Modeled response of Greenland snowmelt to the presence of biomass burning-based absorbing aerosols

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Introduction

- Black carbon (BC): aerosol produced by the incomplete combustion of biomass, biofuels, and fossil fuels.
- BC is highly efficient at absorbing visible radiation.
- Radiative impacts of BC are very pronounced in the high albedo Arctic environment.

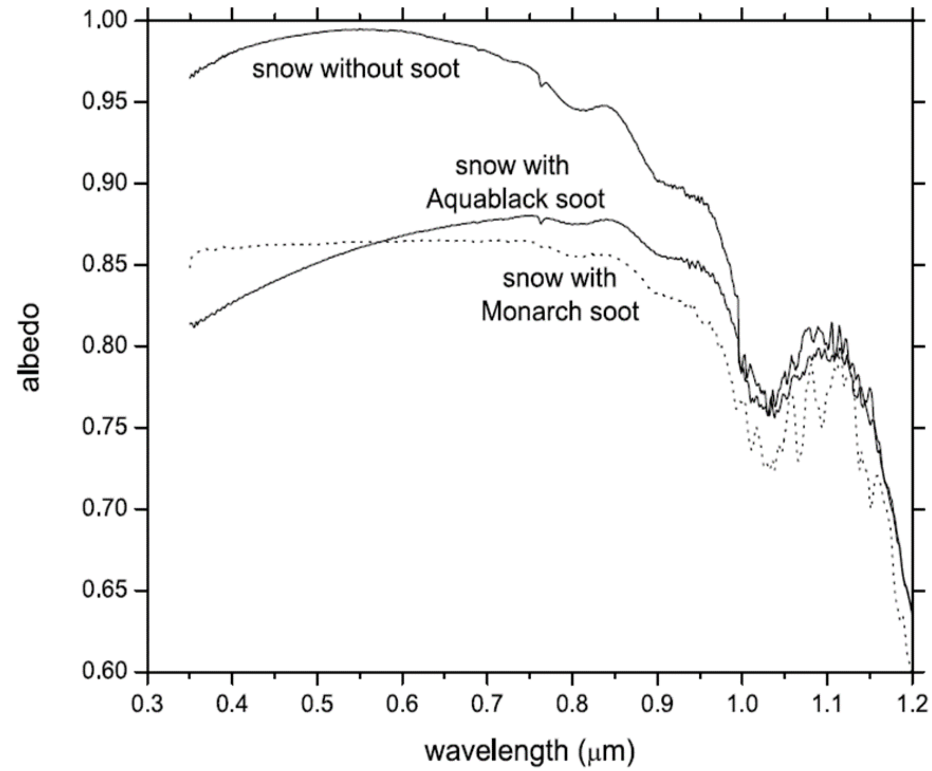

Fig. 1: Deposited BC impacts on snow albedo
(Brandt et al., 2011)

Introduction

- Greenland Ice Sheet (GrIS): largest ice sheet in the northern hemisphere.
  - Entire GrIS melt→~7.4 meters of sea level rise (Hanna et al., 2008).
- GrIS is a perennial, high albedo surface.
- July 2012: >97% of the GrIS (Fig. 1) experienced snowmelt (Nghiem et al., 2012).
- Enhanced biomass burning BC burden in GrIS snow (Keegan et al., 2014).

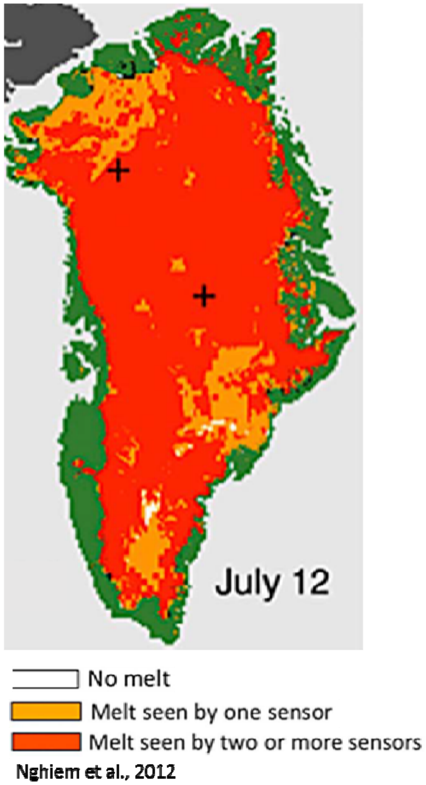

Fig. 2: GrIS melt, July 2012

Science Questions

- What are the relative snowmelt and net surface energy flux effects of suspended and in-snow LAAs?
- For a constant atmospheric LAA burden, to what extent does varying single-scattering albedo (SSA) affect Greenland's climate?
- When we simultaneously perturb atmospheric and deposited LAAs, are the associated climate effects additive?

Methods: Model Specifications

- CESM 1.0.3
  - Spatial Resolution: 1.9°×2.5°
  - Monthly output over 11 years (first year discarded for spin-up)
  - Active, coupled CAM and CLM
  - Prescribed SSTs and sea ice
  - Surface aerosol radiative treatment: Snow and Ice Aerosol Radiation Model (SNICAR) (Flanner and Zender, 2005).
  - Dust are aerosols represented using the Bulk Aerosol Module (BAM).
  - Prescribed 3D aerosols outside of the Greenland region.

Methods: Greenland-specific setup

- Greenland (Fig. 3): 60-80°N, 20-60°W.
- Greenland Cases (18 total):
  1. Atmospheric LAAs only ("AOD-only", constant SSA=0.93).
  2. In-snow BC and dust only ("IN-SNOW").
  3. Atmospheric and deposited LAAs ("BOTH").
  4. Changing SSA ("SSA", constant AOD=0.50).

