21^{st} century Antarctic surface mass balance downscaling from global circulation models

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The problem

1. Modeled surface mass balance is highly sensitive to horizontal resolution
2. A coarse horizontal resolution is inadequate to resolve the steep topographic slopes around the edges of Antarctica
3. High resolution SMB (~10km) from medium resolution atmospheric GCM (~100km) generally increases excessively the computational time
4. A correct method has to adequately capture the impact of fine-scale topography on precipitation
5. Surface Energy Balance (SEB) at high resolution is crucial, particularly at the ice sheet margins
6. General circulation models (GCM) for the future should not be forced with Sea-Surface Characteristics (SSC) taken from a coupled model but should instead be corrected through an anomaly method in which the present-day observed SSC are used for the present-day control simulation (Krinner et al., 2008)

➔ we developed a new, low time consuming downscaling method for high resolution (15km) SMB modeling over long periods (21^{st} and 22^{nd} centuries)

Method : HiDEP model

1. The model computes the adiabatic cooling effect due to the uplift of air masses across the fine topography. Orographic precipitation is computed through an explicit formulation based on gravity wave theory (e.g. Gallée et al., 2011).
2. Meteorological variables are interpolated to force the LMDZ4 surface scheme in order to compute ablation and snow/ice evolution.
3. The downscaling model is applied on AGCM outputs obtained with the anomaly method from Krinner et al. (2008)

