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Effect of biomass burning on black carbon (BC) in South Asia and Tibetan Plateau: The analysis of WRF-Chem modeling

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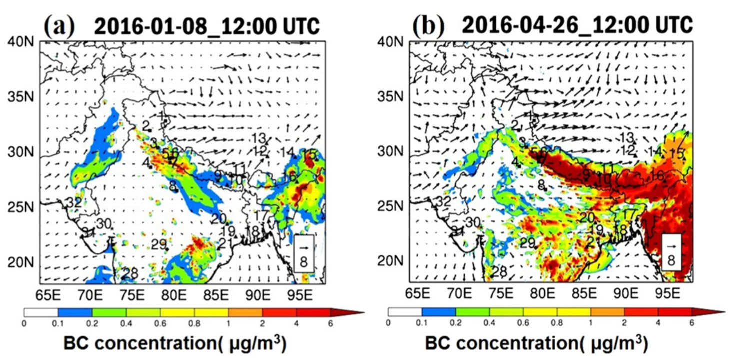
HIGHLIGHTS

- Biomass fires in South Asia measured by Terra and Aqua satellite data from 2010 to 2016 are analyzed.
- The highest biomass burnings located in two regions (along the foothill of Himalayas and Southeastern Asia)
- Biomass burning emissions were highest in spring, producing high BC concentrations (2.0 to 6.0 μg/m^3)
- BC particles were transported to the glaciers in TP, causing significant deposition on the snow surface of the glaciers

GRAPHICAL ABSTRACT



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ABSTRACT

The focus of this study is to evaluate the impact of biomass burning (BB) from South Asia and Southeast Asia on the glaciers over the Tibetan Plateau. The seasonality and long-term trend of biomass fires measured by Terra and Aqua satellite data from 2010 to 2016 are used in this study. The analysis shows that the biomass burnings were widely dispersed in the continental of Indian and Southeast Asia and existed a strong seasonal variation. The biomass burnings in winter (January) were relatively weak and scattered and were significantly enhanced in spring (April). The highest biomass burnings located in two regions. One was along the foothill of Himalayas, where is a dense population area, and the second located in Southeast Asia. Because these two high biomass burning regions are close to the Tibetan Plateau, they could have important effects on the BC deposition over the glaciers of the Tibetan Plateau. In order to study the effect of BB emissions on the deposition over the glaciers in the Tibetan Plateau, a regional chemical model (WRF-Chem; Weather Research and Forecasting Chemical model) was applied to simulate the BC distributions and the transport from BB emission regions to the glaciers in Tibetan Plateau. The result shows that in winter (January), due to the relatively weak BB emissions, the effect of BB emissions on BC concentrations was not significant. The BC concentrations resulted from BB emissions ranged from 0.1 to 2.0 μg/m^3, with high concentrations distributed along the foothill of Himalayas and the southeastern Asia region. Due to the relative low BC concentrations, there was insignificant effect of BB emissions on the deposition over the glaciers in the Tibetan Plateau in winter. However, the BB emissions were highest in spring (April), producing high BC concentrations. For example, along the Himalayas Mountain and in the southeastern Asia region, The BC concentrations ranged from 2.0 to 6.0 μg/m^3. In addition to the high BC concentrations, there were also west and

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south prevailing winds in these regions. As a result, the BC particles were transported to the glaciers in the Tibetan Plateau, causing significant deposition of BC particles on the snow surface of the glaciers. This study suggests that the biomass burning emissions have important effects on the BC deposition over the glaciers in the Tibetan Plateau, and the contaminations of glaciers could have significant impact on the melting of snow in the Tibetan Plateau, causing some severe environmental problems, such as the water resources.

1. Introduction

Biomass burning emissions are produced by the combustion of biomass fuels through either natural (e.g., wildfires) or planned processes (e.g., residential wood combustion in fireplaces and woodstoves). Biomass burning is an important global emission source of aerosols and trace gases, which has significant impacts on air quality, climate change and human health. Accurate estimate of trace gas and aerosol emissions from biomass burning is fundamental and important to further research about global climate change, regional air quality assessment and forecasting (Ramanathan and Carmichael, 2008; Kumar et al., 2015; Xu et al., 2016; Chao et al., 2018). Biomass burning is especially important in South Asia (SA), which is an important pollution source to the air pollution in the regions of Himalayas and the Tibetan Plateau (HTP).

Black carbon (BC) is a distinct type of carbonaceous particulate matter mainly emitted from incomplete combustion of fossil fuels, biofuels, and biomass burning (Zhang et al., 2014). Black carbon (BC) aerosols play a major role in regional as well as global climate by interacting with the changing solar radiation, modifying the cloud properties (semi-direct and glaciation effect) and reducing the snow albedo (Lohmann and Feichter, 2005; Ramanathan and Carmichael, 2008; Flanner et al., 2009; Xu et al., 2009a; Menon et al., 2010; Yao et al., 2012; IPCC, 2013). According to a recent study by Gao et al. (2018), BC has strong feedback mechanisms throughout the affecting BL (boundary layer). They suggest that the absorbing effect of BC heats the air above the BL and suppresses and delays the development of the BL, which leads to further increase in BC surface concentrations.