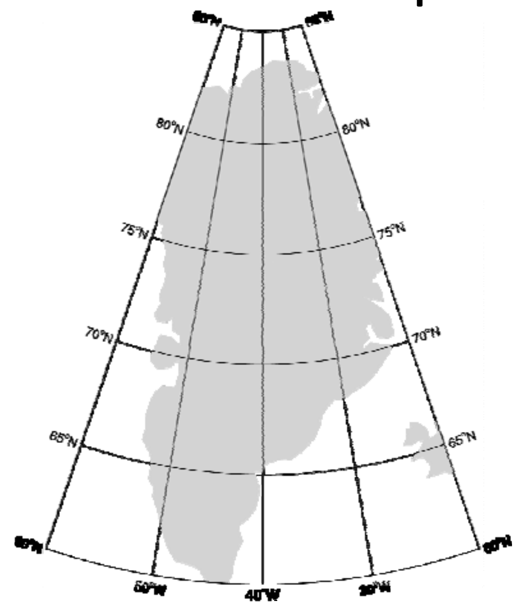

Fig. 3: The area over which aerosol perturbations are imposed for each variable simulation

AOD	0.09	0.21	0.50	0.75	1.0
BCE (ng/g)	2.72	15.73	61.84	92.76	123.68
SSA	0.90	0.93	0.96	--	--

Strellis et al., 2013

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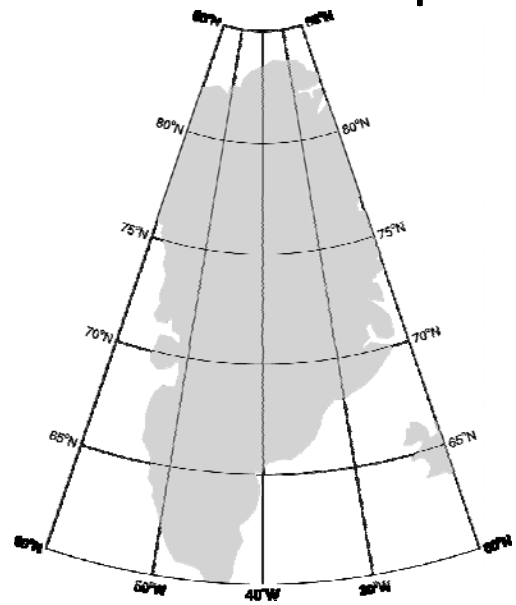

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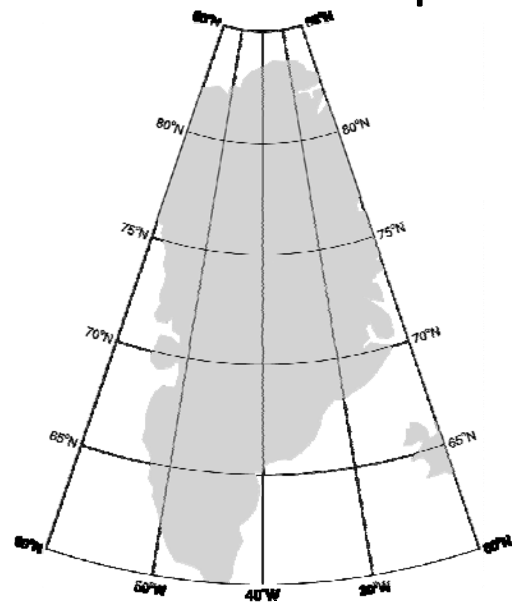

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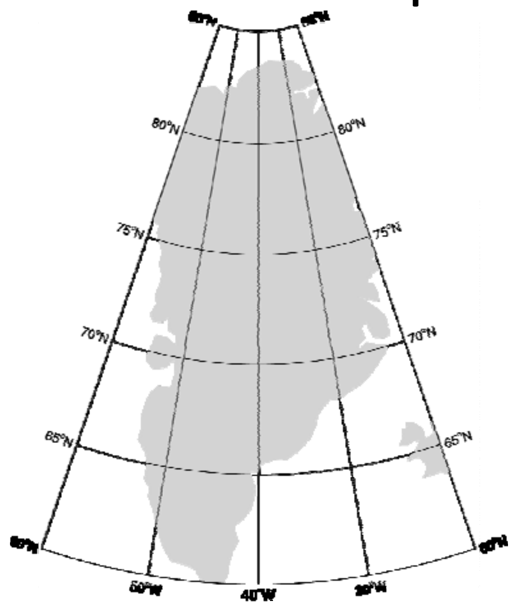

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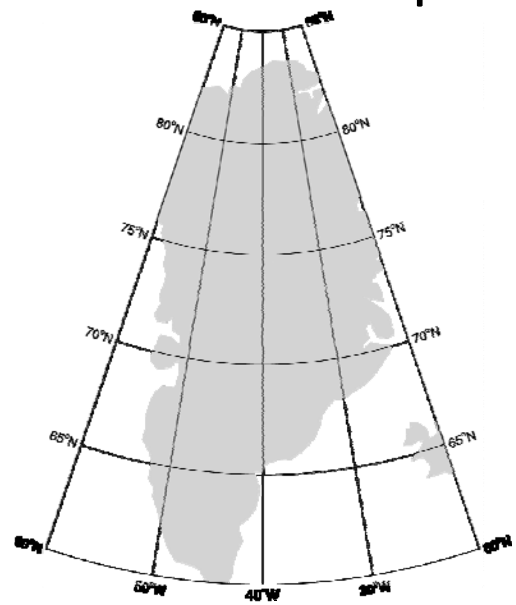

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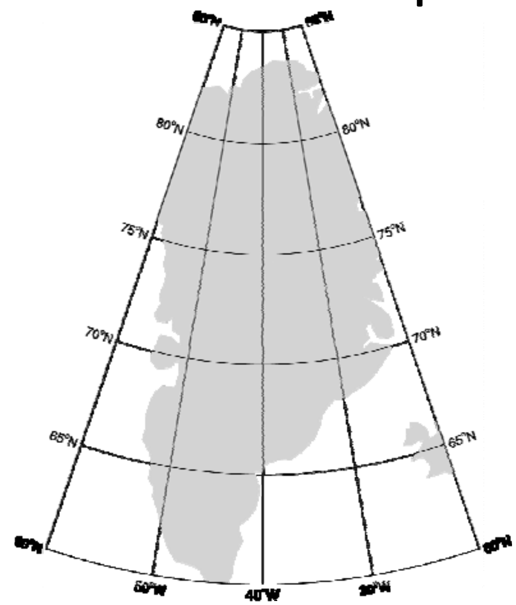

