Project of Strategic Interest NextData

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Report on the "scientific questions"

Resp: Paolo Cristofanelli, CNR-ISAC

During the first project year, several discussions with the researchers who participate in the NextData project, as well as with the scientific community and the representatives of international programmes have allowed for identifying four relevant scientific questions concerning climatic and environmental measurements in high-elevation areas, which are discussed below and which will be addressed in the course of the NextData project.

SQ1: HOW TO OBTAIN MORE ACCURATE OPERATIONAL ATMOSPHERIC COMPOSITION MONITORING AND FORECASTING BY USING NEAR-REAL TIME DATA FROM REMOTE ATMOSPHERIC OBSERVATORIES?

Science and policy background

As indicated by GAW-WMO (2010), operational atmospheric composition monitoring and forecasting are emerging key issues not only for a better scientific understanding of atmospheric processes but also for the verification of environmental treaties and protocols (e.g. UNFCCC, post- Montreal protocols, CLRTAP). In particular, in the framework of the GAW-WMO programme and other research projects (ACTRIS, UNEP-ABC), the following issues emerged, relating to the implementation of NRT data delivery services at atmospheric Observatories.

1) The availability of timely updated atmospheric composition data is the pre-requisite for the implementation of a warning system to be used in the case of extreme air pollution or natural events potentially able to impact health, ecosystems and economy. As an example, during the Icelandic volcano eruption in 2010, the GAW-WMO observation system strongly supported the management of the emergency, providing near real time (NRT) delivery of profiling and in-situ observations of aerosol properties. This helped to gain a more accurate picture of the volcanic ash transport, advancing basic understanding and helping air traffic control. In the framework of the WMO Sand Dust Storm Warning Advisory and Assessment System, NRT observations of aerosol physical and chemical parameters (both from remote sensing and in-situ measurements) are currently used to evaluate the occurrence of mineral dust transport and dust storms (WMO, 2011).

2) Data validation from operational atmospheric composition monitoring is an essential element for quality control of the reanalysis and forecast products of “chemical weather” (i.e. short and medium term forecast of chemical tracers – both gases and aerosol – in atmosphere): calibrated and quality controlled measurements of atmospheric constituents are of great importance in the quantification and description of model errors and biases, the verification of performance in specific geographical regions, and also in process descriptions where models need to be improved.

3) The availability of timely updated atmospheric composition data is also important for assimilation in numerical models (both for chemical and weather forecast). Data assimilation (DA) was originally introduced in numerical weather prediction systems to incorporate observations into prediction models and provide a unified and consistent description of the initial states of the atmospheric system. Assimilation of atmospheric chemistry data in numerical models should follow similar principles. In response to requests to integrate chemistry and meteorology data and models, several projects have recently been initiated. For example, the European MACC-2 project (Monitoring of Atmospheric Composition and Climate – Interim Implementation), has extended the integrated forecast system (IFS) operated by ECMWF by coupling its global weather forecasting system with chemistry transport models (e.g. MOZART, TM5 or MOCAGE). This extended IFS is capable of analysing, modelling and forecasting the atmospheric distribution of major greenhouse and chemically reactive gases, as well as aerosols.

Based on these points, the WMO Executive Council Task Team in its report on “Challenges and opportunities in research to enable improved products and new services in climate, weather, water and environment”, recommended that WMO should strengthen observations to support multiple scale air quality prediction based on NRT data delivery. In particular, as reported by GAW (2011), NRT identifies "specific observations not older than 1-2 hours that can be incorporated into the data assimilation schemes of weather or air quality forecast models". In Europe, these operational monitoring and forecasting activities are organized in the context of the Global Monitoring for Environment and Security (GMES) initiative, jointly funded by the European Space Agency and the European Union. GMES has defined a target to implement a fully operational Atmosphere Service by 2014. Also in the framework of the ACTRIS (Aerosols, Clouds, and Trace gases Research InfraStructure Network) EU Project, the importance of making available a series of NRT data (especially for reactive gases, which are routinely reported only by a few stations, mostly in Europe) has been highlighted.

