Ev-K2-CNR SHARE project

PAPRIKA-Italy

PAPRIKA - CryosPheric responses to Anthropogenic PRessures in the HIndu Kush - Karakoram -HimalayA regions: impacts on water resources and Availability

Period of activity: July 2010 - June 2013

Coordination: A. Provenzale, ISAC-CNR

Overview

The PAPRIKA project, which includes the twin national projects PAPRIKA-France and PAPRIKA-Italy, is devoted to determining the state of the glaciers and of the water reserves in the Hindu-Kush, Karakoram and Himalaya region and to estimating their future conditions in different climate change scenarios, with special emphasis on the role of atmospheric aerosols.

PAPRIKA-Italy, conducted in collaboration with PAPRIKA-France, is devoted to determining the effects of atmospheric aerosols, particularly Black Carbon (BC) and mineral dust, on glacier dynamics, on the hydrologic cycle and on water availability, using both in-situ and remotely-sensed data and an integrated modelling approach. The main focus of PAPRIKA-Italy, in terms of both data collection and modelling, will be on the Karakoram area and, in particular, on Baltoro glacier and the upper Indus basin in Pakistan, and cooperation with research institutions in Pakistan will be encouraged. Another focus of Paprika-Italy will be on Changri Nup glacier, which lies on a lateral valley of the Khumbu region in Nepal, the principal area where PAPRIKA-France is active. A close collaboration with Paprika France in the Khumbu region is envisaged, mainly in terms of modelling based on the data provided by PAPRIKA-France.

In summary, the goals of PAPRIKA-Italy are:
- Obtain a quantitative assessment of the current state of the atmospheric properties and circulation; aerosol load, deposition and chemical properties; glacier status, mass/energy balance and flow estimates; and hydrologic characteristics, including water quantity and quality, in the two study areas.
- Provide an ensemble of integrated modelling tools, based and validated on field and remotely sensed data (satellites and airborne radars), to obtain quantitative estimates of water availability and climate change impacts on agriculture, environment and ecosystems in the coming decades.
- Develop strategies for capacity building, dissemination and information transfer to policy makers.

Description, goals and work plan

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 particular, there are estimates indicating that up to 50% of the water flowing in the Indus river, which originates from the Karakoram, could be due to glacier melt.

The Karakoram is a large mountain range spanning the borders between Pakistan, India and China. This range is about 500 km in length, and is the most heavily glaciated part of the world outside the polar regions. Biafo Glacier at 63 km ranks as the world's third longest glaciers outside the polar regions; Baltoro glacier, largely debris covered, flows at the feet of K2 and Gasherbrum and it is about 60-km long. Due to its altitude and ruggedness, the Karakoram is much less inhabited than parts of the Himalayas further east. On the other hand, this area is placed at the western boundary of the most densely populated areas of India and China, and it is bound to be a receptor of the pollution generated by the increased industrial activities and vehicular traffic in those regions, which lead to a massive growth of anthropogenic pollutant emissions (UNEP 2008).

In the last years, most glaciers in the HKKH region have been retreating and/or loosing mass, owing to a blend of negative effects that include a significant regional warming trend and the effect of the large load of atmospheric aerosols. In South Asia, one of the most impressive effects of natural and anthropic emissions – including the heavy biomass burning and fossil fuels emissions - is the brownish haze that cover and envelope this region giving rise to the Atmospheric Brown Cloud (Ramanathan et al. 2001). Through so-called “direct-effect”, aerosols scatter and/or absorb the solar radiation, thus cooling the Earth’s surface and changing the radiative balance in the atmosphere. Aerosols also affect the water cycle through so-called “indirect-effects”, whereby increasing the number of cloud condensation nuclei, thus inhibiting the growth of cloud drops to raindrops and increasing the lifetime of clouds. This leads to more persistent and less precipitating clouds, increase reflection of solar radiation and further cool the Earth’s surface. When deposited on a glacier surface, the dark aerosols lower glacier albedo and favor ice melt. Both effects potentially lead to negative glacier mass balance, associated with lowered winter precipitation and more intense summer melt.

The southern slopes of the Karakoram are directly exposed to South Asia aerosol emissions. In addition, this mountain ridge is surrounded by desert areas (eg. Thar, Kara-Kum, Kyrgyl-Kum, Takla Makan regions) and the influence of polluted aerosols on size distribution, concentration and chemical composition of particulate matter is very likely augmented by the presence of mineral dust. Aerosols generally scatter solar radiation, but black carbon (BC) and, to a lesser extent, mineral dust absorb solar radiation. Large amounts of these aerosols characterize the Atmospheric Brown Cloud (ABC) and have been revealed at high altitude in the eastern Himalaya (Nepal Climate Observatory - Pyramid ABC site, Nepal) (Bonasoni et al., 2008; ACPD Special Issue, 2009). Studies on the Atmospheric Brown Cloud have shown that this haze blocks up to 15 % of solar radiation, causing cooling of the surface and heating of the atmosphere, which can affect monsoons and other rainfall patterns (Ramanathan et al. 2005). This kind of brown haze has assumed continental scale proportion; moreover in tropical area, the presence of a dry season can increase aerosol and cloud lifetime and thus enhance both direct and indirect effects (Lau et al. 2006).

Preliminary studies at Bishkek and Lidar sites (Kyrgyzstan background), the only in-situ information available in Central Asia, reveal a very large amount of mineral dust and organic aerosol. BC and mineral dust depositions onto snow-surfaces and glaciers may reduce the surface albedo, favouring increased heating of snow and ice surfaces, thus accelerating melting, shortening snow duration, altering mass balance and causing retreat of mountain glaciers, which potential changes on the amount of available water resources in the region. Projections show that if the current rate of retreat continues, glaciers and snow packs are expected to shrink by around 75 per cent before 2050 (Ramanathan et al. 2008), posing a threat to the region's water security and agricultural productivity.

Economic and population growth, on the other hand, mean an ever-greater demand on these shrinking water resources. Many countries in the HKKH region already face major threats to their water security and thus to their ability to provide people with safe drinking water and food, to produce energy and sustain economic growth and to enhance environmental quality. In addition, climate change greatly amplifies the water insecurity of many countries. Climate-induced modifications are already affecting the water balance of this region, and could become even more severe in coming years, both in terms of water quantity and quality.

For these reasons, it is essential to assess the current state of the aerosol load, glacier mass and energy balances and 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. A particularly important issue is to quantify the differences possibly existing between the behavior of the retreating glaciers in eastern Himalaya and those of the Karakoram, whose response is still largely unknown.

The PAPRIKA project, which includes the twin national projects PAPRIKA-France and PAPRIKA-Italy, is devoted to determining the state of the glaciers and of the water reserves in the HKKH region and to estimating their future conditions in different climate change scenarios, with special emphasis on the role of atmospheric aerosols.

PAPRIKA-Italy, conducted in collaboration with PAPRIKA-France and in contact with the Pakistan Meteorological Department (PMD), will be devoted to determining the effects of atmospheric aerosols, particularly Black Carbon (BC) and mineral dust, on glacier dynamics, on the hydrologic cycle and on water availability, using both in-situ and remotely-sensed data and an integrated modelling approach. The main focus of PAPRIKA-Italy, in terms of both data collection and modelling, will be on the Karakoram area and, in particular, on Baltoro glacier and the upper Indus basin in Pakistan, and cooperation with others research institutions in Pakistan will be encouraged. Another focus of Paprika-Italy will be on Changri Nup glacier, which lies on a lateral valley of the Khumbu region in Nepal, the principal area where PAPRIKA-France is active. A close collaboration with Paprika France in the Khumbu region is envisaged, mainly in terms of modelling based on the data provided by PAPRIKA-France. From a modelling standpoint, considering both mountain regions is extremely interesting as these two areas are characterized by different meteoclimatic conditions, with a lower influence of the monsoonal circulation in the Indus basin and possible differences in glacier response in western Himalaya and in the Karakoram.

From a scientific viewpoint, PAPRIKA-Italy includes open and challenging issues, such as:

(1) assess the effect of aerosols on the atmospheric circulation in high-altitude mountain areas and on the thermodynamical processes associated with seasonal snow melt, glacier mass/energy balance and ice ablation;

(2) study the interaction between the western weather systems, particularly important for the Karakoram, and the snow and ice distribution;

(2) understand and model the dynamics of partially debris-covered glaciers (such as Baltoro) and quantify how debris-covered glaciers respond to climate change;

(3) develop downscaling procedures for stochastic sub-grid parameterizations in regional climate models, allowing for consistent communication between atmospheric processes (resolved at scale of some tens of km) and land surface processes (at scale of a few km);

(4) investigate upscaling parameterizations to obtain an average representation, at regional scale, of cryospheric and hydrologic processes that are measured and quantitatively modelled at the scale of individual glaciers and sub-basins;

(5) build and validate an integrated modelling system that uses the boundary conditions provided by a global climate model with aerosol transport and chemistry, includes a regional climate model with snow/glacier/land-surface interactions, and provides the input to hydrological models able to estimate water availability in different scenarios of climate change and aerosol emissions.

An important point is that systematic observations of atmospheric compounds are not available in the Karakoram ridge, especially at high altitude. The foreseen construction of the new Pakistan Climate Observatory – Karakorum (PCO-K) in the framework of the ABC-UNEP project, able to monitor atmospheric composition changes, represents a crucial and necessary step to understand background atmospheric conditions in the Karakoram and to quantify pollution and mineral transport at high altitudes, were they play a key role in delicate climate process. PCO-K would provide extremely relevant information for a better understanding of the complex interactions between high mountain ranges and climate processes, as well as to produce input data for atmospheric chemistry and climate modelling.

From the point of view of climate services, the ultimate goals of PAPRIKA-Italy are:

- **Obtain a quantitative assessment of the current state of the atmospheric properties and circulation; aeorosol load, deposition and chemical properties; glacier status, mass/energy balance and flow estimates; and hydrologic characteristics, including water quantity and quality, in the two study areas.** The observational part of PAPRIKA-Italy will be largely devoted to high-altitude areas of the Karakoram in Pakistan, with a specific focus on the region of Baltoro glacier and the upper Indus basin.

- **Provide an ensemble of integrated modelling tools, based and validated on field and remotely sensed data (satellites and airborne radars),** to obtain quantitative estimates of water availability and climate change impacts on agriculture, environment and ecosystems in the coming decades (2010-2050).

- **Develop strategies for capacity building**, dissemination and information transfer to policy makers.

The activities of PAPRIKA-Italy are structured in a set of four themes, organized in several workpackages as described below. A summary of the worpackages is given in Appendix 1, the list of participating units in Appendix 2, specific collaborations with PAPRIKA-France are given in Appendix 3, and the time table and deliverable list are given in Appendix 4.

THEME 1: Observations

WP1: Cryospheric observations

1.1: Cryospheric resources, snow cover contribution and glacier melting (quality and quantity) [UNIMI, BAW].

The knowledge of the glacier "health state" is crucial for determining water availability, especially during the dry season. It is thus mandatory to collect information on specific, important glaciers, to determine their yearly contribution to river flow.