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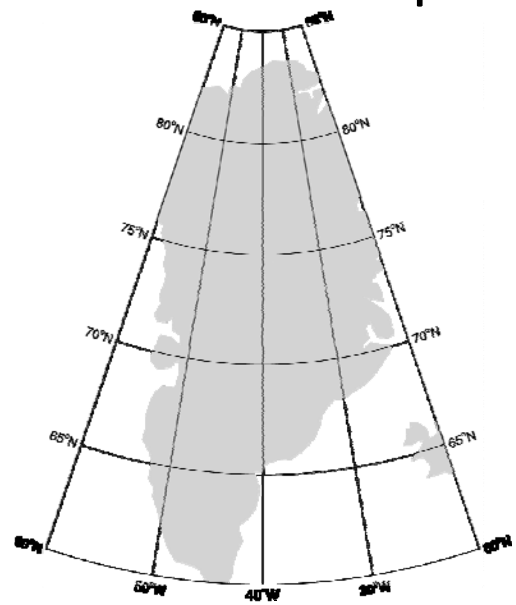

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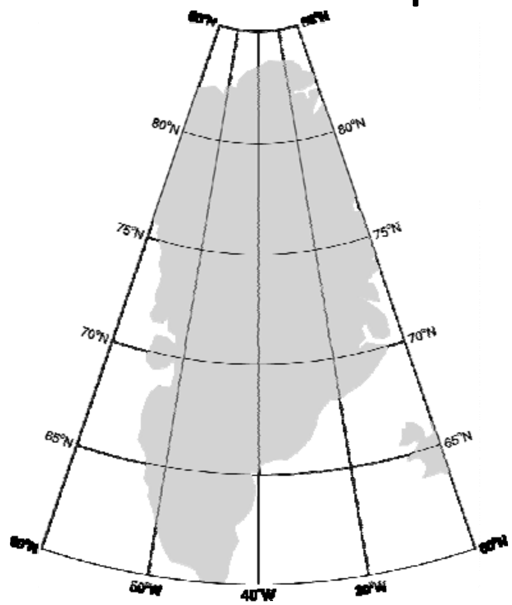

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Methods

- Compare each of these runs to a control run (CONTROL)
  - AOD=0.0; BCE=0.0ng/g
- For each variable of interest, determine the impact of the aerosol load for a given case by

$$\Delta Variable = Variable_{case} - Variable_{CONTROL}$$

- Difference maps, two-sample t-test (grid-by-grid and spatially-averaged).

Results: Snowmelt (ΔM)

- No significant ΔM in the AOD-only and SSA runs.
  - Surface dimming and tropospheric warming offset.
- IN-SNOW and BOTH experiments: larger ΔM signal.
  - “In-snow” direct aerosol effect.

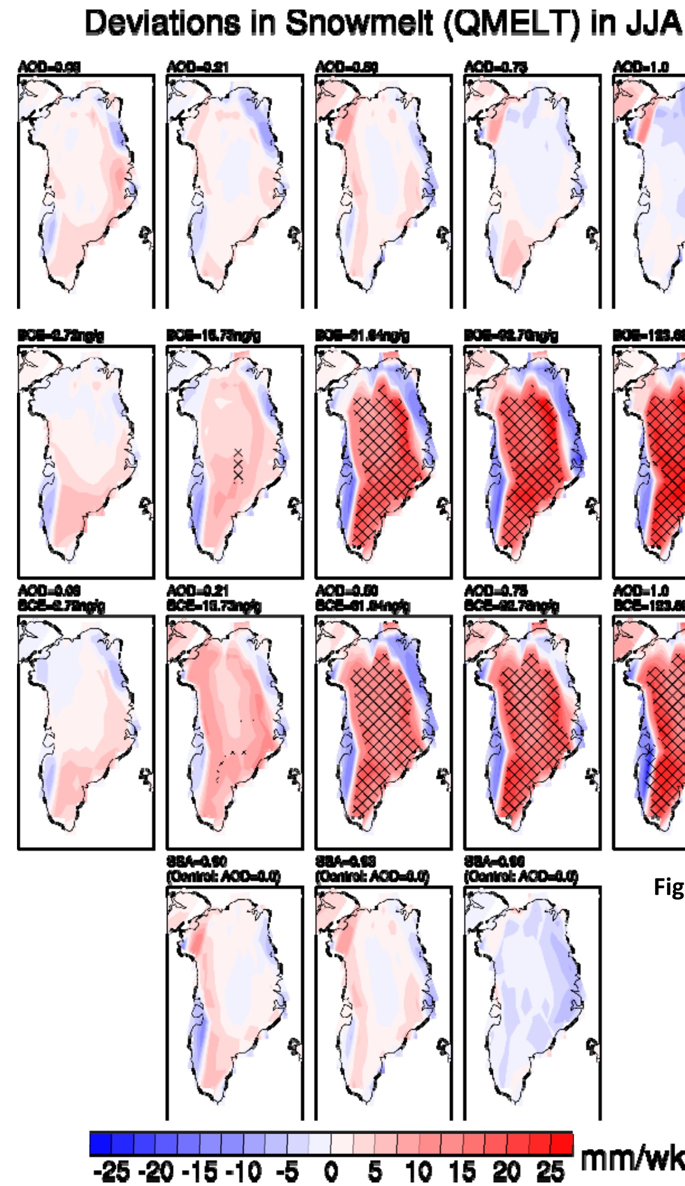

Fig. 4: Spatial ΔM plots

Results: Snowmelt and Net Surface Energy (ΔF_{TOT})

- $\Delta F_{TOT} = \Delta FSNS - \Delta FLNS - \Delta SHFLX - \Delta LHFLX$
- Spatially-averaged ΔF_{TOT} patterns are similar to snowmelt change.

