Abstract Volume
7th Swiss Geoscience Meeting

Neuchâtel, 20th – 21st November 2009

11. Decision oriented modelling of the geosphere

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Geosciences
Platform of the Swiss Academy of Sciences

Centre d'hydrogéologie

11. Decision oriented modelling of the geosphere

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Swiss Academic Society for Environmental Research and Ecology (SAGUF)
Swiss Geographic Society, Swiss Geomorphological Society

11.1

Integrative hydro-geomorphologic modelling in alpine regions: scientific and operational challenges

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Hazard and risk assessment require, besides good data, good simulation capabilities to allow prediction of events and their consequences. Progresses have been done in building different modelling structures (conceptual and physically based, lumped and distributed) at different scales, with different amounts of input data and together with different calibration procedures.
Hazard assessment often requires involvement of decision makers and thus an important challenge is the evaluation of the credibility of the scientific results and the communication of the uncertainty.

The present study introduces an integrated approach based on the coupling of hydro-geomorphologic models, able to cope with uncertainty of input data and model parameters in order to perform a dynamic modelling in space and time of the main rainfall triggered hydro-geomorphologic processes.
The role of uncertainty as a tool to learn how input data could be used to evaluate different modelling structures at different scales has been also investigated.

The study region is represented by two small alpine catchments, the natural reserve of « Vallon de Nant » (13km^2) and the Tintaz catchment in the urbanised Verbier region. The hydrological model in this study is based on the Water Balance Simulation Model, WASIM-ETH (Schulla et al.,1997), a fully distributed hydrological model that has been successfully used previously in the alpine regions to simulate runoff, snowmelt, glacier melt, and soil erosion and impact of climate change on these. This model is intended to be coupled with slope stability methods to simulate the spatial distribution of the ini-

tiation areas of different geomorphic processes such as debris flows and rainfall triggered landslides.
To calibrate the WASIM-ETH model, the Monte Carlo Markov Chain Bayesian approach will be privileged (Balin, 2004, Schaefli et al., 200). Given that the spatial uncertainty of rainfall is an important factor of uncertainty in the hydrological modelling and given the high variability of the rainfall in alpine catchments, a quite dense network of meteorological stations has been implemented to better calibrate the hydrological model. Each step in the hydro-geomorphologic risk assessment undertakes uncertainty: evaluation of the main sources of uncertainty as well as the evaluation and communication of uncertainty is an important aspect of the proposed methodology. The Bayesian approach offers a good compromise between model efficiency and time consumption and represents a straightforward way to deal with different sources of uncertainty, as nowadays this is an important requirement of the decision makers involved in risk assessment.

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11.2

Using predisposition factors for landslide hazard assessment: a new GIS-based methodology

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Switzerland is exceptionally subjected to landslides; indeed, about 10% of its area is considered as unstable. Making this observation, its Department of the Environment (BAFU) introduced in 1997 a method to realize landslide hazard map. It is routinely used but, like most of the methods applied in Europe to map unstable areas, it is mainly based on the signs of previous or current phenomena (geomorphologic mapping, archive consultation, etc.) even though instabilities can appear where there is nothing to show that they existed earlier. Furthermore, the transcription from the geomorphologic map to the hazard map can vary according to the geologist or the geographer who realizes it: this method is affected by a certain lack of transparency and is not really efficient to forecast landslides.

The aim of this project is to introduce the bedrock of a new method for landslide hazard mapping; based on instability predisposition assessment, it involves the designation of main factors for landslide susceptibility, their integration in a GIS to calculate a landslide predisposition index and the implementation of new methods to evaluate these factors; to be competitive, these process will have to be both cheap and quick.

After showing that cohesion and hydraulic conductivity of loose materials were strongly linked to their granulometry and plasticity index, we implemented two new field tests, one based on teledetection and one coupled sedimentometric and blue methylen tests to evaluate these parameters. The hydraulic conductivity of fractured rocks was obtained from the analysis of their geometrical properties (fractures density, aperture size and orientation). The other factors were extracted from DEM and hydrologic mapping.

We added a last factor related to the predisposition of the geotype (new classification for geologic formations, based on genetic standards for loose material and on lithologic standards for hard rock) to slope instability process: the latter enabled us to integrate attributes proper to each geotypes (over-consolidation for ground moraines, stratifications for glaciolacustrine deposits, etc...) and which would be long and complex to integrate to a GIS.

