Seasonal snow albedo in the northeastern United States: measurement uncertainty and controls on albedo evolution

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Workshop on in-situ snow albedo measurements

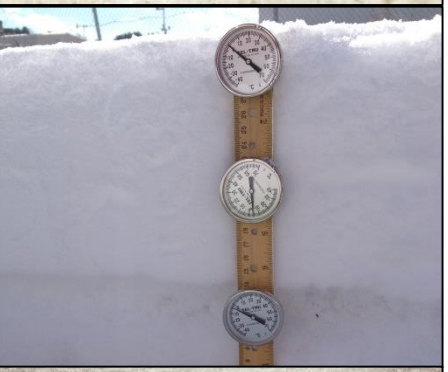
Helsinki, Finland

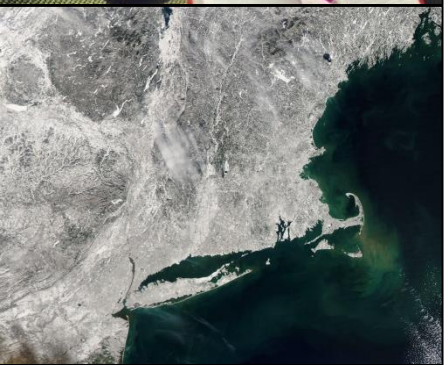
THAYER SCHOOL OF ENGINEERING AT DARTMOUTH

NSF

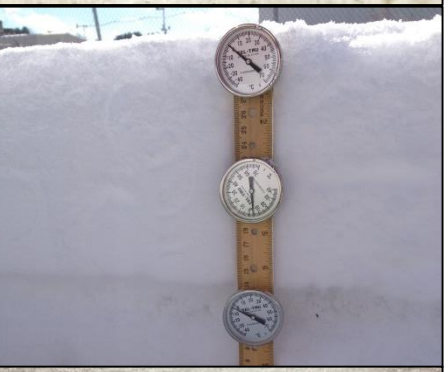
ECOSYSTEMS + SOCIETY

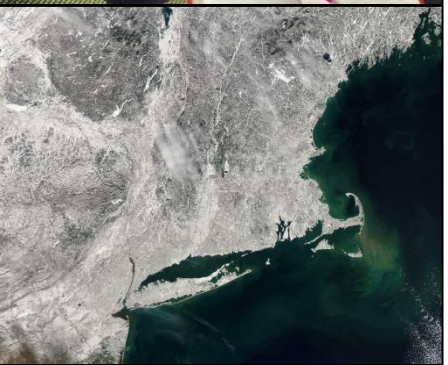
In Revisions at *JGR: Atmospheres*





DATA SET
UNCERTAINTY
RESULTS
CONCLUSIONS



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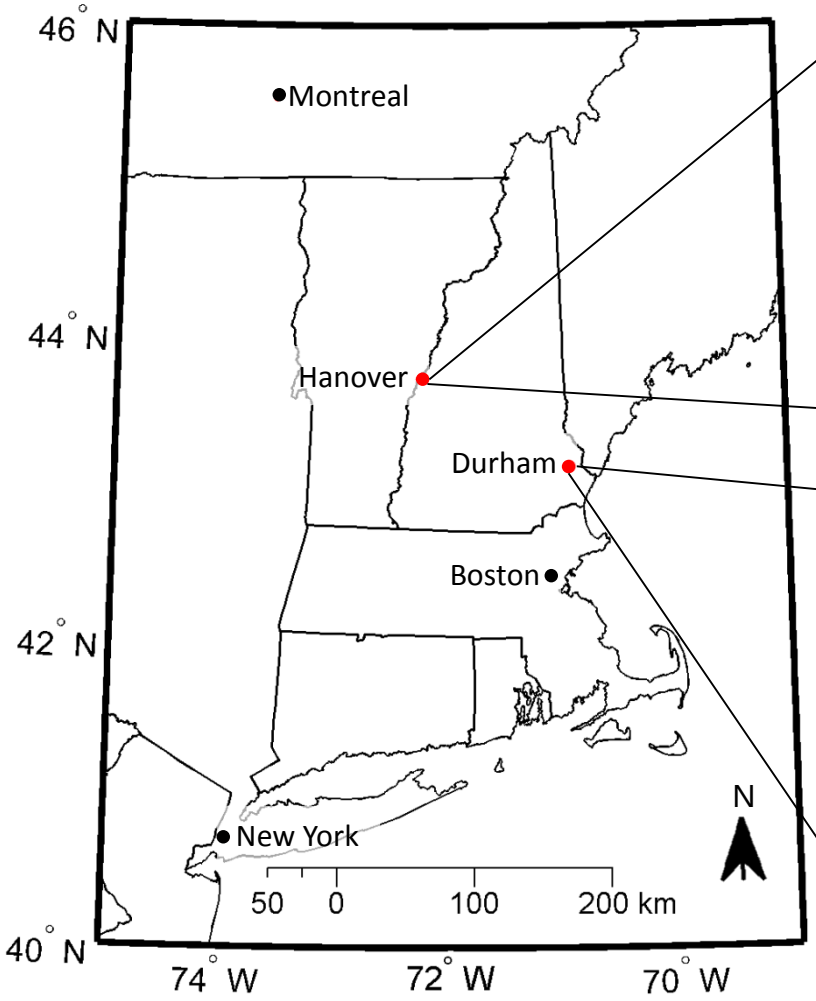
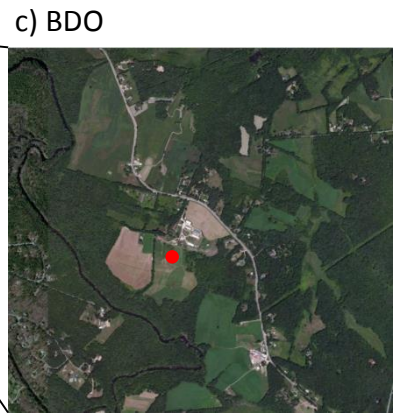
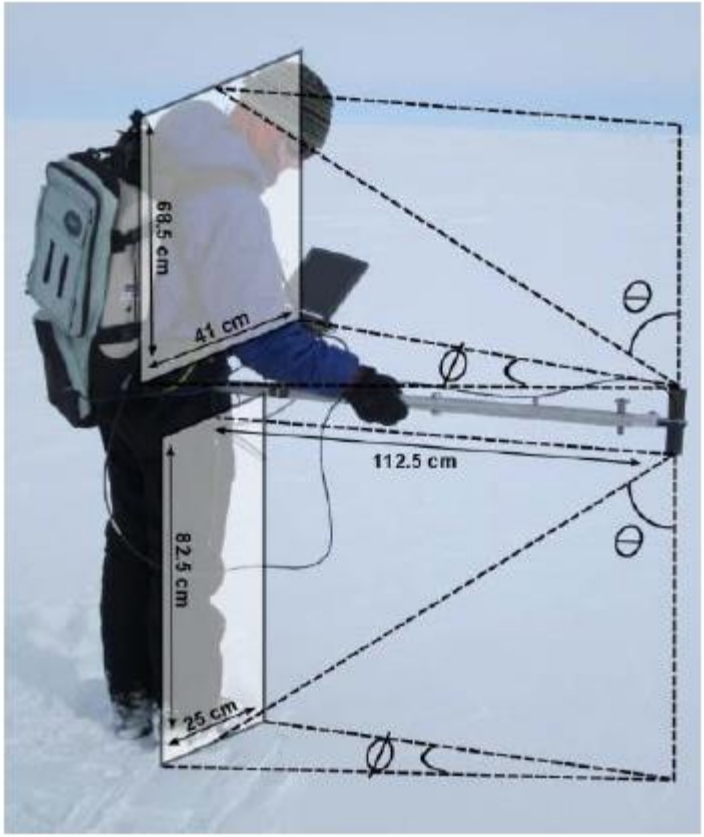
Measurement Sites 2013-2016





Daily Wintertime Measurements

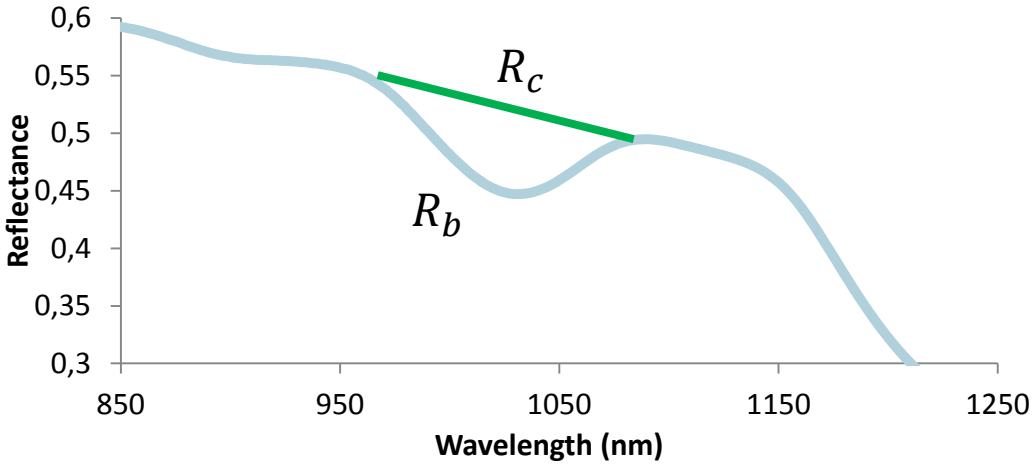
- Spectral Albedo
  - FieldSpec4 Standard Resolution
- Measurements with Depth:
  - Optical Grain Size
  - Stratigraphy
  - Density
  - Chemistry (UNH)
    - Major ions, Black Carbon
- Weather Conditions
  - Cloud cover
  - Met. station data



From Carmagnola et al. 2013

Optical Grain Size
Contact Spectroscopy

- Developed by Nolin and Dozier (2000) for use in snow remote sensing. Adapted by Painter et al. (2007) for use in surface snow.
- Radiative transfer modeling of snow links scaled band area (A_b) to SSA.
- Validation done with comparisons to hand lens measurements.



