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

Sarah Doherty
JISAO, Univ. of Washington
Seattle, WA USA

Stephen Warren, Dean Hegg & Cheng Dang
Dept. of Atmos. Science, Univ. of Washington, Seattle, WA USA

Rudong Zhang, Xin Wang & Jianping Huang
Lanzhou University, Lanzhou, CHINA

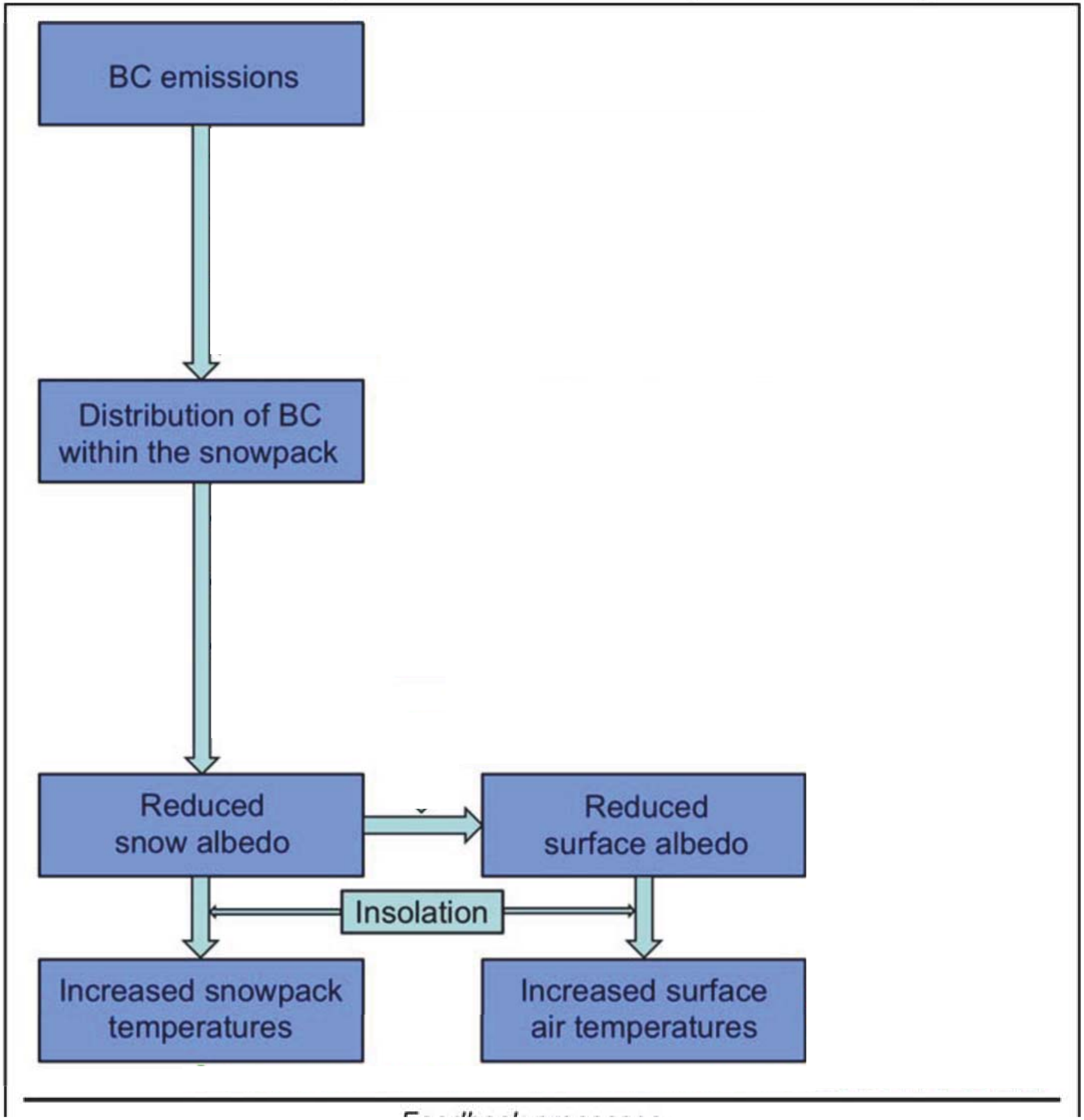
JISAO

Goals

- Constrain amount and sources of BC & other light-absorbing particles in snow: focus on N. American Great Plains
- Comparison of light-absorbing particles in snow in N. American & N. China Great Plains
- Study relative roles of deposition and in-snow processes in surface snow light-absorbing particle mixing ratios / types
- Methods comparison for measuring BC in snow
- Use 2013 N American survey and earlier Canadian Arctic surveys to assess north-south gradients (for indication of N American contributions to Arctic)

Climate forcing by BC in snow

Bond et al., 2013
Figure 7.3



Climate forcing by BC in snow

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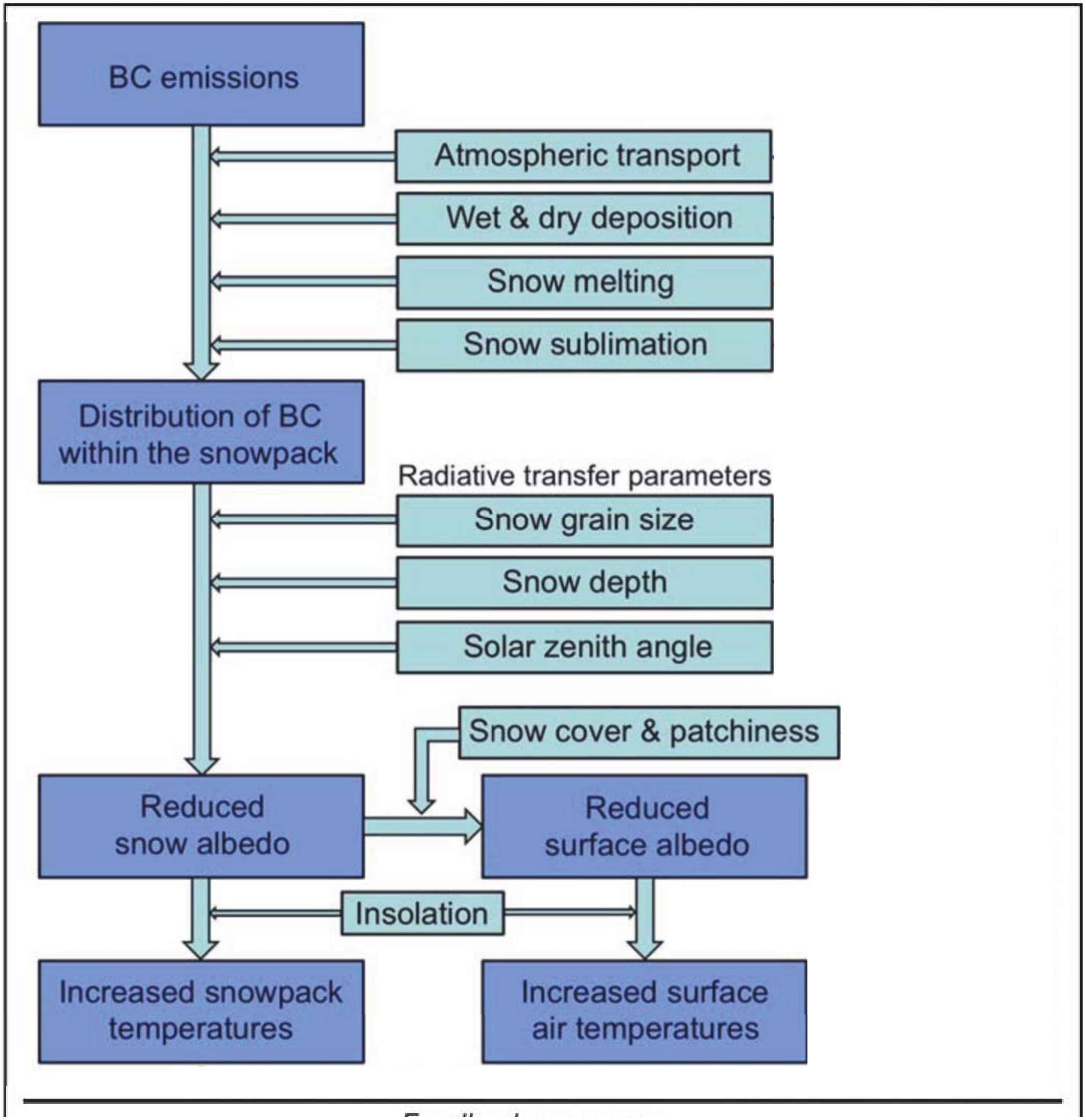
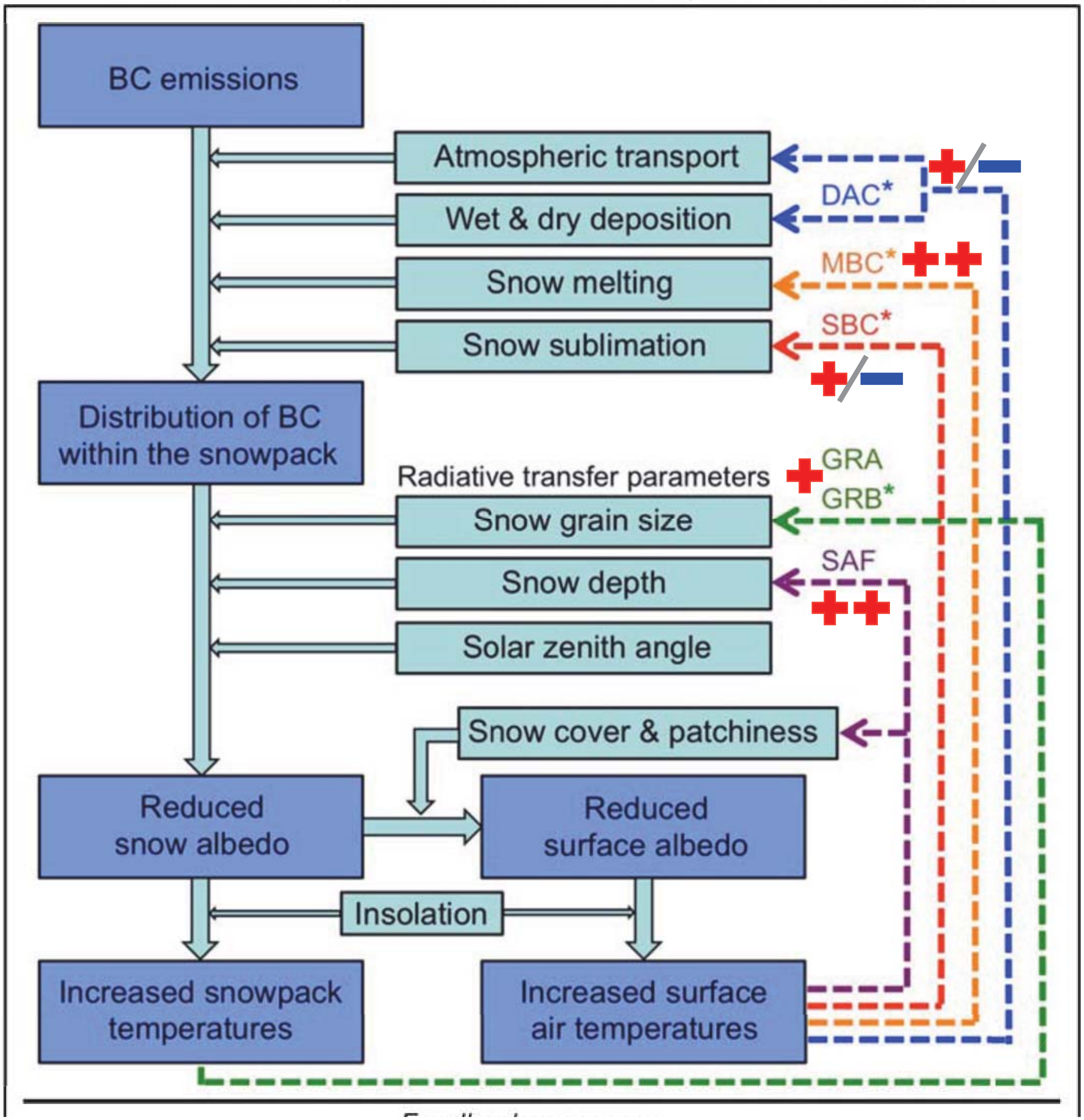


Climate forcing by BC in snow

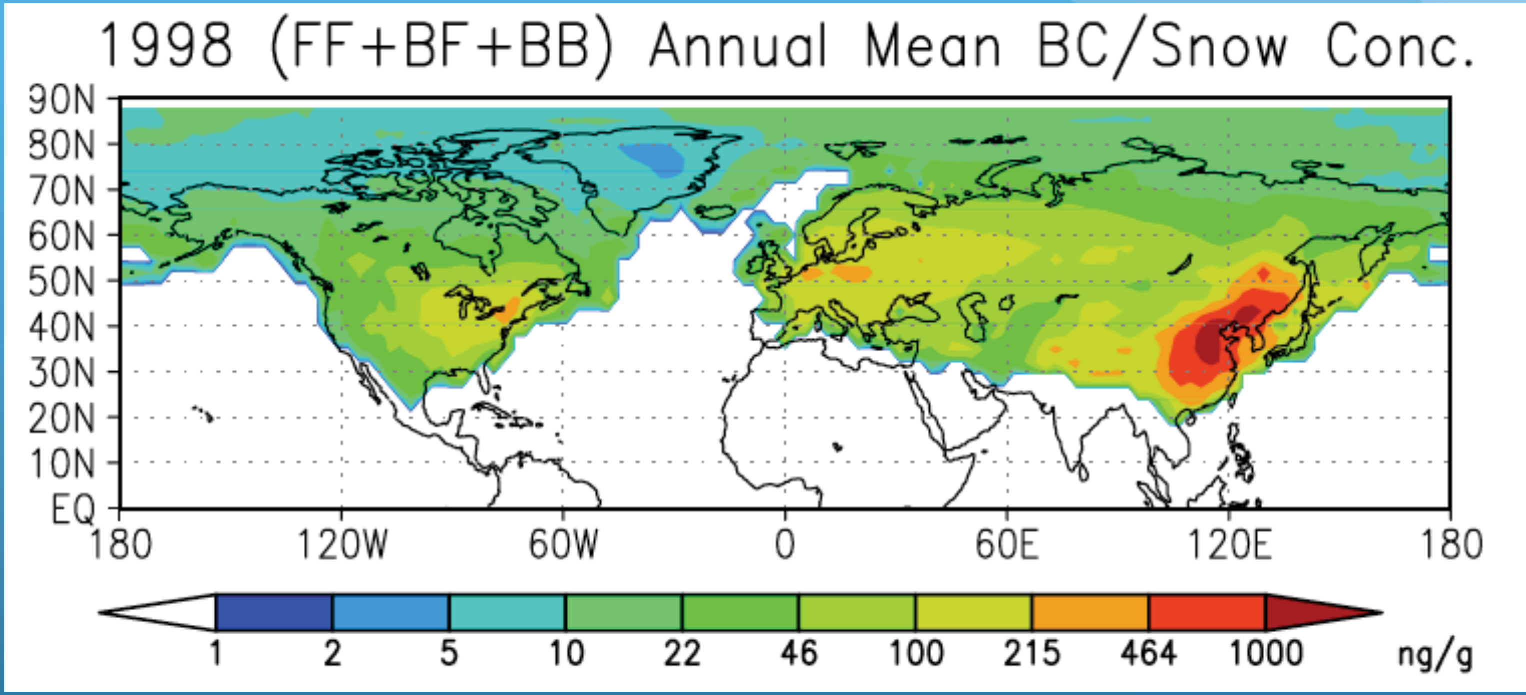
(mostly) strong positive feedbacks to initial positive forcing

Bond et al., 2013 Figure 7.3



Motivation

Flanner et al., 2007 Fig. 5



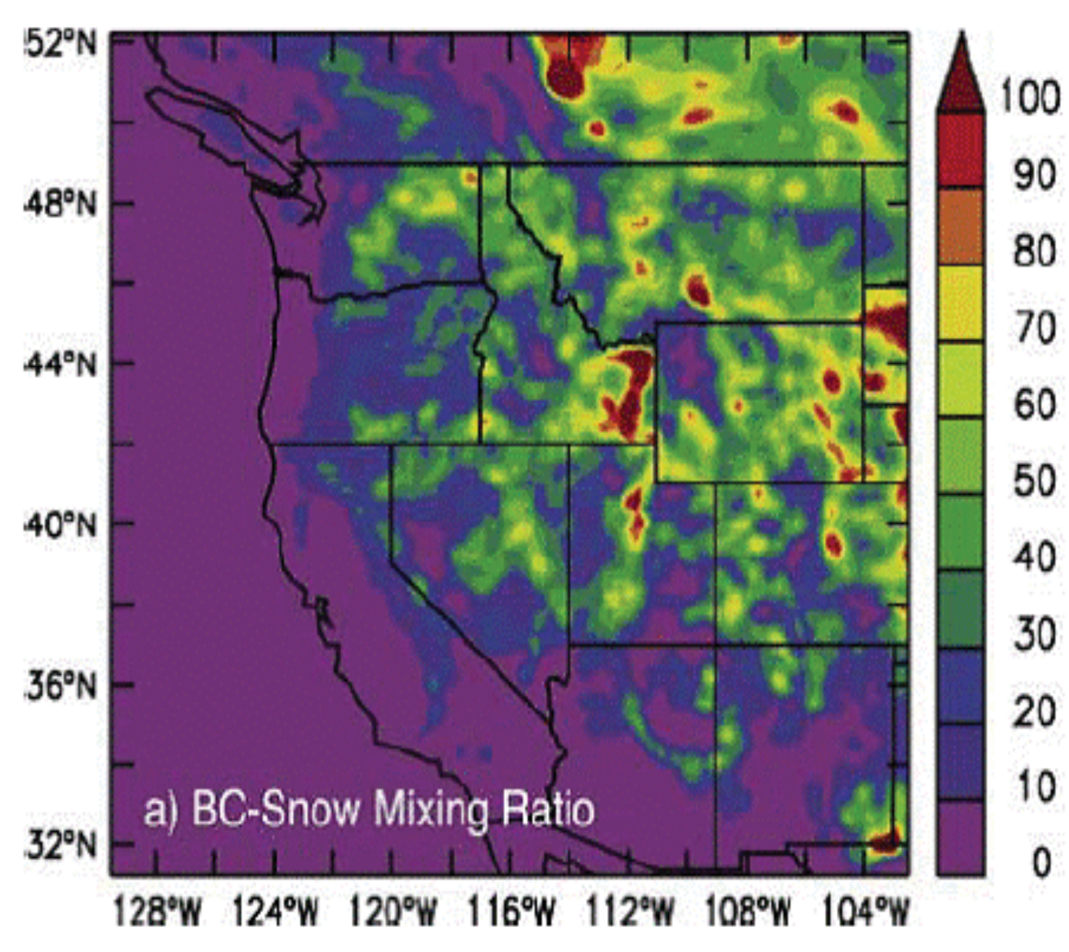
- Focus has mostly been on BC in snow in the Arctic, BUT:
- The highest concentrations of BC in snow are at lower latitudes
- The open plains regions of the northern mid-latitudes are where the snowpack is not masked by vegetation
- Warming due to BC in snow at lower latitudes may contribute significantly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

