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

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Climate and Space Science
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 $\rightarrow \sim 7.4$ 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).

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![Fig. 3: The area over which aerosol perturbations are imposed for each variable simulation](image)

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

Strellis et al., 2013
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

\[ \Delta \text{Variable} = \text{Variable}_{\text{case}} - \text{Variable}_{\text{CONTROL}} \]

• Difference maps, two-sample t-test (grid-by-grid and spatially-averaged).
Results: Snowmelt ($\Delta M$)

• No significant $\Delta M$ in the AOD-only and SSA runs.
  • Surface dimming and tropospheric warming offset.

• IN-SNOW and BOTH experiments: larger $\Delta M$ signal.
  • “In-snow” direct aerosol effect.
Results: Snowmelt and Net Surface Energy ($\Delta F_{TOT}$)

- $\Delta F_{TOT} = \Delta F_{SN} - \Delta F_{LN} - \Delta F_{HFLX} - \Delta F_{HFLX}$

- Spatially-averaged $\Delta F_{TOT}$ patterns are similar to snowmelt change.

Fig. 5: Surface energy flux ($\Delta F_{TOT}$) and snowmelt changes.
Results: Snowmelt and Net Surface Energy ($\Delta F_{TOT}$)

- $\Delta F_{TOT} = \Delta FSNS - \Delta FLNS - \Delta SHFLX - \Delta LHFLX$

- Spatially-averaged $\Delta F_{TOT}$ patterns are similar to snowmelt change.

\[ \implies \text{Surface energy input is the main influence on GrIS snowmelt.} \]
Results: Snowmelt and Net Surface Energy ($\Delta F_{TOT}$)

- $\Delta F_{TOT} = \Delta F_{SNS} - \Delta F_{LNS} - \Delta F_{HFLX} - \Delta F_{LHFLX}$

- Spatially-averaged $\Delta F_{TOT}$ patterns are similar to snowmelt change.

$\Rightarrow$ 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 ($\Delta F_{TOT}$) 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.
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 ($\Delta M$)
  • 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 ($\Delta F_{TOT}$)
  • $\Delta FSNS$ is largest in the IN-SNOW and BOTH scenarios.
  • $\Delta SHFLX, \Delta LHFLX$ are more sensitive to atmospheric LAA presence.
Acknowledgements

• I would like to thank Dr. Mark Flanner for the excellent advice and assistance he provided throughout the progress of this study.

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References


Thank You!

Questions?
Supplementary Information: BCE formula

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

• [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

Vertical Profile Temperature

Difference from CONTROL (K), AOD

Difference from CONTROL (K), SSA

Difference from CONTROL (K), IN–SNOW

Difference from CONTROL (K), BOTH
Snow-water Equivalent
$\Delta F_{TOT}$: Spatial Map
$T_{2m}$ for all runs
Low Cloud Fraction