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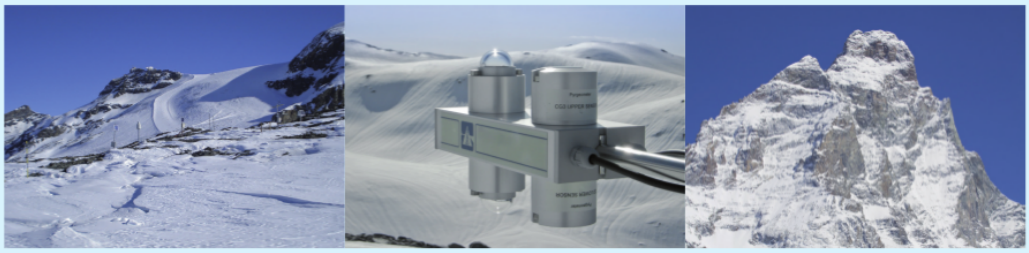
MOUNTAINS UNDER WATCH 2013

Observing climate change effects in the Alps



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Book of Abstracts

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Part I
Plenary solicited

Data sharing and collaborative scientific activities: the example of FLUXNET

Papale D.

Abstract Today there is an enormous quantity of data acquired by monitoring stations, during field and laboratory experiments, produce in modeling activities and coming from satellite sensors. These data are too often kept internally to the research groups that leaded their production or shared only between small groups of institutes or inside specific projects. This attitude precludes the possibility to enlarge the scientific community that make use of our data, reducing not only the scientific progress but also our visibility and the visibility of our measurements and their usefulness, crucial to ensure funding for the data acquisition activities. In the last 15 years the network of sites measuring in continuous carbon, water and energy fluxes between ecosystems and atmosphere using the eddy covariance technique grew continuously, reaching today more than 500 sites in the world. These sites are often organized in regional networks, often at continental level, and funded by an heterogeneous number of sources, from research project to agencies, single universities or research centers and monitoring institutes. Although the eddy covariance technique and all the ancillary measurements needed to interpret the data are quite expensive, both in terms of investment and processing/collection, more and more sites are involved in the global "network of networks" called FLUXNET. FLUXNET is a self-organized coordination that has the aim to collect and standardize the eddy covariance fluxes measurements, share data inside and outside the eddy community and organize common synthesis activities. In 2007 the first really global synthesis activity has been organized on the basis of a standardized database with measurements from about 300 sites from all the continents and 1000 years of data. This heterogeneous group of scientists (with different background, culture, data sharing principles and ideas etc.) has been able to agree on an equilibrated data access and data use policy, open enough to give access to external communities without many problems, that made possible the preparation of more than 50 papers that gave a tremendous visibility to FLUXNET and the eddy covariance technique. In this presentation the strategy followed to achieve this result and the main examples of results obtained by the data sharing activity, otherwise impossible to achieve, will be presented with the aim to stimulate an open discussion about the topic and possible problems.

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Part II
Biosphere oral

Changing winters and alpine plants

Rixen C.

Abstract Alpine shrub-and grasslands are shaped by extreme climatic conditions such as a long-lasting snow cover and a short vegetation period. Such ecosystems are expected to be highly sensitive to global environmental change. Prolonged growing seasons and shifts in temperature and precipitation are likely to affect plant phenology and growth. In this talk I will show examples how snow cover can influence vegetation patterns. I will elaborate on the question if less snow and a shorter snow cover will enhance plant growth. Less snow, albeit potentially prolonging the growing season, may increase the risk of freezing damage and summer drought. Regarding climate change, I will give an overview on what we can learn from snow manipulation experiments, from sensor networks, from world-wide long-term monitoring and from very-long-term monitoring.

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Effects of advanced snowmelt and increased temperatures on flowering phenology of three snowbed species

Petraglia A., Carbognani M., and Tomaselli M.

Abstract Snow cover and temperatures are among the most important factors controlling microclimate and plant growing conditions for alpine ecosystems. Among the expected climate changes, alpine regions will experience warmer temperatures and a different snowfall regime (more rain but less snow), leading to a thinner snow cover which will melt earlier. Thus, the most realistic scenario for probably most alpine regions is the combination of advanced snowmelt and spring and summer warming. As most species start to show signs of phenological development after snowmelt, a declining of the duration of snow cover could lead to change the timing of phenological phases for plant species colonizing habitats with a very short snow-free period. However, as phenological phases are closely linked to temperature too, these two factors should be taken into account to assess the response patterns of alpine species. Several studies showed the effects of an increased summer temperature on the timing of phenological phase for alpine plants, but few studies tested the combined effect of these two environmental factors. In a field experiment performed in an extreme alpine tundra habitat (i.e. snowbeds) we removed manually the snow (i.e. shovelling it away), to simulate an advanced snowmelt, and used OTCs to increase summer temperature. We selected two snowbed species (*Cardamine alpina* and *Veronica alpina*) with relatively different phenological timing and an alpine generalist frequent within snowbeds (*Leucanthemopsis alpina*) to test how these species could be affected by an advanced snowmelt and by an advanced snowmelt coupled with higher summer temperature. The snow removal treatment did not affect significantly the date of achieving of all the phenological phases of the three species studied in comparison with the control. The snow removal + high temperature treatment, on the contrary caused significantly earlier phenological timings of the species studied. The phenological development was significantly extended by the snow removal treatment for the species studied. The same behaviour was registered in the snow removal + higher temperatures treatment with the exception of the last phenophase of *Cardamine alpina*. The species studied did not show any difference in the time needed to achieve the last phenological phase in the control plots; under the two experimental treatments, on the contrary, *Cardamine alpina* showed a significantly faster phenological timing than *Veronica alpina*. These results are not strictly in line with other experiments that showed that species that starts their phenological development early after the snowmelt showed the strongest response. Our study seems to suggest that under the predicted climate change, temperature will be the most important factor in the control of the phenological timing. The snow removal treatment did not changed significantly the phenological timing of the species studied.

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Effects of drought and warming on the water balance of mountain grassland ecosystems

Leitinger G., Obojes N., Niedrist G., Tasser E., and Tappeiner U.

Abstract Climate change induced temperature increase will significantly reduce winter snow cover and increase the probability of extreme drought events in summer. Vulnerability of alpine grassland sites might be different concerning climatic characteristics and main agricultural land management. By using Smart Field Lysimeters (SFL, © UMS, Munich) in sheltering experiments, we investigated the effects of two drought periods (4-6 weeks in both spring and summer) on evapotranspiration and total biomass production for two climatically different study sites in the Alps. By comparing results from a mountain grassland site at 1500 m a.s.l. in an inner-alpine dry area (Matsch Valley, South Tyrol, Italy) and from an alpine grassland site at 2000 m a.s.l. in a humid alpine valley (LTER-site Kaserstattalm, Stubai Valley, North Tyrol, Austria), a clear reduction of biomass and evapotranspiration in dry, sheltered lysimeters was found. However, on abandoned grassland sites, decrease of evapotranspiration and loss of biomass production was lower than on managed grassland sites. Regarding recovery at rewetting periods, at both study sites capacity of vegetation for recovery after drought was high. Although soil water content after short periods of rewetting of former sheltered and former unsheltered soils was comparable, no relevant deep seepage was registered in former sheltered lysimeters. Preliminary results indicate that impacts of drought events and accompanying reduction of plant available water for evapotranspiration and total biomass production is triggered by land management.

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Standardised monitoring of alpine plant diversity: GLORIA's methodological approaches and observed changes on European mountain summits

Pauli H., Gottfried M., Klettner C., Laimer S., and Grabherr G.

Abstract High mountain ecosystems above the treeline are expected to respond sensitively to climate warming, because they are determined by low temperature conditions. Suitable habitats of many high mountain plant species could be drastically reduced or disappear until the end of the 21st century (Gottfried et al. 1999; Engler et al. 2011). Despite the great terrain heterogeneity in mountains areas and a resulting variation in microclimatic patterns, which may buffer against warming threats (Scherrer & Körner 2010), alpine species could experience serious declines, especially where the vertical extension of mountains is low and where climate warming is accompanied by deceased precipitation (McCain & Colwell 2011). Even if alpine plants would not disappear immediately from increasingly unsuitable habitats, a growing 'extinction debt' will have to be paid later on after some decades, if plants are unable to adapt to changing conditions (Dullinger et al. 2012). How severe climate change-induced biodiversity losses will be, can only be documented by long-term in situ monitoring. This was the main motivation to starting the international network of long-term observation sites GLORIA (www.gloria.ac.at) at the turn of the century (Grabherr et al. 2000). Cold high mountain environments above the treeline are suitable for such an endeavour as being the only terrestrial biome with a global distribution from tropical to polar latitudes (Körner 2003; Grabherr et al. 2010). Comparability, simplicity and economy were the main considerations in designing the Multi-Summit approach, GLORIA's standard recording design and method, to make it workable even under expedition conditions in remote mountain regions (Pauli et al. 2004). By 2013, the site network has expanded to 115 active study regions, distributed over six continents.Recent resurveys at European GLORIA sites yielded striking results with respect to the fairly short time-span under observation: Alpine vegetation experienced a transformation towards more thermophilous plant communities across Europe's mountain summits. More warm-demanding species were immigrating or were increasing in cover, while species which mostly dwell at higher elevations were declining (Gottfried et al. 2012). Second, species numbers were increasing on temperate and boreal summits, such as previously observed in the Alps and in Scandinavia, whereas species richness was stagnating or decreasing on Mediterranean summits (Pauli et al. 2012). The decline in Europe's south is likely to be caused by climate warming effects, combined with a reduced water availability and is particularly worrying, because of the large proportion of narrowly distributed endemic species in these mountains.

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Local adaptation in two Apennine plant species along a narrow altitudinal gradient

Gratani L., Catoni R., Pirone G., Frattaroli A.R., and Varone L.

Abstract A recent bioclimatic envelope study on 1,350 European plants underlines that species from mountain areas might be disproportionably sensitive to climate change, and southern mountain regions are predicted to experience particularly severe species losses (Lenoir et al. 2010 J. Veg. Sci. 21: 949964). We analysed morphological and physiological traits of *Crepys pygmaea* L. subsp. *pygmaea* and *Isatis apennina* Ten. ex *Grande* growing at different altitudes (2,250, 2,310 and 2,350 m a.s.l.) on the Gran Sasso Massif (Italy) and included in the Red List of the Italian Flora as low risk (LR) species for Abruzzo. At population level our results underline that leaf mass area (LMA) is 14% lower for *C. pygmaea* and *I. apennina* populations growing at the highest altitude than those at the lowest one. Leaf tissue density (LTD) has the same LMA trend decreasing by 22% from the highest to the lowest altitude. LMA can be considered an index of the construction cost of the protective structures per unit of leaf area and is associated to carbon assimilation. Thus, the lowest LMA and LTD at the highest altitude may be justified by the highest photosynthetic rates (PN) than those at the lowest altitude as a result of a low internal resistance to CO_2 transfer. Both C. pygmaea and I. apennina have the highest PN in July, when leaves are fully expanded, decreasing by 17% in *C. pygmaea* and 30% in *I. apennina*, respectively, in August during flowering, and by 50 and 38%, respectively, in September at the beginning of the senescence phase. One of the predicted consequences of global change is the movement of plants to higher elevations and latitudes as the climate to which they are adapted is displaced (Jump and Peuelas, 2005 Ecol. Lett. 8: 1010-1020). Phenotypic plasticity is likely to play a crucial role in allowing plant species to persist in their environments (Vitasse et al., 2010 Funct. Ecol. 24: 1211-1218) buffering the effects of climatic change (Theurillat and Guisan, 2001 Climatic Change 50: 77-109). *C. pygmaea* and *I. apennina* are able to respond to environmental changes along the narrow altitudinal gradient through a high morphological (PIm) and physiological (PIp) phenotypic plasticity index. In particular, PIm and PIp are 0.35 and 0.50, respectively in *C. pygmaea* and 0.30 and 0.38, respectively in *I. apennina*. The high phenotypic plasticity index underlines the potential of the two wild populations at the lowest altitude to move up in response to the hypothesised air temperature increase. Global warming could drive *C. pygmaea* and *I. apennina* to higher altitudes in the Gran Sasso Massif, *C. pygmaea* being favored by the highest PIm and PIp. Considering that mountain ecosystems are centers of endemism and important areas for biodiversity conservation (Nogués-Bravo et al., 2007 Global Environ. Chang. 17: 420-428) knowledge of life history traits of threatened species is important to assess their response to global warming, in particular, when wild populations number and size are small (Gratani et al., 2011 Photosynthetica 49: 65-74).

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Biogeochemical feedback between plants and soil microbes explain shrub encroachment in peatlands in response to climate change

Bragazza L., Buttler A., and Bardgett R.

Abstract Climate warming has been demonstrated to promote shrub encroachment in peatlands, but the underlying biogeochemical mechanisms are not yet clear. Here, we investigated the interactions between soil microbes and vascular plants in four Swiss peatlands along an altitudinal gradient (from about 600 m to 1900 m asl) that simulated a natural gradient of soil temperature and shrub encroachment. Peat microbial biomass carbon (C) and nitrogen (N), soil enzymatic activity, organic and inorganic exchangeable N, microbial community structure, as well as dissolved organic C (DOC) concentration in pore water were periodically assessed during the plant growing season. We found a significant difference in the seasonal trend of C:N ratio in microbial biomass in relation to both altitude and the abundance of vascular plants. In particular, we observed that at lower altitude, where shrub cover was higher, soil microbes immobilized less N, suggesting a higher competitive ability of plants for N acquisition. We also observed a decreasing concentration of polyphenol in pore water with increasing altitude. This trend was reflected in a lower amount of exchangeable organic N in peat. We hypothesize that ericaceous species can gain a nutritional advantage by accessing organic N through the mediation of their mycorrhizal symbiosis. A positive relationship between vascular plant abundance and DOC concentration in pore-water was also found. Spectroscopic measurement of DOC showed a higher release of labile C compounds at lower altitude, which points to a primary role of root exudates in affecting DOC quantity and quality. The stoichiometry of the main hydrolytic enzymes degrading C and N compounds differed along the altitudinal gradient in relation to the relative dominance of fungi and bacteria in the soil microbial community. Our data suggest the presence of important aboveground-belowground feedback for nutrient acquisition which can explain why and how shrub encroachment can be promoted in peatlands in response to climate warming. We suggest that an increase of vascular plant cover can potentially destabilize the C-sinking capacity of peatlands due to: 1) a negative feedback on the productivity of peat-forming mosses, and 2) by priming the decomposition of old organic matter.

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Mountains under watch: Many eyes see more!

Tappeiner U., Niedrist G., Bertoldi G., Della Chiesa S., Obojes N., Engel M., Bottarin R., and Tasser E.

Abstract Global Change phenomena as land use change and temperature increase are well proved to have significant impacts on biodiversity, water budget and ecosystem functioning of mountain regions. However, many studies act as isolated investigations within a complex, multidimensional space and are thus limited in their significance. Hence, it is rather essential to combine a broad set of ecological investigation methods in order to obtain an integrated comprehension of the highly interlinked ecological processes in such vulnerable ecosystems. By using the example of the 100 km^2 Matscher Valley, we demonstrate an interdisciplinary approach in which ecological measurements, manipulative experiments and modeling activities are strongly linked together in order to quantify land use and climatic change impacts on an inner-alpine catchment. All activities are aimed to cover both the spatial dimension from plot to landscape scale as well as the temporal component considering past, present and future. GIS-based landscape analysis of historical socioeconomic data and ancient land-use map are used to understand development and succession of land cover for the past 150 years. For assessing the current status, fundamental ecological information as biodiversity, water and energy fluxes are being collected at high time resolution in the prevailing ecosystems like grassland (through automatic lysimeters and eddy covariance measurements), forests (sapflow measurements) or freshwater (isotopes and macrobenthos). They get complemented with spatially distributed information on current vegetation and land cover patterns, soil properties and microclimate data. Manipulative experiments (space for time translocations of grassland mesocosms along elevation gradients and rainout-sheltering) as well as modeling activities (hydrological and vegetation modeling) are used to simulate possible future scenarios. Results after a 3 years starting phase prove the usefulness and the particularly high potential of an integrated approach: the plot scale measurements of vegetation and water budget parameters are used for extrapolation on landscape level as well as validation data for modeling. Furthermore, they are combined with spatially distributed soil moisture data, runoff measurements and isotope analysis in order to quantify the entire water cycle and to interpret freshwater diversity fluxes. Results from the manipulative experiments and evapotranspiration measurements along altitudinal transects compared with modeled scenarios provide valuable insights into possible future climate impacts. Considering the numerous possibilities of interconnections found and the resulting potentiation of results we emphasize the importance of strong linkages between different scientific disciplines within a defined catchment. For the future, a longterm-continuation of the activities following LTER standards is targeted in order to obtain a deepened understanding and more holistic perspective of the ongoing changes in mountain areas.

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Ozone removal by a high elevation larch forest ecosystem in the Adamello Natural Park

Gerosa G., Finco A., and Negri A.

Abstract Among the different ecosystem services offered by mountain forests, the air pollutants removal by forests is hard to quantify, even though of great interest for the anthroposphere. Under the EU project of the Alpine Space named MANFRED (Management strategies to adapt Alpine Space Forest to climate change risk) the assessment of the ozone removal capability by a high elevation mountain forest has been challenged. Ozone has been chosen because it is the air pollutant of major concern during the summer semester (while per particular matter is only of winter concern). For this sake, two years of ozone flux measurements were made over a larch forest ecosystem (a secondary laricetum with grass as understory vegetation) in the Italian Alps at 1750 m a.s.l., just at the timberline of the Camonica Valley. The measurements were taken at the top of a 30 m tall tower by means of the eddy covariance technique from June to September each year. Concurrent measurements of water and heat fluxes, as well as of common meteorological parameters, have been taken too. Measured ozone fluxes have been partitioned into a stomatal and a non-stomatal parts by means of an energy budget method based on the derivation of the bulk stomatal conductance from the water fluxes through the inversion of the well known Penman-Monteith equation for evaporation. Results revealed unexpectedly high ozone fluxes, but the stomatal component - the only toxic one for the larch trees - was less then 25% of the total ozone received by the ecosystem. The main part of ozone was removed by non-stomatal deposition, i.e. ozone removal by cuticles and non-transpiring plant surfaces, by soil and by gas phase reactions with volatile organic compound released by plants in the trunk space. Despite the great amount of ozone removed by the forest in a summer season (about 25 Kg / ha), only a 2-3% of biomass reduction should be expected for the trees according to the dose-effect relationship issued by UN/ECE. To get an idea, when ozone concentration is 90 ppb (the warning concentration for human in the Italian regulation) the amount of ozone within a volume of air of 3 m of thickness and 1 ha of base is 5 grams. Thus, plants offered a significant ecosystem service to the anthroposphere with a relatively small impact on their vitality.

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From atmosphere to soil and back: The fate of carbon in a subalpine grassland under N- and O_3-deposition (Seven years Alp Flix Experiment)

Volk M., Blanke V., Fuhrer J., Lehmann M., Enderle J., and Bassin S.

Abstract Air pollution effects still threaten to alter natural and semi natural vegetation even in remote areas. The magnitude of ecosystem responses largely depends on interactions between pollutants and local environmental conditions.In a seven year study we tested the effects of increased N and O_3 deposition on subalpine grassland productivity and the interacting effects of climate on the response to the above pollutants. The fully factorial field experiment had five levels of N deposition (0, 5, 10, 20 und 50 kg ha^{-1} yr^{-1}) and three levels of [O_3] (ambient, amb.x1.4 and amb.x1.7) in a free air fumigation system. We hypothesized that aboveground net primary production (ANPP) is higher under N deposition and lower under O_3 deposition, with favorable climatic conditions increasing the magnitude of the response. The assumed impact of pollutants and climate on ANPP was expected to feed back on ecosystem C budget. A combination of quantitative information (plant yield, soil C-pool sizes, net CO_2-fluxes) and qualitative information (δ13C values) was gathered to help to improve a mechanistic understanding of the C-fluxes. We found that climatic conditions and management change have led to increased productivity and increased soil C content in the Alp Flix grassland. The N-treatment increased productivity, while O_3-treatment did not affect plant growth. Net ecosystem exchange measurements, covering two complete years of contrasting climate, detected extreme short-term effects on the CO_2 C-balance, with antagonistic climate effects on ecosystem respiration and gross primary productivity. Carbon isotope analysis revealed that O_3 and N treatment made soil air, root material and bulk soil δ13C less negative ("older"), but independent of the pollutant deposition treatment bulk soil became more negative ("younger") over the years. In summary, single parameters of climate and atmospheric pollution are not sufficient to predict ANPP responses, and ANPP responses are not sufficient proxies for the ecosystem C-budget. Instead, the interaction of multiple parameters needs to be evaluated.

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Net ecosystem production in a Little Ice Age moraine: the role of plants functional diversity

Varolo E., Zanotelli D., Montagnani L., Tagliavini M., and Zerbe S.

Abstract Current glacier retreat and consequent formation of new habitats is a unique opportunity to understand the ecological factors influencing the dynamics of carbon sequestration in soil, and the role of plant functional diversity. Glacier foreland represents an environmentally extreme habitat where plant communities adopt different life strategies to survive. It is still unclear how different plant physiological traits interact with environmental constraints to determine the pattern of net ecosystem production after glacier melting. We measured the carbon dioxide (CO_2) exchanged with the atmosphere by two vegetation communities on a Little Ice Age moraine at 2,400 m a.s.l. in the Mazia Valley, in the Central Alps, South Tyrol/Italy. The first community was a typical C3 grassland, dominated by *Festuca halleri*, characterized by large annual supply of fresh biomass to the detritus cycle. The second was a community of rocky soils characterized by the succulent chamaephyte *Sempervivum montanum*, species which performs a Crassulacean acid metabolism (CAM).We measured the net ecosystem exchange (NEE) and ecosystem respiration (Reco) in August 2012, using a multiplexed system (Li 8100-105, LiCor, NE, USA) composed by 6 automated closed-dynamic chambers. We selected a total of 5 replicates per plant community, moving the chambers position every two days. At the end of the measurements, we collected a sample of biomass and soil for each replicate, and we measured total carbon and nitrogen content in vegetation and soil, with the FlashEA 1112 Elemental Analyzer, Thermo Fisher Scientific, Germany. To compare plant behaviour, we calculated the parameters Q_{10} and R_{10} following the van t' Hoff equation. The two vegetation communities showed contrasting daily NEE patterns. Relatively large sink and source of CO_2 were observed in the C3 grassland dominated by F. halleri, with an average peak of NEE just before midday of -5.2 $\pm$ 2.3 μmol CO_2 m^{-2} s^{-1}. The plant community dominated by *S. montanum* showed its CAM behavior during the day with average maximal NEE early in the morning (-2.2 $\pm$ 0.5 μmol CO_2 m^{-2} s^{-1}), a cessation of photosynthesis at midday, and a small CO_2 release at night. Respiration was found in both communities strongly depending on temperature, with an apparent Q_{10} in both cases of 2.1 $\pm$ 0.5. On the contrary, R_{10} was different between the two plant types, possibly reflecting the occurrence of night photosynthesis in the CAM species: F. halleri showed an R_{10} = 2.3 $\pm$ 0.4 while *S. montanum* had a R_{10} = 1.2 $\pm$ 0.2. In both vegetation types, respiration was also tightly related with nitrogen content in the biomass. Remarkably, the CAM-dominated plots had a higher overall carbon content than C3-dominated (2.06 $\pm$ 0.23 and 1.76 $\pm$ 0.12 kg C m^{-2}, respectively), indicating that a similar or higher net biome productivity can be reached through the more conservative strategy of the *S. montanum* associated with a lower net ecosystem production.

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Variation in thickness of growth rings and their relationship to climate change in a population of Abies religiosa in "Zamorano" volcano, Queretaro, Mexico.

Cambrón-Sandoval V.H., Suzán-Azpiri H., García-Rubio O., and Luna-Soria H.

Abstract An isolated population of *Abies religiosa* inhabiting "El Zamorano" volcano, México (3246 m) was surveyed in order to determinate growth performance in response to clime changes in the area for the last 25 years. We conducted surveys every 100 m in an altitude gradient (2880 to 3200 m), estimating population structure by Whitaker quadrats (2050m) including recruitment estimation. Four trees per plot were selected for dendrochronological analysis obtaining two cores per individual. Tree ring series were analyzed and compared with climatological data from nearby weather stations. *A. religiosa* habitat range occurs between 2780 and 3272m, and inhabit the altitudinal arboreal vegetation limit. Their population exhibited low recruitment in the last decade; the high density of recruits is restricted to 3100 m. It was possible to observe an altitudinal pattern of growth ring thickness; the thicker rings estimated at the lower limit of the range (5.12 microns) and thinner rings at the upper limit (3.71 microns) with significant differences between sites ($P \leq 0.001$). Climatic series suggested an increase in variation between maximum and minimum temperatures, since 1995, with maximum temperatures of 31 °C and minimum of 4 °C. Survey sites and thickness of growth rings have a negative correlation (r=-0.56, P=0.0012). Results suggest an altitudinal migration of *Abies religiosa* as a result of an increasing temperature since 1995, with lower seedling recruitment in the lower site. Conservation actions must include collection of germplasm and promote reforestation with an "assisted migration" protocol at high mountain ranges, coupling provenances to future climates.

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Characterizing the uncertainty of phenological models with a model-data fusion approach: a case study on the Alps

Migliavacca M., Delestrade A., Yoccoz N.G., Cremonese E., Galvagno M., Morra di Cella U., Carenzo M., Bordoy R., and Richardson A.D.

Abstract Phenology, the timing of recurring life cycle events, controls numerous land surface feedbacks of the climate systems through the regulation of exchanges of carbon, water and energy between the biosphere and the atmosphere. Land surface models, however, are known to be affected by systematic errors in the simulation of spring phenology, which potentially could propagate to uncertainty in modeled responses to future climate change.In this contribution, we analyzed the Phenoclim phenology records to investigate and optimize phenological models for different tree species, and characterize the sources of uncertainty in phenological forecasts.Using a model-data fusion approach, we combined information from about 80 site-years of phenological records of 5 woody species with 12 phenological models of different complexity to predict leaf bud-burst.The evaluation of different phenological models indicated support for spring warming models with photoperiod limitations and, though to a lesser extent, to chilling models based on the alternating model structure.We assessed three different sources of uncertainty in phenological forecasts: parameter uncertainty, model uncertainty, and driver uncertainty. Finally, by using downscaled bias-corrected climate projections at 3 different stations, based on 3 different climate models (RegCM3, REMO and ECHAM5), we projected the budburst up to 2050 using the emission scenario A1B. Finally, we analyzed how the three sources of uncertainty propagated into the future. The uncertainties we have quantified will affect the description of the seasonality of processes and in particular the simulation of carbon uptake by forest ecosystems.