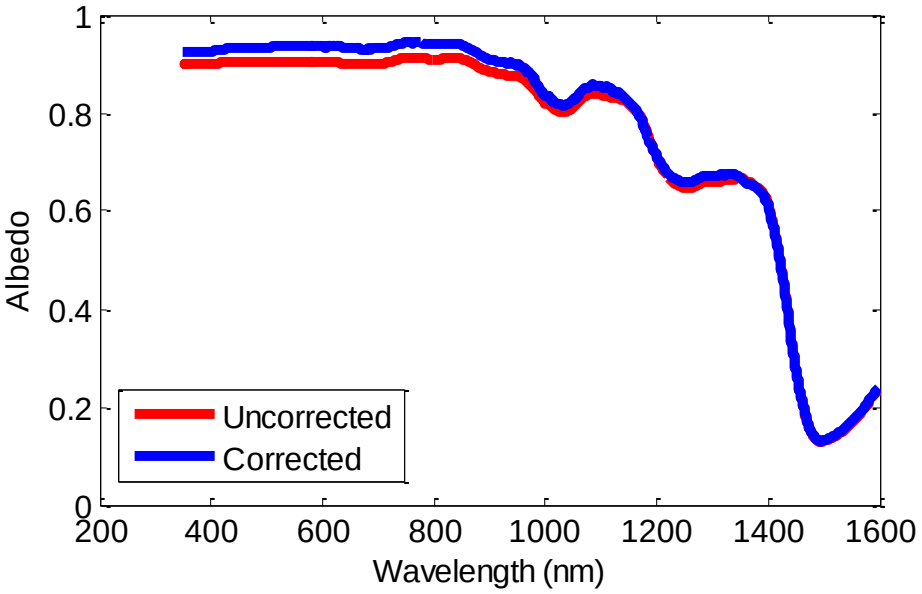
From Painter et al. 2007

Albedo Corrections
(as in Carmagnola et al. 2013)

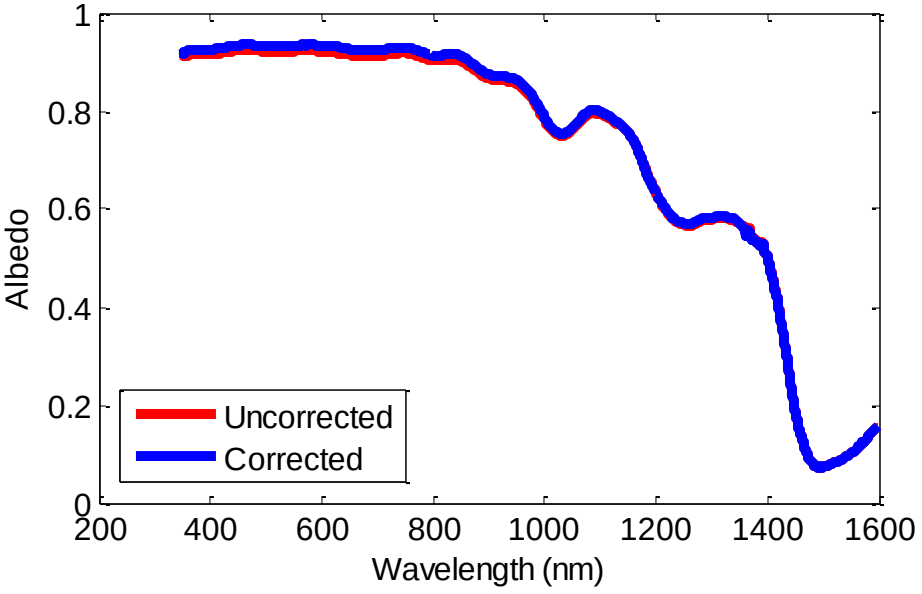
- Solar zenith angle
- Field of view obstruction
- RCR Response
- Partitioning of diffuse and direct light (approximated using Weiss and Norman [1985] formula)

$$\alpha_{\text{true\_iso},\lambda} = \frac{C_\lambda C_\uparrow F^{\uparrow}_{\lambda,\text{dif}}}{C_\lambda C_\downarrow F^{\downarrow}_{\lambda,\text{dif}} + \frac{F^{\downarrow}_{\lambda,\text{dir}}}{1+\varepsilon_\lambda(\theta)}}.$$

Sunny Day – Feb 5

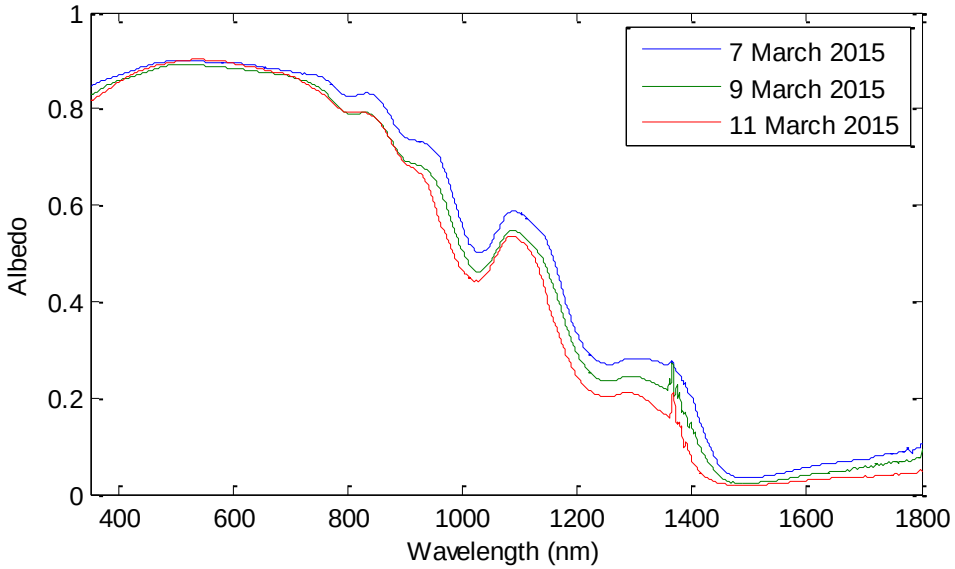


Cloudy Day – Feb 6



Albedo Measurements

Spectral Albedo



Wavelength-integrated albedo

$$\alpha_b = \frac{\int_{350}^{1850} \alpha(\lambda) F_{\downarrow}(\lambda) d\lambda}{\int_{350}^{1850} F_{\downarrow}(\lambda) d\lambda}$$