Implementation of procedures for High Altitude Observatories and possible contribution from NextData

In the framework of WP1.1 and WP1.2 of the Project NextData and under the scientific umbrella of the SHARE Project, meteorological and radiometric measurements together with atmospheric composition observations are carried out at remote high mountain and maritime regions by a network of automated weather stations and GAW-WMO atmospheric observatories.

The full implementation of NRT data delivery services at these measurement sites represents an important contribution to respond to the scientific questions concerning the increase of availability for timely, updated and high quality atmospheric data. In particular, being mostly situated in remote locations, the NextData stations can provide useful information on the background variability of trace gases and aerosol, with particular emphasis on the role played by atmospheric transport processes (occurring on very different spatial scales) in affecting troposphere composition. NextData stations are representative of the atmospheric conditions in specific regions that are considered hot-spots in terms of climate change, air-quality and influence of anthropogenic pressures on the ecosystems (Alps, Himalayas, Mediterranean basin, Andes, Ruwenzori Mountains). Therefore, the availability of NRT information can effectively contribute to:

(1) obtaining accurate and timely descriptions of extreme atmospheric events (e.g. sand storms, dust transport and impact on air-quality, volcanic eruptions, acute pollution events related with biomass burning or heat-waves, long-range transport of pollutants on regional and continental scales);

(2) validating reanalysis or model forecasts over diverse observational conditions;

(3) enhancing the capability of "chemical-weather and weather forecast" by providing operational data input for assimilation in forecasting models.

Application of NRT data delivery techniques

As an example, the Italian Climate Observatory "O. Vittori" at Mt. Cimone (ICO-OV, Italy) and the Nepal Climate Observatory – Pyramid (NCO-P, Nepal), two GAW-WMO global stations, are providing continuous measurements of atmospheric composition (trace gases and aerosol properties) in the scientific framework of the SHARE Project activities. At these stations, data delivery techniques have already been applied to provide NRT visualization of data plot on their web sites (www.isac.cnr.it/cimone/realtime and http://evk2.isac.cnr.it/realtime.html). Recently, a NRT data delivery service was made operative at the ICO-OV in collaboration with the MACC-2 Project. After automated quality check, hourly O_3 mixing ratios observed at this GAW-WMO Global Station are currently provided every hour to the MACC-2 for the evaluation of IFS performance (see Fig. 1).

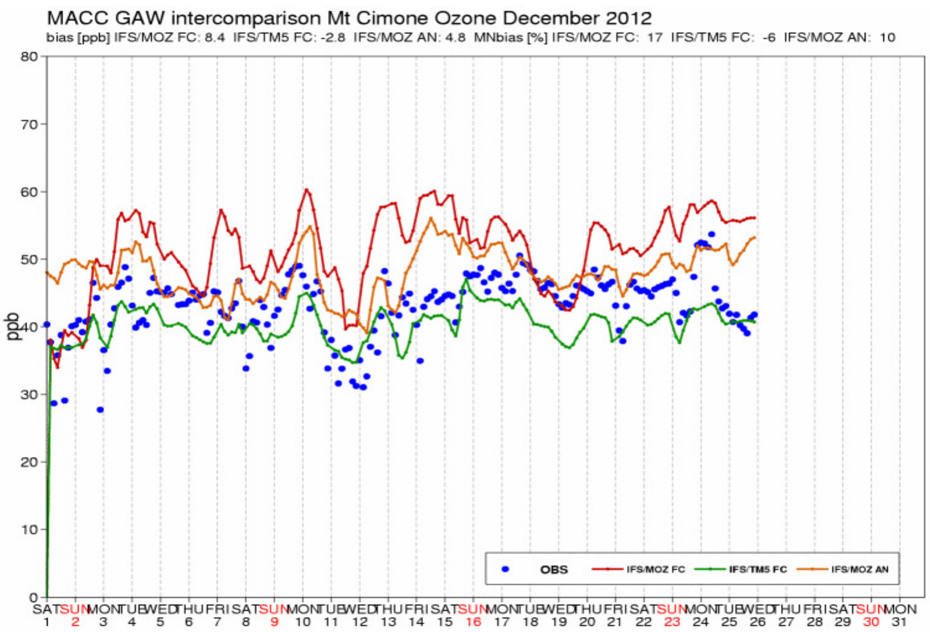

Figure 1. Example of utilization of NRT data form the observatory at Monte Cimone. For December 2012, the comparison between observed mixing ratios of O3 at ICO-OV (blue dots) are compared with the forecast provided by the MACC-2 integrated forecast system: Near-Real-Time forecast with IFS-TM5 with assimilation (red), IFS-MOZART with assimilation (green) and IFS-MOZART without assimilation (orange).

