



CLISP - Climate Change Adaptation by Spatial Planning in the Alpine Space

WP 4 Vulnerability Assessment

SYNTHESIS REPORT

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A Introduction to the CLISP project

CLISP is a transnational European project funded by the Alpine Space Programme under the European Territorial Cooperation 2007-2013. From September 2008 until September 2011 14 Project Partners from six different Alpine countries are tackling the challenges spatial development and spatial planning are facing due to climate change.

Background

Climate change will affect spatial development, including land use, socio-economic activities and life sustaining ecosystem services in the Alpine Space more severely than in other European regions. Climatic changes such as temperature increase, changes in amount, distribution and intensity of precipitation and an increase of extreme weather events are expected to cause a variety of adverse impacts relevant to spatial development. Growing risks from water scarcity, heat waves and natural hazards such as floods, landslides, forest fires etc. will threaten settlements, physical infrastructure, utilities, material assets and human life. As a consequence, future development options may be confined and new spatial conflicts, e.g. between risk prevention and land use interests, may emerge. Since the built environment is highly persistent, planning decisions taken today strongly determine the vulnerability of the Alpine Space in the future. Without preventive and anticipatory action on adaptation, climate change will have potentially severe effects on socio-economic development, growth potentials, welfare of regions and human wellbeing.

In many cases, pressures by climate change are exacerbated by other ongoing environmental change and socio-economic development trends. For example, availability of space suitable for settlement activities in many Alpine regions is limited by nature, and land use demands for development in terms of housing, working, tourism, business and transport are constantly increasing. At the same time, hazard zones are expanding due to climate change, additional space for hazard protection measures is needed, and open space should be preserved for nature protection and to maintain flexibility for future adaptation options. As a result, land for further development is becoming a scarce resource in many Alpine regions, which may lock out both future development and adaptation options. This calls for new spatial planning strategies that explicitly take account of climate change.

Although the Alpine Space is exposed to largely comparable changes in climatic stimuli, the consequences on spatial development will be different between regions, depending on specific climate sensitivities, vulnerabilities and adaptive capacities. Thus, the effects of climate change are distributed asymmetrically across the Alps. Without tailored action on adaptation, interregional disparities in development and growth potentials are likely to grow. Adapting spatial development to climate change is needed to counteract threats to territorial cohesion. Inaction will increase the vulnerability of Alpine regions and municipalities, and therewith lead to further damages and costs.

Both the White Paper on Adaptation to Climate Change of the European Commission and the Territorial Agenda of the EU 2020 emphasize the key role of spatial planning in delivering and supporting adaptation to climate change. But is spatial planning prepared to fulfill that vital task assigned by society? Are the spatial planning systems in the Alpine countries fit to cope with the challenges of climate change?

CLISP is anchored in the belief that spatial planning has large steering capacity in containing vulnerability and increasing resilience of spatial development. However, the knowledge, procedures and tools required for fulfilling this key role in adaptation have still been widely lacking. CLISP tackles for the first time the challenges of climate change to spatial planning in a transnational effort within the Alpine Space. Since climate change adaptation, including an integrated approach to adaptation and mitigation issues is a new field of action for spatial planning policy and administration, CLISP is to be regarded as a strategic pilot project.

Objectives

Building on results of former projects, in particular the Alpine Space Interreg IIIB project *ClimChAlp – Climate Change Impacts and Adaptation Strategies in the Alpine Space (Work Package 7)*, the CLISP project aimed at preventing, reducing and mitigating climate-change related spatial conflicts, vulnerability of spatial development and spatial structures to adverse climate change impacts, and consequential damages and costs. The overarching project objective is to contribute to sustainable, climate-proof spatial planning and territorial development in the Alpine Space by pursuing the following main goals:

- Developing a transnational strategy for climate proof, sustainable and resilient spatial development and an action guide for implementing it on national and regional levels.
- Developing and applying a transferable concept and methodologies of regional spatial vulnerability assessment and assessing vulnerabilities in Model Regions.
- Evaluating the “climate change fitness” of spatial planning systems (legal and institutional framework, instruments, procedures) and identifying strengths, weaknesses, good practice examples, and enhancement options to improve the adaptation performance of spatial planning.
- Promoting risk governance approaches to the management of climate-related risks and conducting and learning from risk communication activities in Model Regions.
- Initiating a transnational expert network on spatial planning and climate change and involving that network in project activities.
- Raising awareness of policy- and decision-makers, planning authorities, stakeholders and the public for climate-related risks and the need for adaptation, stimulating implementation processes and transferring results and experiences to the entire Alpine Space and to other regions.

The CLISP Partnership

The following Project Partners and their external expert teams have collaborated in the CLISP project:

Table 1: The CLISP Partnership structure.

Acronym	Partner Institution – in native language	Partner Institution – in English language	Country	Role
UBA / EAA	Umweltbundesamt GmbH	Environment Agency Austria	AT	LP
BMLFUW	Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Sektion Forst	Federal Ministry of Agriculture, Forestry, Environment and Water Management, Forest Department	AT	WP 6 Responsible
Salzburg	Amt der Salzburger Landesregierung, Abteilung Raumplanung	Regional Government of Salzburg, Department of Spatial Planning	AT	
Steiermark	Amt der Steiermärkischen Landesregierung, Abteilung 16 - Landes- und Gemeindeentwicklung	Office of the State Government of Styria, Department 16 - State Planning and Regional Development	AT	WP 7 Responsible
Ober-österreich	Amt der Oberösterreichischen Landesregierung, Abteilung Raumordnung	Office of the Government of Upper Austria; Department of Spatial Planning	AT	

Acronym	Partner Institution – in native language	Partner Institution – in English language	Country	Role
STMWIVT	Bayerisches Staatsministerium für Wirtschaft, Infrastruktur, Verkehr und Technologie, Abtl. 5 Raumplanung und Fachplanung II	Bavarian Ministry of Economic Affairs, Infrastructure, Transport and Technology, Department for Regional Planning and Development	GE	
MATT	Ministero dell'Ambiente e della Tutela del Territorio e del Mare	Italian Ministry for the Environment, the Land and the Sea	IT	WP 3 Responsible
EURAC	Accademia Europea di Bolzano	European Academy of Bolzano	IT	WP 4 Responsible
Alessandria	Provincia di Alessandria	Province of Alessandria	IT	
UIRS	Urbanistični Inštitut Republike Slovenije	Urban Planning Institute of the Republic of Slovenia	SLOW	
UNEP	United Nations Environment Programme, Interim Secretariat of the Carpathian Convention	United Nations Environment Programme, Interim Secretariat of the Carpathian Convention	AT	
ARE	Bundesamt für Raumentwicklung, Sektion Ländliche Räume und Landschaft	Swiss Federal Office for Spatial Development, Strategy Group Politics of Rural Areas	CH	
Graubünden	Graubünden, Amt für Raumentwicklung	Grisons, Office for Spatial Development	CH	
Liechtenstein	Fürstentum Liechtenstein, Ressort Umwelt, Raum, Land- und Waldwirtschaft	Principality of Liechtenstein, Ministry of Environmental Office, Land Use Planning, Agriculture and Forestry	FL	

Project design

In accordance with the above mentioned objectives, CLISP is divided into four, closely interlinked thematic **Work Packages**:

WP4 – VULNERABILITY ASSESSMENT

WP5 – CLIMATE CHANGE FITNESS OF SPATIAL PLANNING

WP6 – RISK COMMUNICATION AND GOVERNANCE

WP7 – CLIMATE PROOF SPATIAL PLANNING

The **common scope** of all Work Packages are the sectors and systems of spatial development within regions that are vulnerable to climate change and that are, in principle, subject to the steering capacity of spatial planning and spatial risk management.

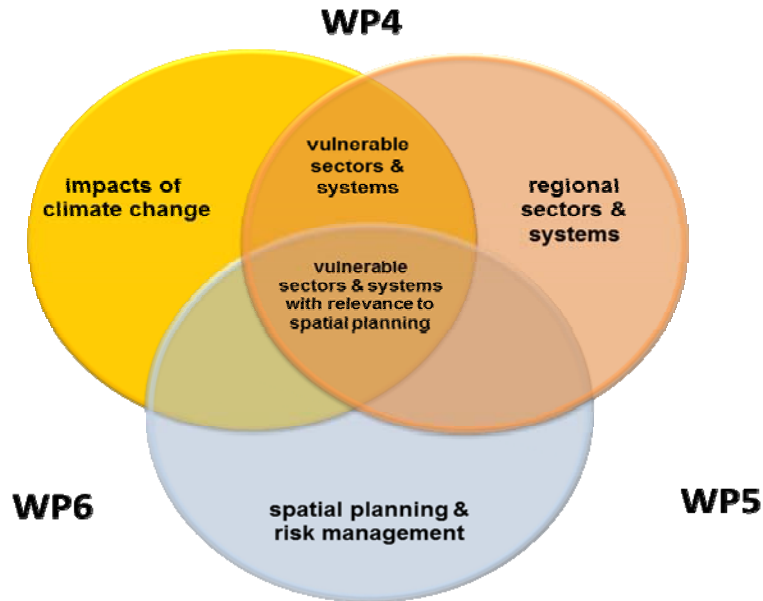


Figure 1: Thematic scope of the CLISP project.

Project activities of all Work Packages have been carried out on two levels: the **transnational level** and the **Model Region level**. Based on common concepts, methods, and guidance developed on the transnational level, project activities have been tailored to the specific requirements and priorities of each Model Region on Partner level. Embedded in a comparable work programme, in-depth investigations and stakeholder interactions with different thematic priorities according to Model region needs have been carried out by Partners in each Model Region. The results of the Model Region work have then been evaluated, synthesized and prepared for further transfer to other regions by the Work Package Responsibles on the transnational project level.

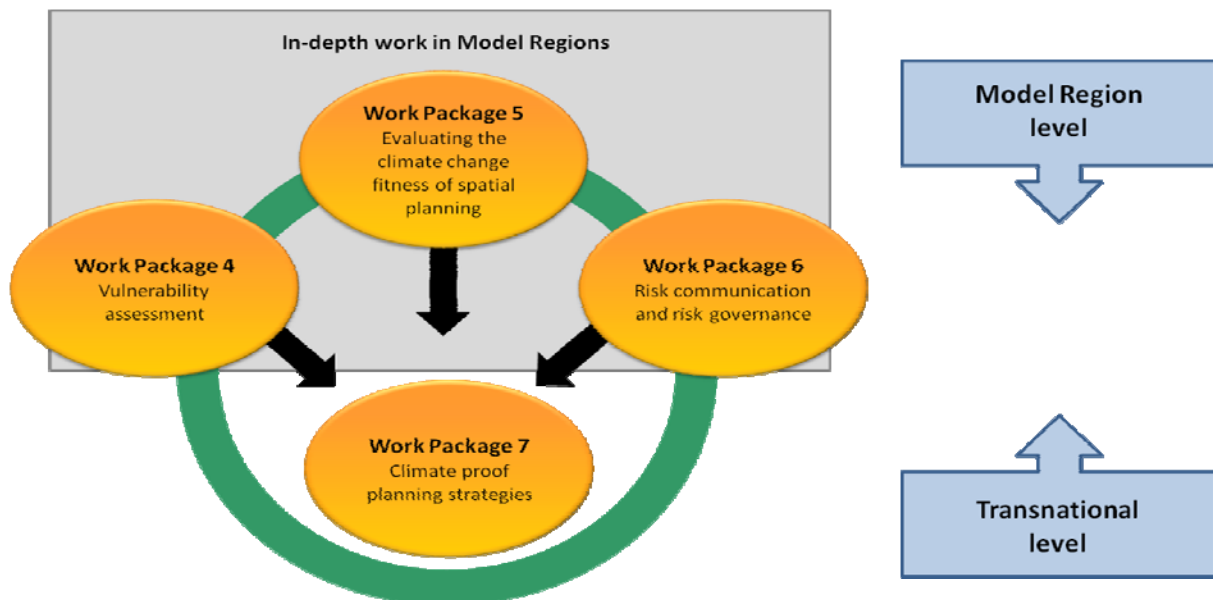


Figure 2: General project structure.

CLISP core activities have been implemented and core outputs generated in each of the following 10 **Model Regions** (mostly NUTS-3 scale) within the Alpine Space.

Table 2: Overview of the CLISP Model Regions per country and responsible Partner.

Model Region		Partner in charge
AT	Oberösterreich	Office of the Government of Upper Austria, Department of Spatial Planning
	Liezen	Office of the State Government of Styria, Department 16 – State Planning and Regional Development
	Pinzgau-Pongau	Regional Government of Salzburg, Department of Spatial Planning
DE	Berchtesgadener Land	Bavarian Ministry of Economic Affairs, Infrastructure, Transport and Technology, Department for Regional Planning and Development
	Miesbach	Bavarian Ministry of Economic Affairs, Infrastructure, Transport and Technology, Department for Regional Planning and Development
SLO	Gorenjska	Urban Planning Institute of the Republic of Slovenia (UIRS)
IT	Provincia Autonoma di Bolzano-Alto Adige	European Academy of Bolzano (EURAC)
	Comunità Monte Suol D’Aleramo and Comunità Montana Alta Val Lemme e alto Ovadese	Province of Alessandria
CH	Graubünden	Grisons, Office for Spatial Development
LI	Liechtenstein	Principality of Liechtenstein, Ministry of Environmental Affairs, Land Use Planning, Agriculture and Forestry

The following map shows the location of the CLISP Model Regions within the Alpine Space programme area.

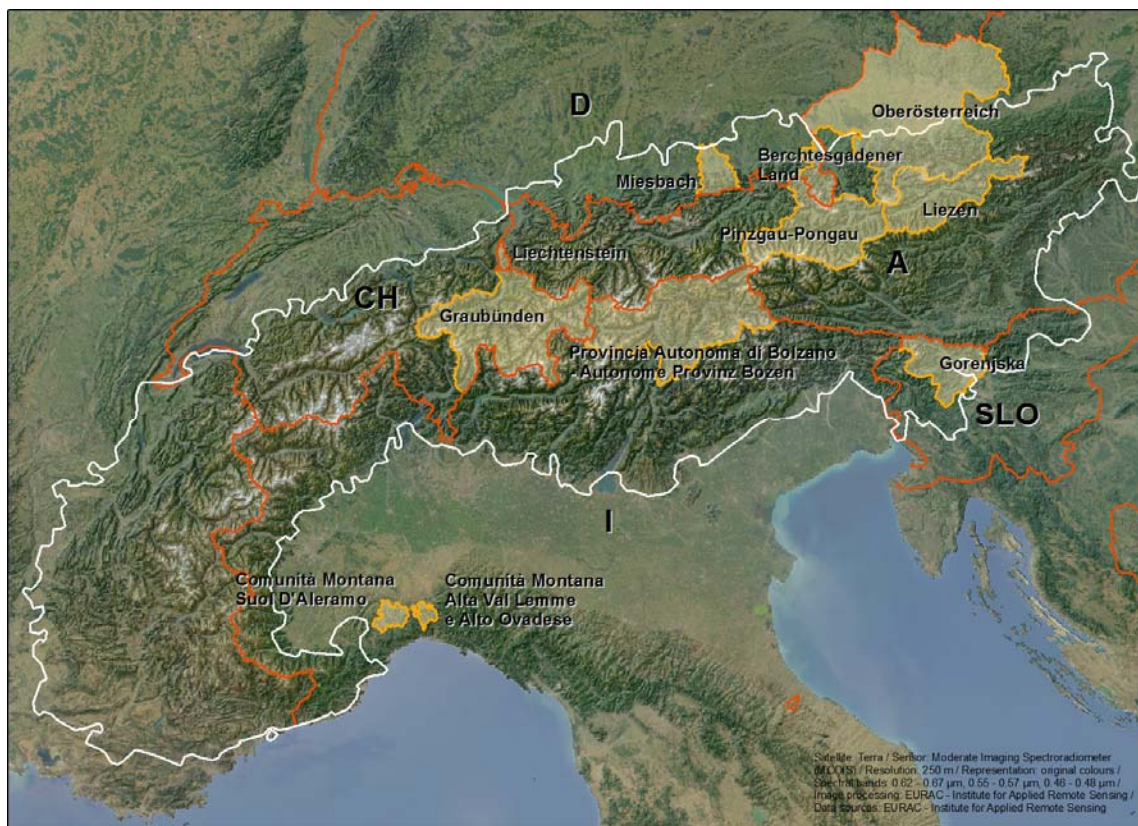


Figure 3: Overview of model regions.

WP4 – VULNERABILITY ASSESSMENT

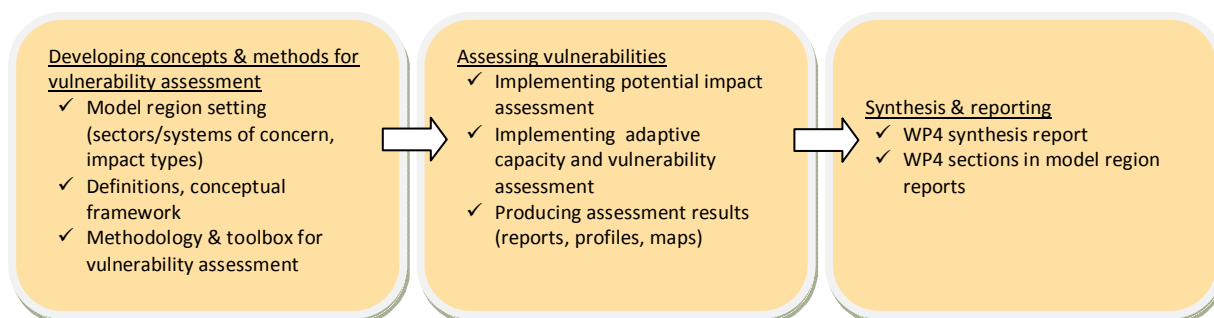
The main goal of WP4 was to develop a transferable concept, methodology and procedure of regional spatial vulnerability assessment to climate change and to assist the project's Model Regions in the set up of a vulnerability self-assessment. In particular, the exposure to climate change (climate scenarios), the sensitivity to climatic changes, and the potential impacts of climate change were identified and characterized as far as possible, using qualitative information as well as quantitative indicators. Besides potential impacts, for each Model Region an assessment was conducted about the capacity to adapt to climate change. By combining expected potential impacts and adaptive capacity, the main points of vulnerability in each Model Region to climate change were identified.

Across all Model Regions, impacts and effects of climate change on the following sectors/systems of concern to spatial development have been investigated within the vulnerability assessment, with the thematic foci in each Model Region being to some extent different and depending on the adaptation needs and priorities determined by Model Region stakeholders:

Table 3: List of systems / sectors of concern and relevant climate change impacts for the vulnerability assessment in the Model Regions.

Sectors/Systems	Climate change impacts (examples)
Build-up areas	Natural hazards (mass movement, floods), melting permafrost, glacier retreat, bio-climate and living quality in urban areas, change of snow cover etc.
Energy	Electricity production problems due to water deficiency, glacier retreat and higher sediment load after intense rain fall etc.
Forestry	Impacts on functionality and stability of protection forests, landslides, soil erosion, avalanches, forest fires, rise in forest line etc.
Agriculture	Reduction of crop productivity, effects on livestock, loss in agricultural productivity, soil erosion etc.
Water management	Water scarcity and supply, impact on downstream areas, change in traditional water management approaches etc.
Tourism	Snow reliability, winter season shortening, increased exposure of tourism infrastructure to natural hazards, economic viability of winter tourism etc.

Summary of the WP4 working flow



Main outputs

WP4 Synthesis Report – incorporating:

- ✓ Vulnerability Assessment Framework (vulnerability concept, process design)
- ✓ Climate Change Impact Chains
- ✓ Climate Change Projections for the Alps
- ✓ Manual for Climate Change Impact Assessment in CLISP Model Regions
 - PART 1 – Guidelines for the Model Regions
 - PART 2 – Toolbox for quantitative assessment
- ✓ Adaptive Capacity Indicator System

WP4 sections of Model Region Reports – incorporating:

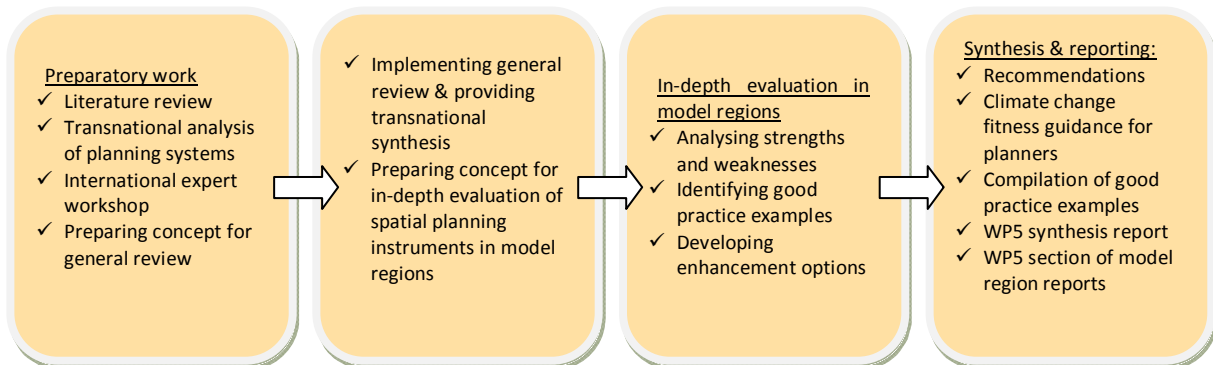
- ✓ Climate Change Projections for Model Regions
- ✓ Model Region Results of Vulnerability Assessment

WP5 – CLIMATE CHANGE FITNESS OF SPATIAL PLANNING

Within WP5 the “climate change fitness” of spatial planning systems was investigated by firstly, evaluating legal and institutional frameworks, secondly, identifying strengths and weaknesses, potentials and constraints of spatial planning instruments and procedures regarding climate adaptation, and thirdly, elaborating

enhancement options to improve adaptation capacities of spatial planning. Further goals were to compile good practice examples of climate-proof planning activities, to elaborate generally applicable evaluation criteria for climate change fitness and to develop a transferable tool for spatial planners to support climate adaptation.

Summary of the WP5 working flow



Main outputs

Assessing the Climate Change Fitness of Spatial Planning: A Guidance for Planners – incorporating:

- ✓ CLISP Climate Change Fitness Check List
- ✓ CLISP Evaluation Criteria for Climate Change Fitness

WP5 Synthesis Report – incorporating:

- ✓ Transnational Analysis of Spatial Planning Systems and Legal Frameworks
- ✓ General Review of Spatial Planning Systems concerning capacities for adaptation to climate change
- ✓ Transnational Summary of In-depth Evaluation in Model Regions
- ✓ Transnational Enhancement Options for Spatial Planning Systems
- ✓ Good Practice Examples of Climate Proof Planning

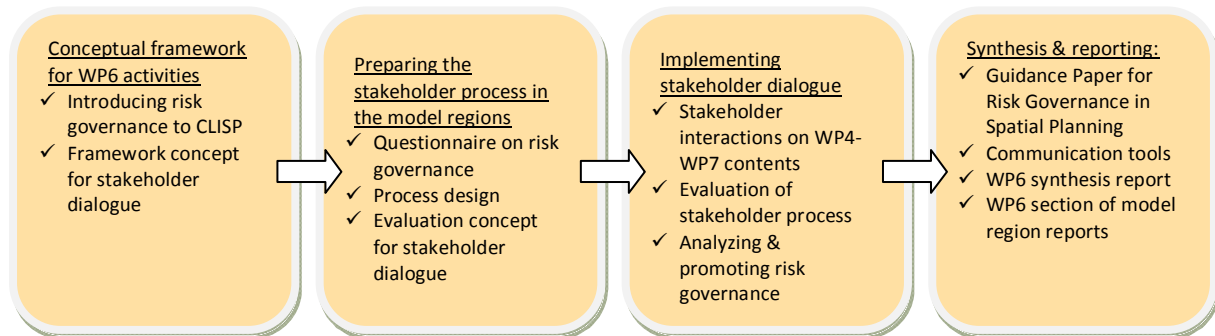
WP5 sections of Model Region Reports - incorporating:

- ✓ Results of In-depth Evaluation of Spatial Planning Instruments and Procedures in Model Regions
- ✓ Enhancement Options for Spatial Planning Systems in Model Regions

WP6 – RISK COMMUNICATION AND RISK GOVERNANCE

The main objectives of WP6 were to promote risk governance approaches to the management of climate related risks in spatial planning and to conduct stakeholder dialogue and risk communication activities. Existing risk management systems and the role of spatial planning in the management of climate-induced spatially relevant risks have been analyzed in the Model Regions. Experiences made and lessons learnt from stakeholder interactions have been evaluated in order to learn for future climate-related risk governance processes. WP6 also aimed at exploring opportunities of employing risk governance principles in planning procedures and contributing to increased consideration of climate change issues in spatial planning.

Summary of the WP6 working flow



Main outputs

Guidance Paper for Risk Governance in Spatial Planning - incorporating:

- ✓ Introduction to state-of-the-art of Risk Governance Concepts and Approaches
- ✓ Recommendations on the Role of Spatial Planning in Climate Change Risk Governance
- ✓ Guidance for Risk Communication and Stakeholder Involvement
- ✓ CC_{mountain} Fitness Guidance Tool

WP6 Synthesis Report - incorporating:

- ✓ Transnational Analysis of Climate Change Risk Governance and Spatial Planning
- ✓ Summary of Risk Communication Activities in Model Regions
- ✓ Test Report and Advancement of Communication and Decision Support (CDT) Tool
- ✓ Lessons learnt from Stakeholder Interactions

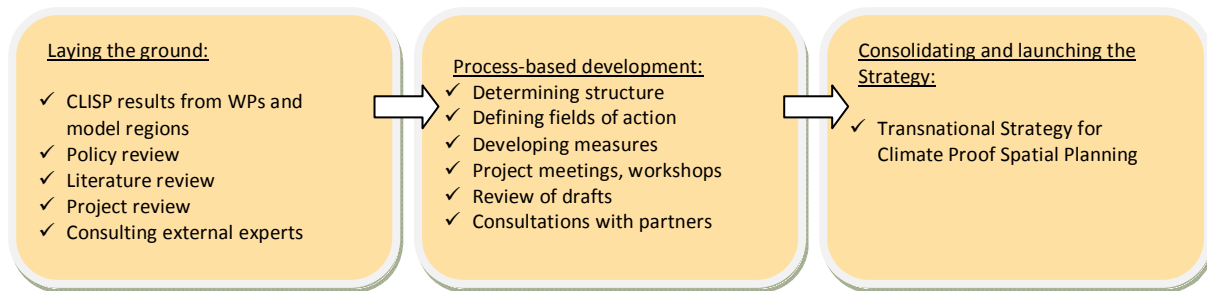
WP6 section for Model Region Reports - incorporating:

- ✓ Risk Communication Activities and Stakeholder Processes in Model Regions

WP7 – CLIMATE PROOF SPATIAL PLANNING

The focus of WP7 was to develop a new transnational strategy for climate proof spatial planning in the Alpine Space. The strategy paper includes an action guide on how to implement the recommendations and options for action on the national and regional levels as well as a compilation of instructive practice examples from the Alps. The development of the strategy built on the outcomes of the CLISP Work Packages 4 – 6 was embedded in an intense collaboration process among the entire Partnership. In order to build on a broad pool of expertise and experience that is available among spatial planning and adaptation experts in the Alpine space, a transnational expert network on climate change and spatial planning was established and has provided valuable inputs to the elaboration of the strategy.

Summary of the WP7 working flow



Main outputs

Transnational Strategy for Climate Proof Spatial Planning - incorporating:

- ✓ Mission Statement and Policy Background
- ✓ General Guiding Principles
- ✓ General and Specific Fields of Action
- ✓ Sets of Objectives
- ✓ Options for Action / Recommended Measures
- ✓ Guidance for Implementing the Strategy on National and Regional Levels
- ✓ Practice Examples

WP7 section for Model Region Reports - incorporating:

- ✓ Outlook on follow-up implementation processes

Overview of CLISP Main Deliverables

The following table provides a quick overview of the main reports that have been produced by the CLISP project. Each deliverable gathers and presents the main outputs produced within each Work Package. All results are available on the CLISP project website (www.clisp.eu). In addition, the Final Results Booklet is also available in print.

Table 4: The structure of deliverables of the CLISP project

WP	Reports, Deliverables	
	Transnational project level	Model Region Level
WP3	Final Results Booklet (printed)	
	Final Project Conference	
WP4	WP4 Synthesis Report	Model Region Reports – WP4 results
WP5	WP5 Synthesis Report	Model Region Reports – WP5 results
	Assessing the Climate Change Fitness of Spatial Planning: A Guidance for Planners (in four languages)	
WP6	WP6 Synthesis Report	Model Region Reports – WP6 results
	Guidance for Risk Governance in Spatial Planning	
WP7	Transnational Strategy for Climate Proof Spatial Planning in the Alpine Space	

The report at hand provides the transnational synthesis of the results of Work Package 4 ‘Vulnerability Assessment’.

B Executive Summary

Objectives

The overall goal of WP4 'Vulnerability Assessment' was to contribute to the improved knowledge and awareness on vulnerability of spatial development to climate change impacts of Alpine regions and to support the integration of the vulnerability concept as key aspect to adaptation into planning practice. This has been achieved by determining the vulnerability of all 11 CLISP model regions to climate change in selected sectors of major concern. In addition, some of the developed techniques for model regional vulnerability studies have been tested for assessing climate change impacts at supra-regional, that is alpine wide scale.

The WP4 outcomes, namely the sector- specific and generic vulnerability assessment for each model region represented the base for further analyses in WP5 and WP6 dealing with the climate change fitness of spatial planning and risk governance issues of each region.

Method and Results

The vulnerability assessment followed in general the concept developed by the Intergovernmental Panel on Climate Change (IPCC 2007) [for more information and reference please see chapter 2.1], see figure below.

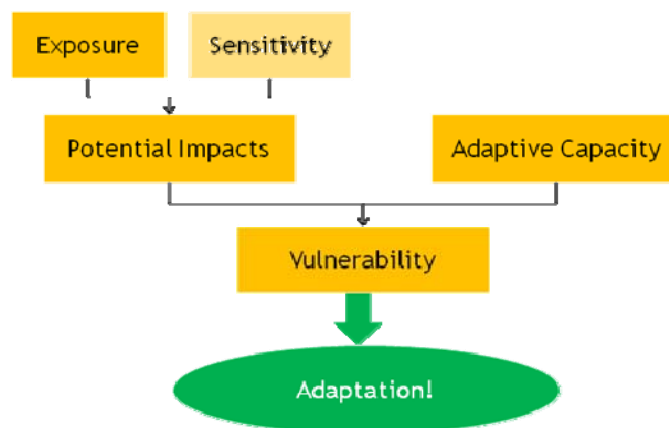


Figure 4: The IPCC vulnerability concept (after Isoard et al. 2008).

In order to identify sectors of major concern as well as most relevant impacts and in order to assess the individual components exposure, sensitivity and adaptive capacity the following working steps were carried out in cooperation with each model region:

- Development of a clear concept and framework as base for determining the vulnerability to climate change in Alpine regions.
- Determining key vulnerability indicators and elaborating a transferable, practice-oriented methodology for an integrated vulnerability assessment of Alpine regions
- Generating a transferable tool box for vulnerability assessment procedures in Alpine regions
- Assessment of potential impacts of climate change in the model regions accounting for quantitative and qualitative aspects
- Assessing the adaptive capacity of model regions to climate change at three levels
- Summary of generic vulnerability to climate change in model regions and generating vulnerability maps, profiles and descriptions

In the following the main pursued methodological steps are described and a summary of main outcomes is given.

Selection of sectors/system and definition of impact chains

A vulnerability assessment can never provide an insight into the entire system considered and thus needs to focus on selected systems/sectors. We used pre-existing local knowledge relating to sectors/systems that are particularly sensitive to climate change as a starting point for the selection of sectors to be investigated more closely. For all sectors and systems of concern so-called conceptual impact chains were developed. These impact chains allow for the structuring of cause-effect relationships and for the visualisation of interrelations and feedbacks. This supports the selection of the most relevant impacts, to which the entire set of subsequent assessment steps (potential impact and adaptive capacity) relates. The impact chain model for a given sector provides a checklist of issues to consider in the assessment, as well as a logical framework to check feedbacks among different effects of climate change, and system responses of the sector of interest.

Exposure – climate scenarios

Exposure includes all elements of expected climate change, e.g. increasing temperature, decrease of rainfall in summer, reduction of snowfall in winter. The results of an assessment of exposure have been derived from regional climate scenarios and includes different emission scenarios. Within the project CLISP, scenarios from the ENSEMBLE project have been processed. From the climate scenarios, averages of monthly and yearly temperatures and precipitation for the periods 2010-2030 and 2030-2050 were derived for use in subsequent analyses. These temperature and precipitation scenarios provide a picture of the possible evolution of the climate, which is essential for the assessment of potential impacts. In addition to precipitation and temperature, other climate variables such as the number of sun or misty days, ice and frost days, tropical nights, wind speed and humidity have been provided. Despite the difference in degree of reliability, an estimate of these variables under climate change may support the assessment of the severity of potential impacts on the different sectors of human activity considered within CLISP. For specific applications the climate scenarios needed to be downscaled to regional level, for example, by statistical downscaling methods. One such application conducted within CLISP has concerned the assessment of snow reliability under climate change scenario for the model regions: South Tyrol/Alto Adige, Salzburg, Bayern, Graubünden, and Gorenjska.

The Exposure studies revealed that the strongest warming in the Alps is expected for summer with a temperature increase between 1.3 °C and 3°C until 2050. In line with the temperature trend of the past, the central Alps are in most scenarios warming faster than the foothills of the Alps. Precipitation shows a quite heterogeneous picture. The clearest trend can be observed for summer, where five out of six scenarios show a trend to a slight decrease of precipitation of up to 55mm.

Assessment of the sensitivity to climate change and potential impacts in the model regions

A large part of the vulnerability to climate change can already be understood by analysing the status quo of the system with respect to the sensitivity of the system to climate and weather extremes now and in the past. In order to compile a picture as complete as possible concerning this current situation of the system quantitative and qualitative data have been gathered.

Qualitative information were collected in a structured and standardized way through expert interviews and stakeholder workshops. In WP4 of CLISP a manual has been developed containing guidelines for the assessment. For each sector of concern, the manual explains which type of information should be collected within a model region having in mind the impacts defined in the impact chain for each sector regarding:

- the general status quo (unfavourable/favourable),
- the general sensitivity to certain weather and climate conditions (lessons from the past),
- recent and potential future trends.

The manual also provides a guideline on recommended methods to develop dialogues with stakeholders and sectoral experts within the model region, aimed at effectively eliciting the necessary information

For selected impacts, simple indicators and models have been used to analyse the potential future impacts, based on regional climate scenarios. Impacts that can be modelled in a reasonably simple way within the scope of a generic vulnerability assessment include for instance, changes in the length of the growing season or changes in snow reliability at ski-resorts. In contrast, it is very complex to project the changes in severity and frequency of natural hazards, particularly the most common gravitational threats in mountain regions (such as rock-falls, debris flows, avalanches, landslides). The reason behind this is that these hazards are part of complex processes closely correlated with extreme precipitation events (an exception constitutes some processes that are directly linked to permafrost thaw). Assuming that there is a general tendency for an increase in such events, bad or worse case scenarios of existing hazard indication maps may hint at areas newly affected by certain hazards.

The EURAC CLISP manual identifies a set of 21 quantitative indicators to describe potential impacts of climate change. These quantitative indicators were computed upon request for the different model regions and are available for the whole Alpine region with the exception of those indicators that require local assessment (floods, avalanches, debris flows, rockfalls, snow reliability). However, for floods and rockfalls a simplified (quasi) pan-Alpine assessment has been conducted under specific assumptions.

Adaptive capacity assessment

In accordance with the main structure of the regional vulnerability assessment that follows a set of selected sectors and impacts of concern, three conceptual and pre-analytical levels of adaptive capacity with a decreasing degree of specificity have been assessed.

1. **The impact specific** adaptive capacity is related to particular climate change impacts, identified as either intermediate or endpoints of impact chains.
2. **The sector specific adaptive capacity** represents the adaptive capacity of a certain sector within a model region, but not directly linked to an individual potential impact as considered at the first level.
3. **The regional generic adaptive capacity** represents the adaptive capacity of a specific test case under consideration. The regional generic adaptive capacity is not directly linked to any specific

For each level of adaptive capacity various topic dimensions of relevance have been selected, from which a number of indicators and criteria have been identified to describe them. Each indicator is assessed and classified according to pre-defined thresholds and rules that are based on existing statistics (for example percentiles of values of all European regions for the same indicator) or on stakeholder and expert opinions. Concrete adaptation measures are additionally assessed according to their effectiveness, cost and degree of implementation within the model region.

Aggregation of components and vulnerability assessment

In this final step the results of the various assessments of the components of potential impacts and adaptive capacity were aggregated to form an overall vulnerability description per sector of concern. This aggregation step is carried out at two conceptual levels, the impact specific and the sector specific level.

Main findings of the overall vulnerability assessment are:

- The potential increase of natural hazards is a major concern for the model regions. Even if the uncertainty of this impact is very high the risk of damage might increase in many regions also due to an expansion of areas for settlements.
- Decrease in water availability and the negative consequences on agriculture, forest (forest fires) and energy production (hydropower and cooling power plants) will be an issue for regions which are dry already now (inner-alpine valleys, southern parts).
- Decrease in snow reliability is threatening low-lying ski resorts, mainly in Austria and Bavaria.

- Adaptation shows a very heterogeneous picture. Missing measures are often more the non-technical measures (legal, institutional, communication). High vulnerability arises often more from missing adaptation options than from particular strong climate change.

The visualisation of the results of the vulnerability assessment are crucial for integrating it into the risk dialogue with stakeholders. At the same time it is a challenge since a number of crucial aspects that determine the vulnerability are of qualitative nature and have no geo-spatial reference for mapping them. In addition to the qualitative description and the classification of individual impacts and sectors we provide a summary of the assessment results in figures and maps as far as possible.

A cross-model region comparison of climate change effects

The CLISP model regions selected different sectors of concern. In general, the vulnerability of different sectors to climate changes varies considerably.

In the case of agriculture, the Southern, more aridity-prone areas (e.g. Alessandria) tend to be vulnerable to climate change although adaptation is already ongoing which limits potential negative effects. In the north of the Alps and at higher elevations, positive effects of climate change may represent opportunities for expanding agriculture although adequate adaption needs to be developed. Aridity and pests and diseases are threats in the long term. It seems that they latter occurred more frequently during extreme events already within the last years.

In the case of built-up areas, natural hazards represent the main concern and, in some areas (e.g. the Austrian regions or Bavaria), floods moves more in the focus of attention since they appear to be more frequent in the last years. Last years' flood and debris flows within Slovenia indicate the possibility of an intensification of these hazards. South Tyrol and Alessandria seem to be well prepared for floods. Current analysis and planning systems are assessed to be sufficiently precautionary to accommodate for an intensification of these phenomena. A general issue about natural hazards is that land development has yielded conditions of risk by accumulating assets in threatened areas even under present hazards in all model regions. Therefore, in comparison to this cause for increasing risk values, adaptation to climate change often appears as a minor issue.

Energy demand is consistently projected to remain stable, as heating demand will decrease but cooling demand will increase. A threat to all model regions concerns hydropower and, in some regions (e.g. Slovenia) power plant cooling, which may suffer from reduced water availability.

Forestry will likely face increased fire hazards in the South of the Alps, while this issue will remain less relevant in the North. Water availability may become an issue in more arid regions of the Alps, while the potential for forest expansion and diversification given by higher temperatures may be out balanced by additional stress (aridity, weather extremes and pests/diseases) induced by climate change. The adaptive capacity appears highly diversified and not always adequate also considering the different economic relevance of the sector in the different model regions.

The Health sector is more and more challenged by heat stress in urban areas. Adaptive capacity measures are partly already in place, namely those dealing with early warning and emergency response (most of these measures having been taken after the hot summer in 2003). Measures dealing with mitigation and preparedness such as the reduction of heat island effects that need to be integrated into long term spatial planning have only been implemented to a limited extend.

Snow reliability appears a strong concern for all model regions where winter tourism is important. The issue is particularly critical in the South of the Alps and at lower elevations. However, adaptation activities to address these threats are already being implemented namely by diversifying the supply of the relevant tourist destinations.

The main concern about water is its future availability. However, a broad range of adaptation measures is being developed in all model regions. Concerns in the future will more likely arise from increasing water consumption by the various users (ecology, agriculture, industry, energy...) and potential conflicts between them. This includes also the question of providing water for upstream versus downstream users.

Testing the applicability of the assessment methodology to coarser scales

The methodology proposed within project CLISP relies substantially on the joint interpretation of some quantitative and many qualitative elements of knowledge. One general issue with climate change impact studies is the lack of hard figures based on which to evaluate scenarios. In particular, potential impact indicators computed on the basis of climate scenarios within CLISP may only provide hints for certain trends and cannot be used as a hard quantitative statement on the evolution of different aspects of the Alpine climate. Nevertheless, general trends that emerge from an overall reading of these indicators are reasonably consistent with evidence of climate variations and currently observed trends.

Some potential impact indicators were designed for assessment at a site-specific level (snow reliability natural hazards). For these indicators, the project has highlighted the difficulty to bring together data which are available, but sparse and heterogeneous, into a single consistent frame. This suggests that the main limitation in the application of such indicators at coarser scales is the construction of adequate databases of weather variables, morphology, and other physical variables.

All other potential impact indicators were designed to be computed at the pan-Alpine level, which suggests that they could be used for coarser scale assessment without particular limitations. Growing season, wine credibility, timberline elevation, forest fire hazard, heating/cooling energy demand, tourism and health related climate indicators retain a meaning for the whole Alpine region, as they highlight trends both in time and space that help supporting an assessment also at coarser scale.

However, an interpretation of indicators of potential impact can only be done on the basis of other evidence from a qualitative inspection of the different contexts, as was done for each model region; the mere use of computed indicators is still too imprecise and unreliable to achieve an assessment at pan-Alpine level. Therefore, the frame for the assessment of potential impacts proposed within CLISP can be considered suitable for the whole Alpine region, provided that an appropriate qualitative assessment is also conducted, which cannot be automated starting from presently available data.

The adaptive capacity assessment relies heavily on region-specific information. An aggregation of adaptive capacity indicators beyond national borders is not useful. From an institutional point of view the adaptive capacity of the overall GAR should look at strengths and weaknesses of the Alpine Convention and should scrutinise relevant policies and programs of the European commission such as the Alpine Space European Territorial Cooperation.

C WP4 Synthesis Report

1 Introduction

1.1 Objectives and scope

Main objective of WP4 'Vulnerability Assessment' is the determination of vulnerability of the CLISP model regions to climate change. WP4 contributes to the improved knowledge and awareness on vulnerability of spatial development to climate change impacts of Alpine regions and supports to promote the integration of the vulnerability concept as the key to adaptation into planning practice

The WP4 outcomes, namely the sector- specific and generic vulnerability assessment for each model region represents the base for further analyses in WP5 and WP6 dealing with the climate change fitness of spatial planning and risk governance issues of each region.

The following are the model region relevant working steps carried out in WP4:

1. Development of a clear concept and framework as base for determining the vulnerability to climate change in Alpine regions.
2. Determining key vulnerability indicators and elaborating a transferable, practice-oriented methodology for an integrated vulnerability assessment of Alpine regions
3. Generating a transferable tool box for vulnerability assessment procedures in Alpine regions
4. Assessment of potential impacts of climate change in the model regions accounting for quantitative and qualitative aspects
5. Assessing the adaptive capacity of model regions to climate change at three levels,
 - a. The potential impact level
 - b. The sector level
 - c. The model region generic level
6. Summary of generic vulnerability to climate change in model regions and generating vulnerability maps, profiles and descriptions.

1.2 Structure of the report

While specific assessments are provided in individual model region reports, this report aims at bringing together the information and knowledge collected within project CLISP, and to draw some synthesis considerations from the comparison of different model regions. In this report we provide a systematic description of the theoretical concepts on which the assessment has been built, and the methods used for identifying potential impacts, adaptive capacity and, eventually, vulnerability of model regions to climate change. Chapter 2 is devoted to the concept of vulnerability assessment; chapter 3 describes the climate scenarios developed for the Alpine region and used as a basis to assess expected changes in the model regions; chapter 4 provides an overview of vulnerability assessment results for the sector considered in the project; chapter 5 includes the executive summaries of the model region reports limited to WP4 activities; finally, chapter 6 attempts an assessment for the whole Alpine region grounding on the considerations emerged in the different model regions and in different sectors (Figure 3).

2 Concept for Vulnerability Assessment

2.1 Framework, terms and definitions

According to the Intergovernmental Panel on Climate Change (IPCC 2007), vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, the sensitivity and adaptive capacity of that system.

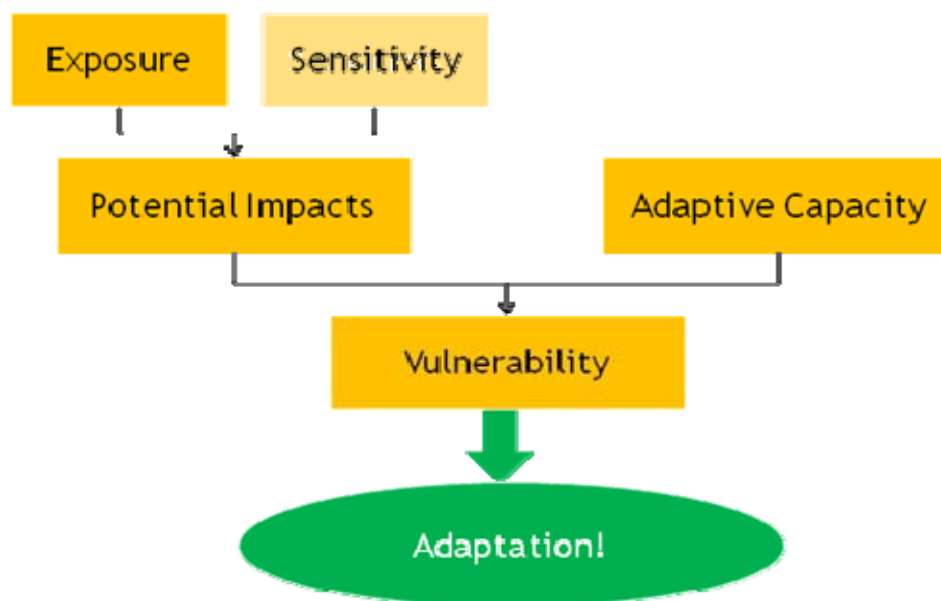


Figure 5: Visualisation of the single elements of the IPCC vulnerability concept (after Isoard et al. 2008).

In CLISP, we consistently strive for the application of the IPCC concept, being aware that a variety of differing concepts exist in other science disciplines, particularly in disaster risk assessments. The interpretation of the IPCC concept needs to match the CLISP requirements for an assessment of 'regional vulnerability' to climate change. Four elements have to be studied to assess vulnerability: Exposure, Sensitivity, Potential Impact, and Adaptive Capacity (see figure 5). Statements on these elements can be either quantitative (e.g. expected increase in temperature by 2°C – 2.5°C) or qualitative (e.g. high sensitivity of elderly people towards health problems caused by heat waves). The regional vulnerability assessment within CLISP follows a step-by-step approach considering all the four elements of vulnerability.

Exposure describes elements of expected climate change, e.g. increasing temperature, decrease of precipitation in summer, reduction of snow fall in winter. Exposure is a variable that is supposed to change in the future.