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Modelling the effect of changing snow cover regimes on alpine plant species distribution and diversity

Randin C.F., Dedieu J-P., Zappa M., Williams M.W., and Dullinger S.

Abstract Improving our understanding of climate, snowpack and alpine plant distribution interactions at fine spatial resolutions (i.e. meters) is an enduring goal of alpine plant ecology. Quantifying these interactions is required to predict future changes in alpine plant species diversity and distribution given anticipated temperature and precipitation changes.Earlier snow melt and an elongation and/or shift of the snow-free period - as a result of increasing summer temperatures observed since the 1990's in some regions of the Alps and the Rockies - might hence severely alter the spatial pattern of suitable habitats of highly specialized plants of snowbed communities. In addition, dominant species of other community types (e.g. dry and wet meadows) could also expand, decline, or shift in distribution.In a first study, we assessed past fine-scale spatio-temporal changes of 80 plant species located in a 350x500 m study area at 3500 m elevation on Niwot Ridge, in the alpine tundra of the Colorado Rocky Mountains. The dataset is composed of 81 permanent plots covering 19 years (records in 1989,1990,1995,1997,2006 and 2008). Partial triadic analysis showed a shift of species structure in vegetation plots from 1989 to 2006. Correspondence analysis of 1989 and 2006 inventories revealed an important species composition shift in plots located at the interface between wet meadow and snowbed communities. In addition, these two communities changed the most during this time period. Analyses of climate data suggest that these community changes are associated with warmer temperatures during the melting period in late spring and summer.In a second study, we used a spatially-explicit and physically-based snow distribution model (Snowmodel) under the A2 IPCC scenario for the end of the 21st century (2081-2100) to predict the combined effect of changing climate and snow cover on alpine plant species in the Alps. We used four different mountain ranges in Austria (Mt. Hochschwab, Mt. Rax, Mt. Schneealpe and Mt. Schneeberg; overall area of about 150 km^2) as a model system and species distribution models (SDMs) to assess potential modification in the area and connectivity of the habitats of a set of 60 alpine plants, in particular those confined to sites with long-lasting snow cover (snowbeds). An ENSEMBLE of SDMs techniques was used to provide the spatial projections of species distribution under current and future climate conditions. The main parameters analyzed were the timing and duration of the snow-free period. This allowed for tracking spatial patterns of snowbed habitats or analysing whether emerging gaps or corridors could prohibit, respectively facilitate, adaptive migration of plants in the future. We showed that ridge species might become rapidly exposed to the effect of climate change (2050's). Impacts on snowbed species may be buffered (2050's) but then could become stronger at the end of the century. Nonspecialized species may be less affected than specialized species in terms of persistence and connectivity of future suitable areas.Taken together, these two studies highlight the importance of the inclusion snow-based

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predictors in assessments and predictions of changes in alpine plant species distribution compared to studies based on climate only.

As simple as possible, but not simpler than that: An efficient soil water content model for broad ecological applications

Hammerle A., Calanca P., Themessl M., Gobiet A., and Wohlfahrt G.

Abstract Available soil water is a major constraint for numerous ecosystem functions and is likely to be considerably affected by projected shifts in temperature and precipitation. Quantifying likely future changes in soil water content is therefore essential for assessing impacts of climate change on ecosystem functions. Soil moisture models of various complexity levels can be used to do so. However, in view of the low spatial resolution and temporal aggregation of climate change scenarios, as well as of the lack of detailed information for calibration, it is questionable whether complex models can offer advantages as compared to more simple computational schemes.Here we present a modeling study addressing changes in future soil water content of temperate grasslands in the Austrian Alps based on the application of "SoilBucket", a soil moisture model characterized by an efficient structure and minimal requirements regarding meteorological inputs (solar radiation, precipitation and air temperature). The model simulates the water budget of a single bucket as a function of infiltration, evapotranspiration and outflow. All these variables are derived from the inputs mentioned above.In our study, the model was calibrated using a Bayesian inversion scheme. The Bayesian method uses parameter probability distributions (pdf) specifying the range in which the real parameter value is located. Once data are collected Bayes' theorem is used to update prior pdfs of the model parameters including the information derived from measurements and the model application resulting in the posterior pdfs for the model parameters. These distributions (posterior parameter pdf and the residual pdf) allow for a reliable estimation of model parameter- and predictive-uncertainties. These uncertainties do account for measurement, model input and model structural errors in a lumped manner.Soil moisture and meteorological data collected at more than ten sites in the Eastern Alps were used for the calibration. Calibrated model runs show a very good performance at the majority of investigated sites. RMSE ranges from 0.02 up to 0.06 (m^3 m^{-3}) for all sites and R^2 is higher than 0.7 for the majority of investigated sites.As an example of scenario development, SoilBucket was used to calculate scenarios of soil water availability reflecting changes in daily temperature and precipitation as specified by regional climate scenarios developed for years 1961-2050 with 5 different climate models (CNRMRM, AITCCLM, KNMIRACMO, DMIHIRHAM, ETHZCLM).

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Modelling soil moisture dynamic of a mountain catchment using multi-source, scale-dependent observations

Bertoldi G., Notarnicola C., Pasolli L., Della Chiesa S., Niedrist G., and Tappeiner U.

Abstract Soil moisture is a key factor for numerous processes, including runoff generation, groundwater recharge, evapotranspiration, soil respiration, and biological productivity. Understanding the controls on the spatial and temporal variability of soil moisture in mountain catchment is an essential step towards improving predictive models of catchment processes and ecosystem services. The interacting influences of precipitation, soil properties, vegetation, and topography on soil moisture have been extensively investigated (e.g. Williams et al, 2009). However, due to the extreme variability in topographic, soil and vegetation proprieties of mountain catchments, obtaining reliable predictions of soil moisture spatial and temporal patterns is still challenging. Physically-based hydrological models, that integrate a large amount of parameters, often face the problem of over parameterization and equi-finality. On the same time, field campaigns are labour intensive and limited to too small areas, while soil moisture retrieval from remotely sensed data in alpine context is promising, but surface heterogeneity and overpassing frequency issues still limit its effectiveness. For this reason, an integration of hydrological models, ground surveys, and new remote-sensing products is essential to improve soil moisture estimation.In this contribution we analyze the spatial and temporal dynamics of surface soil moisture (0 - 5 cm depth) of alpine meadows and pastures in the Mazia Valley (South Tyrol Italy), at different spatial scales and with different techniques: (I) a network of fixed stations; (II) field campaigns with mobile ground sensors; (III) soil moisture retrieval from 20-m resolution polarimetric RADARSAT2 SAR images (Pasolli et al., 2011; 2012); (IV) numerical simulation using the GEOtop hydrological model (Rigon et al., 2006). The strength and weaknesses and the consistency of the different estimation techniques is evaluated and, in particular, the GEOtop model is used to understand the physical reasons of the observed patterns in RADARSAT2 products. Results show that the model, once calibrated for the different soil types, accurately predicts the observed temporal dynamic in stations location. However, RADARSAT2 soil moisture estimation corresponds well with the spatial ground surveys, but shows different patterns with respect to the model, especially for irrigated meadows. Differences are likely due to the strong sensitivity of the SAR signal to surface roughness and vegetation density and to the difficulties to know irrigation amount for model input. Therefore, results suggest that all the considered techniques have limited ability to detect “true” soil moisture dynamics, and that data model integration is the only effective approach to improve surface soil moisture estimation in alpine catchments.

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Climate change and range shifts in plants of the European Alps - what do models tell us?

Zimmermann N.E., Normand S., Psomas A., Schmatz D., Hanewinkel M., and Pearman P.B.

Abstract Plants and animals have started to respond to climate change at a range of scales. Significant range changes can be expected for European plants in response to projected climate change at the scale of the European Alps and across Europe. These range shifts will likely be associated with considerable turnover, which will alter the vegetation structure at large landscapes, associated with shifts in biomes and functional vegetation structure that accompany these changes. While we have a somewhat good knowledge on the degree of expected range shifts, we do not know whether all species will actually be able to cope with the rapid shifts. And for those who likely can make it, we still have considerable uncertainty as to how fast these plant species can migrate to those areas that become suitable in the future.
I will summarize the degree of expected range shifts for tree species across Europe and the European Alps, and for alpine plant species in the European Alps. These results originate from three European projects (FP6 ECOCHANGE, FP7 MOTIVE and FP7 Interreg IIIB MANFRED). All results project partly large range shifts for many European plant species. I will further present two analyses that indicate the difficulties plants face in tracking climate change at the pace it currently occurs. First, the alpine treeline is lagging clearly behind its thermal potential since the 1960ies, and only very slowly responds to increasing summer temperature. The altitudinal lag has accumulated to $>$100m in some regions. Second, the projected discrepancy between the potential range changes of alpine plant species as calculated from a statistical species distribution model and the likely migration of these plants as calculated from dynamic population models that simulate the migration of these species indicate two interesting results. On the one hand, considerable time lags in tracking suitable habitats were observed, and on the other hand, the ranges are adjusted asymmetrically for the front and the rear edge. It seems that the front edge responds more rapidly than the rear edge, which may result in considerable extinction debts once the rear edges start to collapse, which we can expect to happen as an effect of future climatic extremes.

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Heterogeneous climate change effects among Norway spruce populations in Alpine space

Kapeller S. and Schüler S.

Abstract Climate change affects health and productivity of forest ecosystems in Alpine space. Enhancing adaptation of forest ecosystems to prospective climate change is a major challenge in current forest management. A profound understanding of the interrelation between tree growth and climate conditions are necessary for an estimation of potential risks and development of appropriate adaptation measures. Climate change risks are diverse, including prolonged drought periods, accumulations of extreme events and increased damage from pest insects. From a silvicultural point of view, climate change also entails potential positive effects like prolonged vegetation seasons, increases photosynthetic rates and forest net productivity. However, tree populations are often adapted to a wide climatic range and show different reactions to changing climates. In our study we analyzed intraspecific variation in climate response among Norway spruce (Picea abies) populations in the eastern Alpine range. Norway spruce harbors considerable adaptive genetic variation within and among populations. Insights into this intraspecific variation are of paramount importance for climate change adaptation.We used results from a comprehensive Austrian provenance test, comprising tree heights at age 15 from 379 populations planted at 29 test sites across Austria, to calibrate climate response functions for groups of Norway spruce populations. Potential future changes in productivity for climate change conditions as represented by a regionalized A1B scenario were estimated using height at age 15 as a productivity proxy. Climate response functions were calculated for single populations and aggregated clusters of populations from climatically similar origins.Our results hardly revealed any declines in employed proxies for productivity of Norway spruce throughout its current distribution range in Austria. For most parts of Austria an increase of tree heights up to 45 percent can be expected until 2080. However, the impact of a warming climate is different for individual population groups. Especially in areas with low precipitation we recommend to carefully select appropriate seed material to avoid drought damage and productivity losses.

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Droughts weaken, storms kill trees in coniferous forests: analysis of century long time series from seven forests in the French Alps

Csillery K., Bartalucci A-L., Kunstler G., and Courbaud B.

Abstract Over the past two decades, extensive forest death triggered by droughts and extreme climatic conditions has been documented all around the world. Nonetheless, forests response to climate is still not sufficiently well understood to be able to make reliable predictions for the future. One of the least understood demographic processes is mortality. This is because long term observations would be required to estimate this demographic process, which is rare and erratic in nature. At the best, mortality risk has been estimated using a so-called "space for time" substitution, i.e. using climate interpolations to predict individual tree mortality probability on large spatial scales. However, it has been increasingly recognised that, these estimates may lead to large biases in future predictions of forest dynamics and production. Here, we address the temporal aspect of the mortality-climate relationship from, unprecedented, century-long annual mortality and climate time-series. Using forest management data and a Bayesian state-space model, we recovered and characterised, 53 to 90 years long time series of the annual adult tree mortality risk from seven coniferous forests in French Alps. We found that small scale mortality events (less than 5% volume loss) occurred every 1.5 years, on average, while extreme mortality events (more than 5% volume loss) occurred every 60 years, on average, during the twentieth century. Using parallel climate time series, we showed that the presence of storms can lead to up to an average 15 fold increase in the mortality. Nevertheless, there was a great variation between forest stands reflecting the different ecological conditions and expositions to wind. Droughts had a less drastic direct effect on tree mortality: passing from a dry to very dry year (where years are classified to five classes from very dry to very wet) resulted in a 12% increase the mortality. More importantly, droughts had an indirect effect by weakening trees, so they were up to three fold more susceptible to death in a storm. Moreover, the weakening effect of droughts may accumulate over the years. We argue that data sets like ours could be reconstructed in many other countries, where forest management records have been kept, and could make an important contribution to understand the, so far, much neglected temporal aspect of climate on tree mortality.

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The role of mountain forest ecosystems in the overall carbon budget of Italian forests: overview from the National Forest Inventory and results from long term research stations in Apennine and Alpine site

Matteucci G., Callegari G., Veltri A., D'Andrea E., De Cinti B., Montagnani L., Minerbi S., and Pompei E.

Abstract Forest ecosystems play a major role in the global carbon cycle and are important in the cycle of other greenhouse gases (O_3, N_2O, CH_4) and for filtering anthropogenic pollutants. At the same time, forests are exposed to natural (climate, meteorology, site features, etc.) and anthropogenic factors (pollution, nitrogen deposition, management, climate change) that affect their functioning, carbon sequestration potential and that can modify their geographic distribution and biodiversity.In Italy, but also in other Alpine countries, the majority of forest area is located in mountains. Hence, the role of mountain forests in the country ecosystems carbon budget is particularly important. Furthermore, mountain forests are providing a number of other service, such as hydro-geologic protection and are particularly exposed to climate change.Since the 90s' of the last century, research and monitoring of forest ecosystems gained new momentum due to the establishment of experimental sites to investigate their functionality, the drivers of primary productivity and responses to climate and to local and transported pollution with multiple, integrated techniques. A few of these sites are located in mountain forests. The presentation will provide an overview of the role of mountain forest ecosystems in the carbon budget of Italian forests starting from data from the 2005 National Forest Inventory and presenting results from long term research stations in Apennine and Alpine sites. The benefit of the integration of research and monitoring and of the long-term perspective in understanding carbon cycling in forests ecosystems will be also discussed.

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The weight of the past: Effects of land use on ecosystem functions in Sierra Nevada Mountains

Bonet F., Zamora R., Pérez-Luque A.J., and Navarro I.

Abstract Mountains are places traditionally populated by humans. We have been gathering wood, seeds, fiber and other forms of biomass (meat, milk, vegetables, etc.) from mountain ecosystems during millennia. This secular interaction of humans with mountain landscapes has shaped the function and structure of mountain's ecosystems. By the other hand, climate change is expected to provoke important impacts in mountain areas. But it is difficult to distinguish the impacts of climate change from those due to land use in mountain areas. We are presenting a case study showing the impacts of past land use on an important ecological function (oak regeneration below pine plantations). Our work could help to disentangle the differential impacts of climate change and land use changes in mountain.Most of the world's pine plantations were established on previously disturbed sites with an intensive land-use history. This is especially important in mountain areas where pine plantations were considered as tools to avoid soil loss and erosion. Our general hypothesis is that native-forest regeneration within forest plantations depends largely on in situ biological legacies, as a source of propagules. To test this hypothesis, we analyzed the density of native-oak regeneration in 168 pine-plantation plots in Sierra Nevada LTER site in relation to land-use type in 1956, oak-patch proximity and pine tree density. Historical land-use patterns were determined from aerial photography from 1956, and these were compared with inventory data from 2004-05 and additional orthophoto images. Our results indicate that oak-forest regeneration in pine plantations depends largely on land-use legacies, although nearby, well-conserved areas can provide propagules for colonization from outside the plantation, and pine tree density also affected the oak-recruit density. The more intense the land uses in the past, the fewer biological legacies and, therefore, the lower the likelihood of regenerating native forest. That is, oak-recruit density was lower when land use in 1956 was croplands or pasture instead of shrubland or oak formations. Our study shows that land use in the past was more important than propagule-source distance or pine tree density in explaining levels of native-forest regeneration in plantations. Thus strategies for restoring native oak forests in pine plantations may benefit from considering land-use legacies as well as distance to propagule sources and pine density.

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Part III
Biosphere poster

Facing climate change and soil erosion in the high altitude catchment of Valle de Bravo, Mexico

Guevara-Escobar A., Malda-Barrera G., Suzán-Azpiri H., and Cervantes-Jimenez M.

Abstract Valle de Bravo is a high altitude catchment capturing 10% of the 65 m^3 s^{-1} fresh water provided to the Mexico City metropolitan area. Thus, soil erosion from agriculture is identified as a critical problem related to the storage capacity of the Valle de Bravo dam. On the other hand, local farmers see lack of funding and extreme climatic variations as main problems in agriculture, but less than 2% of them identified soil erosion as a problem. Farmers knowledge base to tackle soil erosion include: conservation dams, terracing, channeling and dung application. Increased soil erosion rates and runoff could occur under future precipitation regimes as consequence of changes in precipitation patterns and intensities. The agricultural area of the catchment is very vulnerable due to poor management: 1) summertime maize cropping starts after the onset of the rainy season, 2) widespread removal of crop residues and feeding to housed animals, and 3) bare soil mulch. Adapting to climate change begins with increasing preparedness and investigation of ad hoc protective measurements. Therefore, we calculated the costs of win-win practices that could reduce soil erosion and reduce risk in the activity. Most effective practices were: 1) soil water management along with anticipation of sowing date, 2) winter cover crops and 3) mulching. Most importantly, budgeting of soil water requires: reducing evaporation, increasing water holding capacity, available and pertinent climatic, an stepwise decision process based on production progress and mid-term climate forecasts. An array of seed options should be available to the farmers to capitalize on sowing date flexibility and soil water budgeting.

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Population dynamics of Dendroctonus mexicanus parasiting Pinus cembroides populations in response to climate change

Suzán-Azpiri H., García-Rubio O., Luna-Soria H., Cambrón-Sandoval V.H., and Alvarado-Villanueva O.

Abstract Climatic changes are predicted to significantly affect the frequency and severity of disturbances in mountain forest ecosystems. One severe effect is the exponential growth of bark beetle species pests in temperate forests promoted by the gradual increase in temperatures experienced since 1990; the temperate forests in Central Mexico Mountains are not an exception. This study assessed climatic factors associated to bark beetle (*Dendroctonus mexicanus* Zucc) disturbances on three Mexican Pinyon pine populations (*Pinus cembroides* Hopkins) of the "Sierra Gorda", Guanajuato: El Rucio (Xichú), El Carricillo and Cerro Prieto (Atarjea). Survey plots were established inside *P. cembroides* patches with evident signs of bark beetle infestation. Pheromone traps were installed to collect insects during a one-year cycle. Simultaneously, temperature and relative humidity (HR) were recorded with climatic automatic data loggers (Hobo) each minute. Vegetation structure of healthy and infested patches was determined with 50x20m plots. Significant differences ($P \leq 0.05$) for bark beetle population densities were detected between plots, and "El Carricillo" exhibited the greatest D. mexicanus abundance. Average temperature and relative humidity were 17.9 °C and 66% respectively. El Rucio recorded the highest temperature (19.6 °C). Results suggest that temperature and humidity are important, since the bark beetles' population rises during the drought months, and declines during rainy and cold weather months. A significant increase in mean winter temperatures explain partially the rise in D. mexicanus populations.

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Role of Diatoms in the environmental evaluation of remote Alpine Springs

Battegazzore M., Gaggino A., Gastaldi E., Giordano L., Mattone I., and Molineri P.

Abstract Springs and the headwaters of watercourses in Remote Alpine areas are generally excluded from monitoring programs undertaken in the EU according to the WFD. These environments, however, on the one hand are sentinel ecosystems highly vulnerable to global changes, on the other represent potential resouces for multiple uses on the part of humans. Therefore, legislation, methods and procedures are needed in order to assess their quality and status and to allow their protection. Biotic and abiotic components, which are able to guarantee results in both site-specific and general routine monitoring programs, need to be identified and the procedures for sampling, treatment of samples, taxonomic identification and environmental evaluation should be standardized, as has already been done for the main watercourses of the hydrograpghical network(for example by the WFD in the EU). Mountain springs have different ecological characteristics from watercourses, so specific procedures and protocols are required for all the phases of the monitoring.Among the biotic components, Diatoms are an excellent candidate to be considered for the monitoring of alpine springs and headwaters, due to their widespread diffusion at all altitudes and in all environmental conditions. Moreover, they are well known indicators of environmental quality. The issue of individuating reference conditions for different springs and headwaters is also important. In recent years, we undertook several studies based on Diatom communities in springs of the SW Alpine chain. In the Marguareis Natural Park of the upper Pesio and Tanaro valleys in the Ligurian Alps, a first group of 6 springs was sampled in 2001. In 2009 and 2010, in the same area, a larger group of 30 remote springs were sampled. All the springs sampled in the upper Pesio valley are situated at altitudes between 1000 and 2200 m a.s.l. In the Maritime Alp Natural Park a total of 60 springs were sampled (situated between 1000 and 2400 m a.s.l.) in the years 2008-2010. In 2010, finally, 7 springs in the upper Po basin, in the Cotian Alps, were sampled (altitudinal range 270-2020 n a.s.l.).Some detailed taxonomical results and the environmental analyses derived from these studies have been published in the scientific literature and/or presented at international congresses and symposia in recent years and others will be in the coming years. However, these studies are not sufficient to obtain the standardized procedures mentioned above. We therefore propose that all the groups studying Alpine springs and headwaters in the various countries in which the Alps are situated collaborate, putting together their experiences, their evaluations and their proposals, with the aim of elaborating procedures for the sampling, sample preparation, taxonomical and environmental analysis and the criteria for the individuation and use of reference conditions for these environments with particular emphasis on the Diatom community component. Such a collaboration, necessary in order to obtain results applicable to the entire Alpine chain, could also represent a step towards similar procedures for other mountainous areas in Europe and

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elsewhere. It would also determine a much needed step forward towards improved legislation and monitoring programs for the management and protection of these precious but also often under-studied and under-evaluated mountain systems.

Simultaneous response to climate change and eutrophication in plant communities of an inner-alpine valley, Maurienne, French Alps

Bodin J., Dupouey J-L., and Badeau V.

Abstract In the Alps, herbaceous vegetation should respond to climate warming along the altitudinal gradient by a shift toward higher elevation, and also to the complex gradient of continentality since the Alps are clearly distinguished in pre-, intermediate- and inner-alpine biogeographical zones. Mountains were naturally chosen as study areas since the thermal gradient induced by the relief is strong, and urbanization and agricultural pressure are weaker than in lowlands, thus promoting early and unbiased migratory response of species. However, some alpine valleys have experienced increase in human activities resulting in increasing industrialization, urbanization and road traffic, possibly impacting vegetation through atmospheric deposition.Here, we present the results of a study based on a resampling of a phytosociological survey from the 1950s in the forests of an inner-alpine valley, designed by a sampling scheme stratified on well defined ecological criteria (elevation, exposure, geological substratum type and main tree species). To describe vegetation change between both inventories, a method is developed, based on the modelling of changes in community response to elevation gradient, allowing extending the use of historical data to non-geolocalized dataset. Vegetation communities are described by Ellenberg and Landolt indicator values in one hand, and local indices built thanks to multivariate analysis in the other hand.This study case shows a clear response of species communities to climate change. Two components of climate change - temperature increase and continentality decrease - appeared to be involved in vegetation change, illustrating the change in the complex climate gradient occurring in the inner-alpine valley. However, other phenomena explaining vegetation response became also evident, as vegetation indicator values reveal an important eutrophication of forest communities, probably due to nitrogen atmospheric deposit caused by increasing road traffic. Such direct anthropogenic disturbances play a role comparable in space and time to the indirect anthropogenic impact of climate change. Thus, it is essential to consider them in the observation of vegetation changes, before assigning the effects to climate warming only.

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Linaria: a set of information management tools monitor global change in Sierra Nevada Mountains (Spain)

Bonet F., Pérez-Pérez R., and Pérez-Luque A.J.

Abstract The main objective of the Observatory of Sierra Nevada (Spain) is to monitor the effects of global change in this protected mountainous LTER site. We are monitoring more than 100 environmental variables that are surrogates of ecosystem functions. A large amount of information is being created during the monitoring. This information must be maintained within an information system so that it can be useful both to managers and scientists. The basic idea that has inspired the design of this system is to enhance the creation of useful knowledge from raw data collected in the field. We have considered the need to implement adaptive management of natural resources in Sierra Nevada. We show results obtained when including the above concepts in designing and implementing the information system. This Observatory is generating big amounts of environmental information. In order to simplify, we will distinguish only two types of information. The first type is the raw data directly collected in the field. This information is gathered by means several scientifically validated methodologies. Secondly is the structured information that we can find in a report, scientific paper or slide presentation. Even videos and other multimedia products could belong to this category. If this information is useful to solve a problem, it is called knowledge. We obtain information and knowledge by processing and analyzing the raw data.LINARIA is a modular information system that can satisfy the needs of different types of users from academics to environmental managers. Its conceptual framework is based on the idea of transforming information into knowledge by using the best available technology. LINARIA uses relational databases to store and analyze all the information input. The raw data are documented by using a metadata system that is compliant with several metadata specifications, such as EML, which is the specification for LTER sites and the ISO19115 standard. The core of LINARIA is a repository of models (called ModeleR) that is able to document and execute different kinds of models and analytical procedures. By using ModeleR, LINARIA can process very large amounts of data automatically. This system is especially useful to handle large amounts of data that are generated by meteorological stations, flux towers, or other instrumentally collected atmospheric data. All information processed is visualized on a web page by means of dynamic graphs built with HTML5 standards. LINARIA also contains tools to run OLAP analyses and create multidimensional cubes that are very useful to describe large datasets. The access to the LINARIA system is managed through Single-Sign-on (SSO) technology that allows centralized authentication.

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Alpine Streams under changing climatic conditions

Bottarin R., Folegot S., and Tappeiner U.

