Black carbon & other light-absorbing particles in snow in Central North America & N. China

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Issue: Black carbon in snow

Why does BC in snow matter?

BC in snow lowers snow albedo (reflectivity) so more sunlight is absorbed by the snowpack → snowpack warms → snow grain size increases → albedo lowered further → snow warms further → melts sooner → concentrations of BC in surface snow increase further → more albedo reduction → accelerated snow melt

Net effects:

- forcing (direct albedo reduction) & feedbacks (see above) lower surface albedo → warms climate
- earlier snowmelt → impacts for agriculture, runoff timing


~2-30 ng/g BC


~2-30 ng/g BC


~1100ng/g BC
2010/02/07

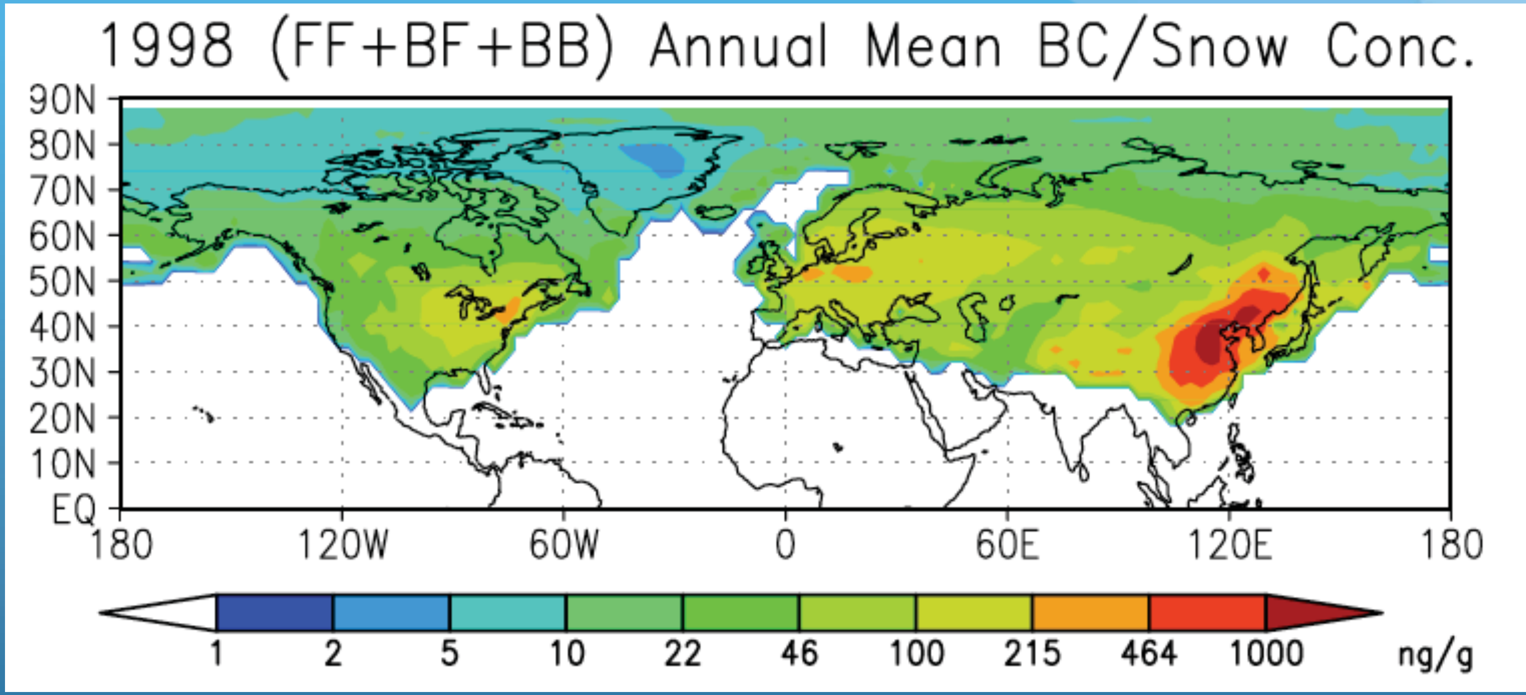

~2-30 ng/g BC


~1100ng/g BC
2010/02/07


???? ng/g BC
dust/soil? algae?

Motivation

Flanner et al., 2007 Fig. 5



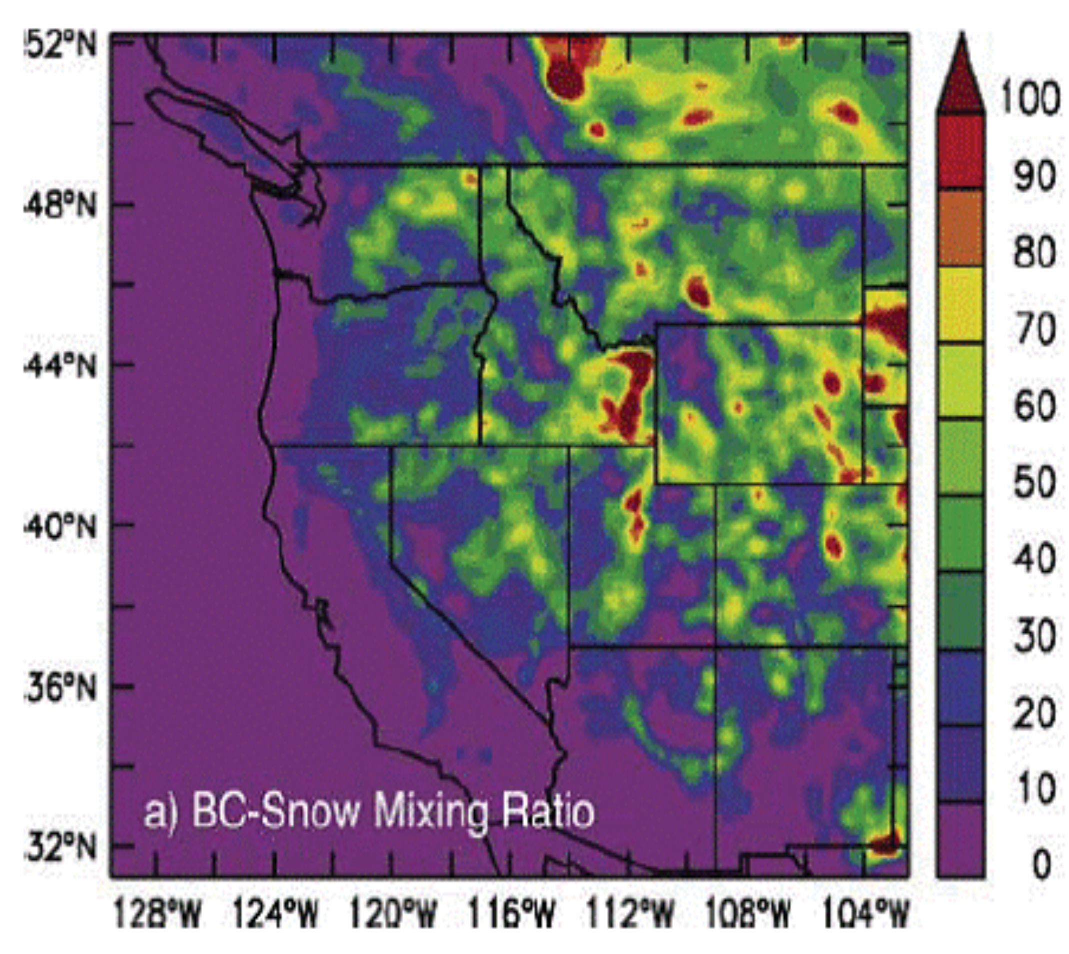
- Focus has mostly been on BC in snow in the Arctic, BUT:
- The highest concentrations of BC in snow are at lower latitudes
- The open plains regions of the northern mid-latitudes are where the snowpack is not masked by vegetation
- Warming due to BC in snow at lower latitudes may contribute significantly to Arctic warming (increased heat advection into Arctic)

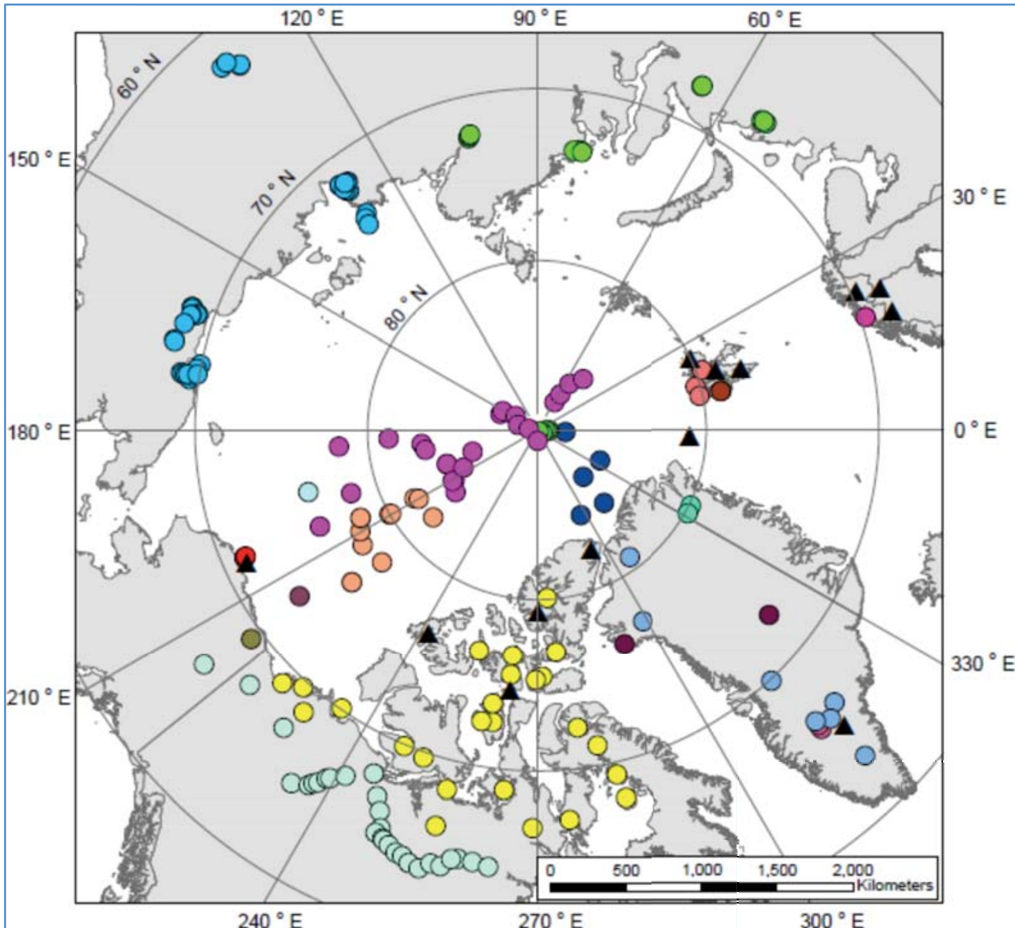
Motivation

Qian et al., 2009

Regional model study of Western U.S. (Qian et al., 2009):

- decreases in snow accumulation rate
- increased runoff in February; decreased runoff March onward
- affects on mountain snowpack & snowpack in agricultural regions





