17th Alpine Glaciology Meeting Program – GRENOBLE
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Session 1: glacier mass balance : observations and processes

*** Ice loss from Glacier d'Estelette since 2000: a comparison of DEM subtraction and field survey methods.**

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Accelerated retreat of an alpine cirque glacier over the last decade is shown to be due mainly to glaciodynamic factors rather than increasing temperatures. Digital Elevation models derived from satellite-borne sensors (ASTER, SRTM), airborne LiDAR, and terrestrial GPS have been constructed for 2000, 2004, 2010 and 2012. These show ice thinning at an increasing rate of up to 6 m yr^{-1} between 2004 and 2010. This is confirmed by field surveys since 2004, which show that the increased rate of thinning is to reduced ice flow as shear stresses decline. Summer temperatures show no overall increase over the same period. Ice velocity has declined catastrophically with thinning causing reduced driving stresses so that ice melt is no longer replaced by flow. A gentler ice marginal slope also means that more horizontal retreat is generated by each unit of thinning. The study cautions that at sub-decadal timescales, variations of retreat rate cannot easily be interpreted as climatic record when dynamic and topographic factors have a greater influence.

*** Mass balance of glacier d'Ossoue, Pyrenees, France, 1924-2012**

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Glacier d'Ossoue is a southernmost European valley glacier, located in the Vignemale massif, French Pyrenees at 42°8N. Its mass balance has been measured continuously with ablation stakes since 2001 and has been extended over the last 88 years based on topographic maps (1924, 1948 and 1983). In addition, topographic surveys performed in 2005, 2011 and 2012 allow the comparison with the stake measurements. The glacier d'Ossoue mass balance is slightly negative between 1924 and 1948 (-0.7 m/an), very slightly positive between 1948 and 1983 (+0.2 m/an), and always negative since then (-1.6 m/an). Aerial photographs have been used to map the glacier extent and show that the glacier area was reduced by 50% between 1924 and 2011 (45Ha). In the last decade, the glacier evolution is characterized by a continuous increase in the ablation rate. The acceleration of general mass balance trend illustrates the impact of the global warming in the Pyrenees, while the ablation patterns reflect the effects of the local topography.

*** Five year mass balance survey of a small polar glacier (2008-2012, Austre Lovénbreen, Spitsbergen, 79°N)**

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Since 2008, mass balance (MB) is measured on the Austre Lovénbreen (4.5 km2) at a very fine scale. In-situ equipment includes: 36 ablation stakes, 42 snow drills, 20 air temperature loggers recording hourly data, automatic cameras providing 3 photos per day. Photos are processed to define the fraction of the glacier surface covered by snow during the season. Regional climatic data are also provided by the Ny-Alesund weather station (6 km further west of the glacier) operating since 1969. For the last five years, the Austre Lovénbreen, like the other glaciers of the area, shows negative MB. Four MB are of the same order of magnitude (-9 cm to -26 cm), while 2010-2011 shows very important ablation everywhere on the glacier (-123 cm), i.e. 7 times the mean of the four other years (-17 cm). 2011's spectacular negative MB may be explained by two main driving parameters. First, a very dry winter resulted in a thin snow cover. Second, a very warm summer followed. For the 4 other years we will discuss the intricate interactions between temperatures and precipitations. It is especially striking to note how different seasonal patterns can lead to very comparable annual MB.

*** Retrieving bulk sensible heat transfer coefficient over melting ice using melt energy**

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Turbulent sensible heat flux is an important energy supply for glacier melt, but is rather difficult to measure over long periods from the gradient method. The bulk sensible heat flux formulation underlies that melt energy of a glacier surface is correlated to the product of wind-speed, air density, and the difference in temperature between air and melting ice. Melt energy can be estimated from ablation data. The slope of the correlation is therefore expected to give an empirical estimate of the bulk transfer coefficient. 40 daily records form an ultrasonic ablation sensor and weather data measured at screen height are used for regression. The stability of the surface layer is assessed by a calculation of the bulk Richardson number. Best linearity is obtained if the static stability of the surface layer is accounted for using stability correction functions for momentum and heat. Best fit are obtained when variations in air density due to temperature and atmospheric pressure fluctuations are considered.

*** Determination of the degree-day factor by *in situ* measurements on the Austre Lovén glacier (Spitsbergen, 79°N)**

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The value attributed to the K degree-day factor used in degree-day models is very variable in the literature (from K=1 to K=9). Basically, due to albedo, K is given as 30 to 40% lower for snow than for ice. In Spitsbergen, the Austre Lovén glacier (4.5 km2) is extensively surveyed since 2007. In 20 locations the amount of snow and ice melted yearly is determined. These measurements are compared to degree-day values obtained with air temperature in-situ measurements. Additional information on snow cover seasonal evolution is brought by a photographic observation network. The daily surface state of the glacier (snow or ice) is therefore known. When derived from these data sources the melting coefficient for snow is consistently higher than that of ice (4.43 mm/°C vs. 3.5 mm/°C on average). These results are not in accordance with what is usually mentioned in the literature.
Focusing on ice it appears that the glacier snout is more widely covered in dark debris and displays high ice melting coefficient compared to the rest of the glacier (6.85 mm/°C *vs.* 3.43 mm/°C). These results are raising the issue of Arctic glacier's specificities.

