High-resolution modeling of the Antarctic surface mass balance

Impact on sea-level change for the next centuries

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Kolloquium

RWTH Aachen University

4/12/2012

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OSUG Observatoire des Sciences de l'Univers de Grenoble

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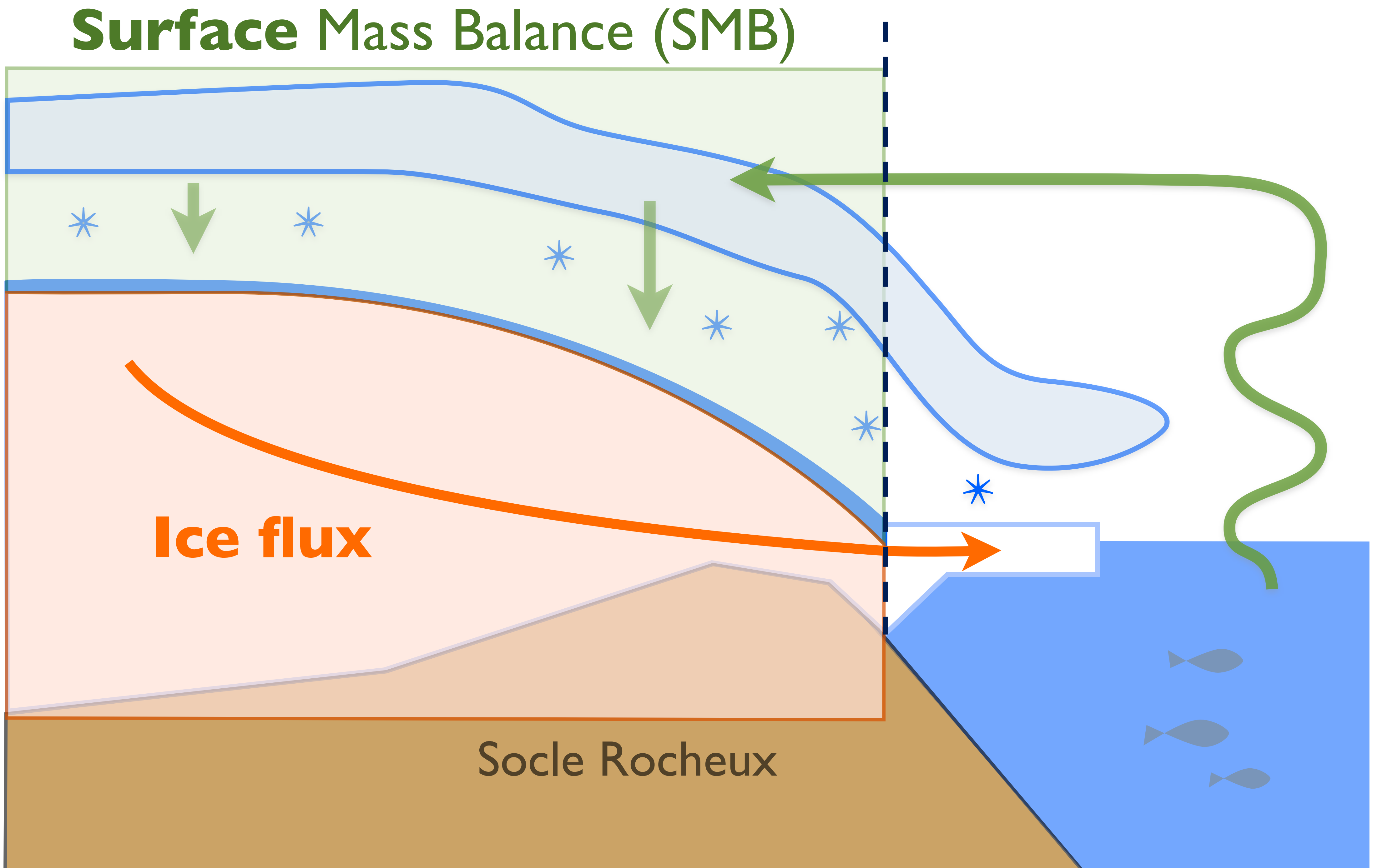
ice2sea

Mass balance uncertainties

Grounded ice sheet :

Surface mass balance + Ice flux

= Mass balance = Contribution to sea level



Mass balance uncertainties

Grounded ice sheet :

Surface mass balance + Ice flux

= Mass balance = Contribution to sea level

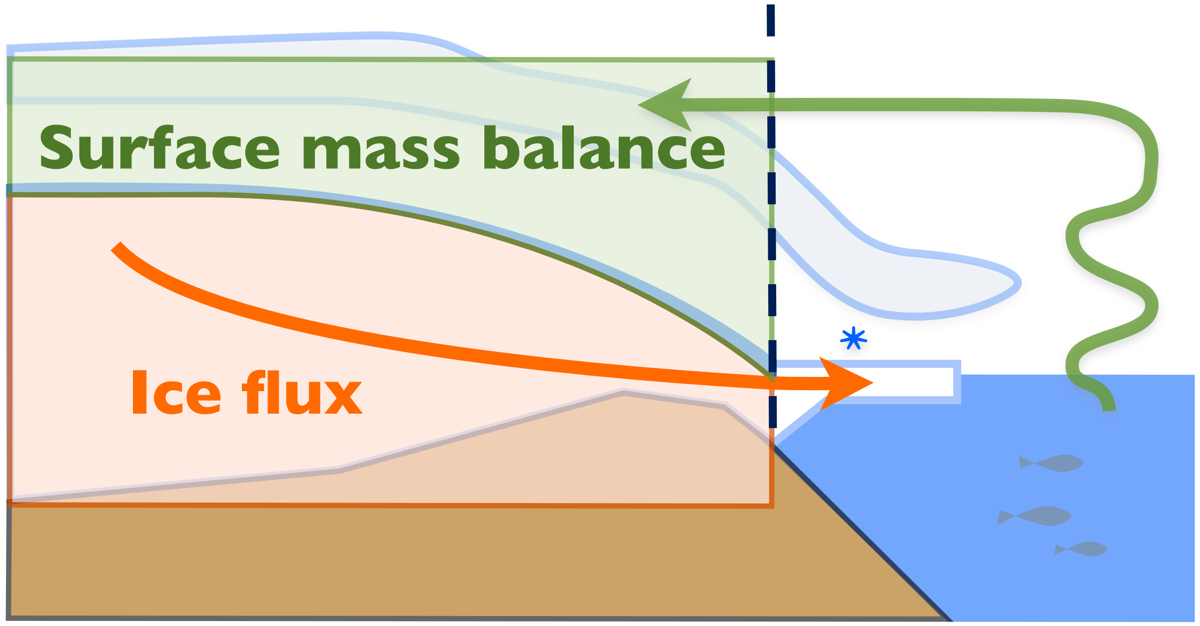
Estimations for the end of the 20th century :

= (-5.5 ± 0.3) + (6.0 ± 0.1) mm/yr s.l.e.

Lenaerts et al. 2012   Rignot et al. 2011

= (0.5 ± 0.4) mm/yr s.l.e.

Observed** sea level rise : **~3 mm/yr



Mass balance uncertainties

Evolution for the next centuries ?

Response to global warming :

Surface mass balance : instantaneous

Ice flux : acceleration, indirect effect

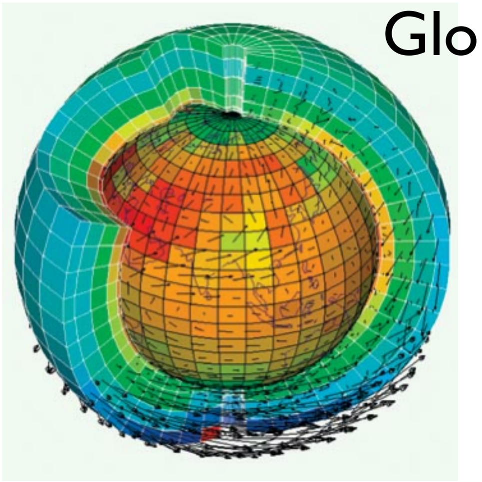
(in West Antarctica, Pritchard et al. 2012)

Aim of the downscaling ?

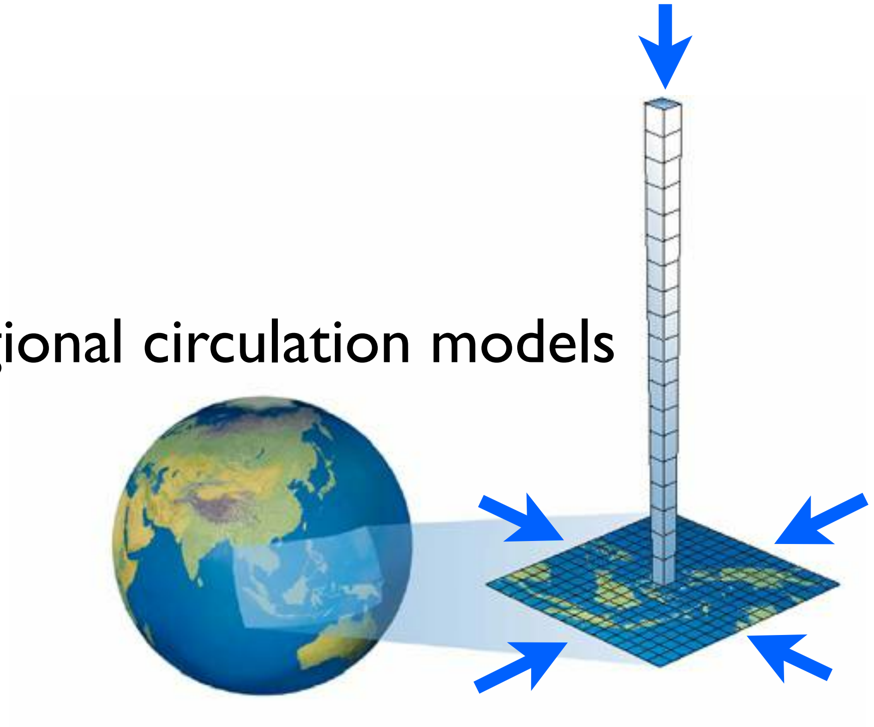
1
Model
2
Valid.
3
Futur
4
Concl.
5

Modeling : only tool to estimate the SMB evolution

Global circulation models



Regional circulation models

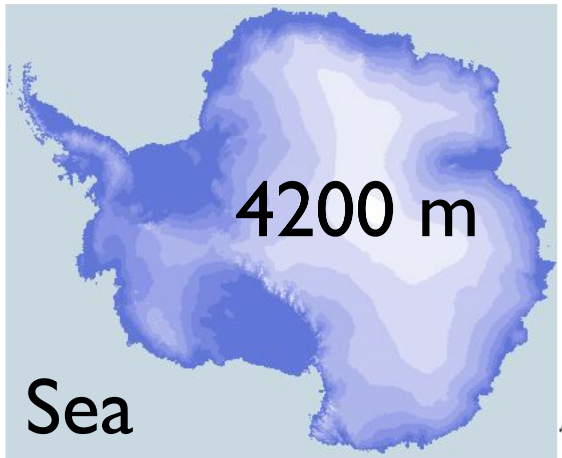


Antarctic SMB estimations

depend on models **resolution**

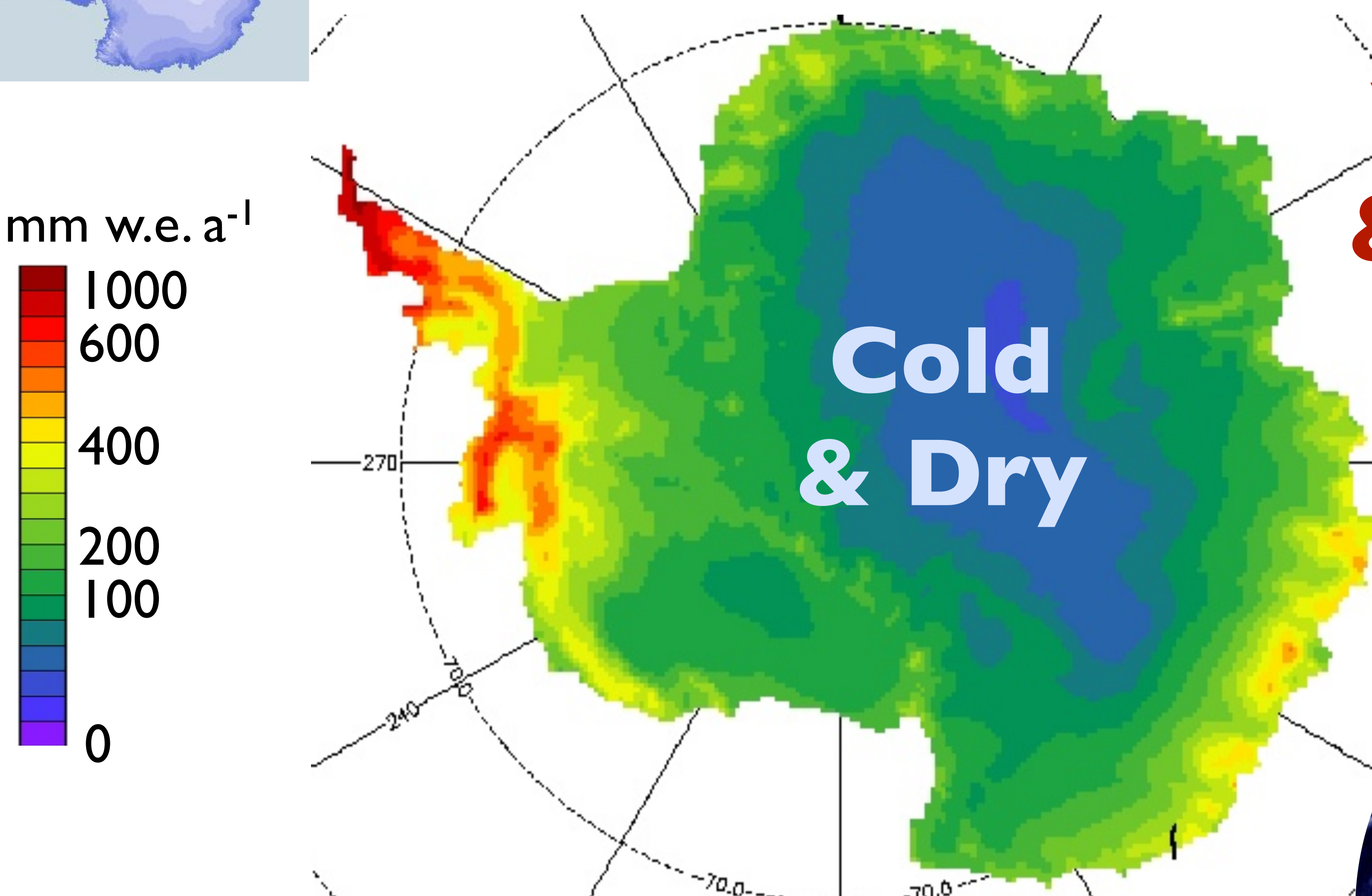
(IPCC 2007, Genthon et al. 2009)

1.2 Aim of the downscaling ?



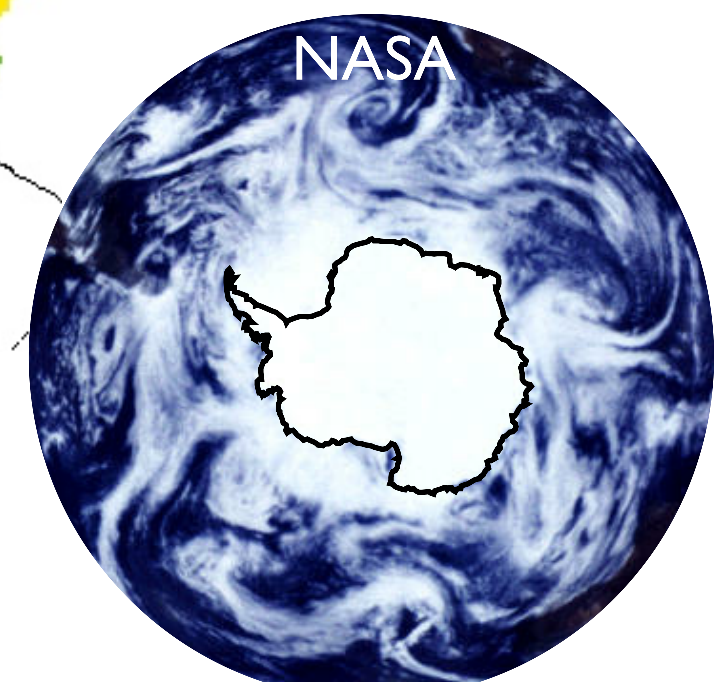
SMB climatology

End of the 20th c. (mm w.e. a^{-1})



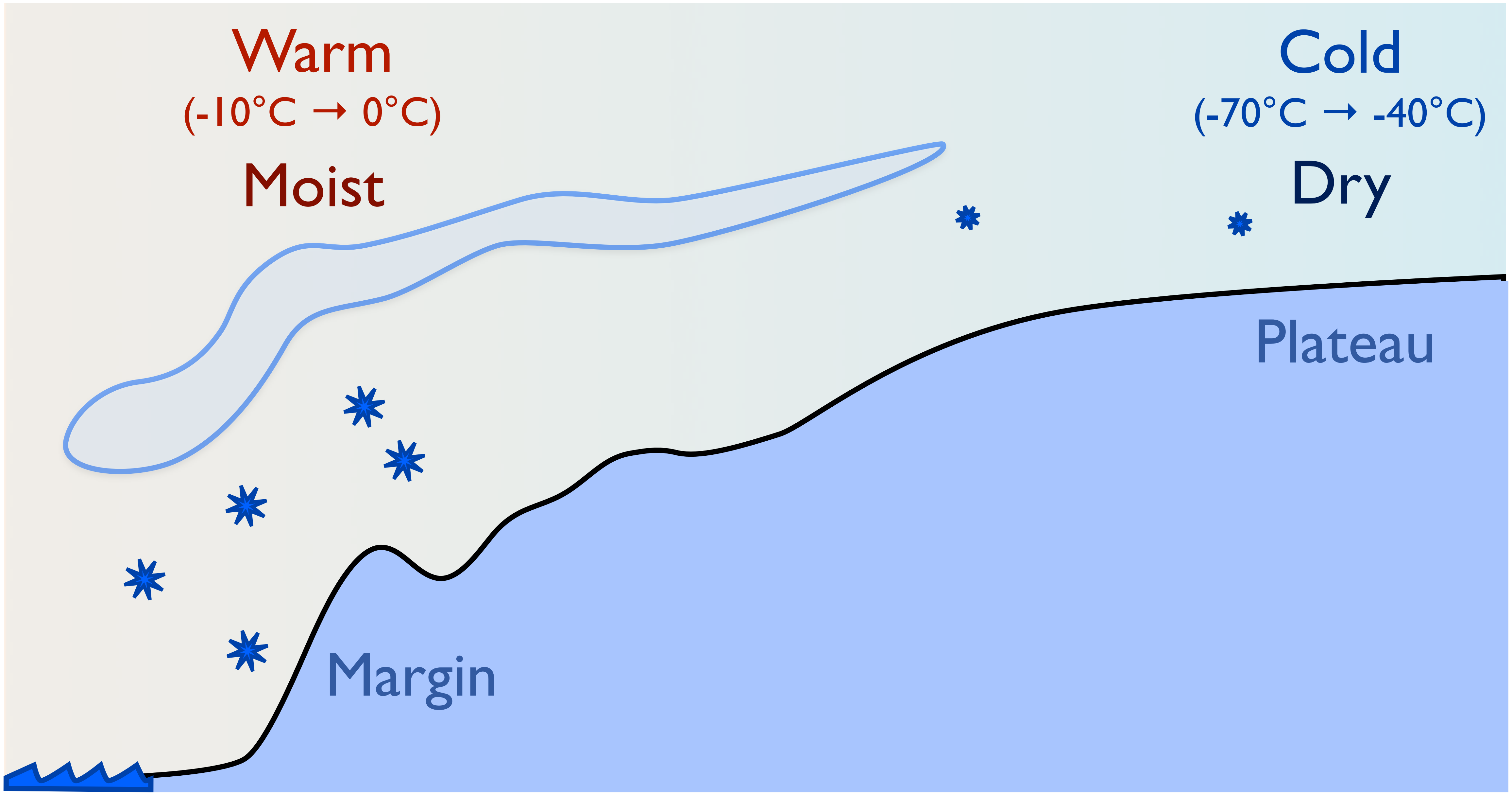
Warm & Moist

Arthern et al. (2006)



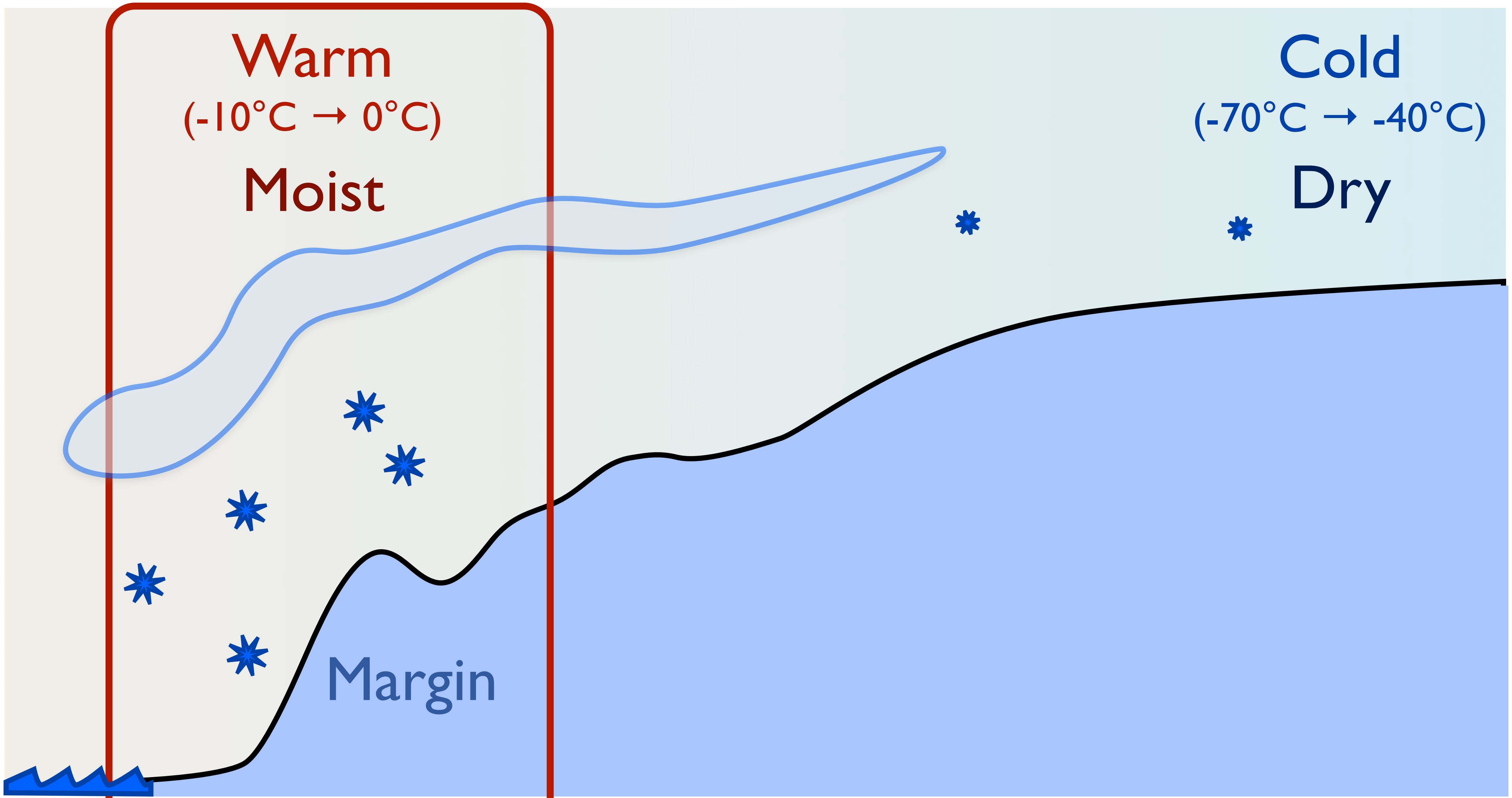
1.2

Aim of the downscaling ?



