

## **Protocol for the Characterization of Carbon and Water Cycles in High-elevation Ecosystems of the Andes**

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## Protocol for the Characterization of Carbon and Water Cycles in High-elevation Ecosystems of the Andes

*The government of Colombia has taken a leadership role in facilitating research in high mountain ecosystems to provide a scientific base for understanding climate change and land use impacts on water and carbon cycles. With support from the World Bank and GEF, the Colombian Institute of Hydrology, Meteorology, and Environmental Studies (IDEAM) has undertaken a national pilot project on integrated adaptation to climate change (INAP). A key component of this project has been the development of a protocol for the characterization of carbon and water cycles in high mountain ecosystems. The protocol is designed for use by government, university, and NGO partners interested in climate change impacts, with IDEAM leading the project and consolidating data and results. The present article provides an overview of the protocol design.*

### The protocol

High mountain ecosystems of the Andes, *páramo*, and Andean forests are potentially significant carbon sinks; together with glaciers they play an important role in regulating water flow. The Andes are unique in the number of large urban centers that are located above 2500 m, and these cities are dependent on mountain ecosystems for their water supplies. Tropical mountain regions of the Andean Cordillera have been identified as vulnerable to climate change (Büchler et al 2004). Anticipated impacts include higher temperatures and consequently greater evapotranspiration, an upward shift in the zero temperature gradient resulting in less snow relative to rainfall, glacial recession, and a vertical displacement of vegetation (Francou et al 2003; Vuille et al 2003; Hooghiemstra and van der Hammen 2004). Simultaneously, mountain headwater catchments

are subject to anthropogenic impacts related to agricultural production, burning, wetland drainage, cattle grazing, and the clearing of forests and riparian vegetation (Hofstede 1995; Diaz and Paz 2002). The hydrologic implications of climate and land use change for the Andes potentially include a flashier runoff regime, less water storage capacity in wetlands, *páramo*, and glaciers, and less water availability in the dry season. Within Colombia the effects of climate change have already been documented; warming trends have been observed in minimum temperatures (Perez et al 1998), and the accelerated loss of ice cover of tropical glaciers is attributed to global temperature change (Ceballos et al 2006).

Management strategies for carbon and water require a scientific information base about the processes that affect the carbon and water cycles, their interactions, dynamics, variability, the practices that optimize storage, the effects of land use, vulnerability to perturbations, and potential implications for local communities. A protocol has been developed in Colombia as a tool to characterize carbon and water cycles in high-elevation Andean ecosystems and to facilitate comparative studies across the region. The protocol aims to establish a monitoring system to understand the impacts of climate change and land use on the capacity of these high mountain ecosystems to regulate water flow and to accumulate carbon.

### The conceptual model

Evaluating the impacts of climate change and land use pressure on high-elevation ecosystems requires an understanding of the factors impacting the pools and flow paths of the carbon and water cycles. Car-

bon and water are stored in pools such as glaciers, wetlands, lakes, soils, and vegetation. Water and carbon pass from one pool to another through flow paths such as precipitation, decomposition, or evaporation. The protocol for the characterization of carbon and water cycles in high mountain ecosystems uses the concept of pools and flow paths to investigate the impacts of climate and land use on the various compartments and ultimately on carbon and water balances (CIAT 2006). Anthropogenic activities such as ploughing, burning, forest harvesting, and grazing modify the natural cycles through vegetation, introduced animals, and human consumption of water and biomass. Human influences are explicitly included within the protocol. The conceptual model is illustrated in Figure 1 for water in a *páramo* ecosystem.

### Algorithm of the protocol

The protocol is organized in a series of blocks. Each block represents a flow of activities, analysis and decisions taken, and supporting documents to facilitate the application of the protocol. Norms and criteria, procedures, formats for data capture and instructions for the measurement of variables are associated with the blocks. The 7 blocks are:

1. Introduction to the protocol;
2. Selection of the sub-watershed and ecosystems to monitor;
3. Selection of research questions;
4. Collection of secondary data through a participatory process;
5. Design of the monitoring network;
6. Monitoring program;
7. Systematization and analysis of information.

