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The ABC-Pyramid Atmospheric Research Observatory in Himalaya for aerosol, ozone and halocarbon measurements

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ARTICLE INFO

Available online 3 December 2007

ABSTRACT

In this work we present the new ABC-Pyramid Atmospheric Research Observatory (Nepal, 27.95 N, 86.82 E) located in the Himalayas, specifically in the Khumbu valley at 5079 m a.s.l. This measurement station has been set-up with the aim of investigating natural and human-induced environmental changes at different scales (local, regional and global). After an accurate instrumental set-up at ISAC-CNR in Bologna (Italy) in autumn 2005, the ABC-Pyramid Observatory for aerosol (physical, chemical and optical properties) and trace gas measurements (ozone and climate altering halocarbons) was installed in the high Khumbu valley in February 2006. Since March 2006, continuous measurements of aerosol particles (optical and physical properties), ozone (O₃) and meteorological parameters as well as weekly samplings of particulate matter (for chemical analyses) and grab air samples for the determination of 27 halocarbons, have been carried out. These measurements provide data on the typical atmospheric composition of the Himalayan area between India and China and make investigations of the principal differences and similarities between the monsoon and pre-monsoon seasons possible. The study is carried out within the framework of the Ev-K²-CNR “SHARE-Asia” (Stations at High Altitude for Research on the Environment in Asia) and UNEP—“ABC” (Atmospheric Brown Clouds) projects. With the name of “Nepal Climate Observatory—Pyramid” the station is now part of the Observatory program of the ABC project.

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1. Introduction

Monitoring the modifications of atmospheric composition at high altitudes can play a relevant role in the climate change studies. This happens through the detection of a wide range of

phenomena, including changes in the average concentrations, variability and seasonality of atmospheric compounds as well as possible variations in the impact from pollution hot-spots (Baltensperger et al., 1997; Bonasoni et al., 2004; Cristofanelli et al., 2007; GTOS, 1999; Hinz et al., 2005; Lee et al., 2007;

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Reimann et al., 2008-this issue; Zanis et al., 2000). As a matter of fact, high mountain stations, located far from direct anthropogenic emissions, are ideal sites for monitoring the atmospheric background conditions. The monitoring of anthropogenic and pollutant compounds (e.g. O_3 , NO_x , CO, CFCs, halons, HCFCs, aerosol, etc.) at these stations can provide reliable information on pollution levels in the free troposphere, which is known to be affected by horizontal and vertical transport of polluted air masses (Henne et al., 2004; O'Connor et al., 2004; Trickl et al., 2003). Furthermore, the Himalayan ridge is located between China and India, two of the most rapidly developing countries and thus primary sources of pollution on a global scale (Ramanathan et al., 2007). In this region, the so-called “Asian Brown Cloud” (Ramanathan and Crutzen, 2003; UNEP & C4, 2002), a 3km thick brownish layer of pollutants, has been seen extending from the Indian Ocean to the Himalayan range. This phenomenon strongly impacts air quality, visibility and the

energy budget of the atmosphere over the entire sub-continental area (Fig. 1). Recently, Lau and Kim (2006) have demonstrated that absorbing aerosols (dust and black carbon), may intensify the Indian monsoon by changing the thermal stratification of the atmosphere through the so-called “Elevated Heat-pump” effect. Beside gaseous pollutants (O_3 , organic trace gases), the haze principally consists of pollutant particles emitted by fossil fuel and biomass burning being composed of nitrate, sulphate, organic and black carbon (Chung and Ramanathan 2006; Ramana and Ramanathan, 2007; Ramanathan and Ramana, 2003; UNEP & C4 2002).

Aerosols have recently received attention given their role in many climate and environmental processes (Andreae and Crutzen, 1997; IPCC, 2007; Ramanathan and Crutzen, 2003). Understanding the chemical and physical properties of background aerosols is useful for determining source regions, elucidating the mechanism of long-range transport of anthropogenic pollutants and validating both regional and global



Fig. 1 – Location of the ABC-Pyramid Atmospheric Research Observatory (Nepal, 27.95 N, 86.82 E, 5079 m a.s.l.) and the Asian Brown Cloud extension over the South East Asia (image acquired by MODIS/Terra NASA satellite on December 4, 2001).

atmospheric models (Cong et al., 2007; Ramanathan et al., 2007), e.g. MACR—Monte Carlo Aerosol-Cloud Radiation Model (Chung et al., 2005), STEM—Sulfur Transport and deposition Model (Tang et al., 2004). On the other hand, tropospheric O₃ is one of the most important trace gases with regard to regional air quality, atmospheric chemistry and climate change. It regulates the oxidative capacity of the atmosphere and it is also an effective greenhouse gas, particularly in the middle and upper troposphere, thus directly contributing to global warming (Derwent et al., 2002; Forster et al., 2007). Halocarbons are recognised to be anthropogenic compounds of great environmental concern. In fact, being powerful greenhouse gases capable of absorbing long-wave radiation re-emitted by the earth's surface, they contribute directly to surface climate change. Another way in which halocarbons containing chlorine and bromine affect climate is via O₃ layer depletion which has an indirect effect on temperature.

