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Impacts of Black Carbon (BC) Pollution on Himalayan Glaciers

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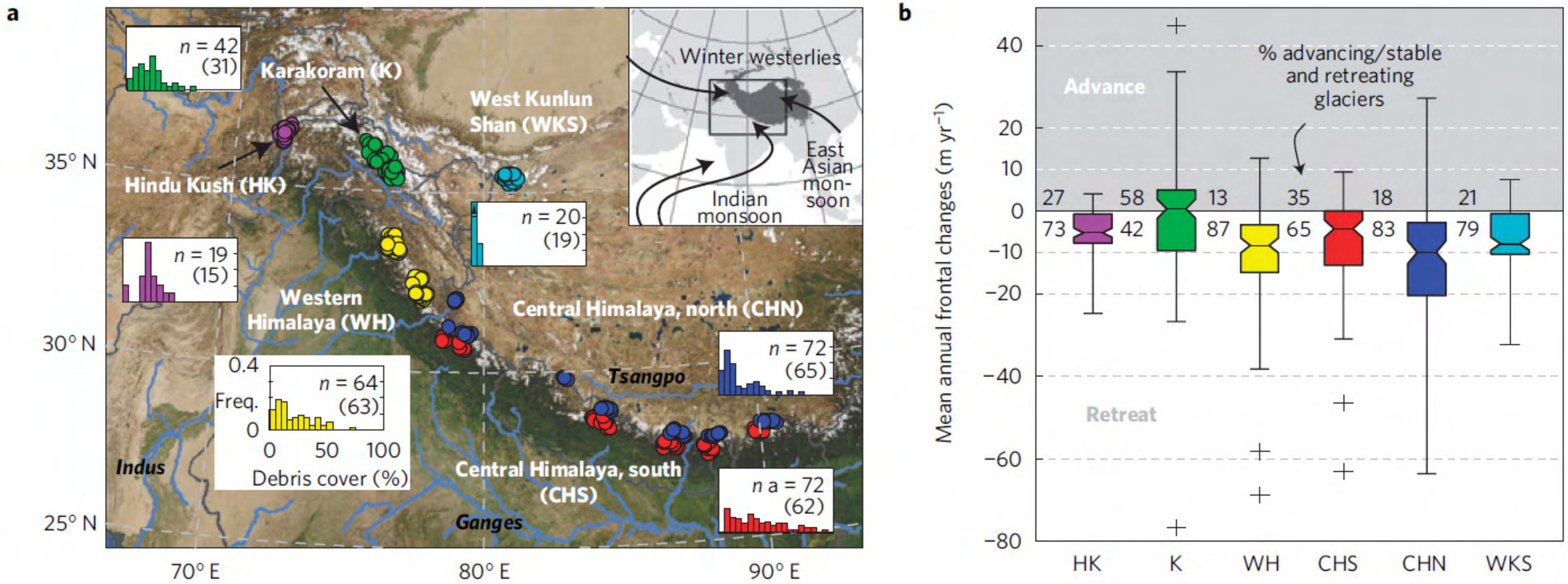
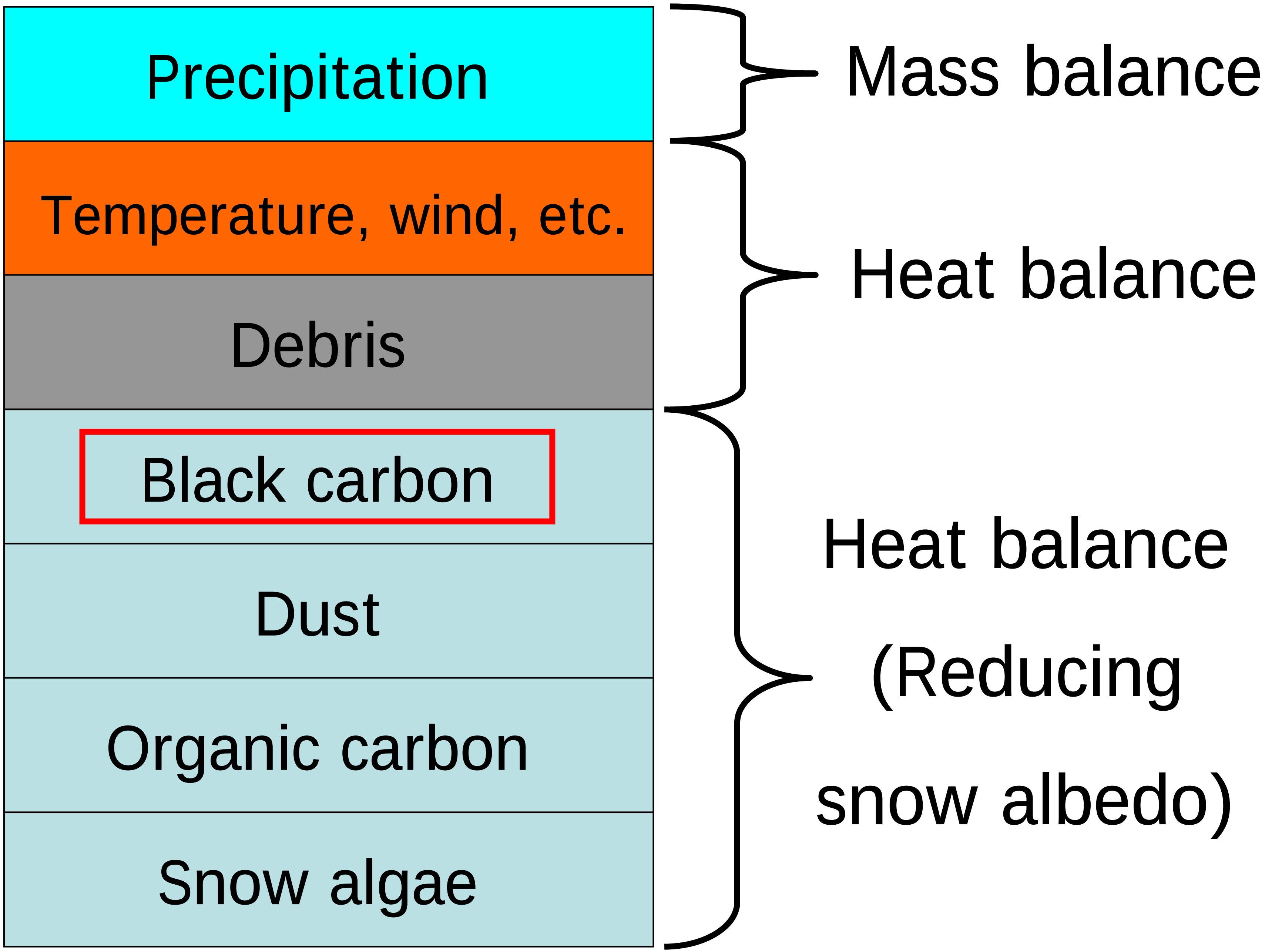
Recently glaciers in the High Asia are mostly retreating, but some are still advancing/stable.