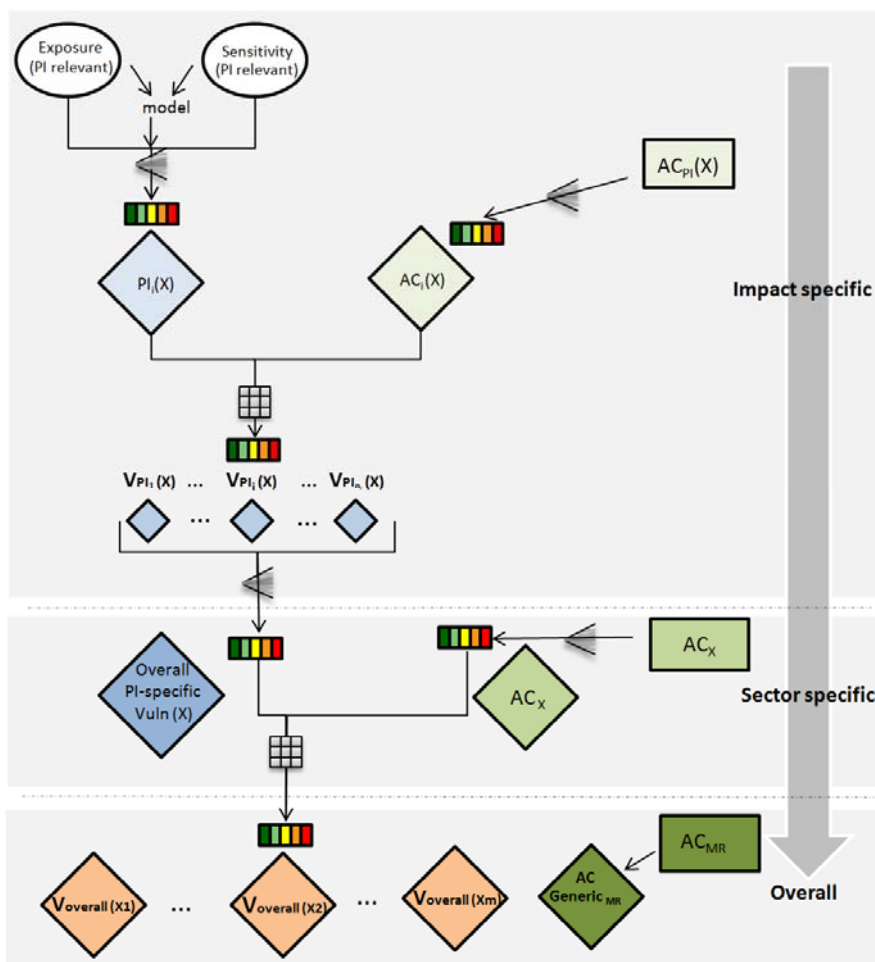
Sensitivity describes how a sector or system will react to a certain exposure in principle (e.g. winter tourism to decreasing snow fall). An assessment of the status quo of a given system in the MR (e.g. critical or noncritical current situation) represents an important part of the sensitivity description. This should also take into account the recent climate situation (e.g. already existing scarcity of snow) and other external drivers (fewer tourists, more elderly visitors). Also lessons learnt from the past can help to understand region-specific sensitivity. For instance how certain sectors or part of the eco-system performed during the hot summer 2003, how they were affected by flood events in 2002 or by the exceptional warm winter in 2005/2006.

Potential Impact is the expected impact to a given exposure (in the future) on a given system taking into account its sensitivity in its actual state. The potential impact can be a direct impact (e.g. decreasing snow reliability for winter sports due to decreasing snow fall) or an indirect impact with a long cause-and-effect chain (e.g. decrease in yield due to lower water availability due to higher evapotranspiration due to increasing temperatures).

Adaptive Capacity is the ability of a system to adjust to climate change, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC, 2007). Adaptive capacity points to the future (the capacity to adapt to future climate change), but is mainly a variable of the current state of the sector or system. Potential changes in adaptive capacity in future are considered where applicable but remain highly speculative.

Finally, the **vulnerability** (see definition above) represents the synthesis of the four elements with a focus on the potential impact and adaptive capacity of a given sector or system to a given exposure. A system with a high adaptive capacity will be less vulnerable (more resilient and better prepared) than one with a lower adaptive capacity. Similarly a low potential impact results in a low vulnerability. Statements on vulnerability are highly qualitative taking into account all quantitative and qualitative information available for the other four elements.

One of the limitations of the theoretical frameworks for vulnerability assessments is the lack of information about the aggregation of the individual framework components. Therefore EURAC has developed an own systematic for combining the outputs of the potential impact and adaptive capacity assessments at the relevant conceptual levels: region, sector and impact. Further details of the method, diagrammatically illustrated in Figure 6, are provided hereafter.



Legend

- PI:** potential CC impact
- AC:** adaptive capacity
- model:** quantitative indicator out of the tool box
- Combination by adjustable rule (e.g. weighted mean)
- Aggregation by pre-defined rule (e.g. matrix)
- Outcome of aggregation and combination (three-class value)
- Composite indicator
- Adaptive capacity indicators
- i:** Specific potential CC impact as numbered in the guidelines
- X:** Specific sector

Vulnerability Assessment

- Indicator based system
- Five-class valuation (high, medium, low) for both qualitative and quantitative indicators
- Five-class valuated indicators are aggregated (through matrix for example) to produce composite indicators (by specified rules).
- The result is a composite indicator evaluated again in 5 classes.

Figure 6: Work flow - evaluation of the overall vulnerability of the Model Regions.

2.2 Process design for vulnerability assessment in model regions

2.2.1 User needs: selection of systems/sectors of concern and identification of most relevant types of impact

Starting point for the assessment of each model's region vulnerability to climate change represents a the selection of sectors of concern by model regions.

Model region priority sectors are selected by the MRs out of the following identified list of major sectors and sub-sectors of concern in the alpine region.

The assessment gives a first impression of relevant climate change impact chains and contributed to the elicitation of the sectors of concern and related impacts.

Table 5: List of systems / sectors of concern for the selection by the Model Regions

System/Sectors	Sublevel
Built-up areas/land development	settlement areas
	transport infrastructure
	supply and disposal infrastructure
Water management	water supply (surface and ground water)
	water ecology
	flood control
Forestry	protection forest
	production forest
	welfare forest
	recreation forest
	protected forest / forest biodiversity
Agriculture	pasture/meadow
	livestock
	arable land
	horticulture, fruit growing, viticulture
Energy production	fossil fuel
	hydropower
	solar power
	wind power
	biomass
Tourism and recreation	winter tourism
	summer tourism
	wellness tourism
	culture tourism
	congress tourism
	recreation
Health	well being of population/population groups
Nature protection	genetic diversity
	diversity of species
	habitat and ecosystem diversity
	protected area management

2.2.2 The implementation of the framework for the vulnerability assessment in practice

One of the limitations of the theoretical frameworks for vulnerability assessments is the lack of information about the aggregation of the individual framework components. Therefore EURAC has developed an own

systematic for combining the outputs of the potential impact and adaptive capacity assessments at the relevant conceptual levels: region, sector and impact.

Starting point for the assessment of each model's region vulnerability to climate change represents a selection of sectors of concern by model regions. For each of these 'sectors of concern' so-called impact chains were developed. These impact chains visualise the potential consequences due to variations in climate as direct or indirect and positive or negative impacts as well as their interlinkages and dependencies. As an example Figure 7 shows the developed impact chain for the sector tourism.

Based on these impact chains and with support of the model regions most relevant potential impacts were selected. The selected sectors of concern and the identified most relevant potential impacts constitute the skeleton for the further assessment of the framework components 'Potential Impact' and 'Adaptive Capacity'.

In the following the developed methodology and systematic how to assess the individual framework components and the overall MR's vulnerability is explained.

Climate change impact chains – Tourism

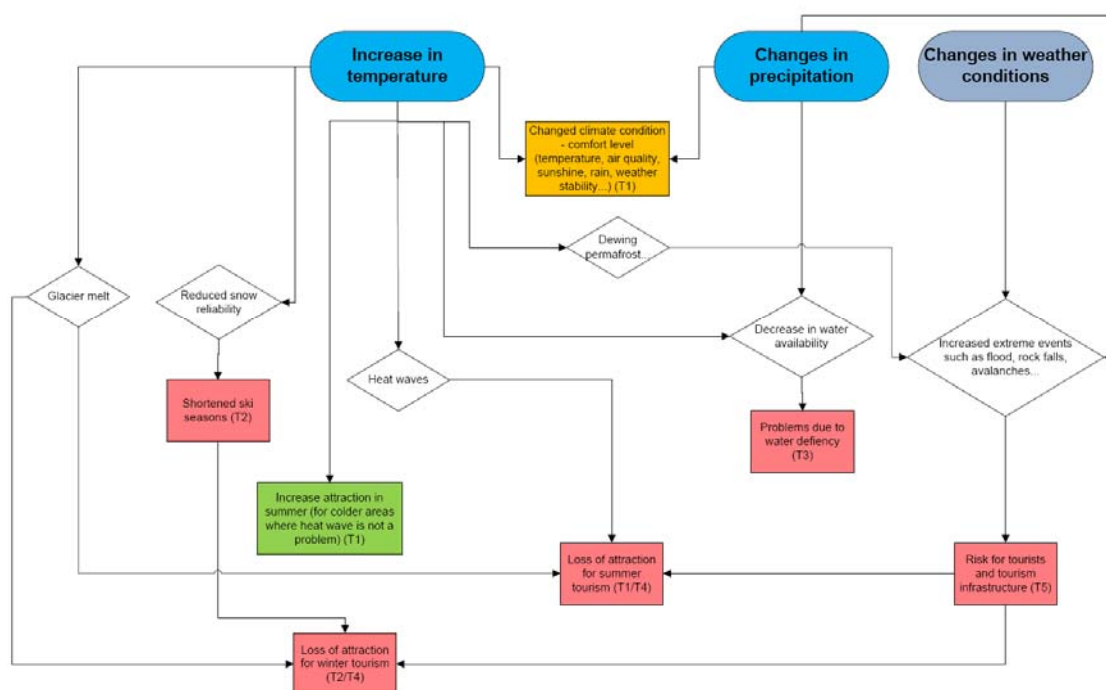


Figure 7: Impact chain for the sector tourism

Exposure

Within CLISP, EURAC provides quantitative scenarios from six regional climate model runs for the most important climate elements with a spatial resolution between 10x10km to 25x25km for the time slices 2001-2030 and 2031-2060.

Sensitivity

In CLISP we assume that the sensitivity is a system variable in the MR and that refers to the current situation. The quantitative part of sensitivity is implicitly considered in the tools (indices, models) EURAC provides for impact assessment. The qualitative aspects of sensitivity is assessed by the MR (in collaboration with EURAC) following the guidelines and criteria developed within the WP4 Manual Part 1 'Guidelines for the model regions' (see attached document).

Potential impact

Within CLISP EURAC provides a set of tools to assess the earlier selected impacts quantitatively and carries out the computation for interested MRs. Other potential impacts that cannot be simulated by models are assessed qualitatively by the MR in collaboration with EURAC. In order to structure and categorise consistently the assessment exercises within CLISP, EURAC has designed tables for which predefined potential impacts on selected systems of concern in Alpine regions have been collected.

The indicators used for the assessment of potential impacts are summarized in the following Table 6.

Table 6: List of quantitative potential impact indicators calculated for the MRs

ID	NAME	RELEVANCE FOR SECTOR	BRIEF DESCRIPTION
11	<i>Growing season</i>	Agriculture Forestry	The Growing season (GS) is defined as the period of the year when the daily mean temperature is above 5°C.
12	<i>Growing degree unit (GDU)</i>	Agriculture	Growing degree unit (GDU) or Growing degree day (GDD) is a commonly used measure of heat accumulation to predict the life stages of insects, date of flowering or crop maturity.
13	<i>Potential evapotranspiration (PET) after Thornthwaite</i>	Agriculture Forestry Tourism Water management	Potential evapotranspiration (PET) is defined as the amount of evaporation that would occur if a sufficient water was available. A dryland is a place where annual potential evaporation exceeds annual precipitation.
14	<i>Meteorological water balance</i>	Agriculture Forestry Tourism Water management	In the meteorological water balance (MWB) = Precipitation - Potential EvapoTranspiration (PET), often PET may be higher than Precipitation (this is the rule south of the Alps); the MWB in itself should not be taken as an indicator of water availability, but rather of meteorological conditions where rainfall may, or may not, be limiting for the growth of certain plants, hence irrigation may be required. It should be only read in relative terms to compare climatic water regimes over large regions. Variations under climate scenarios indicate that water may become more limiting for plant growth. If one is interested in assessing potential water scarcity, a soil water balance should be calculated with reference to specific crops.
15	<i>Drought index (dMI) after De Martonne</i>	Agriculture Forestry Tourism Water management	A drought index expresses the ratio between temperature and precipitation. Less precipitation means increased drought.
16	<i>Crop suitability for wine - the Huglin-Index</i>	Agriculture	The Huglin Index reflects the growing credibility of different grapes sorts.
17	<i>Flood prone areas at hazard index level</i>	Agriculture Build-up areas / land development Forestry Tourism Water management	Within the CLISP project flood prone areas will be detected by flood modelling carried out at hazard index level of detail (Petraschek and Kienholz 2003). The main scope of an analysis at this level of detail is the detection and the classification of possible hazard processes.

ID	NAME	RELEVANCE FOR SECTOR	BRIEF DESCRIPTION
18	<i>Avalanche prone areas at hazard index level</i>	Agriculture Build-up areas / land development Forestry Tourism Water management	A snow avalanche is a snow mass with usually a volume greater than 100 m ³ and a minimum length of 50 meters that slides rapidly downhill. Models for the delimitation of avalanche prone areas are divided into models for identification and the delimitation of avalanche release areas and the calculation of the runout distance and the modelling of the deposition areas.
19	<i>Rockfall prone areas at hazard index level</i>	Agriculture Build-up areas / land development Forestry Tourism Water management	The activity of rockfall processes depends on geological, tectonic and topographical factors, but rockfall processes are also sensitive to meteorological conditions. One climate change phenomena that influences rockfall activities is the degradation of permafrost. Therefore, those areas that are located in rock faces underlying permafrost conditions and could represent starting points for rockfall process are considered to be climate sensitive.
110	<i>Torrential process prone areas at hazard index level</i>	Agriculture Build-up areas / land development Forestry Tourism Water management	We use the term "torrential processes" for debris flow processes. A debris flow is a fast or slow flowing mixture of water and sediments in high concentration, which often moves several surges. The deduction of the most critical factors for hazard assessment under changing environmental conditions is relatively obvious: considering natural hazards related to precipitation the most relevant changes in the environmental parameters due to climatic changes are to be expected in the intensity/frequency relation of precipitation events (rainfall, snowfall).
111	<i>Number of cooling days (CD)</i>	Energy	The number of cooling days (CD) describes the number of days per year with a mean daily air temperature above the cooling temperature threshold (Kühlgrenztemperatur).
112	<i>Cooling degree day (CDD)</i>	Energy	The indicator CDD is used to describe the energy demand needed to cool a building.
113	<i>Number of heating days (HD)</i>	Energy	The number of heating days (HD) describes the number of days per year with a mean daily air temperature below the heating temperature threshold (Heizgrenztemperatur).
114	<i>Heating degree day (HDD)</i>	Energy	The indicator HDD is used to describe the energy demand needed to heat a building.
115	<i>Forest line - isotherm</i>	Forestry	Körner (1999) describes the temperature as most plausible factor amongst all climate parameters to explain the treeline altitude.
116	<i>Nesterov Index (NI) for fire danger rating</i>	Forestry	The Nesterov Index is a simple fire danger rating created in Russia in 1949.
117	<i>Climate indices and indicators for heat stress</i>	Health	Directly derived climate indices/indicators as additional information/input considering heat stress.

ID	NAME	RELEVANCE FOR SECTOR	BRIEF DESCRIPTION
118	<i>Climate indices and indicators for summer tourism</i>	Tourism (summer)	Directly derived climate indices/indicators as additional information/input in combination with the region of interest.
119	<i>Climate indices and indicators for winter tourism</i>	Tourism (winter)	Directly derived climate indices/indicators as additional information/input in combination with the region of interest.
120	Tourism Climate Index (TCI)	Tourism	The Tourism Climate Index (TCI) is a combined index which can be considered as climatic suitability for general summer tourism purposes.
121	Line of artificial snow reliability	Tourism (winter)	The line of artificial snow-reliability indicates the height of artificial snow-reliability.

An overview and detailed descriptions of the tools and indicators developed for the quantitative assessment is given in the Annex.

The results and elaborated trends of the quantitative assessment for each indicator in combination with the climate sensitivity of the sector constituted the base for the judgment of each potential impact.

The adaptive capacity of the sector as a whole was elicited from the combination of judgments on “sector background” and “sector measures” as discussed above. Finally, a combination of potential impact and adaptive capacity was elicited for the sector as a whole and for each potential impact according to the combination rules of Figure 10.

Adaptive Capacity

The evaluation of the Adaptive Capacities of each MR has been considered at three levels with decreasing degree of specificity (see Figure 8). For each level a number of indicators and criteria allows for an assessment of the adaptive capacity. To a certain extent the information required for the assessment indicators/criteria have already been surveyed by WP5, WP6 or through WP4 within the context of the Manual for the climate change impact assessment. Others require additional compilation by the model regions.

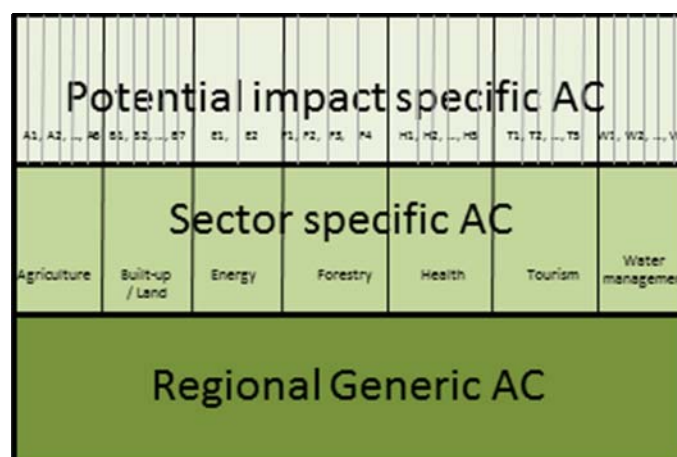


Figure 8: The three levels of specificity for Adaptive Capacity assessment in CLISP Model Regions.

Evaluation criteria

There are two basic principles for the implementation of the AC evaluation process:

- **The evaluation is based on an indicator/criteria evaluation system**
 ‘Indicators/criteria’ may represent quantitative data or qualitative or reflect – in the case of adaptation actions – the effectiveness and costs of measures. The general effectiveness and cost of each indicator has been evaluated beforehand with help of experts and stakeholders. They remain the same for all model regions (with a positive value for low costs and a negative value for expensive measures). However, the degree of implementation of each measure is model region specific. The degree of implementation is the main base for evaluating the indicator for the model region, however, where appropriate this value has been changed. For example if the measure might have counter effects or is very expensive such as the investment in snow canons to overcome snow unreliability.
- **The evaluation is following a five-class approach**
 The rules for the evaluation and aggregation of the indicators, criteria and parameters (as composite values) are either pre-defined or handled with flexibility:
 - Aggregation by pre-defined rule: The aggregation of indicators and parameters (or composite indicators) is inflexible and follows pre-set rules. This rule is applied when indicators from the adaptive capacity and the potential impact assessments are aggregated.
 - Combination by adjustable rule: The ‘combination’ of indicator/criteria values and characteristics (or qualitative information) or of composite indicator values is handled with flexibility in order to consider MR-specific particularities. This approach is followed for the aggregation of indicators only dealing with indicators of one of the assessment areas: within the adaptive capacity assessment or within the potential impact assessment. As standard starting point the indicators are aggregated without weighting factors and following simple average calculation rules. When the results do not reflect the reality in an appropriate way they may be overruled by introducing expert judgments and weighted means (weighting of single input parameters based on discussion with the MRs). In these cases a short explanation is given why and in what way the standard evaluation rules have been changed.

The result of both types of evaluation is evaluated by using a five class approach, the meaning of which for the PI and the AC assessment is shown in Figure 9.

<i>Colour code</i>	<i>Meaning – potential impact</i>	<i>Meaning – adaptive capacity (for measures)</i>	<i>Meaning - vulnerability</i>
++	apparent positive impact	Very high (already implemented to a large extend)	Very low
+	possible positive impact	High (partly implemented)	Low
0	no likely significant effect	Moderate (planned, decision for implementation open)	Moderate
-	possible negative impact	Low (in planning but not implemented yet)	High
--	apparent negative impact	Very low (not implemented and no implementation planned)	Very high

Figure 9: Legend of the colour codes of potential impact and adaptive capacity.

The matrix for the aggregation steps following pre-defined rules is shown in Figure 10.

		adaptive capacity				
		--	-	0	+	++
potential impact	--	--	--	--	--	-
	-	--	-	-	0	0
	0	0	0	0	0	0
	+	0	0	+	+	+
	++	+	++	++	++	++

Figure 10: Matrix for the aggregation steps (adaptive capacity and potential impact).

Principles of the work flow for the overall vulnerability assessment

Potential impact relevant exposure and sensitivity are assessed for each MR in two ways. One is the quantitative model provided by EURAC. The other is qualitative assessment based on the information provided by MRs (result of the WP4 Manual for the climate change impact assessment) and experts' knowledge. The quantitative and qualitative assessment are aggregated by adjustable rules. The outcome is an evaluation within a five class system for each potential impact.

This value for potential impact will be combined with the value for **potential impact relevant adaptive capacity** (see description of the AC concept above) to generate the **impact specific vulnerability** of this sector within one region. This procedure is repeated for impact specific vulnerabilities for all potential impacts and further aggregated through the adjustable rule to generate the overall impact specific vulnerability.

The outcome is again an evaluation within the five class system. This value will be combined with the classified value for sector specific adaptive capacity by pre-defined rule. The result is the overall vulnerability of a certain sector within a certain MR.

The above described procedure is done for all relevant sectors within each MR. For each MR, the final assessment will be a valuation for all relevant sectors and the regional generic adaptive capacity. On this final level of assessment, the indicators will not be further aggregated.

This schematic way of assessing vulnerability allows - in certain limits - a direct comparison of the current situation in the model regions. However, it will always be completed by a more narrative description based on the MR specific analyses. Only the combination of both, the results of the indicator/criteria based system together with the narrative description will provide a good general overview about the MR's vulnerability to climate change.

3 Climate Scenarios

We summarize here the results for climate change scenarios as part of EURAC’s contribution to Action 4.2: determining vulnerability indicators & elaborating assessment methodology within WP4 ‘Vulnerability Assessment’ of the project CLISP.

3.1 Methodology

The presented climate change scenarios were calculated on the basis of eight climate scenarios which are freely available from national sources (Umweltbundesamt Deutschland) or EU-projects (FP6 ENSEMBLES) (see Table 7). The single scenarios differ in:

- the underlying SRES emission scenario (B1 – low emission scenarios, A1B moderate/high emission scenario)
- the driving General Circulation model (GCM) (ECHAM5, HadCm3, ARPEGE)
- the applied Regional Climate Model (RCM) (REMO, CLM, RegCM3, ALADIN)

Table 7: Regional climatic models (RCMs) and their driving global circulation models (GCMs) with corresponding scenarios

	Regional climate model (RCM)	Driving model (GCM)	Scenario	Region
1	CLM (18km) (Consortial)	ECHAM5 (A1B)	A1B	Europe
2	CLM (18k.m) (Consortial)	ECHAM5 (B1)	B1	Europe
3	REMO-UBA-M 2006 (10km)	ECHAM5 (A1B)	A1B	Germany / Northern alps
4	REMO-UBA-M 2006 (10km)	ECHAM5 (B1)	B1	Germany / Northern alps
5	REMO (25km) (Ensembles)	ECHAM5 [r3] (A1B)	A1B	Europe
6	RegCM (25km) Ensembles)	ECHAM5 [r3] (A1B)	A1B	Europe
7	CLM (25km) (Ensembles)	HadCM3Q0 (A1B)	A1B	Europe
8	Aladin (25km) (Ensembles)	ARPEGE	A1B	Europe

These eight scenarios reflect a large range of possible future climate conditions. Accordingly, results can differ greatly depending on GCM, RCM and emission scenario. Since ECHAM5 is widely regarded as a kind of standard driving GCM for Europe most scenarios rely on this GCM (1-6). Results for RCMs driven by other GCMs (7,8) may deviate significantly. Where this applies, we interpret all scenarios as well as the ECHAM5 driven RCMs only.

All parameters were calculated in terms of an absolute change from the reference period (1961-1990) to the 20 year mean of two future periods (2011-2030; 2031-2050). Results are presented as maps (temperature and precipitation only) and as graphs with averaged values for the alpine region.

Climate projection represent future possible scenarios modelled for a large range of meteorological parameters. All modelled projections deal with a certain level of uncertainty, which is particularly true for

complex climate models. Amongst the range of meteorological output parameters temperature is the most reliable one. Nevertheless also the parameter temperature exhibits a great variance at a coarse scale level that even increases when looking at the finer regional scale.

Precipitation projections are subject to much greater uncertainty. Climate models are, for instance, not very good in reproducing convective precipitation events, which could in the Alps make up a considerable part of summer precipitation.

While temperature or precipitation represents quite stable parameters, the variations and uncertainties of the values of other parameters such as wind speed, humidity or cloud cover are significantly greater with the strong potential to influence adversely the outcome of the CLISP indicators describing exposure or sensitivity.

We focused in this document only on relevant indicators with quite clear trends and interpretation potential. Other indicators were calculated and can be provided to the model regions on demand.

Additionally, long-term climate oscillations within the GCM climate scenarios overlay the short term trends with which we deal in CLISP. This may lead for instance to inconsistent trends for 2030 compared to 2050.

In CLISP we will focus on long term (20years) periods and calculate mean values for month, season and year in order to provide relatively robust results. In any case and depending on the parameter at stake, the results will contain uncertainty and represent a large range of possible intensities of impacts. Particularly those impacts relying on parameters with higher uncertainties should be interpreted with care.

Another aspect is the considered mean value for the whole region. It should always be kept in mind that the value represent an aggregate number and is not representative for valleys nor for altitudes over 1500, but covering the whole range of altitudes of the model region or the Alps.

For more information on how to read climate scenarios see http://www.clisp.eu/content/sites/default/files/ARL_Leseanleitung_Klimaszenarien_Deutschland.pdf (in German only).

3.2 Results

The results for temperature and precipitation are visualized in the Annex by maps and graphs for the four seasons winter, spring, summer and autumn (DJF, MAM, JJA, SON). The REMO UBA scenarios had to be excluded for the diagrams, since they do not cover the entire Alps.

3.2.1 Mean Temperature

Seasonal summary of absolute temperature changes

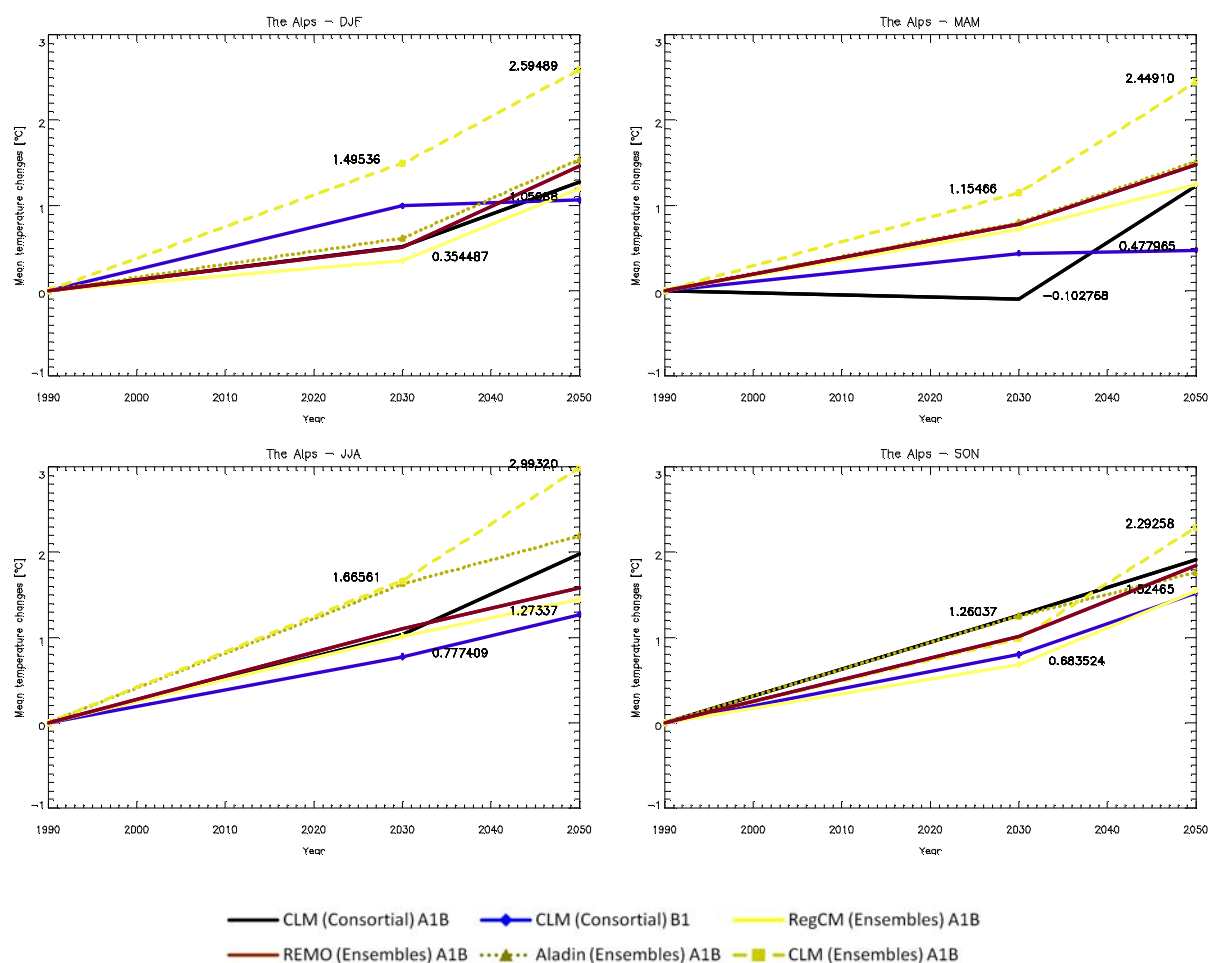


Figure 11: Seasonal summary (winter, spring, summer, autumn) of absolute temperature changes regarding the Alps.

Temperature shows a clear warming trend in all seasons with a more pronounced warming after 2030. The strongest warming is expected for summer with increases between 1.3 °C and 3°C until 2050 (1.3°C - 2°C for ECHAM5 driven RCMs). In line with the temperature trend of the past, the central Alps are in most scenarios warming faster than the foothills of the Alps.

Temperature can be regarded as a rather robust parameter within climate models with a clear trend towards warming. Anyhow, projections show wide ranges of potential changes. While the ECHAM5 driven RCMs are quite consistent, other GCM (ARPEGE and ,even more, HadCM3) show a stronger warming.

3.2.2 Minimum Temperature

Seasonal summary of absolute minimum temperature changes

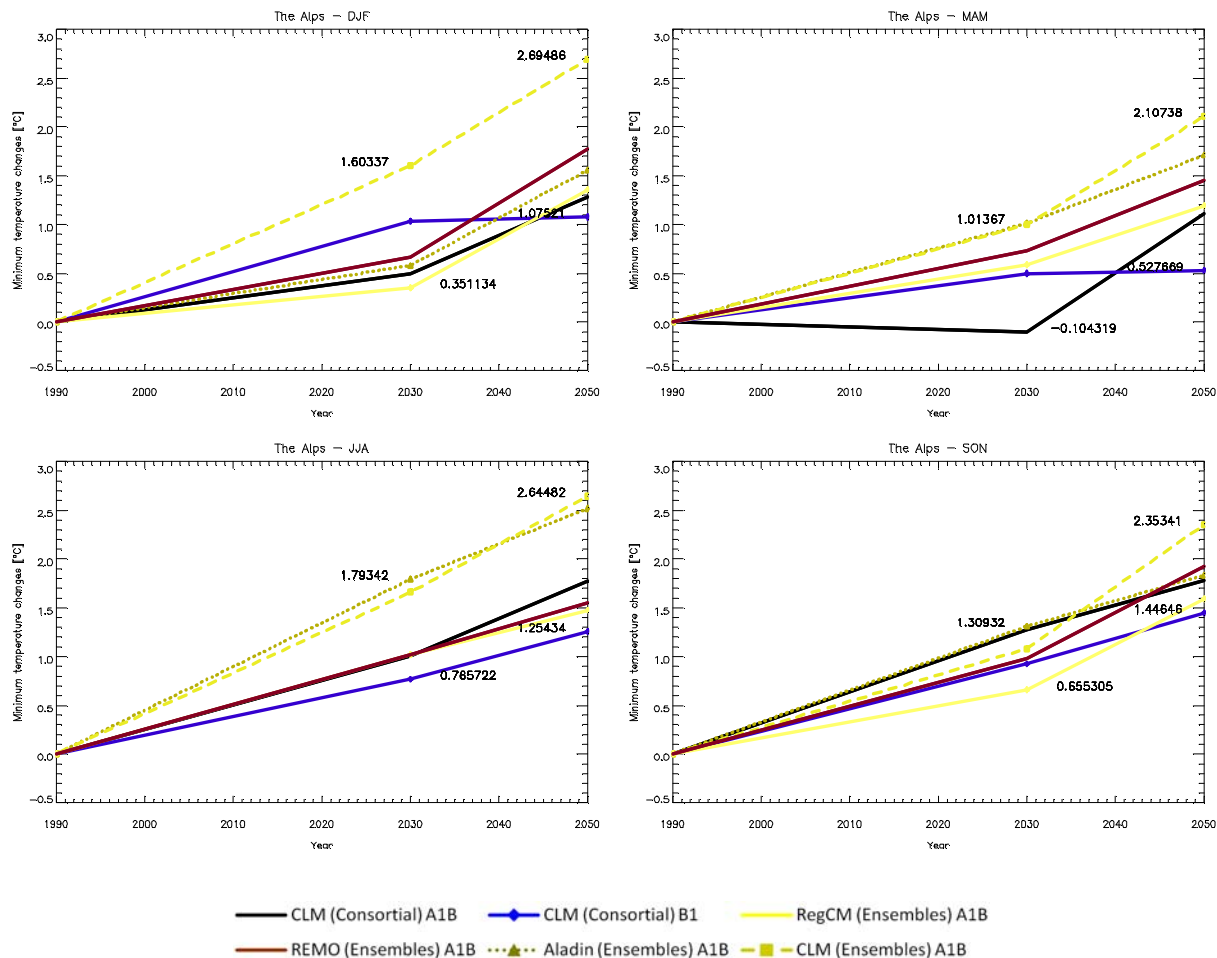


Figure 12: Seasonal summary (winter, spring, summer, autumn) of absolute minimum temperature changes regarding The Alps.

Minimum temperatures show a trend very much in line with average temperatures. However, the trend of increasing minimum temperatures in winter is slightly stronger than the trend in average temperature. This might have implications for frost- and ice days and therefore also on snow cover and glaciers, which reacts sensitive to an increase in minimum temperature.

As average temperature, minimum temperature can be regarded as a quite robust indicator.

3.2.3 Maximum Temperature

Seasonal summary of absolute maximum temperature changes

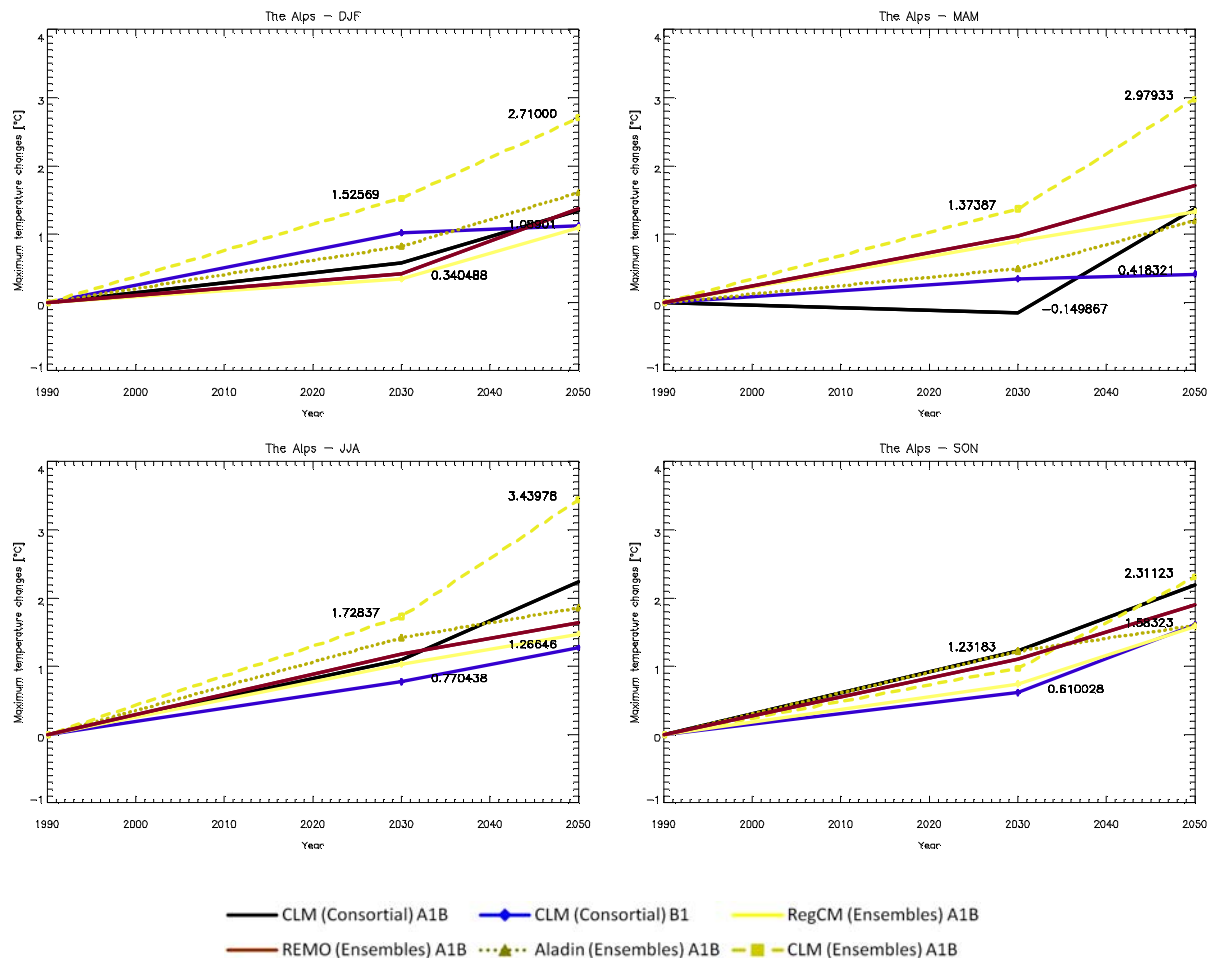


Figure 13: Seasonal summary (winter, spring, summer, autumn) of absolute maximum temperature changes regarding The Alps.

Maximum temperature shows almost the same trend like average temperature, indicating that temperature extremes will become more frequent in the future.

3.2.4 Precipitation

Seasonal summary of absolute precipitation changes

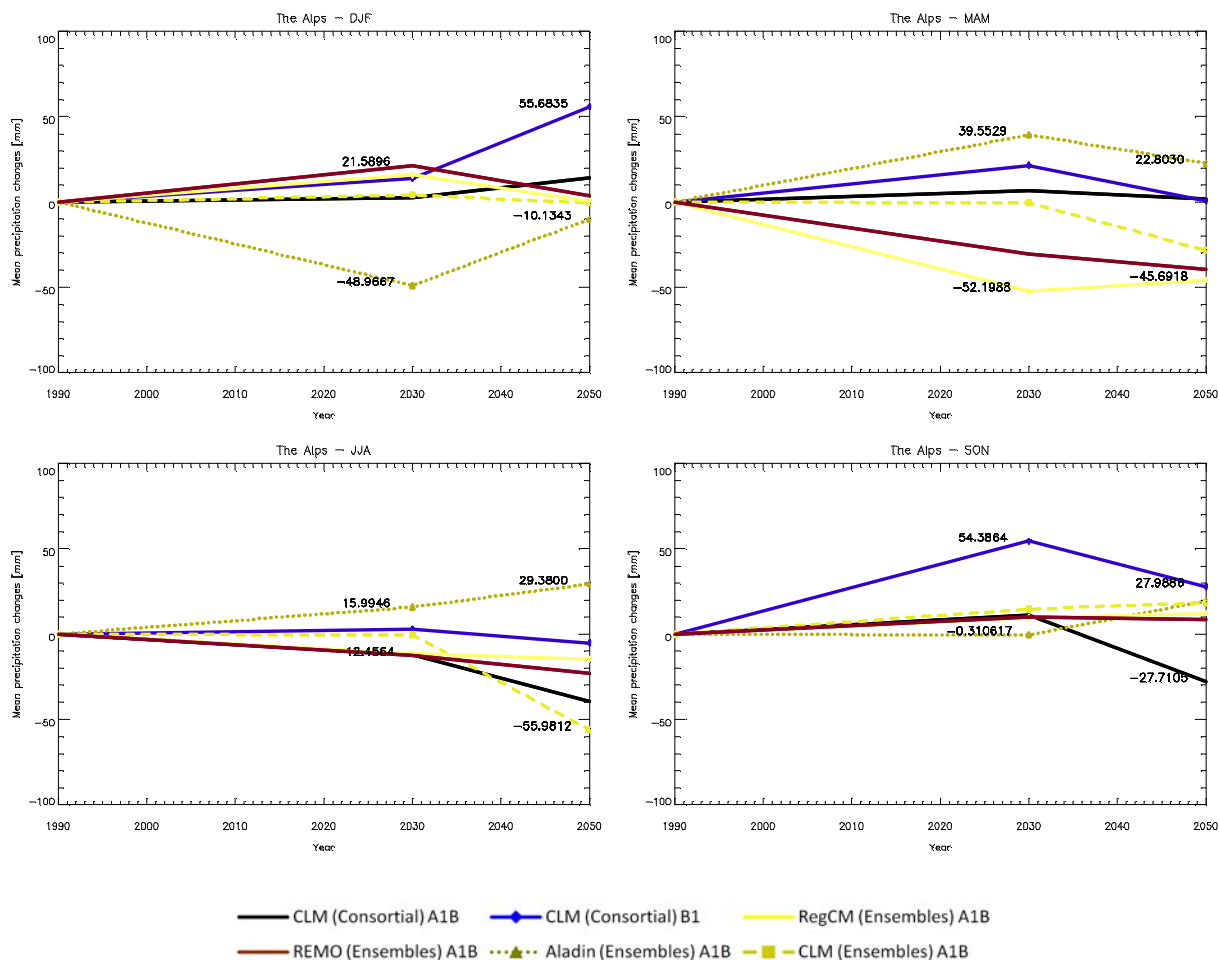


Figure 14: Seasonal summary (winter, spring, summer, autumn) of absolute precipitation changes regarding The Alps.

Precipitation shows a quite heterogeneous picture. The clearest trend can be observed for summer, where five out of six scenarios show a trend to a slight decrease of precipitation of up to -55mm (-5mm - -40mm for ECHAM5 driven RCMs). Winter tends to become wetter or at least stay stable in most scenarios. For autumn and spring no clear trend can be observed. The partly inhomogeneous trend from 1990 to 2030 and from 2031 to 2050 can be explained by long-term oscillations in the driving GCMs.

The geographic distribution of the trend is very heterogeneous. If taking into account only the ECHAM5 driven scenarios in the northern Alps there is a trend of an increase of precipitation in Winter, Spring and Autumn, while summer is getting drier. For the southern Alps all seasons besides Winter show a tendency to less precipitation with strong variances amongst the scenarios.

Precipitation is, compared to temperature, less robust and reliable. Different GCMs produce partly contrasting patterns of spatial distribution of precipitation. Regional projections should be handled with care.

4 Synthesis of vulnerability assessment results by sectors

4.1 Summary of results of the cross-model region comparison

In this chapter, we draw a synthesis of the project results by sector. The following table 8 provides an overview of the sectors considered by the different model regions. Out of a total of 8 model regions, 4 dealt with all sectors considered in the CLISP project; one region only dealt with one sector (water), 2 with 2 sectors (built-up areas and tourism) and one with 3 (built-up areas, tourism and forestry).

Table 8: Sectors selected by the CLISP Model Regions

Sector	Agriculture	Built Up areas	Energy	Forestry	Tourism	Health	Water management
<i>Model region</i>							
<i>South Tyrol</i>	X	X	X	X	X	X	X
<i>Oberoesterreich</i>	X	X	X	X	X	X	X
<i>Bayern</i>		X		X	X		
<i>Salzburg</i>		X			X		
<i>Steiermark</i>	X	X	X	X	X	X	X
<i>Gorenjska</i>	X	X	X	X	X	X	X
<i>Alessandria</i>							X
<i>Graubünden / Liechtenstein</i>					X		X

4.2 Agriculture

4.2.1 Status quo / sensitivity

Agriculture is a very important sector in the Alpine area, although its relevance varies considerably across the different model regions. Within project CLISP, this sector was considered explicitly for South Tyrol, Oberoesterreich, Steiermark and Gorenjska.

For all model regions, agriculture is projected to face more favourable conditions for crop diversification, while increasing water demand may turn to be a critical aspect. This is particularly true in the valley bottoms of semi-arid internal alpine valleys. Agriculture relies on water from snowmelt and glaciers, while climate trends are projected to induce less snow accumulation and glacier retreat, following an evolution already observed in the last decades.

4.2.2 Potential Impact

Traditionally, the Alps represent a water-rich environment where limitations to agriculture are more related to energy (growing season length and degree-days) than to water. Warmer climate projections indicate an increase of opportunities for crops, especially in upper valleys and in the northern side of the Alps. At the same time, warmer and dryer summer climate may increase water demand to a point where conflicts in water usage may arise, especially in areas where water is important for users downstream. This is true in general in the Alps, and in particular on the southern side and in the valley bottoms.

Although this general picture may well correspond to the trend, local variability is very high. Moreover, different climate model scenarios provide very different indications. Therefore, the impacts of climate change on agriculture in the Alps is highly uncertain. In the following figures, we provide a map showing the change of each of the indicators considered for sector agriculture, between present conditions and the average conditions forecasted for 2050 by the ENSEMBLE model scenarios. The changes in the values of the indicators

point at more marked variations in the western Alps, and highlight effects in the valley bottoms especially on the southern side of the Alps and in enclosed valleys.

4.2.2.1 Growing season length (I1), Growing degree-days (I2)

The Growing season (GS) is defined as the period of the year when the daily mean temperature is above 5°C. The beginning of the growing season (BGS), the end of the growing season (EGS) and the length of the GS can be derived for each cell in the grid. The growing degree days (GDD) are defined as the accumulated degree sum above a defined reference temperature (here set to 5°C). Finally the difference of those parameters between future and reference (present) conditions is an indicator of potential changes.

From the climate scenarios considered, it can be seen that an extension of the growing season for the Alps is expected, with respect to reference conditions of the period 1961-1990 (Figure 15). This extension is closely related to an earlier start of the Growing season as well as an later end of it.

It must be clearly borne in mind that this assessment has strong limitations related to the reliability of absolute values of daily temperatures estimated by the climate models. Whenever such daily temperatures are compared to a threshold, as for the present indicator, the bias in model estimates may be reflected in the final result to a significant extent. Despite these limitations, the assessment indicates a potentially significant increase in the length of the growing season, which may result in positive impacts in terms of agricultural production in some areas. However, agricultural water demand may undesirably grow to fully exploit a potentially longer production season (see the following indicators).

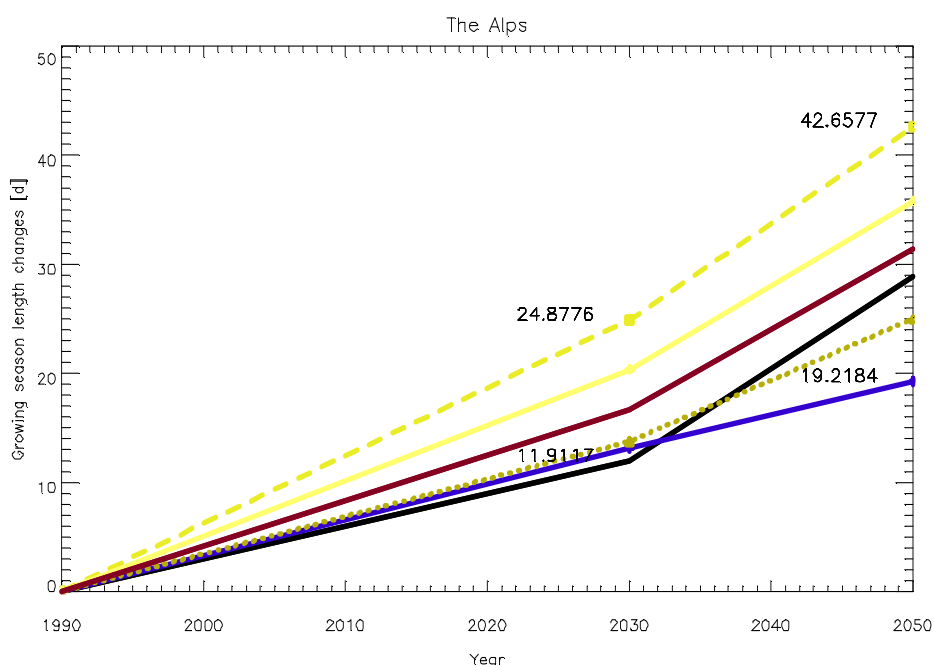


Figure 15: Changes in the length of growing season until 2050.