Motivation

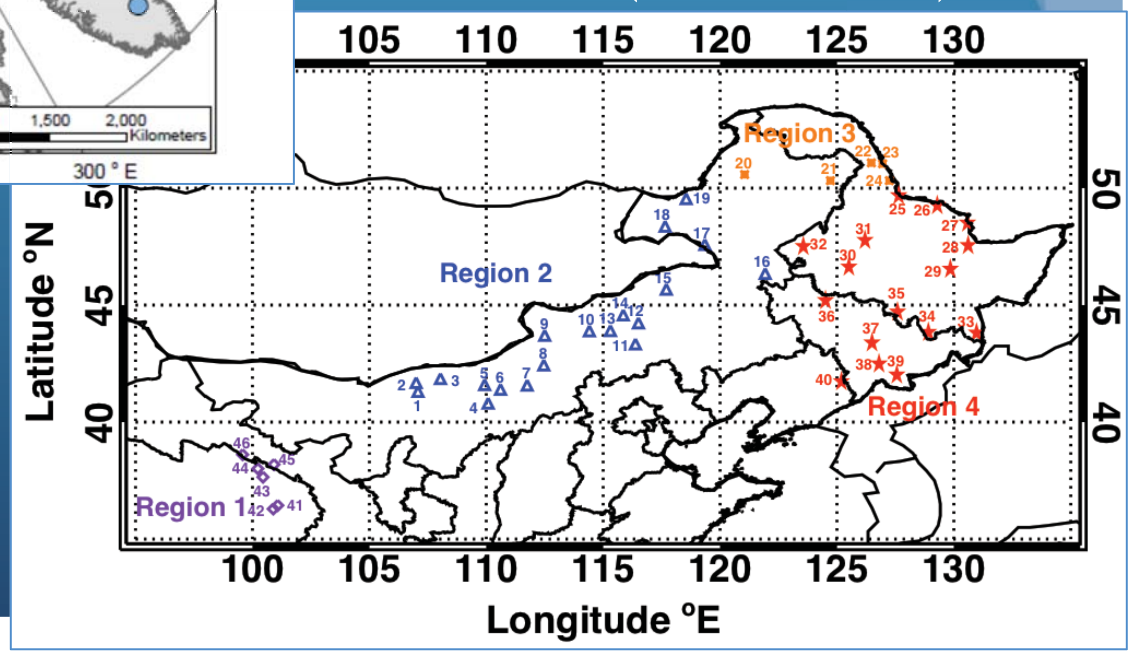
Large-area surveys of:

Arctic (mostly 2007-2010)
previous work under NSF

N. China Great Plains (2010 & 2012)
w/ Lanzhou Univ., China

N. America Great Plains (2013 & 2014)

→ All using the same sampling & analysis technique



Activities

- Measure BC and other insoluble light-absorbing particles in snow across the U.S. Great Plains
- Process samples from:
  - N. China survey (w/ colleagues from Lanzhou Univ.)
  - north-central Utah (w/ colleagues from PNNL)
  - Dye-2 Greenland: study effects of melt on surface BC
- Determine sources of light-absorbing particles in snow
  - U.S. Great Plains & China data sets
- Test method of measuring BC vs. other light-absorbing particles
  - against another method of measuring BC (SP2)
  - by serial extraction of organics & iron analysis
- Study processes driving variations in surface snow mixing ratios
- Measurement/model comparisons

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N. American survey 2013 : 67 sites
+ 3 process study sites in 2014

<u>*2013*</u>

Site 1:
10 Jan

Sites 2-67:
28 Jan – 21 Mar

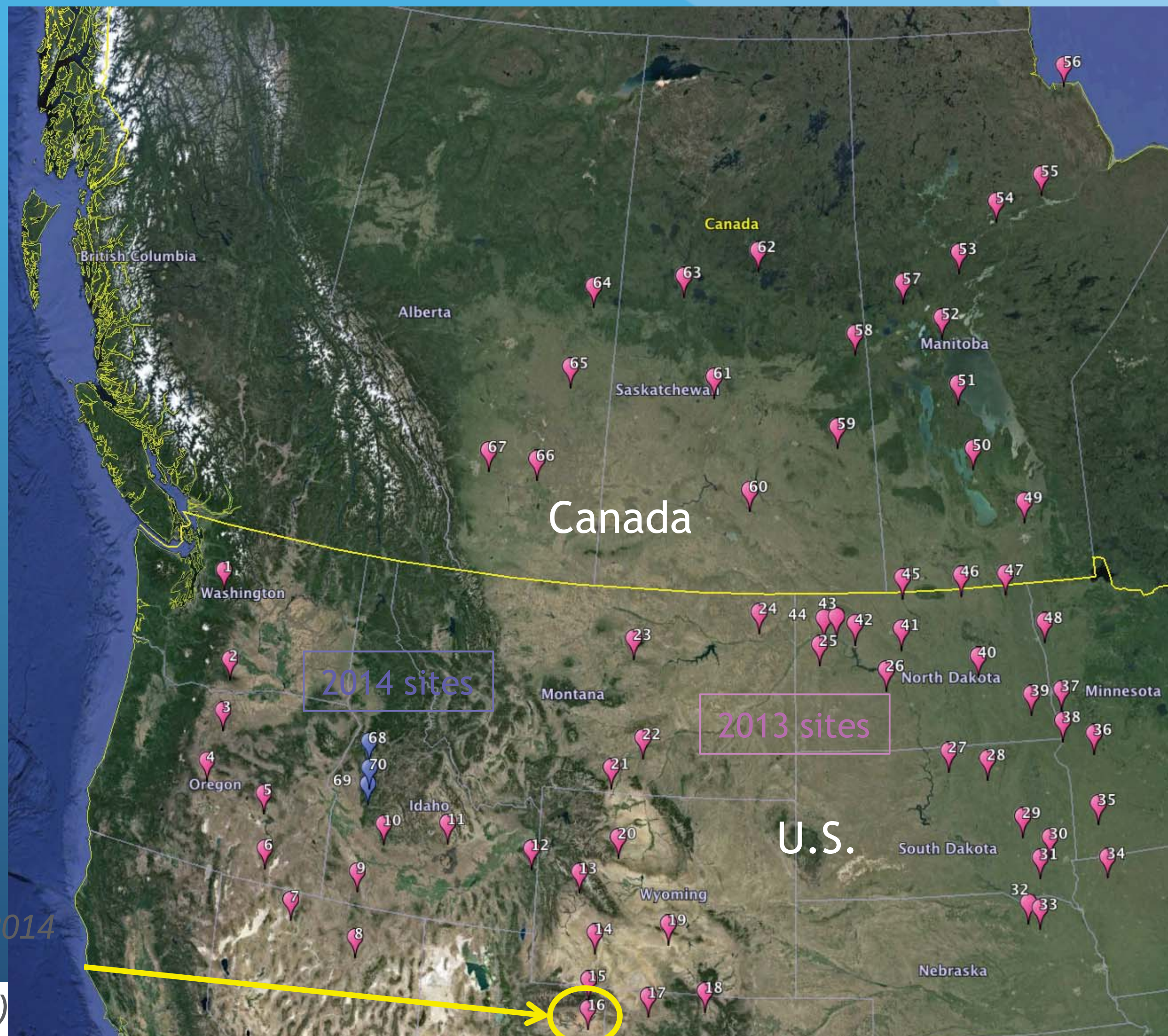
>500 snow samples

<u>*2014*</u>

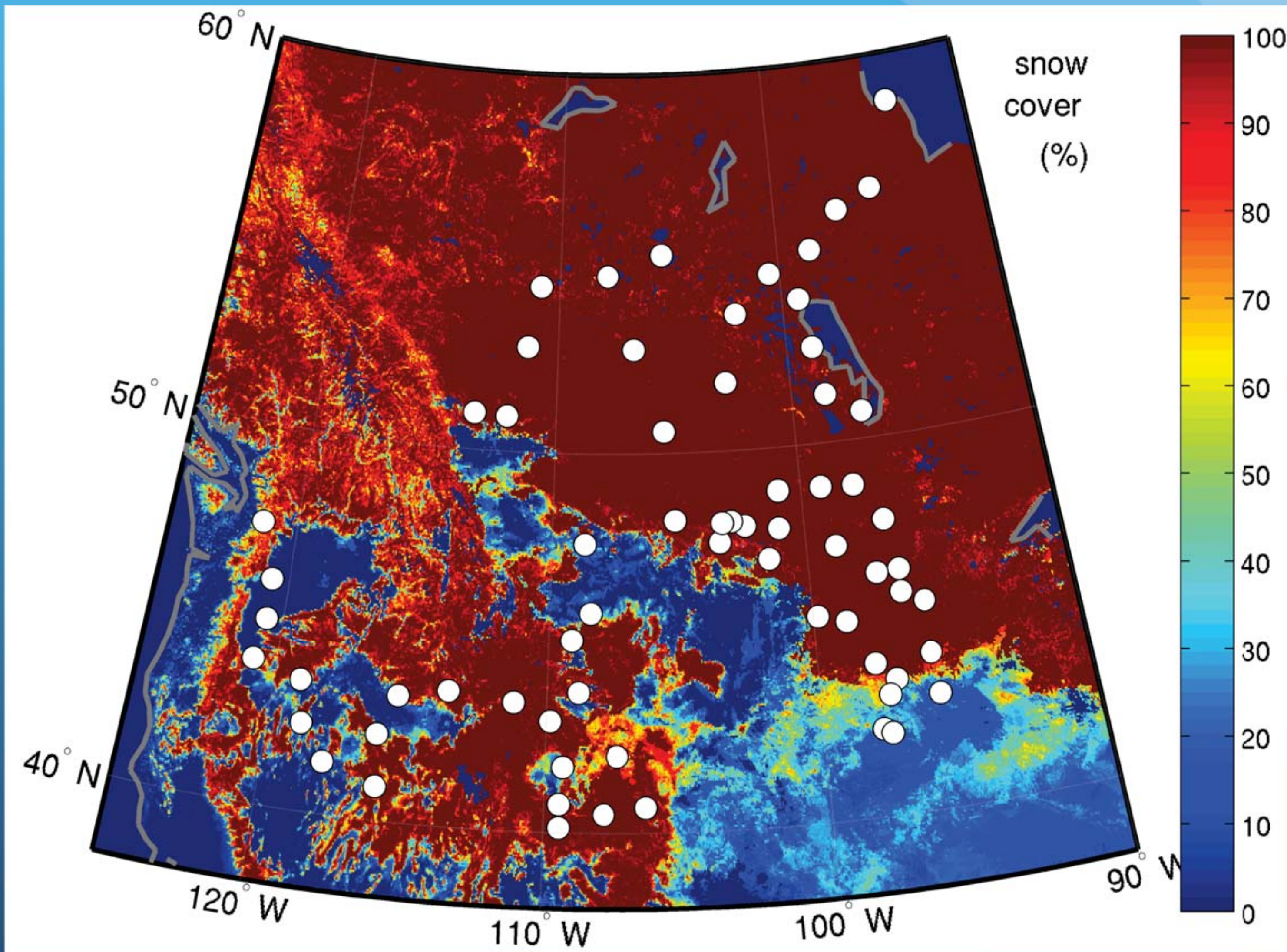
Sites 68-70:
27 Jan – 24 Mar

>360 snow samples

Vernal, Utah: 2013 & 2014 sampling by PMEL
(J. Johnson & T. Quinn)