Installation of a high altitude monitoring station in the Himalayas, named ABC-Pyramid and part of the Ev-K²-CNR "SHARE-Asia" (Stations at High Altitude for Research on the Environment) and UNEP "ABC" (Atmospheric Brown Clouds) projects, was deemed essential to obtain otherwise lacking information on the atmospheric background conditions of this region. The station was equipped to perform continuous measurements of chemical (organic and inorganic, soluble and insoluble), physical (mass and number size distribution) and optical (absorption and scattering coefficients) properties of aerosol. Surface O₃ and climate altering halocarbon concentrations are also measured at ABC-Pyramid. Aerosol sun photometry studies are carried out as well within the AERONET (AErosol RObotic NETwork) program.

The aim of these observations is to increase knowledge on: i) how the physical, chemical, and optical properties of aerosols change over the high Himalayas with season and air mass origins; ii) how aerosol size and light scattering change during pollution and dust transport episodes; iii) how much stratospheric intrusions, long-range transport of polluted air masses and regional pollution episodes contribute to O₃ concentrations in the free troposphere; iv) how the concentrations of climate altering halocarbons change over time (long term monitoring).

Controlled by a remote satellite connection and designed to operate over the long term and in extremely adverse weather conditions, this station is a unique source of data. In this paper, the first six months' results concerning aerosol properties, surface O₃ and halocarbons will be presented.

2. The measurement site and the ABC-Pyramid Observatory

The ABC-Pyramid Observatory (Nepal, 27.95 N, 86.82 E, 5079m a.s.l.) is located in the southern Himalayan region (Fig. 1) at the confluence of the secondary valley of Lobuche (oriented NNW-SSE) and the main Khumbu valley. The ABC-Pyramid Observatory was placed on the top of a hill not far (200m) from the Pyramid International Laboratory/Observatory, a multi-disciplinary high altitude research centre founded by the Ev-K²-CNR Committee and the Nepal Academy of Science and Technology in 1990.

In autumn 2005, a careful test run of the instruments and the remote communication system was carried out at ISAC-CNR in Bologna (Italy) where the entire station was assembled and observed for one month before being shipped to Nepal (Bonasoni et al., 2007). The instrument set-up was defined in accordance with the "ABC" project standards (Ramanathan et al., 2007). The station instruments are:

- a) a Multi-Angle Absorption Photometer (MAAP 5012, Thermo Electron Corporation) which measures aerosol light absorption at 670nm. Black carbon concentration can be calculated using the coefficient found by Petzold et al. (2002): 6.6 g m⁻²;
- b) a Differential/Scanning Mobility Particle Sizer (DMPS/SMPS) to determine the aerosol size distribution from 10 to 500 nm;
- c) an optical particle counter (GRIMM#190) to complete the aerosol size distribution with accumulation and coarse particles up to 32µm in diameter. Assuming a spherical shape for aerosol particles, this instrument makes it possible to evaluate the mass of particle matter with aerodynamic diameters smaller than 1, 2.5 and 10 µm (respectively: PM1, PM2.5 and PM10) from particle counts, using the custom suggested value of 1.66g cm⁻³ for average aerosol density;
- d) an integrating nephelometer (TSI 3563) to determine aerosol total and back scattering coefficients at three wavelengths (450, 550 and 700 nm);
- e) a surface O₃ analyser (Thermo Electron Corporation, 49C U. V. photometric gas analyzer);
- f) a sun photometer (Cimel CE 318). It is an automatic sun-tracking and sky radiometer for measuring the aerosol optical depth at 8 wavelengths between 340 and 1020 nm. This instrument is part of the AERONET project, registered as number 367. Both sun photometer data and specifications can be downloaded from the AERONET web site (<http://aeronet.gsfc.nasa.gov>, station EVK2-CNR).
- g) a high volume aerosol sampler (500 l min⁻¹), operated twice a week for chemical analyses;
- h) a "clean" sampling device to collect grab air samples for halocarbons analyses;
- i) a VAISALA WXT510 meteorological unit, measuring temperature, pressure, relative humidity, rain, wind intensity and direction.

All the instrumentation is housed in a wood and aluminium shelter consisting of two rooms, one for the instruments and a smaller one where batteries for the power supply are stored. The power needed to carry out the experimental activity (~ 3 kW) is provided by 96 photovoltaic panels with 120 electric storage cells. In order to avoid tension jolts, inverter devices ensure a stabilized current. In the case of (infrequent) insufficient power being supplied by the photovoltaic panels, additional energy is provided by the Pyramid electric system (photovoltaic panels and an electric generator).

Through the aluminium roof, four sampling lines allow sampling gas and aerosol particles:

- i) a PM1 Digital head for nephelometer and DMPS/SMPS instruments (flow rate 1m³ h⁻¹),
- ii) a TSP (Total Suspended Particle) head for the optical particle counter having specific probes with a sensor for temperature and relative humidity (0.3 l min⁻¹),

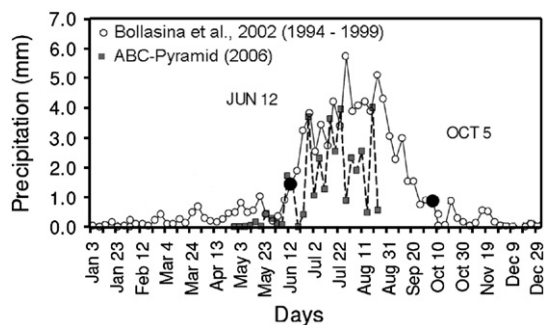


Fig. 2 – Seasonal behaviour of the 5-day centred means of daily total precipitation averaged over 1994–1999 (white circles, adapted from [Bollasina et al., 2002](#)) and as calculated for 2006 at the ABC-Pyramid Observatory (grey squares). Black circles denote the mean onset (June 12) and decay (October 5) of the summer monsoon as deduced by [Bollasina et al. \(2002\)](#).