4.2.2.2 Potential evapotranspiration (I3) and Meteorological water balance (I4)

The meteorological water balance is defined as the difference of precipitation sum and the sum of potential evapotranspiration. It can be used as indicator where reduced rainfall in combination with higher potential evapotranspiration will contribute to higher requirement for irrigation water. In turn, potential evapotranspiration can be seen as an indicator of water demand from crops under given climate conditions. The Alps show a trend in potential evapotranspiration that is up to about an additional 50 mm/y in the valley bottoms and on the southern side, i.e. about +10% compared with current conditions. This will on one side correspond to more crop opportunities, but on the other side to generally higher crop water requirements.

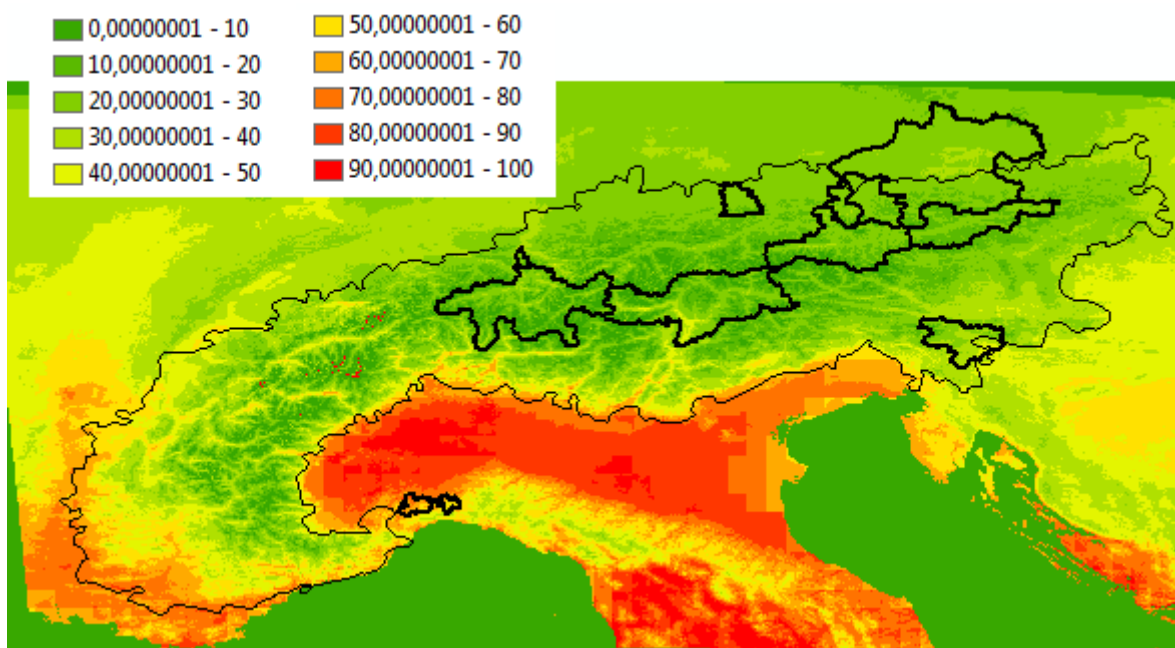


Figure 16: Maximum potential evapotranspiration changes as of 2050, according to the climate scenarios considered in project CLISP (mm/year).

This is reflected in corresponding variations of the meteorological water balance. In higher and more central parts of the Alps, increased precipitation suggests positive changes in the meteorological water balance. On the Southern and less elevated sides of the Alps, however, increased potential evapotranspiration indicates possibility of conditions where water availability is limiting for crop growth.

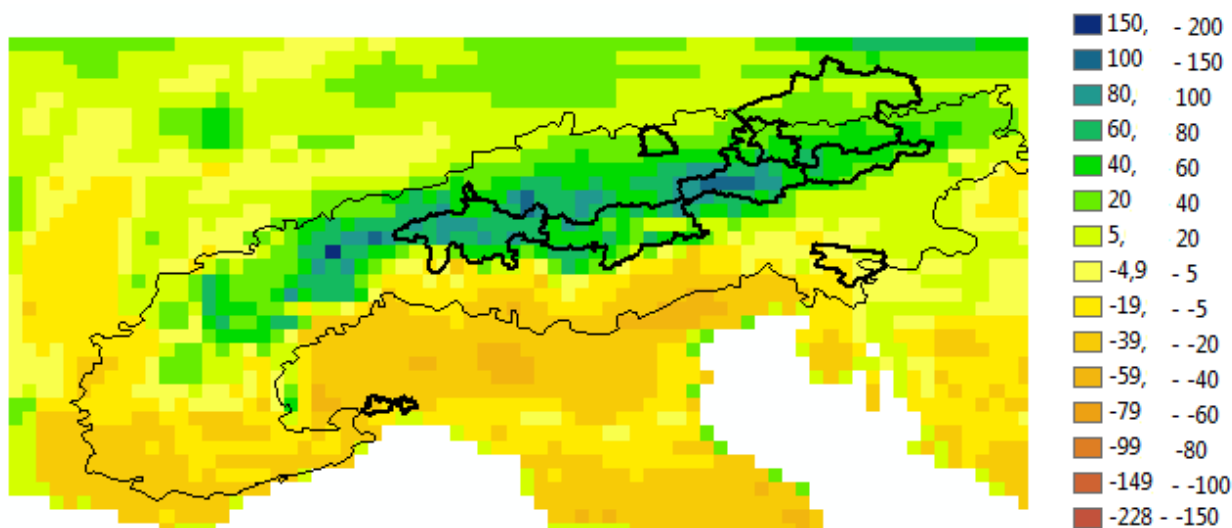


Figure 17: Maximum meteorological water balance changes as of 2050, according to the climate scenarios considered in project CLISP (mm/year).

4.2.2.3 Drought Index (de Martonne) (I5)

This index suggests generally more arid conditions throughout the Alps, with the exception of some central and more elevated parts where the trend could be inverse. The index in itself has a comparative nature, as it is a conventional ratio of precipitation and temperature. The variation of the index provides the relative intensity and sign of aridity changes across the region. The spatial pattern is similar to the one of the meteorological water balance.

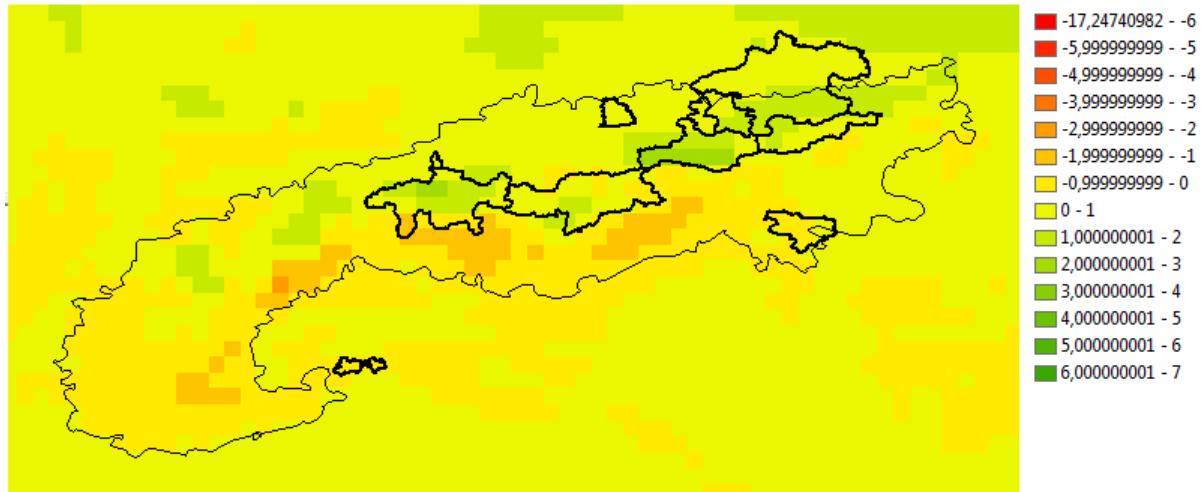


Figure 18: Results of the Drought Index calculation.

4.2.2.4 Crop suitability for wine (Huglin's index) (I6)

Wine credibility is projected to improve on the whole Alpine region; absolute variations may be less important on the north-eastern corner of the Alpine region, but relative variations may be even more significant there as the starting condition is less favourable than in other parts.

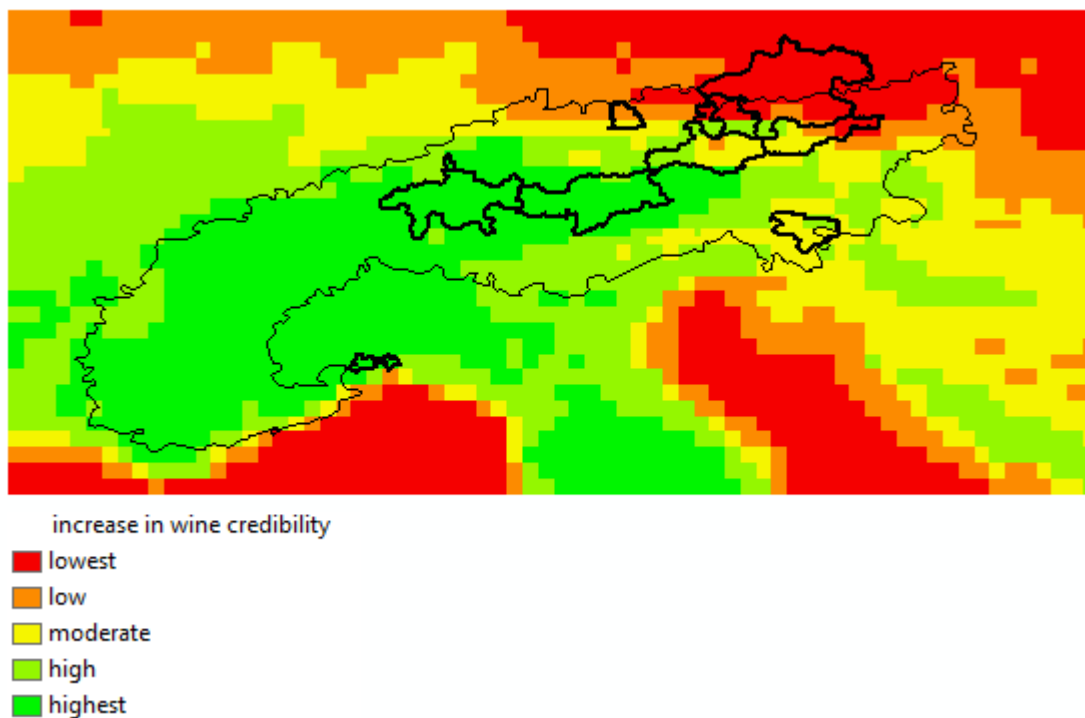


Figure 19: Results of the Crop suitability calculation

4.2.3 Adaptive capacity

Adaptive capacity is highly variable and depends on the capacity of the different communities to cope with reduced water availability, on the one hand, and to seize opportunities for extended cropping possibilities, on the other. A generally warmer climate will also induce potential increase of pests and diseases, which need to be tackled in agricultural management. In the future, a higher capacity to organize and manage agriculture according to precision principles is envisaged. This implies that agro-technologies will be more and more important for production and agri-business will become more and more competitive.

4.2.4 Vulnerability - summary

The vulnerability of the Alpine region's agricultural sector is highly variable. In general, adaptation will critically require capacity to cope with reduced water availability both due to reduced flows, and to increased demand from downstream areas, which will need to be considered in integrated watershed planning. The increase on temperature may result in a temporal extension of growing season and a spatial extension of arable land into higher altitudes. The vulnerability to an increase of water stress is determined by the locally highly diversified adaptive capacity.

4.3 Built-up areas / land development

4.3.1 Status quo / sensitivity

Built-up areas were a sector of concern for all model regions except Alessandria, Graubunden and Liechtenstein. The main issues with built-up areas were identified in natural hazards and extreme weather events. The latter could not be analysed in quantitative terms. The former require on the one side a very local assessment of physical conditions and the exposure of settlements to risks. At the same time, our understanding of the effects of climate change on natural hazards is still very vague and weak.

Another relevant issue with climate change in built-up areas is increased heat stress in cities. Although the Alps are a relatively non-urban context in Europe, settlements tend to concentrate in the valley bottoms, which are also the most sensitive areas for heat waves.

4.3.2 Potential Impact

4.3.2.1 Flood prone areas (17)

It is generally acknowledged that climate change may induce an increase in flood frequency and severity, especially in mountain regions such as the Alps. An increase of flood frequency and magnitude has been observed parallel to the warming of the last years in Switzerland and elsewhere. Several alpine areas have experienced floods, in the recent past, which used to be regarded as exceptional in the past. Allamano et al., 2009, have used a simple conceptual model to predict an increase in flood frequency in the Alps following climate warming. Castellarin and Pistocchi, 2011, by analysing long time series of annual maximum discharges in Switzerland, showed that the simple model of Allamano et al., 2009, is compatible with observations referred to the past. However, our understanding of the exact magnitude of flood frequency and magnitude changes is still rather poor. Within CLISP, we have used a practical, conventional method to estimate expected increases of flood intensity for a reference return period of 100 years. The method points at increments of the 100-year return period flow in the order of 30%. Such increment may be critical in all circumstances where flow is controlled by hydraulic structures such as bridges or levees, having a design conveyance beyond which levee or river bank overtopping is likely to occur. Whenever a floodplain is already interested by a 100-year return period discharge, however, it is likely that the extent of flooded areas does not change significantly. This has been observed in the model regions of Gorjenska and Bavaria, in each of which two sites have been investigated in order to assess the variations of flooded areas following an increase of discharge after climate change. In the four case studies analysed, it appeared that new flooded areas that are presently not affected by water flow are marginal and negligible.

This suggests that, in order to cope with climate change, land planning considerate of present flood hazards is a first and essential step towards improved resistance. Pistocchi, 2011, further generalizes these considerations to discuss scenarios of flood risk and mitigation options in the Alpine area.

4.3.2.2 Avalanche prone areas (18)

Avalanches may be affected by climate change as both snowfall intensity and the parameters controlling snow transformation and the mechanical characteristics of the snow pack may change under future scenarios. However, at present we have no understanding of these changes and, therefore, any consideration on the topic is purely speculative. In general, it is expected that areas presently at risk of avalanches will remain such under climate change. In the same areas, the precautionary principle suggests that avalanches may become more frequent and more severe. In the model regions where avalanches were considered a concern, an analysis has been conducted about present avalanche hazards, with the implicit assumption that future scenarios will affect the same areas. In this perspective, it is extremely important to achieve a sound characterization of potential avalanche release areas (PARAs). Pistocchi and Notarnicola, 2011, characterize PARAs in South Tyrol using a bayesian approach. Lermer et al., 2011, extend the approach to the model regions that provided data on purpose, namely Gorjenska, Bavaria (Miesbach and Berchtesgadener Land) and Salzburg.

4.3.2.3 Rockfall prone areas (19)

Our understanding of climate change effects on rockfalls in general is extremely weak. However, in recent years a concern has been raised by the effects of permafrost melting on rockfalls. Within CLISP, an assessment has been conducted on the extent to which permafrost may melt down and originate additional rockfalls. An analysis of potential permafrost under current conditions has yielded the map shown in Figure 20. All areas judged to likely or very likely host permafrost, and with slopes above 45°, were considered as potential sources of rockfall under climate change scenario. With this assumption, trajectories of rockfall were calculated for the

whole Alpine region (e.g. Figure 21) indicating a rather extended impact. However, this impact generally concerns upper valleys and not the main settlements. A more extensive impact is projected to affect communication infrastructure, in which case some valleys may experience problems of connection with the main centres of the plains whenever rockfall contributes to temporarily closing roads or lifelines. Lerner et al., 2011 (see Annex), provide an example analysis of the impacts of permafrost degradation-triggered rockfall on the Alps.

4.3.2.4 Torrential process prone areas (I10)

The same considerations made for avalanches hold for torrential processes as well.

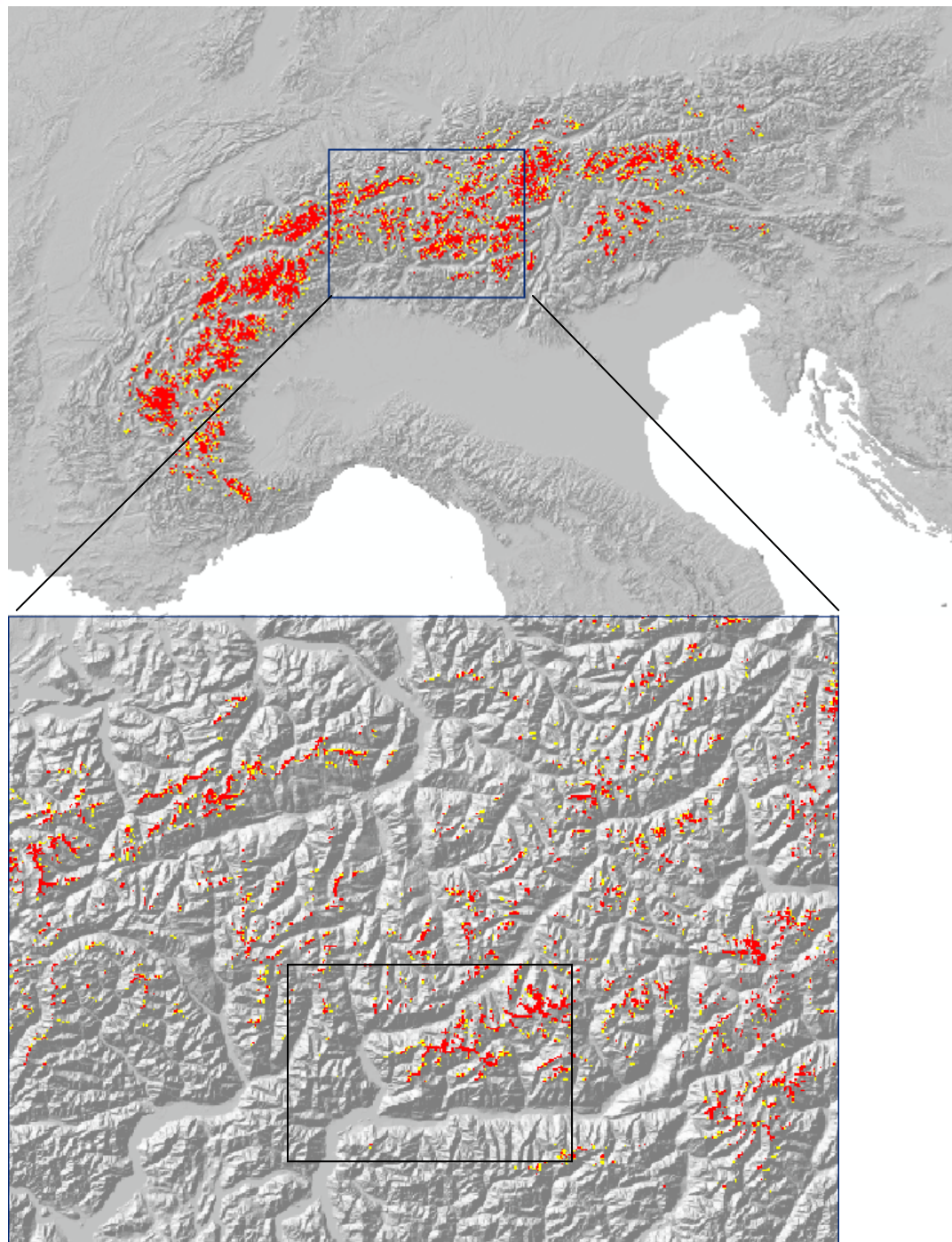


Figure 20: Distribution of very likely (red) and likely (yellow) permafrost areas in the Alps.

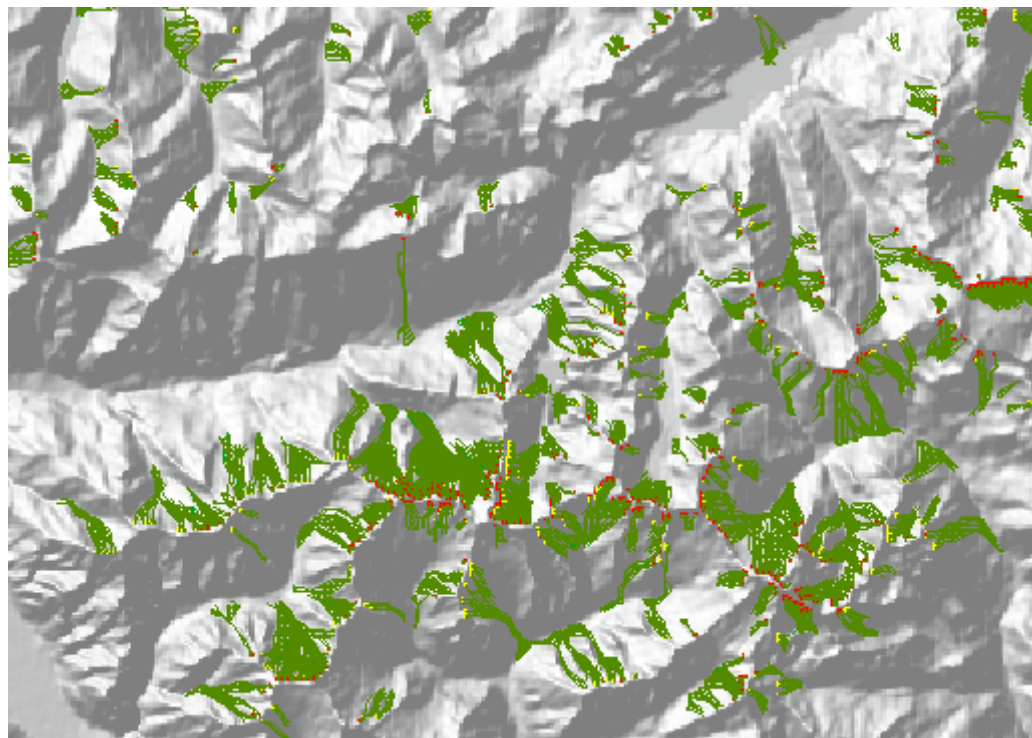


Figure 21: Zoom of the above map, showing the trajectories of rockfall from permafrost melting.

4.3.3 Adaptive capacity

Natural hazards are considered in practically all land management processes. However, throughout the Alps the legal status of hazard maps and the degree of legal enforcement of land use constraints on hazardous areas varies considerably.

The capacity to predict and monitor natural hazards under present conditions is generally quite good. However, the capacity to predict climate change effects on natural hazards is generally poor.

If climate change will make natural hazards more frequent and more severe, but will substantially keep them on the same areas as at present, the adaptive capacity of the Alps can be regarded as satisfactory and, in fact, adaptation is already underway (e.g. through the Flood directive 2007/60/EC).

The capacity to adapt to heat waves and hot climate is highly variable. A point of strength is the tradition for good energy management in buildings within mountain areas. In the future, there will be more and more need for green urban areas, green roofs and similar devices, which may be conflicting with the intensive land uses at the valley bottoms, which represent the few usable areas in a mountainous context.

4.3.4 Vulnerability - summary

Vulnerability of built-up areas to climate change may show up whenever land use inconsiderate of natural hazards is made. Whenever consideration of natural processes is included in land planning, the effects of climate change may become relevant. An issue that has been slightly under-considered so far is the one of heat waves, which tend to affect not just metropolitan areas in the plains but also valley bottoms. More careful planning and management of urban surfaces and land uses is a key element for adaptation, the lack of which may induce high vulnerability under climate change.

4.4 Energy

4.4.1 Status quo / sensitivity

On the side of energy demand, the Alps show a trend in reduced winter heating and increased summer cooling, with a net budget that may be neutral. On the side of energy supply, increased aridity may affect hydropower production, which is one of the key energy sources in mountains.

4.4.2 Potential Impact

The potential impacts in terms of cooling and heating demand are depicted in Figure 22 and Figure 23 respectively. Trends are clear and consistent in all climate model scenarios considered in CLISP.

4.4.2.1 Cooling days (I11), Cooling degree-days (I12)

For the Alps, on average, the number of cooling days may increase up to 20 in 2050. Already in 2030 a significant increase (up to about 14) is predicted.

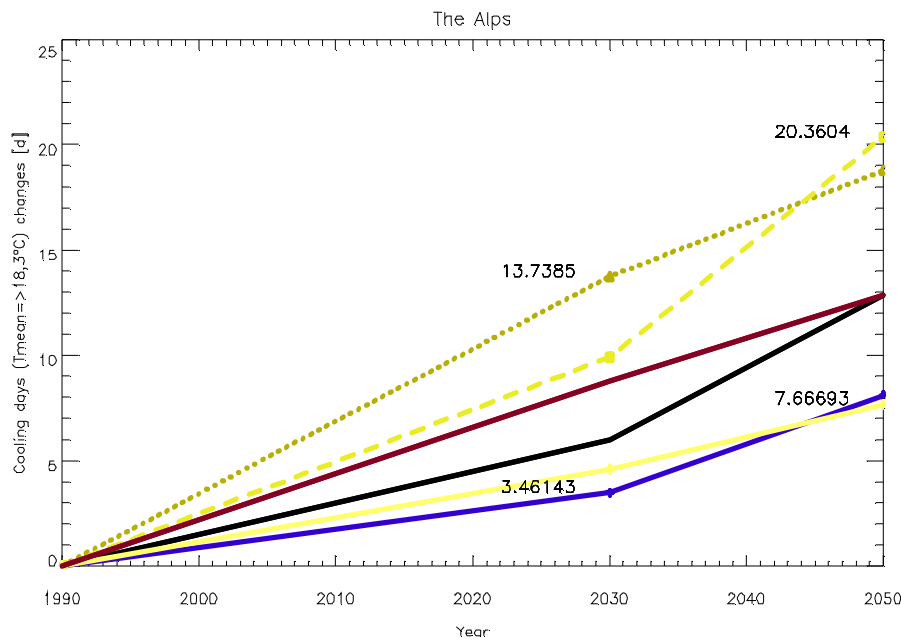


Figure 22: Number of cooling days over the Alpine area – scenario until 2050.

4.4.2.2 Heating days (I13), Heating degree-days (I14)

The trend is consistently complementary to the one of cooling days; the corresponding energy demands may be comparable.

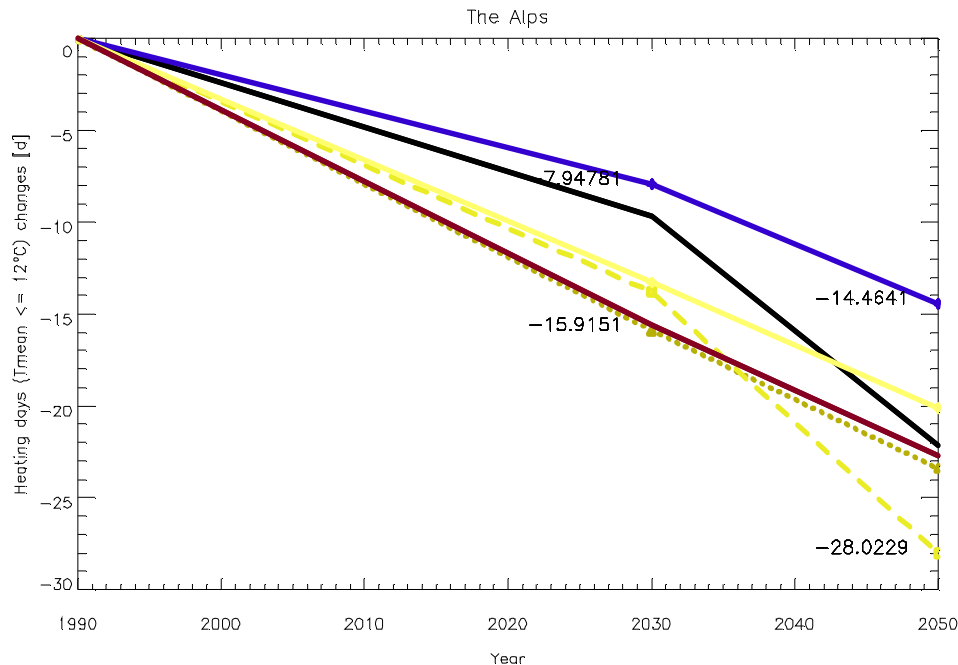


Figure 23: Number of heating days over the Alpine area – scenario until 2050.

4.4.3 Adaptive capacity

In mountain areas, a tradition for wise energy management in buildings exists, mainly motivated by cold winter conditions. This represents a potential for the development of more and more energy efficient buildings, which keep energy demand at a low level. Hydropower production losses from increased aridity may be compensated only by expanding the storage capacity of reservoirs and increasing the efficiency of hydropower equipment. On the other hand, the development of renewable energies stimulates production also from other sources (wind, photovoltaic) in the Alps. Particular the installation of wind power parks however may clash with the interests from the tourist industry that is interested in preserving the beauty of the landscape.

4.4.4 Vulnerability - summary

The main aspect of vulnerability is to be seen in the loss of hydropower production, whenever this cannot be compensated by adaptation.

4.5 Forestry

4.5.1 Status quo / sensitivity

Forestry is a key economic sector in the Alps. Forests provide services ranging from raw materials to recreation, to climate and water cycle control. Climate trends suggest an increase of the elevation of the timberline and an expansion of crop variety. At the same time, more frequent and prolonged stress due to

extreme weather events as well as ecological modifications (more pests, hoofed game etc.) may threaten forests in the future. Climate change may trigger to some extent also forest fire.

4.5.2 Potential Impact

4.5.2.1 Forest line (I15)

Figure 24 shows the projected increase in timberline elevation, according to an analysis further described in Kass et al., 2011. This is based on thermal effects only, inconsiderate of morpho-edaphic limitations. The general indication is that areas suitable for forest may increase significantly over the Alps.

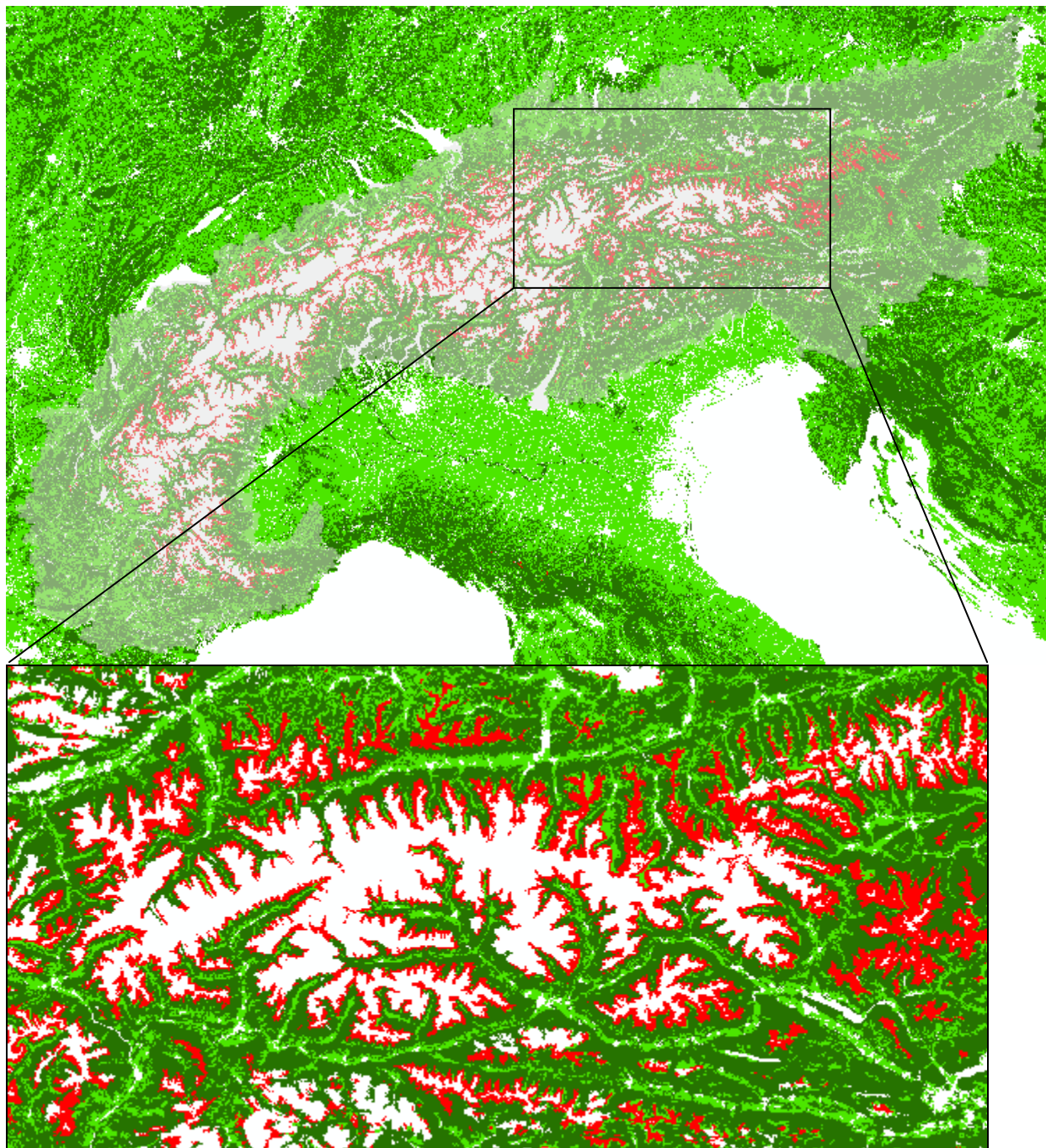


Figure 24: Projected changes in timberline elevation for 2050. Deep green: forest areas as of today; red: areas becoming suitable for forest after climate change; pale green: areas that could be forest today based on temperature.

4.5.2.2 Nesterov index for fire danger (I16)

While the eastern Alps are projected to experience minor increase of forest fire danger, the western (Maritime) Alps are predicted to be much more at risk under climate change due to combined aridity and higher temperature effects (Figure 25). The southern foot of the Alps is also generally more at risk.

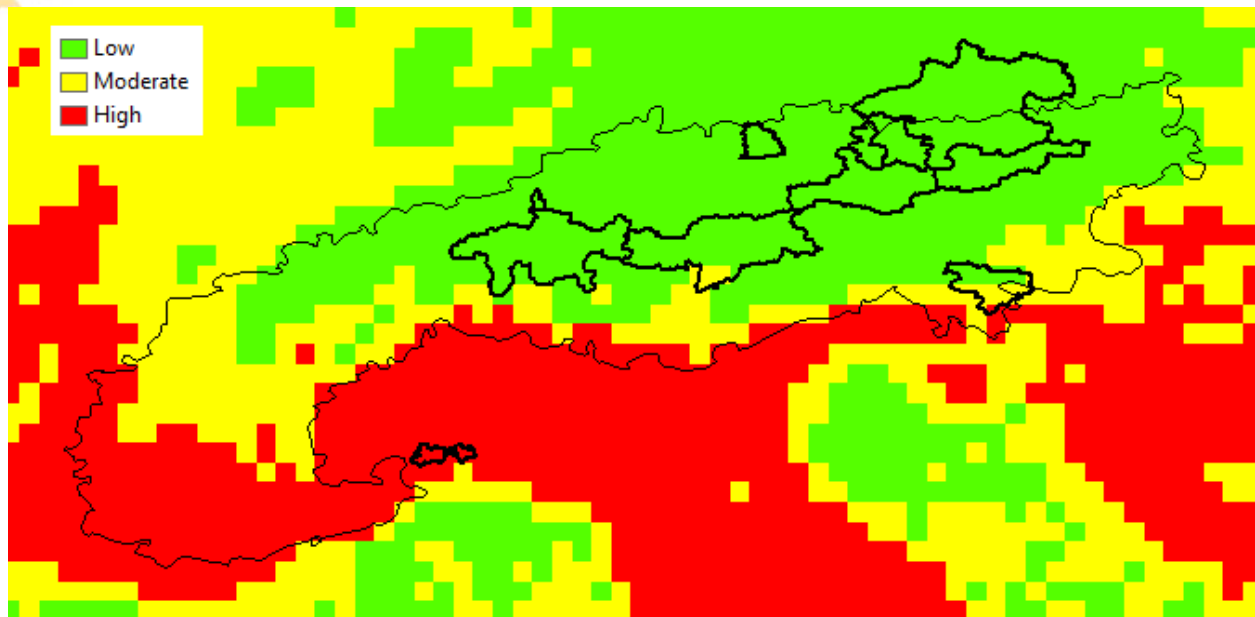


Figure 25: Projected fire danger in 2050 based on the Nesterov index.

4.5.3 Adaptive capacity

Forestry in the Alps is a variedly managed sector, and adaptive capacity depends very much on the specific context. In the model regions examined within CLISP, adaptive capacity tends to be quite good as forests represent a considerable asset in the local economies. A different situation may be present in areas of the Alps where forest management is more dispersed and less associated to local economic activities.

4.5.4 Vulnerability - summary

Whenever adaptive capacity, and in general the management of forest ecosystems does not compensate potential negative effects, prolonged stress of forests may result in their degradation.

4.6 Health

4.6.1 Status quo / sensitivity

Environmental conditions affecting human health, namely heat waves, ultra-violet radiation and atmospheric pollution, are presently not particularly critical in the Alps compared to other areas of Europe and elsewhere. However, urban areas in the valley bottoms are already experiencing heat stress during particularly hot days. An ever-increasing level of traffic is also impacting air quality in many areas, and the valley bottoms are no exception.

4.6.2 Potential Impact

4.6.2.1 Climate indices for heat stress (I17)

In the different model regions, climate indices for heat stress indicate an increasing trend. The impacts will be more important in the valley bottoms in the Southern part of the Alps with focus areas within denser settlements.

4.6.3 Adaptive capacity

The adaptive capacity of different Alpine regions appears varied depending on the level of attention posed to the issue. In general, adaptation to climate change in the sector of health entails structural measures such as the greening of urban areas, the exploitation of natural cooling mechanisms and the improvement of energy efficiency in summer acclimatization, as well as health care system management adaption to increased heat-related problems.

4.6.4 Vulnerability - summary

Although adaptation does not seem particularly expensive compared to other sectors, the main problem with the health system is that awareness of potential heat-related problems is generally rather low. This may make the system vulnerable in the short term, but adaptation may mitigate impacts on the mid- to long term.

4.7 Tourism and recreation

4.7.1 Status quo / sensitivity

Tourism in the Alps relies generally on snow both for the practice of sports, and for the scenic value of winter mountain landscapes. Many areas within the Alpine region, however, have a highly diversified tourism offer, which includes outdoor activities as well as social, wellness and cultural opportunities. Alpine tourism is sensitive to increased frequency and severity of extreme events and reduced snow reliability. Positive impacts of climate change may be related to the improvement of climate for outdoor comfort.

4.7.2 Potential Impact

4.7.2.1 Climate indices for summer tourism (I18) and winter tourism (I19)

Dry days tend to increase although the evidence is not fully consistent among the different scenarios. The implication of more dry days for tourism is an extension of the good season for outdoor activities.

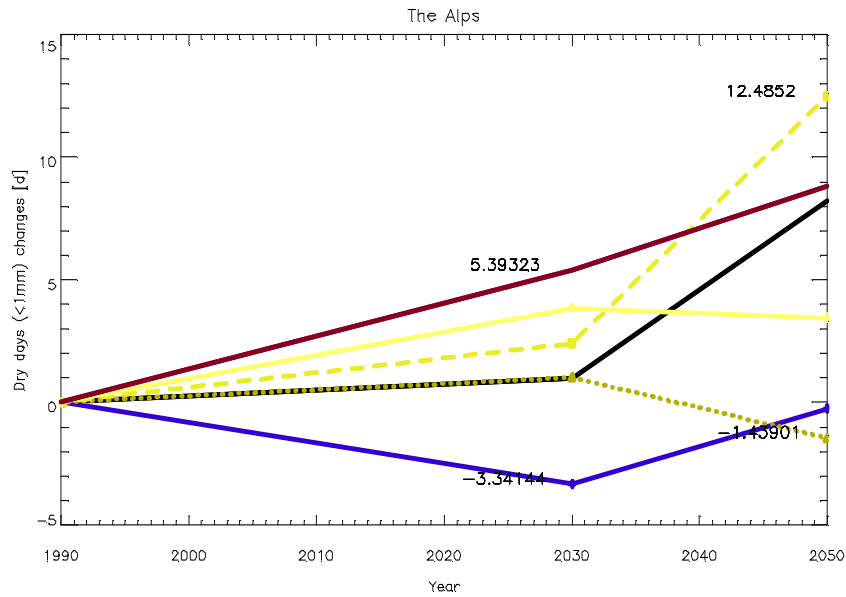


Figure 26: Number of dry days over the Alpine area – scenario until 2050.

The maximum temperature tends to increase; this implies on the one side milder winters, but on the other hotter summers, with contrasting effects on tourism. Complementarily, the number of cold days decreases. The overall effect is predicted to be an extension of the summer season of up to 20 days in 2050.

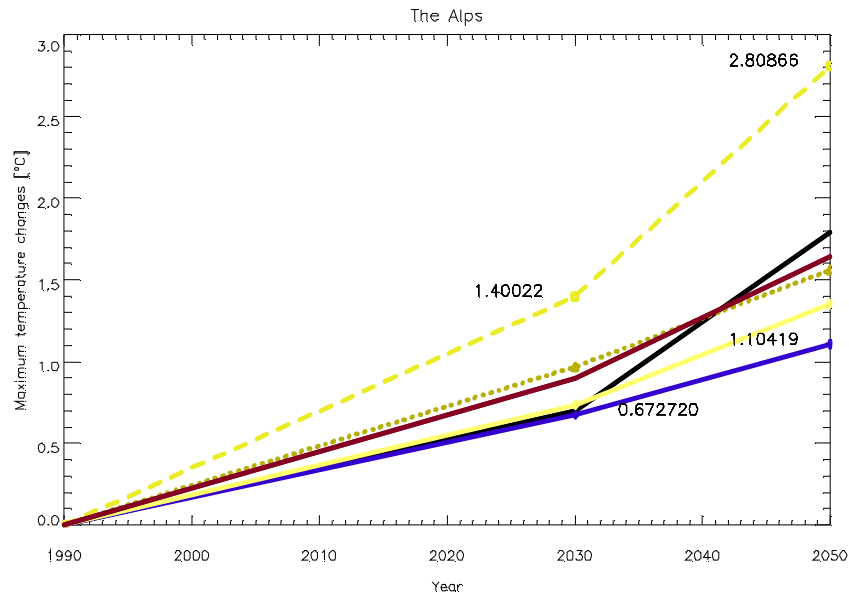


Figure 27: Changes of maximum temperature over the Alpine area.

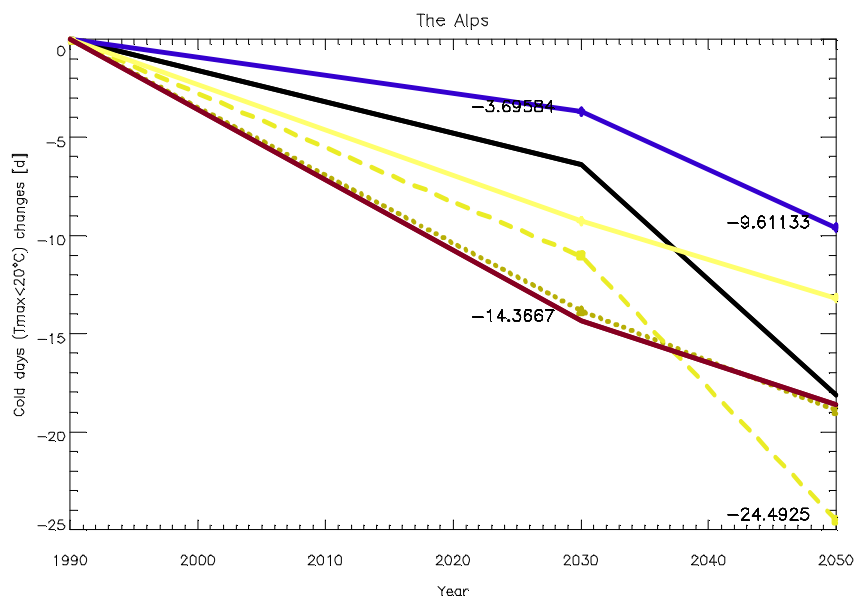


Figure 28: Number of cold days over the Alpine area – scenario until 2050.

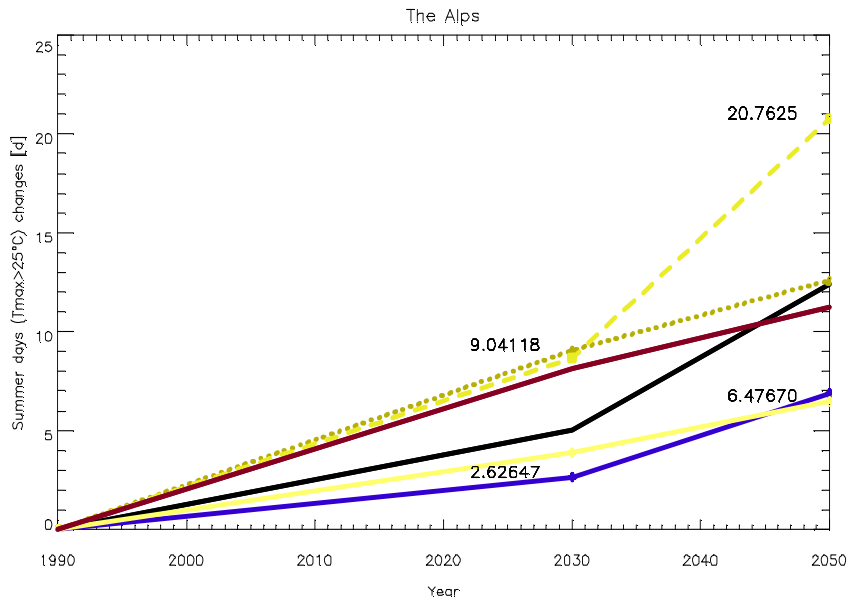


Figure 29: Number of summer days over the Alpine area – scenario until 2050.

4.7.2.2 Tourism climate index (I20)

The Tourism Climate Index (TCI) is a combined index which can be considered as climatic suitability for general summer tourism purposes. It is comprising the climate features temperature, humidity, sunshine, rain and wind.

The current climate trends can be incorporated synthetically in this index. Presently, the TCI is relatively high in valley bottoms and low at high elevations during most of the year. Only in summer there is an inversion with lower values in the valley bottoms, and higher values at mid-elevations. The climate trends will mitigate climate at high elevation and increase heat and/or humidity in the valley bottoms. Therefore, climate tends to improve in the former and to degrade in the latter areas. Figure 30 depicts variations in the TCI by season.

