LGGE measurements, first interpretations, and modeling

Hans-Werner Jacobi (jacobi@lgge.obs.ujf-grenoble.fr)
Laboratoire de Glaciologie et Géophysique de l'Environnement, CNRS / Université Joseph Fourier Grenoble, France

Marco Zanatta, Martin Ménégoz, Julie Cozic, Hubert Gallée, Patrick Ginot, Jean-Luc Jaffrezo, Paolo Laj, Saehee Lim

Yves Balkanski, LSCE

CLIMSLIP

(CLimate IMpacts of Short-Lived pollutants In the Polar region)

Paprika

CLMISLIP Meeting
LATMOS, Paris, 22 November 2012

Field experiments Ny-Alesund 2012

Date	SP2	Aethalom.	COSMOS	Greek Aethalom.	Snow pit	Fresh snow	Surface snow	
	Zeppelin	Zeppelin, Corbel	Zeppelin	Zeppelin		Corbel, NyA	Corbel, NyA, AL, VL	
19/03/2012								
20/03/2012								
21/03/2012								
22/03/2012								
23/03/2012								
24/03/2012								POLAR 5 Flight
25/03/2012								
26/03/2012								
27/03/2012								
28/03/2012								
29/03/2012								
30/03/2012					Kongsvegen			
31/03/2012								
01/04/2012								
02/04/2012								
03/04/2012								
04/04/2012								
05/04/2012					Austre Lovenbren			
06/04/2012								
07/04/2012								
08/04/2012								
09/04/2012								
10/04/2012								
11/04/2012								
12/04/2012								
13/04/2012					Austre Lovenbren			
14/04/2012								
15/04/2012								

~300 samples

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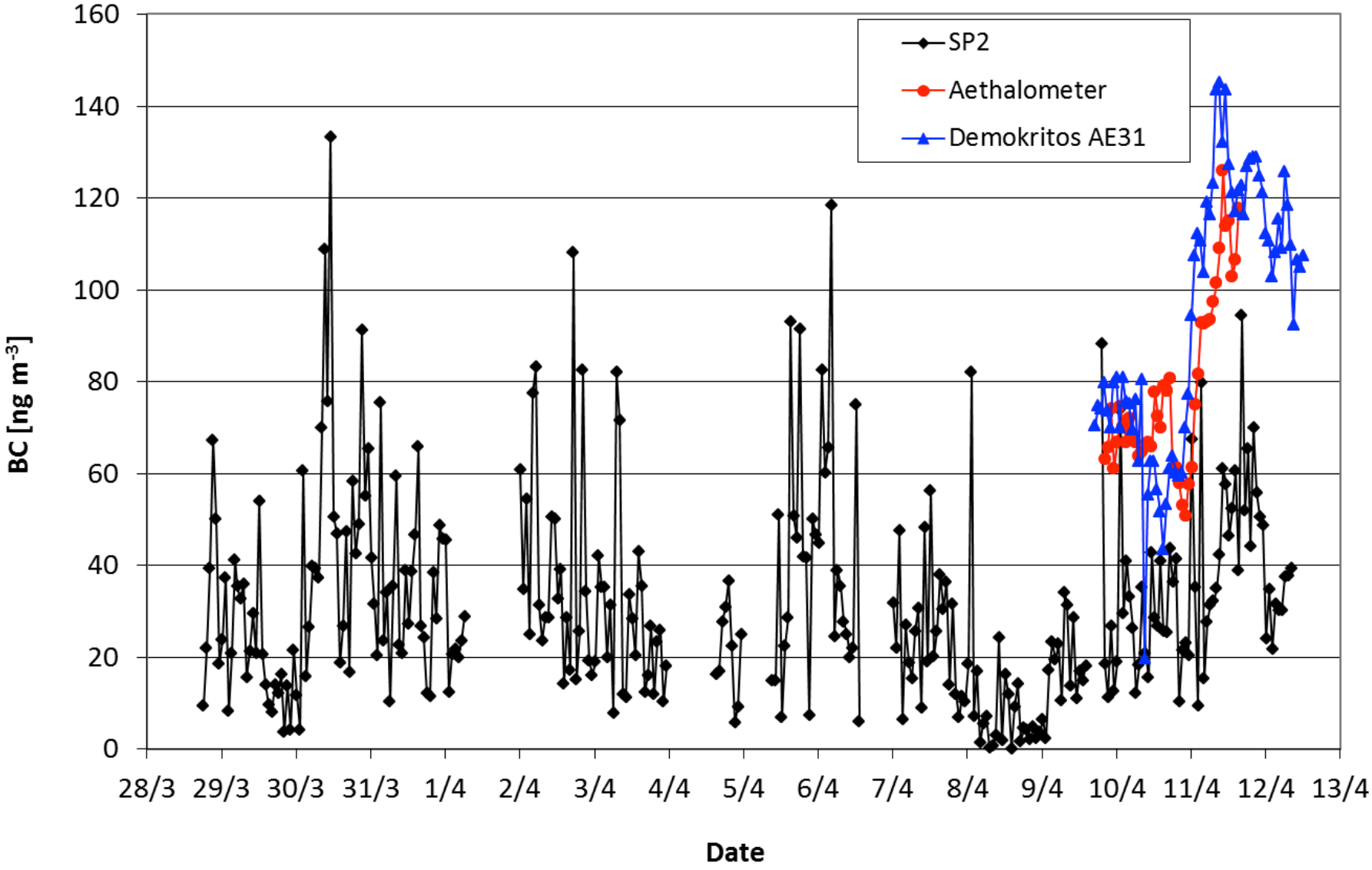
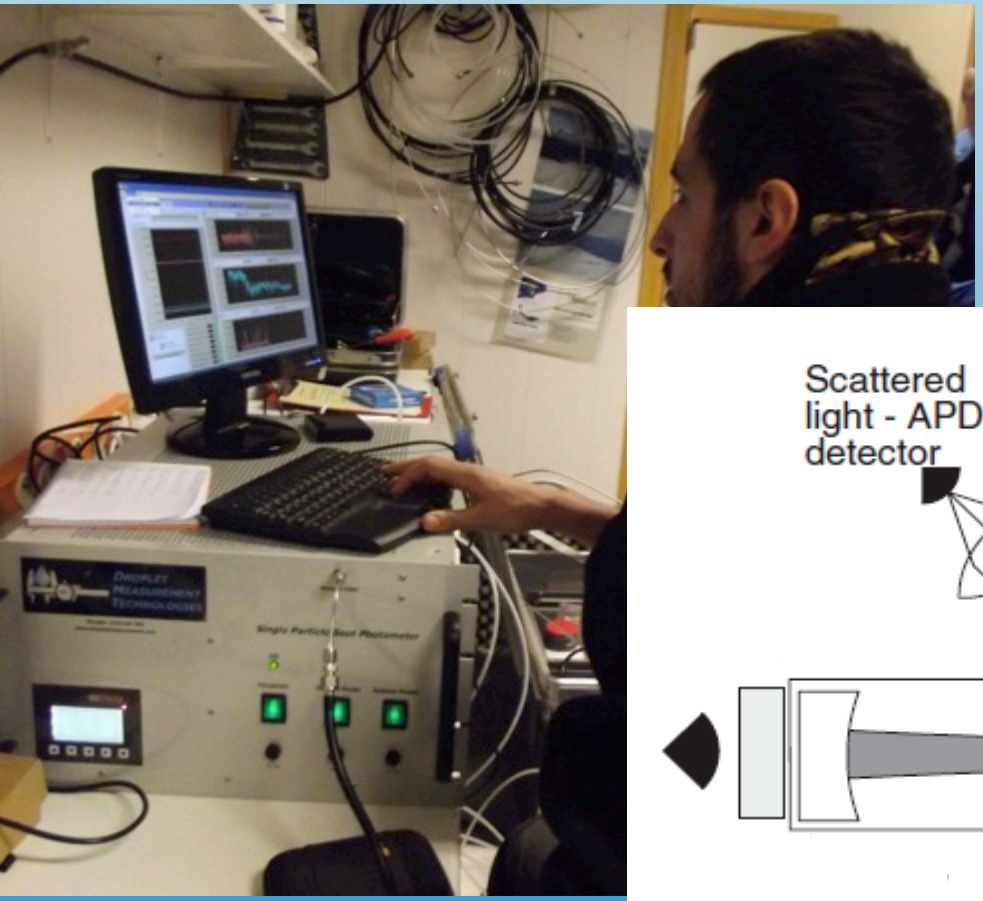
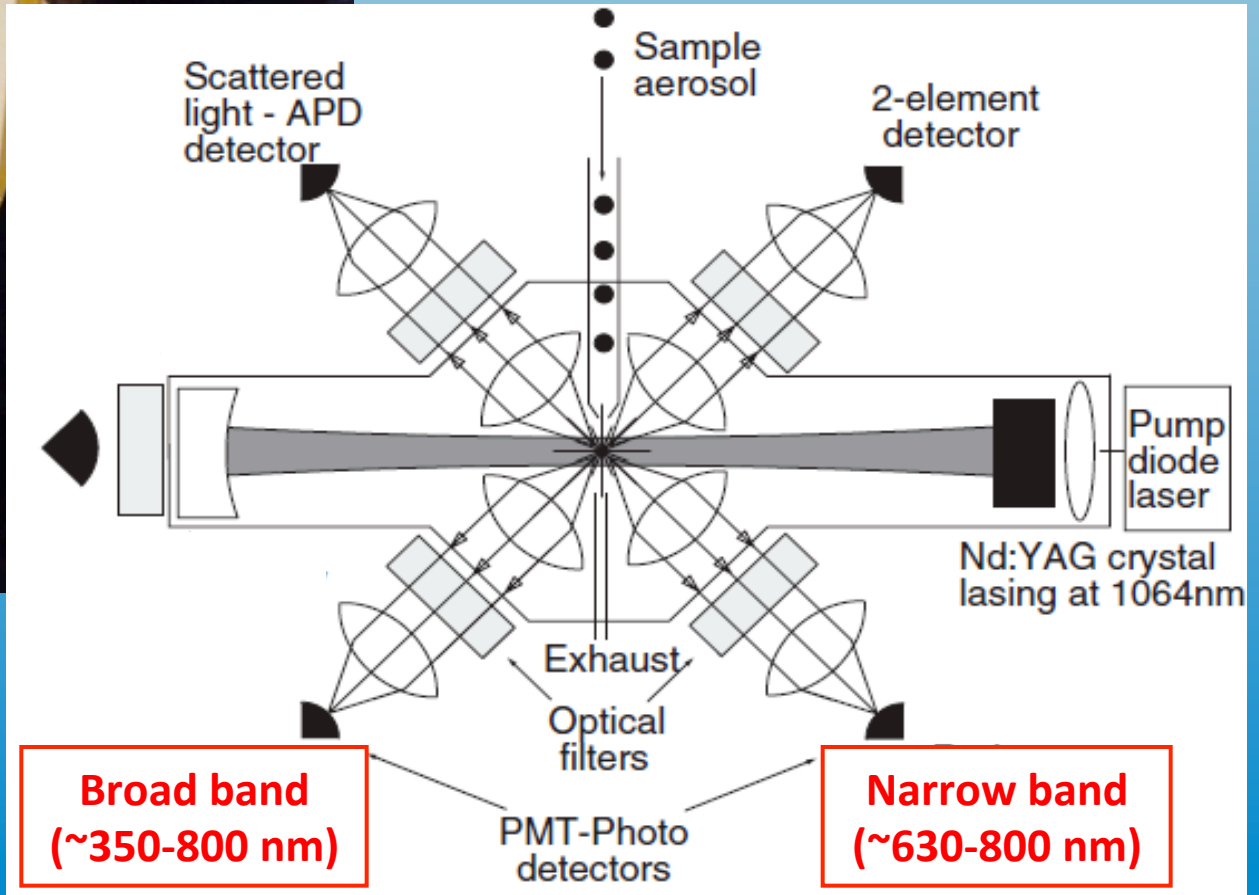
Atmospheric BC at Zeppelin (1-hr averages)



Single Particle Soot Photometer (SP2)



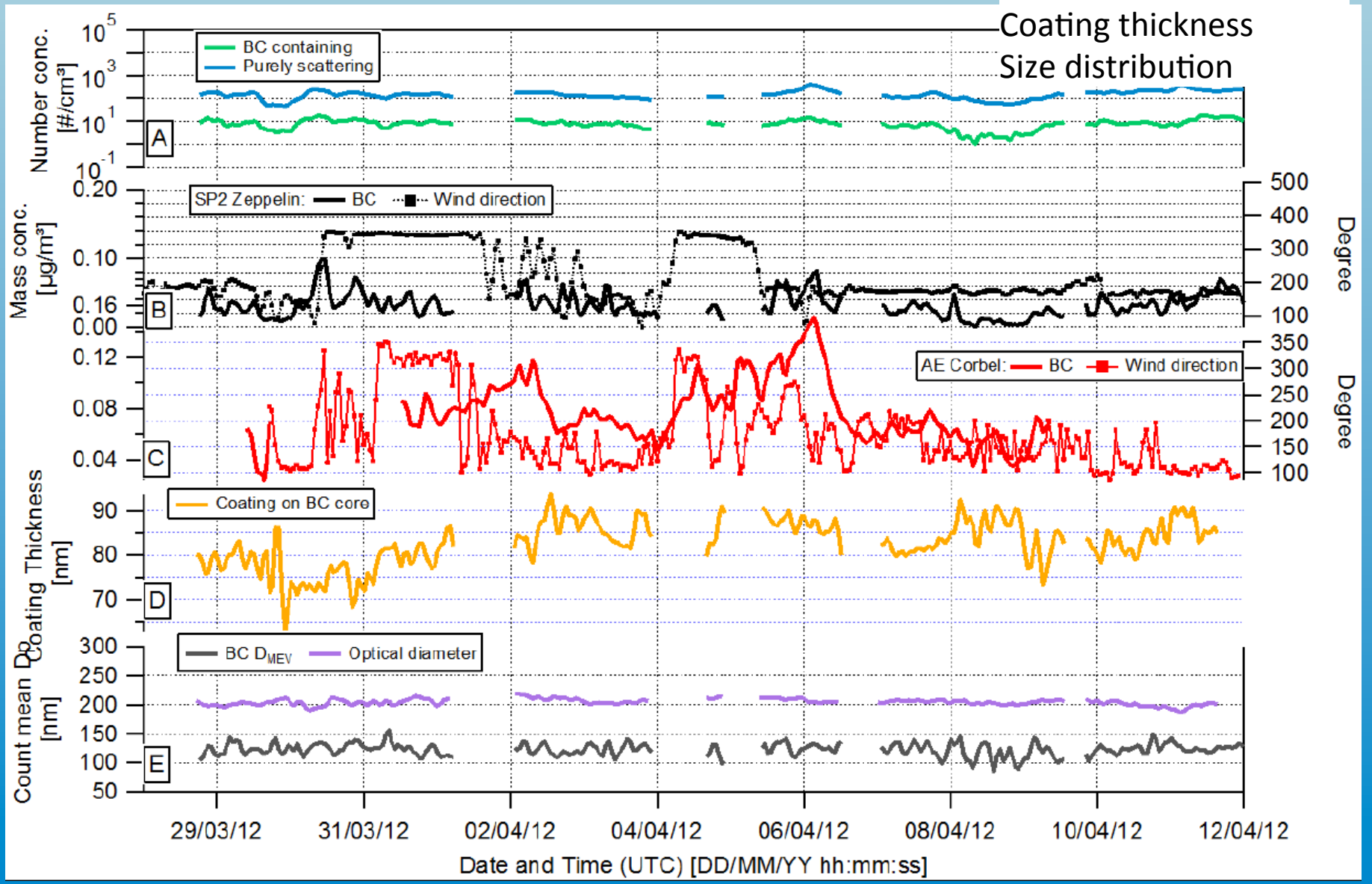


Incandescent light detectors => rBC mass

Schwarz et al., Aerosol Sci.Technol. 2010

SP2 measurements at Zeppelin

Further information:
Number concentration
Coating thickness
Size distribution



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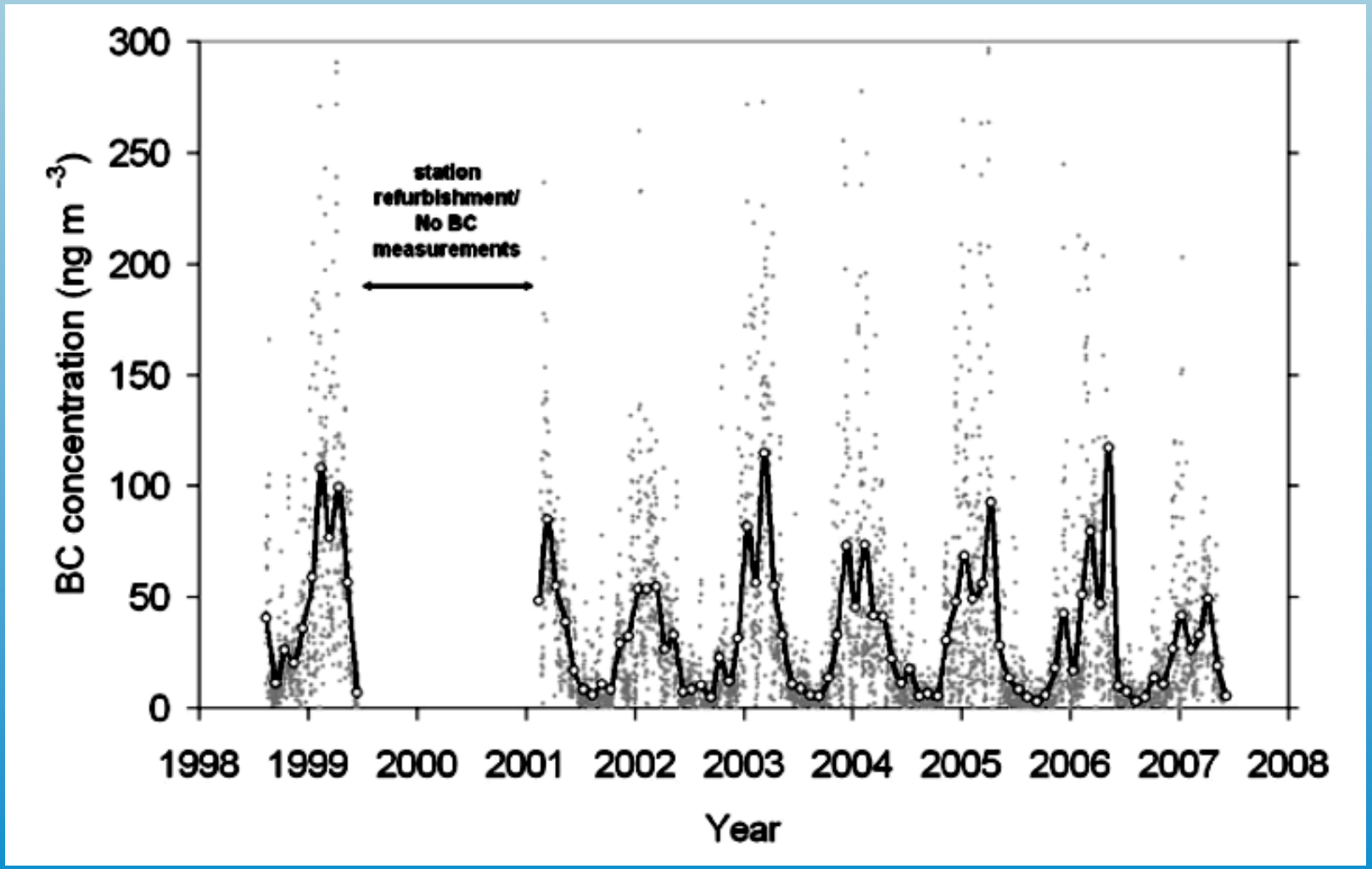
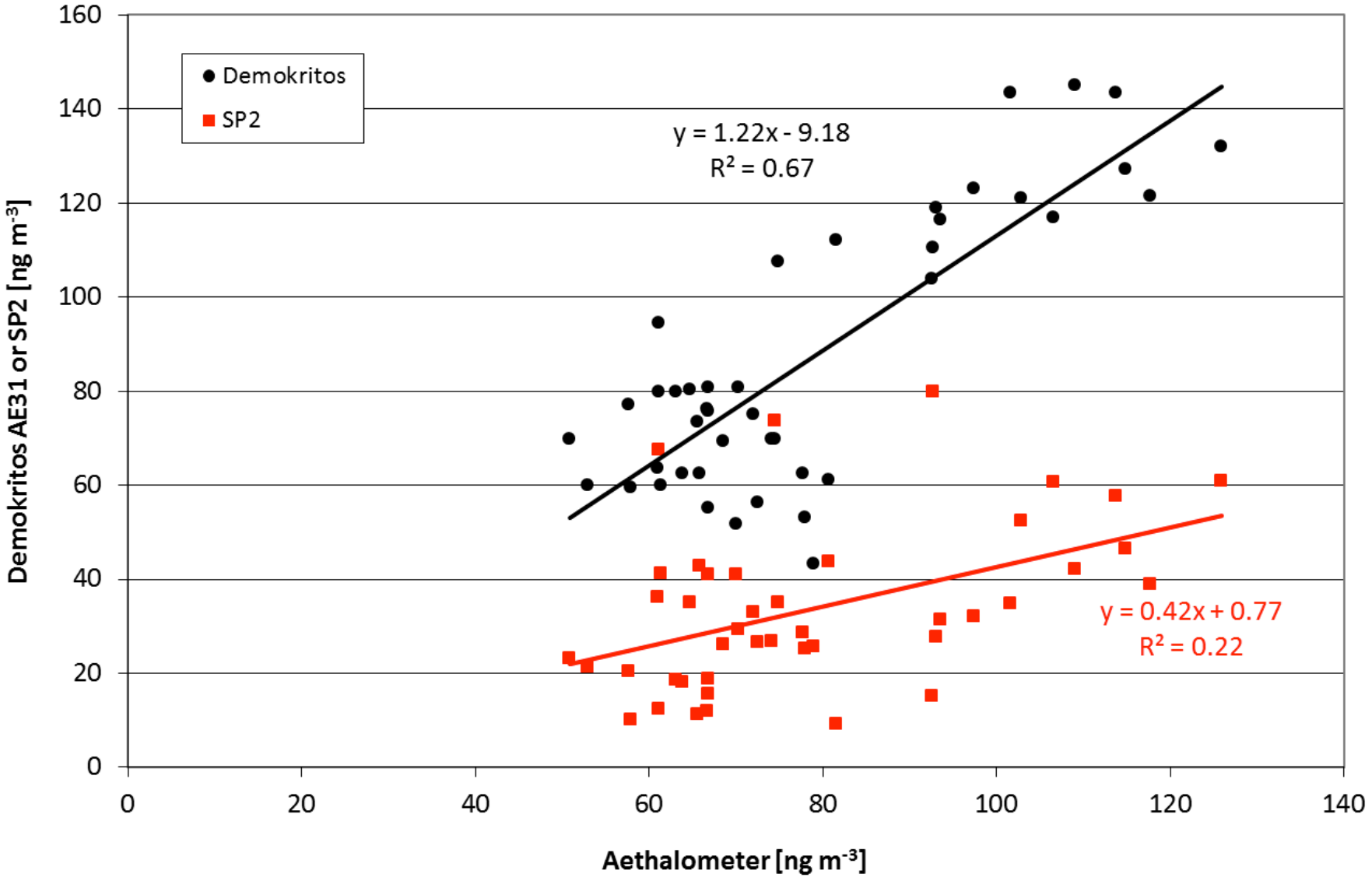
Previous BC monitoring at Zeppelin



Eleftheriadis et al., Geophys.Res.Lett. 2009

Correlations during parallel measurements at Zeppelin



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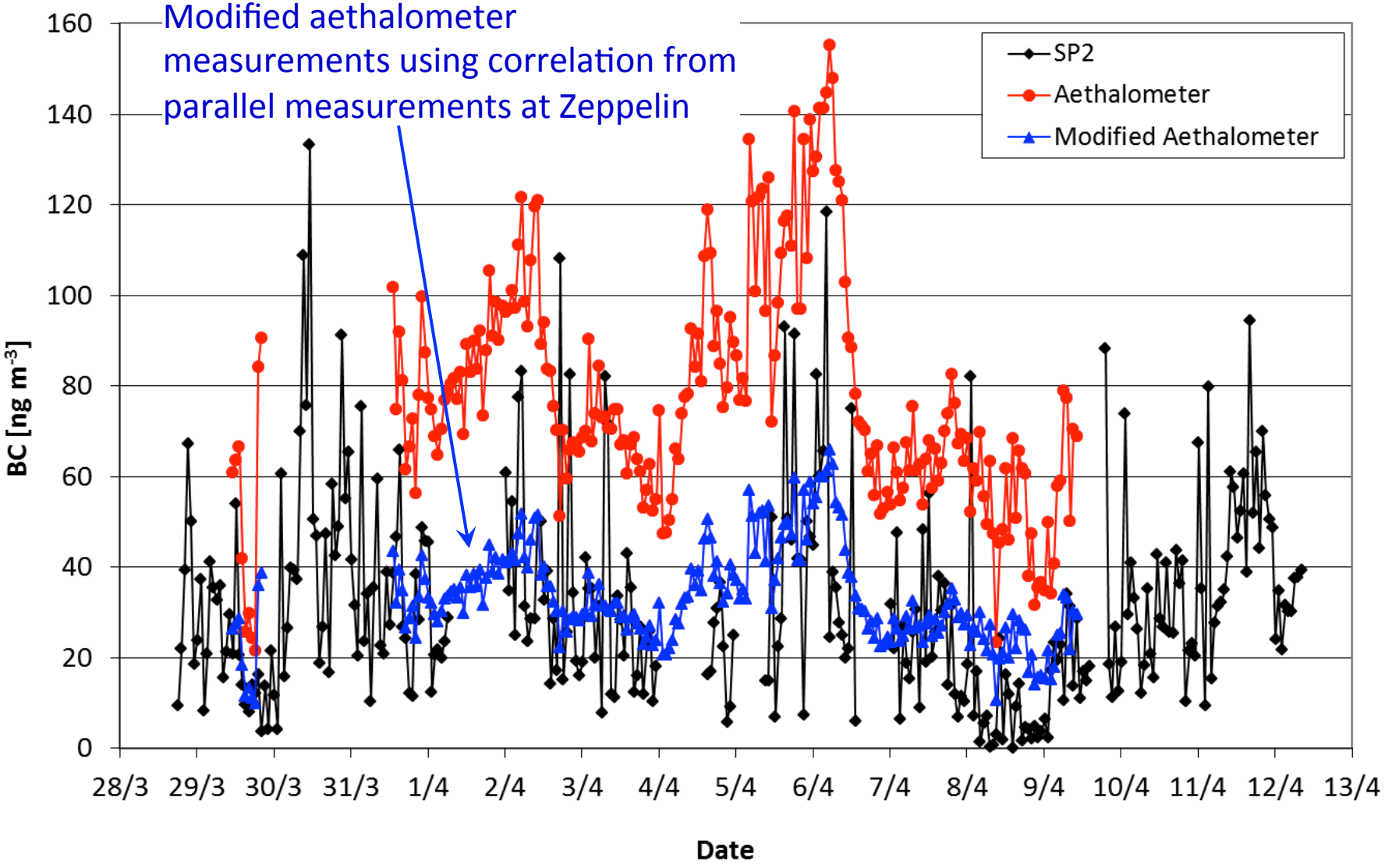
Comparison of simultaneous measurements at Zeppelin and Corbel



