Ice core derived changes in Black Carbon Concentrations

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The presence of black carbon (BC) in snow and ice can significantly reduce the albedo and affect snow and glacier melt. The 2007 Intergovernmental Panel on Climate Change (IPCC) report listed the radiative forcing (RF) induced by “black carbon on snow” as one of the important anthropogenic forcings affecting climate change between 1750 and 2005. BC is estimated to have 55% of the radiative forcing effect of CO_2, yet BC remains one of the largest sources of uncertainty in analyses of climate change. Therefore, quantifying and reducing the albedo and RF errors due to this effect are a priority for improving simulations of climate change and the hydrological cycle using climate models. In addition to black carbon, snow albedo reductions are also due to snow metamorphosis (change of grain size, liquid water content), deposition of mineral dust, and grow of algae. The largest climate forcing from BC in snow and ice is assumed to occur over the Himalayas and Tibetan Plateau (Flanner et al., 2007).
We present here a high-resolution BC record from a Mt. Everest ice core spanning the period AD 1860-2000 (Kaspari et al., 2011) (Fig. 1). The ice core was analyzed for BC using a Single Particle Soot Photometer (SP2, Droplet Measurement Technologies). BC concentrations show a strong seasonality with a maximum in winter-spring, when atmospheric circulation is dominated by the westerlies and low concentrations during the summer monsoon season with prevailing southerly winds. BC concentrations from 1975-2000 are approximately threefold relative to 1860-1975. Air mass back trajectory analyses and the comparison with historical BC emission data indicate that BC from anthropogenic sources in South Asia and Middle East is being transported during recent decades to high elevation sites of the Himalaya. However, whereas BC emissions, mainly from fossil combustion, domestic heating and cooking, and biomass burning are still rising in these regions, BC concentrations do not increase after 1990 in the Mt. Everest ice core. We assume that also long-range transported BC is influencing the ice core site, potentially from Eastern Europe and former USSR countries, where BC emissions have decreased in recent decades.

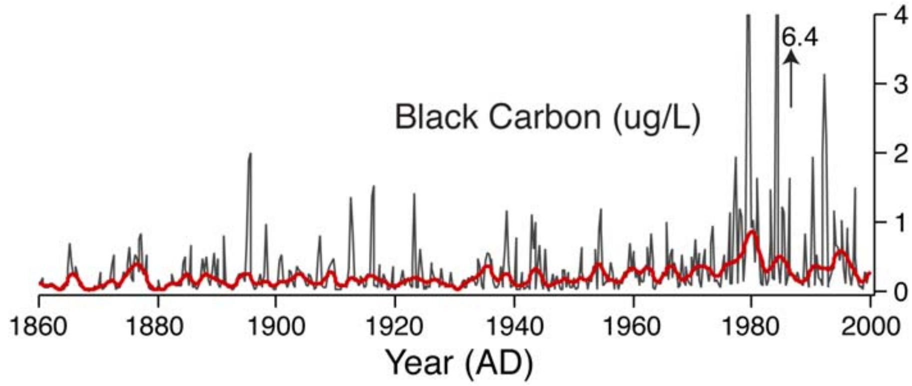

Fig. 1: Black Carbon concentrations in the Mt. Everest ice core covering the period 1860-2000 (Kaspari et al., 2011). Shown are seasonal averages (black) together with a robust spline (red).

An estimation of the surface BC radiative forcing (RF) using the Snow, Ice, and Aerosol Radiative (SNICAR) model (Flanner et al., 2007) suggests that concurrent with the rise in BC concentrations, the spring RF has increased threefold. In contrast, the contribution of mineral dust to the RF did not change over the same time period. Thus, a reduction in BC emissions might be one effective mean to reduce the effect of absorbing impurities on snow and ice albedo and thus, melting of Himalayan glaciers.

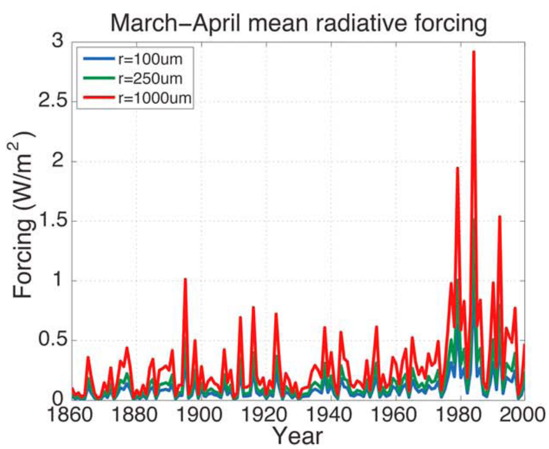

Fig. 2: March-April surface BC radiative forcing (W/m^2) in the presence of average dust mass concentration (466 ppb) as determined using the SNICAR model for snow effective radii (r) = 150 (blue); 250 (green) and 1000 μm (red).

References:

M. G. Flanner et al., Present-day climate forcing and response from black carbon in snow, *J. Geophys. Res.* **112**, D11202, doi:10.1029/2006JD008003, 2007.
S. D. Kaspari et al., Recent increase in black carbon concentrations from a Mt. Everest ice core spanning 1860-2000 AD, *Geophys. Res. Lett.* **38**, L04703, doi:10.1029/2010GL046096, 2011.

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Wir schaffen Wissen – heute für morgen

