21st century high-resolution downscaling of Antarctic surface mass balance from global circulation models

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Antarctic Surface Mass Balance

- Coastal areas: snowy and windy
- Antarctic Plateau: cold and dry

(van de Berg et al., 2006)
Antarctic Surface Mass Balance

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Climate models: major SMB changes expected in coastal areas
SMB Downscaling: Why?

SMB estimation
Precipitation, Sublimation, Melting, Refreezing, Blowing snow

Spatial extent
Antarctica (5600 km x 5600 km)

Time extent
~800 yrs (1980-2200 * 2 Scenarios * 2 Boundary conditions)

GCM resolution: ~ 60 km → Required resolution: ≤ 15 km

→ Reduced computation time needed
The HiDEP model
High-Resolution Downscaling of surface Energy balance and Precipitation

**Inputs (~50 km resolution)**

- GCM Outputs: $P, T, Q_v, U, V, W$
- 3D Fields
  - Time step: 6H
- Surface Fields
  - Time step: 3H

**Outputs (15 km res.)**

- Rain$_{HiDEP}$
- Snow$_{HiDEP}$
- Sublimation$_{HiDEP}$
- Melting$_{HiDEP}$
- Refreezing$_{HiDEP}$
Precipitation downscaling: an orographic precipitation model

Upward wind $\rightarrow$ Adiabatic cooling $\rightarrow$ $\rho_{sat}$ ↓

Integration of the Clausius-Clapeyron equation at saturation:

Precipitation rate $= \frac{\Delta \rho_{sat}}{\Delta t} = F(\rho_{sat}, T, P) \times W$

when $\rho \geq \rho_{sat}$ and $W$ upward
Orographic precipitation: Determination of the vertical wind $W$

At the surface: the wind is tangent to the topography
→ new vertical wind at the surface

→ Computation for $W$: resolution of mountain gravity wave
Total precipitation: \( \text{Orographic} + \text{Non-Orographic} \)

Low-res. \textit{NON-Orographic Precipitation}

- Low-res. Total Precip. \textit{(Interpolated from GCM)}
- Low-resolution Orographic Precip.

+ High-resolution Orographic Precip.

High-resolution Total Precip.
Total precipitation: Orographic + Non-Orographic

GCM Grid (~50 km res.)

- GCM Topography
- Interpolation

HiDEP Grid (15 km res.)

- GCM Interpolated Topography
Total precipitation: Orographic + Non-Orographic

GCM Grid (~50 km res.)

HiDEP Grid (15 km res.)

GCM Precipitation

GCM Topography

Interpolation

Interpolated Topography


Total precipitation: Orographic + Non-Orographic

GCM Grid (~50 km res.)

- GCM Topography
- GCM Precipitation

HiDEP Grid (15 km res.)

- GCM Interpolated Topography
- High-res. Topography
- Low-res. Total Precip. (Oro. + Non-Oro.)

Interpolation
Surface Energy Balance

Extrapolation of GCM surface fields against the topography

Surface Scheme

Sublimation
Melting
Refreezing
Application to LMDZ4: 1980-2007

Arthern et al, 2006

van de Berg et al, 2006

LMDZ4

HiDEP-LMDZ4

SMB (mm w.e. a⁻¹)

4000

2000

1000

700

500

300

200

100

50

20

0

-400

mm w.e. a⁻¹

van de Berg et al, 2006

HiDEP-LMDZ4

LMDZ4

Arthern et al, 2006
Validation with a quality-controlled SMB data-set (Magand et al., 2007) : 90° – 180°E

R2 weighted by the number of observation in LMDZ4 grid boxes

Elevation range of Observations (m)

R2

LMDZ4 vs. Obs
HiDEP-LMDZ4 vs. Obs

Nb. of Obs.

Validation with a quality-controlled SMB data-set (Magand et al., 2007) : 90° – 180°E

Extension of the data quality-control to the rest of Antarctica :
Work in progress at LGGE
(In charge : Soazig Parouty, Vincent Favier)
Grounded SMB 1980-2007

Present SMB (1950-2000):

- Range: 4.1 to 6.4 mm a\(^{-1}\) sea level equivalent  
  (Monaghan et al., 2006)

LMDZ4  
P-E  
\[175.2 \text{ mm w.e. a}^{-1} = \text{kg m}^{-2} \text{ a}^{-1}\]  
\[\Leftrightarrow 6.0 \text{ mm a}^{-1} \text{ sea level equivalent}\]

HiDEP-LMDZ4  
SMB  
\[208.6 \text{ mm w.e. a}^{-1} = \text{kg m}^{-2} \text{ a}^{-1}\]  
\[\Leftrightarrow 6.7 \text{ mm a}^{-1} \text{ sea level equivalent}\]
Projection for the 21st century (A1B)
First results

Grounded ice-sheet

mm w.e. a⁻¹

SMB | Snow | Rain | Melt | Sublim.

LMDZ4
HiDEP-LMDZ4

1980-2007
2071-2099
Projection for the 21\textsuperscript{st} century (A1B)
First results

Melt HiDEP

1980-2007

2070-2099

More melt on the shelves
Conclusion

• High-resolution SMB (15 km) obtained from LMDZ4 downscaling
  Partial validation for present:
    • Increased performance Downscaled SMB close to LMDZ4 SMB
      BUT lack of field data in (crucial) coastal areas
Conclusion

- High-resolution SMB (15 km) obtained from LMDZ4 downscaling

Partial validation for present:
  - Increased performance: Downscaled SMB close to LMDZ4 SMB

BUT lack of field data in (crucial) coastal areas

Further validation:
  - Extended quality-controlled data set over all Antarctica

Model development in progress:
  - More detailed Surface Scheme
Thank you