Time	Glaciers	Retreating glaciers(%)	Advancing glaciers(%)
1950—1970	116	53.44	30.17
1970—1980	224	44.2	26.3
1980—1990	612	90	10
1990 to now	612	95	5



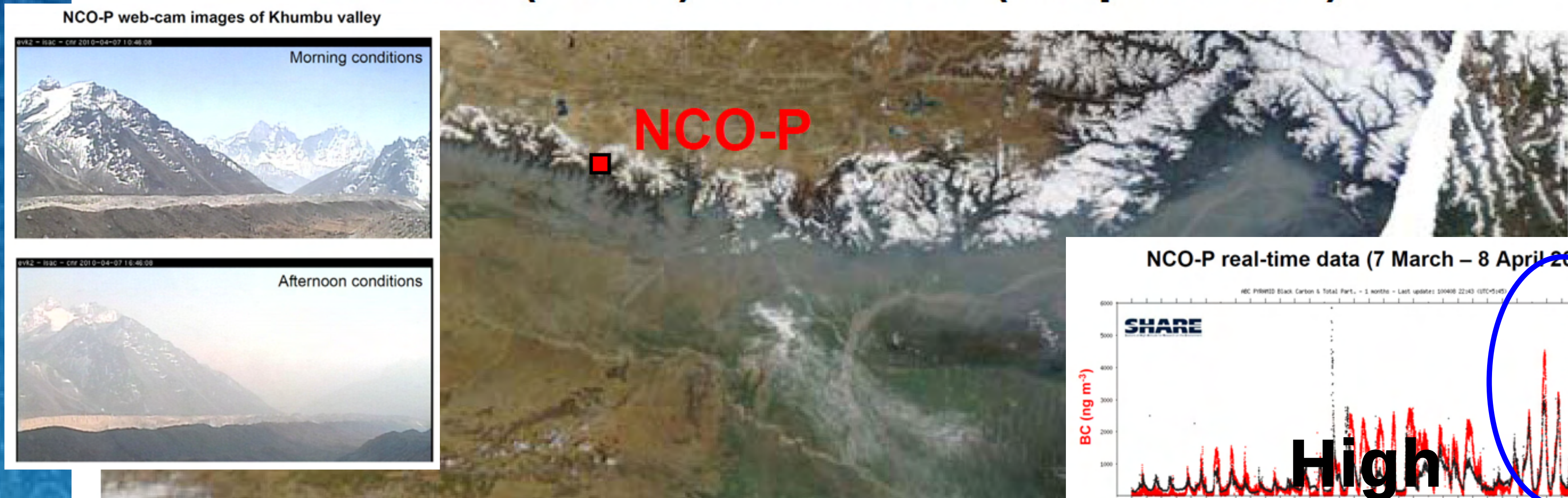
(Zhang et al., 1981; Ren et al., 1988; Yao et al., 1991; Yao et al., 2004; Scherler et al., 2011)

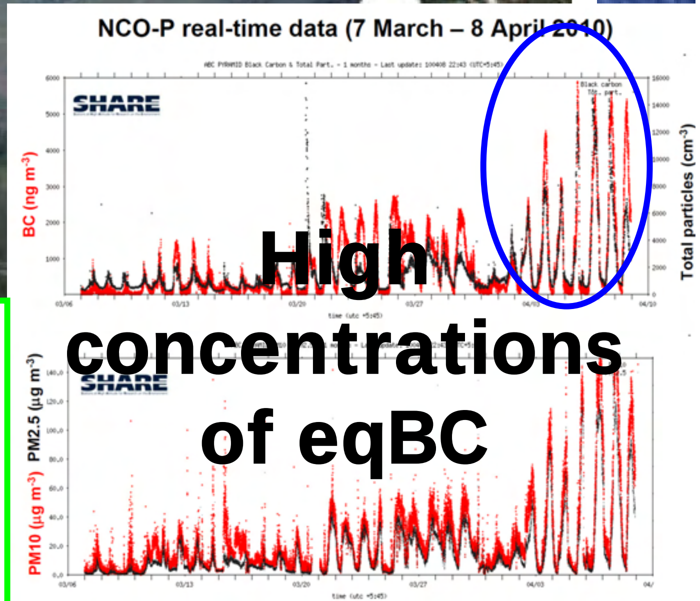
Important factors to determine glacier retreat



High BC pollution from Atmospheric Brown Cloud can be vented by Himalayan valley (e.g. Khumbu) up to Himalayan glaciers

MODIS (Terra) true-color (8 April 2010)



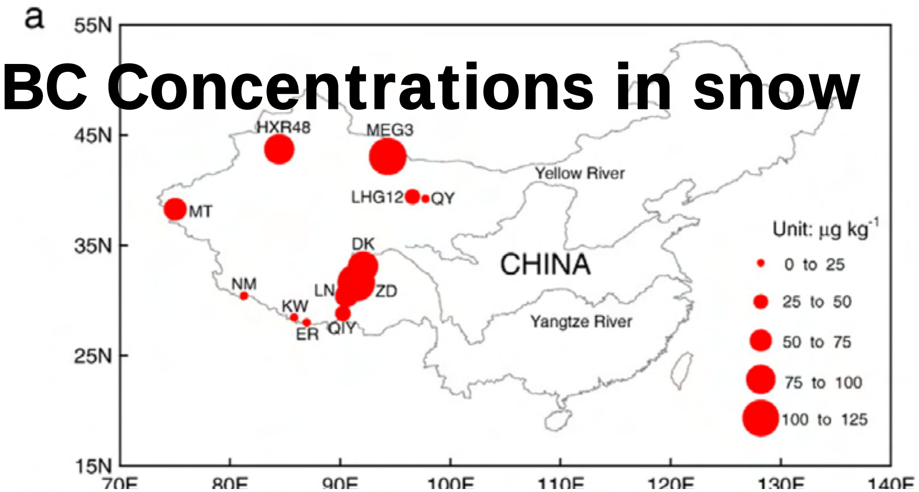


Meteorological parameters, Optical Particle Counter (OPC; 0.25-32 µm), Scanning Mobility Particle Sizer (SMPS; 10-670 nm), and **equivalent Black Carbon concentration (MAAP)** data in 2006 at NCO-P site were observed (Bonasoni et al., 2008; 2010) and used in this study. (**Called NCO-P data**)

Provided by NCO-P members

Very limited BC observations in snow are available to assess the snow albedo reductions over the Himalayas.