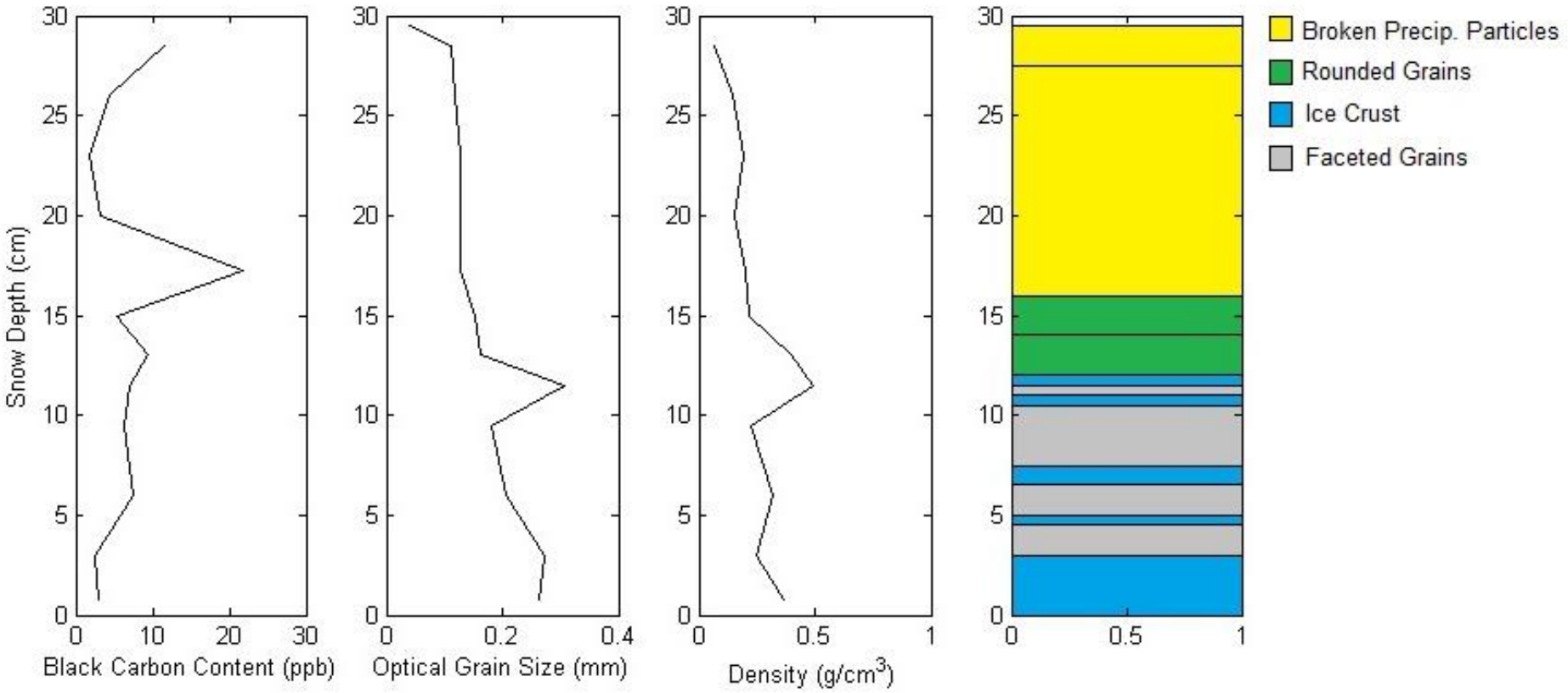
Where $\alpha(\lambda)$ is albedo and $F_{\downarrow}(\lambda)$ is incoming solar irradiance