Afterward, we implemented an ArcGis® toolbox allowing to lead to a landslide susceptibility index. Finally, we applied this methodology (from field survey to GIS operations) to ten sites in different contexts in Switzerland.
This new methodology can be considered as a cheap and efficient way to forecast landslides.

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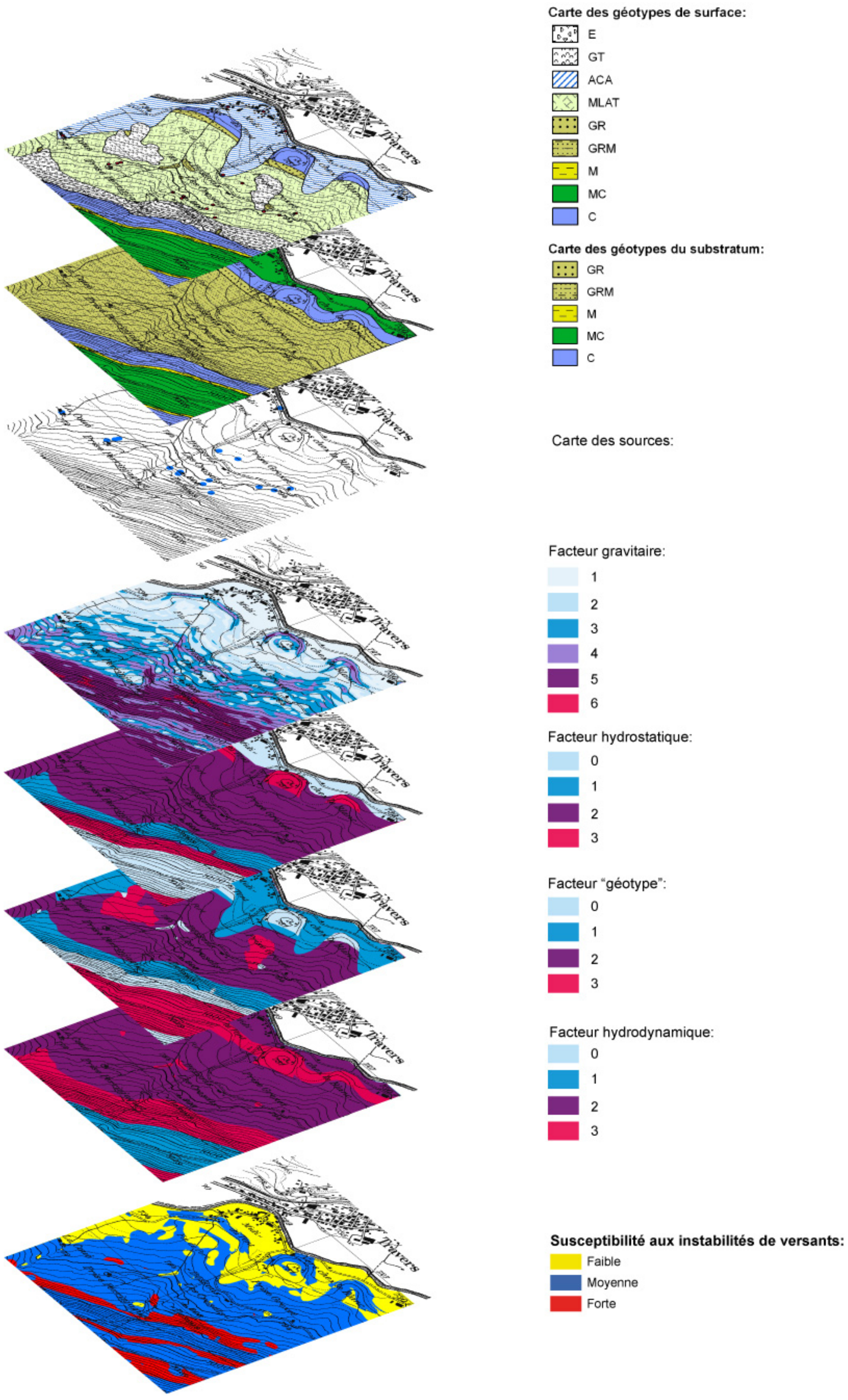