BC Concentrations in snow



Ming et al., ACP, 2008

Xu et al., Ann. Glaciol., 2006; Ming et al., Atmos. Res., 2008

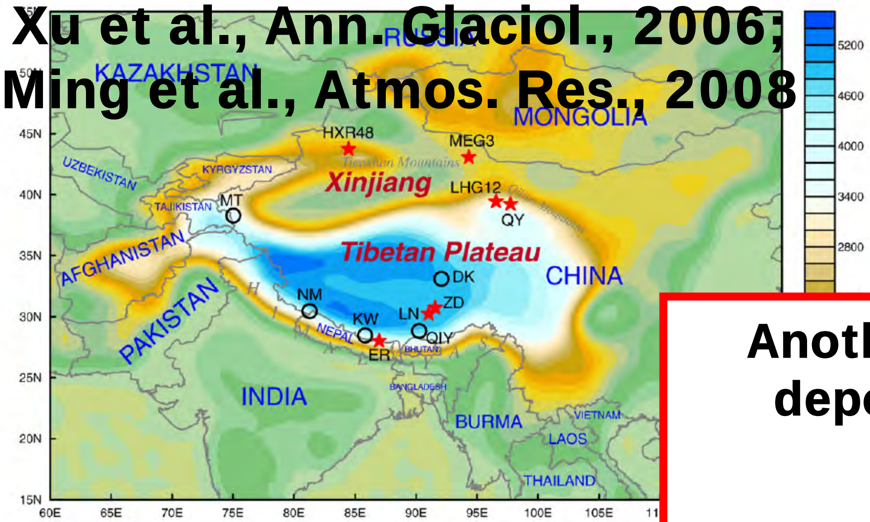
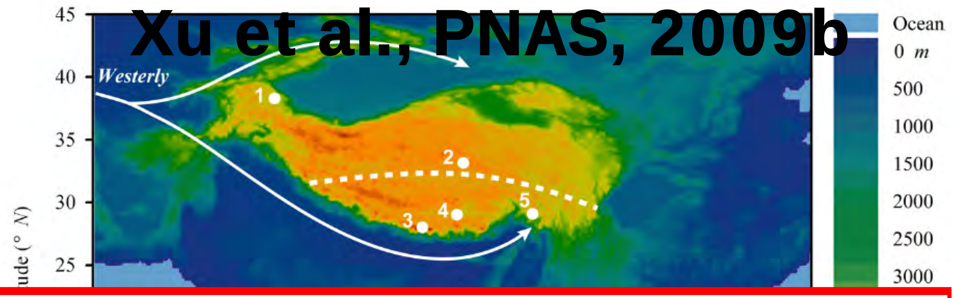


Fig. 1. The topography map surrounding the TP and the distribution of sampling glaciers. Red stars were the sampling were the sampling sites in Xu et al. (2006).

BC (µg kg⁻¹)

Xu et al., PNAS, 2009b



Another method is necessary to estimate BC deposition onto snow over the Himalayas:

We tried to estimate it from

atmospheric observations at NCO-P site.

BC deposition estimate with dry deposition velocity (DDV)

Nho-Kim et al., 2004

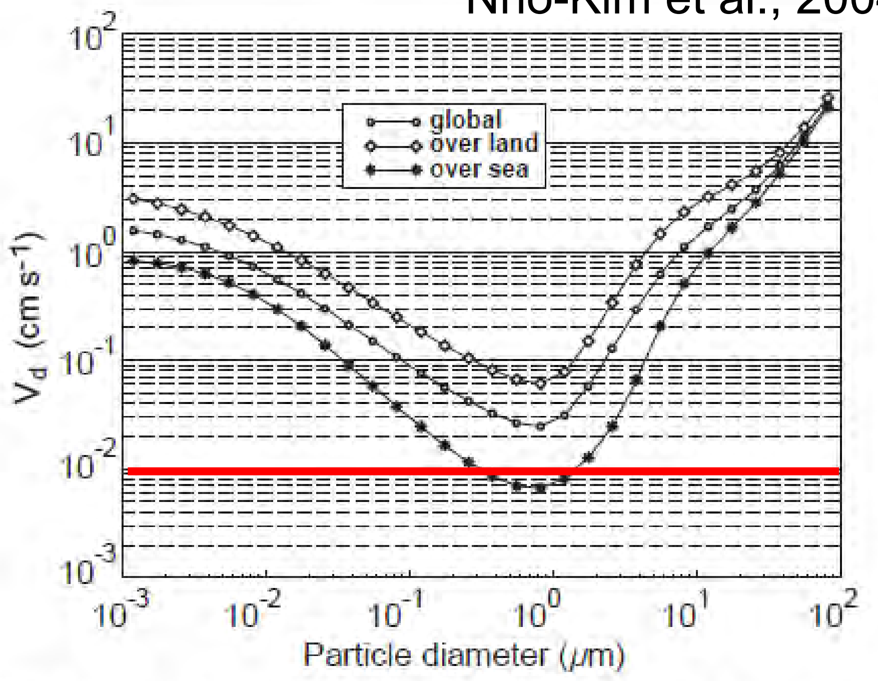


Fig. 1. Annual mean deposition velocities by particle size and surface type (particle density 1000 kg m^{-3}).

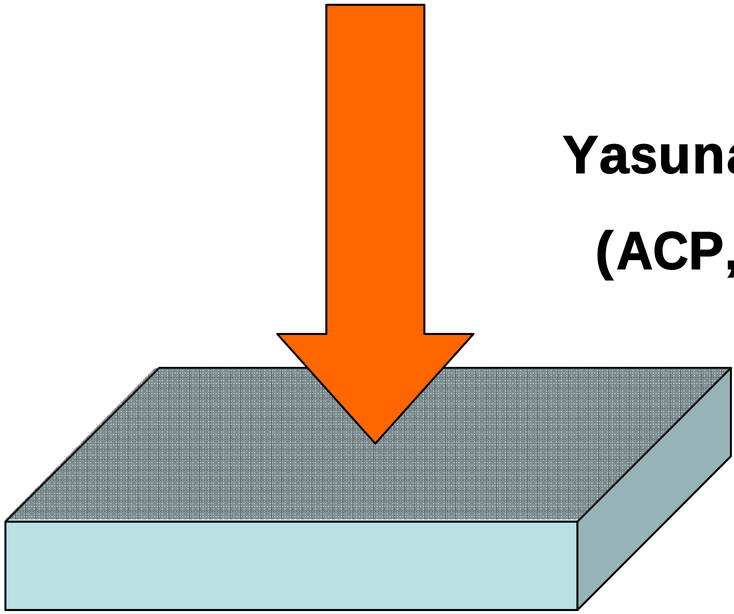
BC mass deposition every 1 hour (μg m^{-2})
= Σ (eqBC mass concentration × DDV × 3600 sec.)

Total dry deposition of BC during March-May:
Sum of 1 hourly deposition data for 3 months

- As a preliminary study, slower deposition velocity of 10^{-4} m s^{-1} (10^{-2} cm s^{-1}) was used to estimate lower bound of BC deposition during pre-monsoon (MAM) in 2006 (Yasunari et al., ACP, 2010).

Estimated "lower bound" of BC deposition over Himalayan glaciers near NCO-P site

BC deposition of **266** μg/m^2 by dry fallout during March-May in 2006
(2.89 μg m^{-2} day^{-1})



Yasunari et al.

(ACP, 2010)

Now, imagine that BC continuously accumulates onto the snow surface over glaciers during pre-monsoon season with less precipitation days.

Errors exist in the estimates of BC depositions

- How much estimation errors do exist from various estimates on BC dry deposition?

- How much those errors do impact on the snow albedo reductions?

- What is the true range of BC deposition and the related snow albedo reduction during pre-monsoon season (March-May)?