Glacial systems work through a delicate equilibrium between snow accumulation and snow-ice melting. In Karakoram, this balance is complicated by the debris cover, widely present on most glacier surfaces. Baltoro Glacier, thanks to its dimensions (about 60 km long and more than 500 km^2 wide) and the fact that it is the way to K2, is one of the symbols of Karakoram glaciers. Owing to the fact that its lower part is debris covered and its upper part is debris free, Baltoro can offer a wide spectrum of the different morphologies and typologies of Karakoram glaciers.

On the Baltoro, the field measurements that will be conducted by the UNIMI and BAW units will focus on determining the geometry and morphology of the glacier, its dynamic state and ablation conditions. The combined analysis of these measurements will provide information on the current state of Baltoro glacier, on its mass budget and on meltwater production. Special attention will be given to ice ablation in the debris-covered areas: during dedicated field campaigns (at least two field surveys in the three years of the project) ablation data will be collected for different conditions and debris thicknesses in various glacier areas. A better quantification of debris properties (i.e.: debris pattern and thickness, lithology, porosity and grain size) will be performed, together with the determination of the debris temporal evolution. Also in this case, field campaigns will be crucial. In the lower part of Baltoro, measurement of debris thickness is too difficult to be performed manually, therefore GPR measurements will be adopted (250-400 MHz). Remote sensing analysis (mainly based on surface temperatures provided by ASTER data) will help mapping and reconstructing the dynamics of debris-cover, see figure 1 for the results of a previous campaign.

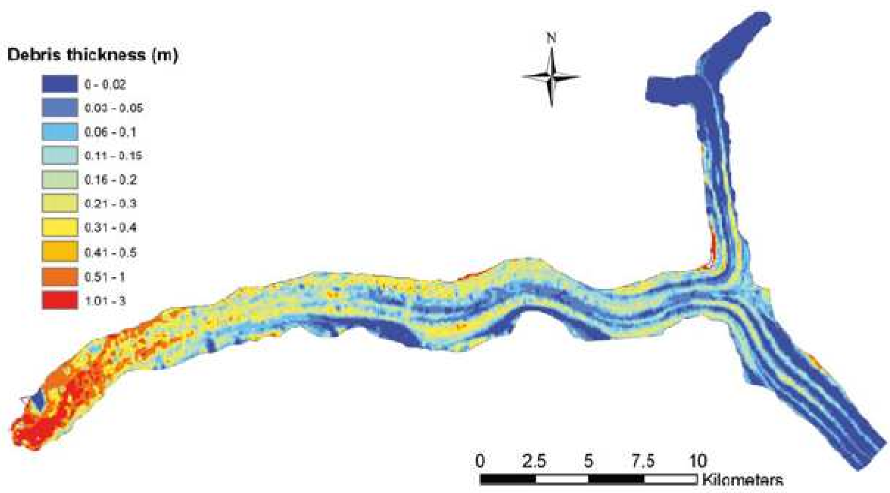

Figure 1. Baltoro Glacier: Debris thickness distribution derived from ASTER surface temperatures (Mihalcea et al, 2008).

To quantify melt conditions with a distributed ablation model, the Urdukas meteo data (Ev-K2-CNR permanent AWS) will be used. Local meteorological gradients on the glacier, and the range and variability of surface albedo, will be measured to obtain a complete quantitative characterisation of glacier conditions. This part requires the installation of a new supraglacial AWS on Baltoro (the AWS should be equipped with all sensors to evaluate the standard 7 meteo parameters plus the ones to evaluate incoming and outgoing energy fluxes).

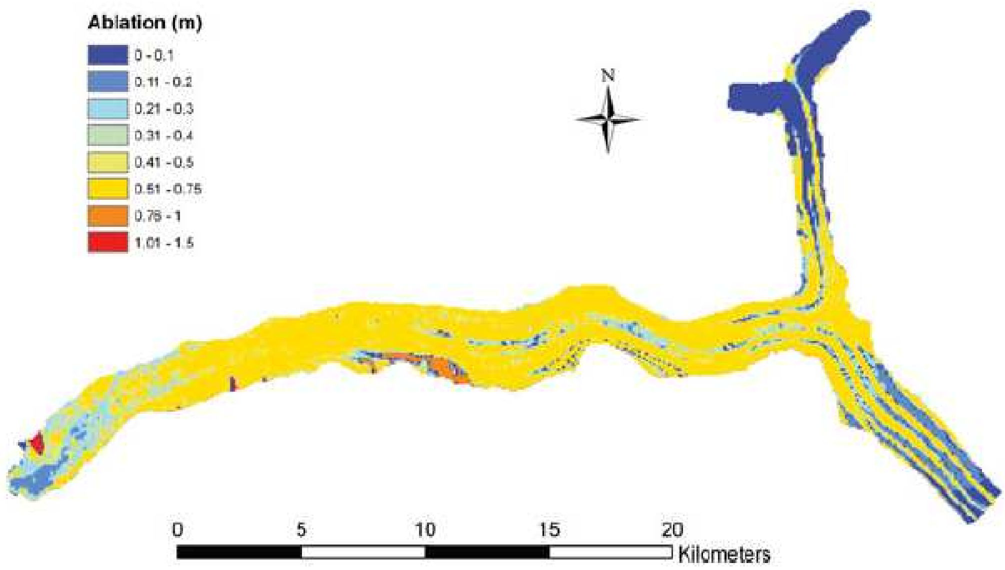

Figure 2. Baltoro Glacier: Calculated total ablation map (1–15 July; values in m) (Mihalcea et al, 2008).

The measurement of snow cover contribution to glacier accumulation and dynamics is a very challenging task, and it matter of serious concern for this project. The problem originates from the fact that all accumulation basins are far from the tongue, and they are far from each other. In the course of the project, we foresee that at least some of them will be visited. The measurement of accumulation will be based on: snow pits, including the sampling; snow depth by probing; shallow coring (hand core-drill, 10 m or so); and, possibly, use of radar for profiling. The local snow depletion curve will be evaluated by coupling snow-field data with remote sensing investigations.

Field data will be supplemented by remote sensing imagery (optical satellites: Aster, Landsat, Spot, Corona) allowing to extrapolate the in-situ point information to the whole glacier surface, in association with the activities of WP 1.3.

1.2: Determination of the ice thickness of Baltoro glacier (Karakoram)
by radar measurements [UNIMI].

Radar survey on continental glaciers is difficult, due to the physical characteristics of these glaciers: crevasses and collapsed ice stratification, ice temperature, water circulation and debris cover. Another source of difficulty is linked to the high radar frequency which is tipically used and the topographic and logistic constraints posed by the glacial environment, associated with diffusive diffraction and strong absorption of the EM wave.

The experiments foreseen in WP 1.2 will consist in the development of several radar systems working at relative low frequency and in their test on a transect at the tongue of Baltoro Glacier.

The radar systems will be designed and realized by INGV (Istituto Nazionale di Geofisica e Vulcanologia, Roma) and will be tested in the field by the UNIMI unit. The following systems will be used:

1. Ground Penetrating Radar GSSI SIR 10B, bistatic configuration working at 40 MHz.
2. Glacio radar INGV, 40MHz, pulse length ranging between 1 a 3 µs, power peack 2kW
3. Glacio radar INGV,15 MHz, pulse length ranging between 1 a 4 µs, power peack 3kW, folded antenna 10m length.

During the field operations, the best array to be used for each radar system will be tested. The measurements will be carried out on four equidistant points distributed on a transect perpendicular to the ice flow, on the tongue of Baltoro Glacier.

Expected outcomes of this activity are indications on how to improve the radar systems and to determine the best frequency and field array to be used. Bottom reflections and ice thickness data will also be obtained. Owing to the complexity of the experiments and the logistic difficulties, full success of this approach is not granted a priori.

1.3: Determination of glacier properties and ice flow by remote sensing
[TU Delft, UNIMI, BAW].

Baltoro glacier is situated in the Karakorum near the border between Pakistan, China and India. Given its location in the high mountains and its extend of about 60 km, remote sensing is a promising method to monitor the state of the glacier through time. Several different remote sensing techniques for assessing topographic changes will be used: space borne laser altimetry, space borne photogrammetry and radar. A technique is suitable if both accuracy and precision and spatial and temporal resolution are high enough to capture relevant topographic changes, related to e.g. accumulation, thinning, glacial extend, debris cover and glacial flow. To assess this suitability in practice, currently case studies over the Karakorum and the nearby Tibetan plateau have been initiated for all three techniques at the Chair of Optical and Laser Remote Sensing, TU Delft. Evaluation of the case studies results will increase insight in the potential of readily available remote sensing data sets for assessing the state of Baltoro glacier. In the following, a short overview is given of the three remote sensing techniques that are currently available to monitor topographic changes over the Tibetan plateau. For each of the three techniques, at least one case study is described evaluating available data. In near future, also radar altimetry data from the Cryosat-2 mission are expected to become available (Wingham et al, 2006). It should be note though that it has a relatively low spatial resolution, of the order of 300m-1km.

Elevation changes along tracks from ICESat laser altimetry: Between 2003 and 2009 the GLAS instrument on board of the ICESat satellite sampled full waveform laser altimetry data along tracks directly below the satellite at an along track distance of 175 m. Each waveform was the result of the interaction of the emitted Gaussian pulse with the terrain surface within an approximately 70 diameter footprint. Because of the near-polar orbit of 94 degrees inclination, distances across track over the Karakorum are of the order of 50 km. As a consequence, only a small part of the Baltoro glacier is actally covered by ICESat data. The ICESat elevations that are available have a vertical accuracy at the decimeter level over flat terrain and a geolocation accuracy in the order of meters, (Duong et al., 2008). In our opinion, ICESat data has two types of application: first as validation data for other altimetry products: its quality is higher than that of other available satellite altimetry data, making it an excellent reference data set. Validation examples will be discussed below. A second application is to directly derive elevation changes from the available repeated tracks. Although ICESat tracks are on average only repeated to distances of a few 100 m, methods exist that optimally profit from the available data, while incorporating short scale topographic relief, (Pritchard et al., 2009).

Glacier velocity fields from SAR speckle tracking: Except for PRISM, the ALOS satellite also carries the PALSAR instrument that acquires Synthetic Aperture Radar images at a resolution of about 5 m in a repeat cycle of 46 days. Using so-called speckle tracking, a glacial flow velocity field can be constructed (Strozzi et al., 2002), by an image matching technique, that matches features (the speckles) in two repeated SAR images. Speckle tracking results from two PALSAR images from the Baltoro glacier will be compared to ICESat derived elevation changes. An example of a velocity field constructed elsewhere is given in Figure 3.

