Carbonaceous particles in the atmosphere and precipitation of the Nam Co region, central Tibet

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Abstract

A continuous air and precipitation sampling for carbonaceous particles was conducted in a field observatory beside Nam Co, Central Tibetan Plateau during July of 2006 through January of 2007. Organic carbon (OC) was the dominant composition of the carbonaceous particles both in the atmosphere (1660 ng/m^3) and precipitation (476 ng/g) in this area, while the average elemental carbon (BC) concentrations in the atmosphere and precipitation were only 82 ng/m^3 and 8 ng/g, respectively. Very high OC/BC ratio suggested local secondary organic carbon could be a dominant contribution to OC over the Nam Co region, while BC could be mainly originated from Southern Asia, as indicated by trajectory analysis and aerosol optical depth. Comparison between the BC concentrations measured in Lhasa, those at "Nepal Climate Observatory at Pyramid (NCO-P)" site on the southern slope of the Himalayas, and Nam Co suggested BC in the Nam Co region reflected a background with weak anthropogenic disturbances and the emissions from Lhasa might have little impact on the atmospheric environment here, while the pollutants from the Indo-Gangetic Basin of Southern Asia could be transported to the Nam Co region by both the summer monsoon and the westerly.

Key words: carbonaceous particle; elemental carbon; organic carbon; Nam Co; Tibetan Plateau

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Introduction

Carbonaceous particles (CPs) in the atmosphere can be generally separated into two portions, i.e., organic carbon (OC) and elemental carbon (EC). They are generated from incomplete combustions of fossil fuels and biomass (anthropogenic and natural). EC could also be called black carbon (BC) for its light-absorbing characteristic. CPs play complex roles in the global atmospheric radiative balance (Jacobson, 2004) and consequently result in climate effects, e.g., precipitation anomaly (Menon et al., 2002; Meehl et al., 2008), accelerating the melt of snow and ice (Hansen and Nazarenko, 2004; Ramanathan et al., 2007), and others. In addition, finer particles enriched with CPs (< 2.5 nm) were harmful to human health (WHO, 2003); and thus, studies on the impacts of CPs on the climate and environment have been highly concerned with by scientists and policy-makers since the 1990s.

Southern Asia, where India is the most important economic member, has been in its blooming period of fast development since the 1990s. The Energy Information Administration estimates of Southern Asia's primary energy consumption showed an increase of 52% from 1993 to 2003 (EIA, 2004). Along with the tremendous fuel (fossil and biomass) consumption, Southern Asia produced severe air pollution from the emission of millions of tons of pollutants. For example, in 2000 Southern Asia emitted 564 Gg ($\times$ 10^9 g) of BC (12.3% of the global emission) and 1520 Gg of OC (16.2% of the global emission) (Bond et al., 2007). The Indian Ocean Experiment (INDOEX) revealed the so-called "brown cloud phenomenon" in Asia is spreading from the northern Himalayas over the Northern Indian Ocean region (Ramanathan et al., 2001). About two million people died of conditions associated with atmospheric pollution in India each year, in terms of adverse effects on environment and human health (UNEP and C4, 2002); and as for its impacts on climate, BC aerosol over Southern Asia intends to increase the precipitation over India during March-April-May (pre-monsoon), while during monsoon season it could reduce monsoon rainfall over India, with some small increases over the Tibetan Plateau (Meehl et al., 2008). The warming caused by BC aerosol in the South Asian Haze is threatening the duration of the glaciers on the southern slope of the Himalayas. Warmer air resulted from BC over the Himalayas contributed to a

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warming of approximately 0.6°C during the past 50 years, which might be partly responsible for the accelerating retreat of the Himalayan glaciers (Ramanathan et al., 2007) and threaten the fresh water supplies and food securities in China and India (Brown, 2008).

Recent aerosol and snow chemistry investigations conducted in the East Rongbuk Glacier (ERG) of the middle Himalayas showed that the anthropogenic pollutants originated from Southern Asia (e.g., sulfate, organochlorine pesticides, and mercury) were deposited in the snow during the monsoon seasons (Ming et al., 2007; Wang et al., 2007; Loewen et al., 2007). BC record in a shallow ERG ice core (aged from 1951 to 2001) also showed a dramatic increasing BC-concentration trend since the 1990s; and the mean BC concentration estimated in the atmosphere over the ERG was ca. 80 ng/m^3 during the past 50 years (Ming et al., 2008), which was comparable with that (86 ng/m^3) measured at the site named "Nepal Climate Observatory at Pyramid" (NCO-P in Fig. 1a) on the southern slope of the Himalayas during 2006 (Bonasoni et al., 2008). These studies implied that pollutants originated from Southern Asia could probably be transported into the upper troposphere by convections and travelled over the high elevated Himalayas, and then invade into the Tibetan Plateau by the Indian summer monsoon.

Nam Co as a hinterland lake of the Tibetan Plateau (Fig. 1a, b), is a remote site away from populated regions without industries and many herders. Intensive investigations on the atmospheric environment here since 2005 showed the air quality was probably influenced by the pollutants from the outside of the Tibetan Plateau. Backward trajectory analysis indicated the pollutants from South Asia might be responsible for anthropogenic trace elements (e.g., Zn and As) rich in the atmosphere during the monsoon seasons (Cong et al., 2007; Li et al., 2007a). BC deposited in the snow of the Zhadang Glacier (Fig. 1b) nearby might also have originated from South Asia (Ming et al., 2009). Nevertheless, no studies on CPs in air for the Nam Co region were reported till now, especially for their concentration levels and seasonal variations. Here we presented a first investigation on atmospheric CPs over this region from the summer of 2006 through the spring of 2007.

