventWebsitePortal/eo4alps/esa

3. Roadmap: priority areas to be addressed in EO4ALPS

Overall Approach

ESA will initiate a set of activities addressing the priority issues raised in the preceding sections of this report. These activities will be grouped into four areas as follows:

1. ***Project Office*** – this will be embedded in a Research Institute or Public Sector Agency and support communication, outreach and stakeholder engagement activities linked to the ESA-funded projects. It will also provide extended support to ESA to identify and elaborate mid-term priorities for expanding the level of activity supported by ESA.
2. ***Science Exploitation Activities*** – these will build on developments in underlying processing capabilities, data collection, algorithm development and understanding of Earth science processes in the Alps region to enhance the exploitation of satellite Earth Observation data in Earth science research addressing the Alps region.
3. ***Application Development Activities*** – these will address current and emerging policy-related issues including environmental protection, climate resilience, natural hazard mitigation, natural resource management and economic development. The priority focus will be to expand the use of EO-derived information within these priority domains for the Alps region. This will be supported by similar developments in processing capabilities, data collection, algorithm development as well as developments within the policy frameworks with respect to the requirements for information and the questions to be formulated with respect to Alpine priorities.
4. ***Data Collection Networks, Data Processing and Platform Capabilities*** – this will provide the infrastructure to exchange with pan-European developments such as the DIAS and TEP capabilities, linking local processing capacity to support Alpine science and application development, enhanced capabilities to access and manipulate in-situ and other data sources in the region (including combination with EO datasets), interoperability and enhanced exchange with existing regional models (e.g. assimilation of new parameters, seamless access to model outputs), customized regional processing tools, a shared environment for the research and application community to exchange information, analysis etc. and state of the art visualization tools.

It should be emphasized that ESA-funded developments will be complementary to and build on existing capabilities and development activities in the region. In particular the following initiatives were identified as existing baseline developments on which ESA-funded actions should build:

- *Mountain Research Initiative* GEO-GNOME (https://www.earthobservations.org/activity.php?id=117), the GEO initiative on monuntains which has four objectives:
    - Delineate mountain regions using best available data – this element will be complemented by all of the ESA-funded activities
    - Identify data providers and user knowledge needs – work done under this activity will be a key input to the Regional Project Office and to wider stakeholder engagement
    - Improve monitoring and understanding of key mountain relevant processes of change – ESA-funded activities will contribute to this agenda point linked to both Earth science and policy developments for the Alps region
    - Link and develop reporting capacities that respond to future policy needs – this will build on ESA-funded developments in addition to already funded research activities.
- *Virtual Alpine Observatory* –a network of European High Altitude Research Stations based in the Alps and addressing scientific problems relating to the atmosphere, biosphere, hydrosphere and cryosphere systems, and also the possible impact of environmental influences on health. This includes the development of the Alpine Environmental Data Analysis Centre (AlpEnDAC) which ensures effective management and access to the in-situ measurements collected as well as other datasets located elsewhere (e.g. EO data). The VAO has been recognized as one of the tools to be used for implementing the Alpine Strategy of the EU
- *EUSALP* which has a number of action groups where EO developments can contribute.

The remainder of this section summarizes the priorities for science exploitation, for application development and for processing and platform services based on analysis of the presentations and posters at the workshop and discussion with the workshop participants.

3.1) Activities to be addressed under Science Exploitation

With respect to regional Earth science in the Alps region, the following areas were identified as being of priority interest to the research community:

- ***Atmospheric processes*** including gravity wave and planetary wave dynamics in the Alps region, aerosol concentration and enhanced capability to assess and quantify GHG emissions in the region.
- ***Snow and ice measurements*** with a particular focus on well characterized snow properties with reduced error levels over all snow cover situations, and robust methodologies for retrieval of micro-structure, as well as more accurate glacier mass balance determination, were identified as priority research domains to be addressed.
- ***Soil moisture and hydrological processes***, in particular putting in place improved, comprehensive soil moisture measurement capabilities mixing EO and ground based networks and improved characterization of evapotranspiration at regional level, considering the peculiarities of mountain areas.
- ***Solid earth physics,*** with a particular focus on improving the measurement and understanding of local tectonic/uplift processes.

These are elaborated in more detail below.

