BC and other light-absorbing impurities in North American Great Plains snow:

Sources, impacts, and a comparison with north China snow

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In collaboration with research group of Jianping Huang, Lanzhou Univ., China; Y. Qian, PNNL; J.P. Schwarz, NOAA; others….

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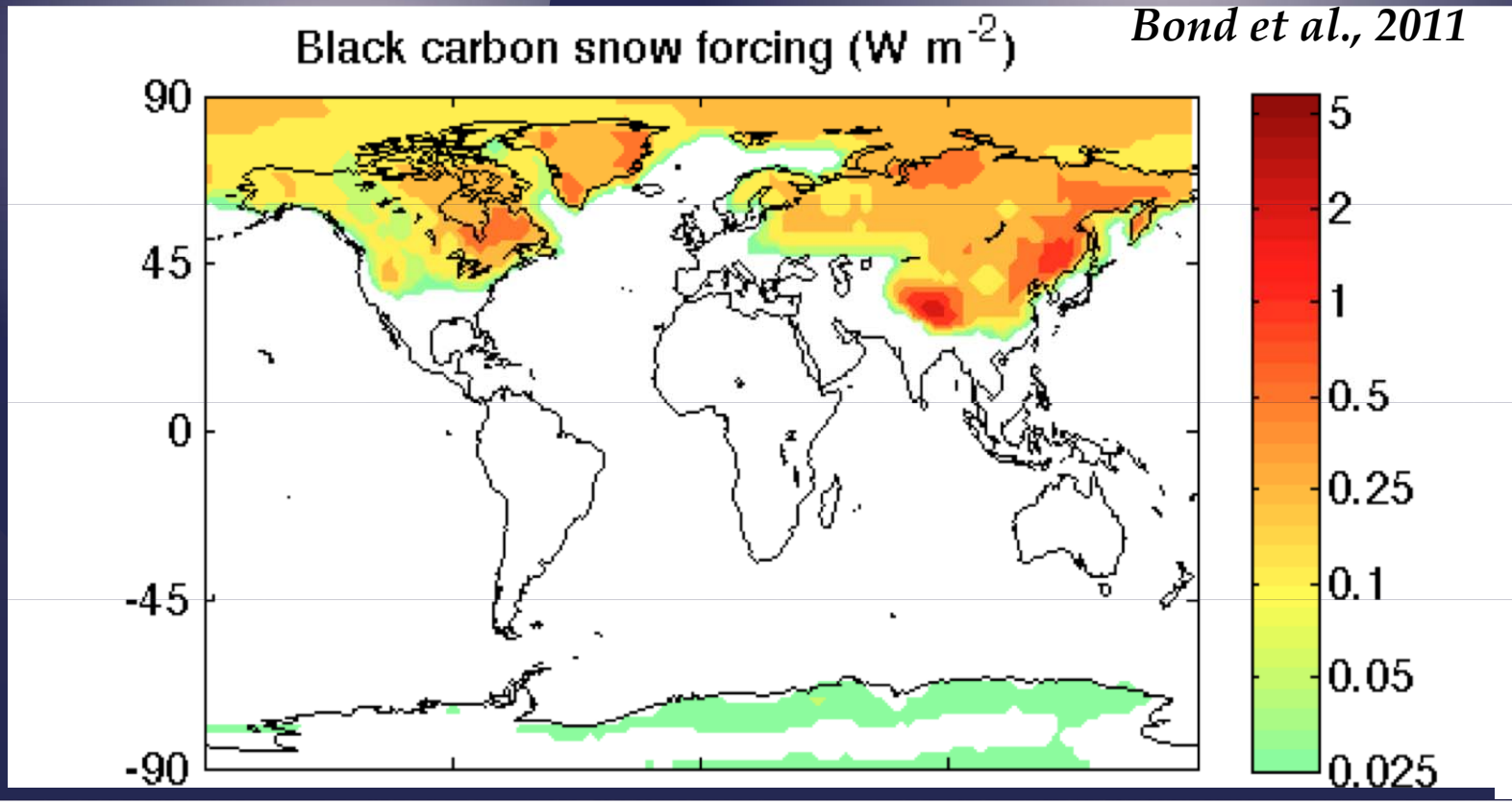
Black carbon in the cryosphere

- BC & other light-absorbing particles in snow reduce snow albedo
  - series of positive feedbacks enhance albedo reduction
  - definitive climate warming
  - all absorbing aerosol (no matter the SSA, including BrC) is a postivie forcing agent



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{important aside #1}

What's not black carbon…

Debris-covered ice in ablation zone of Greenland Ice Sheet… silt, sand and black algae.

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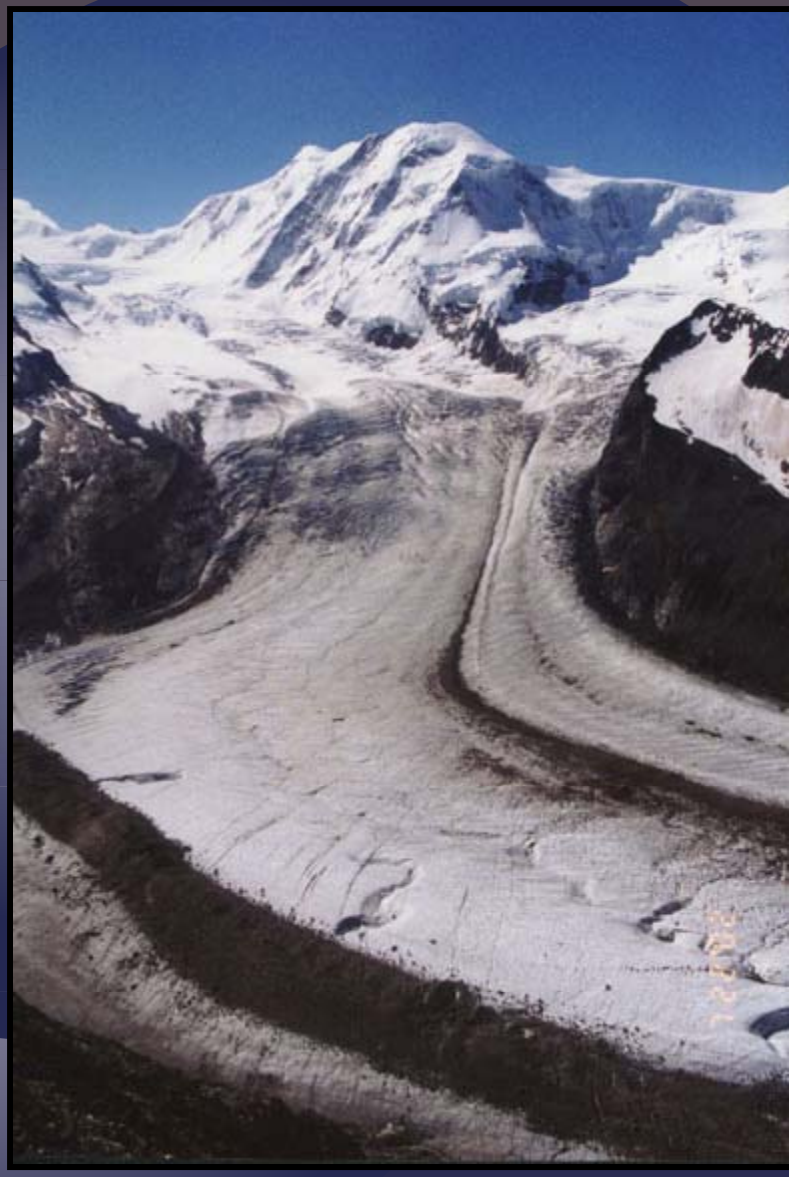

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What realistic concentrations of BC in snow do look like

near Vorkuta, Russia

370 ppb; Δalbedo~5-10%

{highest concentration we saw in Arctic}

{highest concentrations in China ~3x this}

Greenland Ice Sheet

2 ppb; Δalbedo<1%

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Black carbon in the cryosphere

- Main focus of BC in snow has been in the Arctic & Himalayas

However:

- The highest concentrations of BC in snow are expected at the northern mid-latitudes, and the climate impacts of snow BC at these latitudes are relatively under-studied.
- Forcing by BC in snow at mid-/sub-Arctic latitudes may affect Arctic sea ice distributions more than forcing by BC in the sea ice itself [*Goldenson et al., 2012, ACP, in review*]
- Areas where the surface snow is not masked by tree cover are especially susceptible to the reduction of planetary albedo

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Goals:

1. Determine concentrations, sources and regional climate impacts of BC and other light-absorbing aerosol in snow in the N. American Great Plains.
2. Comparison: N. American Great Plains vs. the steppes of North Asia *(w/ Lanzhou Univ., China + modeling work with DOE-PNNL)*
3. Improve understanding of:
   a. the deposition rates of BC to snow
   b. consolidation of BC and other LAA at the snowpack surface during melting, a potentially strong positive feedback mechanism.
4. Methods comparison:
   a. ISSW Spectrophotometer *(our group)*
   b. Single Particle Soot Photometer, SP2 *(NOAA & DRI)*
   c. thermo-optical method *(NPI & Environment Canada)*
5. First-order estimate of the contribution by N. American sources to BC in Arctic snow.