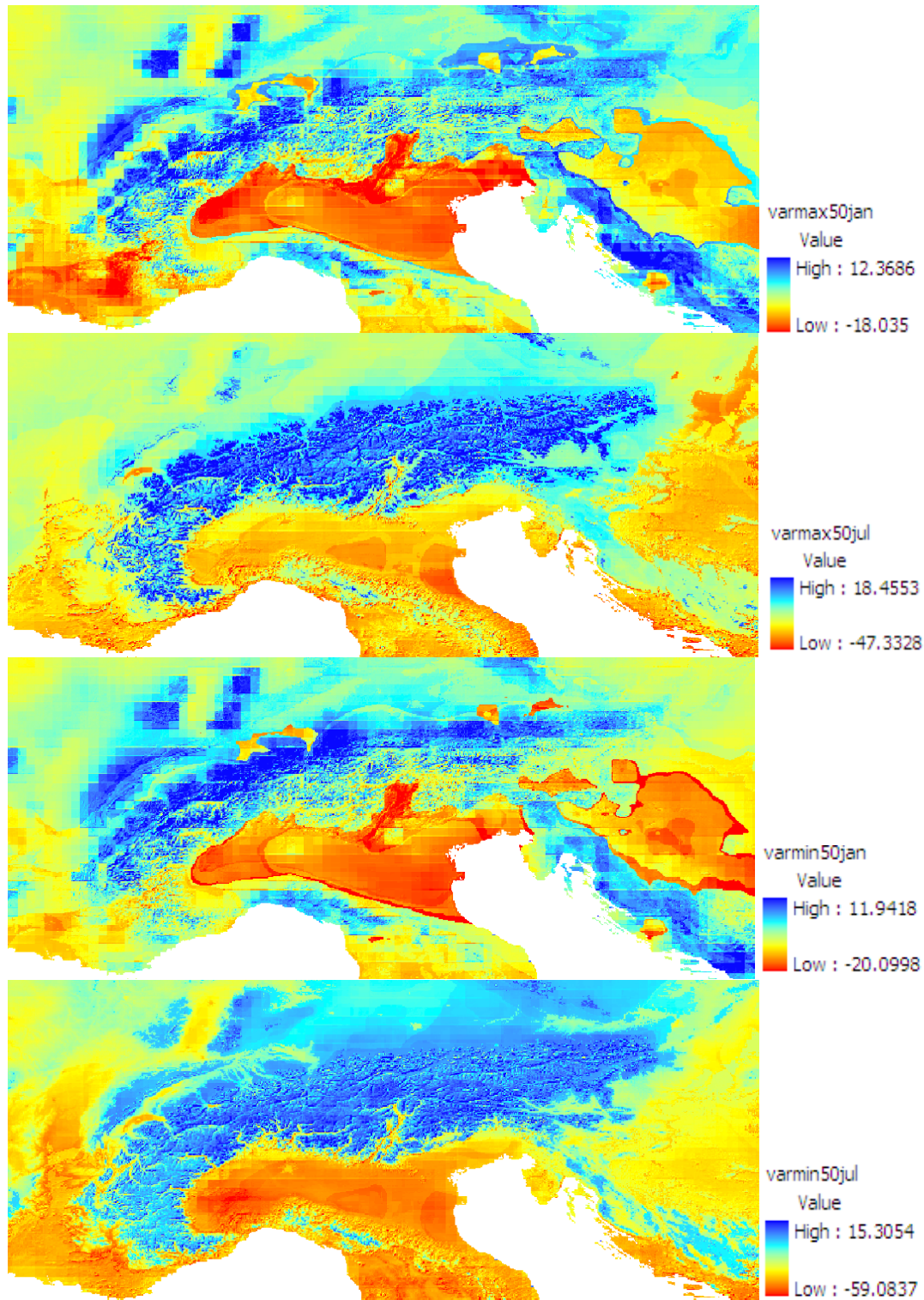


Figure 30: Variations of TCI in January and July for 2050: “varmax” refers to the maximum expected TCI among all climate scenarios, “varmin” to the minimum.

4.7.2.3 Snow reliability (I21)

Snow reliability was investigated with region-specific assessments, for which the individual model region report should be consulted. The general conclusions that can be drawn from the case studies are that snow reliability may become an issue in 2050 for all model regions, and in 2030 for the ones where ski areas are at lower elevation and south-exposed. The extent to which such areas may be affected tends to be higher in the south side of the Alps and at lower elevation. Drawing a general picture for the Alps with presently available data entails processing that goes beyond the limits of the CLISP project.

4.7.3 Adaptive capacity

Nowadays, adaption to reduced snow does mainly signify to adapt to reduced precipitation. In future times according to the results of the climate change scenarios it will be necessary to be prepared for snow reliability problems possible when arising from temperature increase. With the technology currently available the only robust adaptation measures are those aiming at diversification of winter tourism activities, which may be favoured by milder winter climate. During summer, as the plains are projected to experience a clear worsening of climate due to heat and humidity, mountain areas may become more attractive for local tourism.

4.7.4 Vulnerability - summary

Regions within the Alps that rely heavily on winter sports tourism may be vulnerable to climate change unless they develop a strong diversification of tourism. The capacity to diversify, as well as the capacity to seize opportunities from growing local tourism demand in summer, are key to reduce vulnerability. In the context of tourist destination changes due to climate change the Alpine area needs to be looked at within its European context. Since temperatures even in the Southern part of the Alps may remain more comfortable than those of the adjacent areas plains, the Alps may increase in attractiveness providing rather 'fresh weather' conditions in summer.

4.8 Water management

4.8.1 Status quo / sensitivity

The Alps are generally a water-rich context, although in the inner valleys more arid climate may be experienced. In those cases, however, glacier and snow melting from the headwaters contributes to large water abundance. The traditional abundance of water has not always stimulated good water conservation practices and efficient use of water; at the same time, water demand downstream of mountain regions is steadily increasing, which calls for more integrative water management at the hydrographic district level, in line with the European directives on the subject.

4.8.2 Potential Impact

Climate change is projected to reduce water availability for a number of reasons including prolonged and more frequent aridity and drought, flashier precipitation events and higher temperature, in turn shifting precipitation from snow to rain and reducing snow storage.

4.8.3 Adaptive capacity

Adaptation entails adoption of structural measures targeting an increase of water storage capacity in catchments, as well as non-structural measures including more efficient water use, water conservation and appropriate land management. It must be stressed that the whole Alpine region is subjected to river basin management plans according to the European Water Framework Directive (2000/60/EC), a context in which a number of planning and management instruments are being developed and coordinated towards adaptation.

4.8.4 Vulnerability - summary

The capacity of the Alpine region to adapt to reduced water availability appears relatively high although the role of the region as a water tower for large parts of Europe calls for advanced levels of organization, planning and effectiveness in plan implementation. The effects of climate change may exacerbate conflicts on water use and make some economic sectors (e.g. energy, water-intensive agricultural production) vulnerable.

5 Summary of results for model regions

Please find the executive summaries of the vulnerability assessment results of all CLISP model regions in the respective attached documents (www.clisp.eu).

6 Up-scaling of vulnerability assessment framework

6.1 Testing the applicability of the assessment methodology to coarser scales

The methodology proposed within project CLISP relies substantially on the joint interpretation of some quantitative and many qualitative elements of knowledge.

One general issue with climate change impact studies is the lack of hard figures based on which to evaluate scenarios. This is due to the high uncertainties, and even contradictions, associated with different climate change scenarios, the lack of capability to predict certain climate variables to a sufficient accuracy (only temperature predictions appear to be robust enough), and the uncertainty associated with the prediction of consequences of climate change on individual aspects. For instance, while a general intensification of the water cycle is forecasted, the prediction of river discharges as a consequence of this intensification is questionable, and a quantitative prediction of extreme events is beyond our current modelling capacity.

In particular, potential impact indicators computed on the basis of climate scenarios within CLISP may only provide hints for certain trends and cannot be used as a hard quantitative statement on the evolution of different aspects of the Alpine climate. Nevertheless, general trends that emerge from an overall reading of these indicators are reasonably consistent with evidence of climate variations and currently observed trends.

Some potential impact indicators were designed for assessment at a site-specific level (snow reliability natural hazards). For these indicators, the project has highlighted the difficulty to bring together data which are available, but sparse and heterogeneous, into a single consistent frame. This suggests that the main limitation in the application of such indicators at coarser scales is the construction of adequate databases of weather variables, morphology, and other physical variables.

All other potential impact indicators were designed to be computed at the pan-Alpine level, which suggests that they could be used for coarser scale assessment without particular limitations. What should be questioned, however, is their actual usefulness in capturing actual issues. In particular, drought/aridity indicators used in CLISP are rather preliminary and should be replaced by more refined indicators based on an adequate, albeit simplified, representation of the water cycle. This was beyond the scope of the CLISP project, and could be only achieved in certain model regions (Alessandria, Graubünden) where substantial investment has been done for the characterization of the water sector.

Growing season, wine credibility, timberline elevation, forest fire hazard, heating/cooling energy demand, tourism and health related climate indicators retain a meaning for the whole Alpine region, as they highlight trends both in time and space that help supporting an assessment also at coarser scale.

However, an interpretation of indicators of potential impact can only be done on the basis of other evidence from a qualitative inspection of the different contexts, as was done for each model region; the mere use of computed indicators is still too imprecise and unreliable to achieve an assessment at pan-Alpine level. Therefore, the frame for the assessment of potential impacts proposed within CLISP can be considered suitable for the whole Alpine region, provided that an appropriate qualitative assessment is also conducted, which cannot be automated starting from presently available data.

The adaptive capacity assessment relies heavily on region-specific information. An aggregation of adaptive capacity indicators beyond national borders is not useful. From an institutional point of view the adaptive capacity of the overall GAR should look at strengths and weaknesses of the Alpine Convention and should scrutinise relevant policies and programs of the European commission such as the Alpine Space European Territorial Cooperation.

6.2 Test results

In this synthesis report we have shown maps or graphs of potential impact indicators for the whole Alpine region, for those indicators (heating/cooling energy demand, growing season, timberline elevation, forest fire hazard, wine credibility, tourism/health related climate indicators) for which a calculation based on the

present level of knowledge is possible. We used evidence of situations from the qualitative assessment of individual model regions to draw interpretations of both adaptive capacity and vulnerability. A more in-depth assessment is beyond the scope of the project. Attempts at generalizing the indicators of natural hazards have been done for floods (Pistocchi, 2011) and for the impacts of rockfalls related to permafrost degradation (Lermer et al., 2011). However, from these applications it has appeared that indicators at pan-Alpine level only reveal general trends and need to be checked locally for effective decision support.

In the following we provide some important considerations of relevance for the Alpine region related to the potential impact of climate change on natural hazards as a crucial point in regional planning. We also present some more detailed results about the potential impact of rockfall from permafrost degradation.

6.2.1 The investigation of potential impacts of climate change on natural hazards

Within the Interreg IVb Project CLISP, land planners and researchers from 6 Alpine countries have tried to understand the complex issue of how alpine societies may adapt to the potential impacts of climate change through land planning. Among the several difficult questions to answer towards this goal, one concerns the understanding of how natural hazards may be actually modified by climate change.

Although there is relatively broad literature on possible alteration of natural hazards after climate change, the scientific community is far from being able to provide sound and uncontroversial quantitative evidence of the mechanisms by which avalanches, slope instabilities and floods would be altered under presently considered climate scenarios. Yet, the European Flood Directive and other European legislation on natural hazards stimulates, or even requires, that climate change effects be taken into proper consideration.

Here we review briefly the knowledge presently available to assess the potential impact of climate change on natural hazards, and the practical use of such knowledge that is made, or can be made, in land planning. We briefly discuss the contexts of avalanches, rockfall, debris flows, floods, forest fires, and droughts. For each of these contexts, we point out the level of understanding available and we express considerations on possible coping strategies in land planning.

6.2.1.1 Avalanches

The effects of climate change on avalanches are far from being even qualitatively understood: on the one side, more abundant winter precipitation may signal more snow accumulating on the hillslopes, hence more potential instability. On the other hand, climate change models predict winter precipitation to be more and more in the form of rain instead of snow, which indicates a shift of the snowline towards higher, and potentially less inhabited, land. Even less can be said about the influence of climate change on the mechanical parameters of avalanches, which depend on the interplay of temperature and other climatic factors in a way not fully understood even under present conditions. Martin et al., 2001, found that avalanche hazard may decrease and the proportion of wet avalanches over dry ones may increase in the French massifs. In more recent years, several studies have focused on the relationship of climate and avalanche activities (Jomelli et al., 2007; Eckert et al., 2009; Carles et al., 2009, 2010; Schweizer et al., 2009); attempts at reconstructing time series of avalanche activity aimed at analyzing trends were done (Szymczak et al., 2010; Casteller et al., 2011; Corona et al., 2010), but with little conclusive evidence on the impacts of climate change: at present, there seems to be no sound evidence that climate change will induce more severe or more frequent avalanches in a generalized sense.

6.2.1.2 Rockfalls

The one effect of climate change on rockfalls, which is broadly acknowledged to be relevant in mountain environments, is permafrost degradation, which may affect bedrock cohesion mechanisms (Menendez Duarte et al., 2002; Gruber and Haeberli, 2007; Harris et al., 2009). Other mechanisms, such as precipitation, show less clear trends and the impacts of climate change are on purpose rather difficult to identify.

Rockfalls due to permafrost melting are expected to be triggered at high elevation and, most of the times, in low population density areas. The consequences are therefore likely to affect mainly mountain trails and

infrastructures, and the road network. For some isolated valleys in the Alps, this impact is likely to be quite important.

Within CLISP, a pan-Alpine assessment of the potential impacts of permafrost melting in terms of reduction of road accessibility of the valleys has been conducted. The study consisted in identifying the permafrost areas that, under climate change, may generate rockfalls due to permafrost degradation (see example in Figure 31).

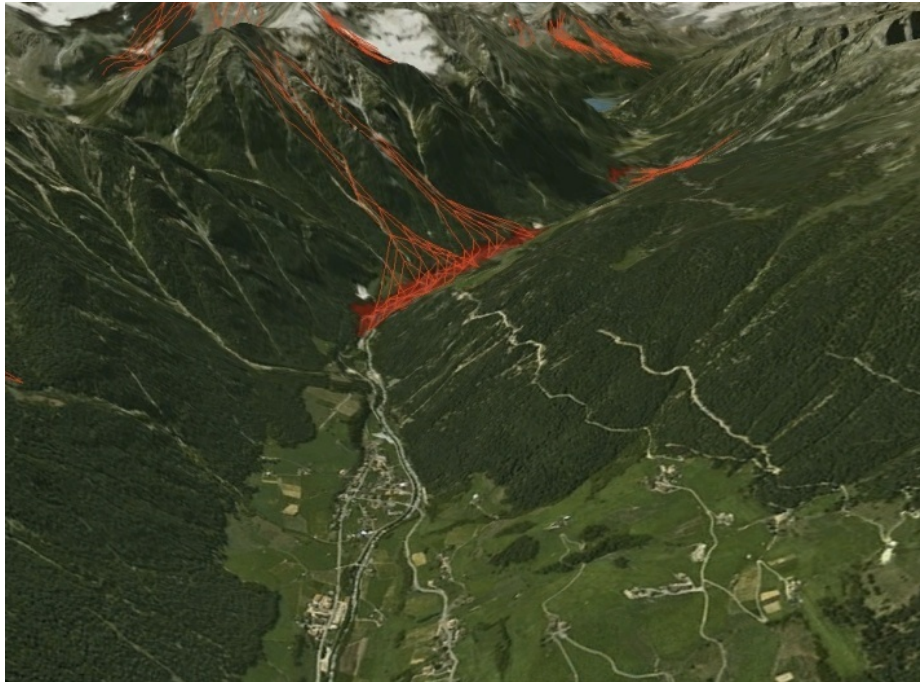


Figure 31: Affected roads trajectories in Martello valley. From Lermer et al., in prep.

This analysis allows to evaluate which roads may be intercepted by the trajectories of potential rockfalls. It is consequently possible to evaluate how many people may be affected by the obliteration of a road, i.e. how many people may suffer from an extension of the time of travel from their residence to central places (either the nearest cities, or the Alpine area border) in the event of rockfalls.

Figure 32 shows the trajectories with highest traffic in the Alpine region, either due to movements towards the nearest city or to the region boundary. In the event of a road hit by a rockfall, it is possible to recalculate the time of travel to the nearest city and to the Alpine region border. The variation of time of travel, multiplied by the population affected by the variation, is an indicator of the magnitude of the potential impact due to rockfalls (Figure 33). From inspection of Figure 3, it is apparent that the phenomenon is quite widespread throughout the region, with several valleys potentially affected by rockfalls under permafrost degradation, hence at risk of suffering from slow communications and the associated economic consequences. Consequently, costs to protect or restore the road network may considerably increase in the future. This may be a relevant management issue in order to adapt to climate change in the Alpine region.

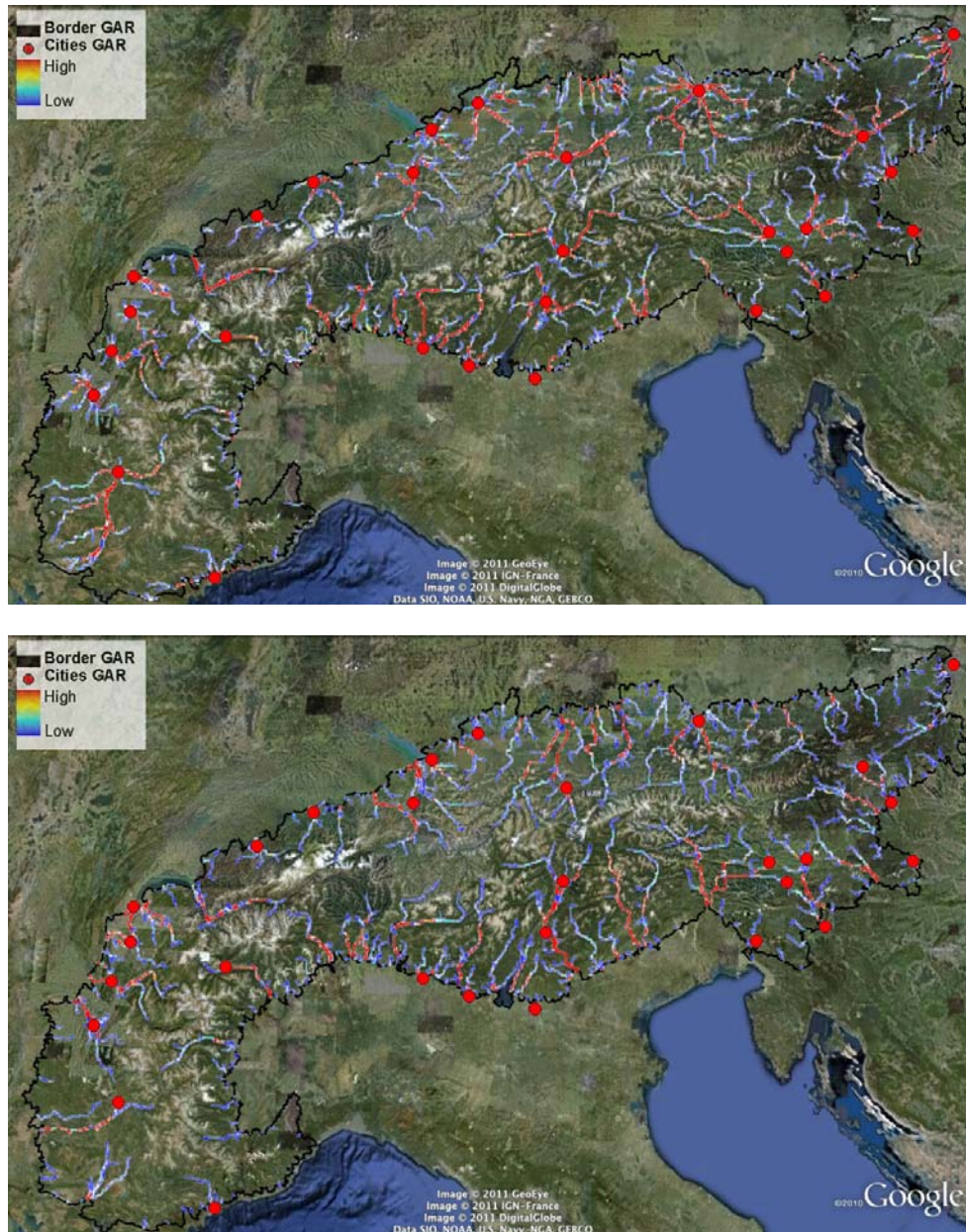


Figure 32: Accumulation of population along the shortest path to the nearest city (above) and the Greater Alpine Region (GAR) border (below). From Lermer et al., in prep.

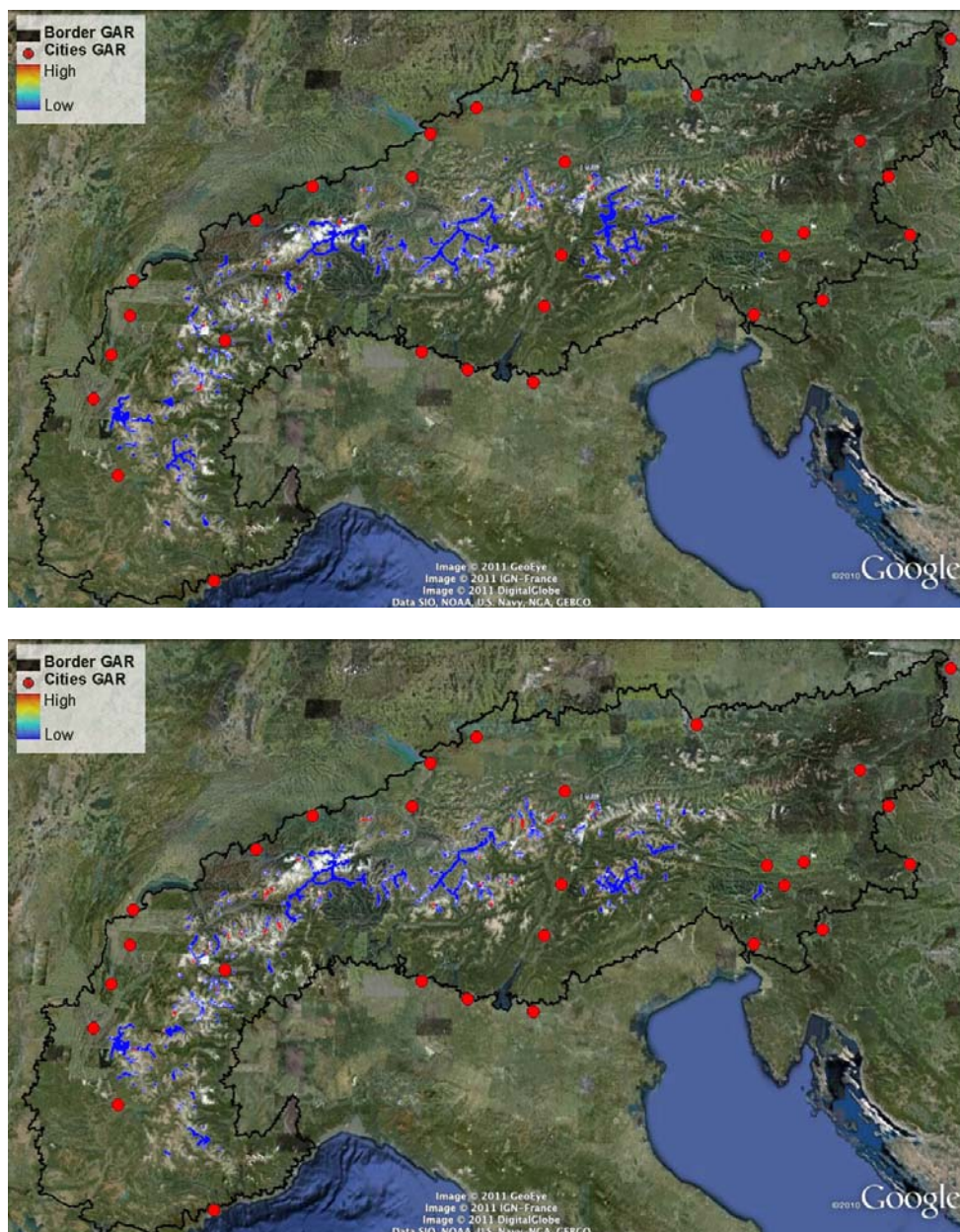


Figure 33: Impact on the road network: traffic to the nearest city (below) or to the border (above). From Lerner et al., in prep.

6.2.1.3 Debris flows

There is no conclusive evidence about a change in frequency and intensity of debris flow. Stoffel et al., 2008, suggest that climate change may imply a reduction in frequency of debris flow in the Swiss Alps. This contrasts with other evidence (e.g. Pelfini and Santilli, 2008, who highlight an increasing trend in the frequency of debris flow in the Central Italian Alps). Debris flow is clearly sensitive to precipitation of high intensity and duration depending on the catchment characteristics. Anyway the linkages between precipitation variation and debris flows are far from being well understood. At present, no widely agreed-upon conceptual model of climate change impacts on debris flow seems to exist.

6.2.1.4 Floods

The assessment of climate change on floods is a prominent topic of interest in land planning. However, so far little evidence has been collected about relationships between climate change and flood frequency and intensity variations. An established reasoning line consists in assuming that, as weather extremes are projected to increase in frequency and severity, floods will follow the same trends in rainfall-dominated flood regimes. A conceptual model has been developed recently by Allamano et al., 2009a,b, that enables linking the change in flood return periods with the extent of the contributing area of a stream above the freezing line. Based on this model, Alpine catchments are expected to exhibit return period (RP) changes of floods such that a 100-years RP today may become a 20-years following climate change. Castellarin and Pistocchi, 2011, observe that empirical evidence from the Swiss Alps is compatible with this model and suggest a practical method to assess design discharges (e.g. 100-years RP discharges) under climate change starting from the assumption of a given (e.g. 100-to-20 years) RP shift.

A map of 100-year-RP discharge variations in the Alps following the conceptual model of Allamano et al., 2009a,b, and the approach proposed by Castellarin and Pistocchi, 2011, is shown in Figure 34.

According to this model, discharges are projected to increase more in catchments at higher elevation, and in the western Alps compared to the East. The most affected catchments seem to be in the Swiss and Italian Alps, where more catchments tend to turn from nival to pluvial regimes.

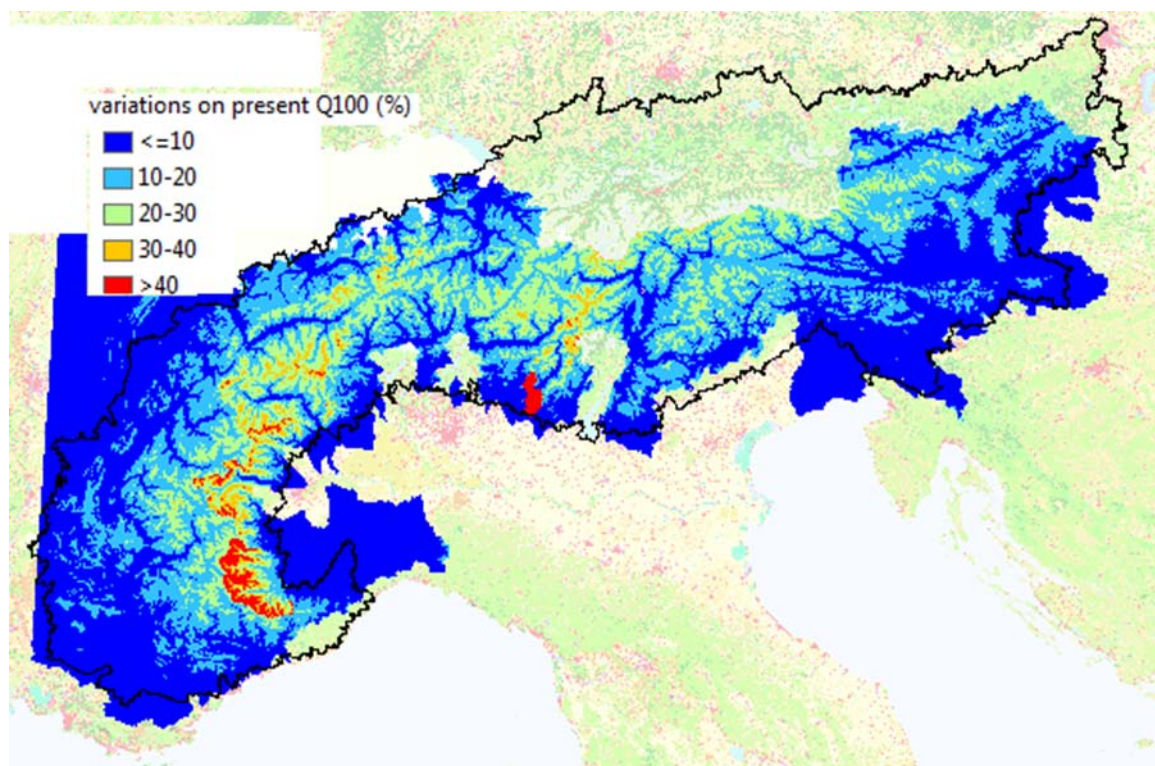


Figure 34: distribution of the variation of present-day 100-year return period floods in the Alps, under worst-case assumptions (from Pistocchi, in prep.).

6.2.1.5 Forest fires

Dryer and hotter summer climate implies apparently higher forest fire danger. This aspect seems to be adequately predictable in climate change impact studies. The map of forest fire hazard (Nesterov's index) change that has been produced for the Alps within CLISP is an example of an assessment of this type.

6.2.1.6 Droughts

Droughts are expected to increase in severity and frequency following climate change. However, a sound quantification of the trend is far from being available. At present, a standard approach consists in using climate scenarios to modify precipitation and temperature inputs to hydrological models. This enables simulating streamflows and water availability under climate change scenarios, and is easily applied at each location where a hydrological model can be soundly calibrated. One such exercise has been developed in model regions Alessandria and Graubunden within CLISP. The results indicate that for Alessandria, which is already a relatively drought-prone area within the greater Alpine context, variations of climate input induce hydrological changes practically encompassing the natural variability of present conditions. On the contrary, in more water-rich areas such as Graubunden a shift of hydrological regimes from nival and glacial to pluvial will have significant impacts on water availability.

6.2.2 Concluding remarks

Although the Alps are among the European regions experiencing the most marked changes in climate over the last decades, there is still little knowledge available to quantify in a well defined way changes in natural hazards that may be triggered by climate change. Uncertainties owe to a large extent to the lack of resolution (in space and time) and clarity in the trends of climate scenarios (e.g. in precipitation). To an equally large extent, however, they also owe to the lack of capacity to model phenomena such as avalanches, debris flows, and rockfalls in a deterministic way. A clearer understanding appears at the level of forest fires and droughts, for which the trends in temperature and aridity suggested by climate scenarios are relatively agreed-upon. Concerning floods, although a general understanding of climate change controls is still far from being reached, a conceptual model has been proposed that provides a reasonable working hypothesis for screening-level assessment of flood hazard changes in the Alps.

Under such large uncertainties, it is recommendable that natural hazards be coped with considering present conditions, by identifying good practices and undertaking no-regret actions to adapt in a robust and socio-economically acceptable way, as pointed out e.g. by Wilby and Dessai, 2010.

7 Conclusions

The assessment of vulnerability to climate change is not an easy exercise. In the first place, it requires to have a critical look at current, and mostly well established, planning practices. Within WP4, a first check-up has been prepared for each model region that helps triggering the discussion on how spatial planning should adapt to climate change: what are the main issues related to a changing climate, which economic sectors are expected to suffer more than others, how well, and how deep, can change impacts be predicted, which practices are good and should be empowered and pursued, and which should be revised as not sustainable in the event of change.

Within the project CLISP, it has been experienced how the assessment of Adaptive Capacity requires specific analysis of the regional context from a highly integrated assessment in the form of specific strength, weakness, opportunity and threat (SWOT) analyses as is common practice already in other contexts (such as strategic environmental assessment (SEA) of plans and programmes). Potential impacts of climate change, on the other hand, may be assessed in some cases on the basis of quantitative indicators derived from the modelling of climate scenarios and their effects. Nevertheless, uncertainty remains high and often no clear trend and, consequently, indication for decision support may be extracted from such assessment exercises. “Pure” climate indicators (i.e. indicators related to temperature, precipitation and similar variables) are relatively easy to derive from climate scenario models. Effects in terms of natural hazards, on the other hand, are ways more complex and uncertain to predict.

In the following a list of strategic recommendations has been compiled that is intended to support practitioners in planning and implementing regional climate change vulnerability studies.

When assessing your vulnerability, use climate change scenarios with care and don't count too much on quantitative approaches

- Climate change scenarios are a useful and necessary input for a vulnerability assessment but regional climate scenarios show a large range of results and a high uncertainty (particular for precipitation)
- Information on changes in extreme events are not reliable (besides temperature extremes)
- Quantitative assessment of impacts (models) are only available for a small number of potential impacts and subject to uncertainty
- Time horizon for most stakeholders: << 20 years but weak Climate Change signal within this time frame

Take a close look on the status quo of your system and learn from history

- A large part of the vulnerability to climate change can already be understood by analysing the status quo of the system with respect to the sensitivity of the system to climate and weather extremes now and in the past (like the heatwave 2003)
- Regions, which are already sensitive to the climate extremes which are expected to increase are the most vulnerable regions

Don't be afraid of being qualitative and narrative, respect stakeholder as experts

- Involve the stakeholders on all levels (farmers, water managers, decision makers, ...) in a vulnerability assessment, and respect them as experts. They are the one who know their system best and the one who have to adapt to climate change in the end.
- Qualitative and narrative information (for instance on the sensitivity of the system) can often better reveal the relevant details for a vulnerability assessment than a purely quantitative approach

For future vulnerability consider also the development of your system and other pressures on your system.

- Climate change is in most cases just an additional pressure, consider also the other ones like land-use change, demographic change, increase in traffic, ...
- Often, vulnerability arises more from a combination of expected change in the system and climate change. E.g. the risk of damage on buildings or infrastructure by natural hazards might increase in future due to an expansion of settlements into hazards zones combined with an increase of the frequency and intensity of natural hazards.

Plan and implement appropriate adaptation measures in time and be ready to act under uncertainty

- Often technical measures (torrent protection, dikes, ...) are already well implemented. What is missing are more “soft” adaptation strategies like a proper “climate-proof” spatial planning, a better coordination of actions within institutions, or better risk-communication
- Adopt “no regret” or “low regret” adaptation measures whenever possible; for instance, energy efficient buildings are good even today, imagine under hotter summers!
- Natural hazards and related impacts will occur more frequently and more severely, but firstly in the same areas where they occur today: good planning of adaptation to current natural hazards is also a good option for adaptation to climate change.

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D Annex

D.1 Literature review

Please find the literature review as a separate annex to this report in the results section of the CLISP website (www.clisp.eu).

D.2 Glossary

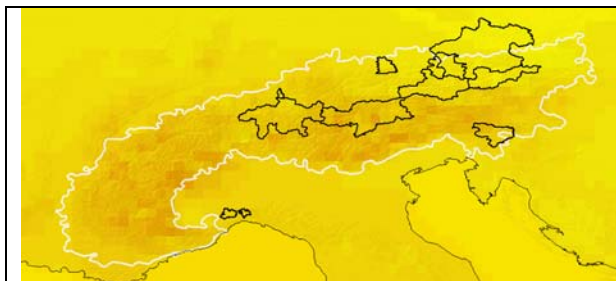
Please find the glossary as a separate annex to this report in the results section of the CLISP website (www.clisp.eu).

D.3 Climate scenario maps

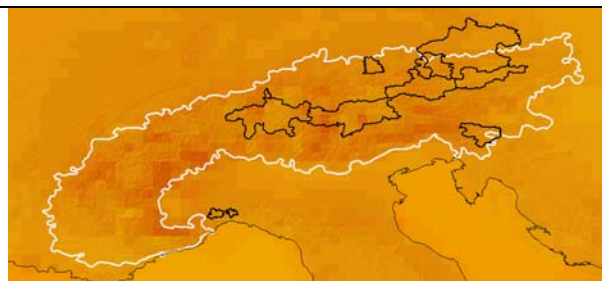
D.3.1 Seasonal (Winter, DJF) absolute temperature changes

DJF: 2011-2030 minus 1961-1990

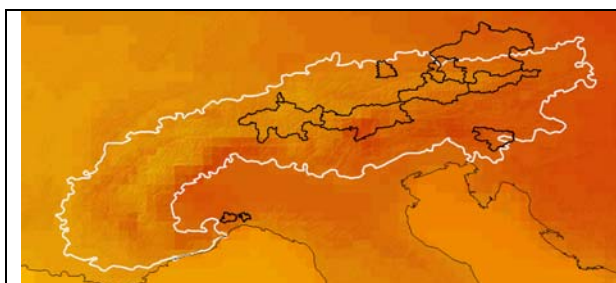
DJF: 2031-2050 minus 1961-1990



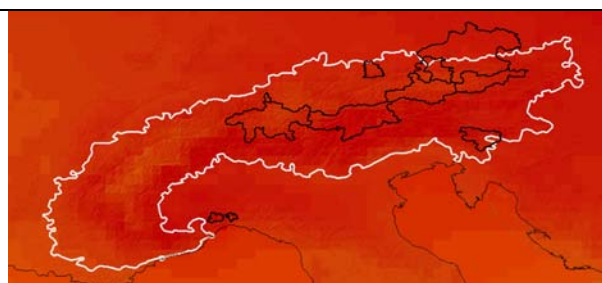
CLM (Consortial) A1B - 2030



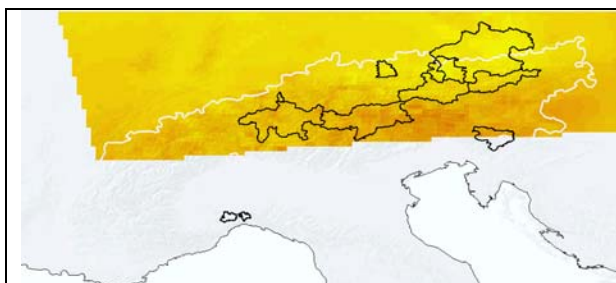
CLM (Consortial) A1B - 2050



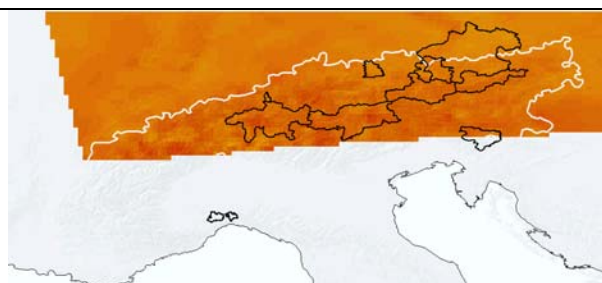
CLM (Ensembles) A1B - 2030



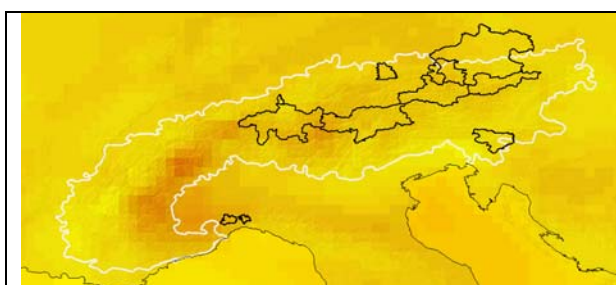
CLM (Ensembles) A1B - 2050



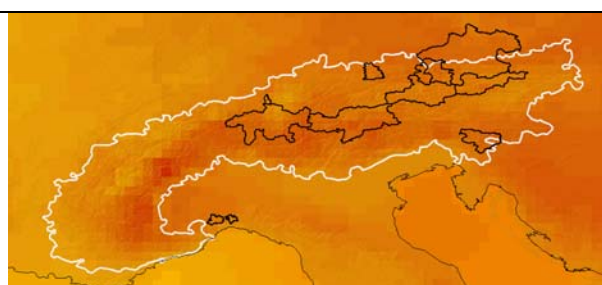
REMO-UBA-M A1B - 2030



REMO-UBA-M A1B - 2050



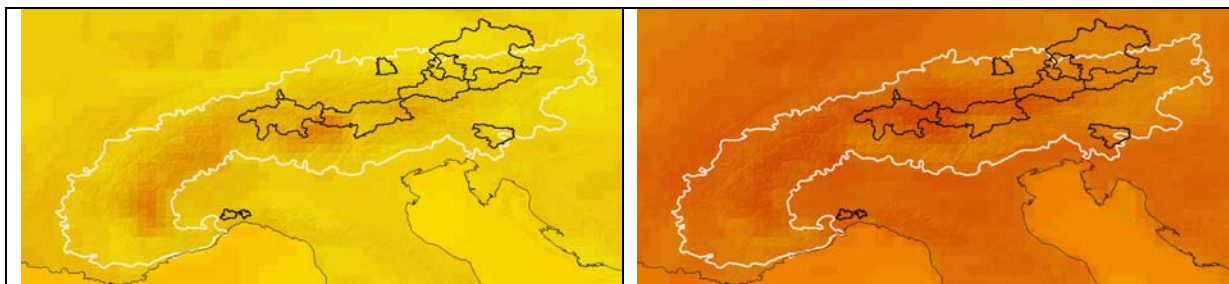
REMO (Ensembles) A1B - 2030



REMO (Ensembles) A1B - 2050

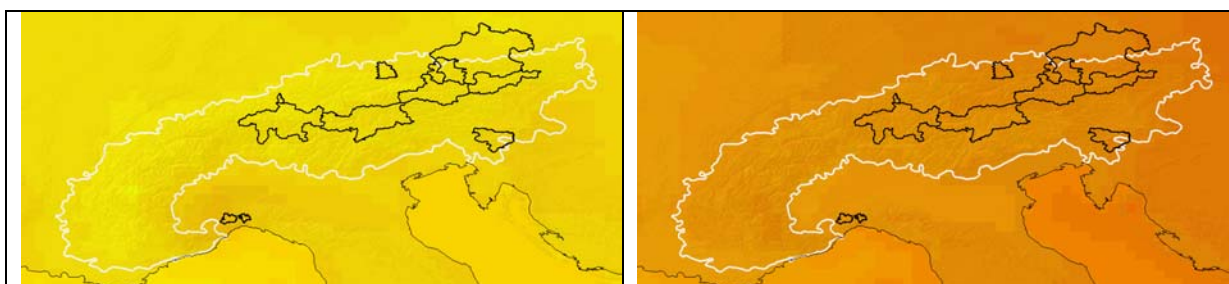
DJF: 2011-2030 minus 1961-1990

DJF: 2031-2050 minus 1961-1990



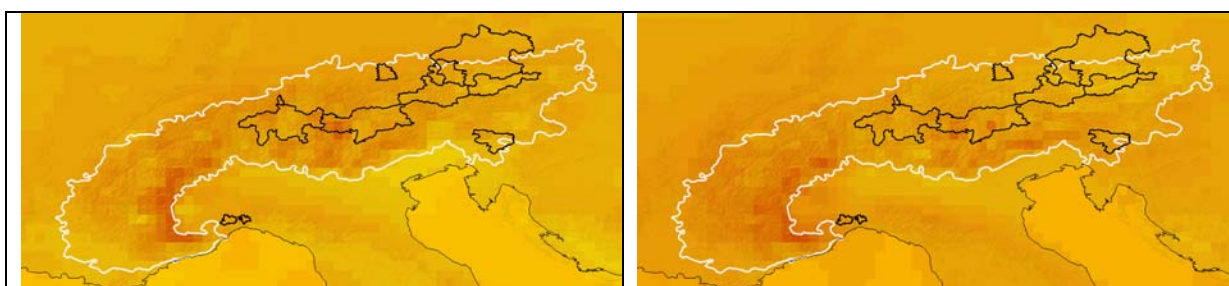
Aladin (Ensembles) A1B - 2030

Aladin (Ensembles) A1B - 2050



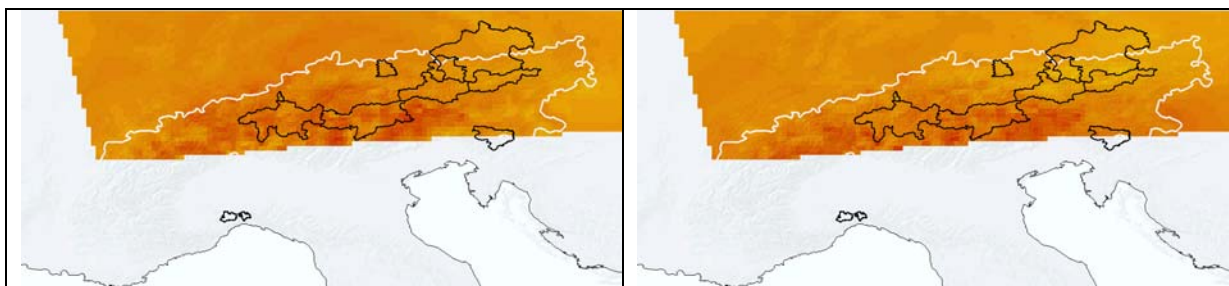
RegCM (Ensembles) A1B - 2030

RegCM (Ensembles) A1B - 2050



CLM (Consortial) B1 - 2030

CLM (Consortial) B1 - 2050



REMO-UBA-M B1 - 2030

REMO-UBA-M B1 - 2050

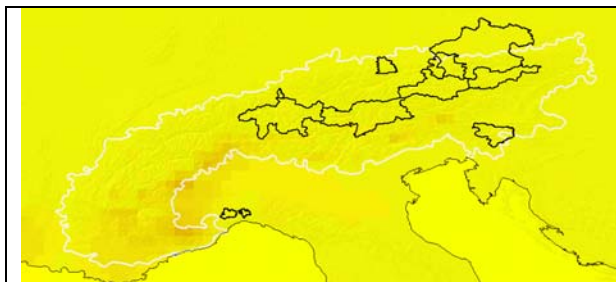


Figure 35: Seasonal (Winter, DJF) absolute temperature changes regarding the Alps for eight climate scenarios. Left: 2011-2030 minus 1961-1990; right: 2031-2050 minus 1961-1990.