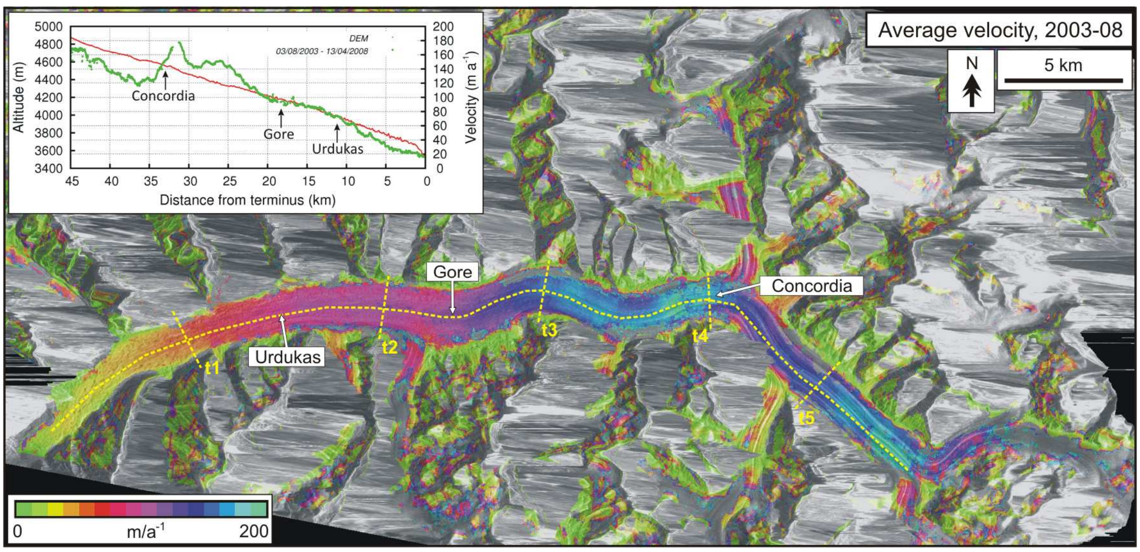

Figure 3. Velocity field of Baltoro glacier, source: http://www.physorg.com/news184253832.html

DTM's from ALOS/PRISM stereo photo's: Using overlapping digital photographs from imaging sensors full coverage digital terrain models can be created. In 2009, the ASTER GDEM global digital elevation model was released, (ASTER, 2010), based on overlapping images from the ASTER instrument on board of the Terra satellite. The ASTER GDEM completely covers the Karakorum at 30 meter a pixel. In a case study the GDEM data was validated against ICESat data, first over the flat Tibetan Nam Co Lake area and second along an arbitrary ICESat track passing through mountainous terrain, Over the lake the average difference between ICESat and ASTER GDEM is 3m, over rough terrain, the average difference increases to 15m. In both cases a significant bias in the GDEM elevations was observed. ASTER GDEM gives a kind of average surface elevation, without an exact date. Alternatively a Digital Elevation Model can be created at certain known dates since 2006 at 2.5 m resolution from panchromatic images from the PRISM instrument on board of the ALOS satellite. In an ongoing case study, an ALOS/PRISM DTM over either the Baltoro glacier iself or over a similar glacier will be validated against ICESat data as well.

WP2: Hydrological observations

2.1: Hydrological characteristics and water quantity [POLIMI].

A first activity will be the definition of the basin portion and river sections that best represent the effect of climate change on the upper Indus basin. The availability and accuracy of in-situ hydrological data in the Indus basin will also be assessed. Analysis of available data will allow for estimating discharge magnitude within the network by upscaling/downscaling against drainage area and to tailor the installation, in the course of the project, of new hydrometric stations.

Based on this information, the POLIMI unit will carry out a feasibility study for the installation of a permanent (seasonal) hydrometric (flow stage) station to measure the glacial stream outflow. The study will define the best tradeoff between representativity of the glacier's outflow (*i.e.* proximity to the glacier mouth), and practical feasibility of the installation, with respect to operator safety, availability of properly shaped stream sections, suitability of building a stage-discharge equation for in-stream flow estimation, and cost. Personnel of POLIMI will take care of determining the best solution for on-site installation of the station, and will provide installation of the station and stage discharge calibration.

The station, which is intended to dwell at least seasonally in order to representatively measure ablation flows for at least two ablation seasons, will require local maintenance. Personnel of the POLIMI unit will be available to instruct local personnel upon how to provide station maintenance. If possible, (PhD) students participating within the SEED exchange program will attend short courses for station operation and maintenance in Italy, and will be able to aid on site stations' operation.

2.2: Water quality [ISE-CNR].

For lakes and streams above the timber line, global and regional warming will lead to ice and rock-glacier melting, an increase in soil microbial activity and an increase in mineral weathering rates causing enhanced nutrient and solute fluxes to mountain lakes and streams. In regions suffering from the impacts of long-distance transported pollutants, warming may also lead to an increase in nitrogen leaching and the release of toxic substances from rock and ice glaciers. Therefore, this part of the activity will focus on the chemical analysis of surface waters to asses their quality.

More specifically, the activities of this WP, conducted by the ISE-CNR unit, will include the following items:

(i) analysis of chemical survey data of high mountain lakes, streams and related potable supply (ions, heavy metals);
(ii) selection of the long-term monitoring sites;
(iii) evaluation of trends in freshwater quality (particularly for drinking water supply);
(iv) investigation of the possible source(s) responsible for the increase of ions and heavy metals released from rock and ice glaciers.

The main study area will be the upper basin of the Indus river, in the area of Baltoro glacier in Pakistan. Water quality samplings will also be conducted in the study areas of the Khumbu region in Nepal.

WP3: Atmospheric observations

3.1: Physical and chemical characterization of aerosol: absorption, scattering, size distribution, atmospheric optical depth, chemistry; atmospheric deposition [ISAC-CNR, Ev-K2-CNR].

The main goal of the activities of WP3.1, conducted by ISAC-CNR and Ev-K2-CNR, is to increase the knowledge on the impact of natural and anthropogenic emissions, also associated with the Atmospheric Brown Clouds (ABC), on the environment and society.

The first step, planned in the framework of the SHARE and ABC projects, not directly included in the PAPRIKA-Italy funding scheme, is the possible installation of a remote monitoring station in the hearth of Pakistani Karakorum, called the Pakistan Climate Observatory – Karakorum (PCO-K) as suggested by the ABC-UNEP project. This action represents a technological and scientific challenge in spite of difficult logistical, infrastructural and power supply conditions, difficult transports and very adverse weather conditions, able to improve the scientific knowledge on atmospheric changes by carrying out a continuous atmospheric composition observation. Optimal sites for a high-altitude PCO-K should be representative of the regional and mesoscale circulation, without being affected in a significant way by local circulations, topographic features and/or proximity of villages and local sources of pollution.

At PCO-K, the foreseen instrumental set-up has been defined in accordance with the ABC standards (Ramanathan et al., 2006), following also the recommendations of GAW-WMO and EUSAAR-EU programs, in order to perform continuous measurements of meteorological parameters, tropospheric ozone as well as a complete aerosol characterization, provided sufficient resources and logistic support will be made available by SHARE Project. Results will be used for a) identifying the periods affected by absorbing aerosol transport events on different temporal and spatial scales; b) estimating the atmospheric radiative forcing and atmospheric heating rate due to absorbing particles, c) comparison with model predictions of aerosol concentration in the high Hindu-Kush-Himalaya region.

As indicated by a preliminary investigation of the atmospheric circulation, an elevated area representative of synoptic scale air mass transports (e.g. in the Baltistan), could be ideal to characterize the chemical composition of the atmosphere as determined by transport from Central Asia, especially during summer, and to estimate the contribution of the westerly outflow to the regional and transcontinental flow of atmospheric compounds in the other seasons (Figure 4). Other candidate sites are also possible.

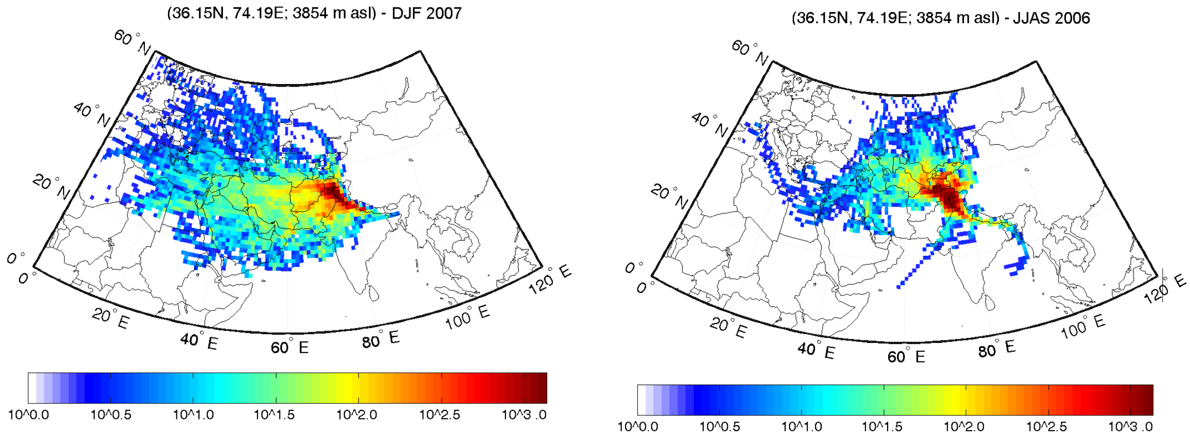

Figure 4. Concentration fields of backtrajectories ending at one of the possible sites of PCO-K during winter (left) and summer (right) 2007.

The objectives of PCO-K observations will be focused on the following themes:

i) determine how the physical, chemical, and optical properties of seasonal aerosol at high altitude in the Karakoram change as a function of the different types and origins of air masses;

ii) assess the aerosol chemical composition disentangling its anthropogenic and natural components

iii) determine how the aerosol size distribution and light scattering properties change during transport of polluted or mineral-aerosol-rich air masses;

iv) evaluate the deposition of absorbing aerosol on glacial areas and estimate the associated effects on the cryosphere.

The observational activities foreseen in WP 3.1 in the framework of PAPRIKA-Italy are associated to the construction of PCO-K. Within PAPRIKA, continuous monitoring of the main anthropogenic and natural compounds will be carried out at the Pakistan Climate Observatory – Karakorum. It will include aerosol mass and complete size distribution, aerosol optical depth, light scattering and absorbing coefficients, allowing to continuous black carbon and mineral dust concentration estimation. Depending on how logistic difficulties are solved, sampling for complete aerosol chemistry characterisation will also be performed. The sampling schedule will be defined on the basis of homogeneous atmospheric conditions for the off-line chemical analyses and in order to provide a basic climatology and seasonal trends for the aerosol chemical components. The chemical analyses include evolved gas analysis for determination of total carbon (TC), water-soluble organic carbon (WSOC), and organic nitrogen, and ion chromatography for determination of major ionic species (sulphate, nitrate, chloride, oxalate, ammonium, potassium, calcium, sodium, magnesium).

Since this area is far from emission sources, the measurement activity carried out at this Karakoram background station will allow the monitoring of long-range and regional transport of air masses and aerosol from the source areas in India, China, Pakistan, Nepal and Middle East. During the project, with the aim of evaluating the aerosol deposition on snow and ice, specific field campaigns will be dedicated to simultaneously investigate the atmospheric composition and the snow-ice composition in the area of Baltoro glacier. In these field campaigns, a specific prototype, developed within the SHARE-TECH project and able to monitor the major atmospheric parameters, will be placed on the glacier surface with the purpose of investigate the air-snow transfer of chemical species and estimating the deposition of absorbing aerosol in the high HKKH region. Experimental efforts will be concentrated in the Karakoram region, where benchmark glaciers and the high-altitude atmospheric observatory is located.