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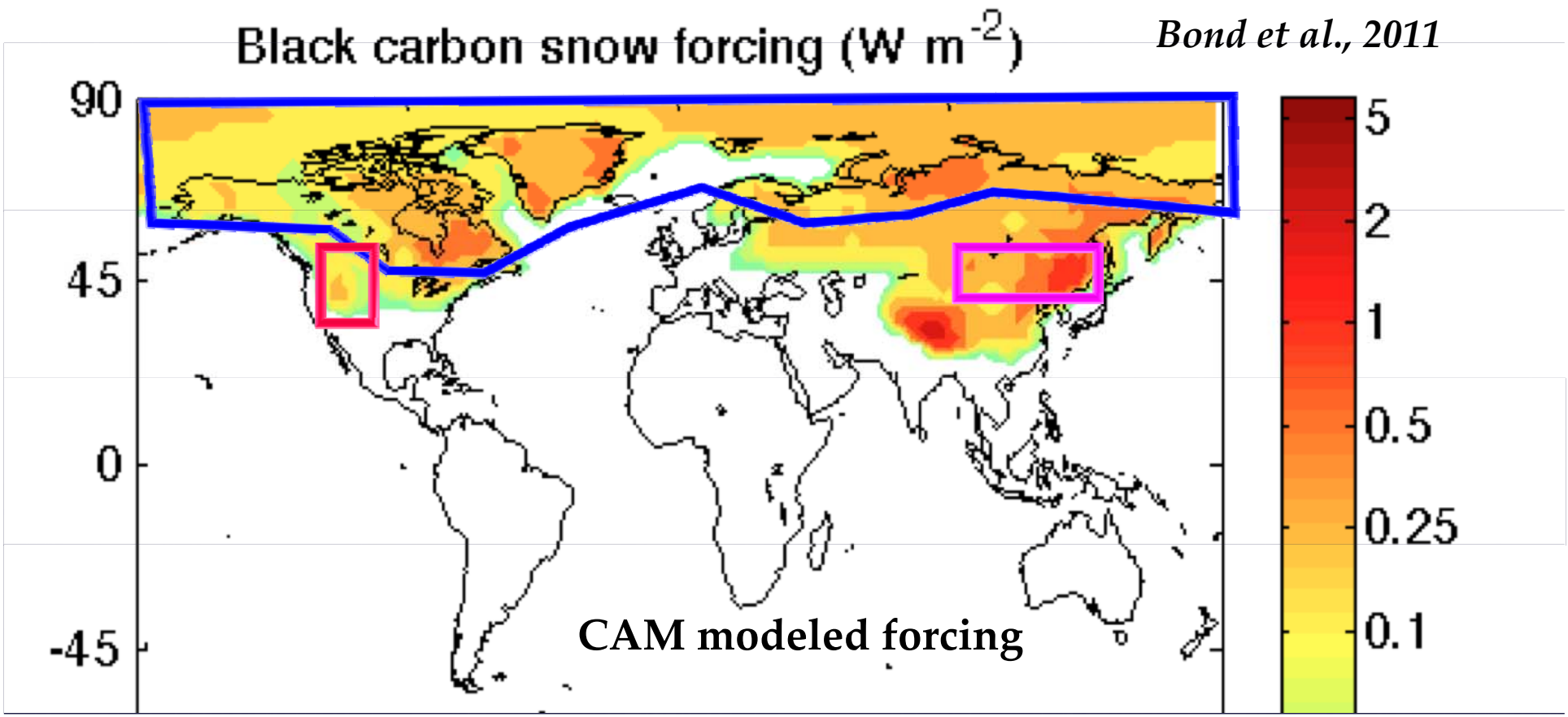
Black carbon in the cryosphere

2006-2009
Arctic Survey

2010-2012
N. China Survey,
Huang et al., Lanzhou University (lead)
in collaboration with Univ. of Washington

2013-2014
N. American Survey



Review of progress on goals:

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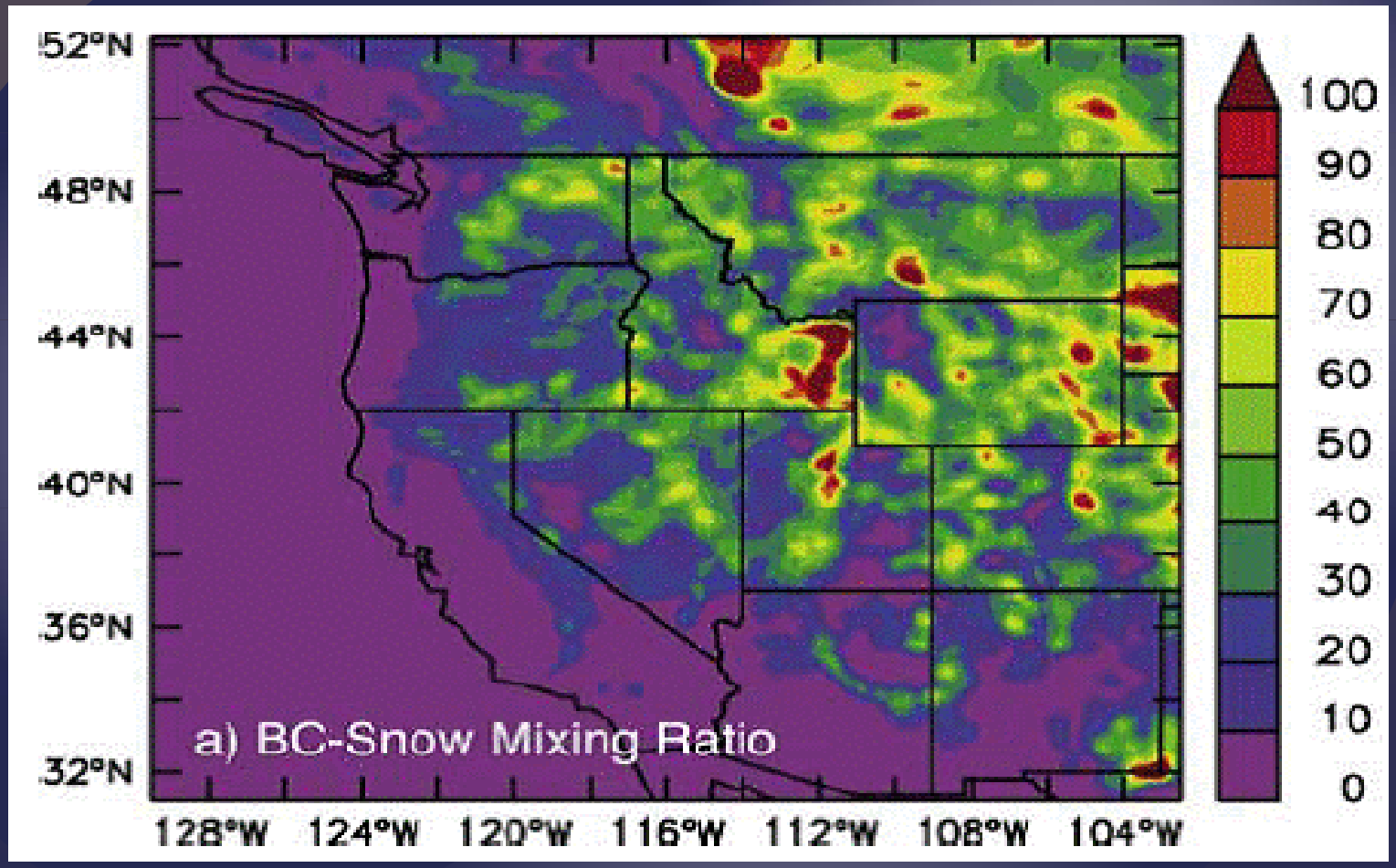
N. American study area



From Qian et al., JGR, (2009)

Snow BC mixing ratio (ng/g) from a regional model (WRF-Chem)

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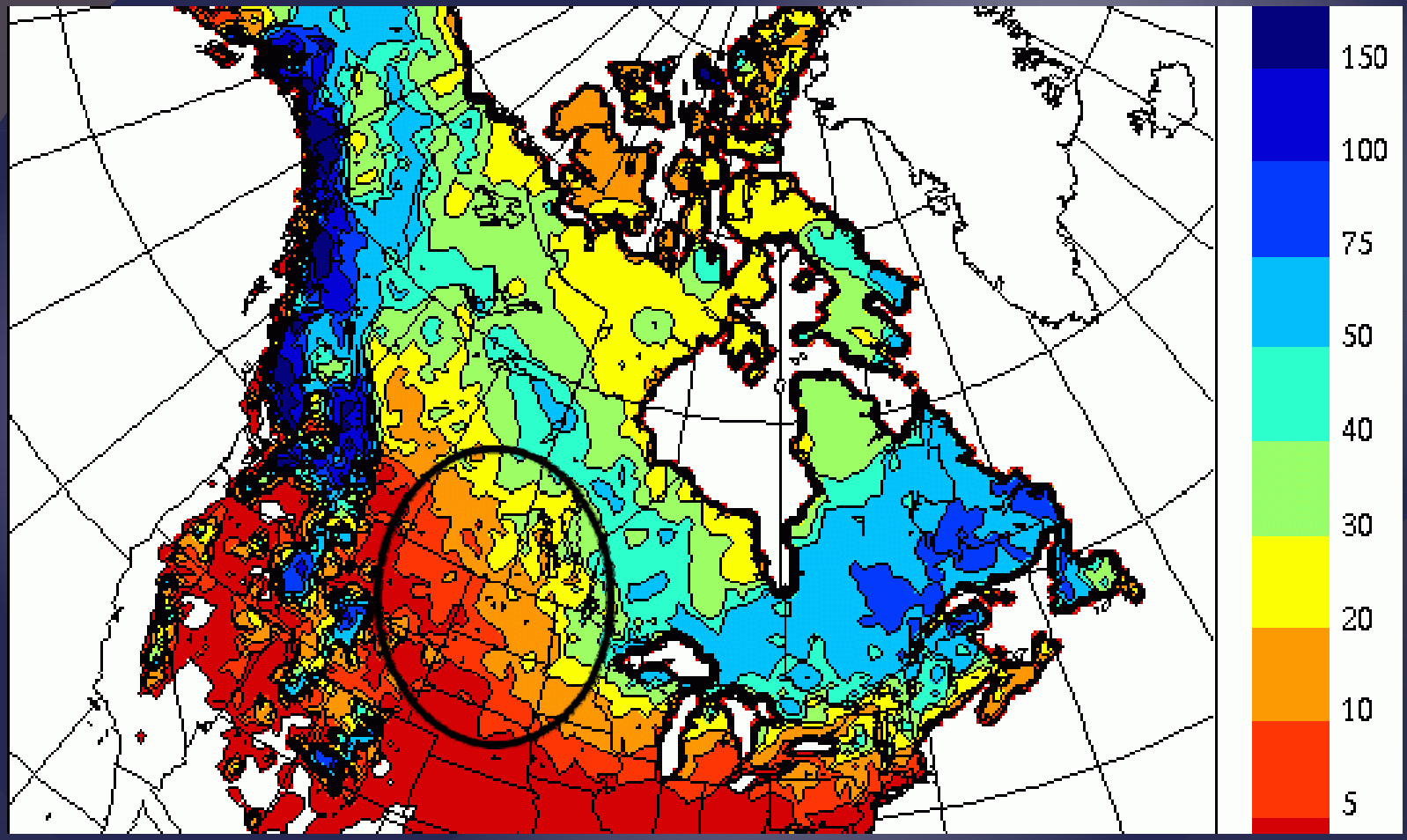
N. American study area