Session 2: Climate change/glacier change

*** Secular atmospheric temperature changes at very high elevation in the Mont Blanc area fron englacial temperatures**

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Given the paucity of observations, a great deal of uncertainty remains concerning temperature changes at very high altitudes over the last century. Englacial temperature measurements performed in boreholes provide a very good indicator of atmospheric temperatures for very high elevations although they are not directly related to air temperatures. Temperature profiles from seven deep boreholes drilled at three different sites between 4240 and 4300 m a.s.l. in the Mont Blanc area (French Alps) have been analyzed using a heat flux model and a Bayesian approach. Atmospheric temperature changes over the last century were estimated by simultaneous inversion of these temperature profiles. A mean warming rate of 0.15°C/decade between 1900 and 2005 was found. This is similar to the observed regional low altitude trend in the North-Western Alps, suggesting that air temperature trends are not altitude dependent.

*** Changes in glacier equilibrium-line altitude (ELA) measured by remote sensing in the western Alps over the 1984-2010 period.**

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We present series of equilibrium-line altitude (ELA) measured from the end-of-summer snowline altitude (SLA) computed on satellite images, for 43 glaciers in the western Alps over the period 1984-2010. A sensitivity study of the ELA to climate and morpho-topographical parameters is presented. Considering each glacier individually, a meridional effect appears; the ELA is about 150 m higher for the glaciers located in the southern sector of the study area than those located in the nothern sector. This observation can be attributed to warmer and drier conditions in the southern part of the study region. However, this meridional effect does not affect the rate of the increasing trend of the ELA over the study time period (160 m in average). Exposure appears to be the most important factor controlling the differences in the rate of increase in ELA between the individual glaciers over the study period, with glaciers exposed to the East experiencing the most important increase. Finally, we can conclude that the interannual variability of the ELA is mainly controlled by climate parameters, as well as the observed increasing trend, with temperature being the main driver. On the other hand, morpho-topographical parameters are the main factors controlling the average position of the ELA.

*** A 1600 year history of Alpine glacier equilibrium line altitude inferred from glacier length records, and the relation to summer temperature and radiation**

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A new history of glacier equilibrium line altitude (ELA) for the time span 400-2010 is inferred from the combined interpretation of length change records of seven glaciers from the Alps with help of a macroscopic model of glacier dynamics. This history is a proxy for summer temperature, and is fully independent of other instrumental or proxy data. The temperature record thus obtained bears close similarity to a tree-ring based reconstruction of central European summer temperature, and to a multi-proxy temperature history. The glacier record shows a prominent low-ELA (cold) phase around 1330, corresponding to rapid glacier advance, which is absent in the other records. The reconstructed ELA history is closely correlated to solar irradiance between 1800-1950, but shows significantly warmer temperatures after 1950. Furthermore, the macroscopic glacier models yields glacier volume changes, and thus one major component of the summer river discharge.

*** Analysis of glacial retreat in the French Alps since the end of the 1960s through the evolution of the topographical and glaciological parameters of the glaciers.**

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Glacial retreat is one of the most evident impacts of climate change in high mountain areas. In the French Alps, data about glacier extension were recently updated in the context of the new French glacier inventory. This inventory is based on (i) manual delineation of the French National Geographical Institute (IGN) orthophotographies from 2006 to 2009 and IGN 1/25 000 topographical maps from the end of the 1960s (1967-1971), and (ii) automatic delineation of 1985-1986 Landsat 5 TM images. Data are integrated in a GIS and topographic parameters are extracted from the IGN 25-m-DEM for the glacier surface area of the end of the 1960s and the ASTER 30-m-GDEM for the 2006-2009 extension. Through a statistical approach, we present here the main characteristics of the present French Alpine glaciers (size, length, aspect, slope angle, minimal, maximal and mean elevations). They are studied as a whole and according to size classes, aspect and location. We also analyze the glacial retreat and the change of topographic parameters between 1967-1971 and 2006-2009. Finally, we compare our results with data from other studies in the Alps.

*** An estimate of the intrinsic uncertainty of volume-area scaling**

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The direct measurement of the total volume of a glacier is virtually impossible. It can either be recovered through interpolation of locally confined measurements, but is more often inferred from the glacier surface by means of inverse modeling. Although a wealth of sophisticated inversion techniques have been proposed, simpler approaches are widely used. The most popular amongst these is volume-area scaling, which simply relates the volume of a glacier to its area. In this contribution, the maximal accuracy which can be expected from the application of volume-area scaling is explored through a series of synthetic experiments, and statistical analysis. The requirements necessary for recovering the total volume of a glacier sample within a given level of accuracy are discussed, as well as the accuracy which can be expected when volume-area scaling is used for estimating volume changes.

