Cloud-driven modulations of Greenland ice sheet surface melt, from 2012 to 2014

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Abstract

Clouds have been recognized to enhance surface melt on the Greenland Ice Sheet (GrIS). However, quantitative estimates of the effects of clouds on the GrIS melt area and ice-sheet-wide surface mass balance are still lacking. Here we assess the effects of clouds with the state-of-the-art regional climate model NHM-SMAP forced by the JRA-55 reanalysis [1], conducting a numerical sensitivity test in which adiabatic atmospheric conditions as well as zero cloud water/ice amounts are assumed (i.e., clear-sky conditions), although the precipitation rate is the same as in the control all-sky simulation. By including or excluding clouds, we quantify time-integrated feedbacks for the first time. We find that clouds were responsible for a 3.1%, 0.3%, and 0.7% increase in surface melt extent (of the total GrIS area) in 2012, 2013, and 2014, respectively. During the same periods, clouds reduced solar heating and thus daily runoff by 1.6, 0.8, and 1.0 Gt day–1, respectively: clouds did not enhance surface mass loss. In the ablation areas, the presence of clouds results in a reduction of downward latent heat flux at the snow/ice surface so that much less energy is available for the surface melt, which highlights the importance of indirect time-integrated feedbacks of cloud radiative effects. Reference [1] Niwano et al. (2018) NHM-SMAP: Spatially and temporally high resolution non-hydrostatic atmospheric model coupled with detailed snow process model for Greenland Ice Sheet. The Cryosphere, 12, 635-655, doi:10.5194/tc-12-635-2018.

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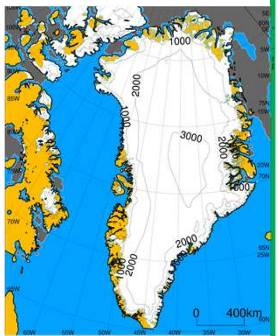
1. Introduction

- Clouds have been recognized to enhance surface melt on the Greenland Ice Sheet (GrIS) (e.g., Van Tricht et al., 2016).
- However, quantitative estimates of the effects of clouds on the GrIS melt area and ice-sheet-wide surface mass balance are still lacking.
- Here we assess the effects of clouds from 2012 to 2014 with the state-of-the-art **polar regional climate model NHM-SMAP** forced by the JRA-55 reanalysis (Niwano et al., 2018).

2. Model description

Domain for NHM-SMAP v.1.00



- The same configuration as that described by Niwano et al. (2018), which is used also for **SMBMIP** recently, is utilized here:
- Data output time interval: **1hr**
- Horizontal resolution : **5km**
- Double-moment bulk cloud microphysics scheme -> mixing ratio and concentration of solid hydrometeors (cloud ice, snow, and graupel).
- Single-moment scheme -> mixing ratio of liquid hydrometeors (cloud water and rain).
- No ice-saturation adjustment scheme and the cumulus parameterization.
- The turbulence closure boundary layer scheme is formulated following the improved Mellor-Yamada Level 3.
- For atmospheric radiation, the transfer function in longwave radiation was computed by a random model developed by Goody (1952), and shortwave radiation was computed by diagnosing the transfer function following Briegleb (1992).

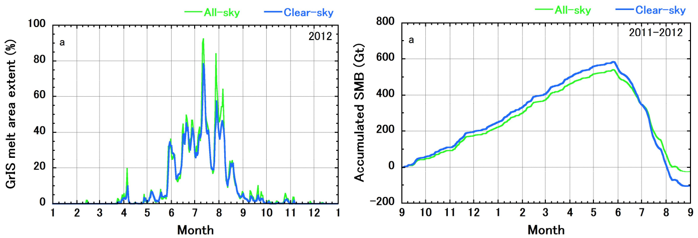
3. Model sensitivity test

- Model performance in GrIS from 2012 to 2014 is reported by Niwano et al. (2018). Based on the ctrl run, we did a model sensitivity test to investigate the effects of clouds. The test procedure is as follows: ***Precipitation is same as the ctrl run.**

Force instantaneous changes		→	Consider time-integrated feedbacks
Adiabatic condition (i.e., latent heat release is forced to zero)	Cloud water/ice content to zero		Changes in atmospheric conditions such as turbulent transport of air parcels due to with/without clouds (instantaneous changes) are internally simulated