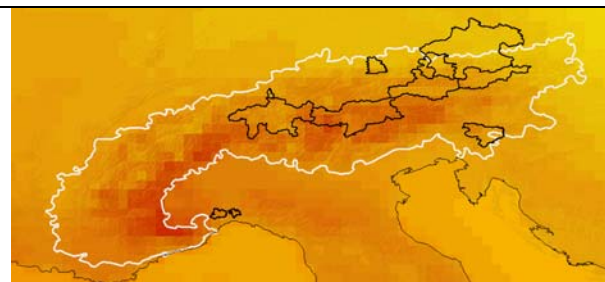
D.3.2 Seasonal (Spring, MAM) absolute temperature changes

MAM: 2011-2030 minus 1961-1990

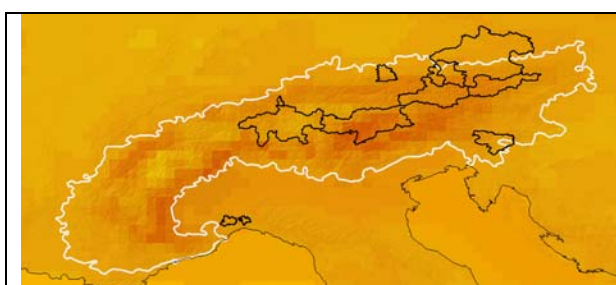
MAM: 2031-2050 minus 1961-1990



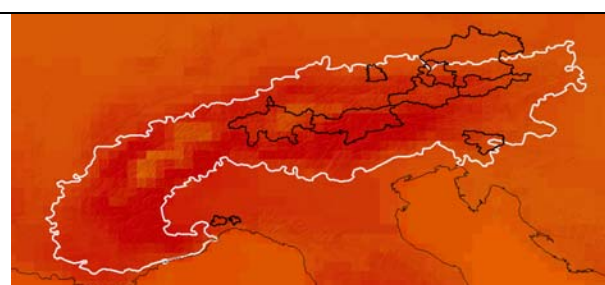
CLM (Consortial) A1B - 2030



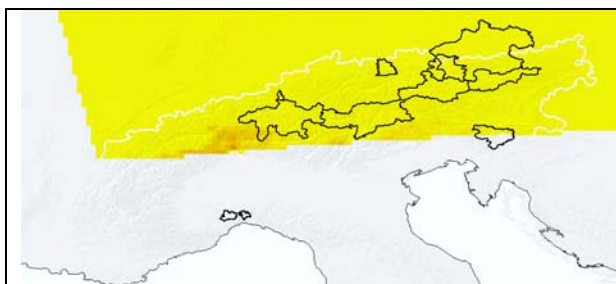
CLM (Consortial) A1B - 2050



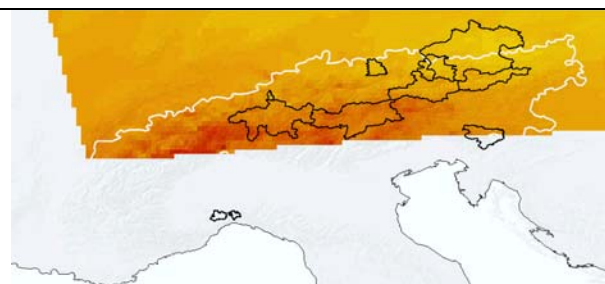
CLM (Ensembles) A1B - 2030



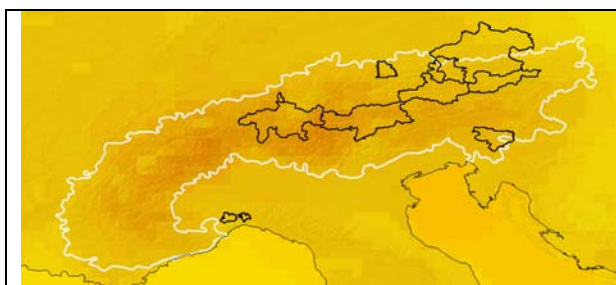
CLM (Ensembles) A1B - 2050



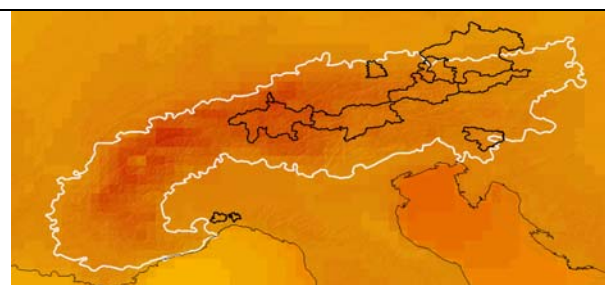
REMO-UBA-M A1B - 2030



REMO-UBA-M A1B - 2050



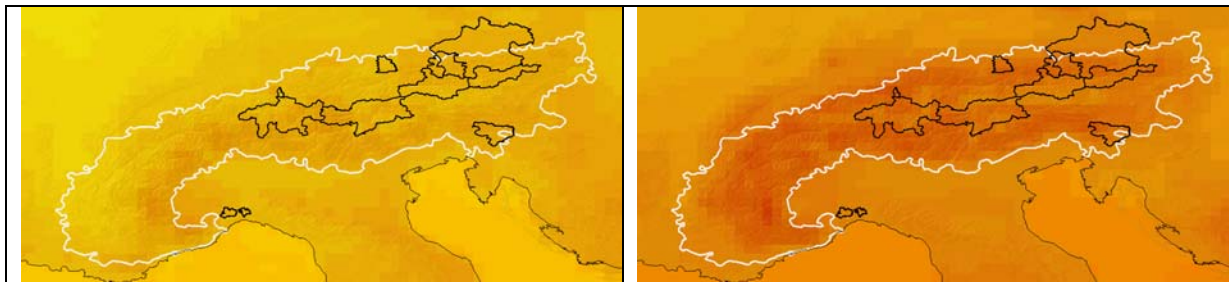
REMO (Ensembles) A1B - 2030



REMO (Ensembles) A1B - 2050

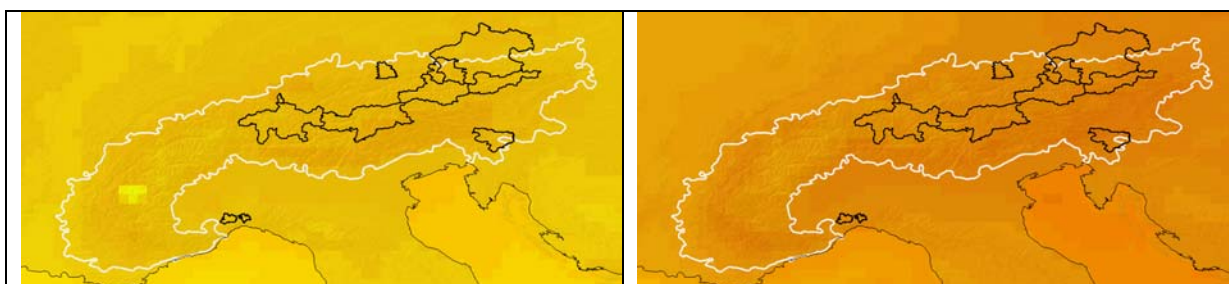
MAM: 2011-2030 minus 1961-1990

MAM: 2031-2050 minus 1961-1990



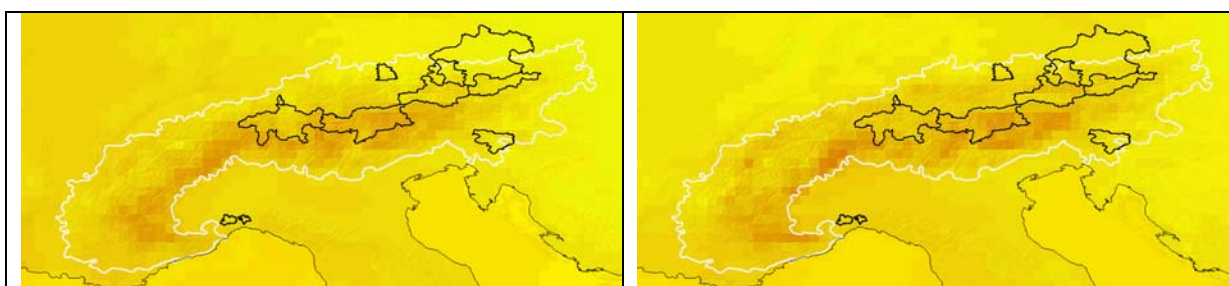
Aladin (Ensembles) A1B - 2030

Aladin (Ensembles) A1B - 2050



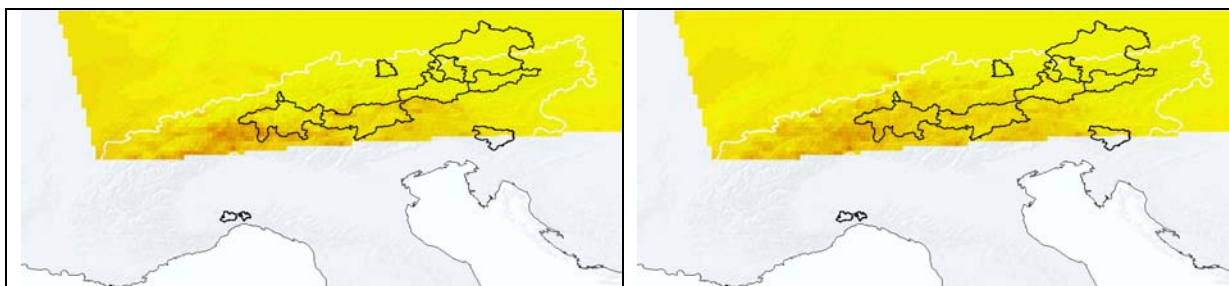
RegCM (Ensembles) A1B - 2030

RegCM (Ensembles) A1B - 2050



CLM (Consortial) B1 - 2030

CLM (Consortial) B1 - 2050



REMO-UBA-M B1 - 2030

REMO-UBA-M B1 - 2050

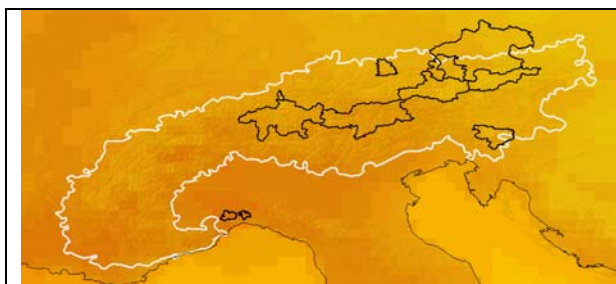


Figure 36: Seasonal (Spring, MAM) absolute temperature changes regarding the Alps for eight climate scenarios. Left: 2011-2030 minus 1961-1990; right: 2031-2050 minus 1961-1990.

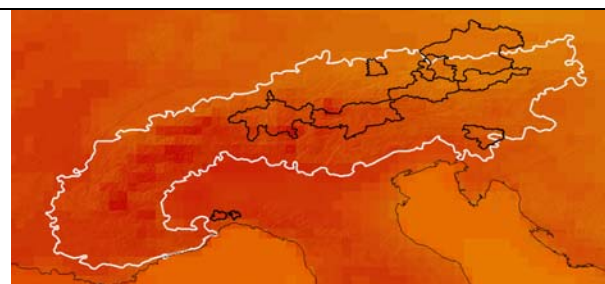
D.3.3 Seasonal (Summer, JJA) absolute temperature changes

JJA: 2011-2030 minus 1961-1990

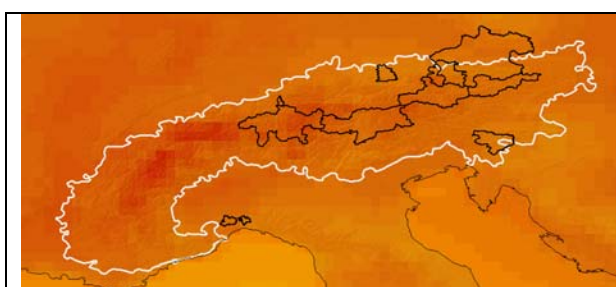
JJA: 2031-2050 minus 1961-1990



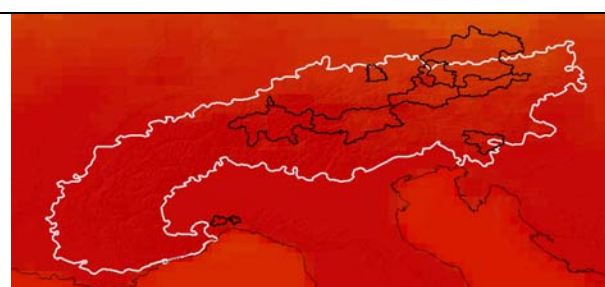
CLM (Consortial) A1B - 2030



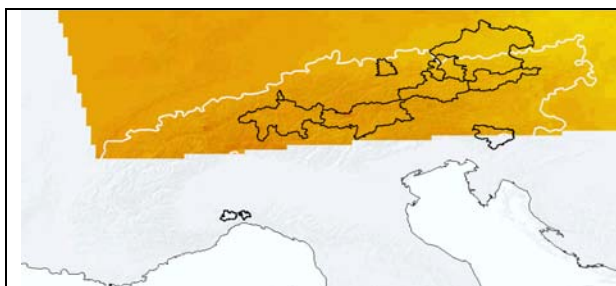
CLM (Consortial) A1B - 2050



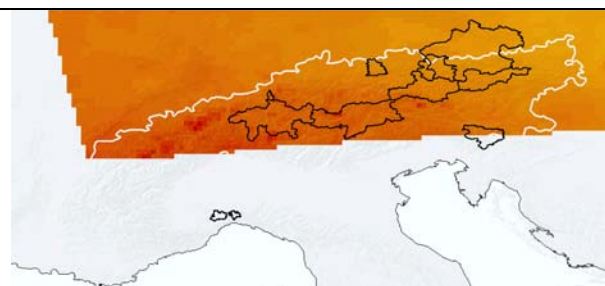
CLM (Ensembles) A1B - 2030



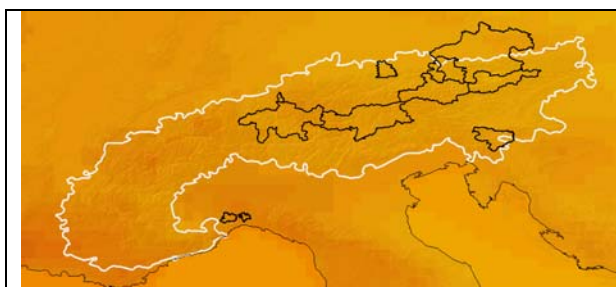
CLM (Ensembles) A1B - 2050



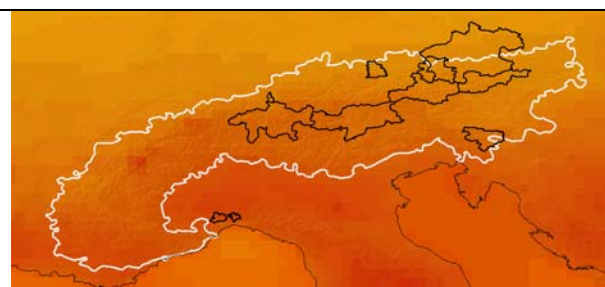
REMO-UBA-M A1B - 2030



REMO-UBA-M A1B - 2050



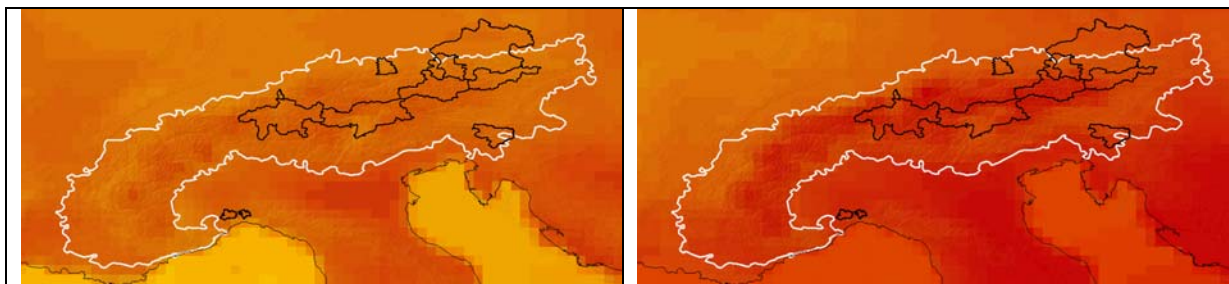
REMO (Ensembles) A1B - 2030



REMO (Ensembles) A1B - 2050

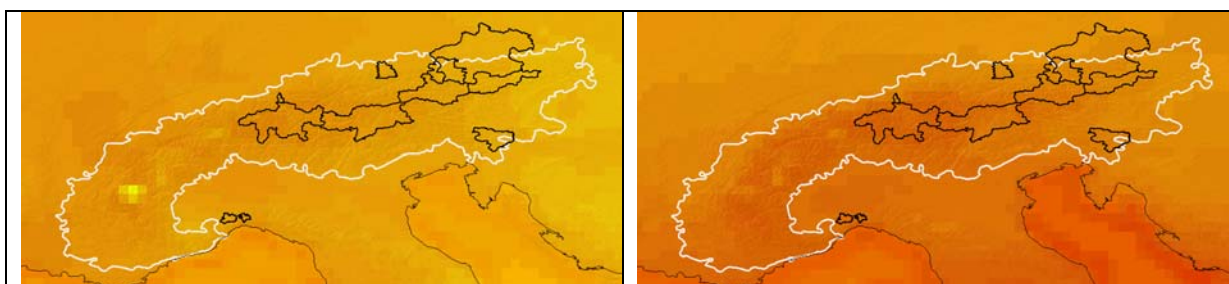
JJA: 2011-2030 minus 1961-1990

JJA: 2031-2050 minus 1961-1990



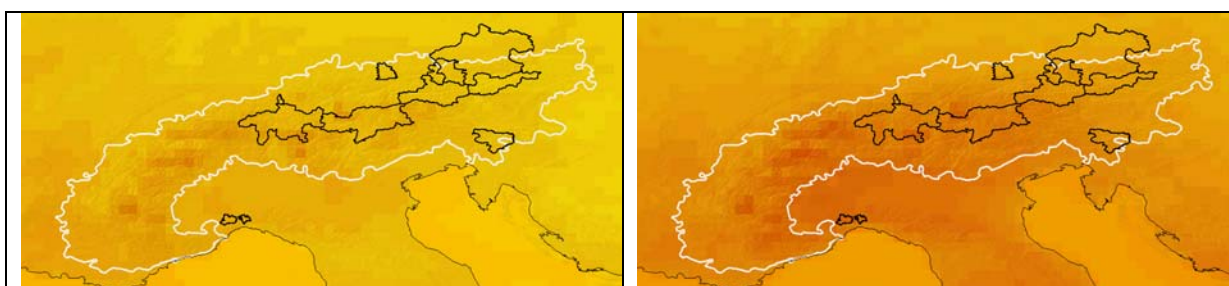
Aladin (Ensembles) A1B - 2030

Aladin (Ensembles) A1B - 2050



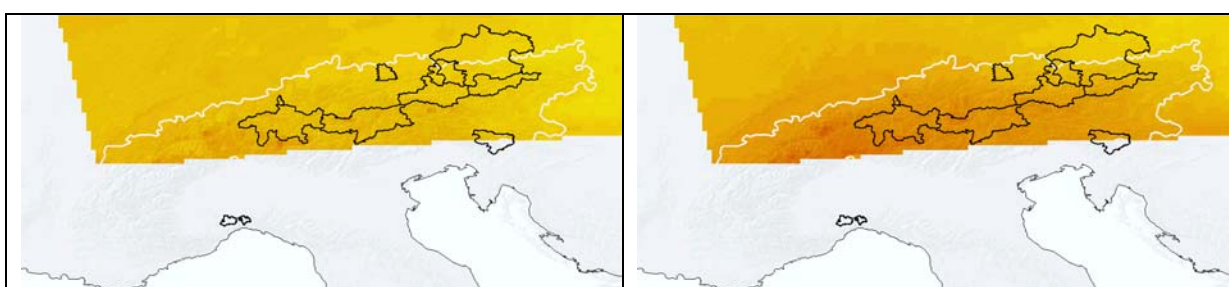
RegCM (Ensembles) A1B - 2030

RegCM (Ensembles) A1B - 2050



CLM (Consortial) B1 - 2030

CLM (Consortial) B1 - 2050



REMO-UBA-M B1 - 2030

REMO-UBA-M B1 - 2050

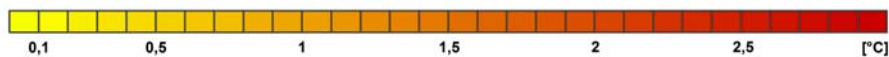
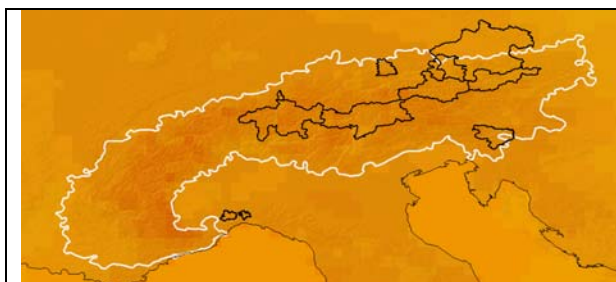


Figure 37: Seasonal (Summer, JJA) absolute temperature changes regarding the Alps for eight climate scenarios. Left: 2011-2030 minus 1961-1990; right: 2031-2050 minus 1961-1990.

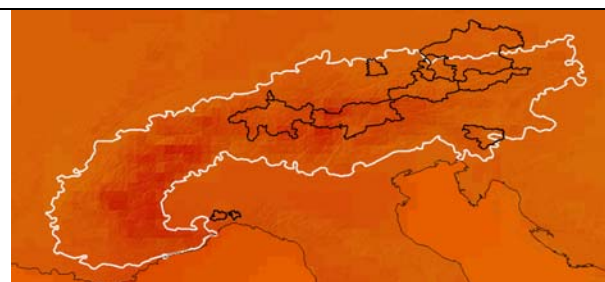
D.3.4 Seasonal (Autumn, SON) absolute temperature changes

SON: 2011-2030 minus 1961-1990

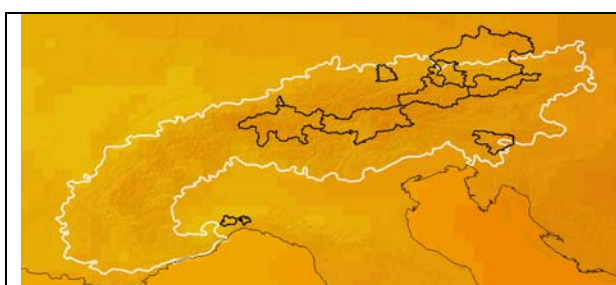
SON: 2031-2050 minus 1961-1990



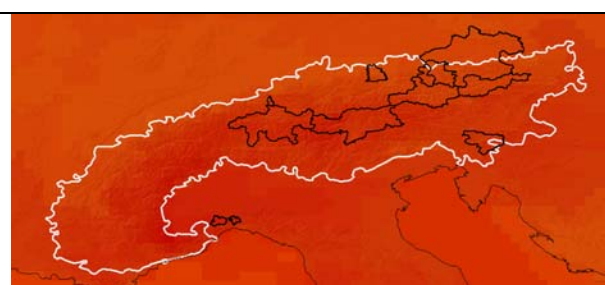
CLM (Consortial) A1B - 2030



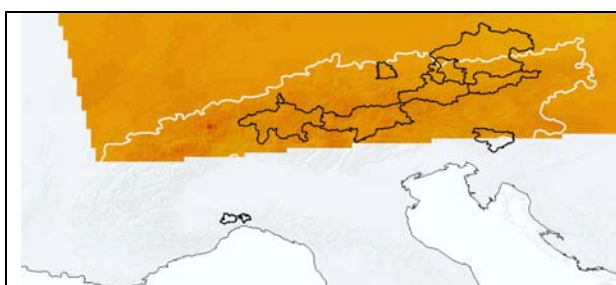
CLM (Consortial) A1B - 2050



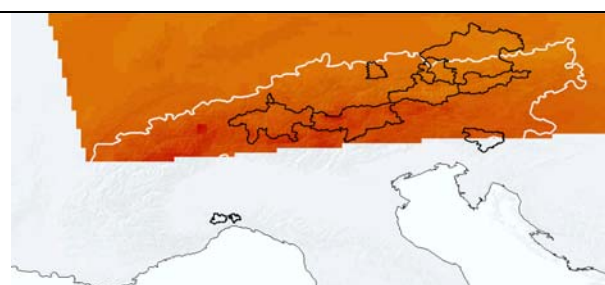
CLM (Ensembles) A1B - 2030



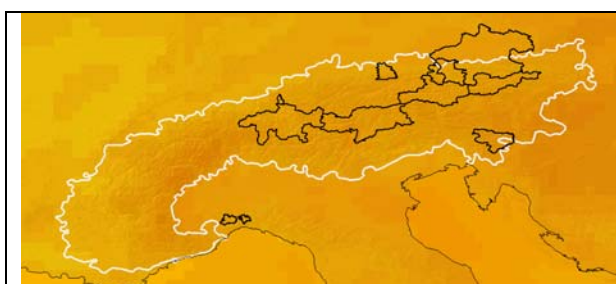
CLM (Ensembles) A1B - 2050



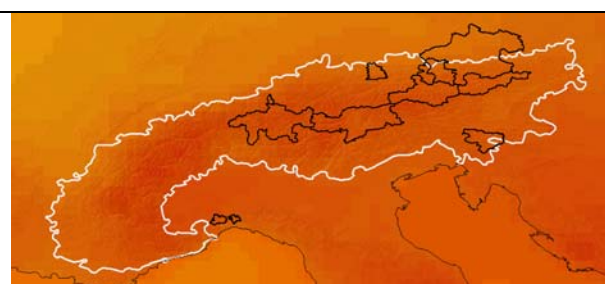
REMO-UBA-M A1B - 2030



REMO-UBA-M A1B - 2050



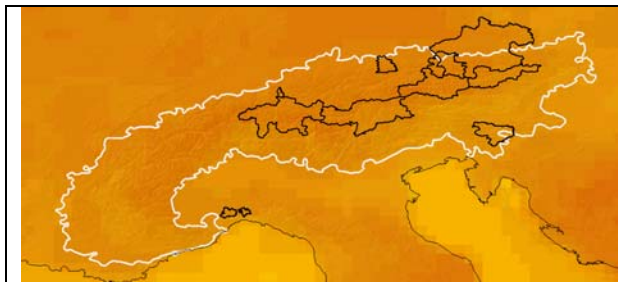
REMO (Ensembles) A1B - 2030



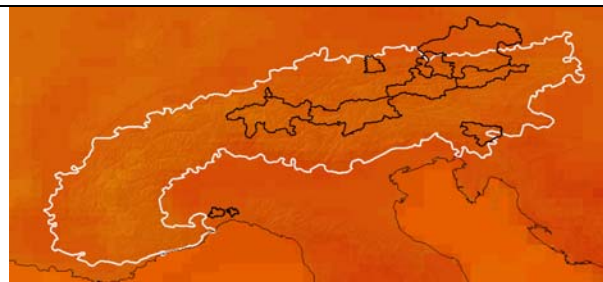
REMO (Ensembles) A1B - 2050

SON: 2011-2030 minus 1961-1990

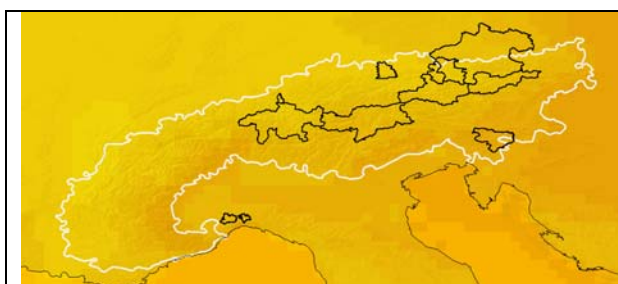
SON: 2031-2050 minus 1961-1990



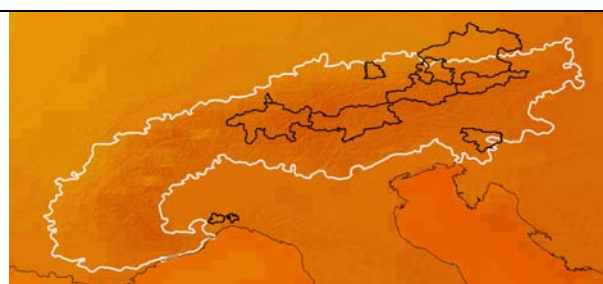
Aladin (Ensembles) A1B - 2030



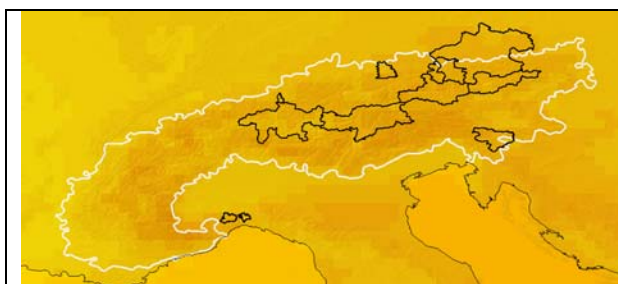
Aladin (Ensembles) A1B - 2050



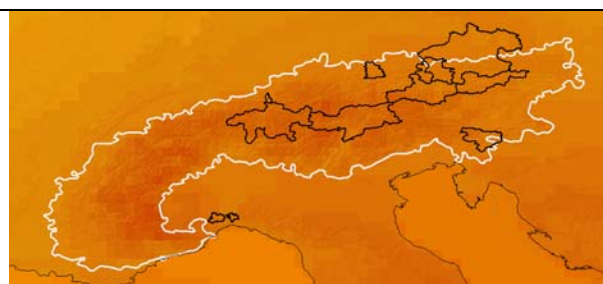
RegCM (Ensembles) A1B - 2030



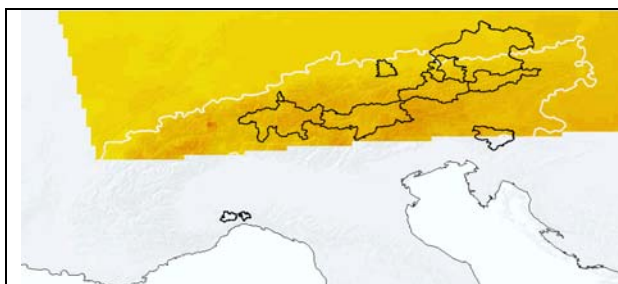
RegCM (Ensembles) A1B - 2050



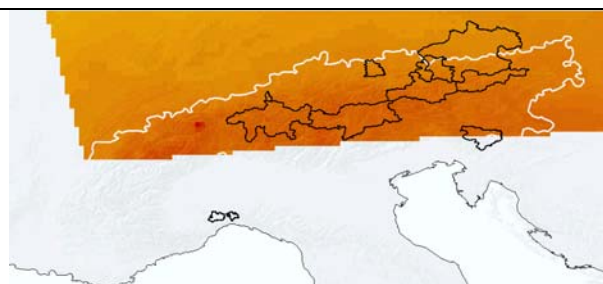
CLM (Consortial) B1 - 2030



CLM (Consortial) B1 - 2050



REMO-UBA-M B1 - 2030



REMO-UBA-M B1 - 2050

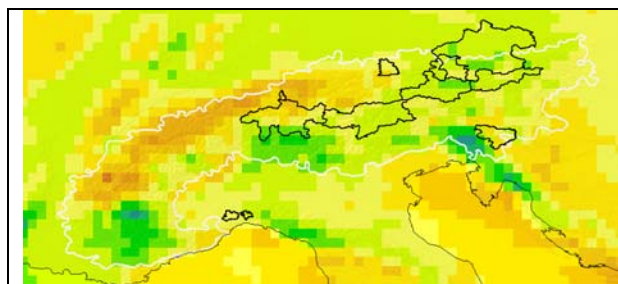


Figure 38: Seasonal (Autumn, SON) absolute temperature changes regarding the Alps for eight climate scenarios. Left: 2011-2030 minus 1961-1990; right: 2031-2050 minus 1961-1990.

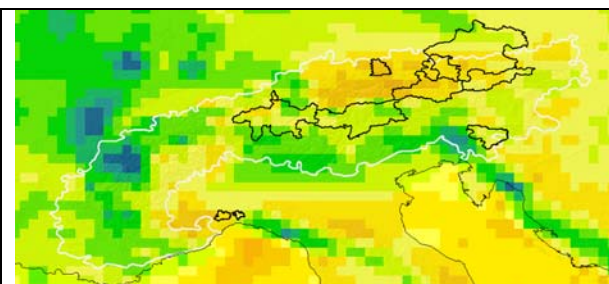
D.3.5 Seasonal (Winter, DJF) absolute precipitation changes

DJF: 2011-2030 minus 1961-1990

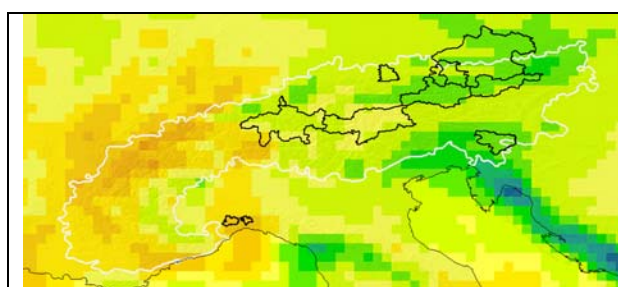
DJF: 2031-2050 minus 1961-1990



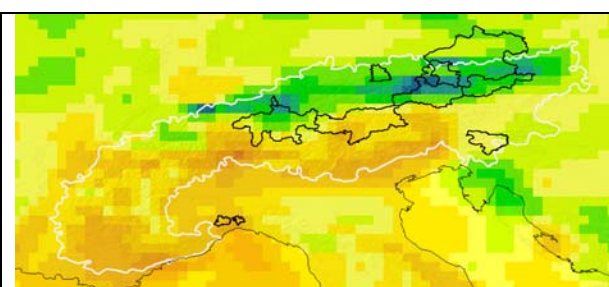
CLM (Consortial) A1B - 2030



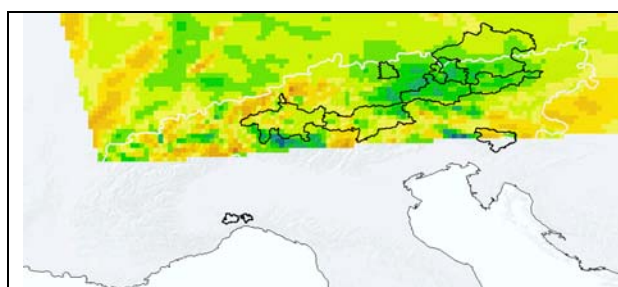
CLM (Consortial) A1B - 2050



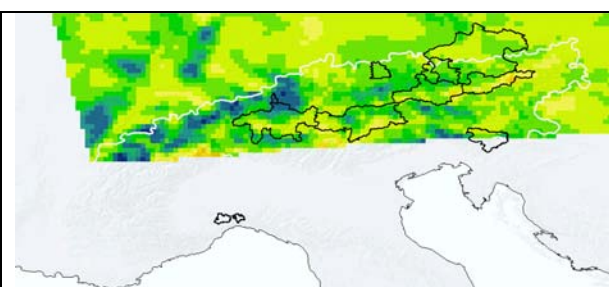
CLM (Ensembles) A1B - 2030



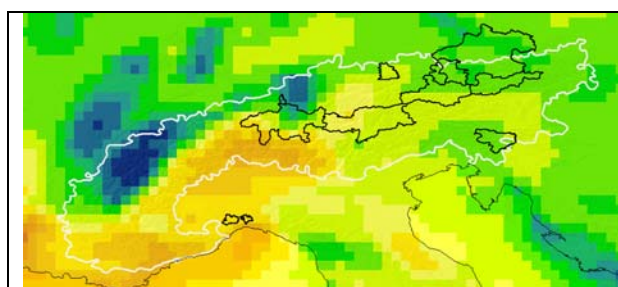
CLM (Ensembles) A1B - 2050



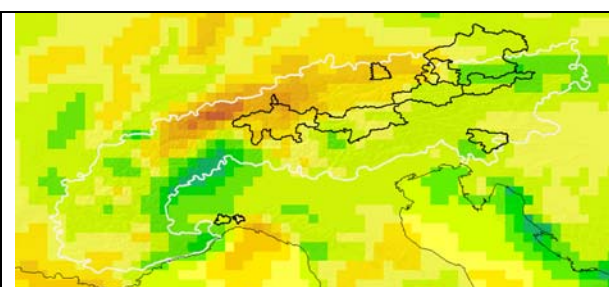
REMO-UBA-M A1B - 2030



REMO-UBA-M A1B - 2050



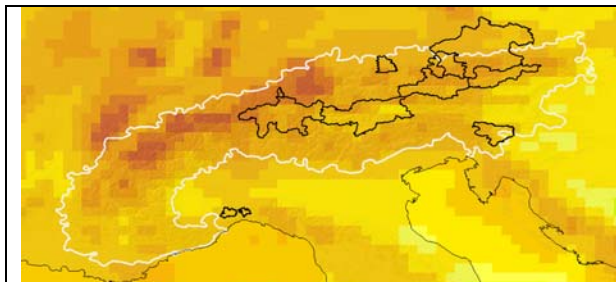
REMO (Ensembles) A1B - 2030



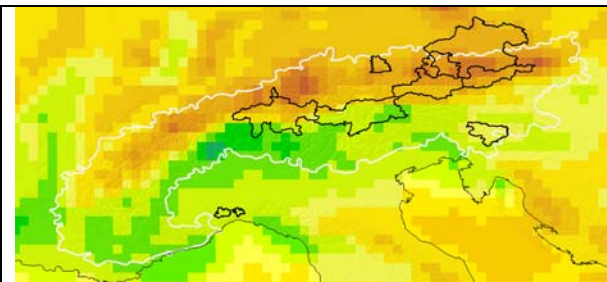
REMO (Ensembles) A1B - 2050

DJF: 2011-2030 minus 1961-1990

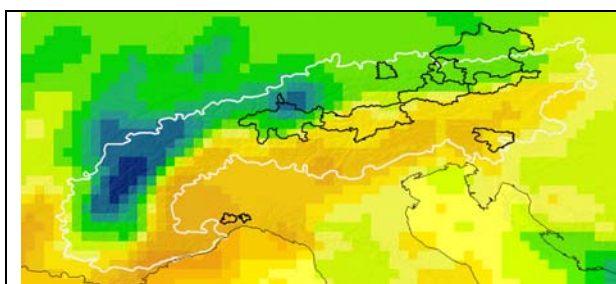
DJF: 2031-2050 minus 1961-1990



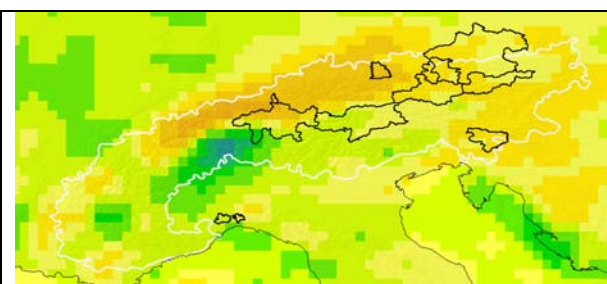
Aladin (Ensembles) A1B - 2030



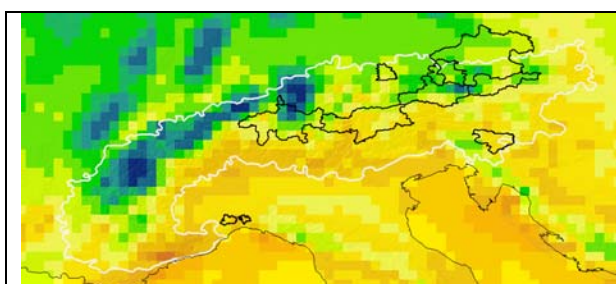
Aladin (Ensembles) A1B - 2050



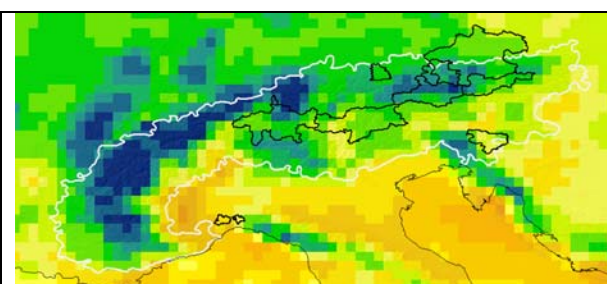
RegCM (Ensembles) A1B - 2030



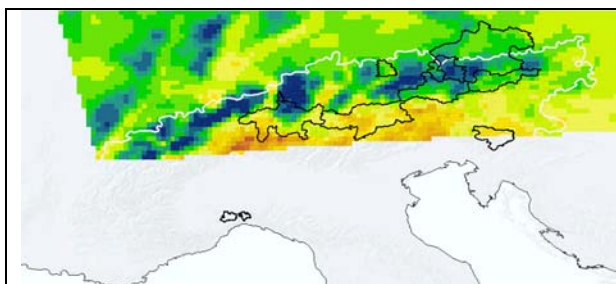
RegCM (Ensembles) A1B - 2050



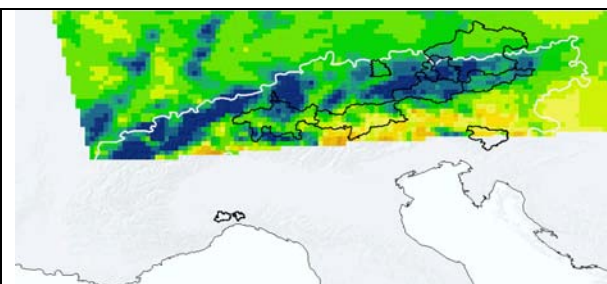
CLM (Consortial) B1 - 2030



CLM (Consortial) B1 - 2050



REMO-UBA-M B1 - 2030



REMO-UBA-M B1 - 2050

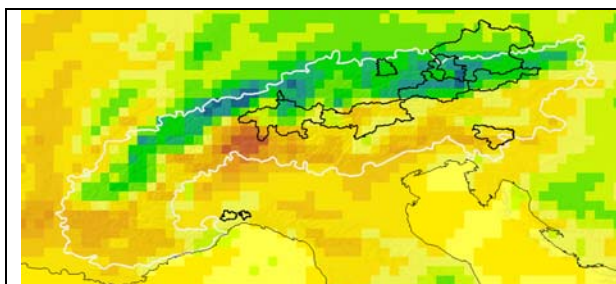


Figure 39: Seasonal (Winter, DJF) absolute precipitation changes regarding the Alps for eight climate scenarios. Left: 2011-2030 minus 1961-1990; right: 2031-2050 minus 1961-1990.

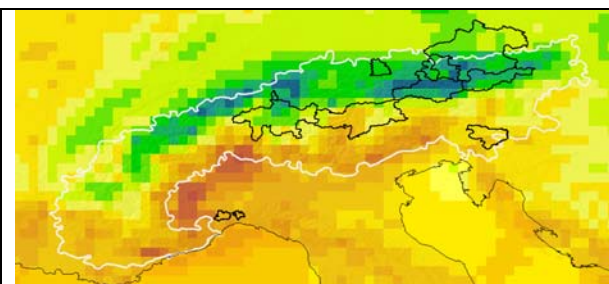
D.3.6 Seasonal (Spring, MAM) absolute precipitation changes

MAM: 2011-2030 minus 1961-1990

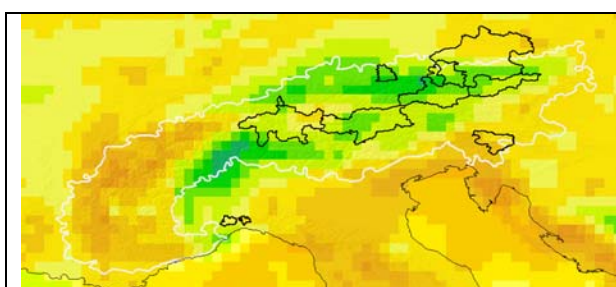
MAM: 2031-2050 minus 1961-1990



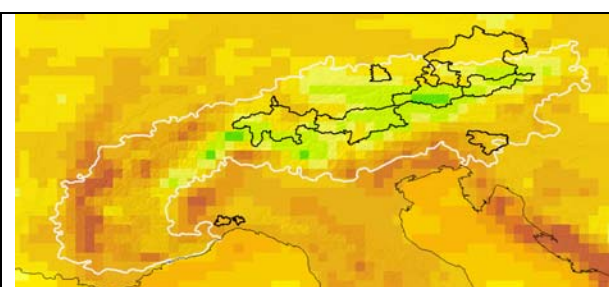
CLM (Consortial) A1B - 2030



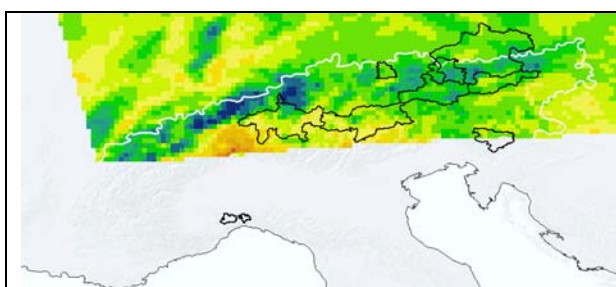
CLM (Consortial) A1B - 2050



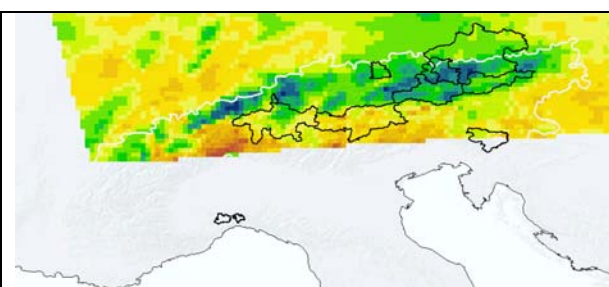
CLM (Ensembles) A1B - 2030



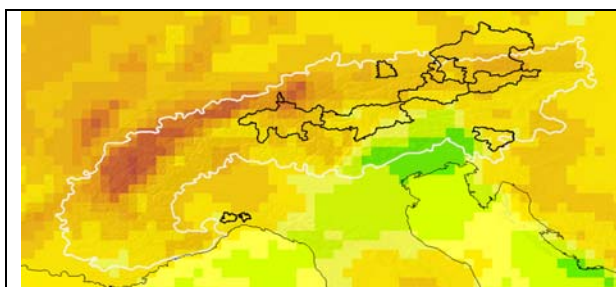
CLM (Ensembles) A1B - 2050



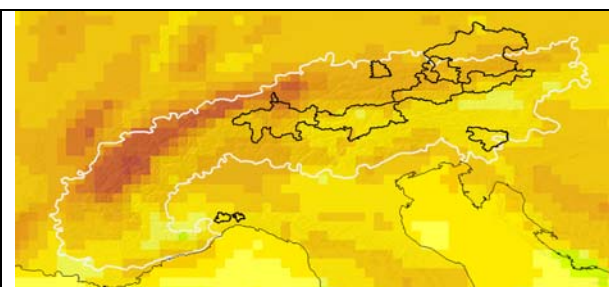
REMO-UBA-M A1B - 2030



REMO-UBA-M A1B - 2050



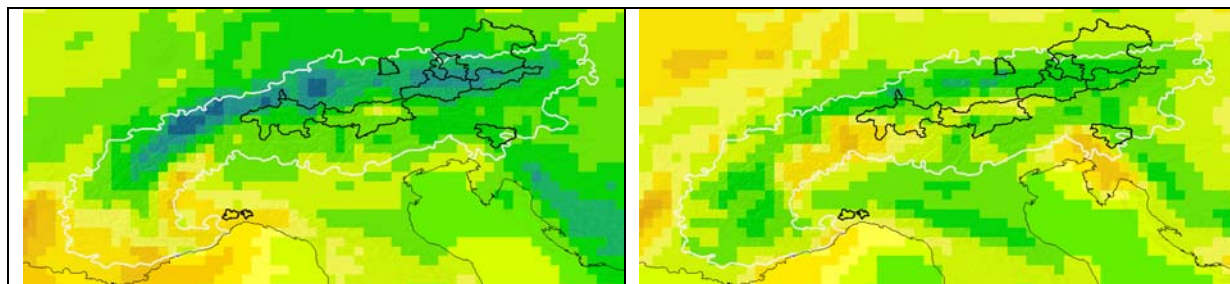
REMO (Ensembles) A1B - 2030



REMO (Ensembles) A1B - 2050

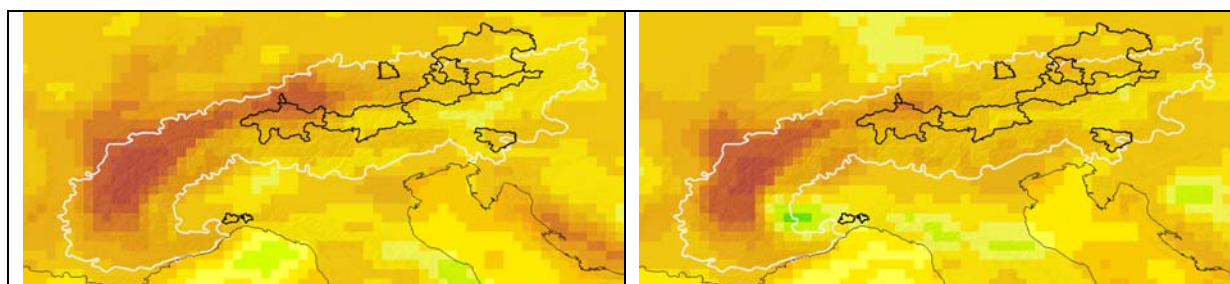
MAM: 2011-2030 minus 1961-1990

MAM: 2031-2050 minus 1961-1990



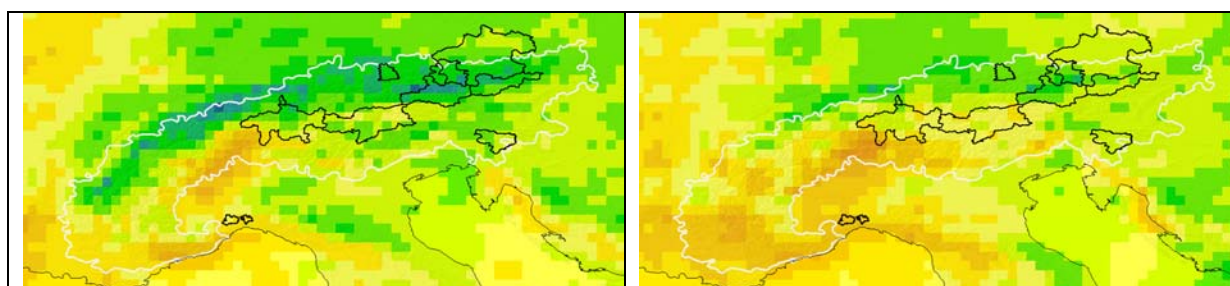
Aladin (Ensembles) A1B - 2030

Aladin (Ensembles) A1B - 2050



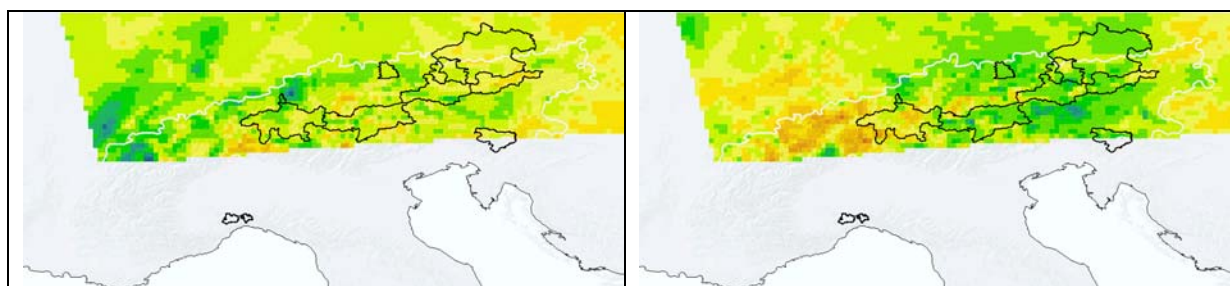
RegCM (Ensembles) A1B - 2030

RegCM (Ensembles) A1B - 2050



CLM (Consortial) B1 - 2030

CLM (Consortial) B1 - 2050



REMO-UBA-M B1 - 2030

REMO-UBA-M B1 - 2050

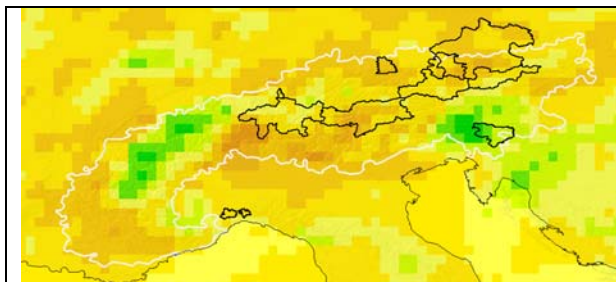


Figure 40: Seasonal (Spring, MAM) absolute precipitation changes regarding the Alps for eight climate scenarios. Left: 2011-2030 minus 1961-1990; right: 2031-2050 minus 1961-1990.