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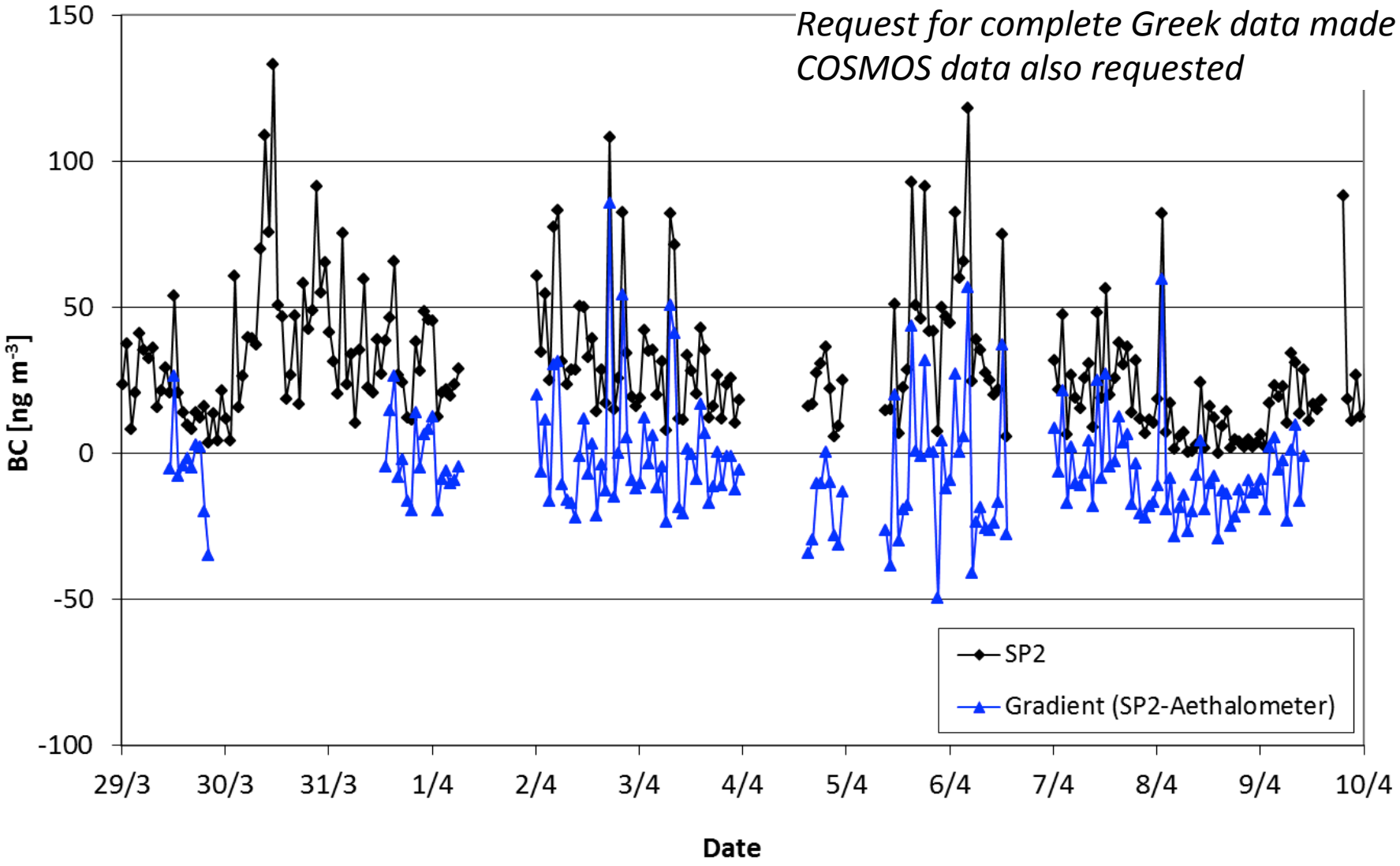
Estimation of BC gradients between Zeppelin and Corbel

(Better) alternative:
Gradient using only aethalometer data
Request for complete Greek data made
COSMOS data also requested



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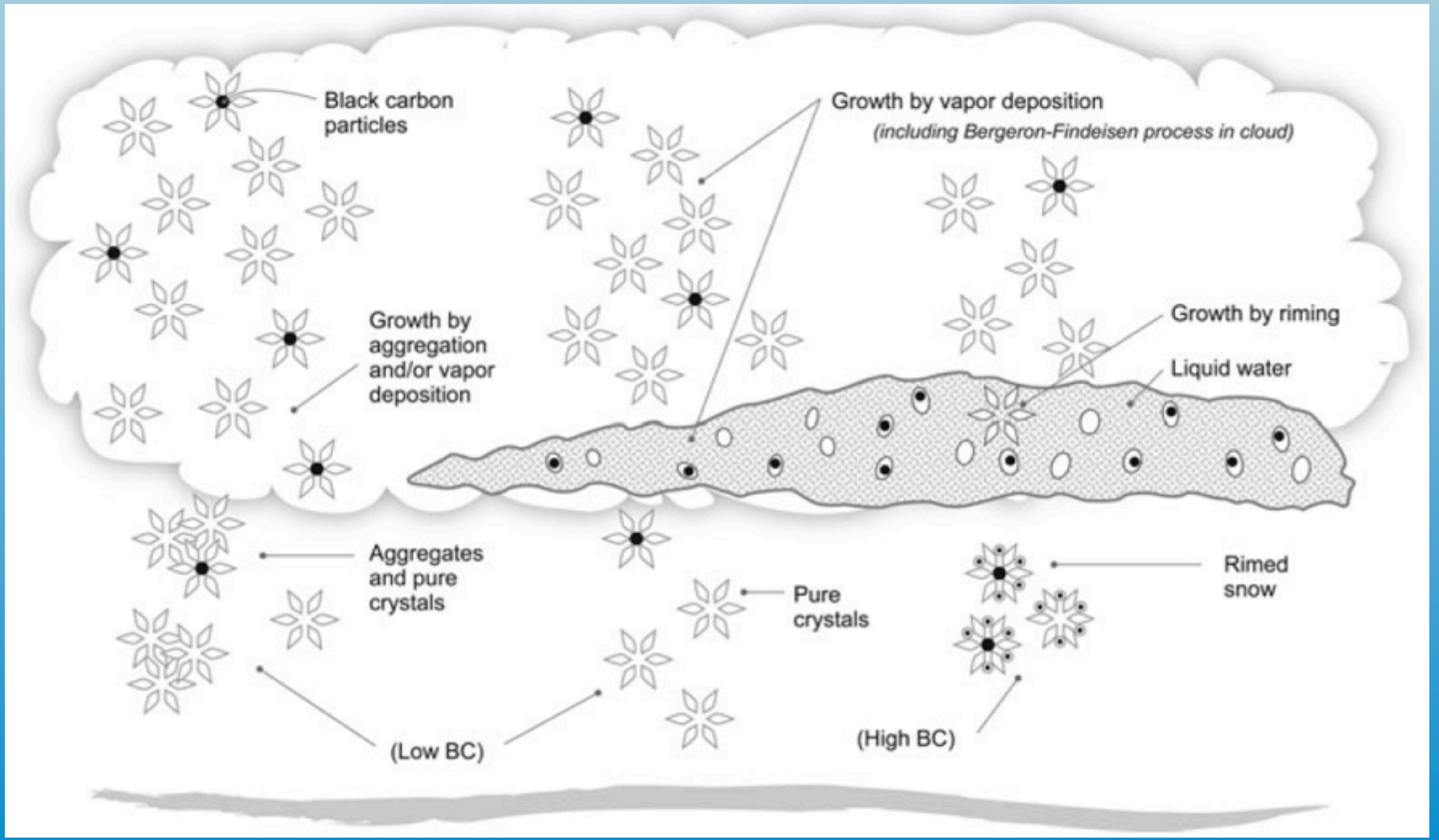
Quantification of incorporation processes of black carbon into precipitating snow



Hegg et al., Tellus 2011

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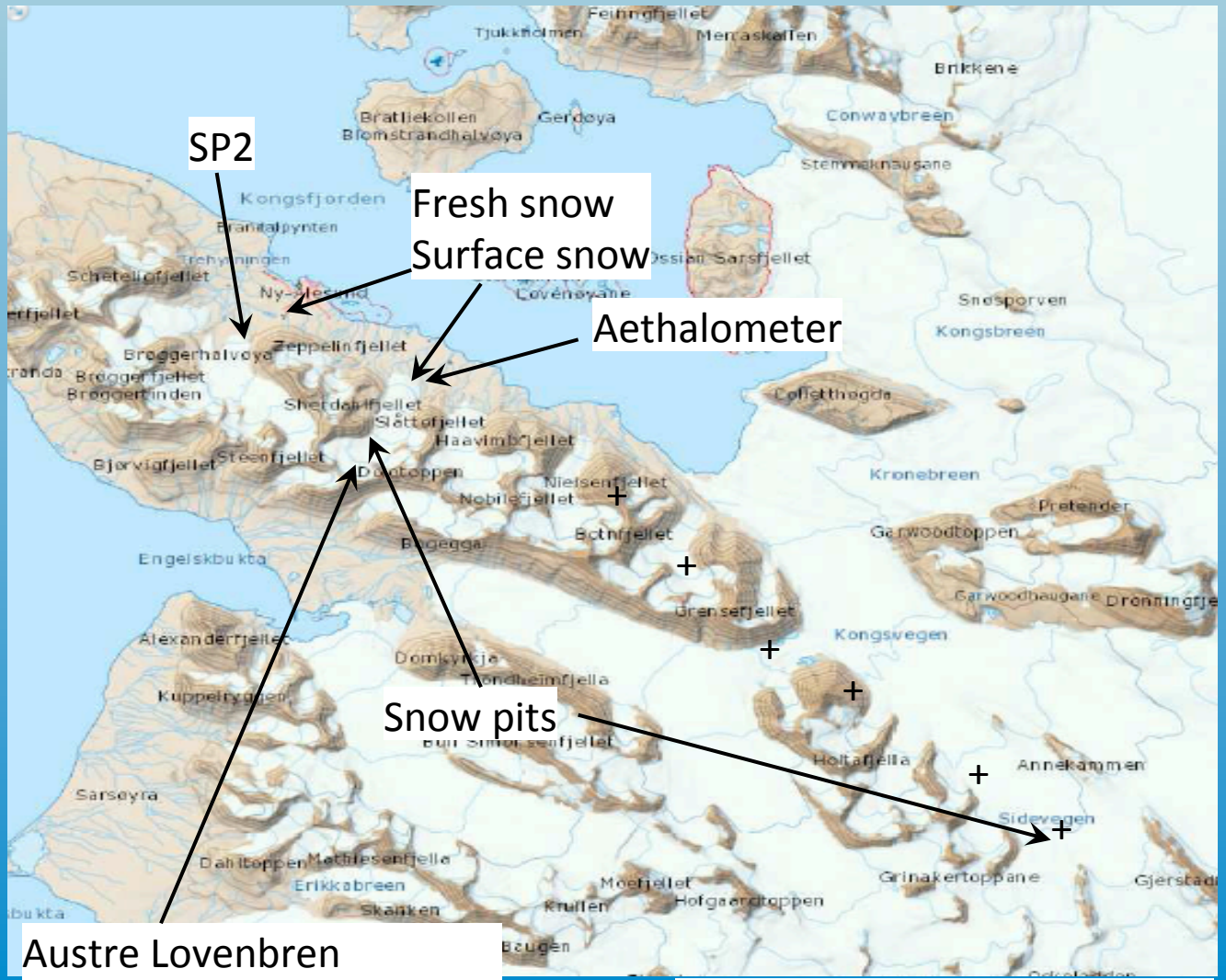
Black carbon in snow at Svalbard



toposvalbard.npolar.no

Kongsvegen snow pit (30/03/2012)

Friday 30 March 2012, 10:00-14:00

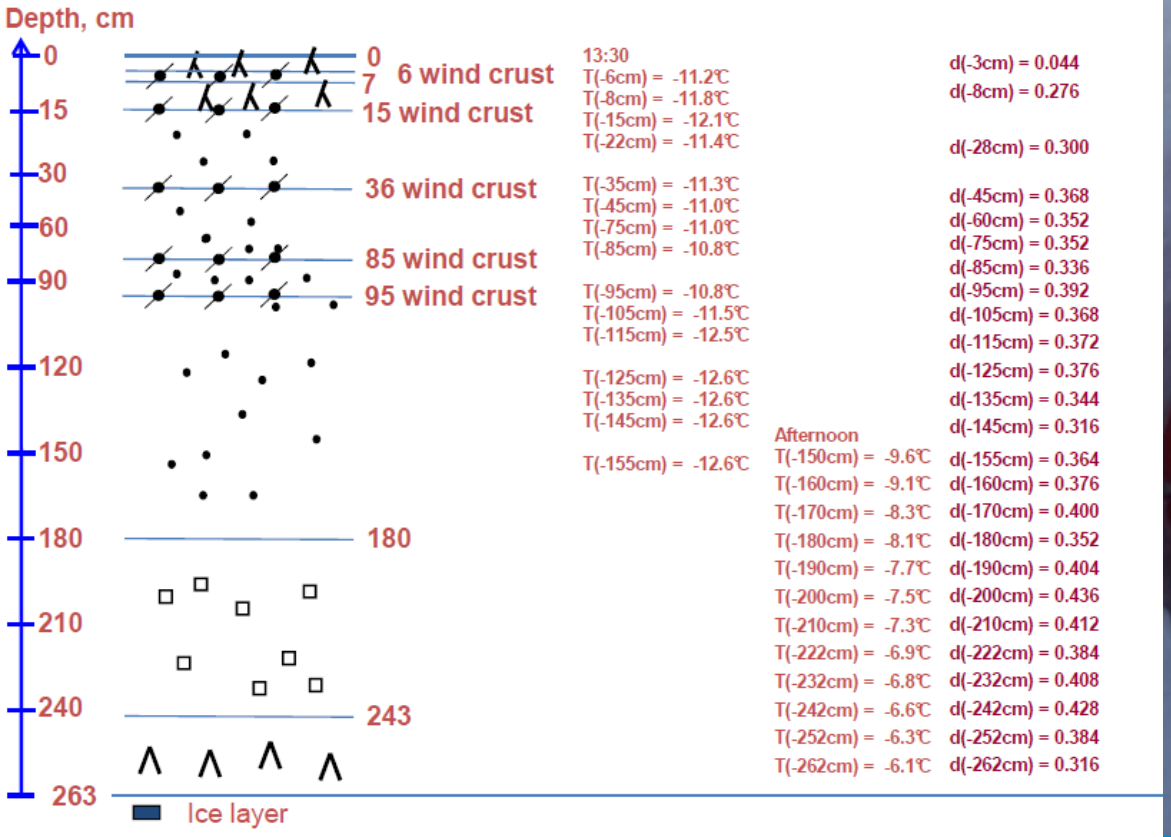
Kongsvegen Glacier
N 78.75487°
E 13.33672°
670 m

Conditions: Sunny, light wind, -10℃

Observations: Full seasonal snowpack

Measurements: Sampling for IC and BC, HULIS, and VOC

T(air) = -11.7 ℃ (13:30)



13:30
T(-6cm) = -11.2℃
T(-8cm) = -11.8℃
T(-15cm) = -12.1℃
T(-22cm) = -11.4℃

T(-35cm) = -11.3℃
T(-45cm) = -11.0℃
T(-75cm) = -11.0℃
T(-85cm) = -10.8℃

T(-95cm) = -10.8℃
T(-105cm) = -11.5℃
T(-115cm) = -12.5℃

T(-125cm) = -12.6℃
T(-135cm) = -12.6℃
T(-145cm) = -12.6℃

T(-155cm) = -12.6℃

Afternoon
T(-150cm) = -9.6℃
T(-160cm) = -9.1℃
T(-170cm) = -8.3℃
T(-180cm) = -8.1℃
T(-190cm) = -7.7℃
T(-200cm) = -7.5℃
T(-210cm) = -7.3℃
T(-222cm) = -6.9℃
T(-232cm) = -6.8℃
T(-242cm) = -6.6℃
T(-252cm) = -6.3℃
T(-262cm) = -6.1℃

d(-3cm) = 0.044
d(-8cm) = 0.276

d(-28cm) = 0.300

d(-45cm) = 0.368
d(-60cm) = 0.352
d(-75cm) = 0.352
d(-85cm) = 0.336
d(-95cm) = 0.392
d(-105cm) = 0.368
d(-115cm) = 0.372
d(-125cm) = 0.376
d(-135cm) = 0.344
d(-145cm) = 0.316
d(-155cm) = 0.364
d(-160cm) = 0.376
d(-170cm) = 0.400
d(-180cm) = 0.352
d(-190cm) = 0.404
d(-200cm) = 0.436
d(-210cm) = 0.412
d(-222cm) = 0.384
d(-232cm) = 0.408
d(-242cm) = 0.428
d(-252cm) = 0.384
d(-262cm) = 0.316

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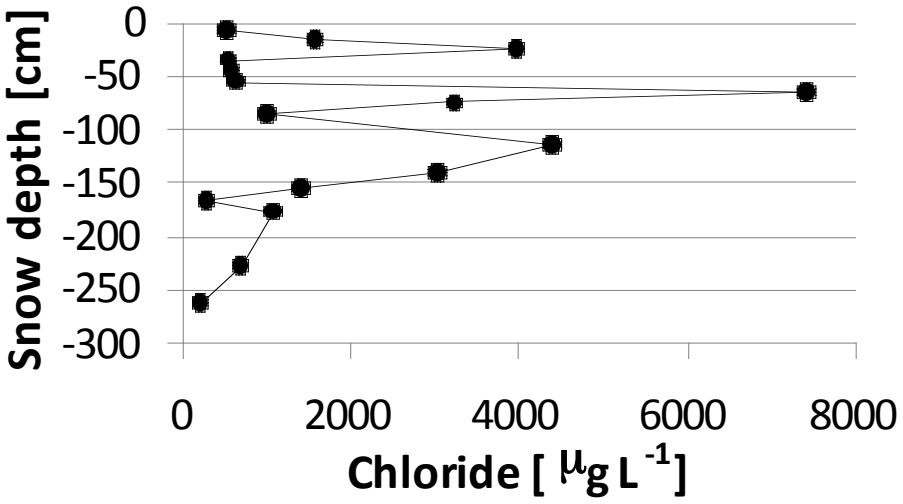
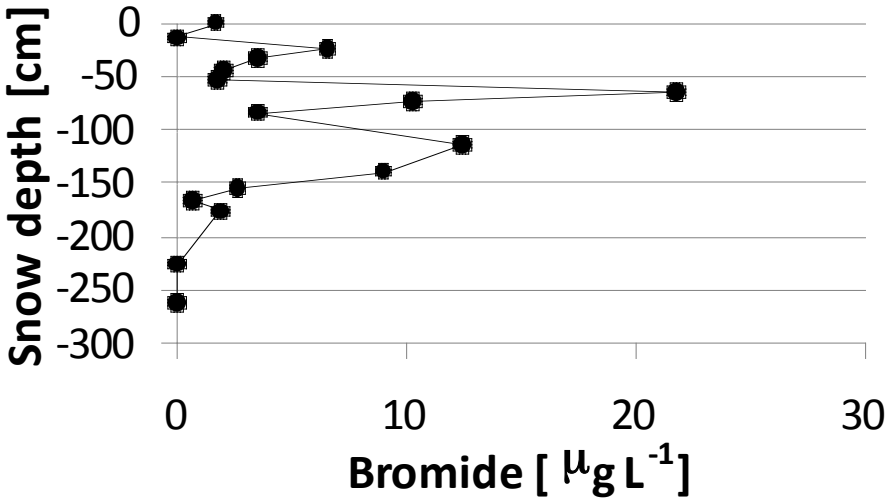
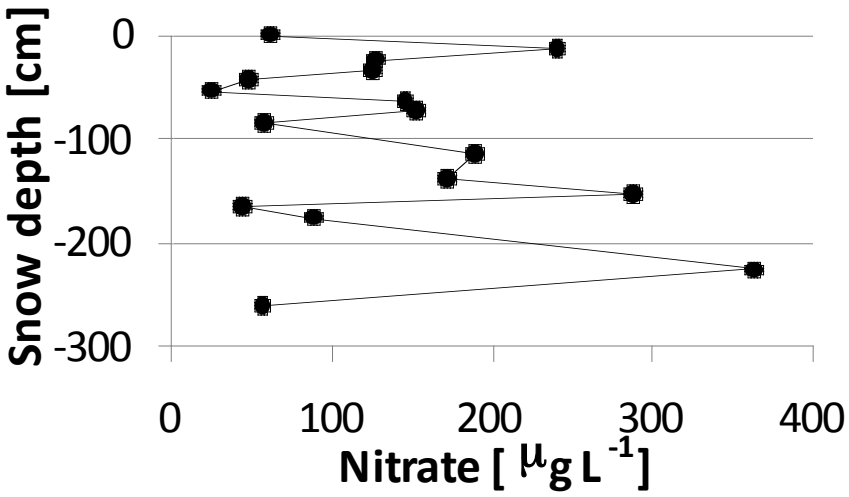
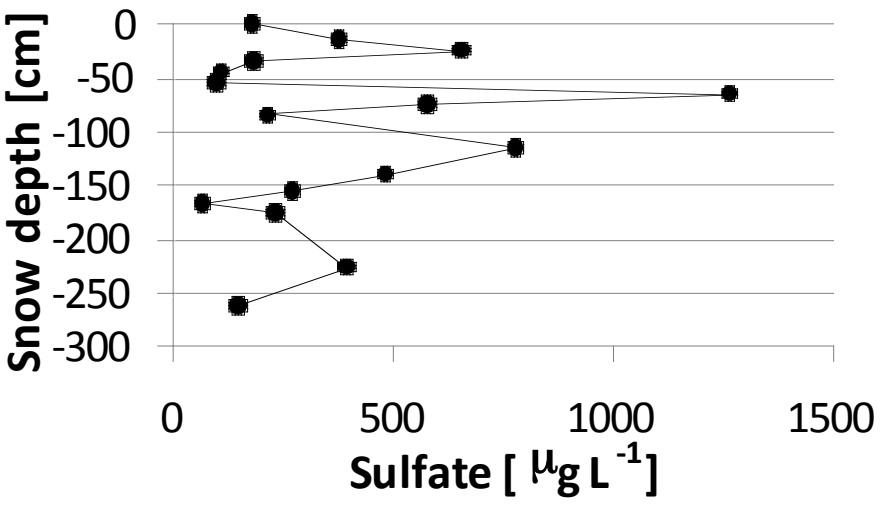
Chemical profiles Kongsvegen snow pit (30/03/2012)









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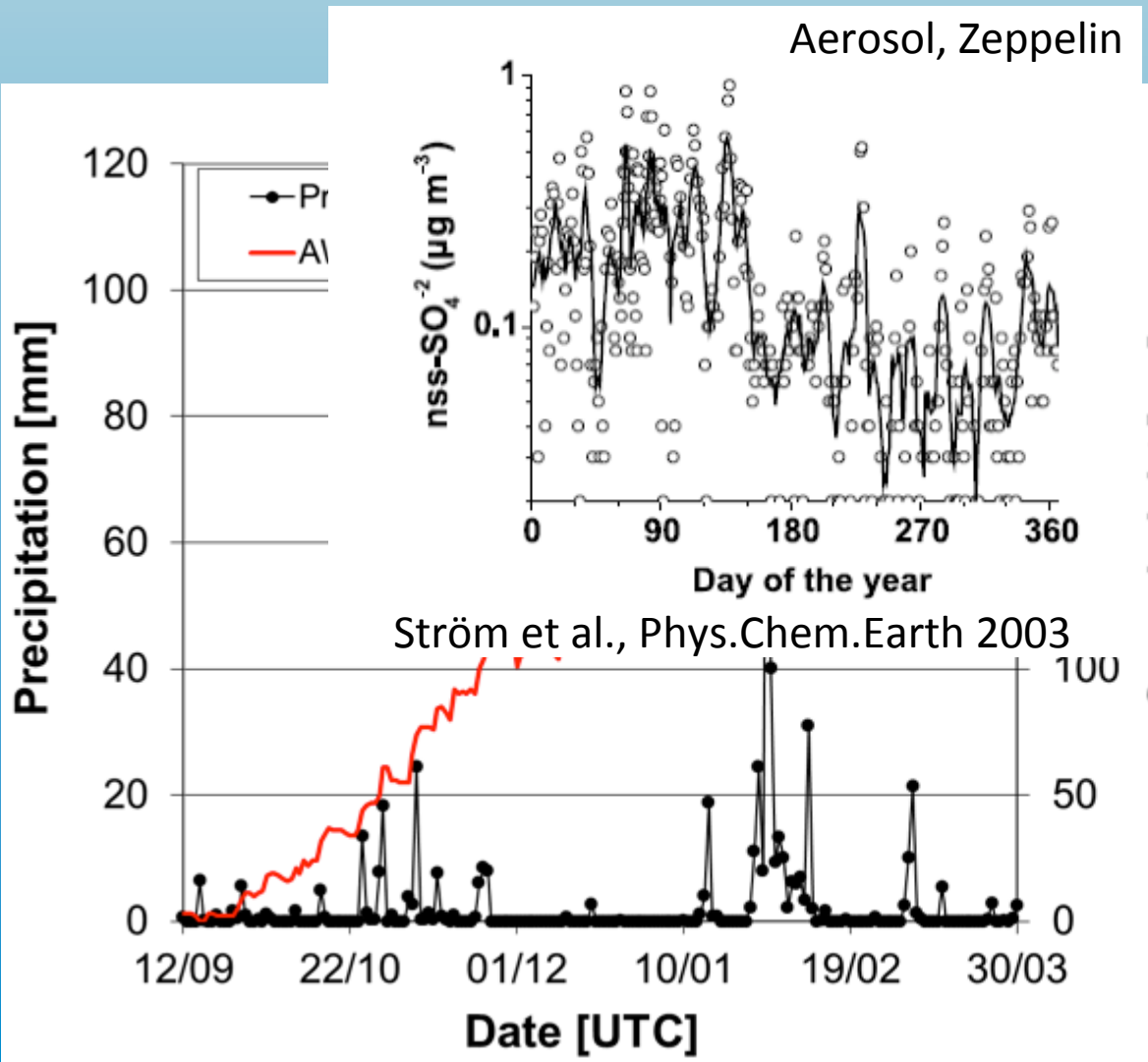
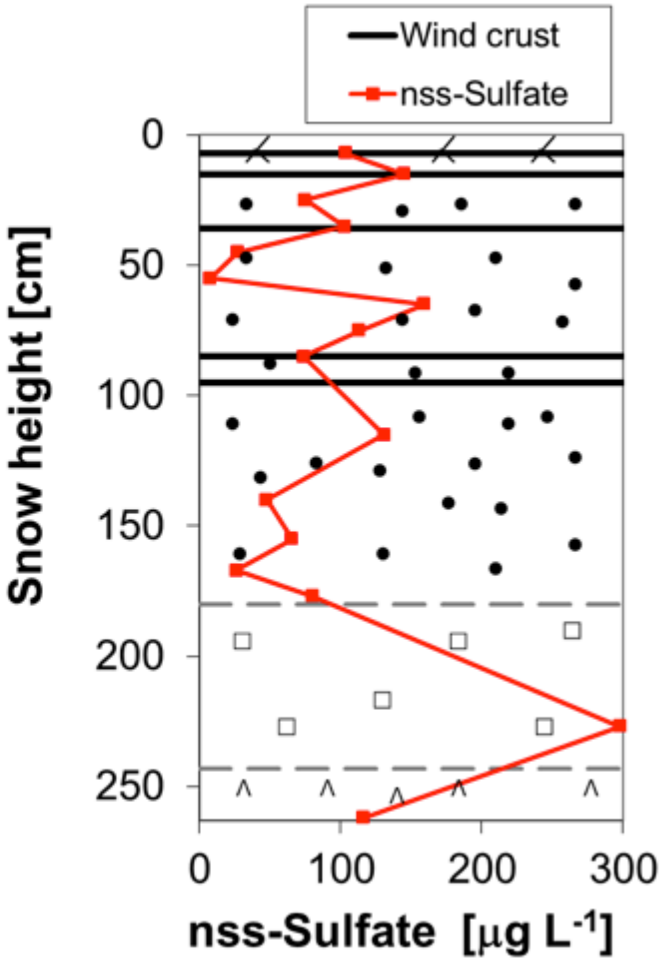
Reconstruction of atmospheric concentrations using chemical profiles combined with snowpack modeling