Criteria are decision making guides such as criteria for the selection of sub-watersheds or prioritization of monitoring variables. Instruction sheets provide detailed explanations and procedures for installation, operation and maintenance of equipment, and standard methods for analysis. Formats are provided for the collection and compilation of field and/or laboratory data. Norms relate to World Meteorological Organization (WMO) or other international standards relative to data collection and/or analysis (eg EUROFLUX).

### Selection of the sub-watersheds and ecosystems to monitor

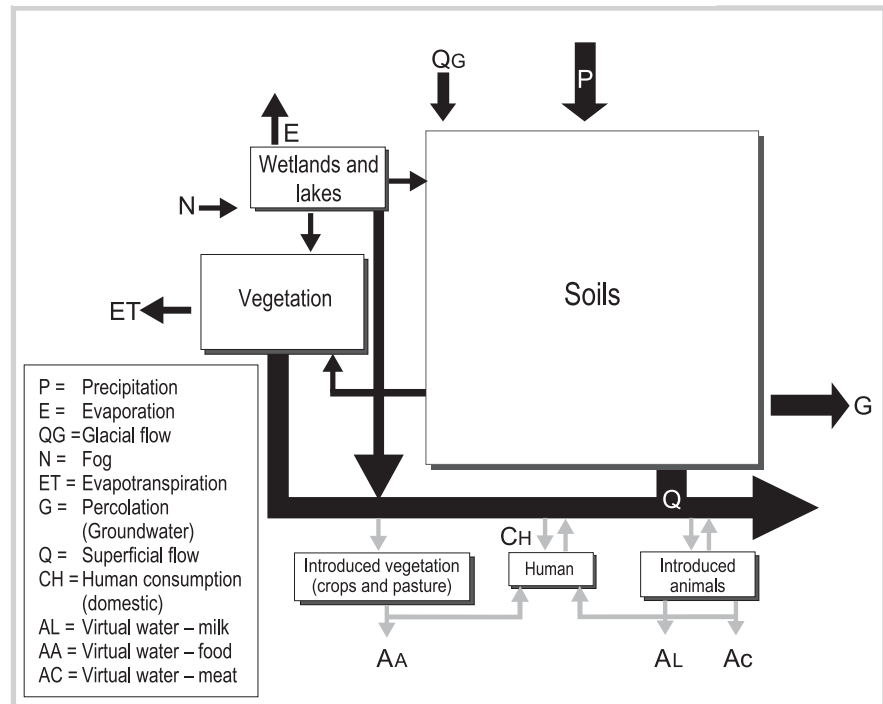
The selection of the sub-watershed and ecosystems to monitor aims to account for the relative importance of the high-elevation ecosystems, their variability, and logistics for the implementation of monitoring. The criteria selected for Colombia are given in Table 1.

### Research questions

Research questions are defined based on the characteristics of the selected micro-watersheds for monitoring, comparison between ecosystems, and consideration of climate change and land use impacts. Potential research questions include:

- Which pools within a non-intervened *páramo* ecosystem have the greatest capacity to hold water and regulate the water balance?
- How large are the carbon pools within a non-intervened high Andean forest ecosystem and what are their C accumulation rates?
- What are the impacts of human intervention on the ability of *páramo* ecosystems to hold water and regulate base flow?
- What are the rates of deglaciation; the principal factors driving deglaciation; and the impact on downstream *páramo* ecosystems?

FIGURE 1 Pools and flows of water in *páramo* with anthropogenic intervention.



### Participatory baseline

Relevant geographical, biophysical, and socioeconomic secondary data are compiled and evaluated for data quality through a participatory process. Interest groups are identified and engaged through the formation of a Learning Alliance (Penning de Vries 2007). Indicators are validated at the local level so that secondary data collection focuses only on data relevant to carbon and water cycles in the specific high mountain ecosystem under study. Geographical data of interest include base maps, land use and land cover maps, and existing imagery. Relevant biophysical data relate to climate, hydrology, water bodies and wetlands, water quality, glacial coverage and characteristics, vegetation inventories, and soil physical and chemical properties. Socioeconomic information of interest includes data on production systems, water use, and socioeconomic indicators such as education and land tenure. Responsibility for the collection of data is assigned to representatives of the interest groups, and existing data

and metadata are compiled centrally and assessed for quality against international standards. Metadata variables to be assessed include the source of information, method of collection, sample size, scale, frequency of data collection, spatial coverage, and year(s) of data availability.