- iii) a PM₁ head for non-continuous high volume aerosol sampling (500 l min^{-1}),
- iv) a second TSP head ($15 \text{ m}^3 \text{ h}^{-1}$) for O₃ and black carbon measurements.

A satellite connection makes remote control of the devices and instrumentation possible so that operating instruments can be directly accessed from ISAC-CNR (Bologna, Italy) and OPGC-CNRS (Clermont-Ferrand, France). The ABC-Pyramid is connected via coupled optical fibre with the Pyramid Laboratory/Observatory and, to ensure permanent connections between ABC-Pyramid and the main laboratory, there are also two back-up connections, one of coupled optical fibre and another using wireless technology. Data recorded at Pyramid Laboratory/Observatory server are transferred via satellite to ISAC-CNR,

where another server automatically downloads data. Data are then systematically checked using QA/QC procedures. The ABC-Pyramid meteorological and atmospheric compound data are plotted in real time along with air mass trajectory forecasts on the web site <http://evk2.isac.cnr.it/realtime.html>. Twenty-seven three-dimensional backward trajectories are calculated daily for the ABC-Pyramid site in order to forecast the origin of air masses reaching the measurement site. To avoid the introduction of excessive errors in computation, each forecasted back-trajectory has a time length of 5 days. The wind fields for these Lagrangian forecasts are based on the operational daily ECMWF forecast, and the LAGRANTO (LAGRANgian ANALysis TOol) model ([Wernli and Davies, 1997](#)) is used to calculate the back-trajectories.

Quality control for instrumentation and data are continuously performed according to EUSAAR (<http://www.eusaar.net/>; for aerosol measurements) and GAW (<http://gaw.kishou.go.jp/>; for surface O₃ measurements) procedures. For halocarbons, calibration of the instruments is conducted using the working standards linked to the AGAGE network calibration scales SIO-98 (Scripps Institution of Oceanography) and UB-98 (University of Bristol) (<http://agage.eas.gatech.edu/>).

3. First measurements and preliminary results

Continuous measurements began at ABC-Pyramid Observatory in March 2006, following careful installation of the instrumentation. Here we focus on the measurements of aerosol, ozone and greenhouse gases, while the analysis of the aerosol chemical composition will be presented in a future publication. These measurements have made it possible to characterize meteorology and air quality at a high Himalayan site over two well defined periods: pre-monsoon and monsoon seasons.

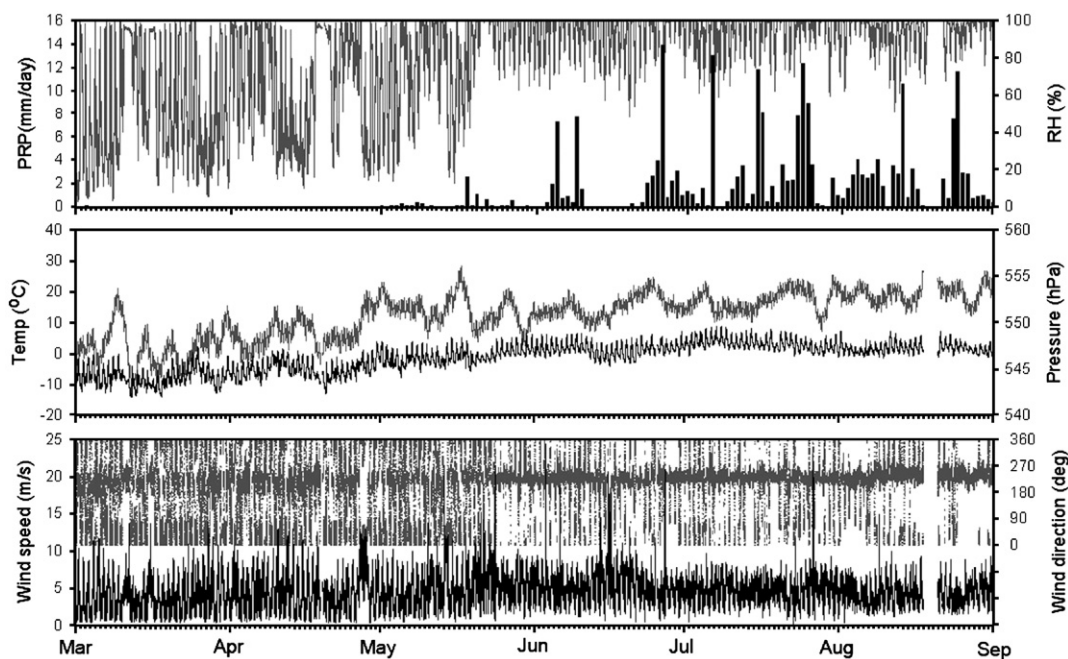


Fig. 3 – Meteorological parameter variations (30-minute average) during March–August 2006 at the ABC-Pyramid Observatory. Precipitation and relative humidity (upper), temperature and pressure (centre), wind speed and direction (lower). Grey dots are scaled on the right axis, the black-ones on the left axis.