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Black Carbon and climate

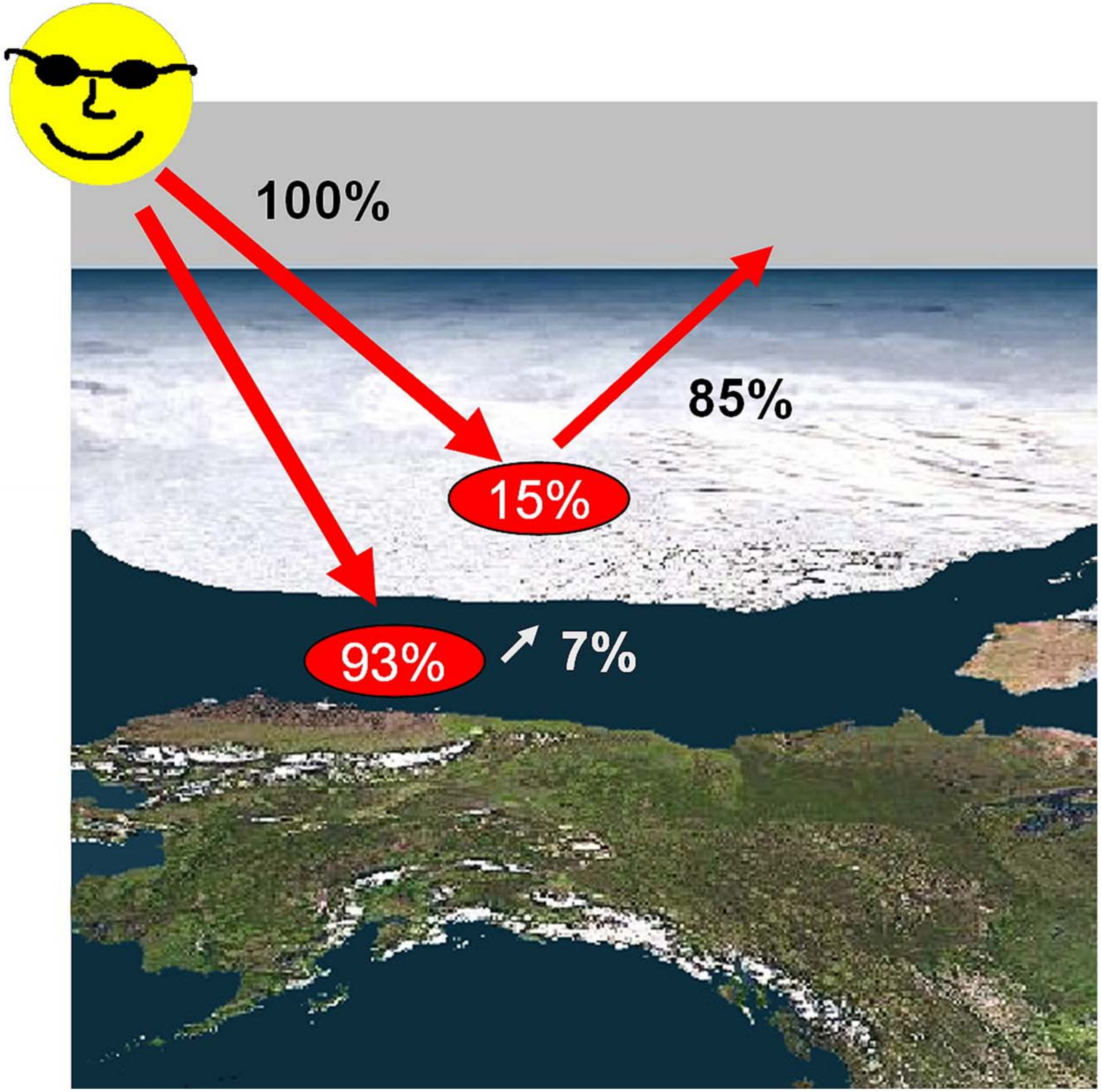
Black Carbon can influence climate by:

• Warming the atmosphere: direct, indirect

• Surface warming: darkening the surface of snow and ice, reducing albedo, leading to accelerated melt