Within WP 3.1, an atmospheric chemistry lab will provide the assessment of the aerosol chemical composition disentangling its anthropogenic and natural components. Laboratory chemical analyses will be performed on samples of particulate matter collected at the Pakistan observatory. The actual sampling schedule will be defined on the basis of an aerosol concentration phenomenology extracted by the on-line physical measurements, in order to collect time-integrated samples in homogeneous conditions for the off-line chemical analyses. Clean quartz-fiber filters will be provided by our lab for sampling at the Pakistan observatory. About 50 - 70 aerosol samples per year (+ 10% of blanks) could be analyzed in order to provide a basic climatology and seasonal trends for the aerosol chemical components. The chemical analyses comprise evolved gas analysis for determination of total carbon (TC), water-soluble organic carbon (WSOC), and organic nitrogen, and ion chromatography for determination of major ionic species (sulphate, nitrate, chloride, oxalate, ammonium, potassium, calcium, sodium, magnesium). Ammonium sulphate is the most typical aerosol component of regional-scale pollution; potassium is a tracer of biomass combustion; calcium is the main water-extractable mineral component; finally WSOC can be associated to both biomass burning and secondary organic aerosol formation from both biogenic and anthropogenic sources. For a more accurate source apportionment of the organic fraction of the aerosol, NMR spectroscopy can be employed on a selected number of samples (ca. 20 per year). Analyses of elemental carbon (EC) must be agreed with the laboratory in Grenoble (JL Jaffrezo). Deeper analyses of the crustal (dust) fraction by PIXE or XRD can be requested to other laboratories, not directly involved in PAPRIKA, depending on fund availability.

Overall, the contribution of this WP to the PAPRIKA scientific objectives is to provide an aerosol climatology for optically-active aerosol based on continuous measurements, for validation of the models developed in the WP 4.1, 4.2, 4.4, 5.1 and estimating the aerosols emission in the Indo-Gangetic plain, Middle East and Central Asia and their transport to the high altitude of Karakorum ridge. The site of PCO-K should be not too far from the strong south Asia emission areas; in this case, observations of aerosol concentrations could allow to investigate the fraction/frequency of regional scale pollution episodes which eventually lead to transport to higher altitude environments. Moreover, the arid areas of Central Asia possibly represent an important source of mineral dust, that can reach the Karakorum summits, alter the radiative forcing at the site and contribute to snow and glacier melting.

The amount of BC deposited on snow and ice surfaces in the higher HKKH region will be measured in the proximity of Baltoro glacier. Snow samples will be collected in both the ablation and the accumulation zones of the glaciers for subsequent analysis of absorbing materials, like BC and mineral dust. The determination of BC and other absorbers in fresh snow samples, and the acquisition of vertical profiles of the absorbers in the surface snowpack formed by subsequent snowfalls will provide the necessary input for the one-dimensional snowpack model developed in WP4.4 and describing the vertical energy fluxes in the surface snow layer and predicting melting rates.

3.2: Impact of anthropogenic (ABC) and natural (STE) processes on surface ozone concentrations and contribution to radiative forcing [ISAC-CNR].

The main goal of the activities of WP 3.2, conducted by the ISAC-CNR unit, is to study the background ozone behaviour and evaluate the contributions of long range and regional transport events of polluted air masses as well as stratospheric ozone intrusions. The WP 3.2 activity is strictly connected with WP 3.1 and with the SHARE project.

The tropospheric O_3 is considered to be the third most important greenhouse gas after carbon dioxide and methane and strongly influences the radiative budget of the atmosphere (Forster et al., 2007) and the oxidation capacity of the troposphere (Gauss et al., 2003). Due to its high chemical reactivity in the lower troposphere, O_3 is considered a dangerous pollutant, causing harm to human health and ecosystems (Forster et al., 2007). Although the greatest contribution to tropospheric O_3 comes from photochemical production (e.g. Jacobson, 2002), other concurring processes like Stratosphere – Troposphere Exchange (STE) cannot be neglected (e.g. Roelofs and Lelieveld, 1997; Wild, 2007).

The activities of WP 3.2 are devoted to increase information on:

i) how long-range transport episodes of pollution and/or upper troposphere-lower stratosphere exchanges affect background ozone concentrations;
ii) quantify how the contribution of pollution and UT/LS transports affect the radiative forcing due to O_3 concentrations change.

3.3: Variability of the atmospheric circulation (from time series and new in-situ measurements) [ISAC-CNR, Ev-K2-CNR].

The activities of WP 3.3 are devoted to study the characteristics and the variability of the atmospheric circulation at the PCO-K site and in the Baltoro glacier area. In the framework of the SHARE project, a complete meteorological characterization of the PCO-K site will be made possible by continuous observation of major meteorological parameters: air temperature, atmospheric pressure, relative humidity, wind speed and direction, and precipitation. Measurements at the PCO-K site will be compared with the meteorological observations available since 2004 in Urdukas (35°43'N; 76°17'E, 3926 m a.s.l.) and Askole (35°40'N, 75°48E, 3015 m a.s.l.) and with the measurements that will be provided by the new AWS to be installed in the upper part of Baltoro glacier. AWS measurements in the area of Baltoro glacier will be thoroughly analysed and compared with reanalyses and with mesoscale weather patterns. Local wind regimes confirm the dominance of W-E systems, both due to the morphology of the valley and to the dominant pattern of local large-scale pressure patterns. Such a regime is also supported by HYSPLIT trajectory analysis over the area. Analysis of the AWS at Baltoro and at PCO-K will provide for a wide range of meteorological records in different conditions and will allow for a preliminary meteorological characterization of the area of the upper Indus basin. Local wind regimes confirm the dominance of W-E systems, both due to the morphology of the valley and to the dominant pattern of local larger scale pressure patterns. Such regime is also supported by HYSPLIT trajectory analysis over the area.

To characterize the origin of air masses reaching PCO-K, 5-day back-trajectories will be calculated with the Lagrangian Analysis Tool LAGRANTO (Wernli and Davies, 1997). Trajectory calculations will base on the 6-hourly operational analyses produced by the European Centre for Medium Range Weather Forecasts (ECMWF). Due to the complex topography of the mountain areas where PCO-K will be located and the influence of local/regional transport phenomena related to thermal valley winds, back-trajectory results should be anyway treated with caution. The atmospheric composition will be characterized for each cluster of back-trajectories in order to determine the influence of synoptic circulation on the atmospheric composition and to apportion different source areas. An example of backtrajectory calculations for an area of Baltistan, one of the possible sites of PCO-K, is given in Figure 4.

THEME 2: Modelling

WP4: Integrated climate-glacier-water modelling

4.1: Global climate simulations and atmospheric variability, including aerosol transport [CMCC, ISAC-CNR].

The CMCC global coupled model will be employed in order to obtain global control runs and scenario simulations for the next decades, to be used as boundary conditions for the regional model described in WP 4.2.

The physical core of the CMCC Earth System Model is composed of a coupled atmosphere ocean sea-ice general circulation model. The ocean model component is the 8.2 version of the Océan Parallélisé (OPA; Madec et al., 1998) with the ORCA2 global ocean configuration. The model horizontal resolution is 2° × 2° cosine (latitude), with increased meridional resolutions to 0.5° near the equator. The model has 31 vertical levels. The evolution of the sea ice is computed by the Louvain-La-Neuve sea ice model (LIM; Fichefet and Morales Maqueda, 1997), which is a thermodynamic–dynamic snow–sea ice model, with three vertical levels. The atmospheric model component is ECHAM5 (Roeckner et al., 2003; 2006). A hybrid sigma–pressure vertical coordinate is used with 31 vertical levels with top at 10 hPa. The ocean and atmosphere components exchange relevant fields [SST, heat, water fluxes, wind stresses, ocean currents] through the OASIS coupler version 2.4 coupler (Valcke 2006; Fogli et al., 2009). No flux corrections are applied to the coupled model.

In the present configuration of the CMCC climate model the distribution and the main properties of sulfate aerosols are prescribed. In order to perform climate experiments including the treatment of aerosol physics, the next configuration of the CMCC climate model will incorporate the representation of the aerosol properties [namely, interactive mass concentration and composition, size distribution, mixing state, refractive index, optical properties, hygroscopicity] for different aerosol species. The implementation of the main aerosol properties and components will make use of the HAM module for aerosol chemistry and transport.

The HAM module (Stier et al. 2005) joins a microphysical core (M7, Vignati et al. 2004), based on the representation of particle size distribution in terms of the superposition of log-normal components, with an explicit representation of the main processes of aerosol emission, sedimentation and deposition. The HAM module includes the dynamics of the main types of aerosols, namely sulfates, black carbon, organic particulate, sea salt and mineral dust, and allows for estimating the optical depth, dimensional spectrum, concentration and spatial and mass distribution of aerosols.

A set of control runs will be carried out in order to assess the performances of the newly coupled aerosol-climate model in simulating the mean climate. Therefore, a set of climate change scenario simulations including aerosol emissions will be performed and will be used as boundary conditions for the regional model.

4.2: Regional climate modelling of the atmosphere/glacier/hydrosphere system, including sources and transport of aerosols at regional scale and subgrid scale parameterizations based on stochastic downscaling methods [ICTP, ISAC-CNR].

The activities of WP 4.2, conducted by ICTP and ISAC-CNR, will be devoted to the upgrading and optimization of the regional climate modeling system RegCM in its newly released version 4 for the area of interest. Of particular relevance for PAPRIKA-Italy are two features of the RegCM model, which are in fact unique among regional climate models:

i) A simplified aerosol module including Sulfate, Organic and Black carbon (OC and BC), desert dust and sea spray. For each of the tracers the aerosol module includes emission sources, transport by resolvable scale winds, sub-grid scale turbulence and deep convection, dry and wet removal processes, simplified chemical transformations, direct radiative forcing both in the solar and infrared spectrum, and a simplified representation of indirect aerosol effects on cloud microphysics. The aerosol module is described in Qian and Giorgi (1999), Solmon et al. (2005), Zakey et al. (2005) and Zakey et al (2008). It has been used to study the effects of sulfate aerosols on the climate of East Asia (Giorgi et al. 2002, 2003), the effect of desert dust on the west Africa monsoon (Konare et al. 2008; Solmon et al. 2008) and the effects of desert dust storms on the climate of north-east Asia (Zhang et al. 2009). Being a simplified aerosol scheme, this module was specifically designed for use in long term climate simulations. Within the context of PAPRIKA-Italy, this module can be used to simulate the effects of aerosol deposition on the snow texture and optical properties.

ii) Capability of representing land surface processes at high resolution sub-grids (Giorgi et al. 2003). With this option, for each model grid point the land surface can be represented on a higher resolution regular sub-grid accounting for local land-use and topography information. This allows the characterization of land surface processes at very fine resolutions, up to a few km or even less, without running the full model at these resolutions. Previous studies have shown that the use of this sub-grid scheme improves in particular the representation of land surface hydrology and the cycle of snow accumulation and melting and thus it is especially suitable for use in PAPRIKA-Italy (Giorgi et al. 2003, Im et al. 2010a,b).