AWS data courtesy of F. Obleitner (University Innsbruck)

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Set-up of black carbon analysis in snow samples

Compressed air → Mass flow controller

Purge air ~0.9 l/min

Self-aspiration ~67 ul/min

Jet-nebulizer

aerosol sample

~0.9 l/min

~0.12 l/min

Exhaust

SP2 + PC

Liquid sample

Liquid drain

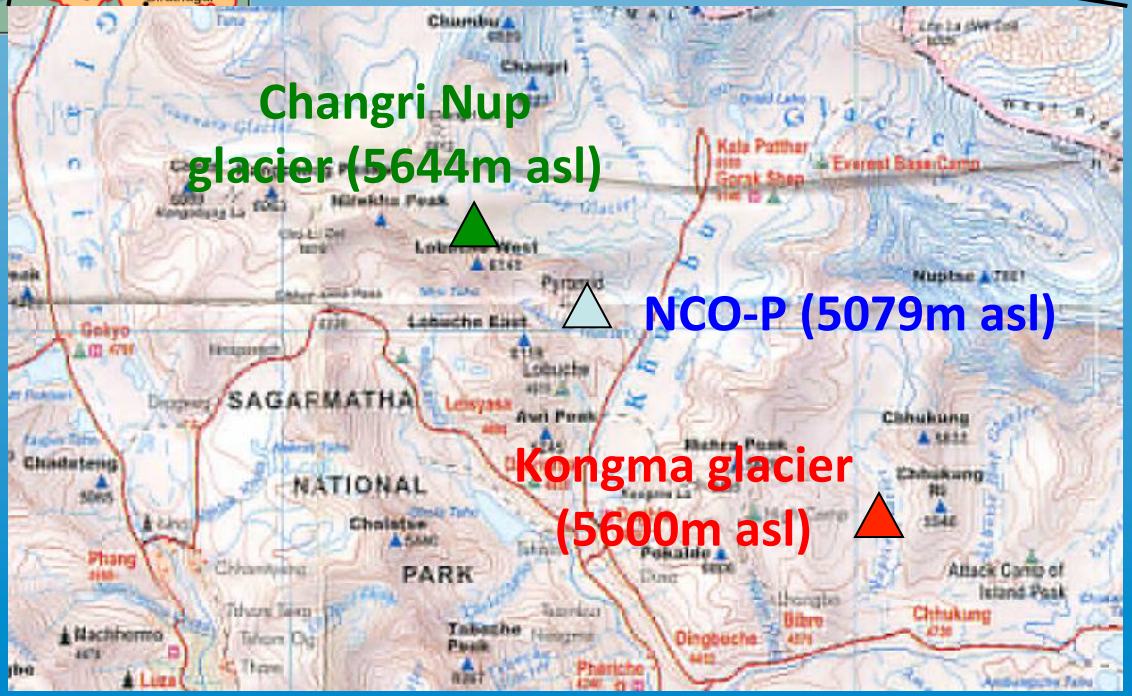
-Polypropylene tube
-Quick melting in warm water
-15 min of sonication

=> Nebulizing efficiency: 56 %

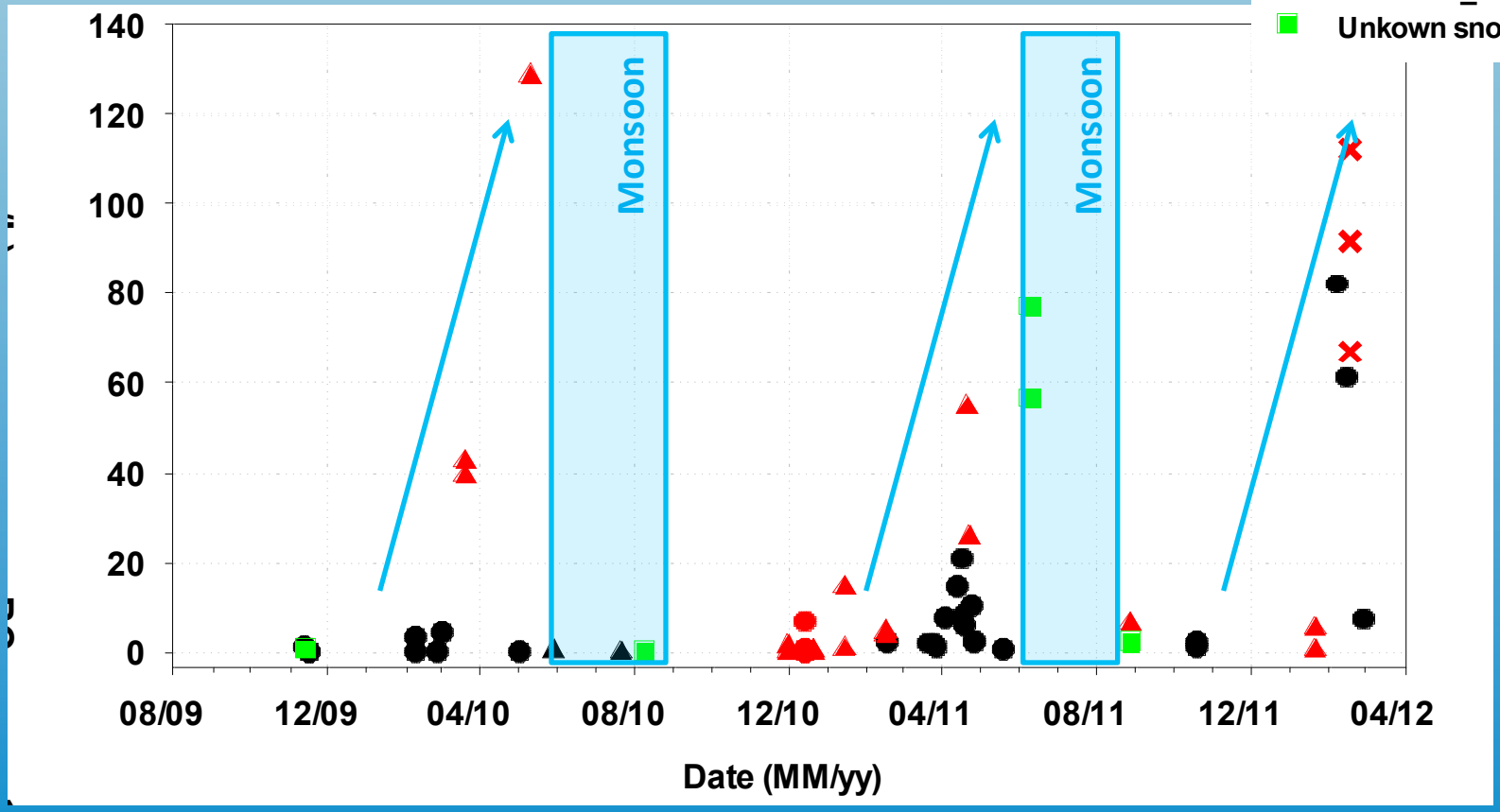
Measurements of black carbon in Himalaya snow

- Period: Nov. 2009 - Feb. 2012
- Location: Khumbu valley
1. NCO-P (5079m asl)
2. Changri Nup glacier (5644m asl)
3. Kongma glacier (5600m asl)

- Number of samples: 56
(fresh snow: 28,
old snow:23,
unknown: 5)



Black carbon concentrations in fresh and surface snow samples from the Khumbu valley



- Annual cycle very similar to atmospheric BC: fresh and old snow
- BC in old snow tends to be higher than in fresh snow during the same season

=> Dry deposition during pre-monsoon is important

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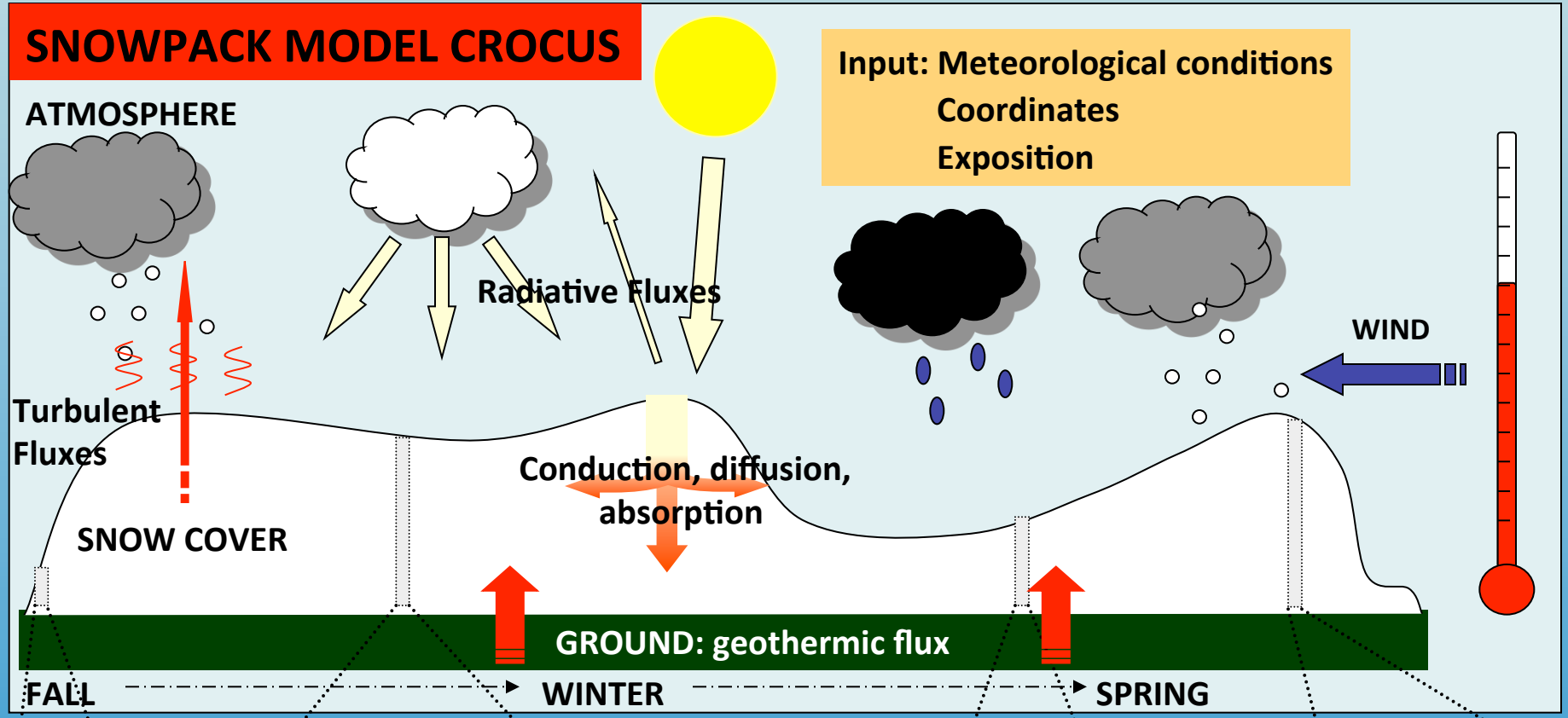
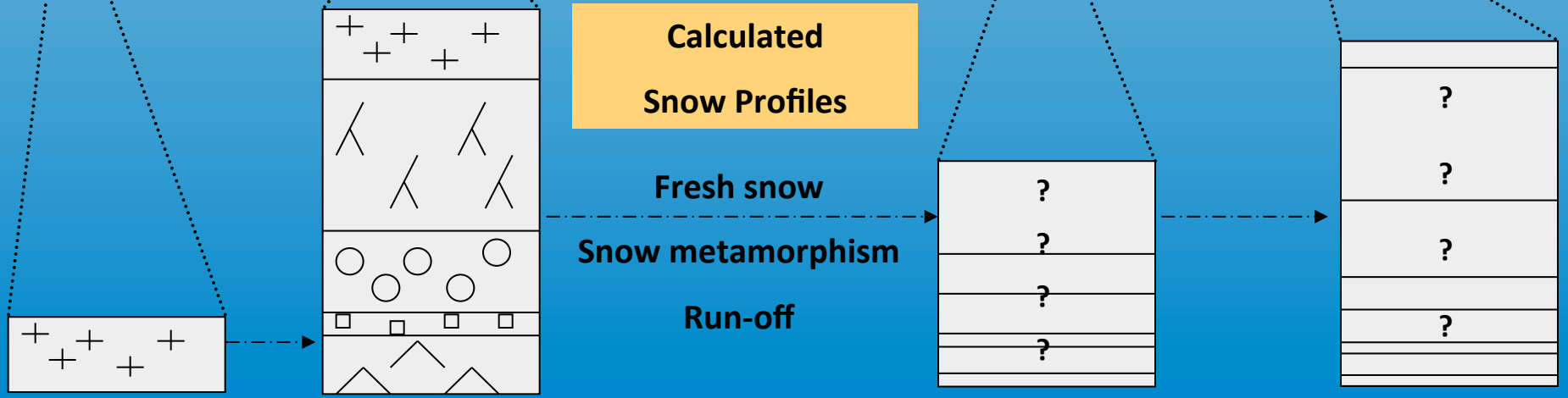
SNOWPACK MODEL CROCUS





Brun et al., J.Glaciol. 1989, 1992

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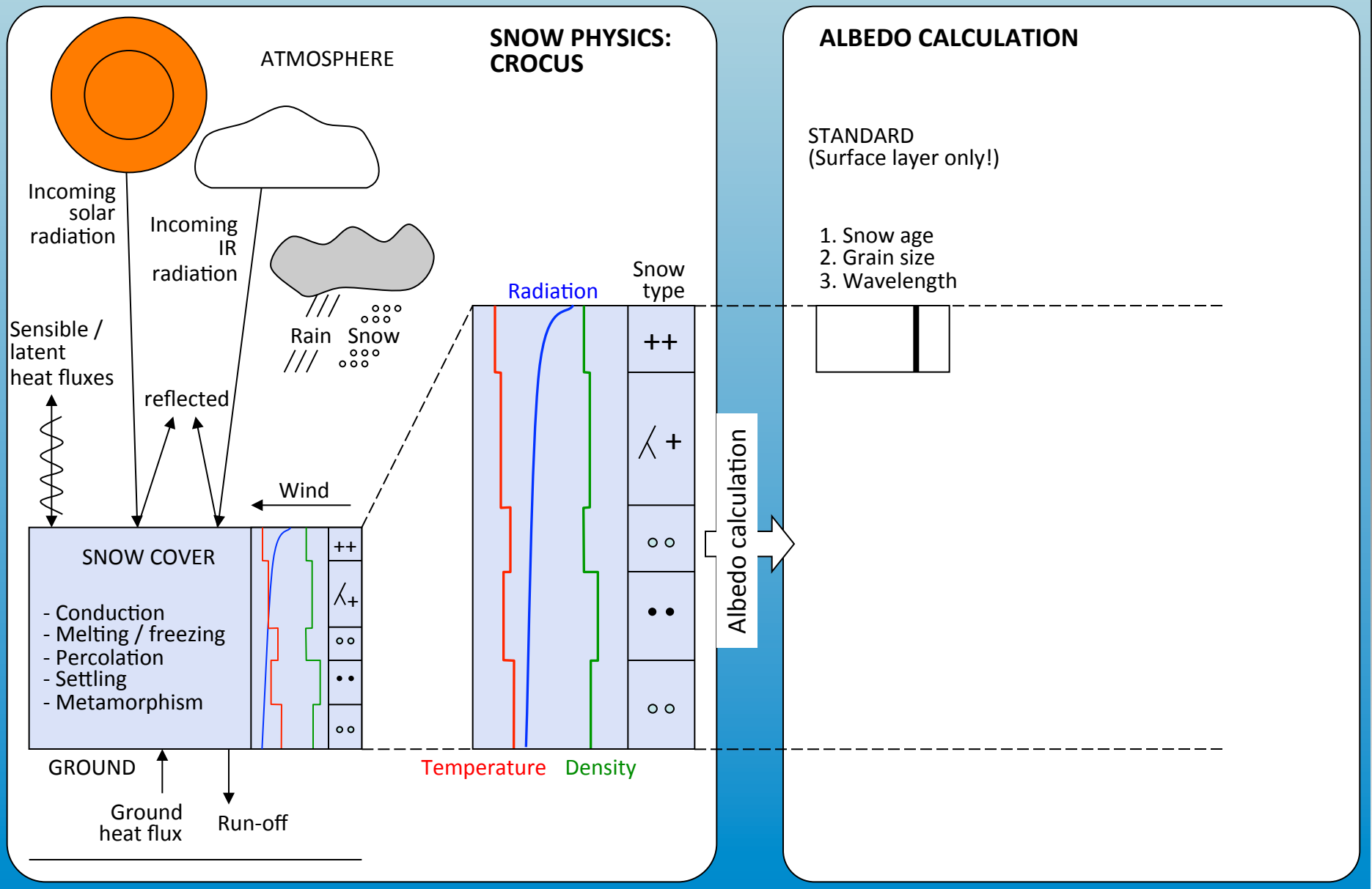
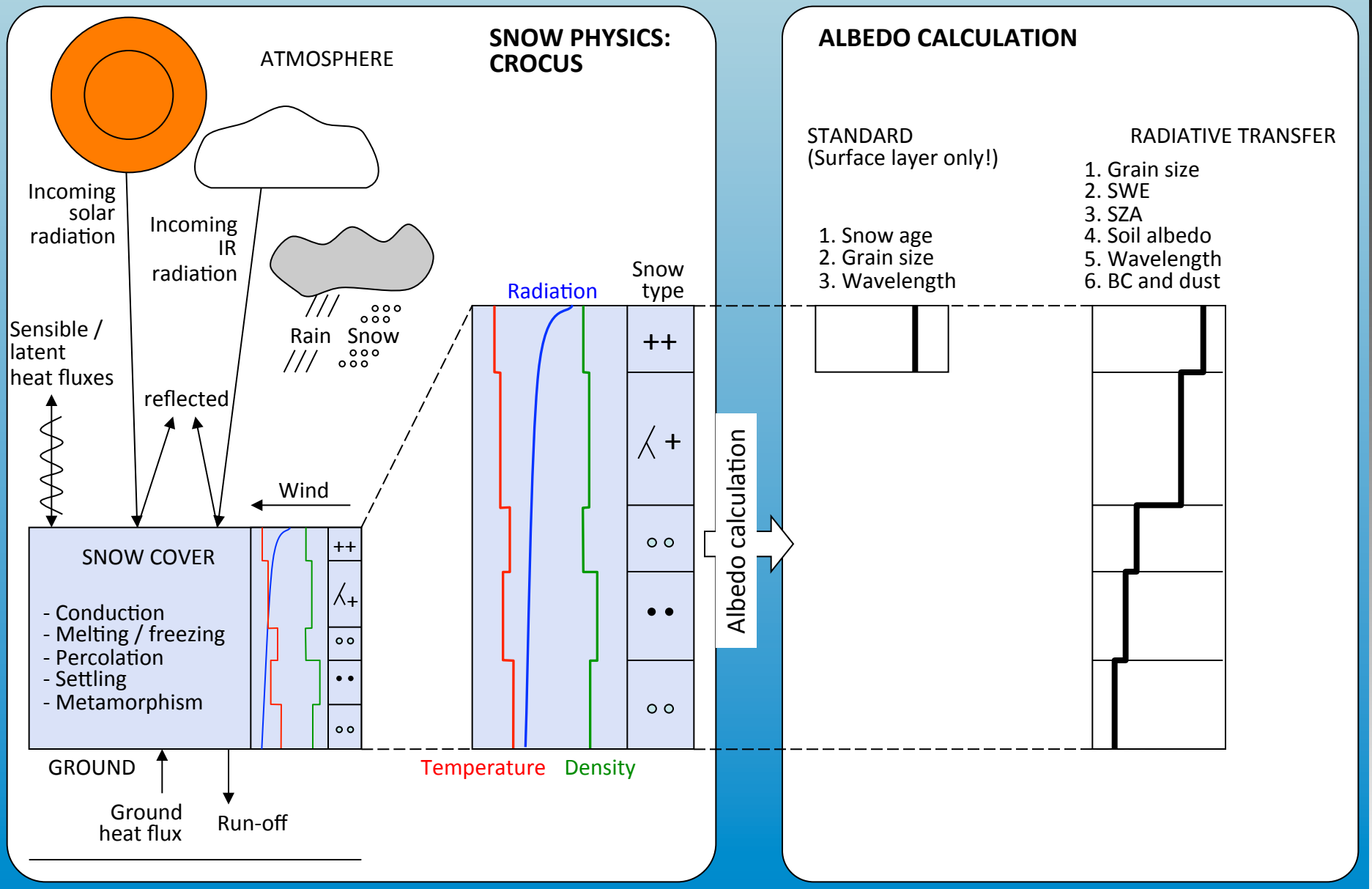
Albedo in the CROCUS snowpack model

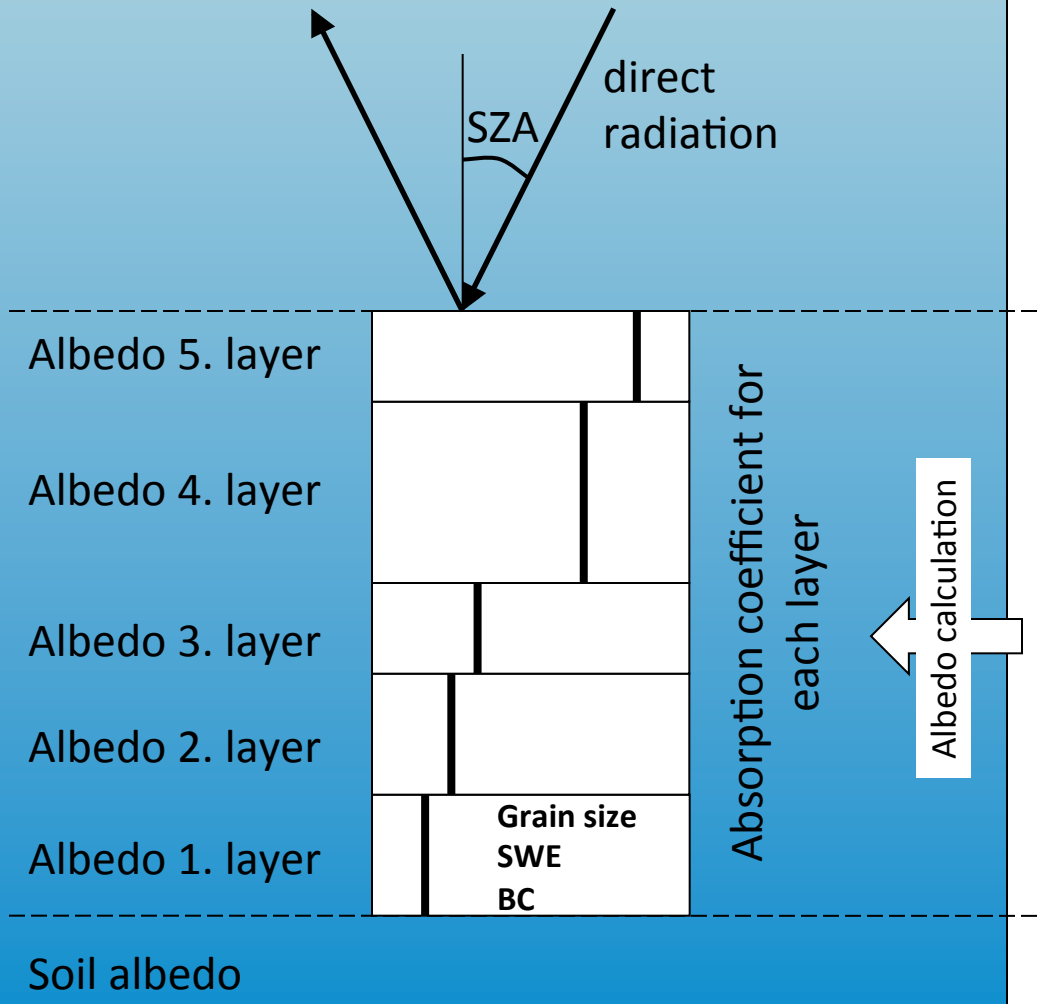


Albedo in the CROCUS snowpack model



Krinner et al., Clim.Dyn. 2006

Albedo modeling in a 1-D snowpack model based on radiative transfer



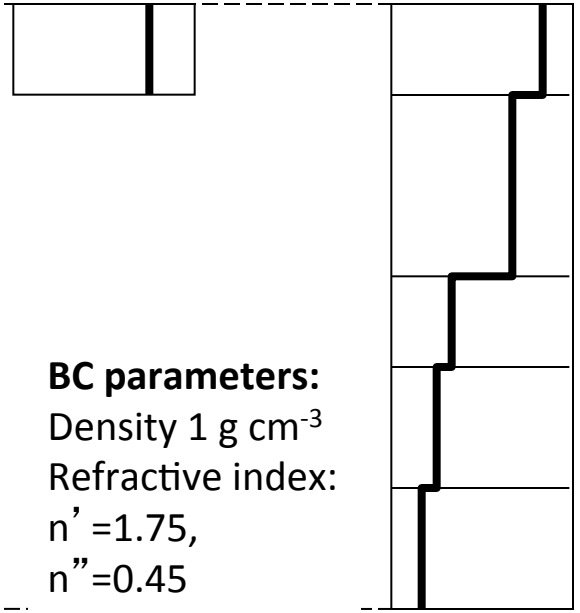
ALBEDO CALCULATION

STANDARD
(Surface layer only!)