Abstract Over the last years the interest of the international scientific community towards high mountain lotic ecosystems has increased considerably. Headwater streams may be small in size, but they provide habitats for a rich array of species, through which they enhance the biological diversity and the importance of the entire lotic ecosystem. This mostly small water habitats result also very sensible to climate changes. Small changes in the environmental conditions can have significant consequences on the biological communities. This increases the importance of small alpine valleys as ideal study sites for analyzing environmental modifications.This study focuses on the effects of environmental parameters on the biota of the Rio Saldura (BZ), a perennial glacier stream and tributary of the Adige River (South Tyrol, Italy). The presence of a glacier (Weisskugel, 3742 m a.s.l.) within the drainage basin has far reaching effects on abiotic parameters (in particular the discharge) over a wide range of time-scales and thus it has fundamental implications for the whole river system. Moreover, the Rio Saldura drains one of the driest valleys of the Alps, which represents the ideal condition to focus on effects of climate changes and on importance and influence of the spatial and temporal dynamics of the melting process on river biota. In particular, two biological communities have been analysed: the benthic macroinvertebrates and the interstitial meiofauna. The effects of the melting process of snow and ice on the vertical connectivity of a water course in relation to the biological parameters represent still an nearly unopened “black box”.In order to evaluate the glacier’s influence and the longitudinal patterns of interstitial meiobenthic and macrobenthic assemblage four sampling stations have been selected at increasing distances from the source (located from 2300 m a.s.l. to 1500 m a.s.l.). The meiobenthic community has been sampled at 30 cm depth within the riverbed applying the Bou-Rouch-method, while the macrobenthic community was analysed applying the multi-habitat sampling methodology. The monthly biological samples have been integrated by chemico-physical analysis of the interstitial and running water in order to correlate community composition, diversity and environmental variables. The results have shown longitudinal as well as seasonal distribution patterns: the increased discharge due to the snowmelt during June and July corresponds to a decrease of faunal density and number of taxa. It seems that the interstitial habitat cannot be used by the macrobenthic community as refuge as described for other water courses, perhaps due to the high instability of the substrate.These first results suggest that the snow-melting process significantly modifies the composition of stream invertebrates assemblages and highlights the importance of including these aspects in impact studies on climate changes and fresh waters: the understanding of hydroecological relationships seems to be essential for the development of alpine rivers’ operative conservation strategies.

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Simulating local adaptation of forest trees to climate using a new model coupling physiology, demography and genetics applied to budburst phenology

Davi H., Csillery K., and Oddou-Muratorio S.

Abstract A challenge for evolutionary ecology is to evaluate the ability of populations to adapt over a few generations to changing environmental conditions. The adaptive potential of forest trees to environmental changes remains largely unknown due to potentially antagonistic features (e.g. high levels of genetic diversity and gene flow but long generation times). We investigated the effect of selection on phenotypic and genotypic phenological clines along an altitudinal gradient and estimated the rate of local adaptation. Models dealing with local adaptation rarely account explicitly for the climate effects. We developed a new physiology-demography-genetic model (PDG) coupling (1) a physical and physiological module simulating individual tree response to environmental conditions; (2) a demographic module converting tree carbohydrates into seed production and modelling dispersion and (3) a quantitative genetics module relating genotype to phenotype. We simulated the evolution of bud burst date in *Fagus sylvatica* populations across five generations along an altitudinal gradient on Mont-Ventoux, France. We showed that few generations were enough for natural selection to result in genetic differentiation for the timing of budburst (TBB) and that the simulated patterns of phenotypic and genotypic variations across altitudes were not monotonic. Such PDG model, for which individual fitness dynamically results from the physiological processes, complements the theoretical models and measurements from common garden for estimating the adaptive potential of tree populations.

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Ecohydrological processes along an elevation gradient in an inner dry alpine valley

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Abstract In mountain regions ecohydrological processes exhibit rapid changes within short distance due to the complex interplay of topography and atmospheric processes. An elevation transect can be seen as a proxy of climate change (CC), as it affects air temperature, precipitation amount and its partitioning into snow and rain, snow cover duration, and the resulting changing length of vegetation period.In order to investigate water budget and vegetation productivity with respect to elevation for mountain grassland ecosystems within an inner dry alpine valley, a transect of three micro-meteorological stations was established since 2009 in the Vinschgau valley (South Tyrol, Italy). It has been designed with an elevation difference of 500 m, which means an averaged temperature gradient of 2.7 K among the stations. In this contribution, the ecohydrological model GEOtop-dv was employed to model the effects of the elevation gradient on snow, soil moisture, evapotranspiration (ET) and above ground net primary production (ANPP) dynamics in two year with different climatic conditions. Simulations have been validated with observations of soil moisture, snow height, ANPP and eddy-covariance measured ET.Considering the observed contrasting natural trends of increasing in precipitation and decreasing in temperature with higher elevation, numerical simulation results show that, in this type of climate, snow dynamics are highly nonlinear with the elevation due to differential precipitation partitioning in early winter and spring. Despite the different climatic conditions, soil moisture dynamics indicate that severe drought occurs in the bottom valley, while it exists an optimal altitude at about 1400 m a.s.l., where temperature and water availability are optimal in terms of maximum annual ET and ANPP. Our result, finally, indicate that for this mountain ecosystem it exist a threshold elevation below which most of the precipitation is used for ET and irrigation is needed for maximize ANPP, and above which an increasing part of precipitation can become runoff and water infiltration. Therefore, a relevant implication is that only above a certain elevation this mountain area acts as “water tower”. A determination of future trends this threshold elevations is crucial to understand the impact of climatic changes on water resources for mountain ecosystems.

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Model data integration for the territorial assessment of future climate change impacts on natural pasturelands of the Italian Alps

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Abstract The Alps have been showing a recent warming roughly three times the global average and, according to climate models projections, it is expected to even worsen in the next decades. Moreover, alpine permanent grasslands, species-rich ecosystems often located over marginal areas and developed by a combination of local climate influence and centuries of livestock grazing, are acknowledged by the IPCC 4th Assessment Report as very sensitive and vulnerable ecosystems to climate change. Building on these premises, the aim of this study was outlined, namely the integration and use of territorial data as input predictors of ground-breaking tools (i.e. classification models coupled with GIS techniques) in order to environmentally characterize the main pasture macro typologies of the Italian Alps and to assess future climate change impacts on these fragile resources. Current distribution and composition of pastures were derived by the acquisition of local pastoral cartographies, CORINE Land Cover Map and Habitats Natura2000 Map. Topographic and climatic parameters, related to the present and future A2 and B2 SRES scenarios, as simulated by HadCM3 General Circulation Model (GCM), were extracted from the WorldClim database; soil data (pH) from the Harmonized World Soil Database. Territorial and pastoral data were then overlain and integrated within a GIS environment in a unique grid spatial dataset at a 1km x 1km of resolution. By means of a methodological approach, seven pastoral main macro-typologies of the Italian Alps were identified, namely pastures dominated by shrubs (SP), by *Carex curvula* (CC), by *Carex firma* (CF), by *Nardus stricta* (NS), by *Festuca rubra* (FR), by *Sesleria varia* (SV) and by xeric species (XS). A machine learning approach (Random Forest - RF) was first calibrated for the present period and then applied to the spatial dataset in order to simulate the potential expansion/reduction and/or shift of the identified pastoral macro types in three future time slices (2020, 2050, 2080) under A2 and B2 SRES scenarios. With regards to present period, the application of RF model proved to be robust and very efficient to predict lands suited to the seven pasture types. Despite a slight contraction of lands suited to pastures, the future climate conditions, as depicted by HadCM3 in A2 and B2 scenarios, will have impacts of great concern on the Alpine pasture composition. In fact, climatic conditions projected in both A2 and B2 SRES scenarios from the middle of the century will likely determinate, with respect to present period, a high decline of areas potentially suitable to the macro types examined. Except for pastures dominated by XS and NS, which showed wide expansions over the study area, a troublesome reduction of lands suited to the rarest pastures or to the macro types currently restricted at the highest altitudes of the alpine range (i.e. CC, CF and SV macro types) was predicted by RandomForest simulations. According to these results, the expected global warming, coupled with an increasing abandonment of the

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traditional grazing practices over the Alps, will likely threat the unique and rare herbaceous biodiversity characterizing the Alpine mountain range.

Snowmelt date and temperature constrain the flowering and vegetative phenology of mountain grassland plant species

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Abstract Understanding the effects of climatic control on high elevation ecosystem phenology is important to evaluate responses and feedbacks of ecosystems to climate changes. Flowering and vegetative phenology data of five plant species located at different elevations in the subalpine zone of the North Western European Alps are presented in this study. Phenological data from 2010 and 2011 were collected from 6 sites to analyze the influence of snowmelt on the timing of phenological events. All the species, although with a specific shift in timing, displayed similar flowering and leaf growth responses according to their growth form. The snowmelt date was the key factor in determining the time of the phenological events of each species. Furthermore, we observed an acceleration of development of the flowering and vegetative phenology, in sites characterized by a later melt. The mean air temperature after late snowmelt was significantly higher than at sites with early snowmelt: this partly explained the faster plant development at high elevations. However there was, also a decrease in heat requirement in sites with late snowmelt. Understanding the effects of the snowmelt date on phenology and of the different growth forms in particular, can improve the forecast of future climatic change impacts on plant phenology in mountain regions.

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Alpine vegetation dynamic in the northwestern Caucasus: long term observations on the permanent plots

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Abstract We observed natural dynamic of alpine vegetation in the Teberda State Biosphere Reserve at the Northwestern Caucasus (Karachaevo-Cherkessian republic, Russia) at the Malaya Khatipara Mountain at ca. 2750 m a.s.l. in four communities: alpine lichen heaths (ALH), Festuca varia grasslands (FVG), Geranium-Hedysarum meadows, and alpine snowbed communities (SBC). These communities occupy habitats along the snow accumulation gradient with ALH located on the windward crests and slopes with low (up to 20-30 cm) or no snow cover during the winter and SBC with high snow accumulation (4 m or more). Vascular plant abundance was estimated by direct count of shoot number on permanent plots of 0.0625 m^2. The number of plots was 80 in ALH and SBC, and 40 plots in FVG and GHM. The period of observations was 30 years (1981-2009) in ALH, 24 years (1986-2009) in GHM and SBC, and 23 years (1987-2009) in FVG. This period was characterized by increase of mean and mean maximal temperatures in summer and autumn months.We estimated significance of linear trends for the species with mean shoot number exceeded 15 shoots per year. To reveal whether these trends are explained by species altitudinal distribution, we ran ordinary least squares (OLS) regressions with per species coefficients at year as response value and mean altitude of species occurrence in Teberda Reserve as predictor. Mean altitudes of species distribution (m a.s.l.) at the Teberda Reserve area were derived from the data set of the vegetation relevs.All communities included species both increased and decreased its abundance. Altitudinal distribution significantly predicted changes in abundance for FVG (26% of variance explained, $p<0.02$, n=23 species), GHM (37%, p=0.001, n=26), and SBC (35%, $p<0.01$, n=19) species with species from low elevations increased their shoot number (for example, *Calamagrostis arundinacea* and *Leontodon hispidus* in FVG, *Phleum alpinum* in GHM and SBC, *Nardus stricta* in SBC) and plants restricted by high elevations decreased (*Catabrosella variegata* in GHM and SBC, *Gnaphalium supinum* in SBC). However, mean altitude didn't predict trends in ALH. Thus, changes in alpine vegetation caused by plant species upward shift were considerable only in communities with higher snow accumulation. It may be caused by elongation of the growing season due to increasing temperatures. This elongation probably restricts specialist snowbed species.

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Is there an impact of tropospheric ozone on the climate change mitigation potential of forests in Trentino (Northern Italy)?

Ferretti M., Cristofori A., Cristofolini F., and Gottardini E.

Abstract Tropospheric ozone has a dual role in climate change. On the one hand, its positive radiative forcing of 0.25-0.65 W/m^2 makes ozone the third most important greenhouse gas, after CO_2 and CH_4 (IPCC, 1997). On the other hand, ozone has been estimated to affect forest health and growth and therefore to reduce their potential C sink (e.g. Wittig et al., 2009). Failure in accounting for ozone effects on C sequestration has been estimated to increase the cost of climate change mitigation (Felzer et al., 2005). It is therefore important to have reliable information on distribution and effects of ozone, especially for mountain forests, which are considered particularly sensitive to climate change and exposed to high ozone levels. In 2007, a five-year meso-scale (6,200 km^2) study was undertaken in Trentino, North Italy, where forests are estimated to stock 31x106 t C in their above-ground biomass (Tonolli and Salvagni, 2007). We (i) measured ozone concentration at 15-20 forest sites according to a systematic grid, (ii) modeled ozone exposure and associated risk for vegetation and (iii) investigated the effects on vegetation by means of field studies and statistical modeling (Gottardini et al., 2012). Results showed that ca. 76-95% of the forest area experienced an ozone concentration that exceeds the EU and UN/ECE risk thresholds, with a potential reduction of growth and therefore C sequestration. However, although specific symptoms related to ozone exposure have been identified on sensitive vegetation, measured effects on growth and health of forests were much less obvious. Despite the high exposure levels recorded, ozone was never a significant predictor of basal area increment and defoliation. Rather, frequency of tree damage and N-related variables were the most important predictors. An ad-hoc investigation based on long-term monitoring data confirmed the scarce relationship existing between ozone exposure and flux and tree defoliation and growth. A complex picture emerged, with potential high risk and early indicators of effect, but apparent limited impact of ozone on growth and therefore on C sequestration and climate mitigation potential in Trentino. There is a clear need to reconcile this picture into a consistent, meaningful frame.

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Assessing grassland phenology with snow depth sensors: methods, issues, perspectives

Filippa G., Cremonese E., Galvagno M., Freppaz M., Julitta T., Morra di Cella U., and Rixen C.

Abstract Snow depth sensors are widespread all over the Alps in a number of meteorological stations. When sensors are located on a grassland, data collected during the snow free season may be used to automatically track plant growth. The analysis of this large amount of data may be of great interest to understand how the phenology of alpine grasslands respond to changing climatic conditions. However, these data greatly vary in their quality from site to site due to different reasons: grass may be cut or grased, the snow sensor may be located on a bare surface, etc. A routine procedure would therefore allow to automatically exclude bad data. We developed and tested such a procedure in the R environment in order to obtain seasonal trajectories of plant growth. The routine was tested on a large number of data (418 year-sites) and included: (1) A bayesian approach to automatically detect the disappearence of snow; (2) a proper growth function to determine phenological metrics such as the beginning of growth, the maximum grass growth, the maximum growth rate; (3) a set of thresholds that can be applied to the data in order to *a priori* discard bad data. The benefit of using automated thresholds instead of manual analysis of individual time series will be discussed and some preliminary analyses on the ecological significance of the extracted phenological metrics will be presented.

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Changing winters and subalpine forest soils

Freppaz M., Viglietti D., Filippa G., and Zanini E.

Abstract In areas with previously stable snow conditions, climate change may cause a reduction in the depth, duration, and stability of the snow cover. Milder winters with thinner or less permanent snow cover are likely to affect the occurrence, depth, and duration of soil frost and are associated with midwinter snowmelts and/or rain on snow events. The experiments sometimes indicate as a consequence of these phenomena a faster mineralization of soil N, higher N_2O emissions related to freeze thaw cycles, and a reduction of respiration rates, buti it is still difficult to derive any general conclusion. Experimental snow manipulations have been carried out in 2 subalpine forests (Larix decidua) sites (at 1400 m asl, Fontainemore LTER site, and 2000 m asl, Claviere) in NW Italy, in order to simulate the influence of a lack of snow cover (LSC) and a change of snow density due to rain on snow events (ROS) on soil properties (soil temperature, soil water content, carbon and nitrogen forms in soil and soil solution). The snow removal treatment determined a significant effect on soil temperature, with mild ($\sim -4\,^{\circ}$C) and hard freezing ($\sim -6\,^{\circ}$C) events, while the change of snow density due to rain on snow events did not cause any significant effect on soil temperature. The microbial N was not affected by the snow removal treatments, revealing the adaptation of the microbial communities to these specific pedoenvironmental conditions. Consequently, the increase of exchangeable soil $NH_4{}^+$ in the snow-free plots may have been due to the release of previously non-exchangeable $NH_4{}^+$ from inorganic or organic colloids by the disruptive action of the freezethaw cycles. The lack of snow cover caused a significant increase of $NO_3{}^-$ in the soil solution during the spring and summer seasons, suggesting a possible reduction of plant uptake caused by roots damages. Our results suggest that the response of subalpine forest ecosystems to increased soil mild-hard freezing frequency due changes of the snow cover properties may be important, with significant effects on the soil nutrient dynamics.

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Water quality, hydrology, and soil properties in a recently deglaciated area (Indren glacier, Valle d'Aosta-NWItaly)

Freppaz M., Martin M., Squinobal E., Morra di Cella U., Confortola G., and Bocchiola D.

Abstract The direct response of glaciers to climate change occurs through ablation, changes in the mass balance and hydrological fluxes. In a warming world, glacier retreat increases and the ice-free areas undergoing soil formation processes. In spite of the linkage between cryospheric, hydrological and biochemical fluxes, their fallout upon water quantity and quality, and ecosystems dynamics, soil-water-ice interaction in mountain areas is poorly studied and potential effects of climate change unknown as yet. This ongoing research is focused on (1) analysis of streamwater and soil characteristics, (2) monitoring and modeling hydrological, biochemical and mass budget of the Indren glacier area (Monte Rosa Massif).Streamwater was sampled (March-November 2012) in 3 locations from the glacier portal (3100 m asl) down to a wet meadow area (2500 m asl). Soils were described and sampled at all the water sampling sites. Water analysis included pH, EC, TDN, DOC, and dissolved anions and cations. Using a semi distributed, altitude belt based hydrological model, we were able to mimic (1) hydrological components in stream fluxes, i.e. rainfall, snow melt, and ice melt; (2) origin of streamwater, i.e. overland flow or ground flow. The hydrological model was tuned by way of daily discharge data at the lowest catchment outlet (2564 masl, 4.6 km^2), providing acceptable depiction of in stream flows during thaw season of 2010 and 2011. We further installed (Spring 2012) a hydrometric station at the Indren glacier's toe (3100 m asl, ca. 1 km^2), to further constrain glacier mass and hydrological budget. The monthly average flow measured therein is 0.25 m^3/s in July, 0.11 m^3/s in August, 0.02 m^3/s in September and 0.01m^3/s in October (data in validation phase).Our results display that bulk meltwaters at the glacier portal contain relatively large quantities of dissolved ions, varying significantly among the seasons, with larger contents of DOC and TDN during Autumn than during Spring and Summer. At lower elevation, where thicker soils are found, streamwater during Summer was characterized by a lower DOC/DON ratio than at higher elevation, revealing a potential leaching of organic nitrogen from the surrounding soils. The DOC concentration, always higher close to the glacier front, highlights the role of the glacier surface, including cryoconite holes, for carbon cycling. DON represented nearly half of total dissolved nitrogen and seemed to increase with soil development. N-NO_3 concentrations (mean value=17.5 $\mu molL^{-1}$) were always much higher than ammonium ones, without significant elevation effect. Generally these preliminary results reveal a significant contribution of the glacier surfaces to the C cycling (more than 700 kg DOC released in July 2012) and suggest a great variability of the monthly fluxes of the different nutrients released from the glacier to the streamwater, with much greater amounts released in early Summer than in Autumn, according to the melting rates.

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Ecosystem responses to extreme variations in snow season: the example of a subalpine grassland in Aosta Valley

Galvagno M., Wohlfahrt G., Cremonese E., Morra di Cella U., and Migliavacca M.

Abstract Mountain ecosystems in the European Alps are expected to be particularly impacted by future rising temperatures, changes in precipitation patterns, duration of the snow-pack and by increasing of extreme events (e.g. winter and summer warm spells, summer drought, changes in snowmelt). Specifically, in seasonally snow-covered ecosystems, earlier snowmelt and later establishment of snow cover are foreseen to reduce the continuous off-season CO_2 losses and to potentially lengthen summer periods of CO_2 uptake. Although several studies have investigated the effect of snow manipulation on the phenology and growth of alpine plants, little is known about the effects of shortened snow seasons on the annual productivity of high-altitude ecosystems, due to the variability of species responses.
This study investigates the effect of an extremely short snow season on the phenology and CO_2 source/sink strength of a subalpine grassland, located in the Aosta Valley region at 2160 m asl. We analyzed three years of net ecosystem CO_2 exchange (NEE) measured by means of the eddy covariance technique.
We compared phenology and ecosystem CO_2 fluxes measured during a year (2011) marked by one of the shortest snow season on record (1928-2010) with those of two average years (2009, 2010). We observed that an earlier snowmelt of more than one month caused a considerable advancement (40 days) of the beginning of the carbon uptake period (CUP) and, together with a delayed beginning of the snow season in autumn, contributed to a two month longer CUP. The shorter snow season and the consequently extended CUP led to an increase of about 100% in annual net CO_2 uptake. Nevertheless, the unusual environmental conditions derived by the early snowmelt led to changes in ecosystem structure and functioning with a reduction in the summer NEE rate. Assuming an increase of extreme changes in snow cover such as the observed, the relationship between lower CO_2 losses during shorter winters and reduced NEE rate during longer CUP will affect the annual carbon balance of this grassland.

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Variation in leaf traits of an Apennine grass Sesleria nitida along a narrow altitudinal gradient at Mount Terminillo (Italy)

Gratani L., Crescente M.F., Di Pietro R., D'Amato V., and Puglielli G.

Abstract The forecasted increase of air temperature could determine the reduction of alpine habitat and loss of many European high-mountain plants (Pauli et al., 2012. Science 336: 353-355) and an increasing number of studies show altitudinal range shifts for mountain species for alpine ecosystems. The current rate of global warming might be too rapid for natural migration to successfully deliver species to suitable habitats. Thus, knowledge on alpine species response to temperature changes can provide insights into our standing how these plants are responding to current and future warming (Shen et al., 2009. J Plant Ecol 2: 207-216). The genus *Sesleria Scop*. constitutes a complex group of similar and closely related taxa distributed mostly throughout Europe (Kuzmanovi et al., 2009. Bot Serb 33: 51-67). The species *Sesleria nitida* Ten. grows in Italy from 600 to 2000 m a.s.l. in the central and southern Apennine (Pignatti, 1982. Flora d'Italia. Edagricole). The aim of this research was to analyze morphological and physiological traits of *S. nitida* growing at different altitudes at Mount Terminillo (42° 28' 28" N, 13° 00' 24" E, Italy) on calcareous rocky slopes. We addressed the question if altitudinal variations in morphological and physiological traits could be indicative of their future adaptive potential to global warming. The results underline a significant variation among morphological and anatomical traits with an increased specific leaf mass area (LMA) and leaf thickness (Lt) in response to variations in microsite from the low altitude (L, 1100 m a.s.l.) toward the top (T, 1895 m a.s.l.). The reduced leaf area and the increased Lt associated to the largest lateral xilem vessels size in T than in L favor the hydraulic conductivity. A higher hydraulic conductivity is adaptive in habitats with high irradiance as it allows water transport rate from roots to the foliage for photosynthesis (Barigah et al., 2006. Tree Physiol 26: 1505-15 16; Nardini et al., 2012. Tree Physiol 32: 1434-1441). The photosynthetic rates (Pn) are 18% higher in L than in T where the temperature is, on an average, 3 °C lower than in L, associated to a stronger wind and high irradiance causing a condition of physiological aridity. Leaf respiration shows an opposite Pn trend with 28% higher rates in T than in L. An important role to the strategy of *S. nitida* to the natural habitat is leaf rolling which increases in altitude. Leaf rolling reduces leaf transpiration through changes in both stomatal conductance and leaf area. The plasticity index sensu Valladares (0.27, mean value of morphological, anatomical and physiological traits of the two monitored populations) is higher compared to other mountain species (Carpenter et al. 1980. Can J Bot 59: 1393-1396) thus, reflecting *S. nitida* capability to maintain function under diverse environmental conditions. The results on the whole suggest that *S. nitida* may sustain the air temperature increasing by shifting toward higher elevation, accordin to Jump and Peuelas 2005 (Ecology Letters 8: 1010-1020) and Gratani et al. 2012 (Photosynthetica 50: 15-23) for other species.

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LTER Italy: Long term research in high altitude lakes in the Himalayas

Lami A., Musazzi S., Rogora M., Boggero A., Manca M., Tartari G.A., Marchetto A., Guilizzoni P., Salerno F., and Tartari G.

Abstract Among the long term measurements initiative, we highlight here some results from the long term research carried out in the Himalayas on a LTER-Italy site: Lake Pyramid. The research activity were carried out in the framework of the SHARE Project (Station at High Altitudes for Research on the Environment). The main objective of SHARE is to assure a continuous environmental monitoring in mountain sites through long-term, high quality data series and contributing to the study of climate changes impacts and adaptation strategies in high mountain regions by making the obtained information available to governments and international agencies.Limnological survey (including chemistry, biology, and sediment core studies) of lakes located between ca. 4500 and 5500 m a.s.l. have been performed nearly every year from 1992 in the Khumbu Valley, Nepal. As an example, among the many possible, here we refer the research focused on the two lakes located near the Pyramid Laboratory in the Khumbu Valley. Lake water chemical surveys over the period 1992-2002 reveal a constant increase of the ionic content of the lake water probably related to glacier retreat. Analysis of the benthic fauna reveals shifts in species composition probably as a response to the recent warming. Paleolimnological reconstructions show the potential use of these sites in providing proxy data of past climatic changes displaying an alternance of warmer/wetter and cooler/drier periods.Future research activities will be needed to integrate lakes, wetland and stream habitats at a catchment scale and to focus on the key drivers of aquatic system change (nutrients, acid deposition, toxic substances) and their interaction with global drivers such as climate using time-series analysis, paleolimnology, experiments, and process modelling at different time scales (seasons/years and decades/millennia).

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The LTER-Italy network 2006-2012. Status and update

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Abstract The Italian Long Term Ecological Research Network (LTER Italy) is part of the International LTER Network (ILTER) since 2006. Work to establish the national network started in late 90s, promoted by the Italian Society of Ecology (SitE), by some Institutes of the Earth System Science Department of the National Research Council (CNR), by the National Forest Service (CFS) and by other italian research institutions. The first institutional framework was provided by CFS within the international Project ALTER-Net. Currently, The Earth System Science Department is supporting the institutional role of LTER-Italy.
At present LTER Italia encompasses 22 parent sites, 20 in the Country territory and two extraterritorial (in Antarctica and Himalaya) with nearly 70 research sites in total. The accession of sites to the network is decided after indipendent review. LTER-Italy is a true multi-ecosystems, multi-disciplinar network, with the involvment of Universities, Research Institutions, National (National Forest service) and local authorities (e.g. national and regional parks, regional protection agencies).
The poster will present the status of the Network with updates on the “formal” five years, on which a book has been published in 2012.

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From monitoring global change to quantifying changes in ecosystem services: conceptual framework to create a eco-hydrological model in Sierra Nevada Mountains

Millares A., Bonet F., Herrero J., Zamora R., and Polo M.J.