Session 3: Dynamic behavior/natural hazards

* Instabilities on Alpine temperate glaciers: new insights arising from a numerical modelling study performed on Allalingletscher (Valais, Switzerland)

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The processes leading to a glacier instability depend on the thermal properties of the contact between the glacier and its bedrock. Assessing the stability of temperate glacier (i.e. the glacier can slide on its bedrock) remains problematic. In order to scrutinize in more detail the processes governing such "sliding" instabilities, a numerical model designed to investigate gravitational instabilities in heterogeneous media was further developed to account for the presence of water at the interface between the bedrock and the glacier for Allalingletscher. This model made it possible to account for various geometric configurations, interaction between sliding and tension cracking and water flow at the bedrock. We could show that both a critical geometrical configuration of the glacier tongue and the existence of a distributed subglacial drainage network were the main causes of the Allalingletscher catastrophic break-off. Moreover, the analysis of the modelling results diagnosed the phenomenon of recoupling of the glacier to its bed followed by a pulse of subglacial water flow as a potential new precursory sign of the final break-off in 1965. This model casts a gleam of hope for a better understanding of the ultimate rupture process resulting from such glacier sliding instabilities.

* Dynamics of subglacial cavities and subglacial erosion

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The dynamics of subglacial cavities play a pivotal role in glacier sliding, subglacial erosion and other processes near the glacier base. Despite a considerable volume of theoretical and numerical treatments of cavity dynamics, data assimilation is hampered by the inaccessibility of the glacier bed. Here we propose a seismological approach to investigating subglacial processes. As a central result, we present evidence that basal seismicity beneath various Alpine glaciers is the result of cavity formation and collapse rather than glacier stick-slip motion.

*** Seismic activity and surface motion on a potentially unstable steep temperate glacier.**

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In the last 15 years Triftgletscher (Bernese Alps, Switzerland) has substantially retreated and the stability of its steep tongue was potentially affected. In order to improve the understanding of the mechanisms leading to such instabilities, the emitted seismicity, the surface motion and glacial runoff were monitored during summer 2008. Recorded icequakes were shown to be composed mostly of a mixture of falls of ice chunks and crevasse openings. A statistical analysis highlighted a power-law behavior of the released seismic energy at certain times of the investigated period. Glacier recoupling phases were shown to be accompanied by peaks of seismic energy ranging over several days, which may illustrate periods with enhanced break-off risk and therefore may be suitable candidate for break-off precursors.

*** Velocity estimation of Grandes Jorasses glacier in the framework of GlaRiskAlp project**

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The Grandes Jorasses hanging glacier, located at 4100 m asl above a populated area, is monitored by Fondazione Montagna sicura since 2007, on account of the Geological Service of the Aosta Valley Autonomous Region. The serac dynamic shows a periodic trend of mass increasing, interrupted by a collapse: The collapse is preceded by an exponential acceleration that lasts few days, as revealed in 1997-98 by Prof. M Funk (ETH Zurich). By tracking the velocity of the ice mass it is therefore possible to forecast its breakdown. At the early stage of the project the native monitoring system consisted of poles with prisms placed on the glacier surface, monitored by an automatic total station (motorized total station) sited at the valley bottom. During bad weather conditions the system could loss measurements, so alternative monitoring systems were designed, installed and tested in the framework of the GlaRiskAlp project (Alcotra program). In particular the new monitoring systems consisted of a low cost, single frequency, GNSS wireless sensors network, able to trace continuously (H24) the receivers positions to measure the displacement in real time, and a seismometer at the top of the glacier was placed in order to follow the seismic activity (that is proportional to the velocity). Furthermore, in order to better characterize the mass evolution, photogrammetric activities were carried out to reconstruct the glacier surface. Prototypes, results and outlooks of these monitoring systems for Grandes Jorasses glacier will be presented.

Session 4 : Hydrology

* Variations in the water balance terms of the high mountain basin of Vernagtferner, Austrian Alps, for the years 1895-2011

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The conceptual hydrological model HBV3-ETH9 is applied in the basin of Vernagtferner, located in the Oetztal Alps, Austria, using as input daily values of air temperature and precipitation. The annual water balance terms are calculated over a period of over 100 years, thus describing the relationship between climate and glacier mass balance in a quantitative way. Calibration of model parameters for the period o f1980 to 2011 was achieved by using detailed measurements of runoff and glacier mass balance of Vernagtferner. For the period between 1895 and 1980 geodetic mass balances were used to calibrate the snow and glacier melt model parameters, while the remaining model parameters were kept unchanged. The results achieved are plausible for the most part of the investigation period. There are two phases, however, that experienced drastic changes of the glacier topography, i.e. the surge-type advance around 1900, and the extreme melt phase during 1938 and 1954. Here, the rapid areal changes of the glacier tongue need to be taken into account for improved calculations.

* Apport d'eau lié à la fonte nivale et restitution en tête de bassin versant à l'échelle locale : exemple du Lignon du Forez, Massif Central, France.