(Courtesy Canadian Cryospheric Information Network)

Mean snow depth (cm), February

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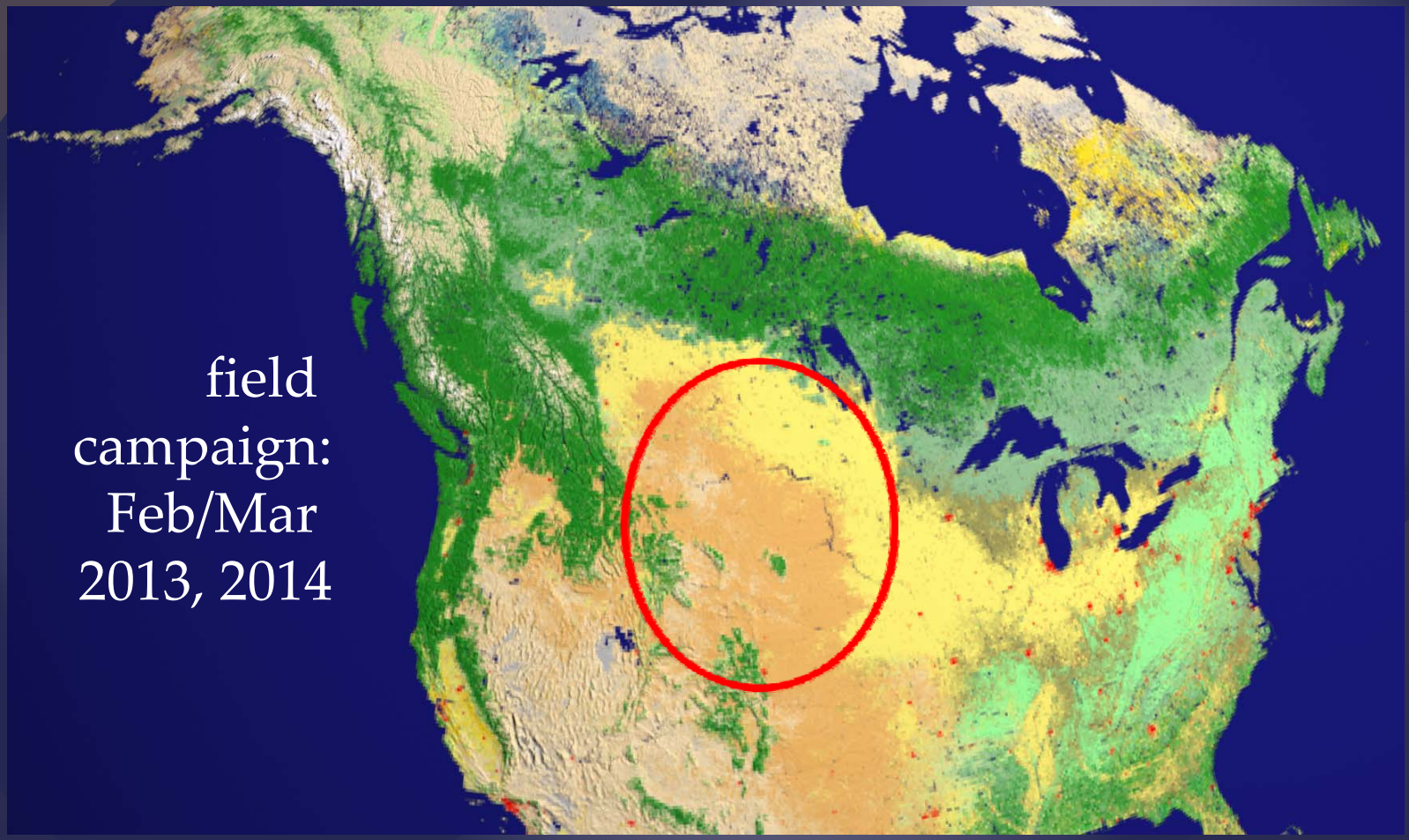
N. American study area



(Courtesy Lynn Chandler, NASA-GISS & Bob Zalisk, Boston Univ., using NASA Terra MODIS Satellite data)

Land cover type:
yellow/orange = grasses/shrubland

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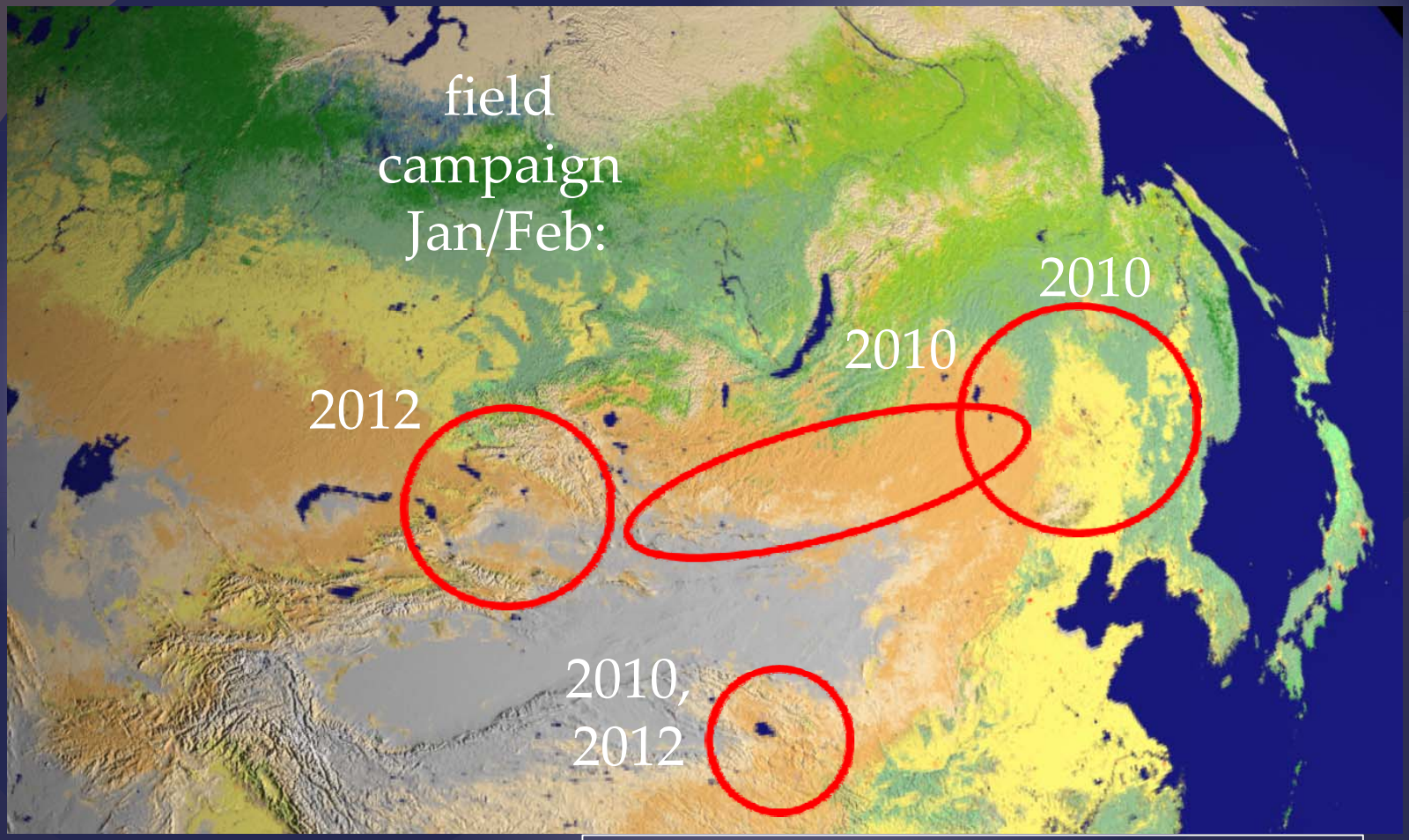
N. China study area

(Lanzhou Univ.)