1. Snow age
2. Grain size
3. Wavelength

RADIATIVE TRANSFER

1. Grain size
2. SWE
3. SZA
4. Soil albedo
5. Wavelength
6. BC and dust



BC parameters:
Density 1 g cm^{-3}
Refractive index:
$n' = 1.75$,
$n'' = 0.45$
Mass mean diameter 85 nm
Log-normal size distribution

Warren and Wiscombe, J.Atmos.Sci. 1980

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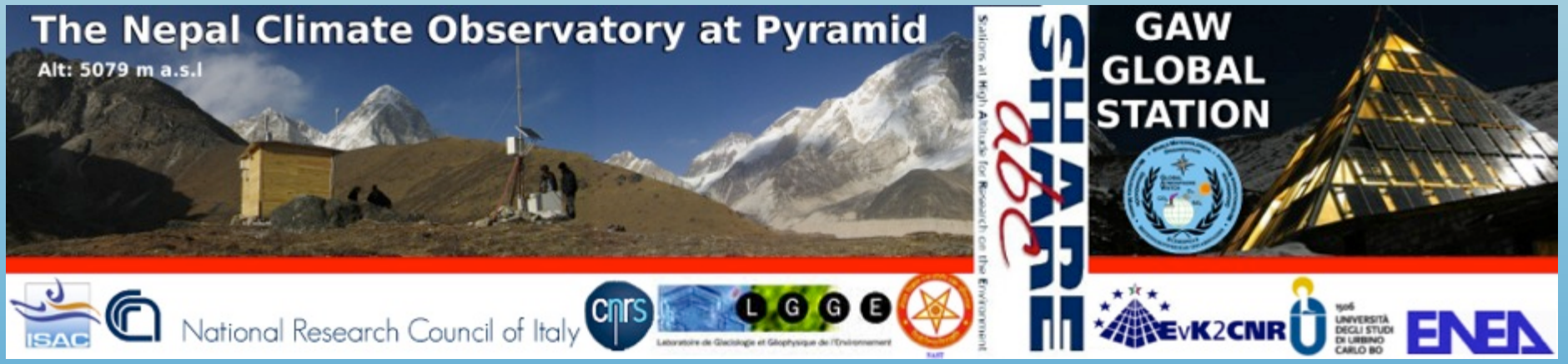
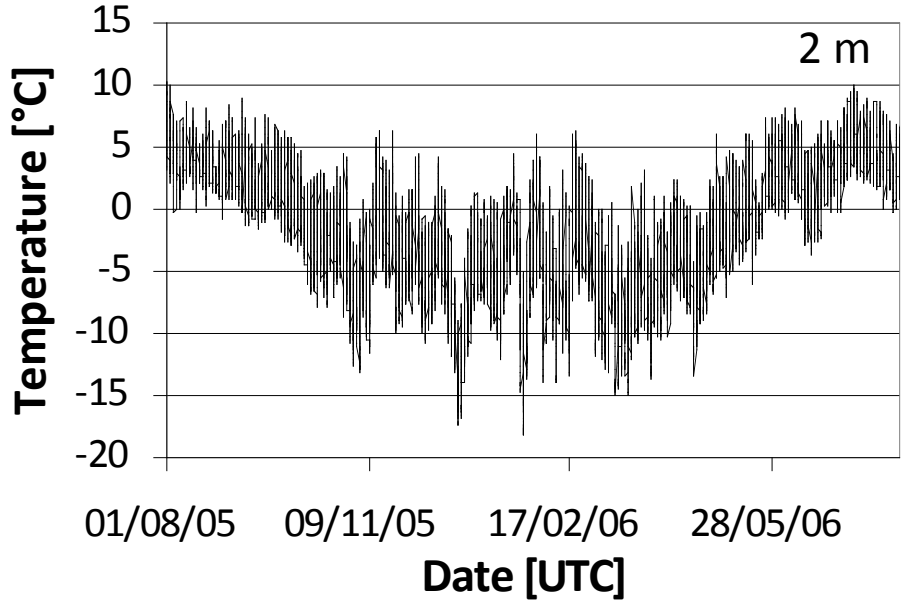
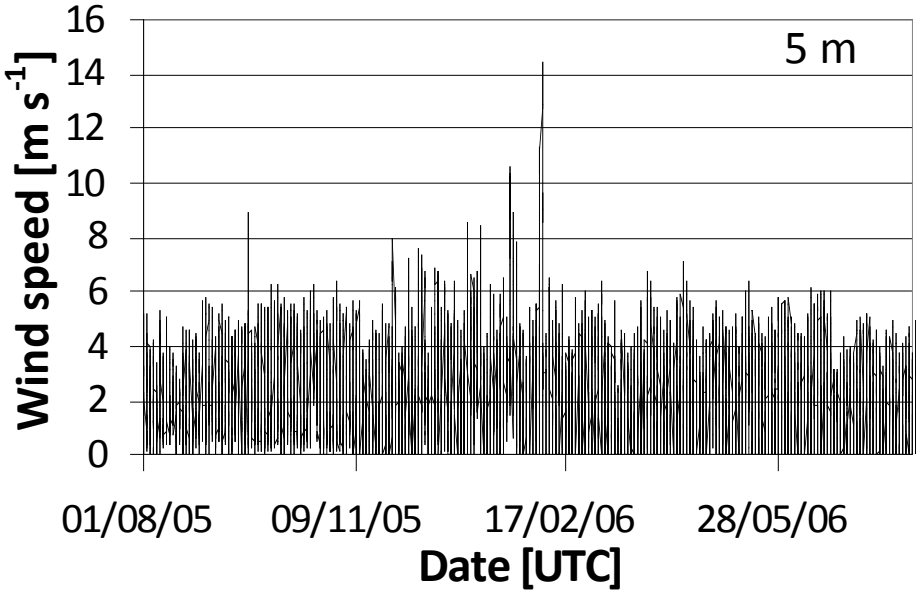
Application of the snowpack model to the Himalayas







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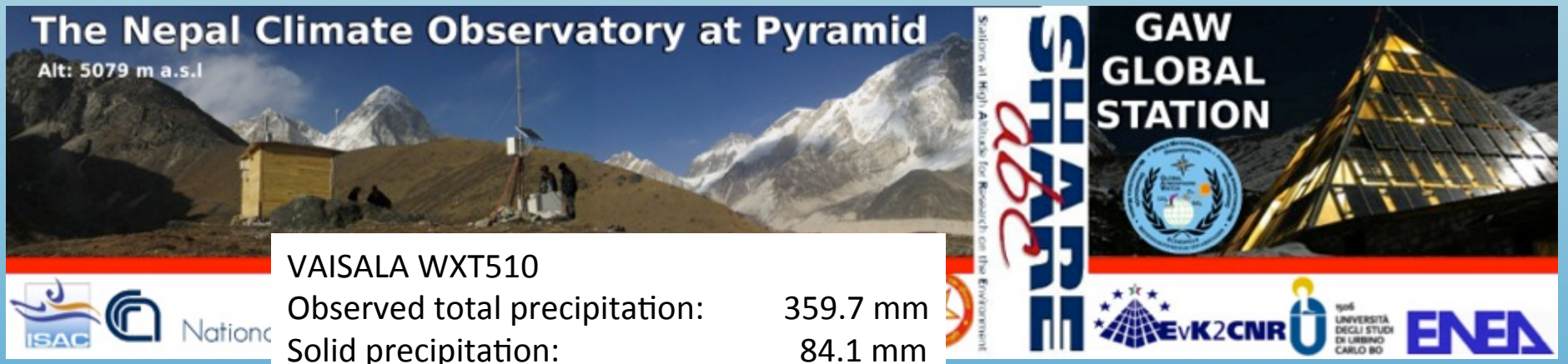
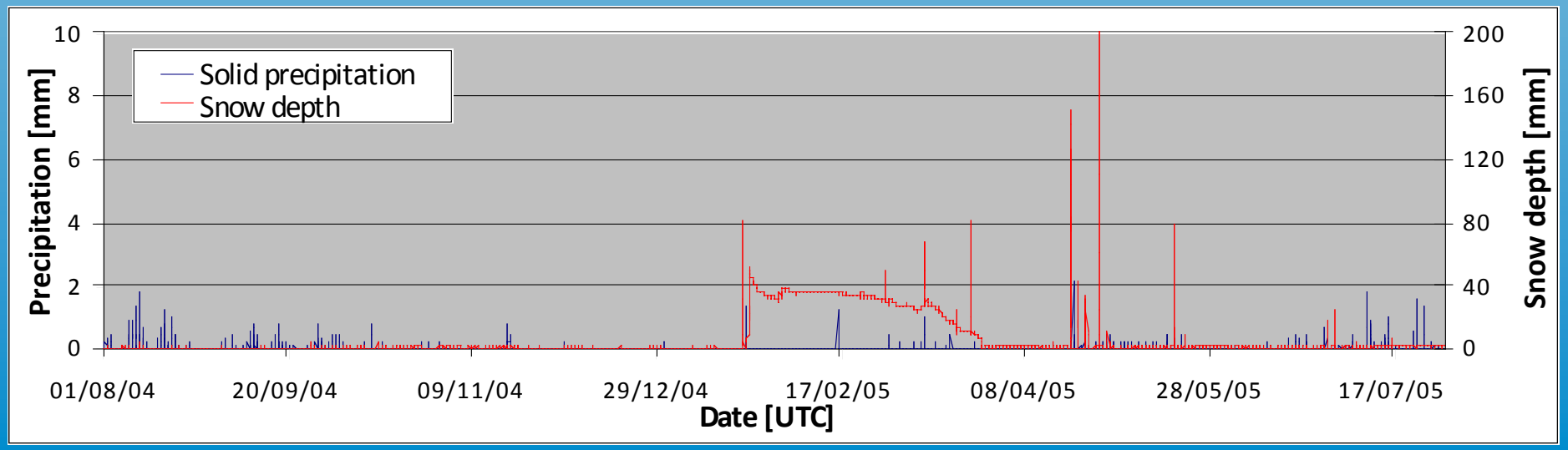
Observed precipitation at Pyramid (2004 – 2005)



VAISALA WXT510

Observed total precipitation:	359.7 mm
Solid precipitation:	84.1 mm

Basin-wide average from run-off: ~2000 mm



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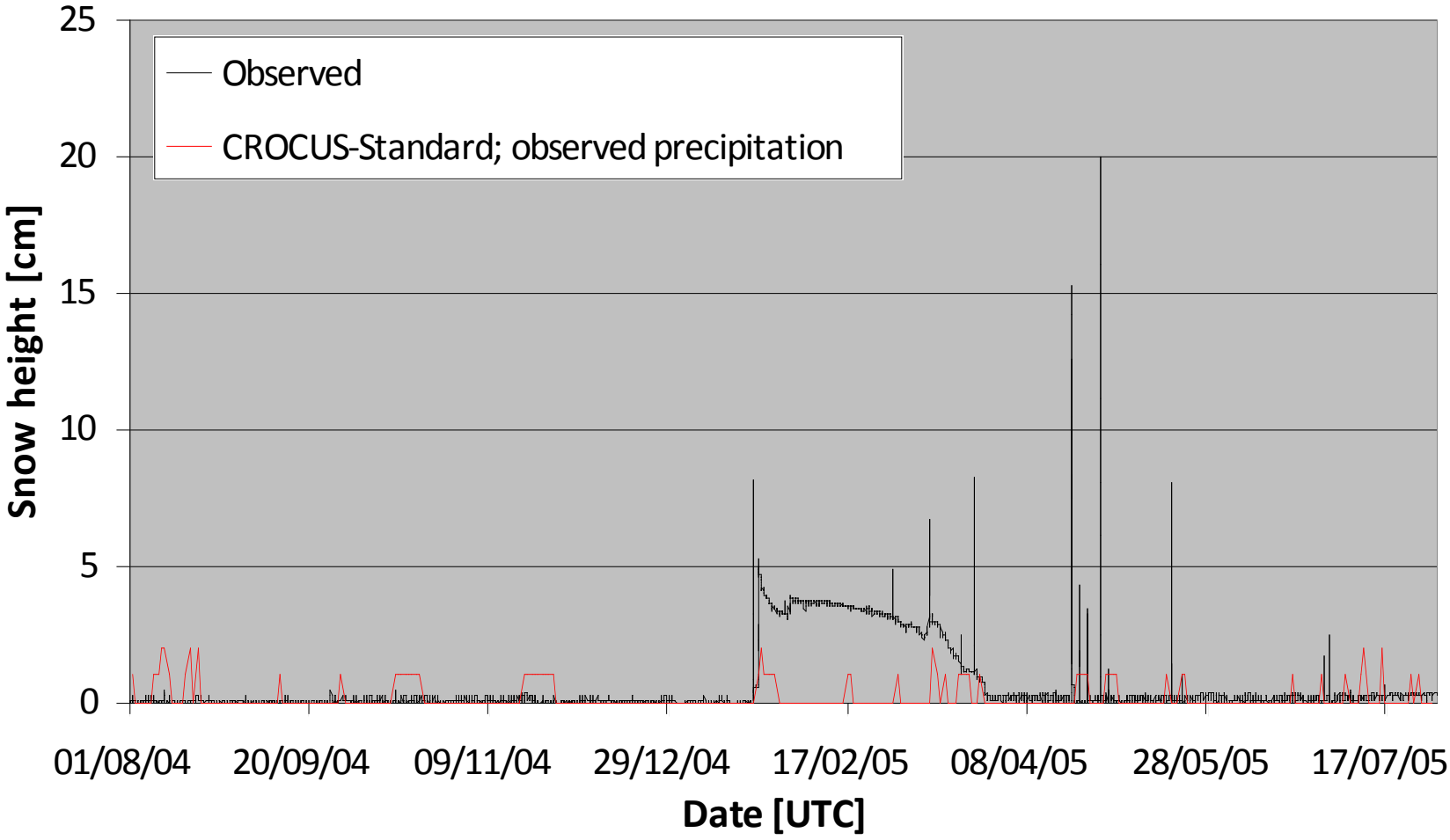
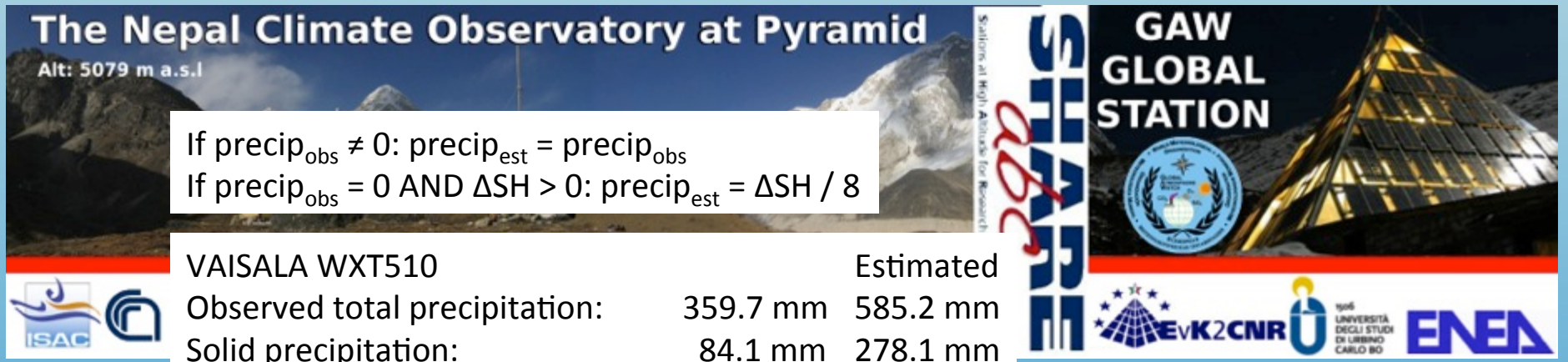
Comparison of observed and simulated snow height at PYRAMID using observed precipitation



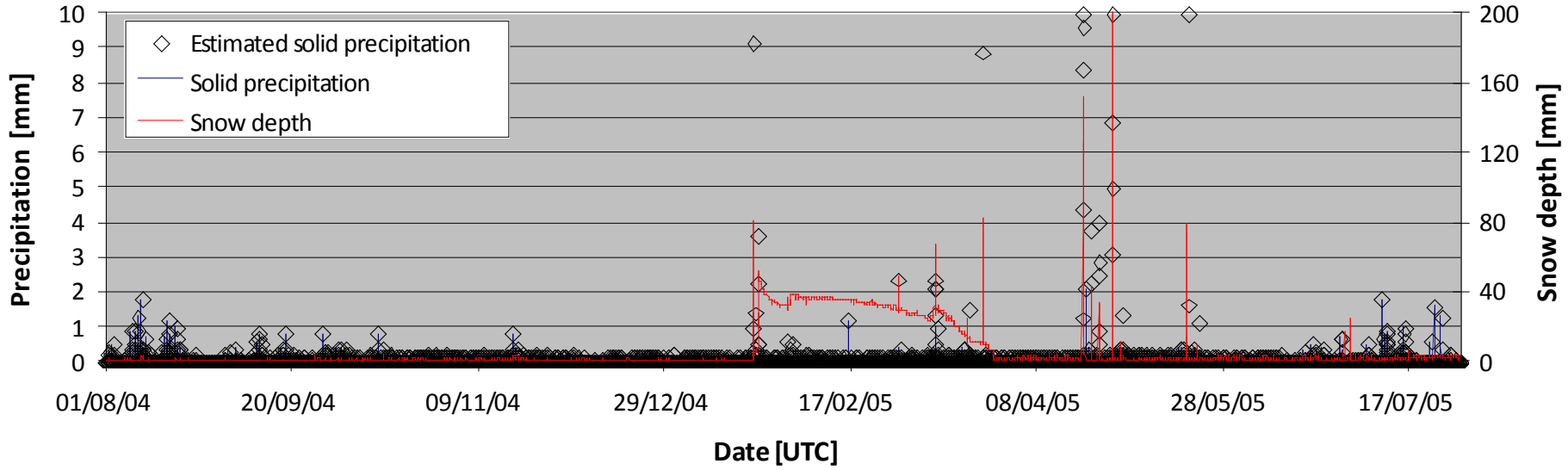
Estimated precipitation at Pyramid (2004 – 2005)



If $precip_{obs} \neq 0$: $precip_{est} = precip_{obs}$
If $precip_{obs} = 0$ AND $\Delta SH > 0$: $precip_{est} = \Delta SH / 8$

VAISALA WXT510		Estimated
Observed total precipitation:	359.7 mm	585.2 mm
Solid precipitation:	84.1 mm	278.1 mm

Basin-wide average from run-off: ~2000 mm



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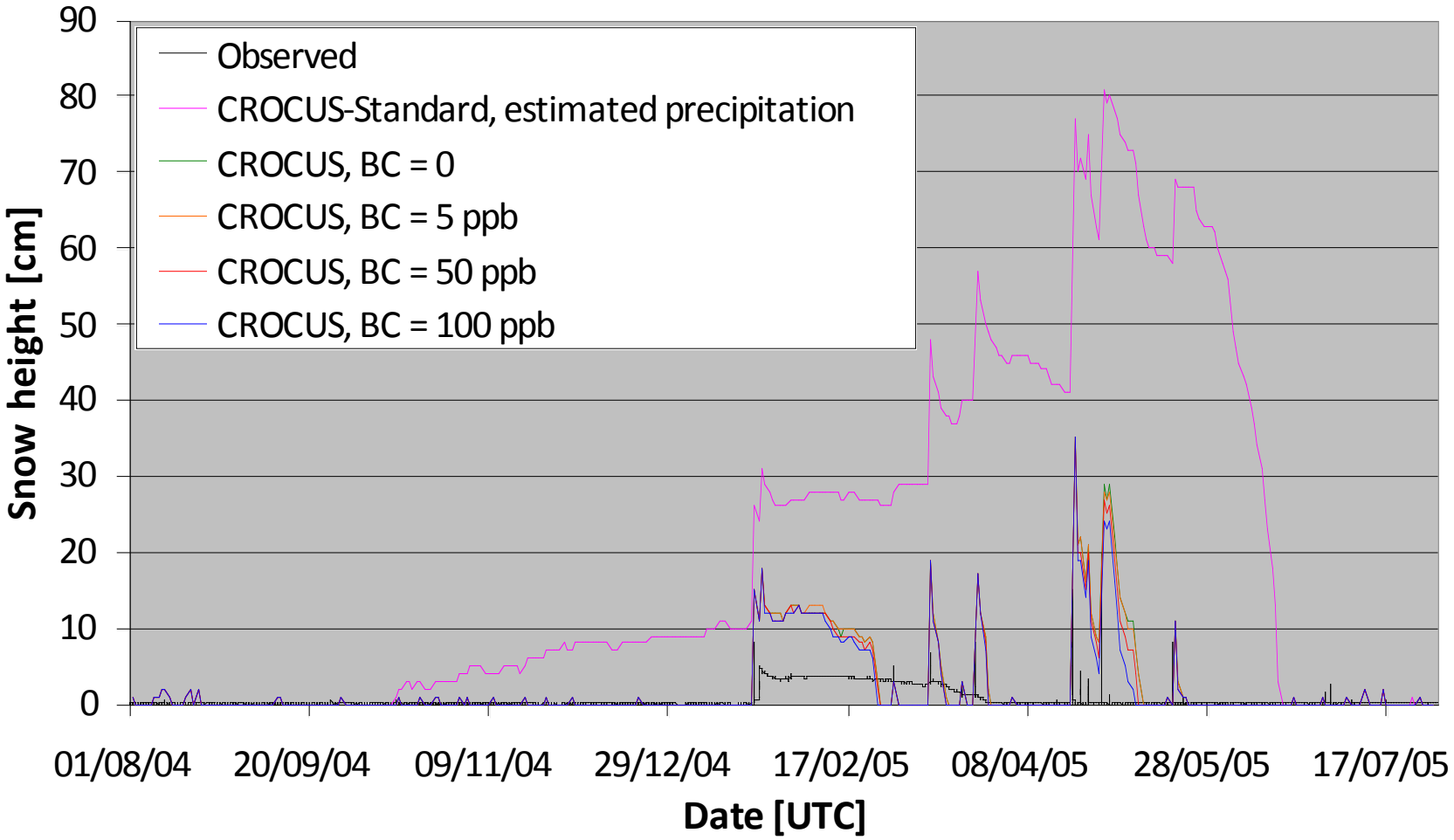
Comparison of observed and simulated snow height at PYRAMID using estimated precipitation (2004 – 2005)



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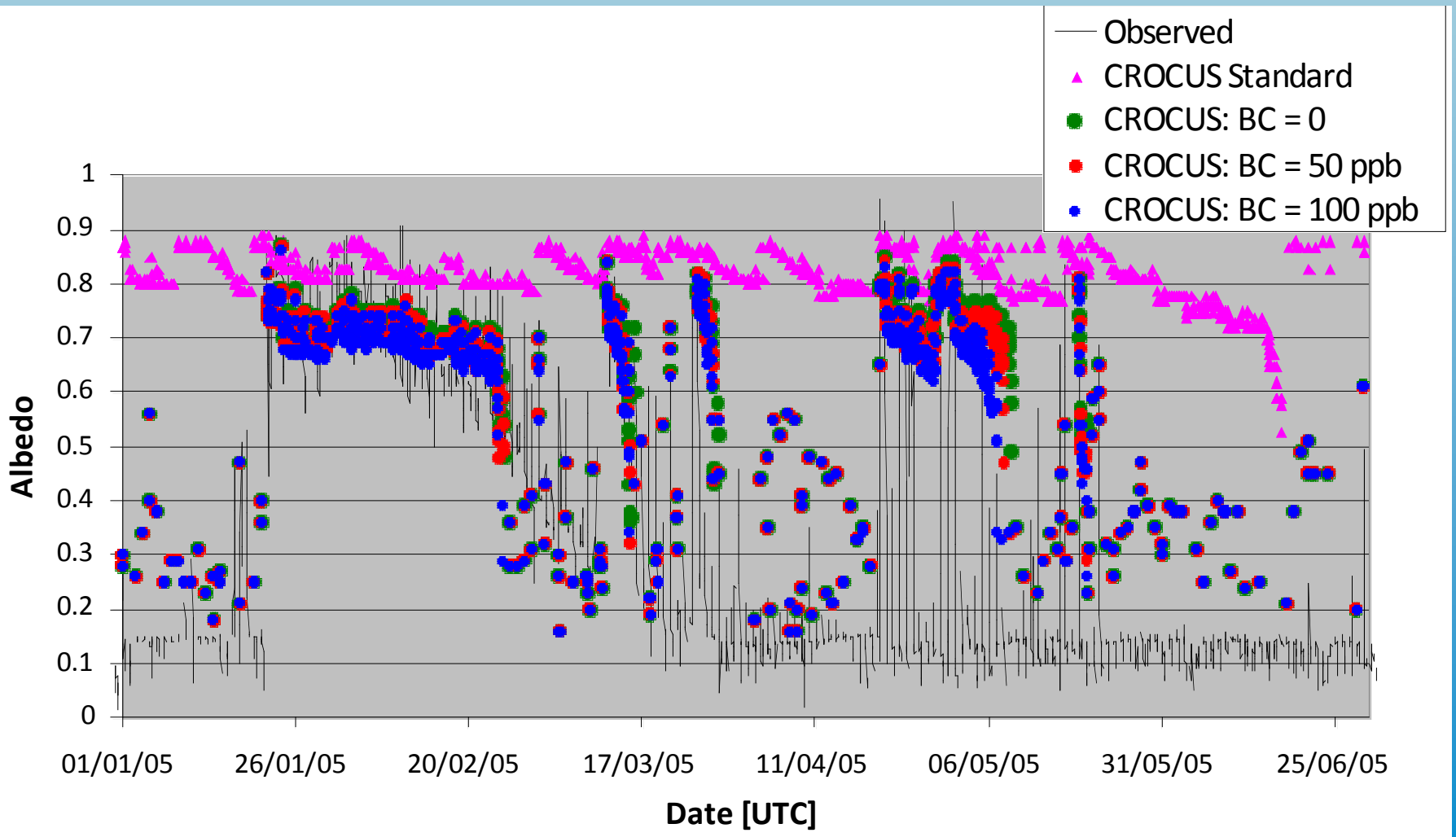
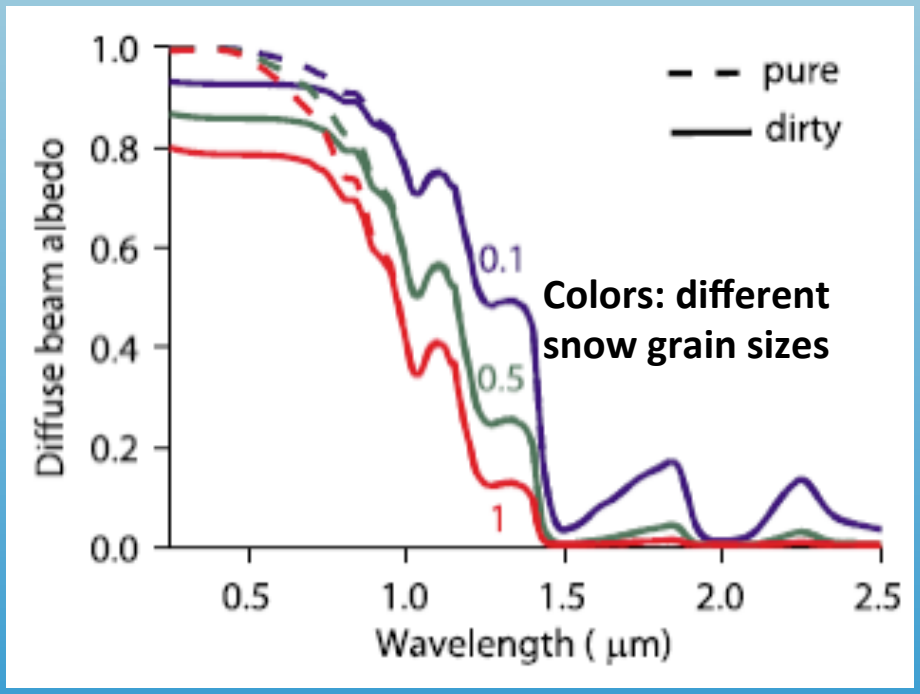
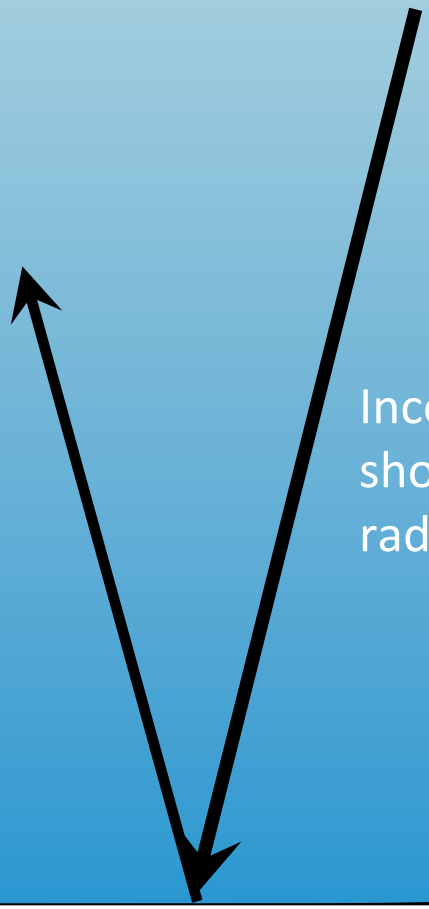
Comparison of observed and simulated albedo at PYRAMID (2004 – 2005)