Limits of integration for

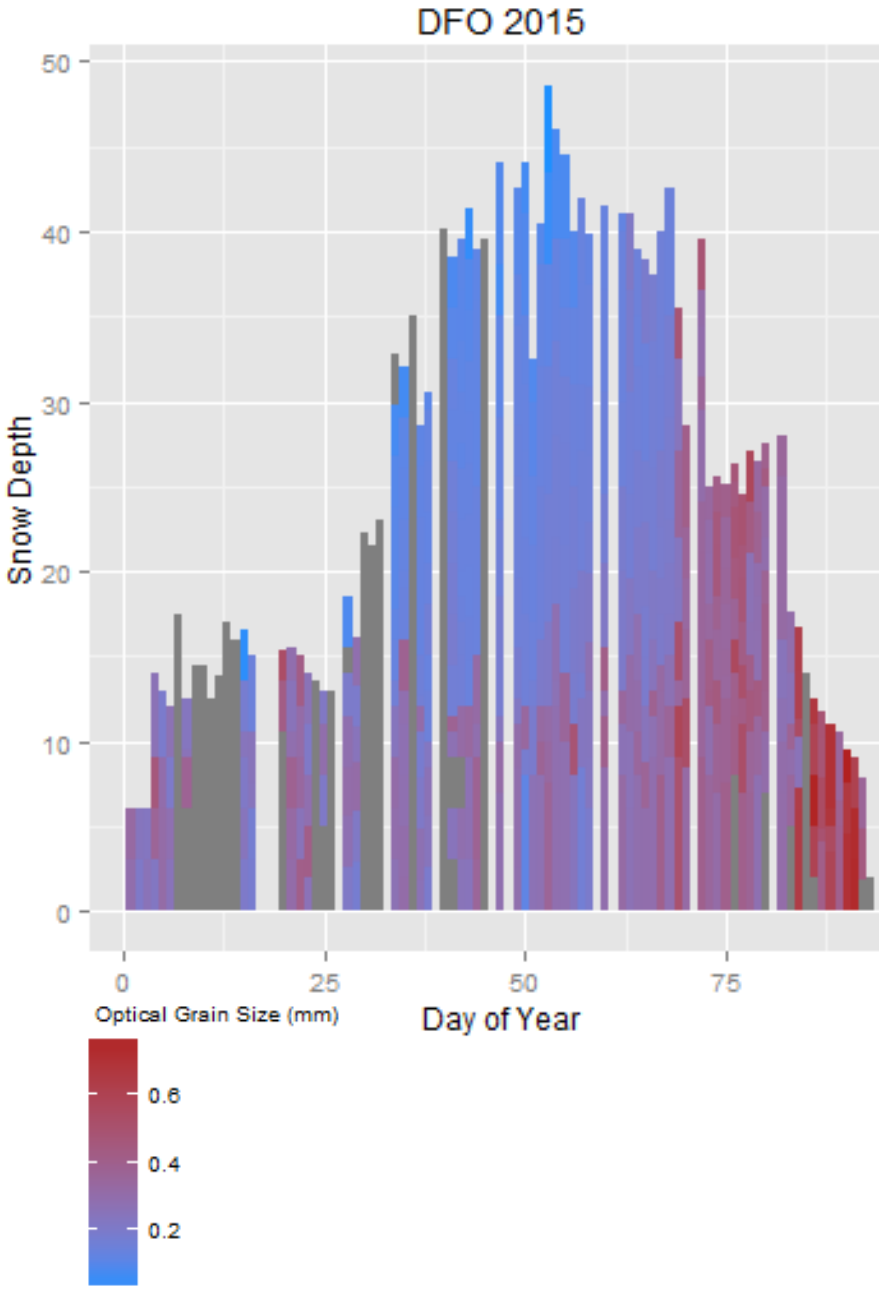
Visible: 350-750 nm

NIR: 750-1850 nm

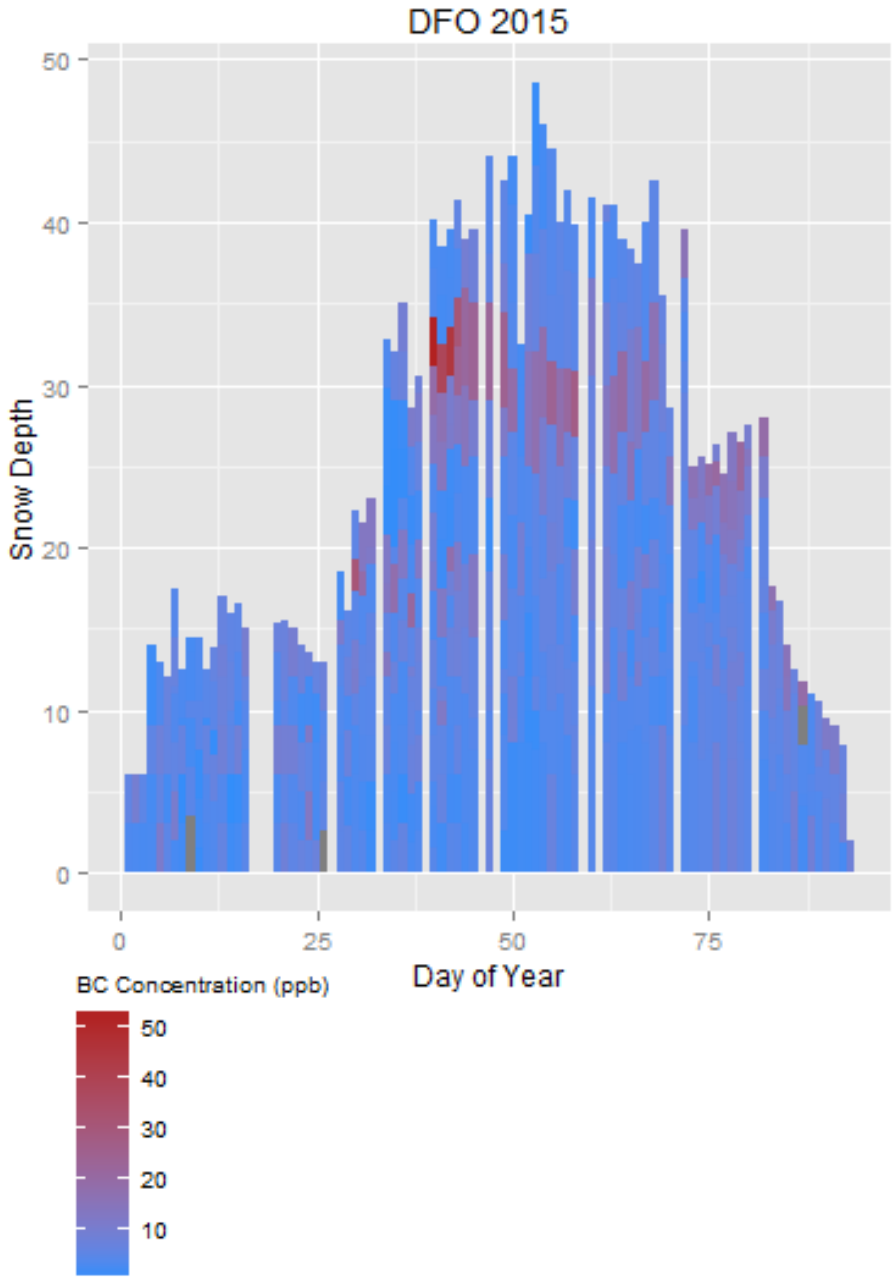
Example of Snowpack Properties

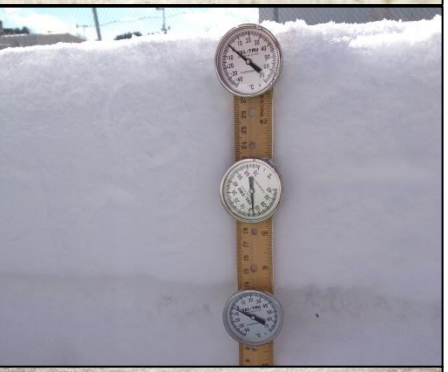


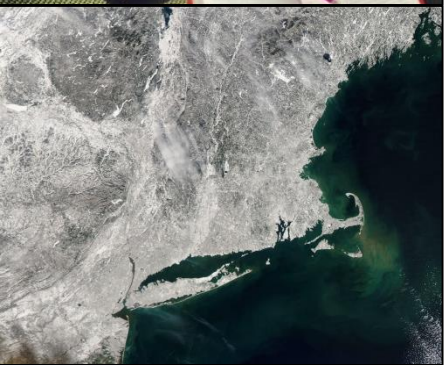
Optical Grain Diameter (mm)



Black Carbon Content (ppb)







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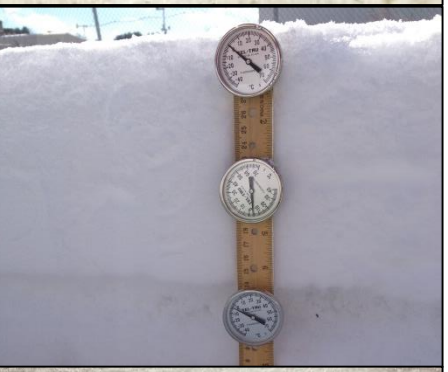
Albedo Spatial Variability

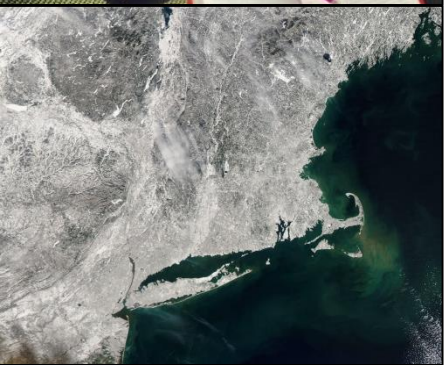
- Average standard deviation of 2.1% in gridded surveys over 20 m x 20 m

Date	Broadband Albedo		# of observations	Sky Conditions
	Mean	Standard Deviation		
7-Feb 2015	0.812	0.028	75	Partly Cloudy
5-Mar 2015	0.779	0.008	27	Overcast
13-Mar 2015	0.683	0.013	27	Partly Cloudy

Albedo Measurement Variability

- 5 repeat measurements each day with total of 366 days of measurements
- **Median standard deviation of 0.007 in Visible and NIR regions of spectrum**
- Passing clouds are largest source of error
- No detectable sensitivity to temperature or to fraction of direct light





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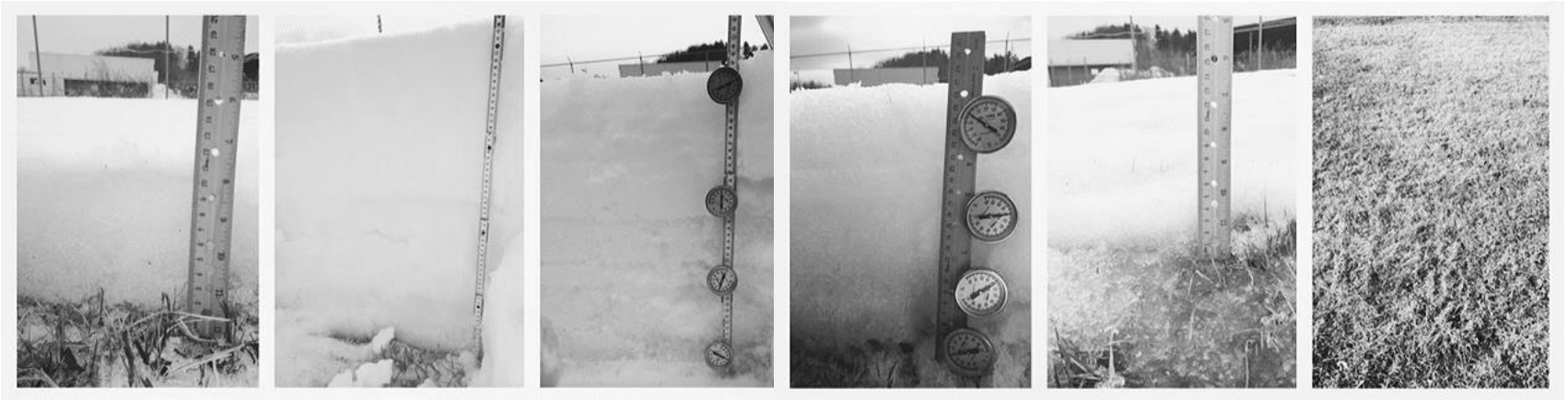
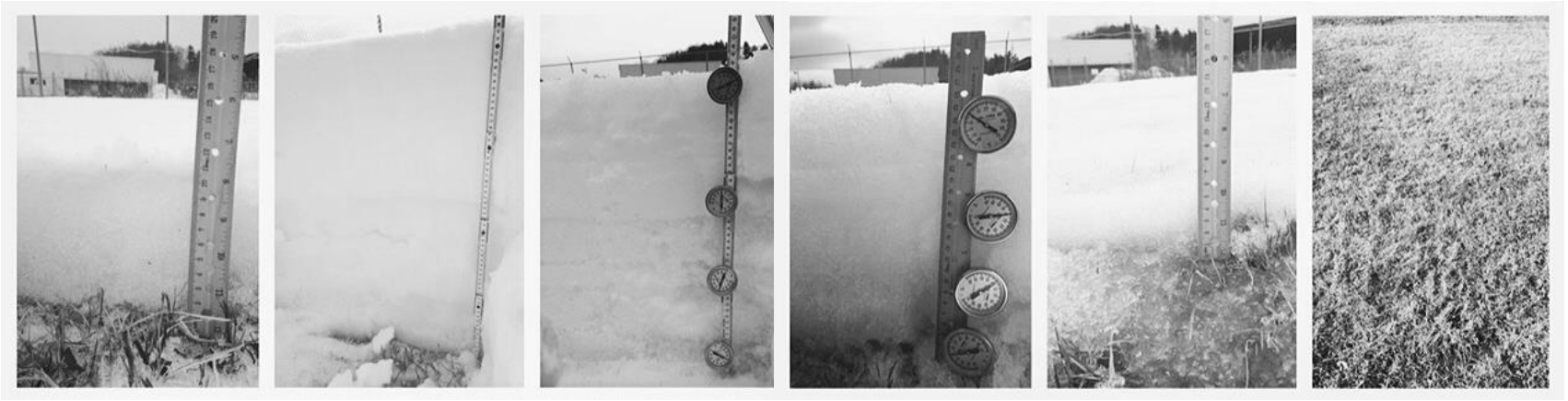


SNOW ALBEDO

- How do storm trajectories impact the impurity loading in snow and the resulting snow albedo?
- What are the dominant physical controls on snow albedo in New Hampshire?