Figure 1. Application to the Travers landslide

11.3

Integrative modelling of pesticide use in developing countries

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The livelihood of small farmers in developing countries depends on their ability to employ ecologically and economically sound production methods. While properly applied pesticides reduce yield losses up to 40% and improve product quality, their misuse might cause serious human health and environmental problems. The World Health Organization (WHO) (1990a) estimates an annual worldwide total of 3 million cases of acute poisoning with 220,000 deaths.
One of the central questions is why, despite all the efforts being made in research, no significant improvements in understanding and modeling farmers' decision-making and connecting it to environmental and human health impacts have been made. Antle et al. (2001) state that one of the reasons is the segregated disciplinary research which leads to the problem that different scientific investigations cannot be linked to provide a system understanding that includes social and natural science variables. However, this understanding is indispensable for science models that provide a sound system understanding and thus, results that are comprehensible and useful for policy makers.

This paper presents an integrative modelling approach to simulate and assess the effect of measures for reducing the human health and environmental risks from pesticide use. Figure 1 shows the conceptual approach underlying the model building process and the methods used thereby.

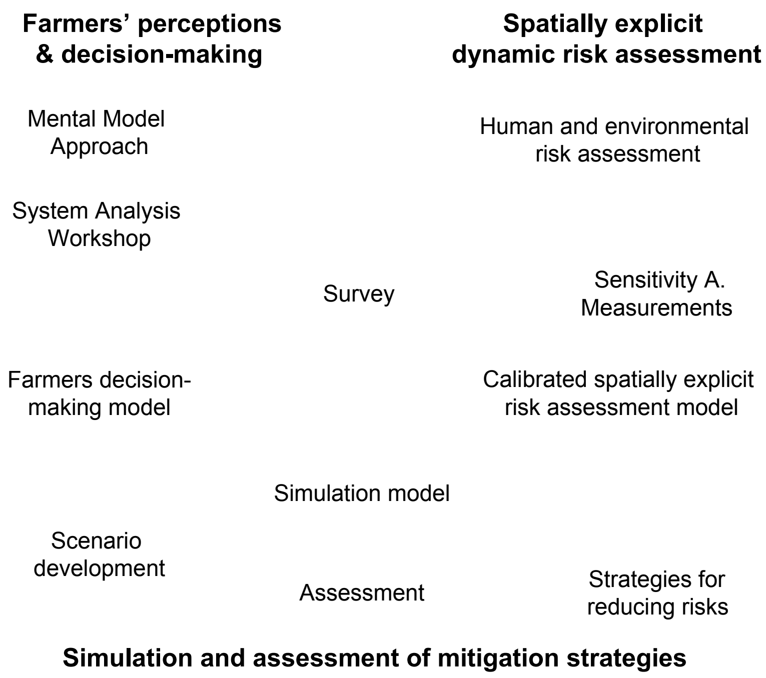

Figure 1. Methodological approach taken for designed the simulation model in the research project. Methods with [1] transdisciplinary methods

The simulation model is composed of two sub-models a farmers decision-making model and a spatially explicit risk assessment model. **Farmers' decision-making model** determines the amount and type of pesticide used and the type and frequency of usage of protective equipment during application. This model is based on a preliminary transdisciplinary analysis of farmers' perceptions on the potential risks of pesticide application and their system view (Schoell & Binder, 2009) and the Integrated Agent Centred (IAC) Framework (Feola & Binder, 2009). Results regarding the use or non use of protective equipment show that the variables mostly affecting this decision were (i) the perception of equipments' comfort, (ii) the practice of reading labels, (iii) the descriptive social norms and (iv) the perceived health impact (Feola and Binder, accepted). The third and fourth variable allow for defining a dynamic model which specifically includes feedback mechanisms as the effect of individual action on social norm.

The **spatially explicit risk assessment model** includes environmental as well as human health related processes and was developed to be spatially explicit. A combination of already existing models and their adaptation was chosen to simulate the fate and risk of the pesticides applied. The necessary input values for the model e.g. pesticide types, physical and chemical properties and pesticide application dates were obtained in the survey 2007. The survey included the spatially explicit application pattern by farmers, linking so the behavioural part with the spatially explicit risk assessment. Specific characteristics of the active ingredients were obtained from literature. The transfer-coefficients to the environmental compartments air, water, soil and plant as well as onto the farmer were obtained empirically using the WSP-uranine extraction.