### Design of the monitoring network

For each selected sub-watershed and the relevant research questions, the monitoring network is designed in accordance with criteria for the prioritization of variables and available resources (human and financial). For each pool and flow path of the water and carbon cycles specific to glaciers, *páramo*, and high-elevation Andean forests, a set of variables, required equipment, and methods of measurement are defined and prioritized. The ranking of variables is based on an index of: 1) contribution to or understanding of the pool or flow path, 2) complexity of measurement, and 3) cost of monitoring in terms of equipment and/or logistics. The monitoring network is then

**TABLE 1** Criteria for the selection of sub-watersheds and ecosystems to monitor.

Criteria for selection	High-mountain zones of interest >2750 m
<b>Indispensable</b>	Security Accessibility
<b>Necessary</b>	Local capacity Representative sub-watersheds Monitorability (area, drainage, homogeneity, etc)
<b>Desirable</b>	Comparable ecosystems Existing monitoring equipment Priority watersheds Use, shortages, or risks

designed schematically considering existing equipment, priority variables for monitoring, and budget constraints. A series of “template” monitoring design drawings, criteria, and instruction sheets are provided as a guide for spatial and technical site selection.

The geographical/spatial monitoring design aims to provide high-resolution baseline imagery for inventory and temporal imagery to assess change in ecosystems and gla-

ciers. The socioeconomic survey design identifies the basic socioeconomic information required for monitoring the carbon and water cycles and focuses on human intervention and adaptation. A draft questionnaire is provided which can be modified based on existing information and local validation. The principal sections of the survey include: family composition, land tenure, agricultural and agroforestry land use, livestock, farm manage-

ment practices, on-farm forest cover, water sources, and water use.

### Monitoring program

The monitoring program provides details for the installation of equipment and procedures for the collection of data corresponding to each selected variable. Key monitoring variables for water and carbon in *páramo*, high-elevation forest ecosystems, and glaciers are summarized in Table 2. For each biophysical variable, instruction sheets include information on equipment requirements, equipment installation (location and technical considerations), field measurements (site selection and technical considerations), maintenance and operation, results and analysis, equipment and laboratory costs, and norms.

Geographical/spatial monitoring is designed to provide baseline inventories of glaciers, water, vegetation, land use, and to monitor change over time (1, 5–10 year intervals). The socioeconomic component focuses on the implementation of the questionnaire, analysis of land management relative to the monitored ecosystems, and the measurement of water consumption.

All monitored variables are specifically linked to pools or flow paths.

### Systematization

The systematization of data refers to the collection and transfer of information to a central database, and the analysis and synthesis of monitored variables to consolidate information at the project scale for the carbon and water cycles. Standard procedures for quality assurance and quality control are provided, including recommendations for station inspection, replicates, standard methods, and expected ranges. Instruction sheets are given for calculations for glacier mass and energy balances, water balance, estimation of the existing carbon pool, and C accumulation.

**TABLE 2** Key monitoring variables for carbon and water cycles in *páramo*, high-elevation forests, and glaciers.

	Water cycle in <i>páramo</i> and high-elevation forest	Carbon cycle in <i>páramo</i> and high-elevation forest	Water cycle in glaciers
<b>Inflows</b>	Precipitation	Biomass production Fertilizer	Precipitation (rain/snow) Condensation
<b>Pools</b>	Wetland water volume Soil water content	Standing biomass C content of biomass C content in soils C accumulation rates (C <sup>14</sup> )	Areal extent of the ice Ice volume (GPR) Glacial regression
<b>Internal flows</b>	Interception Infiltration Surface flow Subsurface flow Stable isotopes	Erosion Decomposition	Sublimation Fusion (climatic variables)
<b>Outflows</b>	Evaporation Transpiration (climatic variables) Stream discharge	Plant respiration Methane emission from wetlands Burning Harvesting	Stream discharge

The protocol is currently being validated at two sites in the Colombian Cordillera. Further information on the protocol is available in Spanish at: [www.ideam.gov.co/inap.htm](http://www.ideam.gov.co/inap.htm) or contact Luz Dary Yepes [luzdary@ideam.gov.co](mailto:luzdary@ideam.gov.co)

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## The Sierra Nevada Lobby Day: Putting the “Range of Light” on the Map

As many mountain scholars have already emphasized, advocacy of the specificity of mountain environments and communities at the international, national and regional levels is a decisive step towards sustainable mountain development. It is an essential task to stress the importance of mountains in the political arena. This short report gives an account of an original initiative: The Sierra Nevada Lobby Day.