Table 1 – Statistics of meteorological parameters at the ABC-Pyramid Observatory for the pre-monsoon and monsoon periods

ABC-Pyramid station		Pre-monsoon				Monsoon			
		Min	Max	Mean	1 σ	Min	Max	Mean	1 σ
Meteorological parameters	Relative humidity (%)	2.5	100	63	29	48	100	95	7
	Precipitation (mm/day)	0	2.55	0.05	0.29	0	13.8	2.14	3.16
	Pressure (hPa)	542	556	549	2.4	547	556	552	1.4
	Temperature (°C)	-14.4	+5.3	-5.2	3.5	-4.2	8.9	1.9	2.0
	Wind direction (sectors)	North-North west (night time)				South west			
		South west (day time)							
	Wind intensity (m/s)	0.3	21.5	4.1	2.4	0.3	24.4	4.8	1.8

3.1. Meteorological characterisation of pre-monsoon and monsoon seasons

At the Pyramid Laboratory/Observatory site, pre-monsoon and monsoon periods have been studied by *Bollasina et al. (2002)* using daily precipitation data from a six-year analysis (1994–1999). According to this study, June 12 was considered the mean onset of the summer monsoon precipitation. Our rainfall data analyses showed a similar onset date at the ABC-Pyramid (*Fig. 2*). Analysis of the local humidity and wind regime showed an abrupt change at the end of May (*Fig. 3*), indicating a time lag between the change of the mountain weather system and the onset of precipitation (*Ueno et al., in press*). We thus define the period “March-end of May” as pre-monsoon, and the period “end of May–September” as monsoon season.

The atmospheric pressure behaviour was characterised by higher values during the monsoon (average value of 552 hPa) and lower values during the pre-monsoon period (average value: 549 hPa). Pressure showed a much greater variability during pre-monsoon (*Fig. 3*) with some rapid variations recorded in connection with the passage of synoptic disturbances favouring a noticeable change of local air mass composition. The temperature behaviour also differs in the two seasons (*Fig. 3*): the pre-monsoon season is characterised by lower temperature values (-5.2 °C) and higher diurnal variations (4.5 °C) than those recorded during the monsoon period (1.9 °C, diurnal variation 3.5 °C). The lower diurnal variation characterizing the summer monsoon temperature (*Fig. 3*) was due to the frequently cloudy conditions occurring at the measurement site (*Bollasina et al., 2002*). During the pre-monsoon period, a valley wind (average intensity: 5.3 m/s) from S to SW prevailed during day time, and a weaker mountain breeze (average wind intensity: 2.5 m/s) from N to NW prevailed during the night. From the monsoon onset and for its duration, a prevailing valley wind was observed during the entire day, characterized by a weaker intensity during the night (*Fig. 3*). In the same period, the behaviour of relative humidity (*Fig. 3*) also shifted from a mean value of 63% (pre-monsoon) to 95% (monsoon). During pre-monsoon, relative humidity values decreased to a small percent while, during the summer monsoon, they rarely drop below 70%, as shown in *Table 1*.

3.2. Aerosol particle characterisation

PM1 behaved differently in the pre-monsoon and the monsoon seasons, as clearly shown in *Fig. 4*. The pre-monsoon period

was characterised by very high variations during March and April (maximum minute values above 80 $\mu\text{g m}^{-3}$, with an average of 5.4 $\mu\text{g m}^{-3}$). The monsoon season showed much lower PM1 concentrations and variability (minute values reaching 10 $\mu\text{g m}^{-3}$ with an average 0.3 $\mu\text{g m}^{-3}$). Usually PM10 did not show large differences between the two seasons (*Fig. 4*), suggesting that local sources can be important for coarse particles. Indeed, coarse particle concentrations often showed a diurnal cycle linked to wind direction (S–SW), with a maximum in the early afternoon, suggesting that re-suspension of soil dust could trigger the enhancement of PM10 levels. On the other hand, in other periods the coarse particle concentrations stayed constantly high for more days, suggesting a contribution of dust from remote sources (e.g. desert areas).

During the pre-monsoon season, PM1 accounts on average for 70% of PM10, while in the monsoon season it accounts only for 40%. This suggests that during the pre-monsoon period anthropogenic pollution can also affect the highest peaks in the Himalayan range. In fact, in this season, the behaviour of aerosol concentrations at the measurement site seems quite similar to the behaviour of aerosol concentrations recorded in the urban area of Kathmandu (400 km away), as shown in *Fig. 5* (daily averaged values, data provided by Nepalese Ministry of Population and Environment). Moreover, the high concentration of aerosol (mass and number) is frequently associated with high concentrations of black carbon and O₃, thus suggesting a strong influence of pollutant transport.

