Yale 耶鲁大学-南京信息工程大学大气环境中心

Yale-NUIST Center on Atmospheric Environment

A discussion on the paper "Black carbon aerosols over the Himalayas:direct and surface albedo forcing"

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Tellus Series B-Chemical And Physical Meteorology

IF:3.76

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2014.10.03

Outline

- Background
- Methods and materials
- Results and discussion
  - BC over the Himalayas
  - BC deposition pathways
  - Radiative impacts of BC over the Himalayas
- Conclusions

Background

- Black carbon(BC) could perturb the radiative balance of the Earth-Atmosphere system through direct, semi-direct and snow-albedo effects and then have great implications on the regional climate and hydrological cycle.

- Deposition of BC onto snow-surface over Himalayas would reduce the surface albedo significantly, lead to accelerated melting of Himalayan glaciers and rusult in positive radiative forcing(warming) at the top of the atmosphere(TOA) .

Methods and materials

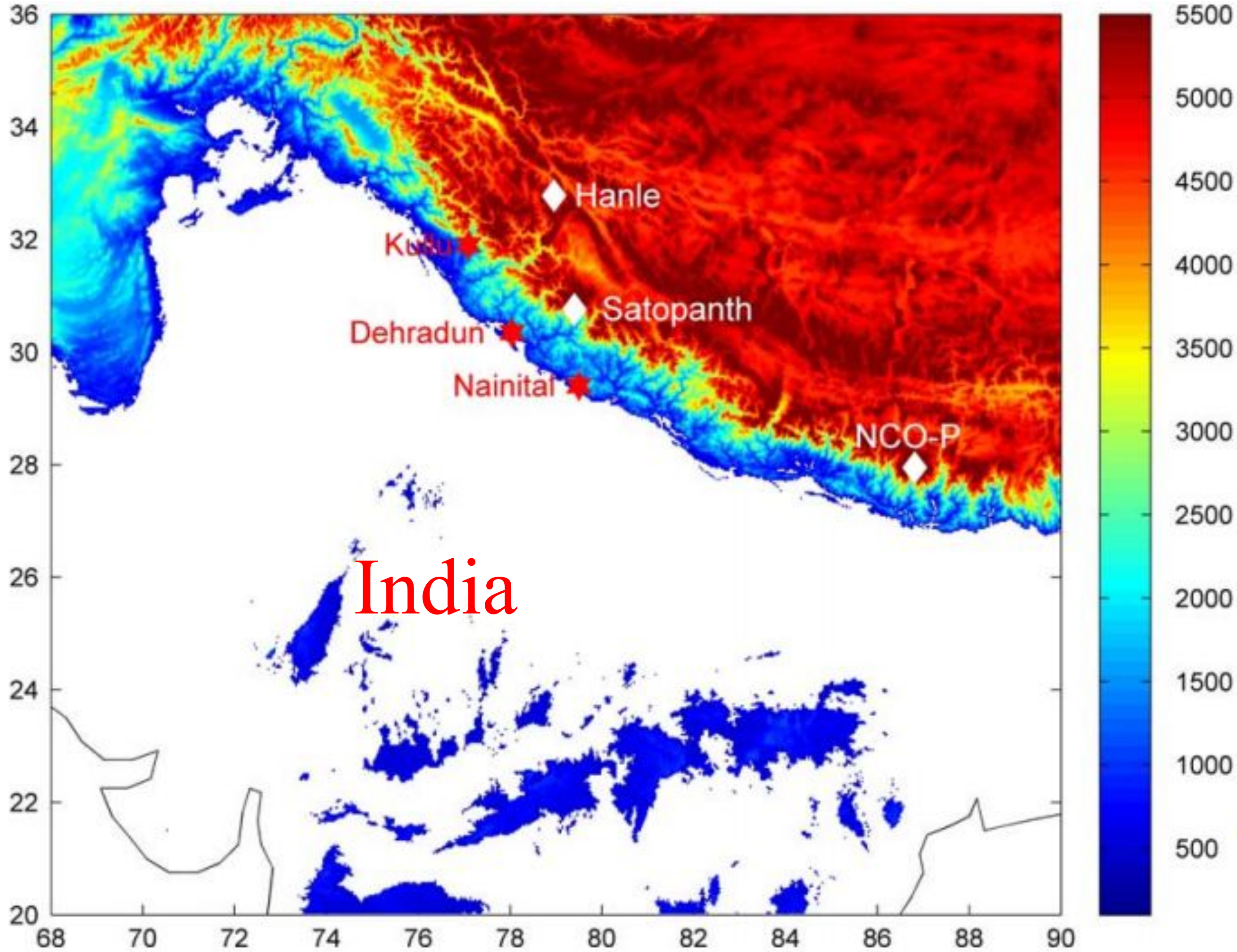


Fig. 1. Locations of measurement sites.