3.1.1) Atmospheric Processes

Gravity wave and planetary wave dynamics

The Alps represent a barrier to atmospheric flow and the perturbations generated by the Alps on this flow cause a range of wave phenomena which may be linked to larger scale planetary phenomena (e.g. extreme events, ENSO etc.). At present, local measurements in the vicinity of the Alps are conducted using OH airglow detectors. However this observation network covers only a very limited portion of the atmosphere. Furthermore the use of airglow as a means to visualize atmospheric dynamics requires quite stringent environmental conditions that are not often met. The combination of airglow with new datasets such as ADM-Aeolus however could link local Alpine in-situ measurements with wider area (i.e. planetary) scale characterizations of these dynamics. As well as direct measurements of the perturbations, proxies such as trace gas concentrations may also be useful to characterize the nature of these dynamics and this can be supported using S5P data. Results developed with respect to the Alps could be combined with results from other regions including the Andes, the Rocky Mountains and the Himalayas.

Aerosol concentration

The difficulties in retrieving aerosol concentrations in the Alps region were discussed. The proposed approach of combining limited ground based measurement stations with UAV based platforms and customized processing of satellite measurements would represent a robust way forward. In addition to supporting an enhanced characterization of the role of the Alps in terms of aerosol variability and processes, this would also support complementary application development linked to assessing the interaction of changing aerosol (and air quality) concentrations on health as well as considering changes in transport policy, tourism management and climate resilience

Green House Gas (GHG) emissions

There are two main in-situ measurement networks which are expanding the coverage of ground based GHG emission measurements. Development of algorithm approaches to include CO2 and CH4 emissions in city environments could support a regional effort in the medium term to validate customized satellite based retrievals of GHGs for the region. Given the current availability of S5P and the medium term developments for Sentinel-4, Sentinel-5 and CO2 monitoring missions this would be a timely development.

3.1.2) Snow and Ice Measurements

Snow extent using a combination of Sentinel-1 and Sentinel-2 with AVHRR is routinely used and achieves classification accuracies in the region of 90%. However extraction of more detailed properties using satellite data is more problematic and methodologies are not sufficiently validated. Two sets of issues have to be addressed here:

- Are the available data collection capabilities being used to support the science community address regional issues? In particular, how can the total mix of available data collection systems (MSG, Metop, Sentinels, Landsat, Airborne/UAV, webcams) be combined to generate snow property information of sufficient reliability?
- How can EO derived information support improved responses to key science questions for the Alps region? These include:
  - Retrieval of snow and glacier properties accepted by the wider scientific community, e.g.:
    - How can satellite methods for snow properties and glacier mass balance estimation be combined with airborne data, in-situ measurements and hydrological modelling to generate catchment level measurements with update times consistent with timescales of the hydrological processes being analyzed? In particular validation of EO methods is required.
    - Retrieval of parameters such as grain size has been demonstrated with imaging spectrometers. How can other data collection methodologies (e.g. X-band SAR, S2) complement such techniques and to what extent can upcoming small satellite systems provide suitable datasets?
    - How can the estimation of snow impurities and micro-organisms be improved (e.g. by better addressing topographic and atmospheric effects)?
  - Understanding the impact of snow and glacier properties on regional dynamic issues, e.g.:
    - What are the controls on and consequences of the spatial and temporal patterns of snow and ice in catchments related to streamflow, ground water recharge and soil moisture?
    - Why and when do rain-on-snow events produce exceptional run-off?
    - What is the contribution of snow and glacier melt to the run-off in alpine catchments, and how is it changing?

3.1.3) Soil Moisture and Hydrological Processes

Developing improved methodologies for the characterization of soil moisture and evapotranspiration variation at the very high resolution is a priority interest for mountain areas. Energy balance ET estimation approaches are limited by the spatial and temporal resolution of available TIR sensors Methodologies for soil moisture based on separate treatment of spatial and temporal variations in water stress coefficient, fractional vegetation cover etc. provide spatial variations in average soil moisture and time varying deviations from this mean value enabling an estimation of missing values. Effective approaches for combining these prototype capabilities together with the snow property estimation described above are a clear priority. This will support the implementation of improved hydrology management in the region as well as support the characterization of the response of Alpine regional hydrological systems to climate change related forcing (e.g. shifts in run-off regimes, increased severity of drought episodes and impacts of rising temperatures in the region).