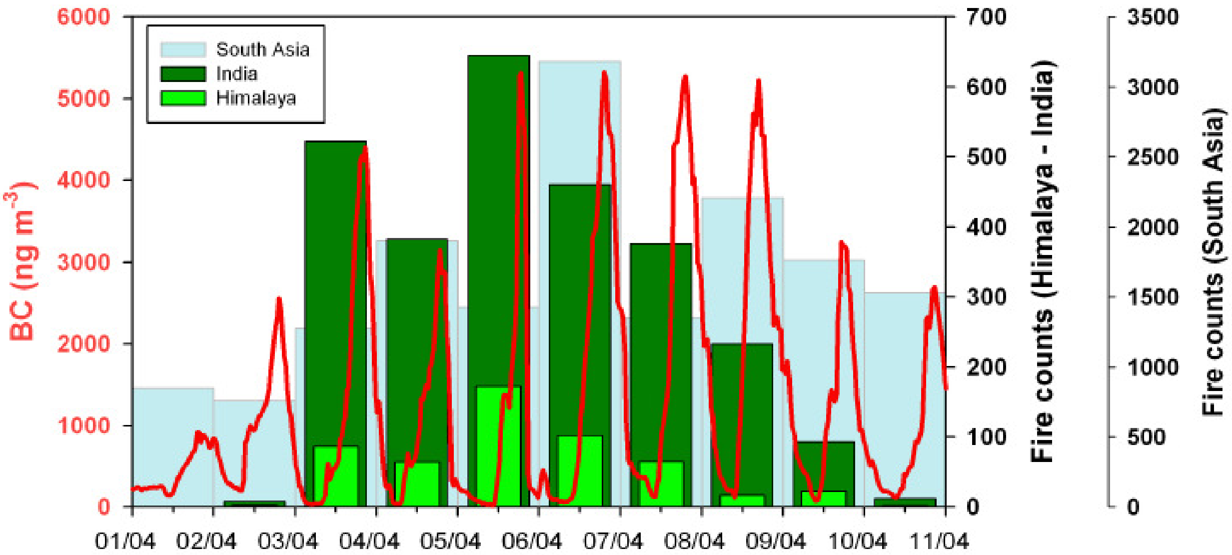

Figure 2. Example of utilization of NRT data -2. 30-minute average values of black carbon concentrations (BC) were disseminated (by e-mails and by the UNEP-ABC web site at http://www.rrcap.ait.asia/abc/userfiles/file/ABC_April2010_NCOP.pdf) shared with the scientific community and the local Nepali Institutions in April 2010, when an acute pollution event (3 – 8 April) affected the central Himalayas due to the occurrence of widespread biomass burning. Here, the BC at NCO-P was compared with NRT satellite data (NASA MODIS) concerning the number of hot-spot fires over different geographical regions (from Bonasoni et al., 2010).

At the NCO-P, the NRT data delivery capacities have already been used to provide accurate and timely information about acute pollution events in the Himalayas region (Bonasoni et al., 2010). For example, during April 2010, widespread open fires affected the Himalayas foothills (see Fig.2). NRT information about the occurrence of extremely high values of O_3, BC, PM1, PM2.5 and PM10 at NCO-P was shared with both the scientific community (ABC-UNEP project) and local Institutions (ICIMOD and NAST in Nepal), to provide timely updates on the regional-scale transport of pollutants in the Himalaya region. The integration with other NRT data from satellite and output from model forecasting, allowed an advanced understanding of the event development.