Results and discussion

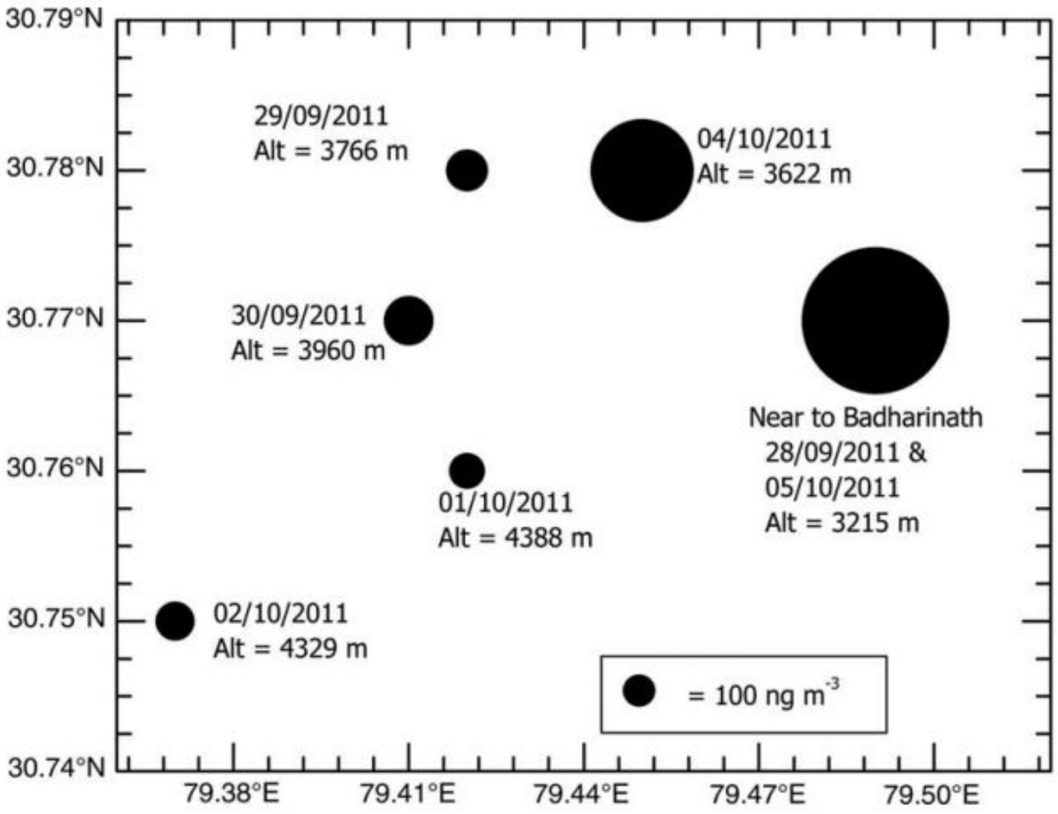
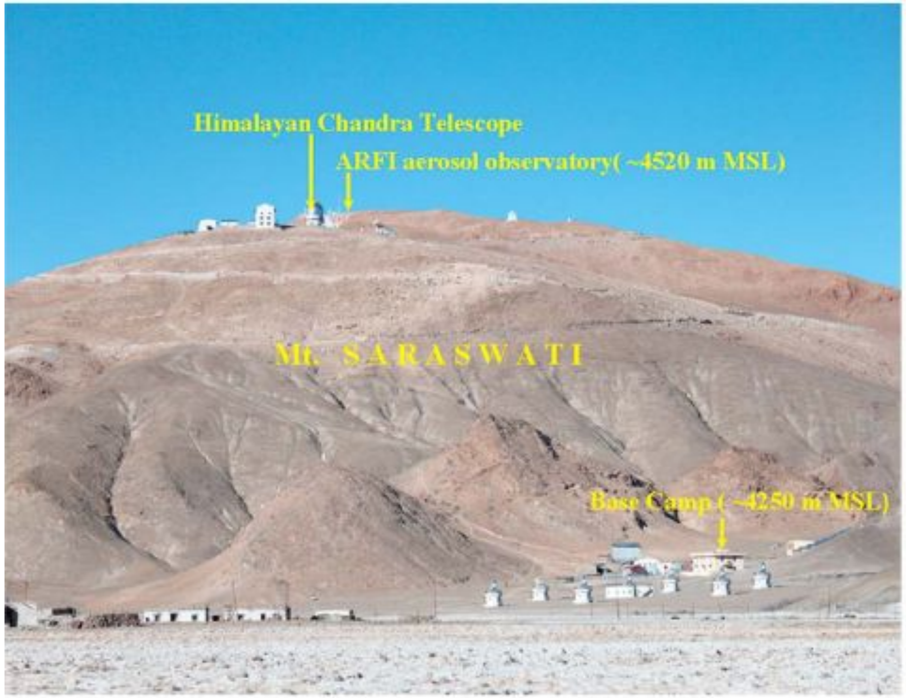
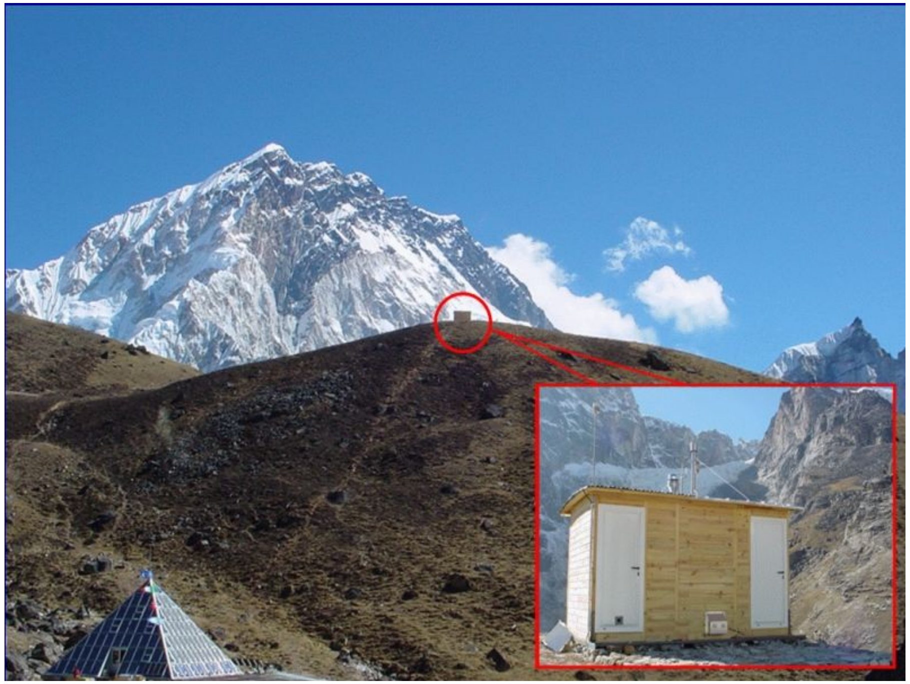


Fig. 2. Spatial pattern of atmospheric BC mass concentrations over the Satopanth region.