Abstract Global change monitoring programs aim to generate useful information to improve our knowledge about ecosystem functioning. These tools are also aiding scientists to know how ecosystems will behave in a global change context. The complexity of the processes involved requires the correct understanding between biophysical variables which represent the actual functioning of the ecosystem. Furthermore, the knowledge of this physical and biotic interaction allows a more complete evaluation of the ecosystem service, concept that lets us transfer to society the impact of human activities on natural systems. The quantification of these services will be increasingly important in order to minimize the impacts of human activities.As the importance of ecosystem services is recognized by society, a growing interest in mathematical models as tools which provide necessary information for decision-making processes has arisen. In this sense, hydrological models have been used for decades to estimate different processes related to the water cycle (snowmelt, flooding, water resource availability, soil loss, etc.). However, although the hydrologic cycle is a clear example of the conceptualization of nature as a set of connected systems (atmosphere-earth-sea) and concatenated physical processes (precipitation, snowmelt, runoff, infiltration, lateral flow, aquifers contribution,...), generally there is a lack of connection with biological variables for a complete modeling and services quantification of the ecosystems.In semi-arid mountain areas, the particularity of the processes related with the snow dynamics determines not only the hydrological cycle but also the associated ecosystems. In these environments, the sensitivity to climate changes is very high with obvious consequences in terms of ecosystem value loss. Here, physically-based and distributed models present advantages because they allow the estimation not only of the water balance, but also of the spatial distribution of the hydrologic variables and the quantification of hydrologic processes and their interactions with biotic systems. In this work we propose a conceptual framework that combines in a particular territory (Sierra Nevada, south-east of Spain) the concepts described above. Our goal is to design and implement an eco-hydrological model that simulates quantity, quality and time evolution of different types of ecosystem services (supporting, regulating, provisioning). The core of proposed model involves the integration of two main modules; hydrological and biological model. The model WiMMED (Watershed integrated Management for MEDiterranean environments) is a distributed and physically based hydrologic model conceived for semi-arid mountainous environments and specially intended for dealing with mountainous basins where snowmelt at low latitudes is present in a context of extreme variability. The results of this model have been connected with a ecological model that simulates the functioning of several ecosystem types. In this first approach we have simulated the biomass produc-

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tion in a holm oak forest (*Quercus ilex* subsp. *Rotundifolia*). This ecological model is able to provide information about biomass production by simulating the individual behavior of each tree. These models are called Agent Based Models. We have also used ecophysiological models like GOTILWA+. The combination of these two models results in a third layer which represent the quantification of ecosystem services calculated from several post-processing algorithms in order to give specific amounts. A first example of the proposed methodology is presented. We have modeled the production of honey as a provisioning ecosystem service in Sierra Nevada mountain.

Chemical weathering characterization in Sabalan mountain, the sample for high freeze area in Iran

Mousavi S.Z. and Ghalamghash J.

Abstract Geochemistry, morphology and mineralogy of soils derived from trachyandesite was investigated in west part of Sabalan mountain, Nw Iran. Mineral weathering was characterized by petrographic microscope and comparison was made with total elemental analysis (XRF) and X-ray analysis (XRD) All evidences showed that there is a close structured relationship between the host mineral and the weathering products however, the weathered rock has also been hydrothermally altered. Mineral composition (confirmed by thin section and XRD) in trachyandesite were plagioclase (labradorit), pyroxene, amphibole and some biotite. However sericite, chlorite, smectite were the most alteration products. Total elemental content of Ca, Mg and Fe as well as solum thickness in field observation and clay mineral content were higher in soils from trachyandesite which can be attributed to the presence of more susceptible ferromagnesian minerals to weathering. The use of shallow geochemical surveys to detect mineralization beneath thick transported cover is a substantial challenge. There is no general agreement on mechanisms that are effective in vertical mobilisation of ions, especially through a thick unsaturated zone, and many factors may affect ion movement.

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Climate-induced zooplankton species turnover in high mountain lakes in the Alps

Nevalainen L., Manca M., Kurmayer R., and Luoto T.P.

Abstract The interaction of multiple anthropogenic environmental stressors in recent decades has impacted freshwater ecosystems, resulting in changes in biodiversity, species distribution, and community composition even in remote lake ecosystems around the world. Remote mountain lakes in the Alps are extremely vulnerable to multiple stressors, e.g. atmospheric pollution, fish introduction, and increased UV radiation. These stressors are superimposed with climate warming and its limnological consequences, including changes in lake thermal structure, ice-cover duration, and hydrological patterns. We compared changes in sedimentary zooplankton assemblages (Cladocera) over the past 300 years of two high elevation lakes (Oberer Landschitzsee and Twenger Almsee) in the Austrian Alps with those of 25 high altitude lakes in the Italian and Swiss Alps, during pre- and post-industrial ages (i.e. 'top-bottom paleolimnological approach'). We aimed at tracking long-term changes in community composition, potentially attributable to the well-documented climate warming in the Alpine region. Both Austrian lakes showed a similar pattern of gradual zooplankton species turnover over the last century: the keystone pelagic grazer Daphnia was first replaced by *Chydorus cf. sphaericus* and eventually during the 20^{th} and 21^{st} centuries by the latest colonizer, Bosmina. Although differing in zooplankton species composition and in magnitude of change, the two lakes shared a common centennial pattern of species succession, likely responding to a common driver, i.e. Alpine climate warming. The long-term Daphnia decline did not match with historical fish stocking records, which started centuries earlier, but the eventual Daphnia extirpation in Twenger Almsee corresponded to start of commercial fish stockings during the late 20^{th} century. The Daphnia decline and a major increase in Chydorus cf. sphaericus was also reported from the modern zooplankton assemblages in Italian and Swiss lakes, while Bosmina did not replace Daphnia in these lakes. Apart from direct climate impacts, common drivers of change in zooplankton assemblages were pH and productivity. We hypothesize that prolonged ice-free season and altered thermal structure resulted in increased productivity, in turn promoting success of opportunistic *Chydorus cf. sphaericus* and, in the Austrian Alps, Bosmina in place of Daphnia. The observed zooplankton changes are likely to result in altered structure and functioning of the high mountain lake ecosystems.

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Grassland transplantations along an elevation gradient: Evaluating impacts of a simulated temperature increase on phytodiversity and aboveground productivity

Niedrist G., Obojes N., Bertoldi G., Della Chiesa S., Tasser E., and Tappeiner U.

Abstract Throughout the last decades different manipulative approaches have been developed to study impacts of temperature increase on grassland ecosystems. They consistently differ in set up and effort, however, regardless whether open top Chambers, above canopy heaters or buried heat wires are used, all of them share the problem of unwanted effects on the surrounding microclimatic conditions. Although some critical restrictions transplantation of grassland mesocoms along straight elevation gradients may be a realistic alternative. Here we present results of a large 3 year transplanting experiment, were grassland monoliths were transplanted from 2000m to 1500m a.s.l. and from 1500m to 1000m a.s.l. respectively along a relative dry inner-alpine elevation gradient in the Vinschgau Valley (South Tyrol, I). All donor and receiving sites are comparable regarding type of management, soil conditions or exposition and are located within a few km distance ensuring comparable weather conditions apart from the intended temperature (0.54 °C/100m) and precipitation (20mm/100m) lapse rate. Phytodiversity and phytomass production of the transplanted 70*70*20cm mesocosms were assessed and compared with locally transplanted monoliths of the respective donor site. Furthermore grassland productivity was continuously observed with a nondestructive method using light extinction information from canopy. Considering aboveground phytomass production data confirm higher productivity on transplanted (lower) mesocosms. The increase seems to be rather evident in late summer and in the higher transplantation (from 1950m to 1450m). Conversely, diversity results show no significant difference in terms of absolute numbers, whereas slight variations were observed regarding species composition. By analyzing Ellenberg values, functional diversity and using multidimensional scaling those shifts could be discriminated between transplantation artifacts and effects of the elevated temperature.Summarizing, gained experiences show that a well-designed transplant approach is a realistic alternative to simulate future climate conditions, especially regarding snow cover duration and length of the vegetation period. However, during the third year results point to increasing invasion phenomena from the surrounding receiving side into the transplanted mesocosms, suggesting that the approach is rather suitable for short-to midterm experiments than for long-term observations.

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Effects of climatic conditions on sap-flow and radial increment of Larix decidua and Pinus cembra in an inner-alpine dry area

Obojes N., Newesely C., Tasser E., Bertoldi G., Mayr S., and Tappeiner U.

Abstract Increasing temperatures and changes of precipitation patterns due to climate change are likely going to alter water relations and growth conditions in mountain forests in the Alps. Inner-alpine dry valley like the Vinschgau/Val Venosta in South Tyrol-Italy are perfectly suited as open air laboratories to investigate these effects as their present climatic conditions will be more widespread in the future. Furthermore taking advantage of temperature and precipitation changes along elevation gradients and opposing aspects enabled us to investigate the influence of different climatic conditions on sap flow and radial growth of trees within the research area Match Valley. We focused our study on *Larix decidua* and *Pinus cembra* which are the most common tree species in the research area besides the *Picea abies*. Starting in April 2012 sap-flow and radial increment was measured at four to six Larch trees at five sites at altitudes ranging from 1100 to 2000 m a.s.l. and at SE- as well as NW-exposed slopes. *Pinus cembra*, which is restricted to the subalpine zone, was investigated at two sites at 2000 m a.s.l. with opposite aspect. The measured trees were selected according to the size distribution at the measuring sites with diameters at breast height ranging from 20 to 65 cm. Preliminary results indicate that sap-flow and radial growth of Larch decrease significantly during longer dry periods at the lowest site but not at the higher ones. At 2000 m altitude sap-flow was slightly lower at the NW-exposed than at SE-exposed slope and higher for Larch than for *Pinus cembra*. These results might have implications for the forestal use of *Larix decidua* and provide insight on the influence of mountain forests on alpine water balance.

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Ten years of GLORIA project in Aosta Valley

Petey M., Morra di Cella U., Galvagno M., and Siniscalco C.

Abstract GLORIA is a global project that studies the potential impacts of climate change on the biodiversity of high mountain areas and aims to establish a worldwide observation network (www.gloria.ac.at). The Aosta Valley GLORIA site (IT-MAV) was established in 2001. Four summits at different altitude were selected: three of them are situated in the Mont Avic Natural Park (Champdepraz) at 2340, 2584 and 2790 m a.s.l., while the fourth summit is located near to Cime Bianche (Valtournenche) at 3014 m a.s.l.. The flora and vegetation in the Mont Avic Natural Park are highly influenced by the presence of several lakes and small wet areas, as well as abundant outcrops of serpentinite rock which provide a shallow infertile soil. The main characteristics of the summits are:

1. first summit (SU1): treeline ecotone, presence of rocks, prairie and shrubs with rare trees and abundance of lichens;
2. second summit (SU2): lower/upper alpine ecotone, alpine prairie, fine schistose detritus and little stone outcrops areas, rupicolous and terricolous lichens, mosses;
3. third summit (SU3): alpine/nival ecotone, richness of schistose rocks and wide fine detritus areas, poorness of lichens cover. Absence of prairie and presence of isolated vegetation sods (less than 10% of total surface);
4. the last summit (SU4): alpine/nival ecotone, characterized by wide big detritus areas with smaller fine detritus zones and cracked rocks (green stones group) and presence of isolated herbaceous vegetation sods (less than 10% of total surface).

Data were inserted in the GLORIA database, managed by the GLORIA network coordination team (University of Vienna). The aim of this study is to provide a first assessment of changes in plant biodiversity at the Aosta Valley summits from 2002 to 2012. Results show that the IT-MAV species list is rich: 122 species in 2002, 123 in 2010 and 124 in 2012. In this contribution data collected during the three surveys are compared, with particular attention to the species average frequency and cover in each summit, and the species number and their abundance in each summit area sections. Cover changes of cryophilous and termophilous taxa, life form groups and chorotype groups is also discussed.

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Reduction of plant community diversity and stability by warming and herbivore removal in the low arctic

Post E. and Sporon Boving P.

Abstract Climate change may influence the persistence of ecological communities by reducing their stability. Species diversity is important to community stability, and may itself be altered by climate change. At our low-Arctic study site near Kangerlussuaq, Greenland, mean annual temperature has increased by 2 degrees Celsius over the past two decades, a rate of warming with the potential to alter plant phenology and community composition substantially. We show here results of a decade-long field experiment investigating effects of ongoing warming and herbivore removal on diversity and stability within the plant community, where, we hypothesize, plant species interactions are mediated by the exploitative effects of herbivory. Both species diversity and stability within the plant community were reduced by warming, herbivore removal, and their interaction. We suggest that top-down species interactions, such as exploitation by herbivores, may buffer plant communities against destabilizing influences of climate change in systems warming as rapidly as arctic and alpine environments. In such systems, intact populations of large herbivores may be important in maintaining and promoting plant community diversity and stability under future warming.

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The first continuous last Late Glacial Holocene peat bog record from the Dolomites (NE Italian Alps)

Poto L., Gabrieli J., Crowhurst S.J., Appleby P.G., Ferretti P., Surian N., Cozzi G., Zaccone C., Kehrwald N., Turetta C., Pini R., and Barbante C.

Abstract The rarity of well-preserved high-altitude deposits and the lack of high-resolution multi-proxy records with adequate chronological data have hampered the paleoclimate and paleoenvironmental studies in the north-eastern Italian Alps. Here we present the first complete last Late Glacial to Holocene peat succession from the Dolomites (Danta di Cadore, Belluno, Italian Alps). We collected a 7 m core and evaluated the potential of the ombrotrophic Val di Ciampo peat deposit (1400 m a.s.l.) as an archive of environmental and climate change. The depth-age scale centred around ^{14}C and ^{210}Pb independent dates and combined with peat stratigraphy demonstrate that the peat core covers more than 13,200 years (cal BP), extending back to the end of the last glacial transition. We determined the bulk density, the inorganic matter content, pore water pH, conductivity, Ca/Mg ratios, and Ca, Sr and Ti trends in order to understand changes in trophic conditions throughout the bog. The boundary between ombrotrophic and minerotrophic conditions occurs at approximately 400 cm and demonstrates that this core is the longest Eastern Alpine ombrotrophic record corresponding to 7000 years cal BP. The high-resolution chemical data of this peat archive improve our capacity to understand European Alpine Holocene climate variability and the natural fluctuations underlying anthropogenic climate change during the present interglacial in the Dolomites.

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Climate change and alpine ecosystems: a new set of permanent monitoring plots in North-western Italy

Rivella E., Bertola A., Loglisci N., Freppaz M., Buffa G., Attorre F., Chiti T., and Certini G.

Abstract High mountain vegetation and edaphic species can be used as sensitive "ecological indicators" of climate change effects in mountain areas. In particular, climate warming has the potential to modify soil carbon and nutrient cycling by altering soil temperature. Changes in soil properties in turn influence the vegetation characteristics. Therefore research initiatives in high mountain environments, with interdisciplinary cooperation, including long-term monitoring and predictive modelling, are needed.This study was carried out in the framework of an EU-INTERREG Italy-Switzerland Project "Biodiversitá: una ricchezza da conservare". Climate, soil, plant characteristics and mesofauna communities were studied along two altitudinal transects (1600-2600 m a.s.l.) in Ossola Valley, Italian North-Western Alps. The study areas, named San Bernardo and Vannino, are located close to the border of Switzerland, in an area characterized by steep slopes, high mountain ranges and strong climatic variations. Along both altitudinal transects, seven sites, prevalently south facing, were selected, from coniferous forest (Larix decidua, Picea abies) to high-elevation prairies. Soil temperature at 10 cm depth was measured by specific sensors and data loggers. Soil organic carbon (SOC) and nitrogen stocks in the top 10 or 20 cm layer were calculated measuring stoniness, concentration of the elements in the fine earth, and the bulk density in a number of soil samples. Three soil samples of 1 dm^3 were collected at a distance of 15 m for analysing the edaphic mesofauna, after extraction through Berlese trap. Data on the vegetation structure were collected close to each sampling points, covering a surface of 16 m^2; each sampling area has been further divided into four 4 m^2 plots. Communities of plants species showed good temperature variation sensitivity, revealed by Landolt ecological values analysis. Consequently, we created a thermosensitive index of the vegetation, which changes as a function of altitude. Carbon concentration in the topsoil was significantly anticorrelated to elevation (r=-0.391, $p<0.05$). The mean SOC stock ranged between 10,294 g m^{-2} under the forest cover and 12,291 g m^{-2} under the alpine meadow. Concerning the mesofauna, we observed a reduction of "adapted" organisms along the altitudinal gradient. In both transects, edaphic biota was more abundant at lowest altitudes in the investigated range, 1600 to 2000 metres.To study the effect of climate change on biodiversity, we based on historical climate records to make future projections. The data coming from automatic weather stations spread over the study area were gridded on a 7 km resolution grid, and applying the Optimal Interpolation methodology. On this basis and using other numerical and statistical downscaling methods, the IPCC SRES climate scenarios A1B and A1F1 were chosen to analyse the biodiversity future trend in the Vannino study area. In particular, to assess the response of the vegetation cover we applied the BIOMOD model, running eighty additional floristic samples, while the Century model was used to determine the response of SOC. Under the A1B scenario the carbon stock

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remained almost constant, while under the A1F1 scenario the C stock decreased in all of the different land covers.

The impact of soil warming on ectomycorrhizal community structure and extracellular enzyme activity at the alpine treeline in Switzerland

Souza R.C., Peter M., Nagy L., Clement C.R., Rixen C., Dawes M.A., Graf F., and Hagedorn F.

Abstract Climate change may strongly influence species distribution and, thus, the structure and function of ecosystems. Many temperate forest tree species form ectomycorrhizal (ECM) associations with soil fungi that are central to ecosystem carbon balance as determinants of plant community structure and as decomposers of soil organic matter. This study will determine the response to a 5-year-long soil warming treatment by ECM fungi associated with Pinus mugo ssp. uncinata and Larix decidua at a treeline site in the Swiss Alps (2180 m a.s.l). Community structure and functioning, as well as extracellular enzyme activity (EEA) in the soil surrounding the host tree, it will be determined. We hypothesize that (1) soil warming leads to a shift in the ectomycorrhizal community structure, given the heterogeneity of species to acclimatize to elevated temperatures and supposedly elevated nutrient availability; (2) soil warming influences the EEA profiles in the ECM root tips and in the soil, given that elevated temperatures normally enhance the chemical reactions in the soil and assuming that changed nutrient availabilities and microbial species composition will impact extracellular enzyme production. We will identify fungi by macroscopic characters and analyzing the nuclear ribosomal internal transcribed spacer region; quantify the fine roots biomass and the rate of root tips infected by ECM fungi as well as the proportion of non-vital root tips; measure the potential enzyme activity of seven hydrolitic and one oxidase enzymes directly on the ECM root tips under optimum conditions, and in different soil layers simulating natural conditions, by using fluorimetric and calorimetric microplate assays. Our analysis will combine morphological/molecular ECM identities with simultaneous ECM root tips and soil enzyme activity profiles contrasting with host tree and soil parameters to identify the levels of organization at which soil warming are translated into altered ecosystem function. We expect to detect changes in the ECM community structure in response to soil warming. The shifts in ECM community can be translated in changes of EEA in the soil surrounding the trees. Furthermore, several warming experiments have shown more active soils with increased temperature, thus it is expected to find enhanced EEA in such conditions. The microbial respiration and mineralization are known to change under experimental warmed conditions in Stillberg, but ECM community composition and the potential of EEA involved in these processes have not been investigated so far. As ECM play a crucial role in host tree and microbial community resilience the inclusion of the study of ECM is a requirement to a mechanistic understanding of functional ecological responses to climate changes.

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Plant cover changes at high elevation in central Apennines within the last 11 years

Stanisci A., Carranza M.L., Evangelista A., Frate L., and Pelino G.

Abstract In the Mediterranean area, high-elevation habitats are represented by a few isolated peaks hosting a high number of endemic and rare plants (e.g., Pauli et al. 2003, 2007; Gutiérrez-Giró and Gavilán 2010), most of them at risk for local extinction as a consequence of climate warming (e.g., Grabherr et al. 1994). In this context, the most endangered plant taxa are those typical of very cold habitats (cryophilous taxa) because of their specific physiological requirements and their weak competitive abilities (Körner 2003) in comparison with invasive thermophilous species.In the high-elevation habitats of central Mediterranean mountains, little is known today about changes at local scale in species density and distribution caused by climate change. In recent papers, concerning GLORIA monitoring network, a thermophilization and a upslope shifting effects were recorded at European scale (Pauli et al. 2012, Gottfried et al. 2012). In that paper we investigated changes in vascular species abundance at local scale (central Apennines) in 48 1X1m permanent plots, established in 2001 (GLORIA network, Pauli et al. 2004; LTER network, Bertoni et al. 2012) and resurveyed in 2008 and 2012, arranged in clusters of four quadrats, between 2405 and 2730 m a.s.l.. We analyzed differences in cryophilous and thermophilous species abundance and cover within 11 years (2001-2012).In our study area (Majella National Park), cryophilous species have an ecological optimum elevation between 2300 and 2800 m a.s.l. and their highest richness at the regional and local scales was found on cliffs and ridges habitats (Stanisci et al. 2010).Results highlight variations in vegetation total cover: a significative increase in the lowest peaks (2405-2635 m) and a significative decrease in the highest peak (2730 m). Such changes correspond to an increase in termophilous species occurrence at the lowest summits and a significative decrease of endemic cryophilous species cover at the highest summit.

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Population dynamics of Dendroctonus mexicanus parasiting Pinus cembroides populations in response to climate change

Suzán-Azpiri H., García-Rubio O., Luna-Soria H., Cambrón-Sandoval V.H., and Alvarado-Villanueva O.

Abstract Climatic changes are predicted to significantly affect the frequency and severity of disturbances in mountain forest ecosystems. One severe effect is the exponential growth of bark beetle species pests in temperate forests promoted by the gradual increase in temperatures experienced since 1990; the temperate forests in Central Mexico Mountains are not an exception. This study assessed climatic factors associated to bark beetle (*Dendroctonus mexicanus* Zucc) disturbances on three Mexican Pinyon pine populations (*Pinus cembroides* Hopkins) of the "Sierra Gorda", Guanajuato: El Rucio (Xichú), El Carricillo and Cerro Prieto (Atarjea). Survey plots were established inside *P. cembroides* patches with evident signs of bark beetle infestation. Pheromone traps were installed to collect insects during a one-year cycle. Simultaneously, temperature and relative humidity (HR) were recorded with climatic automatic data loggers (Hobo) each minute. Vegetation structure of healthy and infested patches was determined with 50x20 m plots. Significant differences ($P \leq 0.05$) for bark beetle population densities were detected between plots, and "El Carricillo" exhibited the greatest *D. mexicanus* abundance. Average temperature and relative humidity were 17.9 °C and 66% respectively. El Rucio recorded the highest temperature (19.6 °C). Results suggest that temperature and humidity are important, since the bark beetles" population rises during the drought months, and declines during rainy and cold weather months. A significant increase in mean winter temperatures explain partially the rise in *D. mexicanus* populations.

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Growth performance and spring freezing resistance in alpine dwarf shrubs

Wheeler J.A., Rixen C., Wipf S., and Hoch G.

Abstract Aims: Climate change is expected to significantly impact growth and fitness traits in alpine plants by altering temperature regimes and snowmelt timing. Reduced snowfall and earlier snowmelt may expose alpine communities to lethal freezing events, particularly during spring, which can kill biomass or reduce plant performance. This study examined growth performance and freezing resistance in four dominant alpine dwarf shrubs (*Vaccinium myrtillus*, *Vaccinium uliginosum*, *Salix herbacea* and *Loiseleuria procumbens*) along an elevational gradient (2000 to 2400 m) and snowmelt gradient (ridge and snowbed) near Davos, eastern Swiss Alps. The goals of this experiment were: i) to assess which environmental factors (elevation, soil temperature, snow cover duration) affect functional growth traits and freezing resistance (LT-50), and ii) to determine if spring freezing resistance can be linked to free sugars in leaf tissue and to frequency / recurrence of lethal freezing events in alpine shrubs.
Methods: Wood and leaf biomass were sampled from 3 specimens of each shrub species at four elevational points along a 400 m transect, and at two snow microhabitat types per elevation: an early-exposure ridge and a late-lying snowbed. Shrubs were sampled at similar phenological stages (newly opened, adult leaf tissue) in late June 2012. Leaf area, annual shoot increment, stem length and total height were measured for each specimen. Live biomass samples were subdivided and exposed to eight different freezing temperature scenarios over a 24-hour period (minimum temperature 4 °C to 20 °C) and then visually assessed for freezing damage to determine LT-50 for each species per sampling site. Non-structural carbohydrate analysis was performed on leaf tissue from the same sites to determine low-molecular weight sugar concentration. Snowmelt date and soil temperature for each site were collected from in-situ data loggers. Frequency and recurrence of lethal freezing events for each site were extrapolated using known snowmelt days (2011 and 2012) relative to an in-situ climate station (2090 m) with a 1975-2012 temperature and snow cover record.
Results: There was no link between elevation and snowmelt timing, likely due to strong microhabitat effects. *V. uliginosum* and *V. myrtillus* demonstrated reduced growth (leaf area and stem length) with elevation. However, no shrub demonstrated a growth response to snowmelt timing. There was no detectable relationship between LT-50 and elevation, snowmelt timing or soil temperatures in any species. Tall, deciduous *V. myrtillus* showed the poorest freezing resistance (mean =-5.5 °C) while prostrate evergreen *L. procumbens* was the most cold-tolerant (mean=-11 °C). *V. myrtillus* was the only species to demonstrate increased freezing resistance with higher free sugar concentrations in the leaf tissue. *V. myrtillus* was also the only species frequently exposed to lethal spring cold events (N= 241 events $\leq$ -5.5 °C) on sites above 2300 m asl during the 37-year temperature record.
Primary conclusions: Taller shrubs characteristic to snow-rich sites such as *V. myrtillus* may

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be more vulnerable to temperature and elevation-driven reductions in growth performance. In addition, they are more likely to be exposed to lethal freezing events and may therefore devote low molecular weight sugars in the leaf tissue to minimize freezing damage.

Long-term changes in plant diversity and composition on alpine summits

Wipf S., Dawes M.A., Stöckli V., and Rixen C.