1 Experiment

1.1 Site description

Nam Co (30°30′–30°56′N, 90°16′–91°03′E) is a great lake in the north of the Nyainqentanglha Mountains, approximately 112 km NNW of Lhasa City (Fig. 1a). The lake with the elevation of 4718 m has a surface area of 1980 km^2 and is the highest salt lake in the world. The Nam Co Observation Station (NCOS) (30.77°N, 90.99°E, 4730 m) was built at the southeastern coast of the lake in 2005 (Fig. 1a, b, c). There are several Tibetan tents of natives living on pasture farming within the 50-km distance of Nam Co. The station uses solar power for scientific utilities and lighting, and burns natural gas for cooking. And it has a natural and flat field (220 m × 100 m) for meteorology, solar radiation, and aerosol observation (Fig. 1c, e).
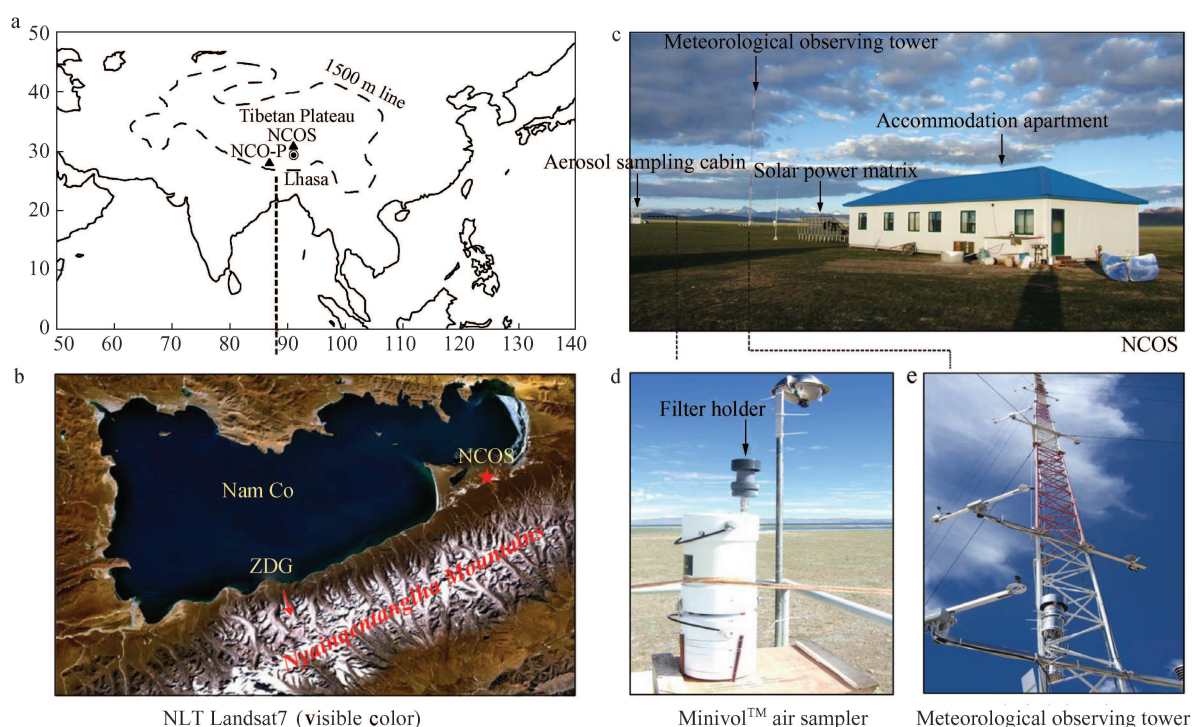
Fig. 1 Location map of the sampling site (a), NLT Landsat7 satellite image of Nam Co and its surroundings, including Nyainqentanglha Mountains with the Zhadang Glacier (ZDG) in its south, where the sampling site (NCOS) is located in the southeast coast of the lake (b), image of spatial distribution of the facilities at NCOS (c), image of the Minivol^{TM} air sampler (d), and image of the 52-m high meteorological observing tower (e).

1.2 Sampling and analysis

1.2.1 Surface air

The portable air sampler (MiniVol, Airmetrics^{TM}, USA) was set on the roof of the sampling cabin (about 3 m high over the ground) to collect total suspended particulates (Fig. 1d). It allowed a quartz filter (Whatman® QMA, UK) with the diameter of 47 mm to be mounted. The quartz filters were pre-heated in an oven at 600°C for 24 hr to eliminate any possible carbonaceous matter, and enclosed in the petri-slides. After a filter was mounted in the sampler, the stream velocity of the pump was adjusted to 5 L/min, which is the recommended value of the manufacturer. The samples were kept pumping for 5–9 days with the volumes of 19.65–38.73 m^3 (calibrated to that at 0°C and 1013 hPa). A special cap designed by the manufacturer was mounted on the top of the filter holder to avoid any influences from different weather conditions. Afterwards the filter would be stored at –20°C until analysis. Twenty nine samples were collected at this site during July of 2006 through January of 2007.