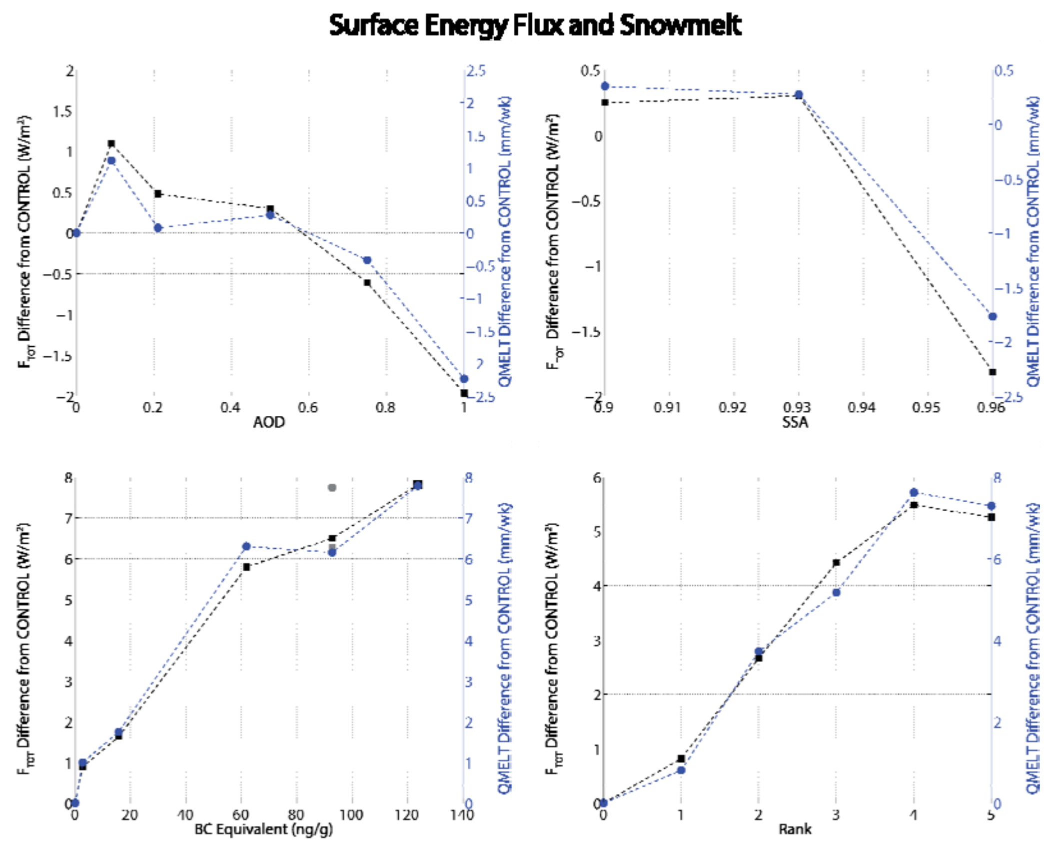

Fig. 5: Surface energy flux (ΔF_{TOT}) and snowmelt changes.

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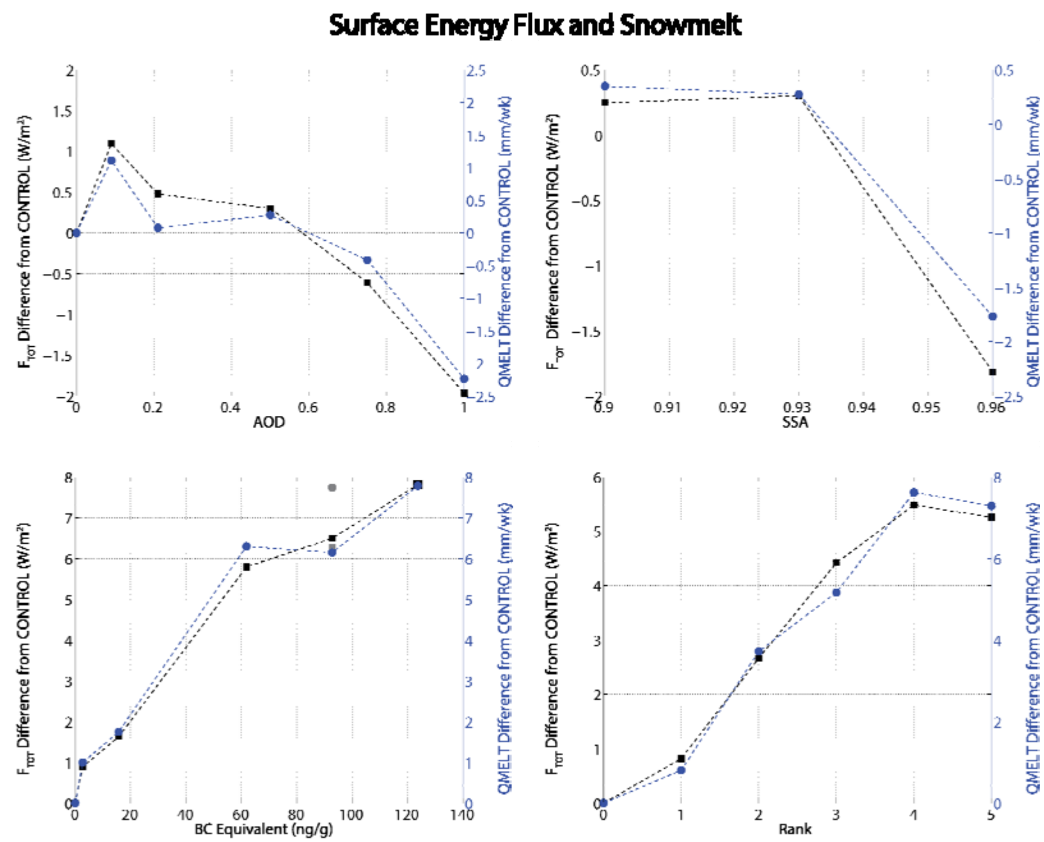

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⟹Surface energy input is the main influence on GrIS snowmelt.