Abstract To study the frontiers of plant life, botanists with mountaineering skills have centuries ago climbed and botanized many high summits in the Alps. Meanwhile, many environmental factors, such as climate, glaciations, human land-use and wildlife populations have changed dramatically. The wealth of historical data collected by our ancestors are thus a valuable baseline to study vegetation changes at high altitudes and their driving factors.In the "Summit Flora Project", we re-surveyed 124 summits between 2450 and 3420 m altitude in the south-eastern Swiss Alps to compare historical and recent species diversity and composition. We recorded biotic and abiotic variables to test their effect on vegetation development. A subset of summits with multiple re-surveys over time allows the analysis of the temporal dynamic of diversity change over the past century. We found an overall pattern of floristic enrichment on alpine summits driven by a general upwards shift in plant species distributions. Mountain altitude was the single most important explanatory variable for the rise in summit species richness, while other factors only slightly modified this pattern. The rate of species enrichment was not uniform over time but greatly increased since the 1980s/1990s, concurrent with recent climate warming. Our findings confirm the observed and modelled trend of a strong upwards shift of plant species, but disagree with predictions of high extinction risks of high-alpine species. Only few species became rarer, and we found no trend that high-alpine specialists were particularly prone to local extinctions. Future resurveys will determine whether the modelled decline occurs after a greater time lag or whether small scale heterogeneity in microclimate and microhabitats allow high-alpine specialist species to co-exist with newly arrived species.

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Part IV
Criosphere oral

Snow in the changing mountain environment: examples from the Alps andthe Himalaya-Karakoram

Provenzale A. and Terzago S.

Abstract For many river basins, winter snow cover and snowmelt are crucial determinants of the amount of water which is to become available in late spring and summer for agriculture, drinking purposes and energy production, and the timing of snowmelt contributes to setting the seasonal pace of river runoff. In addition, the time of snowmelt affects mountain ecosystem functioning and the phenology of several plant and animal species. In this talk we shall first review how snow cover characteristics are changing in the western Alps, exploring some of the effects of these changes on mountain ecosystems. In the second part, we shall extend the view to a larger region going from the Alps to the Himalaya (so the say, the Silk Road area) and discuss the current and projected changes of snow cover, comparing global and regional climate models results with the outcome of the ERA reanalysis.

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Snow cover algorithm based on 250 m modis images for monitoring temporal and spatial changes in the Alps

Notarnicola C., Tetzlaff A., Duguay M., Moelg N., Schellenberger T., Costa A., Monsorno R., Steurerd C., and Zebisch M.

Abstract This paper presents the development and extensive validation of a new algorithm for snow cover monitoring based on 250 m MODIS satellite images. Despite the availability and general performance of the MODIS MOD10 Snow Product, obvious limitations affect the monitoring of local environment and stress the need for an adapted and robust algorithm to map snow cover with the highest possible amount of spatial details. They can enable an improved determination of snow as well as more accurate depiction of the winter snowline. The EURAC snow algorithm has two main characteristics with respect to the NASA algorithm: first, it exploits the bands at 250m in order to have a snow map with improved spatial resolution; second, thanks to a direct broadcast from the EURAC receiving station the snow maps are delivered to the users in quasi real-time i.e. around 4 hours after MODIS image acquisitions (Notarnicola et al., 2013). The algorithm is divided in three main modules. The first module is devoted to snow detection based on the 250m resolution MODIS bands and on NDVI thresholds, the second to the detection of snow in forest and the third to the cloud detection. The snow layer is produced along with 4 quality layers dedicated to:

1. Snow quality flag;
2. Cloud quality flag;
3. Input data quality flag;
4. Satellite viewing geometry quality flag.

The algorithm validation was carried out by using: high resolution snow maps derived from LANDSAT images and snow depth data from ground stations in of selected test sites in Central Europe. A comparison of MODIS snow cover maps to sixteen snow cover maps derived from LANDSAT showed an overall accuracy of 93.6%. The residual mismatch area is often linked to forest, presumably due to changes in forest areas. This behavior can be therefore ascribed to limited abilities of MODIS to accurately detect the snow under forest especially under extreme illumination conditions. For the comparison with ground data, snow depth measurements from 148 ground stations in Germany, Austria, Italy and Slovakia were used. In most of the areas, the overall accuracy is around 95%. It decreases to around 80% in very rugged terrain restricted to in-situ stations along north facing slopes, which lie in shadow in winter during the early Terra acquisition. These snow cover maps are the starting points to extract further information, such as snow cover duration (SCD) and snow cover extent (SCE) from 2002-2003 to 2011-2012. The analysis of the SCD and SCE maps put in evidence the different behaviour of snow due to the landscape variability and meteorological conditions in the last ten years.

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Elevation determines the relative weight of temperature and precipitation on explaining snow cover variability: study case in Switzerland

Tejeda E.M., López Moreno J.I., and Beniston M.

Abstract Snowpack accumulation is a process that is highly dependent on particular weather conditions, namely below-zero temperature and precipitation for triggering the snowfall, and persistent low temperatures for the consolidation of the snowpack. These conditions are customary on mid-latitude mountains, due to adiabatic gradient and enhanced precipitation caused by elevation. However, the elevation at which snowpack can consolidate, may change with climate warming. The main objective of this study is to determine how elevation controls the relative role of temperature and precipitation for explaining the variability of snowpack. The snow and climate data of Switzerland (MeteoSwiss), for the 1967-2011 period, have been used for this purpose. Correlation analysis between snow indices (duration and depth) in winter and spring months, and aggregated temperature and precipitation for the previous months, was performed. Results show, as expected, that in low elevations temperature is the main driver of variability of snowpack accumulation and duration, but at higher elevations, precipitation becomes more important, as temperature is always low enough for snowpack persistence. In more detail, we observe that the duration of snowpack between November and April is explained by temperature up to 1400 m, where precipitation becomes more important. Similar results were obtained for snow depth on February, with an elevation threshold of 1.300 m. We observed as well that this threshold of elevation is not constant on time; rather it depends on the temperature conditions. Thus when dividing the study period in three time-slices, in which an increase in temperature was evident, we found a displacement to higher elevations of the threshold that separates the relative importance of temperature and precipitation as snowpack predictors. Results have outstanding implications for snow-dependent territories, such as the Alps, which could experience an even higher displacement of this elevation threshold, during warmer conditions of future decades.

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Response of snowpack to a warming climate in the Pyrenees: spatial differences induced by slope aspect

López Moreno J.I., Revuelto J., Pons M., Jover E., Esteban P., García C., and Pomeroy J.

Abstract Snowpack exhibits a marked sensitivity to temperature variability and change. Current climate scenarios project a noticeable increase of winter and spring temperature for the next decades in Mediterranean Mountains. Such warming is expected to cause a decrease in snow accumulation and a shorter duration of the snow cover, affecting the hydrological cycle, ecology and winter tourism of mountain areas. However, the response of snowpack to projected climate change is expected to exhibit a marked spatial variability as a consequence of the local magnitude of climate change, the elevation and the topographic conditions. The aim of this study is to focus on the effect of slope aspect on the response of snowpack to climate warming in the Pyrenees. For this purpose, data available from six automatic weather stations have been used to simulate the energy and mass balance of snowpack assuming different magnitudes of climate warming (increases of 1, 2 and 3°C). Snow energy and mass balance has been simulated using the Cold Regions Hydrological Model (CRHM). CRHM permits to adjust the radiation exchange from the observation sites to different slope aspects, which enable to assess the differentiated impact on the interannual evolution of snow processes. Results show a clear increase of the sensitivity of snowpack to climate warming in those slopes that receive higher solar radiation (S, SE and SW) compared to those where the arrival of radiation is more limited (N, NE and NW slopes). The effect of slope aspect on snowpack response to warmer temperatures varies amongst the six different sites, and it is also year to year variable. Normally, as more snow accumulation is observed, the differences in snow sensitivity between contrasted slope aspects were higher.

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Modelling snow, hydrology and their changes at Sierra Nevada, a high mountain in a semiarid Mediterranean environment

Herrero J., Millares A., Aguilar C., and Polo M.J.

Abstract The snow associated with high mountain zones in semiarid climates has a special relevance in terms of management, as water normally becomes a basic resource for the development of these regions. The snow reduces the direct runoff and feeds the aquifers during the spring and early summer. This supply of water at the beginning of the dry season, where precipitation tends to be scarce, diminishes the severity of the droughts. Snow and water are also basic agents in the development of the different ecosystems of these regions. However, it is difficult to derive the exact spatial distribution of these two variables in mountainous areas only from ground based measurements, whether they are ground based or remote, as they exhibit a great spatial variability. This heterogeneity, driven by the interaction of a steep topography with meteorological variables submitted to sometimes strong altitudinal gradients, is especially remarkable in Mediterranean climates. The use of physical and distributed models together with measurements, through model assimilation techniques, allows us to gain a better understanding of the processes and the quantities of the state variables and fluxes taking place in the snow and hydrologic cycle. Besides, a computer model for the simulation of the snow and hydrologic cycle permits, not only being able to better characterize current snow properties, but also to predict behaviours in foreseeable future scenarios. WiMMed is a complete hydrologic model, distributed and physically based, that was especially developed to be applied in high mountain semiarid environments as Sierra Nevada Mountains, in southern Spain. This means that the model is able to simulate snow events as well as torrential storms and persistent droughts. The snow accumulation and ablation is modelled through a mass and energy balance, which is the only proper way to capture the particular behaviour of the snow in this environment, where several snowmelt cycles throughout the year, great spatial and temporal variability, and an outstanding rate of evaporation from the snow are expected. Satellite image and terrestrial photography data can be assimilated into the model simulation and allow it to improve its predictions, usually burdened by the inaccurate spatial interpolation of the meteorological variables due to the lack of real data. Simulations show that evaporation from the snow in Sierra Nevada can range within the same year from 80% in December to 20% during the spring months and from 20% to 40% between years. Projections of more pessimistic climate change scenarios show dramatic reductions in average extension, depth and persistence of the snow, as well as appreciable changes in the hydrologic regimes of the rivers. However, present variability between years showed up in the succession of wet and dry hyper-annual cycles is already very important and tell us about a physical environment that is subdue to variable extremes in snow and hydrologic conditions.

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Climate change impact on the snowpack and resulting vulnerability of the ski resorts in the Pyrenees

Pons M., López Moreno J.I., Revuelto J., and Jover E.

Abstract Climate change is expected to lead to a decrease in snow accumulation and a shorter duration of the snow cover, affecting not only the hydrological cycle and the ecology of the Pyrenees but also the Winter tourism, one of the main source of income and development in this region. In this study, snowpack series modeled using data derived from the HIRHAM Regional Climate Model have been used to analyze the future snow cover in the Pyrenean ski resorts in two different emission scenarios (SRES B2 and A2) by the end of the 21^{st} century (2070-2100). Snow cover data is derived from a 20 points grid covering the different climatic regions of the Pyrenees. Moreover, not only the horizontal variability but also the altitudinal gradient has been considered. In this way, a 125 m of resolution has been assessed ranging from 500 to 3000 m for all the points. Using a ski resort reliability criteria, the changes on the future season length and the vulnerability of the different ski resorts has been analyzed. Most of the existing studies only take into account natural snowpack in order to assess the ski resort vulnerability. However, snowmaking is already a widespread adaptation technique and projections based only in natural snow can be misleading. Therefore, in this work, the potential contribution of snowmaking capacity for each climate change scenario has been included in the vulnerability assessment. Snowmaking potential has been estimated taking into account both technical parameters and projected minimum temperature.

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A temperature tipping point in forest-snow interactions

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Abstract Climate models project warmer winter temperatures leading to earlier snow disappearance from the landscape, which can have deleterious effects on human and natural systems, including a loss of soil insulation, declines in surface albedo, loss of late-season soil moisture for ecosystem health, and declines in late-season streamflow. Forests intercept snow and emit longwave radiation but also shelter snow from wind and solar radiation. Thus, decreased accumulation under trees is generally offset by decreased melt rates, but different processes dominate in different settings. The variable net effects of forest on snowpack have led to apparently conflicting conclusions regarding whether lower-density forests (from cutting, fire, or natural disturbance) result in longer- or shorter-lasting snow. Here we combine a meta-analysis of observational studies across the globe with modeling to show that in regions with average December-February temperatures greater than -4°C, decreasing forest density increases snow duration by decreasing longwave radiation and minimizing mid-winter melt. In many locations, mid-winter melt removes forest snow before solar radiation is great enough for forest shading to matter, and with warming temperatures, mid-winter melt is likely to become more widespread. Currently, these warm-winter forests are found in the Sierra Nevada and Cascades of the western United States and at some locations in the Alps. With warming temperatures, locations where snow has historically melted more slowly and lasted longer under forests may switch so that snow melts faster and lasts a shorter duration under the forest canopy compared to nearby clearings.

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Observing snow storage with GPS receivers

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Abstract Mountain snow storage serves as an essential freshwater resource for the forelands. Therefore profound knowledge about accumulation and ablation of the alpine snowpack is very important for assessing water supply, particularly under future climate change impacts in high mountain regions. However, existing satellite and in situ snow measurement systems are still not sufficient or have to be further developed to meet this task because they are often either expensive, man-power intense or in a low temporal or spatial resolution. We started a snow measurement field experiment by using simple, low-cost GPS receivers at the alpine test site Weissfluhjoch at 2.540 m a.s.l. near Davos in Switzerland. During the entire winter period, GPS data of the globally and freely available L1-band (1575.42 MHz) are continuously collected from one receiver underneath the snow cover and another one above it. Since snow attenuates microwave radiation, the aim of this methodological approach is to derive continuous information about accumulation and ablation of the snowpack and its characteristics from differences in the signal-to-noise ratios of the two GPS receivers. The validation basis includes conventional meteorological and snow-hydrological measurement data, which are recorded in parallel at this test site. Preliminary results of this new approach are presented.

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Modelling glacier changes in western Canada

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Abstract Glaciers are in retreat in western Canada, as in most of the world's mountain ranges, with impacts on water resources and stream temperatures. In the southern mountain ranges, glacier runoff appears to have peaked in recent decades and is now in decline as glacier areas make up less of the landscape. This is an emerging threat to fish habitat in rivers of western Canada, and is also influencing the availability and timing of streamflow in many important river systems. We present an inventory of recent glacier changes in the Coast, Columbia, and Rocky Mountain ranges of Alberta and British Columbia and introduce a regional model of glacier mass balance and ice dynamics to simulate recent and future glacier response to climate change. Within this model we develop a new framework for distributed modelling of snow and ice melt, based on perturbations to the surface energy balance that are informed by field measurements on select glaciers in the region and by climate model scenarios.The model provides an estimate of glacier contributions to streamflow and it allows a separate inventory of the amount of runoff associated with seasonal snow vs. the glacial ice reservoir. We can expect the former to be renewable, whereas the water stored in glacier ice appears to be a diminishing resource. We project a loss of 85% of the glacial ice from the Canadian Rockies by 2100, with associated declines of 5-10% in July-September river flow in Alberta's major urban centres.

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Climate Change Impact on Cryosphere in Central Southern Himalaya (Nepal)

Salerno F., Thakuri S., Viviano G., Guyennon N., D'Agata C., Smiraglia C., and Tartari G.

Abstract With the aim of understanding the relation between climate and glacier dynamics, we analyse glacier changes from 1958 to 2011 and meteorological observations from 1992 to 2011, in Sagarmatha (Mt. Everest) National Park, using satellite imagery, maps and insitu field measurements. Multi-temporal satellite products and topographic maps were used for glacier terminus, surface and snowline altitude (SLA) analysis from 1958 to 2011. We observed the continuous decrease of glaciers in 1958-2011 with accelerated rate in the recent years. The average terminus retreatment of analysed 29 glaciers was about 372±37 m (7.0 m a^{-1}) in 1958 to 2011 with retreat rate of 6.1±1.9 m a^{-1} in 1958-75 and nearly its double in 2008-11. The glacier surface area had loss of 14.3±5.9% (0.27% a^{-1}) from 396.2 km^2 to 339.5 km^2 in 53 years with the loss by 0.12 % a^{-1} in 1958-75 to 0.70% a^{-1} in recent years. The smaller glaciers with <1 km^2 dimension had decreased by 43% in their surface area showing rapid disappearance of very small glacier. The accumulation area decreased by 24.8%, while ablation area increased by 17.7% with nearly 6% increase in debris-cover surface in ablation zone in 1958 to 2011. The accumulation and ablation area changes can be explained by SLA position which was continuously moving upward from 5279 m a.s.l. (σ=144) in 1958 to 5472 m a.s.l. (σ=209) in 2011 with the overall vertical shift of 192±9 m (3.6 m a^{-1}). The rate of SLA shift was the highest in recent years with the rate of 12.8±2.9 m a^{-1} a.s.l. while the rate was observed 2.1±1.7 m a^{-1} in 1958-75. Majority of glaciers are retreating but some glaciers observed as stationary or even advancing in certain period of analysis. The overall glacier change behaviors are similar to glaciers observed in other part of the Himalayan region. We reconstruct single series both for temperature and precipitation through the monthly quantile mapping and expectation maximization techniques from the insitu observations in different automatic weather stations located in the Mt. Everest region. The singular spectral analysis and monthly sequential Mann-Kendall test of the temperature and precipitation for 1992-2011 indicated that the temperature has increased about +0.03°C a^{-1} but statistically significant only for winter months. The precipitation has decreased about 180 mm in the analysis period. The decreases in precipitation are statistically significant for both winter and summer precipitation. We conclude by underlining that the observed variation of glacier surface and SLA changes could be explained by the increase of temperature and decrease of precipitation in recent years.

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Enigmatic glacial ice recession on a sub-tropical glacier, Pico de Orizaba, Mexico

Weissling B.P. and Lewis M.J.

Abstract El Pico de Orizaba (5636 m) is located on the border between the States of Puebla and Veracruz, Mexico and is the third highest mountain in North America, and the tallest peak of the Trans-Mexican Volcanic Belt. In topographic prominence it is ranked second in the world for volcanic peaks behind Mount Kilimanjaro and seventh in the world for all peaks. It is known internationally by mountaineers for moderate slopes, relatively stable weather, high elevation and exceptional climbing opportunities. Pico de Orizaba draws hundreds of visitors each year to climb the Gran Glaciar Norte (aka Jamapa Glacier) and supports numerous local guide and ancillary services. In terms of resource dependence, snow and glacier melt runoff from Pico de Orizaba provides an important water source for local communities surrounding the peak. Since an IGY (International Geophysical Year) study of the glacier in 1957-8 by J. Lorenzo, the Gran Glaciar Norte has seen a 65% loss of glacial area and a 500 m vertical retraction of the primary glacial tongue (Jamapa tongue) as recently assessed with satellite imagery, geophysical investigations, and first-hand accounts from climbing expeditions. The ablation rate of glacial ice on Pico is consistent with recession rates (area and extent) witnessed on other tropical and subtropical glacier systems around the world rates most likely attributed to atmospheric warming and/or drying. However, in the case of Pico, it is unclear as to whether ice loss can be attributed all or in part to climate change forcing. In 2010-11, a 20 month vertical temperature profile was obtained on the mountain, spanning a 1000 m range (4200-5200 m, every 200 m), and sampled at 2 hr intervals. Preliminary evaluation of this data set has indicated a 0°C isotherm, at the end of the primary summer ablation season, well below ($>$ 500 m) the elevation of the current glacier foot, which now stands at 5050 m. A corresponding evaluation of LandSat and MODIS imagery acquired since 2002, has likewise indicated snow line elevations, subsequent to dry (winter) and wet (summer) season storm events, 200-600 m below the present glacier foot. Summer season melt-water has been frequently observed at the foot of the Jamapa tongue, emanating not from the glacier surface but from terminal sub-ice gravels, suggesting perhaps a bottom melt phenomena playing the dominant role in glacier recession. Data and observations from our remote and in situ studies will be presented and discussed in this presentation, in the context of a mountain deservedly a candidate for inclusion as a Mountain Under Watch.

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Morphodynamics of the Mont Blanc massif in a changing cryosphere

Deline P., Gardent M., Magnin F., and Ravanel L.

Abstract One of the most glacierized and elevated areas in the European Alps, the Mont Blanc massif illustrates how accelerated change affects the cryosphere and its related morphodynamics in high mountain environments, especially since the termination of the Little Ice Age. Contrasts between the NW side, gentle and heavily glaciated, and the SE side, steep and rocky, as between local faces of which slope angle and aspect are extremely varying, make the study of the massif particularly relevant. Glacier shrinkage is strong at low elevation - even if less than in other Alpine massifs - whereas supraglacial debris covers develop on all the glaciers, several being debris-covered since the nineteenth century. Lowering of glacier surface also affects areas of the accumulation zone. If modern glaciology is carried out in the massif since several decades, study of the permafrost is under development since few years only, especially in the rockwalls. Many hazards are related to glacier dynamics. Outburst floods, especially from englacial pockets, ice avalanches from warm-based to cold-based glaciers, and possible effects of glacier shrinkage on the rock slope stability, are generally increasing with the current decrease or even the vanishing of glaciers. Active permafrost degradation is likely triggering rockfalls and even rock avalanches, participating to the chains of processes resulting from the high relief of the massif. Generated hazards could increasingly endangered population and activities of the massif valleys.

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Spatial models of mountain permafrost: challenges for the coming decades

Gruber S.

Abstract Models are simplified representations of reality. We use them as concrete formulations of our understanding against which to interpret observations, and for estimating characteristics of natural systems. Research on mountain permafrost has developed largely from geomorphological interest in rock glaciers and issues concerning high-elevation infrastructure or natural hazards in the European Alps. During the past twenty years, however, many changes have occurred: (a) Climate change and its consequences for cryosphere systems have become more pronounced and more recognized. (b) Human infrastructure and activity have continued expanding into areas affected by mountain permafrost. (c) Geospatial technology as well as the availability of corresponding data products and computing power have developed rapidly. As a consequence many aspects of mountain permafrost research, too, are changing: its geographic scope, its societal relevance, the methods used, the disciplines involved, and, last but not least, the permafrost itself may be undergoing differing types of change than what one commonly expected twenty years ago. This contribution will provide illustrative speculations and research results concerning questions such as: What information and accuracy do we really need from our models? Where are mountain permafrost models most useful - in the Alps or in other mountain ranges? How can we make sure that results have a known reliability at every point we simulate? If we already have problems simulating where permafrost is, how can we hope to also model transient changes of the conditions we dont know? Is there really a big difference between lowland and mountain permafrost models?

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Watching permafrost in the Swiss Alps : experiences from the PERMOS network

Delaloye R.

Abstract The Swiss permafrost monitoring network (PERMOS) was launched in 2000 with the aim of documenting the state of permafrost in the Swiss Alps and its changes over time. PERMOS has developed from a loose aggregate of research sites towards an operational system with long-term funding and integration into various national and international monitoring structures. To capture the complex interaction of subsurface thermal conditions with the atmosphere in a comprehensive picture of permafrost in the Swiss Alps, PERMOS follows a landform based approach (rock walls, bedrock outcrops, rock glaciers, talus slopes, ...) with three main elements of observation: (1) ground temperatures in boreholes and at the surface, (2) changes in unfrozen water content at the drill sites (by geo-electrical surveys), and (3) velocities of permafrost creep determined (by geodetic surveys and photogrammetry). The PERMOS network is organized in two groups of sites, namely the (i) temperature and (ii) kinematics sites, each comprising a set of reference and additional sites. After implementation and consolidation of the network structure and monitoring strategies, the main focus currently lies on processing, standardization and archiving of the permafrost data. A PERMOS data base with format and processing standards as well as a user friendly interface is being built up. The data base will include data from the three observation elements from all PERMOS sites with time series up to 15 years and more for temperature measurements.Recent developments in PERMOS and some main results will be presented. A special focus will be on temperature and kinematics time series and their possible relations.

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Permafrost investigation in the Mont Blanc massif steep rock walls: a combined measurement, modelling and geophysical approach

Magnin F., Deline P., Ravanel L., Gruber S., and Krautblatter M.

Abstract We started permafrost investigation in high-elevated steep bedrock of the Mont Blanc massif in order to explore the possible linkage of its degradation with the increasing rock fall activity. We first aim at understanding its characteristics in complex alpine topography, its distribution in the massif, and the relationship between temperature at the rock surface and at depth (below the active layer). Since 2005, a monitoring system has been installed at the Aiguille du Midi (AdM), whose three granite peaks culminate at 3842 m a.s.l., in collaboration with ARPA VdA, the University of Zurich and the Technical University of Munich. Rock temperature measurements around the Piton Central mainly emphasize the importance of the topoclimatic control on permafrost distribution: the difference of Mean Annual Rock Surface Temperature (MARST) is 7-8°C; warm (> -2°C) and cold permafrost coexist within the rock mass, 2010 and 2011 active layer thickness is in the range of 2-6 m according to aspect and slope. The variable amount of short-wave solar radiations received at the rock surface is the dominant factor responsible for spatial contrasts whereas changes over time are mostly controlled by air temperature. Rugged and fractured areas are additionally influenced by heterogeneous snow deposit and interactions in the heat transfer processes which can significantly impact the temporal patterns. Distribution of the MARST at a regional scale (Mont Blanc massif) has been simulated in a GIS-based statistical model based on a 4-m-resolution DEM by using direct solar radiation and air temperature parameters. The model shows that the isotherm 0°C is close to 3600 m a.s.l. on south aspect, and near to 3000 m a.s.l. on northern slopes. By comparison with the AdM data, the simulated MARST appears realistic. However, the modelling procedure does not include possible snow cover or fracture effects which can cause a thermal offset (i.e. temperature difference between rock surface and deeper layers) in the range 1-3°C. Therefore, we assume that permafrost can exist at depth below positive MARST. We evaluate this assumption by performing Electrical Resistivity Tomography (ERT) measurements along five 160-m-long survey lines on various steep rock walls of the massif between 2750 and 3350 m a.s.l. with -1°C to 3°C simulated MARST. ERT has been shown as a reliable tool for permafrost detection in former studies as rock freezing and thawing are associated with significant resistivity changes. The median depth of investigation of the five transects reaches 30 m. The ER tomographies all indicate high resistivity bodies which are interpreted as permafrost occurrence at depth and remarkable patterns coherent with elevation and with topographical settings. They provide data to investigate the topographical control on permafrost occurrence and the relationship between surface temperature and permafrost at depth. An overview of these methods and current understanding will be presented.

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Determining Sources of Nitrate in Surface Waters of an Alpine Basin in the Colorado Front Range using Triple Isotopes of Oxygen in Nitrate

Williams M.W., Hafich K., and Savarino J.