The HTP and surrounding mountains have large ice glacier coverages and an expanded area of seasonal/permanent snow cover, which is an important fresh-water supply to major rivers in Asia. As a result, the HTP region presents the most sensitive and visible indicator of climate change with its unique location for complex interactions among the atmosphere, hydrosphere, and cryosphere (Hansen and Nazarenko, 2004; Seinfeld, 2008; Xu et al., 2009b; Yao et al., 2015 and Zhao et al., 2013). The understanding of BC aerosols in South Asia, including the Ganga Plain, Tibetan Plateau and Himalayan foothills, is important both for their potential health effects on the large resident population (Stone et al., 2010 and Watts et al., 2015) and for their climate/hydrosphere effects.

In recent years, several international and national field experiments such as INDOEX (Ramanathan et al., 2001a, 2001b), ACE-Asia (Huebert et al., 2003; Schauer et al., 2003), TRACE-P (Jacob et al., 2003), APEX (Nakajima et al., 2003), PEACE (Kondo et al., 2004), ABC (Ramanathan et al., 2007), and EAREX (Wang et al., 2010) have been conducted in Asia, to characterize aerosols and trace gases, and to study their effects on environment and climate. Some studies suggest that the developing nations in the tropics and Southeast Asia are one of the major source regions for emission of carbonaceous species (Lelieveld et al., 2001; Bond

Table 1
The information of the measured surface BC concentrations at 32 sites in the south Asia region and the references of the measured results.

Area	Site name	Site type	Lat (°N)	Lon (°E)	Alt. (m)	BC period	Reference
North	1. Hanle	High-altitude	32.78	78.96	4520	2009.08–2011.12	Nair et al. (2013)
	2. Kullu	Lower Himalayas	31.90	77.10	1154	2009.07–2012.03	Nair et al. (2013)
	3. Dehradun	Lower Himalayas	30.34	78.04	700	2007.03–2010.08	Nair et al. (2013)
	4. Delhi	Urban	28.58	77.18	300	2011.01–2011.12	Tiwari et al. (2013a)
	5. Nainital	High-altitude	29.36	79.45	1958	2005.01–2012.08	Nair et al. (2013)
	6. Mukteshwar	High-altitude	29.44	79.64	2180	2005.09–2007.09	Hyvärinen et al. (2009)
	7. Pantnagar	Semi-Urban	29.00	79.50	231	2009–2012	Joshi et al. (2016)
	8. Kanpur	Urban	26.46	80.32	50	2006.12–2011.11	Kanawade et al. (2014)
North-East	9. Kathmandu	High-altitude	27.40	85.20	1500	2009.05–2010.04	Sharma et al. (2012)
	10. Darjeeling	High-altitude	27.01	86.30	2200	2010.01–2011.12	Sarkar et al. (2015)
	11. NCO-P	High-altitude	27.95	86.82	5079	2006.03–2008.02	Nair et al. (2013)
	12. Lhasa	High-altitude	29.60	91.10	3650	2006.01–12	Gao et al. (2007)
	13. Nam Co	High-altitude	30.77	90.99	4730	2006.07–2007.01	Ming et al. (2010)
	14. Lulang	High-altitude	29.50	94.40	3300	2008.07–2009.07	Zhao et al. (2013)
	15. Ranwu	High-altitude	29.32	96.96	4600	2012.11–2013.06	M. Wang et al. (2016)
	16. Dibrugarh	Rural	27.30	94.60	111	2008.06–2009.05	Pathak et al. (2010)
	17. Agartala	Rural	23.76	91.26	15	2010.09–2012.09	Guha et al. (2015)
	18. Kolkata	Urban	22.34	88.22	25	2012.06–2013.05	Talukdar et al. (2015)
	19. Kharagpur	Urban	22.33	87.32	28	2005–2008	Nair et al. (2012)
	20. Dhanbad	Urban	23.47	86.30	222	2012.01–2012.12	Singh et al. (2015)
	21. Bhubaneswar	Coastal	21.25	85.25	113	2010.06–2012.05	Mahapatra et al. (2014)
South	22. Visakhapatnam	Coastal	17.70	83.30	16	2005.12–2006.09	Sreekanth et al. (2007)
	23. Kadapa	Semi-arid Urban	14.47	78.82	138	2011.09–2012.11	Begam et al. (2016)
	24. Ooty	High-altitude	11.23	76.43	2520	2010.04–2012.05	Udayasoorian et al. (2014)
	25. Bangalore	Urban	12.97	77.59	960	2008.01–2008.12	Aswathy et al. (2016)
	26. Anantapur	Suburban	14.62	77.65	331	2010.01–2010.12	Reddy et al. (2017)
	27. Hyderabad	Urban	17.48	78.40	557	2009.01–2010.12	Dumka et al. (2013)
	28. Pune	Urban	18.53	73.85	457	2005–2010	Safai et al. (2014)
	29. Nagapur	Semi-Urban	21.15	79.15	312	2011.01–2012.06	Kompalli et al. (2014)
West	30. Ahmedabad	Urban	23.03	72.60	55	2008.01–2008.12	Ramachandran and Kedia (2010)
	31. Naliya	Rural	22.23	68.89	50	2007.11–2010.06	Gogoi et al. (2013)
	32. Karachi	Coastal	24.94	67.12	45	2006–2007	Dutkiewicz et al. (2009)