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SQ2: HOW TO OBTAIN A MORE COMPREHENSIVE UNDERSTANDING OF THE ATMOSPHERIC ROLE OF NITROGEN OXIDES USING IN-SITU DATA FROM REMOTE ATMOSPHERIC OBSERVATORIES?

Science and policy background

Several governmental and intergovernmental institutions, meteorological services and environmental protection agencies need accurate and updated information on the atmospheric chemical composition and physical processes for understanding atmospheric chemistry and climate change.

Due to their important effects on climate (as direct or indirect forces), atmospheric chemical properties (e.g. self-cleansing capacity and oxidation capacity of the troposphere), air quality implications (both for human health and ecosystems), special attention is required for reactive gases, with special emphasis on surface ozone (O_3), carbon monoxide (CO), volatile organic compounds (VOC) and nitrogen oxides (NOx, which encompassed nitric oxide – NO - and nitrogen dioxide -NO_2).

Increasing interest has recently been shown in increasing the understanding of the role played by NOx. In particular, the European Project ACTRIS Aerosols (*Clouds, and Trace gases Research InfraStructure* Network) assumed the leadership for integrating a ground-based network equipped with advanced atmospheric instrumentation for NOx, to support the building of new knowledge, as well as policy decision-making.

As indicated by GAW-WMO (2011, 2010), implementing NOx measurements having regional to global representativeness is important for the achievement of the following needs:

1) NOx compounds have a central controlling role in free radical chemistry and photochemical oxidation processes in the troposphere. Thus, it is important to assess the NOx influence on hydroxyl and nitrate radicals correctly. NOx can influence a number of atmospheric compounds having important roles on climate, air-quality and ecosystem threats eg. sulphur dioxide, halocarbons, methane, tropospheric ozone, secondary aerosols.

2) NOx can be oxidized to acidic species, forming an acid aerosol and acid precipitation, which in some locations can acidify lakes and soils, causing harm to living organisms. The adverse effects of acid rain on the environment can include acidification of fresh waters and terrestrial ecosystems, and forest damage. Overload of the soil environment with nitrate can lead to transportation to inland water bodies and the oceans, triggering algae blooms which affect oxygen availability (eutrophication). On land, excess of nitrogen is a threat to biodiversity, as shown by the loss of species in the European grasslands. This problem, identified on the European and North American continents (especially from 1960s to 1990s), will be increasingly evident in various parts of Asia, as emissions in these regions increase. Thus, an accurate evaluation of human-created nitrogen deposition from the atmosphere is mandatory to better understand (and prevent) nitrogen deposition in land and water.

3) Atmospheric transport and transformations of nitrogen compounds is a basic component of the cycle of life on the planet, since fixed nitrogen is a major and essential plant nutrient. Thus, the impact of anthropogenic emissions of NOx on the Earth’s biosphere, both on land and in the ocean, should be correctly understood.

4) Recent air-borne and satellite measurements have suggested that high mixing ratios of NOx are present over most of the continents (Fig. 1). Thus, geographically widespread and reliable in-

situ measurements of NOx are needed to validate the measurements from remote sensing observations.

5) NOx is a key element of atmosphere chemistry**.** Thus having reliable in-situ information of NOx variability is vital for the verification and improvement of systems for atmospheric chemistry analysis and forecast.

As pointed out in the framework of the ACTRIS Project as well as by the GAW-WMO (2011), NOx is currently measured at only a few sites continuously (as an example, the locations of stationary measurement sites contributing to GAW-WMO by continuous NOx measurements are reported in Fig. 2) and especially for air-quality purposes. This implies that equipment not specifically measuring NO_2 is often used, thus giving a measurement not accurately representing NOx. Also for these reasons, GAW-WMO (2011) recognized the necessity of establish a global network for the measurement of oxidized nitrogen compound mixing ratios. Especially, for the first phase of implementation it is recommended that "the nitrogen programme should focus on high quality measurements of NO and NO_2 in as many locations as possible".