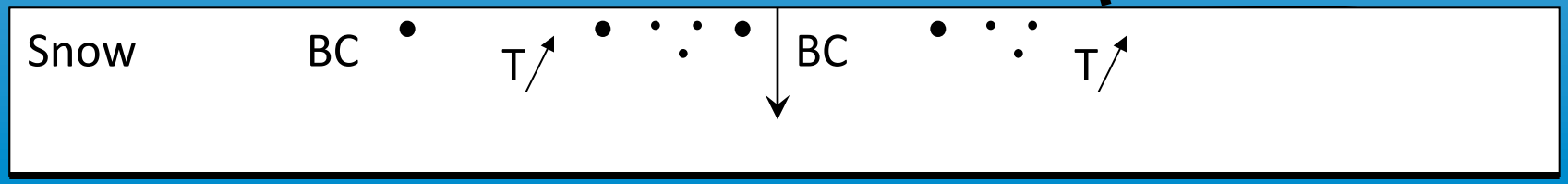


Effect of black carbon in snow on albedo and local climate



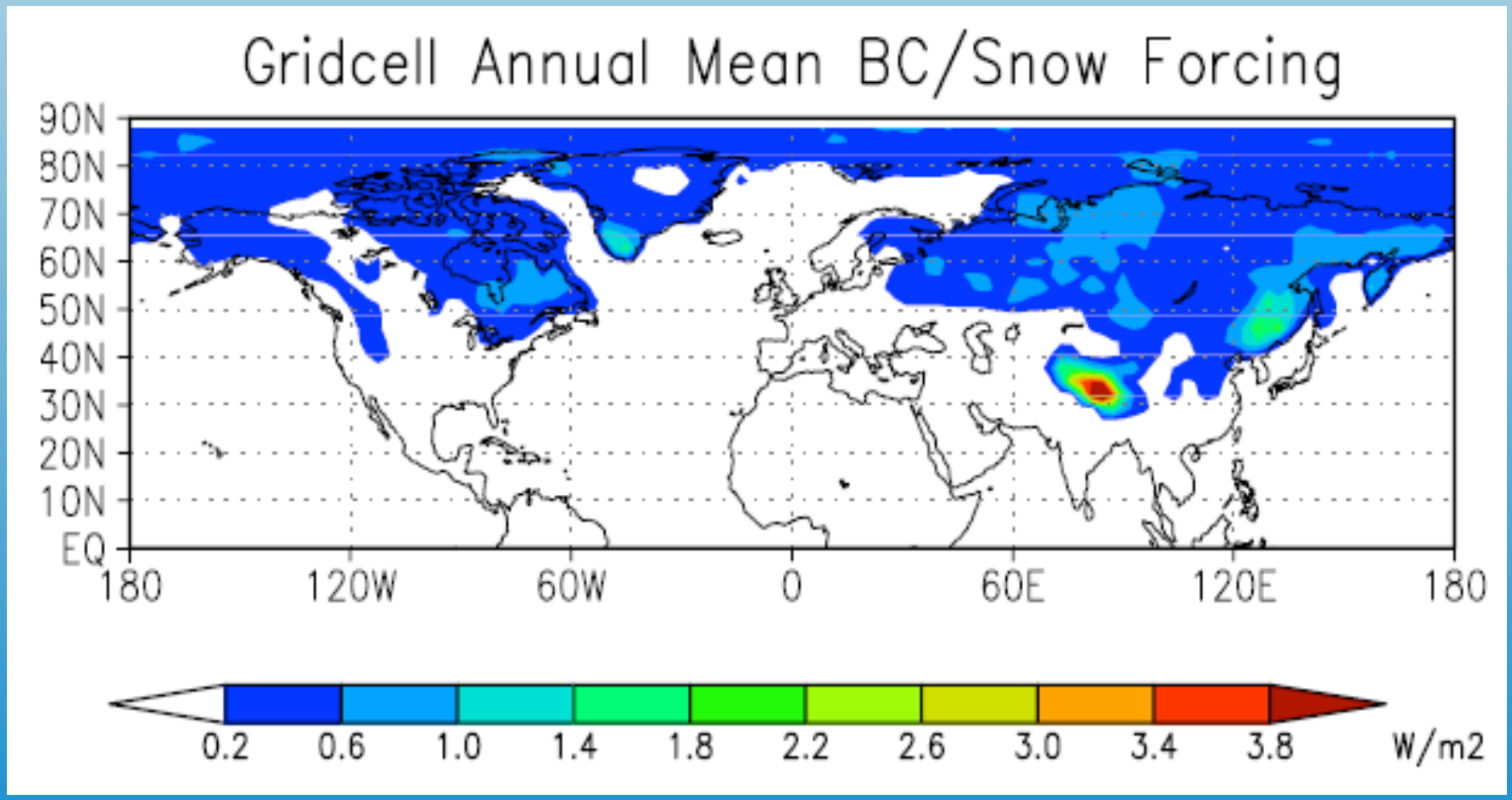
Gardner et al., 2010





Winter Spring Summer

Radiative forcing due to black carbon in snow in a global model



Flanner et al., J.Geophys.Res. 2007

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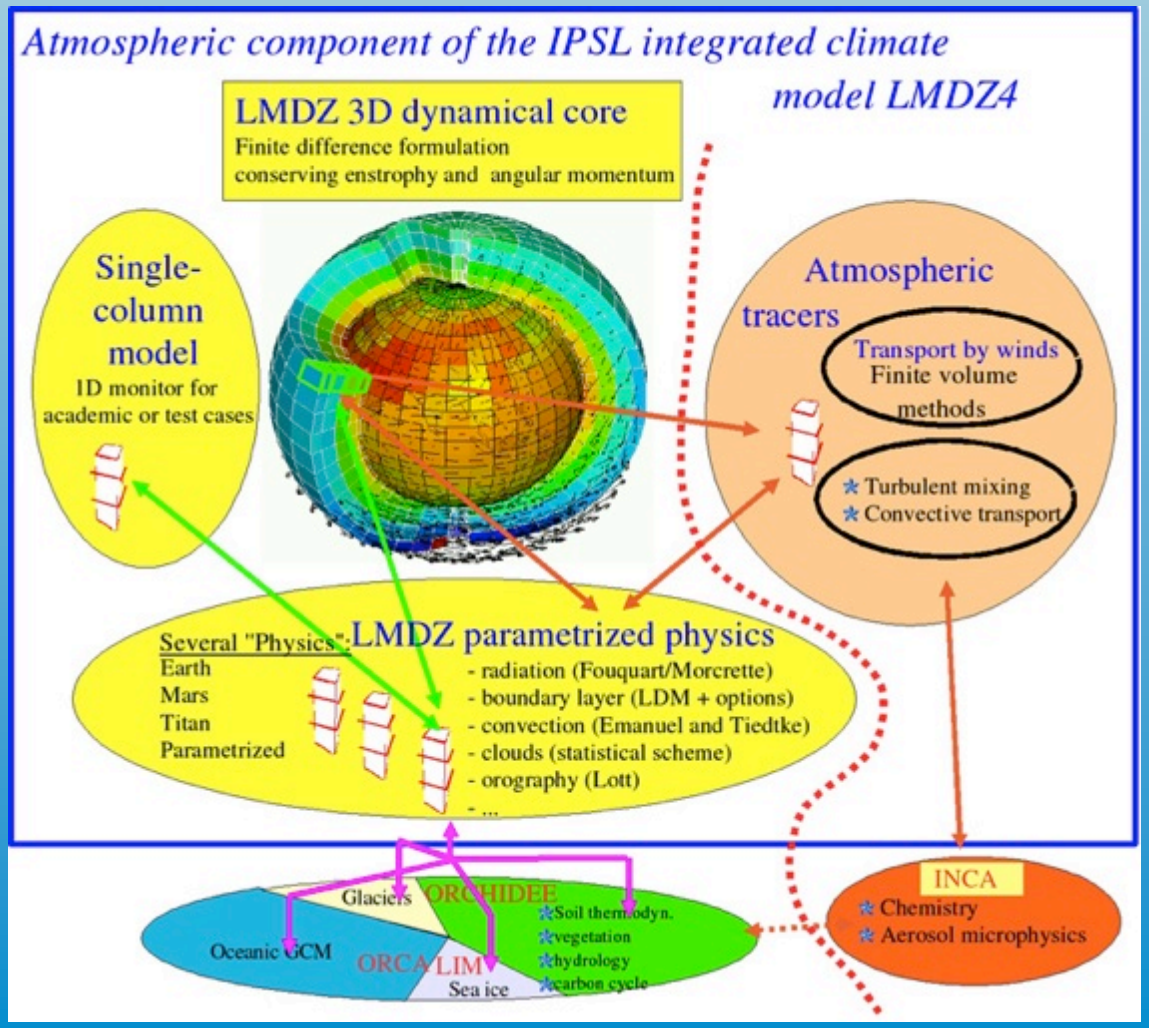
Global modeling of black carbon in the snow with the global climate model LMDZ

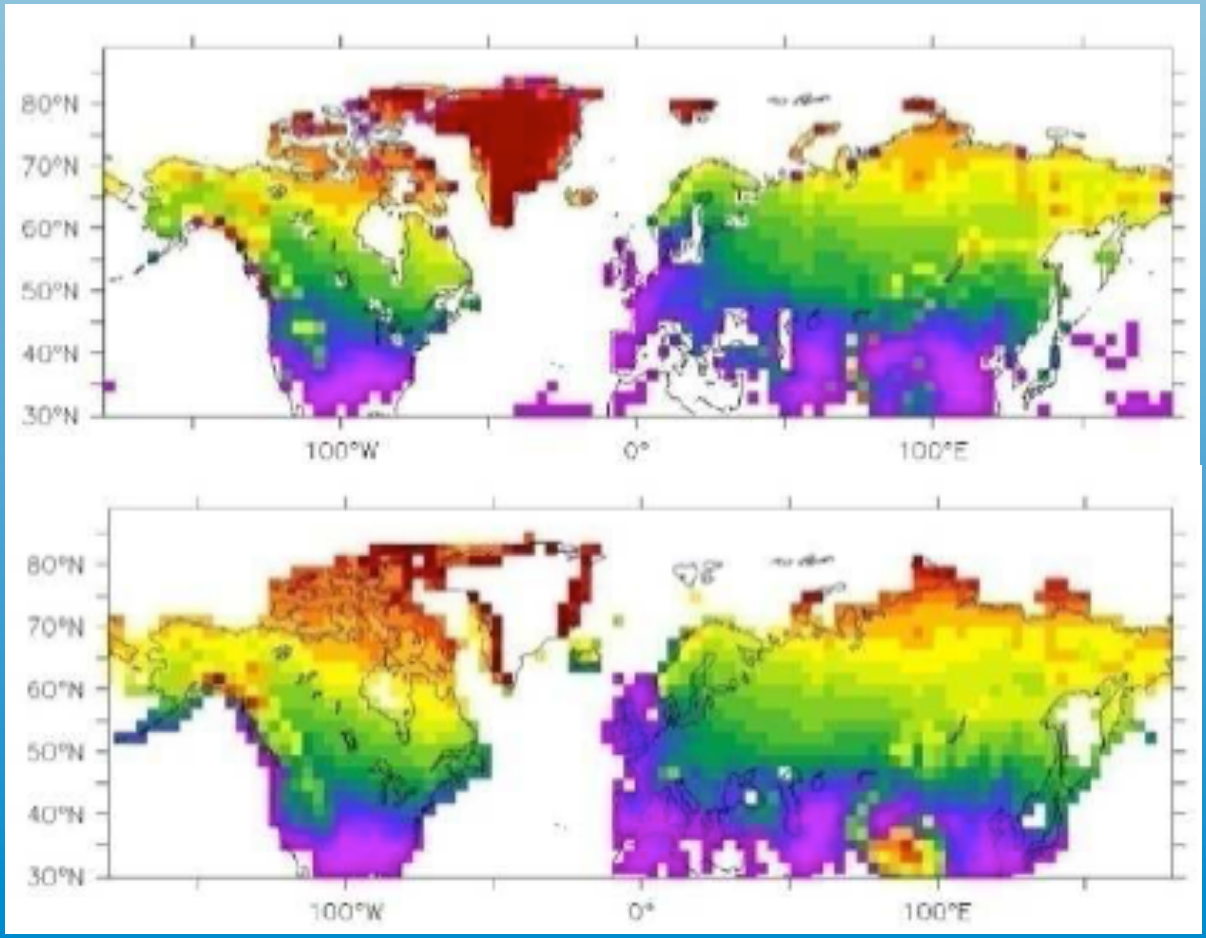
- **11-year simulation for 1998–2008 (present day)**
- **11-year simulation for 2050–2060 with emission scenario RCP8.5 (no climate mitigation policies, total anthropogenic forcing in 2100 of ~8.5 W m^{-2})**
- **Simplified snow model (2 layers) including radiative transfer according to CROCUS**

Sim.	Resolution	Snow albedo
S1	96x95x19	Present day with BC in snow
SB1	96x95x19	Present day no BC in snow
S2	96x95x19	Scenario with BC in snow



Ménégoz et al., Cryosphere Discuss. 2012

Observed and simulated number of days per year with snow on the ground



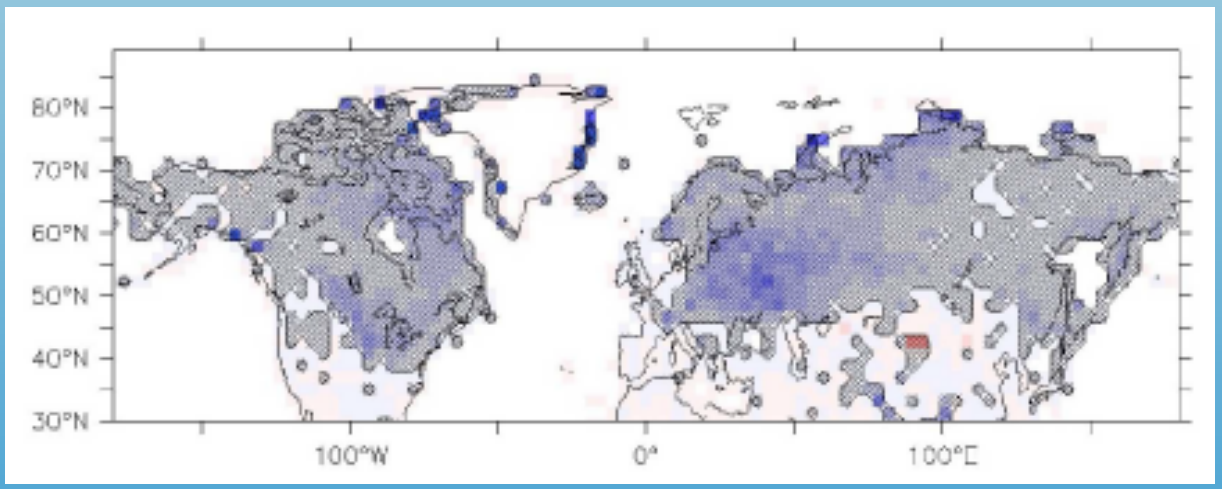
Observations

Present day
No BC in snow

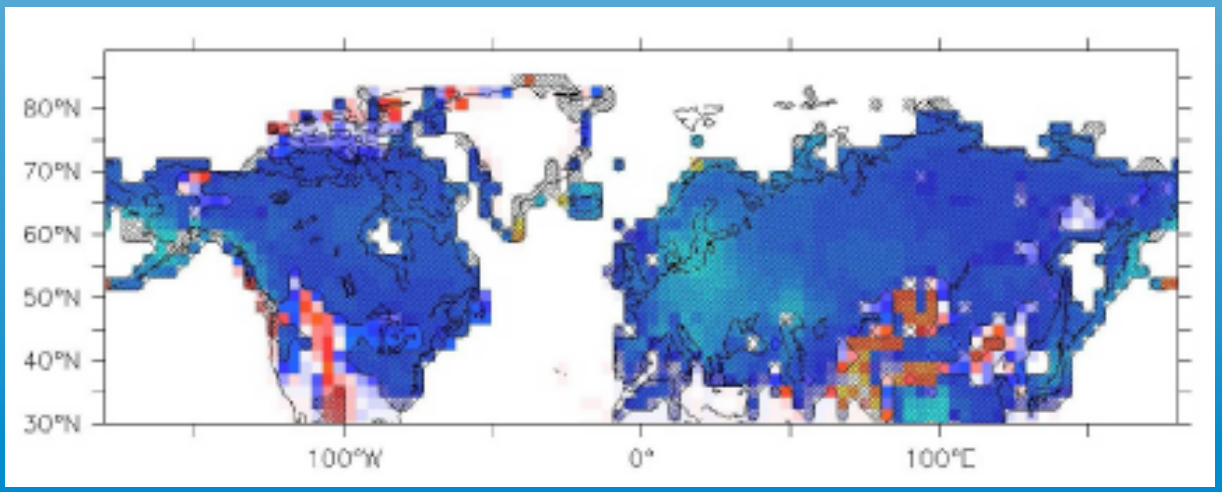
Ménégoz et al., Cryosphere Discuss. 2012

Laboratoire de Glaciologie et Géophysique de l'Environnement, Grenoble, France

Reduction in number of days per year with snow on the ground including BC and for 2050-2060



Present day
impact of BC in the snow



Scenario 2050 - 2060
including BC in the snow

Ménégoz et al., Cryosphere Discuss. 2012

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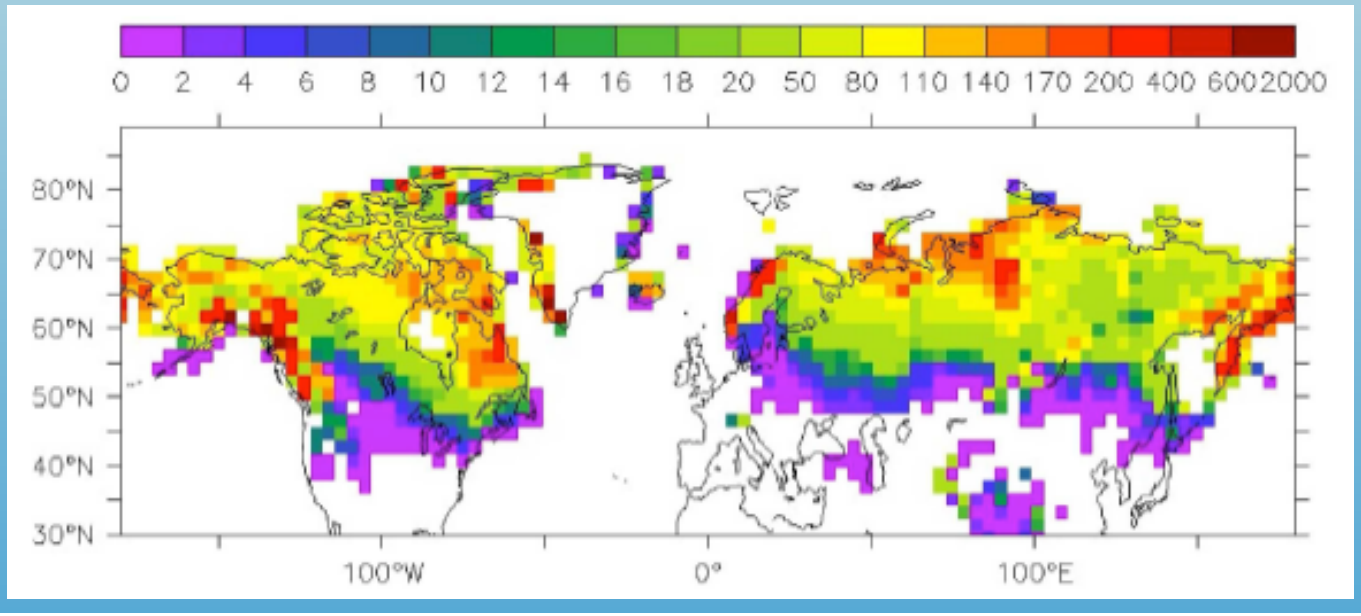
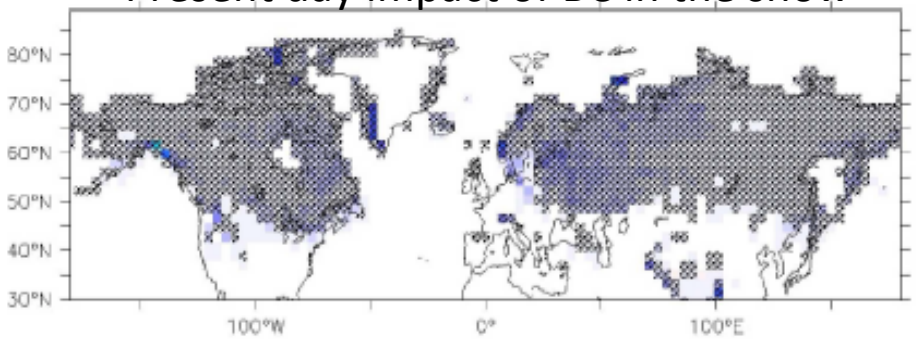
Average of present day springtime (April to June) SWE (mm) and reduction due to BC (present day, scenario)

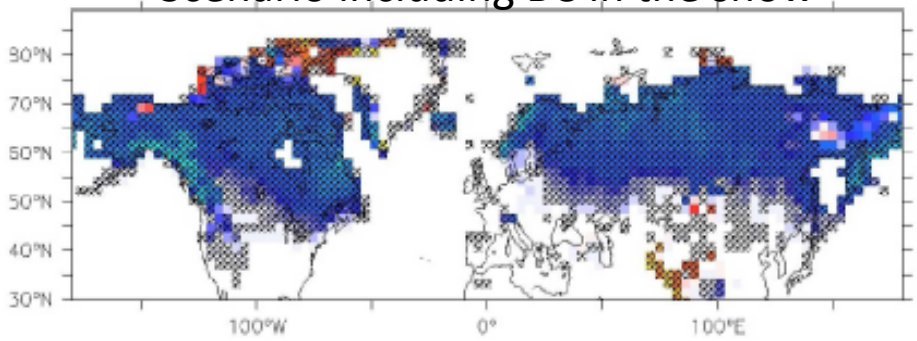


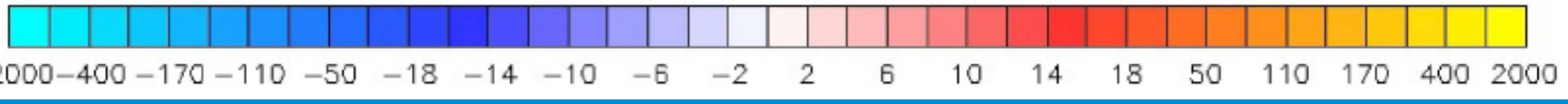
Present day,
no BC in snow

Present day impact of BC in the snow



Scenario including BC in the snow





Ménégoz et al., Cryosphere Discuss. 2012

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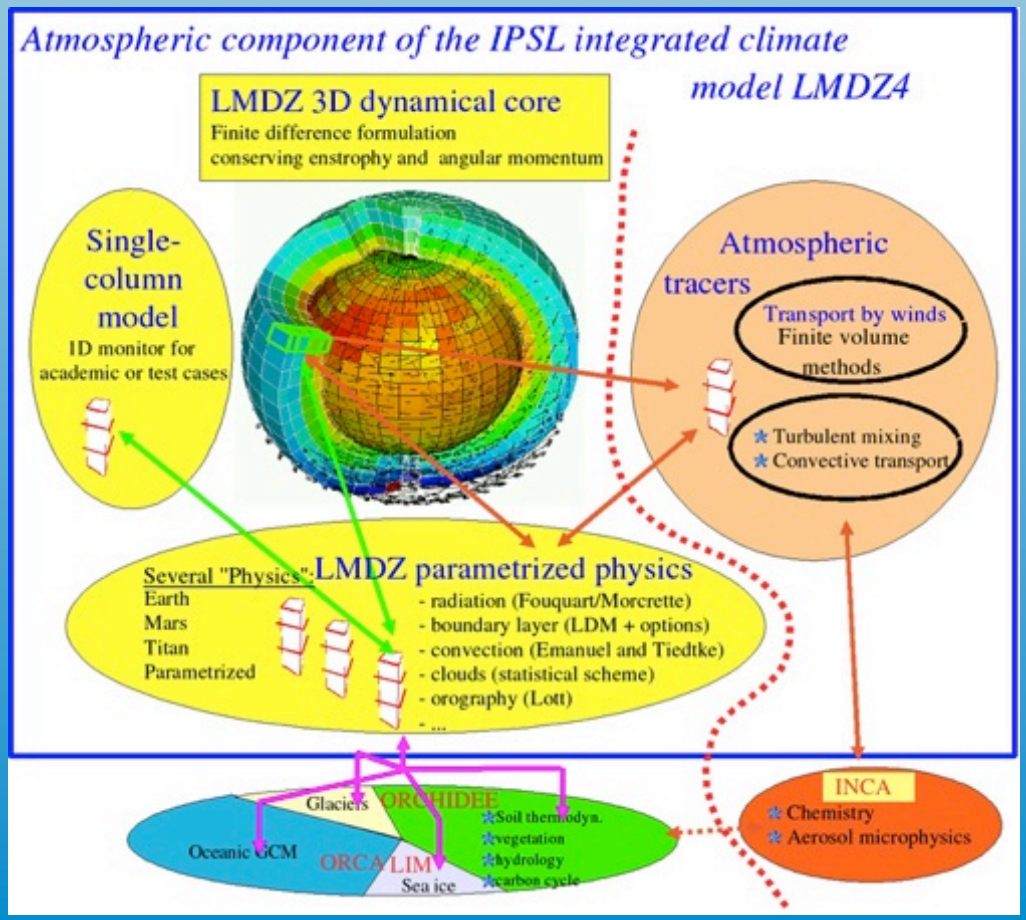
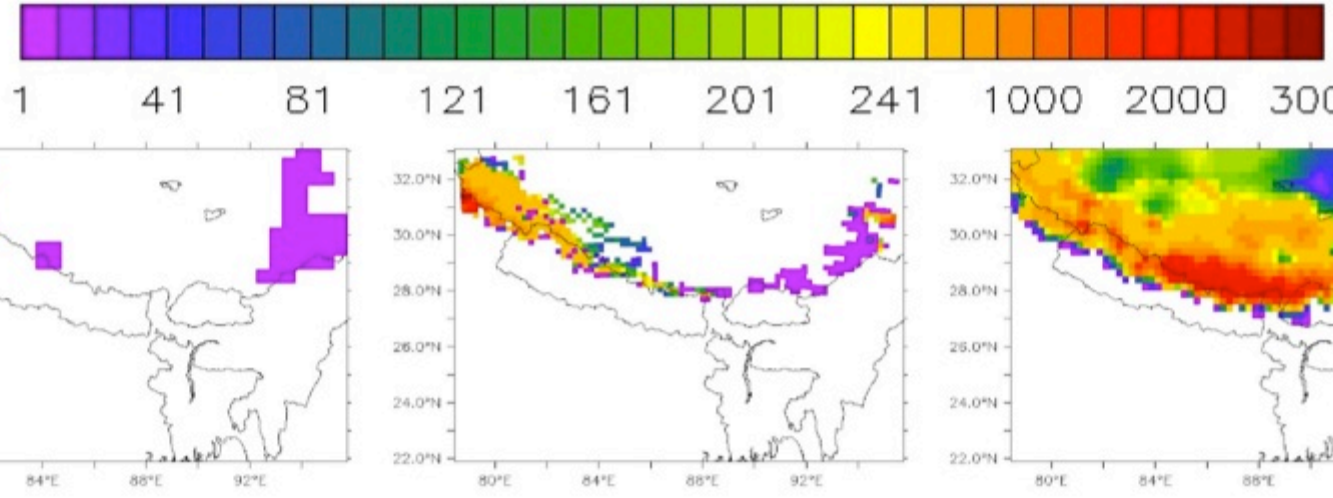
Regional modeling of black carbon in the snow with the global climate model LMDZ zoom