For the regional simulations planned in PAPRIKA-Italy it is envisioned to use the RegCM4 model with interactively coupled aerosols and the sub-grid land-use/topography scheme, complemented by the downscaling methods of WP4.3 and by the glacier models of WP4.4.

The use of the sub-grid land scheme in the regional model RegCM and the modelling of glacier dynamics requires the disaggregation of climate variables from the model grid (say 30-50 km) to the land sub-grid (say 1-3 km). Simple schemes for temperature and atmospheric moisture based on topographical information have been developed in previous studies (Giorgi et al. 2003). The disaggregation of precipitation is however more difficult, and in previous studies either precipitation was not disaggregated (Giorgi et al. 2003) or simple ad-hoc empirical formulae were used (Im et al. 2010). More detailed precipitation disaggregation schemes are instead necessary in PAPRIKA-Italy for a more accurate simulation of the cycle of snow formation and meting in the mountainous areas of Khumbu region and of Baltoro glacier.

In the PAPRIKA-Italy project, ICTP and ISAC-CNR will implement in the regional climate model RegCM a set of stochastic sub-grid scale parameterization techniques based on the precipitation downscaling models developed at ISAC-CNR (Rebora et al. 2006, Brussolo et al. 2008). These techniques produce an ensemble of precipitation fields with small-scale resolution of about 1 km, which are consistent with the large-scale statistical properties of the precipitation field provided by the regional climate model. The downscaling procedures are the "missing link" between the meteorological scales and the scales which are needed for simulating land-surface processes and allow for a proper coupling between the atmospheric dynamics, simulated by the regional model, and the dynamics of the land surface - ice-snow processes.

The stochastic downscaling techniques will also be used to provide estimates of the precipitation and temperature fields at small resolution, to be used as drivers of the rainfall-runoff and hydrological models of the basins in the two study areas.

4.3: Modelling the interaction between snow-pack, radiation and the absorbing material deposited in the snow and models of glacier dynamics [ISAC-CNR, ICTP, UNIMI, POLIMI].

The effect of deposited aerosols on the seasonal snow cover will be simulated using both simplified degree-day approaches and more refined modelling techniques, such as those based on the use of the French model CROCUS (Brun et al. 1989, 1992), already adopted in PAPRIKA-France, which will be adapted to the conditions in the area of Baltoro glacier and of the glaciers in the Khumbu region. This will allow for investigating the effects of optically absorbing impurities (dust, aerosols) on energy fluxes in the snow pack, surface snow temperatures and snow melting rates. Both the aerosol direct effect, in terms of changed snow/ice albedo, and the effects associated with the acceleration of snow metamorphism will be considered. If possible, the new snow module will be implemented, in an interactive way, in the regional modelling system of WP 4.2.

In the case of Baltoro glacier, the one-dimensional physical snowpack module will be complemented by a simplified model for glacier flow and dynamics (e.g., Oerlemans 2001) to assess the response of the whole glacier to changes in climatic conditions and aerosol load and to obtain quantitative estimates of melt water. Particular attention will be devoted to the energy and mass balances in rock-covered glaciers where the impact of aerosol load is more complex and the heat flux throught the rock cover must be modelled. The glacier dynamics will be driven, off-line, by the meteorological forcings provided by the regional modelling system of WP 4.2, with the goal of estimating the amount of water produced by glacier melt.

A major goal of WP4.3 will also be to develop upscaling procedures to estimate snow pack and glacier response at regional scale, blending the information provided by in-situ and remotely-sensed data with the integrated regional modelling system.

Activities in WP 4.3 will be conducted in a close collaboration between ISAC-CNR, ICTP, UNIMI and POLIMI.

4.4: Development of a hydrological model for the upper basin of the Indus river (Pakistan) and for the Koshi basin (Nepal) [POLIMI, TU Delft].

The upscaled information provided by WP 4.3 on the amount of glacier melt water and the the spatial-temporal distribution of rainfall provided by the regional model in WP 4.2, complemented by appropriate downscaling procedures, will be used as drivers for a runoff model of the upper part of the Indus basin in Pakistan and for the Koshi basin in Nepal. For the Indus basin, use of the results on land surface characteristics provided by the SEED project is foreseen.

The POLIMI unit will coordinate with TU Delft to build a hydrological modeling framework (including cryospheric flows in the upper catchment) for the Indus watershed area. In view of the large size (*i.e.* an order of magnitude of $\approx 10^4$ km^2 or more) and response time of the upper Indus basin, the approach will be based on the construction of a properly tailored model, which will explicitly deal with the physical processes required for an accurate depiction of the hydrological cycle, while keeping acceptable computational burden.

One possible modelling approach will be based on the TibWatMod model (Futurewater, Wageningen), currently running for the whole Tibetan plateau and validated on specific basins in China. The model will have to be adapted and validated for the specific case of the upper Indus basin. Other modelling strategies could also be devised by the POLIMI unit. In close collaboration with Paprika-France, the POLIMI unit will also work an a hydrologic model for the Koshi basin.

To validate the hydrological modelling results, model outputs obtained from control runs on past-present conditions will be compared with available hydrologic data and with the measurements obtained during the PAPRIKA project.

WP5: Future scenarios on water availability

5.1: Cryospheric characteristics in regional climate change scenarios [ISAC-CNR, ICTP, UNIMI].

In the activities of WP 5.1, conducted by ISAC-CNR, ICTP and UNIIMI, the integrated atmosphere/aerosol/snowpack/ice model of WP 4.1, 4.2 and 4.3 will be used to determine glacier melt and water availability in a set of standard climate-change and aerosol emission scenarios. The regional model will be nested in global simulations which include aerosol transport and chemistry, which will provide the proper boundary conditions for regional climate assessments.

The spatial resolution of the regional climate model will be 30km x 30km, and the modelling system will include sub-grid scale parametrizations based on stochastic rainfall donwscaling and atmospheric coupling to the seasonal snowpack dynamics. The glacier flow models will be driven, in a one-way mode, by the meteorological outputs provided by the regional climate model. The focus will be on the coming four decades; projections of the cryospheric characteristics in the period 2010-2050 will be provided for the monitored glaciers in two study areas of the PAPRIKA-Italy project. If the upscaling procedures will prove successful, this WP should possibly provide a preliminary assessment of the overall response of the glacier system in the Indus catchement area.

5.2: Hydrological characteristics in regional climate change scenarios [ISAC, ICTP, POLIMI, TU Delft].

The activities of WP 5.2, conducted in collaboration by ICTP, TU Delft, POLIMI and ISAC-CNR, will be devoted to using the results of WP 5.1 to provide estimates of streamflow regimes and water availability in the upper Indus basin. The outputs of the integrated regional climate modelling system (WP 5.1), including the downscaled spatial-temporal distribution of precipitation over the basins of interest and the estimated glacier and snow pack melt water, will be used to drive the hydrological model developed and validated in WP 4.4, to provide estimates of future streamflow regimes and water quantity in the different climate change and aerosol emission scenarios considered.

THEME 3: Impacts

WP6: Impacts and adaptation (in close collaboration with the SEED project)

This aspects will be developed in close cooperation with the SEED project. Realizing the close interrelation between poverty alleviation, social and economic development for local people, environmental research and conservation of the unique natural ecosystem of the area, the SEED project aims to catalyze an integrated social, economic and environmental development, including the realization of Central Karakorum National Park (CKNP).

The SEED activities are focused mainly on a management approach, with the aim to create a management strategy for the Central Karakorum National Park and sustainable development for the local communities living in the valleys adjoined CKNP. For this reason, the data collected and the results obtained in the Paprika project assume special relevance for the SEED approach.

6.1: Impacts of future streamflow regimes on water resources for the communities.

The Central Karakorum National Park represent the largest source of freshwater for Pakistan (and one of the largest mountain glacial system in the world) with the Siachen, Baltoro and Hispar-Biafo glaciers all originating within the park boundaries. In a mostly dry country that is highly dependent on agriculture, these glaciers are quite literally the life-blood of Pakistan, feeding the Indus and other major river systems.

Furthermore, these glaciers are also the key source of water (besides groundwater extraction, exploited to a much lesser extent) for drinking domestic and industrial use and, with increasing importance, for generation of mega-power through hydro-electricity.

The availability of sufficient water of good quality throughout the year very often remains a core issue within the community realm with many communities having settled in present locations based on water, agricultural land and accessibility to pasture for grazing.

In many respects, the management of water within communities living in the Park surrounding area is advanced with traditional irrigation and domestic supply system long in place based on numerous well established criteria (e.g. amount of labour/resources contributed to channel construction, social status within the community, etc..). However, with the onset of potentially severe changes in quantity, regularity and quality of available water as a result of changing demand regimes and climate change many of these traditional management systems may have to be discarded, leading to unsustainable practices and to potential user rights conflicts. This may also be compounded by a large-scale development of dams for both hydroelectric (micro and major) and irrigation/drinking requirements down-country in the very near future.

The activities of WP 6.1, conducted in a collaboration between PAPRIKA-Italy and SEED, will focus on how to use the results provided by the integrated, regional modelling system (WP 4 and WP 5) to estimate the impact of changing water regimes on the local communities.

6.2: Impacts of climate and seasonal water availability on the ecosystem.

The distribution of natural ecosystems, and the related vegetation and fauna, is mainly linked to climatic and topographic conditions, as well as it is increasingly affected by human interferences and pressures. Decreasing diversity of natural habitat vegetation in the CKNP to the north, is due to increasing aridity, and the major cause is the significant difference in precipitation, humidity, and the varying periods of snow coverage.

The climate and seasonal water availability change during the time could strongly affect the ecosystem distribution of the CKNP area expecially for those species that are strictly linked to specific micro-habitats and/or with poor possibility of adaptative migrations.

The activities of WP 6.2 will consider how expected changes in seasonal water availability can affect ecosystem structure and population dynamics, by using the outputs of the integrated, regional modelling system (WP 4 and WP 5) to drive suitable empirical models of species distribution and ecosystem properties that will be developed in the framework of SEED.

THEME 4: Capacity building and dissemination

WP7: Capacity building, dissemination and information to policy makers
[Ev-K2-CNR, ISAC-CNR, UNIMI]

The activities of WP 7, conducted by Ev-K2-CNR, ISAC-CNR and UNIMI with contribution of all units, will focus on the dissemination of information from the project, the development of a dedicated project web-site and bibliography, and the establishment of a project database. All partners will feed into this WP, and the project coordinator will take direct responsibility, in contact with the SEED project. Methodologies for knowledge transfer will involve **creating a web site**, **training for young scientists** and **publication of two annual reports and one final report** (this latter in September 2013), in addition to the peer-reviewed scientific papers which will be published by the participants in the framework of PAPRIKA-Italy. We foresee that **three annual technical meetings**, including all units, and **one mid-term review meeting**, including all group leaders, will be organised during the project. At least **one public conference** will be organised after the end of the project. **All data collected and all outputs of numerical simulations performed in the PAPRIKA-Italy project will be made available to all participants in a restricted area of the project web site.** At the end of the project, the main results and part of the data will be made publicly available on the project web site.