Recent advances in the use of secondary neutrons from cosmic radiation to estimate soil moisture provide measurements at similar spatial scales to satellite based methodologies (e.g. SMOS, scatterometer, etc.), noting that the resolution of these EO missions data is limited for measurements over the Alps region. However these methods have not been applied to any great extent in alpine areas. Moreover in mountain areas because of the orography and landscape heterogeneity, the focus shall be put on high resolution satellites (Sentinel1, ALOS2, SAOCOM combined with Sentinel2). To this purpose, a dedicated validation effort over a range of representative environmental conditions (e.g. soil characteristics, soil humidity, vegetation, and topography) and snow conditions could result in a useful new approach for catchment level soil moisture estimation. Ground based measurement networks are also in place for the Alps region and putting in place a regional project framework where these data can be shared and combined with satellite derived information is an area where a significant contribution could be acheived.

3.1.4) Solid Earth Physics

The Alps region has a complex geological structure and is responding over a range of motion types to the subduction of the European plate. A certain level of characterization of these structures and motions (in particular in the vertical plane for motion) can be achieved using a combination of terrestrial and satellite gravity anomaly mapping. However this requires separation of the impacts of different processes on the gravity signal –in particular deep sub-surface components such as mantle processes and compression driven crustal thickening, shallow sub-surface processes such as distribution of ground water and surface

processes such as changes in glacier distribution. Priority research activity for this domain has been identified as follows:

- Improve the characterization of glacier and lake properties (depth, extent) with remote sensing tools
- Develop robust methodologies for integrating satellite and terrestrial gravity field measurements for the Alps region, customized to account for the various topographic and tectonic elements in the region
- Longer term, understanding detailed Alp dynamics would require an improved satellite based gravity field measurement capability and the requirements from this research community should be explicitly included in the elaboration of any future gravity field mapping mission.

3.2) Activities to be addressed under Applications Developments

With respect to operational and policy driven requirements for enhanced geo-information and analytics, the following areas were identified as being of priority interest to the local, national and international stakeholders with a mandate linked to the Alps region:

- Natural hazards (geohazards and hydromet hazards)
- Operational hydrology and water resources management
- Air quality monitoring and assessment
- Ecosystem status, natural capital and natural resources
- Other topics

The factors that can accelerate the realization of a greater use of EO based applications need to be analysed and this requires to consider user driven criteria about service benefit and utility. It is also needed to define approaches to better harmonize different EO based solutions and maximize user uptake across the region. For the community to successfully and collectively address the challenges associated with a greater use of satellite EO requires to define the role of mandated organisations, the role of industry and whether new partnerships needed to realize this.

Many groups working on satellite EO for developping applications pertinent to the Alps region are using the same data and EO processing chains that have commonalities. Sharing data and information about EO techniques should help harmonise approaches in order to accelerate both science and applications (e.g. better characterize the limits of products & services).

In addition, there is an overall requirement to build the awareness of EO based techniques within the target user communities in these areas. Many stakeholders have limited visibility on the current EO developments.

These five areas are elaborated in more detail below:

3.2.1) Natural Hazards (Geohazards and Hydromet Hazards)

The main Disaster Risk Management (DRM) themes considered for the Alps region where satellite EO can provide a significant contribution are hydro-geological hazards (landslides, glacier lake outburst flooding) and snow avalanches.

For several hazard types both optical and radar methods can be applied to map hazards and characterise their spatio-temporal characteristics and contribute to hazard and risk mapping. Activities to expand the use of satellite EO in the Alps should carefully articulate with available EO capabilities such as in particular the Copernicus Emergency Management (EMS) Service with its Rapid Mapping component dedicated to emergency response and its Risk & Recovery component supporting DRM looking at activities not related to the immediate response phase such as post-disaster needs assessment, recovery, rehabilitation and reconstruction. Looking at risk prevention and mitigation in the Alpine region requires to map hazards, exposure and vulnerability to assess risks in a consistent fashion and provide actionable information for decision making. EO techniques need to be carefully designed to take into account the long-term needs and operational constraints of user organisations and address the harmonisation and standardisation of methods to ensure they are accepted and adopted by them.

If this is taken into account satellite EO can contribute to better understanding hazards and risks and support DRM. In particular it can be used for assimilation in models, for observations to calibrate models and for direct observations to extract relevant indicators. The thematic areas where satellite EO can help include a broad range with priority themes such as for instance landslides/debris flow/rock slope failures, subsidence, snow avalanches, plain flooding while for some hazard types there are known limitations to the capabilities of current EO missions (e.g. torrential/flash floods).