In the laboratory, a smaller piece (0.5 cm^2) was punched out of its original filter (47 mm), and analyzed in a DRI®–2001 model carbon analyzer (USA). The thermochemical analysis for BC and OC content was performed using a thermo/optical reflectance (TOR) method and following the Interagency Monitoring of Protected Visual Environments (IMPROVE) protocol (Chow et al., 2004). The sample filter was heated stepwise at the temperatures of 120°C (OC1), 250°C (OC2), 450°C (OC3), and 550°C (OC4) in a non-oxidizing (He) atmosphere, and at 550°C (BC1), 700°C (BC2), and 800°C (BC3) in an oxidizing atmosphere of 2% O$_2$ and 98% He (Zhang et al., 2008). Evolved carbon was oxidized to CO$_2$, and then reduced to CH$_4$ and detected by the flame ionization detector (FID). The pyrolyzed or charred OC was monitored by the laser reflectance at λ = 633 nm. The portion of BC1 was assigned to pyrolyzed organic carbon (OP) until the laser signal returns to its initial value. The OC was defined by the sum of OC1, OC2, OC3, OC4, and OP; while the BC was defined by BC1 + BC2 + BC3-OP (Zhang et al., 2008). The accuracy of the measurement was ±10% and the detection limit was 2 μg C/cm^2 (Chow et al., 2004). OC and BC concentrations for aerosol samples are calculated and presented in Table 1.

1.2.2 Precipitation

Twelve precipitation samples were collected at precipitation events by an automated precipitation collector during the Nam Co's monsoon season (July to October of 2006). The collector would be open automatically when raining and rainwater would be collected in a pre-mounted

Table 1 Sampling record and measured atmospheric OC and BC concentrations

Code	Period (y/m/d)	Volume (m^3)	OC_DRI[a] (μg/cm^2)	BC_DRI[b] (μg/cm^2)	OC (ng/m^3)	BC (ng/m^3)
AS-1	2006/7/8–13	19.649	3.73	0.33	2268	201
AS-2	2006/7/13–22	30.970	5.15	0.31	1986	120
AS-3	2006/7/22–29	27.647	5.50	0.55	2376	238
AS-4	2006/7/29–8/5	27.680	4.52	0.12	1951	52
AS-5	2006/8/5–13	31.707	6.79	0.35	2558	132
AS-6	2006/8/13–20	27.591	3.70	0.09	1602	39
AS-7	2006/8/20–27	27.700	2.06	0.15	888	65
AS-8	2006/8/27–9/3	23.788	2.26	0.03	1135	15
AS-9	2006/9/3–10	27.867	3.02	0.05	1295	21
AS-10	2006/9/10–17	28.198	1.91	0.08	809	34
AS-11	2006/9/17–24	28.010	3.04	0.11	1297	47
AS-12	2006/9/24–10/1	27.974	3.12	0.56	1332	239
AS-13	2006/10/1–8	28.260	3.71	0.44	1568	186
AS-14	2006/10/8–15	28.597	2.98	0.11	1245	46
AS-15	2006/10/15–22	28.721	3.28	0.26	1364	108
AS-16	2006/10/22–31	38.726	4.77	0.17	1471	52
AS-17	2006/10/31–11/5	19.969	1.76	0.04	1053	24
AS-18	2006/11/5–11	25.356	1.00	0.00	471	0
AS-19	2006/11/11–19	33.192	4.38	0.24	1576	86
AS-20	2006/11/19–26	28.876	5.14	0.41	2126	170
AS-21	2006/11/26–12/3	29.072	5.96	0.11	2449	45
AS-22	2006/12/3–10	29.314	2.54	0.06	1035	24
AS-23	2006/12/10–17	29.342	3.21	0.02	1307	8
AS-24	2006/12/17–24	29.696	2.25	0.17	905	68
AS-25	2006/12/24–31	29.287	2.68	0.11	1093	45
AS-26	2006/12/31–1/7	29.495	10.37	0.00	4200	0
AS-27	2007/1/7–14	29.970	7.14	0.17	2846	68
AS-28	2007/1/14–21	29.885	6.91	0.35	2762	140
AS-29	2007/1/21–28	29.948	2.96	0.25	1181	100
Min		19.649	1.00	/	471	/
Max		38.726	10.37	0.56	4200	239
Average		28.500	3.99	0.19	1660	82
SD		3.491	2.02	0.16	790	70

[a] OC = OC_DRI × 11.95 × 1000/volume, [b] BC = BC_DRI × 11.95× 1000/volume, [c] "/"refers to under the detection limit.

AS: aerosol, OC: organic carbon, BC: black carbon, OC_DRI: organic carbon mass on the punched filter measured by DRI instrument; BC_DRI: black carbon mass on the punched filter measured by DRI instrument; SD: standard deviation.