Impact of **local topography** (surface heighy, slope) on **precipitation** (intensity and spatial pattern)

1.2 Aim of the downscaling ?



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+++

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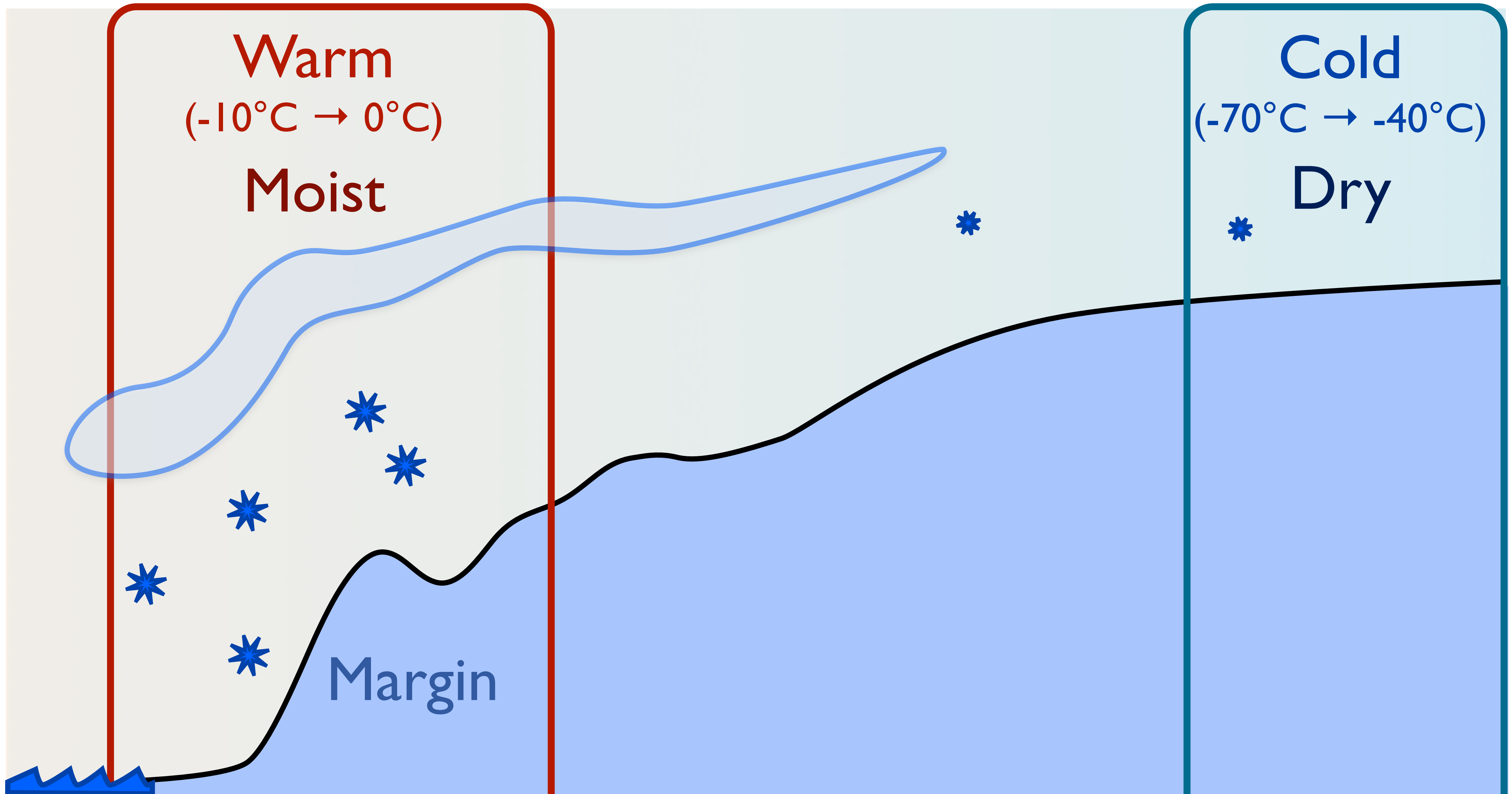
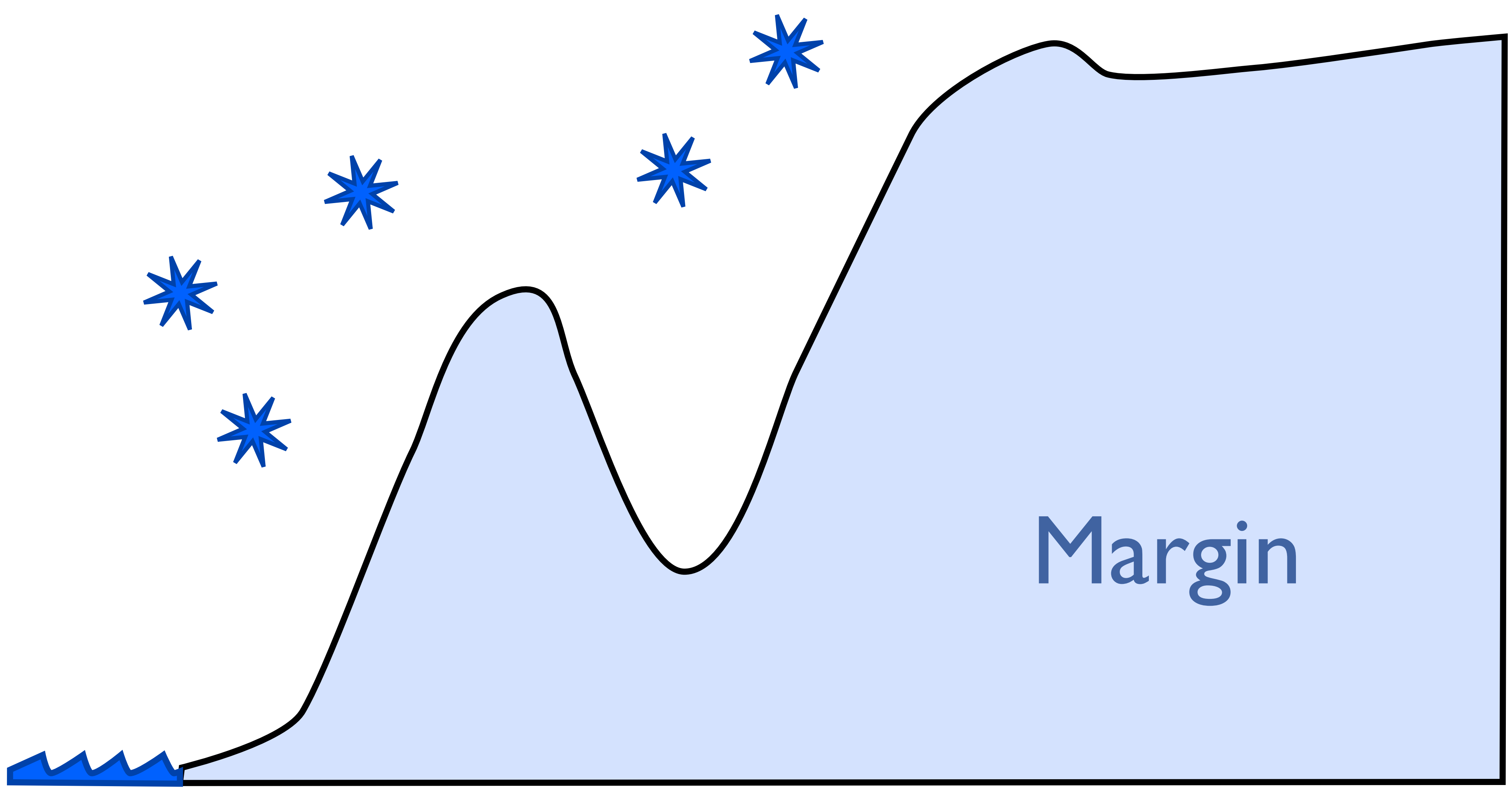


Impact of **local topography** (surface heighy, slope) on **precipitation** (intensity and spatial pattern)

+++ → 0

Aim of the downscaling ?

Topography at the ice-sheet margin



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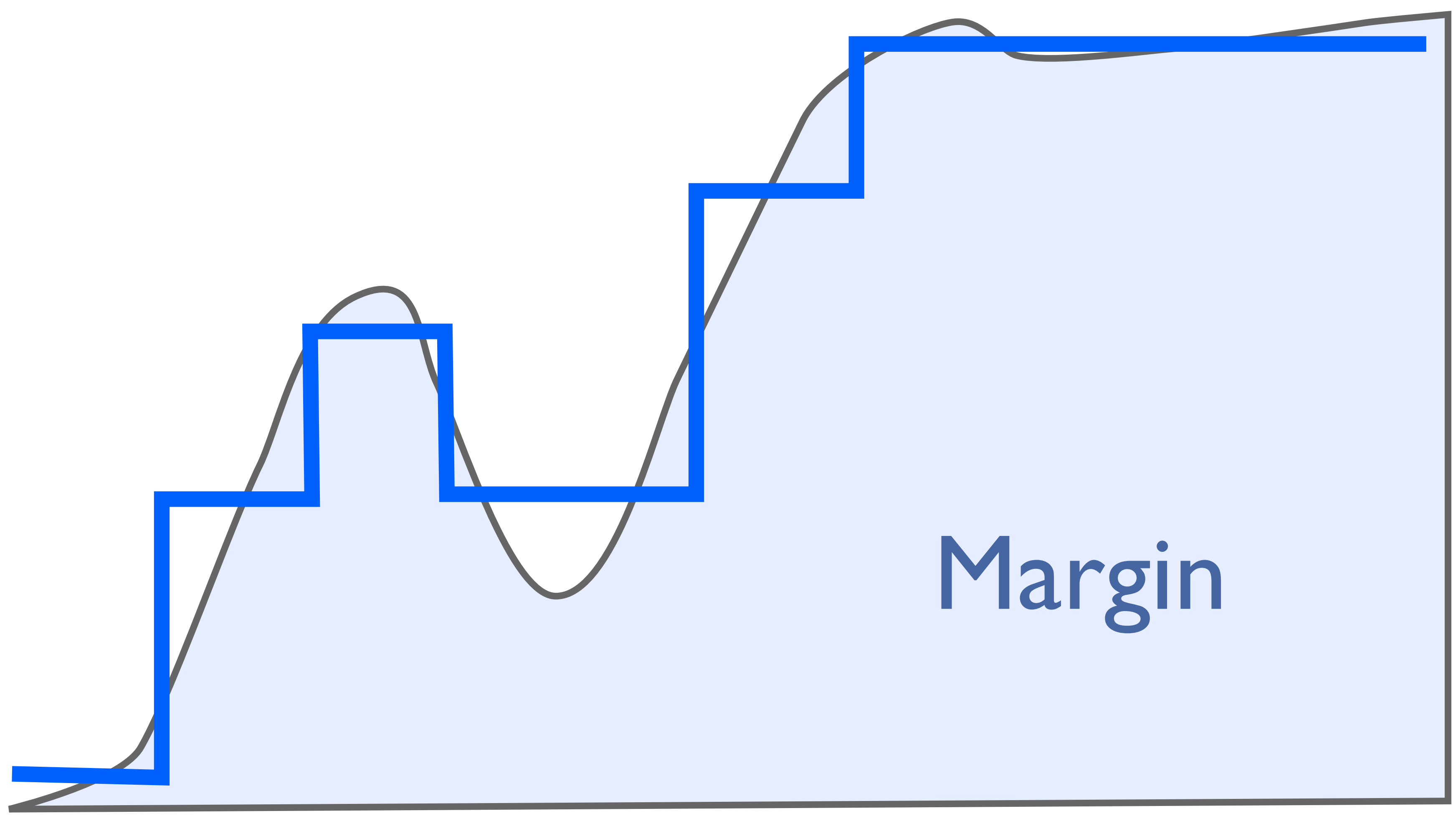
Resolution +



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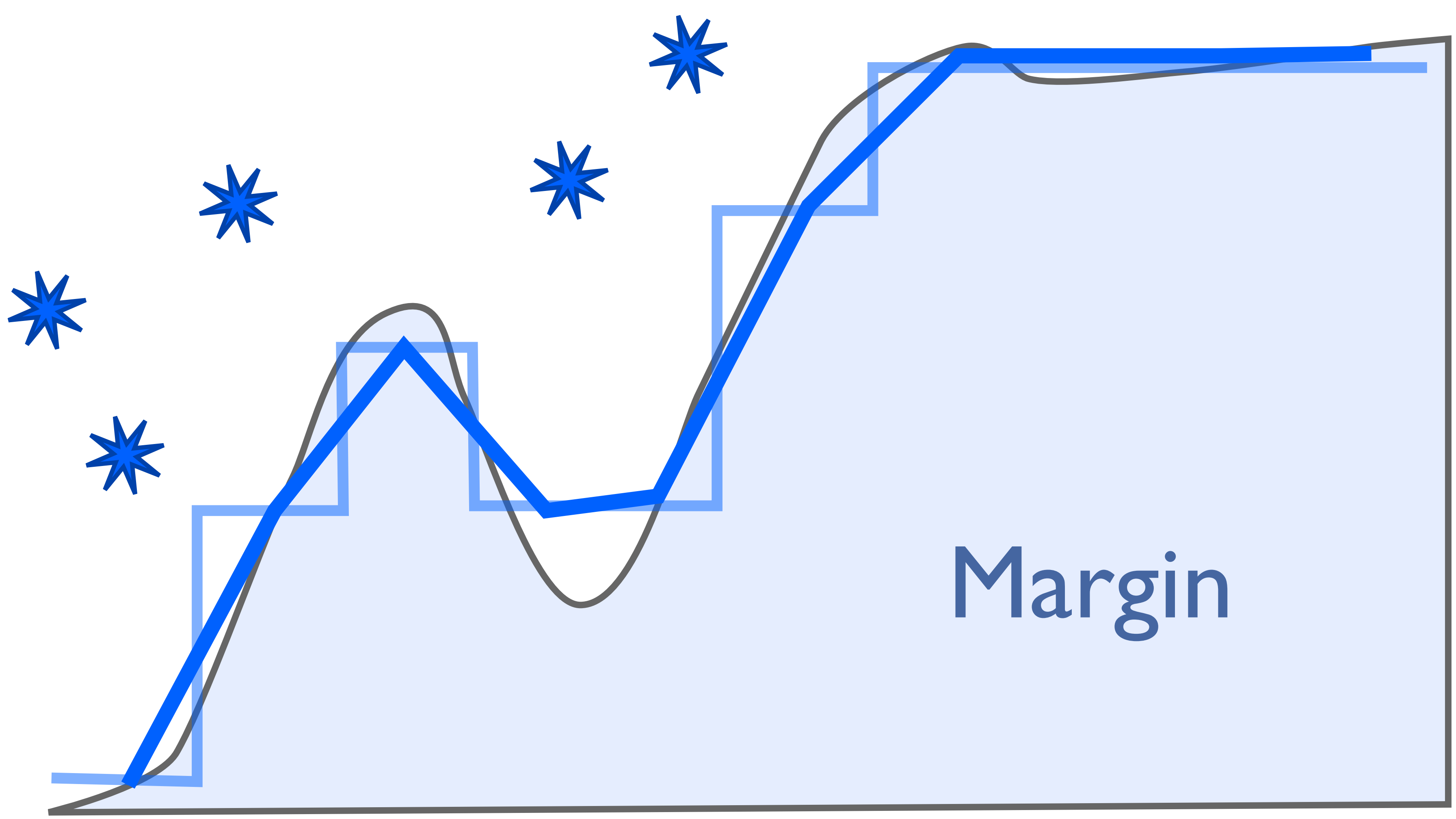

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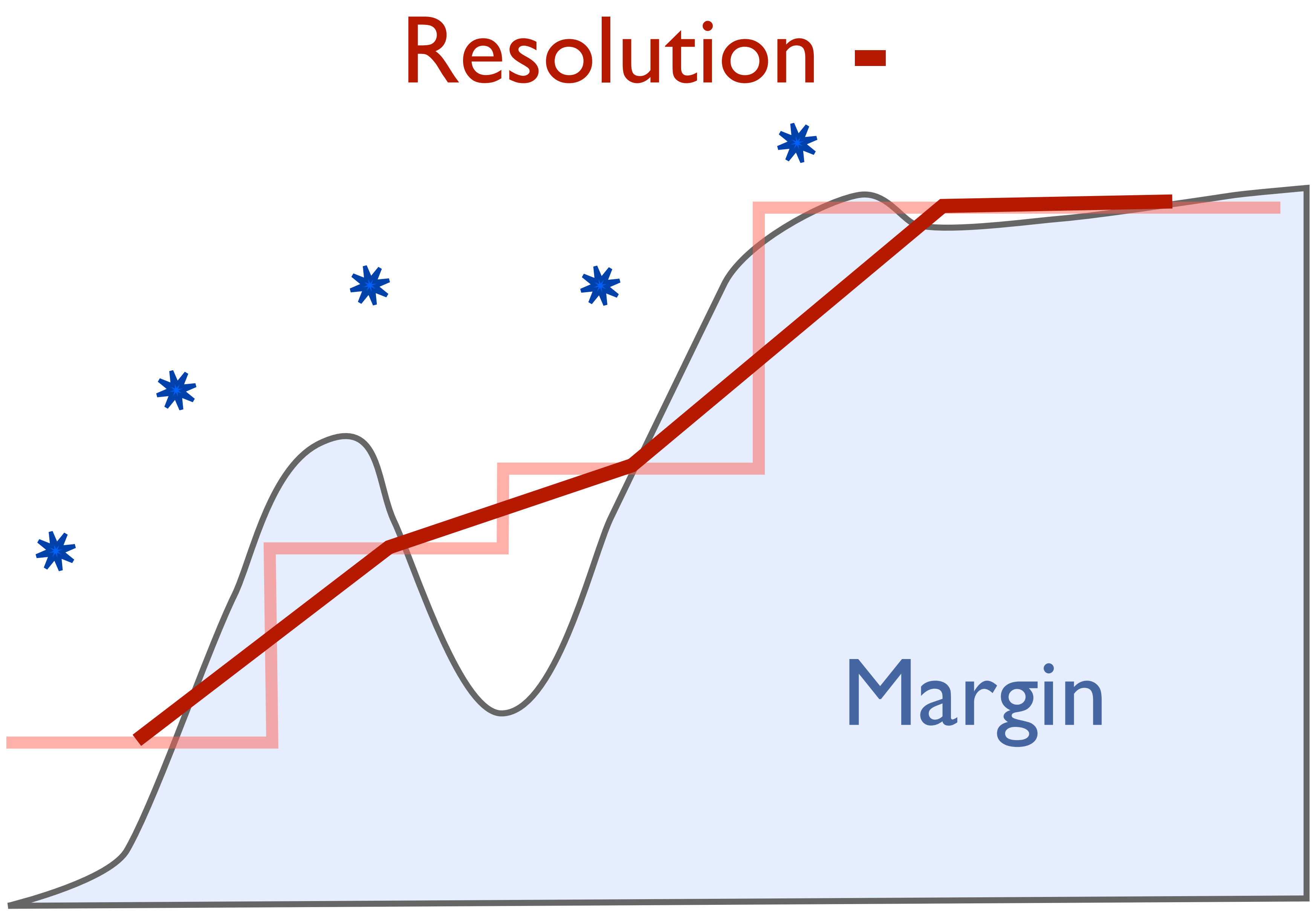


Aim of the downscaling ?