This event, carried out on an annual basis, was held on 5 June 2007 and sponsored by The Sierra Fund and the Sierra Nevada Alliance. The former organization is a non-profit community foundation aiming “to support environmental conservation in the Sierra Nevada region.” The latter is an alliance of conservation groups, with a mission “to protect and restore the natural resources of the Sierra Nevada for future generations while promoting sustainable communities.” The event took place

where decisions concerning the Sierra Nevada are made: in the California State Capitol in Sacramento (USA). In its essence, the Lobby Day welcomes any citizen concerned about the fate of the “Range of Light,” the name bestowed by the famous environmentalist John Muir, which became the common nickname for the Sierra. There were about thirty participants at the 2007 meeting, mainly members of organizations already active in the Sierra.

It is worth noting how this event was organized. First, a plenary session offered the participants a general overview of the issues in the Sierra and the main target objectives for the year. Second, a specialist in lobbying provided insights into this specific activity and tips for carrying it out. Third, small groups of from 2 to 4 newly proclaimed lobbyists were organized. Fourth, the groups went from door to door of the offices of the Senators and Assemblymen in the State Capitol (the elected repre-

sentatives in the two Chambers of the California parliament), calling on them to plead the cause of the Sierra. Finally, the day ended with a debriefing for the participants regarding an evaluation of how the message transmitted was received.

The issue at stake for 2007 was the approval of the budget of the Sierra Nevada Conservancy. This California state agency, created in 2004, “initiates, encourages, and supports efforts that improve the environmental, economic, and social well-being of the Sierra Nevada Region, its communities and the citizens of California.” It covers an area of 25 million acres, all or part of 22 counties. The organization needed this money for its operations and to launch a grant support program (US\$ 17.5 million of a global budget of US\$ 21.6 million). The “day-lobbyists” gave a summary of projects oriented towards the protection and restoration of natural resources, ready to be imple-



mented, and showing that the grants would be well invested. According to information compiled by The Sierra Fund, “in the last 5 years Sierra Nevada stakeholders have identified projects that would require close to one billion dollars.”

The Day was organized with this specific target objective in mind, but it appeared that the budget had been approved by a state commission the day prior to Sierra Nevada Lobby Day. Yet the general objective of this advocacy action—to put the Sierra Nevada on the minds and the agenda of decision-makers—still had to be achieved. During the

debriefing, all groups highlighted the powerful communication tool—the map representing the entire mountain range.

In this context, 2 core messages were conveyed to the legislators:

- The Sierra Nevada exists as an entity and matters!
- All Californians are connected in one way or another to the Sierra Nevada!

The annual organization of Sierra Nevada Lobby Day illustrates that advocacy for the mountains is an ongoing and never-ending task.

## Websites

### Sierra Nevada Conservancy:

[www.sierranevadaconservancy.ca.gov](http://www.sierranevadaconservancy.ca.gov)

**The Sierra Fund:** [www.sierrafund.org](http://www.sierrafund.org)

### Sierra Nevada Alliance:

[www.sierranevadaalliance.org](http://www.sierranevadaalliance.org)

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## Mountain Forum: A Decade of Sharing



### Historical perspective

The Mountain Forum was created a decade ago, as an outcome of the Rio Earth Summit, as a unique global network for information exchange, mutual support, and advocacy of equitable and ecologically sustainable mountain development and conservation. Since its inception it has become a unique network of networks for sustainable mountain development (SMD).

The Mountain Forum operates under a decentralized scheme through regional nodes hosted by centers of excellence worldwide, including the North American Node, hosted by the Banff Centre in Canada, the Latin American node (InfoAndina), hosted by the International Potato Center (CIP) in Peru, the African Mountain Forum, hosted by ICRAF-AHI in Uganda, and the Asia Pacific Mountain Network (APMN), hosted by ICIMOD in Nepal (Figure 1). The activities of the network are coordinated by the global Mountain Forum Secretariat, hosted by ICIMOD in Nepal since 2003.