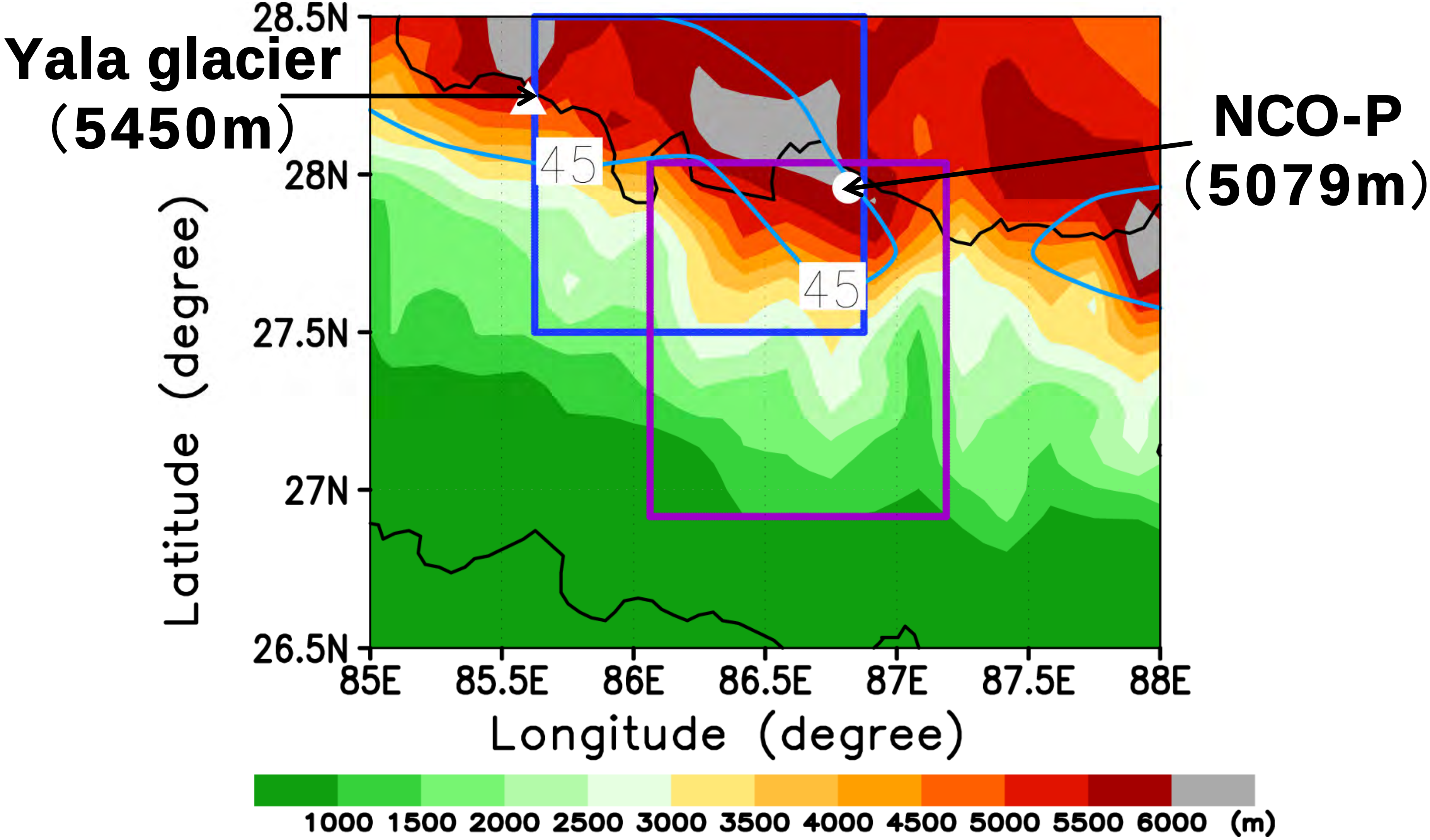
Comparisons of the estimates on BC dry deposition

1. Fixed dry deposition velocity (DDV) of 10^{-4} m s^{-1} with NCO-P data was used (Yasunari et al., ACP, 2010).
2. DDV code in GOCART/GEOS-4 with NCO-P data was used. Ice surface was assumed.
3. DDV theory of MOCAGE by Nho-Kim et al. (2004) with NCO-P data was used. Ice surface was assumed.
4. 1-hourly outputs from GOCART/GEOS-4 simulation was used. Mixed vegetation surface without ice was used.
5. 1-daily outputs from SPRINTARS was used for comparison. (An additional reference)

[cyan box] : Forced by NCO-P data [red box] : GCM outputs

—: GOCART grid point; — SPRINTARS grid point

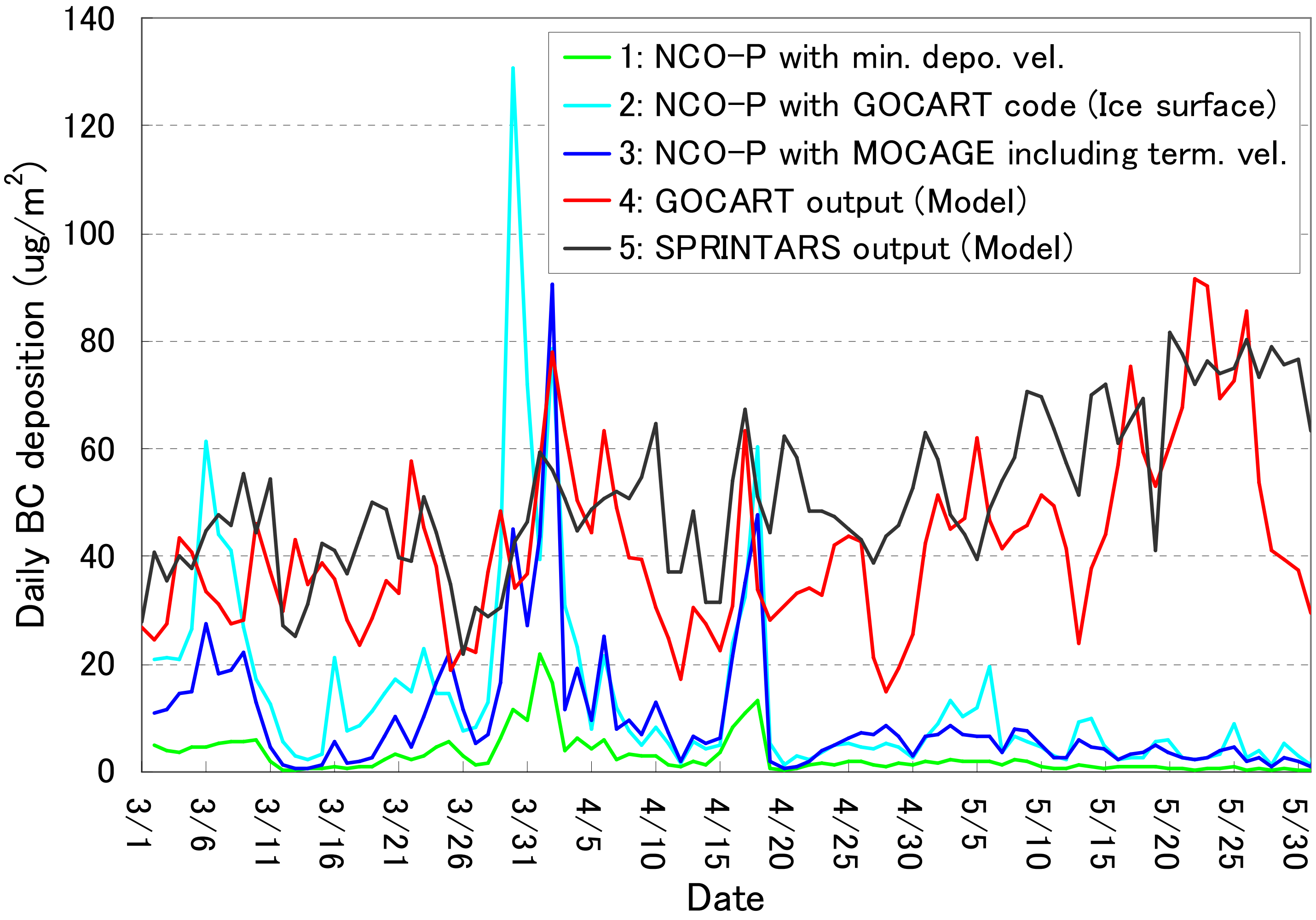
— Sky blue line: Snow water equivalent (SWE) of more than 45 kg m^{-2} calculated from AMSR-E data indicating glaciers (Kelly et al., 2004).