Good SMB estimation :

require **high resolution (<20 km)**

at ice-sheet margins

(high accumulation, complex topography)

BUT :

Large spatial extent (5000 km x 5000 km)

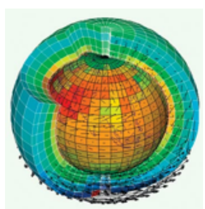
Large temporal extent (hundred of years)

→ Climate models **limited by computational costs**

2.1 Downscaling method

INPUTS
(RESOLUTION : ~50 KM)

Large-scale model outputs :
P, T, Q, U, V, W, R



3D Fields
Time step : 6H

Surface fields
Time step : 3H

High-resolution topography

SMHiL

OUTPUTS
(RES. : ~15 KM)

2.1 Downscaling method

Goals 1
2
Valid. 3
Futur 4
Concl. 5

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(RESOLUTION : ~50 KM)

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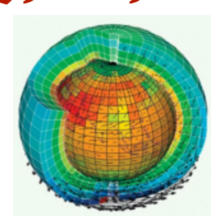

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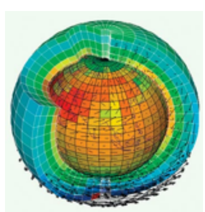

3D Fields

Time step : 6H

Surface fields

Time step : 3H

High-resolution topography

Precipitation

SMHiL

OUTPUTS

(RES. : ~15 KM)

Snow

Rain

2.1 Downscaling method

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(RESOLUTION : ~50 KM)

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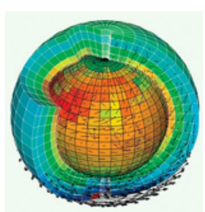

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Surface fields
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High-resolution topography

OUTPUTS
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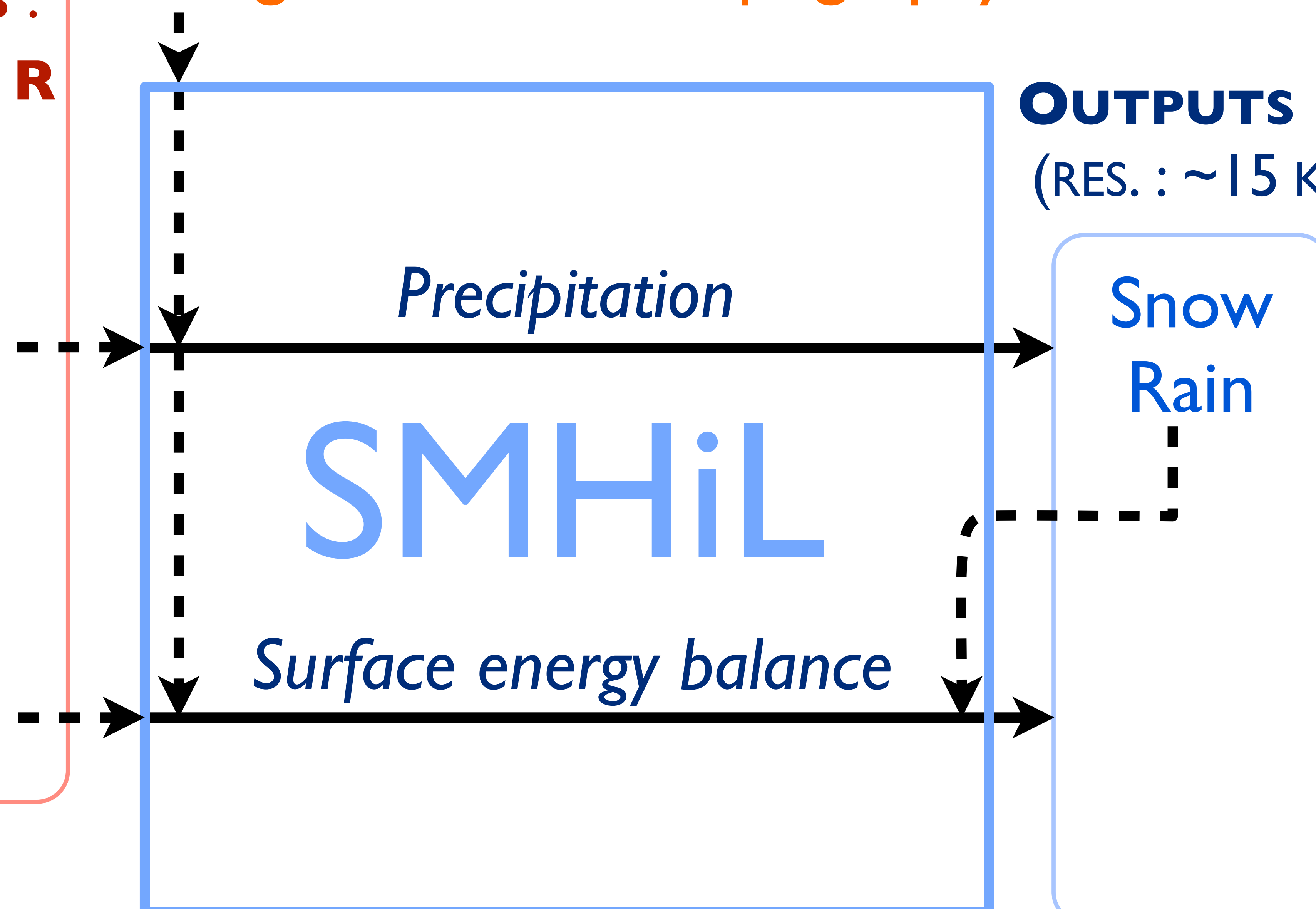

Downscaling method

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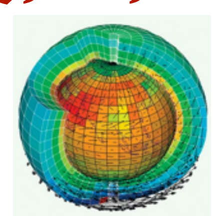


3D Fields
Time step : 6H

Surface fields
Time step : 3H

High-resolution topography

SMHiL

Precipitation

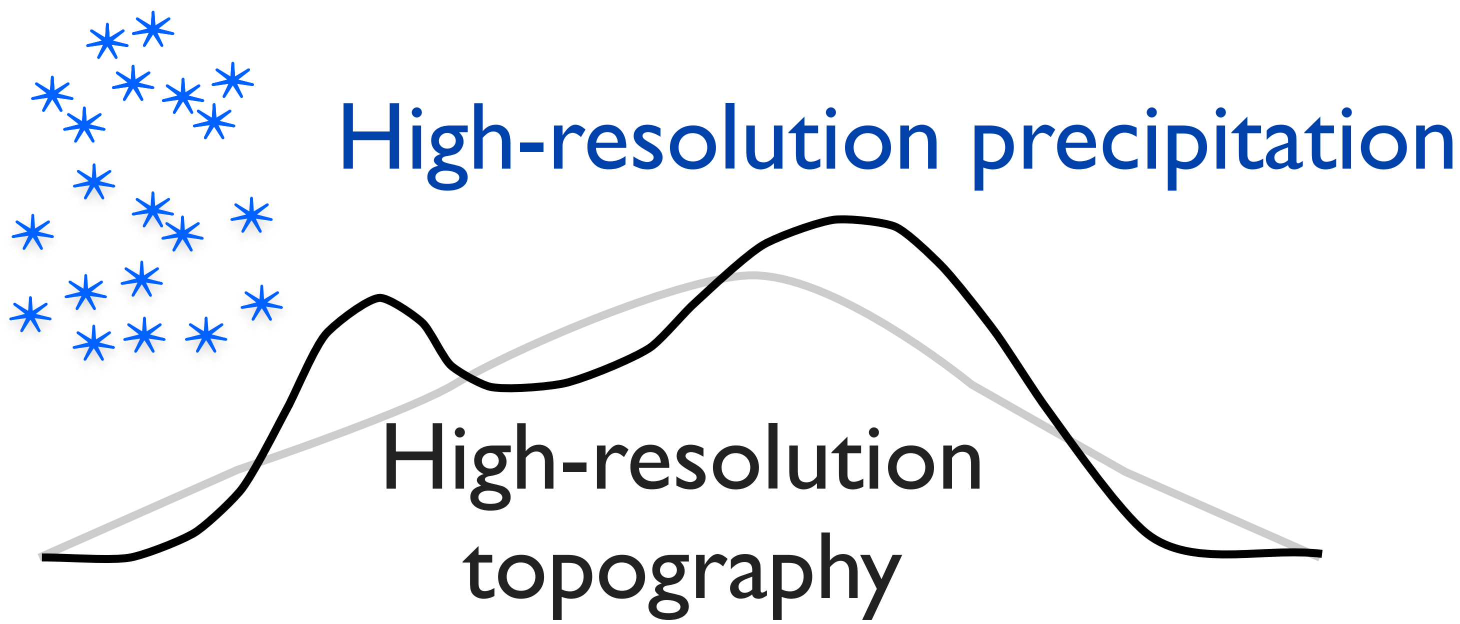
Surface energy balance

OUTPUTS
(RES. : ~15 KM)

Snow
Rain

Sublim.
Melting
Refreez.

Precipitation downscaling



2.2 Precipitation downscaling

Orographic precipitation

Linked to topography

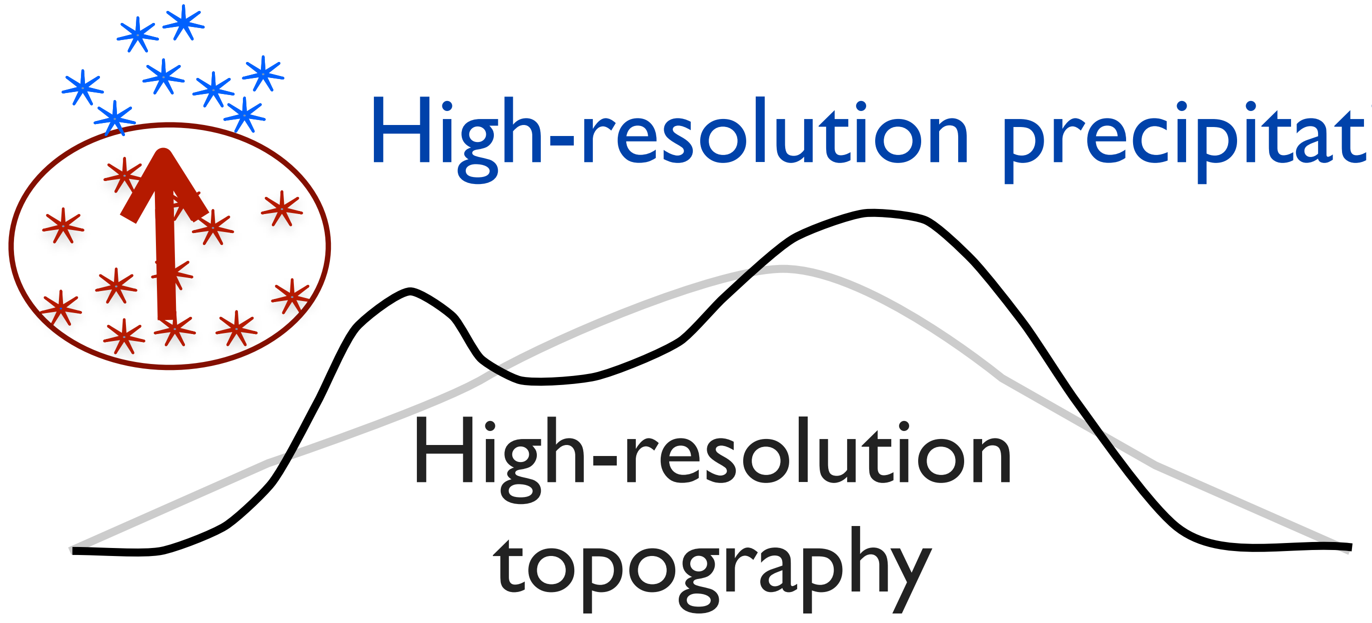
1-D (air column) parametrization

Brasseur, Fettweis, Gallée, Gential

Sinclair, 1994

Funk et Michaelsen, 2004

Durran and Klemp, 1982



2.2 Precipitation downscaling

Non-orographic precipitation

Synoptic scale

Computed from large-scale outputs

Orographic precipitation

Linked to topography

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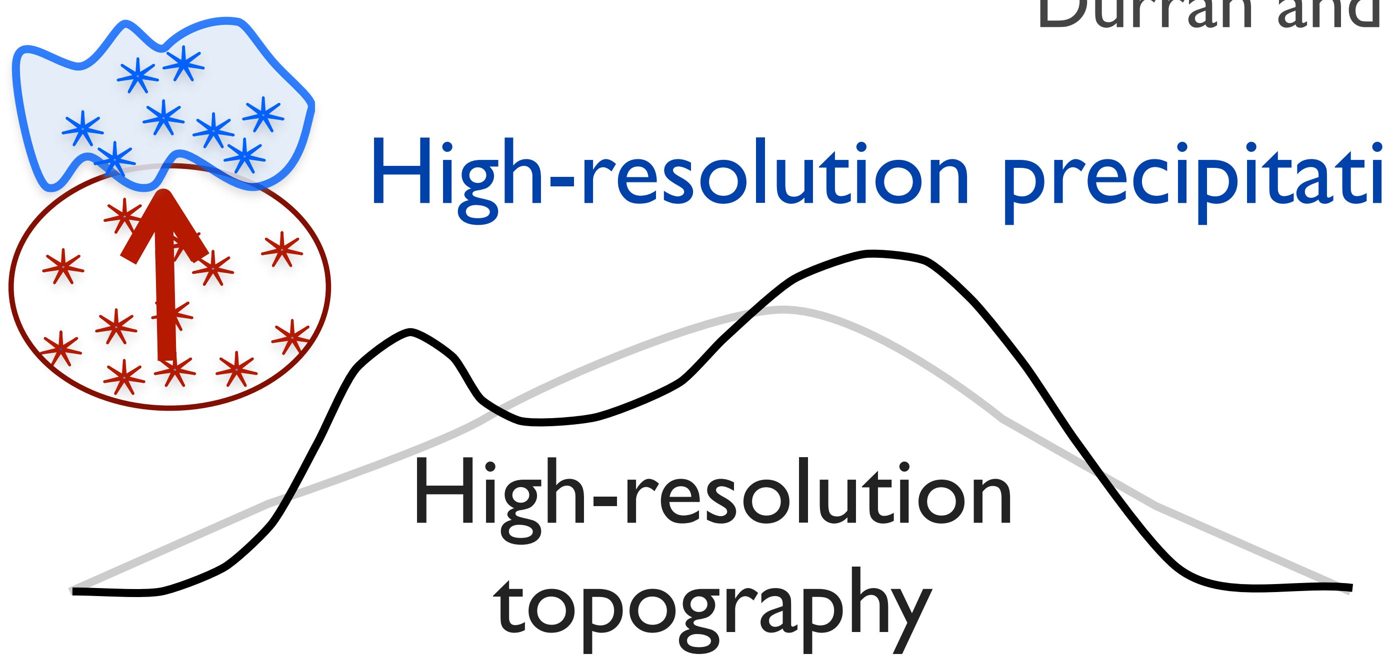
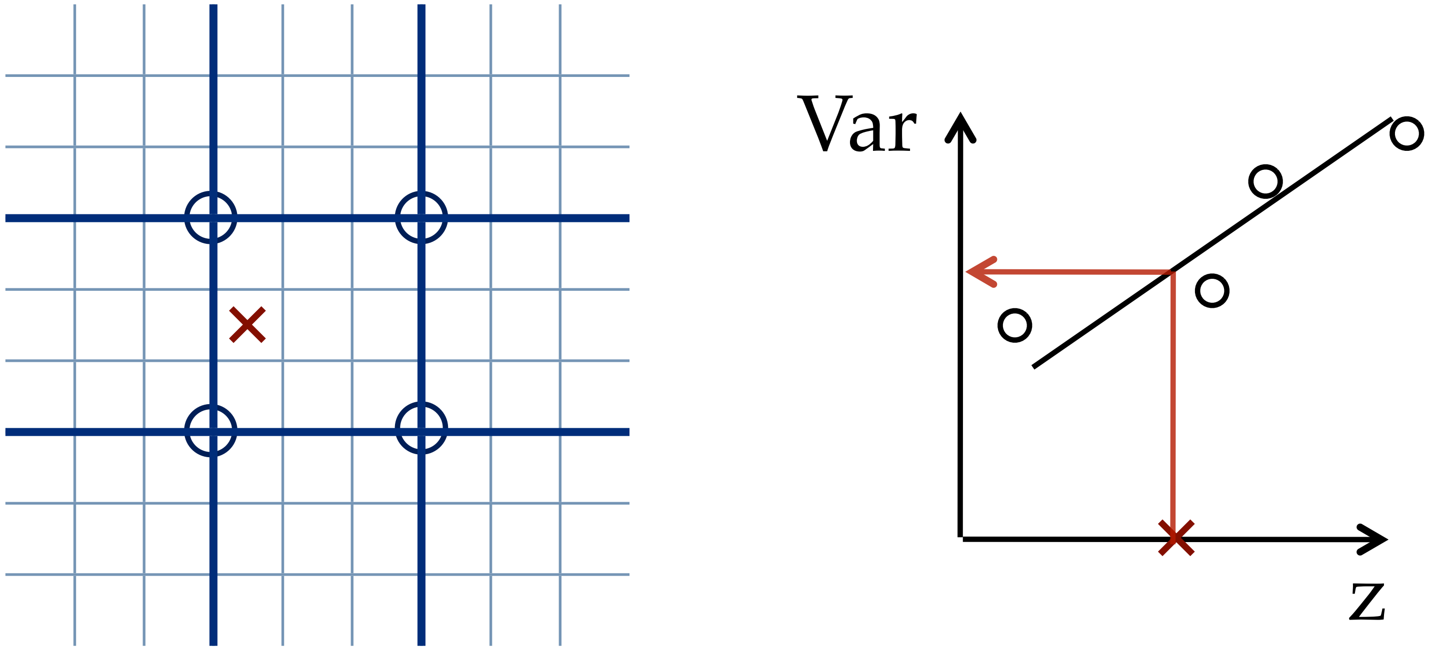


2.3 Surface energy balance downscaling

Local regression of large-scale surface fields against the topography



Surface energy balance downscaling

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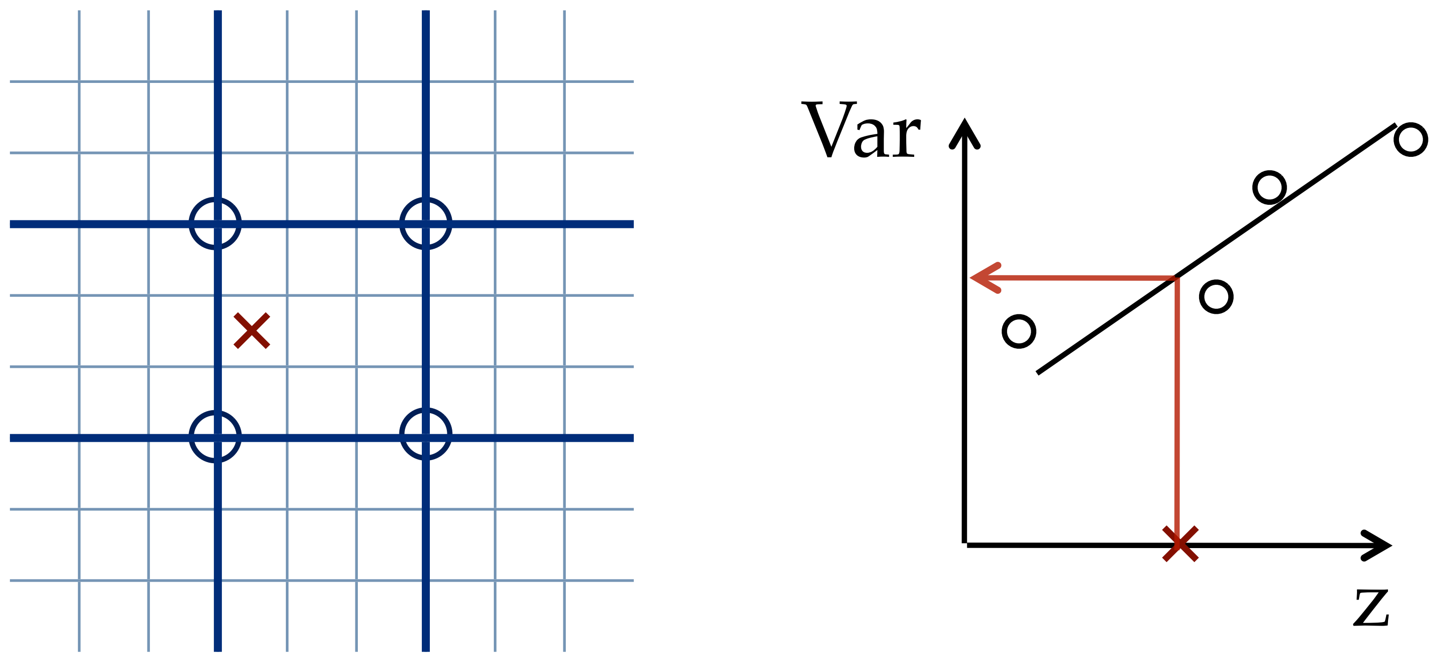
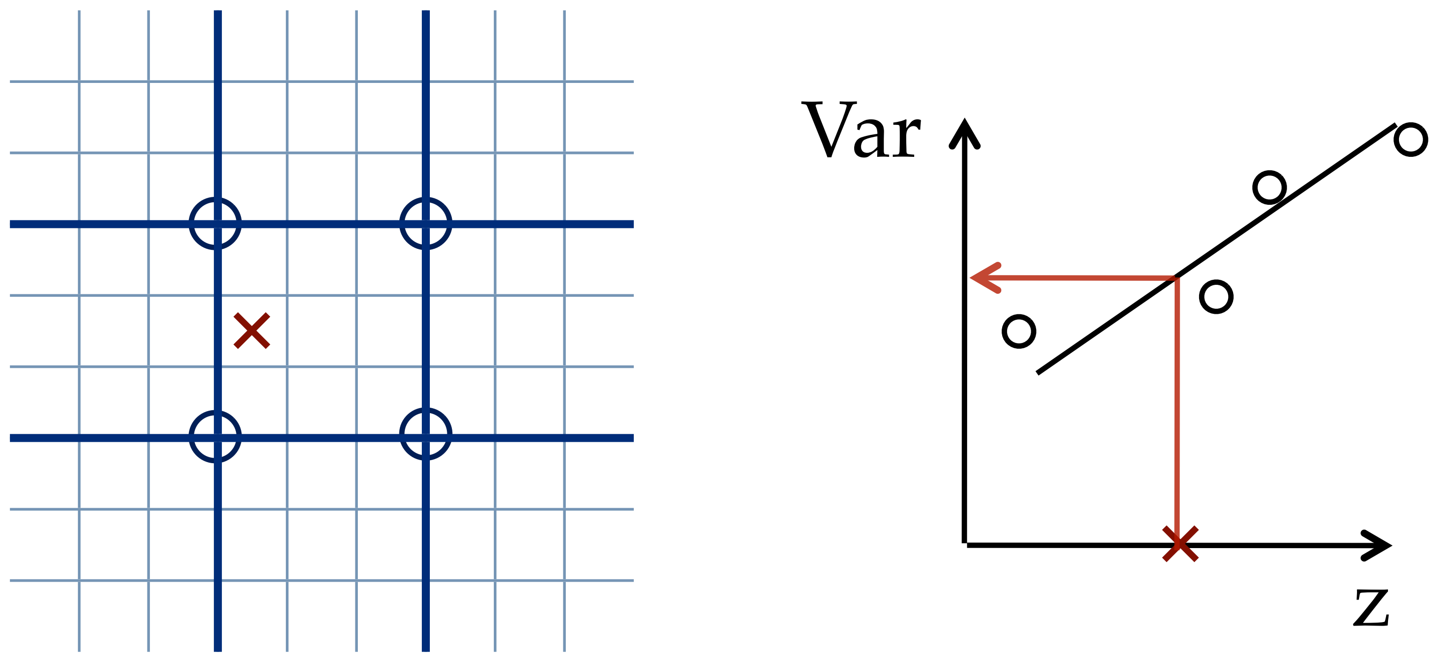