MODIS Snow Cover (%) Feb 2013



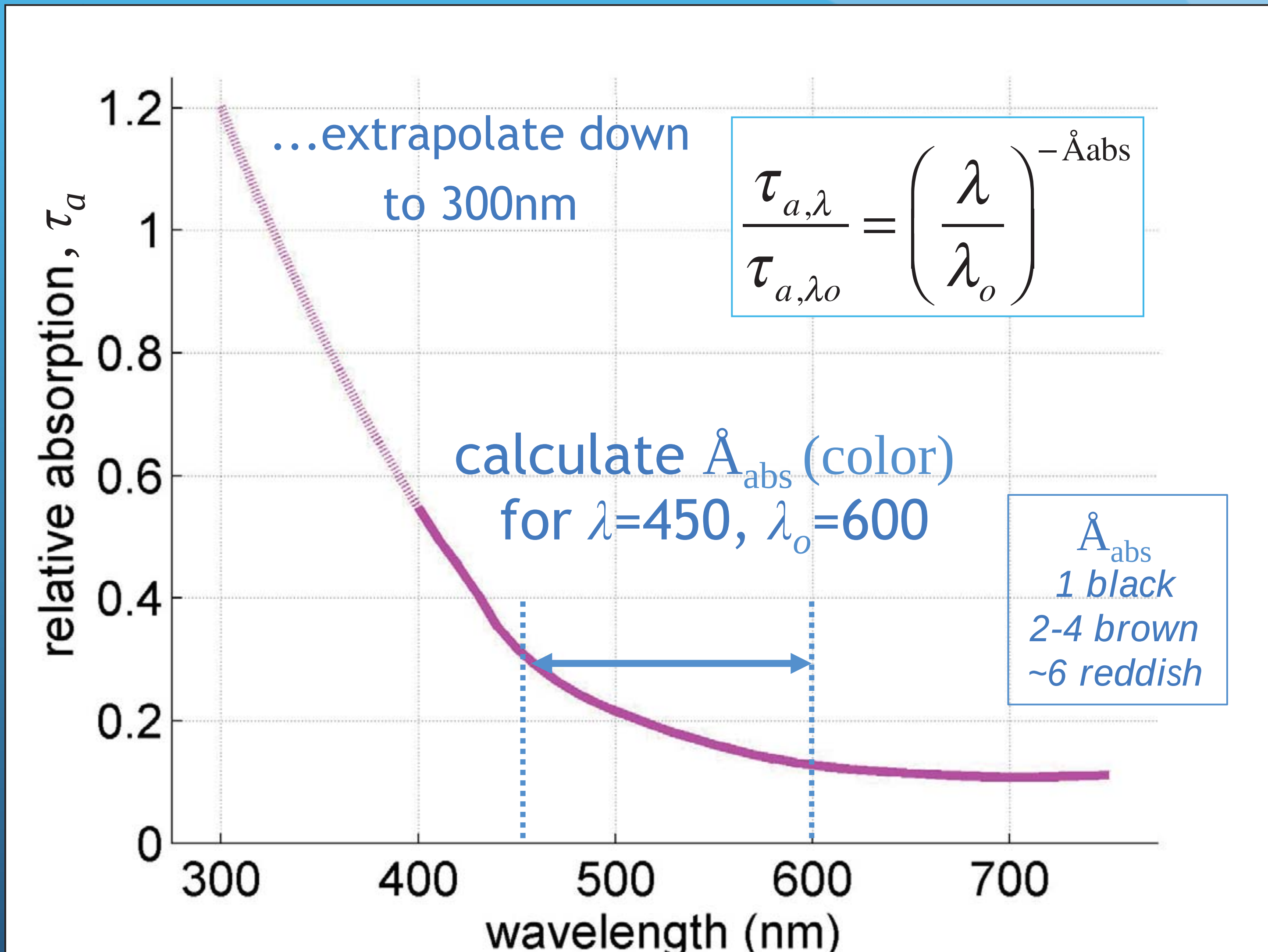
FIELD SAMPLING

- ~2-5cm vertical resolution
- 3 parallel profiles
- collect soil at each site

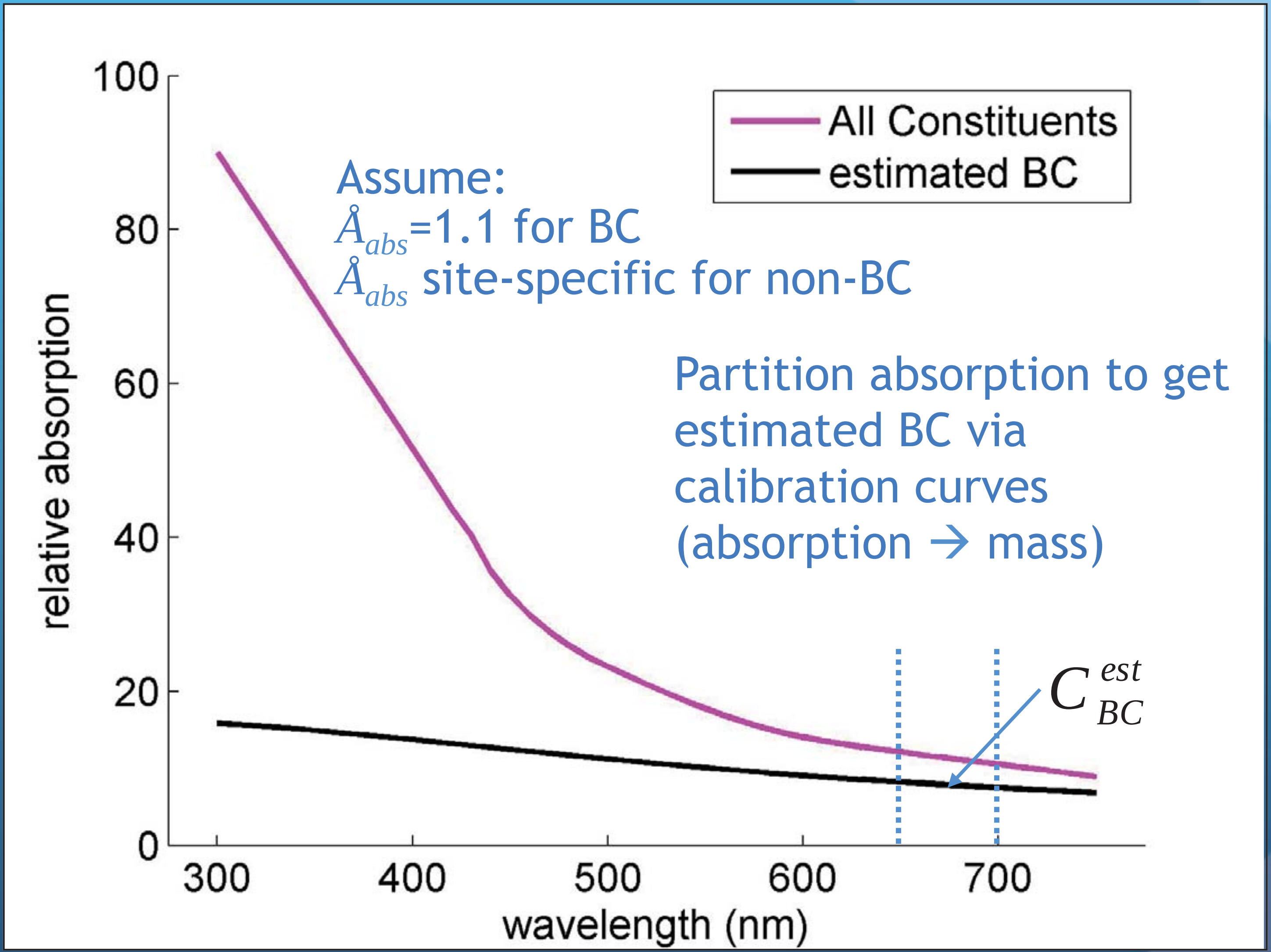
- melt/filter every ~3 days
- re-freeze snow water for chemical analysis

- nuclepore filters
  - 0.4μm pore size
  - ~95% capture efficiency

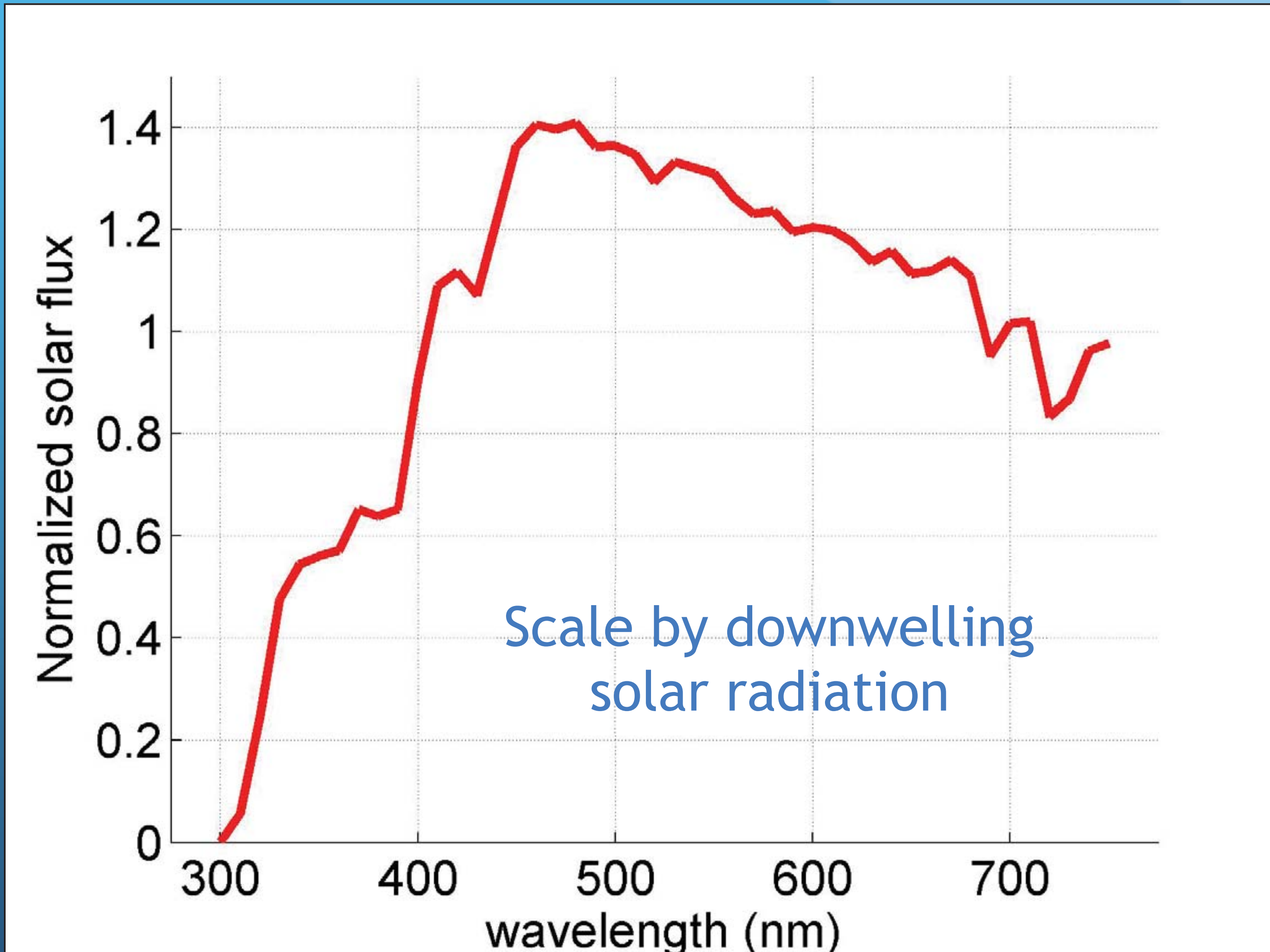
ISSW analysis of filters



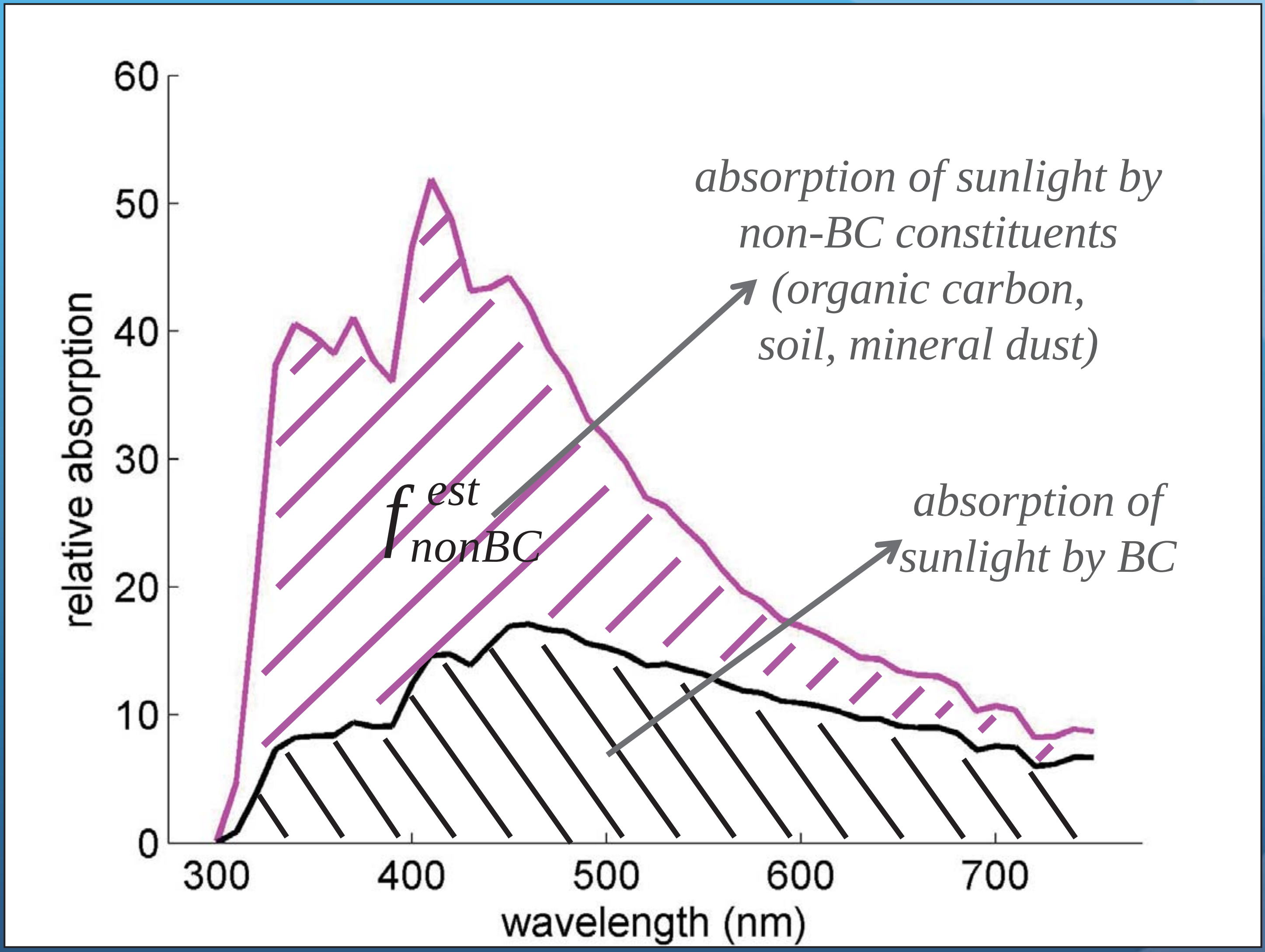
ISSW analysis of filters



ISSW analysis of filters



ISSW analysis of filters



Derived Parameters:

C_{BC}^{est} (ng/g) = estimated BC concentration

C_{BC}^{equiv} (ng/g) = amount of BC needed to account for all light absorption 300-750nm (solar spectrum weighted)

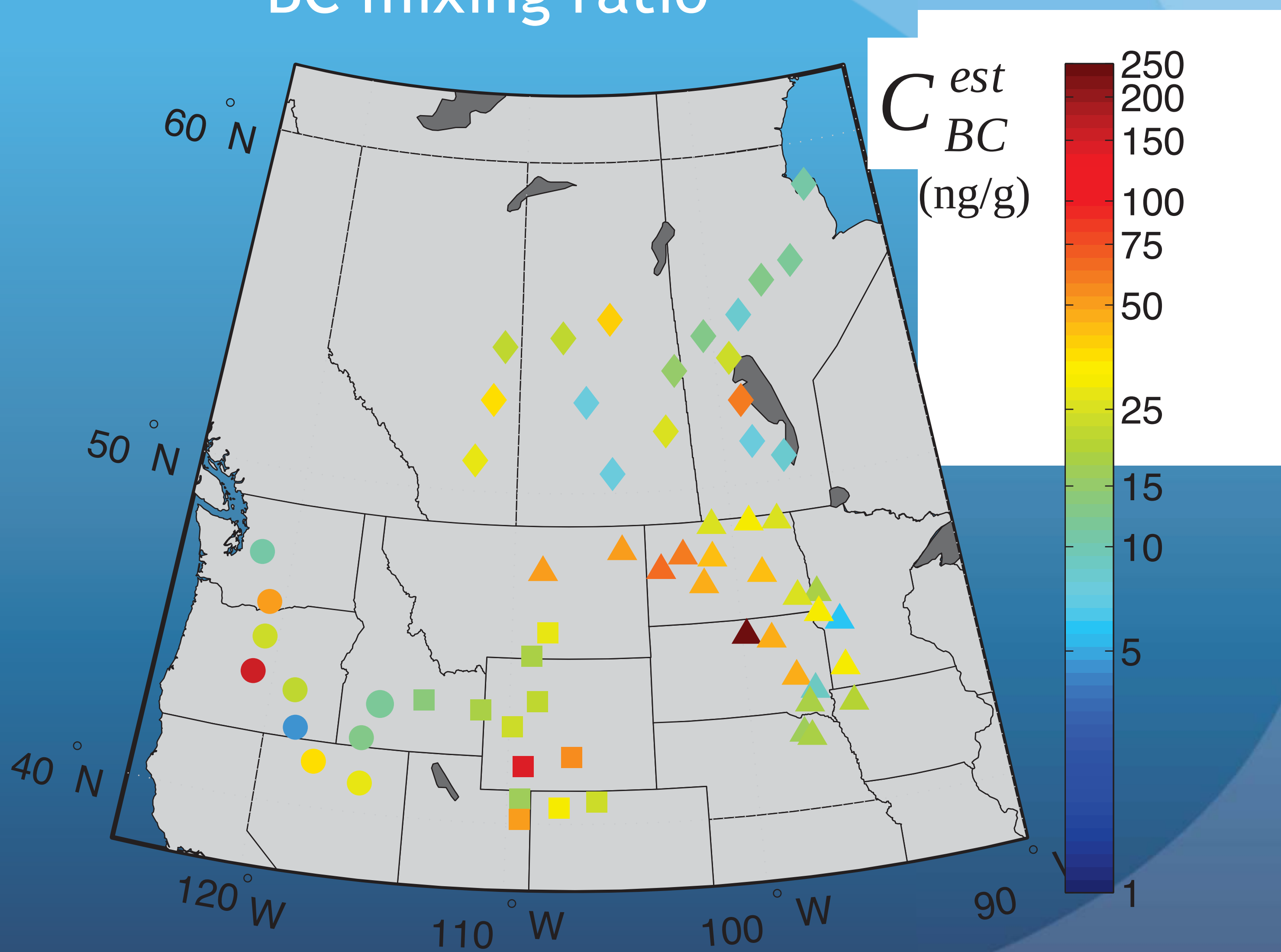
f_{nonBC}^{est} (%) = fraction of 300-750nm solar absorption due to non-BC components

$Å_{tot}$ [450:600nm] effectively the color

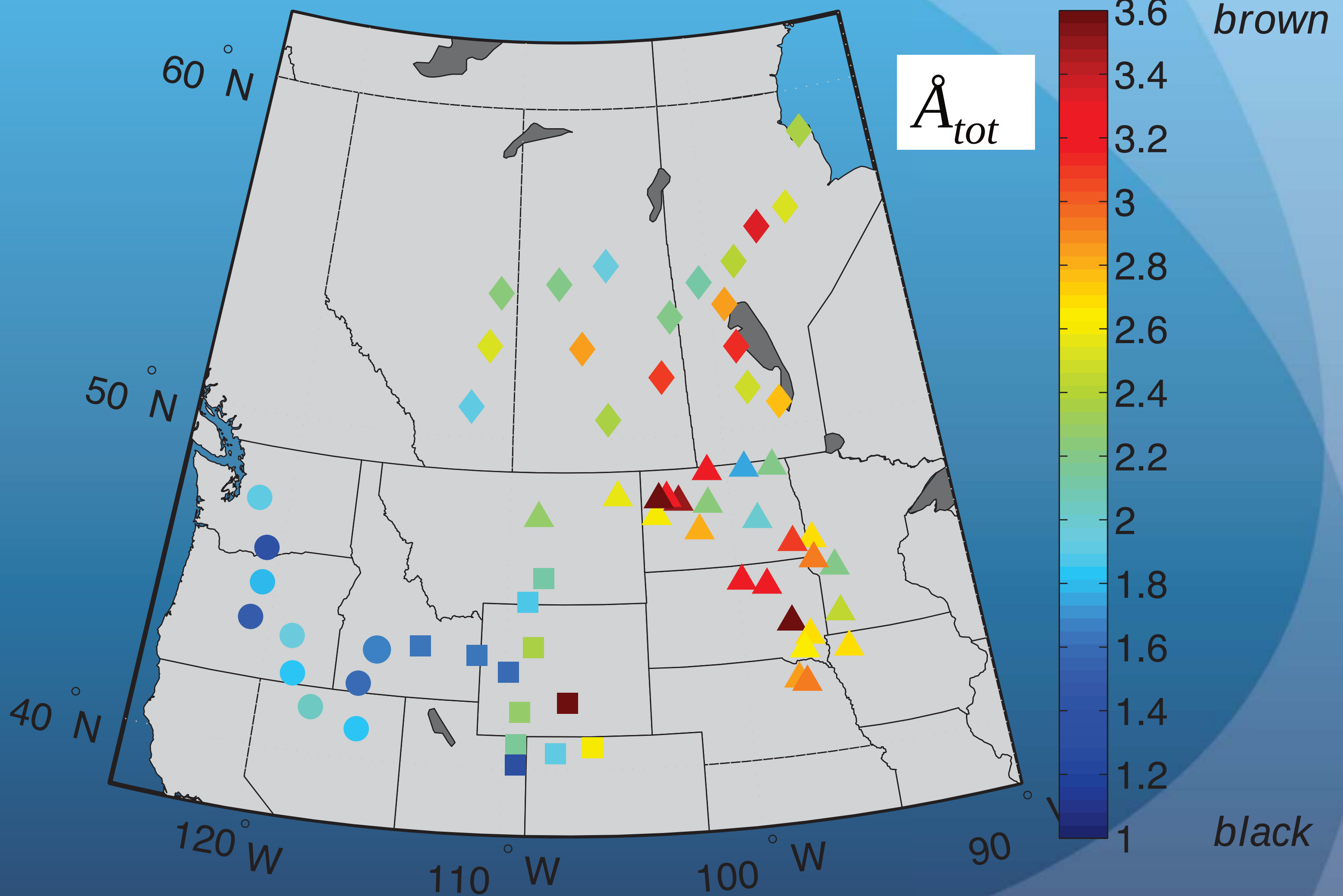
($Å_{abs}$= *1 black 2-4 brown >~6 reddish)*

Surface-most snow samples :