(Courtesy Lynn Chandler, NASA-GISS & Bob Zalisk, Boston Univ., using NASA Terra MODIS Satellite data)

Land cover type:
yellow/orange = grasses/shrubland
gray = deserts

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Measurements/analysis

- Sampling:
  - sample profiles through full snow depth (seasonal evolution)
  - usually, two profiles at each site
  - snow melted, filtered in the field + water samples frozen for chemical analysis in lab
  - catalog of snow depth at sampling sites
- ISSW Spectrophotometer: optical analysis
  - measured all light-absorbing particles
  - Products:
    - maximum possible snow BC concentration
    - estimated snow BC concentration
    - BC concentration needed to account for all spectrally-integrated (300-750nm) snow particulate absorption
    - fraction of spectrally-integrated solar absorption due to non-BC particulates

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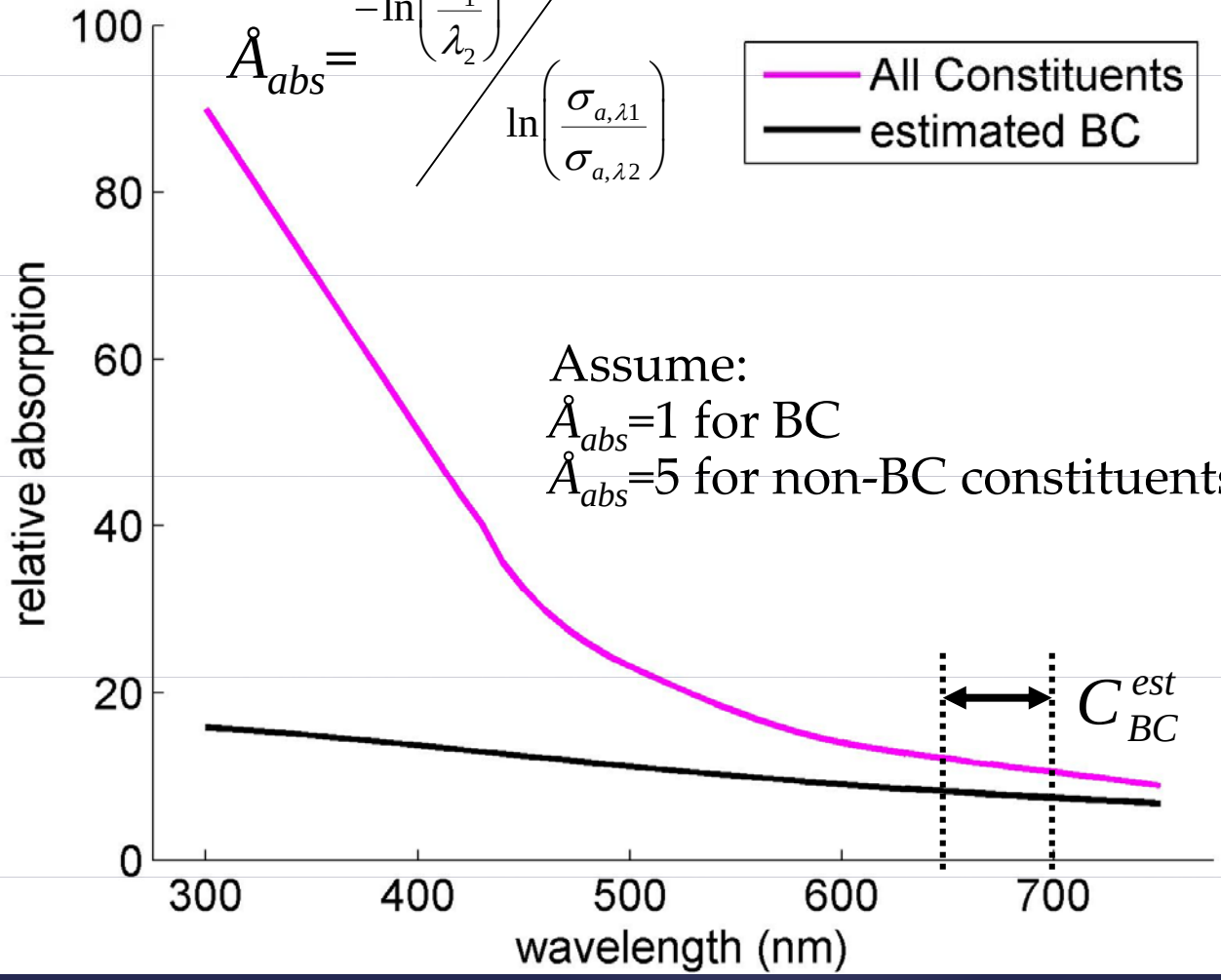
Optical analysis
ISSW Spectrophotometer

$$\mathring{A}_{abs} = \frac{-\ln\left(\frac{\lambda_1}{\lambda_2}\right)}{\ln\left(\frac{\sigma_{a,\lambda 1}}{\sigma_{a,\lambda 2}}\right)}$$



Assume:
$\mathring{A}_{abs}$=1 for BC
$\mathring{A}_{abs}$=5 for non-BC constituents

via calibration curves from BC standard filters

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Measurements/analysis

- Chemical analysis:
  - ion chromatography (IC); liquid chromatography-Mass Spectroscopy (LC-MS)' inductively-coupled plasma-optical emission spectroscopy (ICP-OES)
    - *formate, chloride, nitrate, succinate, sulfate, oxalate, levoglucosan, mannitol, xylitol, vanillin, V, Pb, Na, K, Fe, Se, Si ,As, Mg, Mn, Ca, Al, Zn, Ba, B, Sr, Ti*
  - provides information on non-BC absorbers, used for optical analysis (separation of BC and non-BC light absorption)

- Positive Matrix Factorization (PMF) analysis
  - source attribution (e.g. biomass burning, fossil fuel combustion, dust/soil)

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Comparisons N. America vs. N. China (& vs. Arctic)

- Identical measurement/analysis approaches used for N. China and N. America → direct comparability *(U.W. / Lanzhou Univ.)*
- Also identical to that used in broad Arctic survey
  [Doherty et al., 2010; Hegg et al. 2009; Hegg et al. 2010]
- Comparison of concentrations & sources from these regions.
- Arctic/sub-Arctic data set from Canada can be used with N. American data set to get N-S gradients in snow BC concentrations in western Canada
- Comparison of measured & modeled total deposition & surface concentrations:
  - WRF-Chem *(collaboration with DOE-PNNL)*
  - EPA SMOKE model (deposition only)
  - {not in the proposal, but also CAM}

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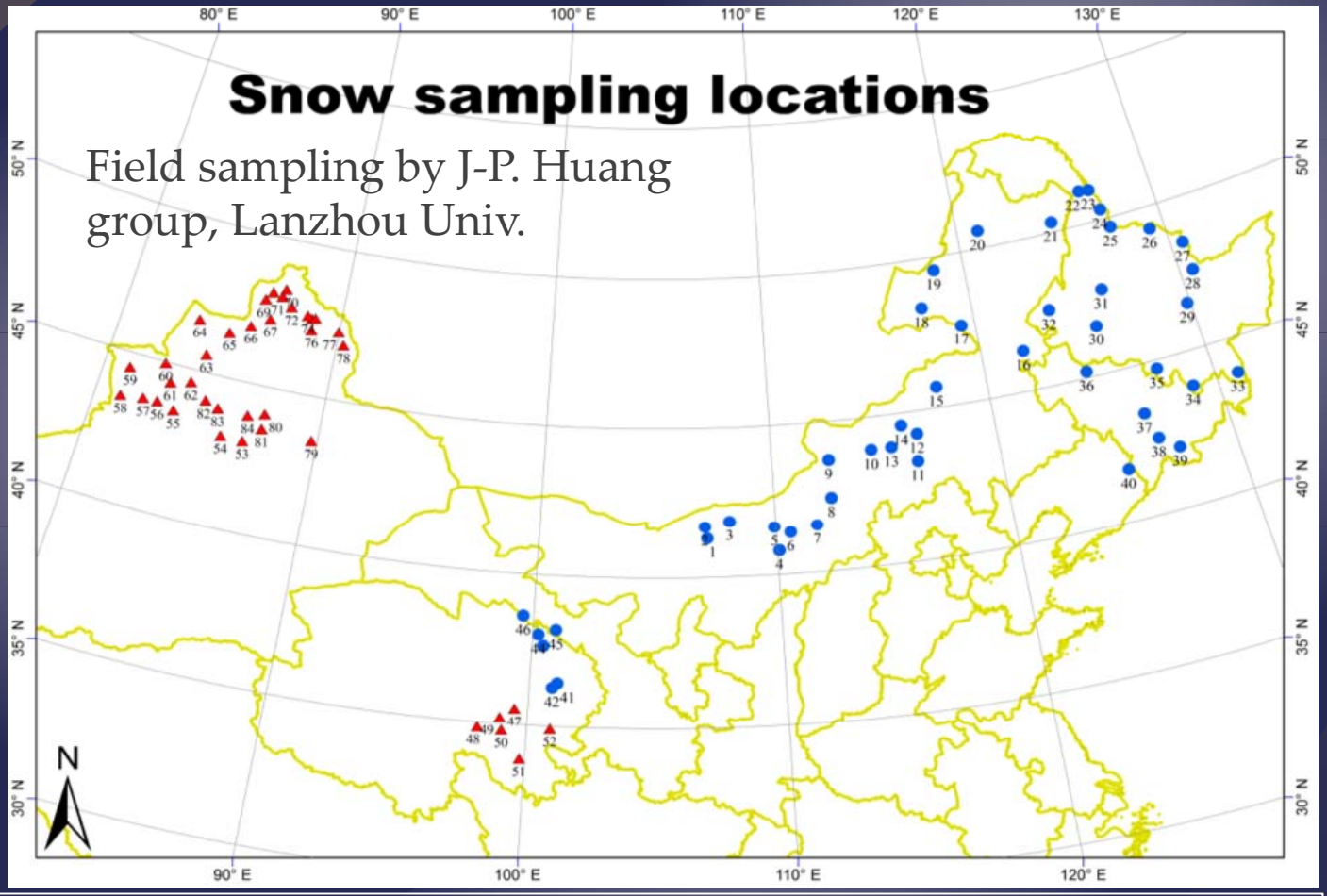
N. China study area 2010 + 2012



Jan/Feb 2010 (blue) and 2012 (red) sampling sites
Lanzhou University / Univ. of Washington collaboration

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STATUS

- 2010 N. China campaign (*w/ Lanzhou Univ.*)
  - complete, data analyzed, paper about to be submitted to JGR on concentrations; source attribution paper in progress
  - this was a significant part of our effort this past year
- 2012 N. China campaign (*w/ Lanzhou Univ.*)
  - field measurements by Lanzhou Univ. colleagues complete
  - sample analysis Fall/Winter 2012

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Review of progress on goals:

STATUS (cont'd)

- Feb/Mar 2013/2014 N. American campaign
  - planning underway; incorporating lessons from China campaign and methods comparisons
  - grad student started Fall 2011
- Model work at PNNL underway
  - training up a student from Lanzhou Univ. to do regional simulations for N. China
- {Tests with existing samples to extract non-BC absorbers from filters; re-measure with photometer; determine accuracy of optical separation of BC/non-BC absorbers}