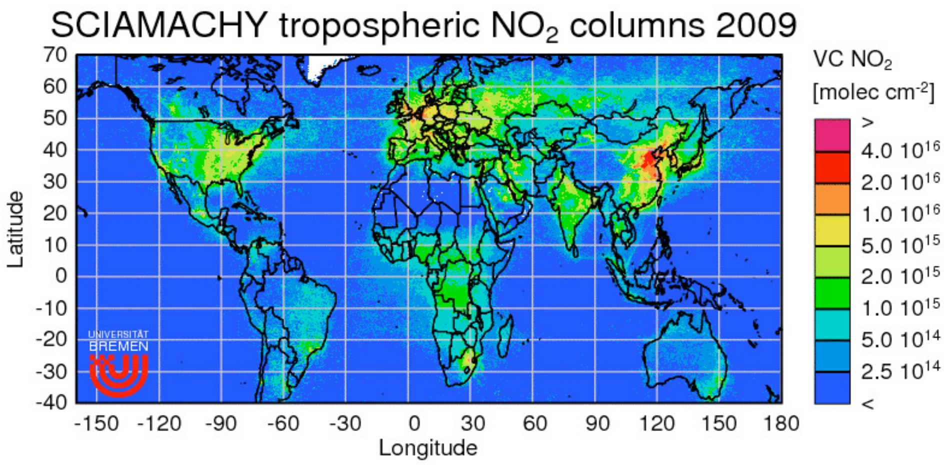

Figure 1. Satellite map of global NO_2 columnar values for year 2009 (from GAW-WMO, 2011).

Possible contribution from NextData

In the framework of WP1.1 and WP1.2 of the Project NextData, atmospheric composition observations are carried out at remote high-mountain and maritime regions by atmospheric Observatories, under the scientific umbrella of the SHARE Project and GAW-WMO programmes. The implementation of accurate and continuous in-situ NOx measurements at these Observatories would significantly contribute to responding to the need of reliable NOx global data. In particular:

(1) As reported by GAW (2011), many of the stations currently reporting NOx observations are significantly influenced by anthropogenic emissions, thus providing data representative only of the regional atmosphere. Being located in remote regions, the Observatories (GAW-WMO and SHARE Stations) supported by NextData would significantly improve the global understanding of NOx.

(2) Being located in different regions and continents, these stations may respond to the GAW-WMO requirements for a spatially distributed measurement network, able to represent the Earth's climatic zones, ecosystems, land uses and human populations.

(3) The implementation of NOx measurements at the atmospheric Observatories supported by NextData would provide useful data to better represent the free tropospheric conditions, as well as the impact of long-range transport. Moreover, NextData will provide information on the impact of emissions from populated and industrialized areas to the more pristine high-mountain or maritime environments.

(4) As shown in Figure 1, Europe and Southeast Asia represents two global hot-spots for NO_2 mixing ratios. In particular, South Asia was characterized by very large emission trends for NOx, which are expected to double in 2030 (UNEP, 2009). The two Global Stations, Italian Climate Observatory "O. Vittori" at Mt. Cimone (ICO-OV, Italy) and the Nepal Climate Observatory – Pyramid (NCO-P, Nepal), represent ideal "platforms" for monitoring the impact of anthropogenic emissions from these specific regions, as well as possible long term trend.

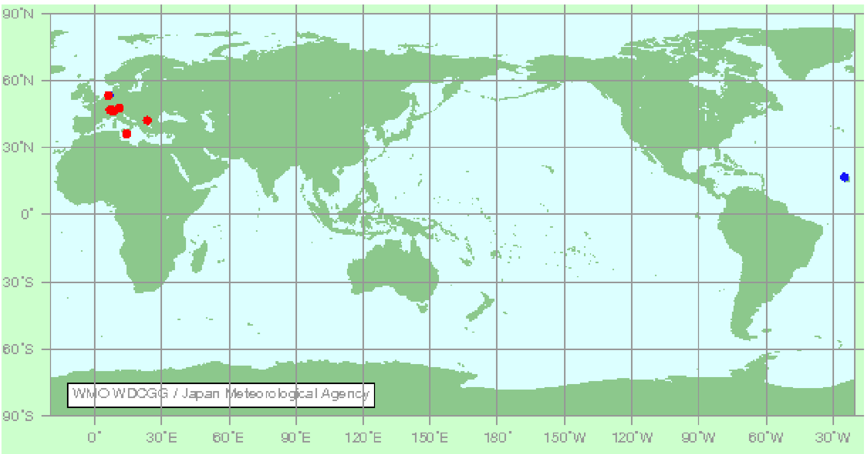

Figure 2. Stationary measurement sites for continuous NOx measurements in the framework of the GAW-WMO programme (courtesy of the World Calibration Center for Greenhouse Gases, http://ds.data.jma.go.jp/gmd/wdcgg/).