Motivation

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

Qian et al., 2009



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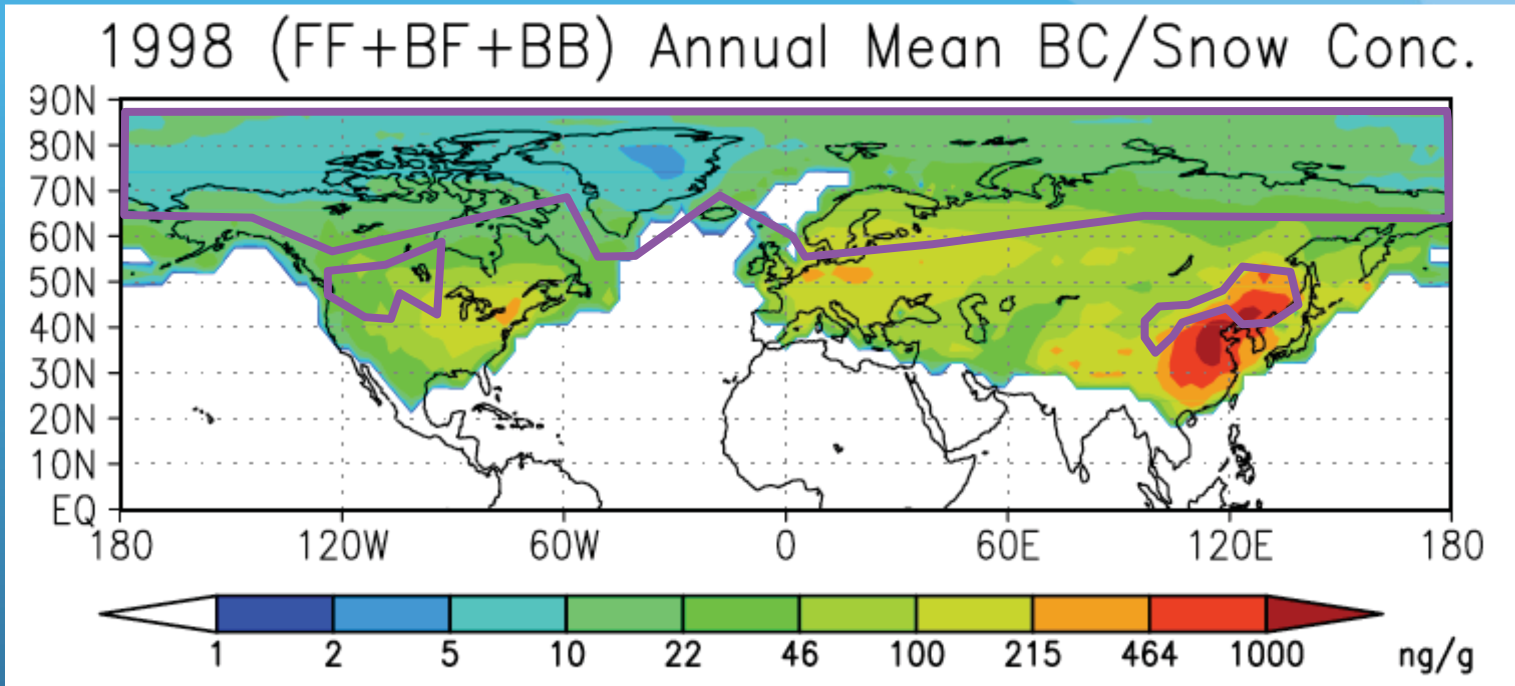
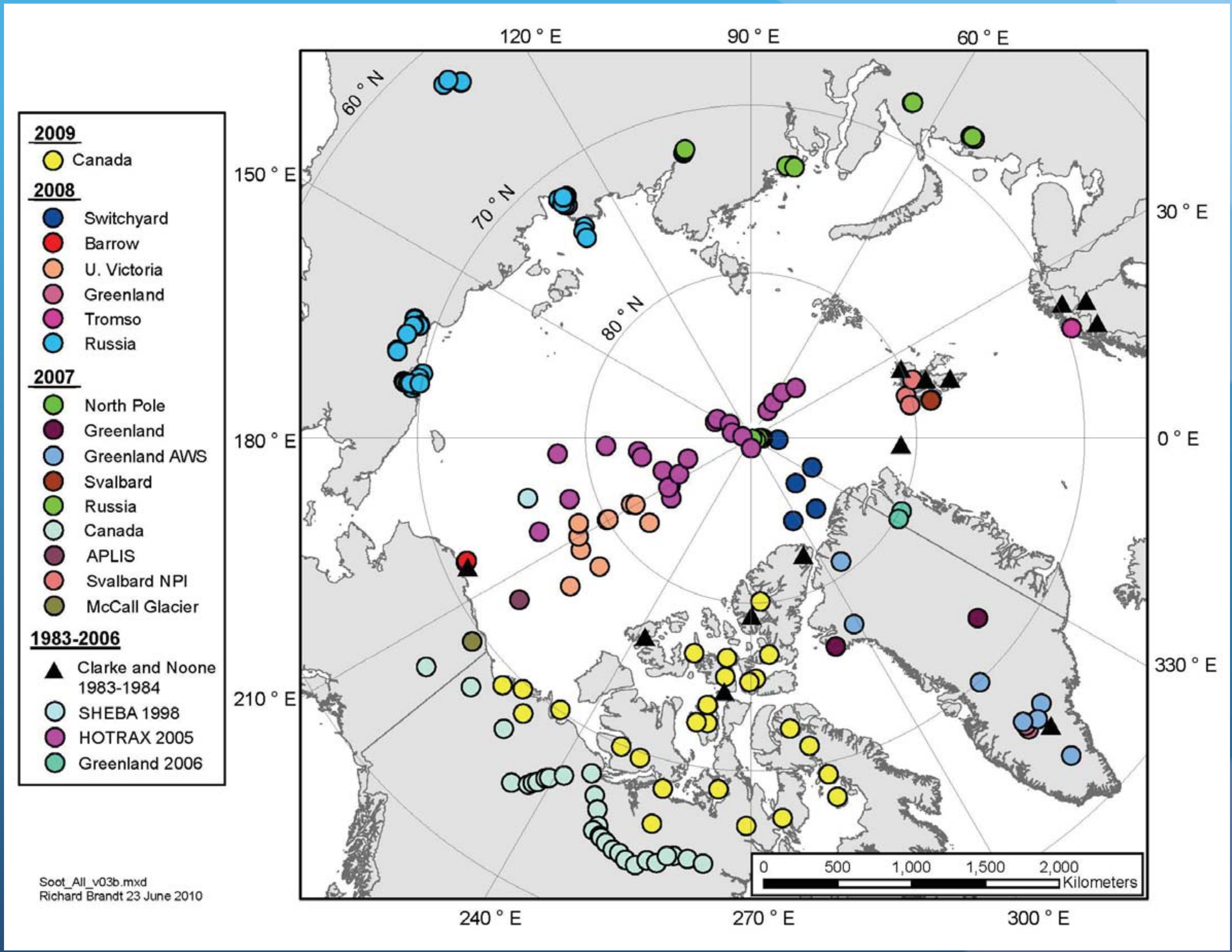


- Large-area surveys of three regions:
  - Arctic (mostly 2007-2010) *previous work under NSF*
  - N. China Great Plains (2010 & 2012) *with Lanzhou Univ., China*
  - N. America Great Plains (2013 & 2014)

→ All using the same sampling & analysis technique

Arctic Survey (mostly 2007-2010)



N. China survey 2010 : 46 sites

{Lanzhou Univ. & Univ. of Washington collaboration}

N. American survey 2013 : 67 sites

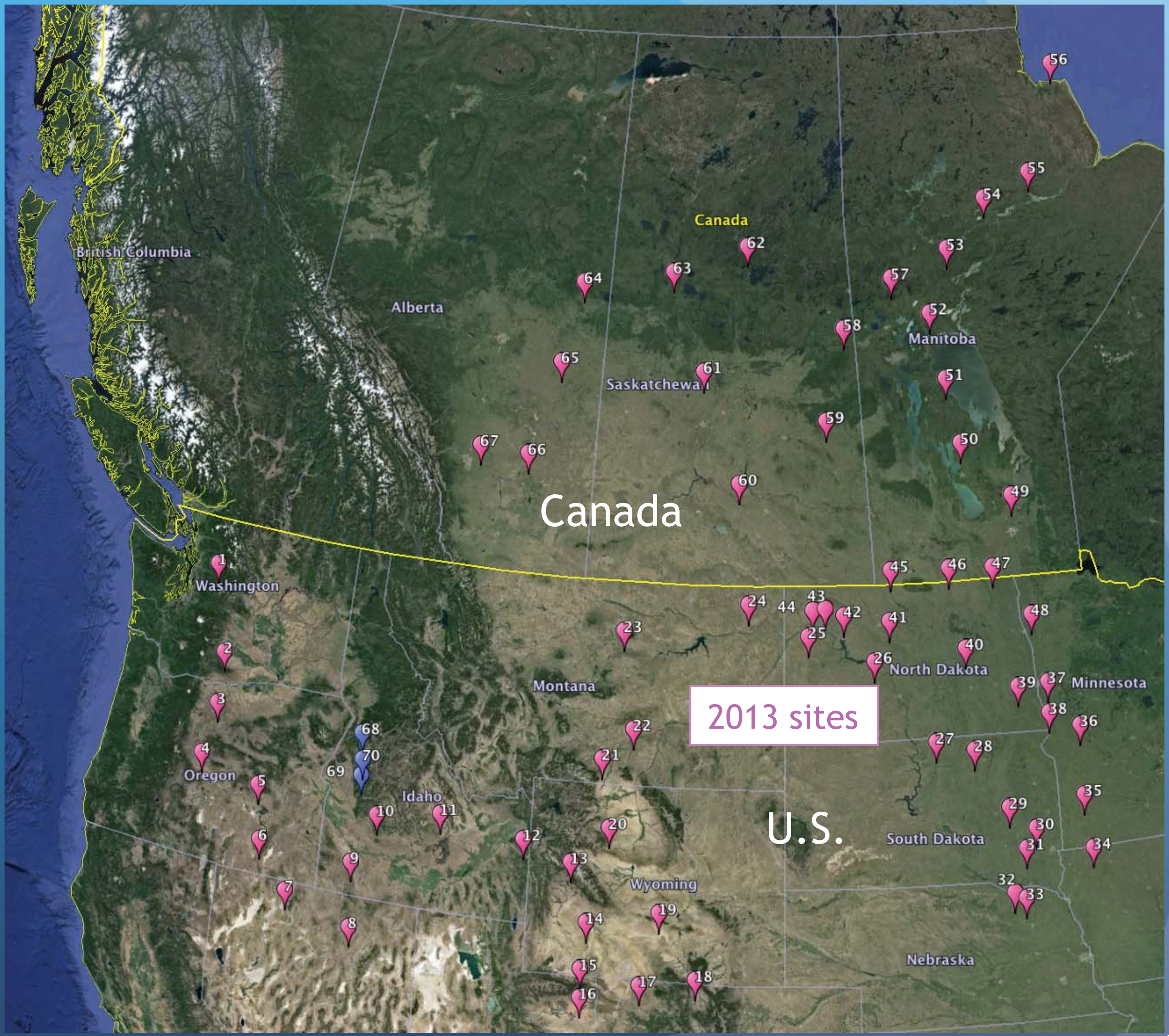
+ 3 process study sites in 2014

2013

Site 1:
10 Jan

Sites 2-67:
28 Jan – 21 Mar

>500 snow samples



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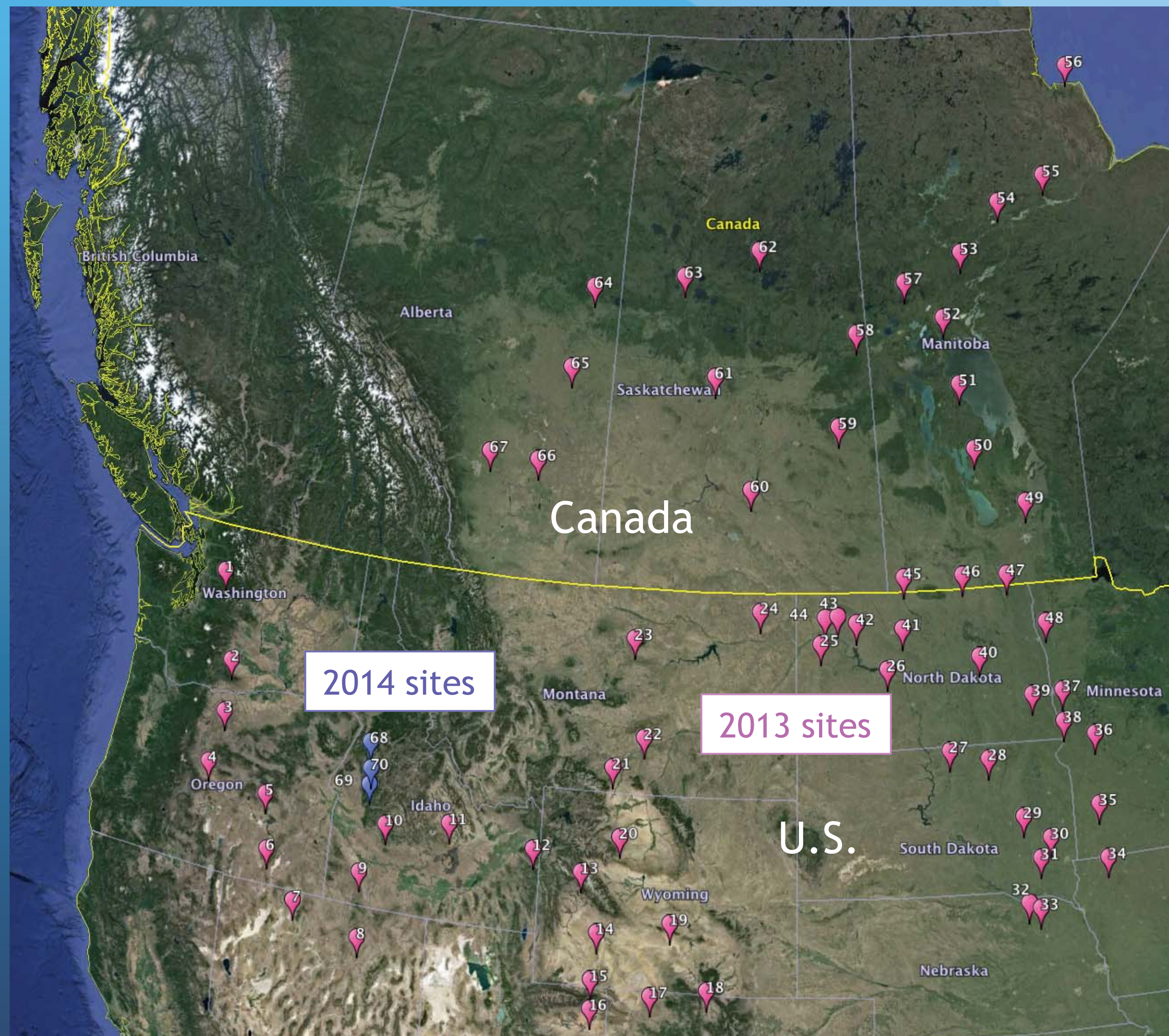
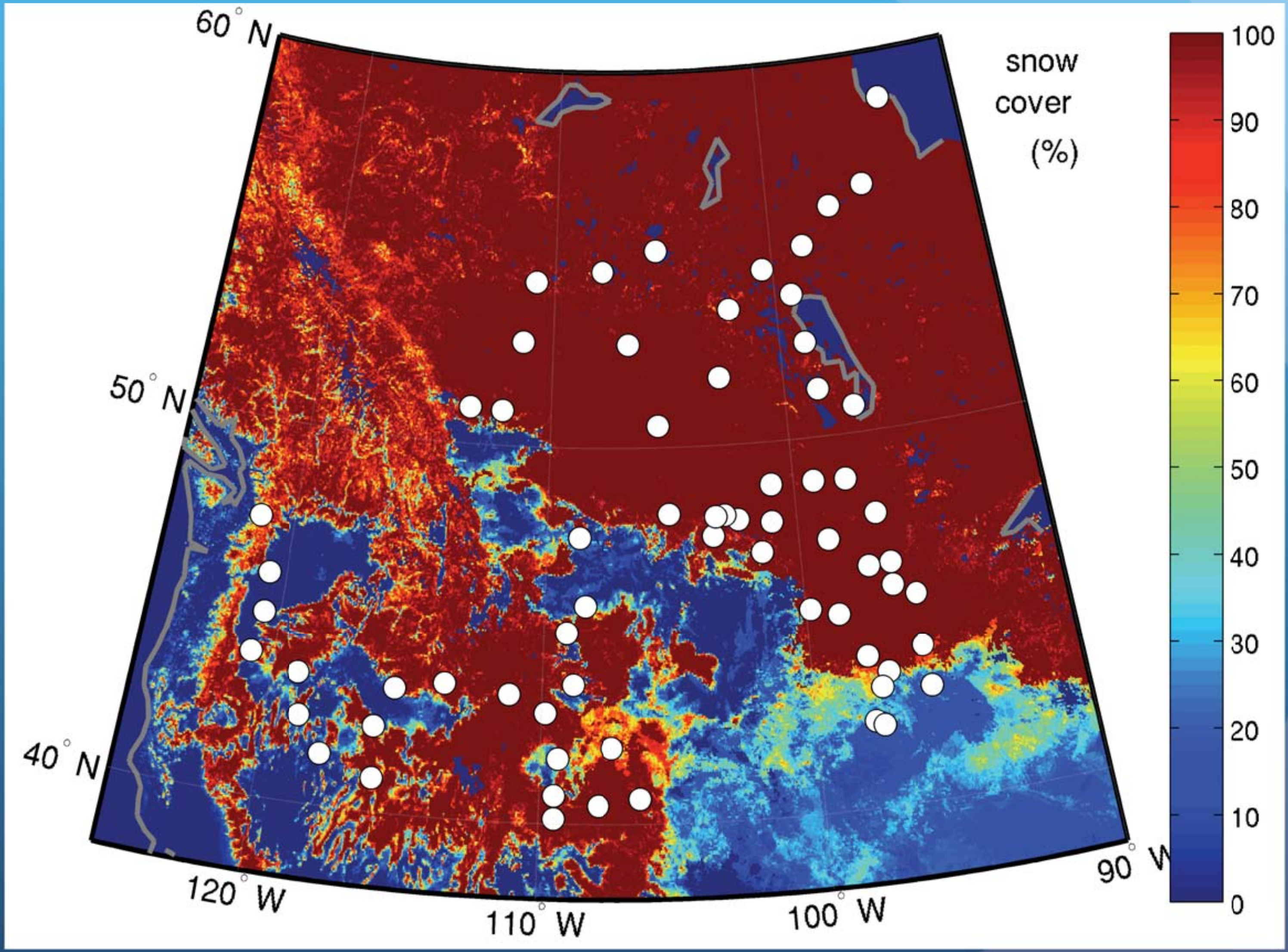
>360 snow samples