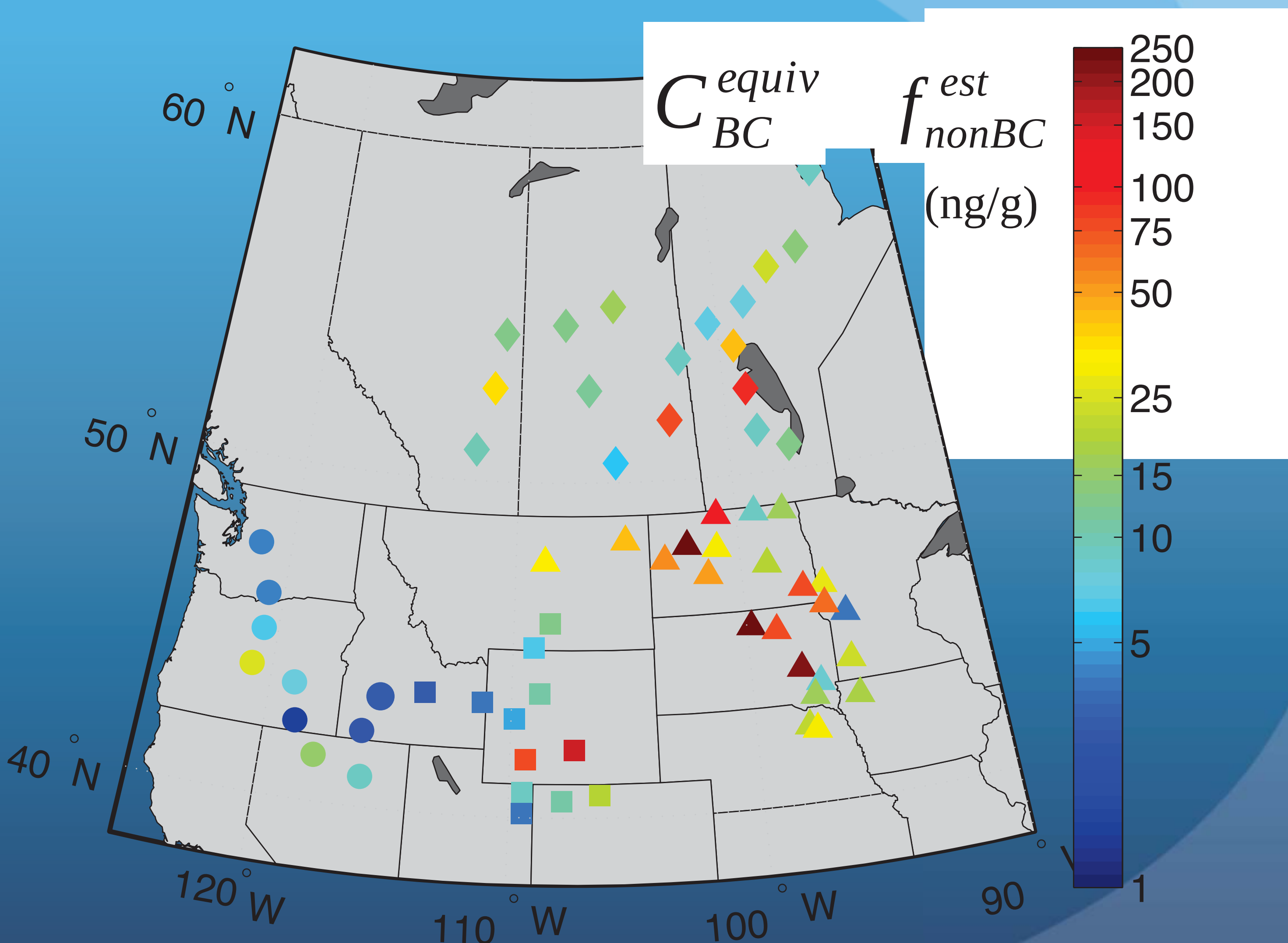
BC mixing ratio



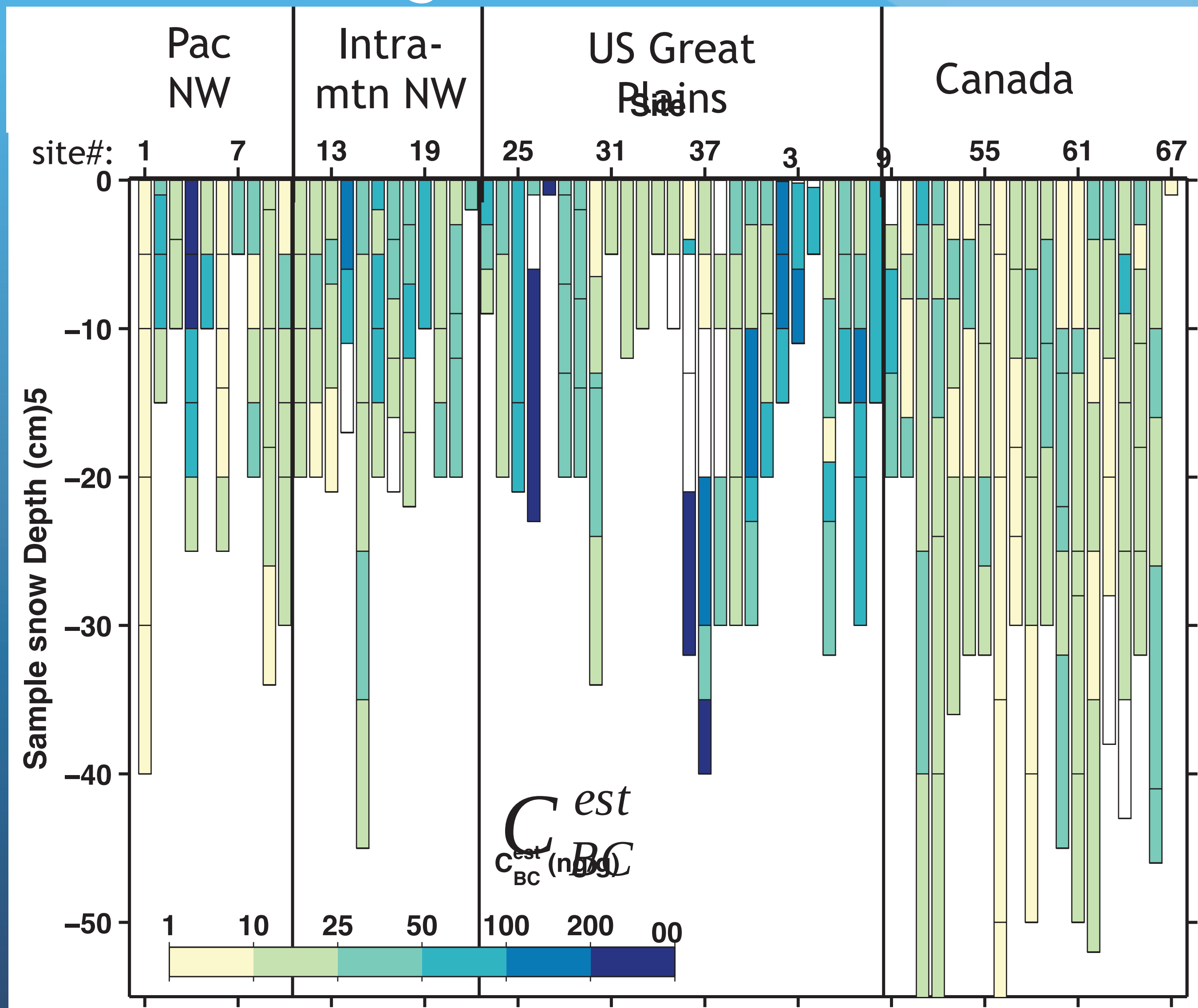
Surface-most snow samples : Absorption Ångström exponent



Surface-most snow : non-BC light-absorbing particles expressed as an equivalent BC mixing ratio

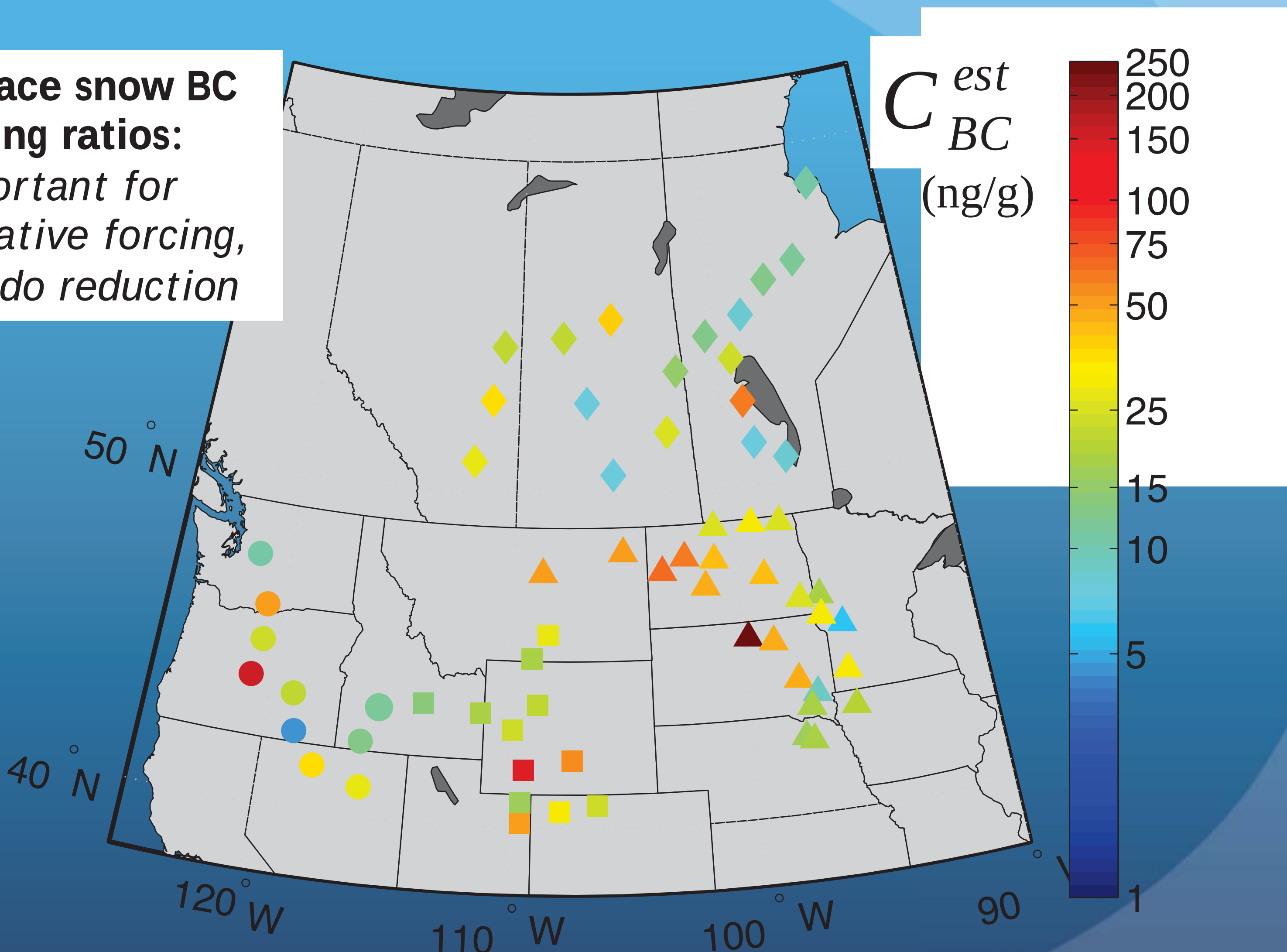


Vertical variability in the mixing ratio of BC in snow



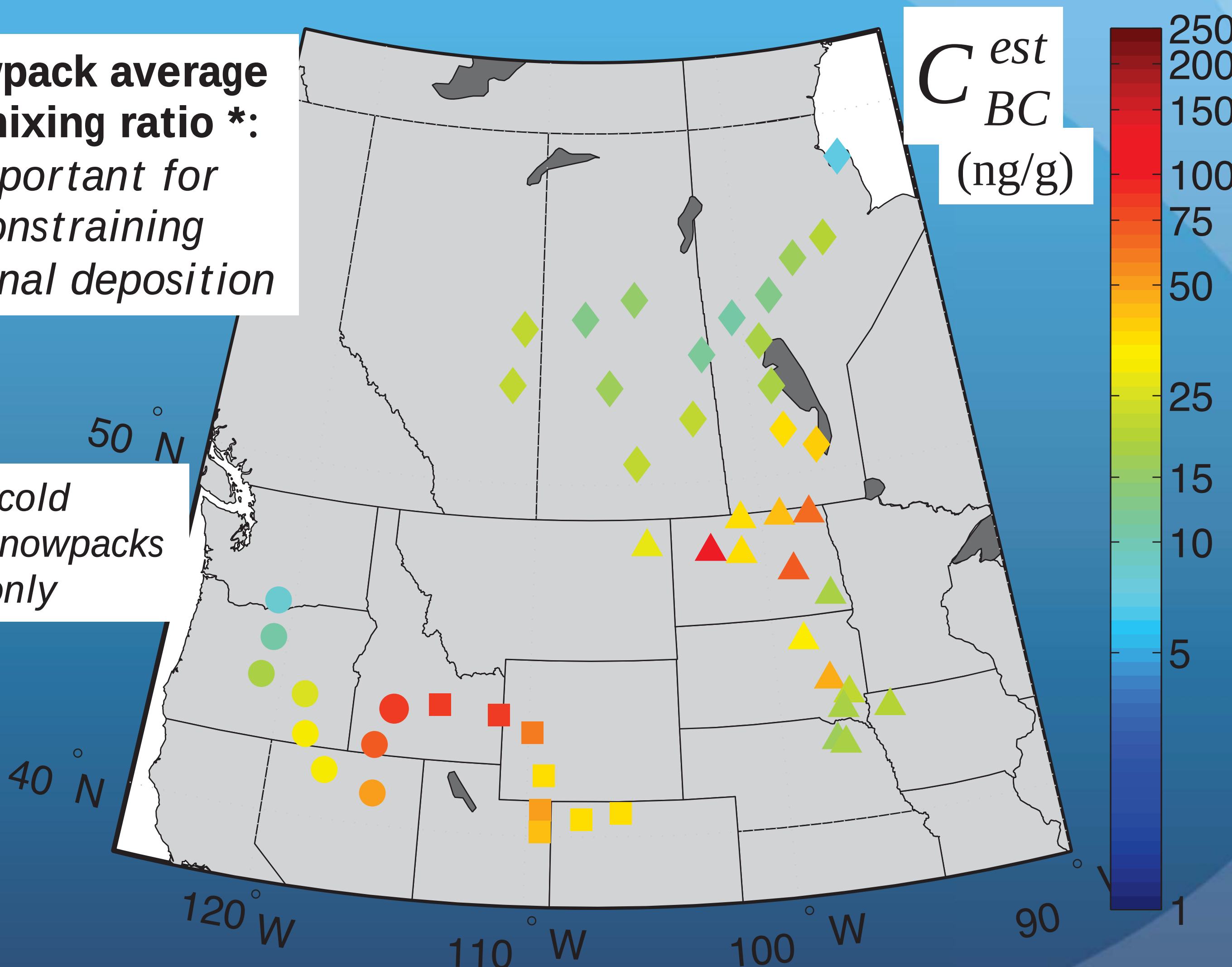
Surface-most snow samples : BC mixing ratio

surface snow BC mixing ratios: *important for radiative forcing, albedo reduction*