The concentration of black carbon shows a very similar time trend to that of PM1, showing large variations in the pre-

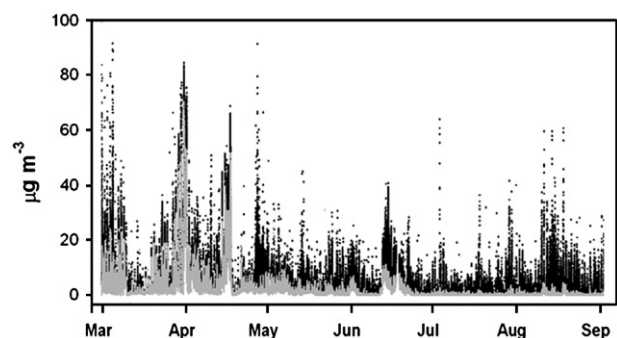


Fig. 4 – PM10 (black dots) and PM1 (grey dots) 1-minute average concentrations during March–August 2006 at the ABC-Pyramid Observatory.

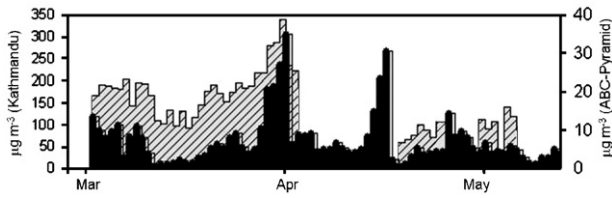


Fig. 5 – PM10 daily averaged values measured at the ABC-Pyramid Observatory (black) and in Kathmandu–Thamel site (grey; data provided by the Nepalese Ministry for Population and Environment).

monsoon season (maximum minute values higher than 5000 ng m^{-3}) and low levels during the summer monsoon (Fig. 6). The average black carbon concentration during the pre-monsoon season was $468 \pm 651 \text{ ng m}^{-3}$ (± 1 standard deviation) while in the monsoon season it was $69 \pm 60 \text{ ng m}^{-3}$. A comparison of black carbon concentrations with fine particle mass (PM1) shows a significant correlation for the pre-monsoon ($R^2 = 0.89$) and an averaged contribution of carbonaceous absorbing material to the PM1 of 9%. The correlation coefficient for the monsoon was $R^2 = 0.94$; nevertheless, due to the very low monsoon PM1 values and the presence of very few (strong) pollution events, this latter coefficient should be taken with caution. In fact, by excluding the two strongest June pollution events, the monsoon correlation coefficient decreased to $R^2 = 0.66$.

The number of particles with mobility diameter between 10 and 500nm did not show any difference between the two seasons investigated. This number (on minute average) ranged from low values to $12,000 \text{ cm}^{-3}$, with an average of $878 \pm 963 \text{ cm}^{-3}$ and a large variability. Very high particle concentrations were observed also when “clean” air masses (characterized by low black carbon concentrations and low relative humidity values) affected the measurement site. In this case, the observed particle concentration increases were associated with bursts of ultrafine particles. This indicates that even if the transport of anthropogenic aerosols and mineral dust appeared as the main process controlling the aerosol mass, the aerosol number concentration was influenced by additional mechanisms, yet to be fully understood. One hypothesis is that the mixing of air masses characterized by different gas, aerosol and water

vapour concentrations can promote new-particle formation processes at the measurement site.

3.3. Aerosol optical depth

The Cimel sun photometer provides a characterization of the optical and microphysical properties of the aerosols in the air column above the station. These measurements make it possible to monitor the time evolution of the aerosol optical depth (AOD) at eight wavelengths, plus other properties, such as single scattering albedo (SSA, fundamental in computing the aerosol effects on solar radiation), particle size distribution (SD, used in assessing the effects on formation and lifetime of water vapour clouds) and refractive index (Holben et al., 1998). Total precipitable water (PW) is also measured by the instrument channel at 940 nm. These observations can be performed only in sunny conditions.

The Ev-K²-CNR Cimel measurements collected in these first eight months of operation are summarized in Fig. 7. Here, monthly means of the 500nm AOD, the precipitable water, and the 440–870 nm Angstrom coefficient (representing the spectral dependence of AOD) are reported. The Angstrom coefficient is larger than one (about 1.8–2) for fine, submicron-sized particles (typical of pollution), while dropping well below one for supermicron-sized ones (typical of natural particles).

On the basis of Fig. 7, we can make the following observations: 1) low and dropping Angstrom coefficients show that coarse particles ($D > 1 \mu\text{m}$) increasingly dominated the AOD from April until August, while fine particles started increasing after that time; and 2) maximum AOD is observed in summer. These points possibly indicate that monsoon-driven cleansing of the atmosphere at pollution sources leaves locally re-suspended natural (i.e. coarse) particles which dominate the AOD at the ABC-Pyramid site during the wet season. Finally, it is interesting to note how the monsoon season leads to an increase of about one order of magnitude in precipitable water.