MODIS Snow Cover (%) Feb 2013



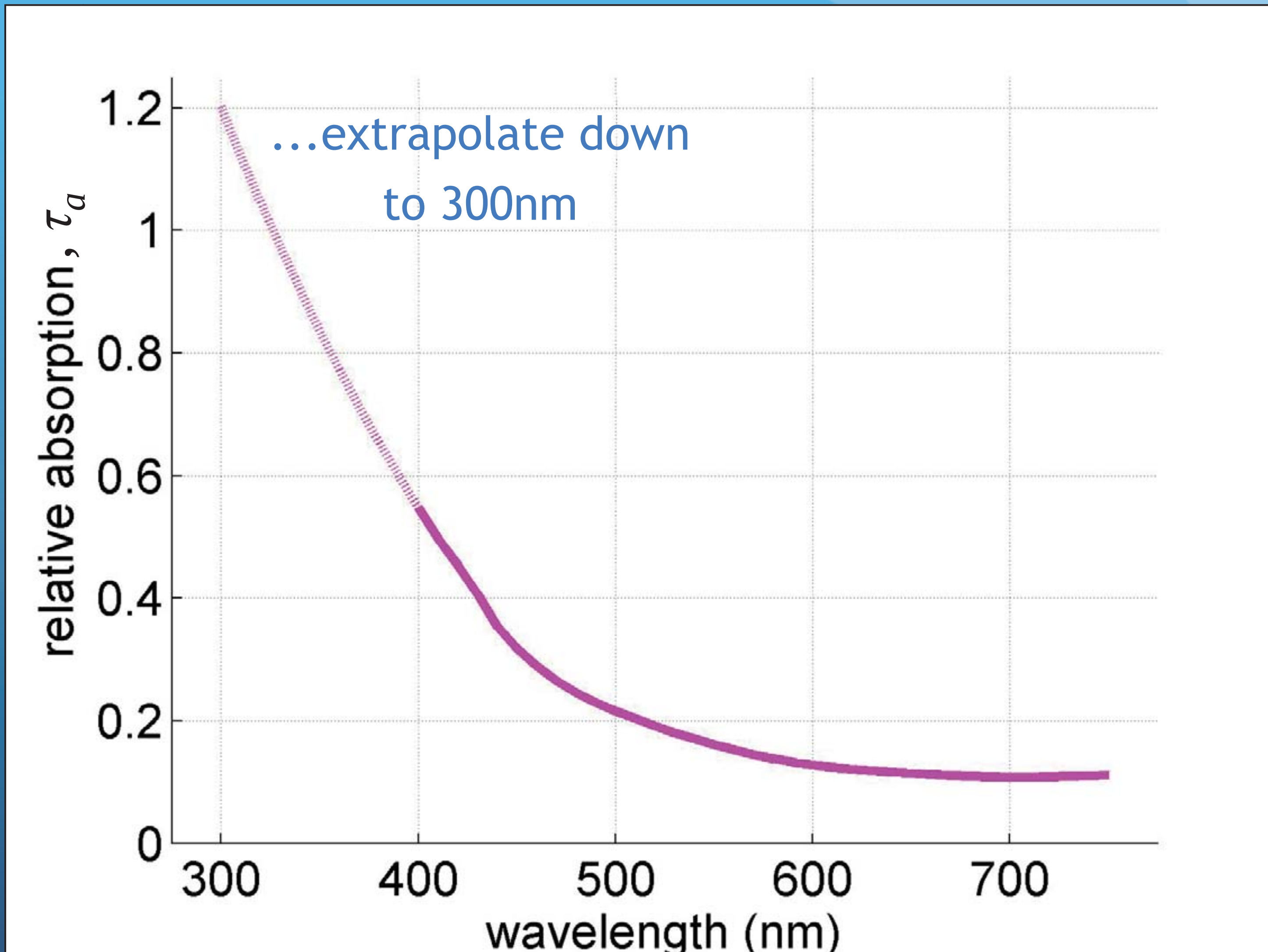
FIELD SAMPLING

- ~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



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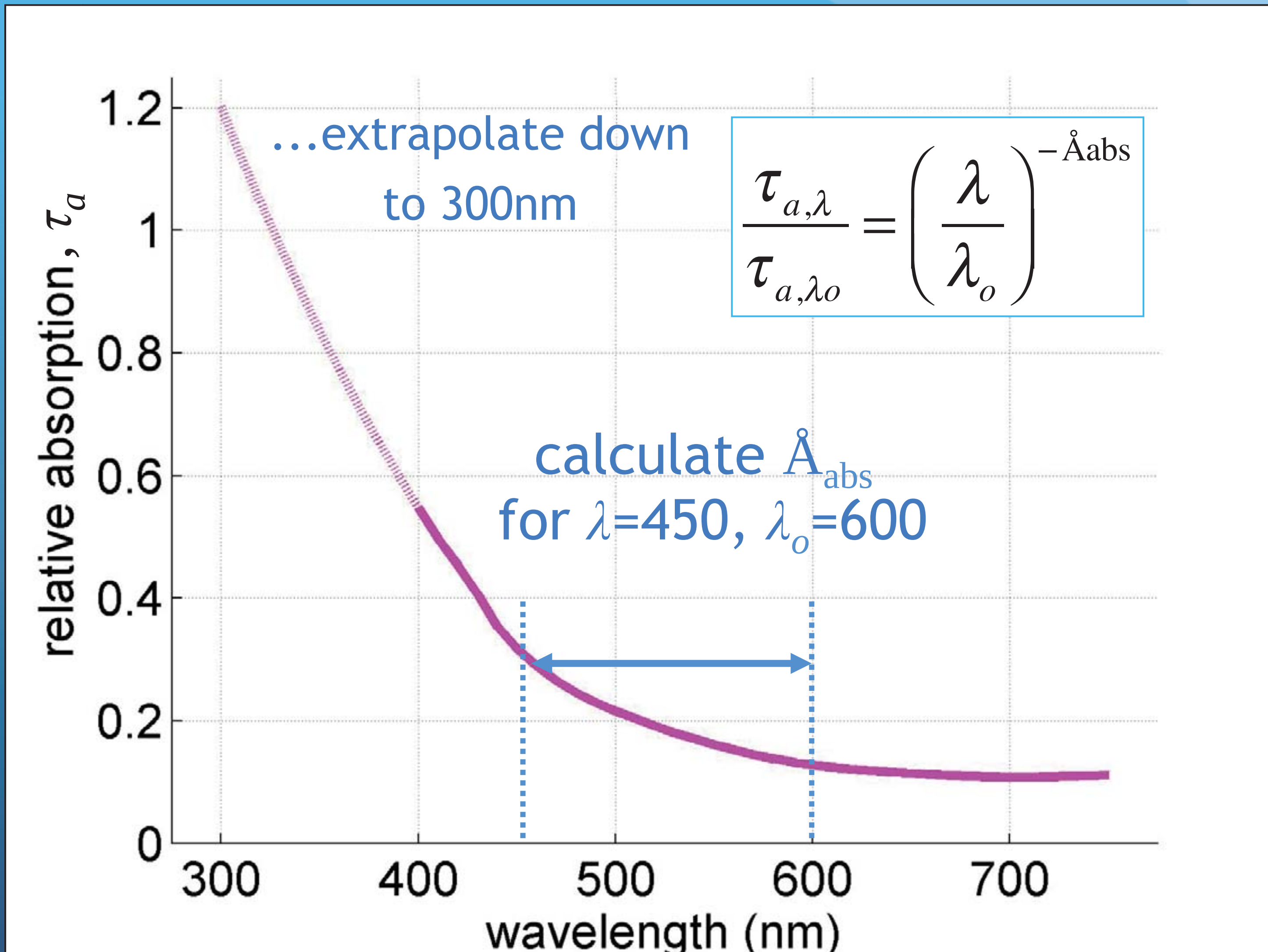

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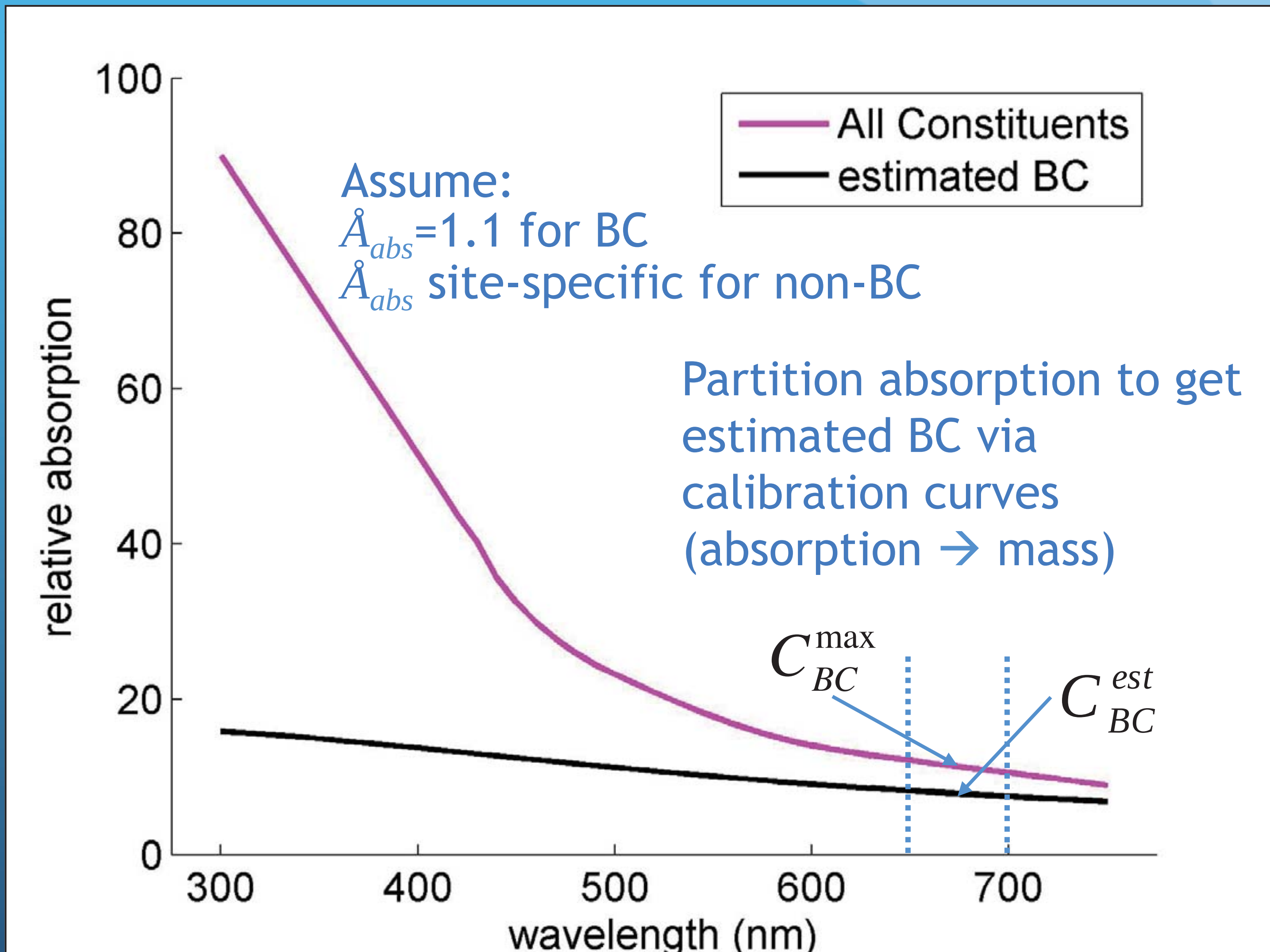

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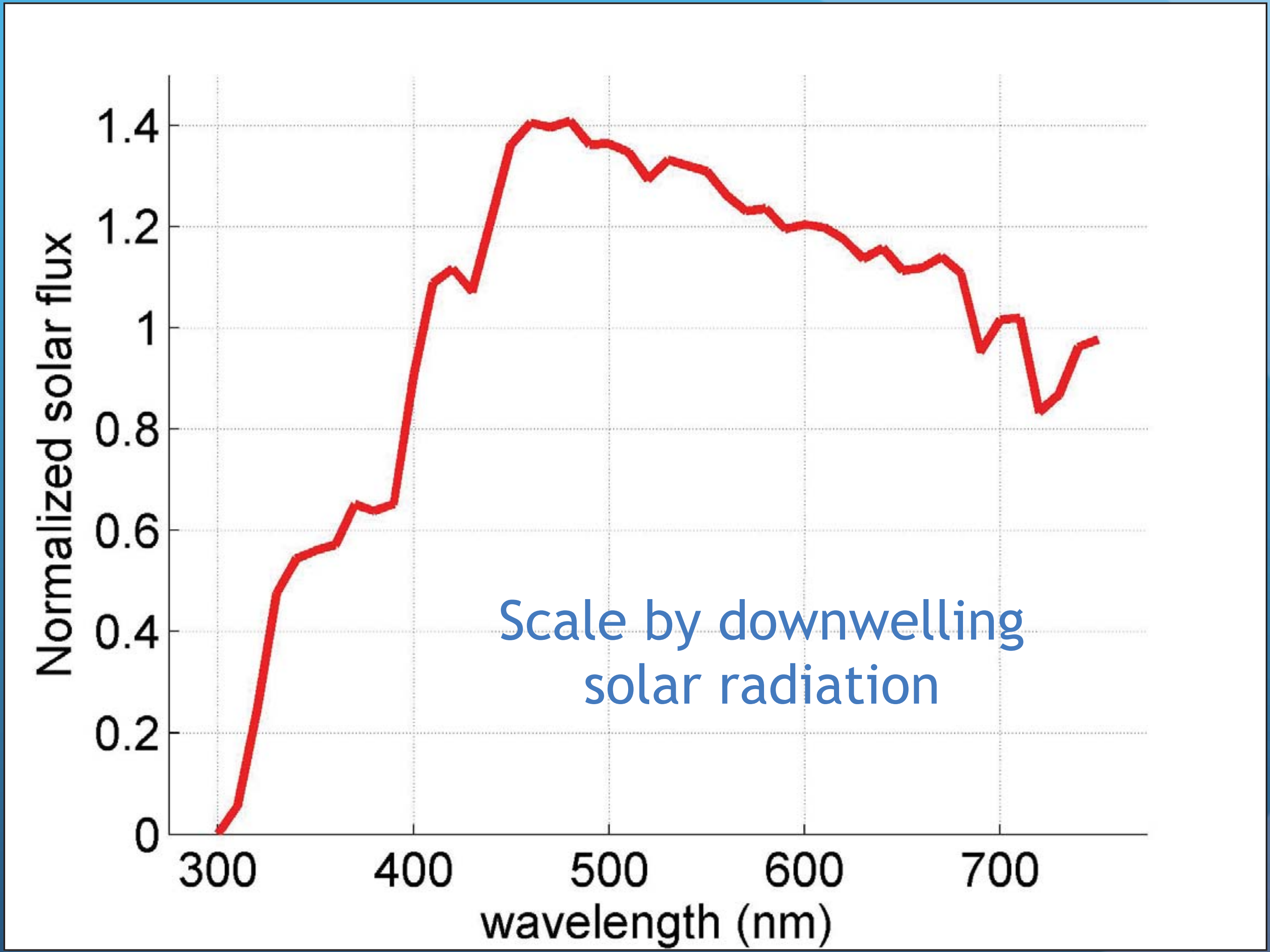
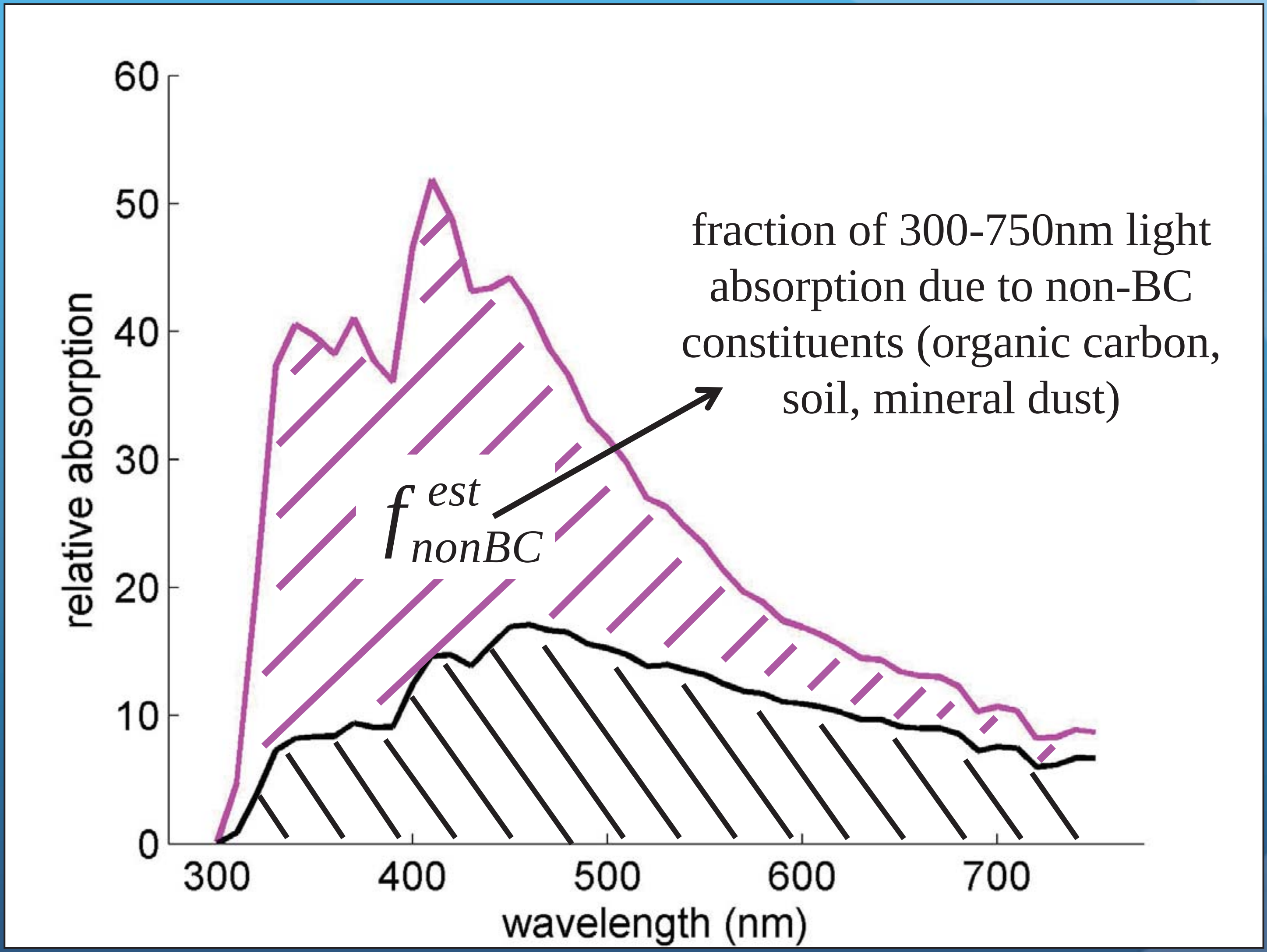


ISSW analysis of filters



Derived Parameters:

C_{BC}^{max} (ng/g) = maximum possible BC concentration

→ *assumes all 650-700nm absorption is due to BC*

→ *assumes MAE of calib. standards matches that of BC on filter*

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

→ *derived using assumption of* Å_{abs}*=1.1 for BC;*

Å_{abs}*= site-specific for non-BC light absorbers*

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

→ *derived using assumption of* Å_{abs}*=1.1 for BC;*

Å_{abs}*= site-specific for non-BC light absorbers*

Å_{tot} [450:600nm]

Derived Parameters:

C_{BC}^{max} (ng/g) = maximum possible BC concentration

→ *assumes all 650-700nm absorption is due to BC*

→ *assumes MAE of calib. standards matches that of BC on filter*

~~C_{BC}^{est}~~ ** NOT ESTIMATED IF f_{nonBC}^{est} >0.85

$Å_{abs}$= site-specific for non-BC light absorbers

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

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$Å_{abs}$= site-specific for non-BC light absorbers

$Å_{tot}$ [450:600nm]