Surface scheme

Surface energy balance downscaling

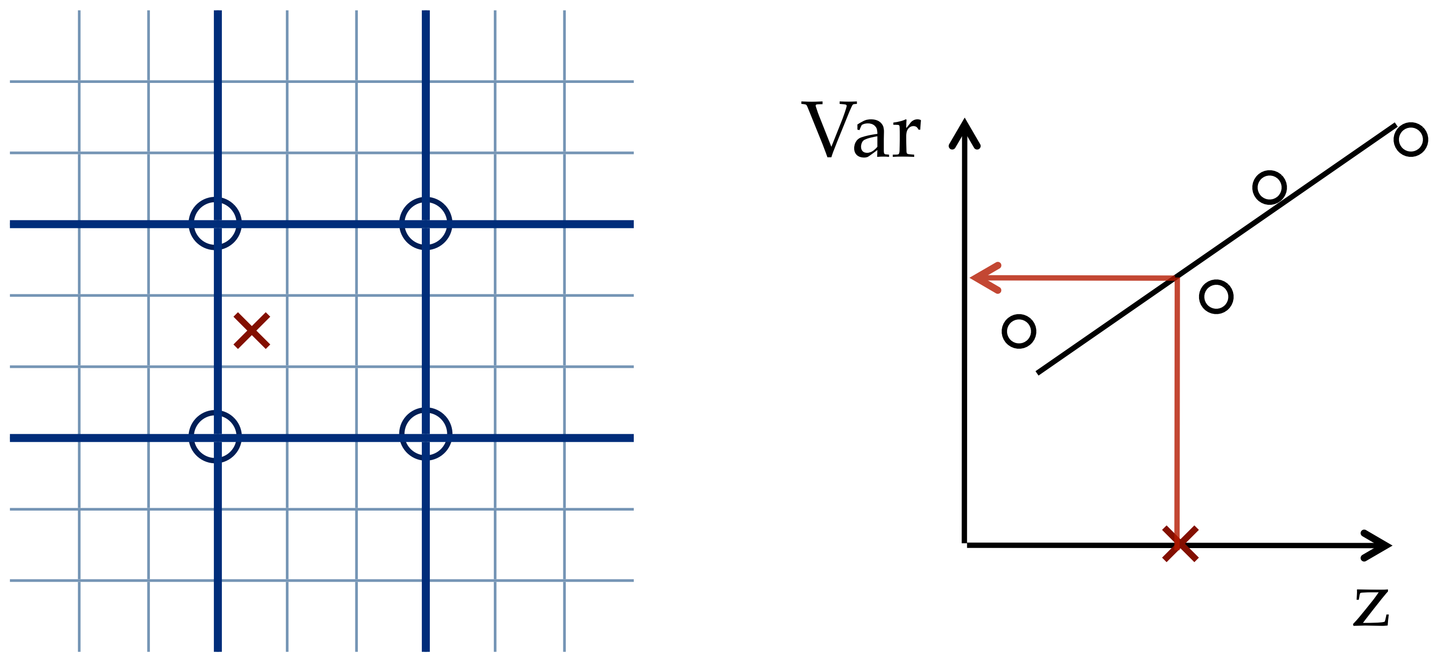
Local regression of large-scale surface fields against the topography



High-resolution precipitation → Surface scheme

2.3 Surface energy balance downscaling

Local regression of large-scale surface fields against the topography



High-resolution precipitation → Surface scheme **SISVAT** (from MAR)

↓

Sublimation
Melting
Refreezing

SMHiL

3.1 Downscaling of an atmospheric global climate model

LMDZ4

French Global Circulation Model (IPCC 2007)

Zoomed on the Antarctic continent

Climatic runs (decadal variability)

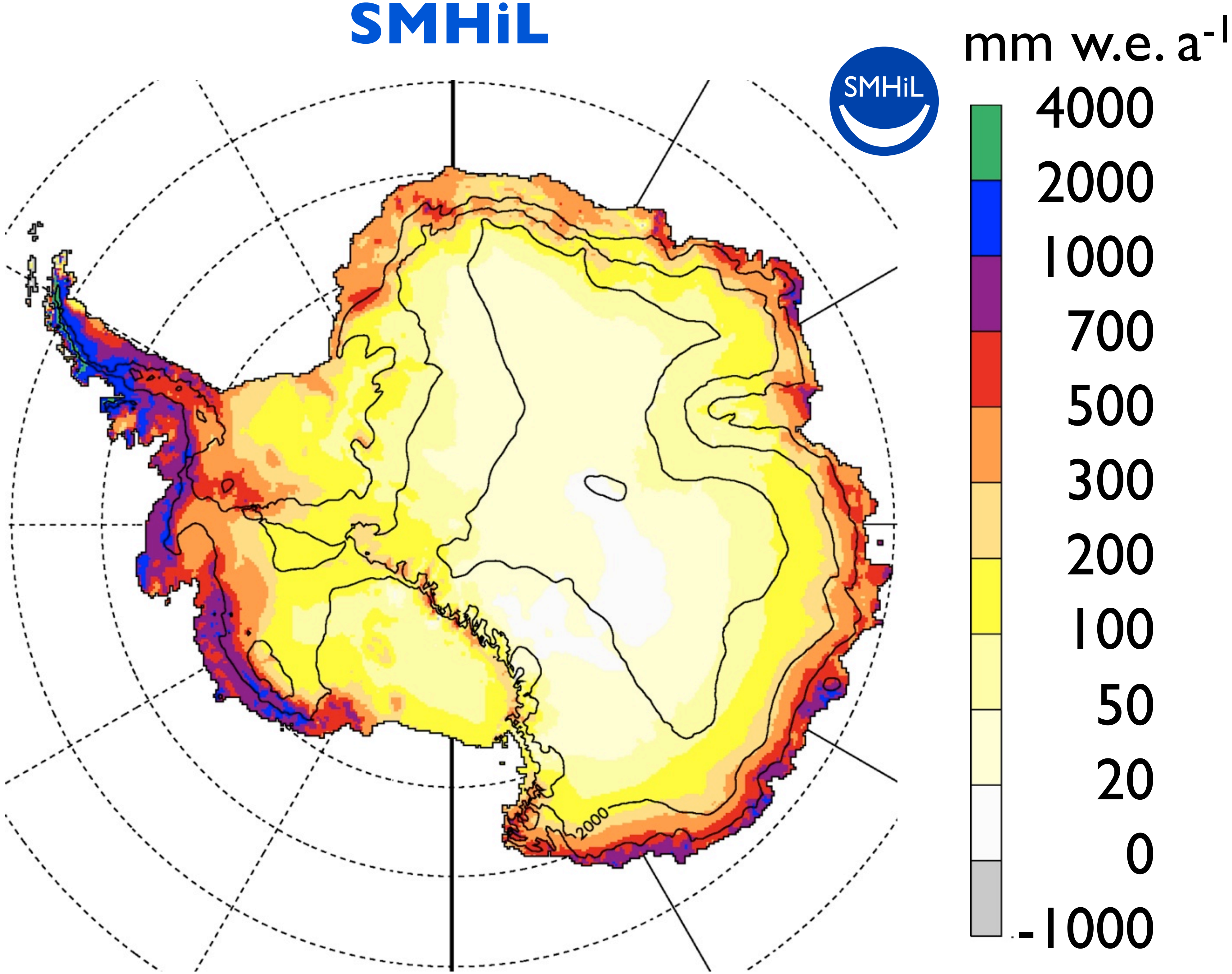
Antarctic horizontal resolution : 60 km

Runs : End of the 20th c. , 21st c. and 22nd c.

3.2 Impact of downscaling on SMB estimation

SMB LMDZ4 1981-2000

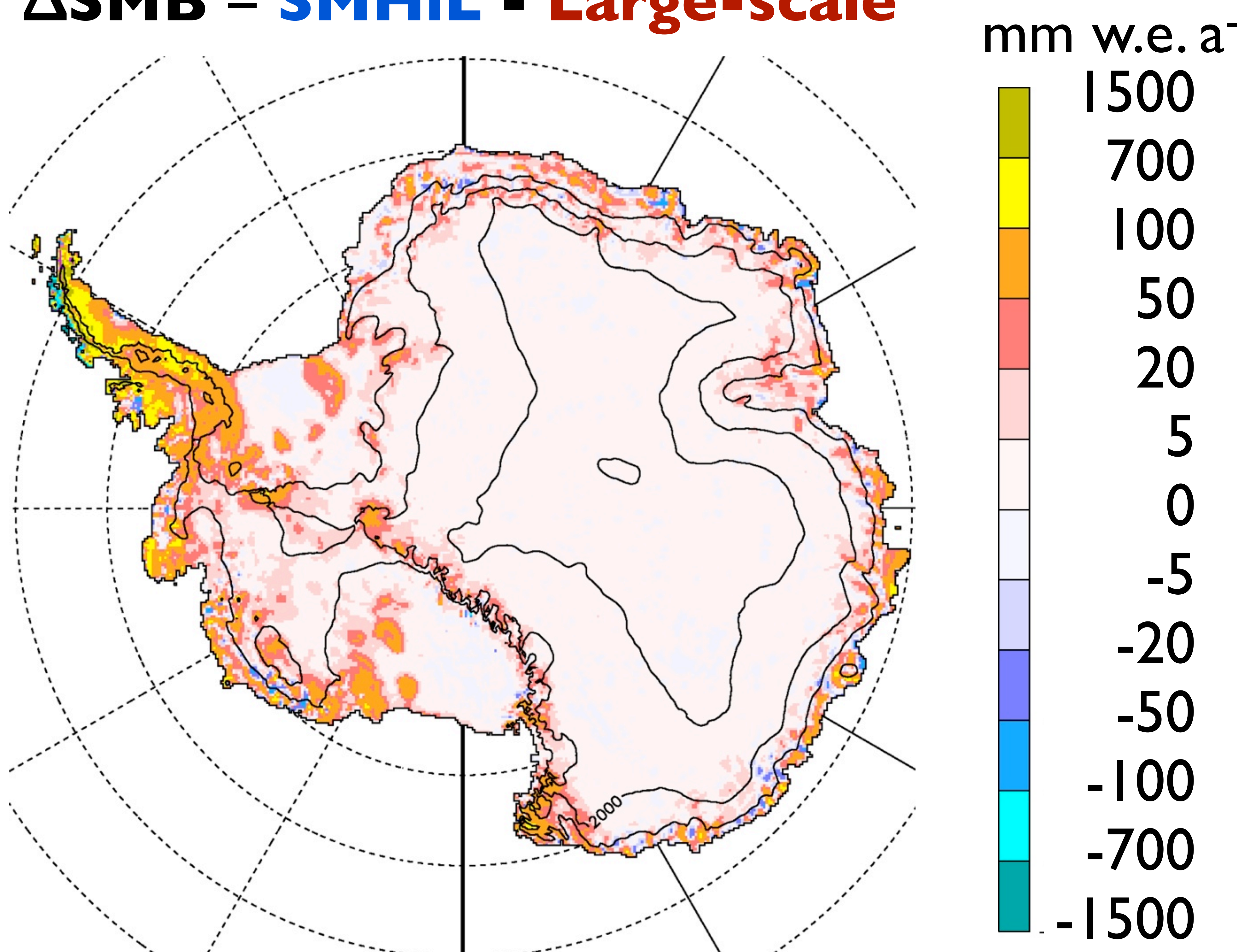
SMHiL



Impact of downscaling on SMB estimation

SMB LMDZ4 1981-2000

ΔSMB = SMHiL - Large-scale



3.2 Impact of downscaling on SMB estimation

Contribution of present Antarctic SMB to sea-level changes

LMDZ4

Large-scale	SMHiL	
- 5,6 mm/yr	- 6,5 mm/yr	(+17%) (- **0,9 mm/yr**)

ERA-Interim

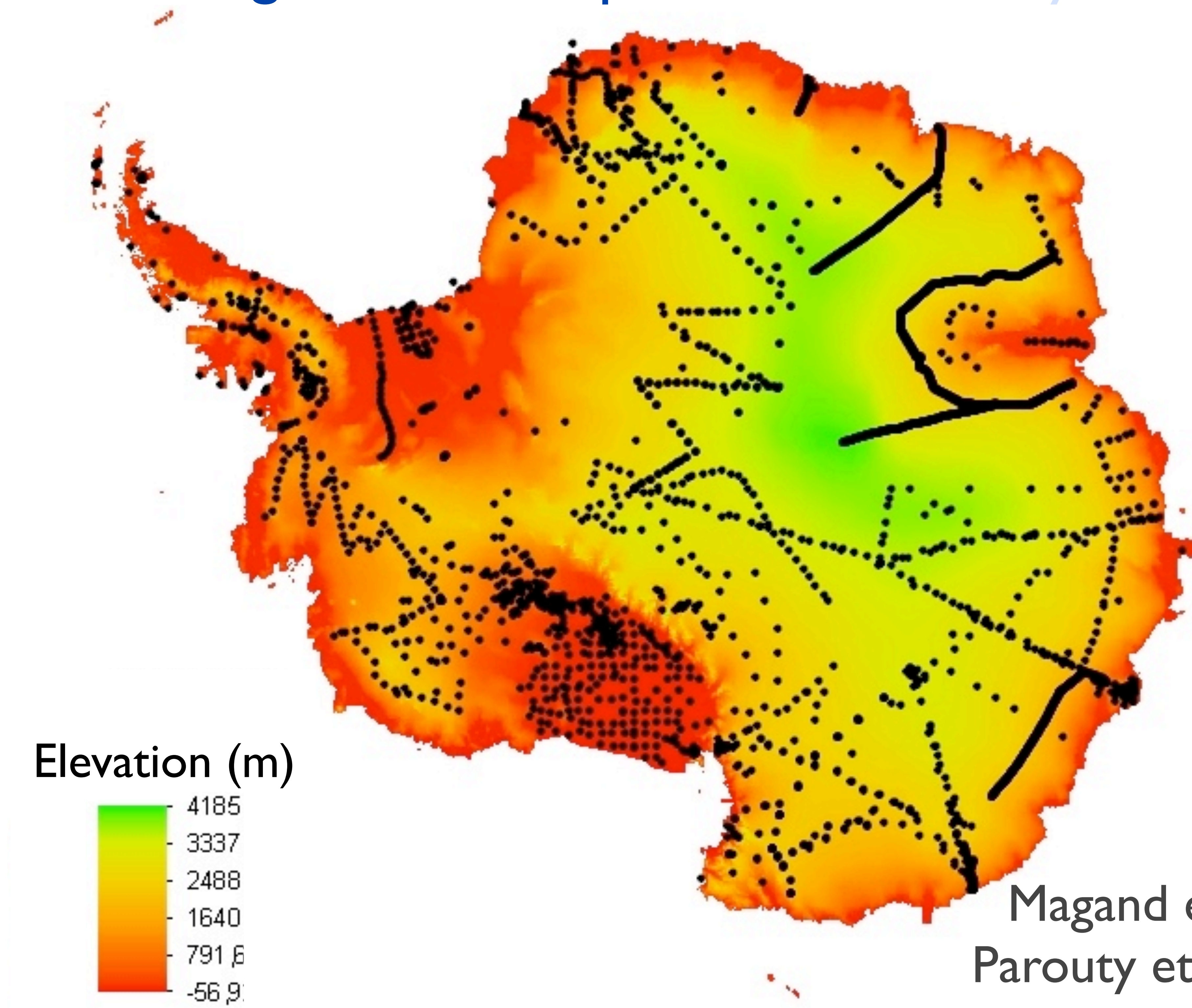
Large-scale	SMHiL	
- 4,4 mm/yr	- 5,5 mm/yr	(+26%) (- **1 mm/yr**)

Significantly different
How to validate it ?

Comparison to observations

SMB observations

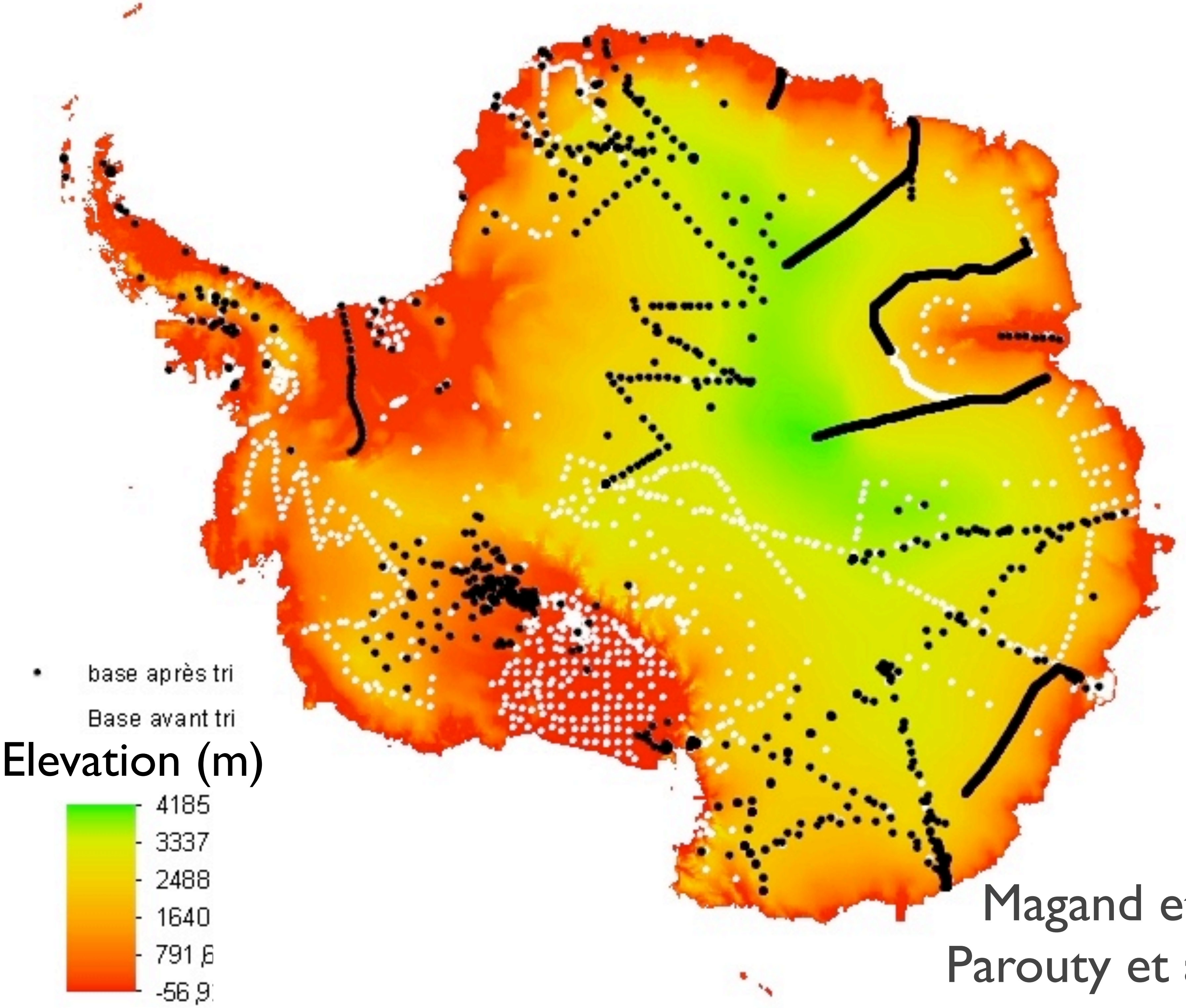
Climatological scale / Up-to-date / Quality-controled



Magand et al. (2007)
Parouty et al. (en prep.)