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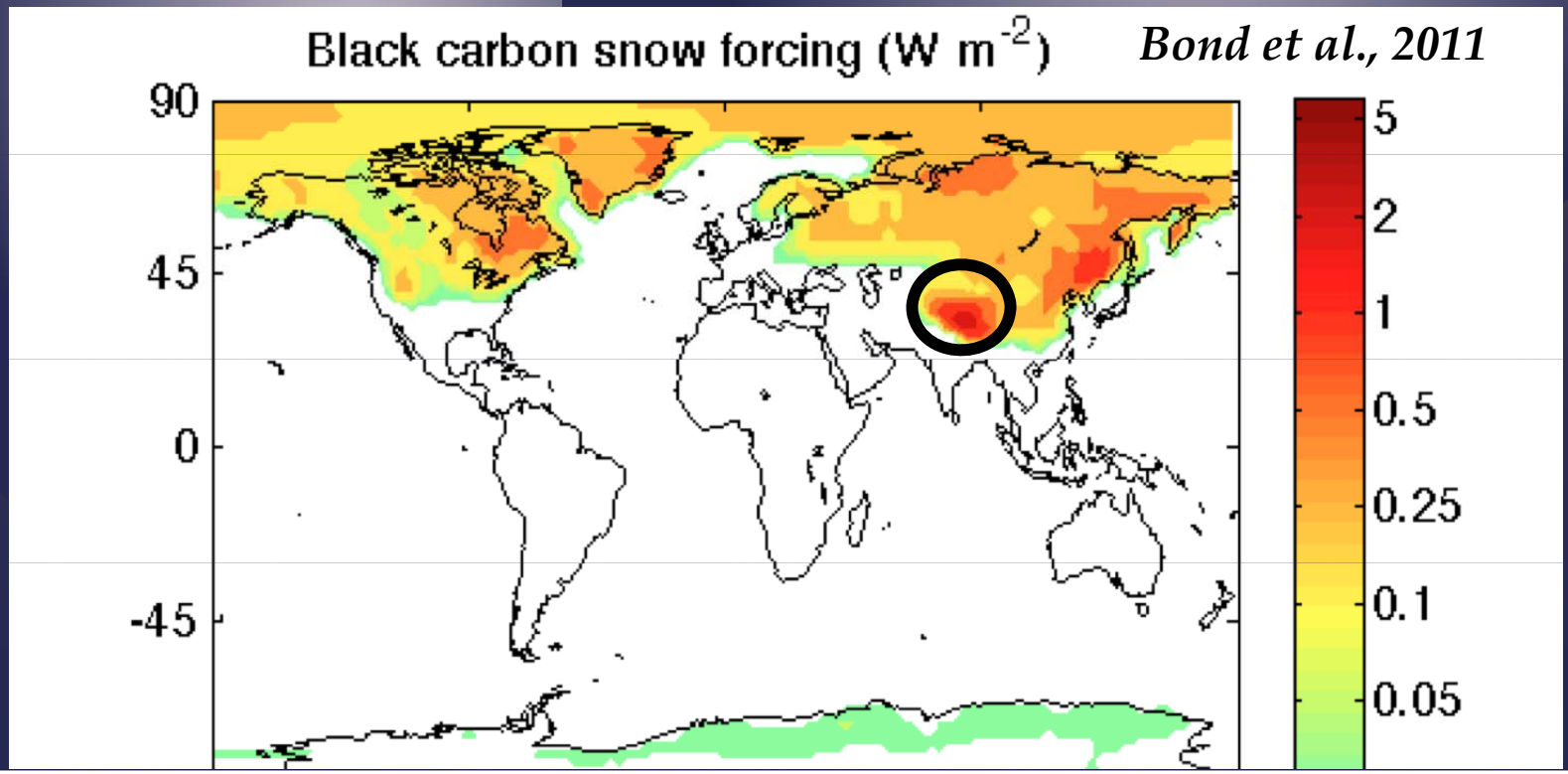
{important aside #2}

- We are focusing on constraining concentrations of black carbon (and other light-absorbing particle) in the snow
- BUT TO ACCURATELY CALCULATE RADIATIVE FORCING YOU HAVE TO GET SNOW COVER CORRECT

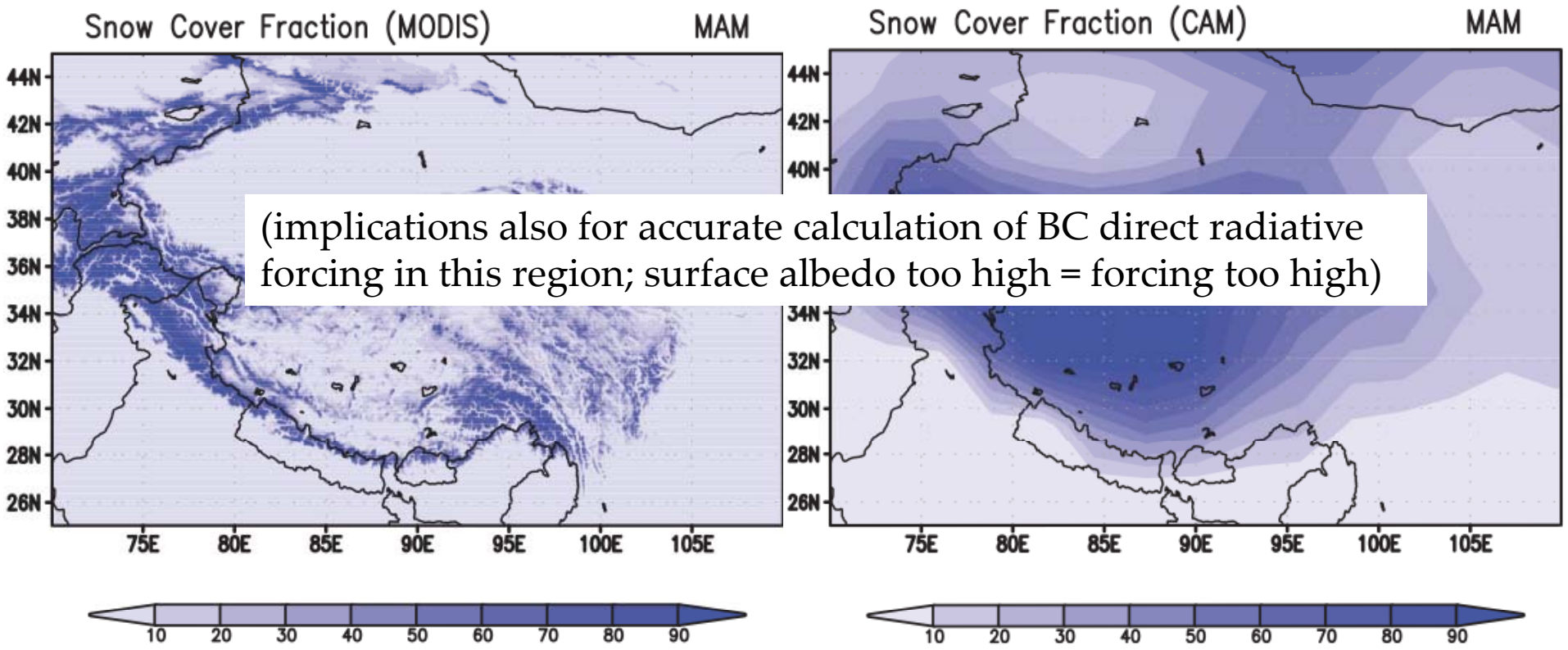
(this is the cryosphere equivalent to Tami's point yesterday about getting cloud distributions correct for BC DRF)



From Qian et al., 2011, ACP

MODIS

CAM



(implications also for accurate calculation of BC direct radiative forcing in this region; surface albedo too high = forcing too high)

(I've no idea how accurate snow cover is in other regions or in other models, but this is IMPORTANT and needs to be looked at in the context of forcing by BC in the cryosphere!)