black carbon on snow

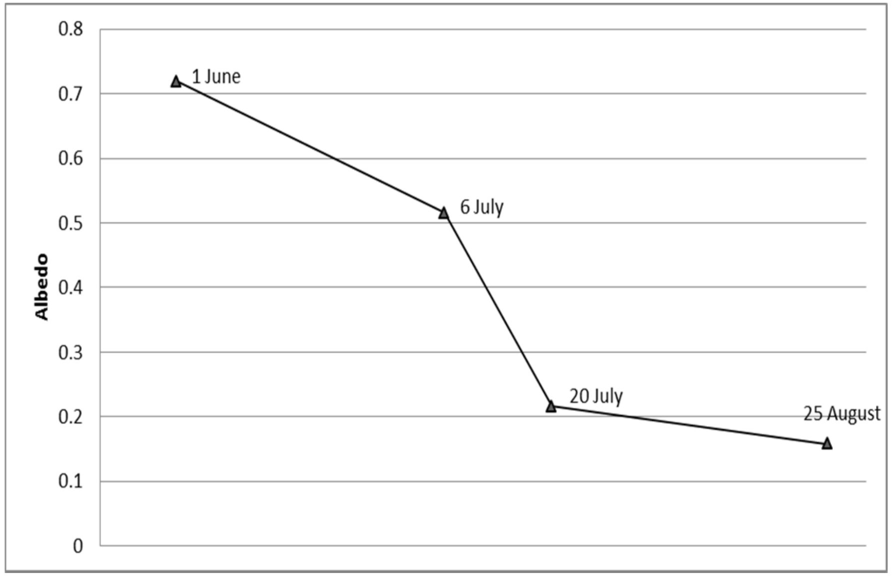
Effect of snow on albedo



http://www.arctic.noaa.gov/essay_serreze.html

Broad band albedo change on Plaine Morte glacier, 2010

1 June: 260 cm snow depth



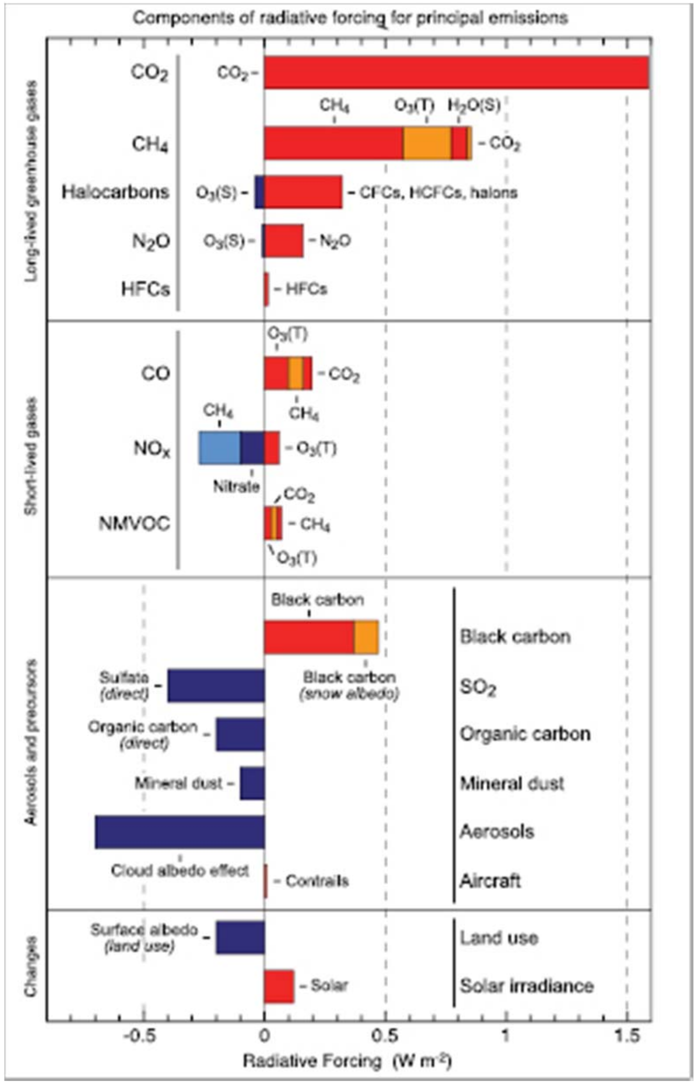
6 July: 110 cm snow depth

20 July, 25 August: mainly snow-free

Radiative forcing of Black Carbon

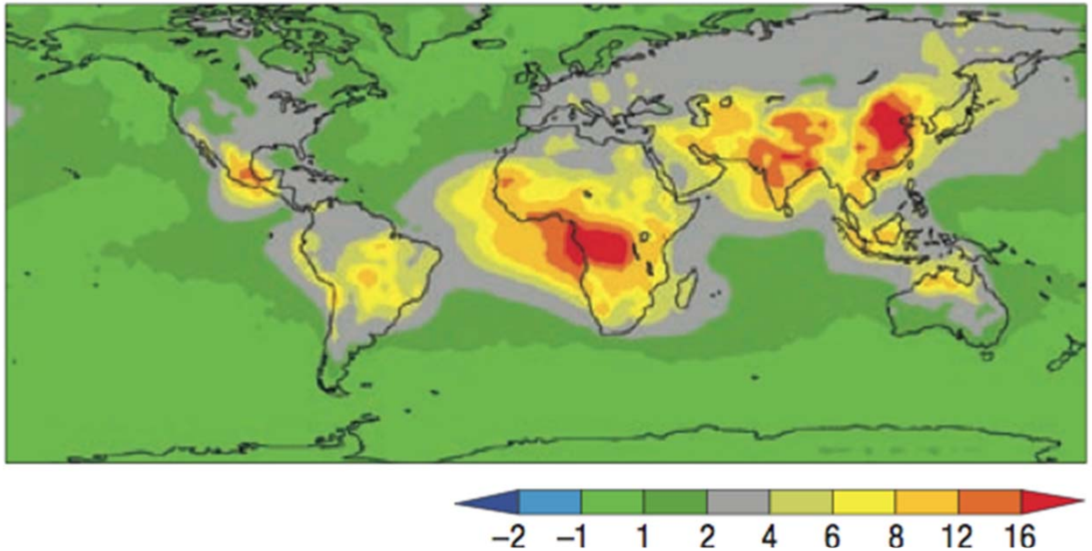
Effect of BC on snow albedo may be responsible for up to a quarter of the observed warming
(Hansen and Nazarenko, 2004)

Quantification of this effect is one of the largest uncertainties in analyses of climate change during the Industrial Era.



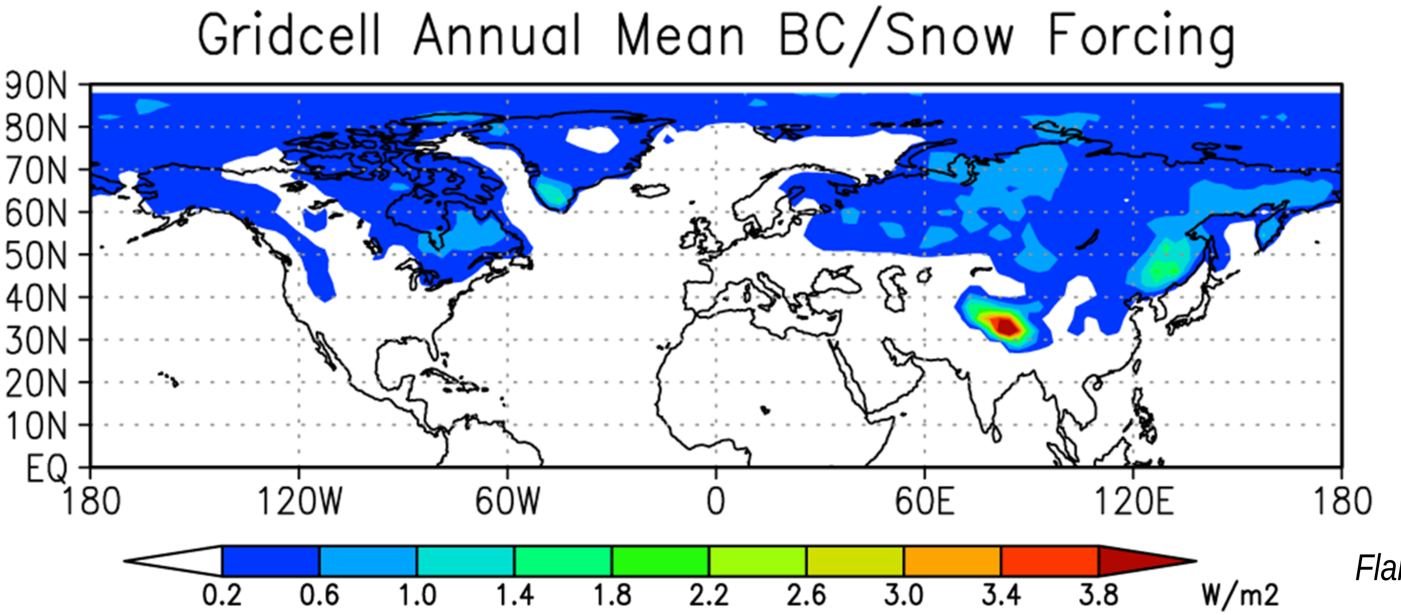
IPCC, 2007

Black Carbon climate forcing



Black Carbon
Atmospheric heating (W/m²)