Comparison to observations

SMB observations
Climatological scale / Up-to-date / Quality-controled



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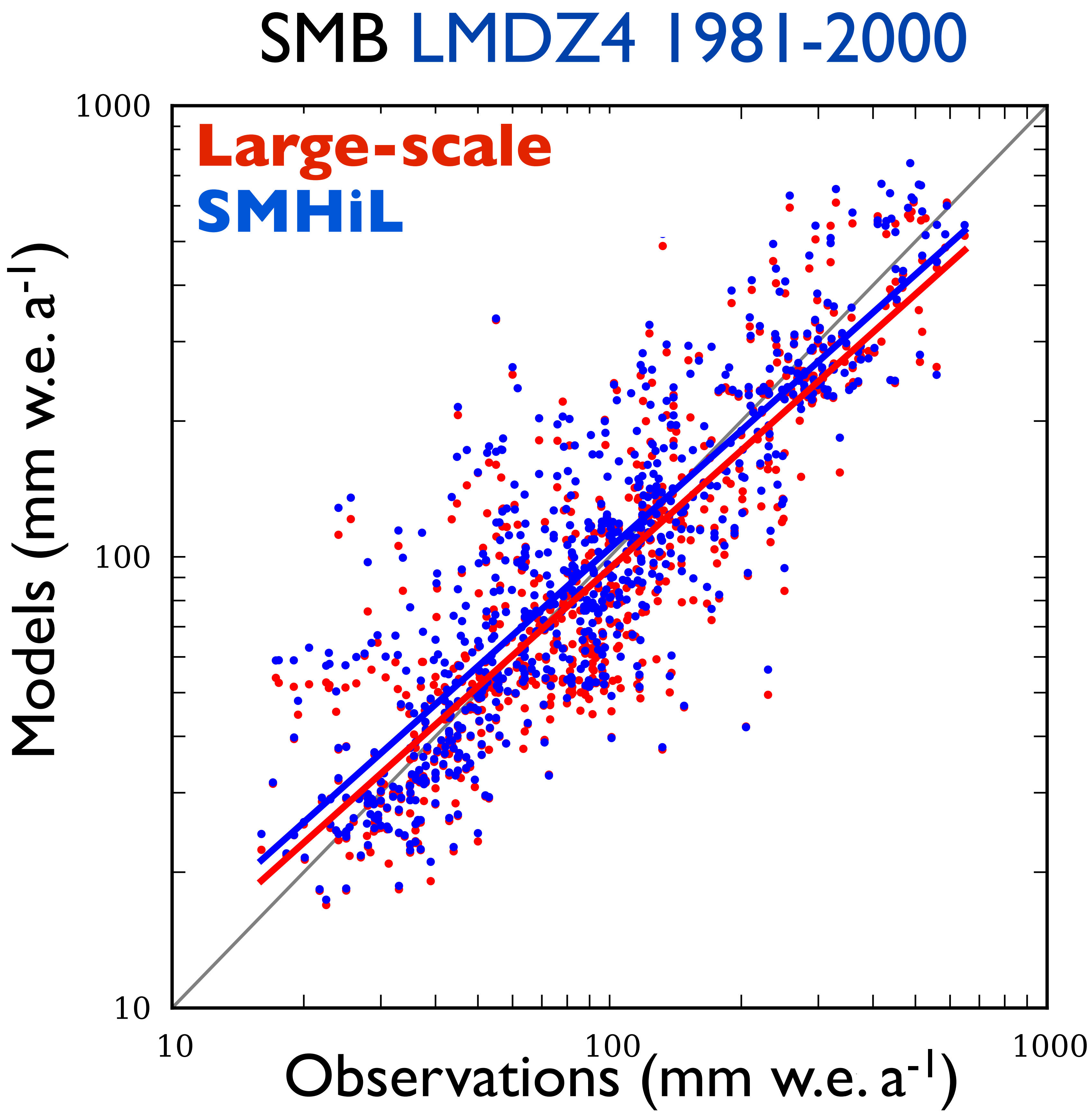
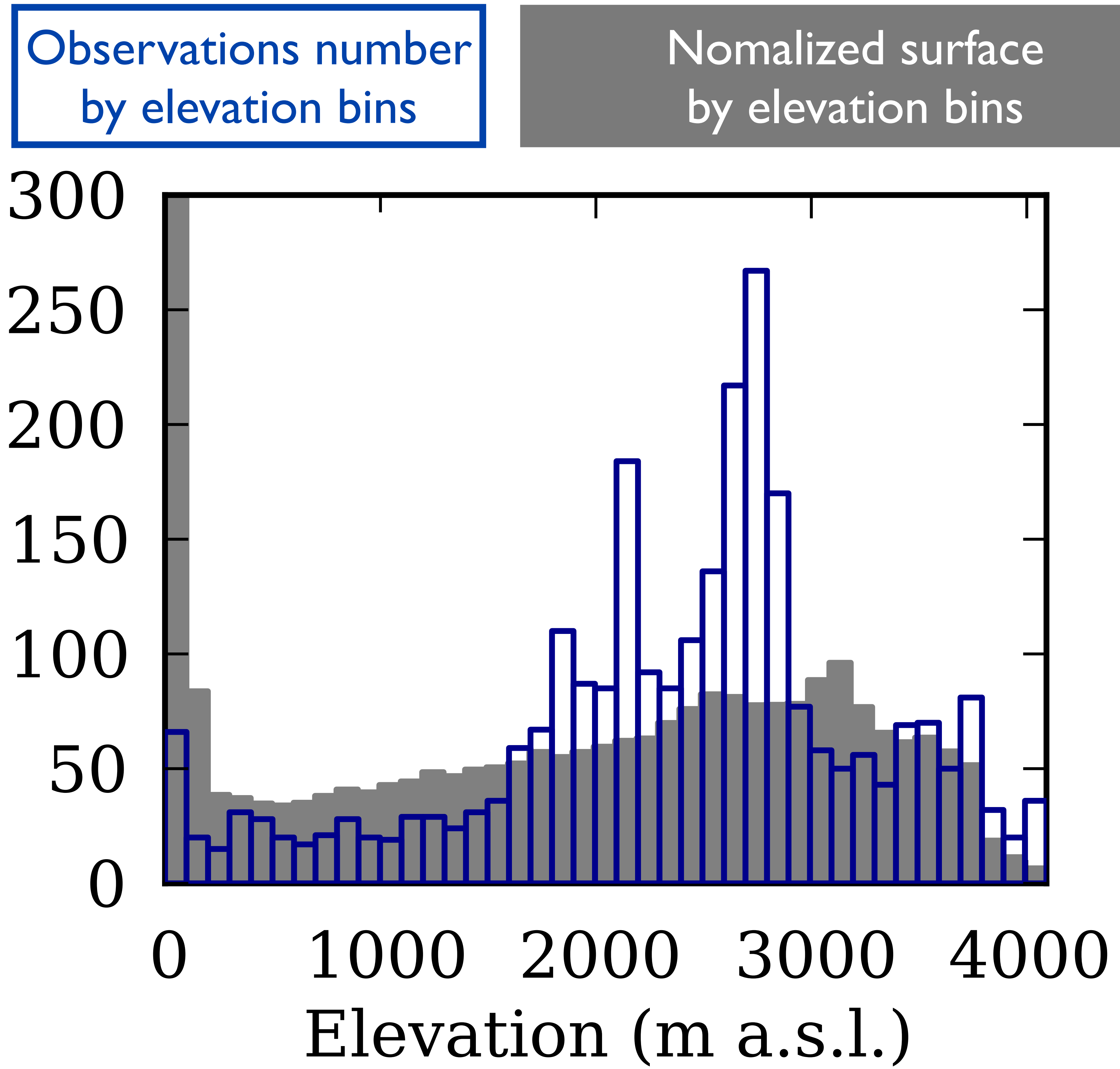
3.3 Comparison to observations

Goals 1
Model 2
3
Futur 4
Concl. 5



3.3 Comparison to observations



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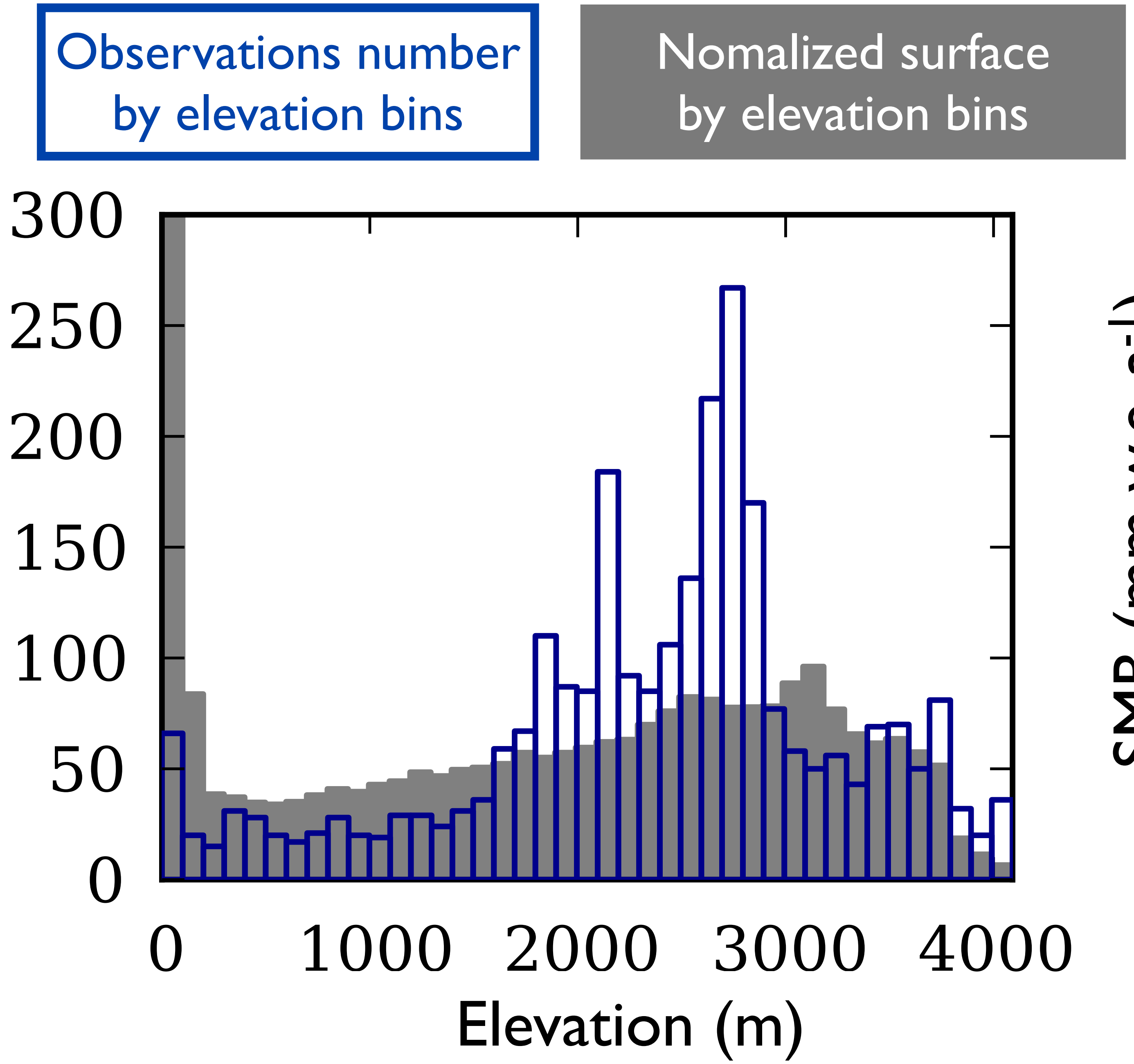
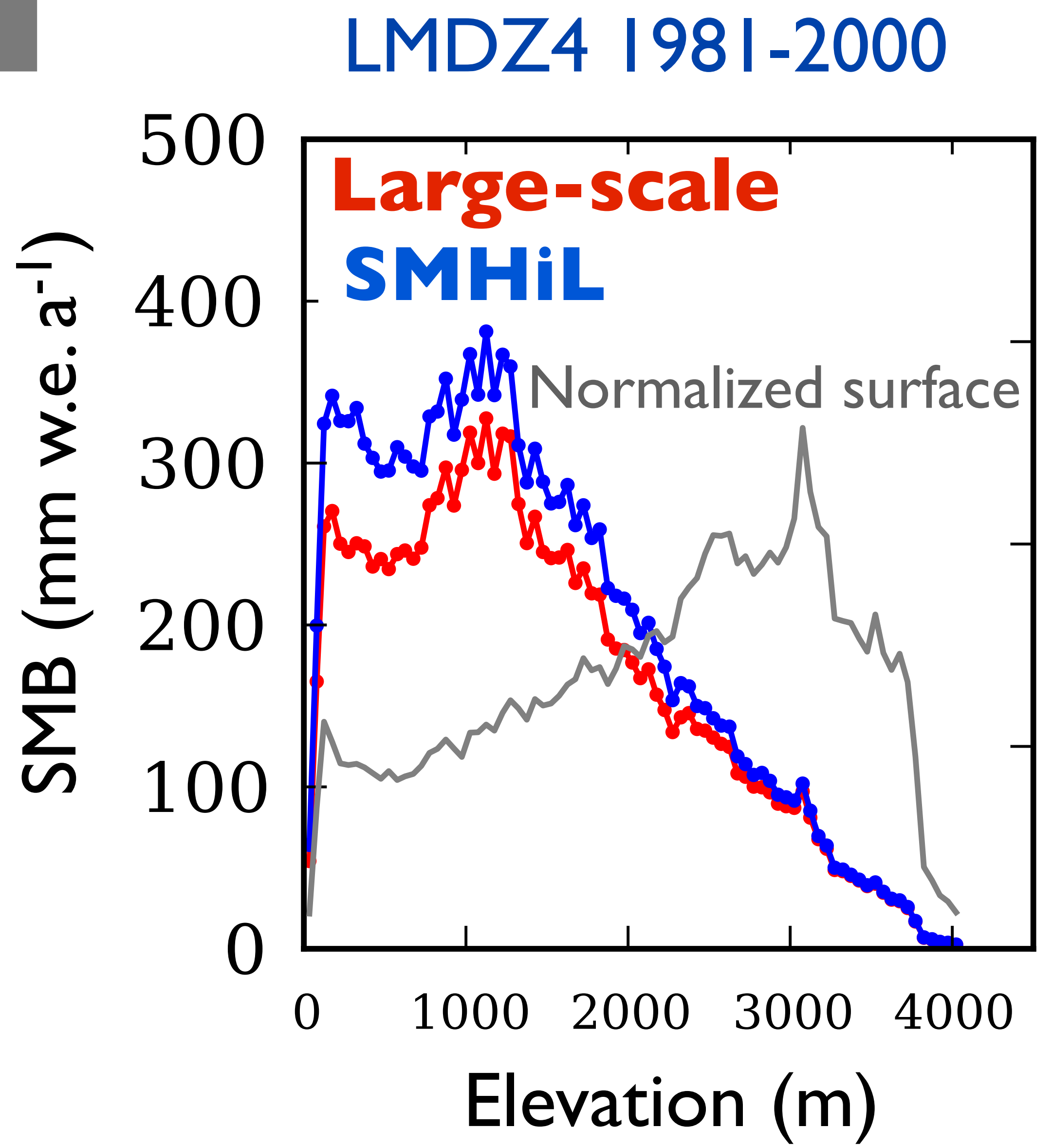
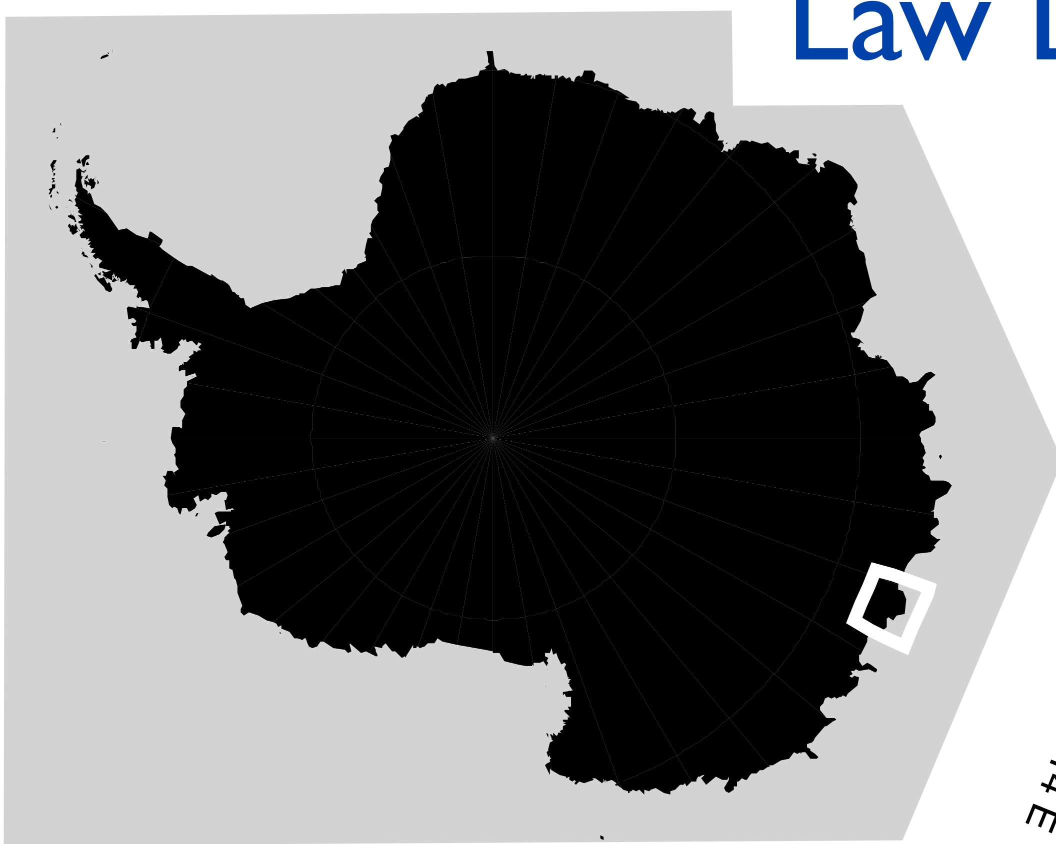
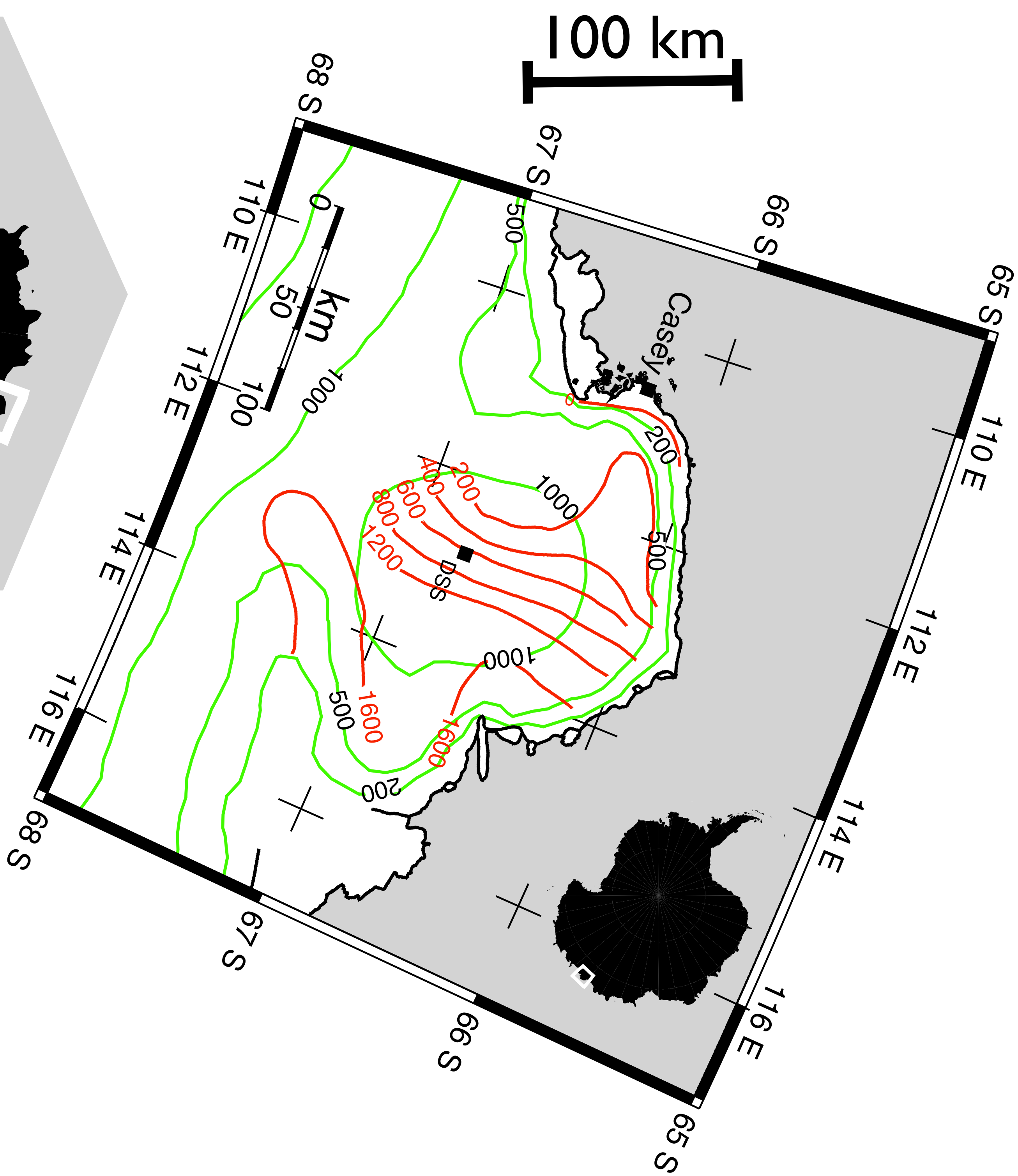