Implementation of in-situ NOx at remote Atmospheric Observatories

At the current stage, accurate NOx measurements are not carried out at the Italian GAW-WMO remote Observatories nor in the SHARE stations included in the NextData Project. Based on the discussions emerging in the framework of the ACTRIS project, the implementation of NOx measurements should comply with the following requirements:

- trends exceeding 1% per year should be discernible, hourly measurements with a minimum 66% coverage and appropriate accuracy are required;
- elevated time resolution (from 30 minutes to days) is necessary for investigation of transport processes and for chemical process studies.

Taking into account the typical lifetime of nitrogen oxides, and the remoteness of the station with respect to distance from source areas, GAW-WMO set three different levels of data quality objectives – DQO (basically as a function of expected NOx mixing ratios):

- Level 1 (basic): Continental basic with NOx typically higher than 1 ppb
- Level 2 (enhanced): Continental background with NOx s from 0.1 to 1 ppb
- Level 3 (high): Pristine, marine background, free troposphere with NOx < 0.1 ppb

Even if the implementation of “Level 3” measurements are recommendable for the NextData remote stations, it is nevertheless clear that the fulfillment of requirements present unaffordable measurement challenges that can significantly constrain the implementation of the observational capacity. In particular, the continuous operation of the extremely advanced research instruments needed to meet the “level 3” DQO, appears to be unlikely in remote and semi-automated stations like the NextData Observatories. Thus, as rationale for the implementation of accurate NOx measurements at the NextData remote observatories, especially at the GAW-WMO Global Stations, the adoption of methodologies to achieve a “Level 2” observing capacity, appears a reasonable compromise between the scientific need and the current implementation feasibility.

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SQ3: WHAT IS THE ROLE OF LIGHT ABSORBING AEROSOL IN REGULATING THE EARTH'S CLIMATE AND IN AFFECTING MOUNTAIN ENVIRONMENTS?

Scientific and policy background

Atmospheric aerosols have many sources ranging from sea spray, mineral dust, volcanos to combustion processes emitting large amount of soot and producing sulphates, nitrates and organics. Aerosol radiative forcing depends either directly or indirectly on several intensive properties of particles, including mass concentration, preponderance of absorbing material with respect to scattering fraction and size distribution.

Absorbing aerosols like black carbon (BC), brown carbon and mineral dust are the focus of increasing attention, due to their role in many atmospheric processes, in particular those involved in the Earth's radiative balance, due to their ability to absorb solar radiation. The uncertainty linked to aerosol forcing and the large uncertainties in emission data are a major obstacle to the accurate prediction of future anthropogenic-induced climate changes. In particular, BC is considered the most efficient absorber of solar radiation in the visible wavelengths, thus having a direct radiative effect on the energy budget of the atmosphere. It is estimated to have a global positive radiative effect which exceedsthat due to methane (Ramanathan and Carmichael, 2008). Brown carbon is characterised by a weaker absorption in respect to BC on visible wavelength in respect to BC. Also mineral dust is more weakly absorbing than BC, but its globally averaged absorption is significant (Bond et al., 2013).