Snow column average : BC mixing ratio

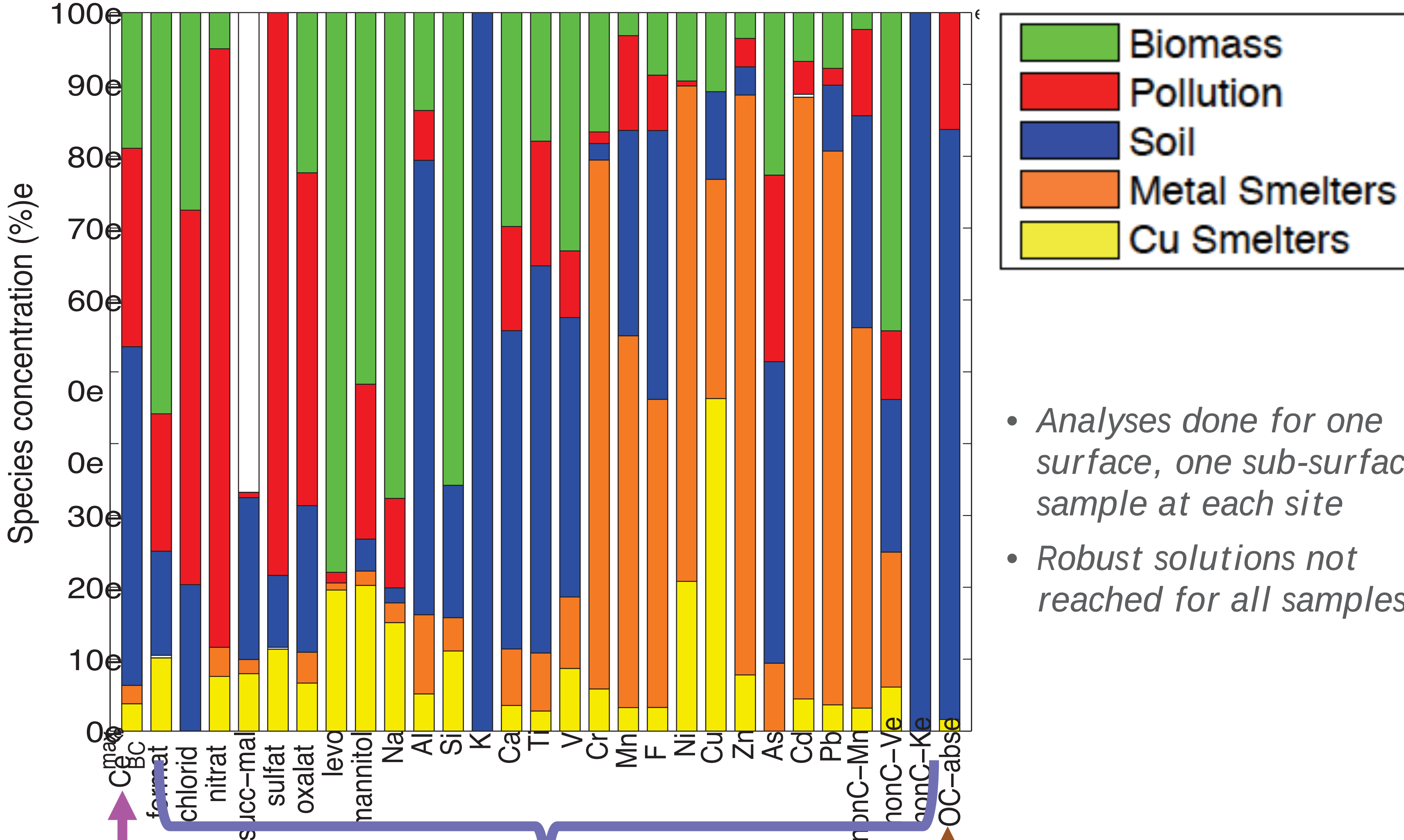
snowpack average BC mixing ratio *:
important for constraining seasonal deposition



**cold snowpacks only*

PMF* Source "fingerprints"

** Positive Matrix Factorization*



- *Analyses done for one surface, one sub-surface sample at each site*
- *Robust solutions not reached for all samples*