3.4 Validation over Law Dome

Law Dome





SMB climatology
van Ommen et al. 2004

3.4 Validation over Law Dome

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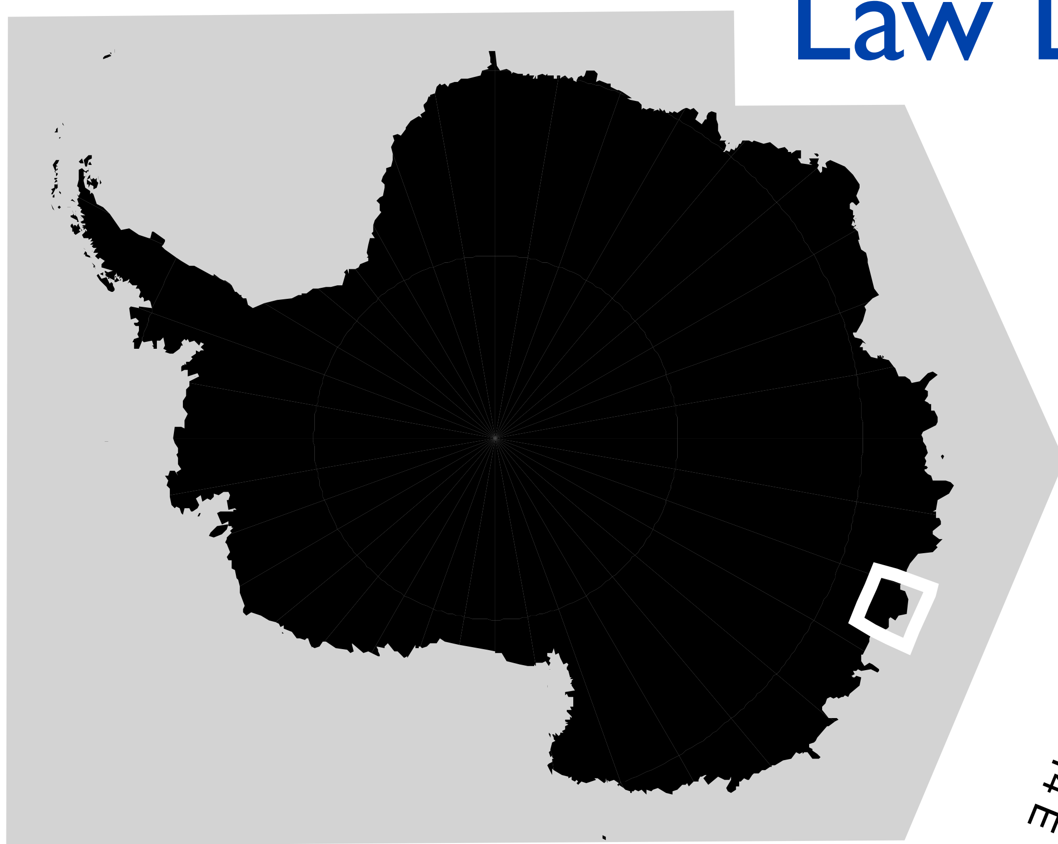

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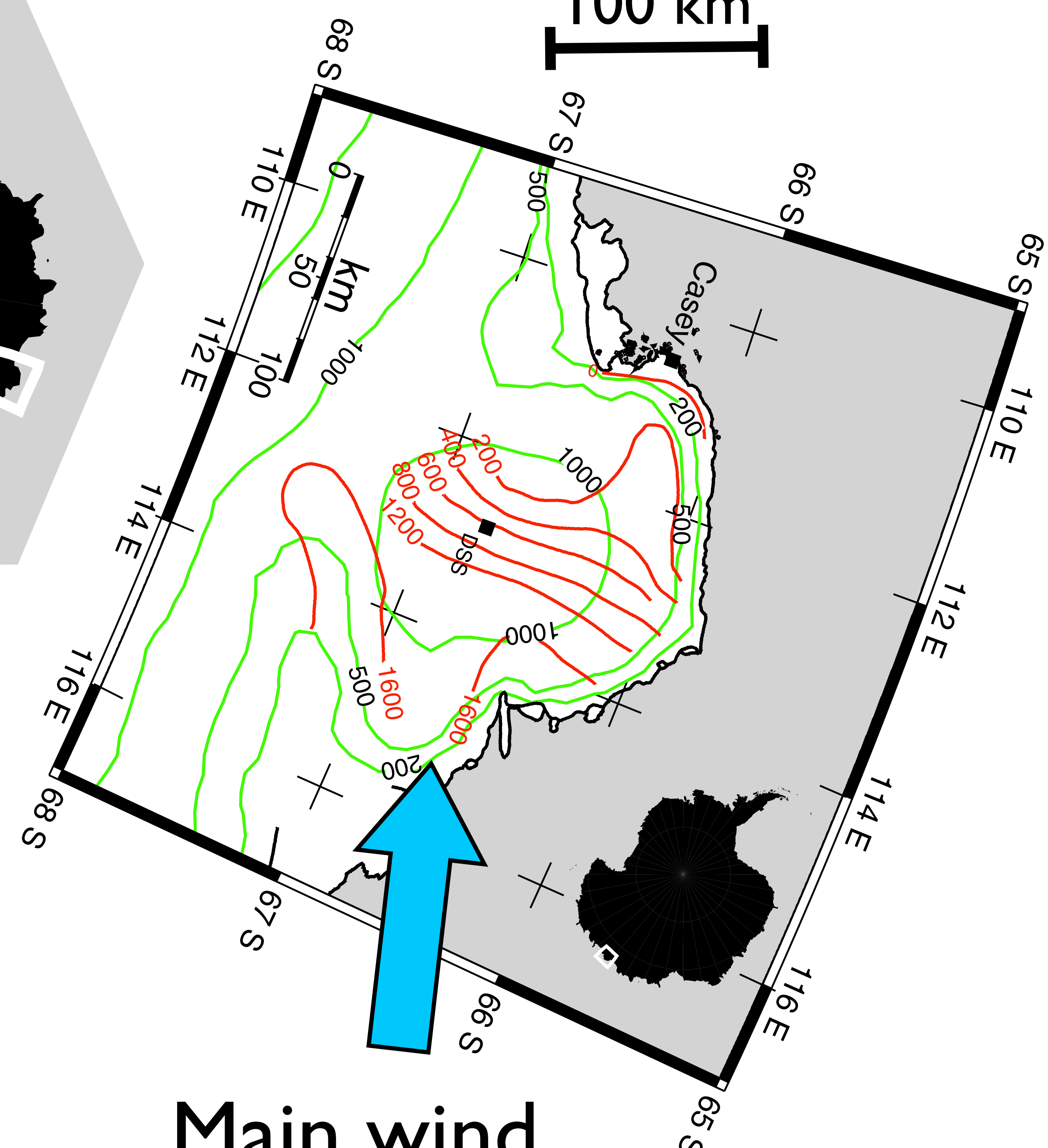
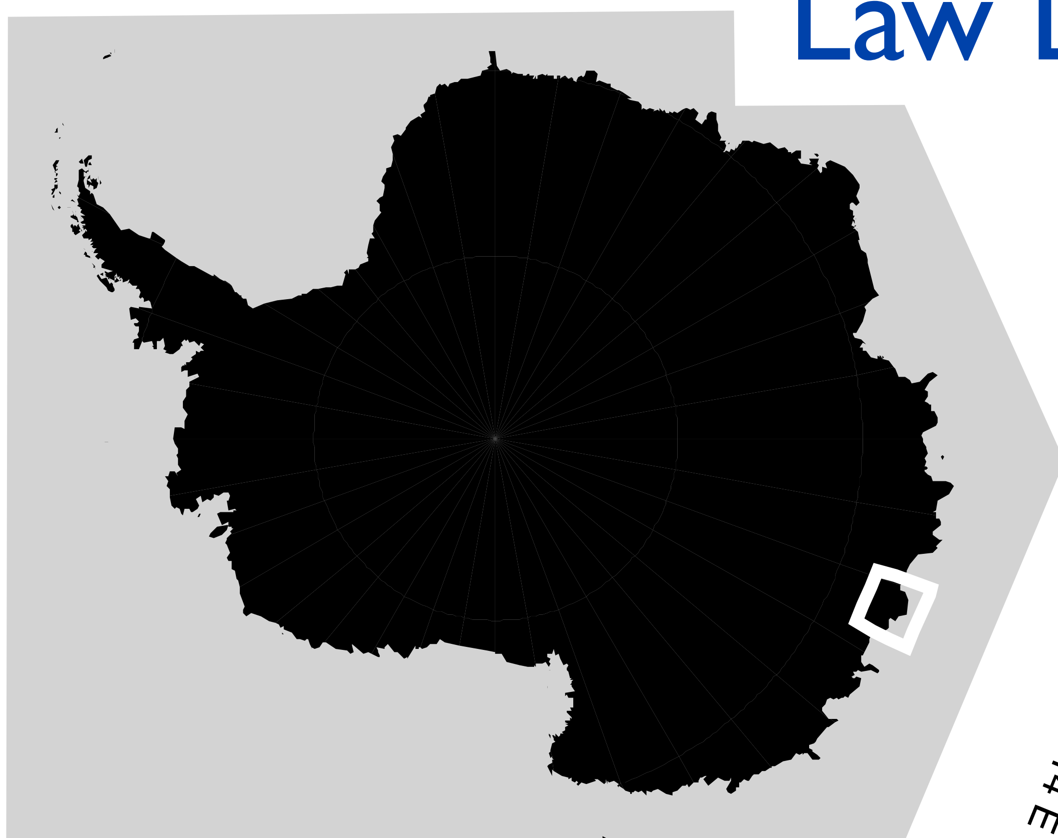


Main wind

3.4

Validation over Law Dome

Law Dome



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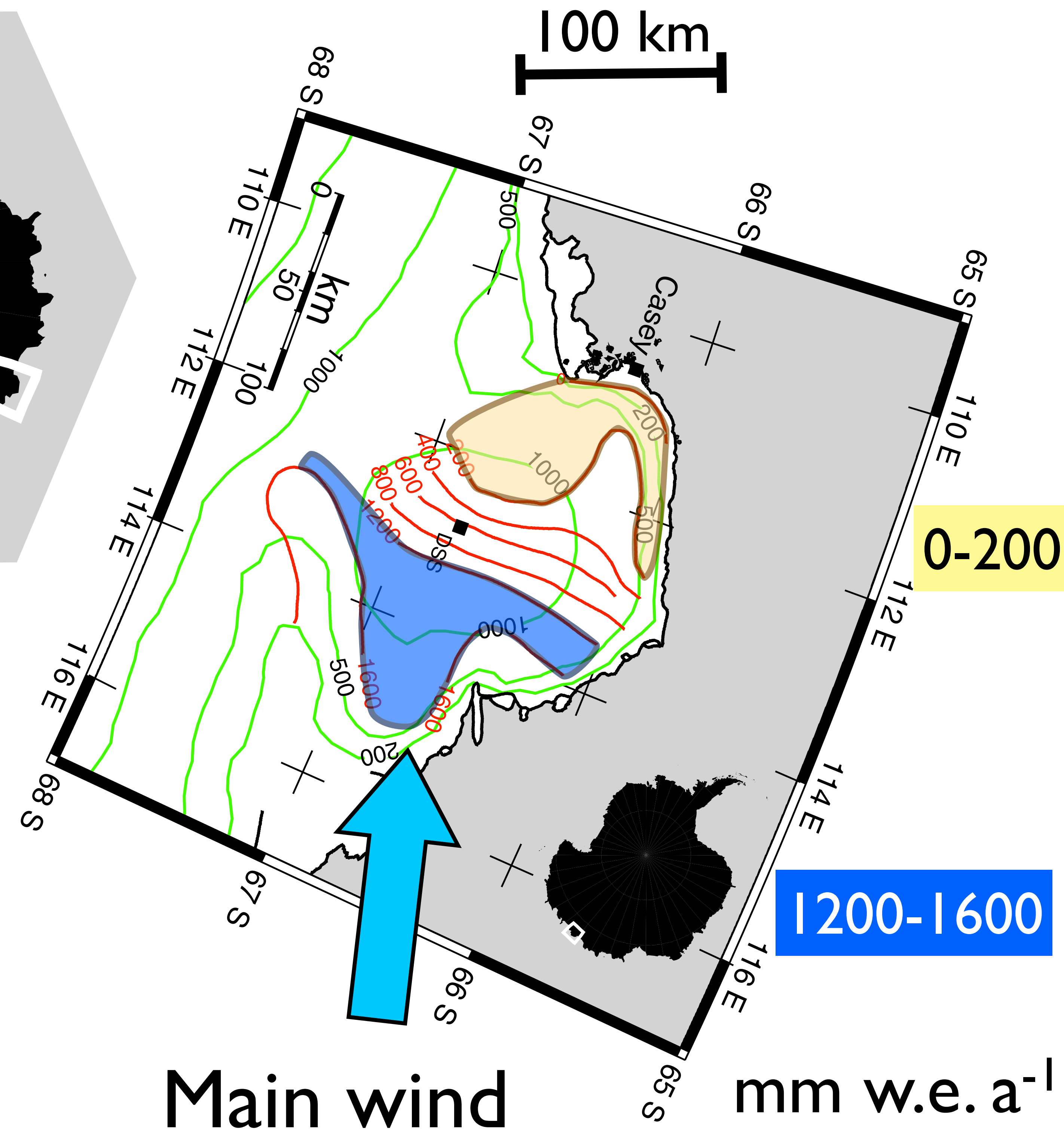

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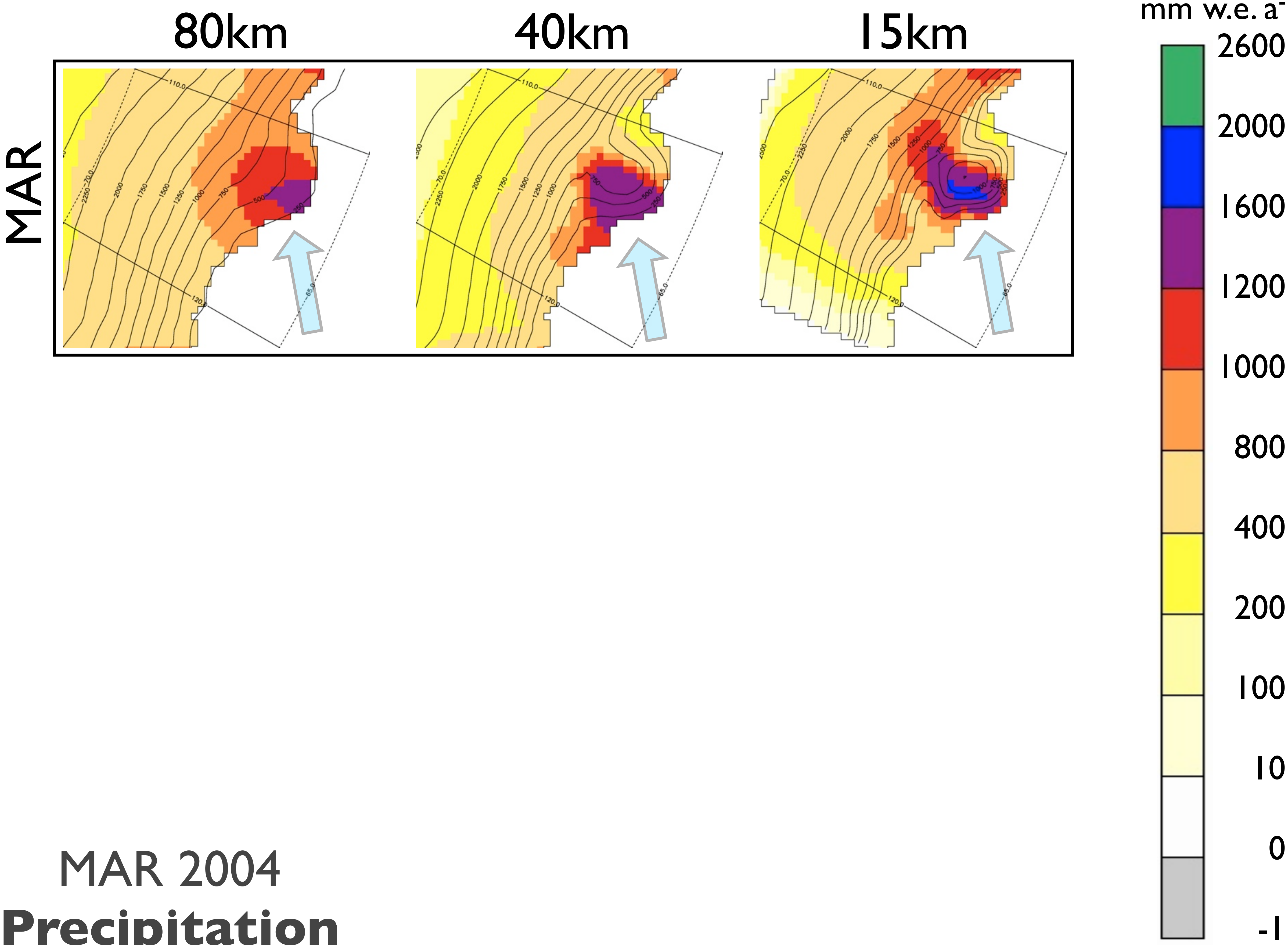
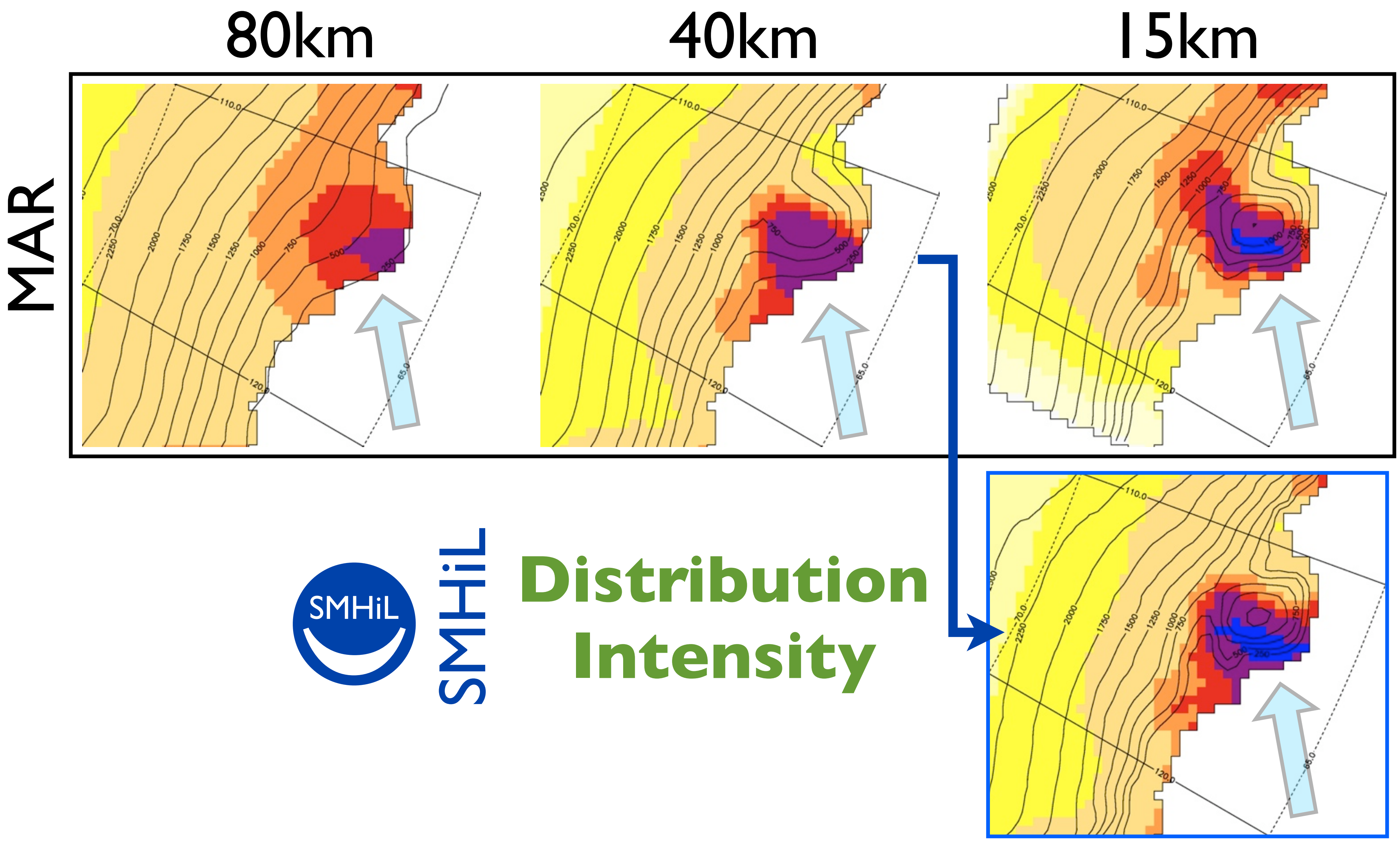
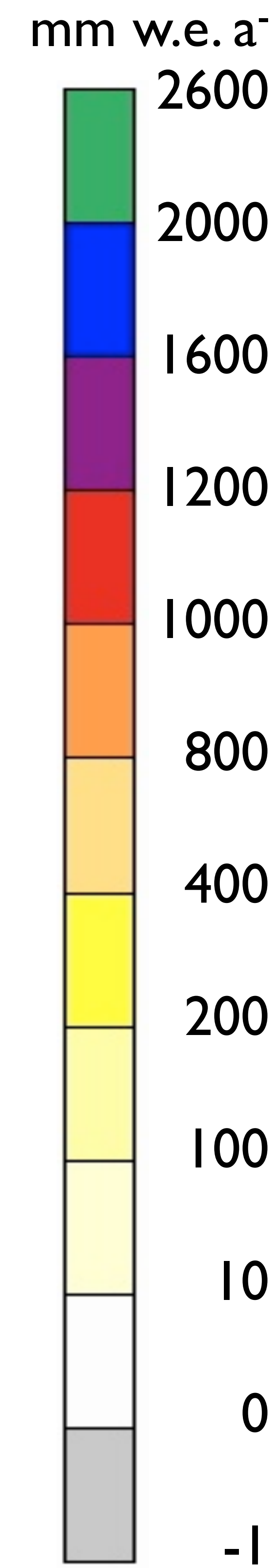