The presentation will focus on the methodological approach taken highlighting the advantages of performing out-front transdisiplinary research to determine the main variables relevant for the system.

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11.4

A clustering method for uncertainty quantification applied to CO2 sequestration

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In order to reduce the atmospheric emission of CO_2 due to human activities, one possibility is to store CO_2 in geological reservoirs. The principle is to extract the CO_2 produced by a polluting factory (a coal fired power plant for instance) and to inject it into a geological reservoir such as a deep saline aquifer. If the caprock's quality is good, the CO_2 will be trapped and will progressively turn into sediments.

To decide upon the viability of such project, one of the main challenges is to quantify the risk of CO_2 leakage. As all the leakage scenarii depend on the growth of the CO_2 plume, it is necessary to study its expansion by numerical simulation (Fig. 1). However, the inputs of the simulation (permeability and porosity fields) are random, and simulating one single injection scheme with a finite volume method accounting the proper equation of states for supercritical CO2 takes around 2 days (20 years of injection with a 2 dimensional model).

As classical Monte-Carlo methods are unaffordable, the method we use here is as described by Caers in [1]. The aim is to select a limited number of simulation runs by applying a non intrusive method based on a proxy simulator (cheap-to-evaluate low-fidelity model). Following [2], kernel methods are used in order to linearize the data, which is supposed to improve the clustering procedure. The method consists of 5 steps:

- Generate *n* fields of permeability and porosity
- Use a proxy simulator to compute the n approximate solutions
- Define a distance between the solutions and create a mapping. This transformation may be based on kernel methods for greater linearity.
- Find *N* centres of clusters
- Run the simulator for the *N* selected points.

The flow simulation is performed using the software Tough2 with a 1 Mt/y injection rate during 20 years. The proxy simulator is a shorten Tough2 simulation of a 1 year injection. The number of initial fields generated is n=100 and the number of complete simulations is N=10. In order to evaluate the efficiency of our method, we perform a classical Monte-Carlo analysis using 100 complete simulations. The results are shown on Figure 2:

This work illustrates that proxy simulators can be used to efficiently select representative simulations. Here the CPU simulation time can be divided by one order of magnitude while keeping good estimates of the probability of presence of CO_2. However the distance definition seems to have a great impact on the final results. Future works may focus on the issue of selecting well-suited distances for importance sampling.

More generally, the proposed approach allows to improve the efficiency of large scale and complex modelling under uncertainty for decision making.