Ramanathan and Carmichael, 2008



Surface forcing
from BC in snow

Flanner et al., 2007

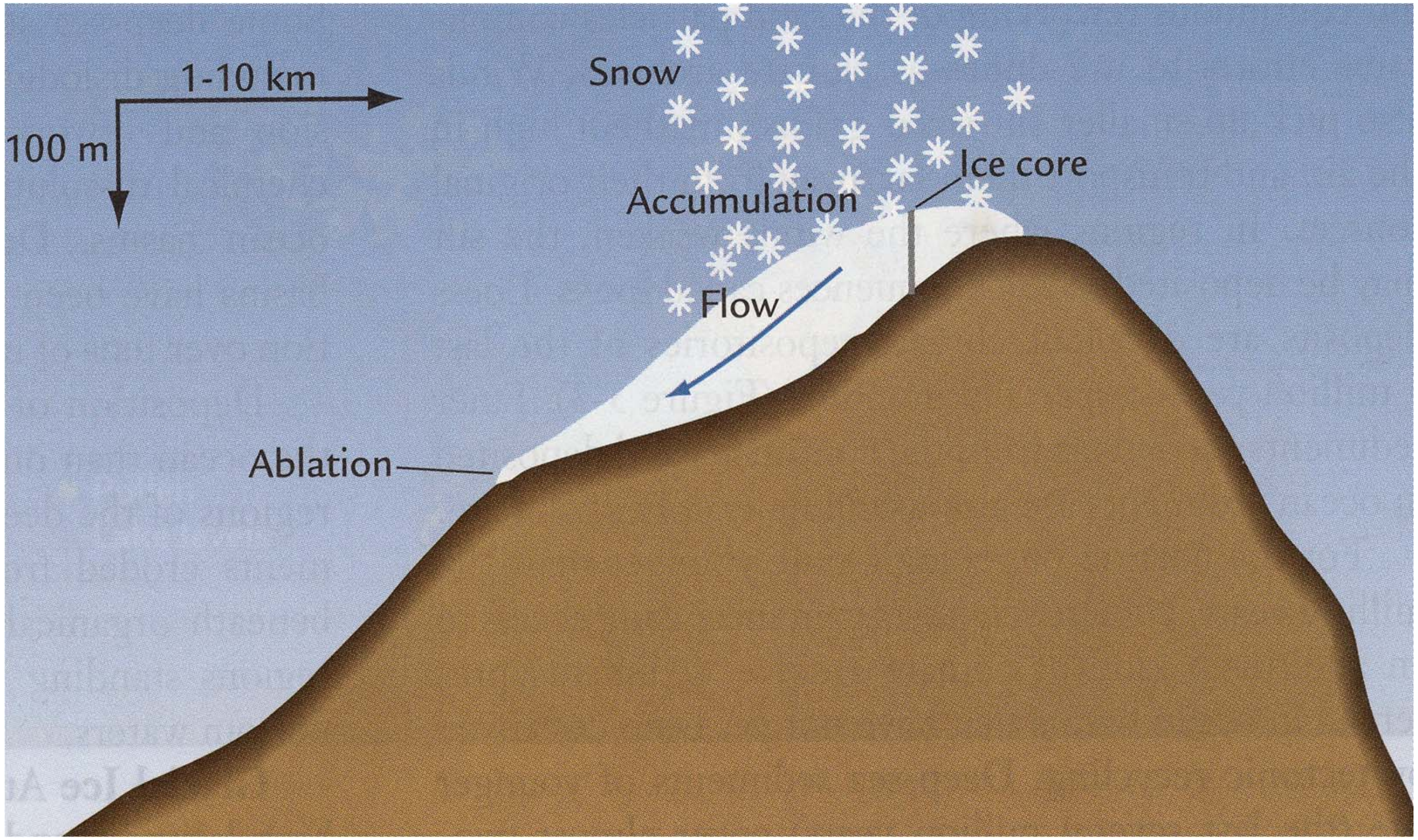
Motivation for this study

View of Mt. Everest region from the International Space Station

Himalayas: strongest forcing from BC in snow

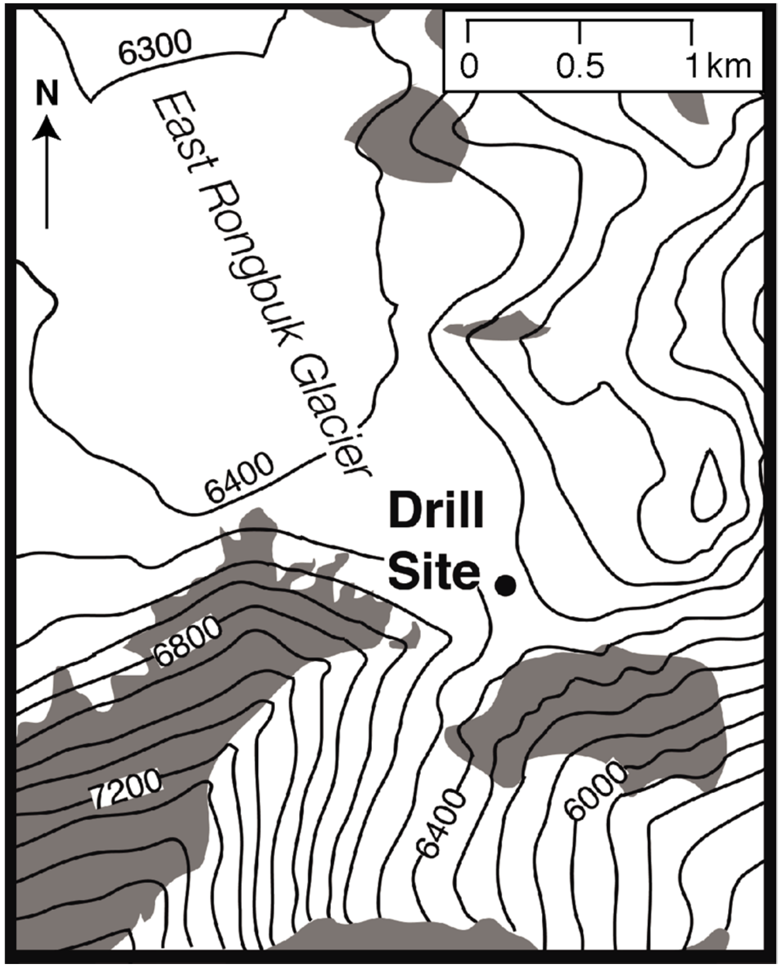
How have Black Carbon concentrations in the atmosphere varied in the past?

