On the Contribution of Clouds to Greenland Ice Sheet Mass Loss

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Clouds over the ice sheets
Why do we want to get them right?

Radiative fluxes

Surface energy budget

Surface temperature

Precipitation

(Surface) mass balance

Global sea level
Clouds over the ice sheets
Why do we want to get them right?

- Radiative fluxes
- Surface energy budget
- Surface temperature
- Precipitation
- (Surface) mass balance
- Global sea level

Introduction
Observations
Cloud impacts on SEB
Cloud impacts on SMB
Conclusion
Clouds affecting the energy budget

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Shortwave reflection
Sun
Cloud
Cloud-albedo forcing
Earth’s surface

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Cloud
Cloud-greenhouse forcing
Earth’s surface

SW cooling
LW warming
Clouds in climate models

Van Tricht et al., 2015 (in press)
CloudSat and CALIPSO
- Combination of active radar and lidar
- Macro- and microphysical cloud properties
- Vertically-resolved
Retrieved cloud properties

Macrophysical properties

Cloud ice water frequency (%)

Cloud liquid water frequency (%)

Van Tricht et al., 2015 (in press)
Microphysical properties

Van Tricht et al., 2015 (in press)
The level-2 “Fluxes and Heating Rates” product

(Henderson et al., 2013)

1. Every vertical profile
2. CloudSat/CALIPSO determined LWP/IWP
3. ERA-Interim humidity and temperature profiles
4. Two-stream RTM
5. Broadband LW/SW radiative fluxes
Cloud radiative effect

Run RTM

- LWP ≠ 0
  - IWP ≠ 0
    - all-sky radiative fluxes

- LWP = 0
  - IWP ≠ 0
    - no-liquid radiative fluxes

- LWP = 0
  - IWP = 0
    - clear-sky radiative fluxes

CRE
Van Tricht et al., 2015 (in press)
Mean CRE = 29.5 ± 5.2 W m⁻²

What does this mean for the SMB?

Van Tricht et al., 2015 (in press)
From SEB to SMB

**Introduction**

**Observations**

Cloud impacts on SEB

Radiative fluxes and clouds
- Downwelling LW
- Downwelling SW
- Cloud optical depth

SEB

Meterological variables
- T2m
- RH
- Wind speed
- Precipitation

RACMO 2.3

Satellite observations

**Conclusion**

Cloud impacts on SMB

- Surface temperature & albedo
- Snow density & snow metamorphosis
- Water retention capacity
- Melt/refreezing

SMB

 offline configuration

Atmosphere

Ice sheet surface
Cloud impact on SMB

- 152 ±20 Gt y\(^{-1}\) lower SMB
- 35% decrease
- Ice and liquid show similar contributions

Where does this mass go?

Van Tricht et al., 2015 (in press)
Melt/refreezing/runoff

- Similar amounts of melt
- 58% refreezing in clear-sky
- 45% refreezing in all-sky

Van Tricht et al., 2015 (in press)
Melt/refreezing/runoff

- Meltwater runoff enhanced by $56 \pm 20 \text{ Gt y}^{-1}$
- = one-third increase
- 25 Gt due to cloud ice water
- 32 Gt due to cloud liquid water

Van Tricht et al., 2015 (in press)
Conclusion and outlook

- Cloud radiative effect estimates using satellite observations show on average **cloud warming**
- Coupling to SMB requires an **integrated** hybrid satellite-climate model approach and a snow model
- Clouds enhance Greenland ice sheet meltwater runoff due to **reduced refreezing**, not by enhancing melt directly
- Cloud representations in climate models need to be further improved in order to look at future cloudiness and ice sheet response
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Further reading:

Satellite observations merged with regional climate model to increase temporal resolution
‘Hybrid’ satellite-climate model dataset
Cloud observations $\rightarrow$ SEB

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2B-FLXHR-LIDAR = Level 2B Fluxes and Heating Rates

Algorithm that uses Coupled CloudSat/CALIPSO/MODIS/ECMWF data
To calculate **LW/SW Radiative fluxes** and heating rates at 126 vertical levels
Radiative flux evaluations

IMAU and GC-Net stations

Compare to Automatic Weather Stations (AWS)
Radiative flux evaluations

Van Tricht et al., 2015 (in press)
LWP/IWP correction

\[ \text{LWP}_{i,\text{corrected}} = \text{LWP}_{i,\text{original}} + CF \times (1 - \exp(-P \times \text{LWP}_{i,\text{original}})) \]

Van Tricht et al., 2015 (in press)
Evaluation of hybrid product

**LW**
- Bias = -3.2 W m\(^{-2}\) (was -9.9)
- RMSE = 6.8 W m\(^{-2}\) (was 10.9)

**SW**
- Bias = 1.8 W m\(^{-2}\) (was 4.4)
- RMSE = 6.6 W m\(^{-2}\) (was 6.6)