For those priority themes the geo-information needs includes (regularly updated) inventories and maps (e.g. susceptibility maps, hazard and risk maps), including location, temporal occurrence, type, area (and possibly volume) of observed phenomena; the updated distribution of affected areas to help understand on-going and future problems; the monitoring of areas of possible danger with regularity and consistency of observation, to improve the understanding of processes and facilitate the assessment of their future evolution; site-specific information is needed to associate changes in impacts with causative factors and triggers; alerting systems in high risk areas; post-event damage assessment, maps of affected areas and the identification of safe zones for relocation of elements at risk; residual hazard and risk zonation, etc. In addition extreme event forecasting and early warning is needed. Concerning disaster response it is noted that rapid mapping capabilities are available with for instance the Copernicus EMS.

In the case of avalanches, the combination of short revisit times enabled by Sentinel-1 and wider availability of Machine Learning based approaches for analyzing large datasets has enabled a more comprehensive capability to automatically map the occurrences of avalanches in the Alps area. This includes the characterization of slope geometry, forest damage and run-out as well as the automatic detection of debris. Priority challenges to be addressed include:

- more extensive validation of avalanche mapping techniques over the entire Alps area and integration with avalanche models and historical event data
- development of improved hazard characterization models based on comprehensive integration of meteorological data, snow pack information and avalanche occurrence information

Avalanche risk forecasting is currently based on the analysis of data concerning snow-pack, weather and avalanche activity within a given time period and spatial coverage. These data are then used to assess the likelihood of future avalanche activity. Unlike information on snow-pack and weather, information on avalanche activity is often very scarce. However variation in measured backscatter over the region of an avalanche enables automatic detection of debris in SAR imagery with a level of accuracy that can support reliable characterization of avalanche occurrence. In the case of SAR data, this requires consideration of layover and shadowing, slope geometry, forest cover and run-out. Such detections can then identify areas where avalanches release repeatedly and use this as a basis to identify synoptic weather patterns related to major avalanche cycles. Also spatially higher resoluted optical data, as derived by Sentinel-2, can be exploited to detect and map avalanche activity at regional scale.

In the case of landslides, rock slope failure and rock falls, both geo-morphological interpretation and terrain motion monitoring are pertinent. Synthetic aperture radar techniques (e.g. simple and advanced interferometry, including persistent scatterers and small baseline subset techniques, multibaseline interferometry, offset-traking, etc.) and techniques based on the correlation of Optical time series (correlograms) can be used to support the effective characterization of factors related to slope stability including the generation of landslide inventories, susceptibility maps and the monitoring of hot spots. Most of these techniques have complementary characteristics, and their integration can be a profitable way to address their specific limitations.For the latter ground based monitoring tools are however the primary observation source. Further characterization of slope stability requires an enhanced capability to combine EO with in-situ data as well as detailed knowledge of the local geological structure and mechanical failure modes. Due to the limitations in detection capability and the difficulties in implementing the specialist processing required, the use of EO techniques remains limited to a small number of experts. Satellite EO has the potential to be used in an operational fashion to monitor zones at risk but the constraints and limitations for a truly operational use need to be defined clearly. As a baseline for the value of satellite EO to be significant requires combination with other data sources. In the case of glacier lake outburst flooding precursor activities have been conducted in the Alps primarily using SAR observations.

In addition establishing susceptibility mapping for all Alpine regions requires to standardise landslide inventories from the different areas of the countries in the region and to agree priorities about thresholds used for risk management in particular in transboundary corridors

To address these challenges, several lines of activity are proposed including:

- dedicated validation of combinations of complementary measurement techniques such as SAR, InSAR and Optical based techniques together with in-situ techniques
- large scale demonstrations to support the acceptance of EO for hazard and risk mapping
- development of structured methodologies to integrate EO derived information with geological and mechanical properties of the slope system and meteorological data to support forecast and alert
- standardisation of landslide inventories to support susceptibility mapping for all Alpine regions.

Although glacier lake outburst flooding is a theme that was not presented at the workshop it is established that satellite EO has the potential to contribute and there have projects using protype services and guidelines have been defined to exploit data for glacial lake mapping and identifying the hazard potential of a lake. However in this area, there are a certain number of limitations to the applicabity of the technique for operational use, and it will be further investigated with a view to starting dedicated EO developments in the future.