CONTRIBUTIONS OF THE INDIVIDUAL PARTNERS TO PAPRIKA-Italy

1. ISAC-CNR

coordination of WP 3.1, 3.2, 3.3, 4.3, 5.1, 5.2

(P. Bonasoni, A. Marinoni, P. Cristofanelli and coworkers)

One crucial activity, planned in the framework of the SHARE and ABC projects, not directly included in the PAPRIKA-Italy funding scheme, is the possible installation of a remote monitoring station in the hearth of Pakistani Karakorum, called the Pakistan Climate Observatory – Karakorum (PCO-K) as suggested by the ABC-UNEP project. This action represents a technological and scientific challenge in spite of difficult logistical, infrastructural and power supply conditions, difficult transports and very adverse weather conditions, able to improve the scientific knowledge on atmospheric changes by carrying out a continuous atmospheric composition observation. Optimal sites for a high-altitude PCO-K should be representative of the regional and mesoscale circulation, without being affected in a significant way by local circulations, topographic features and/or proximity of villages and local sources of pollution.

At PCO-K, the foreseen instrumental set-up has been defined in accordance with the ABC standards (Ramanathan et al., 2006), following also the recommendations of GAW-WMO and EUSAAR-EU programs, in order to perform continuous measurements of meteorological parameters, tropospheric ozone as well as a complete aerosol characterization, provided sufficient resources and logistic support will be made available by SHARE Project. Results will be used for a) identifying the periods affected by absorbing aerosol transport events on different temporal and spatial scales; b) estimating the atmospheric radiative forcing and atmospheric heating rate due to absorbing particles, c) comparison with model predictions of aerosol concentration in the high Hindu-Kush-Himalaya region.

The observational activities of this unit, in the framework of PAPRIKA-Italy, are associated to the construction of PCO-K. Within PAPRIKA, continuous monitoring of the main anthropogenic and natural compounds will be carried out at the Pakistan Climate Observatory – Karakorum. It will include aerosol mass and complete size distribution, aerosol optical depth, light scattering and absorbing coefficients, allowing to continuous black carbon and mineral dust concentration estimation. Depending on how logistic difficulties are solved, sampling for complete aerosol chemistry characterisation will also be performed. The sampling schedule will be defined on the basis of homogeneous atmospheric conditions for the off-line chemical analyses and in order to provide a basic climatology and seasonal trends for the aerosol chemical components. The chemical analyses include evolved gas analysis for determination of total carbon (TC), water-soluble organic carbon (WSOC), and organic nitrogen, and ion chromatography for determination of major ionic species (sulphate, nitrate, chloride, oxalate, ammonium, potassium, calcium, sodium, magnesium).

The contribution of this unit to the PAPRIKA scientific objectives is to provide an aerosol climatology for optically-active aerosol based on continuous measurements, for validation of the models developed in the WP 4.1, 4.2, 4.4, 5.1 and estimating the aerosols emission in the Indo-Gangetic plain, Middle East and Central Asia and their transport to the high altitude of Karakorum ridge. The site of PCO-K should be not too far from the strong south Asia emission areas; in this case, observations of aerosol concentrations could allow to investigate the fraction/frequency of regional scale pollution episodes which eventually lead to transport to higher altitude environments. Moreover, the arid areas of Central Asia possibly represent an important source of mineral dust, that can reach the Karakorum summits, alter the radiative forcing at the site and contribute to snow and glacier melting.

The amount of BC deposited on snow and ice surfaces in the higher HKKH region will be measured in the proximity of Baltoro glacier. Snow samples will be collected in both the ablation and the accumulation zones of the glaciers for subsequent analysis of absorbing materials, like BC and mineral dust. The determination of BC and other absorbers in fresh snow samples, and the acquisition of vertical profiles of the absorbers in the surface snowpack formed by subsequent snowfalls will provide the necessary input for the one-dimensional snowpack model developed in WP4.4 and describing the vertical energy fluxes in the surface snow layer and predicting melting rates.

The tropospheric O_3 is considered to be the third most important greenhouse gas after carbon dioxide and methane and strongly influences the radiative budget of the atmosphere (Forster et al., 2007) and the oxidation capacity of the troposphere (Gauss et al., 2003). Due to its high chemical reactivity in the lower troposphere, O_3 is considered a dangerous pollutant, causing harm to human health and ecosystems (Forster et al., 2007). Although the greatest contribution to tropospheric O_3 comes from photochemical production (e.g. Jacobson, 2002), other concurring processes like Stratosphere – Troposphere Exchange (STE) cannot be neglected (e.g. Roelofs and Lelieveld, 1997; Wild, 2007).

The activities of WP 3.2 are devoted to increase information on:

i) how long-range transport episodes of pollution and/or upper troposphere-lower stratosphere exchanges affect background ozone concentrations;
ii) quantify how the contribution of pollution and UT/LS transports affect the radiative forcing due to O_3 concentrations change.

Another set of activities will concern the study the characteristics and the variability of the atmospheric circulation at the PCO-K site and in the Baltoro glacier area. In the framework of the SHARE project, a complete meteorological characterization of the PCO-K site will be made possible by continuous observation of major meteorological parameters: air temperature, atmospheric pressure, relative humidity, wind speed and direction, and precipitation. Measurements at the PCO-K site will be compared with the meteorological observations available since 2004 in Urdukas (35°43'N; 76°17'E, 3926 m a.s.l.) and Askole (35°40'N, 75°48E, 3015 m a.s.l.) and with the measurements that will be provided by the new AWS to be installed in the upper part of Baltoro glacier. AWS measurements in the area of Baltoro glacier will be thoroughly analysed and compared with reanalyses and with mesoscale weather patterns. Local wind regimes confirm the dominance of W-E systems, both due to the morphology of the valley and to the dominant pattern of local large-scale pressure patterns. Such a regime is also supported by HYSPLIT trajectory analysis over the area. Analysis of the AWS at Baltoro and at PCO-K will provide for a wide range of meteorological records in different conditions and will allow for a preliminary meteorological characterization of the area of the upper Indus basin. Local wind regimes confirm the dominance of W-E systems, both due to the morphology of the valley and to the dominant pattern of local larger scale pressure patterns. Such regime is also supported by HYSPLIT trajectory analysis over the area.

To characterize the origin of air masses reaching PCO-K, 5-day back-trajectories will be calculated with the Lagrangian Analysis Tool LAGRANTO (Wernli and Davies, 1997). Trajectory calculations will base on the 6-hourly operational analyses produced by the European Centre for Medium Range Weather Forecasts (ECMWF). Due to the complex topography of the mountain areas where PCO-K will be located and the influence of local/regional transport phenomena related to thermal valley winds, back-trajectory results should be anyway treated with caution. The atmospheric composition will be characterized for each cluster of back-trajectories in order to determine the influence of synoptic circulation on the atmospheric composition and to apportion different source areas..

(S. Decesari and coworkers)
The primary objective of the atmospheric chemistry lab within WP 3.1 of PAPRIKA-Italy will be the assessment of the aerosol chemical composition disentangling its anthropogenic and natural components. Laboratory chemical analyses will be performed on samples of particulate matter collected at the Pakistan observatory. The actual sampling schedule will be defined on the basis of an aerosol concentration phenomenology extracted by the on-line physical measurements, in order to collect time-integrated samples in homogeneous conditions for the off-line chemical analyses. Clean quartz-fiber filters will be provided by our lab for sampling at the Pakistan observatory. About 50 - 70 aerosol samples per year (+ 10% of blanks) could be analyzed in order to provide a basic climatology and seasonal trends for the aerosol chemical components. The chemical analyses comprise evolved gas analysis for determination of total carbon (TC), water-soluble organic carbon (WSOC), and organic nitrogen, and ion chromatography for determination of major ionic species (sulphate, nitrate, chloride, oxalate, ammonium, potassium, calcium, sodium, magnesium). Ammonium sulphate is the most typical aerosol component of regional-scale pollution; potassium is a tracer of biomass combustion; calcium is the main water-extractable mineral component; finally WSOC can be associated to both biomass burning and secondary organic aerosol formation from both biogenic and anthropogenic sources. For a more accurate source apportionment of the organic fraction of the aerosol, NMR spectroscopy can be employed on a selected number of samples (ca. 20 per year). Analyses of elemental carbon (EC) must be agreed with the laboratory in Grenoble (JL Jaffrezo). Deeper analyses of the crustal (dust) fraction by PIXE or XRD can be requested to other laboratories, not directly involved in PAPRIKA, depending on fund availability.

(J. von Hardenberg, F. Fierli and coworkers)
The HAM module for aerosol chemisty and transport will adapted to the goals of this project and used in WP 4.1 of PAPRIKA-Italy to implement aerosol transport and chemistry in a global climate model. The HAM module (Stier et al. 2005) joins a microphysical core (M7, Vignati et al. 2004), based on the representation of particle size distribution in terms of the superposition of log-normal components, with an explicit representation of the main processes of aerosol emission, sedimentation and deposition. The HAM module includes the dynamics of the main types of aerosols, namely sulfates, black carbon, organic particulate, sea salt and mineral dust, and allows for estimating the optical depth, dimensional spectrum, concentration and spatial and mass distribution of aerosols.

(A. Provenzale and coworkers)
In WP 4.2 of the PAPRIKA-Italy project, this group shall closely cooperate with ICTP and implement, in the regional climate model RegCM, a set of stochastic sub-grid scale parameterization techniques based on the precipitation downscaling models developed at ISAC-CNR (Rebora et al. 2006, Brussolo et al. 2008). These techniques produce an ensemble of precipitation fields with small-scale resolution of about 1 km, which are consistent with the large-scale statistical properties of the precipitation field provided by the regional climate model. The downscaling procedures are the "missing link" between the meteorological scales and the scales which are needed for simulating land-surface processes and allow for a proper coupling between the atmospheric dynamics, simulated by the regional model, and the dynamics of the land surface - ice-snow processes. The stochastic downscaling techniques will also be used to provide estimates of the precipitation and temperature fields at small resolution, to be used as drivers of the rainfall-runoff and hydrological models of the basins in the two study areas.

The effect of deposited aerosols on seasonal snow cover dynamics will be simulated by this group in WP 4.3, using both a simple degree-day approach and more refined modelling techniques, such as those based on the use of the French model CROCUS (Brun et al. 1989, 1992), already adopted in PAPRIKA-France, which will be adapted to the conditions in the area of Baltoro glacier and of the glaciers in the Khumbu region, in collaboration with UNIMI, ICTP and the teams of PAPRIKA-France. This will allow for investigating the effects of optically absorbing impurities (dust, aerosols) on energy fluxes in the snow pack, surface snow temperatures and snow melting rates. Both the aerosol direct effect, in terms of changed snow/ice albedo, and the effects associated with the acceleration of snow metamorphism. In the case of Baltoro glacier, the one-dimensional physical snowpack module will be complemented by a simplified model for glacier flow and dynamics (e.g., Oerlemans 2001) to assess the response of the whole glacier to changes in climatic conditions and aerosol load and to obtain quantitative estimates of melt water. Particular attention will be devoted to the energy and mass balances in rock-covered glaciers where the impact of aerosol load is more complex and the heat flux throught the rock cover must be modelled.