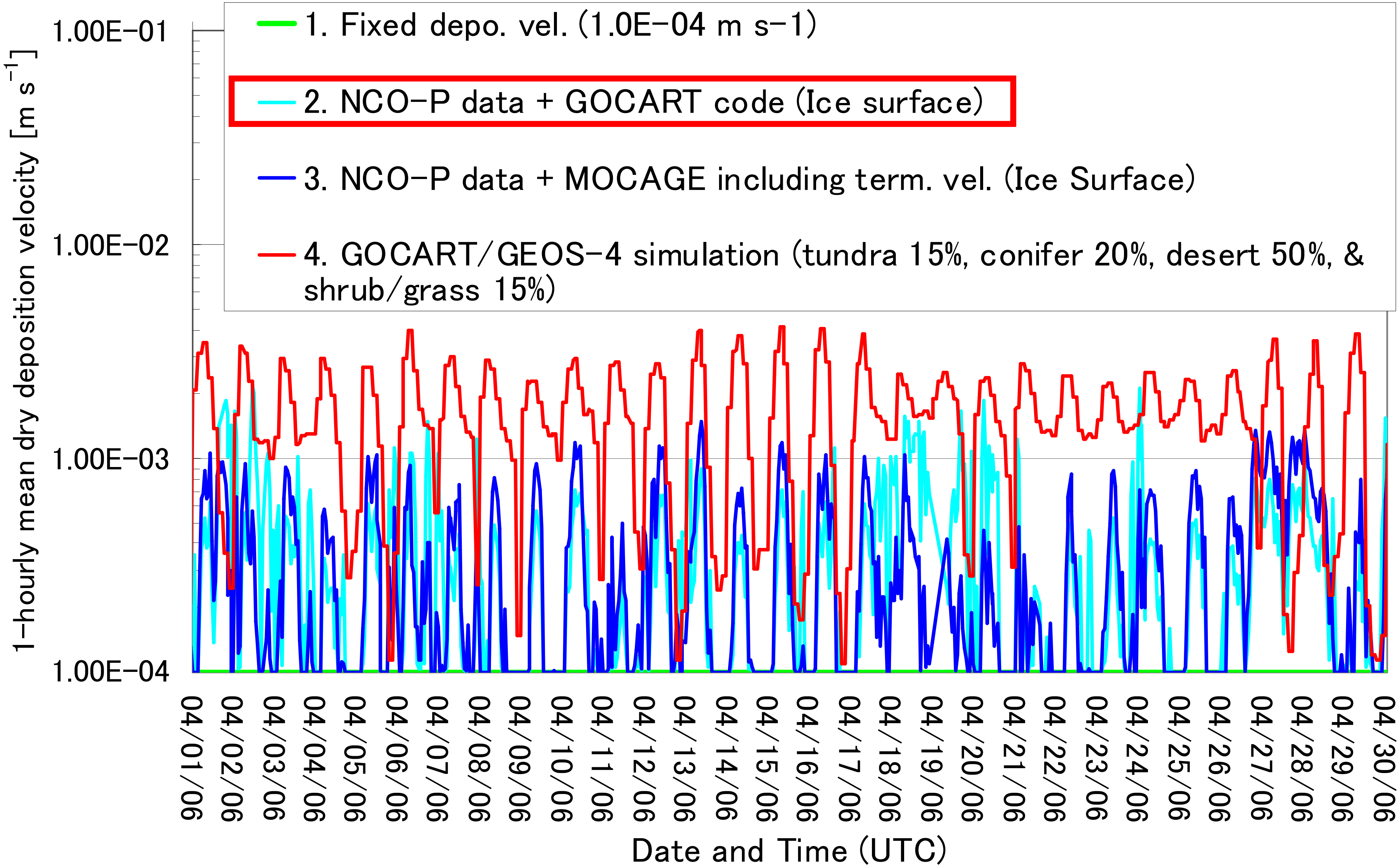
The Merged IBCAO/ETOPO5 Global Topographic Data (Holland, 2000).

The BC dry depositions from GCMs are larger than those estimated from the observations