The Mountain Forum is governed by an independent Board,

composed of a group of representatives from the founding organizations including The Mountain Institute (TMI), the International Potato Center (CIP), the Banff Centre, ICRAF, and ICIMOD. Elected representatives from 3 regions—Africa, Asia, and Latin America—serve as members of the Board for a 3-year period each. The governance body meets annually in different mountain regions to revise progress reports and set strategic guidelines for the network as a whole.

### A decade of sharing

- The Mountain Forum started the MF Global Information Server Node (GISN), hosted at TMI in West Virginia (USA), in 1997. Two regional nodes were created upon its inception: the Asia Pacific Mountain Network (APMN), hosted by ICIMOD, and InfoAndina, hosted by the International Potato Center (CIP).
- In 2001, an Interim Secretariat (IS) for the Mountain Forum was hosted by ICIMOD in Nepal.
- In 2002, the Mountain Forum supported the momentum

behind the International Year of Mountains (IYM2002) through global stakeholder E-consultations (High Summit, Bishkek Global Mountain Summit). The same year, MF facilitated dialogue for the inception of the Mountain Partnership in Johannesburg (Rio+10).

- In 2003, the Global Information Server Node was merged with the Interim Secretariat and both were hosted by ICIMOD in Nepal. In the same year, the North American Mountain Forum (NAMF) was hosted by the Banff Centre in the Rocky Mountains of Canada. In the same year, the European Mountain Forum was created and hosted by IUCN (France).
- In 2004, the African Node was created and hosted by ICRAF-AHI in Uganda.
- The Mountain Forum led the global dialogue among Mountain Partnership members. As a result of this dialogue, the “Cusco Framework for Action” was approved at the Second Plenary of the Mountain Partnership in October 2004 in Cusco, Peru.

### 2006: 10th Anniversary celebrations

- The Mountain Forum celebrated its 10th Anniversary with local celebrations in Banff in May 2006, and in early 2007 an Open House for Members was organized in Kathmandu, Nepal on the occasion of its 10th Anniversary.
- In April 2006, a global E-consultation was organized in the context of the 10th Anniversary celebrations. A large number of members from 41 different countries shared perspectives about the past, present, and future of the Mountain Forum.

### Current achievements

During the past few years, the Mountain Forum Secretariat in Nepal has developed a modern platform for services for its membership worldwide. MF information services include the following:

#### MF membership

Throughout its decade of existence, the Mountain Forum has provided services for thousands of members from 108 countries and a wide base of sectors, including the academic, private, and public sectors. Presently the network has a membership base of nearly 4000 individuals and 500 organizations worldwide. A large percentage of our membership belongs to the research (45%) and NGO sectors (24%) (Figure 2).

#### Global multilingual e-conferences

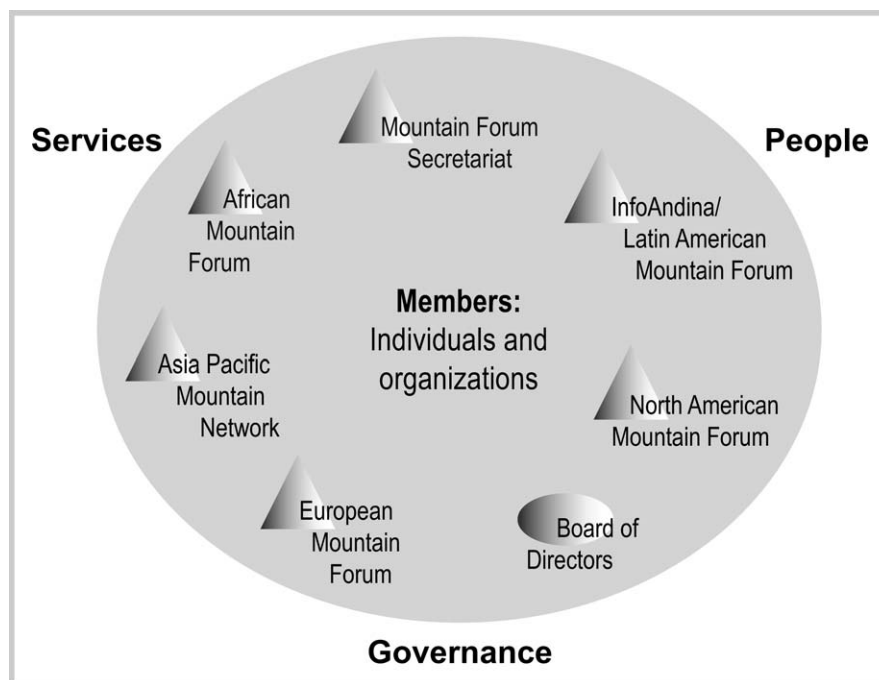
These conferences foster debates on specialized issues, for example:

- Mountain Partnership Organizational Framework (CUSCO Framework for Action) (2004);
- Biodiversity conservation (Himalayas, Andes) (2005);
- Sustainable Agriculture for Mountains (SARD-M) (2007);
- Global change research (Africa) (2007).

#### Mountain Forum online library

The online library is a specialized

**FIGURE 1** Mountain Forum: a global network of individual and institutional members, with regional sub-networks.



catalogue of SMD documents, including:

- 2071 full-text documents;
- 1372 bibliographic references;
- 49 periodicals;
- 222 related links;
- 65 reference items;
- Links between research institutions and SMD-related references.

#### Mountain Forum website [www.mtnforum.org](http://www.mtnforum.org)

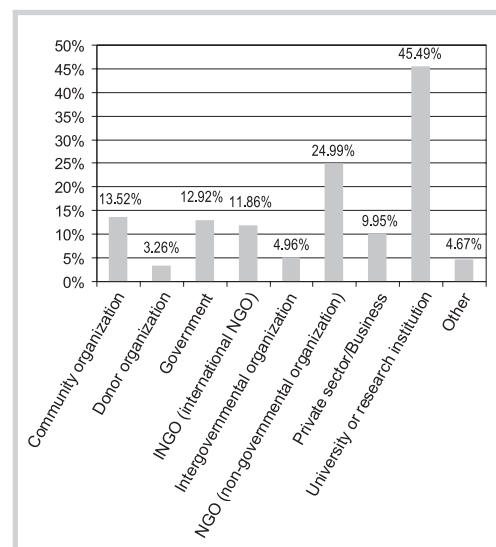
- The website has a new design, content, and information structure.
- A new content management system is in place.
- It focuses on SMD themes.
- Its content and services are highlighted on the homepage.
- The website has an average of 1 million visits per year.

#### Advocacy of the "Mountain Agenda"

- MF supports its partners' Mountain Agenda through focused policy debates, advocacy, and increased awareness of SMD.
- MF fosters capacity building in SMD advocacy among members.

- MF participates in Global Events such as "Women of the Mountains" (Utah, USA, March 2007), and was mentioned in the Orem Declaration of Mountain Women.
- MF publications (MF Annual Report, MF Bulletins) are distributed widely.
- MF conducted an E-consultation on the Draft UN Resolution on SMD for CSD-15 in April 2007.

**FIGURE 2** Individual MF members by type of affiliation.



## Challenges in the globalized world

Frequent natural disasters have occurred during the past few months as a result of global changes including global warming. In Asia, heavy floods affected Nepal, India, and China. These floods have devastating effects on people around the world. Mountain Forum offers a platform to raise awareness about these disasters through our website and regional discussion lists. The July edition of MF Bulletin covered the important issue of "Melting Mountains," including a selection of studies and reports sent by our members. The bulletin is available for downloading from the website in PDF format, and is being printed for wide distribution among our membership.

The second half of 2007 marks the beginning of a transition for the Mountain Forum Secretariat. With the support of Dr. Andreas Schild,

ICIMOD Director General and MF Board Chairman, a selection panel composed of representatives from the Board and the Node Managers is now at work on the selection of the next Executive Secretary of the Mountain Forum, who will be designated by the end of October 2007. After nearly 3 years with the Mountain Forum Secretariat, and nearly 7 years with the Latin American Mountain Forum, I am optimistic about the future of our network. In the framework of the international mountain agenda, Mountain Forum is renewing its collaboration linkages with key stakeholders, including MRD and the Centre for Development and Environment (CDE), the Adelboden Group, and the Mountain Partnership. MF will continue to provide services to stakeholders, including dissemination of information through its global discussion lists, dissemination of "calls for articles" for MRD, and specialized dialogue platforms such as the

E-consultation conducted in April 2007 for the draft resolution on sustainable mountain development for UNCSD.