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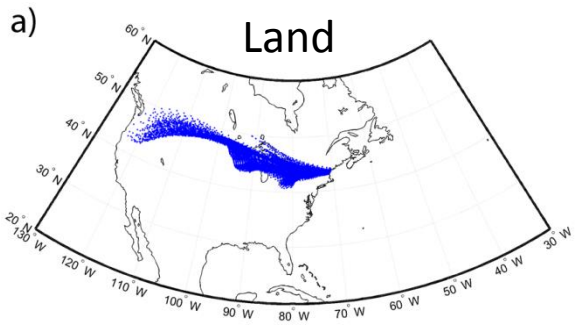
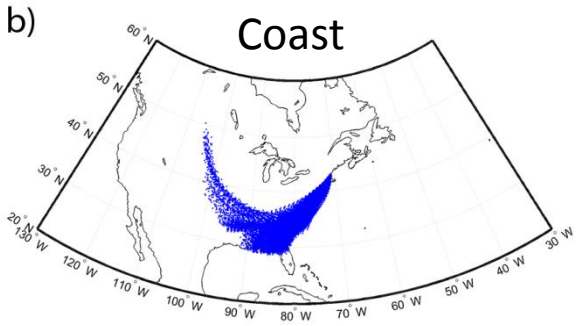
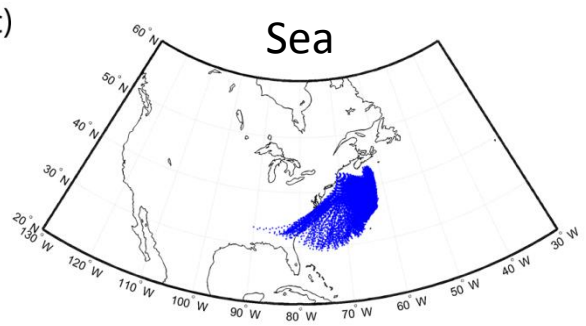
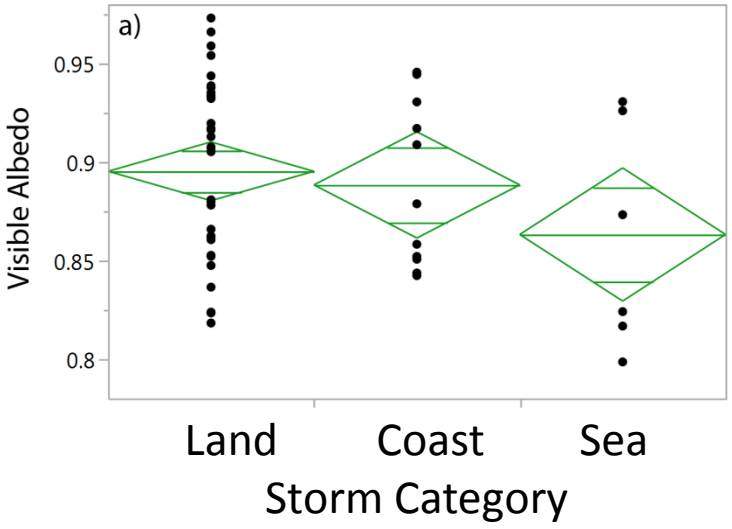
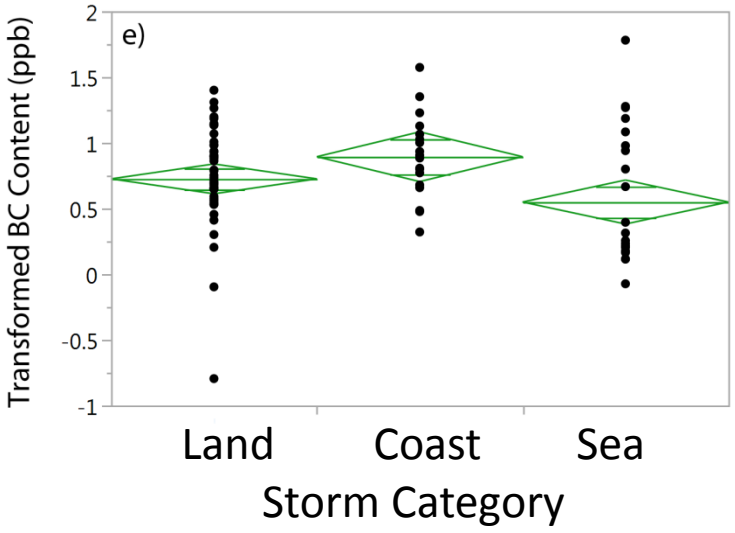
Storm trajectories impact black carbon content, but overall very low quantities.
Only marginal impact on resulting snow albedo

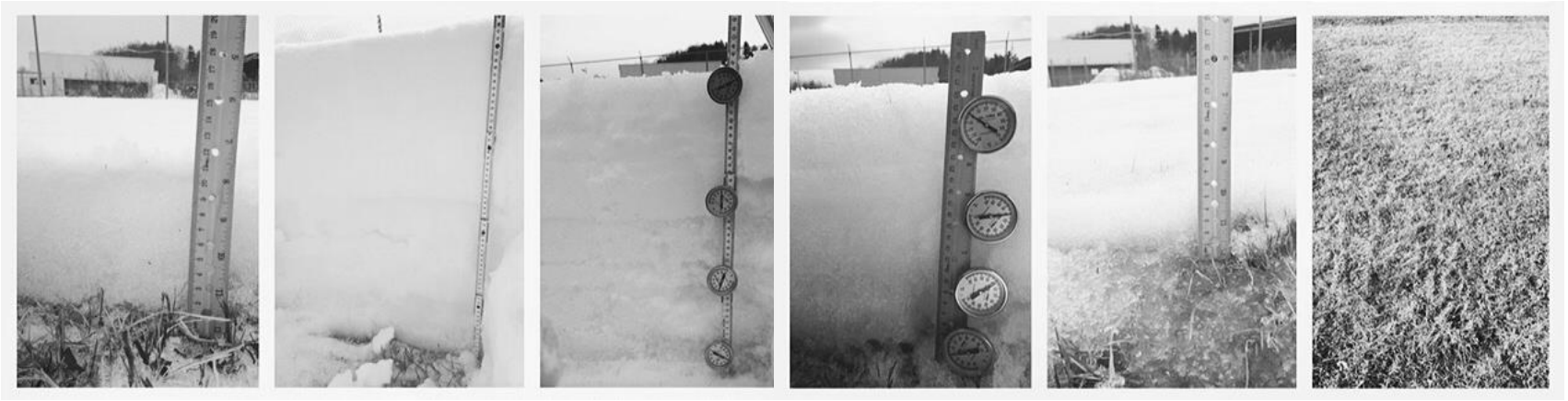












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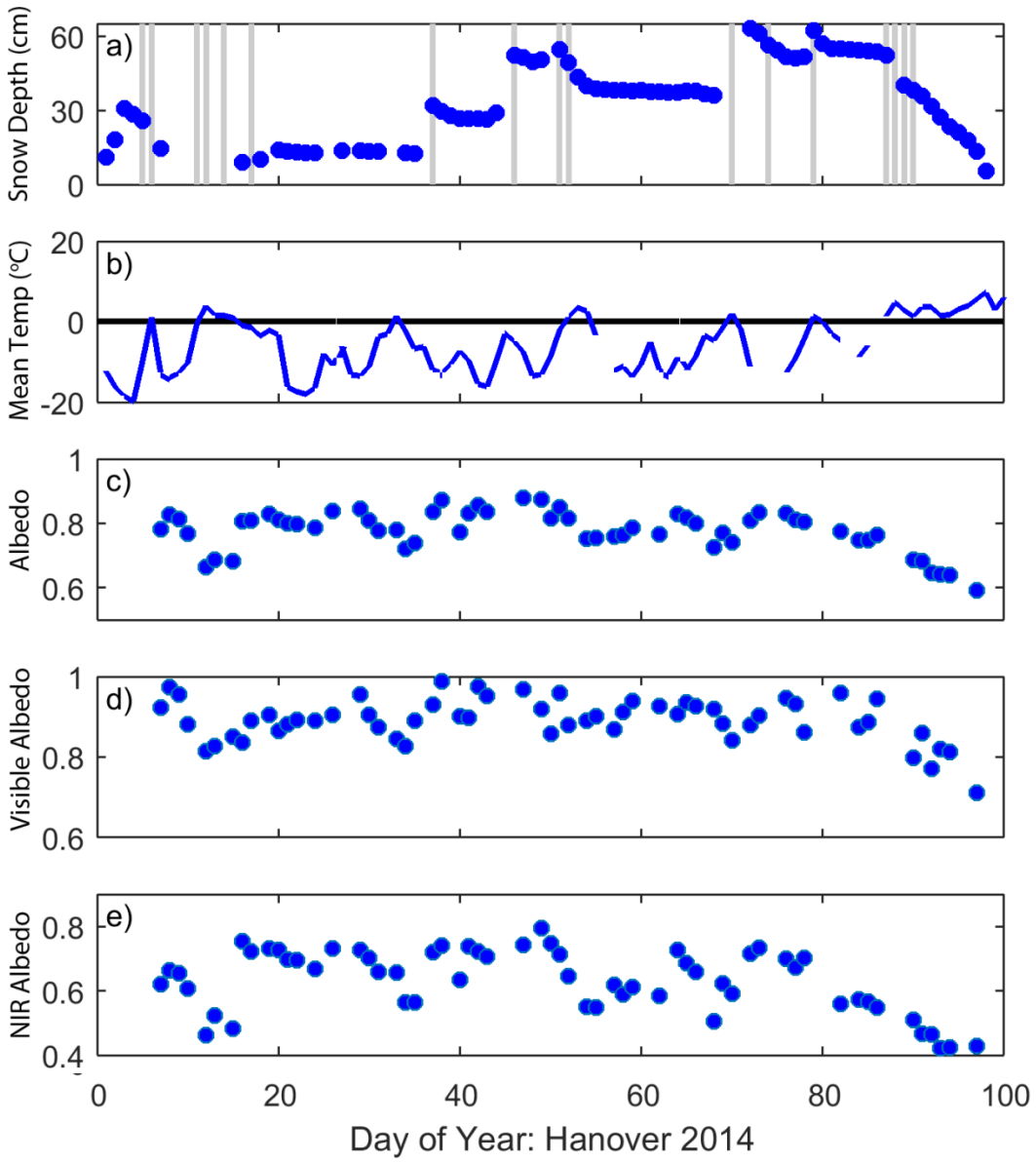
Albedo Evolution: 2014