- How do the energy components of net surface energy change for each aerosol experiment?

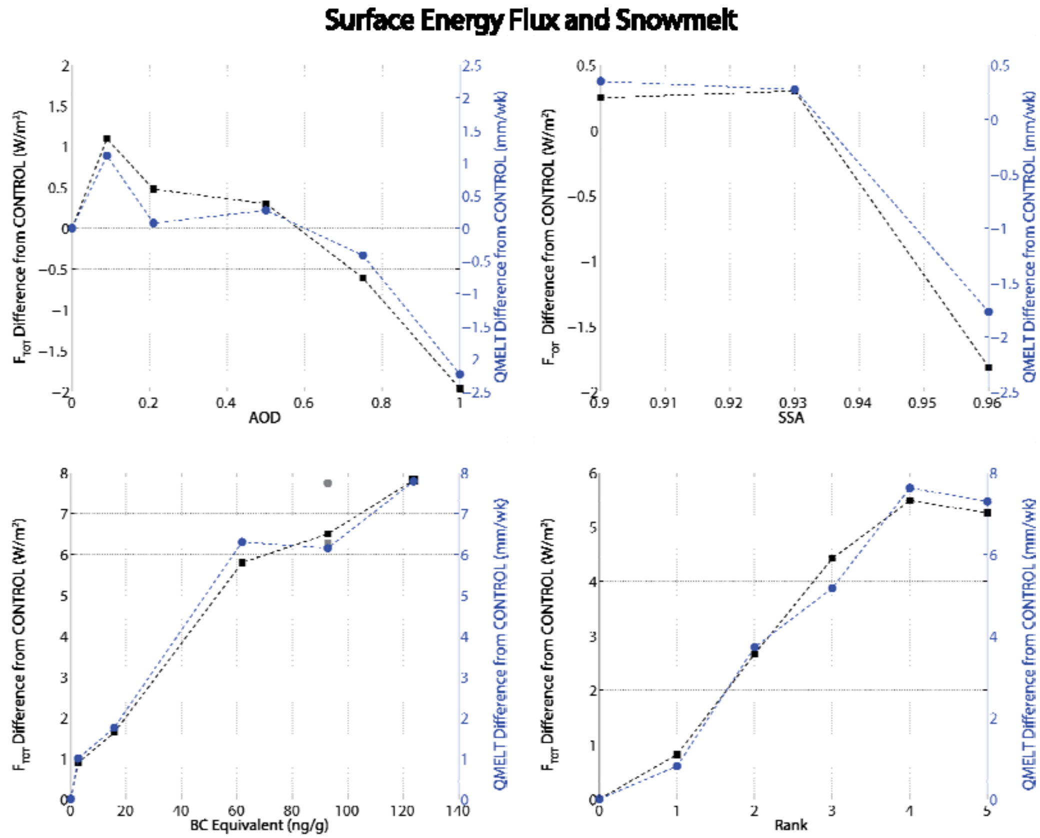

Fig. 5: Surface energy flux (ΔF_{TOT}) and snowmelt changes.

Results: Net Surface Energy Components

- $\Delta FSNS < 0$ for AOD-only* and SSA
- $\Delta FSNS > 0$ for IN-SNOW and BOTH.
    - $*AOD = 0.09, 0.21$ cases: $\Delta FSNS > 0$ because of cloud burn-off, decreasing surface albedo.