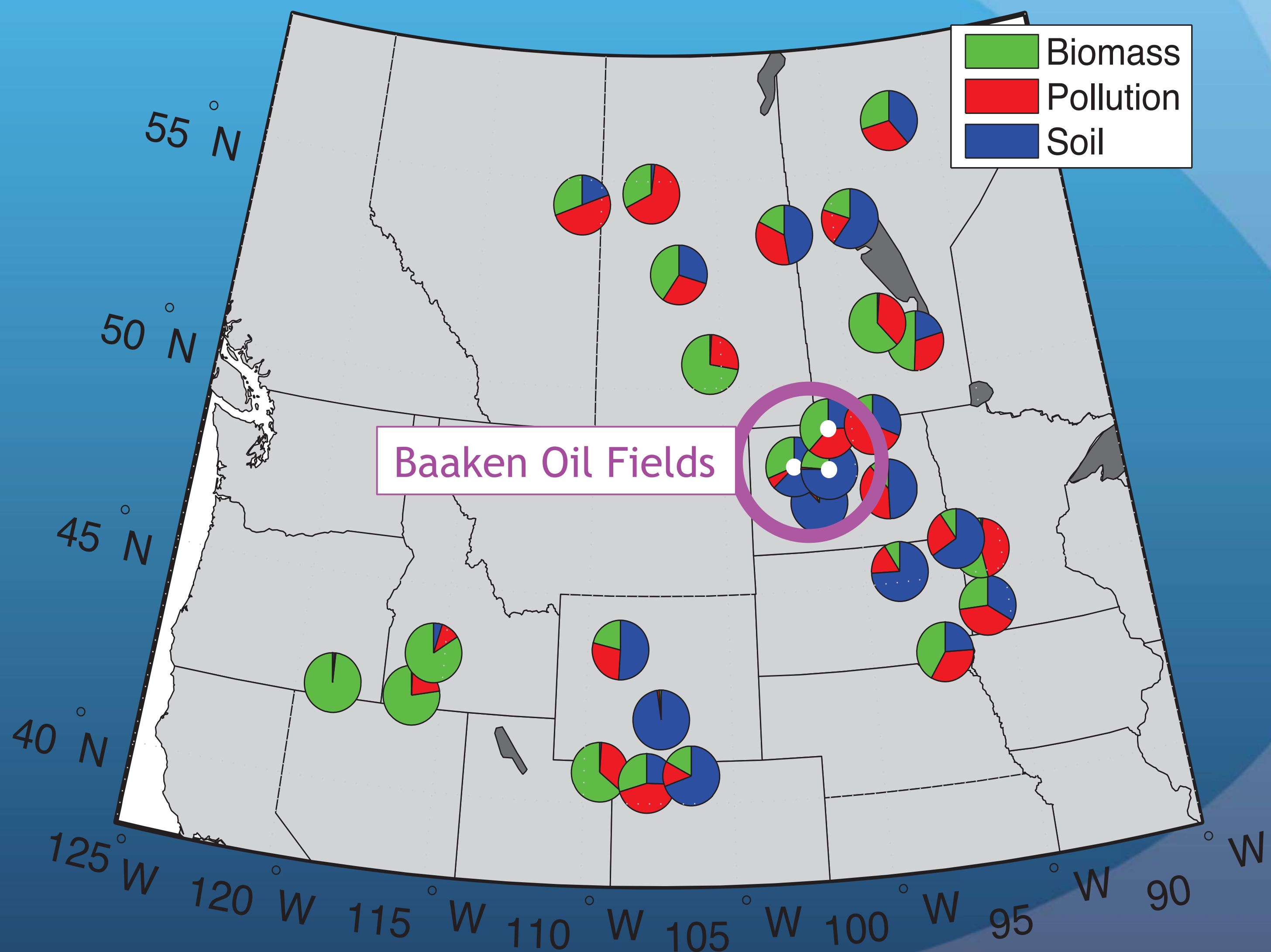
ISSW analysis

chemical analyses

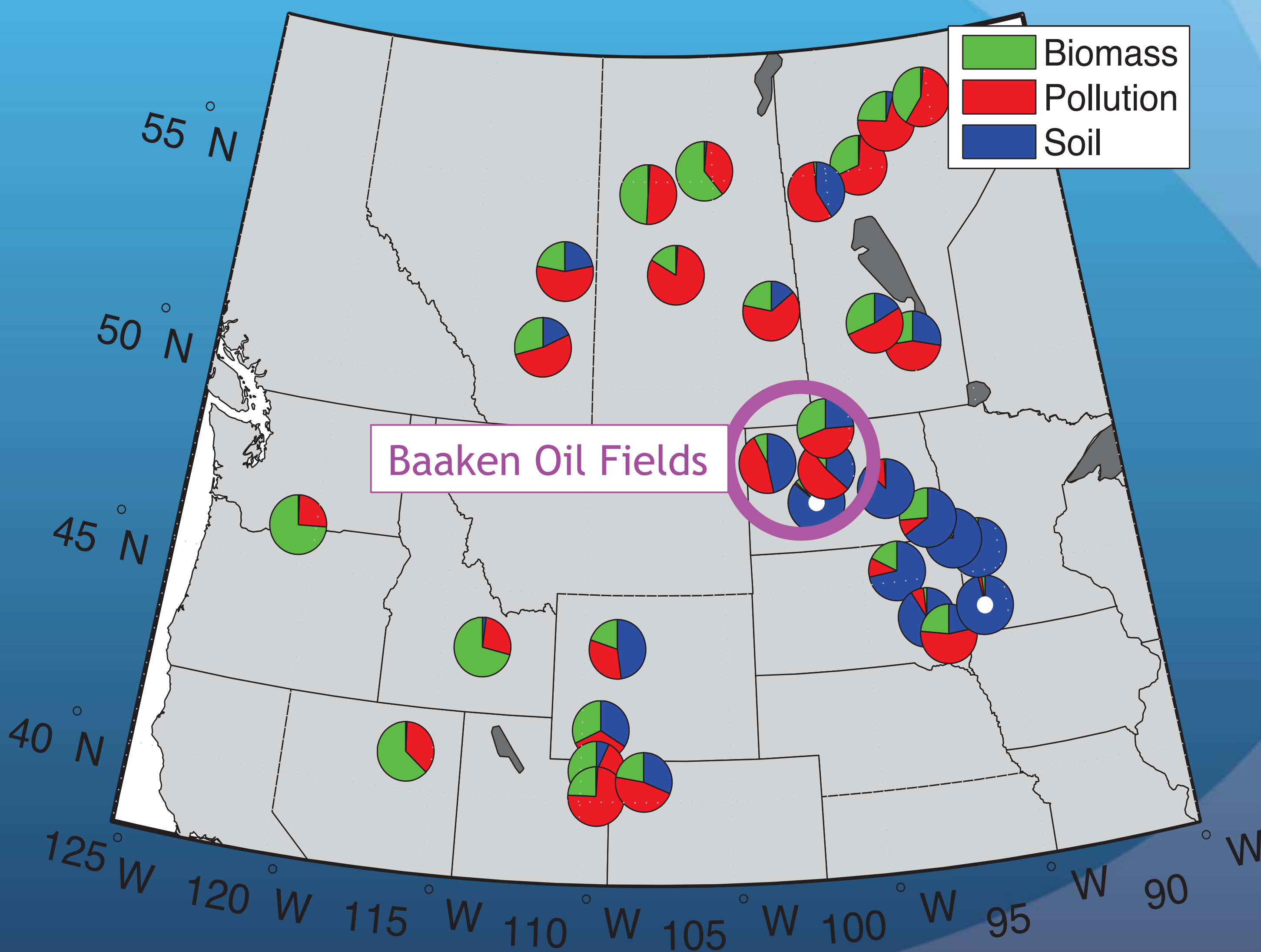
serial extraction

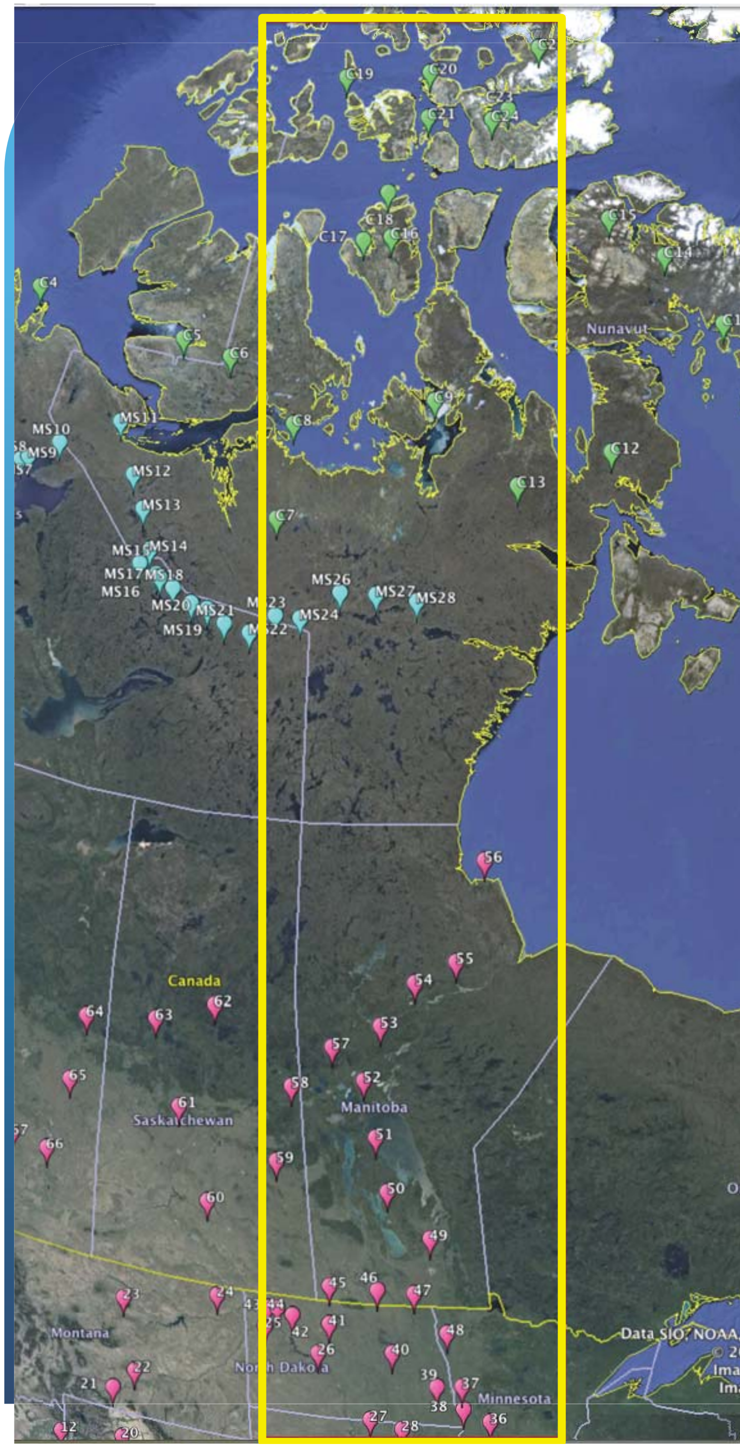
for organics

PMF Analysis : Factor contributions to 650-700nm absorption – Surface snow samples



PMF Analysis : Factor contributions to 650-700nm absorption – sub-surface snow samples



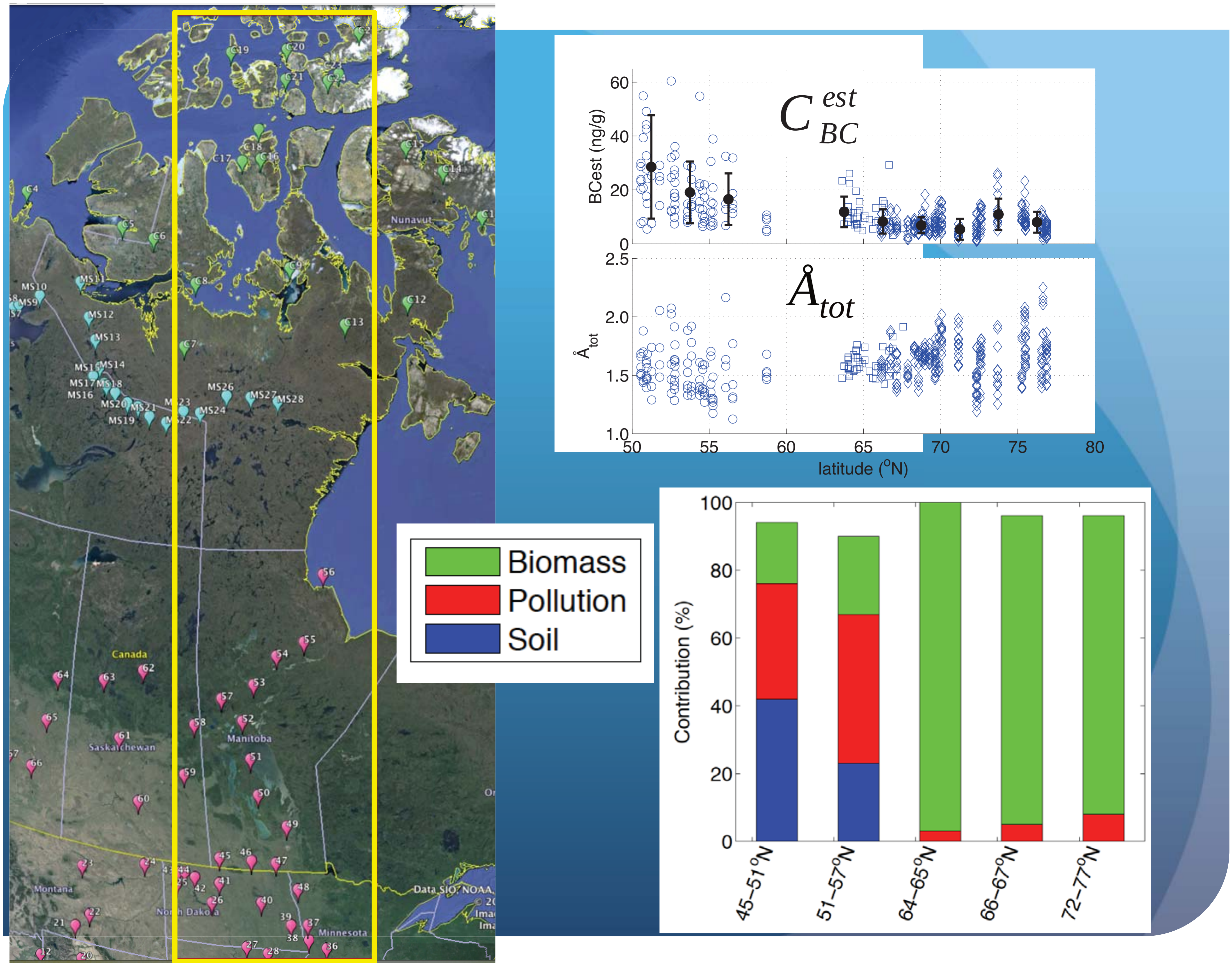


Combining N. American survey & earlier Arctic survey data

2009 Canadian Arctic survey

2007 Canadian sub-Arctic traverse

2013 N. Amer. Great Plains survey



Nunavut
Canada
Saskatchewan
Manitoba
Montana
North Dakota
Minnesota
Data SIO, NOAA,
C_{BC}^{est}
BCest (ng/g)
$\mathring{A}_{tot}$
latitude (°N)
Biomass
Pollution
Soil
Contribution (%)
45–51°N
51–57°N
64–65°N
66–67°N
72–77°N

Re: the relative roles of soil vs. BC in US Great Plains snow albedo

- Great Plains soil contribution is higher in sub-surface samples → likely because this corresponds to when snowpack was shallower, so more exposed soil
- Snow cover in 2013 was not anomalous – but there are years with more extensive & persistent snow cover. In these years, the relative role of BC (vs. soil) in lowering snow albedo will likely be higher
- i.e., BC likely only dominates snow albedo reduction in years with higher snowpack – when retention of the snow is less critical for water resources

Why so much soil in S^{ern} Great Plains snow?

- Almost the entire area is agricultural = disturbed soil (“snirt”)
- It’s windy (!!!) in the winter
- Snow is often thin / patchy
- Snow cover is intermittent, especially to the S and W

→ Dirt mixes in with snow as it’s falling, right near the surface. Regional/global models will not capture this.

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Farming practices may affect the color of snow at least as much as BC emissions in much of the southern Great Plains

Bakken Oil fields

<u>Increased soil disturbance</u>

- clearing for oil platforms
- much more driving on

  dirt / farm roads
- areas cleared for housing

<u>Increased BC emissions</u>

- diesel trucks
- oil flaring (significant?)
- wood stoves in temporary housing?

N. China survey 2010 : 46 sites

Lanzhou Univ. & Univ. of Washington collaboration (Wang et al., 2013)