Himalayan Chandra Telescope
ARFI aerosol observatory(~4520 m MSL)
Mt. SARASWATI
Base Camp (~4250 m MSL)

Hanle

NCO-P



- Long range transport
- Atmospheric boundary layer dynamics
- up-valley breeze

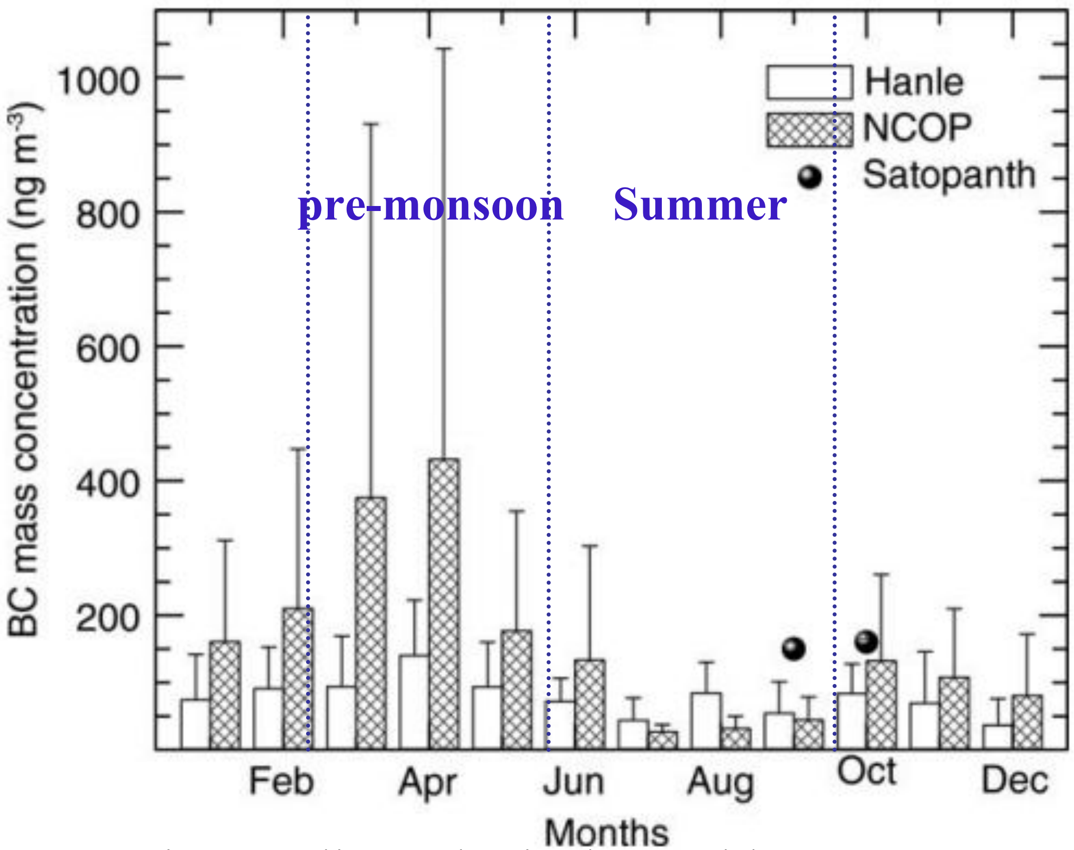


Fig. 3. Climatological monthly mean mass concentrations of atmospheric black carbon (BC) aerosols at Hanle and NCO-P.