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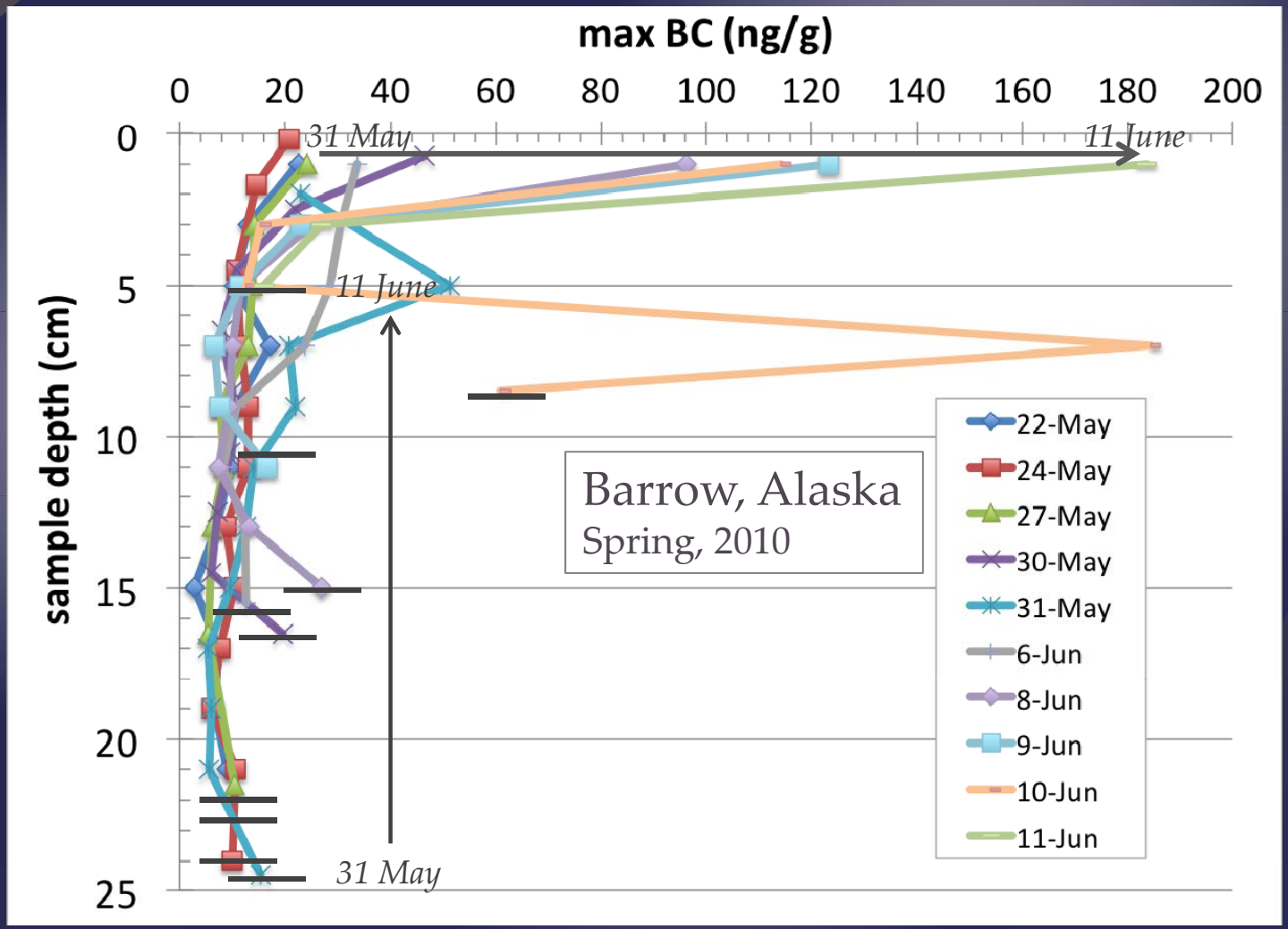
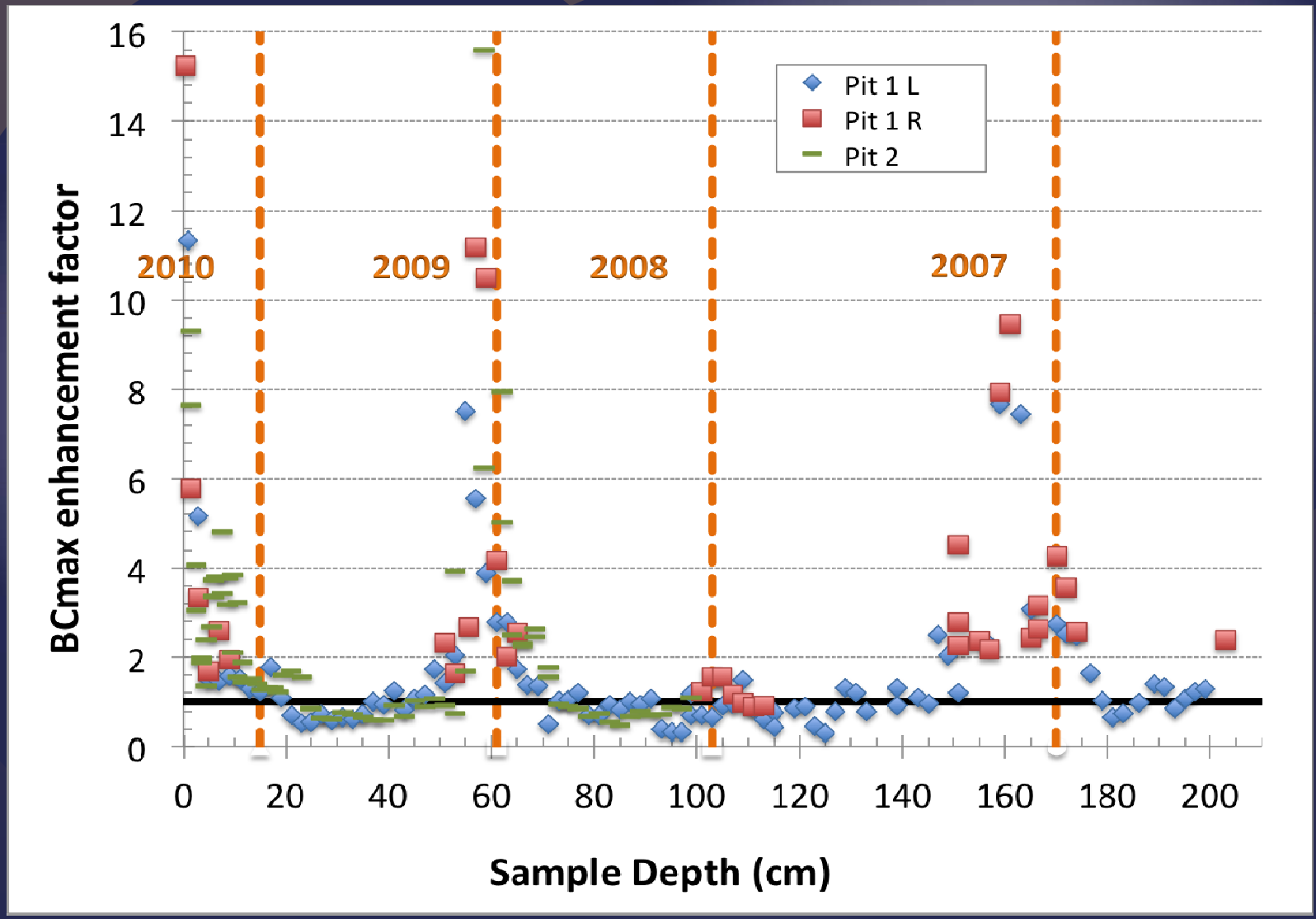
Consolidation of BC in surface snow with melt

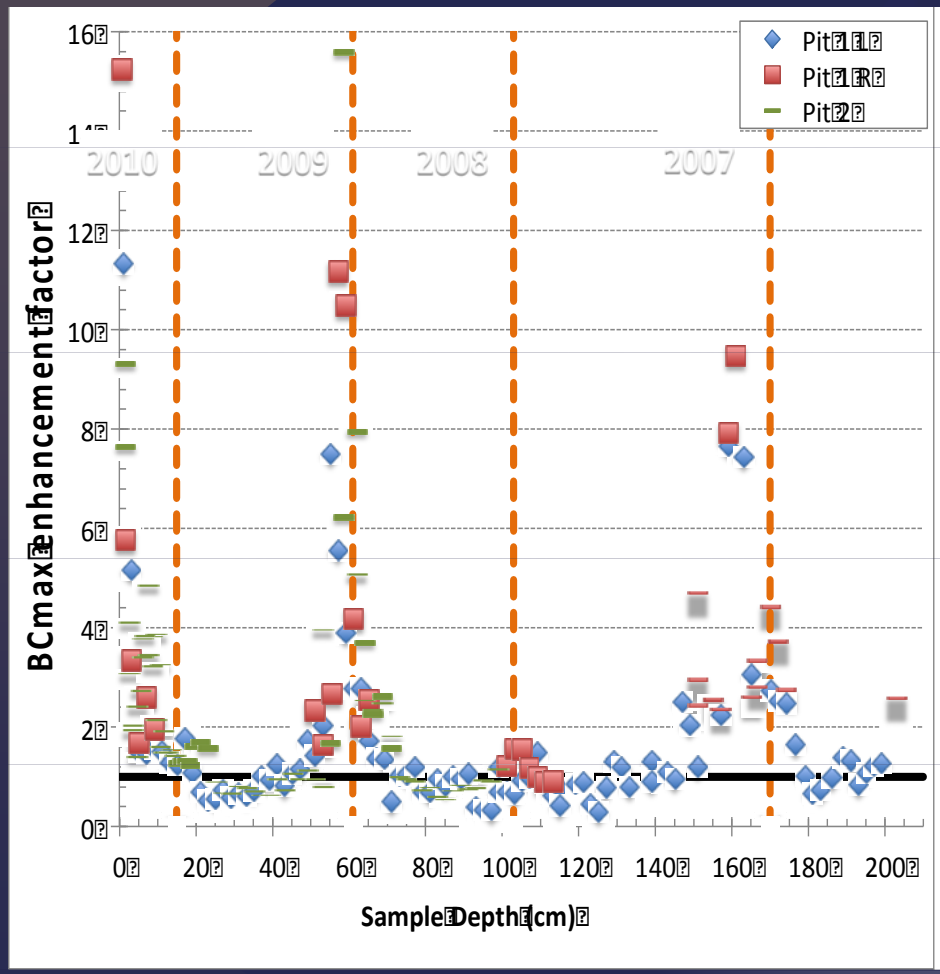
→ *amplified albedo reduction; strong (?) positive feedback*