Analysis for organics' contribution to absorption via serial extractions

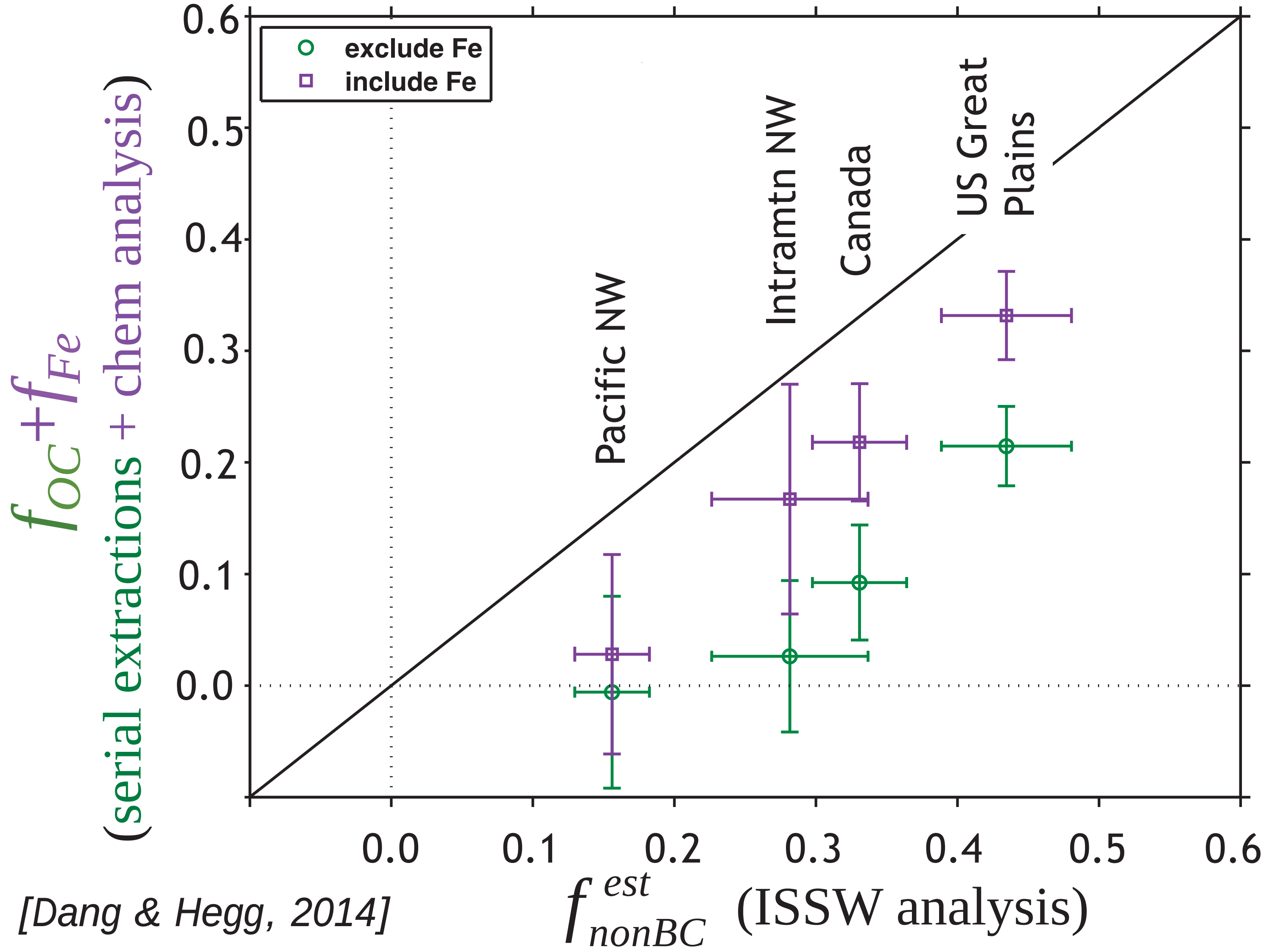
- organics serially extracted from filters using four organic solvents (methanol, dichloromethane, hexane and sodium hydroxide) [*Dang and Hegg*, 2014].
- Particulate spectral absorption measured with ISSW before extraction and after each extraction step
- Thus is a *measurement* of spectral absorption in snow due to different organic groups.
- OC_{abs} = absorption due to all extracted organics
- Note: OC_{abs} includes both "BrC" (light-absorbing combustion organics) & soil organics (e.g. HULIS)

Chemical & PMF analysis

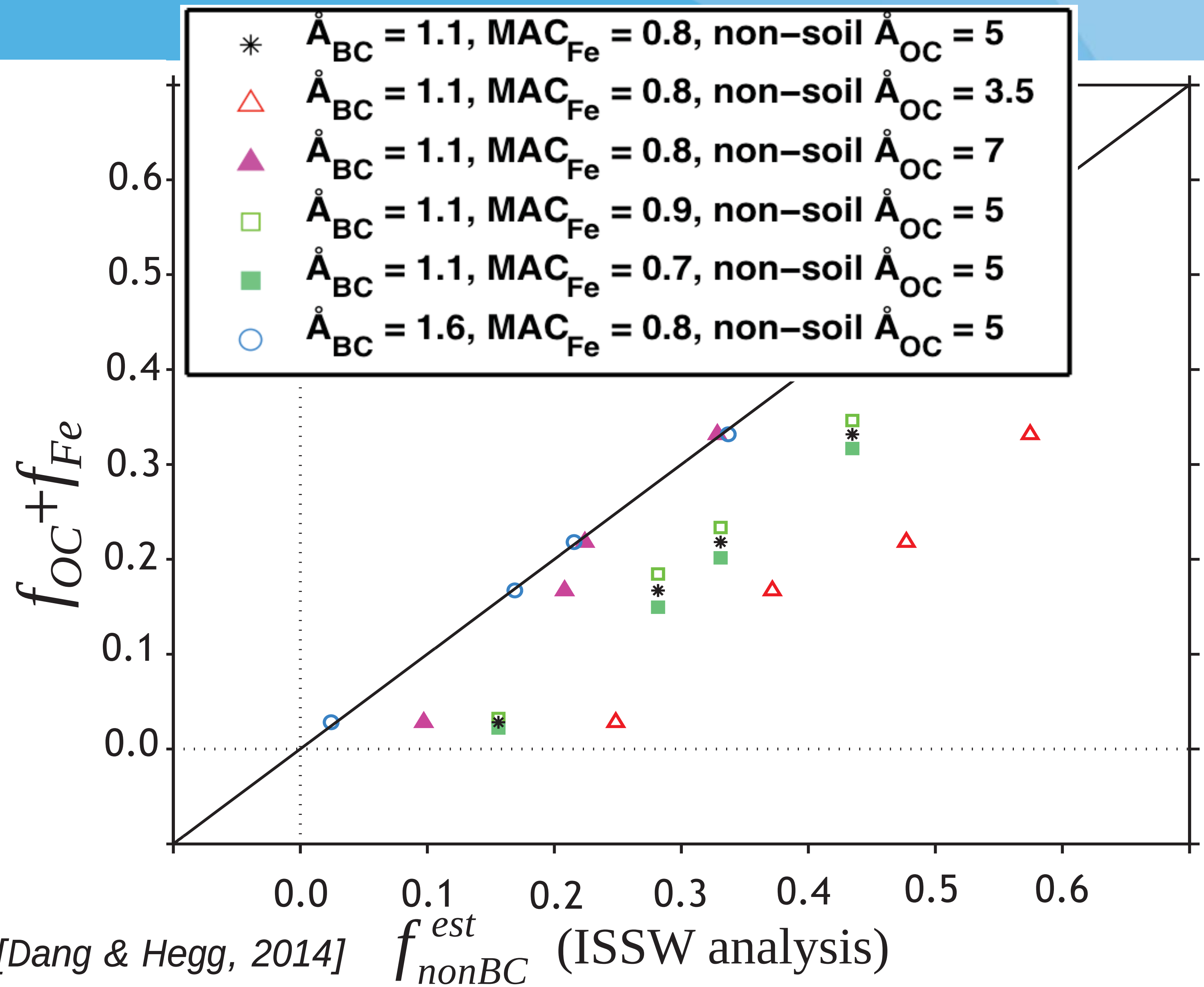
- analyze for a suite of ions, carbohydrates & elements
- Use chemical data, optical data (C_{BC}^{max}) and OC_{abs} (from serial extractions) as input to PMF analysis
- PMF : Positive Matrix Factorization
  - generates factor profiles for orthogonal factors that contribute to the variance in an independent variable (e.g. C_{BC}^{max})
  - provides chemical "fingerprints" of each factor, which are then interpreted for source type (can be a mix)
  - provides the fractional contributions of each factor to the variance in an independent variable

  → source "fingerprints" are not assumed *a priori*

Test of optical (ISSW) estimate of non-BC contributions to absorption



[Dang & Hegg, 2014]



[Dang & Hegg, 2014]

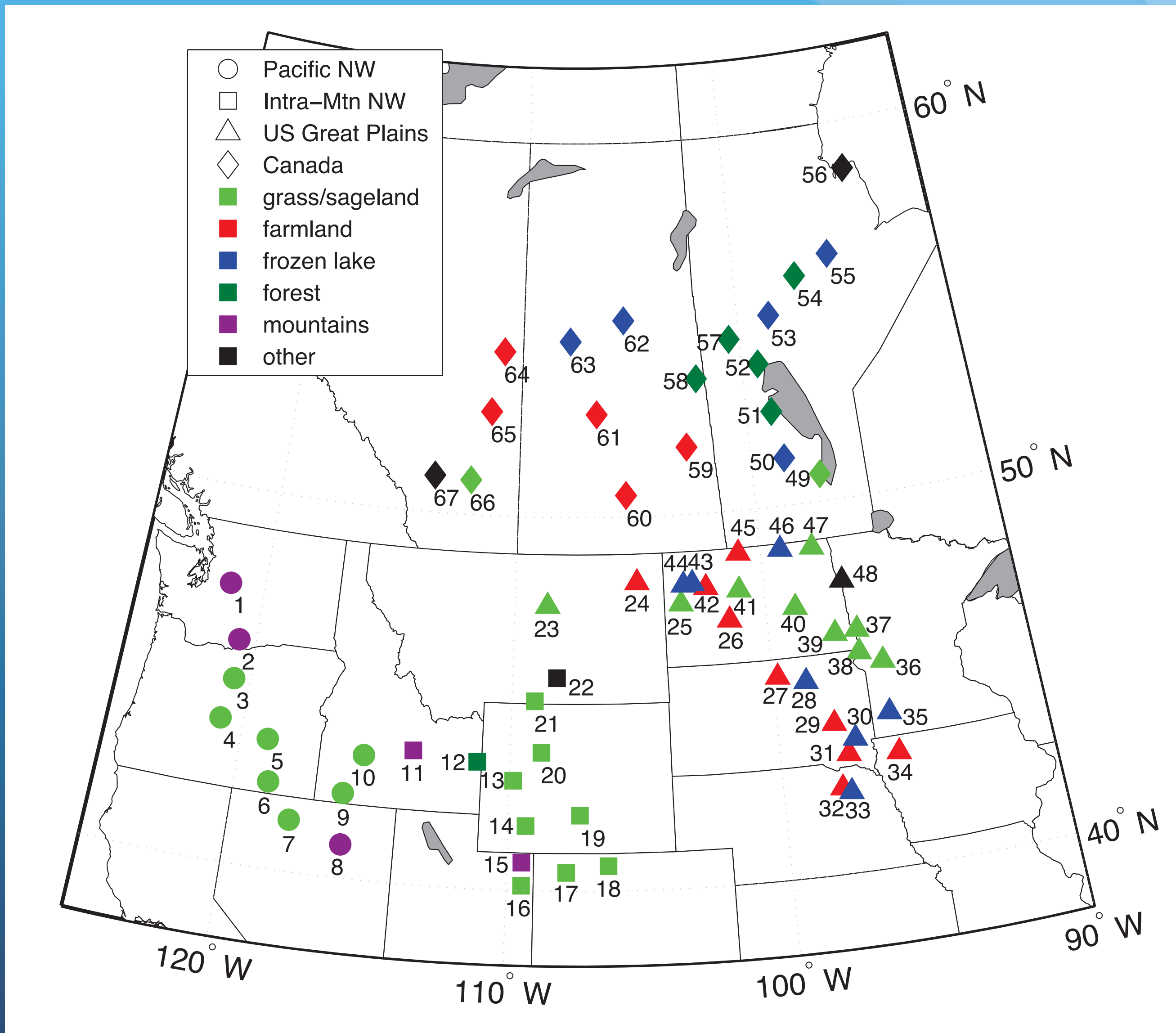
results of ISSW/SP-2 comparison

(ongoing; collaboration with J.P. Schwarz, NOAA)

- First tests comparing BC mixing ratio for samples with:
  - fullerene (synthetic BC)
  - dust standard
  - fullerene + dust standard
  - PSL (non-absorbing spheres)
- Tested both against gravimetric determinations of BC and dust mixing ratio in the solutions
- SP2 and ISSW both agreed well with grav mixing ratios for pure fullerene
- small bias in SP2 for fullerene+dust
- significant high bias (up to factor of 2-3) in ISSW BC mixing ratios for fullerene/dust mixes

[Schwarz et al., 2012]

2013 Results : Grouped by region



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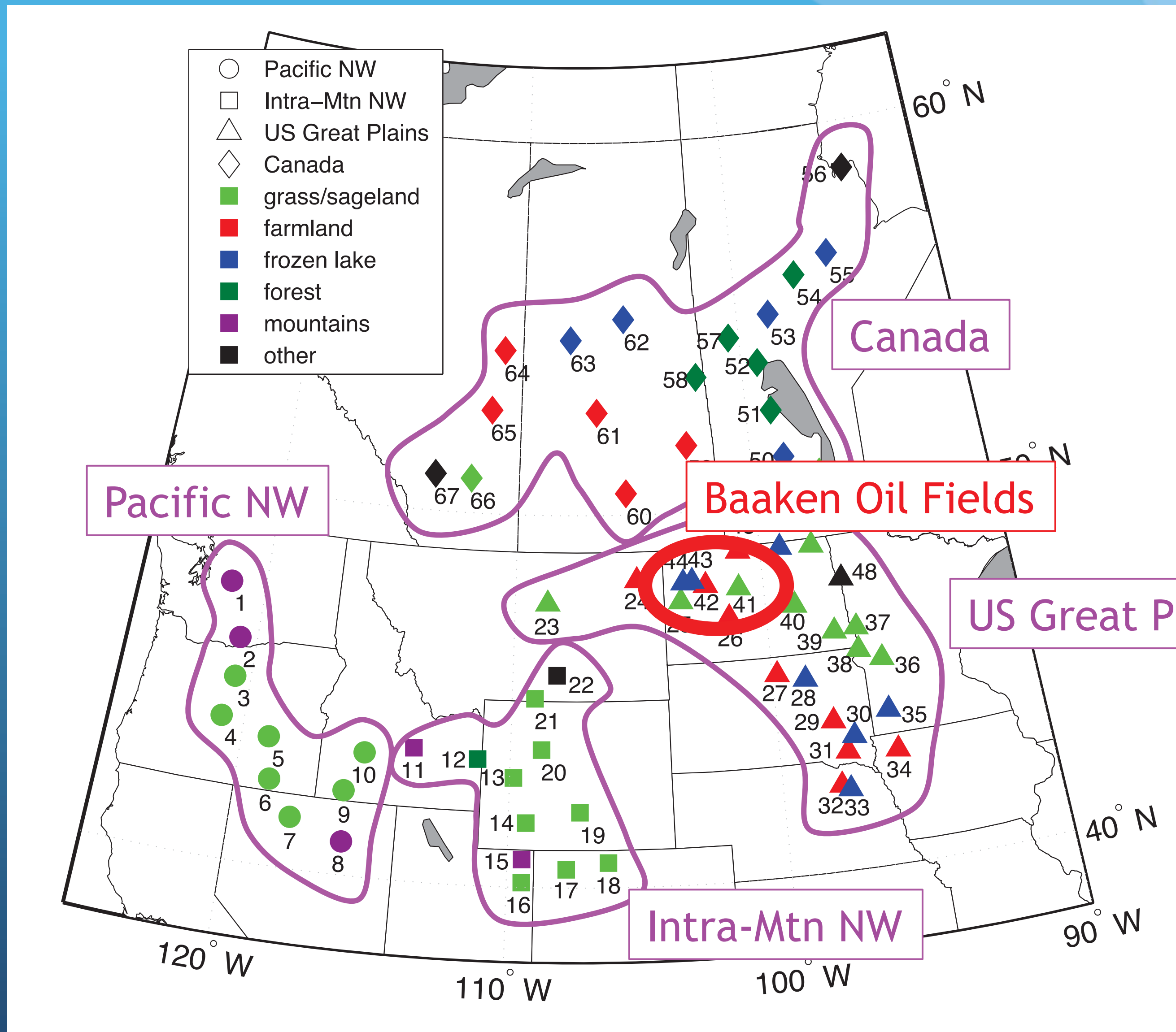
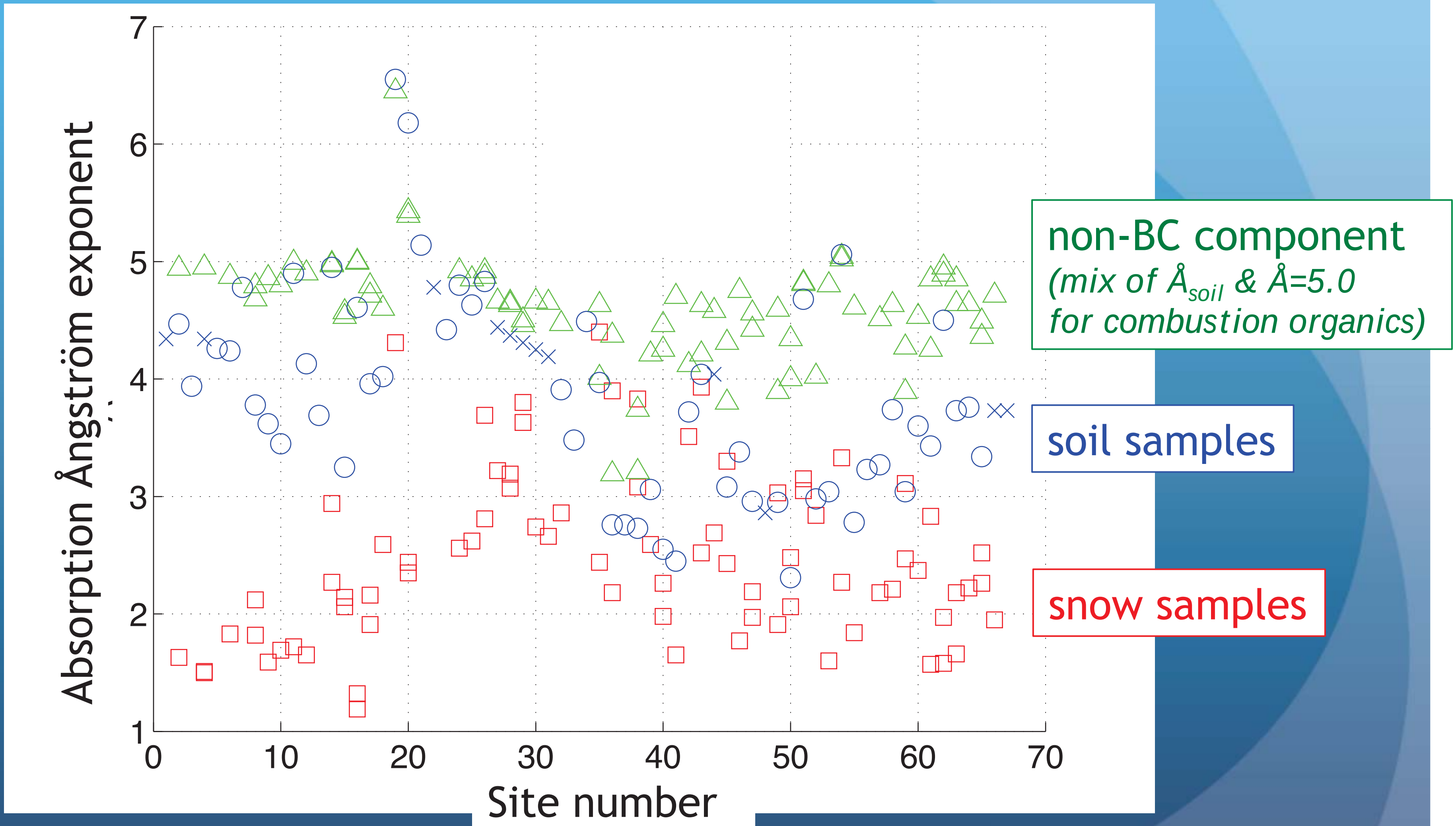
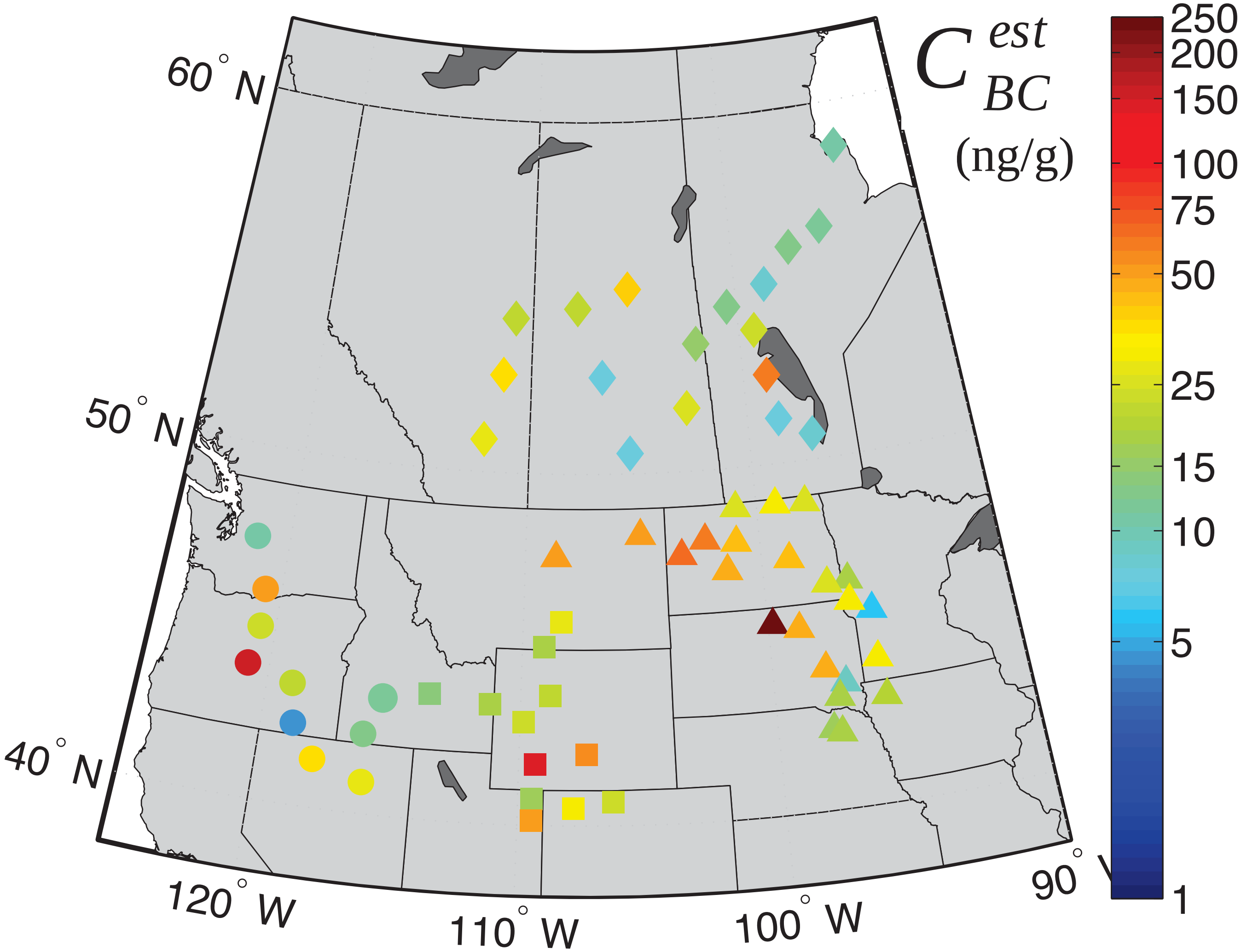