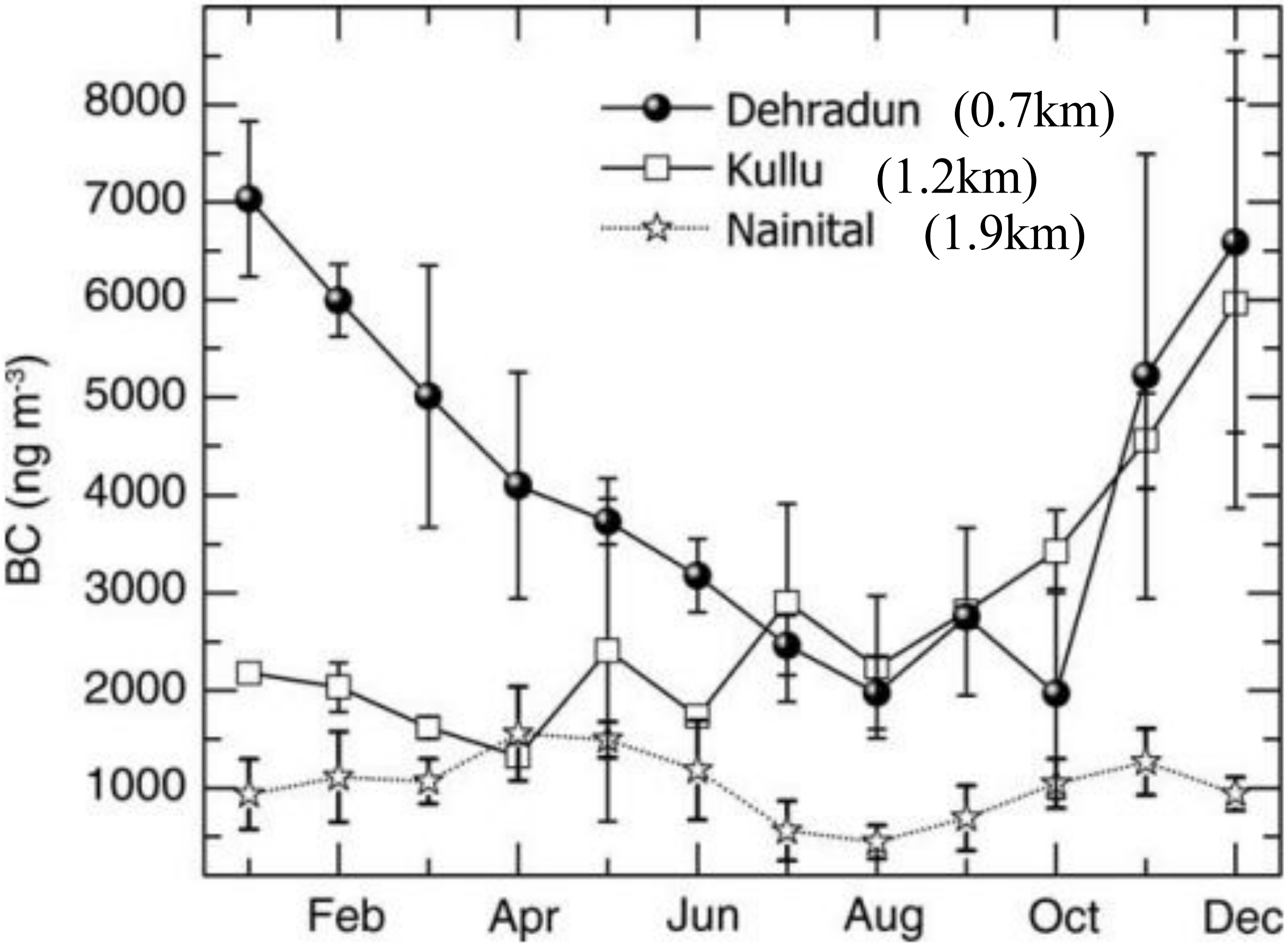


Fig. 4. Climatology of monthly variations of atmospheric BC mass concentrations at Dehradun, Kullu and Nainital.

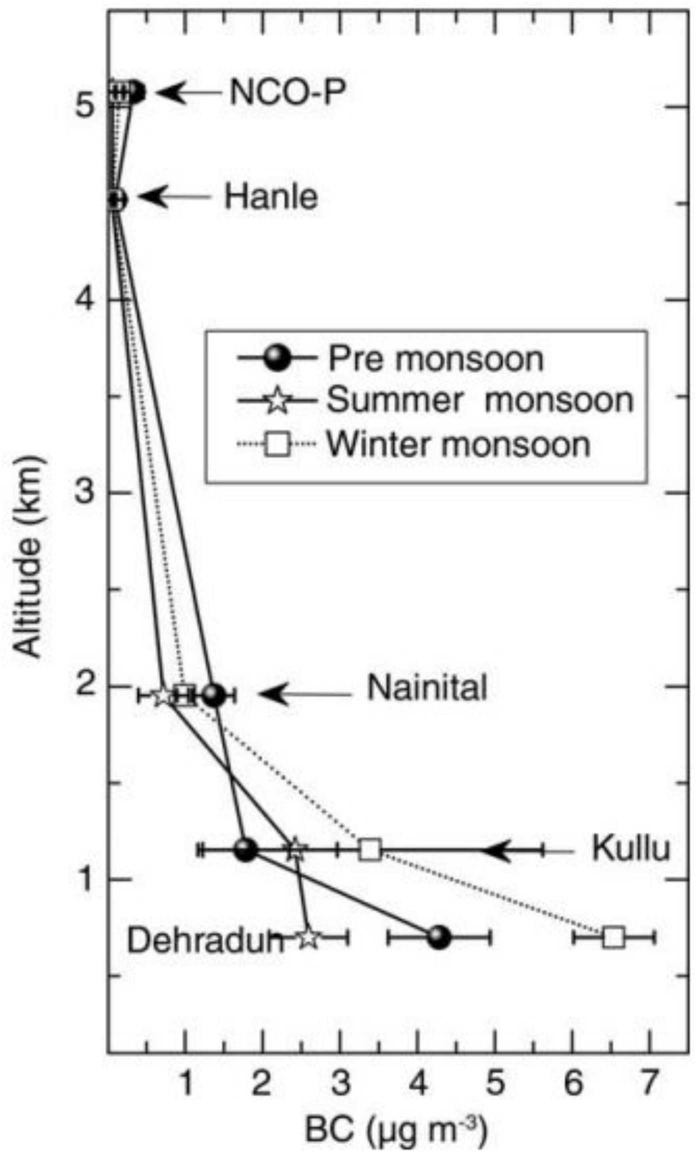


Fig. 5. Seasonal variation of atmospheric BC mass concentrations measured at Dehradun, Kullu, Nainital, Hanle and NCO-P as a function of station altitude.