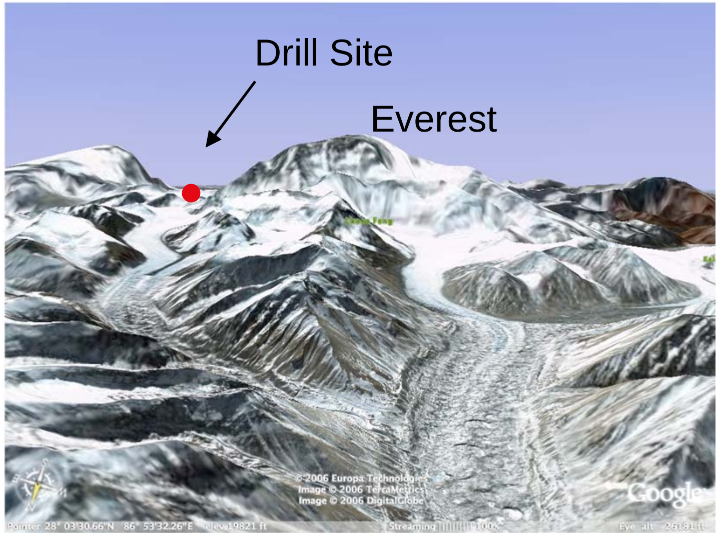
Ice cores as archives of past pollution

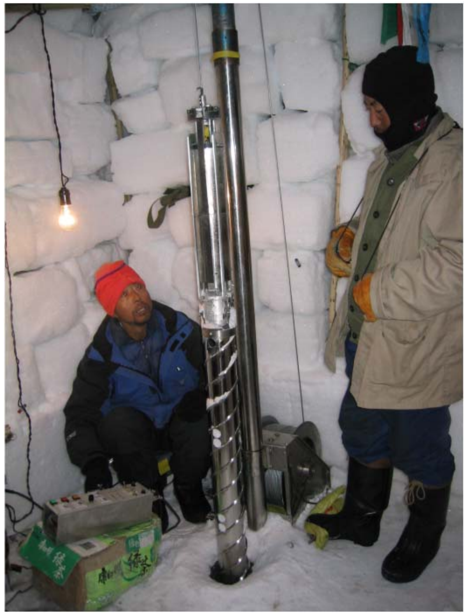


Source: W.F. Ruddiman, Earth‘s Climate

Study site: East Rongbuk glacier, 6500 m

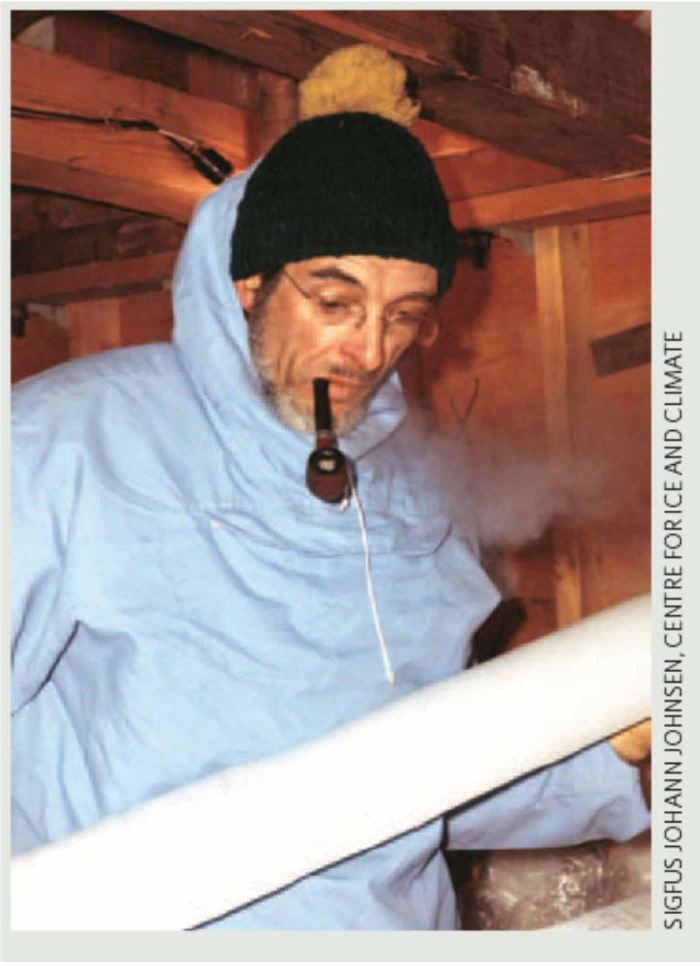






2002: 108 m ice core drilled to bedrock

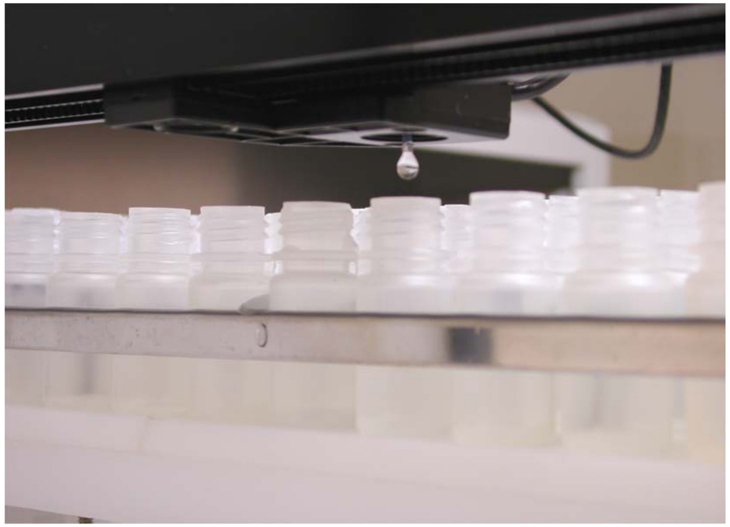
Sampling methods

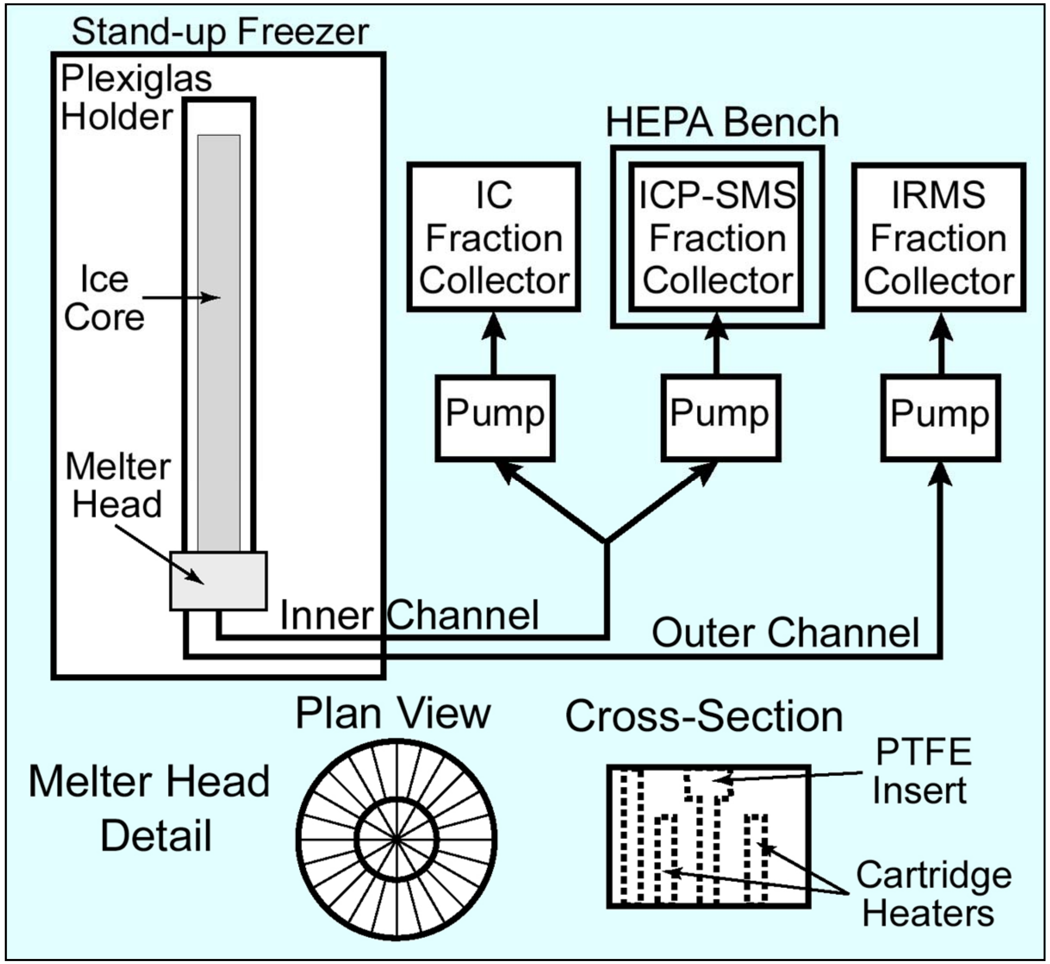


Willi Dansgaard

Nat. Geosc. 4, 2011

Sampling methods: continuos melting system



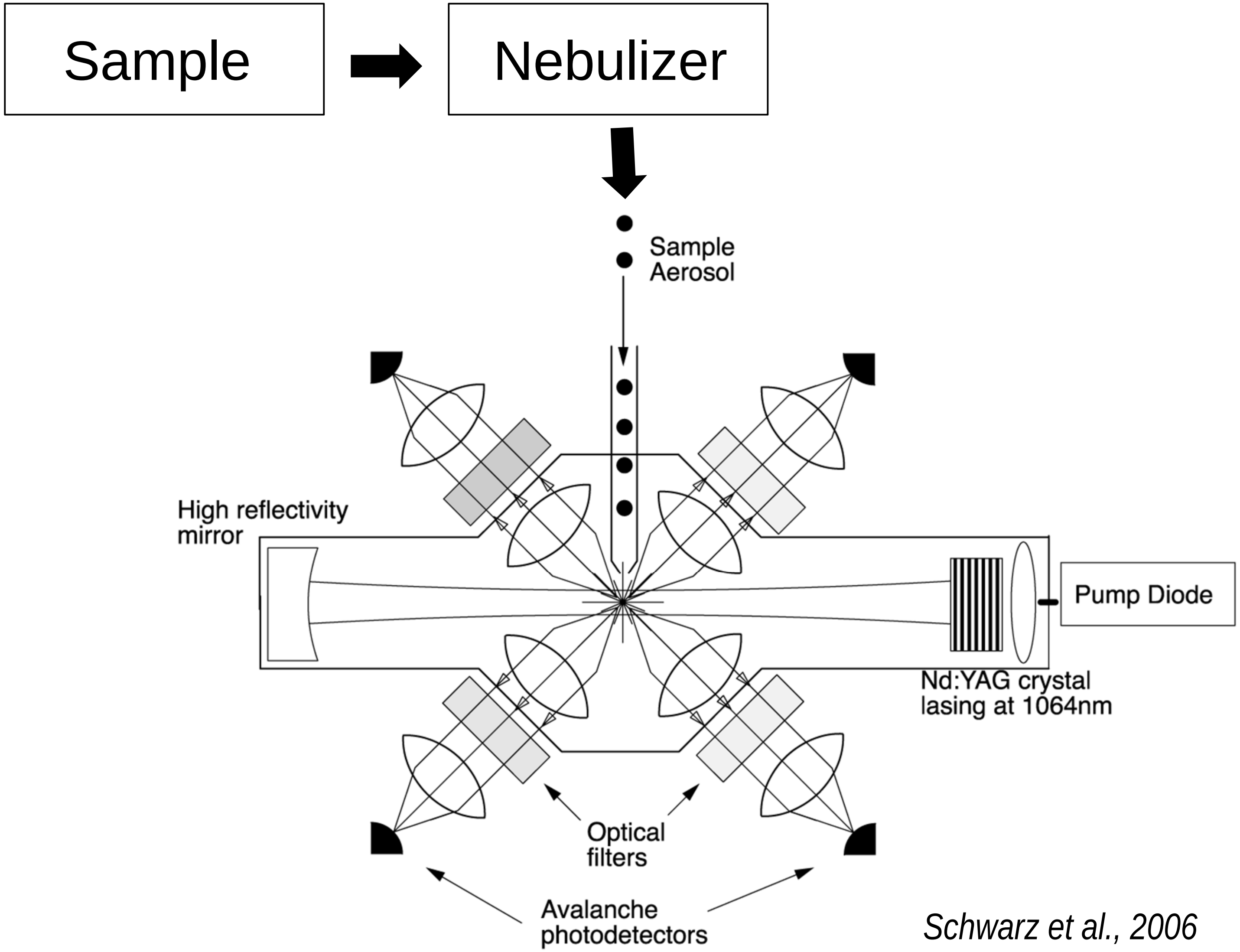


Osterberg et al., 2006

Upper 50 m: period 1850-2002