In a close collaboration with ICTP, the integrated atmosphere/aerosol/snowpack/ice model will be used to determine glacier melt and water availability in a set of standard climate-change and aerosol emission scenarios in WP 5.1. The regional model will be nested in global simulations which include aerosol transport and chemistry, which will provide the proper boundary conditions for regional climate assessments. The spatial resolution of the regional climate model will be 30km x 30km, and the modelling system will include sub-grid scale parametrizations based on stochastic rainfall donwscaling and the coupling, through temperature and precipitation downscaling, to the snowpack and glacier flow models. The focus will be on the coming two decades and projections of the cryospheric characteristics in the period 2010-2050 will be obtained.

In WP 5.2 and in close collaboration with POLIMI, TU Delft and ICTP, the outputs of the regional climate model (obtained in WP5.1), including the downscaled precipitation over the basins of interest and the estimated glacier meltwater, will be used to drive the hydrological model developed and validated in WP 4.4, to provide estimates of future streamflow regimes and water quantity in the different climate change scenarios considered and for the two study areas of the PAPRIKA-Italy project (Khosi basin in Nepal and upper Indus basin in Pakistan).

The ISAC-CNR unit will also participate in the assessment of changing water regimes on ecosystems, WP 6.2, and in the dissemination actions, WP 7.

2. UNIMI and BAW *(C. Smiraglia, G. Diolaiuti, Tabacco, C. Mayer and coworkers)*
coordination of WP 1.1, 1.2

This unit will take care of cryospheric measurements , WP 1.1, 1.2 and 1.3, and will provide glaciological expertise for the construction of the numerical model of glacier mass/energy balance and flow (WP 4.3) and for projections of cryospheric dynamics (WP 5.1).

On the Baltoro, the field measurements that will be conducted by the UNIMI and BAW units will focus on determining the geometry and morphology of the glacier, its dynamic state and ablation conditions. The combined analysis of these measurements will provide information on the current state of Baltoro glacier, on its mass budget and on meltwater production. Special attention will be given to ice ablation in the debris-covered areas: during dedicated field campaigns (at least two field surveys in the three years of the project) ablation data will be collected for different conditions and debris thicknesses in various glacier areas. A better quantification of debris properties (i.e.: debris pattern and thickness, lithology, porosity and grain size) will be performed, together with the determination of the debris temporal evolution. Also in this case, field campaigns will be crucial. In the lower part of Baltoro, measurement of debris thickness is too difficult to be performed manually, therefore GPR measurements will be adopted (250-400 MHz). Remote sensing analysis (mainly based on surface temperatures provided by ASTER data) will help mapping and reconstructing the dynamics of debris-cover.

To quantify melt conditions with a distributed ablation model, the Urdukas meteo data (Ev-K2-CNR permanent AWS) will be used. Local meteorological gradients on the glacier, and the range and variability of surface albedo, will be measured to obtain a complete quantitative characterisation of glacier conditions. This part requires the installation of a new supraglacial AWS on Baltoro (the AWS should be equipped with all sensors to evaluate the standard 7 meteo parameters plus the ones to evaluate incoming and outgoing energy fluxes).

The measurement of snow cover contribution to glacier accumulation and dynamics is a very challenging task, and it matter of serious concern for this project. The problem originates from the fact that all accumulation basins are far from the tongue, and they are far from each other. In the course of the project, we foresee that at least some of them will be visited. The measurement of accumulation will be based on: snow pits, including the sampling; snow depth by probing; shallow coring (hand core-drill, 10 m or so); and, possibly, use of radar for profiling. The local snow depletion curve will be evaluated by coupling snow-field data with remote sensing investigations.

Field data will be supplemented by remote sensing imagery (optical satellites: Aster, Landsat, Spot, Corona) allowing to extrapolate the in-situ point information to the whole glacier surface, in association with the activities of WP 1.3.

The experiments foreseen in WP 1.2 will consist in the development of several radar systems working at relative low frequency and in their test on a transect at the tongue of Baltoro Glacier.

The radar systems will be designed and realized by INGV (Istituto Nazionale di Geofisica e Vulcanologia, Roma) and will be tested in the field by the UNIMI unit. The following systems will be used:

1. Ground Penetrating Radar GSSI SIR 10B, bistatic configuration working at 40 MHz.
2. Glacio radar INGV, 40MHz, pulse length ranging between 1 a 3 µs, power peack 2kW
3. Glacio radar INGV,15 MHz, pulse length ranging between 1 a 4 µs, power peack 3kW, folded antenna 10m length.

During the field operations, the best array to be used for each radar system will be tested. The measurements will be carried out on four equidistant points distributed on a transect perpendicular to the ice flow, on the tongue of Baltoro Glacier.

Expected outcomes of this activity are indications on how to improve the radar systems and to determine the best frequency and field array to be used. Bottom reflections and ice thickness data will also be obtained. Owing to the complexity of the experiments and the logistic difficulties, full success of this approach is not granted a priori.

The UNIMI unit will participate in the dissemination actions, WP 7.

4. POLIMI *(R. Rosso, D. Bocchiola, A. Bianchi, M.C. Rulli, B. Groppelli and coworkers)*
coordination of WP 2.1, 4.4

The POLIMI unit will take care of the hydrological data measurement and analysis, WP 2.2, and will cooperate with TU Delft on the construction of a hydrological model of the upper Indus basin and, if possible, of selected basins in the Khumbu region, WP 4.4. This unit will also provide expertise for the construction of glacier mass/energy balance and flow models, WP 4.3, and participate in the construction of water availability scenarios, WP 5.2.

A first activity will be the definition of the basin portion and river sections that best represent the effect of climate change on the upper Indus basin. The availability and accuracy of in-situ hydrological data in the Indus basin will also be assessed. Analysis of available data will allow for estimating discharge magnitude within the network by upscaling/downscaling against drainage area and to tailor the installation, in the course of the project, of new hydrometric stations.

Based on this information, the POLIMI unit will carry out a feasibility study for the installation of a permanent (seasonal) hydrometric (flow stage) station to measure the glacial stream outflow. The study will define the best tradeoff between representativity of the glacier's outflow (*i.e.* proximity to the glacier mouth), and practical feasibility of the installation, with respect to operator safety, availability of properly shaped stream sections, suitability of building a stage-discharge equation for in-stream flow estimation, and cost. Personnel of POLIMI will take care of determining the best solution for on-site installation of the station, and will provide installation of the station and stage discharge calibration.

The station, which is intended to dwell at least seasonally in order to representatively measure ablation flows for at least two ablation seasons, will require local maintenance. Personnel of the POLIMI unit will be available to instruct local personnel upon how to provide station maintenance. If possible, (PhD) students participating within the SEED exchange program will attend short courses for station operation and maintenance in Italy, and will be able to aid on site stations' operation.

From the modelling standpoint, the POLIMI unit will coordinate with TU Delft to build a hydrological modeling framework (including cryospheric flows in the upper catchment) for the Indus watershed area. In view of the large size (*i.e.* an order of magnitude of $\approx 10^4$ km^2 or more) and response time of the upper Indus basin, the approach will be based on the construction of a properly tailored model, which will explicitly deal with the physical processes required for an accurate depiction of the hydrological cycle, while keeping acceptable computational burden. In close collaboration with Paprika-France, the POLIMI unit will also work an a hydrologic model for the Koshi basin.

To validate the hydrological modelling results, model outputs obtained from control runs on past-present conditions will be compared with available hydrologic data and with the measurements obtained during the PAPRIKA project.

5. ISE-CNR *(A. Lami and coworkers)*
coordination of WP 2.2

This part of the activity will take place in WP 2.2 of PAPRIKA-Italy and it will focus on the chemical analysis of surface waters to asses their quality. Partial support for these activities will also come from funds of the SHARE and SEED projects.

More specifically, the activities of this unit will include the following items:

(i) analysis of chemical survey data of high mountain lakes, streams and related potable supply (ions, heavy metals);
(ii) selection of the long-term monitoring sites;
(iii) evaluation of trends in freshwater quality (particularly for drinking water supply);
(iv) investigation of the possible source(s) responsible for the increase of ions and heavy metals released from rock and ice glaciers.

The main study area will be the upper basin of the Indus river, in the area of Baltoro glacier in Pakistan. Water quality samplings will also be conducted in the study areas of the Khumbu region in Nepal.

6. CMCC *(A. Navarra, C. Cagnazzo, S. Gualdi and coworkers)*
coordination of WP 4.1

The CMCC unit will work on the incorporation of the interactive aerosol component, derived from the HAM module for aerosol chemistry and transport (Stier et al., 2005), in the CMCC global climate model. This activity will be done in collaboration with ISAC-CNR. The new component will include the following aerosol properties for different aerosol species: interactive mass concentration and composition, size distribution, mixing state, refractive index, optical properties, hygroscopicity.

The CMCC unit will also be in charge of performing the following simulations:

- a set of control runs, in order to assess the performances of the newly coupled aerosol-climate model in simulating the mean climate

- a set of climate change scenario simulations including aerosol emissions, to be used as boundary conditions for the regional model.

7. ICTP *(F. Giorgi, F. Solmon and coworkers)*
coordination of WP 4.2, 5.2

The activity will be devoted to the upgrading and optimization of the regional climate modeling system RegCM in its newly released version 4 for the area of interest.

The regional modeling system RegCM is a hydrostatic, sigma-p vertical coordinate limited area model which has been developed since the early nineties and has been used for a wide range of applications, essentially over all continents of the Globe (except the polar regions) (Giorgi and Mearns 1999; Giorgi et al. 2006; Pal et al. 2007). The model includes a non-local planetary boundary layer scheme (Holtslag et al. 1990), a full radiative transfer scheme (Kiehl et al. 1996), options of different convection schemes (Grell 1993; Emanuel 1991), a resolvable scale cloud microphysics scheme (Pal et al. 2000) and full representation of land surface processes (the BATS scheme, Dickinson et al. 2003). The latest version of the model, RegCM4, released in June 2010 also includes a new advanced land surface scheme (the Common Land Model, or CLM, Steiner et al. 2009) and possibility of coupling to the ROMS ocean model and to different gas phase chemistry modules. The code is user-friendly, fully parallel and portable on different computing platforms.

Of particular relevance for PAPRIKA-Italy are two features of the RegCM model, which are in fact unique among regional climate models:

i) A simplified aerosol module including Sulfate, Organic and Black carbon (OC and BC), desert dust and sea spray. For each of the tracers the aerosol module includes emission sources, transport by resolvable scale winds, sub-grid scale turbulence and deep convection, dry and wet removal processes, simplified chemical transformations, direct radiative forcing both in the solar and infrared spectrum, and a simplified representation of indirect aerosol effects on cloud microphysics. The aerosol module is described in Qian and Giorgi (1999), Solmon et al. (2005), Zakey et al. (2005) and Zakey et al (2008). It has been used to study the effects of sulfate aerosols on the climate of East Asia (Giorgi et al. 2002, 2003), the effect of desert dust on the west Africa monsoon (Konare et al. 2008; Solmon et al. 2008) and the effects of desert dust storms on the climate of north-east Asia (Zhang et al. 2009). Being a simplified aerosol scheme, this module was specifically designed for use in long term climate simulations. Within the context of PAPRIKA-Italy, this module can be used to simulate the effects of aerosol deposition on the snow texture and optical properties.

ii) Capability of representing land surface processes at high resolution sub-grids (Giorgi et al. 2003). With this option, for each model grid point the land surface can be represented on a higher resolution regular sub-grid accounting for local land-use and topography information. This allows the characterization of land surface processes at very fine resolutions, up to a few km or even less, without running the full model at these resolutions. Previous studies have shown that the use of this sub-grid scheme improves in particular the representation of land surface hydrology and the cycle of snow accumulation and melting and thus it is especially suitable for use in PAPRIKA-Italy (Giorgi et al. 2003, Im et al. 2010a,b).