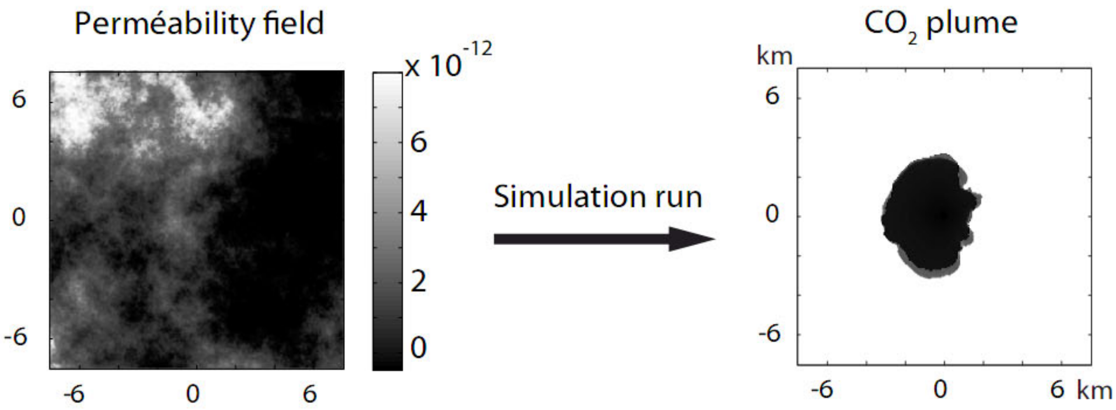

Figure 1. Example of permeability field and result of a 20 years injection

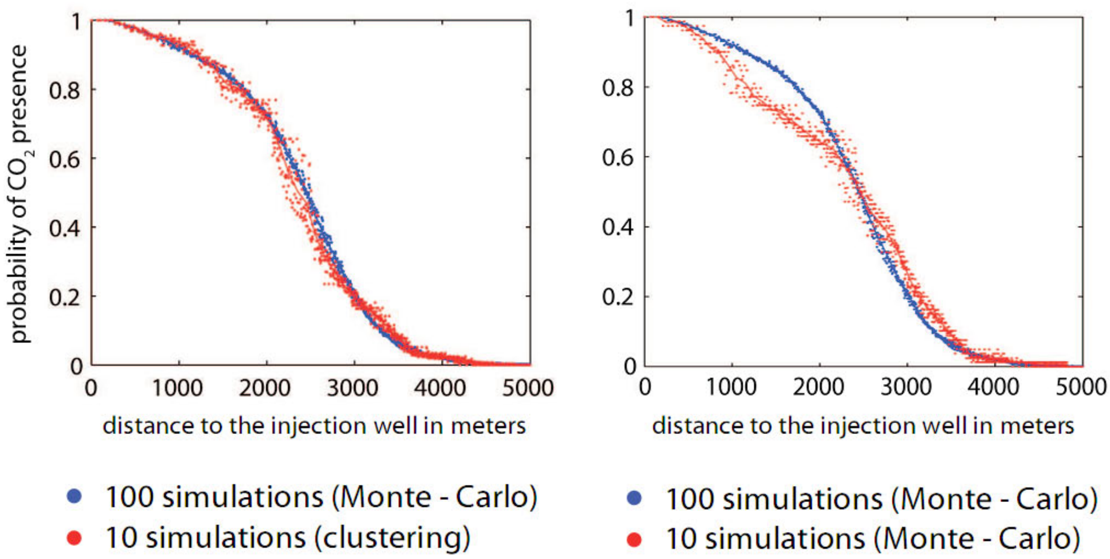

Figure 2. Comparison between clustering method and Monte – Carlo

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11.5

4D information on climate-driven geosystem changes in high mountain areas - experiences and perspectives.

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Integrated geoinformation systems combining data, models and scenarios are increasingly needed to anticipate developments of complex geosystems beyond the empirical knowledge basis from the past. Such geoinformation systems primarily provide an overview of the available knowledge and understanding concerning the most important processes, subsystems and their potential interactions. As a consequence of often incomplete or even missing (spatiotemporal) information, they must apply relatively simple and robust models, which need examination by more sophisticated process-oriented models. They render the corresponding scientific reflection (assumptions, hypotheses, scenarios) transparent, quantify results in the space and time domain and indicate knowledge gaps. Perhaps most importantly, they demonstrate the usefulness of, and the need for, considering complex systems and longer time scales. However, they are - and will always be - far from perfect and need continuous development in view of ongoing rapid changes in nature, technology and scientific understanding. Models of abiotic subsystems such as snow and ice conditions, water supply or hazards from rock falls, debris flows, avalanches and floods are already well advanced and useful. Biotic subsystems – especially vegetation as related to climate change, ice vanishing and effects of grazing – are less well covered by robust spatial models applicable in high-mountain topography: an urgent research need. Experiences are presented from a case study carried out in the Upper Engadin, eastern Swiss Alps, within the framework of the NRP48 and perspectives will be discussed in view of new lakes forming in rapidly deglaciating mountain ranges.

11.6

Simulation-based risk assessment of superimposed groundwater salinisation processes

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Groundwater salinisation is a world-wide major groundwater contamination issue and is related to multiple processes, such as seawater intrusion, agrochemical pollution, geogenic contamination and irrigation-induced pollution. In salinity affected aquifers, the observed concentration of total dissolved solids may result from the superposition of several salinisation processes. In areas affected by groundwater salinisation, correct identification of the spatial distribution and dynamic interplay of the super-imposed salinity components is crucial, since the respective remedial or conservation measures may be entirely different.

Identification of different origins of salinisation can be considered a separate field in hydrogeological research and is efficiently addressed by means various hydrogeochemical techniques (e.g. Custodio, 1997; Vengosh et al., 1999). As opposed to simple salinity measurements, sophisticated techniques that yield clear information about the origin of salinity are often costly and usually only yield snap-shots in time and space. Combining information on the origins of salinity from such investigations with numerical simulations is therefore a promising strategy to investigate the interplay between different salinisation processes.