Table 2   Sampling record and measured rainwater OC and BC concentrations

Code	Sampling date (y-m-d)	Sample mass (g)	OC_DRI (μg/cm^2)	BC_DRI (μg/cm^2)	OC (ng/g)	BC (ng/g)
RF-1	2006-7-10	141	83.37	0.64	657	5
RF-2	2006-7-12	147	67.13	0.90	516	7
RF-3	2006-7-14	89	169.95	2.20	2158	27
RF-4	2006-7-22	339	94.08	2.13	314	7
RF-5	2006-7-28	172	85.88	2.29	564	15
RF-6	2006-8-11	298	47.83	2.92	181	11
RF-7	2006-8-21	396	42.24	3.29	121	9
RF-8	2006-8-25	262	91.31	1.46	394	6
RF-9	2006-9-9	144	58.37	0.13	458	1
RF-10	2006-9-16	292	42.89	1.18	166	4
RF-11	2006-9-24	251	15.37	0.35	69	1
RF-12	2006-10-1	317	32.18	0.28	115	1
Blank			1.38	0.05		
Min		89	15.37	0.13	69	1
Max		396	169.95	3.29	2158	27
Average		237	69.22	1.48	476	8
SD		96	40.46	1.07	565	7

OC = (OC_DRI − 1.38) × 1.13 × 1000/sample mass, and BC = (BC_DRI − 0.05) × 1.13 × 1000/sample mass. RF: rain fall.

HDPE bag. Once a precipitation event was over, the sample would be transferred into a glass bottle immediately. And these samples were stored in a frozen condition until analysis. The melting and filtration for the samples were processed following the method described in literature (Ming et al., 2009).

The analysis procedure of CPs followed the method for the aerosol filters described in Section 1.2.1. The OC and BC concentrations of the precipitation samples are calculated and presented in Table 2. And major ions (Ca^{2+}, NH_4^+, Na^+, SO_4^{2-}, NO_3^-, Cl^-, and so on) were measured using a Dionex® ion-chromatography (USA) and details are available in a previous study (Li et al., 2007b).

2 Results and discussion

2.1 CPs in surface air and precipitation

The mean concentration of BC in the atmosphere over NCOS during July of 2006 to January of 2007 was (82 ± 70) ng/m^3, and OC was (1660 ± 790) ng/m^3 (Table 1). And the mean concentrations of BC and OC in the precipitation during the monsoon season were (8 ± 7) ng/g and (476 ± 565) ng/g, respectively (Table 2). OC was the dominant composition of the CPs in the atmosphere and precipitation, and BC accounted only for 4.7% and 2.4% of the CPs mass in the atmosphere and precipitation, respectively.
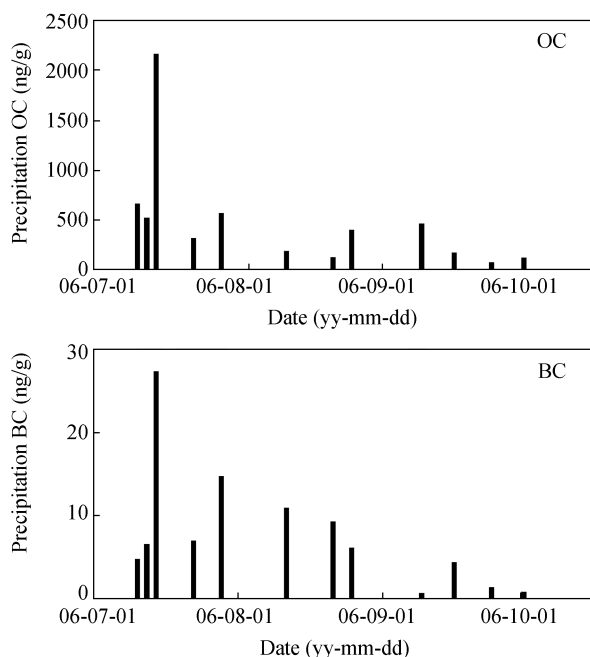
The variations of the CPs concentrations in the atmosphere are displayed in Fig. 2. OC showed a weak increasing trend throughout the sampling period, while BC showed a decreasing trend. For OC, the average concentration (1572 ± 518) ng/m^3 in the monsoon season (May to October) was a little lower (11%) than that (1770 ± 1048) ng/m^3 in the post-monsoon season (November to January), where the highest concentration (4200 ng/m^3) appeared in early January of 2007; while for BC, the average concentration in the monsoon season (100 ± 78) ng/m^3 was much higher (67%) than that in the post-monsoon season (60 ± 53) ng/m^3. There were two distinct peaks (238 and 239) ng/m^3 in July and September and the two values under the detection limit appeared in the post-monsoon season.
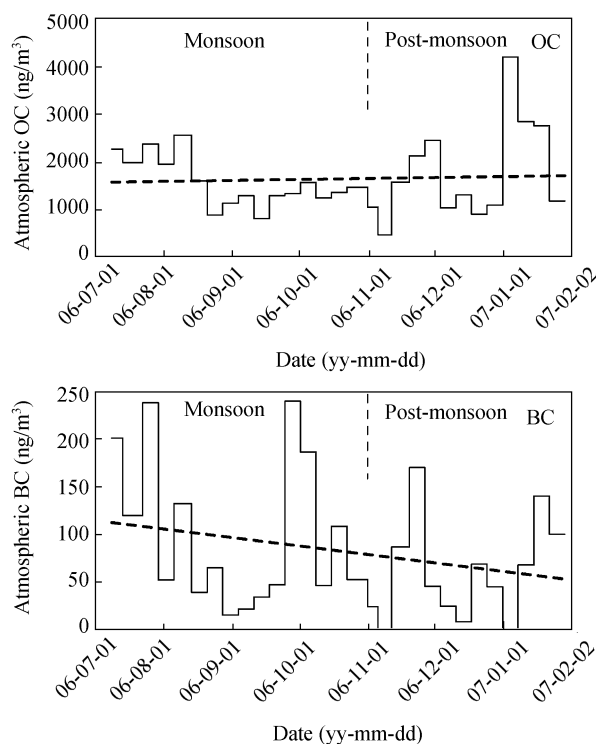
Fig. 2   Variations of atmospheric OC and BC concentrations during July of 2006 to January of 2007, where each step started and ended at sampling beginning and ending time, and dashed lines were the linear fits for OC and BC, respectively.