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Cette communication s'intègre dans l'étude des hydrosystèmes aux interfaces, domaine délicat en hydrologie de montagne à cause du comportement variable des échanges entre la neige, le sol et le sous-sol. Il s'agit d'évaluer les échanges entre la neige et sa restitution en tête d'un bassin versant de moyenne montagne (Lignon du Forez, Massif Central). L'héritage glaciaire du site d'étude donne lieu à une configuration favorable à la naissance des sources du Lignon. La source Nord semble dépendre de la configuration du sol et de l'accumulation neigeuse dont son bassin versant bénéficie pendant l'hiver. L'accent est donc mis sur l'accumulation neigeuse et son équivalent en eau liquide, puis le suivi de son infiltration et enfin sa restitution à la source. La cartographie de l'accumulation neigeuse et de l'équivalent en eau liquide a été réalisée à l'aide d'un radar géologique (Ground Penetrating Radar). Cette même méthode a permis également une cartographie des épaisseurs de sol rencontrées, qui semblent jouer le rôle d'aquifère certaines années. Le suivi de l'infiltration a été mené durant tout l'hiver et la période de fonte grâce à une fosse creusée dans le sol et équipée de sondes de température et humidité du type TDR (Time Domain Reflectometry). Indirectement cette station de mesure permet de détecter la présence de neige sur le sol, donnant lieu à l'estimation d'une vitesse de fonte de la neige. Ce volume d'eau issu de la fonte est quantifié à la source, où il apparaît clairement dans les débits par rapport au reste de l'année.

*** Un modèle glacio-hydrologique conceptuel dans les bassins versants de montagnes**

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La modélisation hydrologique des bassins versants de montagne pose un certain nombre de défis. Les schémas de surface des modèles hydrologiques courants, qu'ils soient à bases physiques ou plus conceptuels, représentent l'évolution de stocks dont le temps de séjour n'excède souvent pas l'année (cas, par exemple, du manteau neigeux). Or, une partie du couvert neigeux alimente les glaciers en altitude avant d'être remobilisé sous forme d'écoulement glaciaire dans des zones d'altitude plus basses où les conditions climatiques moyennes redeviennent favorables à la fonte, et ce, avec un temps caractéristique largement supérieur à l'année. La représentation de cette composante hydrologique basse fréquence, notamment en contexte de changement climatique, est un défi important. Partant de l'observation que les glaciers empruntent le réseau hydrographique comme support d'écoulement et par analogie avec les modèles hydrologiques utilisant les propriétés géomorphologiques du réseau, nous cherchons à construire, une paramétrisation sous-maille parcimonieuse, mais aussi dynamique que possible, du stock glaciaire à l'échelle de domaines hydrologiquement pertinents. Un modèle statistique multi-varié /P(A> a|z)/ des réseaux hydrographiques a ainsi été développé en échantillonant les aires drainées /a /par altitude /z./ Le choix du modèle d'écoulement glaciaire à greffer est à discuter. On s'interrogera également sur la manière d'étudier comment les glaciers confluent et quel en est l'impact sur la longueur de front.

Estimation des stocks de neige et prévision des apports par fusion nivale : utilisation de CROCUS pour répondre aux besoins opérationnels de la gestion des retenues de montagne

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La gestion de la ressource en eau des retenues de montagne doit concilier des usages multiples : production hydroélectrique, fourniture d'eau pour les usages agricoles et respect de cotes touristiques. La difficulté de cette gestion est liée au fait qu'en zone de montagne, la majeure partie des apports se concentre durant le printemps et au début de l'été, lorsque le manteau neigeux fond et libère l'eau stockée sous forme de neige au cours de l'hiver. Pour la Société Hydro-Electrique du Midi (SHEM), gestionnaire de nombreuses retenues dans les Pyrénées, l'évaluation au cours du printemps du volume d'eau stocké par le manteau neigeux et la prévision des apports à venir dans les retenues d'ici la fin de la saison de fonte représentent donc de forts enjeux. Cette prévision se doit par ailleurs de préciser la répartition temporelle des apports et d'intégrer une estimation des précipitations à venir entre la date d'émission de la prévision et la fin de la saison de fonte. Avec la mise en place du pôle hydraulique du groupe GDF-Suez, un rapprochement s'est opéré entre les besoins de la SHEM et les compétences de la Compagnie Nationale du Rhône (CNR) qui a ainsi développé des modèles spécifiques de prévision des apports par fusion nivale sur les retenues de montagne de la SHEM. L'estimation des stocks d'eau présents sous forme de neige sur les bassins versants de chaque retenue est ainsi réalisée à partir des sorties d'équivalent en eau fournies par le modèle CROCUS de Météo France. Ces données, discrétisées par massif, orientation, pente et altitude, sont agrégées via un traitement SIG à l'échelle de chaque bassin-versant. Même si les sorties CROCUS réduites en un point ne sont pas toujours en accord avec les sondages ponctuels de terrain, leur exploitation à l'échelle d'un bassin-versant a été validée par comparaison avec les apports mesurés à la fin des saisons de fonte sur les retenues. A partir de ces estimations de stock, deux types de modèle ont été développés par la CNR pour réaliser la prévision des apports : • un premier modèle, dit « statistique », contraint uniquement par l'estimation du stock de neige en place et considérant des précipitations « encore à venir » conformes à la distribution climatologique du lieu considéré, • et un second modèle, dit « conceptuel », contraint à la fois par l'estimation du stock de neige en place et par la prévision à long-terme des tendances climatologiques pour les mois à venir. Ce second modèle réalise une simulation explicite des phases d'accumulation et d'ablation du manteau neigeux (modélisation degré-jour) à partir de générations stochastiques de chroniques météorologiques cohérentes avec les prévisions à long-terme. Les méthodes développées et la complémentarité des deux types de modèles seront illustrées par les résultats obtenus sur le bassin de l'Oule (Hautes-Pyrénées).