- **Simulation for October 1997 to October 2008**
- **Nudging using reanalysis data**
- **Simplified snow model (2 layers) including radiative transfer according to CROCUS**
- **4 simulations**

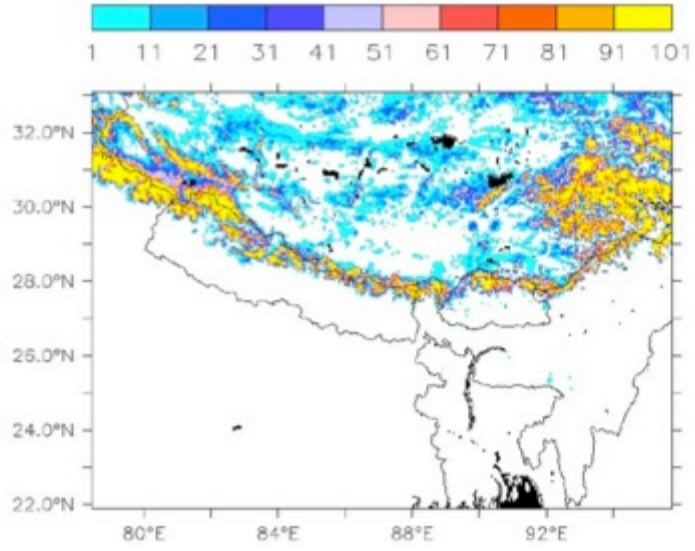
Sim.	Resolution	Snow albedo
SG1	96x95x19	With BC deposition
SG2	96x95x19	W/o BC deposition
SZ1	144x142x19 Zoom	With BC deposition
SZ2	144x142x19 Zoom	W/o BC deposition



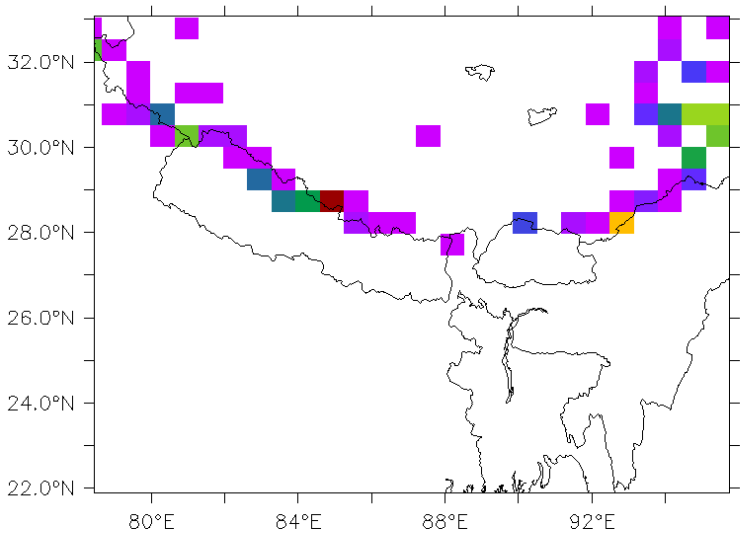
Comparison of SWE from different data products and in different models (April 2001)



(a) SWE ERA-INTERIM (mm) (b) SWE MAR (mm) (c) SWE CMC (mm)



(d) MODIS fractional snow cover extent (%)

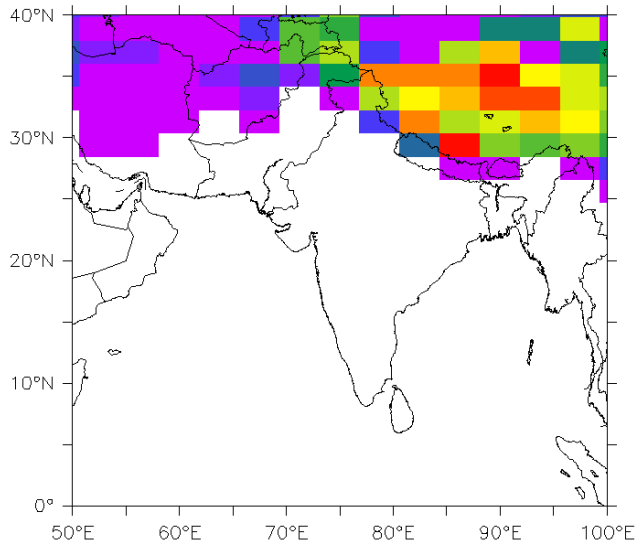


SWE LMDZ (mm)

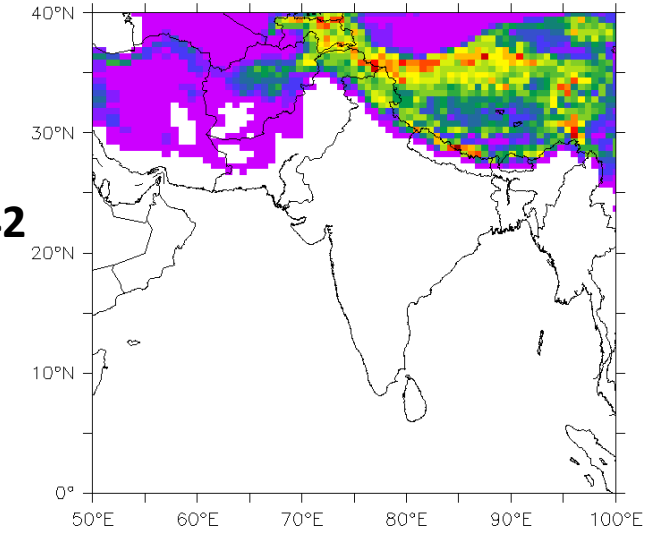
Laboratoire de Glaciologie et Géophysique de l'Environnement, Grenoble, France

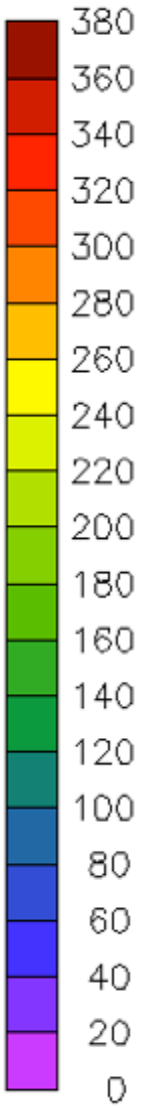
Simulated number of days with snow on the ground

LMD 96x95

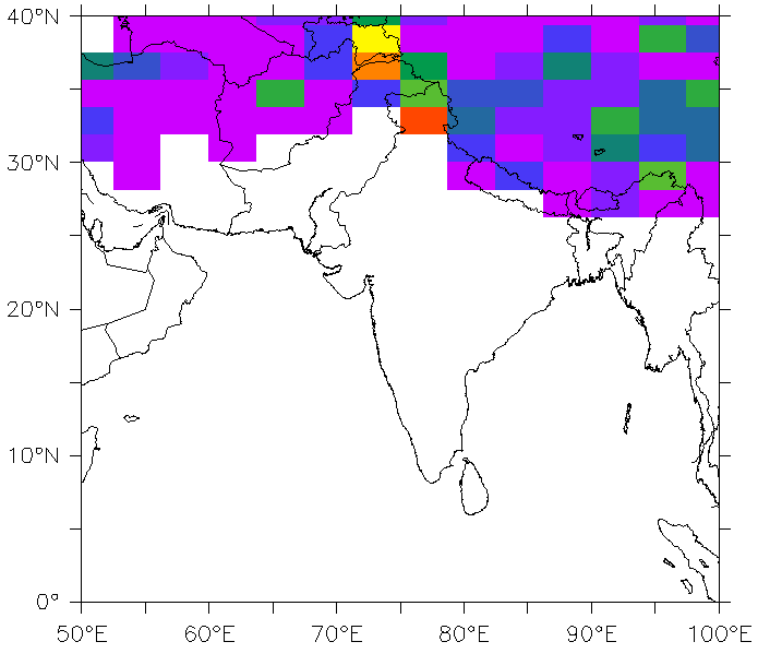


LMDZ 144x142





OBS 96x95



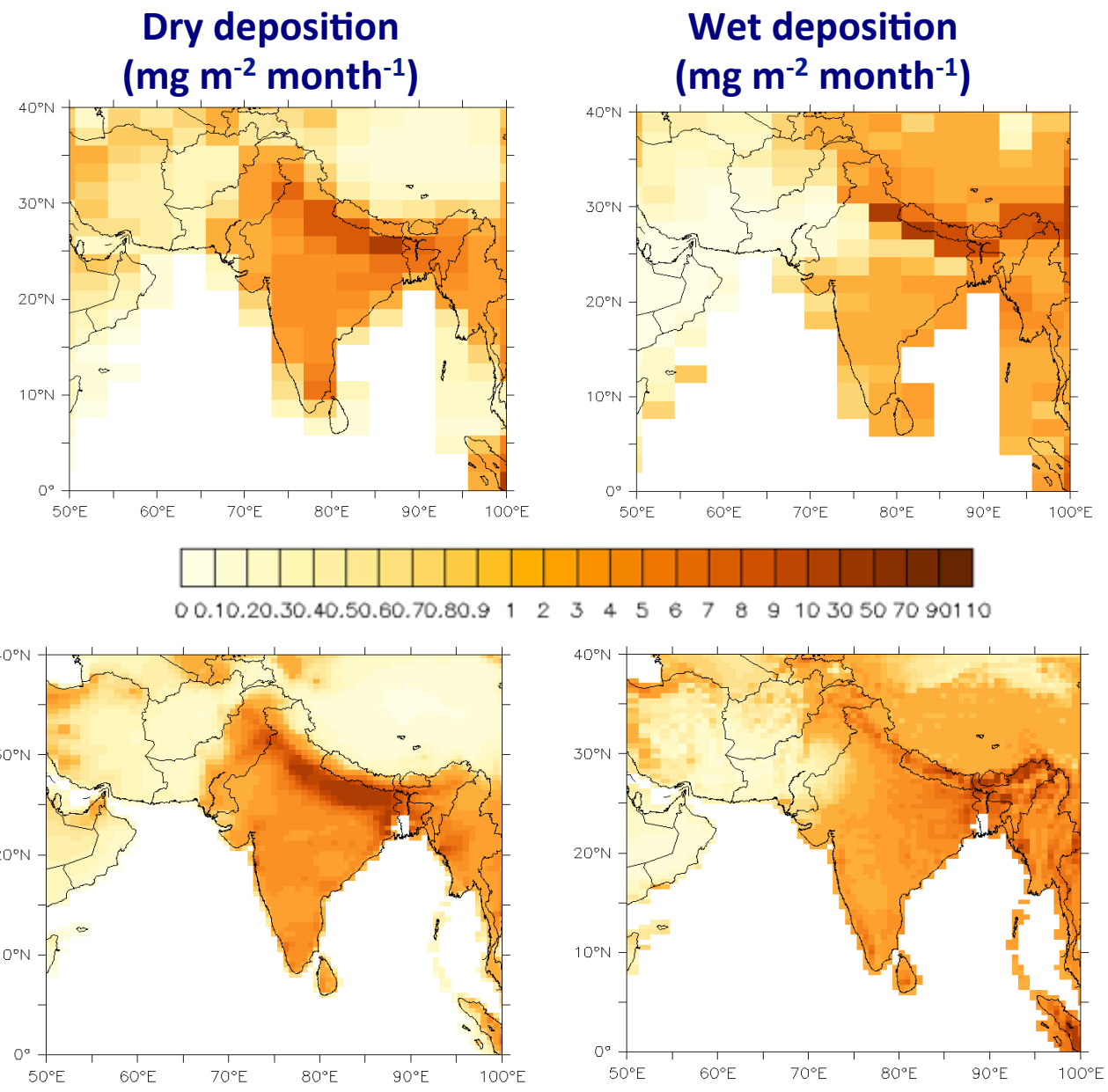
Number of days per year with snow

Laboratoire de Glaciologie et Géophysique de l'Environnement, Grenoble, France

Dry and wet deposition of black carbon in LMDZ

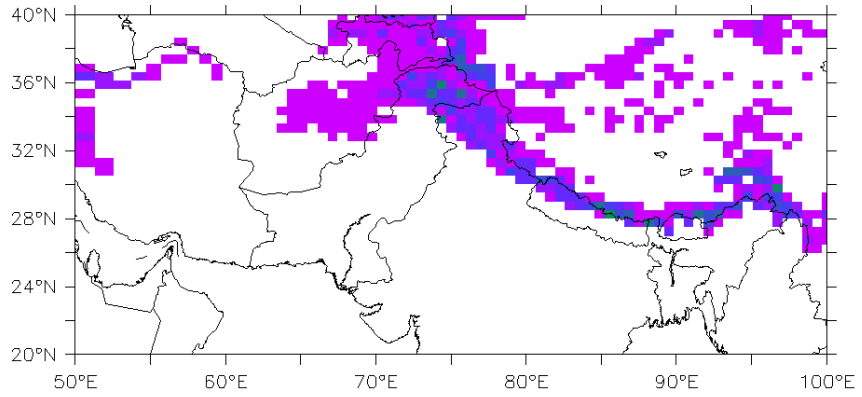
LMD 96x95

LMDZ 144x142

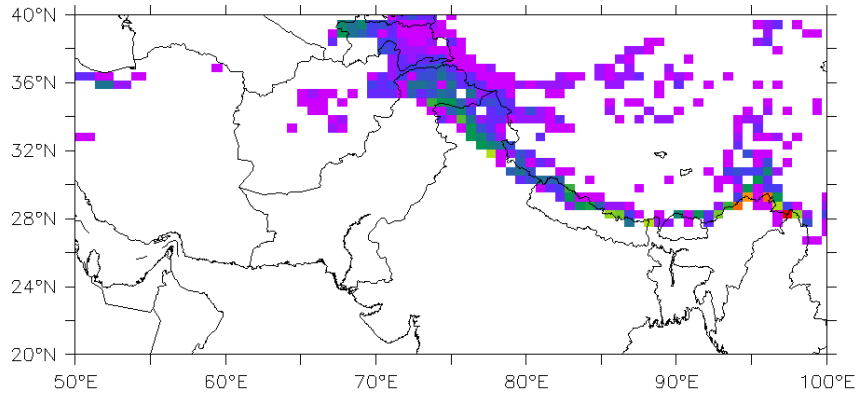


Laboratoire de Glaciologie et Géophysique de l'Environnement, Grenoble, France

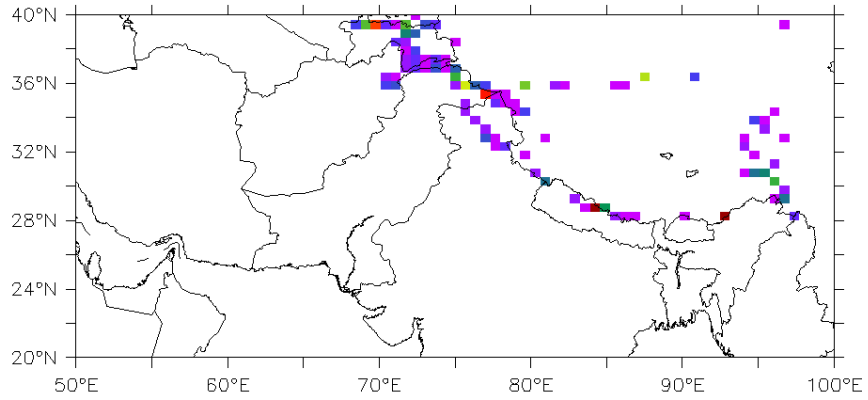
Simulated concentrations of black carbon in the snow



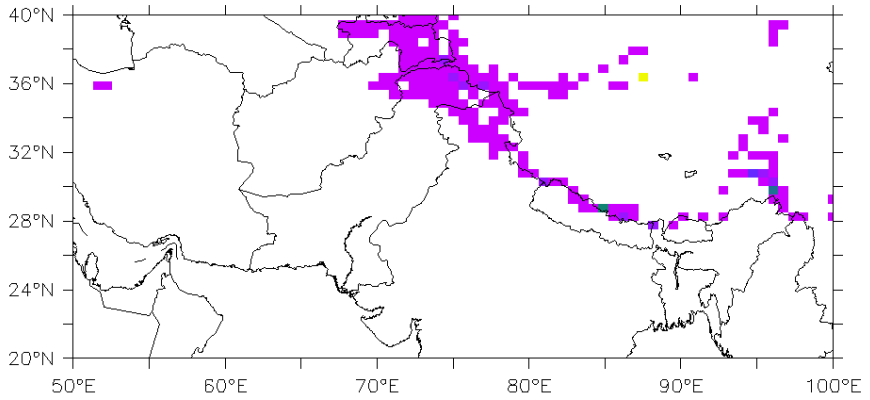
DJF



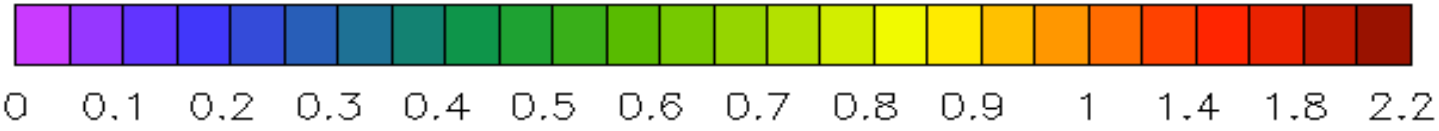
MAM



JJA



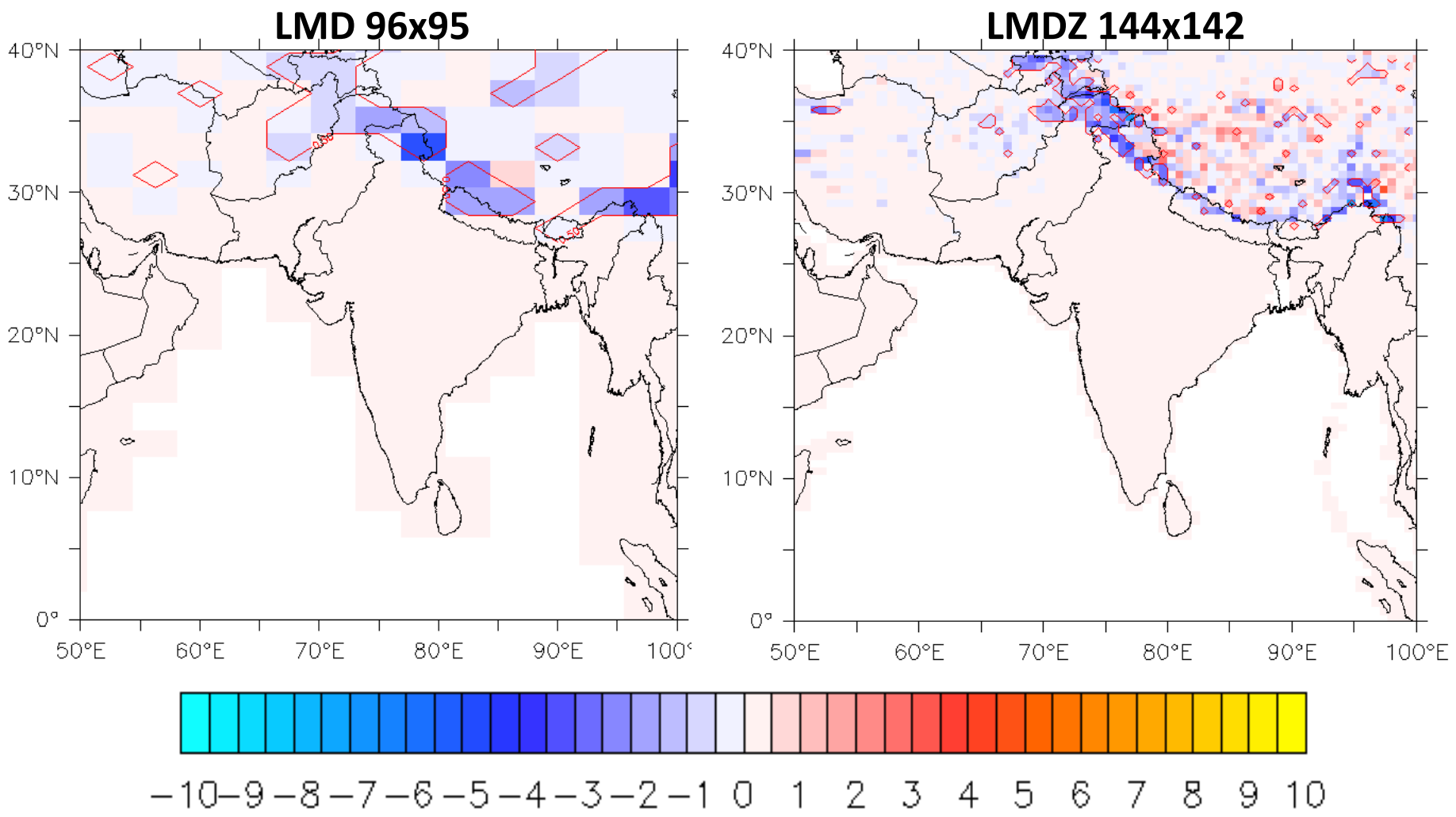
SON



Black carbon in the snow (ppb) – LMDZ 144x142

Laboratoire de Glaciologie et Géophysique de l'Environnement, Grenoble, France

Change of number of days with snow on the ground due to black carbon in the snow



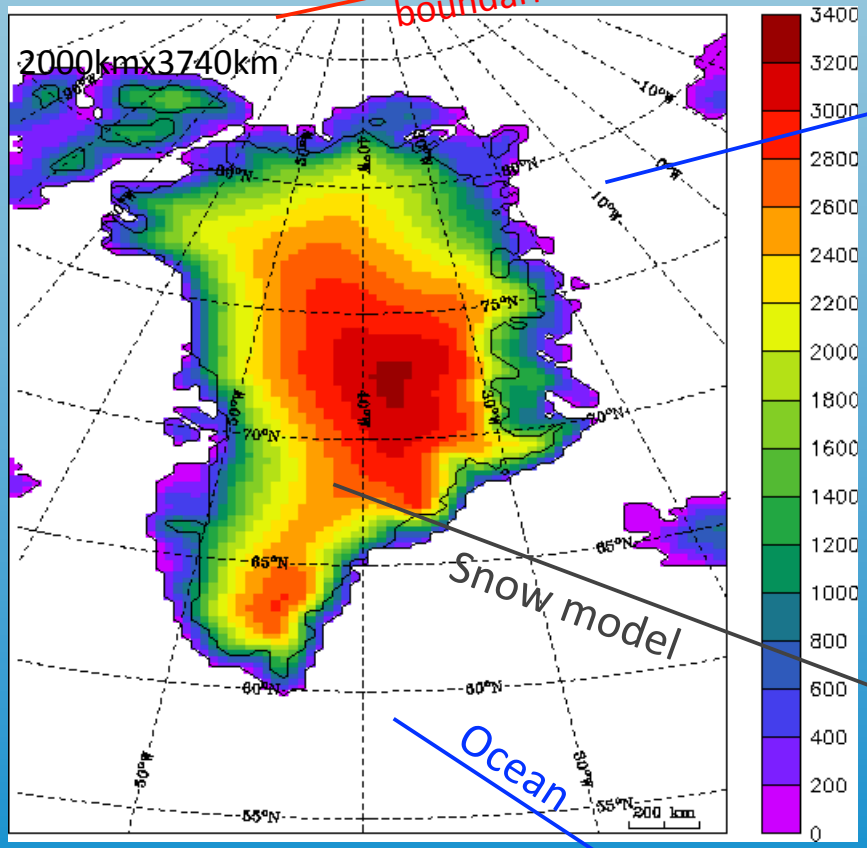
Difference of number of days year^{-1} with snow with and without BC in the snow

Laboratoire de Glaciologie et Géophysique de l'Environnement, Grenoble, France

Regional climate model MAR

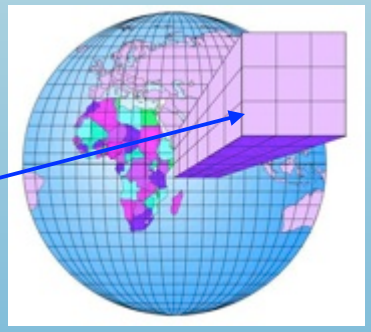
ERA-40 + ERA-INTERIM reanalysis

Atmospheric boundaries



MAR Topography (m)

Atmosphere



1st level: 3m, 25th level ~ 21km

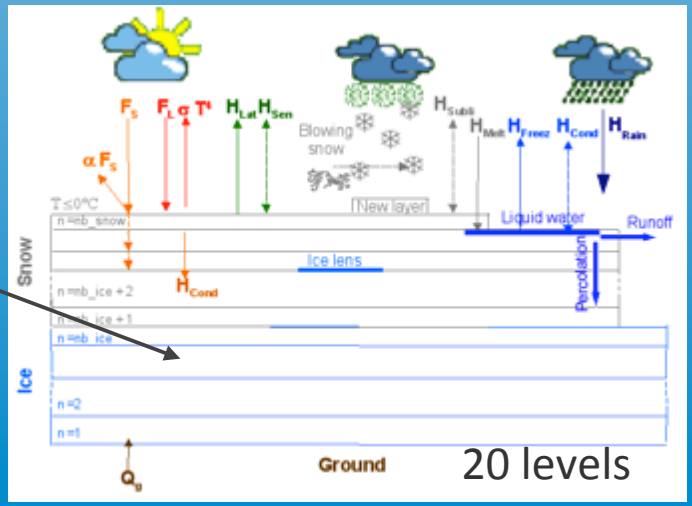
Resolution: 20km

Not coupled with an ice sheet model !