Absorbing aerosols are also one main constituents of the so-called "atmospheric brown clouds" (ABCs), i.e. wide polluted tropospheric layers containing large amounts of aerosol particles (both primary and secondary pollutants as well as mineral dust) and pollutant gases. Over the past decade, scientific researches conducted over the Indo-Asia-Pacific region have led to the discovery of a wide ABC lying over the Indo-Gangetic Plains in South Asia during the winter-spring season with important implications on the regional climate (Ramanathan et al., 2008), human health and agriculture (Agrawal et al., 2008). Beside the Indo Gangetic Plain, others geographical regions are characterized by ABC: East Asia (Eastern China, Thailand, Vietnam & Cambodia); Indonesian Region; Southern Africa extending southwards from sub-Saharan Africa into Angola, Zambia and Zimbabwe; the Amazon basin in South America. In particular, there is a considerable gap in knowledge on the ABC phenomenon, especially over eastern and southern Africa, where anthropogenic industrial activity (including power generation), biomass burning (encapsulated under agricultural activities) and domestic biomass burning can significantly contribute to the emissions of ABC pollutants. In order to fill this gap UNEP convened a scientific consultation focusing in August 2010 in Nairobi. Based on the recommendation of the consultation a Working Group was established to prospect the establishing of an ABC-Africa project.

Moreover, large amounts of absorbing aerosols like BC can affect the mountain cryosphere in several ways. Marcq et al. (2010), based on atmospheric observations at high altitude, calculated that the presence of absorbing particulate material over the Himalayas can locally induce an additional top of the atmosphere forcing of 10 to 20 Wm^{-2} for the first atmospheric layer, and that the warming of the first atmospheric layer is paralleled by a substantial "dimming" of the amount of radiation reaching the surface (ranging from −4 to −20 Wm^{-2} as a function of snow cover and season). As proposed by Ramanathan et al. (2007), the atmospheric warming related to the ABC haze on the south slope of the Himalayas might be sufficient to account for the observed retreat of Himalayan glaciers. Additionally, even small BC amounts can significantly modify snow reflectance, thus altering the snowmelt rate and extension and duration of snow coverage, which influence the climate by the snow-albedo feedback.

Based on atmospheric composition and meteorological observations at NCO-P, Yasunari et al. (2010) estimated that the dry deposition of BC in snow during the pre-monsoon could result in an albedo reduction ranging from 2.0 to 5.2%, with serious implications on the glacier runoff.

Possible contribution from NextData

Knowledge of aerosol absorbing/scattering processes in remote regions is nowadays very scarce, nevertheless this information is very useful to determine emission sources, quantify long range transport and validate both regional and global models. In particular, the execution of similar observations would allow to estimate extensive quantities such as the single scattering albedo that are fundamental for radiative transfer calculations. Moreover, aerosol characterization at remote locations can provide useful data-sets to better investigate the effect of aerosol particles on climate and ultimately also on the hydrological cycle. High-elevation sites are well-suited for documenting components of the free troposphere, in order to characterize its typical background conditions and to investigate the influence of human activity on its composition. Moreover, some components of the atmospheric aerosol, e.g. BC, are considered short-lived climate forcers (SLCF). Thus an improved knowledge of the mechanisms regulating its concentration in the atmosphere can allow to a more effective direct action on climate. As an instance, a correct quantification of source contributions (biomass burning vs. traffic or power production) in South Asia can help to define appropriate measures for emission reduction.

In the framework of WP1.2 of NextData and of the SHARE Project, aerosol absorption and scattering coefficients are continuously monitored at the Nepal Climate Observatory - Pyramid (NCO-P) and at the Italian Climate Observatory of Mt. Cimone “O.Vittori” (ICO-OV), by using Multi Angle Absorption Photometers and nephelometers. Moreover, as reported by WP1.2, a one-month field campaign has been executed at NCO-P on March 2011 by using a 7-wavelenght aethalometer, while a long-term test is currently on-going at the ICO-OV. Due to their different wavelength dependence, using instrumentation (like the aethalometers) able to evaluate the aerosol absorption over different wavelengths can help in quantifying the contribution of different aerosol (BC, brown carbon and mineral dust) to the total light-abosrption. The implementation of measurement programmes aimed in evaluating the absorption (and scattering) properties of aerosol at other remote stations, would significantly contribute to fill the scientific (and measurement) gap which is still existing.