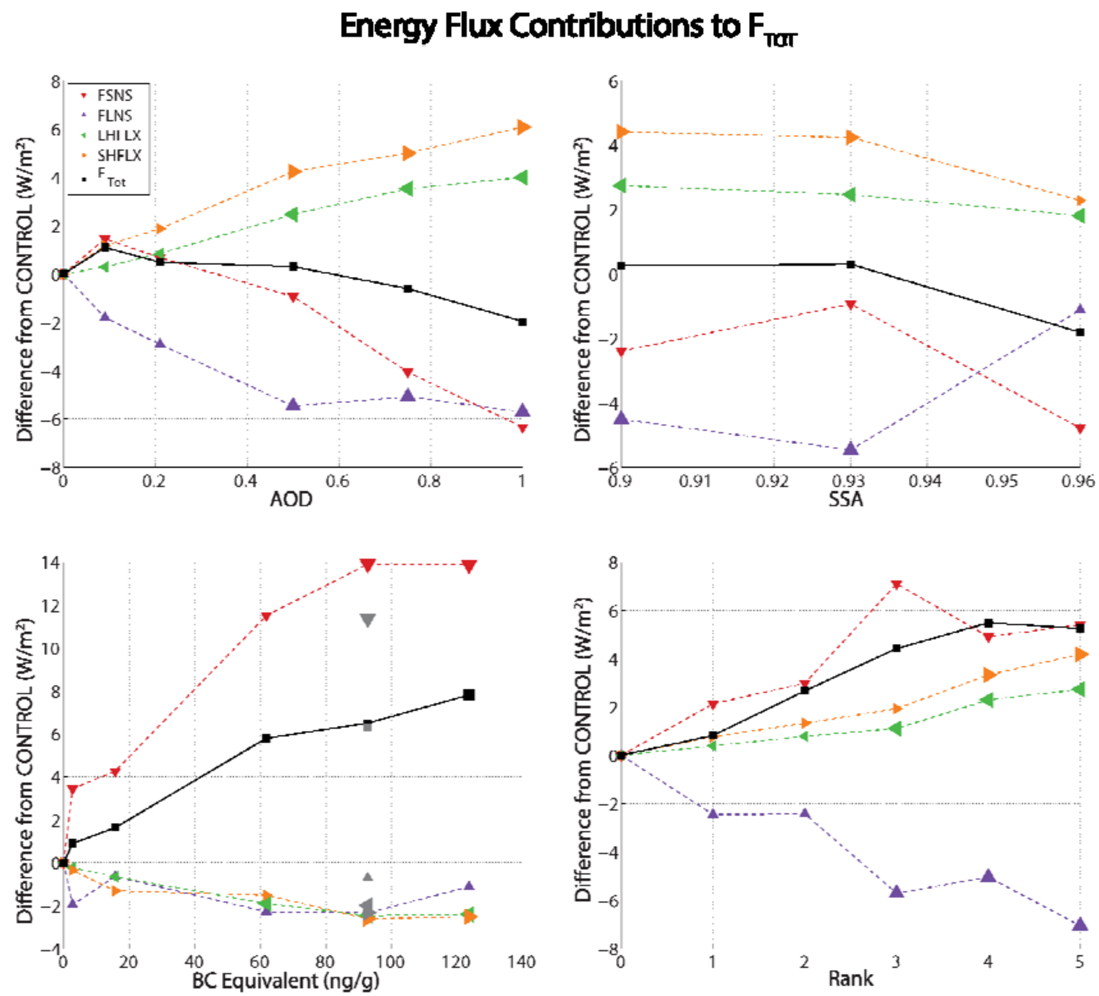

Fig. 6: Net Surface Energy Components for all experiments

Results: Net Surface Energy Components

- $\Delta FLNS < 0$ due to Stefan-Boltzmann response.
- $\Delta SHFLX, \Delta LHFLX > 0$ for AOD-only, SSA, and BOTH experiments.
- $\Delta SHFLX, \Delta LHFLX < 0$ for IN-SNOW experiment.

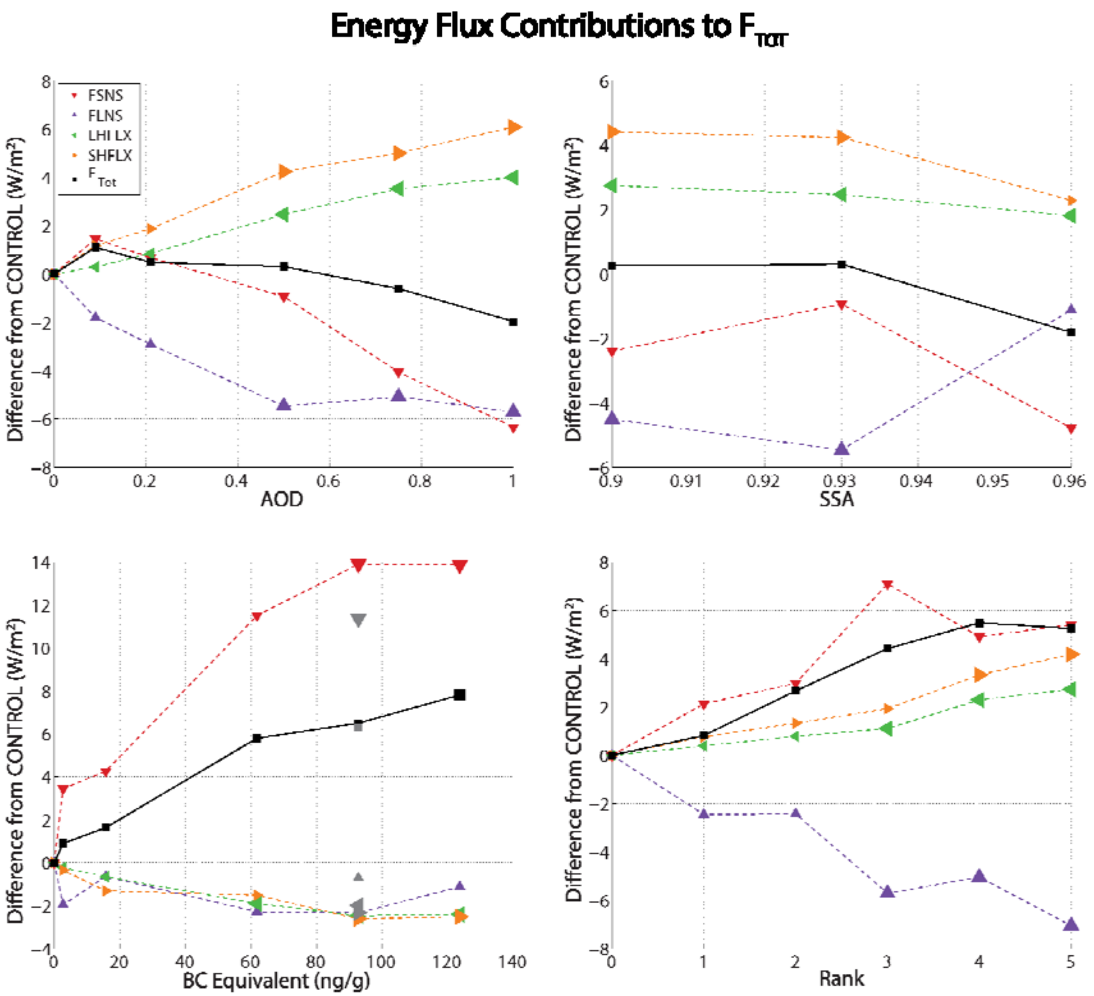

Fig. 6: Net Surface Energy Components for all experiments

Conclusions

- Snowmelt Changes (ΔM)
  - Largest positive changes occur in the IN-SNOW experiment.
  - AOD-only and SSA cases do not have any significant changes due to offsetting surface dimming and tropospheric warming.
  - BOTH magnitude is smaller than IN-SNOW due to the competing atmospheric aerosol effects.
- Net Surface Energy (ΔF_{TOT})
  - $\Delta FSNS$ is largest in the IN-SNOW and BOTH scenarios.
  - $\Delta SHFLX, \Delta LHFLX$ are more sensitive to atmospheric LAA presence.

Acknowledgements

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Thank You!