BC and OC concentrations showed significant positive correlation from July to September of 2006 (0.78, α = 0.01, N = 11, where α represents the confidence level and N represents the sample number), while no apparent correlation between them could be obtained during the post-monsoon season (0.02, N = 18).

The variations of CPs concentrations in the precipitation are displayed in Fig. 3. The highest CPs concentrations in precipitation appeared in mid July of 2006, which were 2158 ng/g for OC and 27 ng/g for BC, respectively. The general trends of CPs in the precipitation were decreasing during July to October of 2006, and this was consistent

Fig. 3 Variations of OC and BC concentrations in precipitation sampled during the monsoon season.

with that in the atmosphere. The BC and OC concentrations in the precipitation showed a significant correlation (0.82, $\alpha = 0.01$, $N = 12$). Different relationships of BC and OC in the atmosphere and precipitation performed during the monsoon and non-monsoon seasons suggested they could be generated from common sources during the monsoon seasons, while during the post-monsoon seasons their unapparent relationships might be attributed to their different sources. In addition, significant relationships could also be found between the CPs and ions, which were associated with fossil/biomass fuel combustion, for example, BC-NH_4^+ (0.807, $\alpha = 0.01$, $N = 9$), BC-SO_4^{2-} (0.793, $\alpha = 0.01$, $N = 9$), and OC-SO_4^{2-} (0.790, $\alpha = 0.01$, $N = 9$). These relationships existed between CPs and ions also indicated their common sources during the monsoon season.

2.2 OC/BC ratio and its implications

OC/BC ratio was usually used to evaluate the combustion fuel sources, although there might be uncertainties when using it. For example, an earlier study on the global CPs emission inventory suggested the global mean of OC/BC by biofuel/biomass burning was ca. 8.0, while that by fossil fuel burning was much lower (ca. 4.2) (Liousse et al., 1996); however, a recent work presented quite different values, in which the mean OC/BC ratios by biofuel/biomass and fossil fuel burning were ca. 6.2 and ca. 0.8, respectively (Bond et al., 2004).

Tibet, where our sampling site was located, has few industries and is a less populated region. An emission inventory released in 2000 revealed the mean OC/BC by biomass and fossil fuel burning were ca. 6.9 and ca. 2.7 in Tibet, respectively (Streets et al., 2003). And an investigation deployed in 2006 showed the mean OC/BC was 6.5 ± 2.2 in Lhasa City (Zhang et al., 2008). The ratio
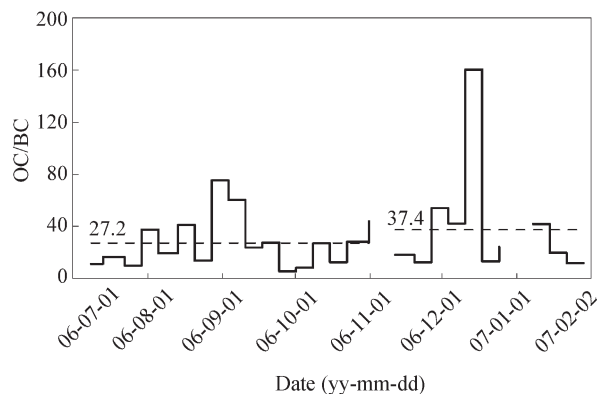
Fig. 4 OC/BC ratios in the atmosphere during sampling time, where two dashed lines presented two mean OC/BC ratios during the monsoon (27.2) and post-monsoon (37.4) seasons, respectively.

OC/BC for the aerosol samples of this work is presented in Fig. 4. The mean OC/BC was 31.9 ± 31.1 throughout the sampling period, which was strikingly larger than any one of the earlier results. The ratio in the monsoon season was much lower than that in the post-monsoon season. The mean OC/BC was 27.2 ± 19.3 during July to October of 2006, while it increased to 37.4 ± 44.9 after then till the sampling end, due to the inverse trends of OC and BC described in Section 2.1.

Some previous studies suggested CPs in aerosols with OC/BC higher than 2.0 could be interpreted as containing significant quantities of secondary organic carbon (SOC) (Gray et al., 1986; Chow et al., 1996). Recently, China Atmosphere Watch Network (China Meteorological Administration) observed relatively higher OC/BC values at its stations around China with the mean of ca. 6.0, which was partly attributed to a strong regional background of SOC in China (Zhang et al., 2008). The OC/BC in the Nam Co region was much higher than that mentioned above, and the mean atmospheric BC concentration was very low and shared less than 5% of the CPs mass. Hence we suggested preliminarily local SOC could be a great contribution to OC in the atmosphere over the Nam Co region, especially during the post-monsoon season; and more BC was originated from remote sources via the long-range transport than that from local combustions.