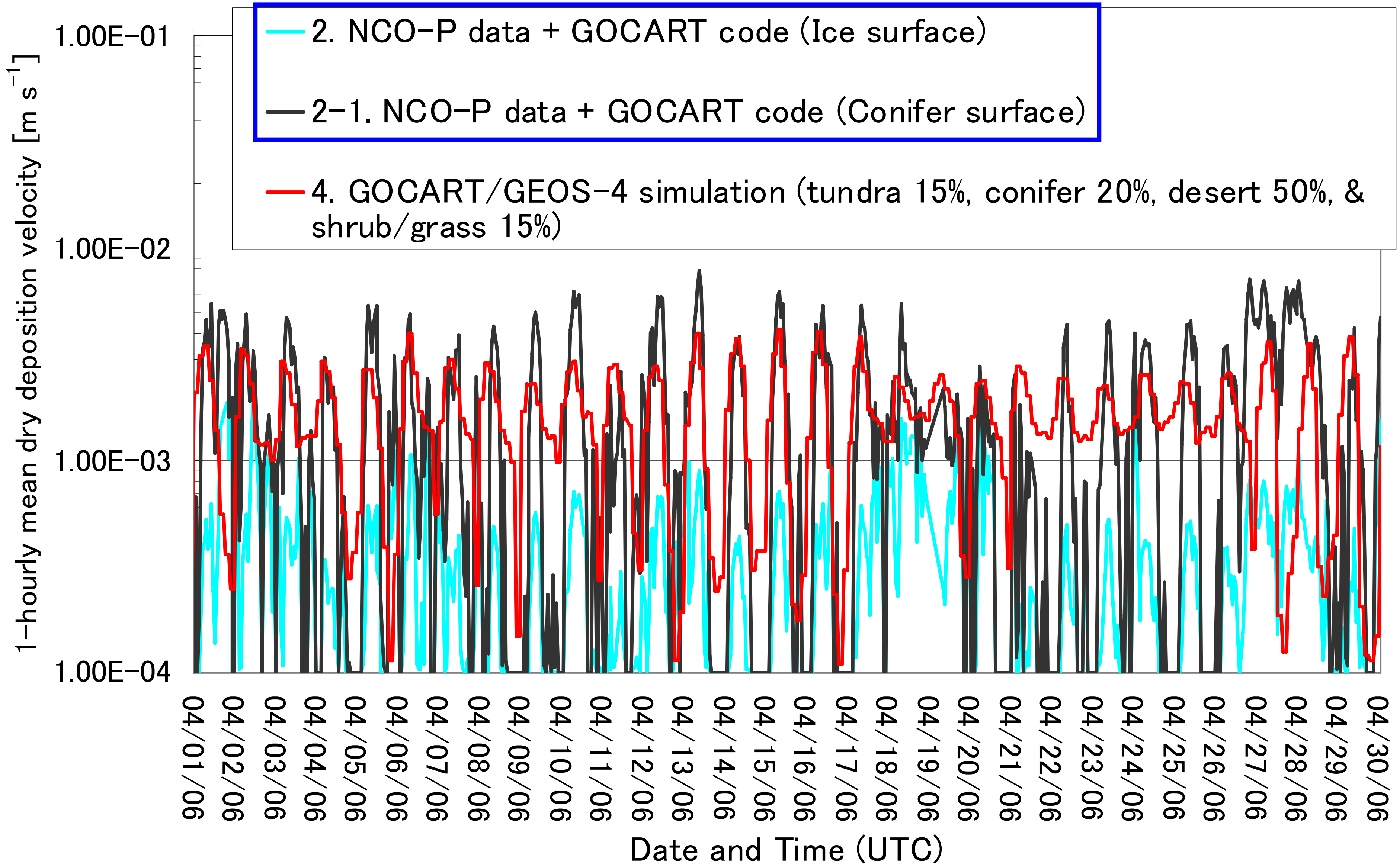
Surface roughness and wind speed are associated with the dry deposition velocity (DDV) and possible reasons to explain the differences.



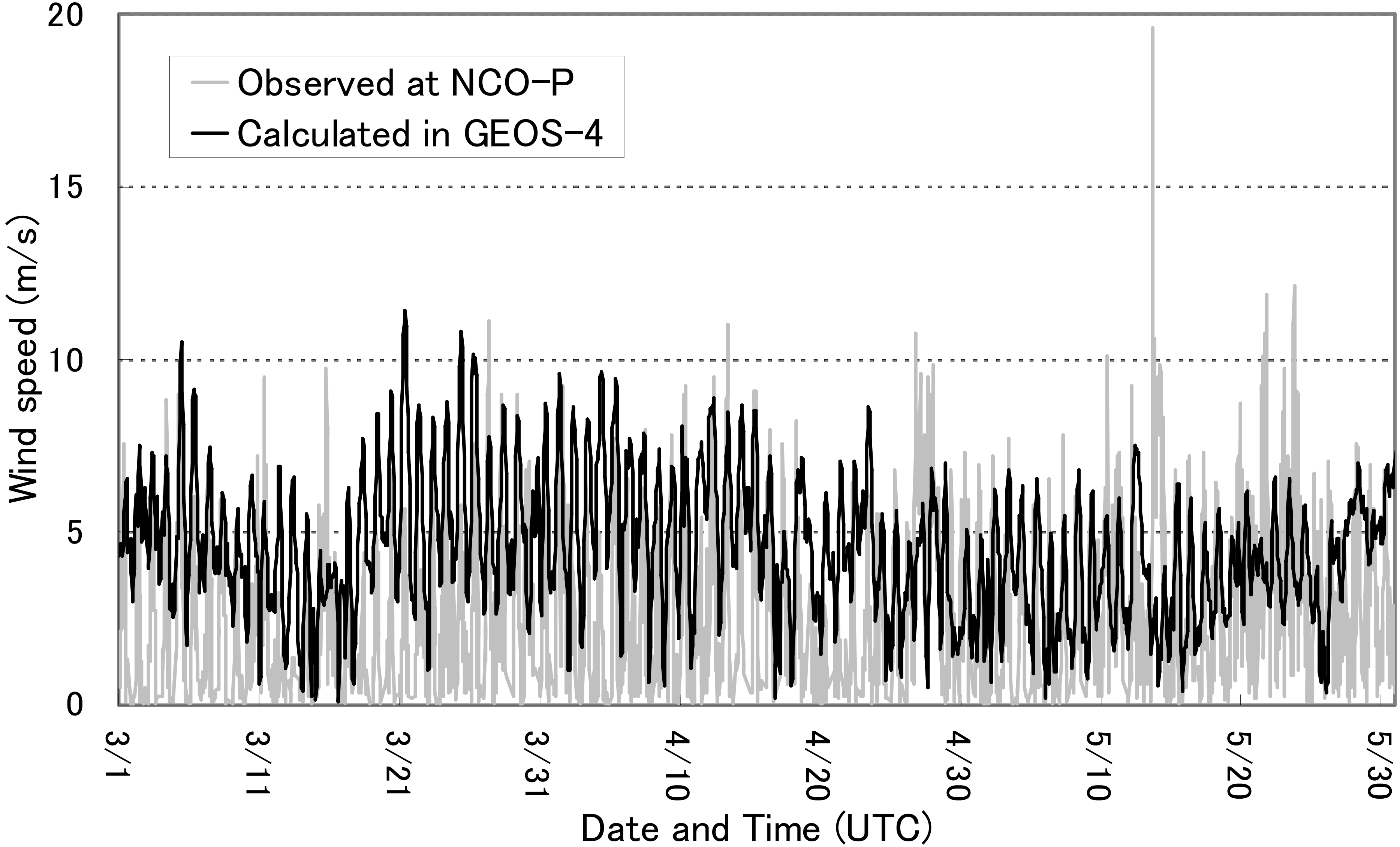
No ice surface assumption over glacial area causes strong DDVs inducing larger BC depositions