Arctic + N. China + N. American surveys

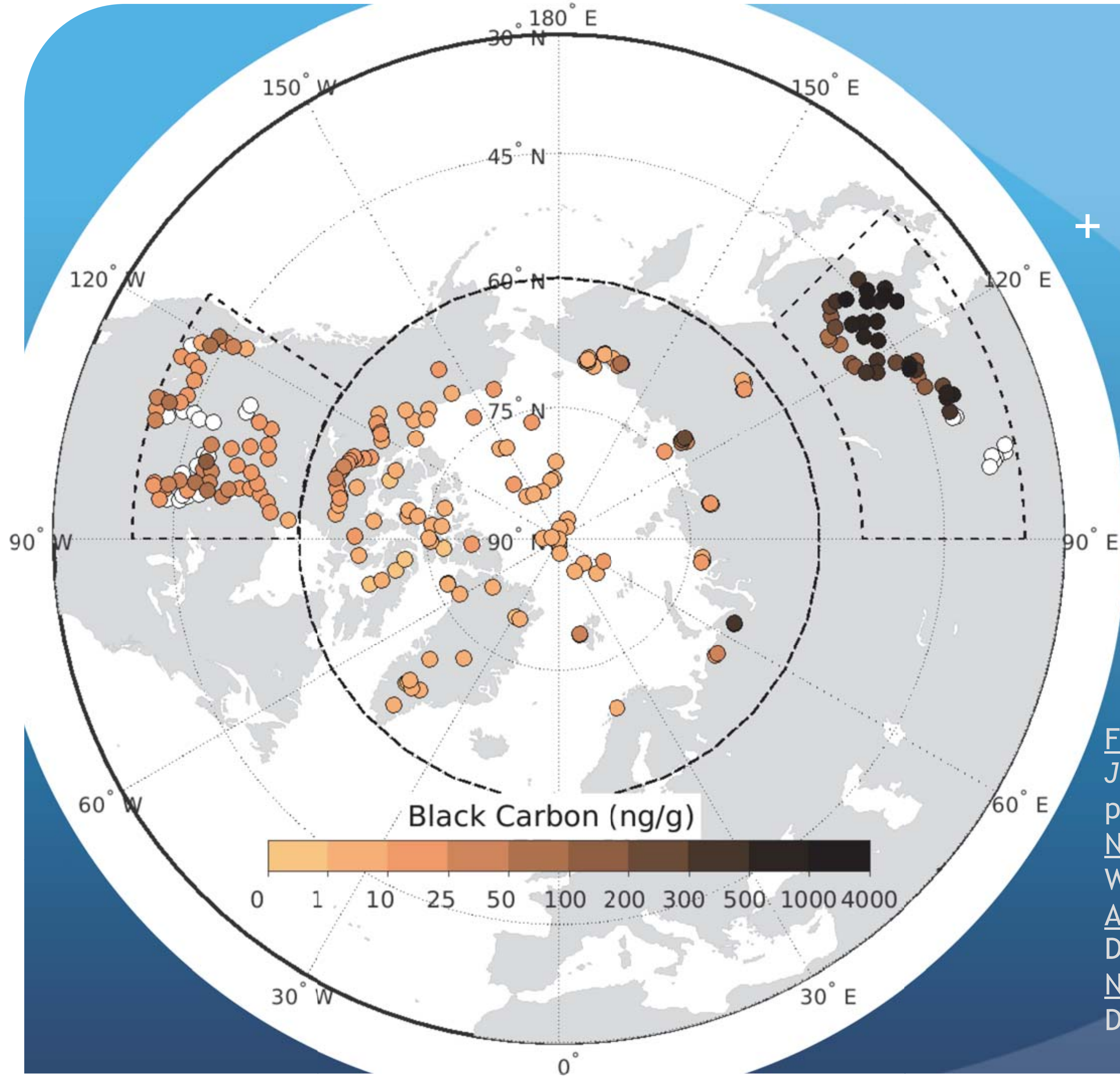
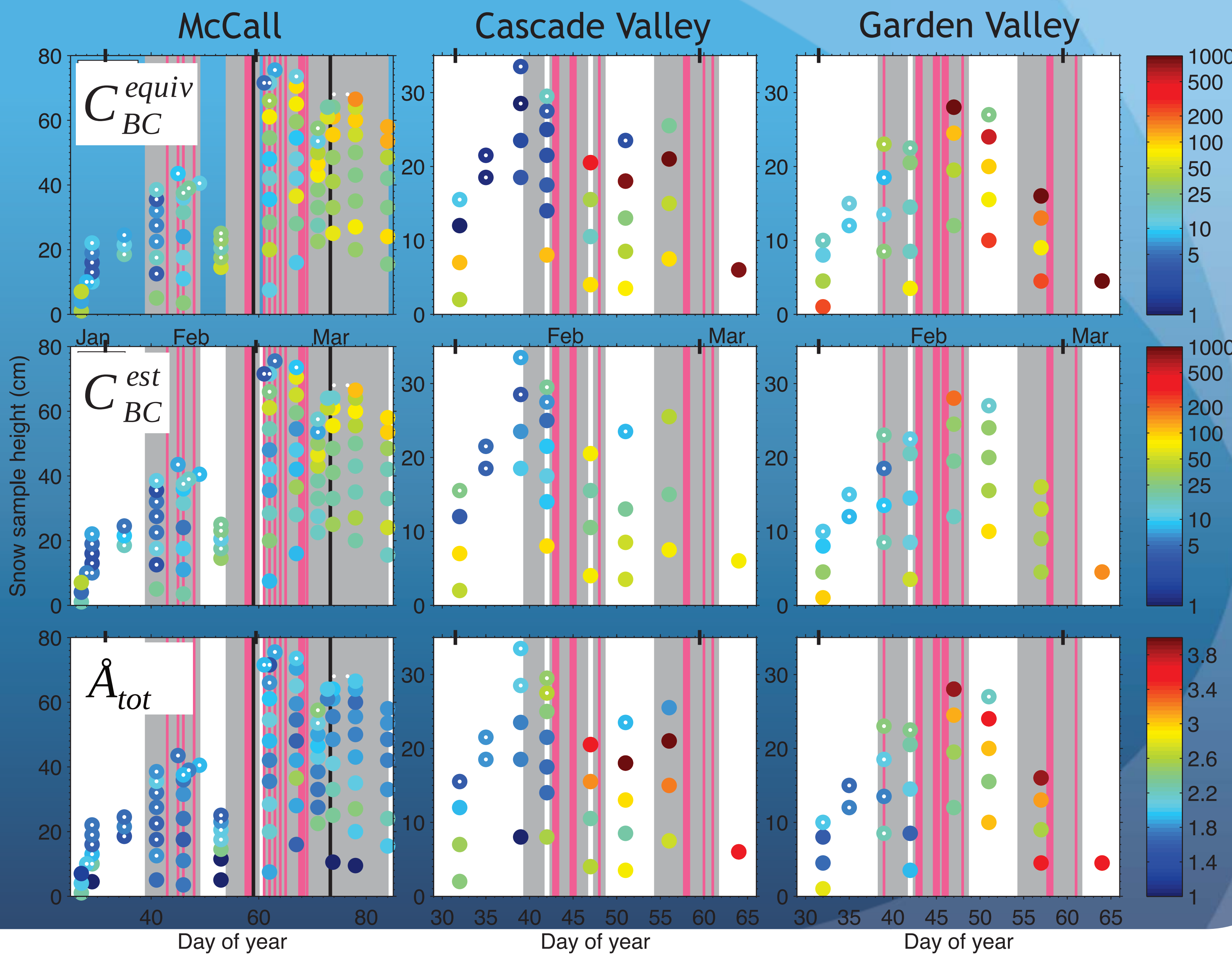


Figure: Cheng, D.et al., *J. Geophys. Res.*, (in preparation).
N. China data: Wang et al., 2013
Arctic data: Doherty et al., 2010
N. Amer. data: Doherty et al., 2014 & 2016

2014 process study: 3 Idaho mountain valley sites



Overall findings

- Dust & soil play a very strong role (sometimes dominate) incidences of high snow particulate light absorption at:

  US Great Plains sites
  2 Idaho mountain valley sites
  SE of Vernal, Utah
  central China sites

  → for the US GP & Idaho sites probably locally transported soil, <u>so will not be captured by regional/global models</u>

  → radiative forcing by BC in snow will be over-estimated if these non-BC components are not accounted for

- Post-wet-depositional processes are important!
  - Most of the variability in snow particulate light absorption is driven by what's happening *between* new snowfall events

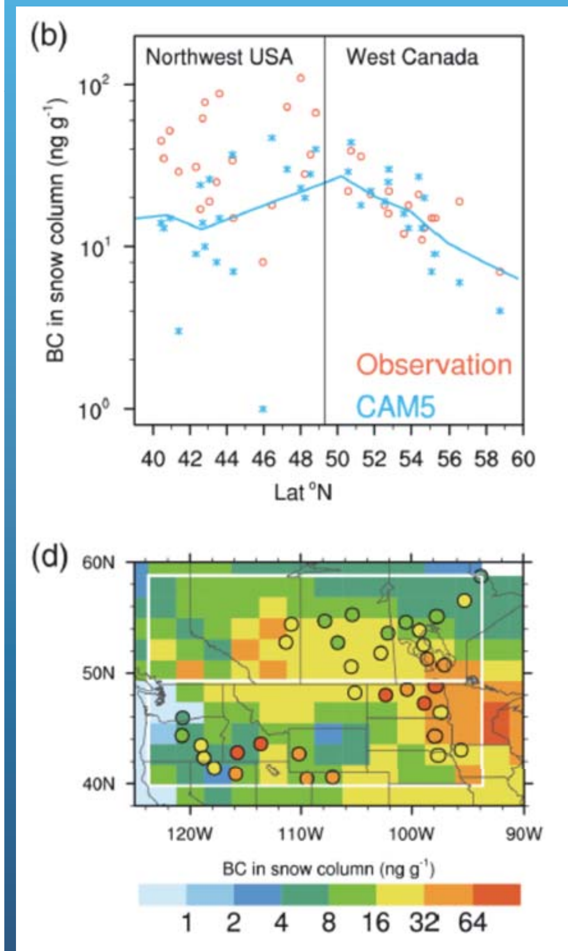
    - dry deposition, sublimation, melting

Overall findings

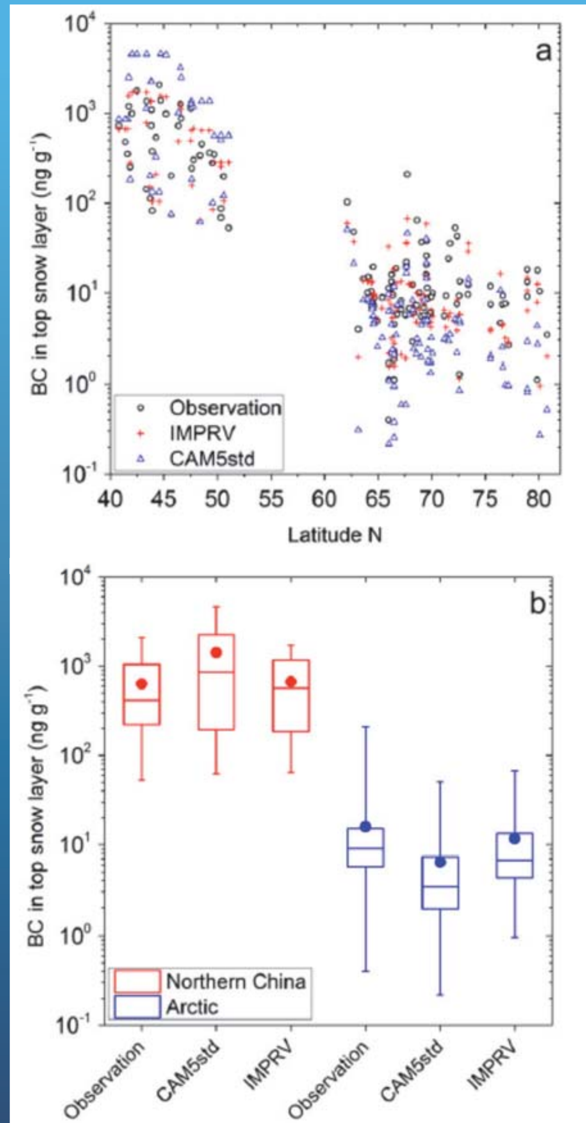
- Melt amplification:
  - generally confined to the top few cm of the snow
  - increases concentrations of BC/absorbing particles

    ~~by up to a factor of about five~~.
  - Scavenging fractions with melt-water: 10-30%
- Idaho & Utah: dry deposition and in-snow processes increase the mixing ratio of :
  - BC by up to an order of magnitude
  - all light-absorbing particulates by up to 2 orders of magnitude
- Spatial variability at a range of scales is considerably smaller than the temporal variations at a given site
  - implications for the representativeness of field samples used in observation/model comparisons.

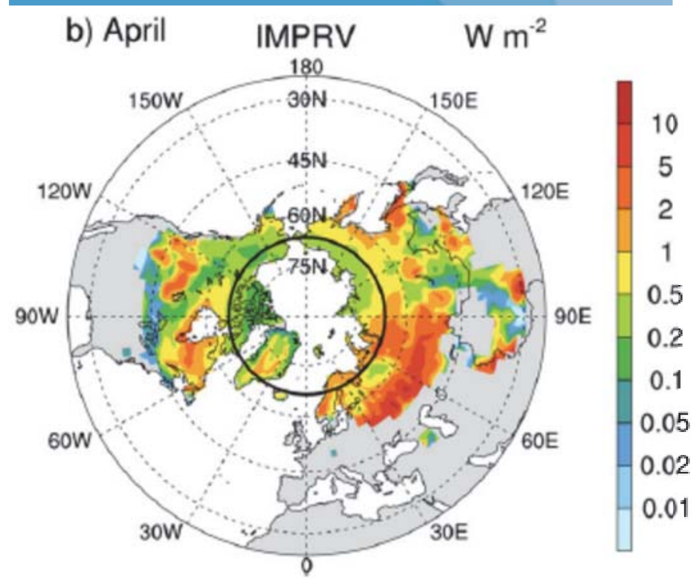
Zhang et al., 2015, ACP
model source study using tagged emissions



Qian et al., 2014, Env. Res. Lett.
study of BC-in-snow radiative forcing



Data are being used to test/adjust models



Radiative forcing by BC in snow

Publications:

Wang, X., S. J. Doherty and J. Huang, Black carbon and other light-absorbing impurities in snow across Northern China, *J. Geophys. Res. Atmos.*, 118 (3), 1471-1492, doi: 10.1029/2012JD018291, 2013.

Doherty. S. J., C. Dang, D. A. Hegg, R. Zhang and S. G. Warren, Black carbon and other light-absorbing particles in snow of central North America, *J. Geophys. Res. Atmos.*, 119, doi:10.1002/2014JD022350, 2014.

Dang, C. and D. A. Hegg, Quantifying light absorption by organic carbon in Western North American snow by serial chemical extractions, *J. Geophys. Res. Atmos.*, 119, 10,247-10,261, doi:10.1002/2014JD022156.

Zhang, R., H. Wang, D. A. Hegg, Y. Qian, S. J. Doherty, C. Dang, P.-L. Ma, P. J. Rasch, and Q. Fu, Quantifying sources of black carbon in Western North America using observationally based analysis and an emission tagging technique in the Community Atmosphere Model, *Atmos. Chem. Phys.*, 15, 12805-12822, doi:10.5194/acp-15-12805-2015, 2015.

Doherty, S. J., D. A. Hegg, P. K. Quinn, J. E. Johnson, J. P. Schwarz, C. Dang and S. G. Warren, Causes of variability in light absorption by particles in snow at sites in Idaho and Utah, *J. Geophys. Res. Atmos.*, 121, doi:10.1002/2015JD024375, 2016.

+ other studies that used our data (e.g. Qian et al., 2014, Environ. Res. Lett.)