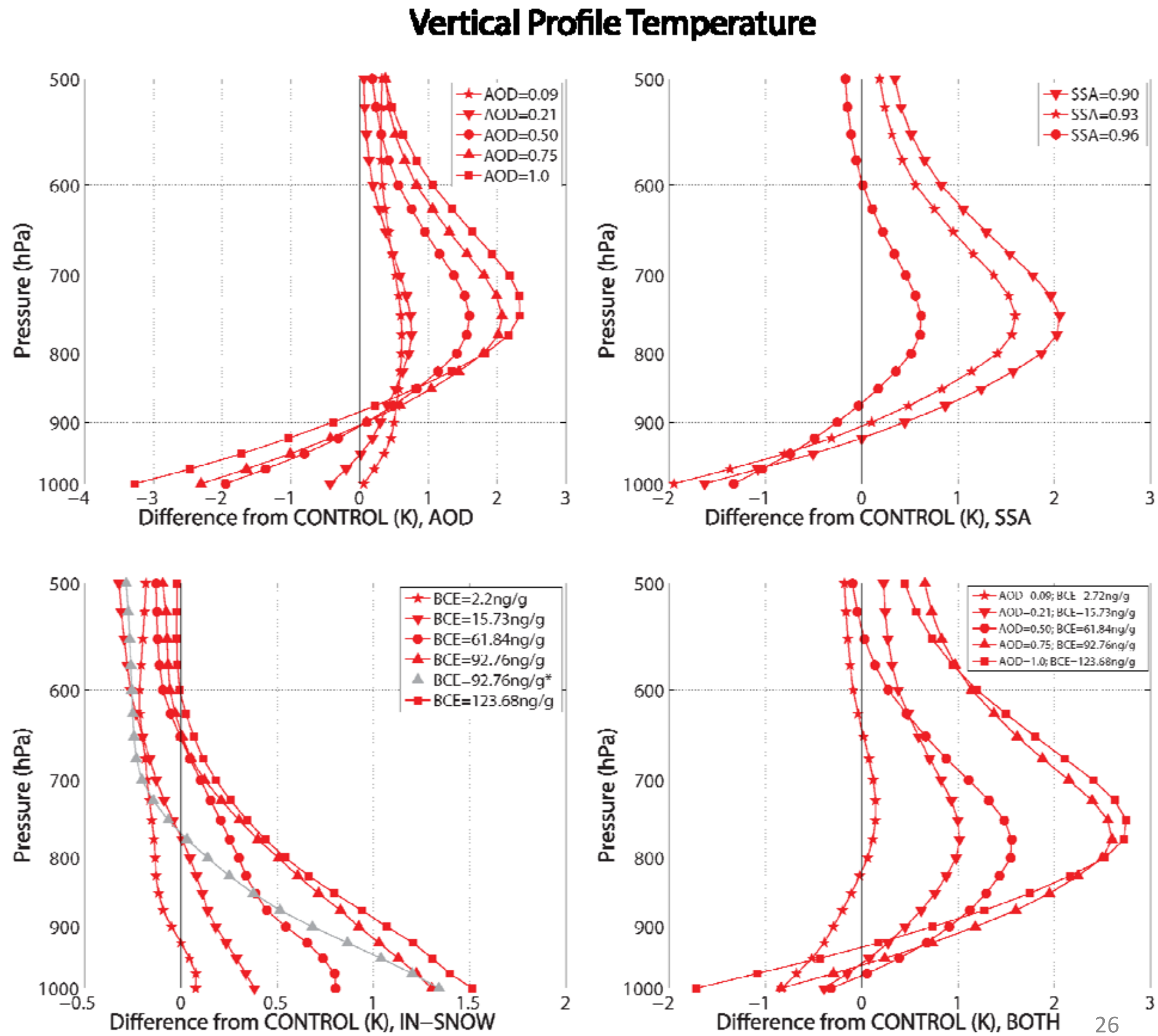
Questions?

Supplementary Information: BCE formula

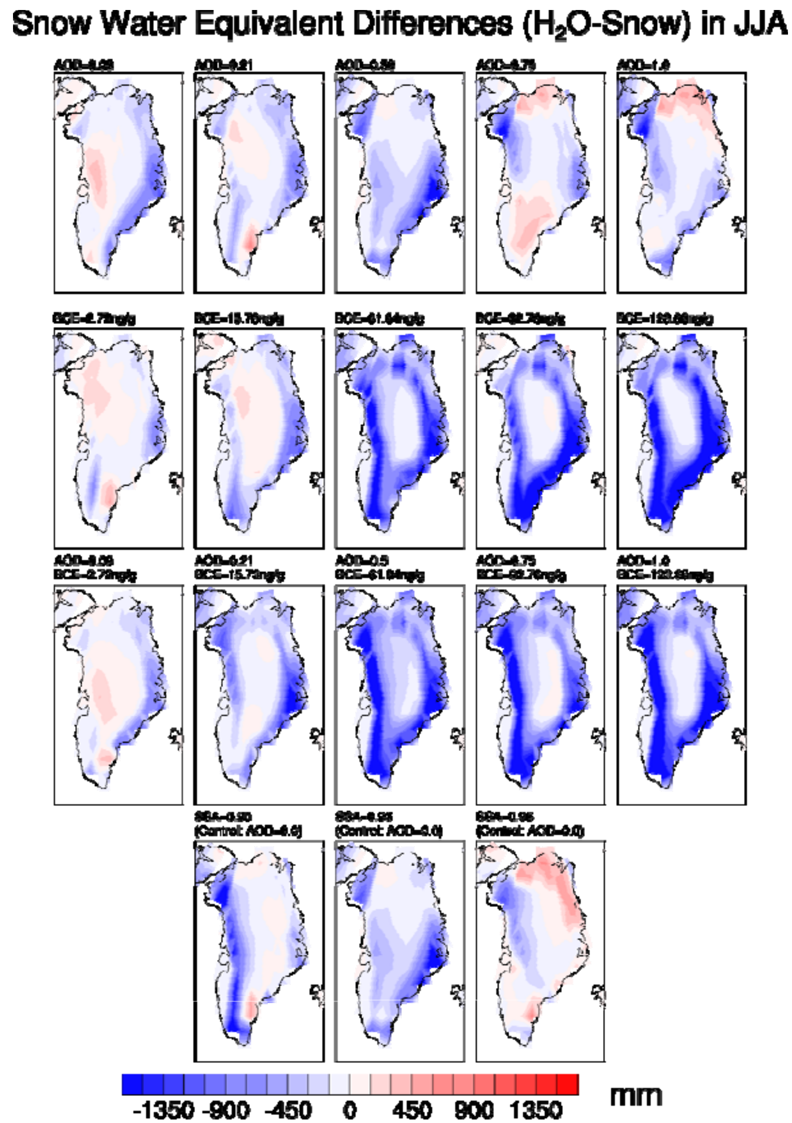
$$BCE = [BC] + \sum_{i=1}^{4} \left([Dust]_i * \frac{MAC_{Dust,i}}{MAC_{BC}} \right)$$

- [BC] is the mixing ratio of BC in the snow.
- [Dust] is the mixing ratio of dust in the snow for bin "i".
- MAC is the mass absorption cross section the aerosol in question.
  - MAC changes for dust depending on the bin designation.