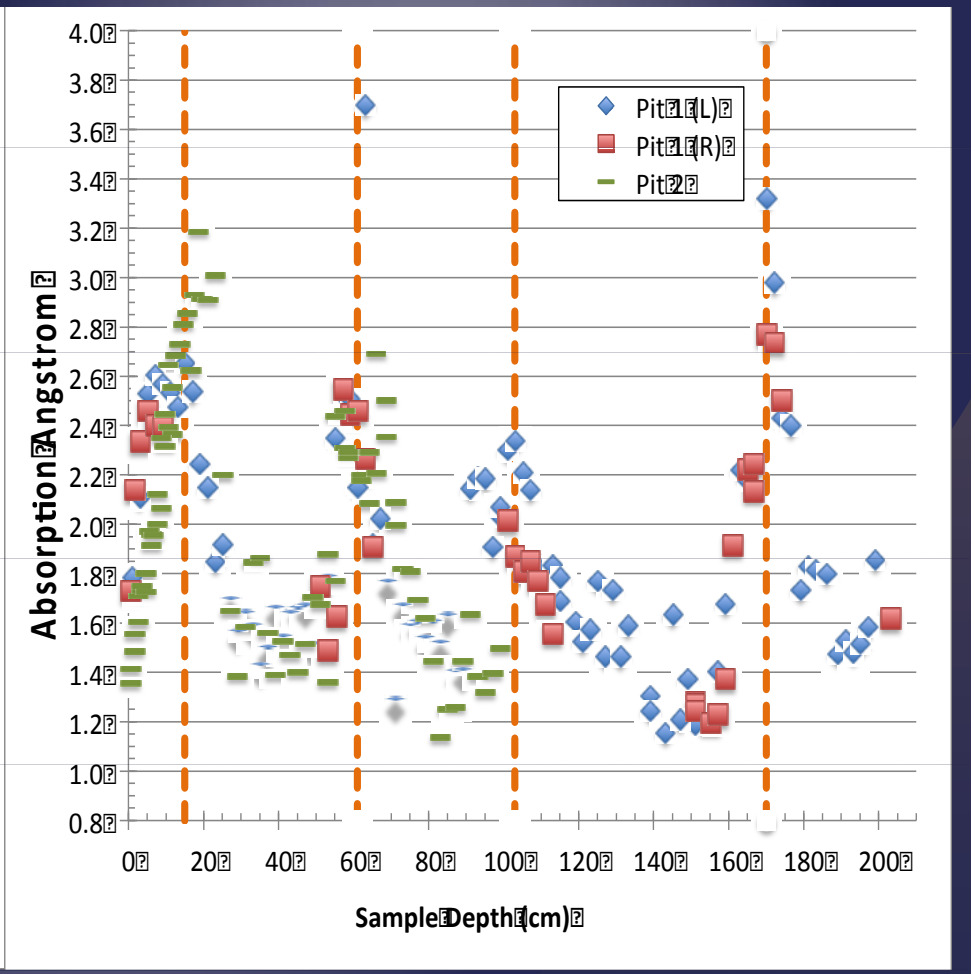


Dye-2, Greenland percolation zone: profile through 4 years' snow melt

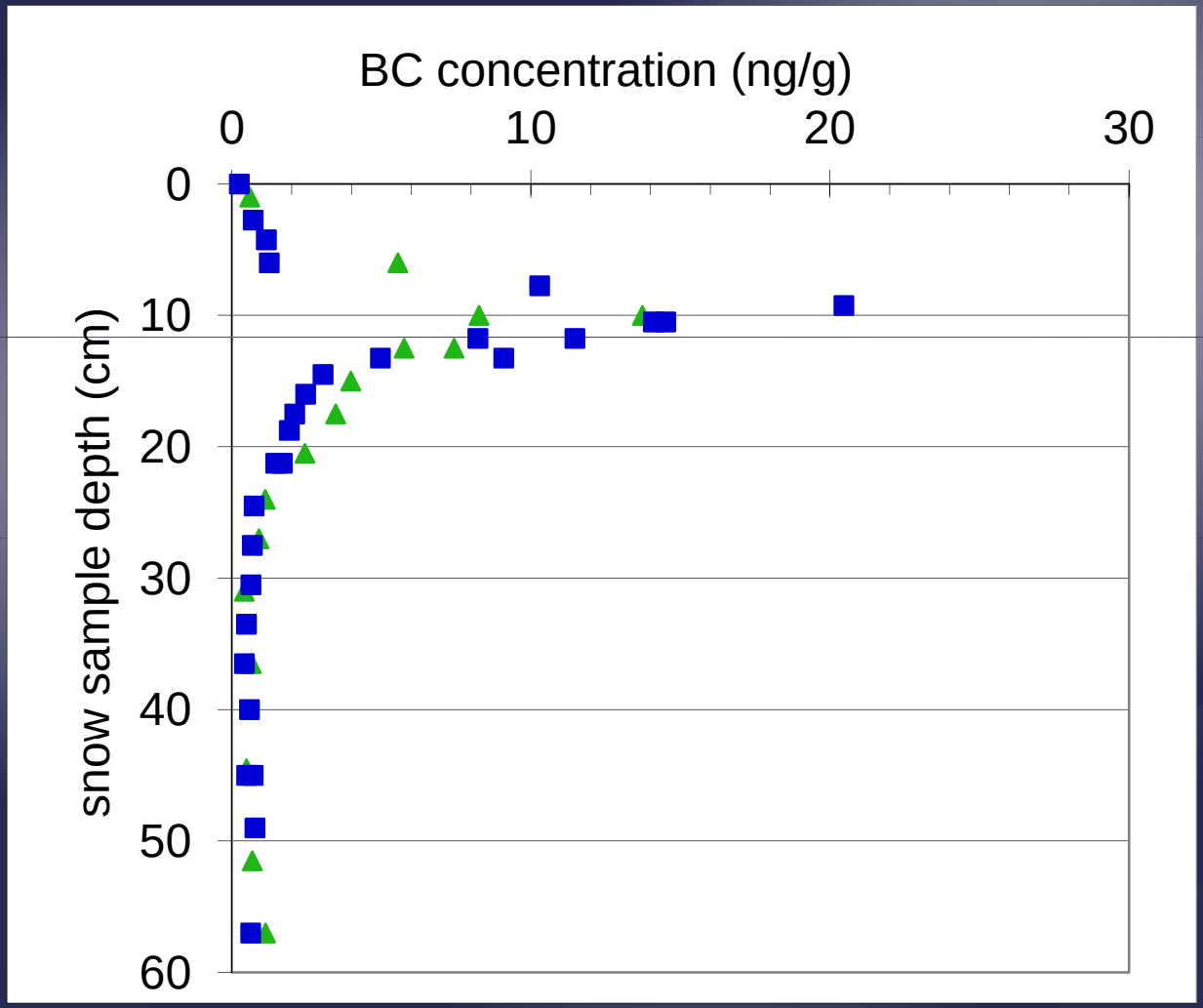


Dye-2, Greenland percolation zone: BC concentration data & Absorption Angstrom for all light absorbing aerosol (= indicator of source type)





Dye-2, July: new snow buries high-concentration layer



Review of progress on goals:

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STATUS

- Samples from melting snowpacks at Barrow, Alaska; Dye-2 (+northeast) Greenland; Tromso, Norway measured
- Analysis of redistribution of BC vs. other constituents (e.g. soluble constituents) in snow
- Paper being written; expected submission this summer
  - metrics being provided for model parameterizations of melt consolidation
  - finding: melt consolidation of BC is significant but may only be important briefly (2-4 weeks max) in annual snowpacks. In Greenland, effect depends on amount of melt and masking by new snowfall in summer.

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Focus of this work:

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Methods comparison

- BC concentrations for air samples have been shown to depend on measurement methodology (optical, T/O, SP2)
- Measurements of BC in snow / water samples has additional complicating factors (e.g. capture efficiency)
- ISSW Spectrophotmeter is a unique instrument
  - comparison with more commonly used methods needed to put large ISSW data set (Arctic, N. China and TBD N. Amer.) into context
- Two parallel efforts:
  - U.W. ISSW spectrophotometer vs. NOAA-CSD SP2
    - analysis complete; paper submitted (Schwarz et al., 2012, *Aerosol. Meas. Tech. Disc.*)
  - U.W. ISSW vs. DRI SP2 vs. Env. Canada thermo-optical/NIOSH

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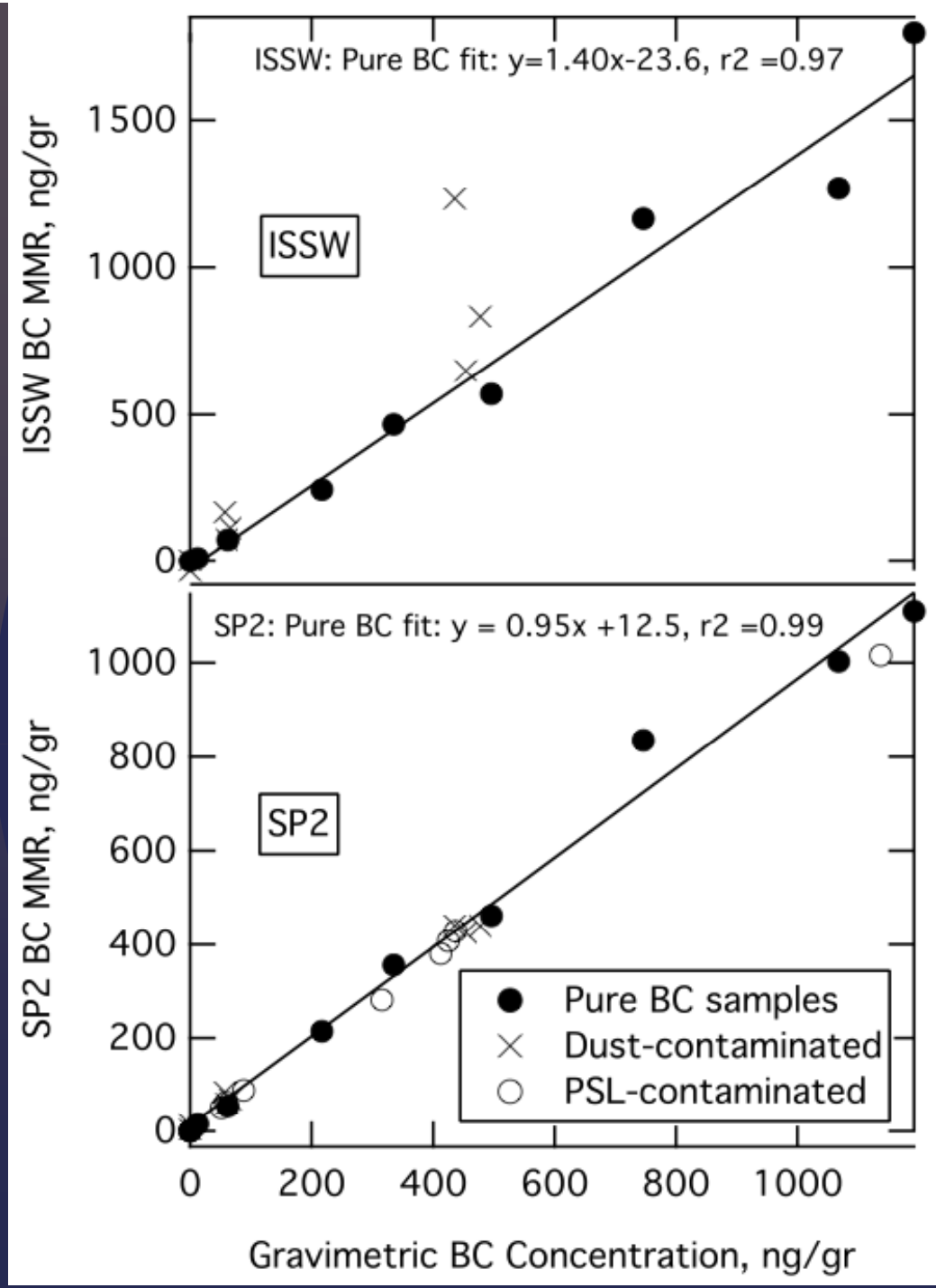