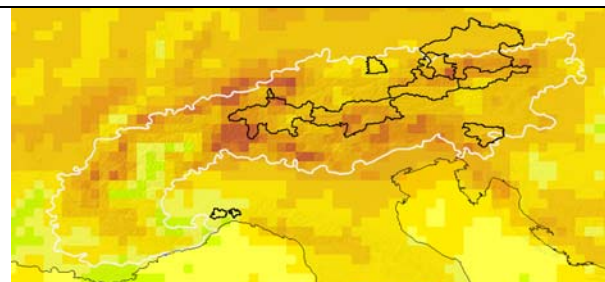
D.3.7 Seasonal (Summer, JJA) absolute precipitation changes

JJA: 2011-2030 minus 1961-1990

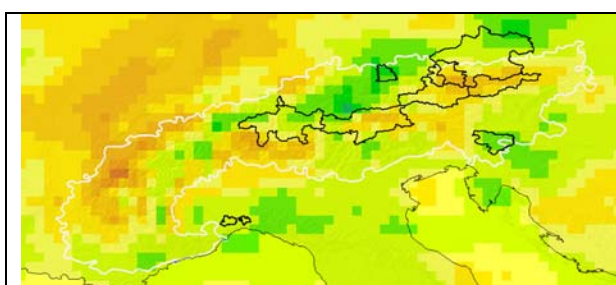
JJA: 2031-2050 minus 1961-1990



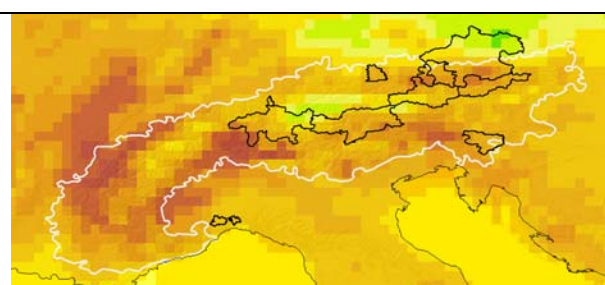
CLM (Consortial) A1B - 2030



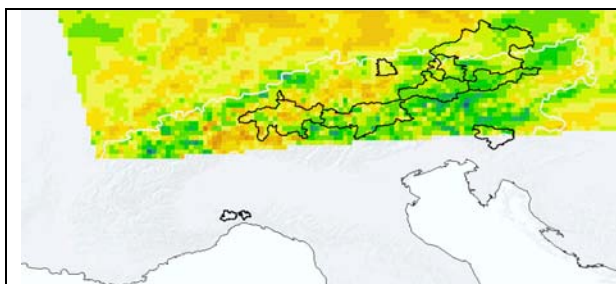
CLM (Consortial) A1B - 2050



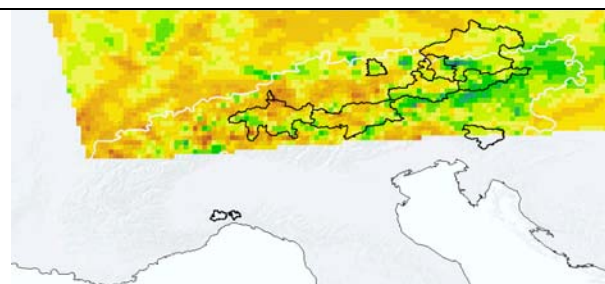
CLM (Ensembles) A1B - 2030



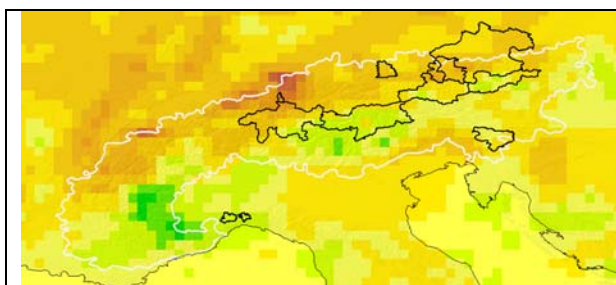
CLM (Ensembles) A1B - 2050



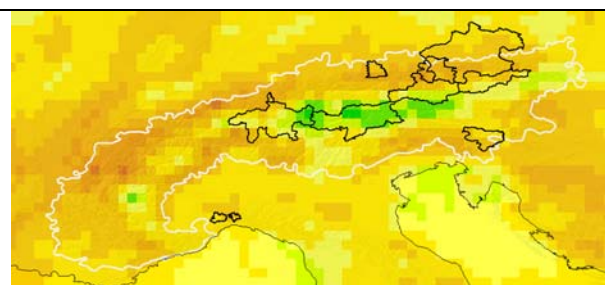
REMO-UBA-M A1B - 2030



REMO-UBA-M A1B - 2050



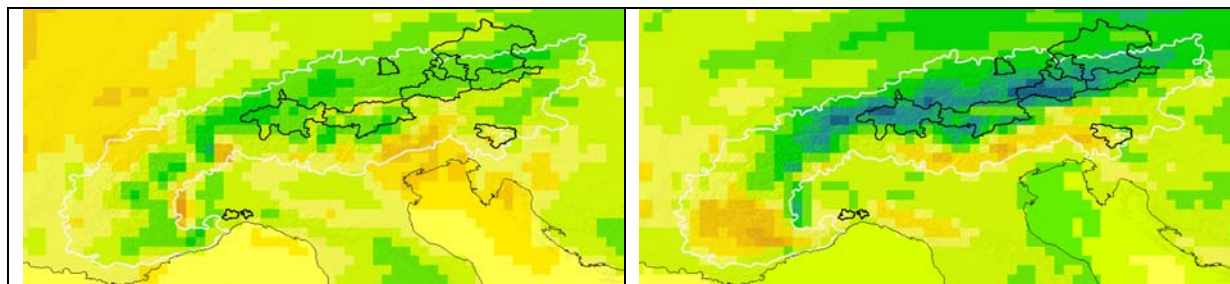
REMO (Ensembles) A1B - 2030



REMO (Ensembles) A1B - 2050

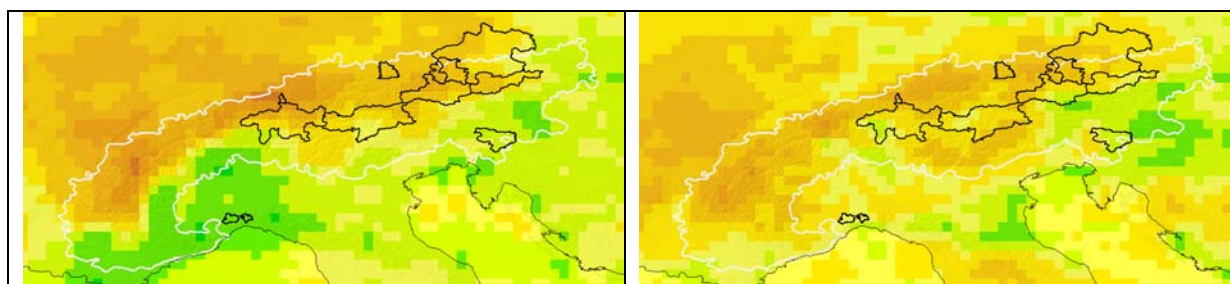
JJA: 2011-2030 minus 1961-1990

JJA: 2031-2050 minus 1961-1990



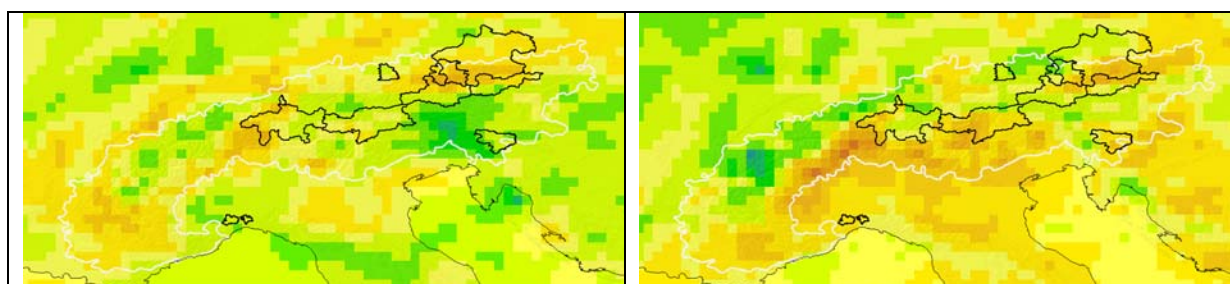
Aladin (Ensembles) A1B - 2030

Aladin (Ensembles) A1B - 2050



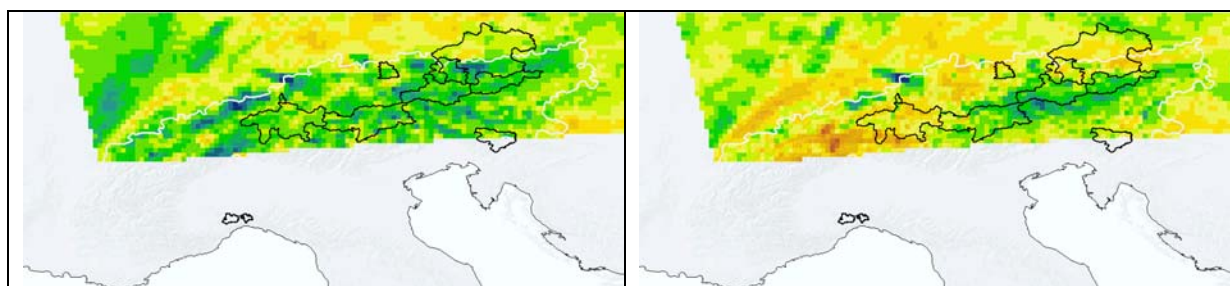
RegCM (Ensembles) A1B - 2030

RegCM (Ensembles) A1B - 2050



CLM (Consortial) B1 - 2030

CLM (Consortial) B1 - 2050



REMO-UBA-M B1 - 2030

REMO-UBA-M B1 - 2050

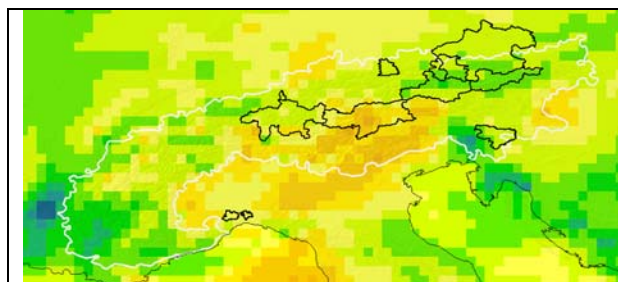


Figure 41: Seasonal (Summer, JJA) absolute precipitation changes regarding the Alps for eight climate scenarios. Left: 2011-2030 minus 1961-1990; right: 2031-2050 minus 1961-1990.

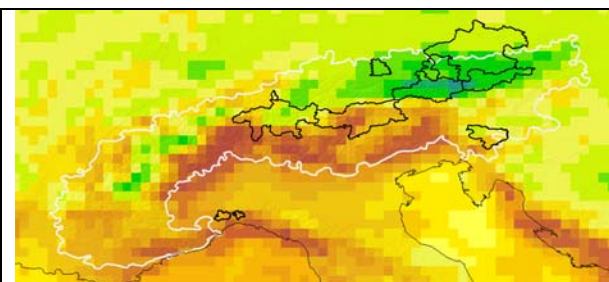
D.3.8 Seasonal (Autumn, SON) absolute precipitation changes

SON: 2011-2030 minus 1961-1990

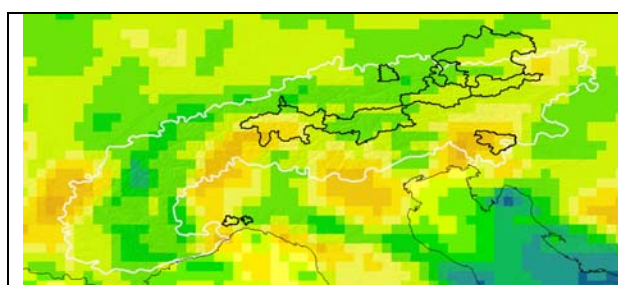
SON: 2031-2050 minus 1961-1990



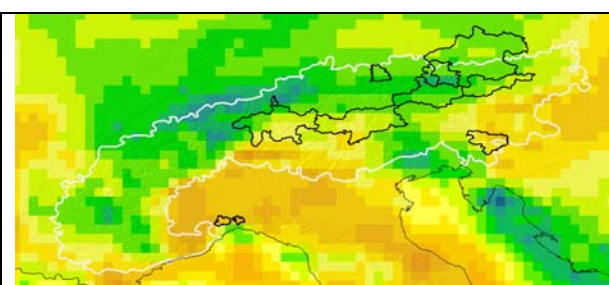
CLM (Consortial) A1B - 2030



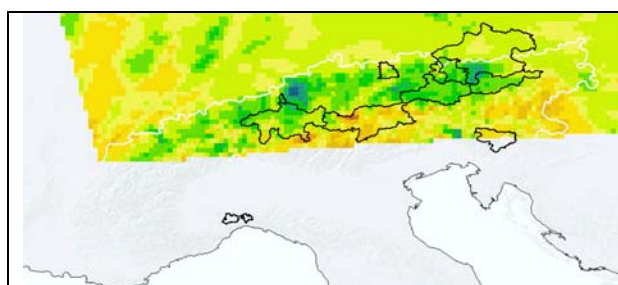
CLM (Consortial) A1B - 2050



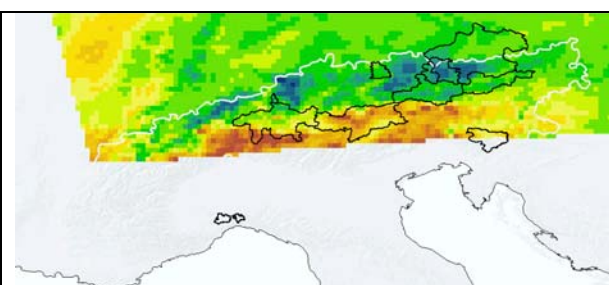
CLM (Ensembles) A1B - 2030



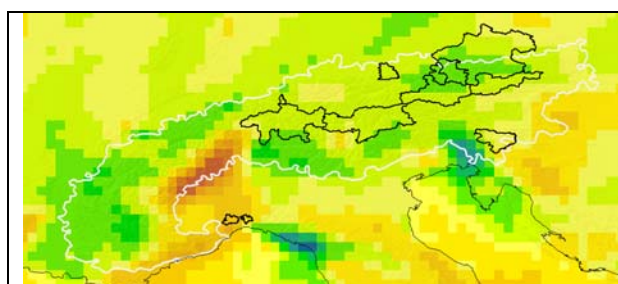
CLM (Ensembles) A1B - 2050



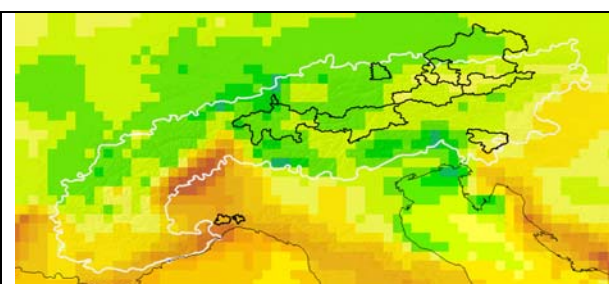
REMO-UBA-M A1B - 2030



REMO-UBA-M A1B - 2050



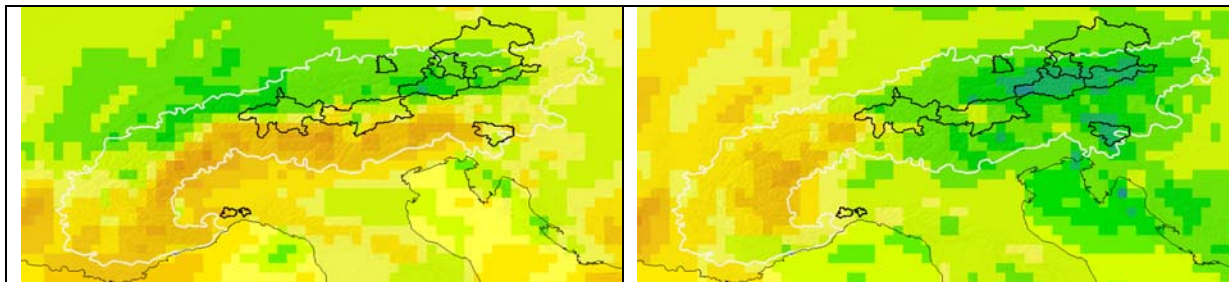
REMO (Ensembles) A1B - 2030



REMO (Ensembles) A1B - 2050

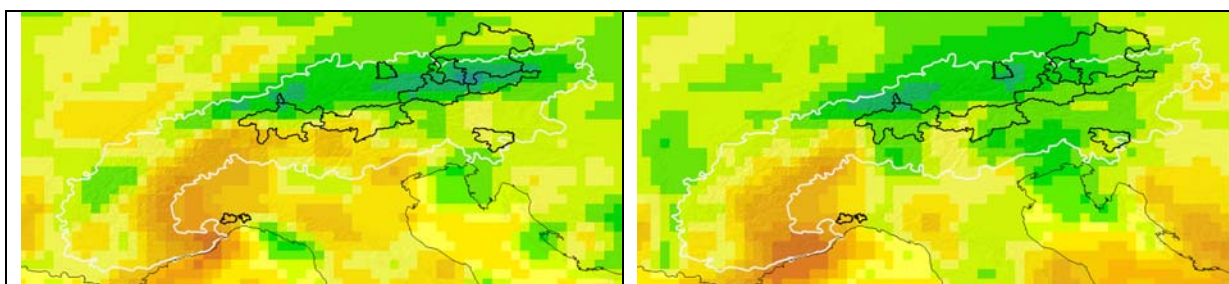
SON: 2011-2030 minus 1961-1990

SON: 2031-2050 minus 1961-1990



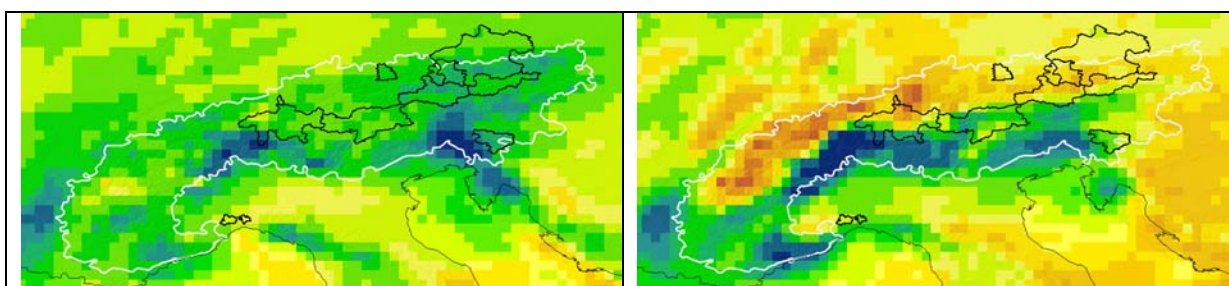
Aladin (Ensembles) A1B - 2030

Aladin (Ensembles) A1B - 2050



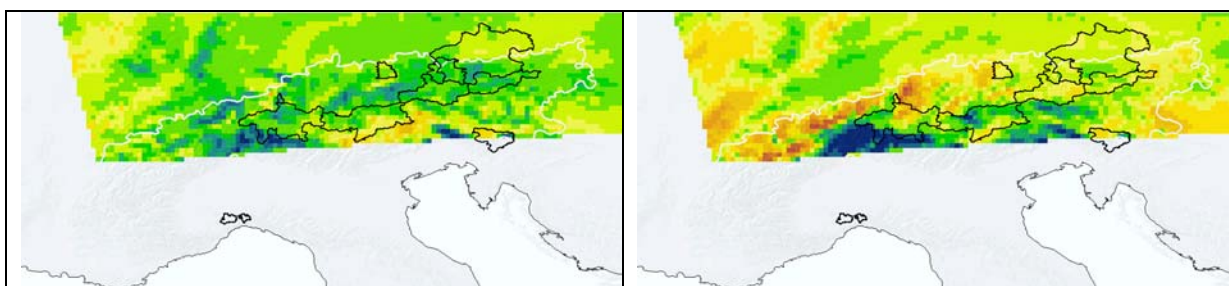
RegCM (Ensembles) A1B - 2030

RegCM (Ensembles) A1B - 2050



CLM (Consortial) B1 - 2030

CLM (Consortial) B1 - 2050



REMO-UBA-M B1 - 2030

REMO-UBA-M B1 - 2050



Figure 42: Seasonal (Autumn, SON) absolute precipitation changes regarding the Alps for eight climate scenarios. Left: 2011-2030 minus 1961-1990; right: 2031-2050 minus 1961-1990.

D.4 Guidelines for assessment of potential impacts for the model regions

Please find the guidelines as a separate annex to this report in the results section of the CLISP website (www.clisp.eu).

D.5 Toolbox for quantitative assessment of potential impacts

In the following, for each of the 21 selected indicators a fact sheet gives background information and specifies the data requirements for its application.

Table 9: Factsheet for calculation I1 - Growing season.

<p>Number of indicator</p> <p>I1</p> <p>Name of indicator</p> <p>Growing season</p>
<p>Identification</p> <p>Indicator description</p> <p>The Growing season (GS) is defined as the period of the year when the daily mean temperature is above 5°C. The beginning of the growing season (BGS), the end of the growing season (EGS) and the length of the GS can be derived for each cell in the grid. The growing degree days (GDD) are defined as the accumulated degree sum above a defined reference temperature. Finally those parameters can be set in relation of future - reference period to derive rate of changes.</p> <p>Unit</p> <p>days</p> <p>Indicator type</p> <p>Indicator describes exposure and sensitivity</p> <p>Relevance for sector</p> <p>Agriculture, forestry</p>
<p>Scientific background</p> <p>References</p> <p>EEA (2008): <i>Impacts of Europe's changing climate - An indicator-based assessment. 4</i>, European Environment Agency.</p> <p>Skaugen T.E. & Tveito O.E. (2004): <i>Growing-season and degree-day scenario in Norway for 2021-2050. Climate Research, 26, 3, 221-232.</i></p> <p>Frame of reference</p> <p>EEA report</p>
<p>Data specifications</p> <p>Data provided</p> <p>$T_{mean,day}$: mean daily temperature [°C] - (Mittlerer Tagestemperatur)</p> <p>T_{ref}: reference temperature at 5 [°C] - (Referenz Temperatur)</p> <p>Data needed</p> <p>Most detailed land-use map - (Detaillierteste Landnutzungskarte)</p> <p>Most detailed digital elevation model (DEM) – (Detaillierteste digitale Geländemodell)</p>

Methodology for indicator calculation

Guidelines for calculating the indicator

GS = period of the year when the daily mean temperature is above 5°C

BGS = start date of the *GS*

EGS = end date of the *GS*

$$GDD = \sum_{day=1}^{365} (T_{mean,day} - T_{ref}) \quad T_{mean,day} \geq T_{ref}; \text{ otherwise } T_{mean,day} = T_{ref}$$

The rate of change, considering *GS*, *BGS*, *EGS* and *GDD* (number of days) will be set in relation: reference period 1971-1990 to future time period 2011-2030, 2031-2050 .

Methodology for gap filling

-

References for the calculation methods

Schulzweida U., Kornblueh L., Quast R. (2009): *CDO User's Guide – Climate Data Operators*. MPI for Meteorology, Brockmann Consult.

Carter TR (1998): *Changes in the thermal growing season in Nordic countries during the past century and prospects for the future*. *Agricult Food Sci Finland* 7(2):161–179.

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Table 10: Factsheet for calculation I2 - Growing degree unit (GDU).

<p>Number of indicator</p> <p>I2</p> <p>Name of indicator</p> <p>Growing degree unit (GDU)</p>
<p>Identification</p> <p>Indicator description</p> <p>Growing degree unit (GDU) or Growing degree day (GDD) is a commonly used measure of heat accumulation for the growth and development of plants and insects. GDUs can be used to (1) assess the suitability of a region for production of a particular crop (2) to estimate the growth-stages of crops, weeds or even life stages of insects; (3) to predict maturity and cutting dates of forage crops; (4) to predict the best moment for fertilizer or pesticide application; (5) to estimate the heat stress on crops; (6) to plan spacing of planting dates to produce separate harvest dates.</p> <p>Unit</p> <p>-</p> <p>Indicator type</p> <p>Indicator describes exposure and sensitivity</p> <p>Relevance for sector</p> <p>Agriculture</p>
<p>Scientific background</p> <p>References</p> <p>Miller P., Lanier W., Brandt S. (2001): Using Growing Degree Days to Predict Plant Stages. Montana State University. MT200103 AG 7/2001.</p> <p>Stock, M. et al. (2005): KLARA - Klimawandel - Auswirkungen, Risiken, Anpassung, Potsdam Institute for Climate Impact Research, PIK Report 99, Potsdam 2005.</p> <p>Frame of reference</p> <p>-</p>
<p>Data specifications</p> <p>Data provided</p> <p>$T_{max,day}$: maximum daily temperature [°C] – (Maximale Tagestemperatur)</p> <p>$T_{min,day}$: minimum temperature [°C] – (Minimale Tagestemperatur)</p> <p>$T_{min,base}$: minimum base temperature (depends on the purpose) [°C] – (Minimale Basistemperatur (abhängig vom Zweck))</p> <p>$T_{max,base}$: maximum base temperature (depends on the purpose) [°C] – (Maximale Basistemperatur (abhängig vom Zweck))</p> <p>Data needed</p> <p>Most detailed land-use map - (Detaillierteste Landnutzungskarte)</p> <p>Most detailed digital elevation model (DEM) - (Detaillierteste digitale Geländemodell)</p>

Methodology for indicator calculation

Guidelines for calculating the indicator

$$GDD = \frac{T_{max,day} + T_{min,day}}{2} - T_{base}$$

if $T_{max,day} < T_{min,base}$ then $T_{max,day} = T_{min,base}$

and if $T_{max,day} > T_{max,base}$ then $T_{max,day} = T_{max,base}$

and if $T_{min,day} < T_{min,base}$ then $T_{min,day} = T_{min,base}$

Methodology for gap filling

-

References for the calculation methods

McMaster, S.G. and Wilhelm, W.W. (1997): Growing degree-days: one equation, two interpretations. *Agr. Forest Meteorol.* 87, 291–300.

<http://www.ipm.ucdavis.edu/MODELS/index.html#DISEASES>

<http://www.ipm.ucdavis.edu/WEATHER/ddconcepts.html>

Gottwald, R. (1996): Prognose der Phänologie wichtiger Schadorganismen im Apfelbau mit Hilfe von Temperatursummen (Phenology-forecasting of important harmful organisms in apple orchards with the help of temperature sums). *Gesunde Pflanzen*, 48. Jahrg., 4.

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Table 11: Factsheet for calculating I3 – Potential evapotranspiration (PET) after Thornthwaite.

<p>Number of indicator</p> <p>I3</p> <p>Name of indicator</p> <p>Potential evapotranspiration (PET) after Thornthwaite</p>
<p>Identification</p> <p>Indicator description</p> <p>Potential evaporation or potential evapotranspiration (PET) is defined as the amount of evaporation that would occur if a sufficient water source were available. Evapotranspiration (ET) is said to equal potential evapotranspiration (PET) when there is ample water. A dryland is a place where annual potential evaporation exceeds annual precipitation.</p> <p>Unit</p> <p>mm</p> <p>Indicator type</p> <p>Indicator describes exposure and sensitivity</p> <p>Relevance for sector</p> <p>Agriculture, forestry, tourism, water management</p>
<p>Scientific background</p> <p>References</p> <p>Lu, J., Sun G., McNulty S. G. and Amatya D. M. (2005): A comparison of six potential evapotranspiration methods for regional use in the south-eastern United States, <i>Journal of the American Water Resources Association</i>.</p> <p>Frame of reference</p> <p>-</p>
<p>Data specifications</p> <p>Data provided</p> <p>$E_{pot,mon}$: monthly potential evapotranspiration [mm] – (Potentielle monatliche Evapotranspiration)</p> <p>$T_{mean,mon}$: mean monthly temperature [°C] – (Mittlere monatliche Temperatur)</p> <p>$S_{mean,mon}$: mean astronomically possible sunshine duration of each month [h] – (Mittlere mögliche Sonnenscheindauer pro Monat)</p> <p>I : monthly heat index – (Monatlicher Hitzeindex)</p> <p>A : empirical coefficient – (Empirischer Koeffizient)</p> <p>Data needed</p> <p>Most detailed land-use map - (Detaillierteste Landnutzungskarte)</p> <p>Most detailed digital elevation model (DEM) - (Detaillierteste digitale Geländemodell)</p>

Methodology for indicator calculation

Guidelines for calculating the indicator

if $T_{mean,mon} \leq 0$ then $E_{pot,mon} = 0$ else:

$$E_{pot,mon} = 0.533 \cdot \left(\frac{T_{mean,mon}}{12} \right) + \left(\frac{10 \cdot T_{mean,mon}}{1} \right)^{0.8}$$

$$I = \sum_1^{12} \frac{T_{mean,mon}^{1,514}}{5}$$

$$a = (0.0675 \cdot I^3 - 7.71 \cdot I^2 + 1792 \cdot I + 49239) \cdot 10^{-5}$$

Methodology for gap filling

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References for the calculation methods

Thornthwaite, C.W. (1948): An approach toward a rational classification of climate. - *The Geogr. Rev.* 38 (1): 55-94.

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Table 12: Factsheet for calculation 14 – Meteorological water balance.

<p>Number of indicator</p> <p>14</p> <p>Name of indicator</p> <p>Meteorological water balance</p>
<p>Identification</p> <p>Indicator description</p> <p>The meteorological water balance is defined as the difference of precipitation sum and the sum of potential evapotranspiration. It can be used as indicator where reduced rainfall in combination with higher potential evapotranspiration will contribute to higher requirement for irrigation water</p> <p>Unit</p> <p>mm/month; mm/year</p> <p>Indicator type</p> <p>Indicator describes exposure and sensitivity</p> <p>Relevance for sector</p> <p>Agriculture, forestry, tourism, water management</p>
<p>Scientific background</p> <p>References</p> <p>EEA (2008): Impacts of Europe's changing climate - An indicator-based assessment. 4, European Environment Agency.</p> <p>Frame of reference</p> <p>EEA report</p>
<p>Data specifications</p> <p>Data provided</p> <p>$P_{sum,mon}$: monthly precipitation sum [mm] – (Monatliche Niederschlagssumme) $E_{pot,mon}$: monthly potential evapotranspiration [mm] - (Potentielle monatliche Evapotranspiration)</p> <p>Data needed</p> <p>Most detailed land-use map - (Detaillierteste Landnutzungskarte) Most detailed digital elevation model (DEM) - (Detaillierteste digitale geländemodell)</p>
<p>Methodology for indicator calculation</p> <p>Guidelines for calculating the indicator</p> <p>$MWB = P_{sum,mon} - E_{pot,mon}$</p> <p>Methodology for gap filling</p> <p>-</p> <p>References for the calculation methods</p> <p>DWD - Deutscher Wetterdienst www.dwd.de</p>
<p>Contact</p> <p>EURAC - Institute for Applied Remote Sensing</p>

Table 13: Factsheet for calculation 15 - Drought index (dMI) after De Martonne.

<p>Number of indicator</p> <p>15</p> <p>Name of indicator</p> <p>Drought index (dMI) after De Martonne</p>
<p>Identification</p> <p>Indicator description</p> <p>A drought index expresses the ratio between temperature and precipitation. The drought index decreases with less precipitation and higher temperatures. Higher temperatures causes higher evaporation. Therefore for a give precipitation amount, drought increases with higher temperature.</p> <p>Unit</p> <p>The values of the dMI cannot be associated to a specific meaning and retain mainly a comparative significance. No threshold associated with a particular condition of aridity can be identified. As temperature increases and precipitation decreases, the index decreases and vice versa. Therefore the variations of the index between present and climate conditions need to be regarded as the relative intensity of change towards more arid conditions across the region.</p> <p>Indicator type</p> <p>Indicator describes exposure.</p> <p>Relevance for sector</p> <p>Agriculture, forestry, tourism, water management</p>
<p>Scientific background</p> <p>References</p> <p>De Martonne E. (1926): Une nouvelle fonction climatologique: L'indice d'aridité. La Meteorologie, 449-458.</p> <p>Frame of reference</p> <p>-</p>
<p>Data specifications</p> <p>Data provided</p> <p>$P_{sum,ref}$: sum precipitation of reference period [mm] – (Niederschlagssumme der Referenzperiode)</p> <p>$T_{mean,ref}$: mean temperature of reference period [°C] – (Mittlere Temperatur der Referenzperiode)</p> <p>Data needed</p> <p>Most detailed land-use map - (Detaillierteste Landnutzungskarte)</p> <p>Most detailed digital elevation model (DEM) - (Detaillierteste digitale Geländemodell)</p>

Methodology for indicator calculation

Guidelines for calculating the indicator

$$dMI = \frac{P_{sum,ref}}{T_{mean,ref} + 10}$$

This index can be calculated for yearly, half yearly, seasonal or monthly reference periods. Lower values indicate drier areas. In our analysis the drought index will be calculated as seasonal values according to De Martonne's method (De Martonne 1926).

Methodology for gap filling

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References for the calculation methods

De Martonne E. (1926): L'indice d'aridité, Bull. Ass. Geogr. De France, Vol. IX.

De Martonne E. (1926): Une nouvelle fonction climatologique: L'indice d'aridité. La Meteorologie, 449-458.

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Table 14: Factsheet for calculation 16 - Crop suitability for wine - the Huglin-Index.

<p>Number of indicator</p> <p>16</p> <p>Name of indicator</p> <p>Crop suitability for wine - the Huglin-Index</p>
<p>Identification</p> <p>Indicator description</p> <p>The Huglin Index reflects the growing credibility of different grapes sorts. It is a heat sum of mean and maxima daily air temperature during the time April to September. This index can be used as an indicator of growing credibility and quality of different grape varieties</p> <p>Unit</p> <p>-</p> <p>The Huglin index reflects the distribution of temperatures. Although it has been associated to quantitative thresholds corresponding to different grapes, what is important within CLISP is the inspection of the changes in the index between present conditions and climate change scenarios. Therefore, results are more interestingly presented on a qualitative scale indicating change in terms of 5 quantiles (i.e. the 20% area with the highest, 20% second-highest, ..., 20% lowest) for each scenario. Each quantile is indicated with a qualitative class from “lowest” to “moderate” to “highest”. This classification allows understanding, in each comparison, what are the parts of the region with more or less marked variation.</p> <p>Indicator type</p> <p>Indicator describes exposure and sensitivity</p> <p>Relevance for sector</p> <p>Agriculture</p>
<p>Scientific background</p> <p>References</p> <p>Stock M. et al. (2007): Perspektiven der Klimaänderung bis 2050 für den Weinbau in Deutschland (Klima 2050) - Schlußbericht zum FDW-Vorhaben: Klima 2050. PIK. p.132.</p> <p>Stock, M. et al. (2005): KLARA - Klimawandel - Auswirkungen, Risiken, Anpassung, Potsdam Institute for Climate Impact Research, PIK Report 99, Potsdam 2005.</p> <p>Frame of reference</p> <p>Project KLARA</p>
<p>Data specifications</p> <p>Data provided</p> <p>$T_{mean,day}$: mean daily temperature [°C] – (Mittlere Tagestemperatur)</p> <p>$T_{max,day}$: maximum daily temperature [°C] – (Maximale Tagestemperatur)</p> <p>Data needed</p> <p>x_{lat}: geographic latitude – (Geographische Breite)</p> <p>Most detailed land-use map – (Detaillierteste Landnutzungskarte)</p> <p>Most detailed digital elevation model (DEM) - (Detaillierteste digitale Geländemodell)</p>

Methodology for indicator calculation

Guidelines for calculating the indicator

$$H = \sum_{t=01\ apr}^{30\ sep} K(x_{Lat}) \frac{(T_{mean,day} - 10^{\circ}C) + (T_{max,day} - 10^{\circ}C)}{2}$$

$$K(x_{Lat}) := \begin{cases} 1.02 & |x_{Lat}| \leq 40^{\circ} \\ 1.02 + 0.04 * \frac{x_{Lat} - 40^{\circ}}{10^{\circ}} & 40^{\circ} < |x_{Lat}| < 50^{\circ} \\ 1.06 & |x_{Lat}| \geq 50^{\circ} \end{cases}$$

Huglin-Index H: growing credibility of different grapes varieties

$H \leq 1500$: no growing credibility suggested

$1500 < H \leq 1600$: Müller-Thurgau

$1600 < H \leq 1700$: Pinot blanc, Gamay noir

$1700 < H \leq 1800$: Riesling, Chardonnay, Sylvaner, Sauvignon blanc, Pinot noir

$1800 < H \leq 1900$: Cabernet franc

$1900 < H \leq 2000$: Chinon blanc, Cabernet sauvignon, Merlot

$2000 < H \leq 2100$: Ugni blanc

$2100 < H \leq 2200$: Grenache, Syrah

$2200 < H \leq 2300$: Carignan

$2300 < H \leq 2400$: Aramon

Methodology for gap filling

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References for the calculation methods

Huglin, P. (1978): *Nouveau mode d'évaluation des possibilités héliothermique d'un milieu viticole*. C.R. Acad. Agric., 1117-1126.

Huglin, P. (1986): *Biologie et ecologie de la vigne*. Ed. Payot Lausanne, Paris, Jones, G.V. and Davis, R.E.

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Table 15: Factsheet for calculation 17 - Flood prone areas on a hazard index level.

<p>Number of indicator</p> <p>17</p> <p>Name of indicator</p> <p>Flood prone areas at hazard index level</p>
<p>Identification</p> <p>Indicator description</p> <p><i>Within the CLISP project, flood prone areas will be detected by flood modelling carried out on a hazard index level of detail (Petraschek and Kienholz 2003). The main scope of an analysis on this level of detail is the detection and the classification of possible hazard processes. Information will be provided on the existence of a hazard, but not information on the degree of danger resulting from hazard impacts.</i></p> <p><i>The area of interest will be chosen by the model region in cooperation with EURAC and will consider a maximum length of 20km with relevant potential damage</i></p> <p>Unit</p> <p>-</p> <p>Indicator type</p> <p><i>Indicator describes the impact.</i></p> <p>Relevance for sector</p> <p>Build-up areas / land development</p>
<p>Scientific background</p> <p>References</p> <p><i>Petraschek, A., Kienholz, H. (2003): Hazard assessment and mapping of mountain risks - example of Switzerland. In: Rickenmann, D., Chen, C.: Debris Flow Hazard Mitigation: 25-38, Millpress, Rotterdam.</i></p> <p><i>BUNDESAMT FÜR RAUMENTWICKLUNG, BUNDESAMT FÜR WASSER UND GEOLOGIE, BUNDESAMT FÜR UMWELT, WALD UND LANDSCHAFT (BAFU)[Hrsg.] (2005): Empfehlungen Raumplanung und Naturgefahren. 50 S., Bern.</i></p> <p><i>Mazzorana B., Hübl J. and Fuchs S. (2009): Improving risk assessment by defining consistent and reliable system scenarios. Nat. Hazards Earth Syst. Sci., 9, 145–159.</i></p> <p>Frame of reference</p> <p>-</p>

Data specifications

Data needed

Topography

Mandatory: Most detailed digital elevation model (DEM) - (Detaillierteste digitale Geländemodell)

Mandatory: Geometry of the riverbed – (Geometrie des Flussbetts)

- Mandatory: Extent of the riverbed (horizontal profile): must be defined by polygon(s) with exact limitations on the right and left hand side – (Ausmass des Flussbetts (Horizontales Profil): muss anhand Polygon(en) definiert sein um detaillierte Abgrenzungen am linken und rechten Rand des Flussbetts zu erhalten)

- Mandatory: Flow section geometries (vertical profile) – (Geometrie (Vertikales Profil) der Abflussabschnitte)

- Optional: Longitudinal profile – (Profil in Längsrichtung)

Mandatory: Information on possible critical configurations (bridges, dams, dikes, embankments, narrowings or channel constrictions) – (Informationen bzgl. kritischer Konfigurationen (Brücken, Dämme, Deiche, Längsverbauung, Einengungen oder Engstellen, ...))

- Mandatory: Position (in point-, lines- or polygons format) – (Lage (in Punkt-, Linien, oder Polygon Format))

- Mandatory: Geometry (vertical profile) of those critical configurations – (Geometrie (Vertikales Profil) dieser Schwachstellen)

- Optional: Further description: constructions and design details, materials, critical elements, ... - (Zusätzliche Beschreibung dieser Daten: Bauweise, Material, Kritische Elemente, ...)

Hydrology

In the context of the CLISP – project no hydrological modelling will be carried out due to restrictions of resources and time. Ideally existing runoff scenarios that had been generated for the specific model region will be used under consideration of the impacts of climate change. Otherwise we plan to use existing discharge data of your region for sensitivity analyses. Starting from a given hydrograph, the outflow will be changed according to the expected impacts of climate change. The extent of this variation is taken from existing literature. In case that no time series of discharge data are available we will either work with modelled hydrographs for the relevant inflow boundaries and important hydrological nodes or we will use empirical formulas applied in the region.

1. Mandatory considering existing runoff scenarios and optional regarding those, that take climate change runoff scenarios into consideration – (Existierende Abfluss Szenarien bzw. welche, die Klimawandel in betracht ziehen)

2. Mandatory: Maximum flood hydrographs for the relevant inflow boundaries – (Maximale Abflussganglinien der relevantesten Zufluss Grenzen)

3. Mandatory: Modelled hydrographs for relevant inflow boundaries and important hydrological nodes - (Modellierte Abflussganglinien von relevanten Zufluss Grenzen sowie wichtige hydrologische Knotenpunkte)

4. Optional (Alternative to point 3): Empirical formulas used in the region – (Empirische Formeln welche in der region herangezogen wurden)

Validation of results

For the validation of the simulations, both historical data and expert knowledge is needed. The expert knowledge has to be collected by the model region partners itself. Information about historical events has to be provided (event documentation database,...), including metadata on the data (report, GIS data, ...) and information on the access to such data.

Optional: historical data about events, floods, catastrophes including further explanation (what, consequences, meteorological conditions, ...), exact location and the available format of information (report, GIS-layer,...) – (Historische Daten bzgl Vorfällen, Überschwemmungen, Katastrophen mit zusätzlicher Beschreibung (Was, Konsequenzen, meteorologische Bedingungen,...), exakte lage dieser Ereignisse in entsprechendem, zur Verfügung stehendem Format (Bericht, GIS-Layer,...)

Optional: expert knowledge (e.g.: about passed events and/or detailed knowledge about critical configurations)– (Expertenwissen – z.B.: über vergangene Ereignisse bzw. detailliertes Wissen bzgl kritischer Konfigurationen, Schwachstellen))

Methodology for indicator calculation

Guidelines for calculating the indicator

The area of interest will be chosen by the model region in cooperation with EURAC and will consider a maximum length of 20km with relevant potential damage

For the delimitation of flood prone areas we propose a two step analysis approach: a first coarse scale analysis and then a fine scale analysis. In the first coarse scale analysis all areas will be investigated that could be potentially inundated. The analysis consists in the simulation of several scenarios using a simple GIS-method. The base of computation is a reference event of a certain return period. Starting with the given hydrograph, we will vary the discharge according to the expected changes in climate. The degree of variation is taken from literature.

Using the results of this analysis highly sensitive areas with a high damage potential will be detected. In the second step these areas will be investigated in a detailed scale analysis following the procedure proposed by Volcan et al. (2008). This procedure has been successfully applied in several test sites within the Autonomous Province of Bozen.

Methodology for gap filling

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References for the calculation methods

Volcan, C., Staffler, H. (2008): Gefahrenhinweiskarte Talflüsse – Prozess Überschwemmung. In: Autonome Provinz Bozen Südtirol - Abteilung Wasserschutzbauten (2008): Informationssystem Hydrogeologische Risiken. Methodischer Endbericht. Bozen.

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Table 16: Factsheet for calculation 18 - Avalanche prone areas on hazard index level.

<p>Number of indicator</p> <p>18</p> <p>Name of indicator</p> <p>Avalanche prone areas at hazard index level</p>
<p>Identification</p> <p>Indicator description</p> <p>A snow avalanche is a snow mass with usually a volume greater than 100 m³ and a minimum length of 50 meters that slides rapidly downhill. Snow avalanches can be divided into powder snow avalanches, dry snow avalanches and wet snow avalanches. The extent, the intensity and the frequency of snow avalanches depends on topographical and nivometeorological parameters. The extent of a snow slab depends on the thickness of the snow cover, the structure and stability of the snow cover, the geomorphologic characteristics of the avalanche release area, the amount of new fallen snow and on the actual meteorological conditions.</p> <p>Models for the delimitation of avalanche prone areas are divided into models for identification and the delimitation of avalanche release areas and the calculation of the runout distance and the modelling of the deposition areas.</p> <p>Unit</p> <p>-</p> <p>Indicator type</p> <p>Indicator describes the impact.</p> <p>Relevance for sector</p> <p>Build-up areas / land development</p>
<p>Scientific background</p> <p>References</p> <p>Zischg, A., Keiler, M., Fuchs, S.; Meissl, G. (2002): Konzept zur flächendeckenden Risikoanalyse für Naturgefahren im regionalen Maßstab. In: Strobl, J., Blaschke, T. and Griesebner, G., (Eds.) <i>Angewandte Geographische Informationsverarbeitung XIV. Beiträge zum AGIT-Symposium Salzburg 2002</i>, pp. 607-615. Heidelberg: Hüthig.</p> <p>Frame of reference</p> <p>-</p>
<p>Data specifications</p> <p>Data needed</p> <p>Most detailed digital elevation model (DEM) - (Detaillierteste digitale Geländemodell)</p> <p>Vegetation map or forest cover map – (Vegetations- oder Waldbedeckungskarte)</p> <p>A reference dataset of well documented snow avalanches (~ 50 - 100 documented events from an event documentation database), not absolutely necessary if pilot regions are comparable to others – (Ein Referenzdatensatz von gut dokumentierten Lawinenabgängen (~ 50 – 100 dokumentierte Abgänge aus einer Datenbank), nicht unbedingt nötig, wenn Modellregion vergleichbar mit anderen ist.)</p>

Methodology for indicator calculation

Guidelines for calculating the indicator

Within the CLISP project the avalanche release areas will be identified by evaluating the following parameters: altitude, slope inclination, slope curvature, variations of the slope exposition at small scale, and minimum extent of the release areas.