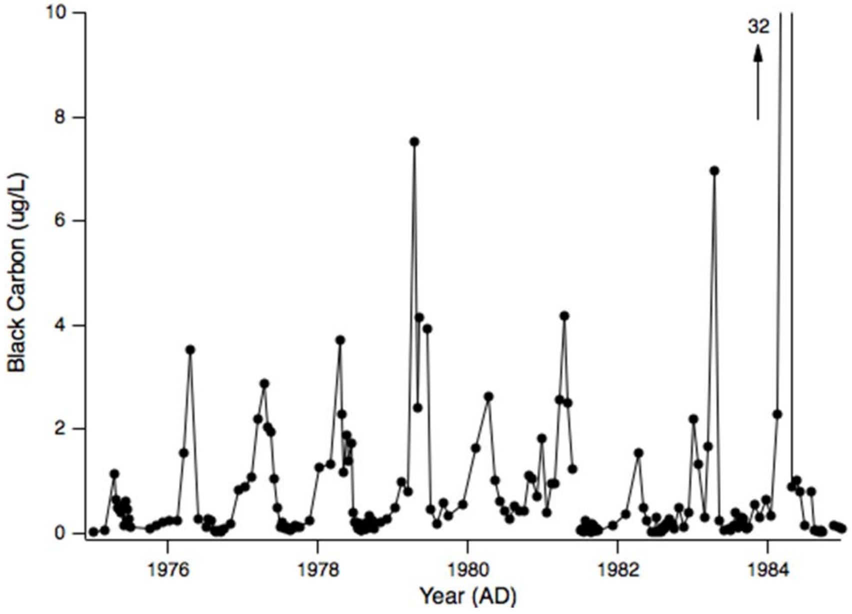
Measurement of BC in snow and ice

SP2: Laser induced incandescence



Schwarz et al., 2006

BC record Mt. Everest ice core



Kaspari et al., 2011

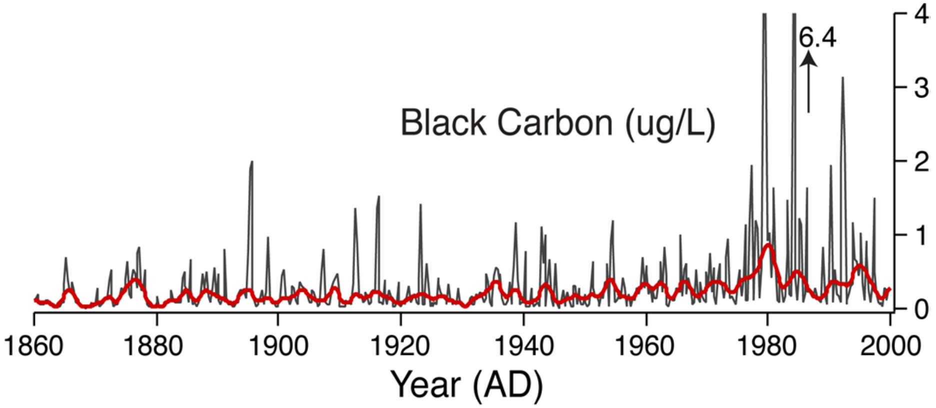
Strong seasonal cycle:

High concentrations: winter/spring (westerlies)

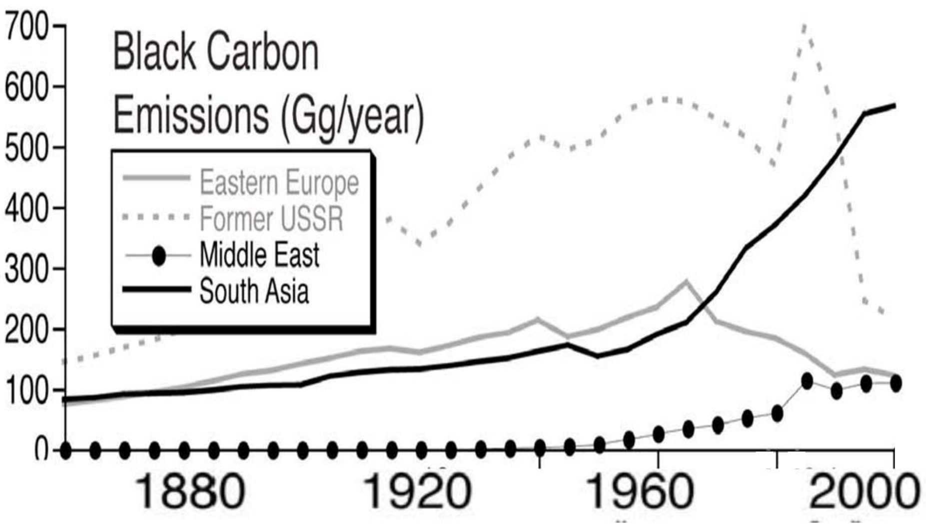
Low concentrations: summer monsoon (southerly winds)

BC record Mt. Everest ice core

BC record 1860-2000



Kaspari et al., 2011



3-fold increase in mean: 0.2 → 0.7 μg/l
(between 1860-1975 and 1975-2000)

Anthropogenic:
fossil fuel (coal, petrol, diesel used in power generation, transportation, domestic uses, steel manufacturing)
Biogenic (cattle manure, fuel wood, forest fires)

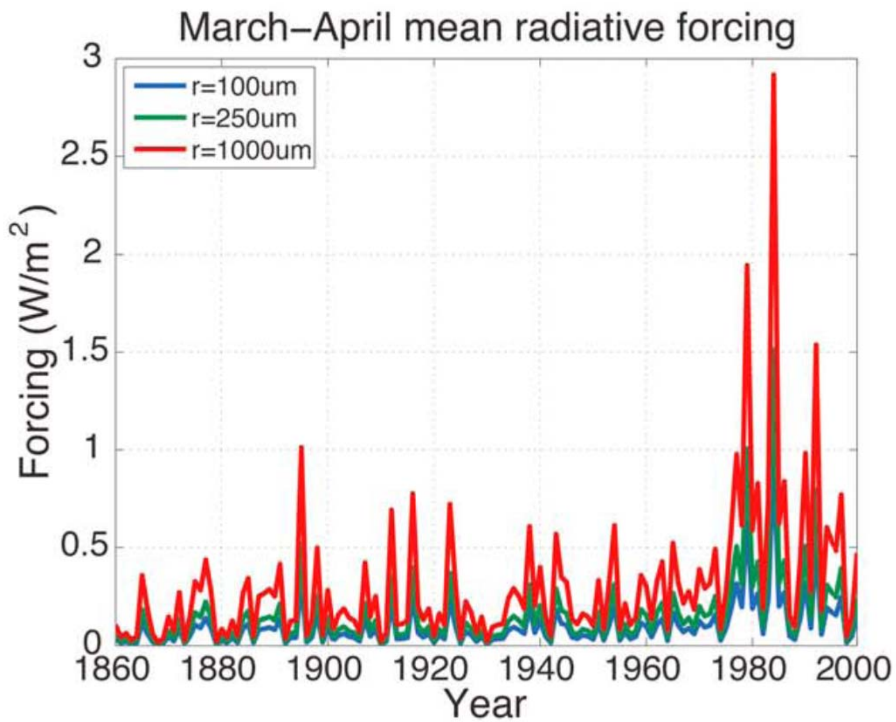
Source regions

South Asia, Middle East, (Eastern Europe)

Not from Western Europe, China

Estimation of BC radiative forcing

Snow, Ice, and Aerosol Radiative (SNICAR) model (Flanner et al, 2007):



Radiative forcing spring: periods 1860-1975 and 1975-2000, conservative estimation

3-fold increase $0.11 \rightarrow 0.36$ W/m^2 (r=250μm) (dust = 466 ppb)

$0.22 \rightarrow 0.69$ W/m^2 (r=1000μm)