Abstract High elevation ecosystems throughout the Colorado Front Range are undergoing changes in biogeochemical cycling due to an increase in nitrogen deposition in precipitation and a changing climate, resulting in changes in alpine biota and water quality. Between 1985 to 2009, nitrate concentrations in the outflow of Green Lakes 4 (GL4), at the headwaters of Boulder Creek, have increased 0.27 μmol L^{-1} per year, yet the question remains whether the primary source of increasing nitrate in Green Lakes Valley (GLV) is atmospheric or terrestrial. Previous research in the GL4 catchment suggests that nitrification in barren soils, talus and rock glaciers, not atmospheric deposition, is the primary source of nitrate in surface waters. Additionally, increasing nitrate levels could be attributed to melting ice features-permafrost and a rock glacier-in the valley associated with increasing hydrologic connectivity. Coinciding with climatic changes (drought), the nitrate-N yield of the GL4 catchment increased by 40%, from a mean of 1.7 to 2.3 kg N $ha^{-1}yr^{-1}$ between the periods 1985-1999 and 2000-2009. During the dry period, 2000-2009, noticeably high nitrate concentrations were recorded from the rock glacier above GL4 of up to 135 μmol L^{-1}, as well as high concentrations in talus runoff of up to 94 μmol L^{-1}. A synoptic survey of talus streams from summer 2012 showed similar results, with a maximum nitrate concentration of 84 μmol L^{-1} and a mean concentration of 33 μmol L^{-1}. We aim to characterize nitrate pathways in GLV with an analysis of triple oxygen isotopes of the nitrate molecule, a new method that allows us to disseminate whether nitrate in surface waters is from atmospheric deposition or produced by nitrification by microbial communities. Samples were collected weekly throughout summer 2012 from surface streams, talus streams, snowpack, snowmelt, soil water and precipitation. High nitrate concentration values found in GLV are consistent with carbon limitation in barren soil areas combined with increasing nitrogen deposition, resulting in an increase in net nitrification and nitrogen export from microbially dominated landscape types-talus, rock glaciers, permafrost-to streams draining alpine watersheds.

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Stream ecology in Alpine streams: does management overwhelm climate change?

Bruno M.C., Maiolini B., Carolli M., Siviglia A., and Zolezzi G.

Abstract Flow and temperature regimes are the main driving forces influencing habitat structure and ecological functions in lotic ecosystems. The five major components of flow regime: magnitude, duration, frequency, timing and rate of change regulate the ecological processes in river ecosystems. The natural temperature regimes of rivers provide thermal cues that stimulate responses in many aquatic species, and affect many physical and chemical processes which play a crucial role for community composition of stream macroinvertebrate communities and for individual species. In Alpine streams, the presence of hydropower plants can significantly alter the hydrological and thermal regimes. Water is abstracted from headwaters, stored in artificial, high elevation reservoirs, used to produce hydropower and finally released downstream in the form of "hydropeaking" (i.e. sharp releases of water which, in Italian rivers, can increase the discharge of 10x the baseflow). On a yearly time scale, hydropower production has been impacting the temperature and flow regime of most Italian Alpine rivers from the middle of the last century. In general, a progressive flattening in the hydrograph occurred. The alterations in temperature are represented by a decrease of water temperatures from the beginning of spring to the end of summer downstream of the point where hypolimnetic waters are released, and a warming of the receiving waterbody from the beginning of autumn to early spring. Examples from rivers of different typology are presented to show the alterations of the thermal and discharge regime, and their ecological effects, based on the results of our research. In Alpine streams, the impacts of climate change will sum to those of management. Because the hydrological cycle will be enhanced under warmer climatic conditions, the current distribution, seasonality, and amount of precipitation will undergo significant changes. Due to the forecasted glacier retreat, in glacierized basins a temporal shift of discharge peaks due to increase of snowmelt vs glaciermelt towards early summer instead than mid summer will occur; as a consequence, there will be an increase of water to be abstracted and stored in reservoirs in the short term, but less water in the long term when smaller glaciers will disappear. Due to reduced snowfall, more water will be needed for production of artificial snow. In view of the forecasted climate change and consequent increase in water demand in the Alps, it is crucial to direct Alpine research to a better understanding of the changes occurring in freshwater ecosystems in order to produce new ecologically sustainable management recommendations.

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Observing and simulating hydrological variability in a changing alpine watershed: The Durance River case-study (French South Alps)

Kuentz A., Mathevet T., Gailhard J., Perret C., and Andréassian V.

Abstract Improving the understanding of mountain watersheds hydrological variability is a great scientific issue, for both researchers and water resources managers, such as Electricit de France (Hydropower Company). The current climate change context enhances interest on this topic. The Durance river watershed (14000 km^2), situated in the French Alps, is a good example of the complexity of this issue. It is characterized by a variety of hydrological processes (from snowy to Mediterranean regimes) and a wide range of anthropogenic influences, which mixes numerous potential causes of changes in its hydrological regimes. As water related stakes are numerous in this watershed, improving knowledge on the potential hydrological variability of the Durance River appears to be essential. As future remains unknown, the only observed information available about this variability is past, and this is one explanation of hydrologists' interest about historical data and long climatic or hydrologic series. For the Durance watershed, historical searches allowed to bring to light about ten long historical series of daily streamflows, beginning on the early 20^{th} century. After a quality and spatio-temporal homogeneity analysis, these series lead to a better knowledge of the hydrological variability of the Durance River over the last century. This type of series is unfortunately not always available, and the more we go back to the past, the weaker spatial density of such data becomes. We propose in this paper a methodology to build long climatic series (air temperature and precipitation), mixing large scale climatic data (geopotential fields, some of them available from 1850) and local observations. Streamflow series are then easily obtained using a hydrological model. Application of this method on several points of the Durance waterhed, and comparison of the results with the collected long historical streamflow data allows us to validate the whole reconstruction chain. Surprisingly, results reveal a rather good reconstruction of the interannual variability, streamflow distributions and hydrological regimes. Finally, up to 25 centennial daily streamflow series have been reconstructed on the watershed, offering a new vision of low-frequency hydrological variability in this region. Next step will be to link this low-frequenty variability to large scale climatologic indices like NAO (North Atlantic Oscillation) or AMO (Atlantic Multi-decadal Oscillation).

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Increasing solute contents in high altitude lakes as an effect of climate warming

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Abstract The water chemistry of mountain lakes and its change in time is affected by variation in atmospheric deposition and climate. Climate warming is proved to be particularly pronounced in the Alpine region. It may affect both quantity and quality of water in mountain areas. The effects of climate warming on mountain lakes are mainly indirect, and result from a combination of multiple stressors. Temperature increase may enhance biological processes, both in soils and water, leading for instance to increasing nutrient uptake. Mineralization and nitrification are also temperature dependent processes, and may be speed in a warming climate. Climate also affects physico-chemical processes such as weathering of rocks and soils, changing the amount and typology of solute release from the catchment to the lakes. In this context, even more important than the direct role of temperature, is the indirect effect of the change in snow cover. A reduction of snow cover in space and time means indeed a greater exposure of rocks and soils in the watersheds, and possibly a greater amount of solutes export to surface water. In this study we focused on the possible effect of these processes on long-term changes in the chemistry of alpine lakes. We analysed long-term chemical data (major ions and nutrients) available for a number of high altitude lakes in different regions of the Alps and analysed changes in relation to the main meteorological variables (temperature precipitation, snow cover). Continuous data over a 30 year period are available for a few lakes in the Central-Western Alps. These data allow us to analyze both long- and short-term trends, considering for instance the interannual variability in lake chemistry in relation to striking meteorological condition. Beside this high-frequency monitoring of a few sites, surveys of lakes in different Alpine areas (e.g. Ossola and Sesia Valleys, Piedmont; Stelvio National Park, Lomabardy) allowed a comparison with data available on these sites since the 1980s from previous research projects. This dataset altogether was used to test the occurrence of common trends in the chemistry of high-altitude lakes over the last 30 years. A general tendency to increasing solute content during the observation period was detected, with more pronounced trends at lakes with highly mineralized water. A positive trend of sulphate concentrations was observed at most of the lakes, sharply in contrast with the decrease of sulphate deposition which has occurred in the Alpine region as over most of Europe in the last decades. Hence a climate signal may be hypothesized to explain this trend. The observed trends in the Alps were compared with those occurring at mountain lakes in other remote regions. Long-term chemical data are available in particular for two lakes in the Khumbu Valley (Himalaya, Nepal), as part of the LTER network. These lakes showed positive trends of the conductivity and major ions, more evident in the last few years. As for the Alps, also these trends may be put in relation to changing climate condition, in particular to increasing temperature and reduced snow cover in the catchment.

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Nitrogen dynamics at high elevation basins in the Khumbu Valley (Nepal Himalaya), combining isotopic and geochemical tracers

Balestrini R., Polesello S., and Sacchi E.

Abstract Among the alpine environments of the world, the region of Mount Everest, is a unique ecosystem with a degree of biodiversity among the highest existing, but characterized by a recognized fragility and low resilience. There is a growing concern about the potential effect due to the global warming and other large scale phenomenon such as the atmospheric brown cloud on aquatic undisturbed systems in the Himalayan region. A yearly sampling campaign was conducted in the Khumbu Valley, within the Sagarmatha National Park, during the monsoon season in 2008 to collect surface water samples at high elevation from 4300 to 5500 m asl. In addition during 2007 and 2008 the daily sampling of wet deposition was carried on at 5050 m asl at the Nepal Climate Observatory - Pyramid ABC site located in the same area. We determined the main hydro-chemical species and the stable isotopes of oxygen (δ18O) and deuterium (δ2H) on both rain and surface water samples Nitrate was the dominant nitrogen species in running waters, with a median concentration equal to 7 μeq l^{-1}, while ammonia and organic nitrogen were below the detection limit. For comparison, nitrate concentration doubled the value measured in rain. The yearly N deposition load, equal to 0.31 kg ha^{-1} y^{-1}, was remarkably lower than that measured at high elevation areas in Europe and North America. The δ18O and δ2H compositions of the precipitation showed a large variability, ranging from -1.9 δ‰ to -23.2 δ‰, and -0.79 δ‰ to -174 δ‰, respectively. Also the deuterium excess was highly variable, ranging from 7.4 δ‰ to 19.8 δ‰ with an average value of 12.2 δ‰. Based on weekly precipitation values, we defined the equation of the local meteoric water line (LMWL), which is remarkably close in slope to the global meteoric water line (GMWL), but with a higher intercept. The isotopic composition of precipitation is strongly influenced by the amount of precipitation: depleted values, associated to large precipitation amounts, characterize the central monsoon period. In comparison, the isotopic composition of stream water only show minor seasonal fluctuations, of about 2 ‰ in δ18O. Stream water isotopic composition falls on the previously defined LMWL, indicating a minor influence of evaporation. Stable isotopes and geochemical tracers (e.g. electrical conductivity and ion concentrations) were used to infer the streamflow components, and derive information on runoff processes and flowpaths.

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Part V
Criosphere poster

Recently deglaciated areas in Aosta Valley and geotechnical properties detection

Arato A., Ferrero A.M., Filippa G., Franco D., Godio A., Migliazza M.R., Morra di Cella U., Pogliotti P., Vagliasindi M., Sambuelli L., and Théodule A.

Abstract Over the last decades, especially since the second half of the eighties, an increasing glaciers shrinkage has been observed worldwide. In Aosta Valley glaciers reduction has been evaluated for the periods 1975-1999 and 1999-2005 by comparing glaciers outlines manually drawn in GIS using orthorectified aerial photography. A surface area reduction about 18 km^2 was found for the 1999-2005 period and about 34 km^2 in the period 1975-1999, with a total amount of 52 km^2 in the interval 1975-2005. Area loss percentage is strongly affected by initial glaciers dimension (basins with smaller glaciers have encountered greater percentage area loss) and by altitude range. Considering the interval 1999-2005, most part of recently deglaciated areas are located in the range between 2750 and 3250 m asl. A considerable part among them (5.3 km^2) is covered by loose debris. Glaciers shrinking thus results in surfacing of large recently-deglaciated areas, where rapid and active geomorphological processes usually occur due to geotechnical characteristics of glacial deposits, strong melt and water runoff, glacial lakes floods, permafrost degradation. These processes may result in increasing of natural hazards in mountain areas. In order to better understand processes occurring in these areas and their possible effects, specific surveys and tests have been carried out in the frame of GlaRiskAlp project (funded by the Alcotra Italy-France 2007-2013 territorial cross-border cooperation program) in a selected test-site. Geophysical surveys (GPR and seismic) allowed to detect thickness and some physical properties of the deposits, and water content and inside temperature have been continuously measured over two years, while laboratory tests allowed to understand mechanical properties and their correlation with lithology, temperature, water content and other parameters. Interesting correlations have been pointed out.

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Hazard assessment of debris-flow originating from alpine permafrost area, two case studies in Valais

Bardou E., Favre-Bulle G., and Rouiller J.D.

Abstract In the framework of the project "Safety management of cross-border mountainous territories" (RiskNat-Alcotra), two sites were studied in Valais. This assessment assumes that the permafrost has been already detected on the site. Therefore, its exact local extension as well as its dynamics should be evaluated. The results of these investigations have been compiled in the form of guidelines (available on www.crealp.ch/permafrost). The proposed stepwise procedure is as follow:

1. Preparation and literature compilation
2. Dedicated mapping
3. Displacement analysis
4. Geophysical investigations
5. Control drilling
6. 3D modeling and calculations

Several methods have to be adapted to the conditions of the high mountain. In addition, the final result requires the combination of all the methods, which required the use and development of software ensuring consistency between data from various sources. This integrated procedure can lead relatively quickly to an estimate of the downstream risks. Although it should be known that the duration of the study cannot be reduced under 2 years).

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Evaluation of MODIS Snow and LST data in Arunachal Pradesh: Heat pump or Freezer

Baruah U.D. and Saikia A.

Abstract The NSIDC (National Snow Information Centre) archives and snow cover and sea ice data products from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on NASA's Earth Observing System (EOS) Aqua and Terra satellites. The MODIS/Aqua Snow Cover Monthly MYD10CM data set used in the study, consists of 7200 column by 3600 row global arrays of snow cover in a 0.05 degree Climate Modeling Grid (CMG). The MODIS snow cover data are based on a snow mapping algorithm that employs a Normalized Difference Snow Index (NDSI) and other criteria tests. Additionally MODIS MYD11CMLST (Land Surface Temperature) data comprising of daytime and nighttime LSTs was used. The objective of this paper is to validate MODIS snow and LST data, to evaluate the relationship between LST and snow and to estimate the temporal change in LST and snow cover in Arunachal Pradesh (AP). Data was processed for a period of 10 years for randomly selected study sites in Arunachal Pradesh using a geographic information system (GIS). When plotted in scatter diagram a linear positive relationship between 8-daily LST and monthly average snow is seen. This means that the study sites are also experiencing more heat and less snow fall with increases in temperature and other climatic attributes. The fast retreating snow line shift in the month of July and heavy snowfall in January is one of the evidences of the effect of heat over the earth's surface.

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Application of image correlation techniques to TLS datasets for quantifying surface displacements of rock glacier

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Abstract In the context of climate change, mountain permafrost is affected by a pluri-decadal warming that has strong implications in terms of slope stability and dynamics. Permafrost degradation is well exemplified by recent acceleration and destabilization of rock glaciers, suggesting that potentially catastrophic phenomena may threaten societies. Therefore, it is necessary to better understand the deformation mechanisms of ice-rich permafrost along mountain slopes. In this sense, this study aims at using Terrestrial Laser Scanning (TLS) to accurately quantify surface deformation of rock glaciers at an interannual and pluri-annual scale. We focused on the Laurichard rock glacier (Hautes Alpes, France, $\sim$ 2500 m asl) which is already subjected to an annual geodetic survey since more than twenty years. The surface of the rock glacier was scanned three times with an average density of 7 points m^{-2} and referenced using DGPS-measured fixed points. The main challenges arose from the topographic variability: microtopographic features like plurimetric ridges and furrows shield some areas from the laser, whereas surface roughness of the pluri-decimetric coarse blocky cover is difficult to cope with when comparing point-clouds between each others. We employed 3D point-cloud processing and image correlation tools to

1. adjust separately annual scenes;
2. georeference them;
3. compare 3D-datasets together with a sub-decimetric precision and;
4. extract various spatially-distributed measurements.

High resolution maps of surface kinematics quantities were validated from comparison to in situ high precision geodetic measurements: at the various considered time scales, the differences between TLS-derived measurements and geodetics measurements are lower than 5 cm a^{-1}. The spatially-distributed information provides rich insights into the deformation mechanisms of rock glaciers and open new challenging opportunities to move further into rheological laws and physical models.

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Geophysical investigation of a rock glacier

Cadet H. and Brenguier O.

Abstract In the European Alps, global warming has been characterized by increasing minimum temperatures of about 2 °C during the 20th century. Such changes have caused pronounced effects on glacier and permafrost. Permafrost is ground with a temperature below 0 °C for at least two successive years. In France, permafrost covers about 6% of the Alps surface and may exist above 2300 m a.s.l.. Due to global warming, lower altitudes of permafrost occurrence in the Alps could rise several hundred meters. Furthermore, temperature changes imply changes in mechanical properties of the affected materials that reach a disequilibrium point. Pronounced disequilibria could increase natural hazard and thus risks regarding individuals and infrastructure in Alpine environments. As these mechanicals properties changes can often not be detected from outside, the detection and anticipation of this hazard is difficult. Therefore geophysical approach was performed to investigate the permafrost body. Permafrost has different kind of occurrence, rock glacier is one of the most recognizable one. It is a mix of ice and debris. This work had two main objectives. The first objective was to determine the thickness of a rock glacier to give a first estimation of the volume. The second objective was to determine the thickness of the active layer which is highly instable in case of high precipitations. Finally the achieved experiences have helped us to propose a methodology for rock glacier characterization. Investigations were carried out on the Bellecombes rock glacier, located in the French Alps, at the "2 Alpes" winter ski resort (Isre, France). Investigations were composed of borehole, electrical tomography profiles, seismic tomography profiles, seismic profiles for surface-wave inversions, H/V measurements, and ground penetrating radar (GPR) measurements. Results show that geophysical investigations improve knowledge of internal structure of rock glacier when they are combined with preliminary geomorphological study and boreholes. The active layer is well characterized by H/V method (a low-cost and fast deployment method) combined to local Vs estimation. GPR characterizes also well the active layer. Electrical tomography detects very well the presence of ice but could not estimate permafrost depth due to equivalence principle. The permafrost thickness is difficult to image with electrical tomography or seismic methods whereas GPR with low frequency antenna shows clearly permafrost body. Finally boreholes are essential to calibrate geophysical results. The methodology to characterize such rock glacier is:

1. Geomorphological study to determine the potential surface limits of the rock glacier;
2. Electrical and seismic profiles to confirm and precise the ice occurrence;
3. Temperature measurements to cross-check the results with steps 1 and 2;
4. Boreholes to fix the rock glacier thickness locally;
5. GPR investigation to define the thickness of the rock glacier globally.

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This study was financed by the MAIF project “Analyse des risques induits par la dgradation du permafrost alpin”, Permanet, the PARN 2010 project and the 2 alpes ski resort. All these studies enhance understanding of permafrost characterization, evolution and modeling of their degradation.

Verification of thermal values forecasted in the valle d'Aosta region by the meteorological model COSMOI2 and the algorithm Multimodel

Cassardo C., Diémoz A., Pellegrini U., and Ratto S.

Abstract In recent years, the development of computers led to the increase of the resolution of numerical models meteorological, increasing also the number of processes explicitly solved and, consequently, the quality of the forecasts themselves. However, even if the evaluation of the latter has been done extensively, the number of studies conducted at the local level and in situations of complex terrain is much more limited. This study focused on the verification of the temperature prediction in a morphologically complex territory as the Valle d'Aosta. The Regional Functional Center of Valle d'Aosta makes meteorological forecasts and possesses the archives of the forecasting model COSMOI2 and the post-processing algorithm Multimodel developed by ARPA Piemonte. This center aims to provide for the minimum and maximum daily temperature on a selection of locations. To this end, a verification of the predictions of maximum and minimum 2m daily temperature by the two above-mentioned systems has been carried out. The results have shown that COSMOI2 predictions are, in general, less reliable than those of the Multimodel, in both cases showing significant errors in some peculiar situations. A common difficulty is the reproduction of the topography, which affects the poor reproduction of some very local scale phenomena, such as temperature inversions, the foehn winds and breezes, the differential solar radiation depending on exposure and elevation. In conclusion, the reliability of the Multimodel, calculated as the percentage of predictions within 2.5 °C of error, has resulted 80-90% for the minimum temperatures and just over 70% for maximum in all seasons.

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Five years of microseismic activity and temperature monitoring at J.A. Carrel hut (3829 m s.l.m.), Matterhorn

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Abstract The permafrost degradation is a probable cause of the increase of rock instabilities observed in recent years in the Alpine region. In warm periods, the thaw of the ice filling rock discontinuities and the deriving hydro-thermal heat transfer induce strength reduction in rock masses; during the cold season, the thermo-mechanical forcing are reinforced by the cryogenic process that freezes water circulating in rock fractures. These processes induce stresses in the rock mass that may lead, in the medium-long term, to rock-falls. In the meanwhile, the formation of cracks in rocks is often accompanied by a sudden release of energy, which propagates in form of elastic waves and can be detected by a suitable transducer array. Therefore, if geophones are among the most effective monitoring devices to investigate eventual precursors of rock-fall phenomena, monitoring the thermal regime in steep rock walls is of paramount importance to investigate the effect of climate on high mountain rock instabilities. The awareness of these phenomena was raised in summer 2003, when an exceptional heat wave hit central Europe and was accompanied by a large series of events along the entire alpine chain. As a consequence, to investigate these processes a monitoring system composed by geophones and thermometers was installed in 2007 at the J.A. Carrel hut (3829 m a.s.l., Matterhorn, NW Alps) as part of the activities carried out within the Interreg IIIA Alcotra project PERMAdataROC. In 2010, in the framework of the Interreg 2007-2013 Alcotra project MASSA, the microseismic monitoring system was empowered and renovated by the CNR IRPI Torino with the financial support of Regione Valle d'Aosta. The network presently includes five triaxial high frequency geophones (100 Hz), three triaxial low frequency geophones (4.5 Hz), two air and surface rock temperature sensors and it is equipped with a wireless data transmission system. Temperature measures of a 10m deep borehole recently drilled on the south face of the ridge by ARPA VdA are also available since August 2012. The data processing relates to the classification of recorded signals, the identification of the most important trace characteristics in time and frequency domain and the analysis of their distribution in space and time. A correlation between temperature trend and events occurrence has been evidenced in the whole dataset: cold periods characterized by a rapid temperature decrease present an higher concentration of microseismic activity. Preliminary results also indicated a concentration of events in specific sectors of the rock mass. The research is still in progress and the data recording is planned for a longer period, with specific attention to the warm season, to better investigate the microseismic activity spatial-temporal distribution and correlation with the rock temperature.

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The evolution of Dolomitic glaciers during the last century

Crepaz A., Cagnati A., and De Luca G.

Abstract The increase of temperatures, associated with the decrease in snow precipitations in the recent period is one of the causes of the present, generalized withdrawal phase of alpine glaciers. Dolomitic glaciers (Italian Eastern Alps) and glacierets, due to limited extension, show a very fast reaction to the ongoing climatic changes. In this poster Dolomites glaciers area variation during the last 10 years is shown. First data were collected by Austrian alpinists at the end of 800 (i.e. Richter, 1888). Marinelli (1910) investigated all the Veneto glaciers during the first ten years of XX century. In 1958/1960 CGI (Comitato glaciologico Italiano) made the first Italian glaciers inventory. During '80 all glaciers information were collected to form WGI (World Glacier Inventory). Since 1999 to nowadays ARPAV-CVA carried out some glaciological survey campaigns, using orthophotos and other pictures in order to create a detailed inventory of Dolomitic glaciers, that reports all recent variations. In September 2004 a GPS and GEORADAR survey has been carried out over some glaciers (Marmolada, Antelao Superiore e Fradusta), in order to quantify both the nivo-glacial volumes and masses. Through the topographical survey in 2004, the necessary data aimed to the creation of a digital terrain model (DTM), both of the surface and of the bedrock, have been collected. In September 2009, 75 Dolomites glaciers or glacierets were surveyed using airborne Lidar and mass balance was determined comparing these data with those obtained from the previous georadar campaigns. In this work, historical and recent area data of 27 glaciers area are reported. DTM model, derived from Lidar data for the main part of the glaciers, was compared with DTM obtained by GPS technologies. In the last century the total glaciered area in the Dolomitic region decreased from 9.2 km^2 in 1910 to 4.7 km^2 in 2009 (-48.8%). Marmolada, the most important glacier, lost 1.75 km^2 (48.8%) while in some cases area decrease was dramatic, Fradusta dropped from 1.07 km^2 in 1910 to 0.11 km^2 in 2009 (-95%). In 2004/2009 period all glaciers lost consistent ice volume. Marmolada ice volume decreases of about $5.65 \cdot 10^6$ m^3, Antelao Superiore lost $1.32 \cdot 10^6$ m^3, Fradusta about $0.7 \cdot 10^6$ m^3, corresponding to a mean annual mass balance of -1.02 m w.e, 1.11 m w.e and 0.79 m w.e. respectively. As future goals, we would repeat Lidar surveys and extend mass balance analysis to the other glaciers.

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The permafrost monitoring site of Piz Boè (Dolomites/Eastern Italian Alps) Two years dataset

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Abstract In the framework of the PermaNET project (Alpine Space Programme) the Piz Boè area has been choosen as monitoring area to study and evaluate the periglacial processes in the Dolomitic region. The Piz Boè site is located in the North-Eastern Italian Alps, on the border of Veneto region, on the Sella Group, near Piz Boè Peak, at an elevation of 2900 m a.s.l. At North-East of the peak there was a glacier (Glacier of the North-East of Piz Boè), listed in 1980's campaign survey with an exposed surface of about 0.04 km. Nowadays the glacier area is very limited (about 0.014 km), but a rock glacier has been formed below the glacier, investigated in the last decade by geoelectric measurements. Close to the rock glacier, a 30 m deep borehole has been drilled in the Dolomite bedrock and then instrumented with a thermistor chain (16 sensors). Moreover, a fully equipped automatic weather station (AWS) and a GST network (20 loggers) were installed in 2011. A topographic survey (by laser scanner and topographic total station) was carried out on the rock glacier area, to investigate both the geomorphology and its relative displacements in the last two years. At the bottom of the rock there is a small shallow lake felt by a few seasonal springs; here and from the inlet springs, fresh water samples have been collected from the beginning of snow melt to the start of the following snow accumulation season in order to evaluate geochemical and isotopic characteristic. In the poster we are going to show borehole, GST and topographic results. Regarding borehole data, during the last two years temperatures below 9 m was negative, quite stable. Maximum annual active layer thickness was progressively increasing from 2011 and reached the maximum extension later in the autumn. Borehole winter temperatures were lower in 2011/2012 due to limited snow pack height. Later autumn temperatures were very high in 2012 due to early snowfall in October (at 30 cm monthly mean temperature was 0.69 °C, 0.05 °C in 2011), while September temperatures near surface were higher in 2011 due to very high air temperatures (at 30 cm 5.06 C in 2011, 3.57 °C in 2012). GST network indicates a very irregular behaviour in 2011/2012 winter season, due to discontinuous snowpack extension, influenced by winds. Anyway loggers covered by snow during all the winter reveals increasing values at lower altitude and far away from the rock glacier. In September 2011 a topographic survey was carried out and it has been repeated a year later. We marked 26 points on the rock glacier. All points are moving, respect to Azimuth, with a minimum displacement of 0.01 m to a maximum of 0.58 cm, with an average movement of 0.13 m, mainly to East direction. Afterwards all marked boulders are sinking by some centimetres to a maximum of 0.39 m (average 0.14 m). In the future we are going to drill a borehole on the rock glacier, collecting the ice sections, and to repeat topographic measurements.