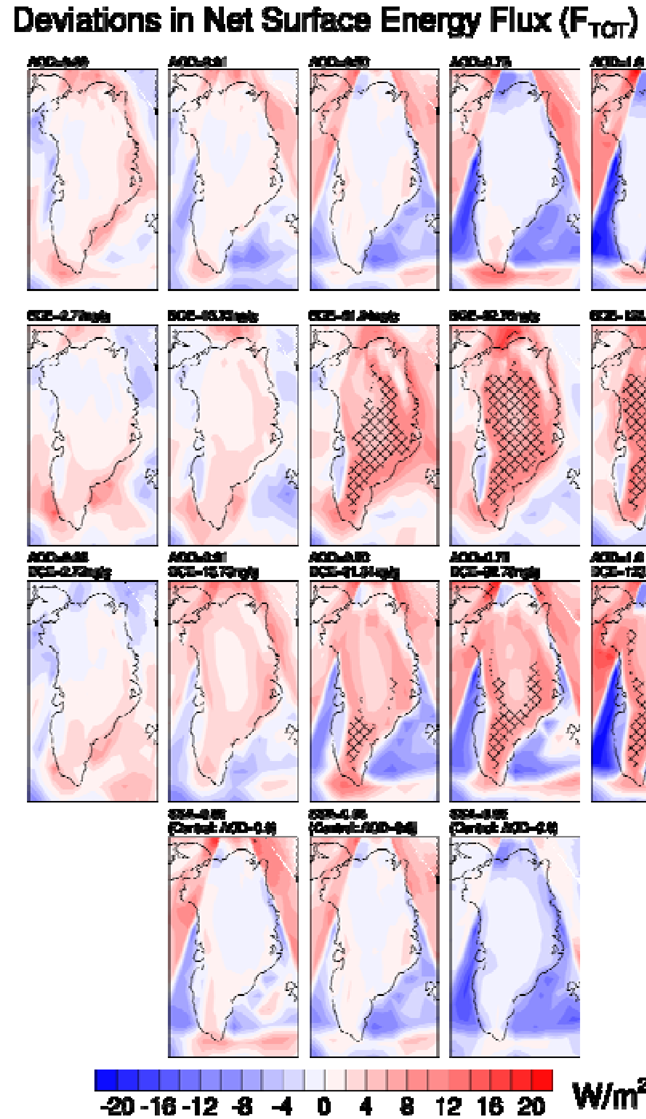
Tropospheric Warming



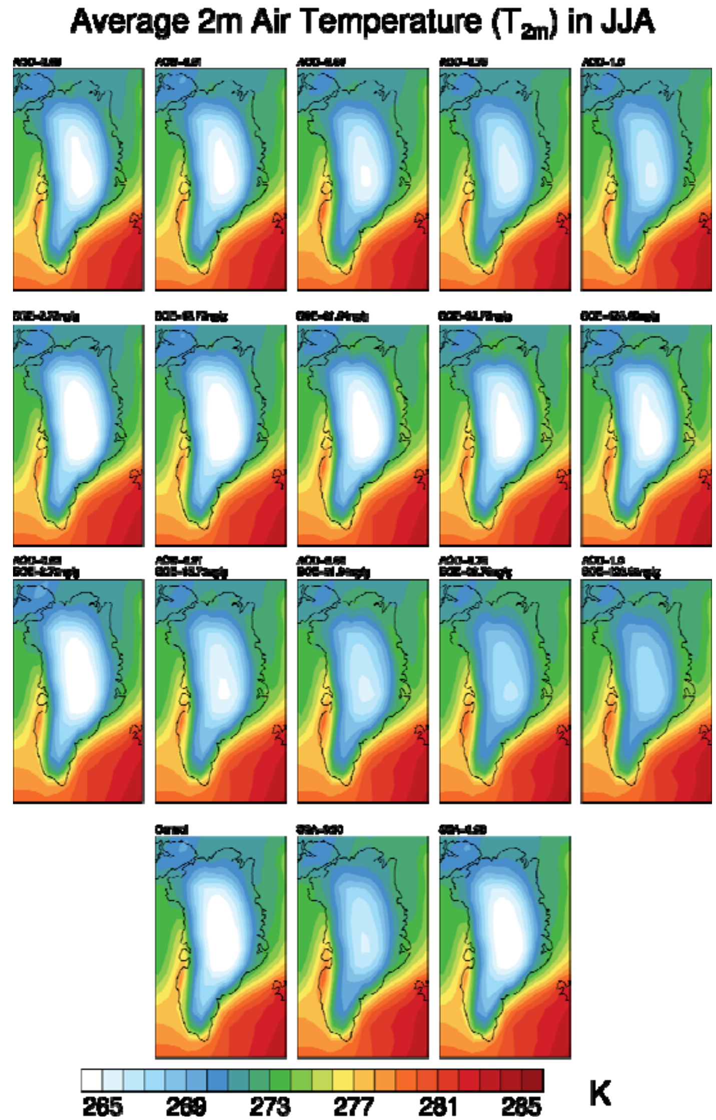
Snow-water Equivalent



ΔF_{TOT}: Spatial Map



T_{2m} for all runs



Low Cloud Fraction