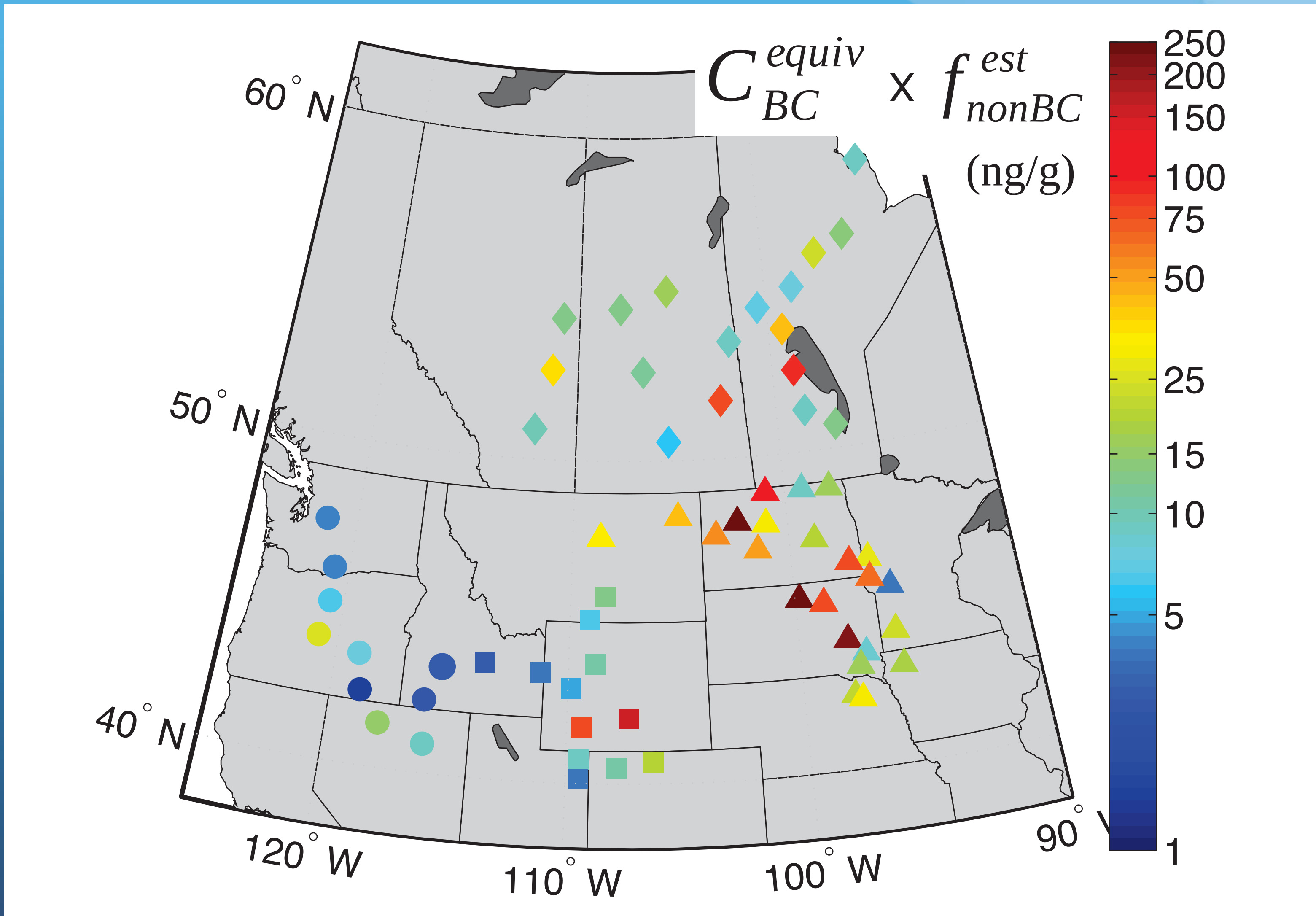
Absorption Ångström exponents



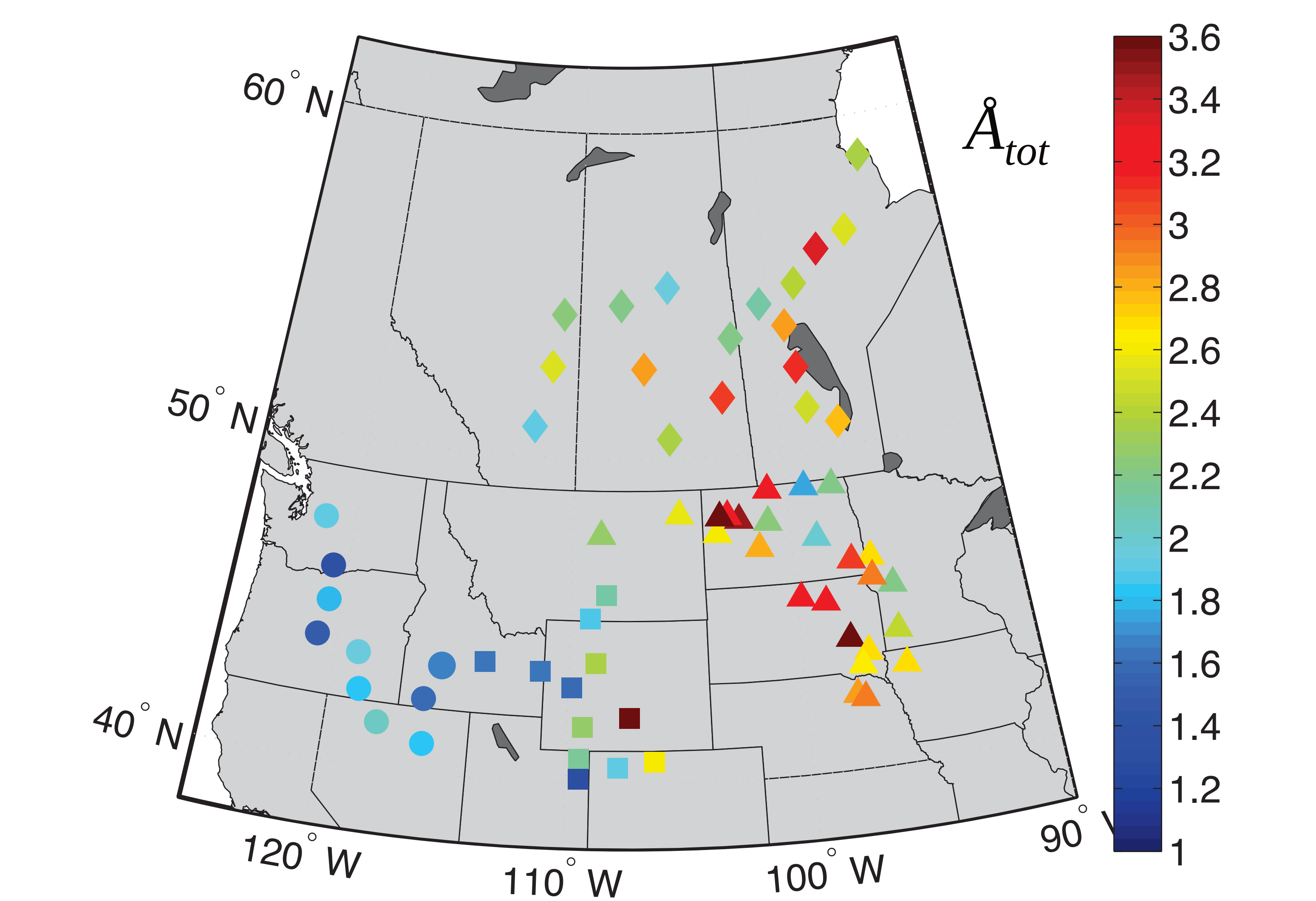
Surface-most snow samples : BC mixing ratio



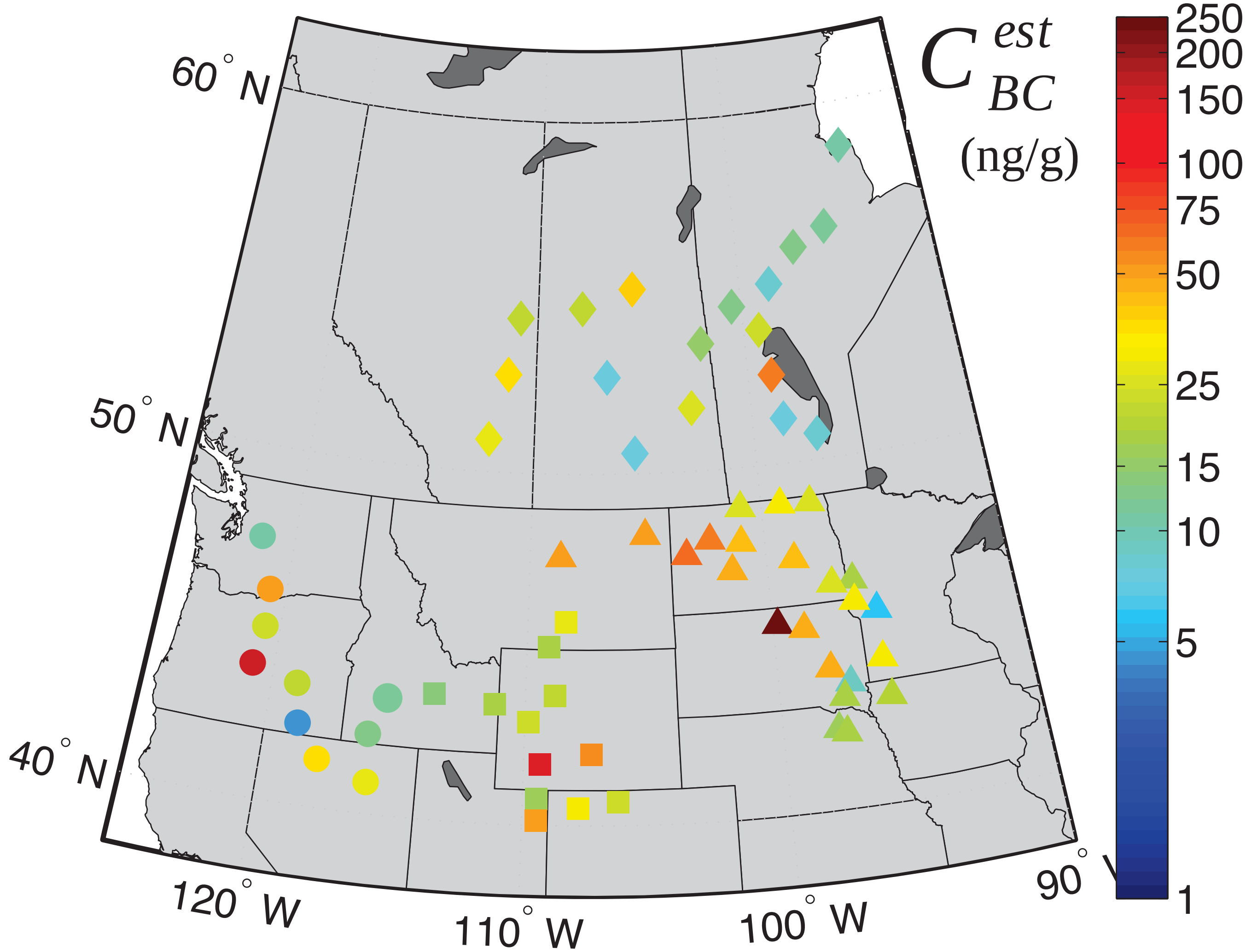
Surface-most snow samples : equivalent BC mixing ratio needed to account for non-BC absorbers



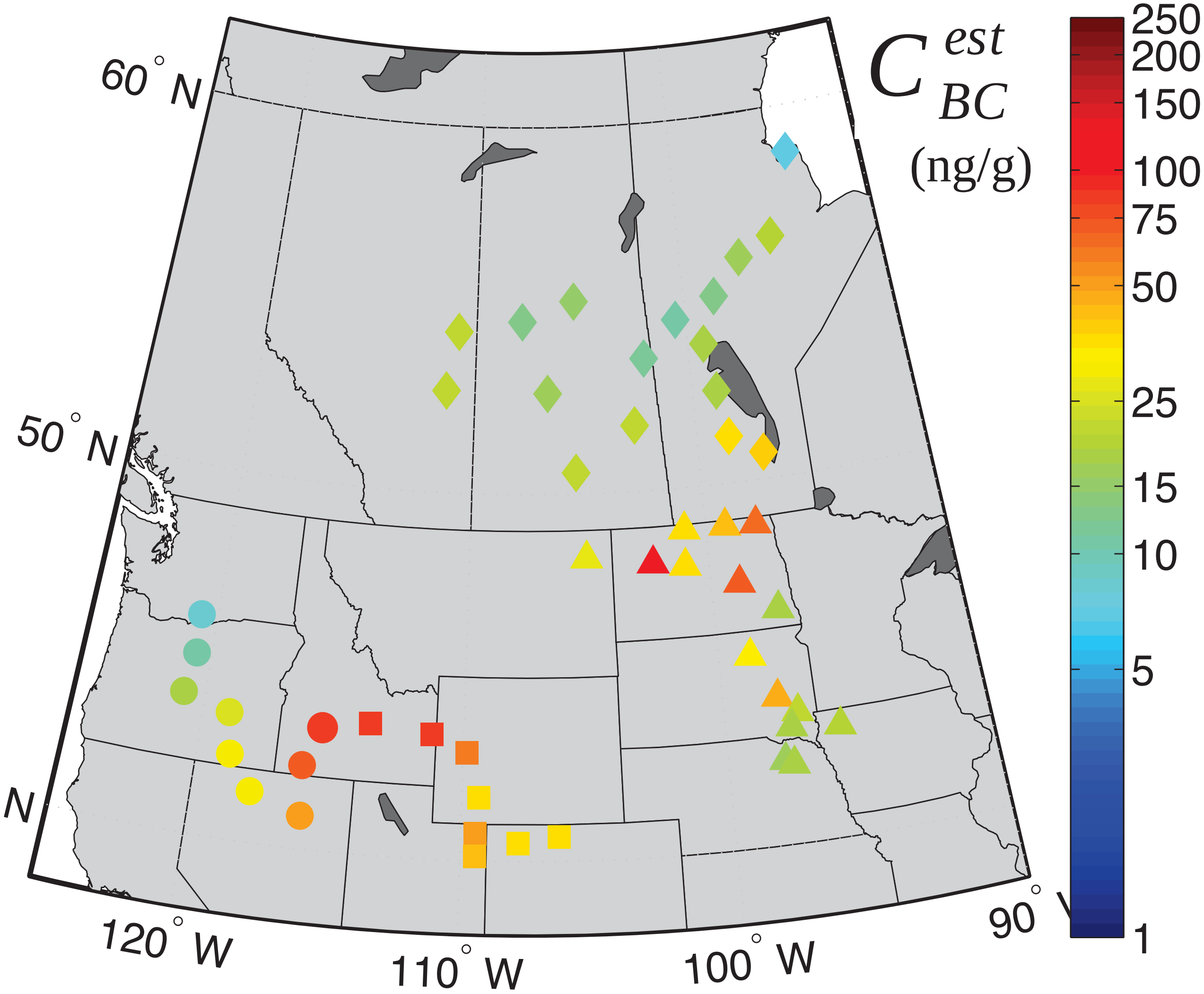
Surface-most snow samples : Absorption Ångström exponent