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A web 2.0 framework for alpine glaciological monitoring

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Abstract The current trend of area and volume reduction of the european alpine glaciers has led to a dramatic decline of these resources in recent decades, and striking phenomena such as morphological changes, glacier fragmentation and even extinction of glacial bodies are increasingly frequent. This trend makes even more urgent the need of systematic and spatio-temporal dense monitoring of glacial bodies. These investigations are often restricted, mainly because glaciers are located in areas of difficult access, the time window in which it is possible to get statistically significant data is limited, and the funds allocated to the monitoring activities are often scarce and non-continuous. Moreover, despite the valuable work of several research groups and associations, there is a strong need for operators and work teams collecting data in the field. To meet this need, several local groups of specialized volunteers arose in Italy and in other alpine countries, which collaborate with scientists in the monitoring tasks during the annual measurement campaigns. Despite this complex network of research bodies, local associations, and volunteered operators strives year after year to maintain up to date the knowledge of alpine glaciers, the monitoring effort is far from exhaustive. An unexpected help can come from an alternative source, i.e. a parallel, unofficial and far more chaotic network made up by enthusiast hikers, climbers and mountaineers who observe and document the alpine environment in an heterogeneous way (pictures, tweets, maps, GPS points, blog posts, comments etc.). They, in a free and autonomous way, already exchange information, meet up on the web, and publish private material related to alpine glaciers. A large set of these information are available on the web in several formats on disparate channels, and therefore are usually scattered and not taken in account by specialists in glaciology. If properly managed, they can be a significant complement - and a supplement - for the traditional glaciological data, and can work to create a more complete and up to date overview of the studied phenomena. The challenge that we propose is to involve these non-professional volunteers in a participative project, in which the multiple forms of glaciological information - from expert and non-expert sources - are integrated in a scientific framework, and to manage them in a controlled workflow, taking full advantage of the web 2.0 technology and methods. A participative web platform has been designed following these key requirements:

- full customization and control by the coordination body;
- maximum accessibility and productivity in the task of collecting information;
- ease of use, attractiveness and gratification for contributors.

The application, that can be shared at a regional, national or international level, is currently in a testing phase. Here we present the project, showing its characteristics and features, but also the issues that must be addressed to fully achieve the targeted results.

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Glaciers risk in Aosta Valley (NW Italy): observations, changes and monitoring

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Abstract Glaciers and periglacial areas are naturally subject to several dynamic processes which, under certain conditions, may result in hazardous phenomena, thus generating risk in inhabited areas. Processes include, e.g., icefalls from hanging glaciers and glaciers collapses, which can evolve in ice or snow/ice avalanches, and outburst floods from inner water pockets or glacial lakes. All these processes usually result in sudden, fast and far-reaching phenomena, thus involving high danger level. Moreover, detection of hazard situations, monitoring and forecasting of phenomena are usually difficult, due to hard operating conditions and lack of knowledge. Due to its geographic features, the Autonomous Region of the Aosta Valley is strongly affected by such processes. The region territory is located in the far north-western part of Italy, bordered with Switzerland and France, and is completely mountainous, ranging from a lowest altitude of 345 m asl to the highest of 4810 m asl, with an average altitude of over 2000 m asl. Glaciers cover an area of about 135 km^2 (2005) out of a whole surface extent of about 3200 km^2. Anthropic pressure is quite strong, mainly because of touristic development, and often reaches high altitude or glaciers-dominated areas. As a result of climate change, in the last decades glaciers encountered rapid evolution. In Aosta Valley a strong area and mass reduction was observed, as well as morphological changes such as the separation between glaciers lower and upper parts generating new hanging glaciers or formation of new glacial lakes and inner cavities. Evolution due to climate change affects instability processes (e.g. cold glaciers turning into polythermal or temperate ones), and may results in new hazards, increase in frequency or magnitude of existing phenomena, or even in the decrease of hazards. In order to take into account glaciers hazards in land management and civil protection practices, the Autonomous Region of the Aosta Valley together with Fondazione Montagna sicura (Safe Mountain Foundation) set up a Glaciers hazard monitoring plan which includes:

1. an inventory of potentially dangerous glaciers, detected both from historical analysis of past events and geomorphologic analysis;
2. an yearly photographic aerial survey of all glaciers in order to understand morphologic changes and detect new possible hazards;
3. a specific monitoring of recognized hazard cases.

All available data are stored and updated within a purpose-made database, also including existing scenarios.

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Crowdsourcing snow data through mobile technologies

Dall'Amico M., Cremonese E., Morra di Cella U., Diotri F., Pogliotti P., Galvagno M., and Filippa G.

Abstract The knowledge of the snow water equivalent in a catchment is extremely important in many aspects. In agriculture, it allows to assess the water availability for the downstream cultivations, in civil protection it allows to estimate the flood risk during the meting period, and finally in hydropower it represents a gross estimate of the potential water inlet available for energy production.The calculation of snow water equivalent in an area may be done through statistical modeling based on the punctual measures of snow height, snow density and the topographical characteristics of the area, whereas the statistical performance of the analysis depends on the number and the representativeness of the punctual measures. However, the collection of snow measures in remote area is not easy, as it requires to organize measurement campaigns and to keep track of the timing and position of the measures. In order to ease the collection of snow data, the new App "SnowAlp" has been realized: this App allows the mountaineer to collect a snow height measure and to send it to a server where all measures are stored. The advantage is to increase the number of measures and reduce the costs of collection, simply by involving the mountaineers in the monitoring activity.The poster describes the features of the App, its functioning and the expected outcomes.

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Fast primary succession and pedogenesis on proglacial areas: examples from Valle d'Aosta Region (north-western Italian Alps)

D'Amico M.E., Freppaz M., and Zanini E.

Abstract Climate changes have huge impacts on alpine ecosystems. One of the most visible effects is glacial retreat since the end of the Little Ice Age (190-190 years ago), which caused the exposure of previously glaciated surfaces. These surfaces are open-air laboratories, verifying theories regarding ecosystem and soil development. In order to increase our knowledge on the effect of time and substrate on vegetation primary succession and soil development in proglacial areas, we sampled soils and surveyed plant communities on stable points in the proglacial areas of the Lys and Verra Grande glaciers, in the Italian north-western Alps (Valle d'Aosta). Sampling sites were located on dated sites (based on literature or historical photographs). Glacial till is attacked by weathering processes immediately after deposition and stabilization, such as loss of soluble compounds, acidification, primary mineral weathering. The speed of these processes are largely increased after the establishment of a continuous vegetation cover, thanks to organic matter accumulation caused by litter input and root decomposition below the surface. On sialic glacial tills, below timberline, patches of larch-Rhododendron forest were formed in less than 90 years, and a quasi-climax subalpine forest was formed on surfaces deposited before 1921. Under a larch - Rhododendron forest, a fast and steady decrease in pH values, increase in organic matter content and horizon differentiation is observed. In particular, genetic eluvial horizons form in just 60 years, while diagnostic albic horizons are developed after ca. 90 years, evidencing an early start of the podzolization processes. Cheluviation of Fe and, secondarily, Al are analytically verified. However, illuviation of Fe, Al and organic matter in incipient B horizons was not sufficient to obtain diagnostic spodic horizons on LIA materials. Under grazed grassland below timberline and alpine prairie above timberline, acidification and weathering were slightly slower, and no redistribution with depth of Fe and Al oxi-hydroxides was observed. The slower rate of soil development was related with the slower vegetation succession from pioneer communities to more evolved, quasi-climax ones. On ultramafic materials, vegetation succession was inhibited by toxic concentration of available Ni and Mg and scarcity of nutrients, which inhibited the organic matter input on the soil surface, slowing down acidification, base leaching and mineral weathering. In fact, plant cover remains scattered and dominated by heavy metal-adapted species for more than 150 years. However, soon after the establishment of the typical subalpine larch-Rhododendron forest on 190-260 years old moraines, acidification and weathering became extremely fast, and a visible E horizon could form, overlying an organic matter and metal-enriched incipient Bs.

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Emerging ecosystems after glacier retreat - A new study site for interdisciplinary research in the Central-eastern Alps

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Abstract Global warming strongly affects mountain ecosystems worldwide. At high altitudes, consequences are retreating glaciers and decreased snow coverage and duration. The Alps with their specific ecosystems and landscapes are influenced and re-organised. Therefore, it is important to understand the complex interactions between those compartments and their adaption to climate change. As mountains play an important role e.g. as resource of freshwater and as hotspots of biodiversity, these issues are of high practical relevance. The EMERGE project ("Retreating glaciers and emerging ecosystems in the Southern Alps") aims to understand the dynamics of high mountain watershed ecosystems from an interdisciplinary point of view. Therefore, the project interacts strongly with local stakeholders and benefits of numerous national and international cooperations. Research activities have been carried out since 2011 in the Matsch valley (South Tyrol, Italian Alps). The Saldur river drains the valley with an elevation range between 900 m and 3,700 m a.s.l.. The main glacier hosted in the basin lies between 2700 and 3700 m a.s.l., with a current extent of 2.8 km^2. The study site is located in the upper part of the valley, above the treeline (area 19 km^2, elevation $>$ 2000 m a.s.l.) where the glacier has retreated since the 1850s. In the glacier forefield, various monitoring activities are carried out encompassing hydrological, zoological, microbiological and botanical aspects. Hydrological investigations focus on the integration of experimental activities such as the analysis of water discharge, stable isotope composition of water, conductivity and turbidity to improve the understanding of the role of glacier melt and snowmelt in the catchment runoff response. Therefore, geochemical data are applied to identify the different origin of water within the Saldur river, its tributaries and spring sources at different spatial and temporal scale. Data are then integrated to calibrate a distributed hydrological model. The zoological part of the project investigates the effects of snow melting trends on the biological and chemical compartments of lotic ecosystems. Therefore, the influence of the glacier on the distributional patterns of biological assemblage is evaluated. The microbiological research aims to emphasize the role of microbial communities in the pedogenesis and nutrient cycles, their response to the change in hydrological dynamics and their adaptions to life under extreme conditions using both traditional and molecular methods for fingerprinting, functional studies and characterization of the main bacteria involved in the ecosystem development. Additionally, these data will be correlated to the geology of the substrate and the water parameters measured for the hydrological studies.The botanical aspect is highlighted by the study of the primary succession that developed in the forefield of the glacier. Along the same stages of the succession, the presence of different vegetation communities is determined and their corresponding driving factors are analysed. Indirect measured variables are

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evaluated for predicting vegetation patterns. Furthermore, the influence of small-scale variability of different vegetation communities on the carbon accumulation rate and fluxes are investigated by means of chamber-based measurements.

Winter climate indices applied to ski tourism over Andorra: recent trends and future projections

Esteban P., Pons M., and Maciá S.

Abstract Detection of climate change using instrumental records is a solid tool for confirming not only its existence at a local scale, but is also a useful resource for building models and future projections and assessing the potential impacts. Recently, interesting results were obtained for the calculation of annual and seasonal trends of maximum and minimum temperature and precipitation from three climatic series of the Principality of Andorra (Pyrenees), located between 1140 and the 1645 m. For winter (December February) a 0.23 to 0.29°C/decade for maximum temperature (statistically significant), 0.13 to 0.18°C/decade for minimum temperature (partially statistical significant) and -4.3 to -4.5 mm/decade for precipitation (none statistically significant) were obtained for the period 1950-2008. Furthermore, at a daily resolution, the indices of change defined by the ETCCDMI (Expert Team on Climate Change Detection Monitoring and Indices) were also calculated. The continuity of the data used and the geographical location of the observatories, the in deep quality check applied to the daily series, and the homogenization of the data based on the HOMER method (derived from the European project COSTES0601) reinforces the value of these meteorological series covering since 1935 to nowadays in this central area of the Pyrenees range. In this way, winter season ETCCDMI daily indices (November April) are now obtained to analyze the climate change impact on winter tourism and snow production over Andorra analysis. Furthermore, some of the existing indices (frost days) are adapted using interesting thresholds for its use on climate change impact on the ski resorts activity, and some new indices are obtained with the inclusion of snow depth data (snow days vs. rain days) and the treatment of the evolution of the melting days sequences. Finally, and based on future projections results calculated by Metofrance (SCAMPEI project) and AEMET (Agencia Espaola de Meteorologa), first preliminary results about the future evolution of the climate indices over the Andorran area are also obtained. All this work is being obtained on the framework of a Pyrenean project (Spain, France, and Andorra) oriented to help on a better management of the snow tourism under the future climate change scenarios.

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The contribution of soil properties to snow gliding phenomena under a changing climate

Freppaz M., Ceaglio E., Viglietti D., Maggioni M., Filippa G., and Zanini E.

Abstract The snow gliding is defined as the slow downhill movement of the snow cover on smooth or wet ground. The presence and the amount of liquid water in the snowpack, together with a scarcely rough snow/soil interface, have been proven to be the main mechanisms controlling snow gliding. In particular the formation of a soft slushy soil film, may influence the gliding mechanism: the more this film is thick the more the ground roughness is limited and the snow gliding is large. The formation of folds and cracks, which generate from the snow gliding, is considered as precursor of glide-snow avalanches. However, not always a glide crack does end in an avalanche release and, when it does, it could happen after few hours or months. Consequently glide snow avalanches, and more in general wet snow avalanches, represent a major point of uncertainty in the forecasting activities because of their hard predictability. Moreover, the interest on this kind of phenomena is increasing, because climate change is expected to lead to more wet snowfall or rain on snow events, also at high altitudes, determining a higher occurrence of warmer and wetter snowpacks. Three different monitoring sites were settled in the NW Italian Alps (Valle d'Aosta Region), at different elevations (2000-2400 m asl) and different land covers (subalpine forest, subalpine meadow and alpine tundra), in areas generally characterized by moderate snow gliding (subalpine forest), or characterized by large glide cracks, leading to the release of full-depth avalanches (subalpine meadow and alpine tundra). The plots were equipped with snow glide shoes, while temperature and water content sensors were located at different depths in soil and snow. The mean snow gliding rates ranged between 0.6 cm d^{-1} and 6.3 cm d^{-1} in the subalpine meadow, 0.4 cm d^{-1} and 1.9 cm d^{-1} under the forest cover (Larix decidua and Picea abies, respectively), while in the tundra site (2400 m asl) they were comprised between 0.1 cm/d and 4.2 cm d^{-1}. During winter the temperature of the upper soil horizons remained close to 0°C, controlled by the timing and depth of the snow cover accumulation, whereas the increase in soil water content was mainly controlled by the meteorological conditions (e.g., sharp air temperature increase during winter, rain on snow events). In turn, soil temperature and moisture seemed among the main driving factors of the snow gliding processes. Moreover, in the subalpine meadow site, the soil liquefaction has been identified as a potential factor contributing to the snow gliding processes, but it is an issue needing further specific investigations.

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A snow model intercomparison project for the evaluation of Snow Water Equivalent in Valle d'Aosta

Gabellani S., Cremonese E., Morra di Cella U., Pogliotti P., and Rudari R.

Abstract Models mimicking snow evolution can be developed for several purposes: water management, avalanches forecasting, energy fluxes estimation in meteorological and climatological models. The degree of complexity of these models range from simple index methods to physical multilayer models. Each of them can be a good choice for a specific task. The goal of this work is to understand the behavior of different models that are operative in Valle d'Aosta region during both the melting and the accumulation periods with the final aim of identifying advantages and weaknesses for their in estimating Snow Water Equivalent from point to regional scale. The performances of the model will be evaluated at a point scale on a very monitored site (Torgnon) performing a set of experiments that gradually degrade the inputs: starting from a configuration that feeds the model with all the observed variables until a configuration that uses input from interpolated fields or climate models analyses. Their performance will be eventually tested at regional scale comparing the outputs with measurements from available field campaigns exploiting manual observations and other campaigns that use an advanced combination of such manual data with estimations retrieved by air dispatch sensors.

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Geochemical and isotopic characterization of discharge waters from the Piz Boé active rock glacier, Dolomites, Eastern Italian Alps

Gabrieli G., Crepaz A., and Barbante C.

Abstract Rock glaciers are debris-covered mixtures of rock and ice common in many alpine and arctic regions and represent the most widespread periglacial phenomena on the Earth. Beside the importance as striking geomorphological forms, rock glaciers also contain significant amount of ice preserved from ablation by several meters of debris. While the kinematics and thermodynamics of rock glaciers have been extensively studied in the past decades, only little information is available on the hydrological regime and the geochemical characteristics of active rock glaciers. Here we present the preliminary results of the Piz Boé hydrological system, an active "ice-cored" rock glacier from the Dolomites (2900 m a.s.l.), North-Eastern Italian Alps. Gaging stations have been installed to measure continuously the discharge of two streams, which drain surface and melting waters form the hydrological basin. Electrical conductivity (EC) has also been measured continuously by specific dataloggers, submerged into the spring waters. A complete hydrological station was also installed on the shallow lake just downstream the rock glacier to monitor air temperature, liquid precipitation, barometric pressure, water depth and temperature and EC. Water samples from the springs and the shallow lake have been collected weekly from the second half of June to the first half of October, starting from 2011. Snow and rain samples have also been collected from snowpits and through rain collectors respectively. All the samples have been analyzed for a large suite of chemicals such as pH, major ions, nutrients, trace elements, rare earth elements and water stable isotopes. Strong diurnal variations characterize both the discharge and the geochemical features of the springs until the seasonal snow is completely melted (second half of August). Water precipitation from rainfall summer events is quickly released from the rock glacier within a few hours causing sharp peaks in discharge and severe decrease in EC and trace elements concentration. After the snow-melting period the discharge rapidly decrease with less evident diurnal fluctuations. The concentrations of all the chemical parameters increase reaching a maximum at the end of August. In this period an increasing in the heavy metals (Pb, Zn, Cu, Cd) content is also evident with values that greatly differ with the local geochemical characteristics. The geochemical and isotopic features suggest that the hydrological budget of this rock glacier is mainly influenced by water from snow-melting, rainfall and, to a lesser extent, from rock glacier ice melting. On the other hand, this seems to strongly impact the geochemical features of surface waters. Further studies are required to determine more precisely the amount of water released from the rock glacier and how these phenomena could impact the water resource, both from a quantitative and qualitative point of view.

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Measurements of CO_2 and thermal fluxes at a periglacial site in the Ortles-Cevedale Group

Gerosa G., Finco A., and Marzuoli R.

Abstract CO_2 and thermal fluxes have been measured on hourly basis at a periglacial area at 3400 m asl for three weeks between July and August 2012. The measuring site was located near the Alpine huts Casati and Guasti in the Ortles Cevedale group in Italy. A soil flux measuring system based on four authomatic diffusive chambers and an infrared gas analyser (SASSFLUX, Ecometrics, Italy) has been placed just at the edge of the Cedec Glacier. Three chambers were placed over ground surfaces consisting of rock debris just 1 meter away the snowfield edge and one chamber were placed directly on the snow, 30 m away the snowfield edge. Once a hour every chamber closed for 15 minute and the CO_2 concentration were measured with a period of one second. Then the CO_2 fluxes were derived from the registered accumulation (or disappearance) curves. At the same time four soil heat flux plates (hukseflux) have been installed 2 cm below the ground and snow surfaces as well as four thermal probes. The results revealed a weak but clear net CO_2 efflux from the ground surfaces covered by glacial debris, between 86 and 226 umol CO_2 m^2 d^{-1}. On the contrary the net CO_2 emission from the snow surface was practically zero. The emission dynamics show two clear daily peaks, one in the early morning driven by the change in the atmosphere-surface concetration gradient, and the second in the early afternoon driven by the thermal heating of the ground. It was not possible to conclude whether the CO_2 came from the deepened permafrost or else, but it is likely it origins from the weak heterotrophical activity of microrganisms within the first debris layers involved in the exchange processes.

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Periglacial area sediment budget of a rapidly retreating glacier inferred from four years of detrital flux monitoring (Bossons stream, Mont-Blanc massif, France)

Guillon H., Godon C., Goupy B., Pohl A., Buoncristiani J.F., and Mugnier J.L.

Abstract A better knowledge about present day erosion is needed to understand long-term relief evolution of periglacial areas. Bossons glacier in the Mont Blanc massif is rapidly retreating and its partially glaciated watershed is left in a natural state. Thus, it was chosen to estimate sediment budget, study its variation in relation to climate change and meteorological events and characterize involved processes. Sediments come from two reservoirs : the glacier and the lateral moraines. Both interact with a third reservoir: the alluvial area through which the subglacial Bossons stream flows and where hillslope processes provide material. The studied area, called Plan des Eaux, is roughly 35 meters wide, 420 meters long and its highest point is located at nearly 500 meters from the ice front. Sediment budget was determined using: i) annual DGPS measurements of elevation evolution; ii) three calibrations curves suspended load/water discharge, suspended load/turbidity and bed-load/water discharge built through high frequency sampling of water discharge and turbidity since 2009. Identifying each sedimentary flux is performed by determining:

1. relationships between the sedimentary flux that enters in the alluvial area, the released one and the stored one;
2. grain size characteristics of each sedimentary source and how they mix in the river and its exported load.

Considering that 60 percents of the alluvial plain particles are coarser than 2 centimeters, it is interesting to study the movement of this grain size fraction. Since 2011, this work was achieved through 20 monitoring campaigns of 185 PIT-tagged pebbles ranging from 2 centimeters to 32 centimeters. Results show that:

1. sedimentation occurs in the plain at a mean rate of 54.7 mm yr^{-1};there is inter-annual and intra-seasonal variations in the sediment budget;75% of the 4000 t yr^{-1} of exported material are fine particles (i.e. silts and sands), mainly coming from lateral moraines during extreme rainy events;the stored sediment volume corresponds to about 25% of the exported sediments (1000 t yr^{-1});within two melt seasons, the maximum travel distance observed is 360 meters; thus, the mean transit time of gravel in the studied area is greater than two year.

This combined methodology applied to the Bossons watershed demonstrates that erosion mainly concerns the recent exposed periglacial surfaces (i.e. moraines), while the Plan des Eaux is globally aggradating. It also provides keys for the analysis of inter-annual and intra-seasonal variations of the sediment budget.

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Glacier surface instability and melt stream changes reconstructed by means of tree-ring data at Miage Glacier (AO)

Leonelli G., Bollati I., and Pelfini M.

Abstract Debris-covered glaciers may host several biological forms that colonize the debris coverage, especially if the glacier tongue develops at sufficiently low altitudes and debris thickness reaches a critic value, thus allowing also supraglacial tree growth. When trees are present, the application of dendrochronological techniques may allow the assessment of current and past dynamics not only of the glacier debris coverage but also of the proglacial area, at the mid to long-term scale, in remote sites too. The Miage Glacier is the most important Italian debris-covered glacier which tongue lobes are covered by a growing forest dominated by European larch (Larix decidua Mill.). This feature confers to this complex geomorphosite a relevant scientific value, especially in term of rarity and ecological support role. Supraglacial trees colonizing the debris-covered tongue are strongly stressed in their growth and conditioned in their distribution, depending on substrate characteristics and instability. Trees germination is mainly associated with fine debris presence and trees age distribution presents a positive gradient towards the glacier terminus, which is related to the decreasing glacier surface velocity. Supraglacial trees' life time is mainly controlled by glacier surface displacements and by backwasting and downwasting processes. Moreover, supraglacial trees react to glacier ice and debris movement, assuming typical shapes and modifying their radial growth by producing compression wood, abrupt growth changes, resin ducts, etc., all indicators that may be exactly dated with yearly (and sometime seasonal) resolution. The analysis of growth anomalies of trees growing on the glacier debris surface and at a control site at the tree line, over the 20-years period 19872006, showed that trees growing on the glacier significantly presented high percentages of abrupt growth changes (AGCs) $>$ +70% calculated each year respect to the four previous years. Comparing the recorded AGCs with the trees displacement on the glacier surface over the same 20-years period, it was found that the central-lower portion of the southern lobe towards the margins was the most unstable one. The analysis of AGC $>$ +40% over time confirmed a period of higher glacier surface instability, reaching a maximum in the years 1988 (on the Southern lobe) and 1989 (on the Northern lobe), probably related to the passage of a kinematic wave in the glacier tongue, firstly reaching the Southern lobe. Hence, supraglacial trees record useful information on the glacier tongue dynamics. Trees in the proglacial area are continuously impacted by the remobilization of the debris by the glacial streams: dating stem scars, compression wood and AGCs allowed the determination of stress areas directly affected by glacial discharge or characterized by boulders falling from the glacier front and the melt stream course variations. The concentration of growth anomalies starting from 1984 likely indicates a more intense glacial activity starting from this year. Tree rings, providing abundant glaciological and geomorpho-

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logical information, are a useful proxy for reconstructing mid to long-term dynamics and may be used also for validating models applied on different landforms in the Alpine environment.

A measurement of the erosion beneath the Glacier des Bossons (Chamonix, France)

Mugnier J.L., Godon C., Buoncristiani J.F., Guillon H., Trouvé E., Pohl A., and Paquette J.L.

Abstract The relative efficiency of erosion beneath cold glacier, beneath temperate glacier, and on ice-free mountain slopes is one of the key parameter in the development of relief during glacial periods and on the effects of climate change on highly glaciated alpine environment. In order to study the distribution of erosion in the shed of the Glacier des Bossons (north face of the Mont Blanc, France) and to estimate the efficiency of the different erosional processes, four approaches have been used:

- Continuous monitoring of the water discharge and suspended sediment concentration of the lower most (1450 m) stream outlet (2009-2012);
- modeling with GSM-Socont (Glacier and SnowMelt - SOil CONTribution) in order to determine the watersheds distribution of the three sub-glacial streams flowing beneath the Bossons glacier (2009-2012);
- Three-dimensional (3D) glacier surface velocity determination from high resolution (HR) SAR (Synthetic Aperture Radar) images (TerraSAR-X (TSX) satellite) (2010);
- Clast provenance study deduced from detrital geochronology methods and applied to the three sub-glacial streams outlets located at altitudes of 2300 m, 1760 m and 1450 m, respectively. The lithology of this area is composed of a $\sim$ 303 Ma old granite intruded within an older polymetamorphic complex and we use U-Pb dating of zircon (of $\sim$ 500 grains) and macroscopic criteria (on $\sim$ 10 000 clasts) to determine the provenance of the sediment transported by the glacier and by the sub-glacial streams (2011).