Vulnerability and risk assessments are becoming a standard approach in groundwater management when dealing with water quality and contamination issues. The most commonly used vulnerability mapping procedures are based on empirical point rating systems that bring together key factors. It has been found that the vulnerability and contamination risk can rarely be predicted with these key factors which is why there is a growing need for physically based risk and vulnerability assessments (Gogu & Dassargues 2000).

A simulation-based salinisation risk assessment methodology is proposed that allows mapping of areas at risk with respect to different salinisation processes. A numerical groundwater simulation procedure is presented which allows decomposition of a measured bulk salinity distribution into components derived from different salinisation processes. In a first step, a numerical groundwater flow and transport model accounting for all identified salinisation processes is calibrated, using the observed salinity distribution. Then, the observed salinity distribution is replaced by the simulated salinity distribution. By adapting the boundary conditions of the model each salinisation process can then be simulated separately. The simulation results are then used to obtain risk index distributions for each salinisation process, reflecting the spatial variation of possible future relative salinity increase with respect to a given process. In the last step, these risk index distributions are then overlain with defined threshold salinities, revealing areas requiring remediation or conservation measures.

The different steps of the salinisation risk mapping procedure are illustrated on a real aquifer system in Southern Cyprus (Akrotiri), where three major salinisation processes are superimposed (seawater intrusion, evaporation and irrigation-induced salinisation), revealing the possible usefulness in groundwater management decision-making process.

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11.7

The Road to Climate Stabilization: Insights from Carbon Cycle - Climate Models

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The UN Framework Convention on Climate Change calls for "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous interference with the climate system". Future climate stabilization will ultimately require stabilization of atmospheric greenhouse gas concentrations and substantial reductions in anthropogenic greenhouse gas emissions compared to present-day emissions. For CO2, the most important anthropogenic greenhouse gas, the amount of carbon emissions that can be released in order to reach a given CO2 stabilization target (i.e. the "allowable" emissions) will depend on how much of the extra CO2 will be removed from the atmosphere by natural CO2 sinks, mainly the oceans and the land biosphere. Ocean and land biosphere currently remove about 50% of the man-made annual CO2 emissions, and thereby substantially helped mitigating the rise in atmospheric CO2 over the last 200 years. Unfortunately, these natural sinks can not be expected to continue forever. Observational evidence and evidence from coupled climate - carbon cycle models suggest that increasing CO2 levels and climate change will likely decrease the ability of the natural system to take up extra CO2 in the future, leaving larger fractions of the anthropogenic CO2 emissions in the atmosphere, and therefore further raising CO2 levels and accelerating climate change. The reductions in global carbon emissions for a given CO2 stabilization target thus needs to be substantially larger if carbon cycle - climate feedbacks are accounted for. In my presentation, I will (1) quantify the impact of carbon cycle - climate feedbacks on the projected "allowable" emission for CO2/Climate stabilization in the current generation of carbon cycle - climate models and (2) highlight uncertainties in the model representation of carbon cycle processes resulting in substantial spread in both the model response to increasing atmospheric CO2 and climate change.

11.8

Seasonal climate predictions: From theory to end-user applications

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Seasonal forecasting, i.e. the provision of information on the expected tendency of the climate of the coming months and seasons, has become a well-established technique with applications world-wide. Indeed, seasonal forecasts are successfully applied for climate-risk management in many climate-sensitive sectors such as energy, health, water management, agriculture and the insurance industry.

Since 2005, MeteoSwiss issues seasonal forecasts on an operational basis, both for the public and for private customers. However, due to the wide range of uncertainties involved, seasonal climate predictions are inherently probabilistic, requiring significant efforts both from forecast providers and users. While the former need to make sure that the uncertainties are appropriately quantified and communicated, it is the task of the latter to make optimum use the uncertainty information provided. For applications in central Europe, these challenges are further aggravated by the fact that the prediction skill is very low in this region, i.e. that the predictable climate signal is often very weak in comparison to the unpredictable noise.

In this presentation, an overview of our experience gained in the field of seasonal forecasting will be presented. In particular, the following issues will be discussed and illustrated with examples: (i) How can the uncertainty range of climate predictions be accurately determined? (ii) How can the uncertainties and the prediction skill of seasonal forecasts be accurately communicated to the user community? And finally: (iii) How can seasonal forecasts be successfully applied, even if the prediction skill is very low?