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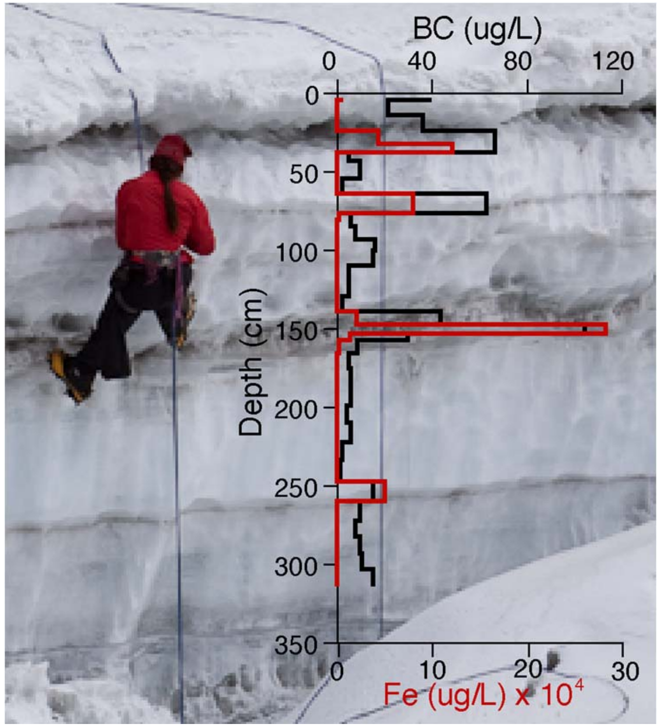
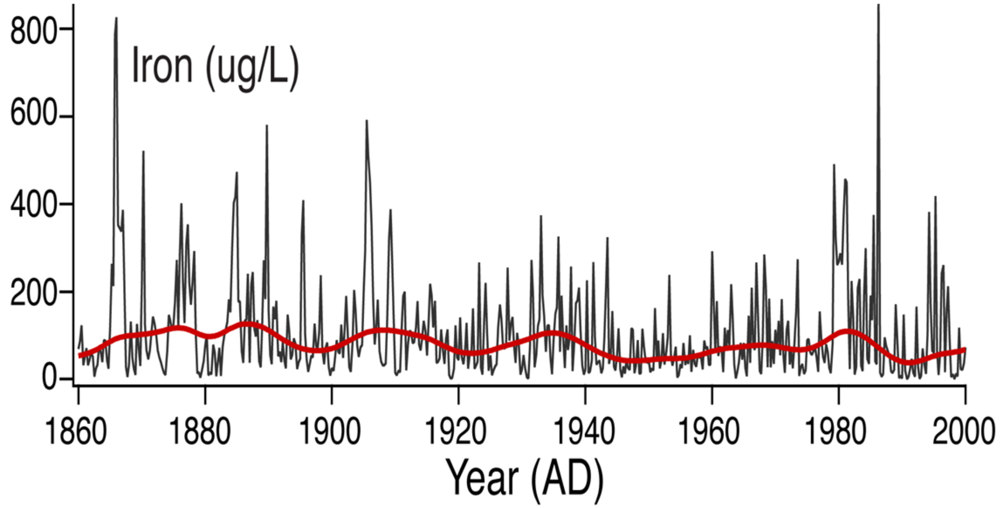
Conclusion

Reduction BC → one effective mean to reduce effect of absorbing impurities on snow and ice albedo (melting of Himalayan glaciers)

Changes in BC versus changes in dust



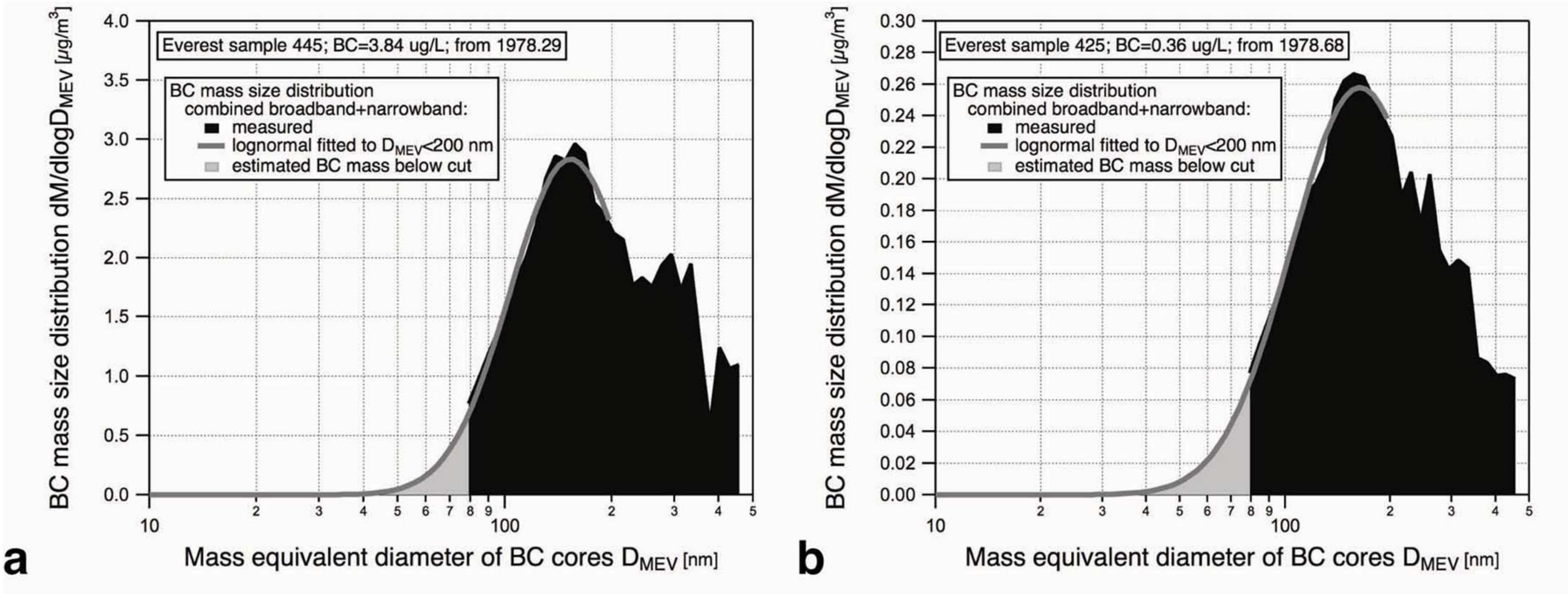
Mt. Everest:



S. Kaspari:
Crevasse profiles on Mera glacier (5400m):
BC and dust enriched at the surface during spring melt

No temporal trend in dust concentrations

Mt. Everest Ice Core Example Mass Size Distributions



High

Low