dry deposition

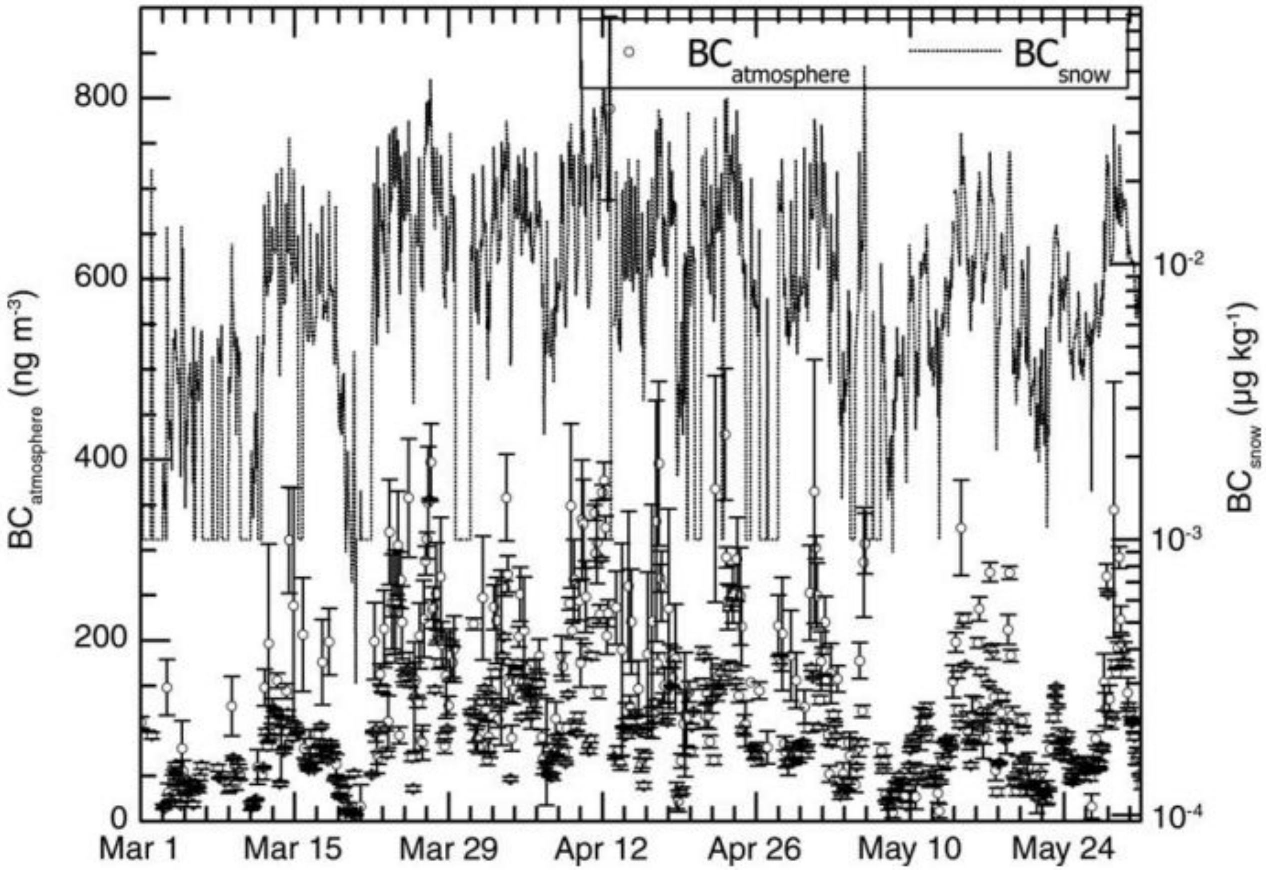


Fig. 5. Hourly mean values of BC in the atmosphere and the estimated mass concentrations of BC in the top snow layer over Hanle.

$$F_{BC}=C_{air}*V_d$$

$$C_{snow}=\frac{F_{BC}*t}{D_{snow}*\rho_{snow}}$$

The amount of BC in the snow during the pre-monsoon period was estimated as 20.8μg kg^{-1}.

C_{air}: atmospheric BC concentrations
V_d: dry deposition velocity
F_{BC}: flux of atmospheric BC
t: time
C_{snow}: BC mass concentrations in snow
D_{snow}: snow depth
ρ_{snow}: snow density

Table 1. The estimated amount BC on snow through dry deposition over Hanle and Satopanth during pre-monsoon season

Station	BC ($ng\ m^{-3}$)	Dry deposition velocity ($cm\ s^{-1}$)	Snow density ($kg\ m^{-3}$)	Snow depth (cm)	Accumulated deposition ($\mu g\ m^{-2}$)	BC on snow ($\mu g\ kg^{-1}$)
Hanle*	109	0.01	195	2	84.8	21.7
	109	0.054	195	2	457.7	117
	109	0.01	512	2	84.7	8.3
	109	0.01	512	10	84.7	1.7
Satopanth**	190	0.054	195	2	147.7	204.6
	190	0.01	512	10	797.8	2.9

*Climatological mean BC value.
**Measured during September–October 2011.
The dry deposition velocity of BC and snow density are taken from Yasunari et al. (2010), Yasunari et al. (2013).

The amount of BC on snow over Hanle due to dry deposition during the pre-monsoon season would be 1.7-117$\mu g\ kg^{-1}$.