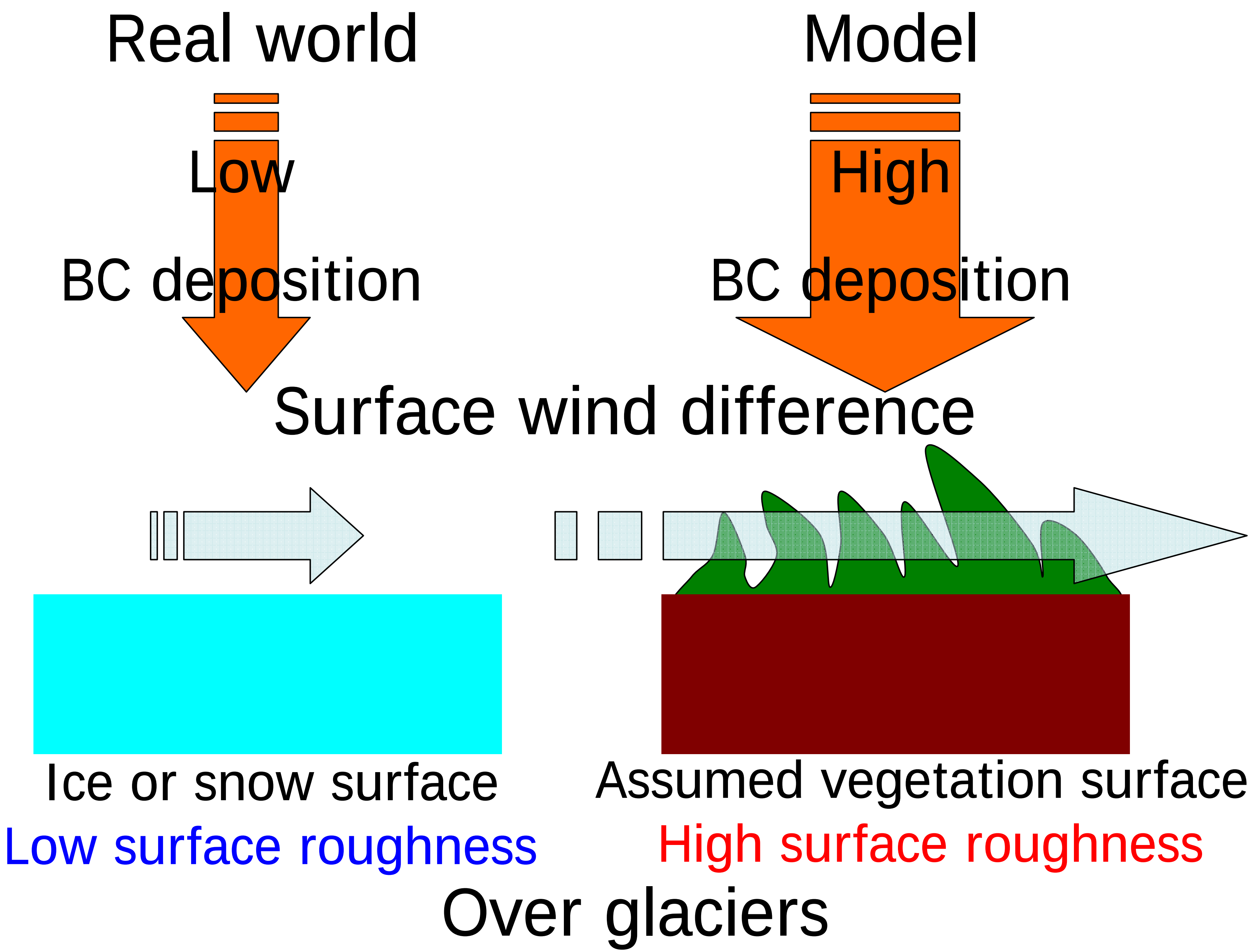


Surface roughness change largely impacts on DDV intensity



Strong surface wind (mostly nighttime) in GESO-4 model also causes larger BC depositions.




Real world
Model
Low
BC deposition
High
BC deposition
Surface wind difference
Ice or snow surface
Low surface roughness
Assumed vegetation surface
High surface roughness
Over glaciers

GCMs overestimated BC dry depositions over Himalayan glaciers probably due to vegetated surface and strong wind speed.

March – May 2006

		Total BC dry deposition ($\mu g\ m^{-2}$)
Fixed DDV + NCO-P data	Case 1	266
GOCART DDV + NCO-P data	Case 2	1333
MOCAGE DDV + NCO-P data	Case 3	916
GOCART/GEOS-4 outputs	Case 4	3852
SPRINTARS outputs	Case 5	4711

Ice surface assumption	Case 2	1333
Conifer surface assumption	Case 2−1	4651

The estimation errors on BC dry deposition themselves induce the errors on snow albedo reductions of more than 5.6%.

Snow density	Hydrophobic BC New snow 110 kg m^{-3}		Hydrophobic BC Old snow 500 kg m^{-3}		Hydrophilic BC New snow 110 kg m^{-3}		Hydrophilic BC Old snow 500 kg m^{-3}	
	VIS	NIR	VIS	NIR	VIS	NIR	VIS	NIR
pure							0.954	0.515
Case 1							0.924	0.513
Case 2							0.903	0.508
Case 3							0.911	0.510
Case 4							0.858	0.497
Case 5							0.844	0.493
MIN							0.844	0.493
MAX							0.924	0.513
DIFF (%)							8.0	2.0

The GCM estimates are probably out of realistic range because of non ice surface assumption and strong wind speed at the lowest layer.

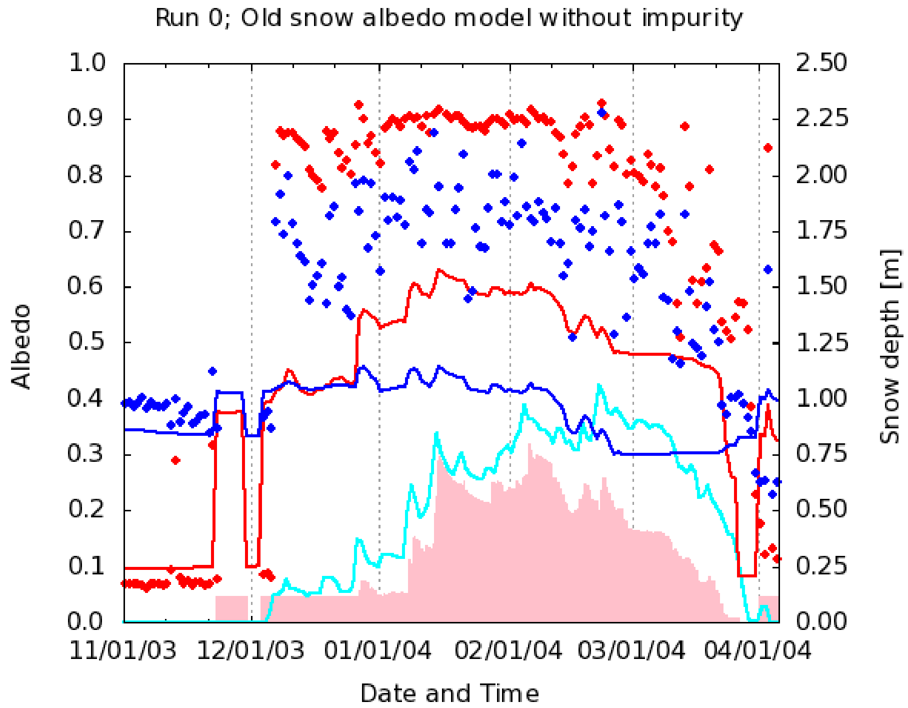
Snow albedo reductions in VIS of 4.3−5.1% are considered to be the true range during pre-monsoon 2006 in the condition of aged snow and BC.