Session 5: Permafrost/geomorphology/ debris cover

* Modelling debris-cover evolution

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In high mountain areas such as the Himalayas and Andes, many glaciers are partly covered by debris and this number increases as a result of global warming. Debris on a glacier surface has a large impact on the glacier mass balance. Both the extent and the thickness of a debris cover evolve in a changing climate. Evolution of the debris cover needs to be taken into account when modelling glaciers, because changes in the debris cover feed back on the glacier response. I intend to develop a glacier model that integrates glacier mass balance, ice flow, and debris distribution, accounting for the complex interactions between these components to describe the evolution of the debris cover. I would like to discuss the possibilities and problems of this idea.

* Geomorphology and dynamics of supraglacial debris covers in the Western Alps

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In the alpine regions of France and NW Italy, many glaciers of a variety of sizes are at least partly debris-covered, but these have received less scientific research than clean glaciers. During the present period of glacier shrinkage – the area of glacier cover in France has reduced by 26% over the last 40 years –, growing debris cover needs to be understood as an influence on continuing retreat, with consequences for natural hazards, water resources and tourism. We present here some results of a combined ongoing study of an inventory of debris-covered glaciers in France with site-specific studies of several glaciers of contrasting types, in order to understand spatial and temporal changes in supraglacial debris cover. Specific aims of our study are:

- To understand the geomorphology of debris-covers and their formation, investigating the types of debris cover in relation to formative processes including extraglacial supply and development during transport.
- To document the changing extents of supraglacial debris covers, using historical documents and aerial photographs.
- To interpret areal changes in terms of glaciological and topographical controls on different glacier and debris cover types (catchment morphology, glacier structure, mass balance history, and rock wall collapse magnitude and frequency).
- To understand the effect of debris cover on glacier dynamics and geomorphological evolution, related to insulation-related modifications to AAR, long profiles, and length changes on both short and long timescales. This includes investigation of the characteristics of debris-covered glacier depositional systems resulting from their modified dynamics.

*** Heterogeneous ground ice distribution in glacial and periglacial sedimentary environments and its influence on current geomorphological dynamics: geoelectrical tomography results in the Rognes sector (Mont-Blanc, France)**

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This presentation exposes the results of an electrical resistivity tomography (ERT) campaign in the Rognes ridge sector (2450 - 3050m a.s.l). In summer 2012, 10 48electrodes and 5 24electrodes ERT profiles have been carried out in order to characterize the internal structure of local landforms. Indeed, with the presence of glacier forefields, push moraines and rock glaciers, this site is one of the largest area containing ground ice in the Mont-Blanc Massif. Measurements cover three main sites: *the Rognes area* (continuum between upslope debris-covered glacier, ice-free glacier forefield and marginal rock-glacier), *the Pierre Ronde site* (ice-free glacier forefield and marginal rock glacier that has been affected by the Tête Rousse glacier water-pocket outburst in 1892) and *the Dérochoir* slope (talus-derived hanging rock glacier feeding torrential stream paths). Results illustrate the local heterogeneity of ground ice occurrence, which has a fundamental relevance for local geomorphological dynamics.

*** Permafrost temperature regimes in boreholes in the French Alps – three years of monitoring 2009-2012**

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Within the PermaFrance observing network, a total of 6 boreholes has been drilled and equipped for temperature monitoring in the mountain permafrost of the French Alps, in three different configurations: Three 10 m long horizontal boreholes in subvertical rockfaces of the Aiguille du Midi at ca 3800 m a.s.l, realized in 2009. Two 15 m deep vertical boreholes in an ice-rich rockglacier at ca 2700 m a.s.l. in the 2Alpes ski resort, realized in 2009. One 100 m deep vertical borehole in flat bedrock at 3065 m a.s.l. in the 2Alpes ski resort, realized in 2010, and equipped with both a classical thremistor chain and an optic fiber for DTS measurement. The results permit to compare temperature profiles and regimes of bedrock vs ice-rich permafrost, or of rockfaces of various aspect.

* Progress and changes in the IGS in the past year

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I will discuss the progress and the changes that have occurred in the IGS in the past year. I will talk about where the IGS is heading in the changing climate within scientific publishing. I will review upcoming IGS symposia in the next 5 years.

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

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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.