wet deposition

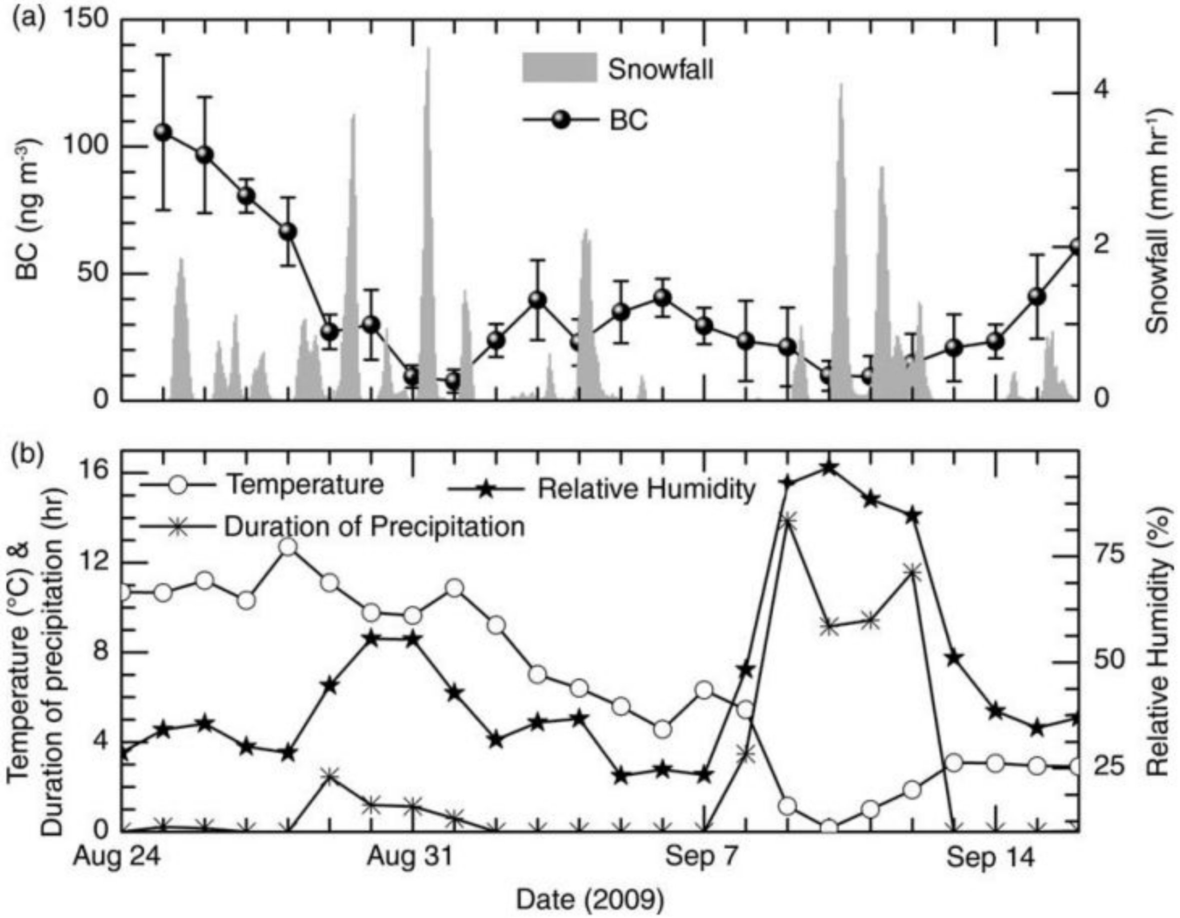


Fig. 6. Temporal variation of BC concentration and meteorological parameters during the snowfall event observed at Hanle(25 August-20 September 2009).

$$F_{BC} = \int_{0}^{z=1000\ m} \beta(z) C_{BC}(z)\, dh = \beta C_{BC} z$$

Scavenging coefficient

$$\frac{dC_{BC}}{dt} = -\beta C_{BC}$$

$$\beta(d_p) = \int_{D\min}^{D\max} A(V_t - v_t) E(D, d_p) N(D)\, dD$$

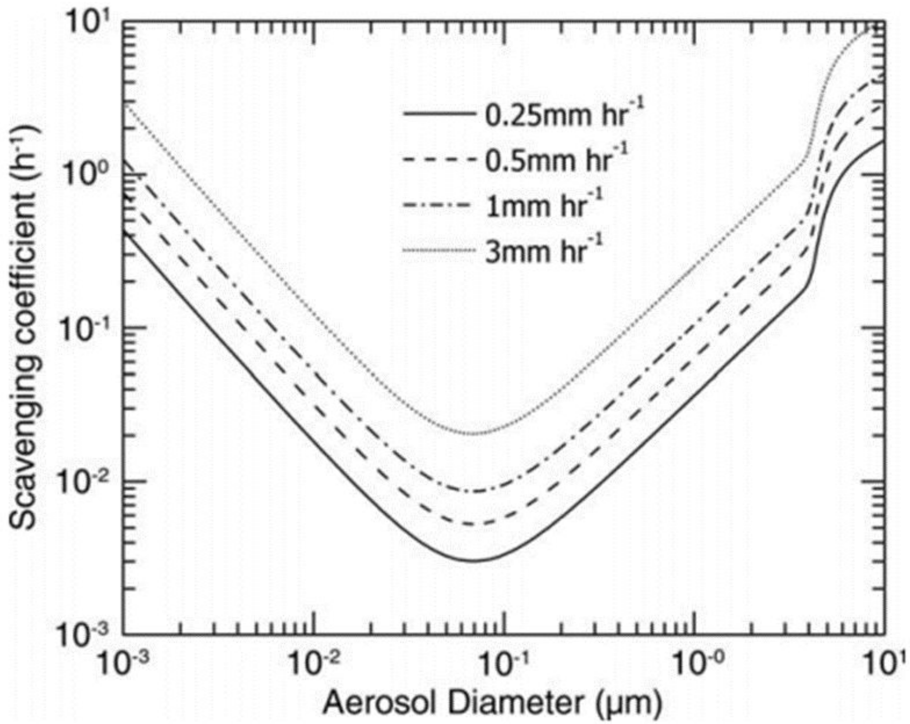
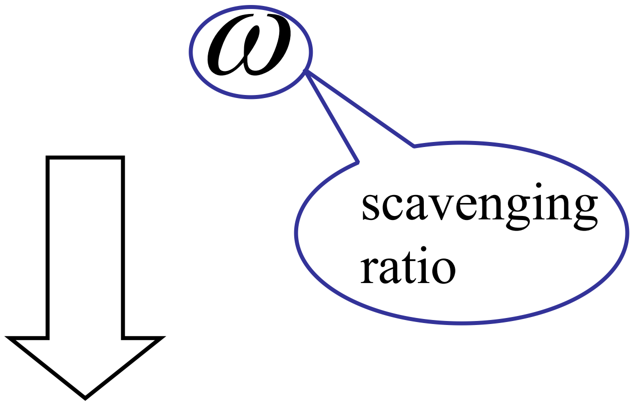


Fig. 7. Size-resolved scavenging coefficients for different snow-fall rates estimated using Feng (2009).

- The amount of BC scavenged during the first snowfall(25-31 August) had beed estimated as **~6μg kg^{-1}** for a precipitation column of 1000m and accumulated snow depth of ~9cm.