2.3 Potential sources and transport of BC in Nam Co

The BC emissions in Tibetan Plateau is much weaker than the other surrounding regions. For example, the BC emission in Tibet was only ca. 1.1% of the South Asia's total emission in 2000 (Streets et al., 2003). BC measured in the Himalayan snow suggested the pollutants were probably transported from Southern Asia as a great source for BC deposits (Ming et al., 2009). The meteorological investigations showed southerly winds dominated the weather during May to Oct., while westerly winds took its advantage during Nov. to April (You et al., 2007). And this circulation allowed BC emitted from Southern Asia could be transported into the hinterland of the TP.

We used a trajectory model (HYSPLIT) to investigate the air masses transported to NCOS

during the sampling period, which had been applied in the previous studies (Ming et al., 2009). The model-compatible gdas1 meteorological data (ftp://www.ready.noaa.gov/pub/archives/gdas1) was used to calculate 5-day backward trajectories. The clustering tool assembled in the model software was applied to form clusters of the trajectories and then to calculate the mean trajectory for each cluster (Draxler and Hess, 1998). Eight mean trajectories for the eight clusters are calculated based on the trajectories from 1-July-2006 to 31-January-2007 (Fig. 5a). The air masses over NCOS were primarily from Bangladesh (red trajectory), eastern India (blue trajectory), northwestern India (Indo-Gangetic basin) (cyan trajectory), and Pakistan (yellow trajectory) during the sampling period, which accounted for 84% of the trajectories (Fig. 5b). And seasonal variations of the trajectory number for these four clusters are displayed in Fig. 5c. The air masses were mainly from Bangladesh

and eastern India by the southerly winds (Trajectory 1, 2) during the monsoon season, while afterward the air masses were mainly from the Indo-Gangetic basin by the westerly winds (Trajectory 4, 6).