3.4. Surface O₃

O₃ concentrations (average value: $50 \pm 15 \text{ ppbv}$) exhibited a clear seasonal cycle (Fig. 8) with high values during the pre-monsoon (average value: $63 \pm 9 \text{ ppbv}$) and lower values during the monsoon period (average value: $39 \pm 11 \text{ ppbv}$). As suggested

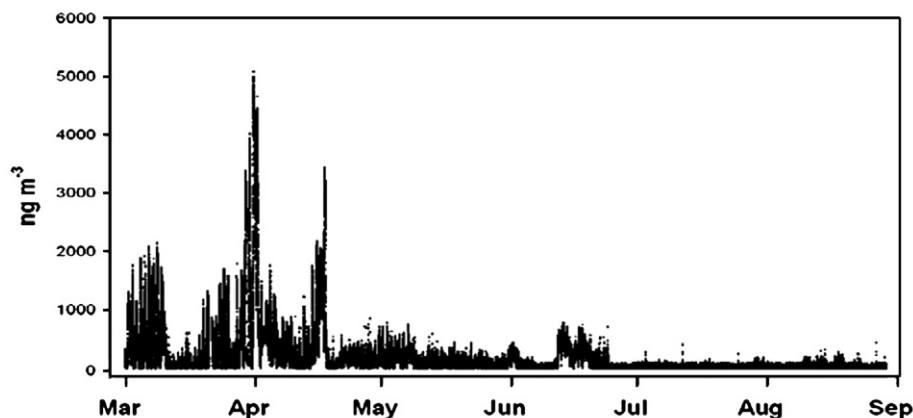


Fig. 6 – Black carbon 1-minute average concentrations during March–August 2006 at the ABC-Pyramid Observatory.

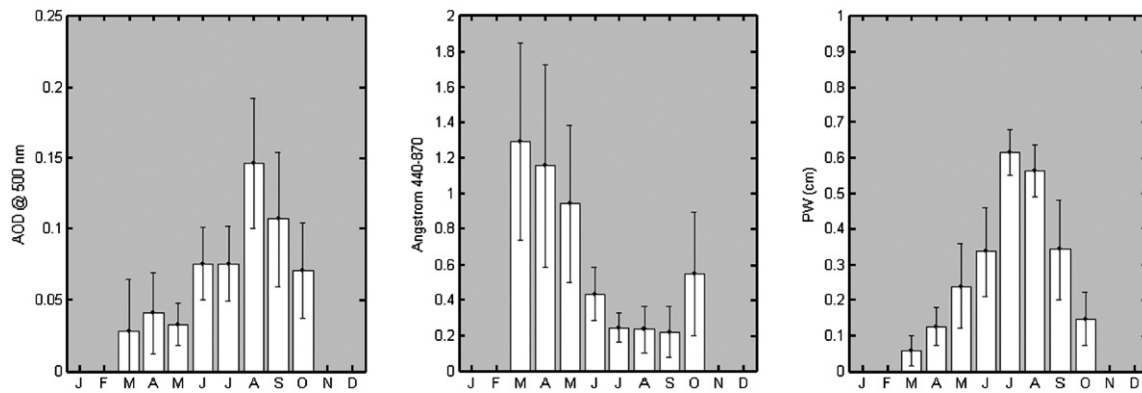


Fig. 7 – Monthly averages (white columns) and standard deviations (black lines) of aerosol optical depth at 500 nm (AOD, left), 440–870 nm Angstrom coefficient (Angstrom, centre) and precipitable water (PW, right) measured at the AERONET ABC-Pyramid Observatory station of EV-K²-CNR, in the period March–October, 2006.

by LAGRANTO back-trajectories, the high pre-monsoon O₃ concentrations were probably related with continental outflow of Eurasia and with UT/LS transport (Akimoto, 2007; Pochanart et al., 2004). The low values registered during the monsoon season were due to cleaner SW winds from the Arabian Sea transporting air masses poor in O₃ (Chand and Lal, 2004; Naja et al., 2003). In fact, low O₃ concentrations have been found over the Indian Ocean due to the lifting of air masses from the tropical marine boundary layer (Taupin et al., 1999). No O₃ diurnal cycle was recorded on average at ABC-Pyramid, indicating that there were no persistent local sources and sinks for this atmospheric compound. However, in several days of the pre-monsoon season, the O₃ concentrations did exhibit a clear diurnal behaviour with high values in the afternoon due to the transport of polluted air masses by valley breezes, suggesting that vertical transport phenomena affected the O₃ at this high mountain site in specific periods.

High O₃ concentrations recorded on different time scales from a few hours to a few days are probably related to stratospheric intrusion events or to polluted air masses coming from South Asia. In fact, one of the highest O₃ events (87ppbv) was recorded on March 11–12, 2006 (Fig. 8), when the atmospheric pressure dropped to 542hPa (the lowest value ever recorded since the start of monitoring activity, see Fig. 3). Such an increase is associated with a strong and fast decrease of aerosols (black carbon, ultrafine particles, PM₁, PM_{2.5}) thus revealing the occurrence of clean and relatively dry (relative humidity down to 50%) air masses at the measurement site.

The analysis of wind at 300hPa (not shown), revealed a trough moving (and finally dissipating) eastward over the measurement site, from March 11 to 12, 2006. Since this synoptic feature in the Himalayan area can be often related with tropopause folding (Moore and Semple, 2004), these high O₃ values and very low aerosol concentrations could be assigned to the transport of air masses from the upper troposphere/lower stratosphere to the measurement site.

Polluted air masses can also contribute to considerable increases in the O₃ concentration at the ABC-Pyramid site during pre-monsoon and monsoon seasons. During this last period, in mid-June, an air mass with a large burden of dust mixed with pollution blew through the Indus Valley, along the border between Pakistan and India to the edge of the Himalayas. The polluted air mass reached the Khumbu valley and the ABC-Pyramid site between June 12 and 22, simultaneous with a break in precipitation (Fig. 3, upper plate). Very high O₃ concentrations for the season (June 12–22 O₃ mean value = 64 ppbv, Monsoon mean value = 39 ppbv) were recorded at the measurement site. These high O₃ levels, together with high PM₁₀ (12 μg m⁻³ on average) and black carbon (306 ng m⁻³ on average) values suggested that long-lasting pollution events can affect the high Himalayan mountains also during the monsoon season.