*** Le comportement physique et mécanique des dépôts glaciaires dans les secteurs récemment déglacés**

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Dans le cadre du projet simple "GlaRiskAlp" (Programme Opérationnel de coopération territoriale européenne «Alcotra») des études visant à donner des réponses pratiques et théoriques aux risques causés par la réduction de l'extension des glaciers dans les Alpes Occidentales (France et Italie) ont été réalisés. La Vallée d'Aoste (IT) a étudié, dans les secteurs récemment déglacés de deux sites pilotes, le comportement mécanique des dépôts glaciaires sujets aux extrêmes variations météo-environnementales des ces lieux. Des investigations géophysiques et photographiques ont été réalisés sur le terrain et des analyses en laboratoire on été exécutées sur des échantillons de sol à différentes températures. Les résultats, couplés avec deux années de mesures en continue des paramètres météorologiques et physiques du sol, on permit d'étudier des intéressantes corrélations entre la teneur en eau des dépôts, la neige au sol et les conditions thermiques du site. Les tests en laboratoire sur les dépôts des deux sites étudiés ont finalement confirmé la forte dépendance entre la lithologie régionale et les caractéristiques géotechniques des matériaux qui en résultent.

Session 6: Snow processes

*** Dry and wet snow analysis in Alpine regions using Radarsat-2 full polarimetry data. Comparison with *in situ* measurements .**

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This study is focused on the advantages of RADARSAT-2 sensor in fully polarimetric mode at C-band for snow properties retrieval. The project was run for winters 2009 to 2011 (10 images) over an instrumented area ("*Gd. Rousses – Oisans*") located in the French Alps (N 44°.15' / E 7°.15'). One added summer image was acquired for SAR reference under snow free conditions (land cover). This high mountain area is characterized by a strong topography involving layover/shadowing effects and affecting the SAR local incidence angle calculation.
The results retrieved from two different polarimetric decomposition methods (Yamaguchi, Cloude-Pottier) are compared with simultaneous fieldwork measurements (10 sites). Both methods are according to a satisfactory correlation with the liquid water content (LWC) measured at the snow surface in wet conditions. One indicates a correlation with the snow depth and the snow water equivalent (SWE) only in the case of dry snow layers.

* **Development of a snowpack model to study the impact of black carbon**

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Several global model studies have indicated an impact of light absorbing aerosols in the snow on the albedo. As a result, the seasonal snowpack can melt earlier compared to the unaffected snow leading to a strong warming effect on the atmosphere. Due to its strong light absorbing properties, black carbon may play an important role in this process. We upgraded the existing one-dimensional physical snowpack model CROCUS to account for the influence of black carbon on the absorption of radiation by the snow. A radiative transfer scheme was implemented into the snowpack model taking into account the solar zenith angle, the snow water equivalent, the snow grain size, the soil albedo, and the concentration of black carbon in the snow. The upgraded model was applied to locations in the French Alps and in the Himalayas to test the improved model. First results of these simulations will be presented.

*** Simulation de la rupture fragile de la neige à partir d'images de micro-tomographie.**

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Les propriétés mécaniques de la neige sont déterminantes dans la formation des avalanches. En particulier, ses propriétés en rupture sont essentielles pour comprendre le départ d'avalanches de type "plaque". Les tests mécaniques sur la neige sont difficiles à mettre en oeuvre et à interpréter. D'une part, la neige est un matériau très fragile. L'échantillon de neige peut donc être facilement endommagé avant que le test ait pu avoir lieu. D'autre part, le manteau neigeux n'est pas homogène mais généralement stratifié en fines couches. Il est alors difficile d'identifier le rôle de chacun des types de neige dans le processus qui a mené à la rupture. Pour ces raisons, nous avons implémenté un modèle numérique qui prend en entrée la microstructure de la neige obtenue par micro-tomographie. La microstructure des échantillons de neige a été obtenue, de manière non destructive, par tomographie X en chambre froide. Puis la contrainte à la rupture en traction a été mesurée sur les échantillons. Un sous-volume (30 mm^3) représentatif de la zone où a effectivement eu lieu la rupture est ensuite soumis numériquement à une contrainte en traction. Dans le modèle numérique, la matrice de glace est décomposée en éléments finis constitués par un matériau élastique fragile représentatif de la glace. Les contraintes à la rupture simulées sont en bon accord avec les valeurs mesurées pour le type de neige considéré, des grains fins de densité 350 kg m^{-3}. Le modèle numérique permet de suivre la distribution des contraintes dans la structure de glace et la propagation de la fissure entre grains dans l'échantillon. Le modèle montre une distribution de contraintes très hétérogène avec des valeurs localement 100 fois supérieures à la valeur moyenne. L'ensemble des micro-fissures entre grains semble s'organiser rapidement sur la surface de rupture macroscopique.

Poster Session

*** An integrated geophysical approach to glacial moraine dam assessment**

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Moraine dams can be inherently unstable, and glacial lake outburst floods catastrophic, but effective assessment strategies remain poorly identified. Electrical resistivity tomography (ERT) have been integrated with electrical self-potential (SP) and lake-level measurements to investigate the structure of, and hydrological processes within, a moraine dam complex adjacent to Miage glacier, Italy. ERT data reveal a continuous free surface within the complex, whose morphology reflects the topography of the moraine complex akin to unconfined groundwater aquifers. SP data were corrected for spatial changes in the thickness of the upper unsaturated layer using principles of electrography. The residual streaming-potential map is consistent with Darcian flow of lake waters through the moraine complex. Such geophysical methods promise to be powerful in assessing the long-term stability of moraine-dammed glacial lakes.