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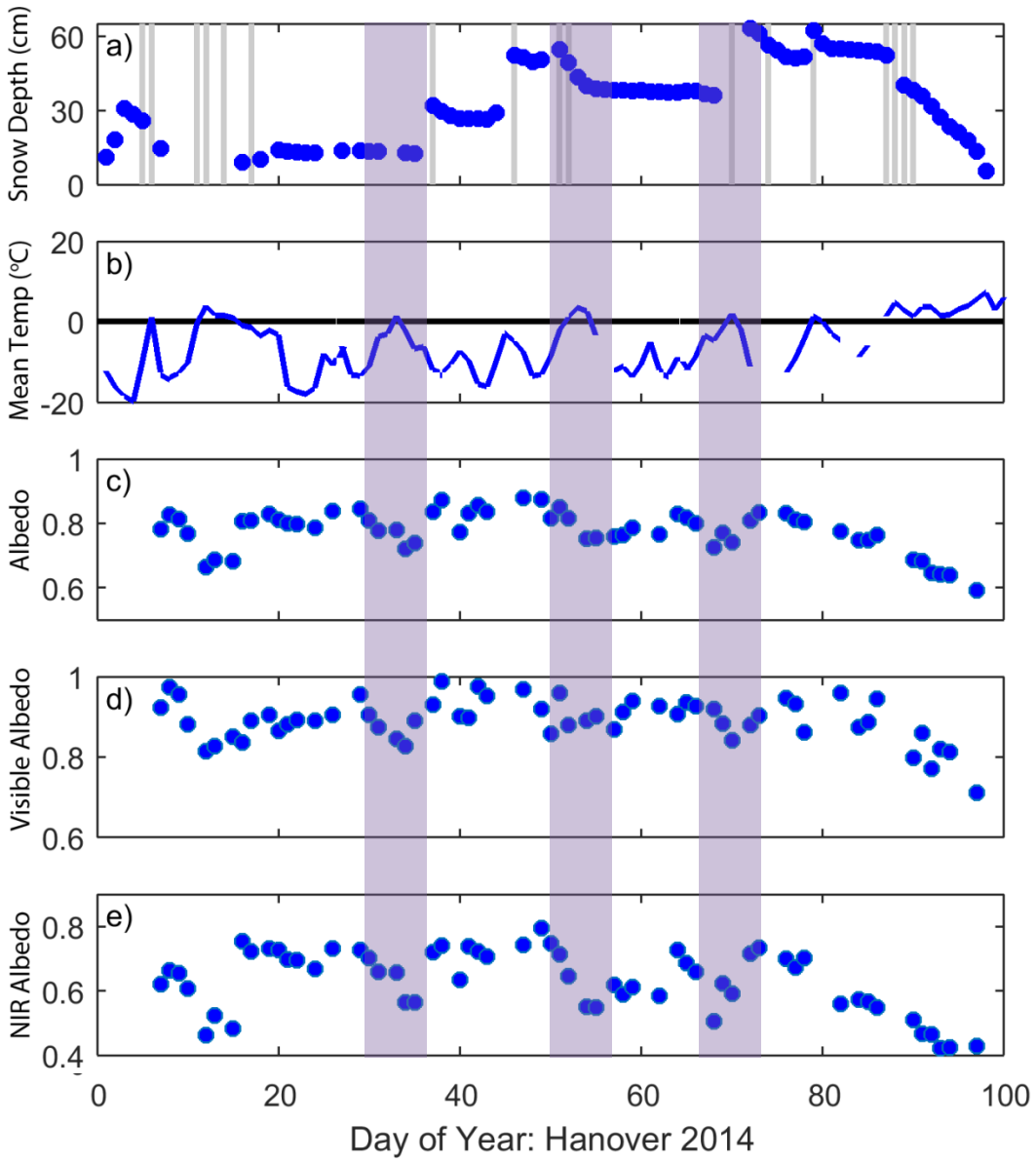
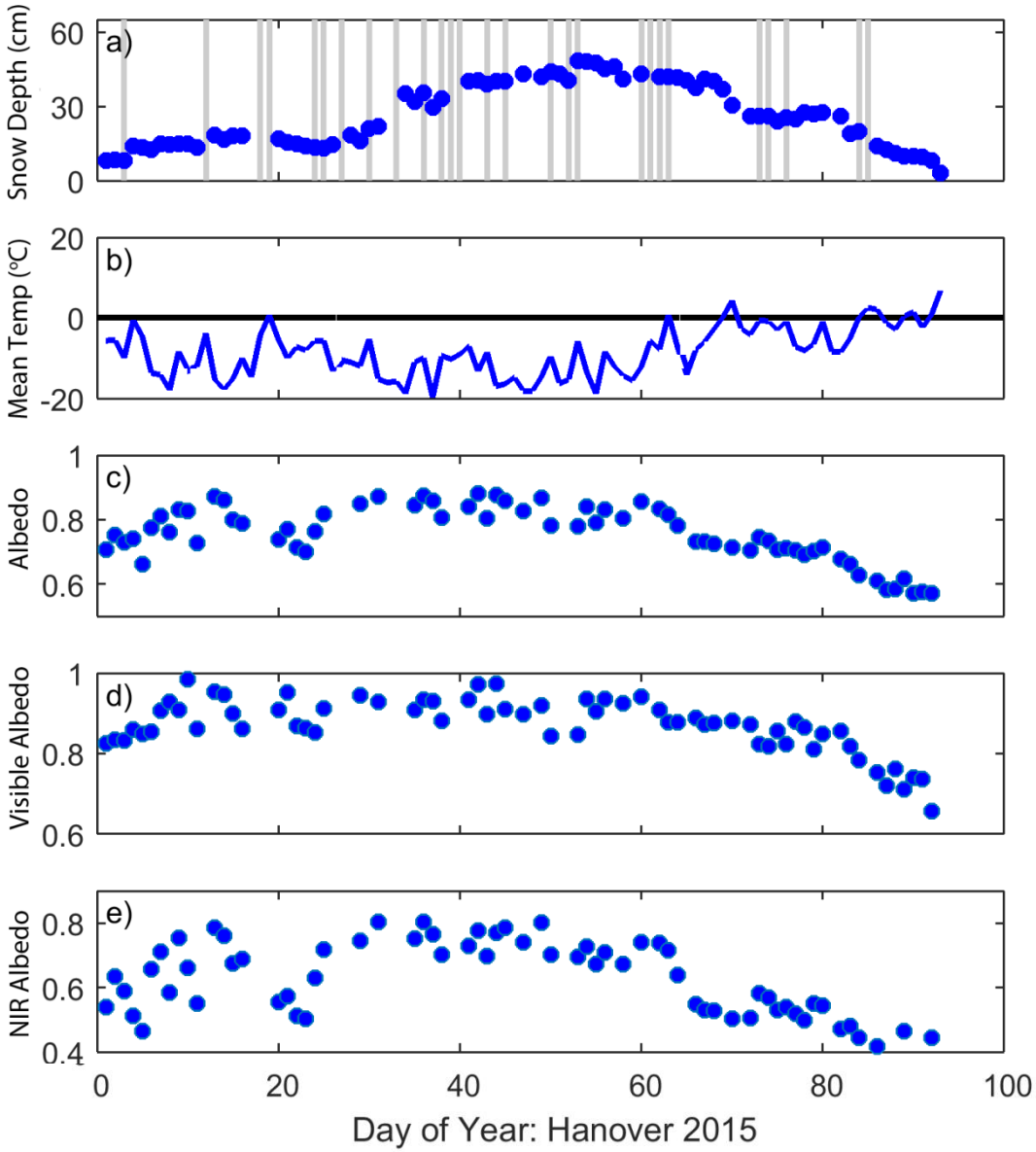
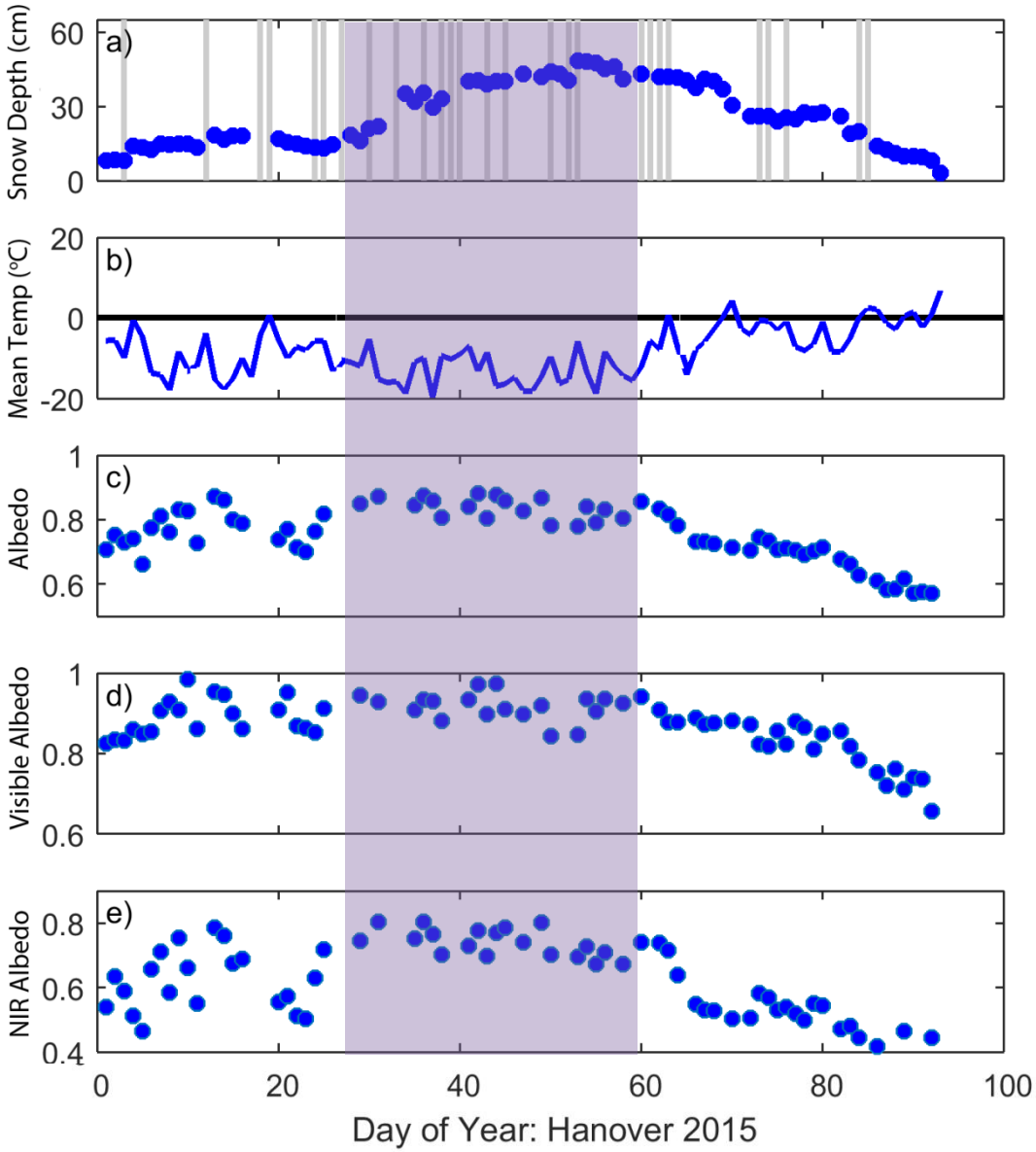