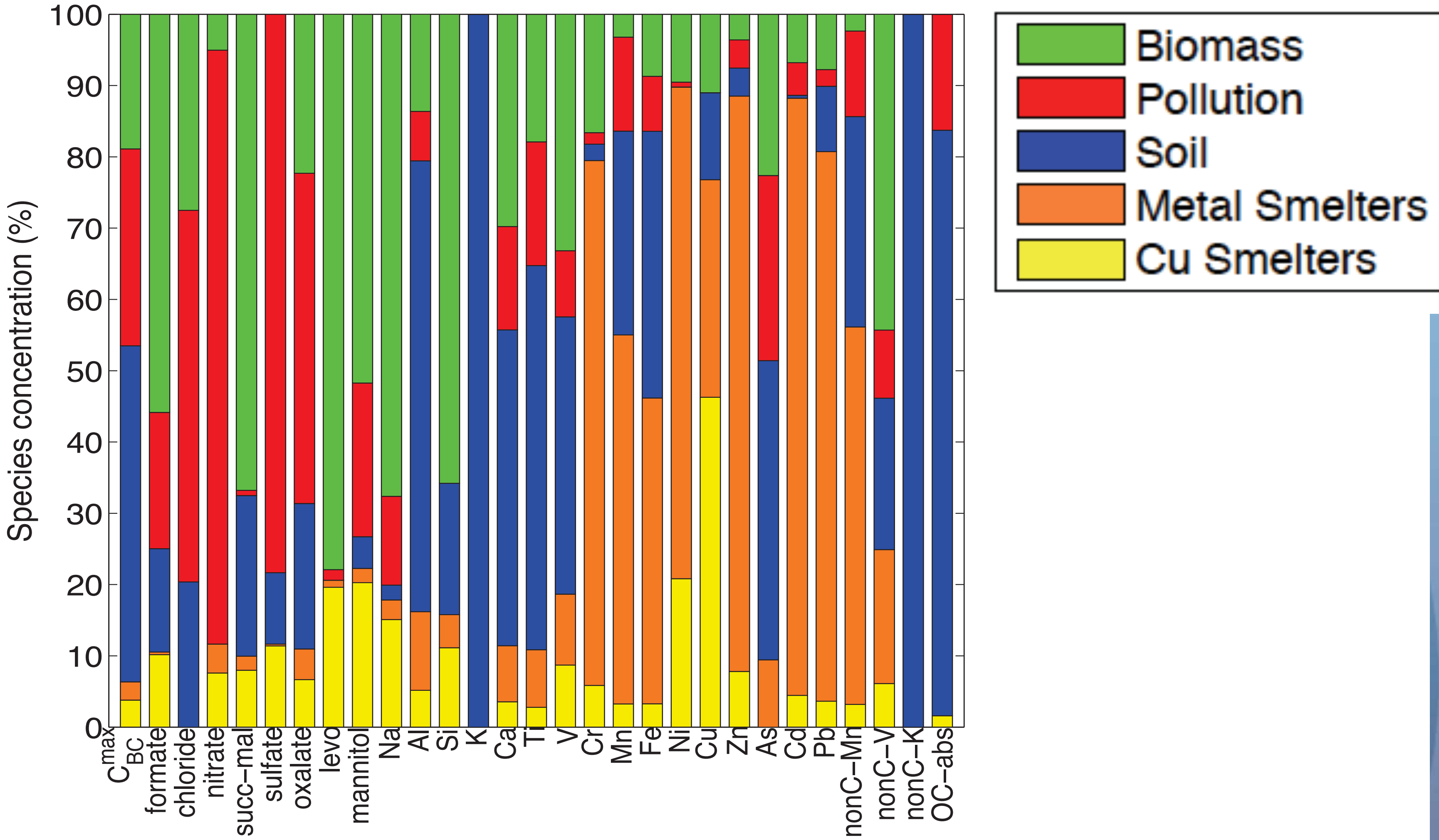
Surface-most snow samples : BC



Snow column average : BC



PMF Source "fingerprints"



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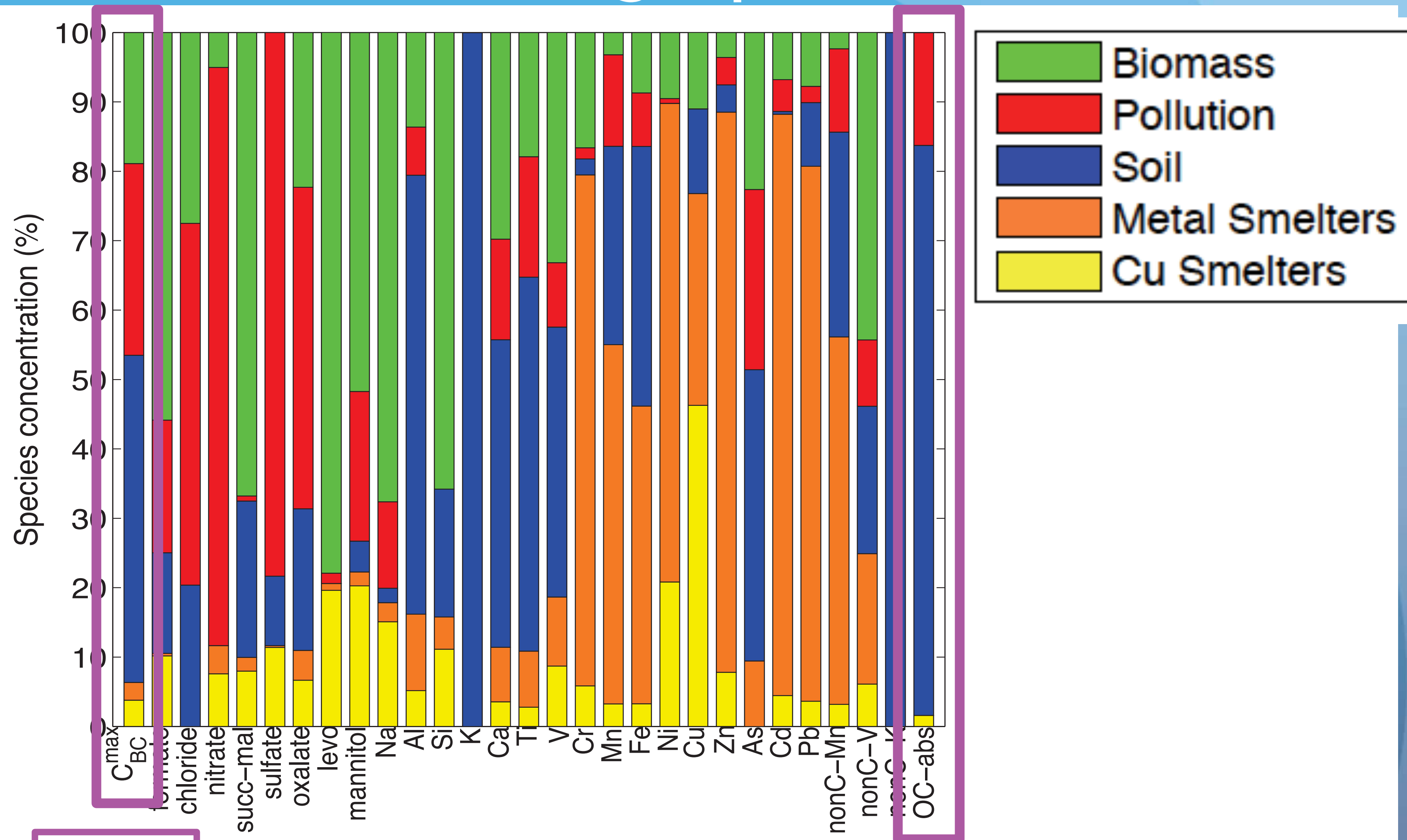
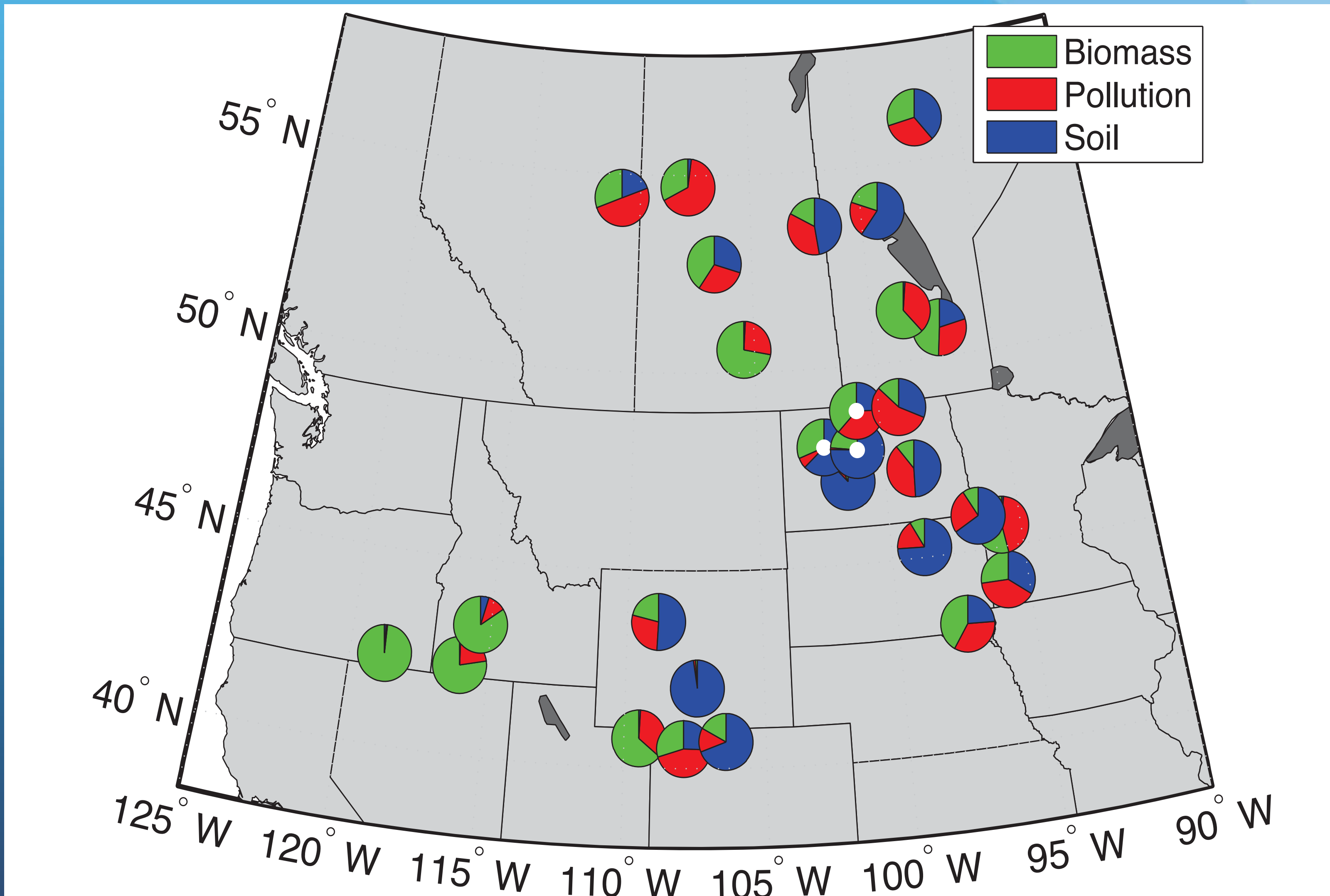


$C_{BC}^{\max}$

OC_{abs}

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



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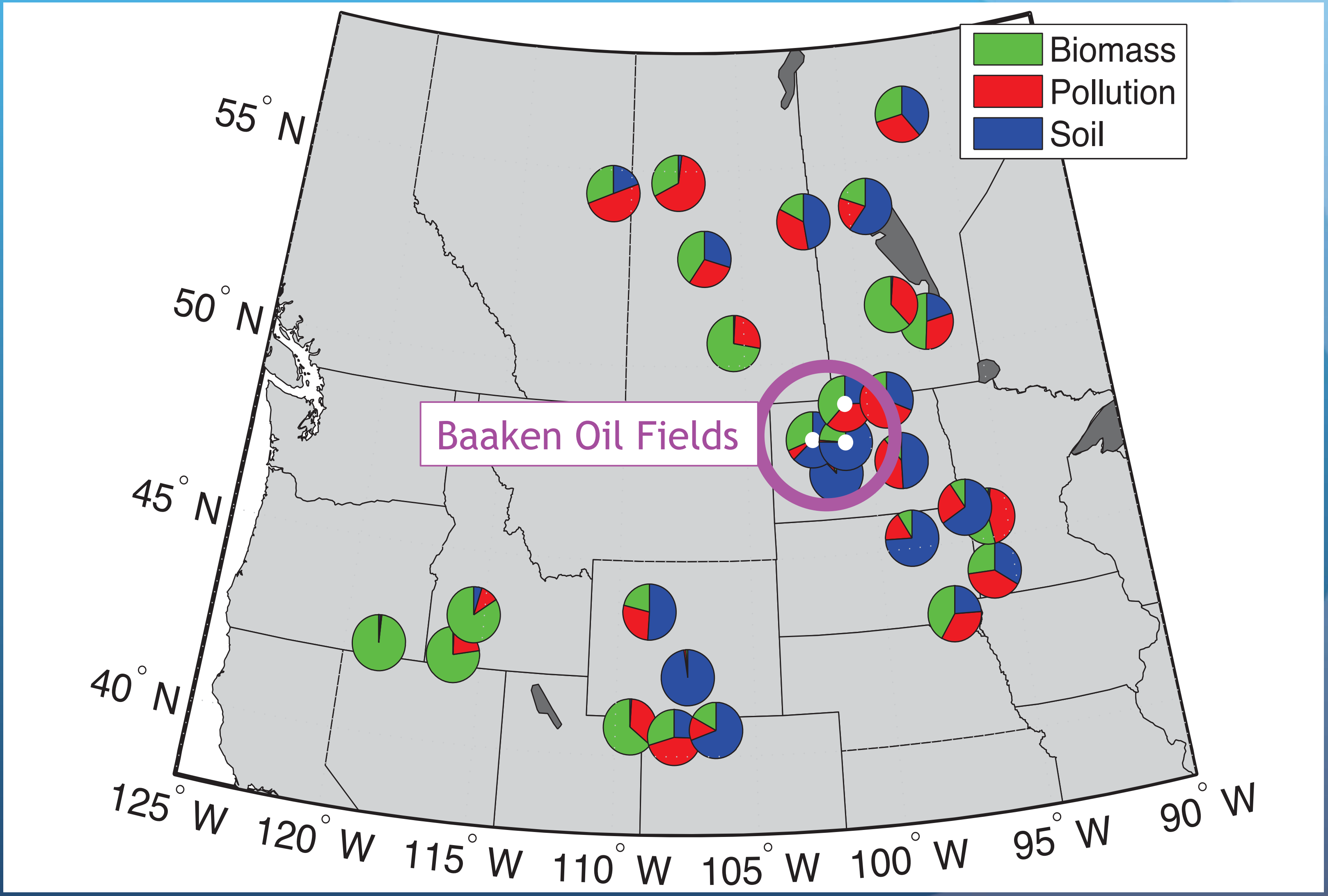

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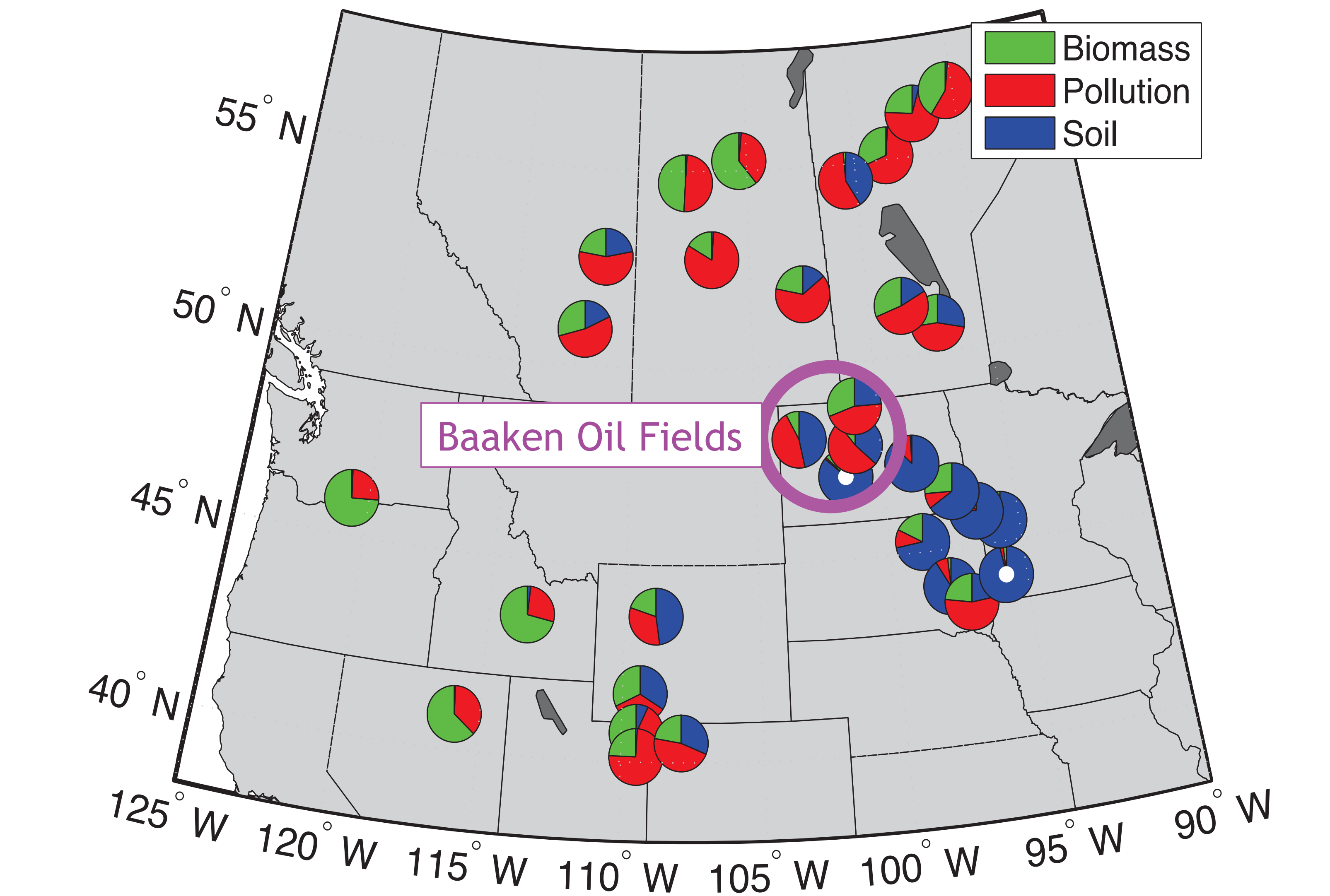

A note regarding the relative roles of soil vs. BC in lower US Great Plains snow albedo

- Great Plains soil contribution is higher in sub-surface samples → likely because this corresponds to shallower snowpack, so more exposed soil to contribute
- Snow cover in 2013 was not anomalous – but there are years with more extensive and persistent snow cover. In these years, the <u>relative</u> 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? ("snirt")

- Almost the entire area is agricultural = disturbed soil
- 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?