4. Results

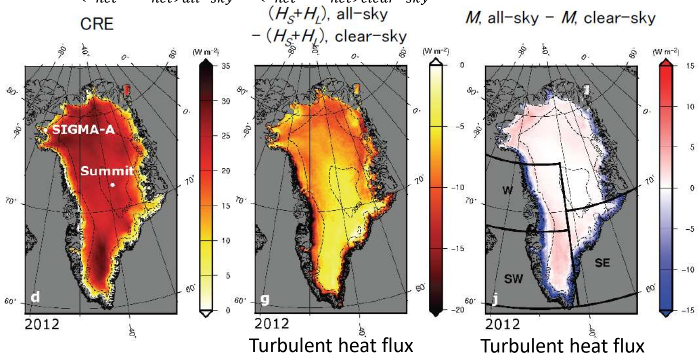
Melt area extent and surface mass balance



- JJA **surface melt area** is enhanced under **cloudy-sky condition** by **3.1%** .
- JJA **SMB loss** is enhanced under **clear-sky condition** by **1.6 Gt day^{-1}**.

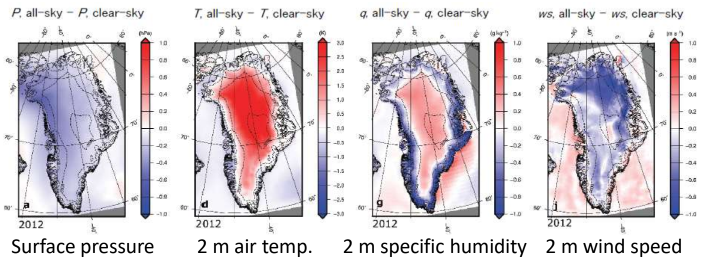
Differences in Surface energy balance

- (**All-sky ctrl run**) – (**Clear-sky sensitivity test**)
- $\mathrm{CRE} = (S_{net} + L_{net})_{all\text{-}sky} - (S_{net} + L_{net})_{clear\text{-}sky}$



- **Positive values** indicate these properties are **enhanced under cloudy-sky condition**.
- **Negative values** indicate these properties are **enhanced under clear-sky condition**.

Differences in surface meteorological conditions



- **Positive values** indicate these properties are **enhanced under cloudy-sky condition**.
- **Negative values** indicate these properties are **enhanced under clear-sky condition**.

6. Summary

- We conducted a NHM-SMAP numerical sensitivity test in which adiabatic atmospheric conditions as well as zero cloud water/ice amounts are assumed (i.e., clear-sky conditions), although the precipitation rate is the same as in the ctrl all-sky simulation.
- By including or excluding clouds, we quantify time-integrated feedbacks for the first time.
- We find that clouds were responsible for a 3.1%, 0.3%, and 0.7% increase in surface melt extent (of the total GrIS area) in 2012, 2013, and 2014, respectively.
- During the same periods, clouds reduced solar heating and thus daily runoff by 1.6, 0.8, and 1.0 Gt day^{-1}, respectively: **clouds did not enhance surface mass loss** (also reported by Hofer et al., 2017). In the ablation areas, the presence of clouds results in a reduction of downward latent heat flux at the snow/ice surface so that much less energy is available for surface melt, **which highlights the importance of indirect time-integrated feedbacks of cloud radiative effects**.

References

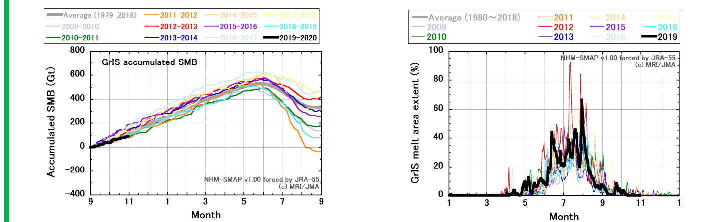
- **For the full story of this study, check**

Niwano, M., Hashimoto, A., and Aoki, T., 2019: Cloud-driven modulations of Greenland ice sheet surface melt, *Sci. Rep.*, **9**, 10380, doi:10.1038/s41598-019-46152-5.

- **For the NHM-SMAP RCM, check**

Niwano et al. (2018) NHM-SMAP: Spatially and temporally high resolution non-hydrostatic atmospheric model coupled with detailed snow process model for Greenland Ice Sheet. *The Cryosphere*, **12**, 635-655, doi:10.5194/tc-12-635-2018.

Interested in NHM-SMAP data? We can provide model data!



- 40-year (including near-real-time) simulation data over the GrIS are now available. For more details (e.g., physical properties that can be provided), feel free to ask the authors.