Albedo Evolution: 2015

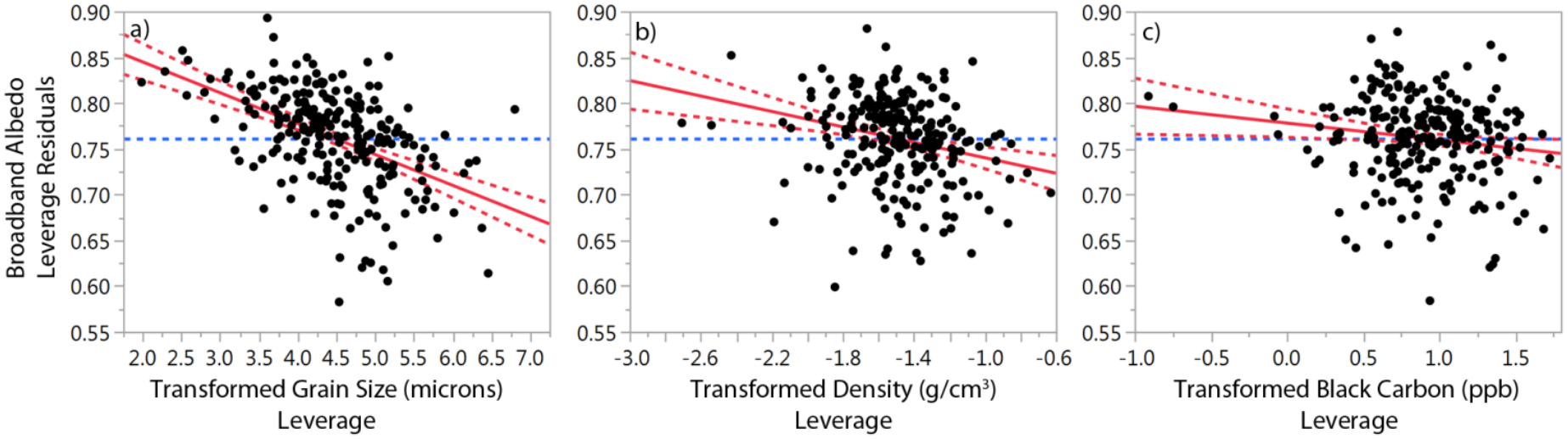


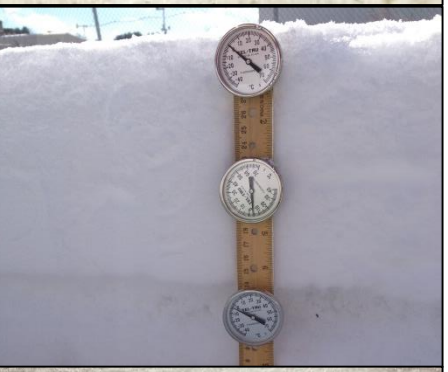
Albedo Evolution: 2015

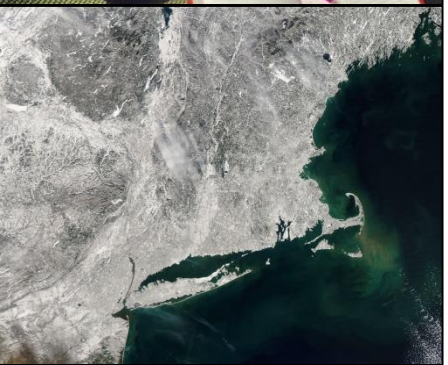


Grain size dominates variability in snow albedo in all ranges of the solar spectrum.

Percent of albedo variance explained by each variable in a multiple linear regression			
	Broadband	**Visible**	**NIR**
Transformed Grain Size (µm)	45%	15%	54%
Transformed Black Carbon Content (ppb)	3.2%	9%	0.6%
Transformed Density (g/cm³)	10%	1%	16%