- The average concentration of BC on snow during pre-monsoon season via wet scavenging was estimated to be **29μg kg^{-1}** using the modelled mean scavenging efficiency of 0.008h^{-1} for an accumulated snow depth of 27 cm and an ambient BC mass concentration of 109ng m^{-3} in the air.

$$C_{air} = \frac{\rho_{air} C_{snow}}{\omega}$$



The mean BC concentration in the snow for the pre-monsoon season was estimated as **19.5μg kg^{-1}**.

Direct radiative forcing

Table 2. Optical properties of aerosols over measurement sites during pre-monsoon and winter season.

Station	Season	AOD	SSA	BC (ng m^{-3})
Hanle	Pre-monsoon	0.063 ± 0.002[a]	0.97[a]	109 ± 27[b]
	Winter	0.040 ± 0.001[a]	0.96[a]	67 ± 28[b]
NCO-P	Pre-monsoon	0.050 ± 0.004[c]	0.844[d]	320 ± 469[e]
	Winter	0.045 ± 0.004[c]	0.869[d]	125 ± 147[e]
Nainital	Pre-monsoon	0.21 ± 0.08[b]	NA	1340 ± 50[b]
	Winter	0.09 ± 0.09[b]	0.9[f]	1100 ± 60[b]
Kullu	Pre-monsoon	0.41 ± 0.14[b]	NA	6922[b]
	Winter	0.27 ± 0.15[b]	NA	3730[b]
Dehradun	Pre-monsoon	0.25 ± 0.10[b]	NA	6646 ± 492[b]
	Winter	0.24 ± 0.07[b]	NA	4282 ± 606[b]

$$DRF = \frac{\int_0^{24} (F_{no-aero} - F_{aero})\,dh}{\int_0^{24} dh}$$

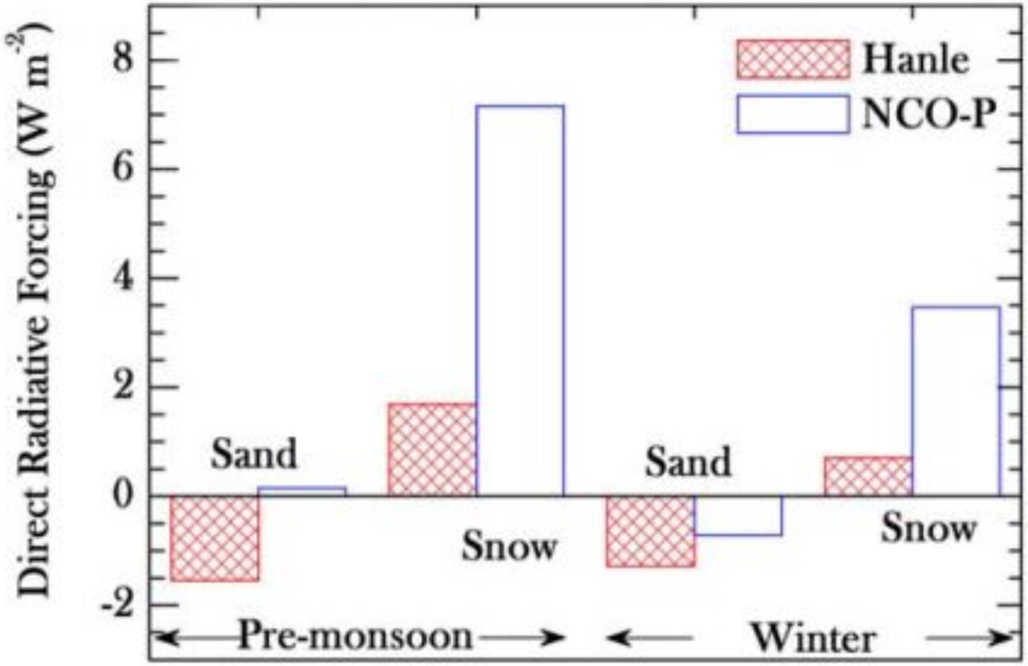


Fig. 8. Direct radiative forcing due to composite aerosols on snow and sandy surfaces over Hanle and NCO-P during pre-monsoon season and winter season.