3.5. Halogenated compounds

Flask samples are collected and then analysed by off-line GC-MS for the determination of 27 climate altering gases, like CFCs,

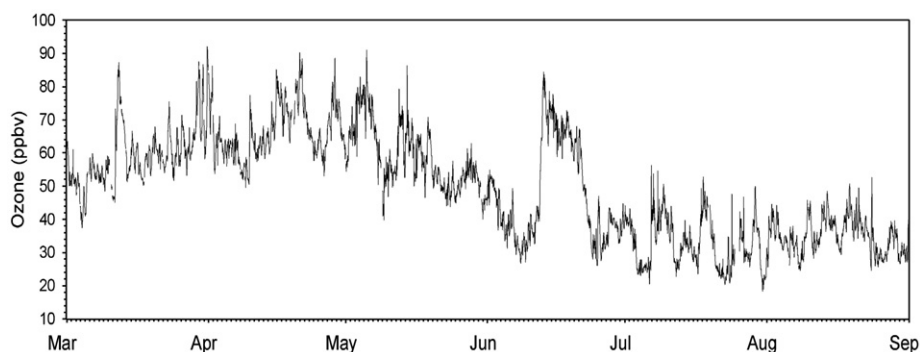


Fig. 8 – Ozone 30-minute average concentrations during March–August 2006 at the ABC-Pyramid Observatory.

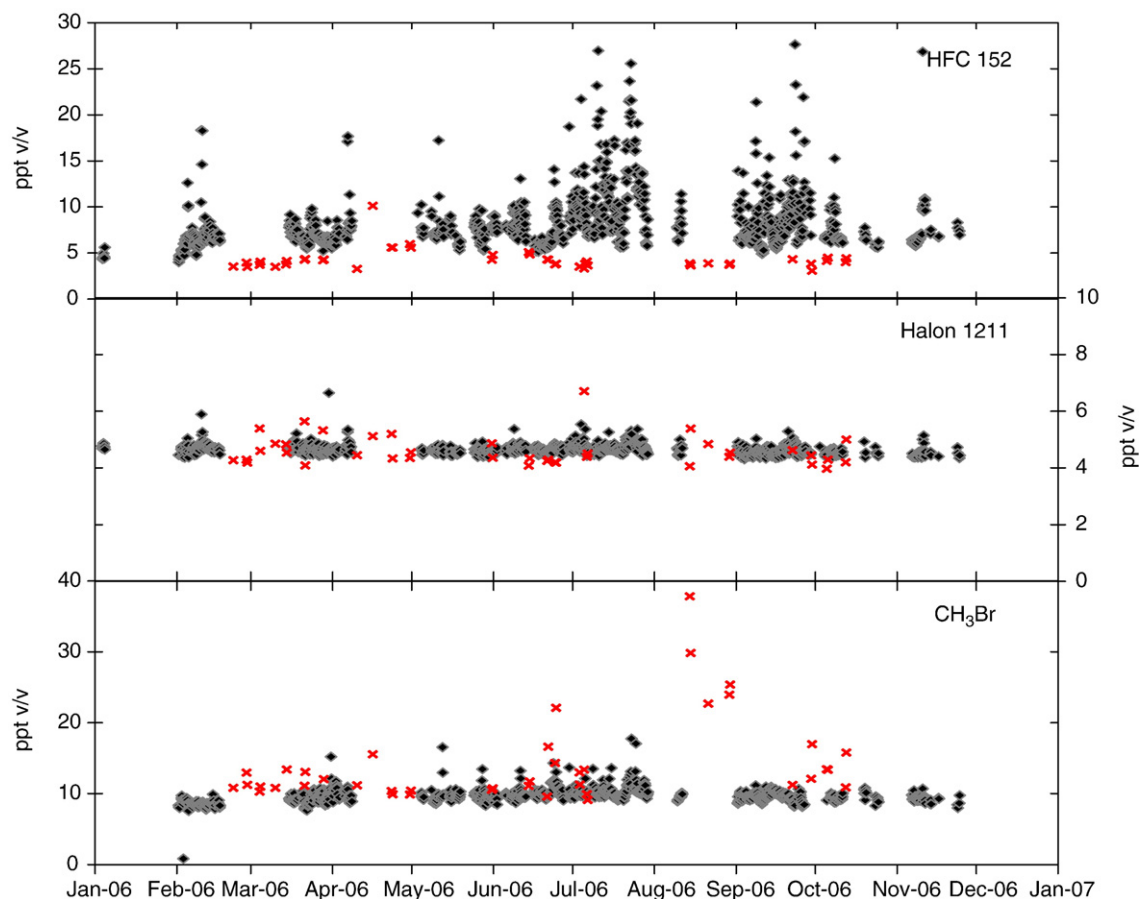


Fig. 9—Mixing ratios for selected halogenated gases (HFC 152 for Kyoto gases, halon 1211 for Montreal gases and CH_3Br for methyl halides) recorded in the period February–August 2006 at the Himalayan site (crosses, ABC-Pyramid Observatory) compared with those recorded in a European Continental site (circles, “O. Vittori” Mt. Cimone station).