We retrieved the monthly mean aerosol optical depth (AOD) over the TP and its adjacent areas (15°–35°N, 65°–95°E) from the Terra satellite data during June of 2006 to January of 2007. The pollutants over the Tibetan Plateau transported by the summer monsoon could be observed in Fig. 6. In general, the AOD over the Tibetan Plateau was much smaller than that over Southern Asia. The AOD over the TP during the monsoon season was higher than that during the post-monsoon season, and this was consistent with the atmospheric BC observed at NCOS. And a significant high AOD area was observed stretched along with the southern slope of the Himalayas during the sampling period, where could be a potential pollutants' source for the atmosphere of Nam Co indicated by the
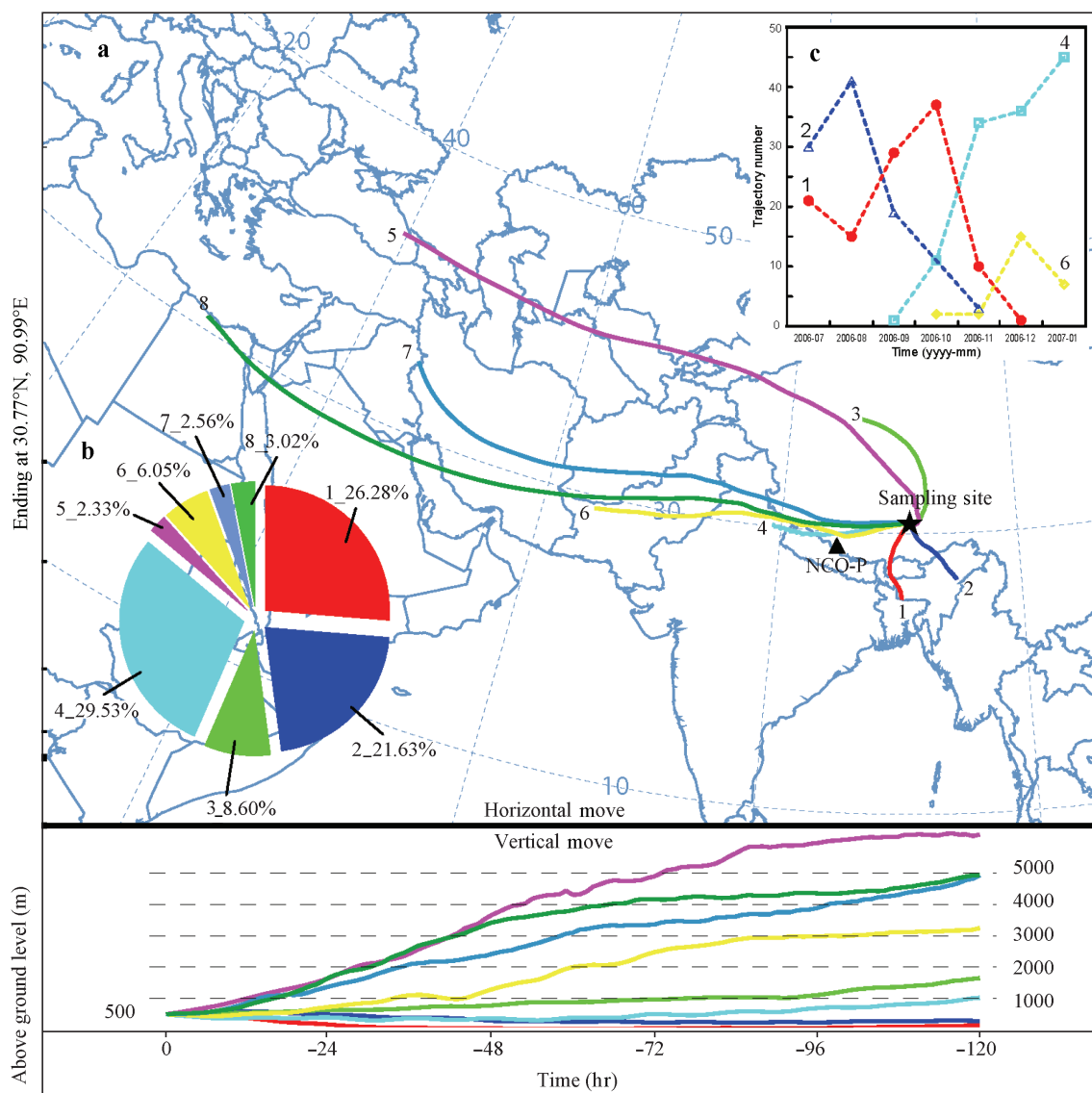
Fig. 5 Cluster-mean 5-day backward air trajectories simulated by the HYSPLIT_V4.8 model, where the NCO-P site was located between mean trajectory 1 and 4, and the vertical moves of the trajectories indicated trajectory 1, 2, 4 were travelling through the boundary layer of the near surface on the southern slope of the Himalayas (a), percentages of the trajectory numbers of the 8 trajectory clusters (b), and variations of the dominant trajectory's monthly numbers (c).
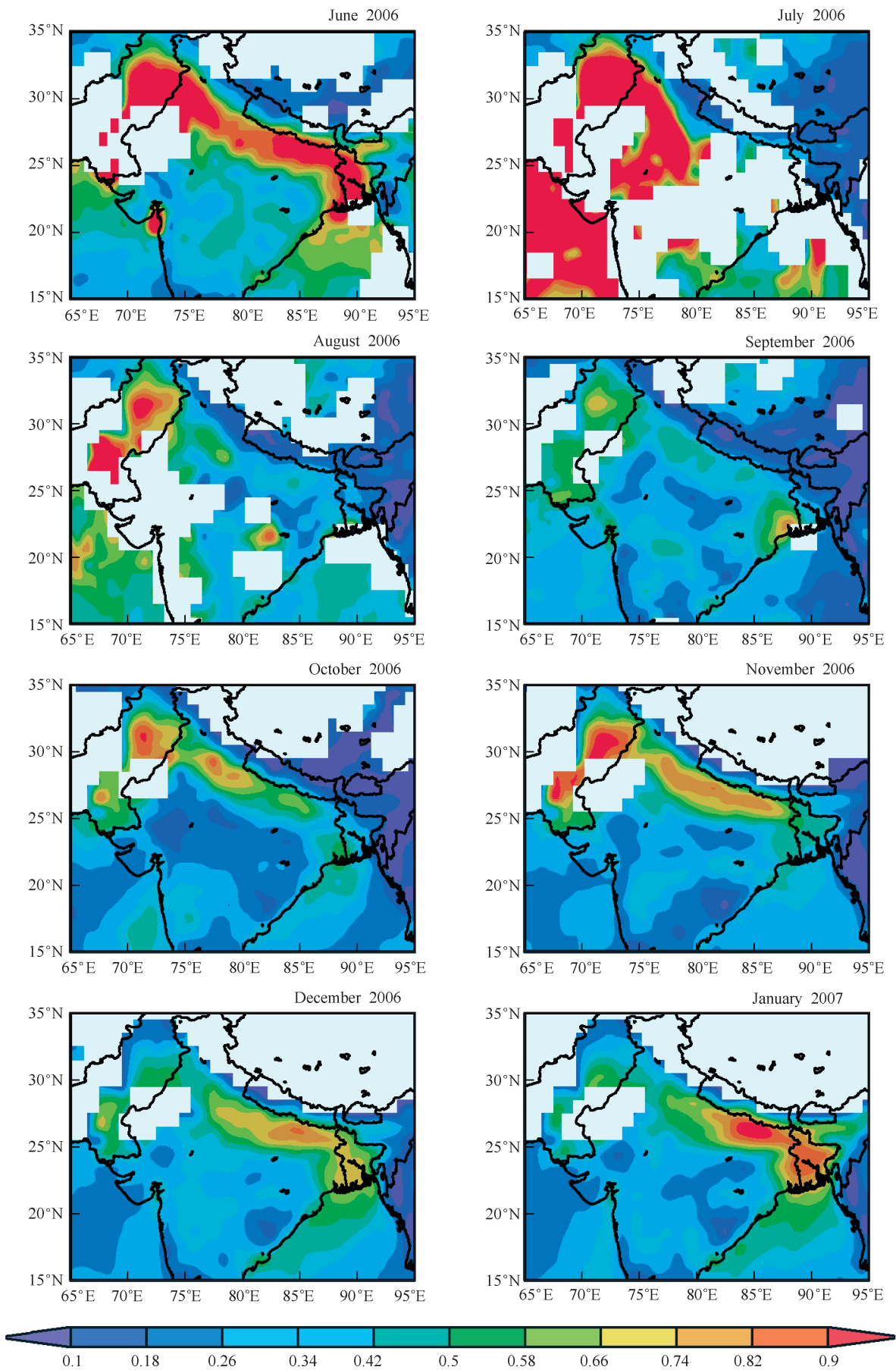
Fig. 6 Monthly AOD area-average distribution over the area of 15°–35°N and 65°–95°E during July of 2006 to January of 2007.

trajectory analysis.