Snow albedo forcing

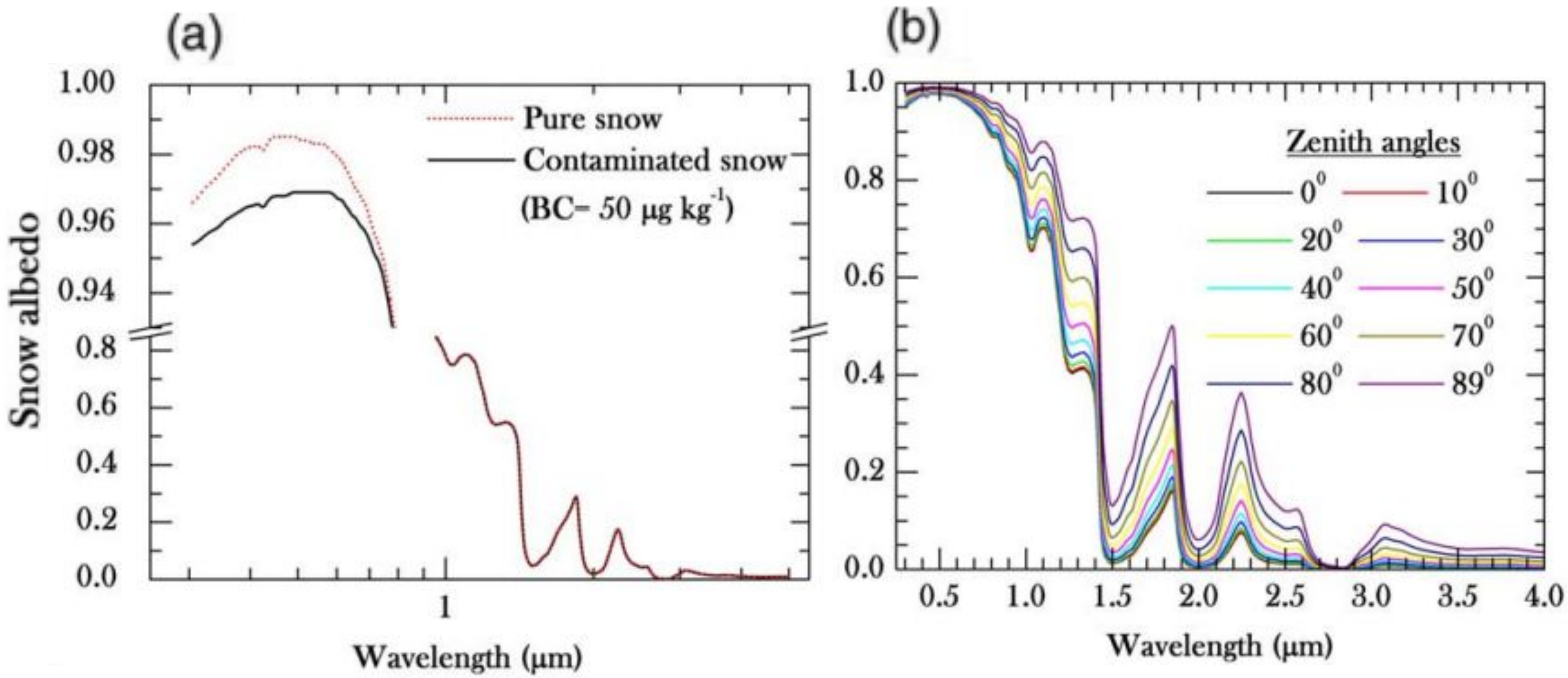


Fig. 9. (a) Spectral variation of snow albedo for pure and contaminated snow (BC loading of 50μg kg^{-1}) simulated using SNICAR model**;** (b) spectral variations of pure snow albedo for different zenith angle conditions.

- For the range of 10-200μg kg^{-1} of BC in snow, the diurnally averaged forcing due to snow darkening had been found to vary from 0.87 to 10.2W m^{-2} for fresh snow and from 2.6 to 28.1W m^{-2} for the aged snow.

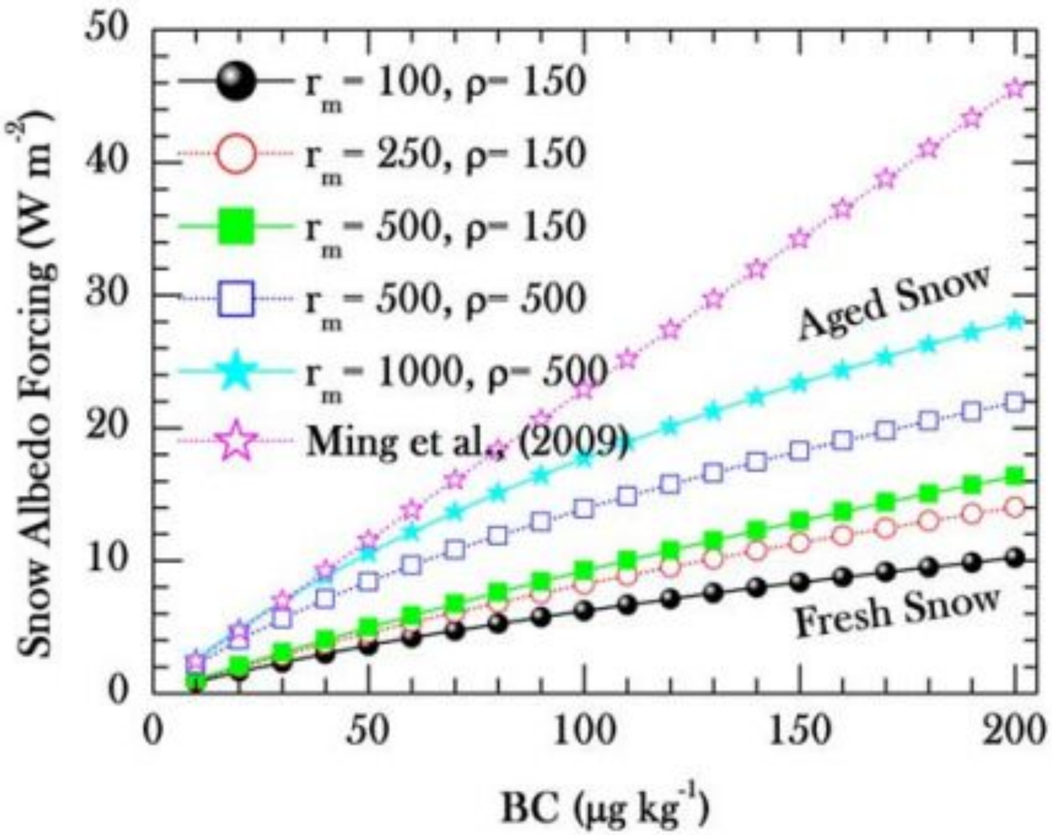


Fig. 10. variation of snow-albedo radiative forcing.

Conclusions

- The measurements of BC concentrations from Hanle and NCO-P showed strong seasonal variations with pre-monsoon high and summer minimum.

- The estimated amount of BC in the snow due to dry deposition at Hanle varied from 1.7-117μg kg^{-1} during pre-monsoon season and the amount of BC due to wet deposition was estimated to be 29μg kg^{-1}.

- The estimated DRF over a snow surface was ＋1.69W m^{-2} compared to －1.54W m^{-2} over a sandy surface. The snow-albedo forcing estimated for the range of BC in snow (10-200μg kg^{-1})varied from 0.87 to 10.2W m^{-2} for fresh snow and from 2.6 to 28.1W m^{-2} for aged snow.

Thank you