Halons, HCFCs, HFCs, chlorinated solvents, and methyl halides. Calibration is reported to the SIO-98 and UB-98 scales (Maione et al., 2004). In this preliminary phase, flask samples were collected once a week at two different times on the same day, in order to verify whether changes in local circulation could affect the halocarbons’ mixing ratios. Furthermore, values measured in the Himalayan samples have been compared with time series available at the Italian “O. Vittori” Mt. Cimone station, which is representative of the continental Europe free troposphere. Preliminary results are the following: i) for the more recently introduced hydrofluorocarbons (HFCs) Kyoto gases, mixing ratios measured at the Himalayan site were below the European baseline with no high concentration peaks (except in one case) which, on the contrary, are commonly detected at Mt. Cimone (Fig. 9, upper plate); ii) mixing ratios of the well mixed Montreal gases (i.e. CFCs, halons and methyl chloroform) were similar at the two sites (Fig. 9, middle plate); iii) the methyl halides, like methyl chloride and methyl bromide which are also emitted by biomass burning, oceans and marshland, were frequently higher in the Himalayan samples particularly in the monsoon period (Fig. 9, bottom plate); iv) changes in local circulation did not seem to affect the concentrations measured, whereas a probable episode of long-range transport of polluted air masses occurred on April 17, 2006 when a significant increase in the mixing ratio of all the HFCs was observed.

4. Conclusions

In February 2006, a new high mountain station for atmospheric and climate studies was installed in the Himalayan Khumbu valley at 5079 m a.s.l. (Nepal, 27.95 N, 86.82 E). The ABC-Pyramid Observatory, developed in the framework of the Ev-K²-CNR “SHARE-Asia” (Stations at High Altitude for Research on the Environment in Asia) project is also part of the UNEP—“ABC” (Atmospheric Brown Clouds) observatory program, with the name of “Nepal Climate Observatory—Pyramid”. After a careful test installation of instruments at ISAC-CNR in Bologna (Italy) in autumn 2005, continuous measurements of aerosol particles (optical and physical properties), O_3 and meteorological parameters as well as weekly samplings of particulate matter (for chemical analyses) and grab air samples (for the determination of 27 halocarbons) in Nepal began in March, 2006. In this work we present the first six months of results.

The background atmospheric conditions were characterised by low black carbon (some tenths of ng m^{-3}) and aerosol number concentrations (less than $300 \text{ particles cm}^{-3}$), a low aerosol mass (PM_{10} smaller than $1 \mu\text{g m}^{-3}$), a high $\text{PM}_1/\text{PM}_{10}$ ratio (0.75) as well as an average aerosol size distribution with a principal mode in the Aitken range. In agreement with the sun photometer measurements, the aerosol mass at the ABC-

Pyramid Observatory was strongly affected by the presence of large particles, due to both dust transport and local particles re-suspension. Coarse particles dominated the AOD from April until August, with a maximum in summer, while fine particles started to increase at the end of the monsoon season.

The surface O₃ behaviour (average value 50ppbv) is typical for the representative background conditions and on average no diurnal cycle was evident. Several high O₃ concentrations were recorded on different time scales probably due to the influence of stratospheric and/or polluted air mass transport. The well mixed fully halogenated gases had concentration levels similar to the global baseline. The HFCs were characterized by concentrations lower than the European continental baseline conditions while, on the contrary, Himalayan methyl halides concentrations showed higher values in particular during the monsoon.

The first six months of measurements showed large differences between pre-monsoon (March–end of May) and monsoon (end of May–August) season for meteorological parameters, surface O₃, black carbon and fine aerosol mass concentrations as well as for AOD, Angstrom coefficient and precipitable water, while no clear differences were observed for particles number, coarse particles mass and halocarbon concentrations. The PM₁ behaviour showed a clear change between the two investigated seasons, with high concentrations and large variability during the pre-monsoon (average value 5.4 μg m⁻³), and much lower concentrations in the monsoon season (average value 0.3 μg m⁻³). PM₁₀ did not show large differences between the two seasons, suggesting that the most important source for coarse particles was local. Surface O₃ showed high values (63 ppbv) during the pre-monsoon and lower (39 ppbv) in the monsoon even if transport of polluted air masses, observed also during the monsoon (e.g. 12–22 June 2006), could favour strong rises of the O₃ and aerosol concentrations.

Acknowledgments

This study was carried out within the framework of the Ev-K²-CNR Project in collaboration with the Nepal Academy of Science and Technology as foreseen by the Memorandum of Understanding between Nepal and Italy, and thanks to contributions from the Italian National Research Council and the Italian Ministry of Foreign Affairs. Part of this work was supported by ACCENT (GOCE-CT-2003-505337). The authors would like also to thank the "Nepalese Ministry of Population and Environment" for providing Kathmandu PM₁₀ data; the Nepalese and Italian staff working at the Pyramid Laboratory, NASA for providing MODIS/Terra image; EUSAAR, SOGE and AGAGE networks for providing the calibration scale. Authors thanks the EMPA—World Calibration Centre for Surface Ozone for supporting the instrument calibration in Himalayas. Finally, the authors are also thankful to the two anonymous reviewers for their constructive suggestions.

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