Similarly the flood theme wasn't part of the session topics presented during the workshop, however feedback from the EO & DRM community indicate that satellite EO can contribute to flood hazard mapping although there are limitations in mountain environments. Thanks to the systematic observing capability of current systems such as the Sentinel missions, EO based observations could become a primary source of measurements. However the robustness of such EO based techniques is generally better in the case of large plain flooding and limited in the case of torrential flooding and rapid on-set events developing in mountainous regions. Urban flood monitoring is also an domain where EO techniques have limitations although innovative methods combining the backscatter and coherence could help achieve better performance criteria. In this area, the current capabilities of satellite EO do not appear to sufficiently meet the operational requirements of mandated user organisations to support a dedicated activity in the short term but this is an area that will be further investigated with a view to starting dedicated EO developments in the future with the following priority challenges to be addressed:

- automation of methods to generate hazard maps with multi-year EO based flood records
- demonstration of solutions combining flood records with hydraulic / hydrologic modelling to better understand risks in representative river basins of the Alps

3.2.2) Operational Hydrology and Water Resources Management

Snow property characterization supports the management of hydroelectric plants and ski resorts as well as providing essential input to water management policies in the region. There are two elements that can be addressed separately: the characterization of snow properties to support tourism and snow water equivalent (SWE) estimation and characterization of the various hydrological issues for effective water management; this is related to parameters such as for instance surface water coverage, water resources and water storage, seasonal run-off, climate change effects (drought, snow cover, etc.), soil moisture (SM), evapotranspiration (ET), etc.

For water resource management, the availability of fast revisit SAR and optical data from the Sentinels supports a significant improvement in the capability to characterize the status of water resources in the Alps. However there are limitations (e.g. cloud cover effects on optical data, lack of an effective source of thermal data and limited canopy penetration by current SAR systems, the complex topography of the terrain, which is limiting imaging capabilities of both optical and SAR systems). The implementation of sustainable water management practices in the region require effective characterization of hydrological processes at a range of length scales combining a broad range of available EO data with in-situ data collection networks.

Precursor activities have existed in several alpine countries with both public users (environment agencies looking at the availability abd quality of water resources) and private users (hydropower organisations, ski lift operators, etc.). A major barrier to uptake of EO techniques is the limited level of acceptance of the user with currently available services and the lack of customization of products to transform measurements into actionable information for decision making by the user.

The primary gap at present is a sufficiently comprehensive high resolution analysis capability covering a sufficiently representative portion of the Alps region. Addressing this requires the development of tailored products at high ground resolution for the whole Alpine arc, combining different data sources (EO, models, ground data) and with focus on validation and addressing the main hydrological issues (SM, ET, surface water etc.). This is a critical area as the increasing frequency of droughts in the region combined with decreasing snow cover and increased average temperatures result in a continuously increasing risk to agriculture.

To support snow property characterization investigations of point measurements have concluded that these are not representative for wider area characterization while airborne optical and LIDAR measurements do give snow depth and SWE estimates that are considered fit for operational purposes up to entire catchment areas. Regional techniques using a combination of Sentinel-3 SLSTR/OLCI, Sentinel-1 snow melt and Sentinel-2 snow cover provide wide area snow cover information (extent and melt area) but do not adequately address snow depth and SWE requirements. S1 and S2 methods for these parameters are not sufficiently validated with the additional caveat that wet snow causes additional problems for SAR based methodologies. Priority areas to address are therefore the following:

- development of operational methodologies to combine satellite (optical and SAR) based measurements with modeling (e.g. SNOWGRID, SNOWPACK, SNTHERM, CROCUS) and optimized airborne data collection (including options to utilize airborne platforms for one country to monitor snow cover areas of other countries in the region). These will also require dedicated validation exercises
- development of an improved total snow extent and melt area mapping capability including optimized algorithms for Sentinel-2 and Sentinel-3 (in particular for steep terrain) with enhanced cloud screening and topographic corrections. The combination of this information with snow depth and SWE estimates would also be of interest to stakeholders in the hydropower, water management, transport and tourism sectors

Operational hydrology in the Alps is also linked to monitoring lake waters with both quantity and quality; in particular to address deterioration in lake water, a number of pilot activities have been set up to monitor lake conditions. In most cases, these include in-situ measurement of temperature and water quality parameters and these are combined with satellite measurements. Several gaps need to be addressed however and, in particular, the challenges associated to monitoring water properties in the case of mountain lakes. Areas to be addressed include:

- the development of customized mountain lake water property retrieval algorithms from Sentinel 2 data and the validation of these algorithms in order to expand the pilot measurements to all of the sufficiently large lakes in the region
- the development of systematic methods to address cloud cover and cloud/topography shading effects on water property retrieval algorithms
- the development of data analysis methodologies to link changes in land use (e.g. agricultural practices, urban expansion) to changes in particular lake groupings
- characterization of icing dynamics in lakes and the detection of long term trends in these indicators

3.2.3) Air Quality Monitoring and Assessment

Historically, the Alps region has been regarded as having reliably high levels of air quality. Due to topography, distance from sources and the nature of land use in the region, concentrations of particulate matter (PM), trace gases (SOx, NOx etc.) and other contaminants such as aggressive pollen spores have been among the lowest in Europe. Over the last two decades however this situation is changing. There is increasing levels of air pollution and PM contamination as well as progressive spread of aggressive pollen spores into higher altitude region.

Inferring useful estimates of trace gas concentration over terrain such as the Alps by combining satellite and in-situ data is extremely complex. The Copernicus Atmospheric Monitoring Service (CAMS) provides information such as ozone concentration, PM concentration etc. but these must be combined with comprehensive in-situ measurement network (e.g. from the VAO) to have any applicability in the region. In addition work is on-going to generate regional climatologies based on in-situ measurement networks that can then be used to provide an augmented Copernicus air quality information service.

The priorities for short term developments are therefore the operationalization of methodologies for combining CAMS, customized EO derived information and in-situ measurements to provide regional AQ information services. In addition the development of methodologies to link AQ analysis to regional economic development priorities (tourism, transport) is a priority interest. Both of these developments should build on the science exploitation developments described above.

3.2.4) Alpine Ecosystem Status and Reporting

EO can be used to support activities concerning biodiversity, nature protection and natural capital. At present there are several small scale developments linked to monitoring the sustainable exploitation of ecosystems and natural resources in the region and there appears to be a high level of acceptance among local and national stakeholders that EO derived information can represent a useful contribution in this domain. The following main chalenges and opportunities have been identified:

- The contribution of satellite EO to ecosystem reporting activities such as the NATURA 2000 (e.g. habitat types, diversity, disturbances) has a high potential and requires the integration of ecological knowledge with EO based observations
- It is needed to better characterise how EO can support Biodiversity and natural protection and the Essential Biodiversity Variables (EBVs)
- The effective characterization of the ecological status of ecosystems requires a more complex mapping approach than that currently provided by the Copernicus Land Information Service. Elements such as functional diversity can be characterized to a certain extent using Sentinel-2 data (i.e. there appears to be a correlation between functional diversity and Sentinel-2 measurements) but more work is required to make this more robust. This is also an issue for grassland mapping where a wider range of parameters (beyond NDVI) needs to be developed and demonstrated. This would require combination of multiple data sources rather than exclusive reliance on Sentinel-2/Landsat. However NDVI also remains a useful tool, in particular when available at high temporal frequency where it can enable more detailed analyses such as characterization of grassland mowing frequency.
- While there are a number of projects investigating or verifying the use of EO derived information to characterize a range of habitats and ecosystems (e.g. grasslands, forests, surface water, snow fields etc.) these are primarily based on the use of Sentinel-2 data (and historical data such as Landsat) and to some extent Sentinel-1. In many cases other datasets would make a significant contribution (in particular VHR imagery). Addressing this issue on a systematic basis is needed if these demonstrations are to be scaled up to the entire region. In particular for forest, grasslands and agricuagricultural areas methodologies for Sentinel-1/ Sentinel-2 and Sentinel-2/VHR Optical combinations should be further developed. Structured methodologies for integrating Sentinel-1/ Sentinel-2 and Airborne Laser are also required.

3.2.5) Natural Resources Management

The main application areas where EO based techniques were presented in detail include *agriculture* (including grassland) and *forest* monitoring two areas where the spatial scale and phenology of Alpine land have specific characteristics; the workshop had different presentations about these two areas and the interest and potential of satellite EO is clear.
In these priority areas it is needed to better characterize and demonstrate the ability of EO to:

- support the management of agriculture and forestry by providing key parameters such as biomass, phenology, soil moisture (for agriculture)
- assess damages and threats (e.g. impact of droughts, pest- and diseases, storm, hail

Another area where EO can contribute is the management of *georesources* such as geothermal sources although this wasn't addressed at the workshop.