The analysis of the source distribution takes into account the characteristics of the glacier (areas above or below the ELA (Equilibrium Line Altitude), beneath temperate or cold ice), its surface flow lines and the extent of the watershed of the three sub-glacial outlets. A comparison between the proportion of granite and polymetamorphics in the sub-glacial streams with the distribution of bedrock sources indicates that:

1. glacial transport does not mix the clasts derived from sub-glacial erosion with the clasts derived from supra-glacial deposition, except in the lower tongue where supra-glacial streams and moulins move the supra-glacial load to the base of the glacier;
2. the glacial erosion rate beneath the tongue is $\sim$ 0.4 mm yr^{-1} and is smaller than the erosion rate of non-glaciated areas;
3. glacial erosion beneath cold ice is at least sixteen times less efficient than erosion beneath temperate ice.

Our results indicate that the low rates of subglacial erosion on the north face of the Mont Blanc massif means that the glaciers are protecting Europe's summit from erosion. A long-term implication would be a growing of the maximum altitude of the Alps.

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The permafrost monitoring network in Piedmont Alps: establishing, problems and solutions

Paro L. and Guglielmin M.

Abstract Since 2006 Arpa Piemonte is studying permafrost and periglacial environment of Piedmont Alps in collaboration with Insubria University. During the European project "PermaNet" (2008-2011), an alpine permafrost monitoring network composed by 6 stations in different sectors of high mountain areas (from 2490 to 3020 m of altitude) of Piemonte region has been established. The boreholes were drilled in near flat rocks, range between 30 and 100 m of depth, and are instrumented with thermistor chains linked to dataloggers for data collecting. Some technical problems related to the first planned design obliged to re-install a new set of stations between the 2010 and 2012. All damaged stations now have been recovered, installing datalogger above the ground surface, clearing the boreholes and protecting the head of the boreholes from water infiltrations. In the 2013, all stations will be tested and first permafrost data will be available to compare with the climate data. In the next future, all permafrost stations of Piedmont Alps will be linked to the Global Terrestrial Network-Permafrost (GTN-P). Meanwhile, many other activities have been carried out in Piemonte by Arpa Piemonte and Insubria University to assess permafrost distribution and its ice content (e.g. BTS, electrical tomographies, empirical and physical models) but it has been realized also the inventory of the permafrost-related morphologies. In addition also the relationships between change stability, hydrogeological characteristics and permafrost evolution were carried out. Finally a quite robust dissemination and training activities have been done. These activities and results allow to better understand the complex environment of high mountain, its phenomena and evolution, especially in the present framework of the important transitional phase from glacial environment to periglacial one. These studies are much more important in the Piedmont Alps, as the permafrost an periglacial processes have been practically unknown for years.

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The Alpine Permafrost Database: a webtool for permafrost data sharing

Pogliotti P., Cremonese E., Morra di Cella U., and Bredy R.

Abstract The investigation and modeling of permafrost distribution, particularly in areas of discontinuous permafrost like the Alps, is challenging due to the spatial heterogeneity and remoteness of measurement sites. Moreover the data collected are scarce and spatially scattered between many institutions and often are neither homogeneous nor comparable.
The Alpine Permafrost Database (APD) is a free on-line service for collecting and sharing high-quality data on permafrost throughout the European Alps. It is based on an alpine-wide standardized collection of evidence of the presence or absence of permafrost realized within the framework of the Alpine Space PermaNET project between 2008 and 2011. The first development and implementation was a collaborative effort of ARPA Valle dAosta (Italy), the University of Zurich (Switzerland) and the WSL, Swiss Federal Institute for Snow and Avalanche Research SLF (Switzerland). Besides the PermaNET team, thirty-five individuals and institutions from Austria, Germany, France, Italy and Switzerland provided valuable data for feeding the first release of the database.
After the PermaNET project, ARPA Valle d'Aosta is making the effort to maintain and implement the database for the coming years. A website for the on-line submission and updating of permafrost data has been developed with tools for consulting and downloading the whole dataset and for participating in the development of the database. The final goal of the APD is to provide the scientific community with periodic, consistent and homogenized dataset exploitable for alpine-wide analysis on permafrost state.The website is addressed to all researchers and permafrost enthusiasts who are working in the Alps. Beside the pure scientific mission of data sharing the website aims to become a landmark in the panorama of European permafrost research for interactive discussions, sharing ideas, news, proposing meeting, workshops...
www.alpine-permafrostdata.eu

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Rockfall hazard in high mountain areas increased by the current atmospheric warming

Ravanel L. and Deline P.

Abstract The study of rockfall (volume $>$ 100 m^3) in high mountains is essential to understand landscape evolution and to evaluate natural hazard. The number of rockfalls seems actually to rise in the European Alps, while vulnerability is increasing from high elevation areas (e.g. cable cars, huts) to valley floors (e.g. urbanization, transport). Recent rockfalls from high-Alpine steep rockwalls are hypothesized to be a consequence of the climate change through the warming of the permafrost. Given the lack of systematic data on rockfall, this relationship has however remained difficult to assess despite few evidences including laboratory tests and temperature measurements indicating permafrost degradation, while the increase of rockfall frequency and magnitude remained conjectural. Here we analyse several inventories of rockfalls acquired in the Mont Blanc massif (France and Italy) by innovative methods in order to characterize the rockfall triggering conditions and to emphasize the role of permafrost:

1. In two sectors of the massif (Drus and Aiguilles de Chamonix), a comparison of photographs from the end of the Little Ice Age to 2011, combined with field geomorphological data, allowed the identification of more than 50 rockfalls during this period, ranging in volume from 500 to 265000 m^3.
2. A network of local observers (guides, hut keepers, mountaineers) allowed the documentation of all rockfalls occurred in 2007 (n = 45), 2008 (22), 2009 (72), 2010 (47) and 2011 (65) in the central part of the Mont Blanc massif, ranging in volume from 100 to 43000 m^3.

Furthermore, 182 rockfalls were identified at the end of the 2003 Summer heatwave through the analysis of a satellite image of the whole massif. A strong correlation between the rockfall occurrences and the hottest periods at the time scales of the century and the year strengthens the hypothesis of the relationship between permafrost degradation and rockfall at high elevation. Moreover,

1. modelling suggests the presence of permafrost in nearly all affected rockwalls;
2. massive ice was observed in at least 40 scars during the period 2007-2011;
3. and different other elements (e.g. mean elevation of the detachment zones, topography prone to permafrost degradation) support the permafrost degradation as the main triggering factor of rockfall.

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Monitoring snow dynamics in the Pyrenees with a long range Terrestrial Laser Scanner

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Abstract In recent years, Terrestrial Laser Scanning (TLS) is arising as a promising tool for monitoring snow depth in mountainous areas. TLS data provides representations of the terrain at a very high resolution. It permits to deal with the large spatial variability of the snow pack much better than traditional measurement techniques, normally based on manual measurements or automatic sensors. The aim of this study is to assess the operational capability of a long range terrestrial laser scanner (RIEGL LPM-321) and to analyse the snow accumulation and melting patterns in a small (55ha) watershed in the Central Spanish Pyrenees, located at 2056 m a.s.l.. Six scans have been taken during the winter and spring of 2012. In addition, manual measurements were taken in order to assess the quality of the obtained data. Distribution of snow depth at each time of the snow season was related with topography (elevation, slope, curvature, wind sheltering and exposure to solar radiation). Results have confirmed the usefulness and accuracy of TLS technique for snow monitoring even at long distances (1000 meters). However, a careful consideration of several error sources must be taken into account to get reliable information. Acquired snow data has allowed obtaining very detailed representations of snow distribution. Results have highlighted the extreme spatial variability of snowpack in the study area. Topography, in particular variables related with wind redistribution and exposure to solar radiation, exerts a strong control in the accumulation and melting processes between the different dates of measurement. The application of this technique for long-term monitoring of snow variability at the basin scale will provide valuable information of the spatially distributed response of snowpack to climate variability and change in the Pyrenees.

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Standard Software for Multifunctional Alpine Monitoring: From Avalanche Warning and Hydrometric Monitoring to Climate Change

Ruggiero G., Egeling M., and Funke R.

Abstract As a consequence of climatic changes or human impacts, the number of avalanche threats, floods and other extreme situations has been increasing in the Alps and other alpine regions, with fatal consequences for nature, people and infrastructures. Continuous long term monitoring of all relevant natural phenomena, well organised data archiving and intense data analysis of these valuable data sets are necessary for an appropriate management of water and related resources, modelling and prediction as well as the right decisions. Since now the 25 years experienced and commercially available software WISKI information management system integrates system measurement data and turns it into information needed by the users and their organisations. Various alpine organizations worldwide are managing their monitoring networks with it since years. In the Alpine area the Avalanche Warning Services of South Tyrol (Provincia autonoma di Bolzano - Hydrographical Service of Bolzano), Tyrol (LWD Tirol), Salzburg (LWD Salzburg), Bavaria (LWZ Bayern), the Flood Forecast centre of the Hydrological Service of Lower Austria; the Switzerland cantons St.Gallen, Thurgau and Aarau, the Switzerland Federal Office for the Environment FOEN are well known WISKI users., Furthermore the system supports environmental monitoring as in hydro-meteorological services, flood forecast centres, water boards, hydro power companies, environmental agencies, municipalities, etc. The implementation of a modern modular multi-user and multi-tier architecture provides high investment security and technical advantages. The system is combining interdisciplinary demands on time series processing with regard to mass data capabilities, scalability, modular design and flexibility to work in diverse specialist areas. It has a high level of automation, reliability, security, integration potential, broad platform independence, redundancy and resilience. WISKI is OpenMI compliant and time series data are accessible for any water resource related observation for OpenMI compliant models. Involved services and operations are automated and managed by WISKI. The highly configurable backend is able for permanent execution of distinct tasks such as importing of data, documents or cyclical provision of updated measurement data or documents. The KiAM-Alarmmanager is the central alarm application for information and message management in exceptional situations. It handles incoming event messages, classifies them, and reacts accordingly as well distributes messages with additional information to recipients via several media types. Integration with GIS application together with web solution provides spatial data analysis and data dissemination for public or restricted zones. The result of new approach to cloud technology is the KISTERS Web Interoperability Solution (KiWIS) which has been developed as a contribution to interoperability experiments at OGC. Used in combination with WISKI, KiWIS is able to consume and publish real-time hydrological data over the Internet using open standards like e.g. WaterML 2.0 and SOS.

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Hydro-climatological and biogeochemical research project on high mountain regions: SHARE Water Resources

Salerno F., Balestrini R., Guzzella L., Freppaz M., Viviano G., Thakuri S., and Tartari G.

Abstract The mountain region of the Hindu Kush, Karakoram and Himalaya (HKKH) contains a large amount of glacier ice and it is considered to be the "third polar ice cap" of our planet. Glaciers in this area play the role of "water towers" in the hydrologic balance of the region, and provide significant amounts of melt water, especially in the dry season, for agriculture, drinking purposes and power production. In the recent years, most glaciers in the HKKH region have been retreating in accelerated rate and loosing mass, owing to regional warming and the increase of aerosols loading. Consequently, it is essential to assess the current state of the aerosol load, glacier mass and energy balances, water availability and quality in the HKKH region, as well as to develop modelling tools to obtain reliable projections of water resources in the coming decades. SHARE - Water Resources promotes the definition of water resources and the causes of their quantity and quality variations on the principal water towers of Asia (Central Karakorum National Park and the Sagarmatha National Park SNP), Europe (Stelvio National Park) and Africa (Ruwenzori Mountains National Park). The project is structured in 5 sub-packages: Glaciology, Precipitation, Rivers, Lakes and Biodiversity. Climate change and direct anthropogenic impacts have to be considered as fundamental cross-cutting elements. In this work, we focus our attention on SHARE - River and SHARE - Precipitation sub-packages. SHARE - River is finalized to provide a general assessment of quantity of rivers and running waters in SNP (upper catchment of Dudh Koshi river basin) with a focus on the evaluation of potential impacts on future water availability caused by climate change occurring at local and regional level. In this context the attention will be also addressed to some water quality indicators to detect local and global impacts. In particular the project promotes a long term quality and quantity monitoring of freshwater in order to develop a reference case-study for the Southern Central Himalayan region. The project individualizes four main research activities: characterization of hydrology of main rivers; evaluation of changes in precipitation and temperature characteristics; assessment of impacts of climate change on river discharges; evaluation of effects of main natural and anthropic compounds on river water quality. In the framework of SHARE - Precipitation project, coinciding with the Global Atmospheric Watch Programme, the goal is to monitor the long-term evolution of the atmospheric composition and properties on global and regional scales in order to assess their contribution to climate change and other environmental issues. Specific objectives include the quantification of patterns and trends in the atmospheric composition, the improvement of the understanding of the aerosols circulation and chemistry and the definition of the deposition role in the biogeochemical cycles. In this regards the first field activity was conducted on June/July 2012 focusing on main river water sampling, soil description and sampling, and the

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installation of multiparametric probes to monitor water quality and quantity in selected river sections.

A worldwide inventory of high-mountain lake outburst floods

Schaub Y., Würmli S., Huggel C., and Haeberli W.

Abstract Glaciers worldwide are mostly retreating and lakes are forming in the newly exposed glacier beds. GIS-based models show that this evolution will continue in future. These lakes are located in a fast-changing and unstable environment and are therefore prone to different outburst mechanisms. In regions such as in the European Alps or in the Cordillera Blanca in Peru, where valley bottoms are densely populated, these far-travelling, high-magnitude events can endanger areas with huge damage potential. Therefore process knowledge for hazard assessment is crucial. Many single outburst events have been reported and described in the literature, and corresponding databases exist. A worldwide compilation of lake outburst events including corresponding disposition and trigger factors, however, is still missing. We here present a worldwide inventory of outburst flood events of high-mountain lakes consisting of 559 outburst events. Information was gathered from existing databases or reports and from literature. The main factors investigated are outburst date, lake type, predisposing and trigger factors, outburst mechanism, outburst volume, peak discharge, flow type, damages. Evaluation of the database showed that most events were reported from the European Alps, from Norway's West coast, and from North America's West coast. Outburst volumes were predominantly smaller than 200x106 m^3, single events however featured up to 5400x106 m^3 (Rasselfjord, Alaska, USA, 1986). Lake types, outburst mechanisms and triggers were put into relation and the frequency of combinations discussed. Overall, the combination of melt water together with strong precipitation, leading to a progressive extension of subglacial channels was the most frequently observed or assumed lake outburst mechanism found. The inventory, however, also shows that in many cases, important information on preconditions of lake outbursts is unavailable. Special efforts should be put into describing them in case of reporting a future lake outburst.

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The study of snow avalanches from a climate change perspective

Segor V., Sovilla B., Pitet L., Bovet E., Dellavedova P., Steinkogler W., Veitinger J., McElwaine J., Maggioni M., and Chiambretti I.

Abstract In the last thirty years an increase in air temperatures, a possible increase of extreme rainfall events and an altitude increase in the snowline have been observed. These changes influence the snowpack and will therefore change the type, magnitude, frequency and dynamics of avalanches. Currently we cannot assess the influences of these changes on avalanche dynamics, due to the lack of dynamics models, which accurately include the influence of the snowpack properties. The STRADA project was founded in 2010 to fill this gap and to develop strategies for adaptation of the management of natural risks to climate changes in Switzerland and Italy. This project is part of the Operational Programme of Collaboration in European cross-border zones, Italy/Switzerland 2007/2013. The project aims to account for the impact of climate changes on avalanches, springs and lakes, taking into consideration different elements of land planning and management. The project includes the development of methodologies for the study of frequent avalanches in a changing climate context. These methodologies combine the most advanced knowledge in the field of modelling avalanche dynamics and simulating the evolution of the snowcover. They will be used in risk mitigation strategies, such as transport links and ski-resorts management. During the project, many measurements were made at the experimental sites Valle de la Sionne (Valais, Switzerland), P.ta Seehore (Aosta Valley, Italy), Aprica (Lombardy Region, Italy) and Passo Moro (Piemont Region, Italy): mass, speed, flow regimes and runout distances of numerous avalanches were recorded. The corresponding snowpack characteristics were directly measured in the field or indirectly determined using the numerical model SNOWPACK. The combined analysis of this data has shown, for the first time, the importance of the variation of the snowpack temperatures along the avalanche track on the avalanche dynamics and therefore on the runout distance. This analysis has also shown how the distribution and height of the snowpack can change the effective ground morphology, changing particularly the effective roughness, with a direct influence on the location and extent of the avalanche starting zones. These new findings will be implemented in RAMMS, an advanced avalanche dynamics model, which takes into consideration, in addition to the erosion processes, the characteristics of the snowpack, including its temperature. STRADA has shown that recent climate changes, most likely, have affected avalanche dynamics. The outputs from STRADA will result in the proposal of new procedures to be used in risk mitigation strategies.

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Medium-term analysis of nivo-meteorological parameters in the Aosta Valley (NW Italy)

Segor V., Antonello G., and Burelli G.

Abstract The main feature of the Aosta Valley - far North-West of Italy - is to be a mountainous region, with an average altitude of over 2000 m a.s.l. and a glaciated area of about 135 km^2. IPCC scenarios - agreed by most - indicate the Alps as one of the most sensitive areas to climate change. In this sense the meteorological data play a key role; as a consequence a huge amount of data are available. Here we focus on temperature, snow depth and occurrences of unusual atmospheric events. The goal of this article is to find evidence of a possible trend of these parameters in the last 10 years, compared to the historical data - available since 80s for only few automatic and manual weather and snowpack observation sites - which could go in the direction of a change. The manual stations network consists in many sites, where weather and snowpack observations are collected following the AINEVA (Associazione Interregionale NEve e VAlanghe) Mod. 1 standard, together with ram penetrometers, snow profiles (AINEVA Mod. 2-3-4) and avalanches observations (AINEVA Mod. 6). The automated snow and weather observation network is composed by 81 stations, equipped with different sensors and managed by the Centro Funzionale (part of the Assessorato alle Opere Pubbliche, Difesa del Suolo e Edilizia residenziale pubblica) and by the ARPA (Agenzia Regionale per la Protezione dell'Ambiente). The Autonomous Region of the Aosta Valley together with Fondazione Montagna sicura (Safe Mountain Foundation) is in charge - among other tasks - of the study of the snow and avalanches, thanks to the activity of the "Snow and Avalanche Forecast Service". The Foundation in fact operates as an applied research centre for snow and avalanches, glaciers and permafrost, natural risks in high mountain, safeness and mountain medicine, environment and sustainable development.

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The Ortles Project: a high-altitude observatory of the changing cryosphere in the Eastern European Alps

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Abstract The alpine cryosphere is undergoing significant changes under the current climatic warming. Negative mass balances on glaciers and warming permafrost highlight the high sensitivity of the cryosphere to climate change, even at high altitude. These changes strongly affect the availability of water resources, the stability of slopes and the touristic appeal of mountain areas. Mt. Ortles (3905 m a.s.l.) is located in South Tyrol and is the highest peak of the Eastern European Alps. Its summit is covered by the Alto dell'Ortles glacier, an ice body facing northwest. Mt. Ortles is a well suited site for studying the effects of climate change on the high-altitude cryosphere of the Eastern Alps and for detecting possible signals of degradation. For this purpose, we started a research program that has as main objectives i) to retrieve and study the first glacial archive of the Eastern Alps, ii) to investigate the energy and mass exchange processes in the upper part of the glacier, iii) to study the modern climate of the area, and iv) to assess the permafrost conditions of the ice-free areas near the mountain summit. In Autumn 2011, four ice cores were drilled at 3860 m a.s.l. Three of them reached the bedrock, at approximately 75 m of depth. Cold ice conditions were found below the firn/ice transition (ca. 30 m of depth) and the ice temperature at the base of the glacier is at about $-2.8\,^{\circ}$C. Preliminary analyses of the ice cores showed a well preserved stratigraphy, with clearly distinguishable annual layers. A preliminary age of the bottom ice (652 BC, during the Iron Age) was provided by radiocarbon dating of a larch leaf found at 74 m of depth.Direct mass balance measurements begun in 2009 on the upper part of the glacier, at an altitude between 3800 and 3900 m a.s.l. The results show that this area is above the current Equilibrium Line Altitude and still experiences net accumulation, with annual values of 1151, 439 and 1076 mm w.e. from 2009 to 2011. An automatic weather station (AWS) was installed on the glacier Alto dell'Ortles in Autumn 2011 at 3830 m a.s.l., close to the drilling site. This is the highest AWS in this region of the Alps. It records sub-hourly values of the following variables: air temperature, relative humidity, wind speed and direction, snow depth, incoming and outgoing shortwave and long-wave radiation, and snow temperature from the surface down to a depth of 15 m. Investigations on permafrost include measurements of the surface and subsurface temperature at several sites located around the Ortles summit, both on flat, debris-covered areas and on nearly vertical rockwalls. The measurements on the ground are performed using thermistor probes placed under a thin layer of debris, while in the rockwalls the thermistors are placed at three different depths (10, 30, 55 cm). These measurements will allow us to observe the behaviour of the ground temperature and its relationship with the meteorological variables recorded by the nearby AWS.

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PERMAQUA: Permafrost and its impacts on water resources and water ecology in high mountain areas

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Abstract Permafrost has become an important issue in the European Alps. In South Tyrol (Italy), the area of permafrost covers about 440 km^2, and in the Austrian Alps about 2000 km^2. Active rock glaciers are a common feature of high mountain permafrost and due to their location near the lower boundary of permafrost, their mean annual surface temperature is close to melting conditions (Haeberli et al., 2006), which indicates their particular sensitivity to climate warming. Air temperature in the Alps has substantially increased during the past decades and climate warming is projected to become even more pronounced until the end of the 21th century. Increasing instability of slopes, landslides and floods, as well as alterations in the hydrological regime can be anticipated. Up to now, studies on the effects of active rock glaciers on hydrology and water chemistry of adjacent surface waters are still rare (e.g. Williams et al., 2006; Krainer et al., 2007; Thies et al., 2007; Baron et al., 2009). Results from the previous EU-RTD project EUROLIMPACS and the Interreg IV-Alpine Space project PermaNET showed that waters draining from active rock glaciers may contain high concentrations of solutes and at some sites also metals (e.g. nickel, aluminium), which can exceed the limit for drinking water by far. The origin of these metals is yet unresolved. Potential effects of solutes and metals on the ecology and on freshwater biota in high mountain lakes and streams in the Alps are still unknown. The current PERMAQUA project (Interreg IV Italy-Austria, European Regional Development Fund) combines studies on geology, hydrology, contemporary aquatic chemistry and freshwater biota, the analysis of lake sediment cores, peat cores and rock glacier ice cores near selected rock glaciers in South Tyrol (Italy) and North Tyrol (Austria). The PERMAQUA project aims to assess the impact of permafrost melt on high mountain freshwaters. The state-of-the-art knowledge about potential ecological impacts of permafrost melt and its consequence for man and the environment will be transferred to decision makers, managers, local residents and the general public. The present permafrost monitoring system, anchored at international level, will be updated and further developed in order to assure the future recording of permafrost variations due to climatic changes and to release estimation of danger situations arising in permafrost areas. Guidelines for possible risk mitigation strategies will be proposed and their implementation shall be tested in cooperation with public authorities, alpine associations, managers of protected sites, national parks, and of mountain shelters.

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Reconstructing the history of the Rosa dei Banchi glacier in the Champorcher valley, Valle d'Aosta, by use of multisourcing data over the past two centuries

Villone B. and Vassoney A.

Abstract Presently the Rosa dei Banchi Glacier, the only glacier in the Champorcher Valley, located in the southeastern part of the Aosta valley, has almost disappeared. Being less relevant than the most glaciers in the Aosta Valley, there are not many recorded past data about it. In order to reconstruct its back history, we have used "mixed" data, i.e. data from multiple sources types as literature and geography book (for the nineteenth century), tecnical reports, photos etc. We show the result of our research describing a mean decrease in volume of this glacier over the two past centuries. Problems of multisourcing data are also discussed.

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Remote Sensing of Mountain Environment - State of the Art and Outlook

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Abstract In a changing world, environmental monitoring and assessment is a field of growing demand, expressed for instance in rising obligations to report on the status of the environmental system, the request for monitoring climate change impacts or the appraisal of risk to natural hazards. This work will present state of the art and outlook on remote sensing as a very useful tool for environmental monitoring of mountain environment. Satellite data today offers a huge range of scales and sensor types from weather satellites to high resolution radar satellites. Still the most common used sensors are optical sensors. Spatial resolution is usually a tradeoff of temporal resolution and the area covered. While large scale satellites cover whole mountain ranges within one scenes and can provide several acquisitions a day, with finer spatial resolution the coverage shrinks to an image with of 100-200 km at a resolution of 10-30m and a revisit time of several days to a coverage of below 20 km at a resolution of 40 cm. Latest developments are more spectral bands, new bands, which allow for better classification of vegetation and a higher temporal coverage through wider swath and satellites constellation with more than one satellite. New high resolution SAR Satellites allow Earth observations also under cloudy conditions. With ESA's new Sentinel family a whole series of new satellites with free data access will be available. Parallel to new sensors the potential for fast processing and semi-automatic image analysis classification and interpretation have improved in the last years by introducing techniques like Object Based Classification or Machine Learning Techniques. A few applications of remote sensing in mountain regions may illustrate the capabilities of these techniques: Snow Cover monitoring: with optical data based on daily MODIS satellite data an operational snow cover monitoring product which covers the Alps as well as the Carpathians is presented. The data is processed in near real time with a time lag of 2 hours and produced with a resolution of 250 m. Snow cover and soil moisture monitoring with SAR data: high resolution X-band as well as C-band data is used to provide weather independent information on snow and soil moisture status. Habitat Mapping and Monitoring: NATURA2000 habitats are mapped with multi-temporal high resolution RapidEye satellite data. Also conservation status is assessed. Forest Damage Assessment with change detection techniques. Damage after storm events is analyzed with change detection techniques in high detail. Mapping of land-slide movement with SAR interferometry. Based on high resolution X-Band Radar data by COSMO-SkyMed movements of a large landslide are studied. We assume that remote sensing can particular contribute to environmental monitoring when integrated with in-situ data and other techniques such as modeling, making use of the greatest advantage of remote sensing, the area-wide data availability and overcoming the strongest constraint, the "fuzziness" of the data (accuracy, resolution, data gaps).

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