*** On climatic and glaciological changes in the Khibiny Mountains**

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Reductions of the duration of snow cover existence and snowfield and glacier areas in the Khibiny Mountains (Kola Peninsula, Russia) were observed in recent decades. These processes are due to a significant decrease (30%) of solid precipitation in the mountains and, to a lesser degree, due to an increase of air temperature in the warm part of a year. The role of the solid precipitation is especially important because of that the Khibiny's snowfields and glaciers are approximately 500 m below snow line in the region and exist only due to intensified snow accumulation during winter time. Since the amount of solid precipitation in the surrounding plain for the same time has not been changed the general decrease in the mountain precipitation has occurred due to its orographic component.

*** Glacier mass balance distributions of the French Alps from 1996 to 2010, based on a spatialization of ground measurements**.

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Consequences of glacier volume changes in response to climate change consist in modifications of their extension, water production, and related glacial hazards. However glacier volume changes computed from direct mass balance measurements are performed worldwide on a limited number of mountain glaciers. Furthermore the spatial distribution of monitored glaciers is very unequal. The need

to extrapolate the measurements to unmonitored glaciarized regions is widely recognized (Meier, 1984; Arendt et al., 2006; Leclercq et al., 2011; Marzeion, 2011; Huss, 2012). However, even in regions with a developed monitoring network as the french Alps, field measurements only cover in this region about 13% of the total glacial coverage. The present work aims at producing quantitative information for the 87% unmonitored glacier cover. Using the existing mass balance measurements in the french Alps, we first established a parameterization of its dependancy to morpho-topographical data. Then this parameterization was used to produce annual mass balance regionalisation at the scale of the whole French alpine range and bordering glaciers. A total of 82 mass balance series from point measurements over the 1996-2010 period were obtained from the monitored glaciers of the GLACIOCLIM observatory, plus one glacier of « Parc National des Ecrins ». Measurements are available accross the french Alps from the Mont Blanc Massif in the northern sector of the Alps to the Ecrins Massif in the south. Measurements cover a wide range of aspects. A sensitivity analysis of the 82 series was conducted to elevation, aspect and latitude, showing an average multiple regression coefficient of 0.98, and allowing to produce annual parameterizations from 1996 to 2010. These parameterizations were used to compute annual mass balance distributions over the whole domain, using the QGIS geographical information system. Input data for elevation, aspect and latitude were derived from the SRTM digital terrain model at 90-m pixel size. The glacier outlines were provided by a glacier inventory realized using 2003 satellite images for the french glaciers plus outlines provided by H. Motta (Fondatione Montagna Sicura) for 2 Italian glaciers. The result is a 90-m mass balance distribution grid for french and bordering glaciers. From this grid, mass balance series of individual glaciers, as well as for larger areas (i.e. mountain ranges, valleys, ...) can be computed.

*** Changes in glacier mass balance over the past 50 years on Antisana Volcano (Ecuador) from DEMs computed by aerial photogrammetry**

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In Ecuador, two glaciers are monitored since 1994 (#12 and #15 of the Antisana Volcano) with mass balance and surface energy balance measurements. These data allow to understand the links between glacier changes with climate and topographical forcings. Nevertheless these results concern a very local scale and cannot directly be generalized to other glaciers without field measurements. Fortunately, Digital Elevation Models (DEMs) computation from aerial photographs provide an accurate alternative to study temporal and spatial geometric changes of glaciers. This study aims at reconstructing the glacier mass balance at the scale of the Antisana Massif (17 glaciers) using aero-photogrammetry for five dates since the mid-20th century. The stereo-preparation was performed using ground control points from a GPS network distributed around the volcano with a root mean square error (RMSE) between ±0.5 m y ±4 m in both horizontal and vertical components. Manual photogrammetric restitutions were carried out on the stereoscopic models to create the point clouds. Then, five interpolation methods were tested to find the best interpolation technique and the optimal pixel size to represent the glacier topography. These tests were conducted according to: 1) the statistical analysis of the residuals obtained by the comparison of DEMs altitudes and DGPS field measurements on non-glaciated areas; 2) the capacity of the DEMs to represent glacier features; and 3) the processing time of the algorithms. The minimum curvature method and a 15-m pixel size give the most accurate results (RMSE = ±2m).

*** Morphometric reconstruction of glacial outlines from Little Ice Age to the present (Western Italian Alps).**

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Glacial and periglacial areas evolve quickly in relation to climate variations, because of the morphogenetic action produced by advancing and receding glaciers and by ground ice growth/thawing. Since the end of the Little Ice Age, radical changes in Western Italian alpine glacier outlines have occurred: in the last 150 years the glaciated areas have decreased from 48.4 km^2 to 10.7 km^2 with an overall reduction of 78%. Some morphometric parameters as maximum and minimum altitude, snout position, length and area were measured for 95 glaciers, set in Torino and Cuneo Provinces, using historical carthography, stereo interpretation of aerial photos and field surveys. The aim of this work is to give statistical analysis of resulting data, presented in framework of the Alcotra 2007-2013 n. 56 project GlaRiskAlp.