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SQ4: HOW RELIABLE ARE PRECIPITATION MEASUREMENTS IN HIGH-ALTITUDE REGIONS AND WHAT STRATEGY SHOULD BE USED TO ACHIEVE THE BEST INFORMATION FROM THE AVAILABLE OBSERVATIONS?

Science background

Though in the last decades there has been substantial progress in expanding the station coverage over mountains using automatic weather stations (Barry, 2012), high-resolution in-situ measurements of climatic variables in high-altitude regions are still rare. The observational effort provided by in-situ stations remains extremely uneven and non-homogeneous, leading to a bias towards the lower elevations in the observations.

In-situ precipitation measurements in mountain regions are particularly affected by uncertainties, owing both to the sparseness of raingauges and to the technical difficulties in measuring the snowfall contribution accurately (Winiger at al., 2005; Rasmussen et al., 2012). Measurement errors for solid precipitation, in fact, can range from 20% to 50% due to undercatch of automatic collecting devices in windy conditions (Rasmussen et al., 2012); this can lead to a strong underestimation of total precipitation measured in mountain areas and especially in winter, when the contribution of solid precipitation dominates.

In the last decades there have been several initiatives to collate the available, though sparse, historical raingauge measurements and create gridded archives with the highest possible spatial resolution,. Gridding, based on different interpolation techniques, is a necessary step that reduces biases arising from the irregular station distribution. Of course, the poor spatial coverage and high sparseness of raingauges constitute a potential source of uncertainty when interpolating grid point values from the nearest few available stations. On the other hand, a great advantage of raingauge-based gridded datasets is their long temporal coverage, extending back to the early decades of the twentieth century.

Unlike the in-situ station measurements, remote sensing techniques, especially satellite-based, can provide spatially-complete coverage of precipitation estimates, but they do not extend back beyond the 1970's and as such are not yet suitable for assessing long-term trends and performing climatological studies. As well as in-situ station data, the satellite instruments have difficulties in detecting the snow component of precipitation, due to problems of satellite-based sensors in identifying snow crystals.

Another possibility for precipitation analysis in mountain areas is to make use of reanalysis systems, which use data assimilation techniques to keep the output of a numerical global circulation model close to observations. Contrary to most observations, reanalysis data do account for total precipitation (rainfall plus snow). However, it is worth pointing out that climate trends obtained from reanalyses should be regarded with caution, since continuous changes in the observing systems and biases in both observations and models can introduce spurious variability and trends into reanalysis output (e.g., Bengtsson et al., 2004).

There are severe difficulties in considering any of the observational/reanalysis datasets as a reference or ground truth for precipitation in the complex mountain environments, and thus we think that multi-probe source data, hopefully accompanied by regional and high-resolution model data, should always be considered for estimating the hydrological cycle in these areas.

Possible contribution from NextData

In the framework of WP1.1 and WP1.2 of the Project NextData and under the scientific umbrella of the SHARE Project, meteorological measurements are continuously carried out at remote high mountain regions by a network of automated weather stations and GAW-WMO atmospheric observatories.

The implementation of accurate precipitation measurements would represent an important contribution to wards a more reliable investigation of hydrometeorology, especially at high altitude regions. This is particularly evident, considering that the stations supported by NextData are representative of the meteo-climate conditions of hot-spot regions in terms of climate change. In particular, the adoption of:

(i) collecting devices able to minimize the undercatchment of the solid precipitation

(ii) measurement protocols and data validation procedures optimized for the precipitation observations in the high mountain regions investigated by the Project would increase the availability of reliable time series of data useful for weather/climate investigation as well as for ground- truth studies.

Global, regional and high-resolution models, developed and verified in the framework of the project Next-Data should always be analysed in conjunction with the measurements for estimating the hydrological cycle in these areas and their possible changes under different future scenarios. We will contribute to this issue providing the necessary tools, in particular the outputs of global climate models, dynamically-downscaled hydrostatic and non-hydrostatic regional models, as well as the results of stochastic precipitation downscaling procedures. The implementation of such a “modelling chain” will allow to obtain high-resolution precipitation scenarios for present and future conditions, suitable to perform 1) comparisons with high-resolution measurements and 2) further assessment and impact studies.

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