For the regional simulations planned in PAPRIKA-Italy it is envisioned to use the RegCM4 model with interactively coupled aerosols and the sub-grid land-use/topography scheme, complemented by the downscaling methods of WP4.3 and by the glacier models of WP4.4. The implementation of stochastic downscaling and sub-grid scale parametrization techniques will be conducted in close cooperation with ISAC-CNR, and the inclusion of the glacier-snowpack modules will be conducted in collaboration with ISAC-CNR and UNIMI.

8. TU Delft *(M. Menenti and coworkers)*
coordination of WP 1.3

This group is active in WP 1.3, 4.4 and 5.2.

For what concerns WP 1.3, three remote sensing techniques that are currently available to monitor topographic changes over the Tibetan plateau will be considered. For each of the three techniques at least one case study is described evaluating available data. In near future, radar altimetry data from the Cryosat-2 mission is expected to become available (Wingham et al, 2006). It should be note though that it has a relatively low spatial resolution in the order of 300m-1km.

Elevation changes along tracks from ICESat laser altimetry: Between 2003 and 2009 the GLAS instrument on board of the ICESat satellite sampled full waveform laser altimetry data along tracks directly below the satellite at an along track distance of 175 m. Each waveform was the result of the interaction of the emitted Gaussian pulse with the terrain surface within an approximately 70 diameter footprint. Because of the near-polar orbit of 94 degrees inclination, distances across track over the Karakorum are in the order of 50 km. As a consequence, only a small part of the Baltoro glacier is actally covered by ICESat data. The ICESat elevations that are available have a vertical accuracy at the decimeter level over flat terrain and a geolocation accuracy in the order of meters, (Duong et al., 2008). In our opinion, ICESat data has two types of application: first as validation data for other altimetry products: its quality is higher than that of other available satellite altimetry data, making it an excellent reference data set. Validation examples will be discussed below. A second application is to directly derive elevation changes from the available repeated tracks. Although ICESat tracks are on average only repeated to distances of a few 100 m, methods exist that optimally profit from the available data, while incorporating short scale topographic relief, (Pritchard et al., 2009).

Glacier velocity fields from SAR speckle tracking: Except for PRISM, the ALOS satellite also carries the PALSAR instrument that acquires Synthetic Aperture Radar images at a resolution of about 5 m in a repeat cycle of 46 days. Using so-called speckle tracking, a glacial flow velocity field can be constructed, (Strozzi et al., 2002), by an image matching technique, that matches features (the speckles) in two repeated SAR images. Speckle tracking results from two PALSAR images from the Baltoro glacier will be compared to ICESat derived elevation changes.

DTM's from ALOS/PRISM stereo photo's: Using overlapping digital photographs from imaging sensors full coverage digital terrain models can be created. In 2009, the ASTER GDEM global digital elevation model was released, (ASTER, 2010), based on overlapping images from the ASTER instrument on board of the Terra satellite. The ASTER GDEM completely covers the Karakorum at 30 meter a pixel. In a case study the GDEM data was validated against ICESat data, first over the flat Tibetan Nam Co Lake area and second along an arbitrary ICESat track passing through mountainous terrain, Over the lake the average difference between ICESat and ASTER GDEM is 3m, over rough terrain, the average difference increases to 15m. In both cases a significant bias in the GDEM elevations was observed. ASTER GDEM gives a kind of average surface elevation, without an exact date. Alternatively a Digital Elevation Model can be created at certain known dates since 2006 at 2.5 m resolution from panchromatic images from the PRISM instrument on board of the ALOS satellite. In an ongoing case study, an ALOS/PRISM DTM over either the Baltoro glacier iself or over a simular glacier will be validated against ICESat data as well.

TU DElft will also contribute to WP 4.4, to the construction of a hydrological model for the upper Indus basin and for selected basins in the Khumbu region. The modelling approach of this unit is based on the TibWatMod model (Futurewater, Wageningen), currently running for the whole Tibetan plateau and validated on specific basins in China. The model will have to be adapted and validated for the specific case of the upper Indus basin and, possibly, for selected basins in the Khumbu region.

9. Ev-K2-CNR *(A. Da Polenza, E. Vuillermoz, G. Lentini and coworkers)*
coordination of WP 7.1

This unit will contribute to the the study of the characteristics and the variability of the atmospheric circulation at the PCO-K site and in the Baltoro glacier area, WP 3.3, and it will coordinate the activities on the dissemination of information from the project, the development of a dedicated project web-site and bibliography, and the establishment of a project database. The project coordinator will take responsibility through a Communication and Outreach specialist group and in close collaboration with the dissemination activities of the SEED project.

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Appendix 1. Summary of work packages.

		W No	sub WP	WP TITLE	PARTICIPANT
Observations	WP 1	Cryospheric observations	1.1	Cryospheric resources, snow cover contribution and glacier melting (quality and quantity).	UNIMI / BAW
			1.2	Determination of the ice thickness of the Baltoro glacier (Karakorum) by radar measurements.	UNIMI
			1.3	Determination of glacier properties and ice flow by remote sensing.	TU Delft, UNIMI / BAW
	WP 2	Hydrological observations	2.1	Hydrological characteristics and water quantity.	POLIMI
			2.2	Water quality.	ISE
	WP 3	Atmospheric observations	3.1	Physical and chemical characterization of aerosol: absorption, scattering, size distribution, atmospheric optical depth, chemistry; atmospheric deposition.	ISAC / Ev-K2-CNR
			3.2	Impact of anthropogenic (ABC) and natural (STE) processes on surface ozone concentrations and contribution to radiative forcing.	ISAC
			3.3	Variability of the atmospheric circulation (from time series and new in-situ measurements).	ISAC / Ev-K2-CNR
Modelling	WP 4	Integrated Climate-glacier-water modelling	4.1	Global climate simulations and atmospheric variability, including aerosol transport.	CMCC / ISAC
			4.2	Regional climate modelling of the atmosphere/glacier/hydrosphere system, including sources and transport of aerosols at regional scale and subgrid scale parameterizations based on stochastic downscaling methods.	ICTP / ISAC
			4.3	Modeling the interaction between snow-pack, radiation and the absorbing material deposited in the snow.	ISAC / ICTP / UNIMI / POLIMI
			4.4	Development of a hydrological model for the upper basin of the Indus river (Pakistan) and for the Koshi basin (Nepal).	POLIMI / TU Delft
	WP 5	Future scenarios on water availability	5.1	Cryospheric characteristics in regional climate change scenarios.	ISAC / ICTP / UNIMI
			5.2	Hydrological characteristics in regional climate change scenarios.	ISAC/ ICTP / POLIMI / TU Delft
Impacts	WP 6	Impacts and adaptation (with the SEED project)	6.1	Impacts of future streamflow regimes on water resources for the communities.	SEED
			6.2	Impacts of climate and seasonal water availability on the ecosystem.	SEED
	WP 7	Capacity building	7.1	Capacity building, dissemination and information to policy makers.	Ev-K2-CNR / ISAC / UNIMI

Appendix 2: Participating units.

List of participating units, researchers involved in the project and WP to which the various units contribute. If a WP is listed in bold it indicates that the unit is leading the activity. The name of the unit responsible is underlined.

1. ISAC-CNR: Istituto di Scienze dell'Atmosfera e del Clima.
A. Provenzale, P. Bonasoni, P. Cristofanelli, F. Fierli, J. von Hardenberg, A. Marinoni and coworkers
(WP **3.1**, **3.2**, **3.3**, 4.1, 4.2, **4.3**, **5.1**, **5.2**, 7.1)

2. UNIMI: Dipartimento di Scienze della Terra, Università di Milano.
C. Smiraglia, G. Diolaiuti, I. Tabacco and coworkers
(WP **1.1**, **1.2**, 1.3, 4.3, 5.1, 7.1)

3. BAW: Bavarian Academy of Sciences and Humanities.
C. Mayer and coworkers
(WP 1.1, 1.3)

4. POLIMI: Dipartimento di Ingegneria Idraulica, Ambientale, Infrastrutture Viarie, Rilevamento - Sez. Costruzioni Idrauliche e marittime, Idrologia (DIIAR-CIMI).
R. Rosso, A. Bianchi, D. Bocchiola, B. Groppelli, M.C. Rulli and coworkers
(WP **2.1**, 4.3, **4.4**, 5.2)

5. ISE-CNR: Istituto per lo Studio degli Ecosistemi
A. Lami and coworkers
(WP **2.2**)

6. CMCC: Euro-Mediterranean Center for Climate Change
A. Navarra, C. Cagnazzo, S. Gualdi and coworkers
(WP **4.1**)

7. ICTP: International Center for Theoretical Physics
F. Giorgi, F. Solmon and coworkers
(WP **4.2**, 4.3, 5.1, 5.2)

8. TU Delft: Technical University Delft
M. Menenti, R. Lindenbergh, W. Immerzeel and coworkers
(WP **1.3**, 4.4, 5.2)

9. Ev-K2-CNR: A. Da Polenza, E. Vuillermoz, G. Lentini and coworkers
(WP 3.1, 3.3, **7.1**)

10. SEED project: F. Mari and coworkers
(WP **6.1**, **6.2**)

Appendix 3: Collaborations with Paprika-France.

WP 1.1: collaboration with FLTHE-LGGE for Changri glacier. Reference: Y. Arnaud

WP 1.2: Ph.D thesis onthe evolution of Himalyan glaciers. Reference: Y. Arnaud

WP 1.3: collaboration with LEGOS. Reference: E. Berthier

WP 2.1: collaboration with LTHE. Reference: I. Zin

WP 3.1: collaboration with LGGE. Reference: P. Laj

WP 3.2: collaboration with LGGE. Reference: P. Laj

WP 3.3: collaboration with LGGE. Reference: H. Gallée

WP 4.1: collaboration with LSCE. Reference: Y. Balkanski

WP 4.2: collaboration with LGGE. Reference: H. Gallée

WP 4.3: collaboration with LGGE. Reference: H.W. Jacobi

WP 4.4: collaborations with IRD (reference P. Chevallier) and LTHE (reference I. Zin)

WP 5.1: collaborations with LGGE (references H. Gallée, H.W. Jacobi)
and LSCE (reference Y. Balkanski)

WP 5.2: collaborations with IRD (reference P. Chevallier) and LGGE (reference H. Gallée)

WP 6.1: collaborations with IRH. Reference: J. Smadja