MAR 2004

Precipitation

Validation over Law Dome





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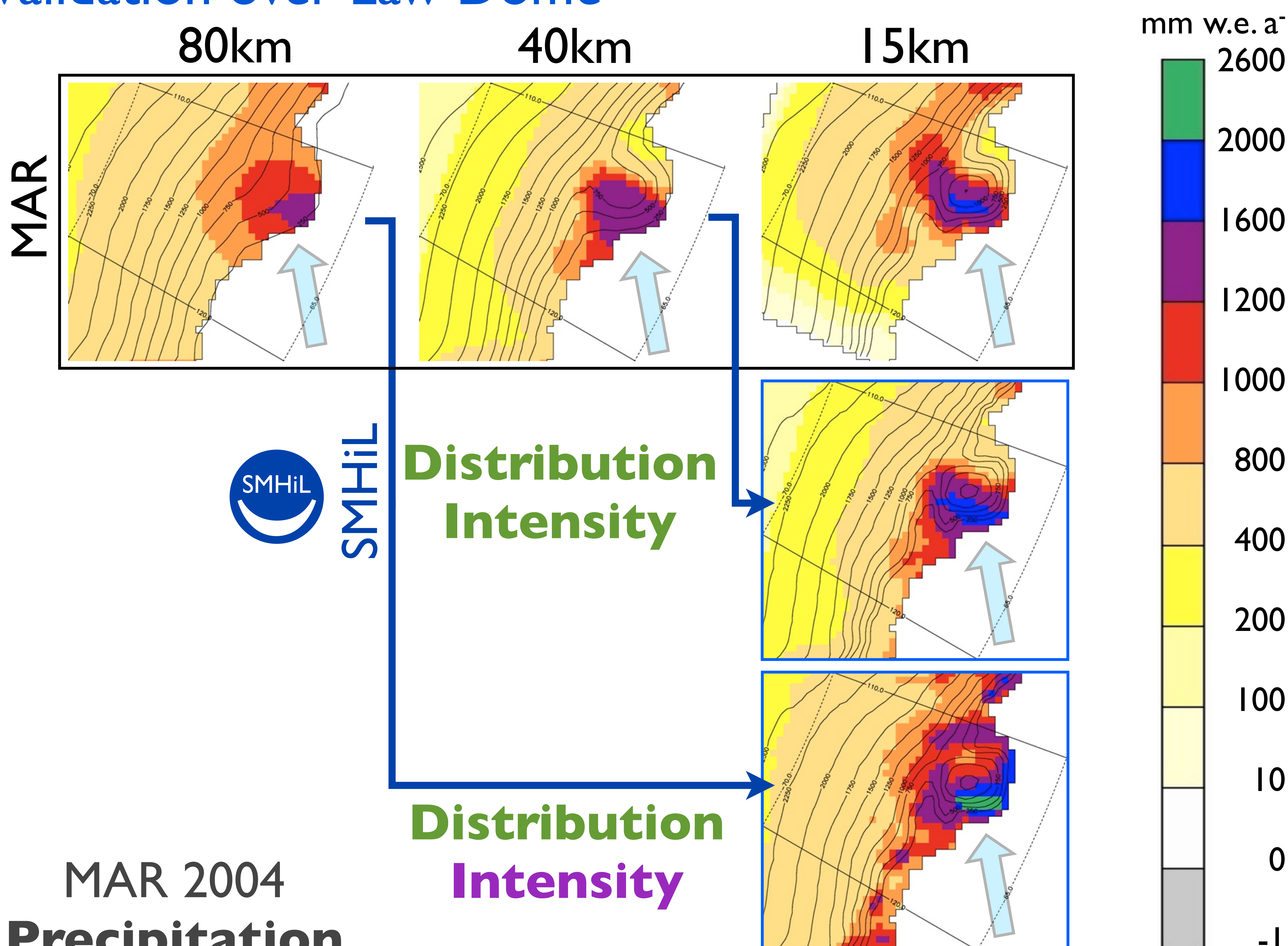

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3.4 Validation over Law Dome

SMHiL

Spatial pattern and intensity better displayed

Air drying to be improved

Linked to **large-scale model** processes and resolution

Scenarios and forcings

LMDZ4

Atmospheric global climate model

	End of the 20th century	21st century / 22nd century
Green-house gases emission scenarios	Observations	A1B *«Realistic»* E1 *«Optimistic»*
Ocean forcings *Sea surface temperature* *Sea-ice concentration*	Observations	HADCM3 ECHAM5 *Anomalies*

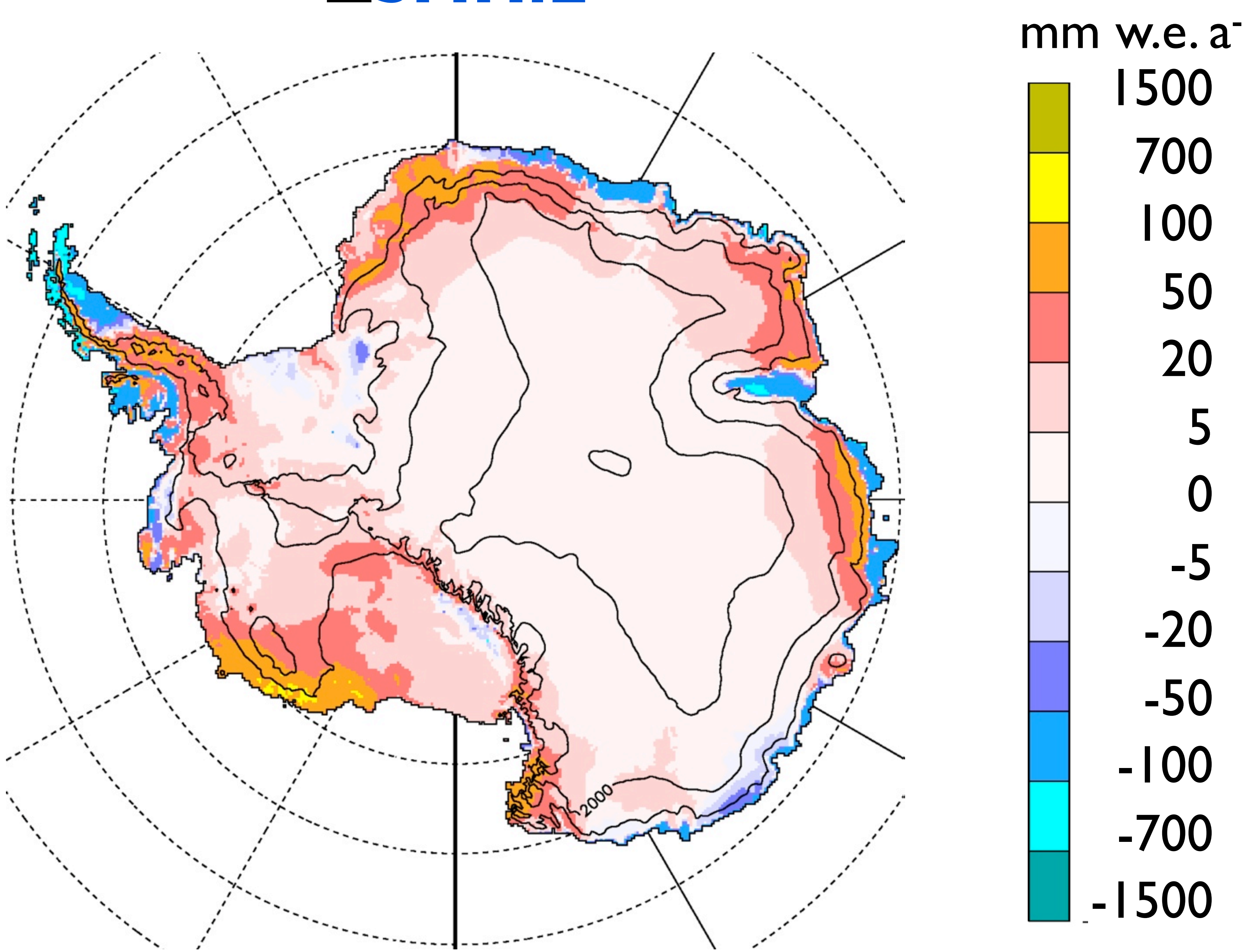
→ **700 years**

SMB evolution

A1B
HADCM3

Δ = SMB End 21st - SMB End 20th century

ΔSMHiL

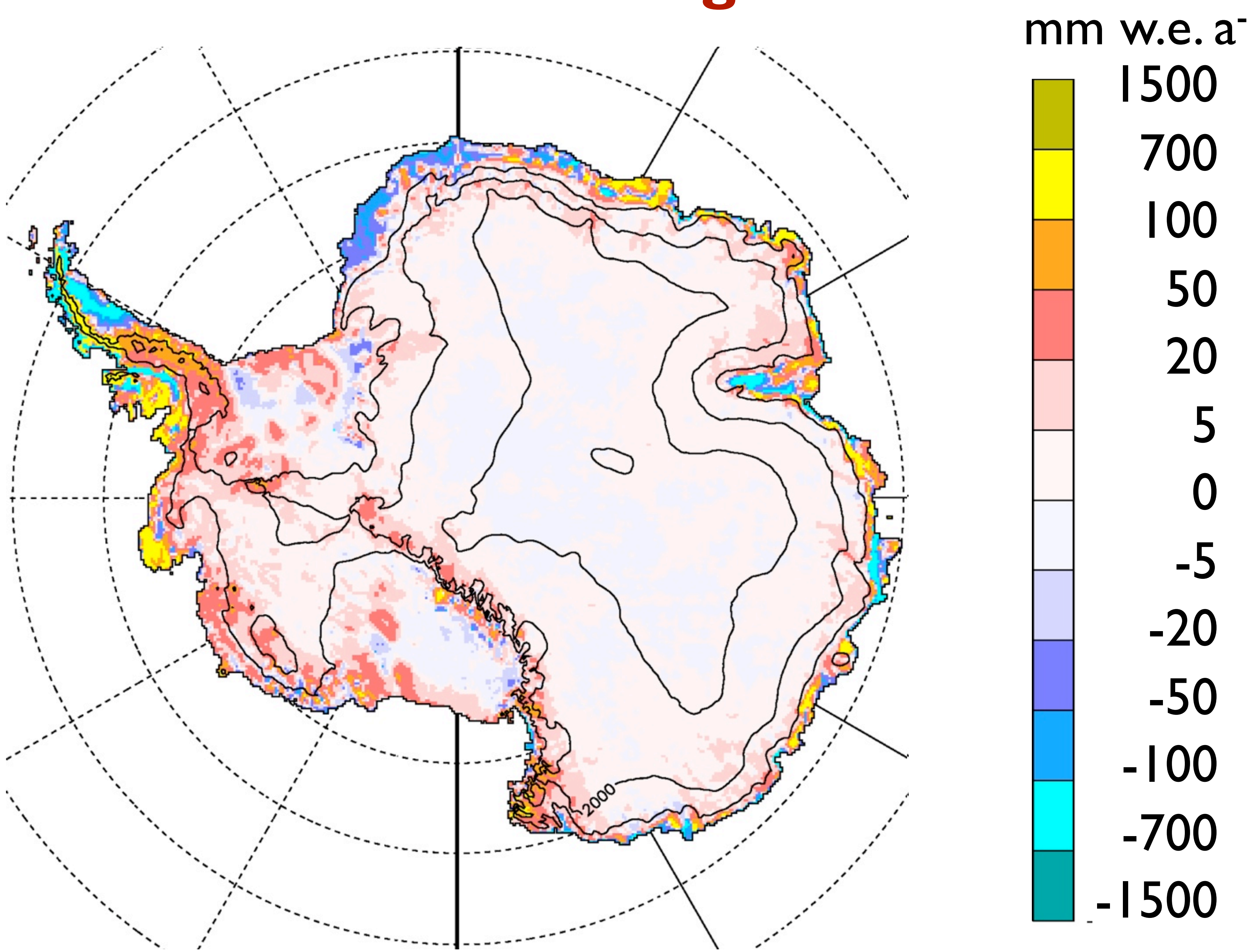


4.2 SMB evolution

A1B
HADCM3

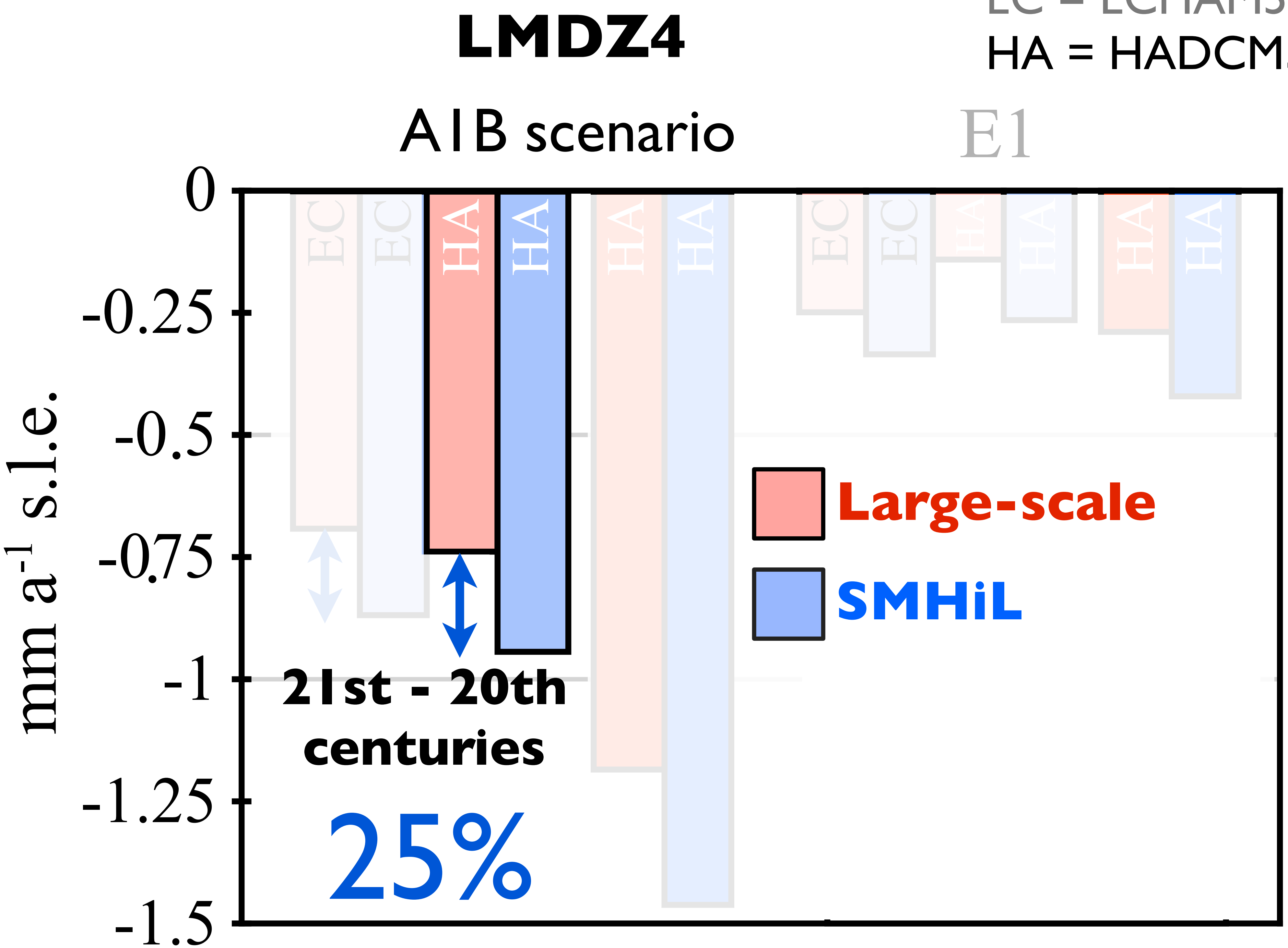
Δ = SMB End 21st - SMB End 20th century

ΔSMHiL - ΔLarge-scale



4.3 SMB contribution to sea-level changes

EC = ECHAM5
HA = HADCM3



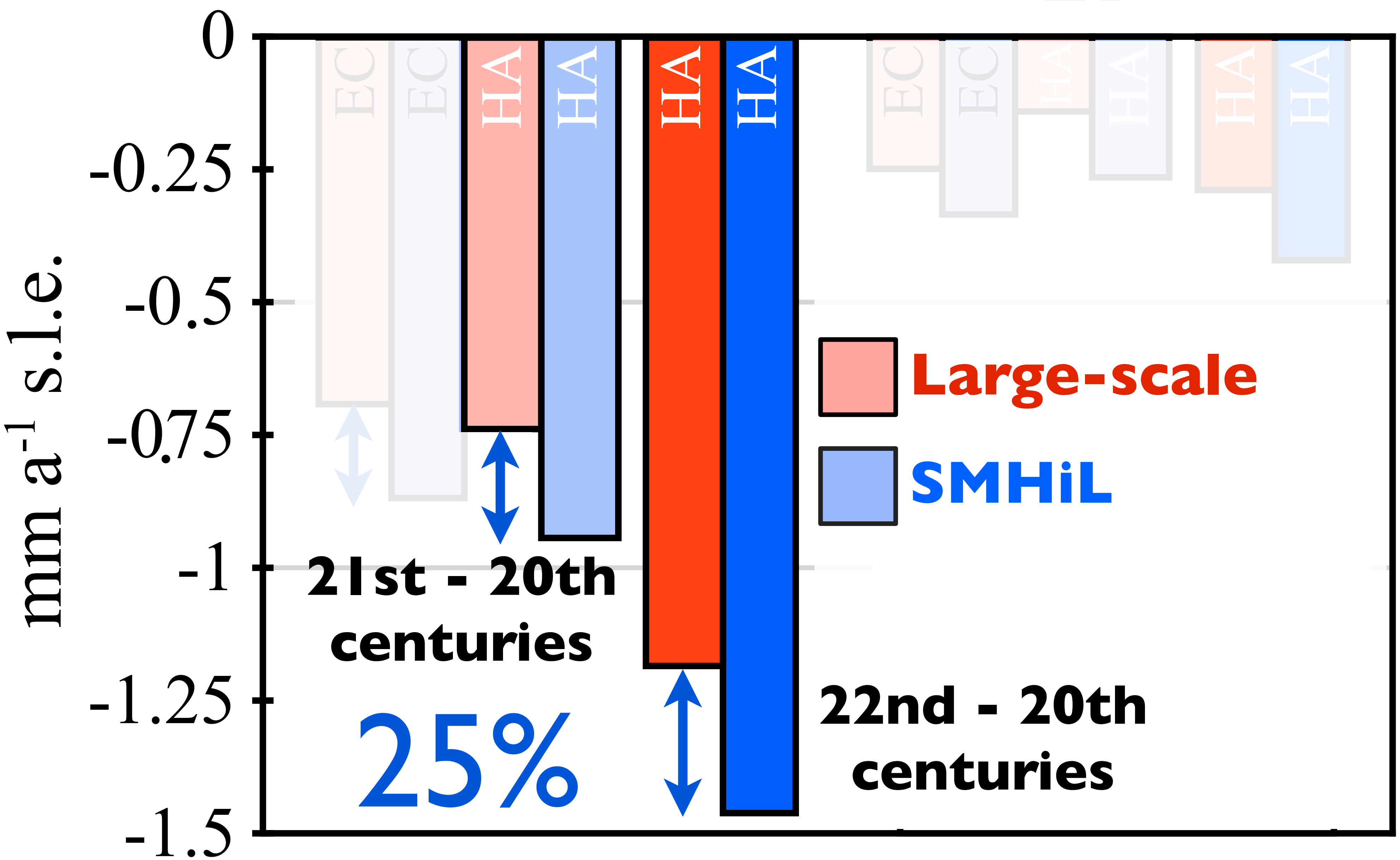
SMB contribution to sea-level changes

EC = ECHAM5
HA = HADCM3

LMDZ4

A1B scenario

E1



Conclusions

SMHiL

Based on physical parametrization

Performant over ice-sheets

Fast computing

Conclusions

SMHiL

Based on physical parametrisation

Performant over ice-sheets

Fast computing

Compute the impact of the high-resolution topography on surface mass balance

Highest resolution ever tested for climatic runs over Antarctica

Outcomes

High-resolution SMB (present / evolution) significantly different from large-scale SMB

To be implemented

Moisture advection

Under-representation of observation in low-elevation areas where the SMB variability/amount is the highest

Crutial need of observations :

In coastal areas / Large spatial extent / Long-term measurements

Other methods for downscaling validation :

Comparison to a regional climate model

Outcomes

High-resolution SMB (present / evolution) significantly different from large-scale SMB

To be implemented

Humidity advection

Snow drift ?