Less precipitation and highly polluted air during pre-monsoon periods suggest aged BC (hydrophilic) and old snow over the glaciers.

Note: we assumed five 2-cm snow layers, BC deposition onto the top 2-cm, and BC concentrations of 18 μg kg^{-1} for 2-5 layers using the snow albedo model (Yasunari et al., JGR, 2011). Visible (305-705 nm) and near IR (715-2805 nm) ranges were spectrally integrated. Solar zenith angle corresponds to 50 degrees.

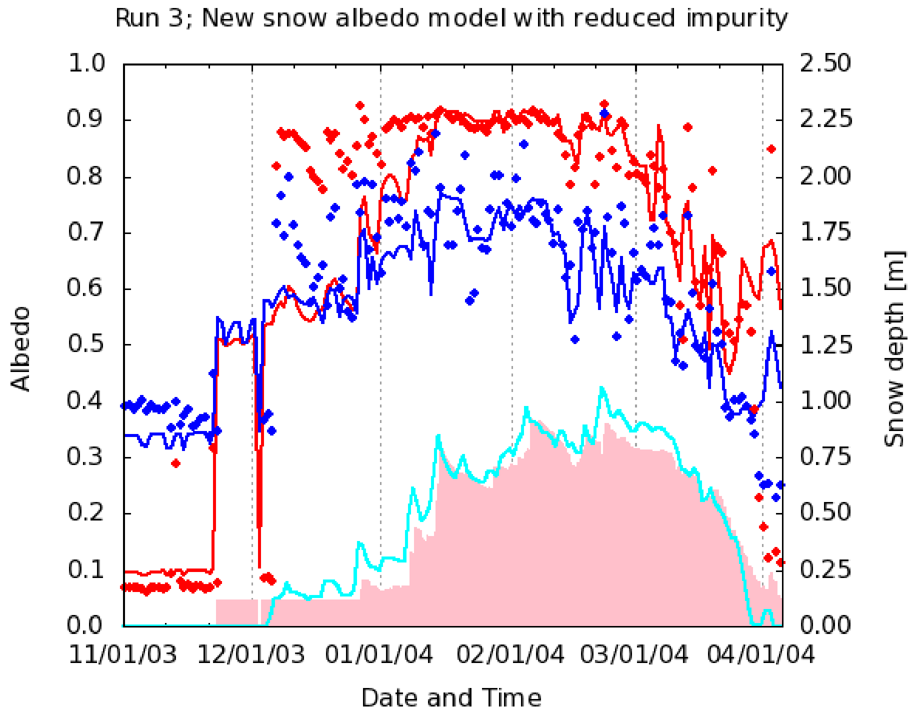
New NASA GEOS-5 land surface model (LSM) will be used to assess BC, dust, and organic carbon on snow albedo reduction over the Himalayas in near future.

Original GEOS-5 LSM



No impurity effect

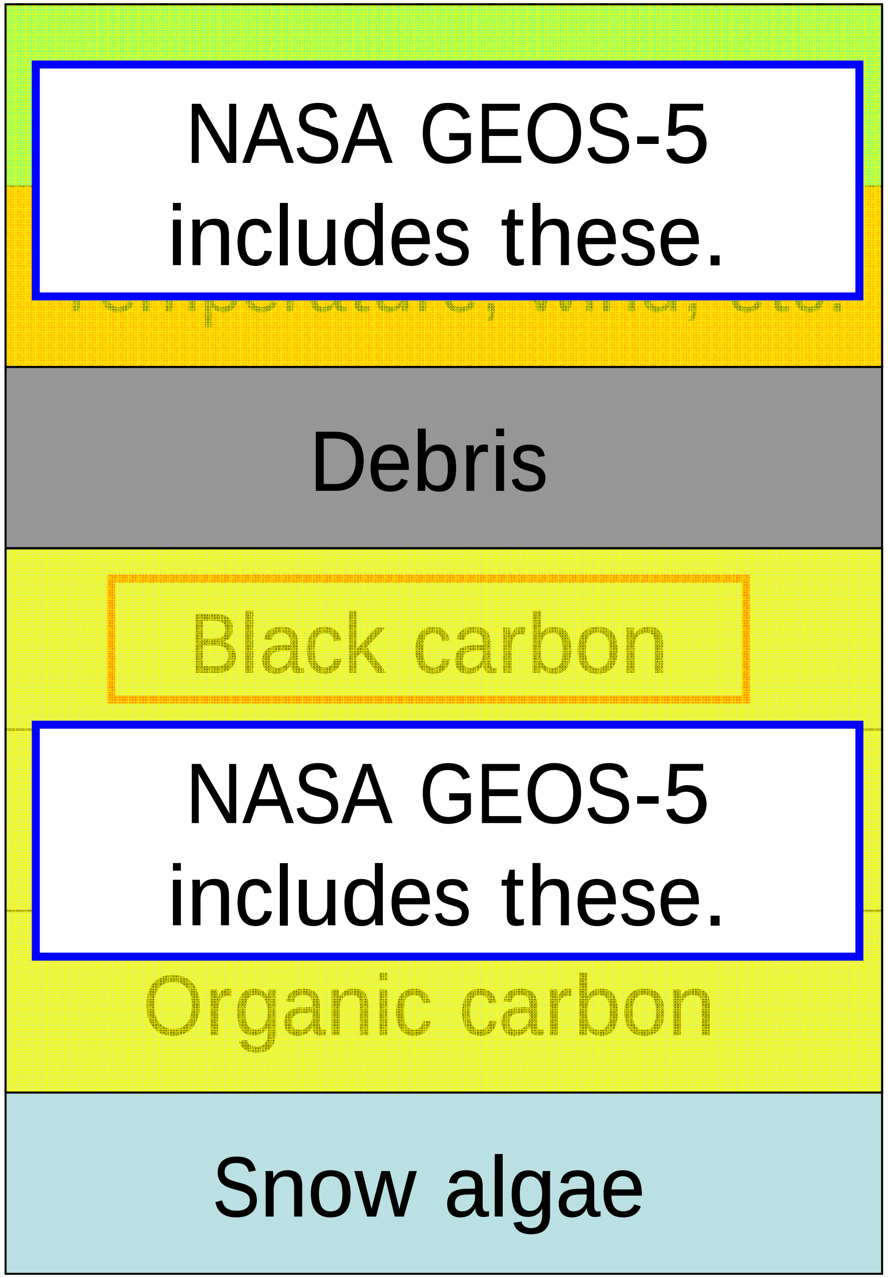
New GEOS-5 LSM



Considering BC and dust

A case study for model validation in Sapporo, Japan, (2003/2004 winter) (Yasunari et al., JGR, 2011)

Today's take home message



During pre-monsoon 2006

- The estimation errors on BC dry deposition at NCO-P grid point induce snow albedo errors of more than 5.6%.
- The true range of snow albedo reduction due to aged snow and BC is 4.3-5.1%.
- We need to reduce uncertainties in each component discussing the causes of whole glacier retreat.

Thanks

for your attention!