Quick-look comparison : Snow BC mixing ratios

ARCTIC *[Doherty et al., 2010]*

< 10 ng/g regional medians all regions other than Norway (~20 ng/g) and Russia (~30-40 ng/g)

N. CHINA *[Wang et al., 2013]*

~300-400 ng/g in north-central China
>100 ng/g near the N border of NE China
>900 ng/g in the industrial northeast

N. AMERICA *[Doherty et al., 2014]*

~ 5-40 ng/g : Pacific Northwest
~ 10-50 ng/g : Intramountain NW
~ 15-70 ng/g typical, but many >100 ng/g : U.S. Great Plains
~ 5-25 ng/g : Canada

Quick-look comparison :
Sources of light-absorbing particles in snow

ARCTIC *[Hegg et al., 2009; Hegg et al., 2010]*

- mostly biomass/biofuel burning
- pollution in some locations/seasons (NW Russia, N. Pole, Greenland summer)

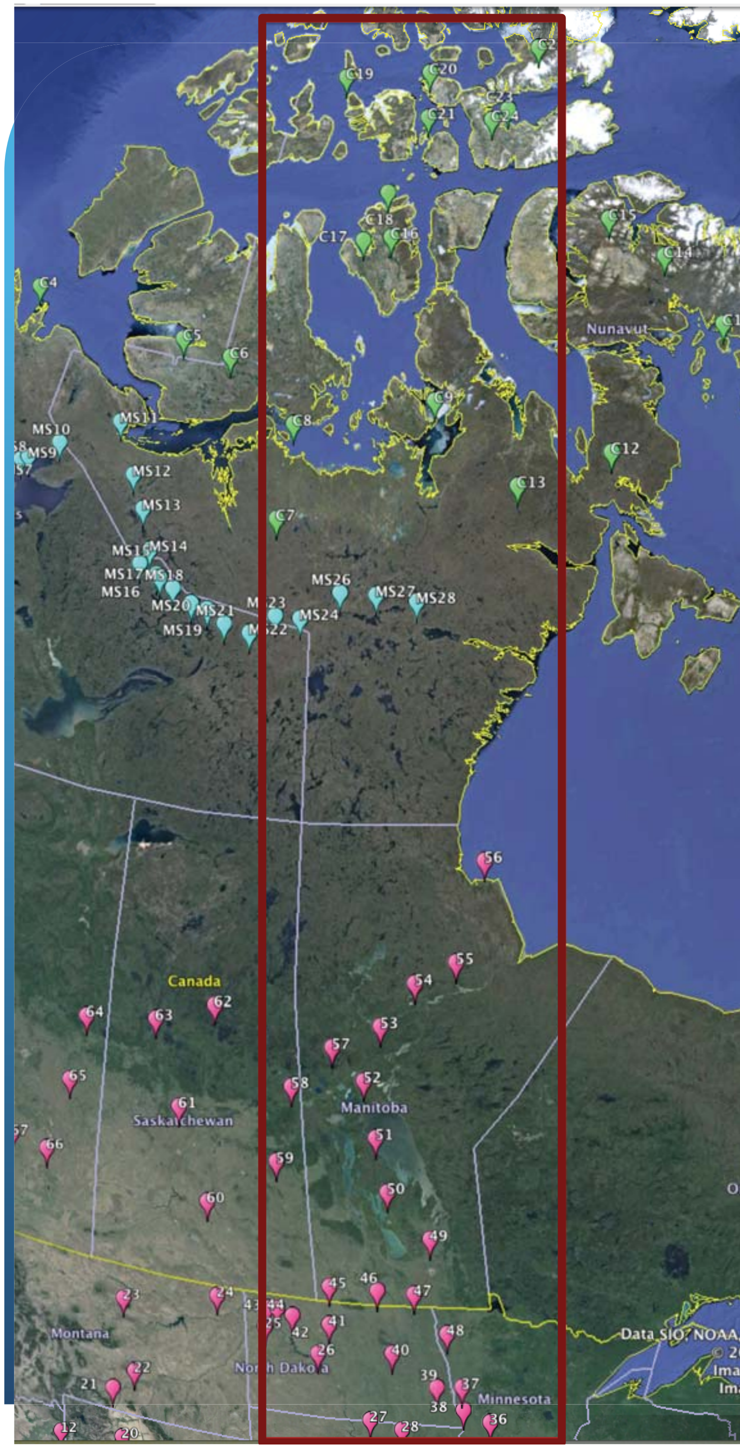
N. CHINA *[Zhang et al., 2013]*

- NW (desert) & N-central (great plains) : dominated by soil & mineral dust ; remainder is biomass/biofuel burning
- NE : mix of biomass/biofuel burning & industrial/urban pollution

N. AMERICA *[Doherty et al., 2014]*

- Pacific NW : mostly biomass/biofuel; remainder (~25%) fossil fuel Intramountain NW : mix of soil, fossil fuel & biomass/biofuel U.S. Great Plains : dominated by soil in many locations; remainder a variable mix of biomass/biofuel & fossil fuel
- Canada : variable – mix of fossil fuel, soil & biomass

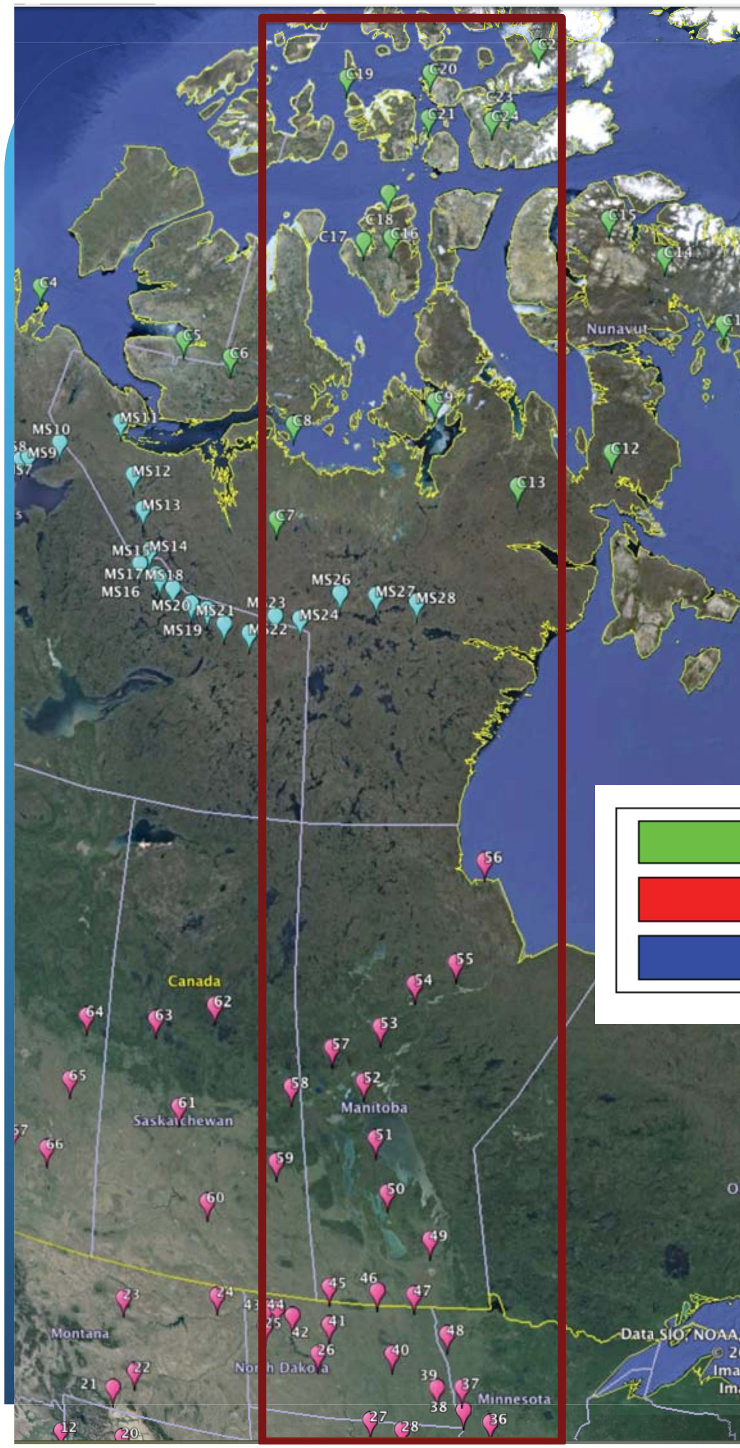
→ biomass:fossil fuel ratio increases later in winter season



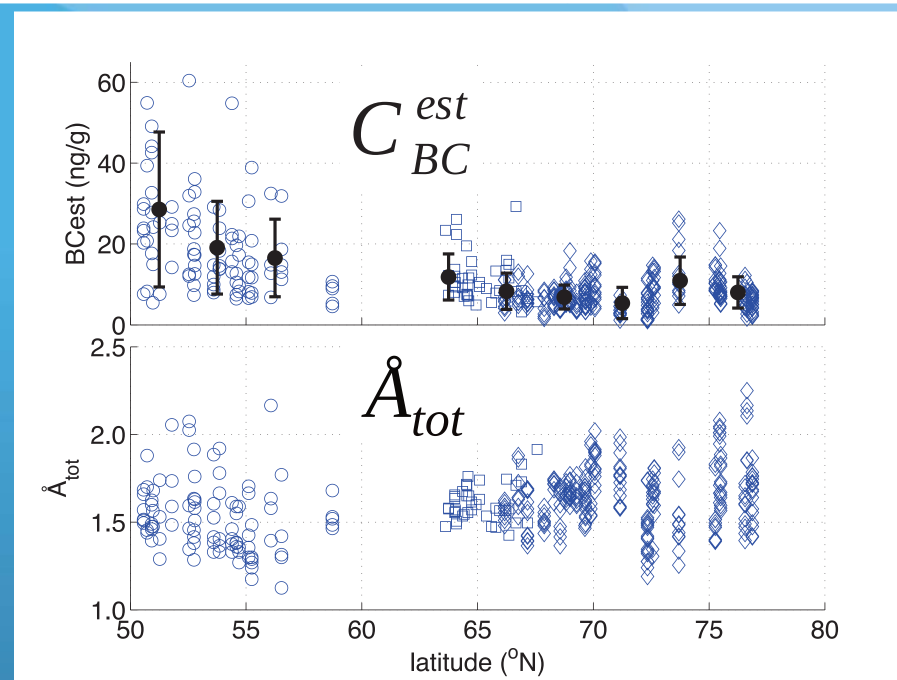
2009 Canadian Arctic survey

2007 Canadian sub-Arctic traverse

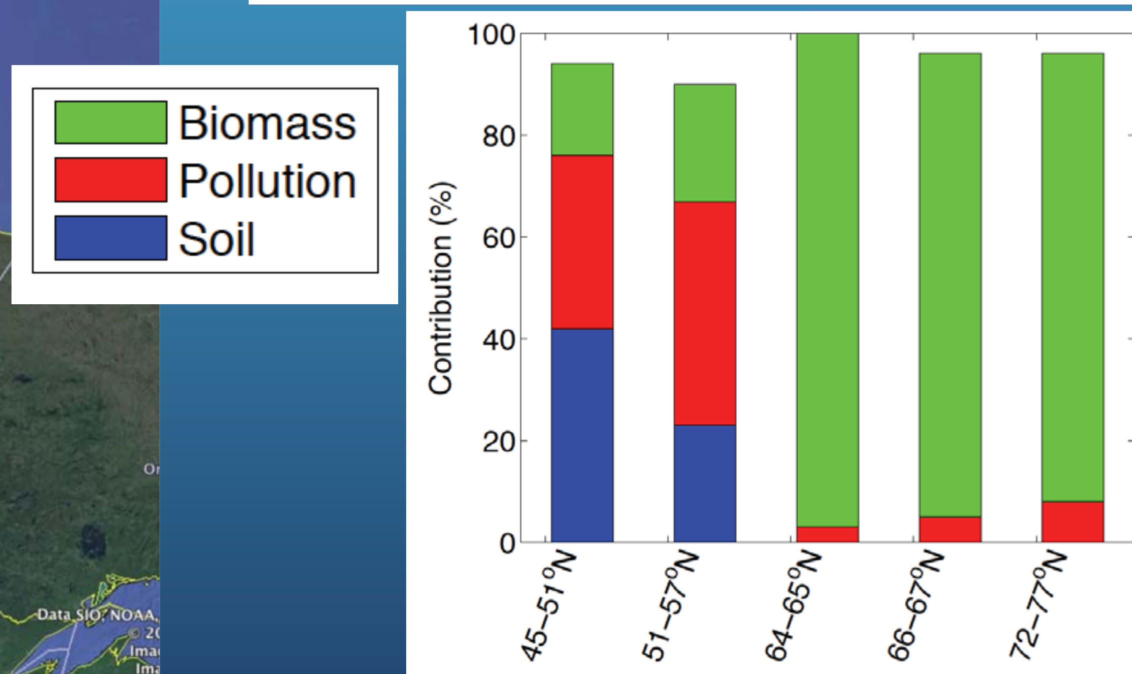
2013 N. Amer. Great Plains survey



Nunavut
Canada
Saskatchewan
Manitoba
Montana
Minnesota
Data SIO, NOAA,



C_{BC}^{est}
BCest (ng/g)
60
40
20
0
$\mathring{A}_{tot}$
2.5
2.0
1.5
1.0
50
55
60
65
70
75
80
latitude (°N)



Biomass
Pollution
Soil
Contribution (%)
100
80
60
40
20
0
45–51°N
51–57°N
64–65°N
66–67°N
72–77°N

N. American survey 2013 : 67 sites

+ 3 process study sites in 2014

2013

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>500 snow samples

2014

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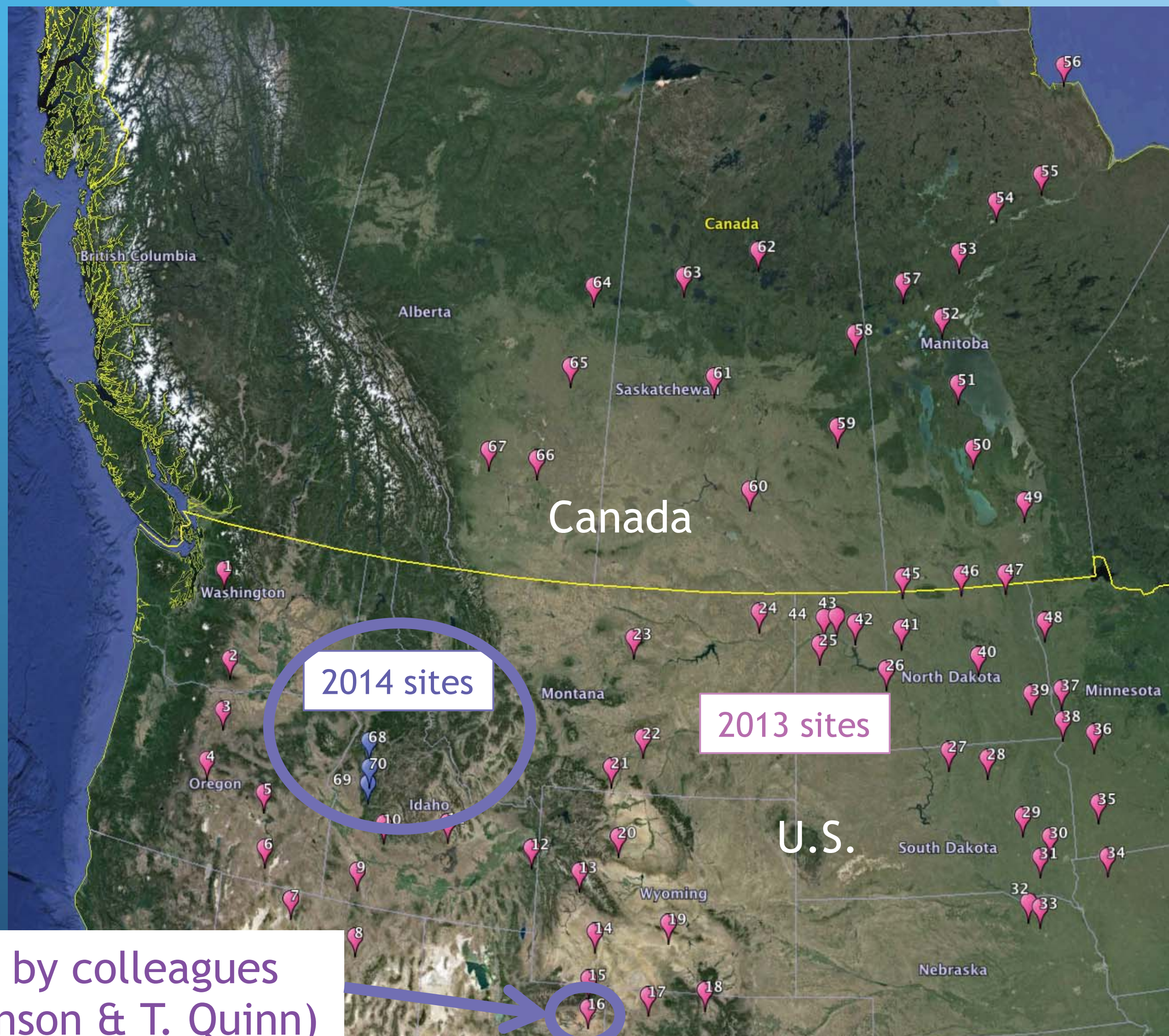
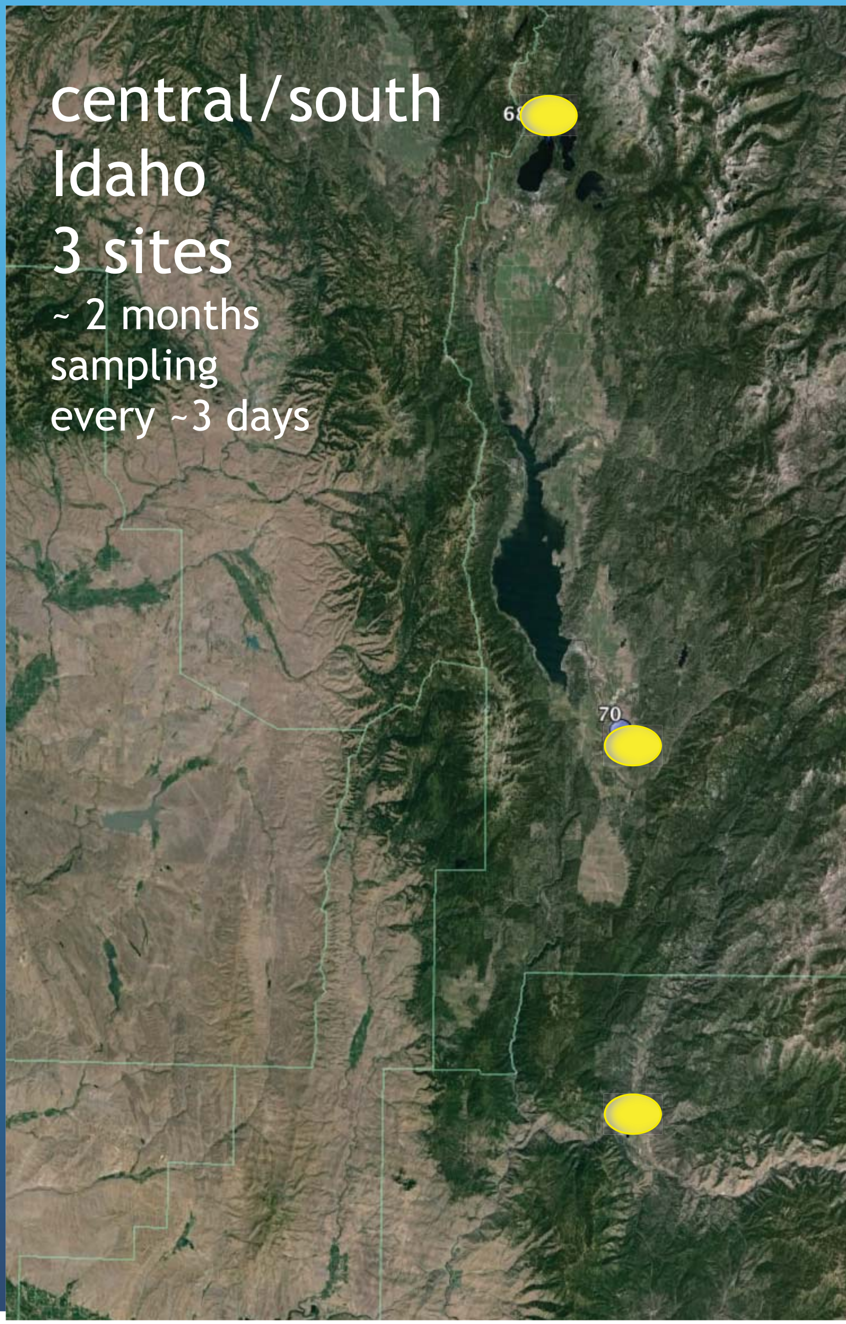
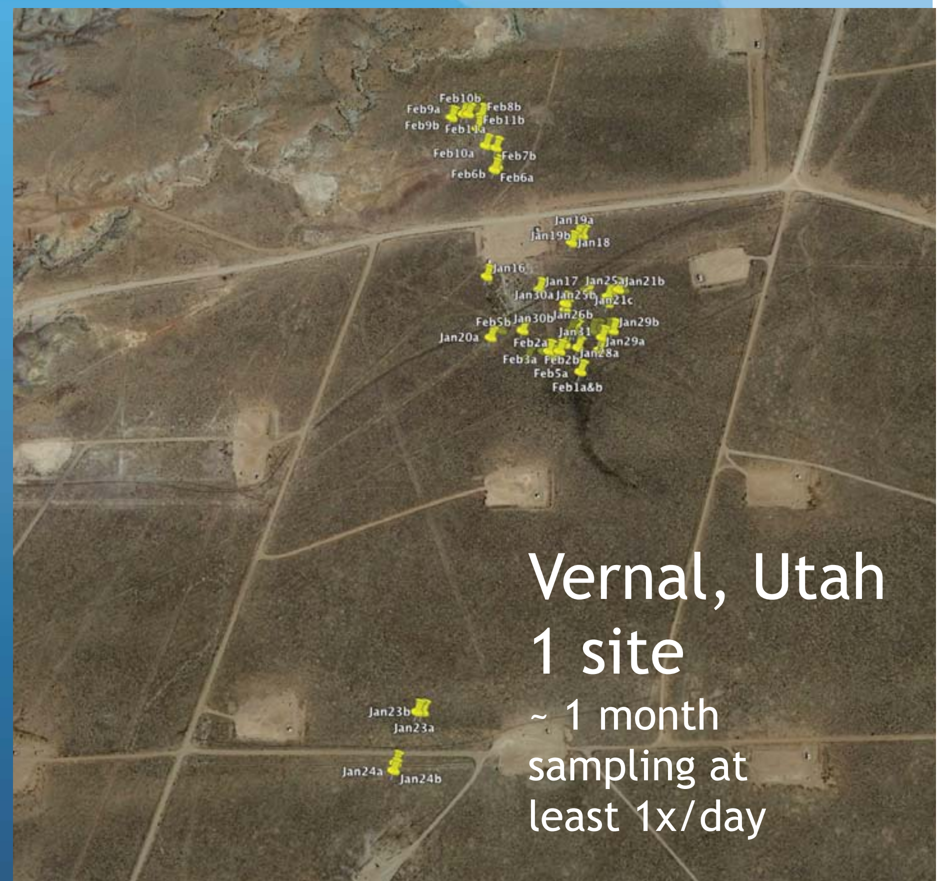