Snow model

Ocean

ERA SST + sea-ice



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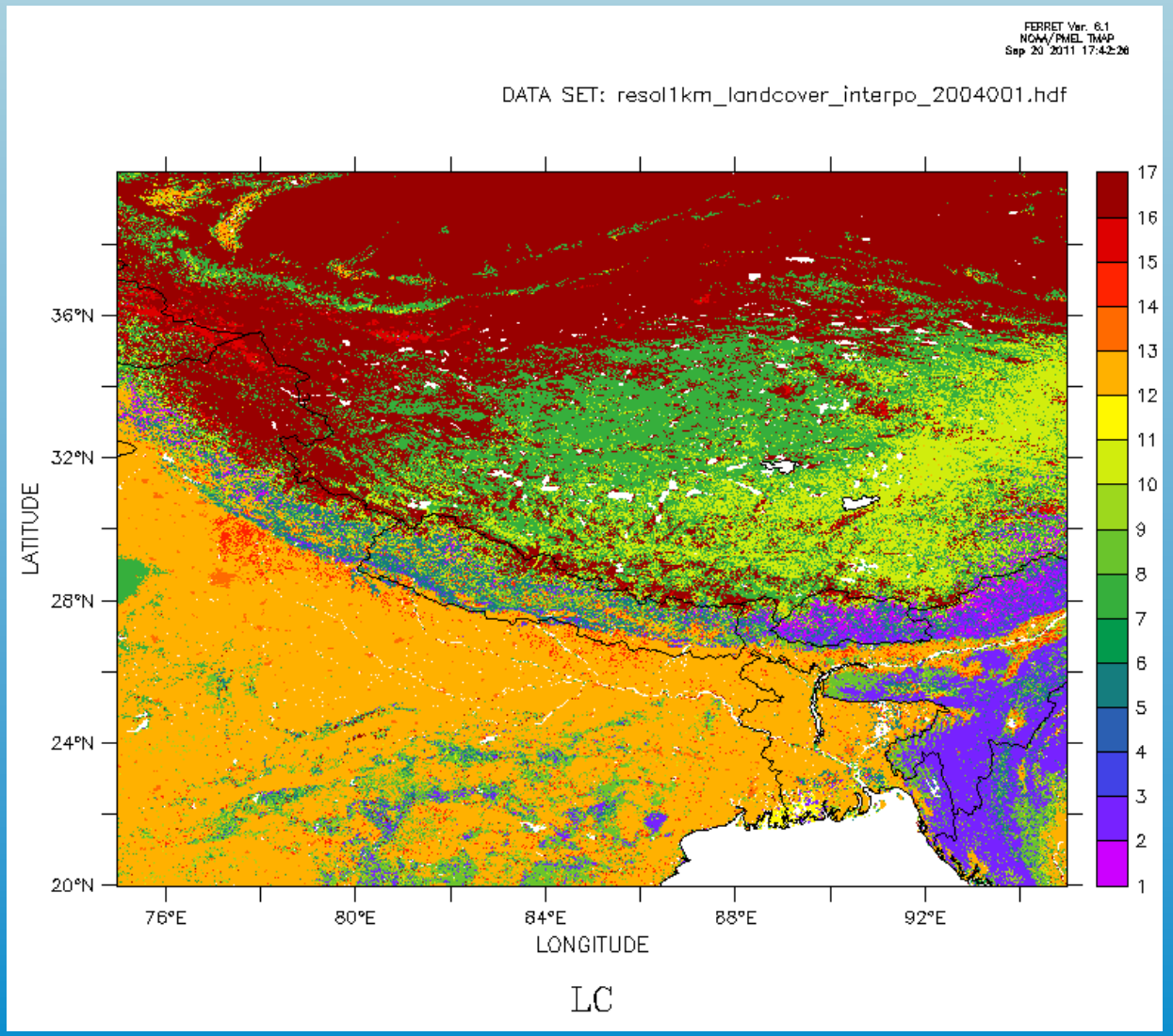
Regional climate modeling with MAR for Himalaya

- 3-year simulation for 2000–2002 centered around Nepal
- boundary conditions from ERA-INTERIM
- land-surface scheme SISVAT including snow model according to CROCUS
- no radiative transfer in the snow
- code not yet parallelized
- merging of MAR and LMDZ planned

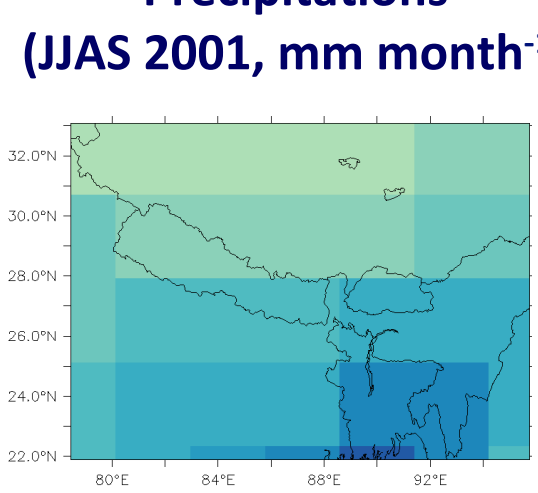


Land cover type from MODIS
(1 km resolution, classification IGBP)

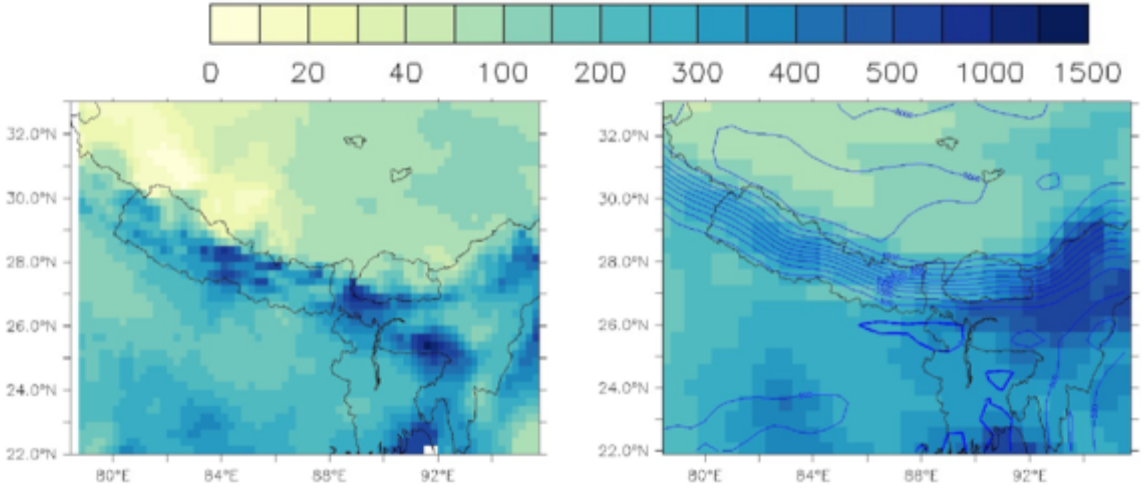
Laboratoire de Glaciologie et Géophysique de l'Environnement, Grenoble, France

Comparison of precipitation from different data products and in different models

Precipitations (JJAS 2001, mm month^{-1})

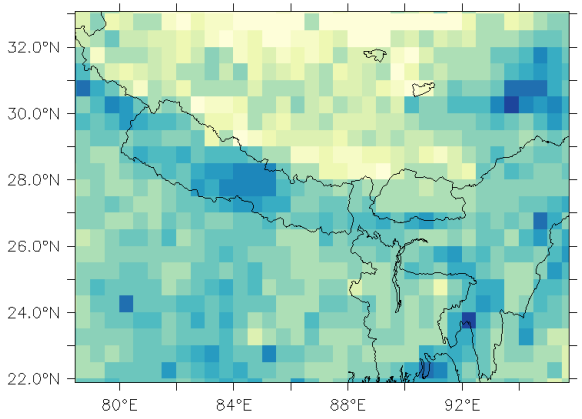


GPCP (~280 km)

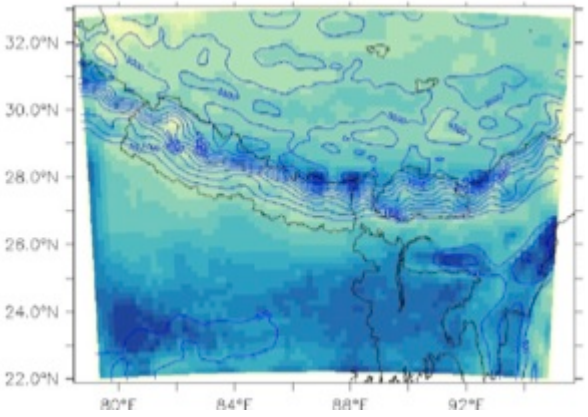


APHRODITE (~25 km)

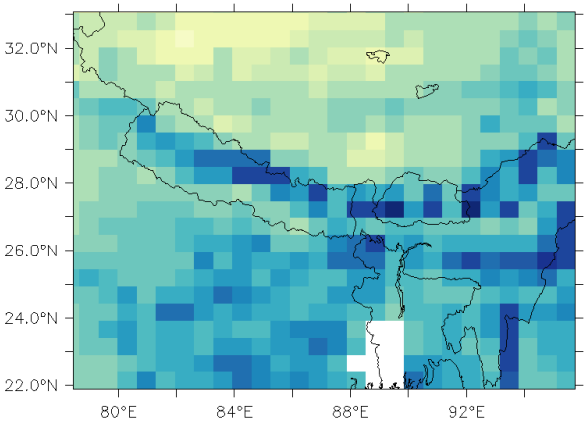
ERA-INTERIM (80 km)



TRMM (~50 km)



MAR (20 km)



LMDZ (50 km)

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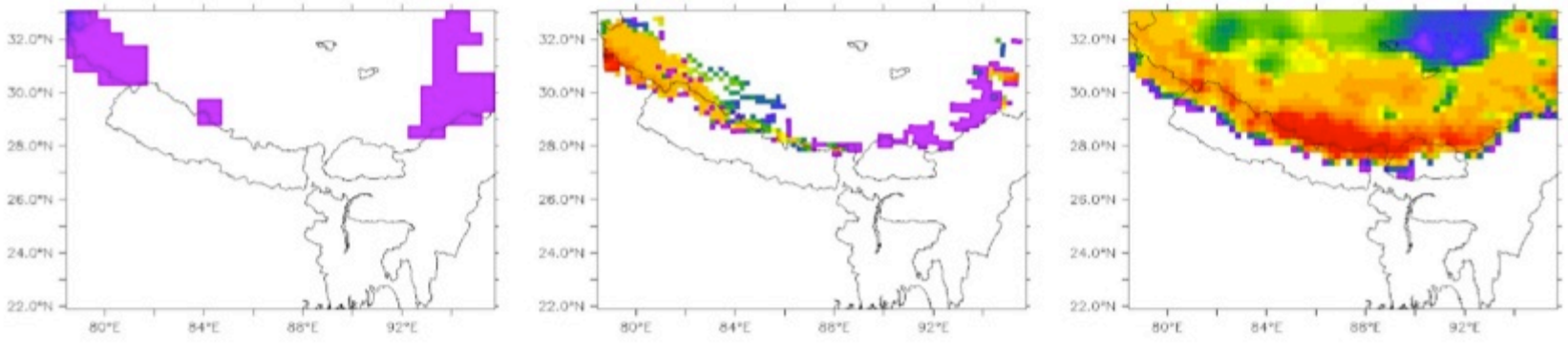
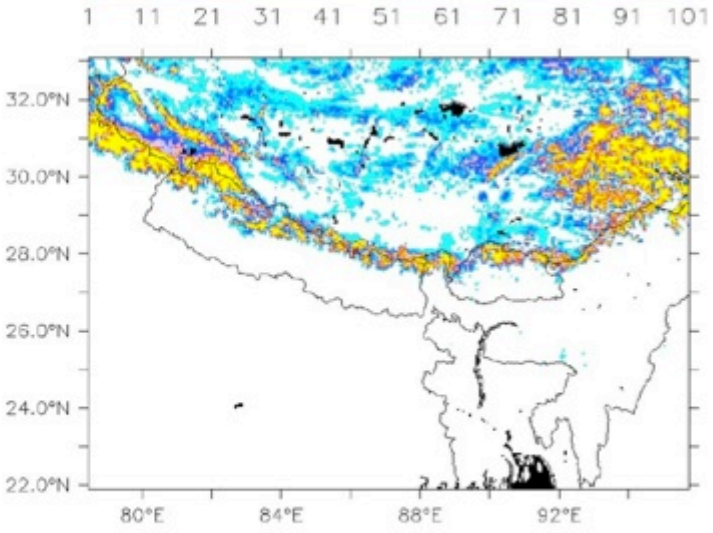
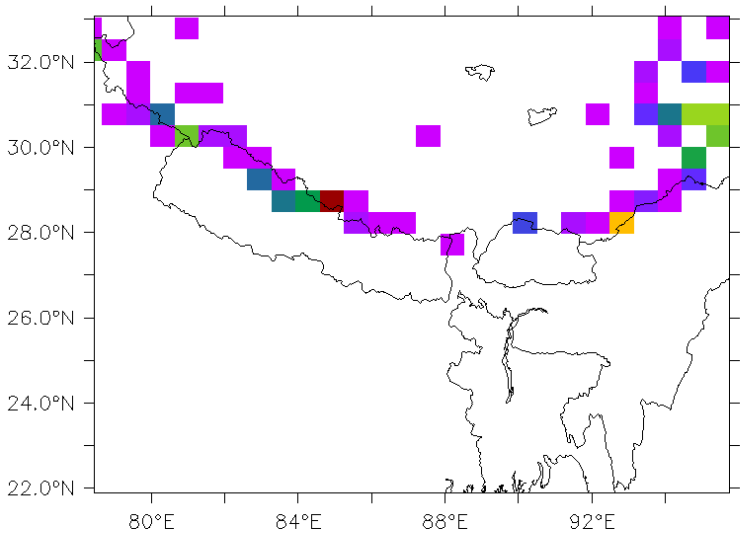
Comparison of SWE from MAR with different data products and models (April 2001)



(a) SWE ERA-INTERIM (mm) (b) SWE MAR (mm) (c) SWE CMC (mm)



(d) MODIS fractional snow cover extent (%)



SWE LMDZ (mm)

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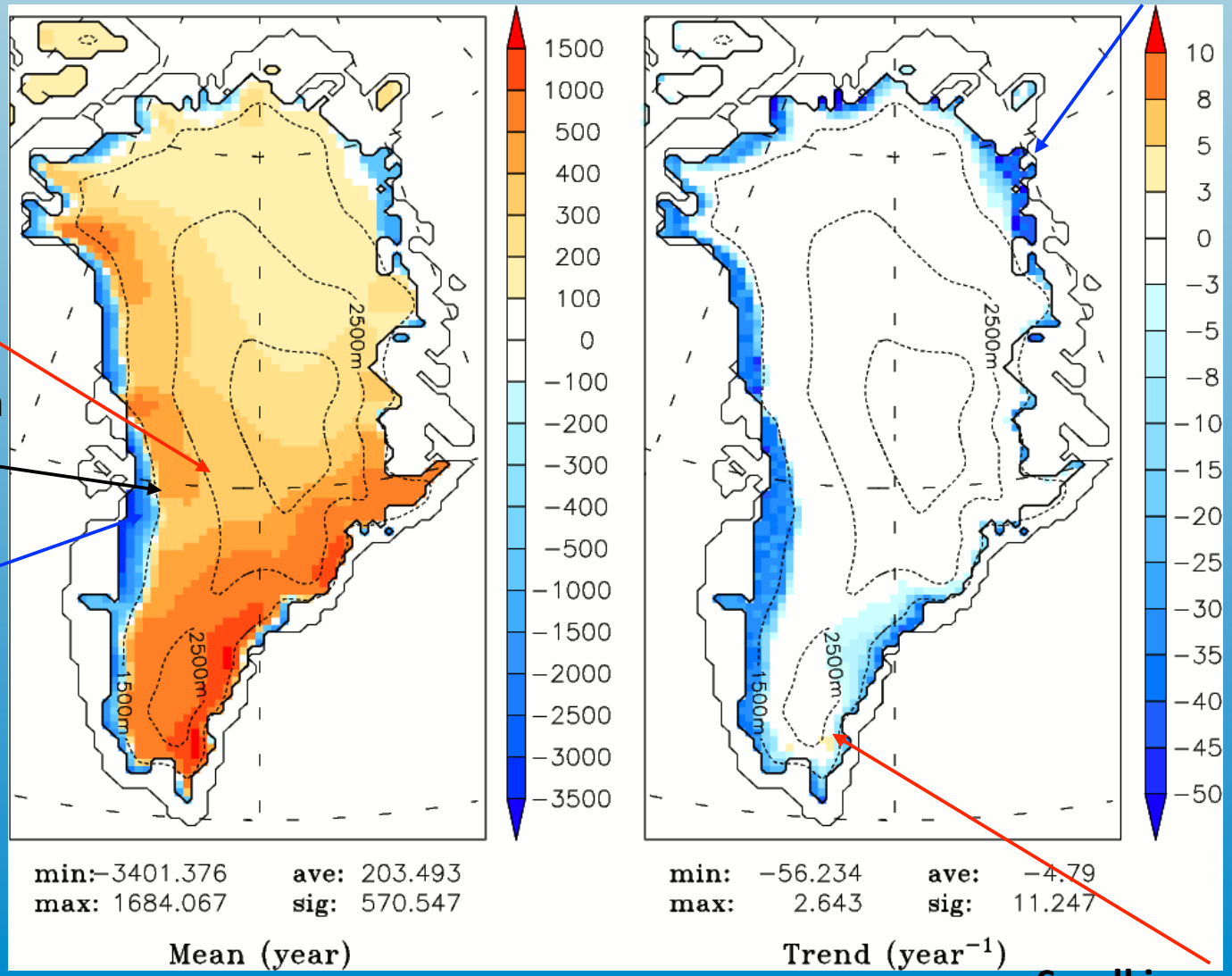
Greenland Ice Sheet surface mass balance simulated with MAR

Decrease in the ablation zone

Accumulation zone

Equilibium line

Ablation zone



Period: 1979-2008

Small increase in the accumulation zone

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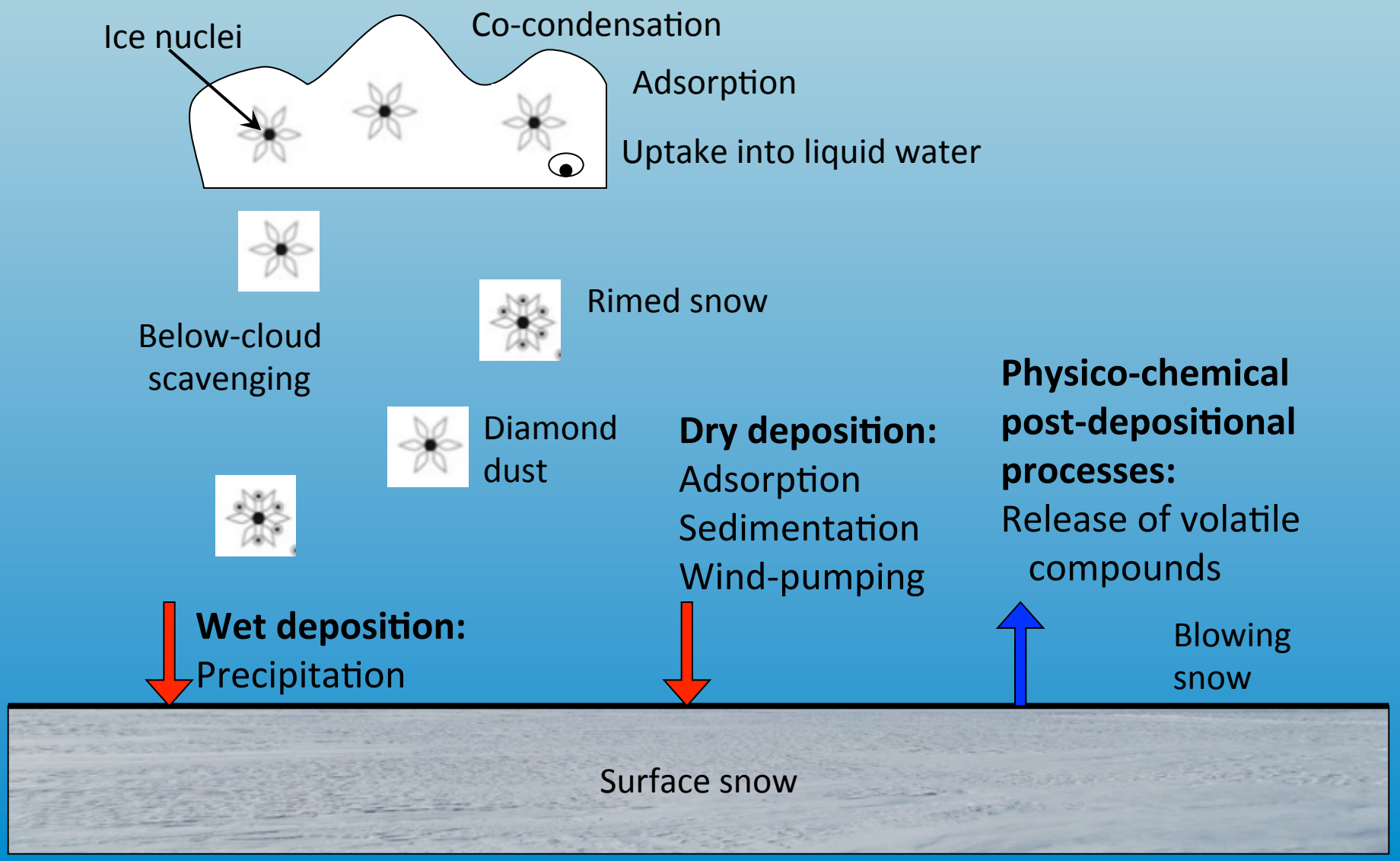
Input of impurities into the snow (and loss)



Conclusions

• CROCUS model has been upgraded including a physically based description of the radiative transfer within the snowpack.

• The upgraded model can consider absorbing impurities like black carbon or dust in the snow.

• First simulation for high-altitude conditions in the Himalayas indicate a better representation of the albedo.

• Behavior of BC in the snow: Flushing-out with run-off?
Accumulation at the surface during snow melt? Water solubility? Chemical reactivity?

AGENCE NATIONALE DE LA RECHERCHE
ANR
Paprika

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  LGGE

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  Ev-K2-CNR Committee, Bergamo, Italy

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  Bergische Universität Wuppertal, Germany

- **James France, Martin King**
  Royal Holloway, University of London, UK

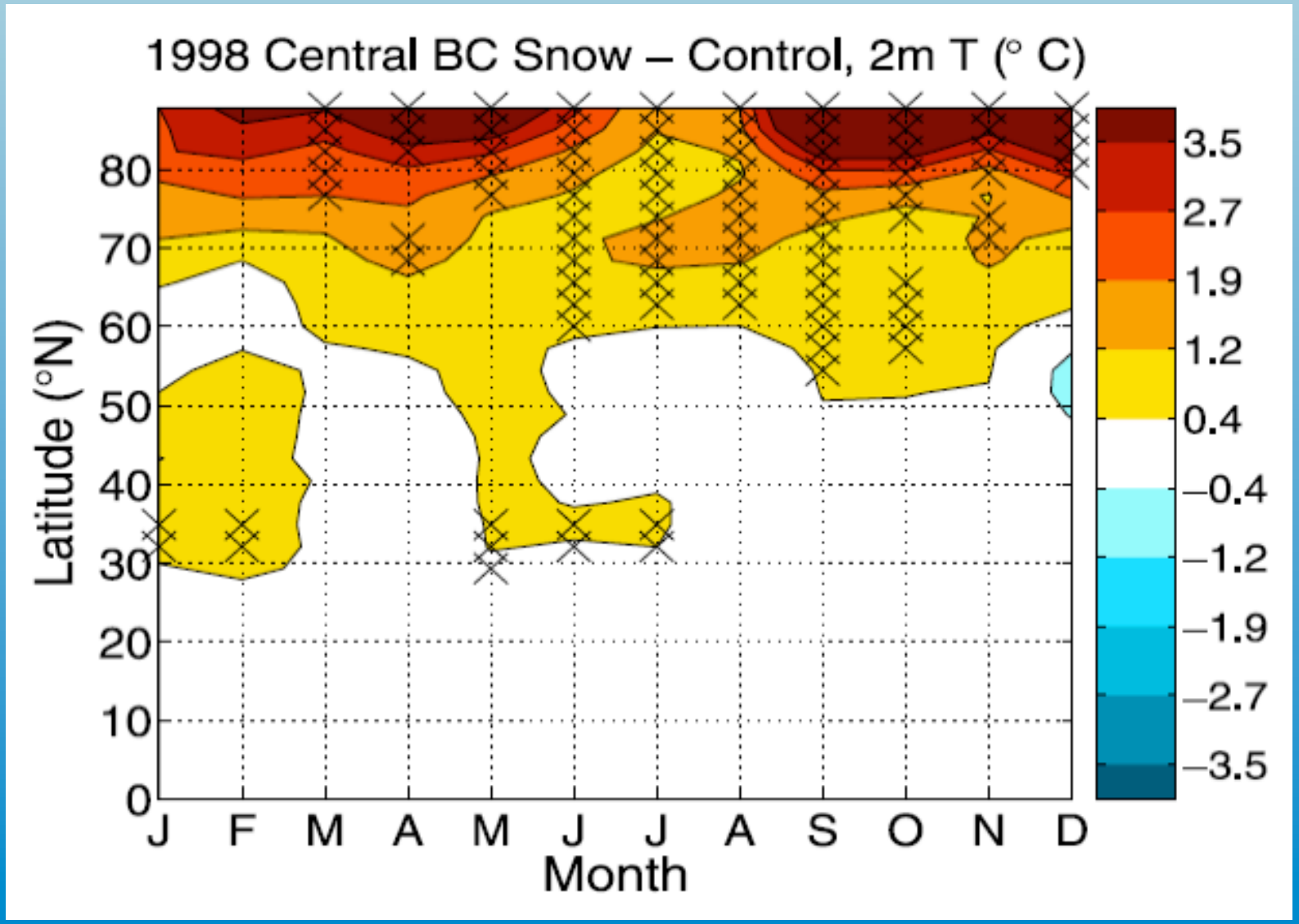
- **Yves Balkanski**
  LSCE, Paris, France

CLIMSLIP

(CLimate IMpacts of Short-Lived pollutants In the Polar region)