The calculation of the runout distance can be carried out with two possible approaches. One is the empirical-topographical model of Lied et al. (1995) which calculates the runout distance on the bases of the geometric form of the slope. The other approach is the runout calculation model of Perla et al. (1980). This is the first choice, but requires data for the parameterization of the model variables.

The course of the avalanche process will be modelled by using the approach D16 of Meissl (1998) combined with a Monte Carlo approach according to Gamma (2000).

Climate change effects will be considered indirectly by modelling the behaviour of the snow avalanches under changing conditions. Therefore the friction parameter could represent different avalanche types or different dimension. Temperature increase could increase the minimum altitude level at which snow avalanches are plausible to release from.

Methodology for gap filling

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References for the calculation methods

Gamma, P. (2000): *dfwalk – Ein Murgang-Simulationsprogramm zur Gefahrenzonierung*. Geographica Bernensia G66. Bern.

Lied, K., Weiler, C., Bakkehøj, S., and Hopf, J. (1995): *Calculation Models for Avalanche Run-Out Distance for the Austrian Alps*. Unveröffentlichter Abschlußbericht der Wildbach- und Lawinenverbauung Sektion Tirol.

Meissl, G. (1998): *Modellierung der Reichweite von Felsstürzen - Fallbeispiele zur GIS-gestützten Gefahrenbeurteilung aus dem Bayerischen und Tiroler Alpenraum*. Innsbrucker Geographische Studien, 28.

Perla, R., Cheng, T., and McClung, D. (1980): *A Two-Parameter Model of Snow-Avalanche Motion*. *Journal of Glaciology*, 26(94): 197-207.

Zischg, A., Keiler, M., Fuchs, S.; Meissl, G. (2002): *Konzept zur flächendeckenden Risikoanalyse für Naturgefahren im regionalen Maßstab*. In: Strobl, J., Blaschke, T. and Griesebner, G., (Eds.) *Angewandte Geographische Informationsverarbeitung XIV. Beiträge zum AGIT-Symposium Salzburg 2002*, pp. 607-615. Heidelberg: Hüthig.

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Table 17: Factsheet for calculation 19 -Rockfall prone areas on hazard index level.

<p>Number of indicator</p> <p>19</p> <p>Name of indicator</p> <p>Rockfall prone areas at hazard index level</p>
<p>Identification</p> <p>Indicator description</p> <p>The activity of rockfall processes depends on geological, tectonic and topographical factors, but rockfall processes are also sensitive to the meteorological conditions. During extreme precipitation events, a general increase of rockfall activity is observed. In altitudes around the 0°celsius amplitude the activity of rockfall processes is driven by changes between temperatures above and under freezing temperature. Therefore, the expected climate changes have effects on rockfall processes.</p> <p>Unit</p> <p>-</p> <p>Indicator type</p> <p>Indicator describes the impact.</p> <p>Relevance for sector</p> <p>Build-up areas / land development</p>
<p>Scientific background</p> <p>References</p> <p>Strada, C.; Piacentini, D. (2008): Gefahrenhinweiskarte Sturzprozesse. In: Autonome Provinz Bozen Südtirol: IHR - Informationssystem zu hydrogeologischen Risiken. Methodischer Endbericht. Bozen.</p> <p>Frame of reference</p> <p>-</p>
<p>Data specifications</p> <p>Data needed</p> <p>Most detailed digital elevation model (DEM) - (Detaillierteste digitale Geländemodell)</p> <p>Most detailed land-use map - (Detaillierteste Landnutzungskarte)</p> <p>Ideally but not absolutely necessary: geological map – (Ideal aber nicht unbedingt nötig: Geologische Karte)</p> <p>Permafrost distribution map – (Permafrost Verbreitungskarte)</p> <p>Some geomorphologic maps of rockfall areas for calibration of the model parameters – (Geomorphologische Karte mit Felssturzgebieten zur Kalibrierung der Parametern des Modells)</p>

Methodology for indicator calculation

Guidelines for calculating the indicator

Models for the delimitation of rockfall prone areas are divided into models for identification and the delimitation of starting zones and the calculation of the runout distance and the modelling of the process paths.

Depending on the data availability the rockfall starting zones can be delineated either from the rock face signature of the topographic maps, from geologic maps or from land cover maps. Due to having set the focus on delimitating the climate-sensitive rockfall areas, the procedure requires a permafrost distribution map that allows to select the rockfall starting zones in permafrost areas.

The runout distance is calculated on the basis of the angle between the highest point of the rock face (potential starting zone) and the lowest point of the deposition area. This approach is also used in the elaboration of hazard index maps in wide areas (Heinimann et al. 1998; Meissl 1998; Zischg et al. 2002).

The process path will be modelled by using the approach D16 of Meissl (1998) combined with a Monte Carlo approach according to Gamma (2000).

A special phenomena of climate change effects that influences rockfall activities is the degradation of permafrost. Therefore, those areas that are located in rock faces underlying permafrost conditions and could represent starting points for rockfall process are considered to be climate sensitive. The modelled rockfall runout areas from blocks starting in permafrost areas are considered as climate-sensitive areas resp. areas in which the activity of rockfall process is likely to be modified under future climate conditions.

Methodology for gap filling

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References for the calculation methods

Gamma, P. (2000): dfwalk – Ein Murgang-Simulationsprogramm zur Gefahrenzonierung. Geographica Bernensia G66. Bern.

Heinimann, H., Hollenstein, K., Kienholz, H., Krummenacher, B., Mani, P. (1998): Methoden zur Analyse und Bewertung von Naturgefahren. BUWAL, Umwelt-Materialien Nr. 85, Naturgefahren. Bern.

Meissl, G. (1998): Modellierung der Reichweite von Felsstürzen - Fallbeispiele zur GIS-gestützten Gefahrenbeurteilung aus dem Bayerischen und Tiroler Alpenraum. Innsbrucker Geographische Studien, 28.

Strada, C.; Piacentini, D. (2008): Gefahrenhinweiskarte Sturzprozesse. In: Autonome Provinz Bozen Südtirol: IHR - Informationssystem zu hydrogeologischen Risiken. Methodischer Endbericht. Bozen.

Zischg, A., Keiler, M., Fuchs, S.; Meissl, G. (2002): Konzept zur flächendeckenden Risikoanalyse für Naturgefahren im regionalen Maßstab. In: Strobl, J., Blaschke, T. and Griesebner, G., (Eds.) Angewandte Geographische Informationsverarbeitung XIV. Beiträge zum AGIT-Symposium Salzburg 2002, pp. 607-615. Heidelberg: Hüthig.

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Table 18: Factsheet for calculation I10 - Torrential process prone areas on hazard index level.

<p>Number of indicator</p> <p>I10</p> <p>Name of indicator</p> <p>Torrential process prone areas at hazard index level</p>
<p>Identification</p> <p>Indicator description</p> <p>We use the term "torrential processes" for debris flow processes. A debris flow is a fast or slow flowing mixture of water and sediments in high concentration, which often moves several surges. The activities of debris flow processes in alpine torrents are mainly driven by the discharge, the sediment budget and the sediment transport capacity. The sediment transport capacity is influenced by short precipitation events (thunderstorms) or by longer precipitation events.</p> <p>The deduction of the most critical factors for hazard assessment under changing environmental conditions is relatively obvious: for natural hazards related to precipitation, the most relevant changes in the environmental parameters due to climatic changes are to be expected in the intensity/frequency relation of precipitation events (rainfall, snowfall). Indirect effects are shifts in altitude levels due to rising temperatures, e.g. rising of the altitude of the limit between snowfall and rainfall or morphological changes such as the retreat of glaciers and the degradation of permafrost.</p> <p>Unit</p> <p>-Most of the times, it is not possible to associate climate change with changes in the frequency and severity of debris flows. Therefore, in most cases the simple identification of areas subject to debris flow under present conditions is already an indication of where the problem may become more important under climate change.</p> <p>Indicator type</p> <p>Indicator describes impact.</p> <p>Relevance for sector</p> <p>Build-up areas / land development</p>
<p>Scientific background</p> <p>References</p> <p>Staffler, H., Pollinger, R., Zischg, A. & Mani, P. (2008): Spatial variability and potential impacts of climate change on flood and debris flow hazard zone mapping and implications for risk management. <i>Natural Hazards and Earth System Sciences</i>, 8, 539-558.</p> <p>Heinimann, H., Hollenstein, K., Kienholz, H., Krummenacher, B., Mani, P. (1998): Methoden zur Ana-lyse und Bewertung von Naturgefahren. BUWAL, Umwelt-Materialien Nr. 85, Naturge-fahren. Bern.</p> <p>Frame of reference</p> <p>-</p>

Data spec *Staffler, H., Pollinger, R., Zischg, A. & Mani, P. (2008): Spatial variability and potential impacts of climate change on flood and debris flow hazard zone mapping and implications for risk management. Natural Hazards and Earth System Sciences, 8, 539-558.*

Geologic map (basis for the delimitation of sediment delivery areas, (Geologische Karte (Grundlage für Abgrenzung von Sedimentursprungsgebieten))

Most detailed land-use map (basis for the delimitation of rock faces, scree slopes, glaciers) – (Detaillierteste Landnutzungskarte (Basis für Abgrenzung von Felsoberflächen, Geröllhängen, Geröllflächen, Gletschern))

River channel network – (Karte des Gewässernetz)

Most detailed digital elevation model (DEM) (Minimal resolution: 20m) - (Detaillierteste digitale Geländemodell (Minimalste Auflösung: 20m))

Landslide inventory (event documentation) – (Hangrutsch Inventar, bevorzugt in Kartenform (Vorfallsdokumentation))

Glacier inventory - (Gletscher Inventar, bevorzugt in Kartenform)

Permafrost distribution map – (Permafrost Verbreitungskarte)

Rockfall hazard index map (see "Rockfall prone areas on hazard index level")

Documentation of debris flow processes (event documentation data base, for calibration and validation) – (Dokumentation von Murabgängen (bevorzugt in Kartenform), zur Kalibrierung und Validierung)

Methodology for indicator calculation

Guidelines for calculating the indicator

Because of its the wide use and a number of successful validations it is suggested to use the modelling approach shown in Heinimann et al. (1998), Zimmermann et al. (1996) and Mani et al. (2008). This concept is a GIS-based approach for the assessment of torrential processes and includes the following steps:

- surface runoff formation
- delivery of transportable sediment
- transport of sediment within channels
- propagation and deposition of sediment

With this procedure potential debris flow areas can be identified and delimited. From these areas can be selected a subset of areas prone by debris flows starting in torrent catchments that are sensitive to selected effects of climatic changes following the approach of Staffler et al. (2008).

Methodology for gap filling

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References for the calculation methods

Heinimann, H., Hollenstein, K., Kienholz, H., Krummenacher, B., Mani, P. (1998): Methoden zur Analyse und Bewertung von Naturgefahren. BUWAL, Umwelt-Materialien Nr. 85, Naturgefahren. Bern.

Mani, P., Staffler, H., Berger, E. (2008): Gefahrenhinweiskarte Murgang und Übersarung. In: Autonome Provinz Bozen Südtirol: IHR - Informationssystem zu hydrogeologischen Risiken. Methodischer Endbericht. Bozen.

Zimmermann, M., Mani, P., and Gamma, P. (1997): Murganggefahr und Klimaänderung - ein GIS-basierter Ansatz. vdf Hochschulverlag an der ETH, Zürich.

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Table 19: Factsheet for calculation I11 – Number of cooling days (CD).

<p>Number of indicator</p> <p>I11</p> <p>Name of indicator</p> <p>Number of cooling days (CD)</p>
<p>Identification</p> <p>Indicator description</p> <p>According to the number of heating days (HD), which is strongly related to the temperature threshold of the heating degree days (HDD), we introduce the number of cooling days (CD), being related to the temperature threshold of the cooling degree days (CDD). The number of cooling days (CD) describes the number of days of a year with a mean daily air temperature above the cooling temperature threshold (Kühlgrenztemperatur). Within the CLISP project we use 18,3°C as cooling temperature limit.</p> <p>Unit</p> <p>-</p> <p>Indicator type</p> <p>Indicator describes exposure and sensitivity.</p> <p>Relevance for sector</p> <p>Energy</p>
<p>Scientific background</p> <p>References</p> <p>Christenson M., H. Manz, D. Gyalistras (2006): Climate warming impact on degree-days and building energy demand in Switzerland. In: Energy Conversion and Management 47 (2006) 671–686.</p> <p>ZAMG - Klimadaten von Österreich http://www.zamg.ac.at/klima/klimadaten/</p> <p>Prettenthaler, F., Gobiet, A., Habsburg-Lothringen, C., Steinacker, R., Töglhofer, C., Türk, A. (2007): Auswirkungen des Klimawandels auf Heiz-und Kühlenergiebedarf in Österreich. Project Report StartClim2006.F. Wegener Center University of Graz, Joanneum.</p> <p>Frame of reference</p> <p>-</p>
<p>Data specifications</p> <p>Data provided</p> <p>$T_{mean,day}$: daily mean temperature [°C] – (Mittlere Tagestemperatur)</p> <p>Data needed</p> <p>Most detailed land-use map – (Detaillierteste Landnutzungskarte)</p> <p>Most detailed digital elevation model (DEM) – (Detaillierteste digitale Geländemodell)</p>

Methodology for indicator calculation

Guidelines for calculating the indicator

Cooling days (CD): Number of days in a year with $T_{mean,day}$ above or equal $18,3^{\circ}\text{C}$

Methodology for gap filling

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References for the calculation methods

Prettenthaler, F., Gobiet, A., Habsburg-Lothringen, C., Steinacker, R., Töglhofer, C., Türk, A. (2007): Auswirkungen des Klimawandels auf Heiz-und Kühlenergiebedarf in Österreich. Project Report StartClim2006.F. Wegener Center University of Graz, Joanneum.

ZAMG - Klimadaten von Österreich

<http://www.zamg.ac.at/klima/klimadaten/>

Contact

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Factsheet for calculation I12 - Cooling degree days (CDD).

<p>Number of indicator</p> <p>I12</p> <p>Name of indicator</p> <p>Cooling degree day (CDD)</p>
<p>Identification</p> <p>Indicator description</p> <p>The indicator CDD is used to describe the energy demand needed to cool a building. The cooling degree days are calculated for all days with a daily mean temperature above or equal a certain temperature threshold as the sum of the temperature difference between the daily mean temperature and the temperature threshold. Following the approach of Prettenthaler et al. (2007) we use 18,3°C as threshold temperature.</p> <p>Unit</p> <p>-</p> <p>Indicator type</p> <p>Indicator describes exposure and sensitivity.</p> <p>Relevance for sector</p> <p>Energy</p>
<p>Scientific background</p> <p>References</p> <p>Christenson M., H. Manz, D. Gyalistras (2006): Climate warming impact on degree-days and building energy demand in Switzerland. In: <i>Energy Conversion and Management</i> 47 (2006) 671–686.</p> <p>Prettenthaler, F., Gobiet, A., Habsburg-Lothringen, C., Steinacker, R., Töglhofer, C., Türk, A. (2007): Auswirkungen des Klimawandels auf Heiz- und Kühlenergiebedarf in Österreich. Project Report StartClim2006.F. Wegener Center University of Graz, Joanneum.</p> <p>Frame of reference</p> <p>Project StartClim2006</p>
<p>Data specifications</p> <p>Data provided</p> <p>$T_{mean,day}$: daily mean temperature [°C] – (Mittlere Tagestemperatur)</p> <p>Data needed</p> <p>Most detailed land-use map – (Detaillierteste Landnutzungskarte)</p> <p>Most detailed digital elevation model (DEM) – (Detaillierteste digitale Geländemodell)</p>

Methodology for indicator calculation

Guidelines for calculating the indicator

$$CDD(T_1, T_2) = \sum_{T_1}^{T_2} (T_{mean,day} - 18,3)$$

for days with $T_{mean,day} \geq 18,3^{\circ}\text{C}$

(T_1, T_2) time period

Methodology for gap filling

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References for the calculation methods

Prettenthaler, F., Gobiet, A., Habsburg-Lothringen, C., Steinacker, R., Töglhofer, C., Türk, A. (2007): Auswirkungen des Klimawandels auf Heiz-und Kühlenergiebedarf in Österreich. Project Report StartClim2006.F. Wegener Center University of Graz, Joanneum.

Contact

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Table 20: Factsheet for calculation I13 - Number of heating days (HD).

<p>Number of indicator</p> <p>I13</p> <p>Name of indicator</p> <p>Number of heating days (HD)</p>
<p>Identification</p> <p>Indicator description</p> <p>The number of heating days (HD) describes the number of days of a year with a mean daily air temperature below the heating temperature threshold (Heizgrenztemperatur). Within the CLISP project we follow the approach of ZAMG and use 12°C as heating temperature limit.</p> <p>Unit</p> <p>-</p> <p>Indicator type</p> <p>Indicator describes exposure and sensitivity.</p> <p>Relevance for sector</p> <p>Energy</p>
<p>Scientific background</p> <p>References</p> <p>ZAMG - Klimadaten von Österreich http://www.zamg.ac.at/klima/klimadaten/</p> <p>Prettenthaler, F., Gobiet, A., Habsburg-Lothringen, C., Steinacker, R., Töglhofer, C., Türk, A. (2007): Auswirkungen des Klimawandels auf Heiz-und Kühlenergiebedarf in Österreich. Project Report StartClim2006.F. Wegener Center University of Graz, Joanneum Research Graz, Austria.</p> <p>Frame of reference</p> <p>Project StartClim2006</p>
<p>Data specifications</p> <p>Data provided</p> <p>$T_{mean,day}$: daily mean temperature [°C] – (Mittlere Tagestemperatur)</p> <p>Data needed</p> <p>Most detailed land-use map – (Detaillierteste Landnutzungskarte)</p> <p>Most detailed digital elevation model (DEM) – (Detaillierteste digitale Geländemodell)</p>

Methodology for indicator calculation

Guidelines for calculating the indicator

Heating days (HD): Number of days in a year with $T_{mean,day}$ below or equal 12°C

Methodology for gap filling

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References for the calculation methods

ZAMG - Klimadaten von Österreich

<http://www.zamg.ac.at/klima/klimadaten/>

Contact

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Table 21: Factsheet for calculation I14 - Number of heating degree day (HDD).

<p>Number of indicator</p> <p>I14</p> <p>Name of indicator</p> <p>Heating degree day (HDD)</p>
<p>Identification</p> <p>Indicator description</p> <p>The indicator HDD is used to describe the energy demand needed to heat a building. The heating degree days are calculated for all heating days of a year as the sum of the temperature difference between a certain constant room temperature and the daily mean. Within the CLISP project we follow the approach of ZAMG Austria and use 20° as constant room temperature in our calculation.</p> <p>Unit</p> <p>-</p> <p>Indicator type</p> <p>Indicator describes exposure and sensitivity.</p> <p>Relevance for sector</p> <p>Energy</p>
<p>Scientific background</p> <p>References</p> <p>ZAMG - Klimadaten von Österreich http://www.zamg.ac.at/klima/klimadaten/</p> <p>Christenson M., H. Manz, D. Gyalistras (2006): Climate warming impact on degree-days and building energy demand in Switzerland. In: Energy Conversion and Management 47 (2006) 671–686.</p> <p>Prettenthaler, F., Gobiet, A., Habsburg-Lothringen, C., Steinacker, R., Töglhofer, C., Türk, A. (2007): Auswirkungen des Klimawandels auf Heiz-und Kühlenergiebedarf in Österreich. Project Report StartClim2006.F. Wegener Center University of Graz, Joanneum Research Graz, Austria.</p> <p>Frame of reference</p> <p>Project StartClim2006</p>
<p>Data specifications</p> <p>Data provided</p> <p>$T_{mean,day}$: daily mean temperature [°C] – (Mittlere Tagestemperatur)</p> <p>Data needed</p> <p>Most detailed land-use map – (Detaillierteste Landnutzungskarte)</p> <p>Most detailed digital elevation model (DEM) - (Detaillierteste digitale Geländemodell)</p>

Methodology for indicator calculation

Guidelines for calculating the indicator

$$HDD(T_1, T_2) = \sum_{T_1}^{T_2} (20 - T_{mean, day})$$

for days with $T_{mean, day} \leq 12^\circ\text{C}$

(T_1, T_2) time period

Methodology for gap filling

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References for the calculation methods

Christenson M., H. Manz, D. Gyalistras (2006): Climate warming impact on degree-days and building energy demand in Switzerland. In: *Energy Conversion and Management* 47 (2006) 671–686.

ZAMG - Klimadaten von Österreich

<http://www.zamg.ac.at/klima/klimadaten/>

Contact

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Table 22: Factsheet for calculation I15 - Forest line – isotherm.

<p>Number of indicator</p> <p>I15</p> <p>Name of indicator</p> <p>Forest line - isotherm</p>
<p>Identification</p> <p>Indicator description</p> <p><i>Körner (1999) describes the temperature as most plausible factor amongst all climate parameters to explain the treeline altitude. Within the framework of StartClim2005 Schaumberger et al. (2006) proposed a methodology for determining the treeline altitude. They correlated the forest line with the isotherme of the mean air temperature of the growth period from May to October. According to Körner (1999) growing season means between 5.5 and 7.5°C are closely correlated with treeline altitudes.</i></p> <p>Unit</p> <p>-</p> <p>Indicator type</p> <p><i>Indicator describes exposure and sensitivity.</i></p> <p>Relevance for sector</p> <p>Forestry</p>
<p>Scientific background</p> <p>References</p> <p><i>Schaumberger, J., Schardt, M., Guggenberger, T., Gallaun, H., Schaumberger, A., Deutz, A., Gressmann, G., Gasteiner, J. (2006): GIS-gestützte Ermittlung der Veränderung des Lebensraumes alpiner Wildtierarten bei Anstieg der Waldgrenze aufgrund Klimaveränderung. Endbericht StartClim 2005, Universität für Bodenkultur, Wien, 42 Seiten.</i></p> <p><i>Körner, CH. (1999): Alpine plant life. Functional Plant Ecology of High Mountain Ecosystems. Springer-Verlag Berlin Heidelberg.</i></p> <p>Frame of reference</p> <p>Project StartClim2005</p>
<p>Data specifications</p> <p>Data provided</p> <p><i>$T_{mean,day}$: daily mean temperature [°C] – (Mittlere Tagestemperatur)</i></p> <p>Data needed</p> <p><i>Most detailed land-use map – (Detaillierteste Landnutzungskarte)</i></p> <p><i>Most detailed digital elevation model (DEM) - (Detaillierteste digitale Geländemodell)</i></p>

Methodology for indicator calculation

Guidelines for calculating the indicator

Within the CLISP project we will follow the methodology proposed by Schaumberger et al. (2006). For the region of interest we will use existing data sets for the delimitation of the local forest area extent, eg. Corine land cover. With this information we will determine the corresponding isotherme of the growth period mean temperature. In the next step we will investigate the rise of the forest line using regional climate model data by determining the position of the prior identified isotherm.

Methodology for gap filling

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References for the calculation methods

Schaumberger, J., Schardt, M., Guggenberger, T., Gallaun, H., Schaumberger, A., Deutz, A., Gressmann, G., Gasteiner, J. (2006): GIS-gestützte Ermittlung der Veränderung des Lebensraumes alpiner Wildtierarten bei Anstieg der Waldgrenze aufgrund Klimaveränderung. Endbericht StartClim 2005, Universität für Bodenkultur, Wien, 42 Seiten.

Contact

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Table 23: Factsheet for calculation I16 - Nesterov Index (NI) for fire danger rating.

<p>Number of indicator</p> <p>I16</p> <p>Name of indicator</p> <p>Nesterov Index (NI) for fire danger rating</p>
<p>Identification</p> <p>Indicator description</p> <p>The Nesterov Index is a simple fire danger rating created in Russia in 1949. This index is based on the difference between temperature and dewpoint, and is weighted by temperature. The calculation takes place on a daily basis and is cumulative since a last rainfall greater than 3 mm. Values of NI greater than 300 indicate moderate ignition potential; 1000 to 4000, high ignition potential, and above 4000, extreme potential.</p> <p>Unit</p> <p>°C²</p> <p>Indicator type</p> <p>Indicator describes exposure.</p> <p>Relevance for sector</p> <p>Forestry</p>
<p>Scientific background</p> <p>References</p> <p>Nesterov, V.G. (1949): <i>Combustibility of the forest and methods for its determination</i>. USSR State Industry Press.</p> <p>Goldammer, J.G., Furyaev, V.V. (Eds.) (1996): <i>Fire in Ecosystems of Boreal Eurasia</i>. Kluwer Academic Publishers, Dordrecht - Boston - London. 528 pp.</p> <p>Thonicke, K. (2003): <i>Fire disturbance and vegetation dynamics - analysis and models</i>. Dissertation. Mathematisch-Naturwissenschaftliche Fakultät der Universität Potsdam.</p> <p>Patzelt, S.T. (2008): <i>Waldbrandprognose und Waldbrandbekämpfung in Deutschland - zukunftsorientierte Strategien und Konzepte unter besonderer Berücksichtigung der Brandbekämpfung aus der Luft</i>.</p> <p>Frame of reference</p> <p>A-Team</p>
<p>Data specifications</p> <p>Data provided</p> <p>$T_{max,day}$: maximum daily temperature [°C] – (Maximale Tagestemperatur)</p> <p>D_{day}: daily dew-point temperature [°C] – (Tagestaupunkttemperatur)</p> <p>$P_{sum,day}$: daily sum precipitation [mm] – (Tagesniederschlagssumme)</p> <p>Data needed</p> <p>Most detailed land-use map – (Detaillierteste Landnutzungskarte)</p> <p>Most detailed digital elevation model (DEM) - (Detaillierteste digitale Geländemodell)</p>

Methodology for indicator calculation

Guidelines for calculating the indicator

$$NI = \sum_i^W T_{max,day} \cdot (T_{max,day} - D_{day})$$

W: number of days since the last rainfall greater than 3 mm

T_{max,day}: maximum daily temperature [°C] – (Maximale Tagestemperatur)

D_{day}: daily dew-point temperature [°C] – (Tagestaupunkttemperatur)

The computations begin on the first spring day when the high temperature is above freezing after snow melts and continue until a rainfall of 3 mm, whereupon the process starts anew.

In the analysis, the daily values of the Nesterov index will be averaged for the year. The index shows the fire danger:

VALUE OF NI

Between 0 and 300

Between 301 and 1000

Between 1001 and 4000

Above 4000

FIRE DANGER

Minimal

Moderate

High

Extreme

Methodology for gap filling

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References for the calculation methods

Nesterov, V.G. (1949): *Combustibility of the forest and methods for its determination*. USSR State Industry Press.

Contact

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Table 24: Factsheet for calculation I17 - climate indices and indicators for heat stress.

<p>Number of indicator</p> <p>I17</p> <p>Name of indicator</p> <p>Climate indices and indicators for heat stress</p>
<p>Identification</p> <p>Indicator description</p> <p>Directly derived climate indices/indicators as additional information/input for the region of interest. In order to analyse the impact of temperature rise on human health 3 climate indicators are considered: heat days, heat waves and tropical nights. One tropical night could have the same effect on human health as a heat wave of 3 days and a tropical night in the middle of 2 heat days enhances the heat stress for human health (Helga Kromb-Kolb et al. 2005).</p> <p>Unit</p> <p>[d], [°C]</p> <p>Indicator type</p> <p>Indicator describes exposure and sensitivity</p> <p>Relevance for sector</p> <p>Health</p>
<p>Scientific background</p> <p>References</p> <p>Kromb-Kolb H., Schwarzl, I. (2006): <i>Climate Change and Human Health. StartClim2005. Institute of Meteorology, Department of Water-Atmosphere-Environment, BOKU - University of Natural Resources and Applied Life Sciences, Vienna.</i></p> <p>Kropp J. et al. (2009): <i>Klimawandel in Nordrhein-Westfalen Regionale Abschätzung der Anfälligkeit ausgewählter Sektoren, Abschlussbericht des Potsdam-Instituts für Klimafolgenforschung (PIK) für das Ministerium für Umwelt und Naturschutz, Landwirtschaft und Verbraucherschutz Nordrhein-Westfalen (MUNLV)PIK, Potsdam.</i></p> <p>Frame of reference</p> <p>Project StartClim2005</p>
<p>Data specifications</p> <p>Data provided</p> <p>$T_{max, day}$: maximum daily temperature [°C] – (Maximale Tagestemperatur)</p> <p>$T_{min, day}$: minimum daily temperature [°C] – (Minimale Tagestemperatur)</p> <p>Data needed</p> <p>Most detailed land-use map – (Detaillierteste Landnutzungskarte)</p> <p>Most detailed digital elevation model (DEM) - (Detaillierteste digitale Geländemodell)</p>

Methodology for indicator calculation

Guidelines for calculating the indicator

Heat days: Amount of days with $T_{max,day}$ over 30°C per year

Tropical nights: Amount of days with $T_{min,day}$ over 20°C per year

Heat waves duration index: Number of heat waves longer than or equal to 3 days

Methodology for gap filling

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References for the calculation methods

Schulzweida U., Kornblueh L., Quast R. (2009): CDO User's Guide – Climate Data Operators. MPI for Meteorology, Brockmann Consult.

Contact

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Table 25: Factsheet for calculation I18 - Climate indices and indicators for summer tourism.

<p>Number of indicator</p> <p>I18</p> <p>Name of indicator</p> <p>Climate indices and indicators for summer tourism</p>
<p>Identification</p> <p>Indicator description</p> <p>Directly derived climate indices/indicators as additional information/input in combination with the region of interest.</p> <p>Unit</p> <p>[d], [mm], [°C]</p> <p>Indicator type</p> <p>Indicator describes exposure</p> <p>Relevance for sector</p> <p>Tourism (summer)</p>
<p>Scientific background</p> <p>References</p> <p>Fleischhacker, V. & Formayer, H. (2007): Die Sensitivität des Sommertourismus in Österreich auf den Klimawandel. StartClim2006.D1. Institut für touristische Raumplanung - ITR, Institut für Meteorologie Universität für Bodenkultur.</p> <p>Matzarakis A. & Koch E. (2007): Auswirkungen des Klimawandels auf das klimatische Tourismuspotenzial. StartClim2006.D2. Meteorologisches Institut, Universität Freiburg; Zentralanstalt für Meteorologie und Geodynamik, HoheWarte Wien.</p> <p>Krajsits C., Andel A., Neugebauer W., Stanzer G., Wach I, Kroisleitner C., Schöner W. (2008): ALSO WIKI - Alpiner Sommertourismus in Österreich und mögliche Wirkungen des Klimawandels. StartClim2007.F. Institut für touristische Raumplanung - ITR, Zentralanstalt für Meteorologie und Geodynamik - ZAMG.</p> <p>Prettenthaler, F., Formayer, H., Haas, P., Hofstätter, M., Habsburg-Lothringen, C., Vettters, N., (2008): Global Change Impact on Tourism, Zwischenbericht im Projektjahr 1, 2 und 3, Wien.</p> <p>Frame of reference</p> <p>Project StartClim2006</p>

Data specifications

Data provided

$T_{max,day}$: maximum daily temperature [°C] – (Maximale Tagestemperatur)

$T_{min,day}$: minimum daily temperature [°C] – (Minimale Tagestemperatur)

$T_{mean,day}$: mean daily temperature [°C] – (Mittlere Tagestemperatur)

$W_{mean,day}$: mean daily wind speed [m/s] – (Mittlere Windgeschwindigkeit pro Tag)

$RH_{mean,day}$: mean daily relative humidity [%] – (Mittlere relative Feuchte pro Tag)

$R_{sum,day}$: daily precipitation sum [mm] – (Tagesniederschlagssumme)

$TCC_{mean,day}$: daily mean total cloud cover [%] – (Mittlere Tagesbewölkung)

Data needed

Most detailed land-use map – (Detaillierteste Landnutzungskarte)

Most detailed digital elevation model (DEM) – (Detaillierteste digitale Geländemodell)

Methodology for indicator calculation

Guidelines for calculating the indicator

Summer days: Amount of days with $T_{max,day}$ over 25°C per year

Heat days: Amount of days with $T_{max,day}$ over 30°C per year

Cold days: Amount of days with $T_{max,day}$ below 20°C (Average over June, July, August)

Windy days: Amount of days with $W_{mean,day}$ over 8 m/s per month/year

Misty days: Amount of days with $RH_{mean,day}$ over 93% per month/year

Dry days: Amount of days with $R_{sum,day}$ below 1mm per month/year

Sunny days: Amount of days with $TCC_{mean,day}$ below 5% per month/year

Rainy days: Amount of days with $R_{sum,day}$ over 1mm per month/year

Heavy precipitation days: Amount of days with $R_{sum,day}$ over 10mm per month/year

Very heavy precipitation days: Amount of days with $R_{sum,day}$ over 20mm per month/year

Precipitation sum: Sum of precipitation per month/year

Monthly mean maximum temperature

Monthly mean temperature

Methodology for gap filling

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References for the calculation methods

Schulzweida U., Kornblueh L., Quast R. (2009): CDO User's Guide – Climate Data Operators. MPI for Meteorology, Brockmann Consult.

Contact

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Table 26: Factsheet for calculation I19 - Climate indices and indicators for winter tourism.

<p>Number of indicator</p> <p>I19</p> <p>Name of indicator</p> <p>Climate indices and indicators for winter tourism</p>
<p>Identification</p> <p>Indicator description</p> <p>Directly derived climate indices/indicators as additional information/input for the region of interest. A frost day has a temperature minimum less than 0 °C, while a day with a temperature maximum less than 0 °C is called ice day.</p> <p>Unit</p> <p>-</p> <p>Indicator type</p> <p>Indicator describes exposure.</p> <p>Relevance for sector</p> <p>Tourism (winter)</p>
<p>Scientific background</p> <p>References</p> <p>Matzarakis A. & Koch E. (2007): Auswirkungen des Klimawandels auf das klimatische Tourismuspotenzial. StartClim2006.D2. Meteorologisches Institut, Universität Freiburg; Zentralanstalt für Meteorologie und Geodynamik, HoheWarte Wien.</p> <p>Kromp-Kolb, H. (2006): Klimawandel und Wintertourismus. In: Klima-Wandel-Alpen. Tourismus und Raumplanung im Wetterstress. CIPRA Tagungsband 23/2006.</p> <p>Prettenthaler, F., Formayer, H., Haas, P., Hofstätter, M., Habsburg-Lothringen, C., Vettors, N., (2008): Global Change Impact on Tourism, Zwischenbericht im Projektjahr 1, 2 und 3, Wien.</p> <p>Frame of reference</p> <p>-</p>
<p>Data specifications</p> <p>Data provided</p> <p>$T_{min,day}$: minimum daily temperature [°C] – (Minimale Tagestemperatur)</p> <p>$T_{max,day}$: maximum daily temperature [°C] – (Maximale Tagestemperatur)</p> <p>$W_{mean,day}$: mean daily wind speed [m/s] – (Mittlere Windgeschwindigkeit pro Tag)</p> <p>$RH_{mean,day}$: mean daily relative humidity [%] – (Mittlere relative Feuchte pro Tag)</p> <p>$R_{sum,day}$: daily precipitation sum [mm] – (Tagesniederschlagssumme)</p> <p>$TCC_{mean,day}$: daily mean total cloud cover [%] – (Mittlere Tagesbewölkung)</p> <p>Data needed</p> <p>Most detailed land-use map – (Detaillierteste Landnutzungskarte)</p> <p>Most detailed digital elevation model (DEM) - (Detaillierteste digitale Geländemodell)</p>

Methodology for indicator calculation

Guidelines for calculating the indicator

Frost days: Number of days with $T_{min,day}$ below 0°C

Ice days: Number of days with $T_{max,day}$ below 0°C

Windy days: Amount of days with $W_{mean,day}$ over 8 m/s per month/year

Misty days: Amount of days with $RH_{mean,day}$ over 93% per month/year

Dry days: Amount of days with $R_{sum,day}$ below 1mm per month/year

Sunny days: Amount of days with $TCC_{mean,day}$ below 5% per month/year

Rainy days: Amount of days with $R_{sum,day}$ over 1mm per month/year

Heavy precipitation days: Amount of days with $R_{sum,day}$ over 10mm per month/year

Very heavy precipitation days: Amount of days with $R_{sum,day}$ over 20mm per month/year

Precipitation sum: Sum of precipitation per month/year

Methodology for gap filling

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References for the calculation methods

Schulzweida U., Kornblueh L., Quast R. (2009): CDO User's Guide – Climate Data Operators. MPI for Meteorology, Brockmann Consult.

Contact

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Table 27: Factsheet for calculation I20 - Tourism climate index (TCI).

<p>Number of indicator</p> <p>I20</p> <p>Name of indicator</p> <p>Tourism Climate Index (TCI)</p>
<p>Identification</p> <p>Indicator description</p> <p>The Tourism Climate Index (TCI) is a combined index which can be considered as climatic suitability for general summer tourism purposes. It is comprising the climate features temperature, humidity, sunshine, rain and wind</p> <p>Unit</p> <p>-</p> <p>Indicator type</p> <p>Indicator describes exposure and sensitivity</p> <p>Relevance for sector</p> <p>Tourism</p>
<p>Scientific background</p> <p>References</p> <p>Amelung, B., and D. Viner (2006): "Mediterranean tourism: Exploring the future with the tourism climatic index". <i>Journal of Sustainable Tourism</i>, 14(4), 349-366.</p> <p>EEA. (2008): <i>Impacts of Europe's changing climate - An indicator-based assessment. 4</i>, European Environment Agency.</p> <p>Frame of reference</p> <p>EEA report, project PESETA</p>
<p>Data specifications</p> <p>Data provided</p> <p>$T_{max,day}$: maximum daily temperature [°C] – (Maximale Tagestemperatur)</p> <p>$RH_{min,day}$: minimal daily relative humidity [%] – (Minimale relative Feuchte pro Tag)</p> <p>$T_{mean,day}$: mean daily temperature [°C] – (Mittlere Tagestemperatur)</p> <p>$RH_{mean,day}$: mean daily relative humidity [%] – (Mittlere relative Feuchte pro Tag)</p> <p>$R_{sum,day}$: daily precipitation sum [mm] – (Tagesniederschlagssumme)</p> <p>S_{day}: daily sunshine duration [h] – (Tagessonnenscheindauer)</p> <p>$W_{mean,day}$: mean daily wind speed [m/s] – (Mittlere Windgeschwindigkeit pro Tag)</p> <p>Data needed</p> <p>Most detailed land-use map – (Detaillierteste Landnutzungskarte)</p> <p>Most detailed digital elevation model (DEM) - (Detaillierteste digitale Geländemodell)</p>

Methodology for indicator calculation

Guidelines for calculating the indicator

$$TCI = 8 * Cld + 2 * Cla + 4 * R_{sum,day} + 4 * S_{day} + 2 * W_{mean,day}$$

Cld is a daytime comfort index, consisting of the mean maximum air temperature [$T_{max,day}$ (°C)] and the mean minimum relative humidity [$RH_{min,day}$ (%)], *Cl_a* is the daily comfort index, consisting of the mean air temperature [$T_{mean,day}$ (°C)] and the mean relative humidity [$RH_{mean,day}$ (%)]. *R_{sum,day}* is the precipitation (mm), *S_{day}* is the daily sunshine duration (h), and *W_{mean,day}* is the mean wind speed (m/s). In contrast to other climate indices, every contributing parameter is assessed. Because of a weighting factor (a value for TCI of 100), every factor can reach 5 points. TCI values ≥ 80 are excellent, while values between 60 and 79 are regarded as good to very good. Lower values (40 – 59) are acceptable, but values < 40 indicate bad or difficult conditions for tourism (Mieczkowski 1985)

Methodology for gap filling

-

References for the calculation methods

Mieczkowski Z (1985): *The tourism climatic index: a method of evaluating world climates for tourism. The Canadian Geographer* 29: 220-33.

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Table 28: Factsheet for calculation I21 - Line of artificial snow reliability.

<p>Number of indicator</p> <p>I21</p> <p>Name of indicator</p> <p>Line of artificial snow reliability</p>
<p>Identification</p> <p>Indicator description</p> <p>The line of artificial snow-reliability indicates the height of artificial snow-reliability. For artificial snow-reliability the so called 100-day rule has to be fulfilled (30 cm of snow depth for at least 100 days per season). The upper half of the altitudinal range of a ski area has to be located above this line to be classified as artificial snow-reliable.</p> <p>Unit</p> <p>-</p> <p>Indicator type</p> <p>Indicator describes exposure and sensitivity.</p> <p>Relevance for sector</p> <p>Tourism (winter)</p>
<p>Scientific background</p> <p>References</p> <p>Scott, D, McBoyle, G, Mills, B. 2003. Climate change and the skiing industry in Ontario: Exploring snowmaking as a technical adaptation. Climate Research, 23, 171-181.</p> <p>Pröbstl U., Prutsch A., Formayer H., Landauer M., Grabler K., Kulnig A., Jesch M., Dallhammer E. and Krajasits C. (2008): Climate change in winter sport destinations – transdisciplinary research for implementing sustainable tourism. Sustainable Tourism III - Ecology and the Environment volume 115.</p> <p>Frame of reference</p> <p>OECD study</p>
<p>Data specifications</p> <p>Data provided</p> <p>Expected temperature increase [°C] – (Voraussichtlicher Temperaturanstieg °C)</p> <p>Data needed</p> <p>Reference meteorological data: Ideally above 1000m. Considering daily precipitation, temperature (minimum, maximum) and snow depth data over the winter season (novembre – april) for the timeperiod:1961-1990 – (Meteorologischer Datensatz – Ideal oberhalb 1000m Höhe, welcher Auskunft über tägliche Niederschlagssummen, Temperatur (Minimum, maximum) und Schneehöhe gibt über die Wintersaison (November – April) sowie den Zeitraum 1961-1990)</p> <p>Most detailed land-use map – (Detaillierteste Landnutzungskarte)</p> <p>Most detailed digital elevation model (DEM) - (Detaillierteste digitale Geländemodell)</p> <p>Boundary of ski and glacier resort areas - (Abgrenzung von Skigebieten und Gletscherskigebieten)</p>

Methodology for indicator calculation

Guidelines for calculating the indicator

The values for the recent altitude of artificial snow-reliability will be modelled by the Scott et al. approach, having been improved and adopted for the Alps (Steiger 2009). It considers change in ski season length and the ability to produce artificial snow. If sufficient data is available in the study regions (meteorological data, ski area boundaries, etc.) the original model will be run for all ski areas. Combining the information on the annual temperature increase of the regional climate models with the information on the actual line of artificial snow-reliability will allow the generation of maps with the projected line of artificial snow-reliability.

Methodology for gap filling

If this is not possible, the results of the model for Tyrol (Steiger 2009) will be taken to derive temperature thresholds defining the mean altitude of technical snow reliability (at least 100 operation days in 7 out of 10 winters with current snowmaking technology). For Model region where no meteorological data will be available, we will allocate the outcome of previous modelled regions to the climate zones distinguished by the OECD and assign the corresponding altitudes.

References for the calculation methods

Scott, D, McBoyle, G, Mills, B. 2003. *Climate change and the skiing industry in Ontario: Exploring snowmaking as a technical adaptation*. *Climate Research*, 23, 171-181.

OECD (2007): *Climate change in the European Alps. Adapting winter tourism and natural hazards management*. Organisation for Economic Co-operation and Development. Ed. by Shardul Agrawala. Paris.

Steiger, R. (2009): *SkiSim - A tool to assess the impact of climate change on ski season length and snowmaking*. In: Schweizer, J., van Herwijnen, A. (eds.): *International Snow Science Workshop. 27. September to 2 October 2009, Davos, Switzerland. Proceedings*. Birmensdorf, Swiss Federal Institute for Forest, Snow and Landscape Research WSL. p. 239-243

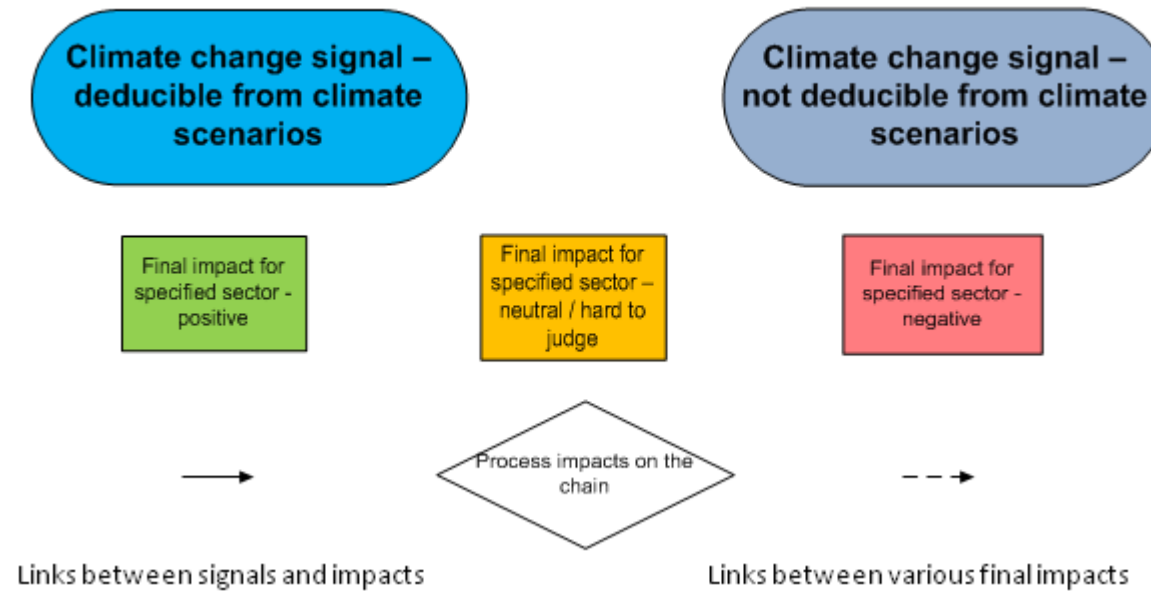
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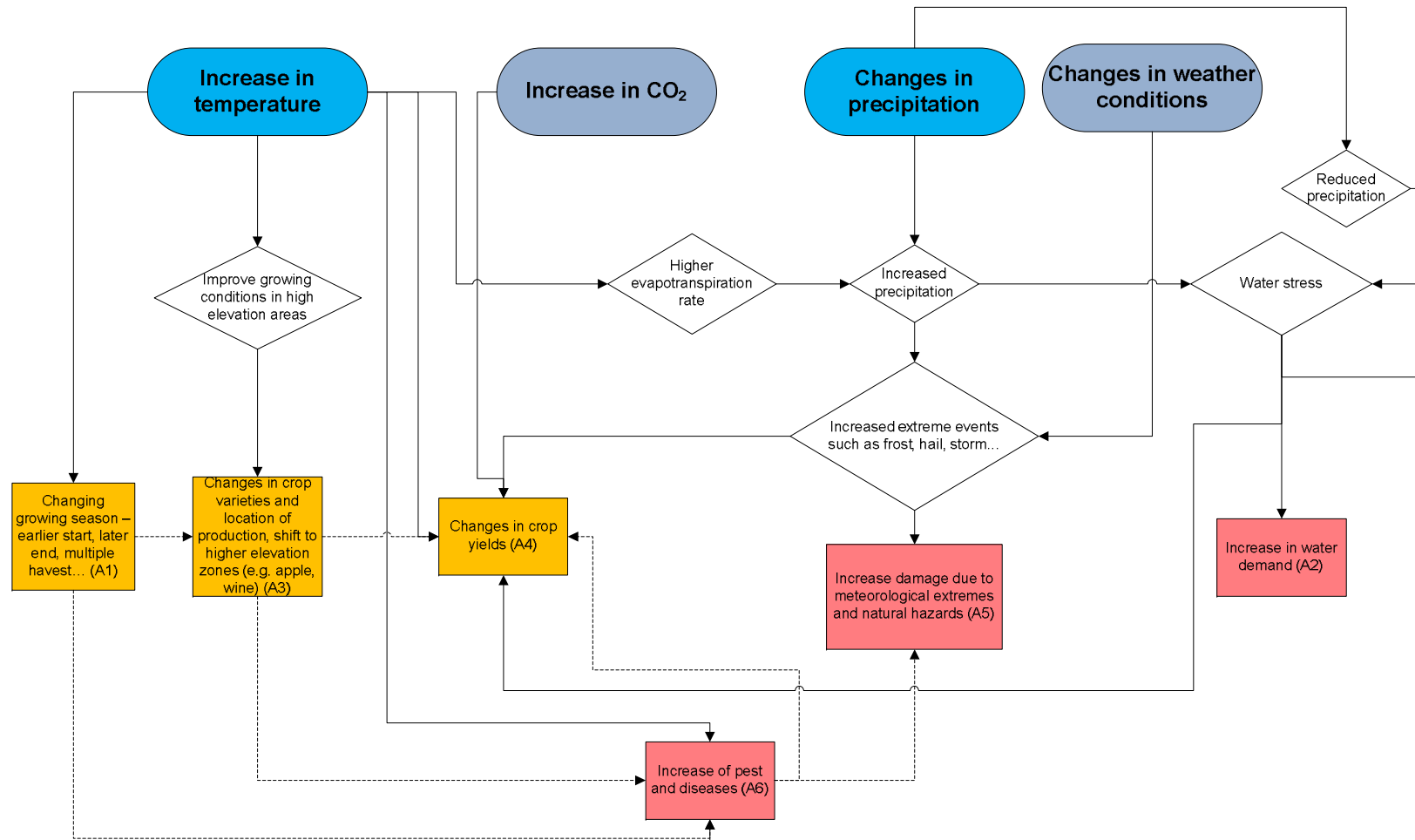
D.6 Impact chains

Impact chains are general cause-effect relations that describe how, in principle, climatic changes are expected to cause impacts on the sectors of concern. Impact chains name the most important chains of cause and effect leading to the potential impacts as they were identified and described in the MR guidelines.