*** Glaciers one-time. The society becomes protagonist and share in glaciological research**

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Glaciers one-time involve the citizenship in the development of a popular scientific project, which, among its objectives, aims to make the society conscious of the glacial retreat in action and to quantify the changes in the mountain landscape. All are invited to take photographs of the modern Italian glaciers with the exact points of view of historical photographs, and to make photographic comparisons. *Glaciers one-time* is carried out in collaboration with the Comitato Glaciologico Italiano, and institutions that carry out glaciological activities
The important institutional network so has the goal to cooperate together for the promotion and dissemination of research within the society, the enhancement of the mountain environment and of tourism activities, the understanding of the landscape changes due to retreat of the glaciers.

* **An integrated analysis of glacier evolution**

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The glacier of the Pré de Bard (Mont Blanc, Italy) has been monitored by Fondazione Montagna sicura and ARPA Valle d'Aosta since 2005. In the framework of several projects some activities have been carried out: a) measurement of daily ablation rates using stakes; b) calculation of the mass balance of the glacier with traditional methods; c) analysis of differential ablation due to the debris cover; d) reconstruction of the glacier front surface using different topographic techniques (photogrammetry and terrestrial LIDAR); e) measures of the in- and out- coming solar radiation; f) reconstruction of the potential incoming shortwave radiation. At the end of August 2012, the intense ablation and the effect of bedrock morphology resulted in the separation of the lower part from the glacier body. Therefore, the terminus is becoming dead ice and Pré de Bard, one of the two last valley glaciers of the Italian Mont Blanc massif (with the Miage glacier), is evolving in an hanging glacier.

In this poster we will present a summary of the main outcomes and the morphological evolution of the glacier since 2005.

*** Bedrock mapping using Radar measurements on two tropical glaciers: Zongo and Charquini Sur (Cordillera Real, Bolivia)**

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We present the results of a field campaign conducted in August 2012 on Zongo and Charquini Sur glaciers (Cordillera Real, Bolivia) to measure the ice thickness using an Ice Penetrating Radar in order to map the glaciers bedrock and to quantify the volume of water available. The maximum thickness of the Charquini Sur glacier is about 45 m while it approximates 110 m for the Zongo glacier. Ice volume was estimated to nearly 65.3 million m3 for the Zongo Glacier and nearly 4.8 million m3 for the Glacier Charquini Sur. It should be noted that these estimates are minimum values due to the fact that some areas of the glaciers could not be covered.

*** A pilot study to evaluate sparse supraglacial debris coverage and its influence on ice albedo at the Forni glacier tongue (Stelvio National park, Italian Alps)**

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In this study we propose a method to describe sparse debris coverage at the glacier surface and its relations with ice albedo. We developed a simple protocol to evaluate debris distribution and pattern on the glacier surface and its influence on ice reflectivity, tested on the Forni Glacier. On the ablation tongue we selected some sites featuring different debris coverage, morphology, topography and elevation. At each site we measured debris presence and pattern (by acquiring high resolution digital images) and ice reflectivity; moreover, we sampled the surface debris to describe its sedimentological properties and we installed ablation stakes to evaluate ice melt rates. An exponential correlation $\alpha = 0.22e^{-0.009d}$ between ice albedo (α) and the percentage of debris covered ice surface (d) is found. Our research also permitted to highlight the influence of other forcing factors in ice albedo as the occurrence of melting water and the color of the sediment.

*** Automatic snowline detection from repeated standard digital camera images**

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Standard digital camera images can be used to monitor remote places at high temporal and spatial resolution. We utilise georeferenced hourly images taken of Findelengletscher, Switzerland in spring 2011 and 2012 to automatically map the snowline and snow covered area. Snow cover is detected by application of a self-adjusting threshold filter and corrections for daylight-dependent cast shadows. The stack of classified images can be fed to glacier mass balance and snow melt models.

*** Volumetric mass-balance of Sarennes glacier (French Alps) using terrestrial digital photogrammetry**

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Sarennes is a small south-facing glacier located in the Grande Rousses range (45°07'N, 06°07'E, French Alps). Traditional glaciological measurements on Sarennes glacier started in 1949, with systematic ice cores/density measurements for winter mass balance and ablation stakes measurements for summer mass balance. Sarennes data series is the longest mass balance record in the French Alps and the third longest series in the world. Sarennes data series have been checked by aerial photogrammetric techniques in 1952, 1981 and 2003. In order to check the glaciological mass balance over a small time lag and help to the small size of the Sarennes glacier (0.4 km^2 in 2003) terrestrial photogrammetric images have been obtained in 2009 (1 stereoscopic pair) and 2011 (1 stereoscopic pair). The aim of this paper is to present the terrestrial photogrammetric outline (geometric considerations, camera calibration, and resulting accuracy) implemented at Sarennes, and to present de volumetric mass balance of Sarennes glacier between 2009 and 2011. Finally, we compare de geodetic mass balance method and the traditional glaciological mass balance method of Sarennes glacier between October 2009 and September 2011.