ISSW & SP2 vs. gravimetrically determined concentrations ("truth")

range of concentrations of three mixtures:

- fullerene (= synthetic BC)
- fullerene + dust standard
- fullerene + PSLs (no absorption)

Schwarz et al., 2012, *Aerosol. Meas. Tech., submitted*

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Methods comparison

- ISSW:
  - Small high bias in ISSW-derived BC accounted for by different mass absorption efficiencies of fullerene vs. that of synthetic BC used to calibrate the system
  - Significant high bias (up to factor of 2-3) for mixes with high mass fractions of dust
    - allocation of scattering to absorption?
    - → *Instrument is being redesigned to try and correct for this*
- → *Means current estimates are upper limit on snow BC concentrations*
- SP2: Good accuracy **if:**
  - appropriate nebulization system is used & passing efficiency properly accounted for, and
  - larger size dist. of snow water BC is accounted for
- Thermo-optical:
  - Under-catch by quartz filters is large and variable [10-90%; Gayle Hagler & Tami Bond, personal comm.]

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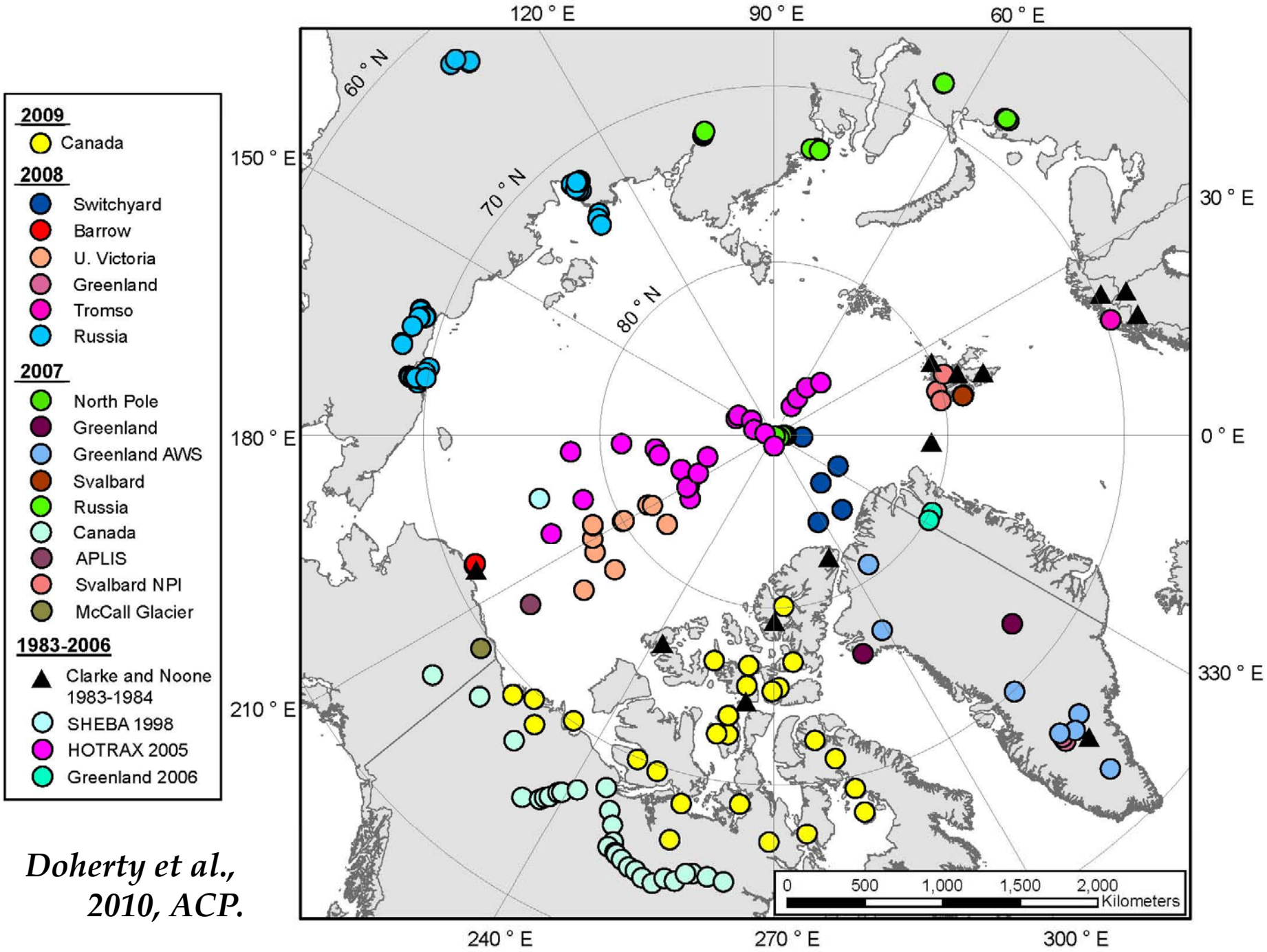
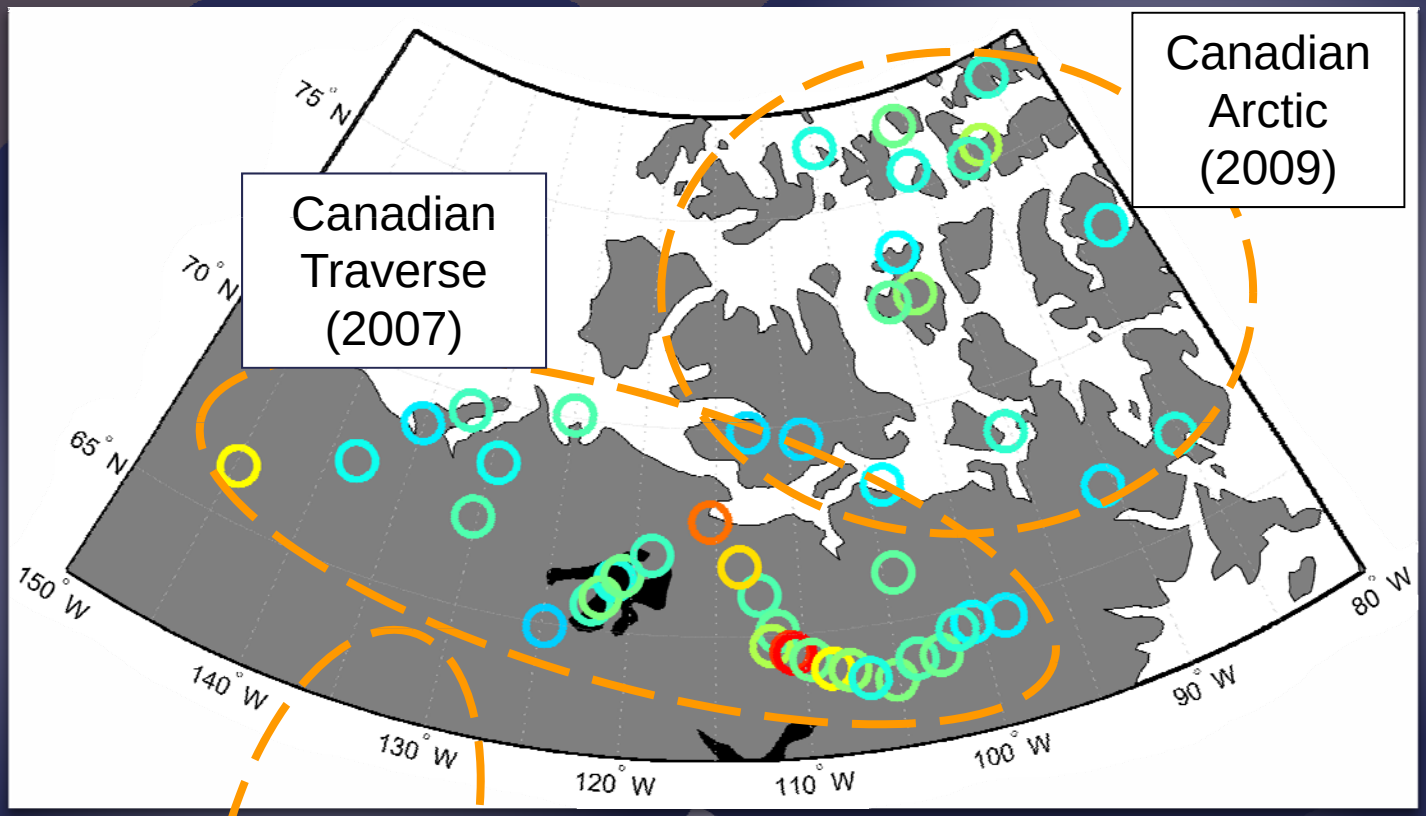


Doherty et al., 2010, ACP.



Summary

- Emphasis in first year was on:
  - collaboration with Lanzhou Univ. on analysis of 2010 China field data set
  - methods testing, comparisons, improvements in method in preparation for 2013/2014 N. American field campaign
    - instrument design is being modified (sensitivity to scattering)
    - improvements to field sampling techniques developed
  - analysis of BC consolidating at snow surface with melt
  - {Related work not funded by this grant:
    - "Bounding the role of Black Carbon in Climate"
    - Warren et al. paper on why satellites can not be used to determine snow BC concentrations / BC impacts on snow albedo }
- Emphasis in second year will be on:
  - implement/test instrument redesign
  - N. American field campaign
  - assisting with analysis of 2012 N. China samples
  - collaboration with PNNL on regional modeling

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