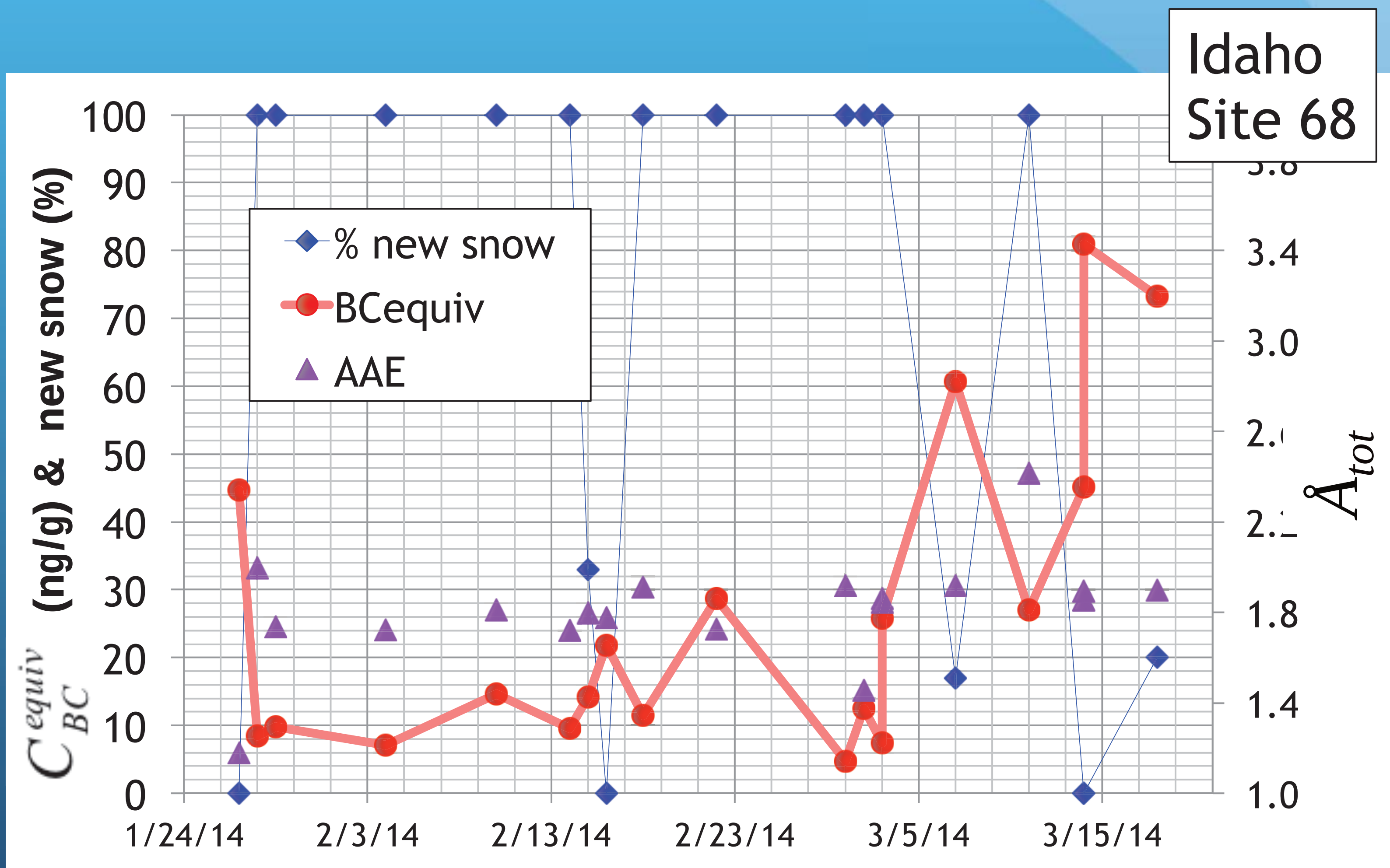
Vernal, Utah sampling by colleagues at NOAA-PMEL (J. Johnson & T. Quinn)

2014 field measurements





Some quick initial results from 2014 field measurements …



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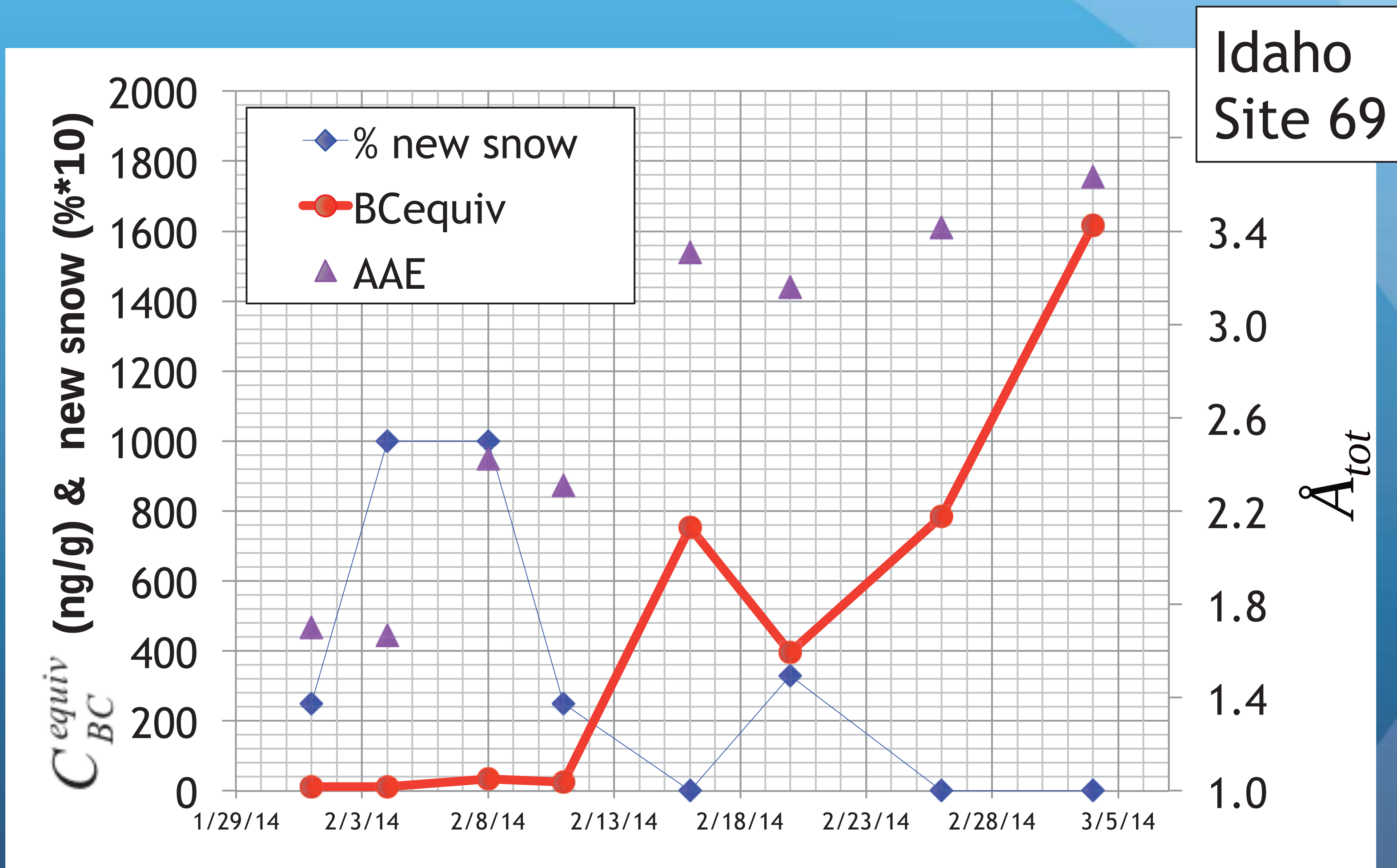

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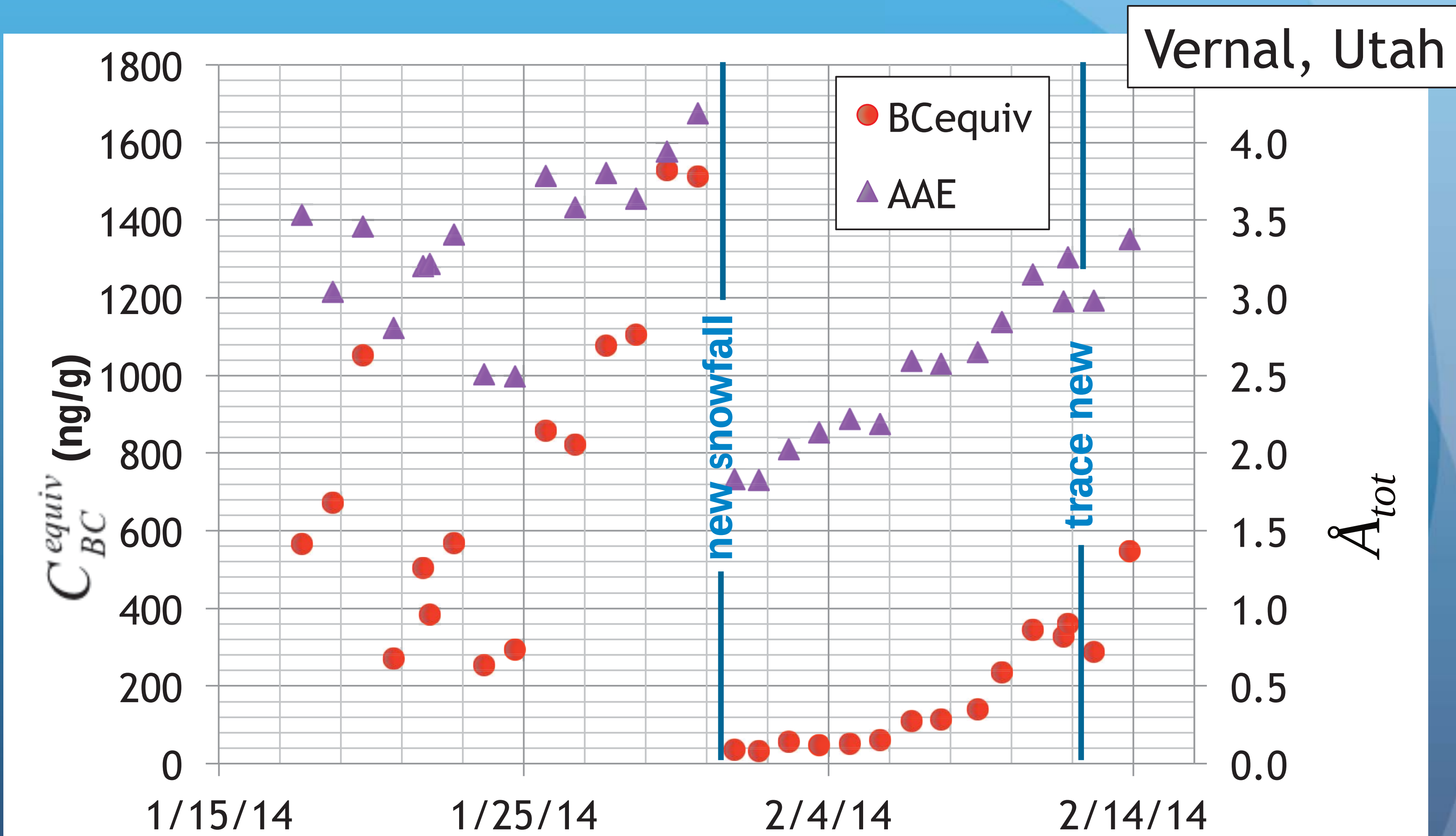



~2-30 ng/g BC

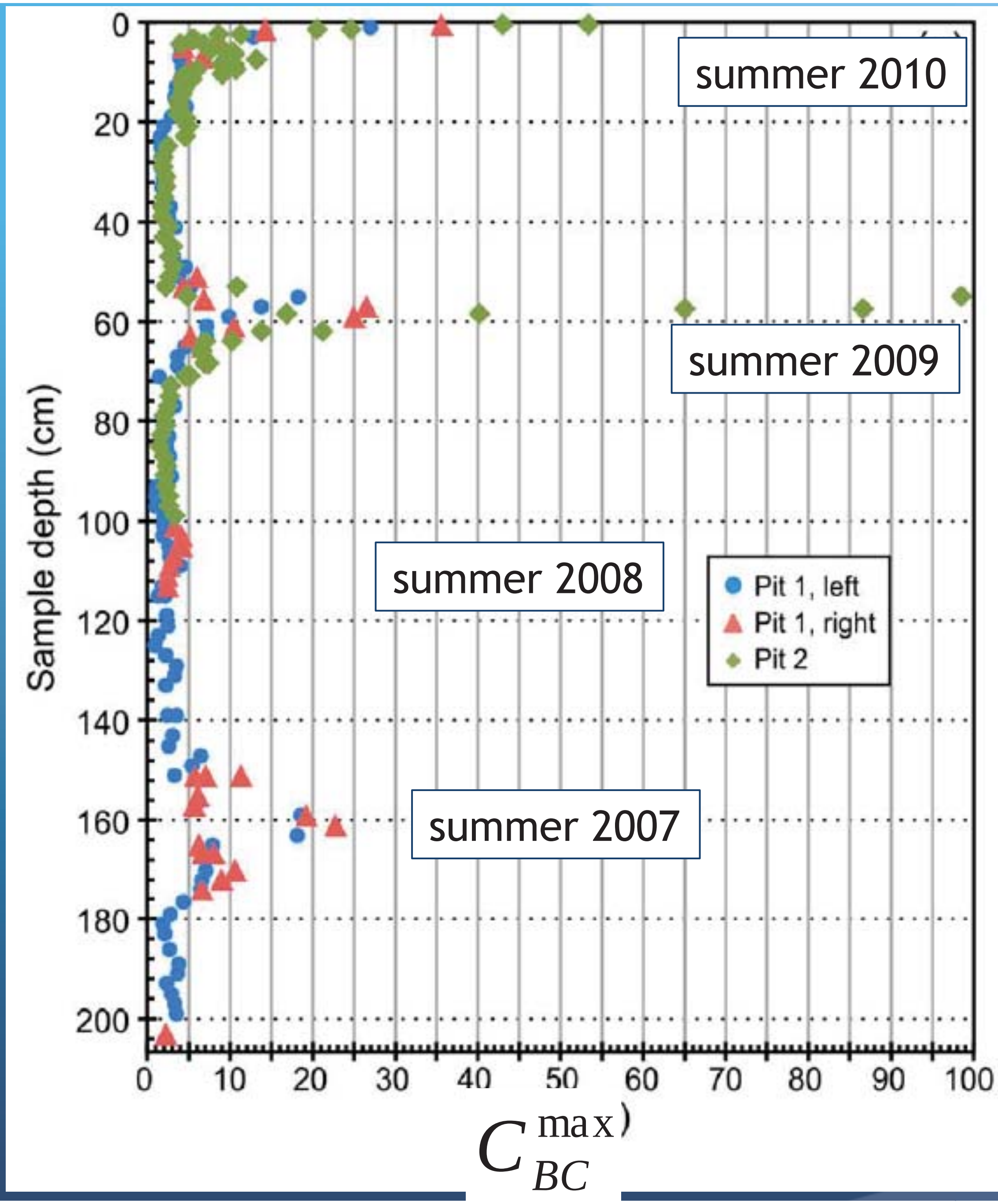

~2-30 ng/g BC


~1100ng/g BC
2010/02/07


~2-30 ng/g BC


~1100ng/g BC
2010/02/07


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



Greenland (Dye-2 site) vertical profile through 4 yrs melt layers

Doherty et al. 2013

The importance of post-wet-deposition processes

- Most of the variability in snow particulate light absorption is driven by what's happening *between* new snowfall events
- Dust & soil play a very strong role (dominate?) incidences of high snow particulate light absorption at:
  - US Great Plains sites
  - 2 Idaho mountain valley sites
  - near Vernal, Utah

  → for the US GP & Idaho sites this is mostly very loca.ly transported soil, so will not be captured by regional/global models

TBD

- finalize analysis / publication of 2014 field samples
- ongoing collaboration with DOE-PNNL to improve regional (WRF-Chem) and global (CESM) modeling of BC and dust in snow
- comparisons ISSW / SP2 of BC in snow from field samples

Publications:

Schwarz, J. P., S. J. Doherty, G. L. Kok, F. Li, S. T. Ruggiero, C. E. Tanner, A. E. Perring, R. S. Gao and D. W. Fahey, Assessing Single Particle Soot Photometer and Integrating Sphere/ Integrating Sandwich Spectrophotometer measurement techniques for quantifying black carbon concentration in snow, *Aerosol Meas. Tech.*, 5, 2581-2592, doi:10.5194/ amt-5-2581-2012, 2012.

Doherty, S. J., T. C. Grenfell, S. Forsström, D. L. Hegg, S. G. Warren and R. Brandt, Observed vertical redistribution of black carbon and other light-absorbing particles in melting snow, *J. Geophys. Res.*, 118(11), 5553-5569, doi:10.1002/jgrd.50235, 2013.

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

Dang, C., and D. A. Hegg (2014), Quantifying light absorption by organic carbon in western North American snow by serial chemical extractions, *J. Geophys. Res.* Atmos., 19, 10,247–10,261, doi:10.1002/2014JD022156.

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.*, accepted, 2014.

(results from 2014 field samples in preparation)