We believe innovative partnerships and collaboration among stakeholders are the best way to face these challenges and achieve effective development in a globalized world. We reiterate our gratitude to the Swiss Agency for Development and Cooperation (SDC) for their continued support of Mountain Forum throughout its decade of existence, and we look forward to continued achievements of our network on behalf of the welfare of mountain communities worldwide.

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## Third Global Change Research Networking Meeting for European Mountains

From the Strategy to the Project (Innsbruck, Austria, 18–19 October 2007)

*The 68 global change scientists from 15 nations who met in Innsbruck at a 2-day meeting organized by the Mountain Research Initiative had in common a willingness to cross their disciplinary boundaries, share project ideas, and engage in international projects.*

### The GCRN\_EM

The meeting was one of a series of meetings of MRI's Global Change Research Network in European Mountains, GCRN\_EM, initiated and moderated by Dr. Astrid Björnson Gurung, MRI science officer. These meetings are shaped by the participants' topics and requests, and are designed to stimulate innovation and facilitate networking by providing time for interaction. Thematic inputs are kept

short and concise. The meetings are complemented and documented by a GCRN\_EM website and Newsflash, and the MRI database of experts (see links below).

### Thematic inputs

The availability of funding is crucial for research. Experts provided first-hand information on the European Union (EU) funding instruments FP7, COST (European Cooperation in the field of Scientific and Technical research), and Interreg IV B: Alpine Space Programme 2007–13. Six speakers focussed on interdisciplinarity and presented their experiences in EU projects: Andreas Muhar (BOKU); Martin Price (Centre for Mountain Studies); Axel Borsdorf (IGF); Carmen de Jong (Institut de la Montagne); Michael

Tyrkas (Alpenforschungsinstitut); Andreas Gobiet (Wegener Center).

### Mountain Research Market

Participants displayed their ideas, project experiences and expertise. The functioning of a network is determined by its nodes, the contacts between people and institutions. A networking meeting is only successful if new nodes are created and new linkages established. When asked to indicate the number of "promising new contacts," most participants noted between 5 and 10, some "more than 10."

### Coffee table discussions

The coffee table discussions followed the idea of Open Space. Participants had the chance to propose topics for which they seek discus-



sion partners. Rooms and visualization material were provided to such self-elected groups to meet and interact during one or several time slots of 90 minutes.

The Coffee Table themes were: unexpected / accelerated impact of climate change in the alpine environment; (water) conflicts in mountains; the crisis in the mountains: social, geographical, and political factors; climate change-caused disturbances and their impacts on mountain regions; “Endeavour Alp”—an Interreg IVB proposal; linking patterns and processes in mountain ecosystems (FP7); IT support for large databases; GCRN\_EM proposal for an ESF Research Network Project; and FP7 research infrastructures.

The MRI has a vivid interest in the outcome and success of these discussions, but its role is limited to that of a facilitator. It will be up to

the initiators whether the discussions lead to “real projects in real places.”

#### Outlook

With this very successful meeting, the GCRN\_EM has been firmly established. The European network has now taken on the form which MRI envisages for all its regional networks. The event was co-organized by MRI and the Institute for Mountain Research (IGF) of the Austrian Academy of Sciences (ÖAW), and co-financed by MRI, IGF, ÖAW, alpS (Centre for Hazard Management), and the University of Innsbruck: regional research institutions have taken ownership of this European network whose existence once depended on MRI alone. This is a crucial step in establishing a functioning and purposeful network. Two institutions have signalled their interest in host-

ing the next meeting. Apart from the positive feedback from participants, this was the most valuable sign of success.

#### Websites

**MRI:** <http://mri.scnatweb.ch>

**Global Change Research Network in European Mountains (GCRN\_EM):**

<http://mri.scnatweb.ch/content/category/3/47/68/>

**MRI database of experts:**

<http://mri.scnatweb.ch/index.php/content/view/40/44/>

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