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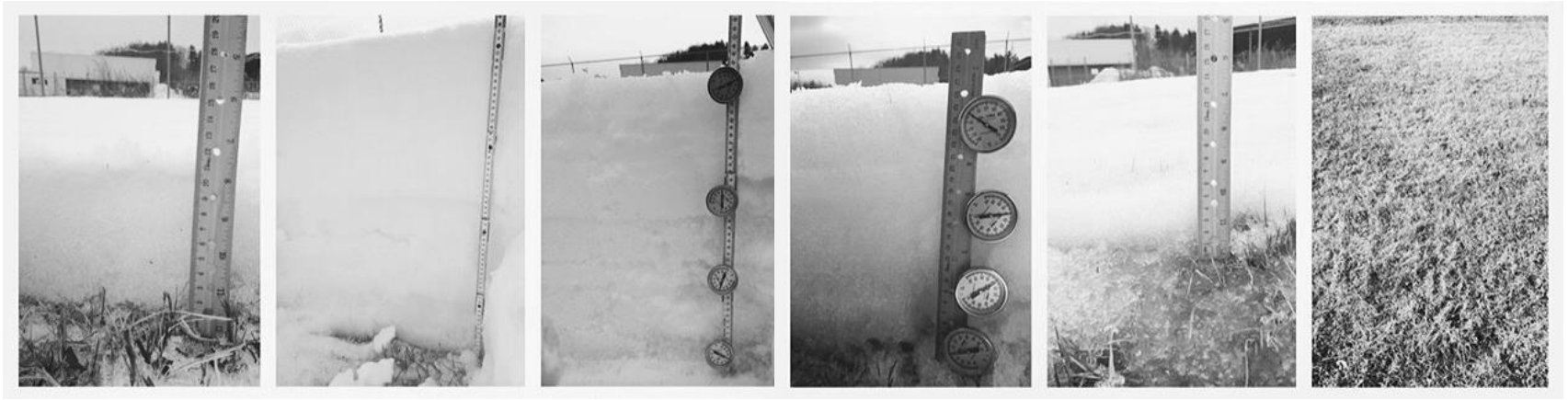
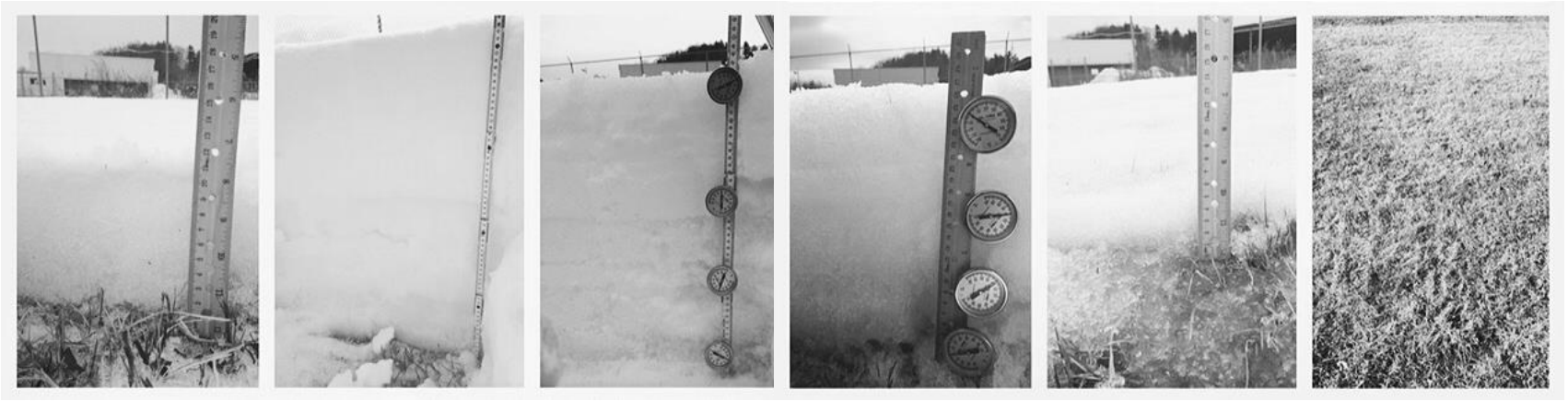


CONCLUSIONS

- DATA SET: We have collected a unique spectral albedo dataset with paired snow property measurements in northeastern USA
- UNCERTAINTY: Spatial variability of the snow is estimated at 2% standard deviation in broadband albedo. Repeat measurements indicate standard deviation of 0.007 in broadband albedo.
- RESULTS: Storm path impacts snow properties in northeastern USA, but only marginally impacts albedo. Changes in broadband albedo are driven by grain size in this region.



Thanks for your attention!

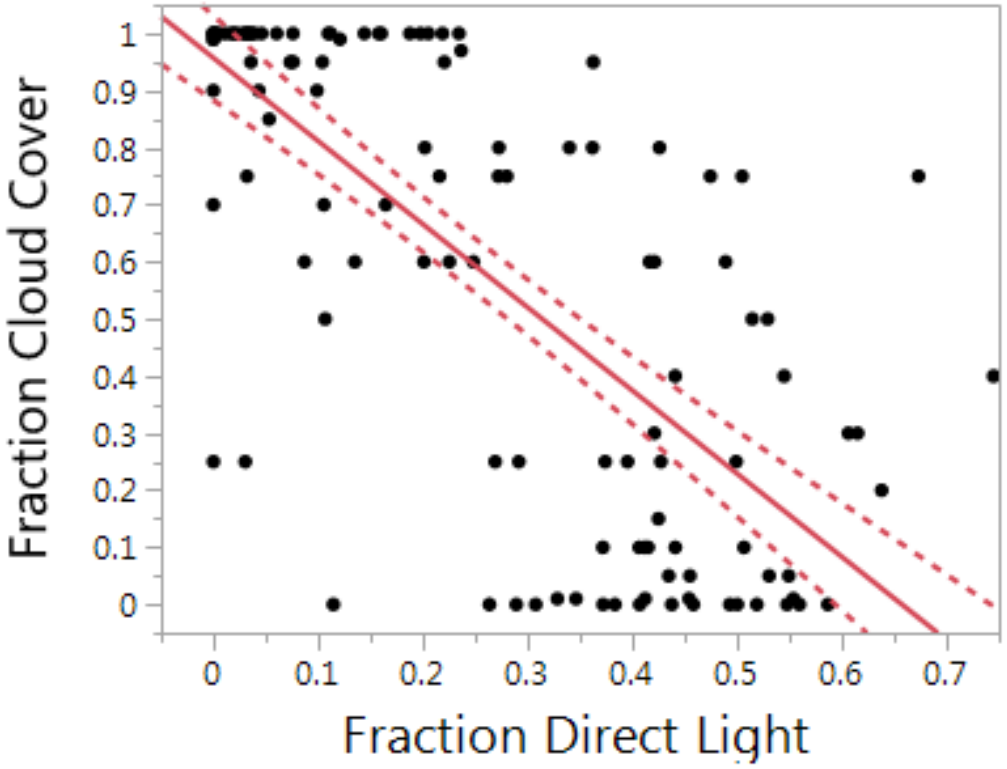
NSF Graduate Research Fellowship
NSF IGERT Fellowship
NSF NH EPSCoR – Ecosystems and Society
NSF PIRE – Ice Core Research

Jack Dibb, James Lazarcik, Jacki Amante, Cameron Wake, Liz Burakowski

Don Perovich, Zoe Courville, Arnold Song, Mike Reynolds, Karen Foley

Thayer School Marc Fragge Fellowship
Snow and Ice Lab Group; Field Assistants: Cecilia Robinson, Andrea Price, Beth Bloom, Amanda Zhou, Russel Primeau, Ross Lieb-Lappen, Ben Kopec, Ruth Heindel

Fraction Direct Light



Calculated based on empirical formula from *Weiss and Norman* [1985]
Compares favorably with fractional cloud cover observations ($R^2 = 0.58$, $p<0.0001$)

Spatial Variability

- Gridded Surveys over 20 m x 20 m grids

	7-Feb 2015 Partly Cloudy n = 75		5-Mar 2015 Overcast n = 27		13-Mar 2015 Partly Cloudy n = 27		All Dates
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Average % Deviation
Broadband	0.812	0.028	0.779	0.008	0.683	0.013	**2.1%**
Visible	0.893	0.026	0.881	0.008	0.832	0.014	**1.8%**
Near Infrared	0.706	0.031	0.626	0.008	0.495	0.012	**2.7%**

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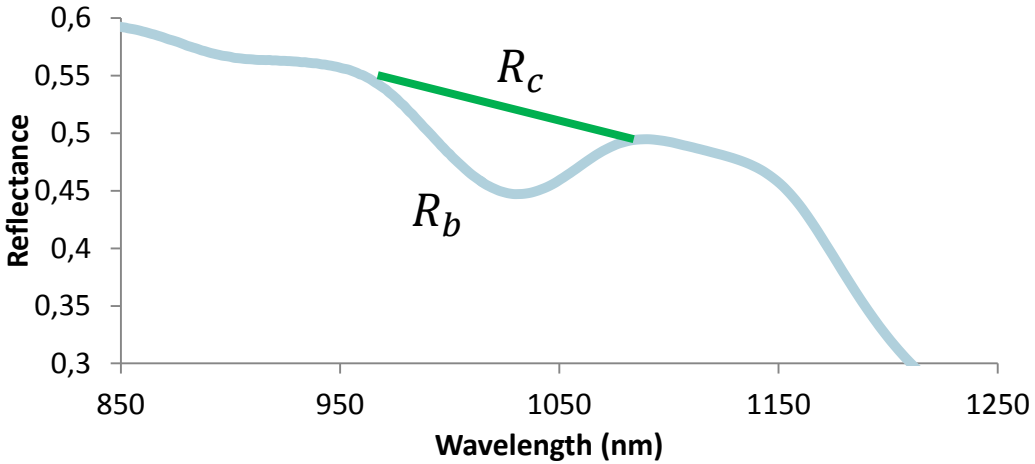

$$A_b = \sum_{\lambda=950nm}^{1090nm} \frac{R_{\lambda,c} - R_{\lambda,b}}{R_{\lambda,c}}$$

From Painter et al. 2007