2.4 Comparison between atmospheric BC in Lhasa, NCO-P site, and Nam Co

During sampling at NCOS, two other simultaneous measurements were also deployed at the Tibetan Plateau. One site was located in the Lhasa City (29.67°N, 91.13°E, 3663 m), and the NCO-P site was on the southern slope of the Himalayas. The comparison between the atmospheric BC concentrations at the three sites is presented in Fig. 7. The mean BC concentration in Lhasa (3522 ng/m^3) was much higher than those at NCOS (82 ng/m^3) and the NCO-P (86 ng/m^3), this could be primarily attributed to the different emission backgrounds of urban and remote sites.

Although NCOS is not very far from Lhasa, the different varying trends and magnitude discrepancy of BC concentrations at these two sites suggested that BC at NCOS might be not mainly from Lhasa City, but could have other source areas. No co-variation of BC concentrations at NCO-P and NCOS could be observed during the monsoon season of 2006. However, there were three simultaneous BC spikes appearing after October of 2006 when the air mass pathways shifted from the summer monsoon to the westerly as indicated in Fig. 5. This suggested that atmospheric BC at NCOS was possibly transported from Southern Asia during the post-monsoon season, for the air masses impacting NCOS and NCO-P were both mainly clustered in trajectory 4 (Fig. 5).

3 Conclusions

During July of 2006 to January of 2007, a continuous air and precipitation sampling for CPs was conducted beside Nam Co, central Tibet. The mean BC and OC concentrations in the atmosphere and precipitation were 82 and 1660 ng/m^3, and 7.8 and 476 ng/g, respectively. OC was the dominant composition of the CPs both in the atmosphere and precipitation in this region. During the monsoon season, OC and BC could have common sources due to their significant positive correlation; while after that, no relationship existed between them. Extremely high OC/BC ratio suggested local SOC could be a dominant contribution to the atmospheric OC, while BC could be mainly transported from Southern Asia, associated with the trajectory analysis and AOD. A comparison was made between BC concentrations in Lhasa, NCO-P, and NCOS. The result suggested the concentration level reflected a background of light anthropogenic disturbance for BC in the Nam Co region as a remote site; and the emissions in Lhasa had little impact on the atmospheric environment here; while BC emitted from Indo-Gangetic Basin of Southern Asia could be transported to Nam Co by both the Indian summer monsoon and the westerly.

Acknowledgments
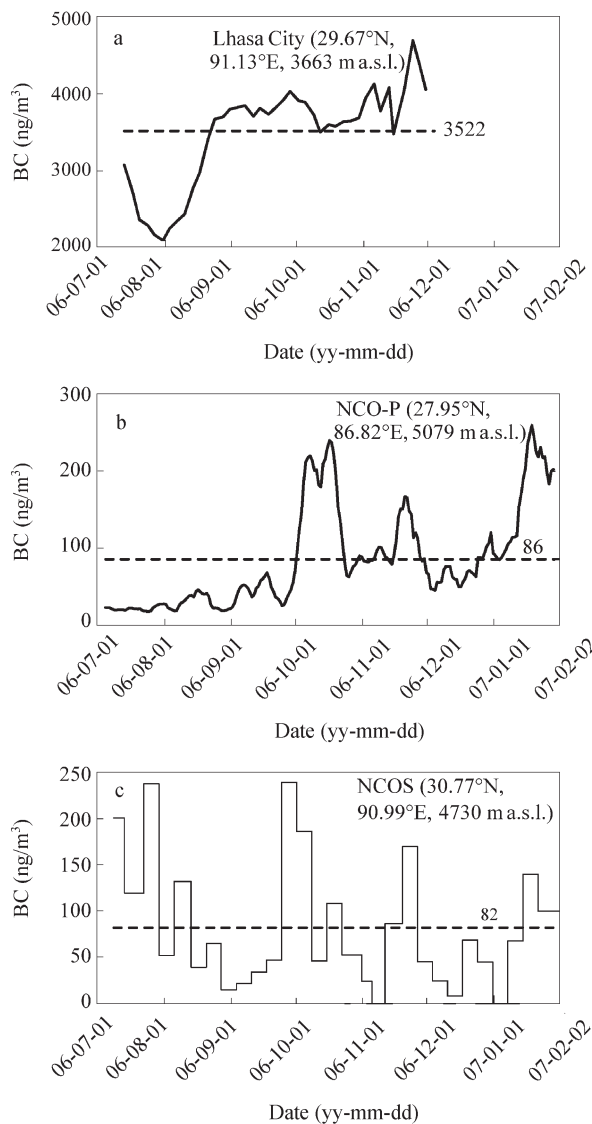
Fig. 7 Atmospheric BC concentrations. (a) Lhasa City (7-day running average) during the second half of 2006; (b) NCO-P (7-day running average) during July of 2006 to January of 2007; (c) NCOS during the sampling period. Dashed lines represent the mean concentration levels.

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