In addition, EO can contribute to monitoring *land use* in Alpine regions and can be used to monitor land take and soil sealing. In the context of the Alps, several factors need to be addressed in the short to medium term:

- For the routine provision of land surface information the Copernicus Land Information Service are limited by the topography impacts and the small-scale structure of many land parcels. There are several standard capabilities used for habitat mapping and natural resource management (e.g.

PROSPECT4, 4SAIL, Copernicus High Resolution Layers) but customized classification is usually necessary in many domains.

The level of engagement for all of the relevant stakeholders is not clear and could benefit from more comprehensive demonstration exercises validating the extent to which EO based techniques can be integrated and are able to enhance existing methods.

3.2.6) Other Topics

Some of the issues identified by stakeholders require a territorial planning and management context in order to be framed effectively. This is true for addressing trends such as warming, eutrophication and surface extent reduction in lakes (see section 3.2.2); it also applies to different areas such as for instance sustainable tourism development and, secondly, the resilience of the Alpine region to anthropogenic forcing factors. These areas require multi-disciplinary, cross-border actions.

Sustainable tourism addresses primarily winter sports, summer hiking and the infrastructure supporting access to cultural heritage. Due to the geography of the region, this requires common information collection and effective information exchange between the Alpine countries. This is clearly an economic priority for the region and an important element of the EU Strategy for the Alps. However at present, precise requirements for EO derived information have not been elaborated. This is an area that will be further investigated as the ESA funded Regional Initiative progresses forwards. Dedicated information addressing the tourism sector is developing but remains quite limited such as for instance concerning trekking, mountaineering and ski touring but the uptake remains quite limited. Dedicated effort on this linked to start-ups and innovation clusters in the region could encourage a wider set of customized information products.

Resilience to anthropogenic forcing and response to climate change: the characterization of the overall resilience of the region to both direct anthropogenic forcing and by consequences of anthropogenic response to climate change is an overarching concern of both the Alpine convention and the EU Strategy for the Alps. This requires an inter-disciplinary characterization of trends such as drought statistics, soil property evolution and land degradation, reduction in glacier cover, urban expansion, air quality, changes in natural hazard risk due to temperature increase (e.g. permafrost melting) and changes in the regional hydrology and ecosystem evolution. In this area, the framework for the integration of EO-derived information does not appear to be sufficiently mature at present to support a dedicated activity in the short term but this is also an area that will be further investigated with a view to starting dedicated EO developments in the mid-term.

3.3) Activities to be addressed under Data Collection Networks, Data Processing and Platform Capabilities

Several different cloud based platforms and applications have been presented in the workshop. The common denominator was that a platform is a virtual environment offering data, tools, functions and expertise to process and analyse them in a time and cost efficient way. They implement the new data exploitation paradigm to bring users to the data.

For what concerns the different sources of data and measurements discussed during the workshop it is worth to highlight that they span a broad range as they include:

- Satellites;
- Airborne;
- in-situ;
- models;
- user provided data.

A key aspect to take into consideration is interoperability which allows applications to be combined between each other, even if provided on different environment by different entities. Main relevant standards are those provided by the Open Geospatial Consortium and those which are under definition by

the H2020 project openEO. The standardisation of the interfaces of the diverse platform service offerings is a topic that needs to be addressed to boost collaboration and combination of services.

It also emerged in the workshop that there is a use of different infrastructures both at national and European level which are accessed via partnerships. They range from a single computing center to multi-cloud solutions to High-Performance Computing Centers. It will therefore necessary to provide acess to such diverse resources in a coherent and user friendly way.

In this area several technologies are relevant for sustaining the creation of applications for the benefit of the Alpine region:

- Datacubes: they offer the capability to access to just the quantity of data needed in the required projection. They can provide not only EO satellite data but also in-situ and value added data. Different offerings in terms of data, area covered and technology are already present

- Data Discovery Services: Heterogeneous data needs to be described well and be both browseable and searchable, so that e.g. the aforementioned data cubes can be found in international catalogues such as GEOSS. This is relevant both for machine to machine linking of data as well as for users to identify relavant data sets

- Processing frameworks: they allow to define new algorithms which can scale easily in a cloud environment and that therefore can be used to implement operational services. Different alternatives which have they specific application field are available

- Analytic frameworks: they allow the easy interpretation of remotely hosted data and information extraction via a web interface.

Platforms are seen also as an important tool to transfer scientific development to operational solution, as the same environment support all the phases of the journey of an idea to a full-fledged service that can be exploited in a scalable fashion in the user community. Therefore the involvement of scientists and operational users are key for the definition and evolution of platform capabilities. The different user driven use cases to be supported (Near Real Time monitoring, HPC processing, research projects, e-collaborations, commercial apps, data calibration) is also a key factor to be considered.