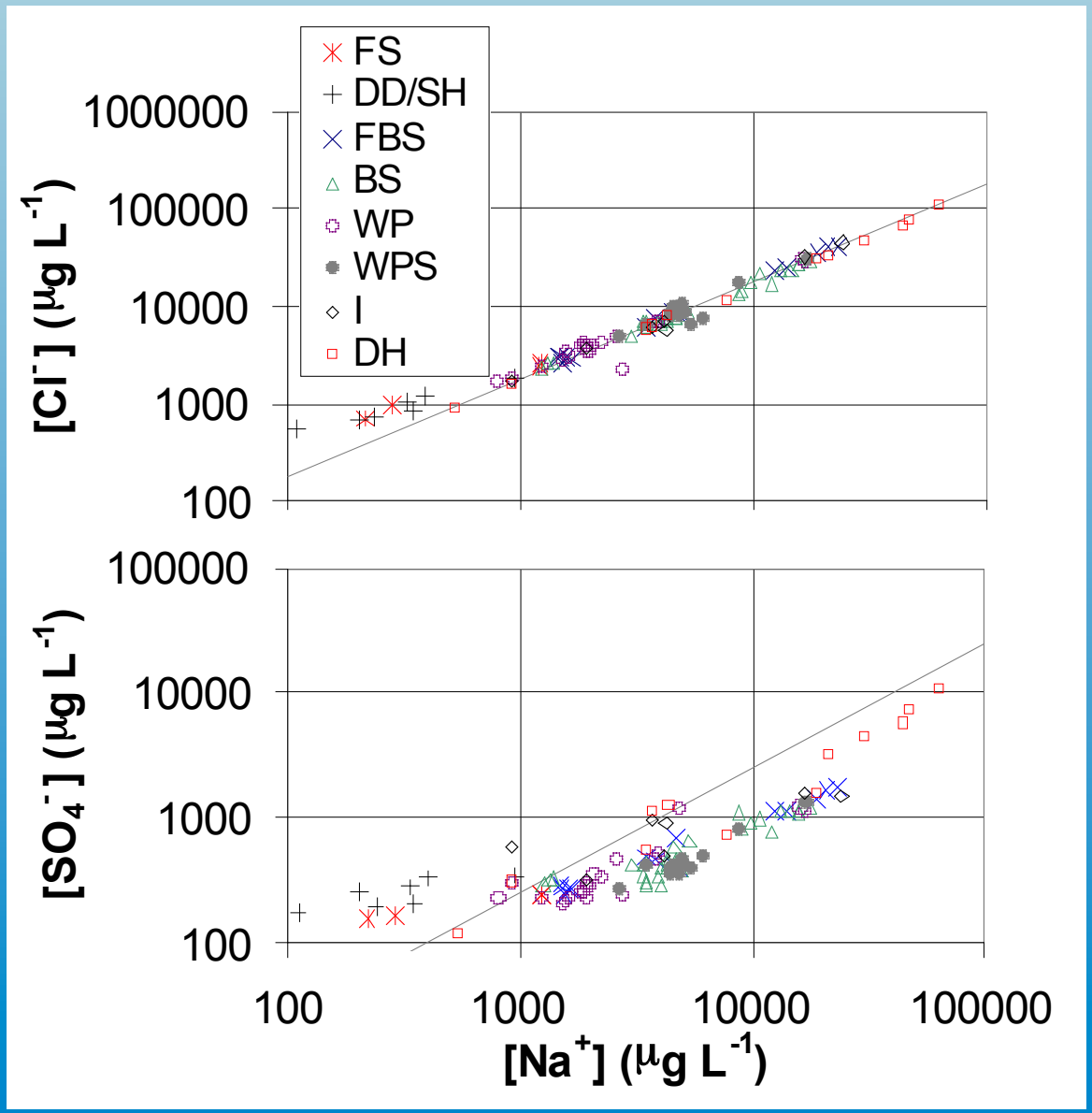
Paprika

Air temperature increase due to black carbon in the snow in a global model



Flanner et al., J.Geophys.Res. 2007

Relationship between chloride, sulfate, and sodium concentrations and snow type



Jacobi et al., J.Geophys.Res. 2012

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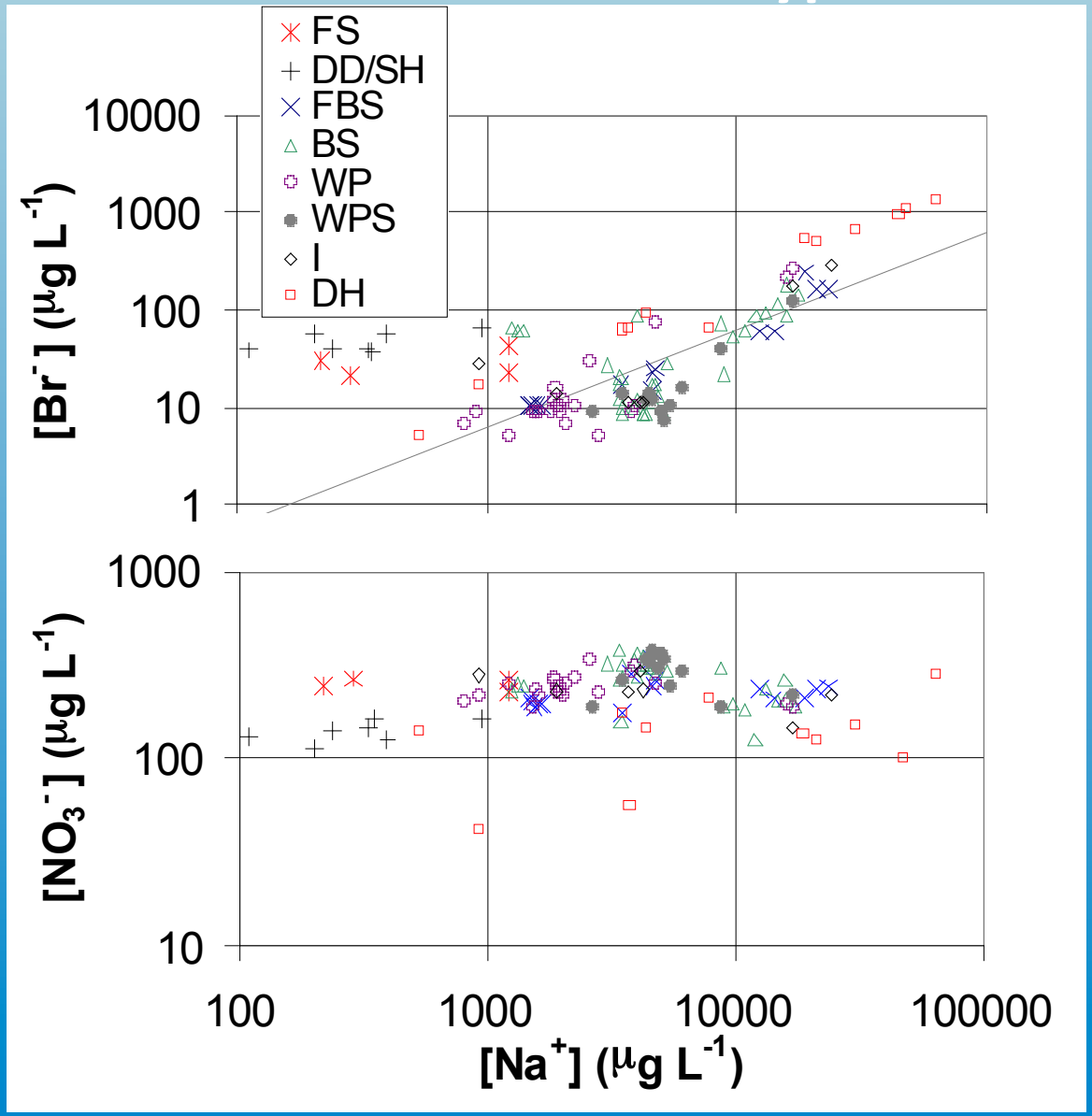
Relationship between bromide, nitrate, and sodium concentrations and snow type



Jacobi et al., J.Geophys.Res. 2012

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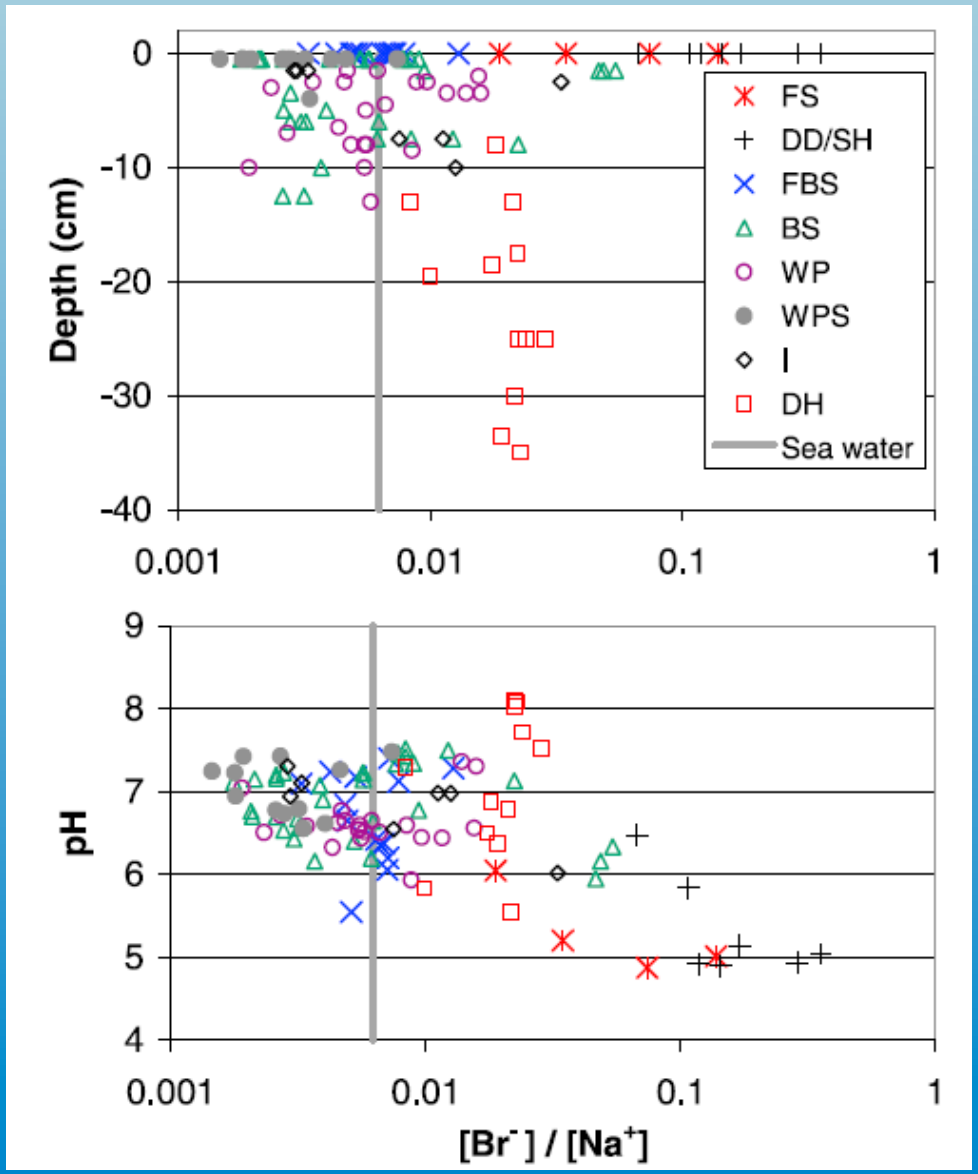
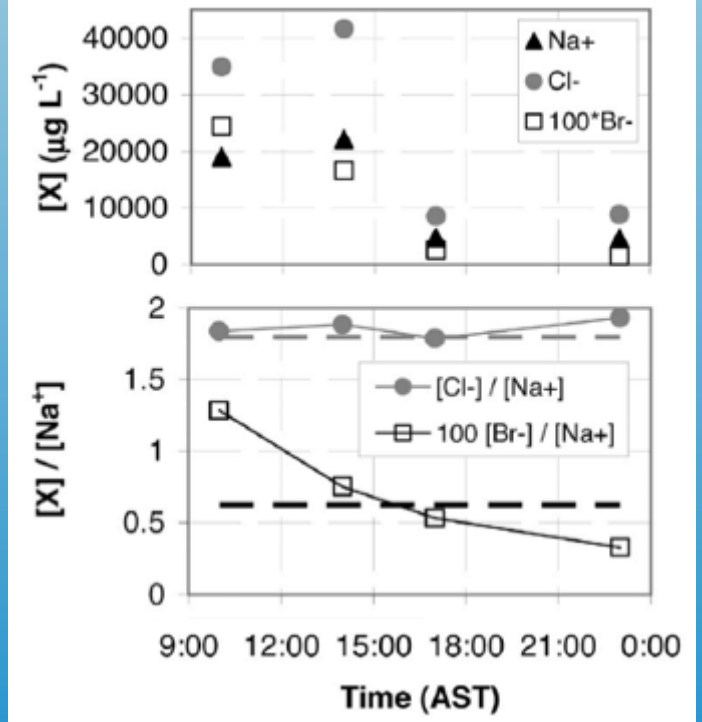
Bromide-to-sodium ratio as function of depth and pH and during a blowing snow event



Blowing snow event, 9 March 2003



Jacobi et al., J.Geophys.Res. 2012

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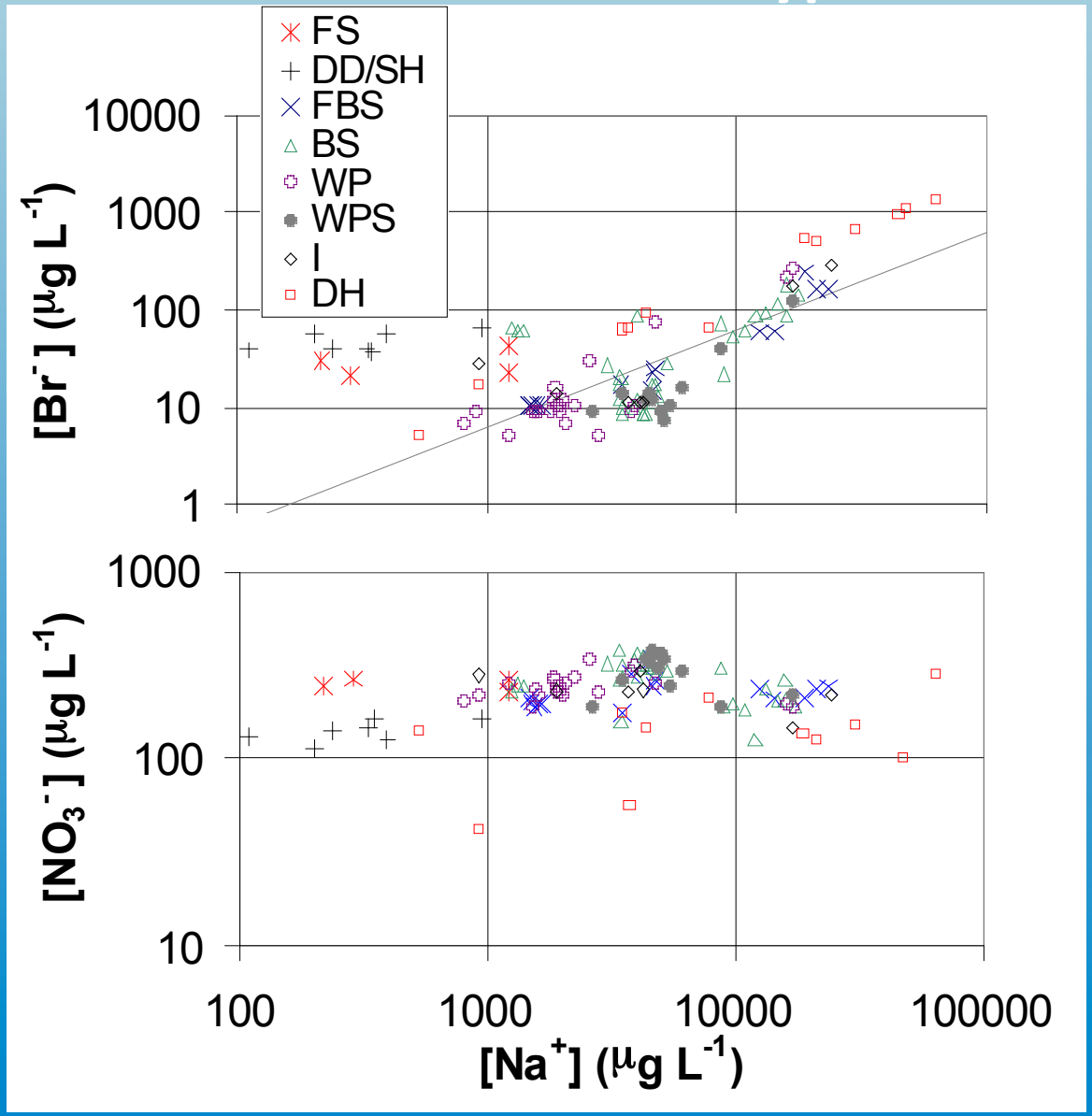
Relationship between bromide, nitrate, and sodium concentrations and snow type

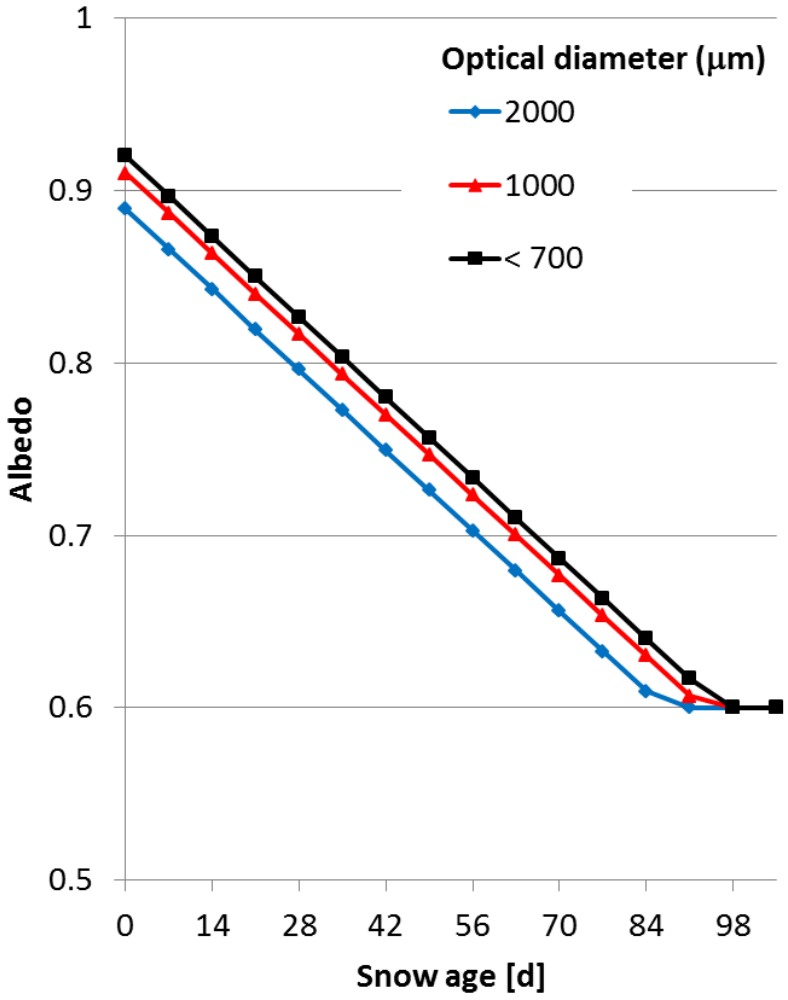


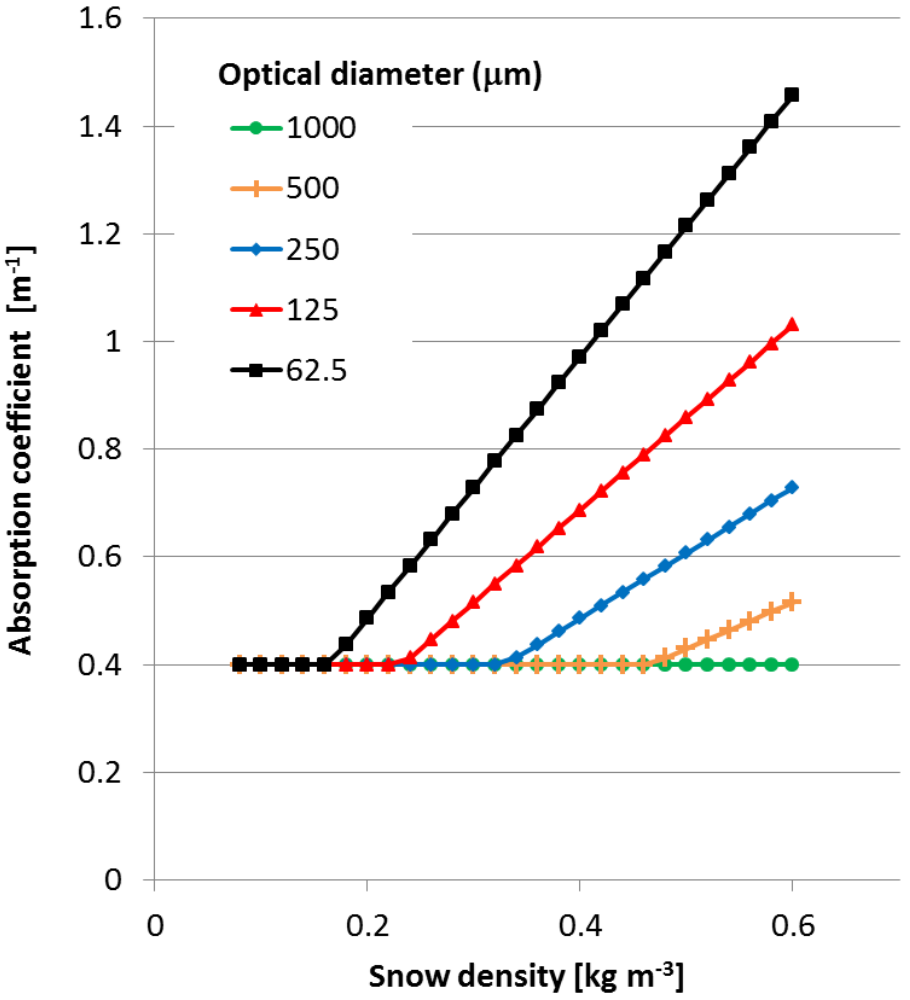
Jacobi et al., J.Geophys.Res. 2012

Laboratoire de Glaciologie et Géophysique de l'Environnement, Grenoble, France

Chemical profiles in the Kongsvegen snow pit (30/03/20

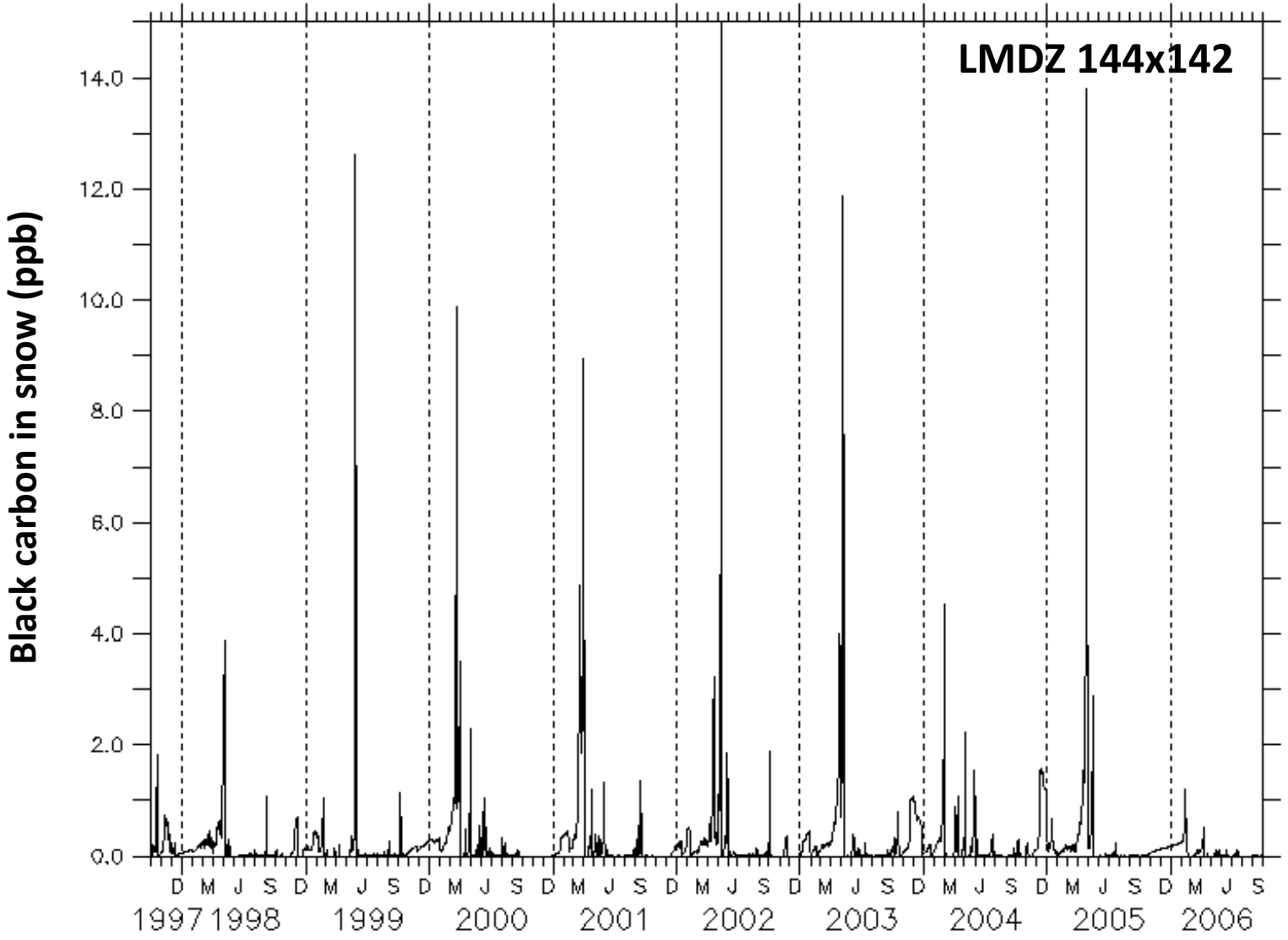
Albedo parameterization in the standard CROCUS model (300 - 800 nm)





Vionnet et al., Geoscientific Model Development 2012

Black carbon concentrations in the snow around Mera glacier (28°N, 86.5°E)



Laboratoire de Glaciologie et Géophysique de l'Environnement, Grenoble, France

Simulated SWE from MAR during springtime

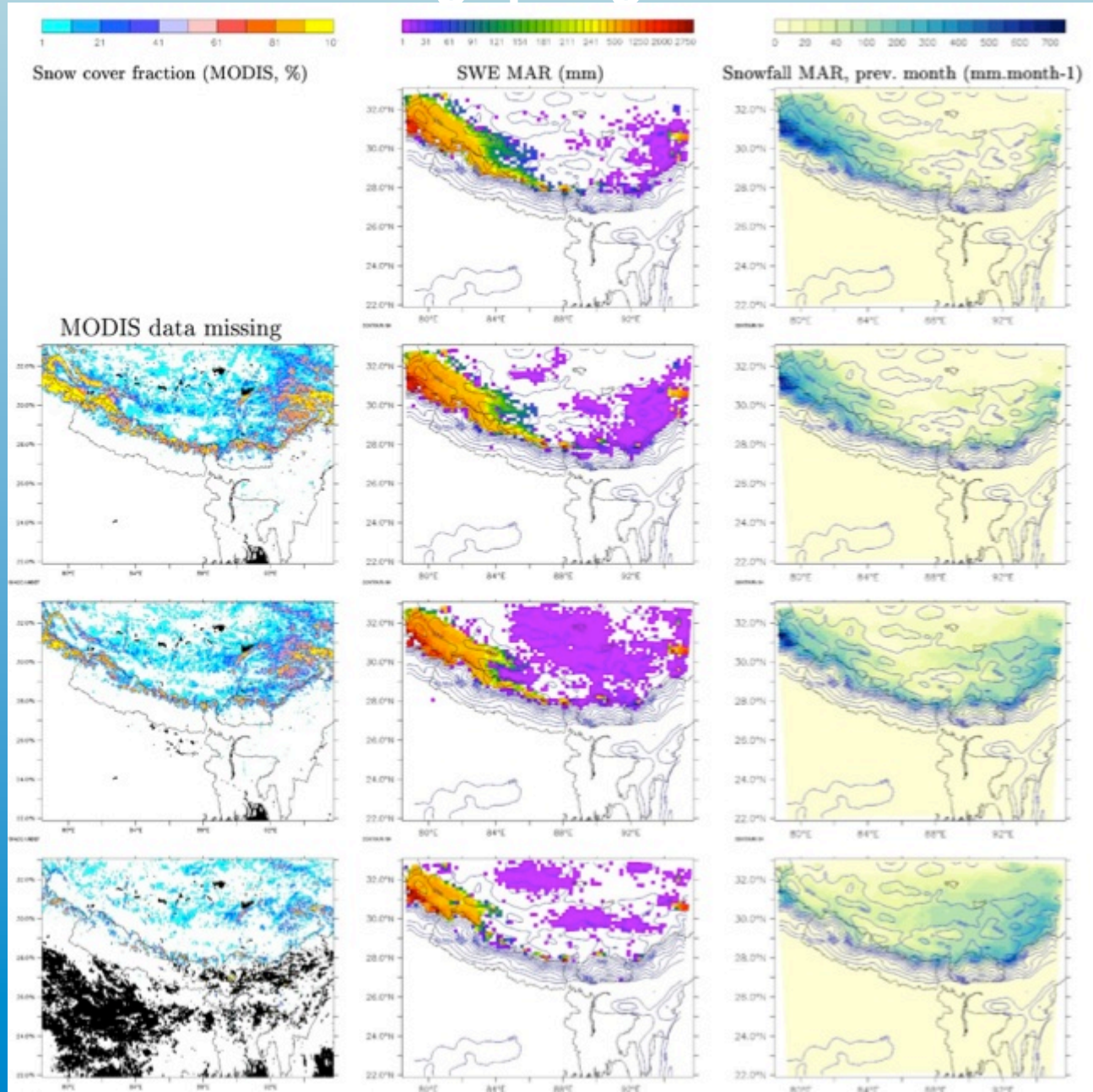
Printemps 2002

Mars 2002

Avril 2002

Mai 2002

Juin 2002



Laboratoire de Glaciologie et Géophysique de l'Environnement, Grenoble, France