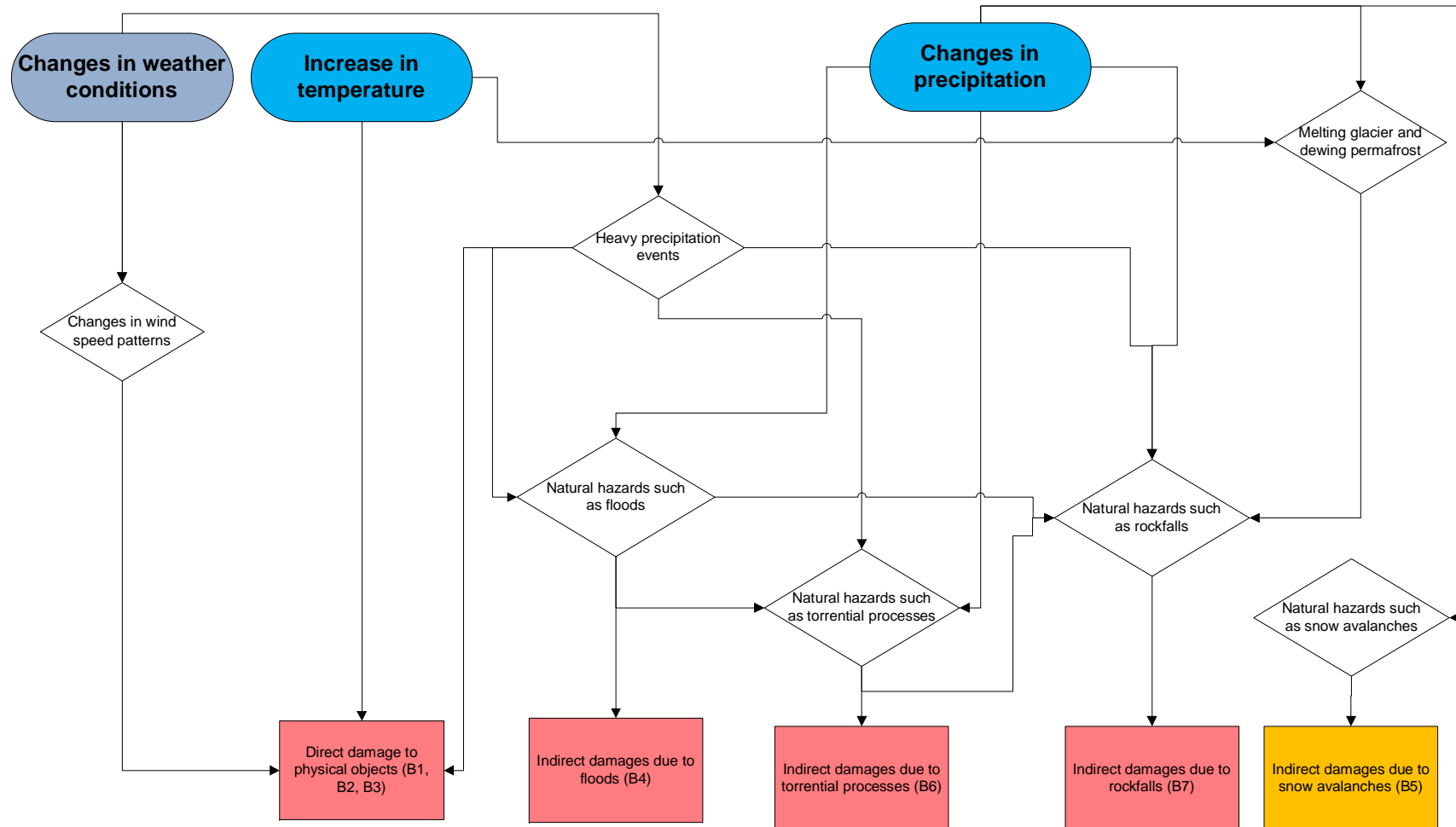
Legend



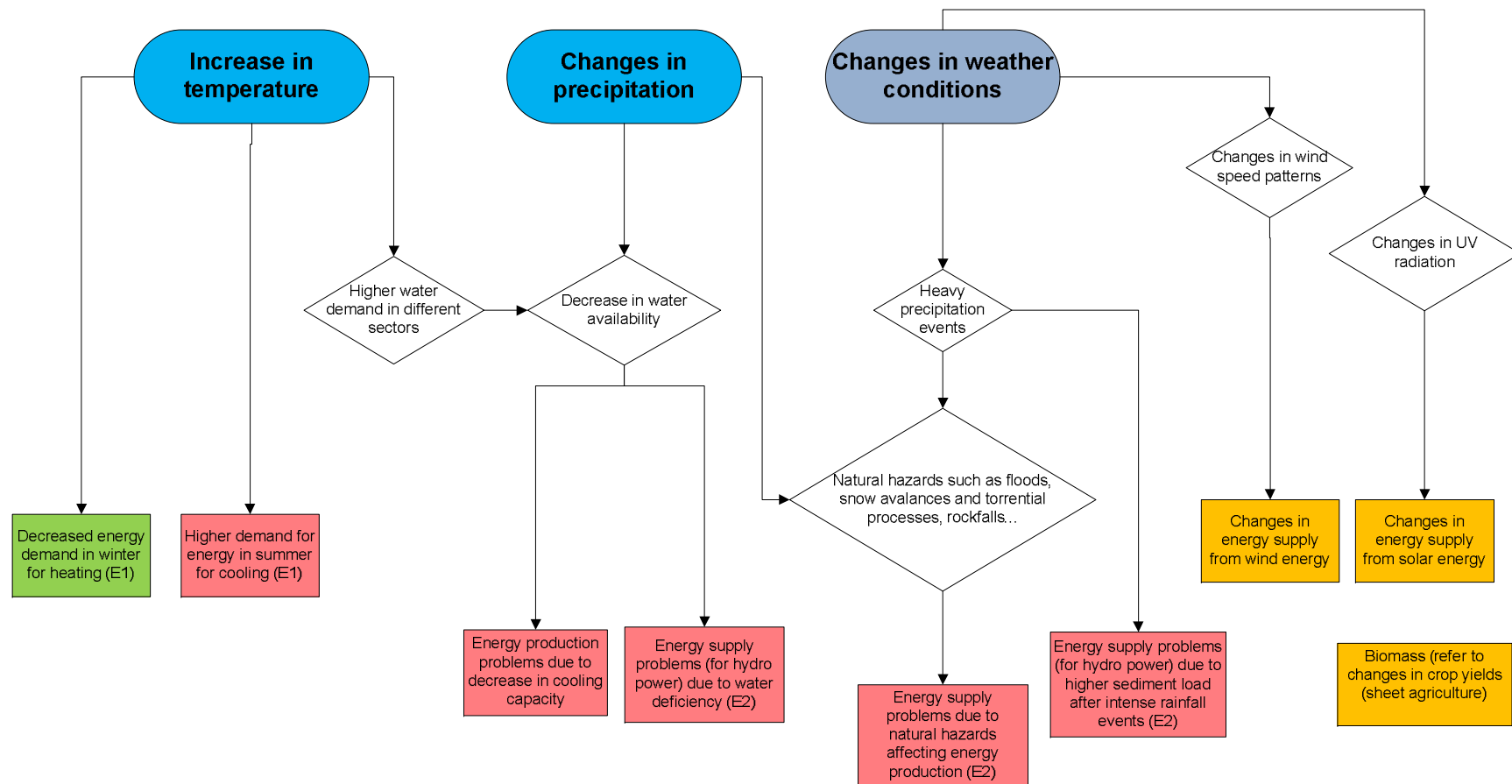
Climate change impact chains – Agriculture



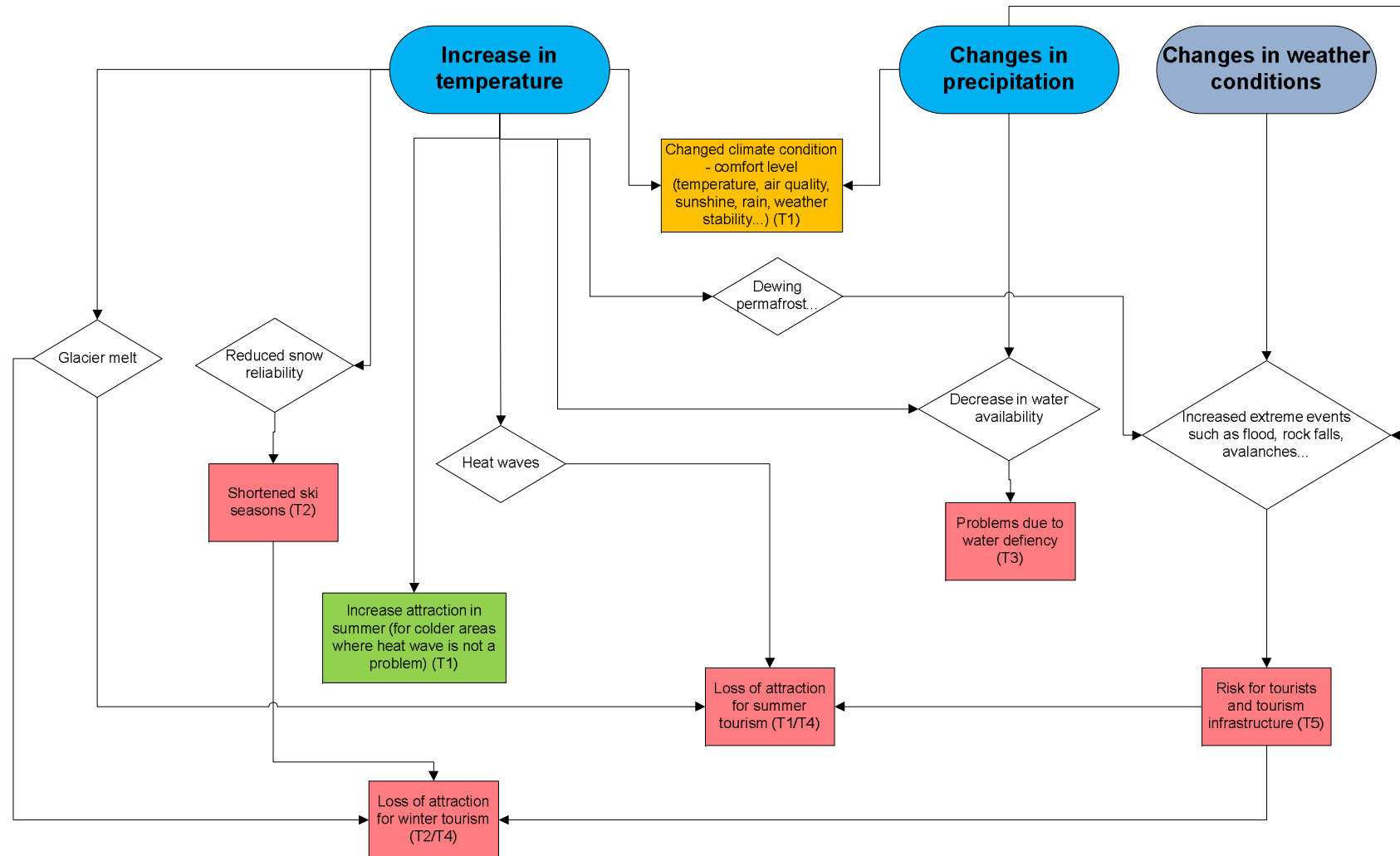
Climate change impact chains – Built-up areas / land development



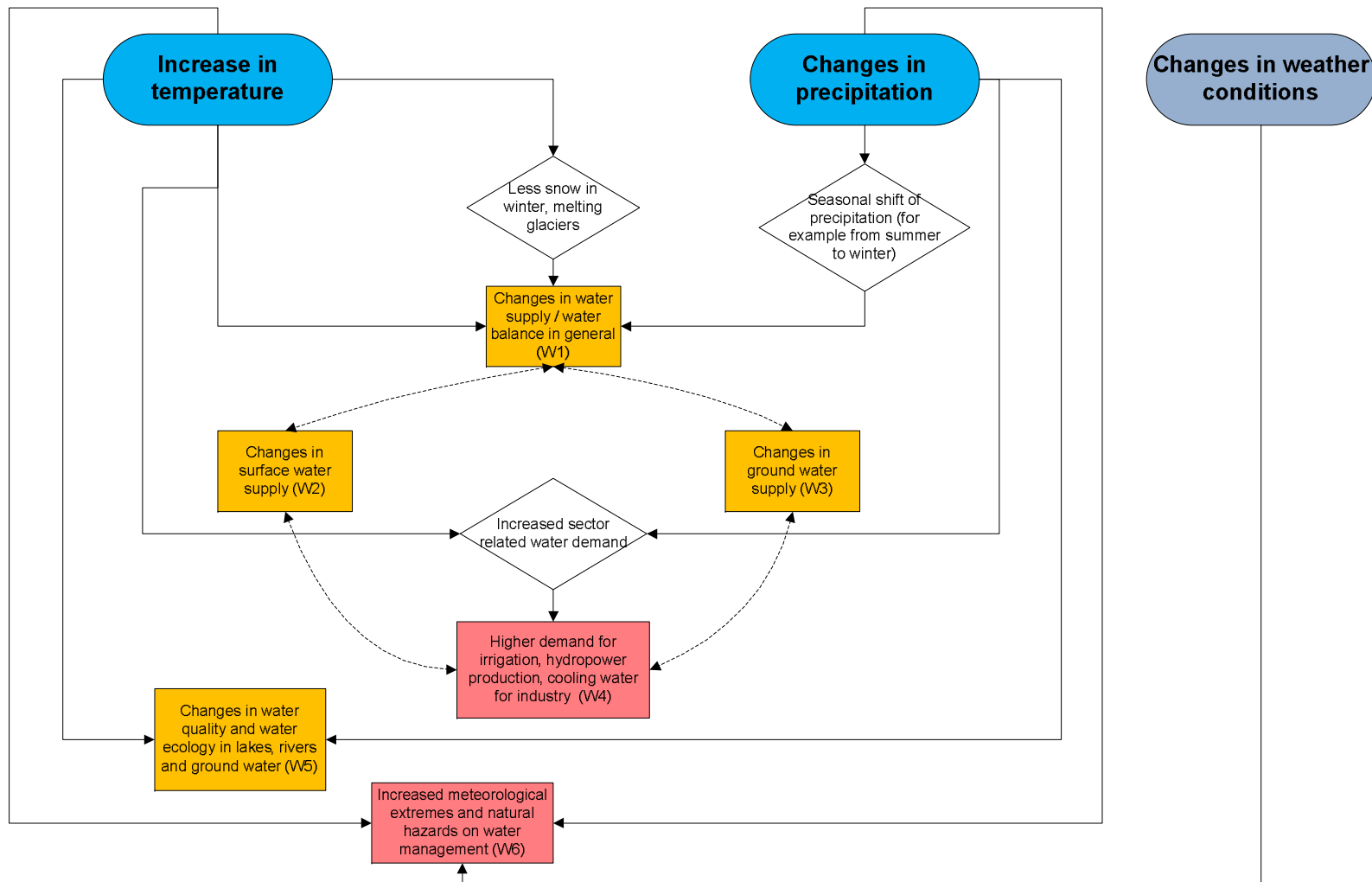
Climate change impact chains – Energy



Climate change impact chains – Tourism



Climate change impact chains – Water management



D.7 A preliminary assessment of the impacts of rockfall from permafrost degradation in the Alps

D.7.1 Introduction

Permafrost is described as subsurface material at temperatures lower than 0°C in two consecutive years. The conditions favorable for existence of permafrost can be found at arctic environments as well as at high mountain sites at low latitudes. Permafrost is the largest component of the Cryosphere, and as it is defined primarily on a thermal basis, its variability is highly determined to changes in climate. Recent warming trends in air temperatures led to a degradation (changes in thermal conditions and thawing) of permafrost. Consequences coming along with degradation have an effect on ground stability, e.g. subsidence of large areas had been observed in the Tundra of the Northern Hemisphere, and on the global carbon cycle. Carbon is stored in arctic permafrost soils, and after thawing micro-bacterial activity cause a release of mainly Methane to the atmosphere. As Methane is a highly effective greenhouse gas, increasing release could lead to an accelerated warming (IPCC 2007). Changes in thermal ground conditions affect permafrost at different temporal and spatial scales and can cause variations in magnitudes and timing of geomorphologic processes. It is well accepted to distinguish in immediate and shallow response which comes along with active layer (layer between permafrost table and ground surface containing the annual freeze thaw cycle) formation or thickening. Responses on scales of seasons to several years causing huge active layer thickening which was observed as a result of the warming trend during the last decades. Deep disturbances leading to widespread permafrost degradation of which the effects may be delayed by decades, centuries or millennia (NÖTZLI AND GRUBER 2005; FISCHER ET AL. 2006; GRUBER AND HAEBERLI 2007).

In the alpine environment permafrost is a widespread phenomenon. It exist mainly as frozen rock or frozen sediments and is determined by ground surface temperatures. Ground surface thermal conditions depend on the one hand on air temperature, which is a function of altitude, and solar radiation. In addition snow depth, point of first snow and the type of soil are on the other hand factors which affect the temperatures at ground surface. Especially snow is a very important factor regarding permafrost, because it can take two controversial positions depending on time and volume of the snowpack. In winter huge snowpack isolates against winter coldness, but huge snowpack in spring delays ground surface warming (NÖTZLI AND GRUBER 2005). Like air temperatures also permafrost temperatures show a warming trend. Within the last century the first 10 m of Alpine permafrost shows a warming trend of 0.5° to 0.8° C (GRUBER AND HAEBERLI 2007; HARRIS ET AL. 2003). It is therefore very important to understand where and at which scale the penetration of frost thaw cycle increases. Research on steep rock (inclination > 37°) slope instabilities had been done in the past and its common sense that geologic conditions e.g. lithology, stratification, fracturing of bedrock and degree of weathering and geometric conditions e.g. complex topography are the driving factors causing instabilities. Factors that could trigger a rockfall event had been described as frost-thaw activity (DORREN 2003; GROVE 1972; PORTER AND OROMBELLI 1980, 1981; COUTARD AND FRANCOU 1989, MCCARROL ET AL. 1998; MATSUOKA AND SAKAI 1999), seismic (DORREN 2003; ZELLMER 1987; BULL ET AL. 1994; VIDRIH ET AL. 2001) or human activity (DORREN 2003; SELBY 1982). Ice-filled cracks or fractured zones which are also widespread in alpine bedrock can take a stabilizing position, but are prone to degradation due to increasing ground temperatures, too (NÖTZLI AND GRUBER 2005; GRUBER AND HAEBERLI 2007; DORREN 2003). Degradation at high altitude sites lead mainly to instabilities and higher mass movement activity. Research on high rock fall activity during the hot summer in 2003 in the Alps show, that the activities could be related to a more intensive active layer formation. It is thought this could be caused by heat wave activity between mid-June to August (GRUBER ET AL. 2004; GRUBER AND HAEBERLI 2007). Due to high population density in the Alpine space also human activity is connected to permafrost. Settlements, infrastructure, communication lines or cable car masts are prone to changes in ground conditions at high altitudes and are under a certain threat.

As permafrost responses to any changes of climate, active layer variability (layer between permafrost and ground surface with annual freezing and thawing) and thermal states can be used to trace changes (ANISIMOV AND NELSON 1996; HARRIS ET AL. 2003). Therefore active layer and thermal state have been selected as one of 6 key variables for cryospheric observations within the GTOS/GCOS (General Terrestrial/Climatic Observing System), which was implemented by the World Meteorological Organization (WMO), the International

Oceanographic Commission (IOC), the United Nations Environmental Program (UNEP) and the International Council of Scientific Unions (ICSU) (CHILAR ET AL. 1997; BURGESS ET AL. 2000; HARRIS ET AL. 2001 a,b; HARRIS ET AL. 2003).

Several borehole network and observation programs had been implemented in the last two decades. In 1997 started the multinational project 'Permafrost and Climate in Europe: climate change, mountain permafrost and geotechnical hazard' (PACE) of the EU which uses a borehole network of seven boreholes in Europe (from Svalbard to the Sierra Nevada) to investigate thermal state of permafrost (HARRIS ET AL. 2001 a,b). Further a Global Terrestrial Network for Permafrost (GTNet-P) for investigations on the active layer and the thermal states had been implemented in 1999, until 2008 the GTNet-P expanded to 66 bore hole sites in Europe (BURGESS ET AL. 2000; HARRIS AND ISKASEN 2008). RAVANEL ET AL. 2010 observed rockfalls in the Mont Blanc Massif for 2007 and 2008. They developed an observation network through the employment of guides, mountaineers and hut wardens. During the two years of observation 61 rockfalls were documented of which 61% (41 events) occurred in areas where permafrost is likely. This areas had been identified by mean annual ground surface temperature (MAGST) < -1°C. RAVANEL ET AL. conclude that the rockfalls are triggered by permafrost degradation, 90% of the observed events took place in summer, where the air temperatures are at highest. The years 2007 and 2008 are reported to have the seventh and eighth highest mean annual air temperatures in Chamonix for the last 100 years (RAVANEL ET AL. 2010). In 2008 started the multinational Permafrost Long-Term Monitoring Network (PermaNET) under the leadership of the Autonomous Province of Bolzano (Office for Geology and Building Materials Testings). The main goals are to implement an alpine wide monitoring network and to create a permafrost map for the entire Alpine Space. Further guidelines to consider permafrost in natural hazard, risk and water management had been developed. On regional scales there are many projects dealing with monitoring of Alpine permafrost, e.g. the Permafrost Monitoring Switzerland (PERMOS) project (VONDER MÜHLL ET AL. 2008) or Permafrost Observatory Project: A Contribution to the Thermal State of Permafrost (TSP) project (CHRISTIANSEN ET AL. 2010; JOHANNESSON ET AL. 2007).

The interest on high mountain permafrost increased steadily during the last decades within the scientific community. Main topics of research are improvements in process understandings e.g. atmosphere-permafrost coupling in complex topography and the assessment of impacts of climate change to permafrost and the resulting hazards e.g. related to rockfall and debris flows at permafrost underlying slopes (HAEBERLI AND GRUBER 2008). In this paper we present an analysis aimed at identifying areas where an assumed permafrost degradation is likely to bear more severe practical consequences. We focused as an example on the problem of rockfall due to permafrost degradation; we assumed that the main impact is on the interruption of communication infrastructures, and we use a set of GIS models to identify where rockfall may cause an impact in terms of isolation of mountain settlements.

First we describe a simple GIS model for identification of like and very likely permafrost distribution and the delineation of potential rockfall runout areas in the Greater Alpine Region (GAR). Then we explain the GIS procedure used to assess the impact of rockfall on the increase of travel time along communication networks. Finally, we used the procedure to compute impact indicators of rockfall for the Alpine region, and discuss the results.

D.7.2 Materials and methods

Modeling runout areas and trajectories of denudative slope processes e.g. rockfalls, landslides or debris flows are very important factors in hazard and risk assessment for people and infrastructure in the Alpine Space. Several studies and investigations had been done on modeling rockfalls applying and testing several methods. At the beginning of investigation on trajectories simple models included flow direction by determine flow from one cell to one of its eight neighbors, hereby the direction of flow represents the steepest descent between two cells. Till today the method is very common not only for modeling trajectories but also in Hydrology (NOETZLI ET AL. 2006; O'CALLAGHAN AND MARK 1984; JENSON AND DOMINGUE 1988; MARTZ AND GARBRECHT 1992).

BOTTINO ET AL. 2002 applied several methods including numerical, 2D and 3D models to rock avalanches in glacial environments and concluded that the best approach is the one of EVANS AND CLAGUE 1988. NOETZLI ET AL. model rock-ice avalanches from Alpine permafrost areas distinguishing 2 different parts of modeling.

First they apply a modified version of flow direction method for modeling trajectories, including a spreading function to account lateral spreading which is a typical behavior of avalanches. Second they introduce a function to determine conditions at which a avalanche stops. This is based on the empirical concept of the angle of reach defined as a ratio of vertical and horizontal displacement (NOETZLI ET AL. 2006; HEIM 1932). Research showed that the angle of reach depends on the volume of moving mass (NOETZLI ET AL. 2006; COROMINAS 1996; SCHEIDEGGER 1973; HSÜ 1975; TIANCHI 1983). NOETZLI ET AL. modified the function introduced by EVANS AND CLAGUE 1988 by analyzing several events in the Alps. Results of the model were compared to three large past rockfall events and they conclude that the application is a suitable method in modeling rock-ice avalanches (NOETZLI ET AL. 2006).

Approaches in modeling denudative slope processes are quite similar. Starting zones or release areas of the moving material had to be identified, in our case all areas identified as permafrost likely or very likely, within the GAR. A numerical model which describes the trajectories of every rockfall event, is also needed. Figure 43 shows the used input data and the performed steps.

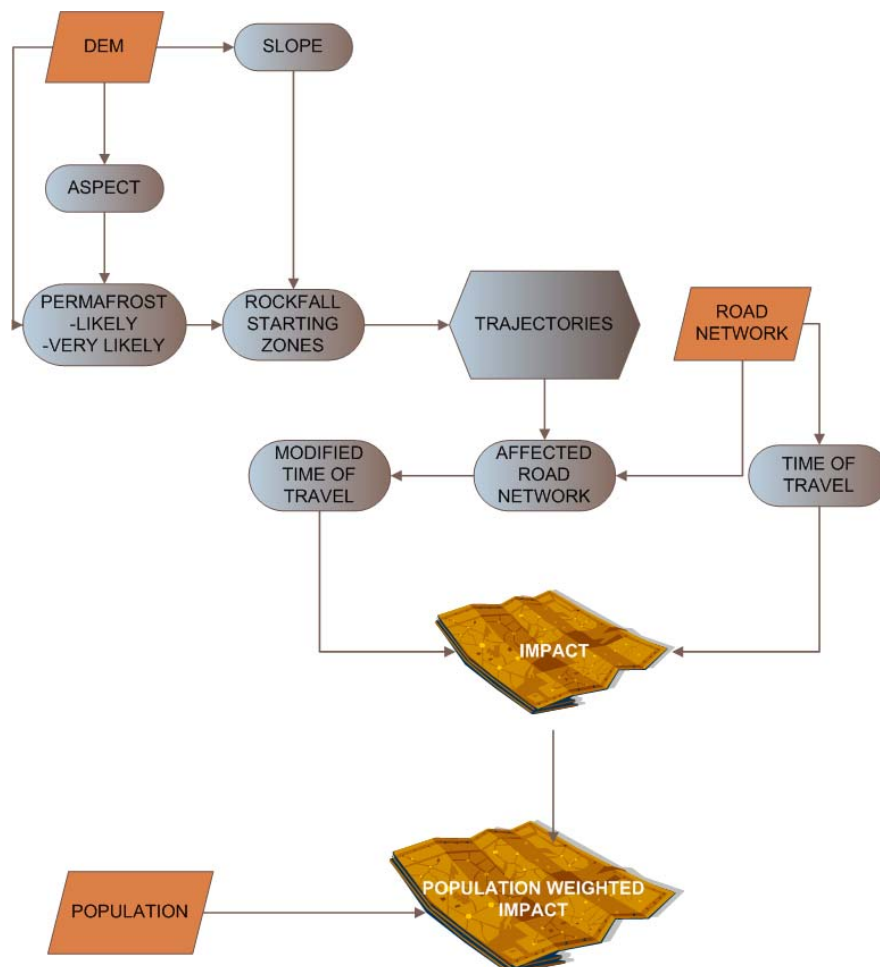


Figure 43: Working flow chart

D.7.2.1 Permafrost Identification and delimitation

Permafrost has been mapped using the approach of HAERBERLI (1975). Based on the SRTM Data (100x100m), potential permafrost areas have been identified and differentiated in likely and very likely. The approach refers to slope thresholds, relating aspects with height intervals and the correspondent occurrence of potential permafrost areas (See Figure 44).

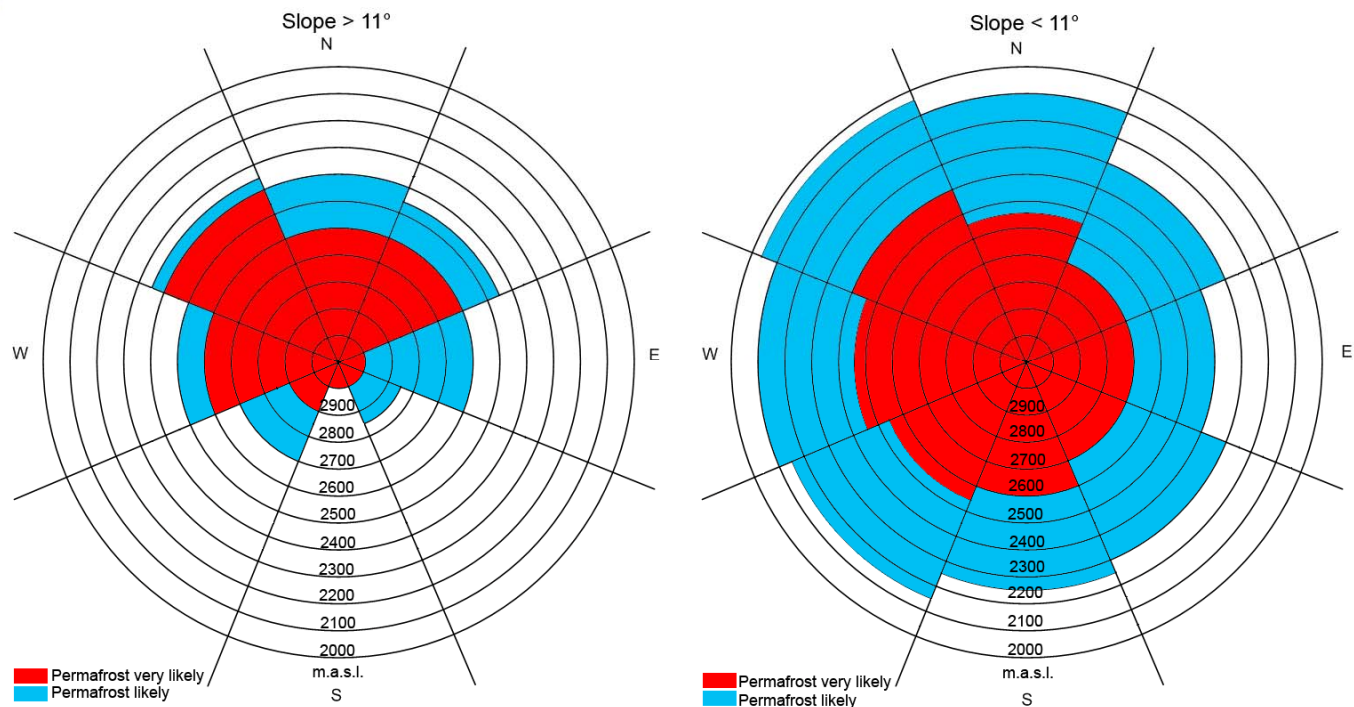


Figure 44: Interpretation key regarding permafrost occurrence (after HAEBERLI 1975)

D.7.2.2 Delimitation of rockfall starting zones

The assessment of likely and very likely permafrost areas is followed by the analysis of rockfalls sensitive starting zones. We considered the Corrine land cover as surface coverage reference. Based on the masking out of Bare rocks, Sparsely vegetated areas as well as Glaciers and perpetual snow, within the potential permafrost areas, slopes steeper than 45° were considered to be sensitive for rockfalls starting zones. Finally, the differentiated of permafrost likely as well as permafrost very likely starting zones was defined.

D.7.2.3 Rockfalls trajectories modelling

Rockfalls trajectories have been modelled considering their run out distance and their process path.

The calculation of the run out distance is calculated on the basis of the angle between the highest point of the rock face (potential starting zone) and the lowest point of the deposition area (Pauschalgefälle). The modelling approach refers to the method developed by LIEDL ET AL. (1995) and widely used in the elaboration of hazard index maps (MEISSL 1998, ZISCHG ET AL. 2002).

In order to calculate the runout distance, only the starting point as well as the angle is required. Typically, this value ranges from 30° and 38°. On the basis of statistical analysis, different authors proposed following selection of possible slope angles (STRADA AND PIACENTINI 2008):

- ONOFRI AND CANDIAN (1979): 27°, 41°
- TOPPE (1987): 32°
- HEINIMANN ET AL. (1998): 33°-37°
- FOXCARDI AND IOTTI (2001): 27°-29°
- JABOYEDOFF AND LABIOUSE (2003): 33°
- COROMINAS ET AL. (2003): 26° - 54°

Different block dimension could be simulated in the same area by considering different slope angles. For the alpine wide assesemnt we refered to an angle of 35°.

The process path of rockfalls is modelled by using the approach D16 of MEISSL (1998). In order to consider lateral propagations or deviations from the most suited path, a Monte Carlo approach was used to simulate the most likely possibilities of process propagations following the approach of Gamma (2000, random walk). The pixels of the DTM overpassed by each run (calculation of a single path) of the Monte Carlo simulation, are modified subsequently. The modification is done by increasing the absolute height of these pixels for a certain amount, after which, a subsequent run computes another rockfalls path accordingly to the modified DTM. We used an increasing value of 0.1 m.

D.7.2.4 Cost distance analysis

The cost distance analysis is a common approach in vulnerability analysis of a population regarding an impact. In general the method consists in comparison of particular situations before and after an impact. In our analysis, we define an impact as destroyed or blocked roads due to rockfall events, which have an effect on travel time within the Alpine Space.

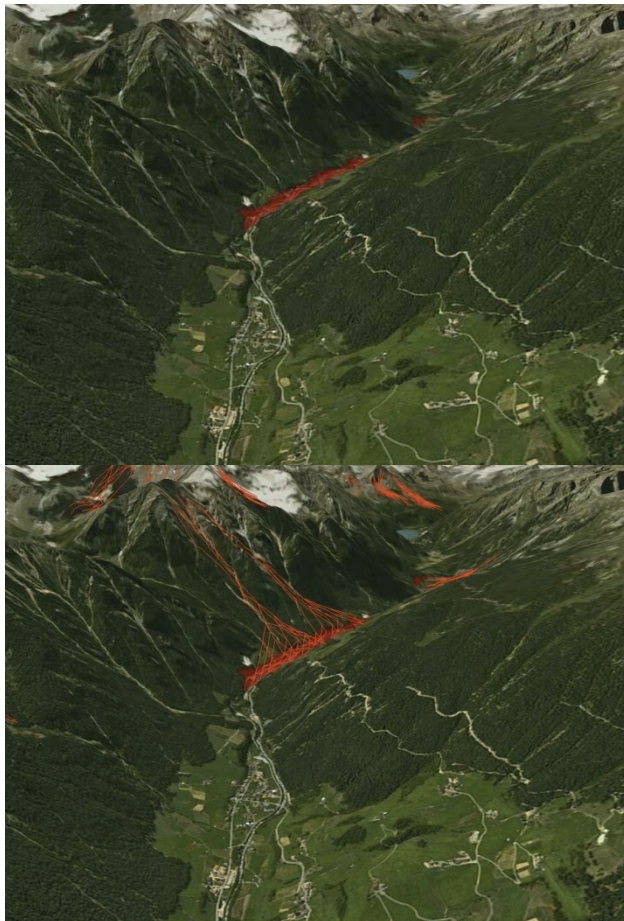


Figure 45: Affected roads trajectories in Martello valley.

Road network data based on the Tele Atlas of 2006 was taken and buffered in a distance of 1000 m. The buffer was sent to the weight of 10, because we assumed that people living in this certain distance can reach the streets within a certain velocity on roads which are not mapped on the road network (e.g. small steep roads leading to farms at valley slopes). In the Alpine Space mean traveling velocities can differ to a certain degree, to get a proper result in the analysis we had to set weights to different type of roads. In our case we assumed simply that the traveling velocities depend on the altitude of the road, so we combined the raster dataset of

the roads with the DEM. After this we set assumed traveling velocities to roads ≤ 800 m altitude to a weight 50, between 800 m and 1000 m to 40, between 1000 m and 1500 m to 30 and ≥ 1500 m to 20. For calculations on travel time the velocities had to be transformed by the statement:

$1/\text{weight}$

to get the crossing time per pixel. Based on this settings the cost distance calculation was performed in ArcGIS to the present conditions.

In the second step we performed a cost distance calculation after an impact. We identified parts of roads , which are affected by rockfalls and changed their weight to 1000 (in this case we did no transformation). This was done because the impacted parts represent barriers for travelers, so for the calculation they will cause a high increase of travel time. We assumed two different scenarios for the analysis, first people moving to the closest large cities, adapted after EuroGlobalMap provided by EuroGeographics (2001) (a Table with the cities could be found in the Annex), and second people moving out of the Alps to the border of the GAR. This analysis is very flexible could be done for different questions (e.g. people moving to their workplace or the next unaffected valley etc.), too.

At last we computed the impacts on traffic, because it depends essentially on the number of people trying to use certain roads. We used traffic to get an idea of how serious, in case of number of affected people, the impact is. What we did, was simply applying the Flow Accumulation tool of ArcGIS for calculation of number of people travelling on roads of the GAR. Population data was extracted out of the Gridded Population of the World, version 3 (GPWv3) dataset of 2005, provided by SocioEconomic Data and Applications Center (SEDAC). The calculation bases on a DEM where we combined the travel time raster and a path distance raster. At last Flow Accumulation was applied weighted by the gridded population to get a raster data set providing information about traffic on roads.

Afterwards we combined the dataset of increase in travel time and traffic to get an idea which roads are affected at most.

D.7.3 Results

The results of our analysis are shown in the following maps

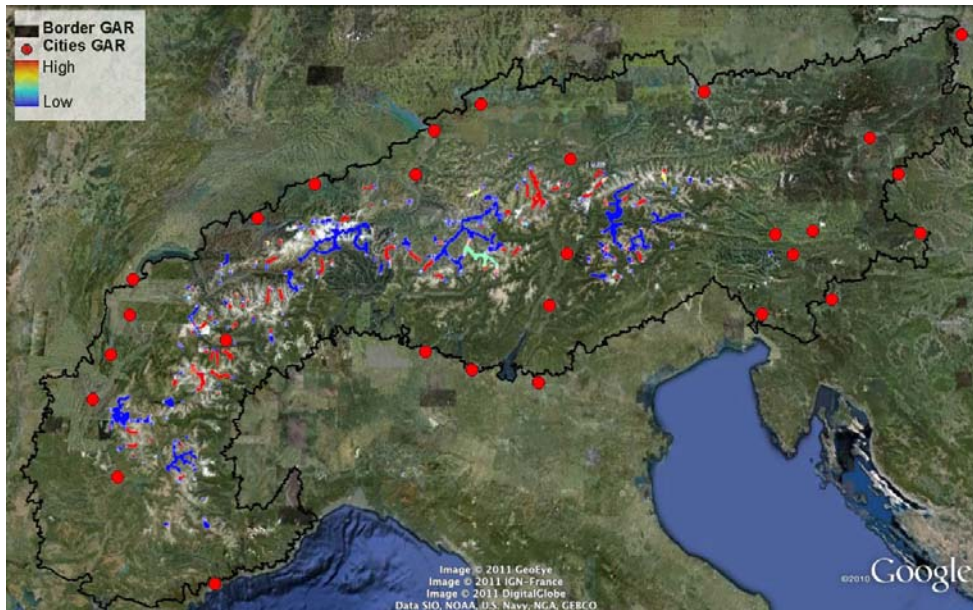


Figure 46: Maximum impact on travel time population forced to border

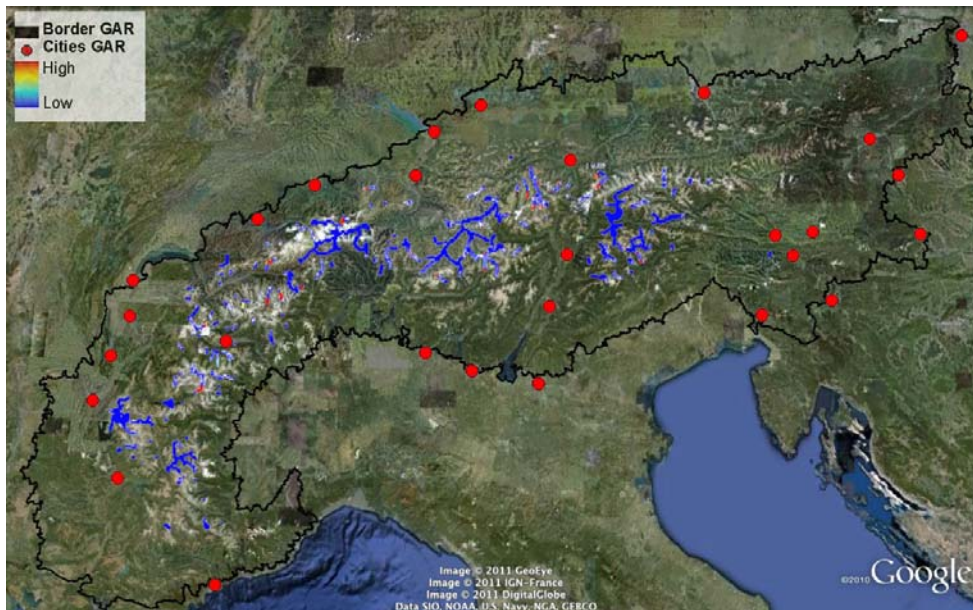


Figure 47: Maximum impact on traffic population forced to border.

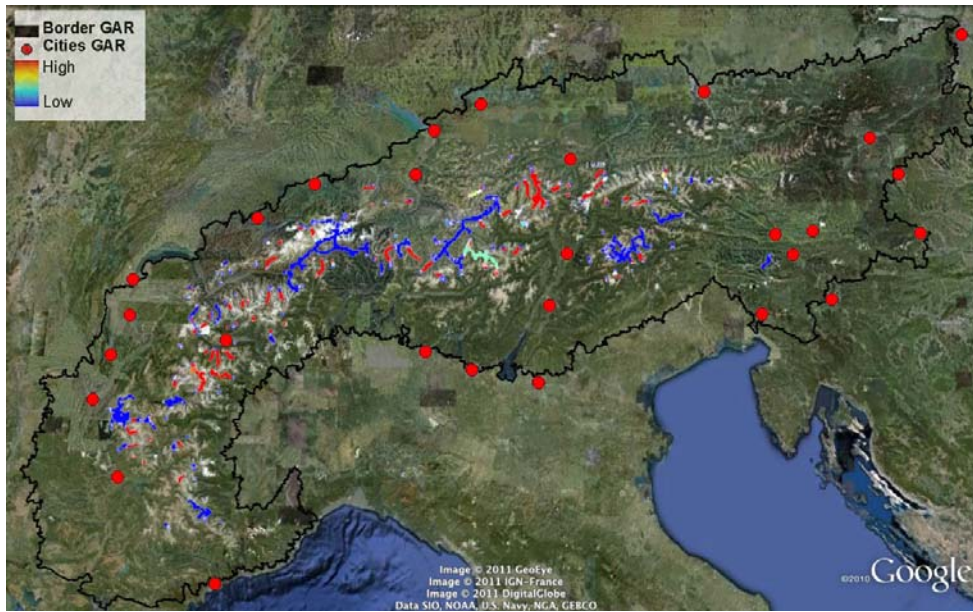


Figure 48: Maximum impact on travel time population forced to cities.

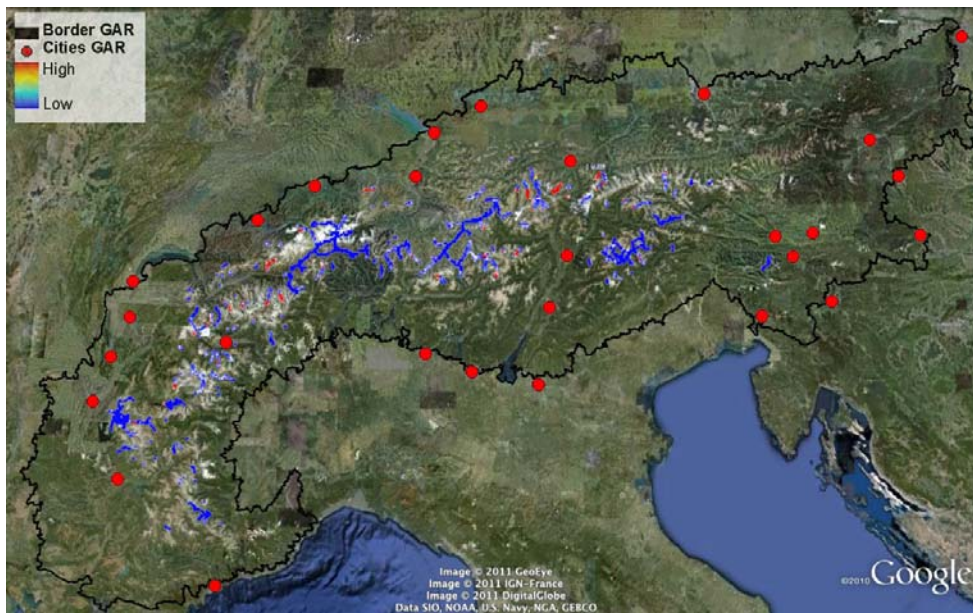


Figure 49: Maximum impact on traffic population forced to cities.



Figure 50: Roads with maximum traffic without an impact, population forced to border.



Figure 51: Roads with maximum traffic without an impact, population forced to cities.

Table 29: Cities in GAR

Country	Name	Population class
France	Annecy	50,001 - 100,000
Italy	Aosta	< 50.000
Italy	Bérgamo	100,001 - 500,000
Italy	Bolzano	100,001 - 500,000
Austria	Bregenz	50,001 - 100,000
Italy	Bréscia	100,001 - 500,000
France	Chambéry	50,001 - 100,000
France	Gap	< 50.000
Switzerland	Genève	100,001 - 500,000
Austria	Graz	100,001 - 500,000
France	Grenoble	100,001 - 500,000
Austria	Innsbruck	100,001 - 500,000
Slovenia	Jesenice	50,001 - 100,000
Germany	Kempton	50,001 - 100,000
Austria	Klagenfurt	50,001 - 100,000
Austria	Leoben	50,001 - 100,000
Slovenia	Ljubljana	100,001 - 500,000
Switzerland	Luzern	50,001 - 100,000
Slovenia	Maribor	100,001 - 500,000
France	Nice	100,001 - 500,000
Slovenia	Nova Gorica	50,001 - 100,000
Austria	Salzburg	100,001 - 500,000
Switzerland	Thun	50,001 - 100,000
Italy	Trento	50,001 - 100,000
Liechtenstein	Vaduz	< 50,000
Italy	Verona	100,001 - 500,000
Austria	Villach	50,001 - 100,000
Austria	Wien	> 500,000