Still linked to the data, their availability in a way that can be easily analysed, Analysis Ready Data (ARD), has been widely recognized as a boosting factor for multi-sensor combination and the development of related applications or scientific projects. The automatic generation of such data from raw sources is also an important topic which need to be further tackled in the future and for which the offering need to be increased. Also the data access mechanism need to be consolidated in order to allow an easy data retrieval, exchange and integration from different sources.
The integration of Data Collection Networks in cloud based platforms data offering is also a key factor for the intergration and explotitation of such data in conjunction with EO derived information.

In addition to the above and to support the needs identified in the workshop the following capabilities are considered relevant:
- A platform capability as a basis for expert users to develop higher level applications based on open standards, that can then be shared with non-expert users.
- provision of tailored front-end interfaces to enable non-experts to effectively utilize EO based techniques within the broader range of tools that they use in their operational environment
- visualisation functions to support the interpretation of heterogeneous measurements
- platform functions to support product demonstration, benchmarking and validation in order to increase the acceptance of EO based products by the user community and to support use case tailored experiences in terms of visualization and communication of scientific discoveries
- support operational services to decision makers on the political level as well as for business applications in various relevant sectors like agricultural, tourism, etc.

3.4) Synthesis and Roadmap for the EO4ALPS Regional Initiative

*The roadmap concerning the EO4ALPS regional initiative fincludes a **Phase 1** with timeframe Q1 2019 – Q1 2021 and a **Phase 2** with timeframe Q2 2021 – Q2 2024.*

*Concerning Phase 1 activities the symbol * designates activities to be started within the first half of 2019.*

Alpine Regional Project Office

- *Establishment of a Project Office under ESA supervision to address stakeholder engagement, requirements consolidation, outreach and communication including a community portal, strategy development and to function as liaison to the stakeholders in the different regions (Q1 2019 – Q1 2021)

Science oriented activities
(Q1 2019 – Q1 2021)

- Atmospheric processes - physics and chemistry (clouds, wind, temperature, precipitation, radiation, gravity waves, planetary waves, aerosol concentration, GHG emissions)
- *Snow and ice measurements
- Soil moisture and hydrological processes
- Solid Earth physics (gravity field measurement, alpine tectonics / uplift processes)

Application oriented activities
(Q2 2019 – Q1 2021)

- *Risk mitigation for Geohazards and Hydromet hazards (landslides, avalanches)
- *Operational hydrology & water resources management (opt. properties, catchments/runoff, drought, snow extent, lake water quality)
- *Air quality (pollution)
- *Alpine ecosystem status & reporting (biodiversity, nature protection, natural capital)
- Management of natural resources (forestry, agriculture)

Cross-cutting activities
(Q1 2019 – Q1 2021)

- *ICT resources
- Platform service layers/key enablers of a satellite – airborne- and in-situ EO– network, developing and including efficient tool kits – with a common architecture – in terms of: data product/format, data access, data integration - in-situ/RS, Application Programming Interface (API), Analysis Ready Data (ARD), Data Cubes, link to common platform(s)

Phase 1 Activities will be implemented taking into account Alpine Convention and EUSALP and in ordination with relevant initiatives such as activities under EC H2020, NATURA 2000 reporting, activities of relevant topic centres of the European Environment Agency, of the Mountain Research Initiative and Euromontana, etc. Specific attention will be given to capturing user needs, taking stock of existing projects and identifying gaps and synergies.

Activities in the post 2021 timeframe may be part of a potential **Phase 2** (Q2 2021 – Q2 2024) with study activities and pilot projects on developing a strategy for harmonisation of practices and procedures in terms of EO data and services enablement, addressing in particular:

- combination of EO and in-situ data, topographic correction,
- data/product validation,
- cross-comparison of variable retrievals,
- establishment of time series for forecast and projection.

Activities under Phase 2 will build upon achievements, expand the range of customized scientific and application capabilities - and continue longer lead activities of Phase 1 and the on-going dialogue with European stakeholders – for a common Strategy for Earth observations in the Alps. This is being proposed as part of the Programme Proposal for 'Future EO1' to the Council at Ministerial level in 2019 (Space 19*).
A second EO4ALPS workshop is planned in 2020/2021 in order to provide inputs for a further consolidation of the Phase 2 content.