Under-representation of observation in low-elevation areas where the SMB variability/amount is the highest

Crutial need of observations :

In coastal areas / Large spatial extent / Long-term measurements

Other methods for downscaling validation :

Comparison to a regional climate model

Outcomes

Best use of SMHiL :

SMHiL ~15km — 3

↑

Best **regional atmospheric model** over Antarctica
(polar processes, high resolution)
MAR ~40km — 2

↑

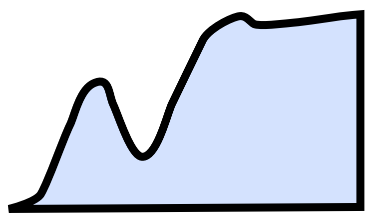
Best **GCM** over Antarctica
(circulation - temperature - albedo)
to be chosen among CMIP5 GCMs ~80km — 1


Thank you

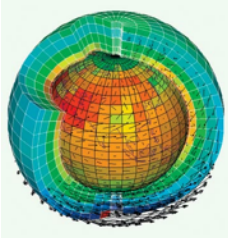
Aim of the downscaling ?

Surface mass balance downscaling

High-resolution
topography



Complex models outputs
Physics + / Resolution -



Simplified physical equations
Limited computational costs

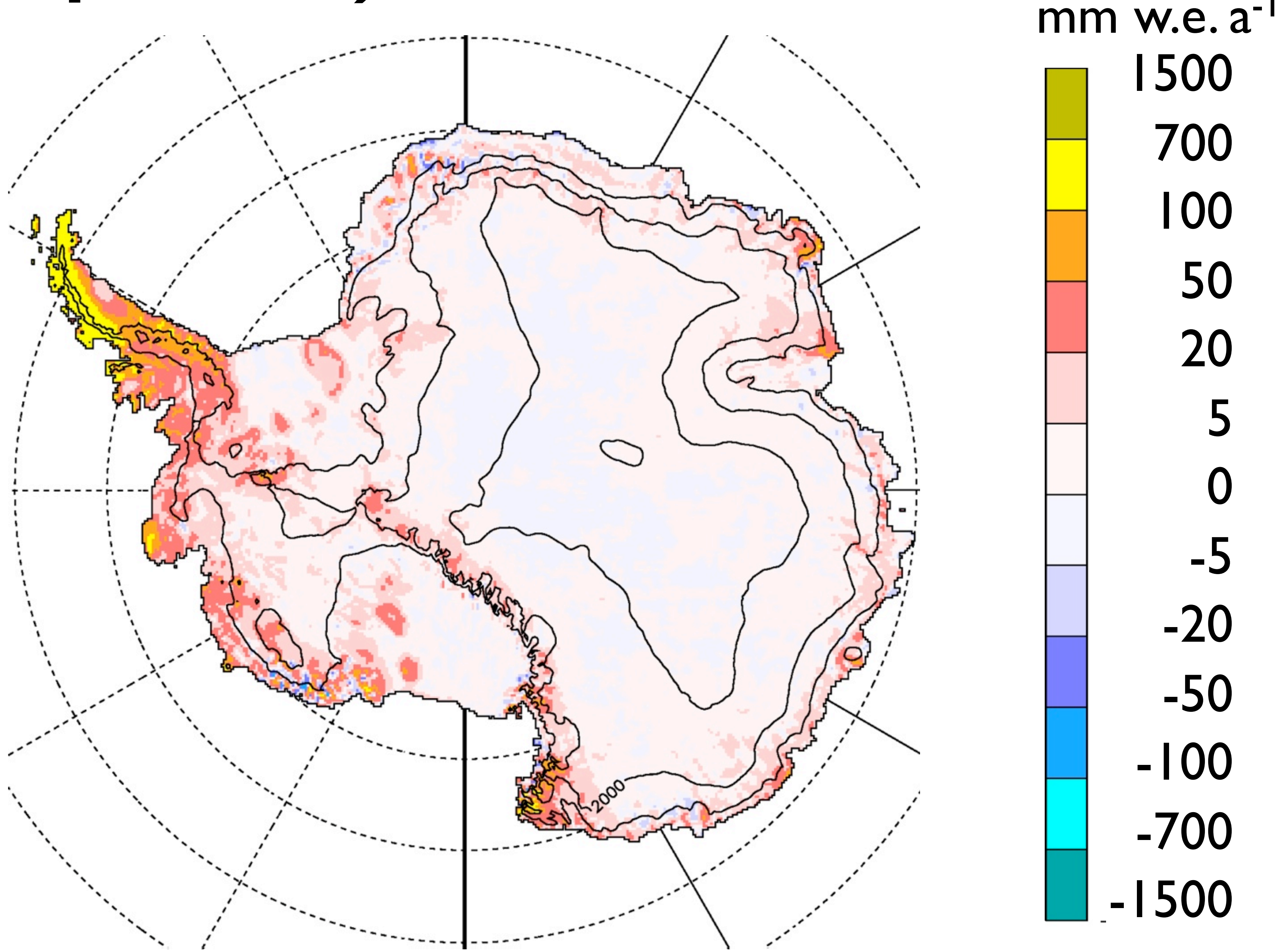
High-resolution SMB

from various large-scale climate models

4.2 Evolution du BMS

ΔLMDZ4 = 21e - 20e siècle (évolution)

Δ(ΔPrecipitations) = ΔSMHiL - ΔGrande échelle



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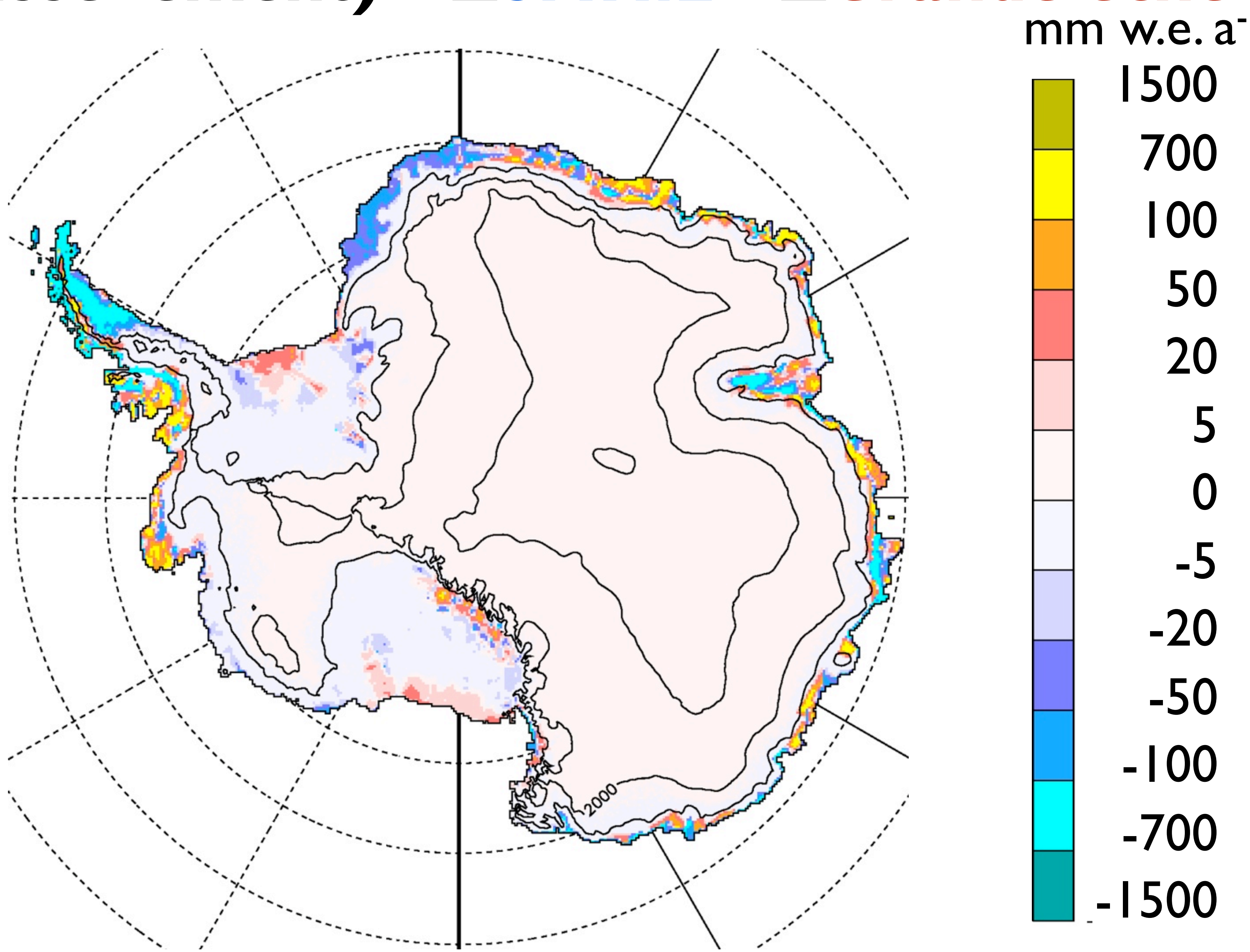
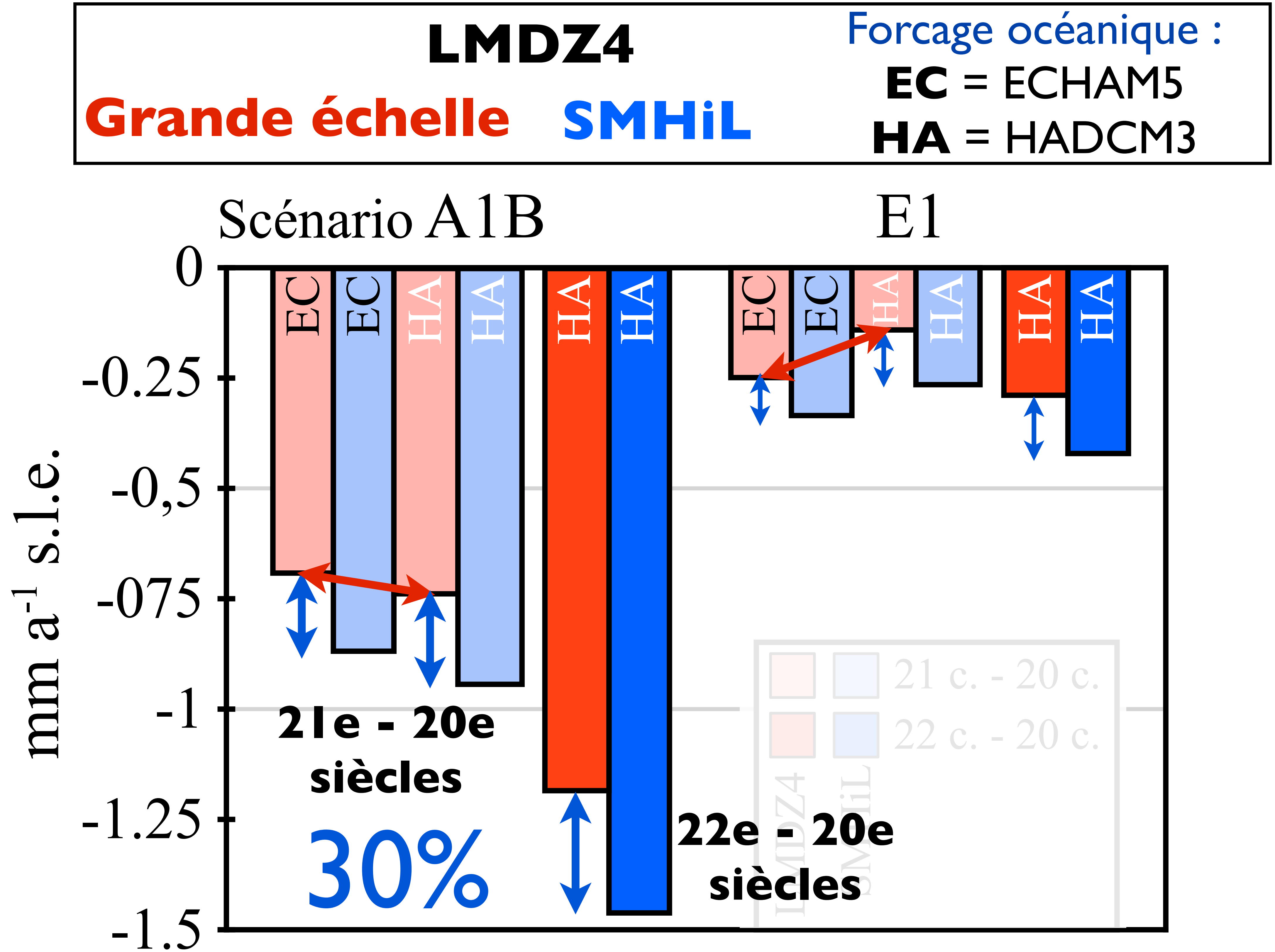
ΔLMDZ4 = 21e - 20e siècle (évolution)

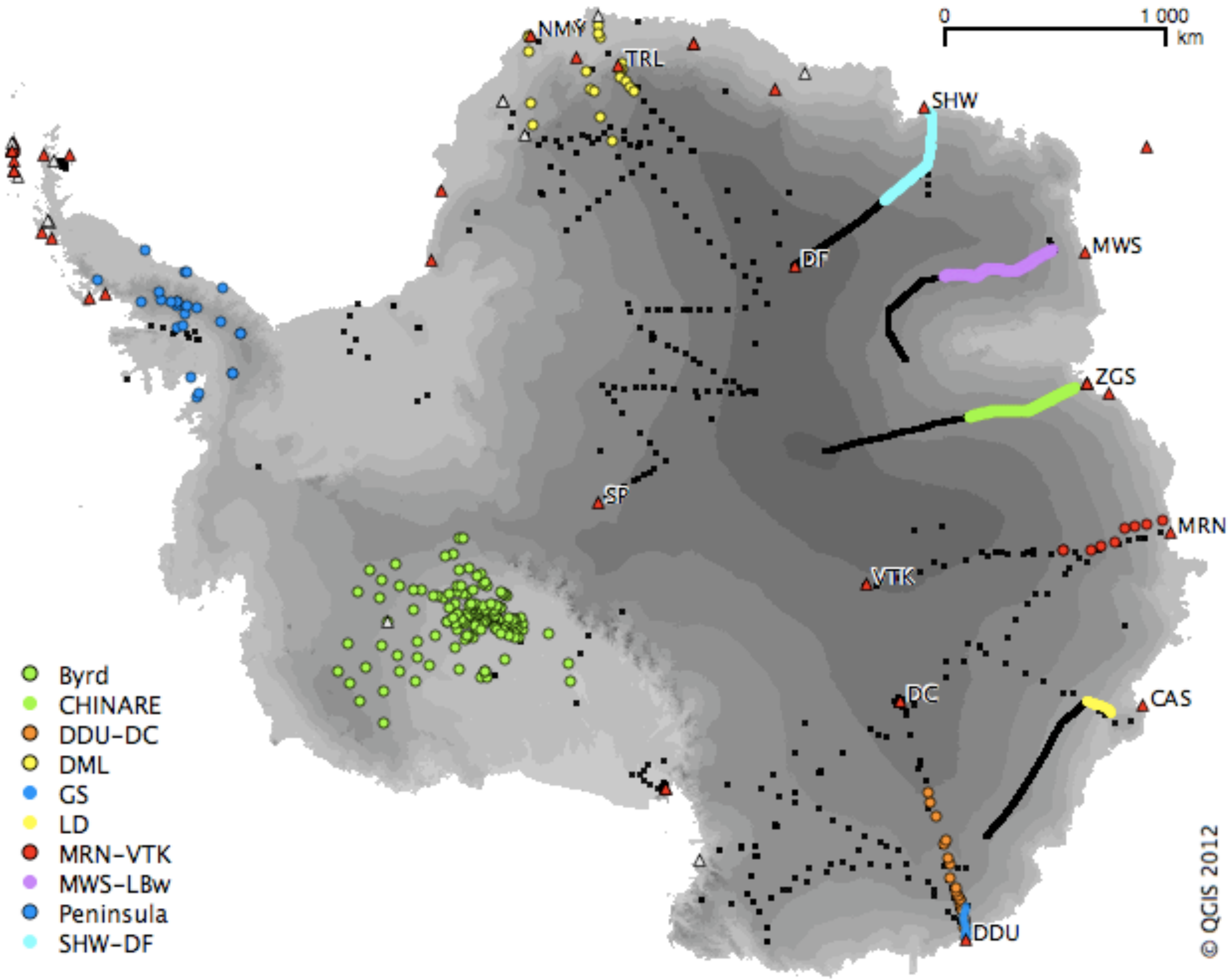
Δ(ΔRuissellement) = **ΔSMHiL - ΔGrande échelle**



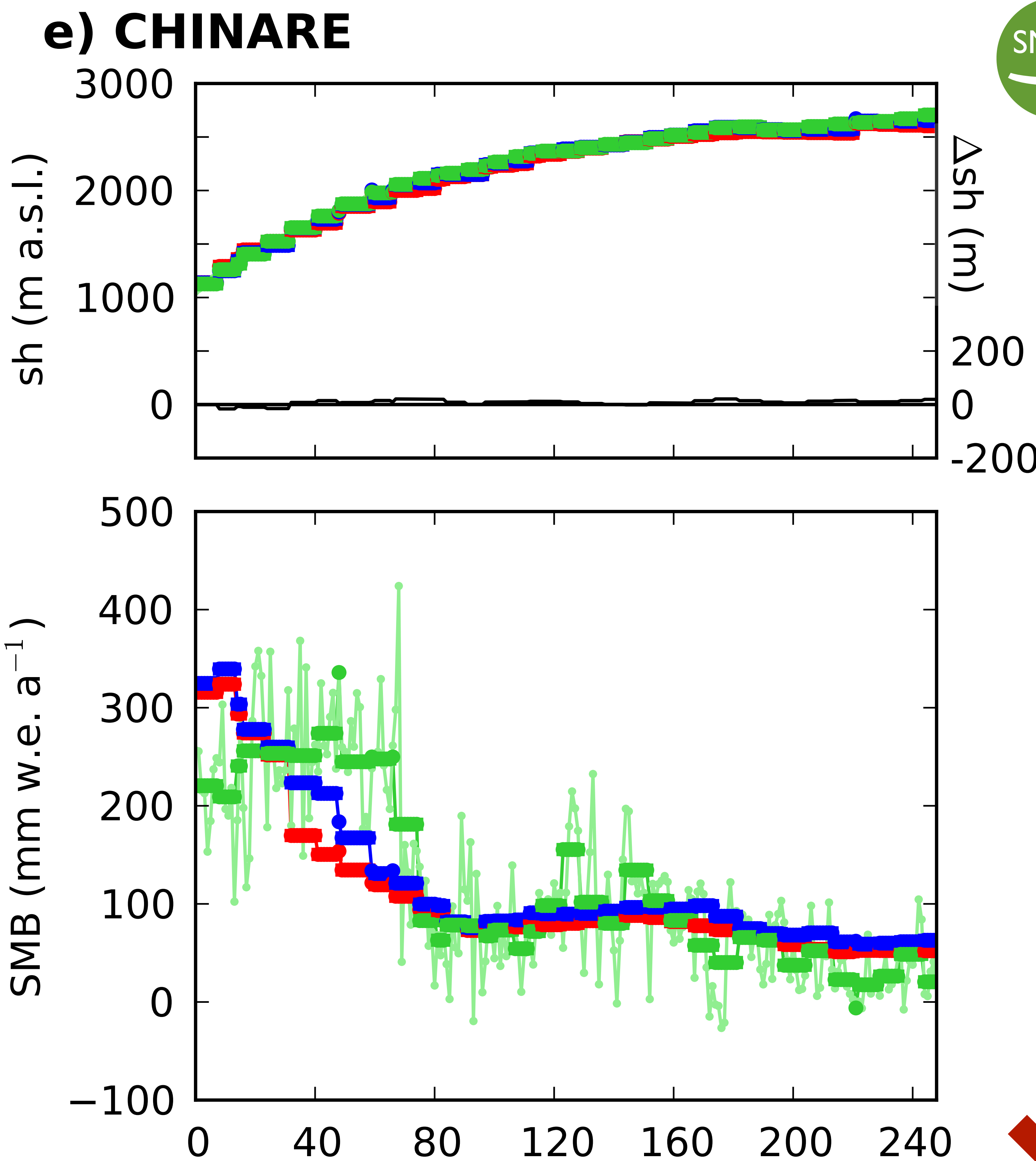
4.1 Augmentation du BMS au cours des prochains siècles



3.4 Comparaison à des observations



1.1 Comparaison à des observations de qualité contrôlée



SMHiL

Légende

1.1

Comparaison à des observations de qualité contrôlée