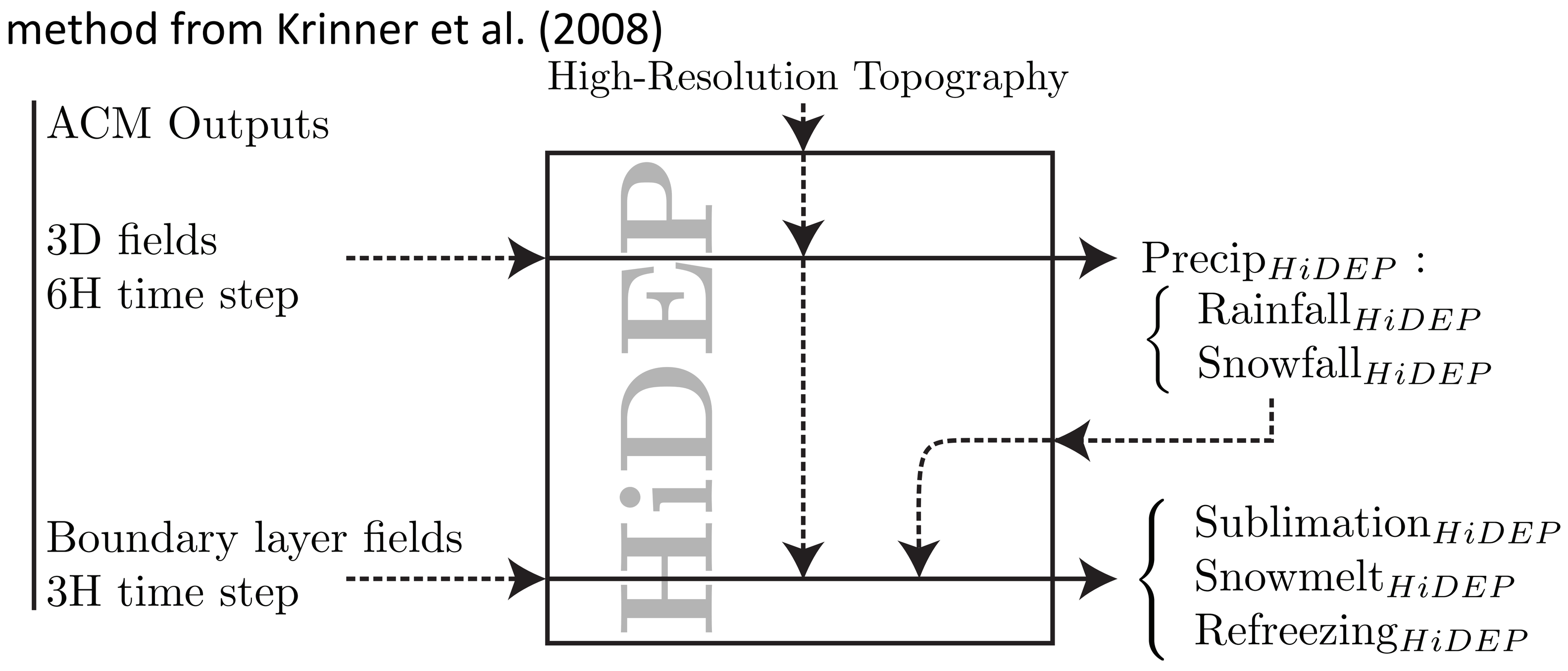

***Figure 1** : HiDEP model : inputs and outputs*

Runs

The HiDEP model was forced by lower resolution climate forcing from ERA-Interim and from LMDZ4 Atmospheric GCM, including several improvements for the simulation of polar climates. For LMDZ4 simulations, we prescribe anthropogenic forcing (greenhouse gas concentrations (CO2, CH4, N2O, CFC11, CFC12) following the SRES-A1B scenario and SSC anomalies using the oceanic output of two coupled ocean-atmosphere (MPI-ECHAM5, HADCM3) model experiments from CMIP3 climate projection. We also used data from the E1 scenarios of the FP6-ENSEMBLE program.

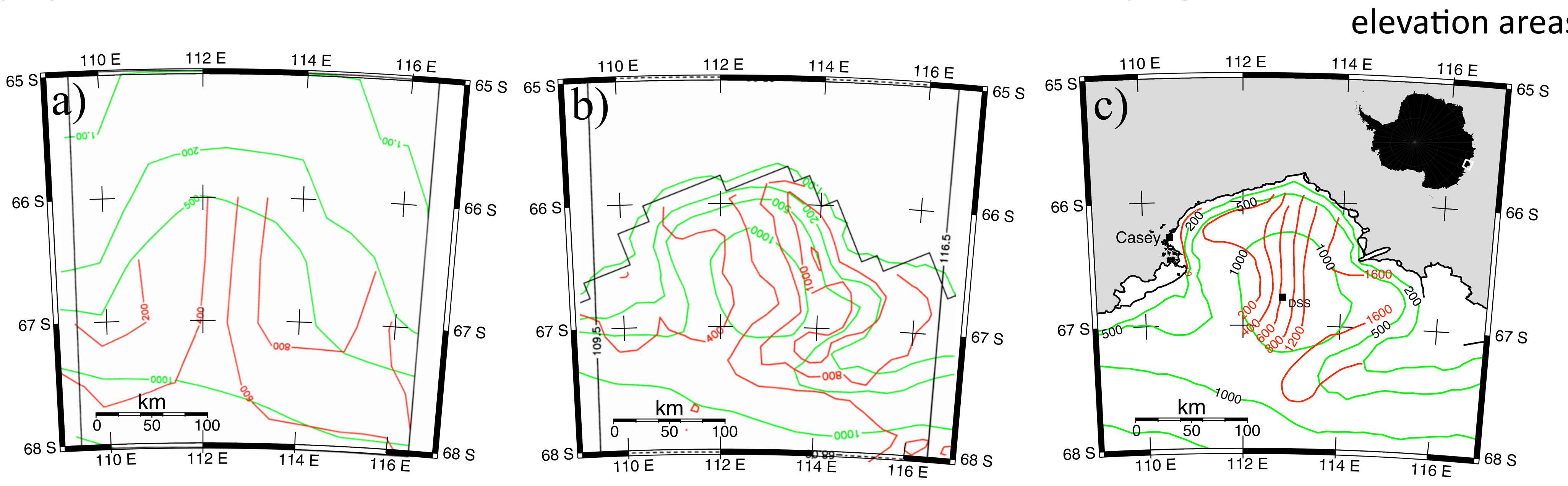

***Figure 2** : Red lines are SMB contours for 1980-2007 period at Law Dome for a) ERA-Interim b) HiDEP forced by ERA-Interim. c) SMB pattern based on observations from van Ommen et al. (2004). Green lines are elevation contours.*

Validation

Low resolution ERA-Interim and high resolution HiDEP SMB data were compared to point data from Vaughan et al. (1999). Regional SMB pattern is in good agreement with the current general picture of SMB in Antarctica, and the downscaled SMB better reproduces the field data in the low elevation areas (Figures 2 & 3).

For instance, SMB distribution at Law Dome (Figure 3) is also improved. The SMB distribution pattern is quite similar to the figure given by van Ommen et al. (2004).

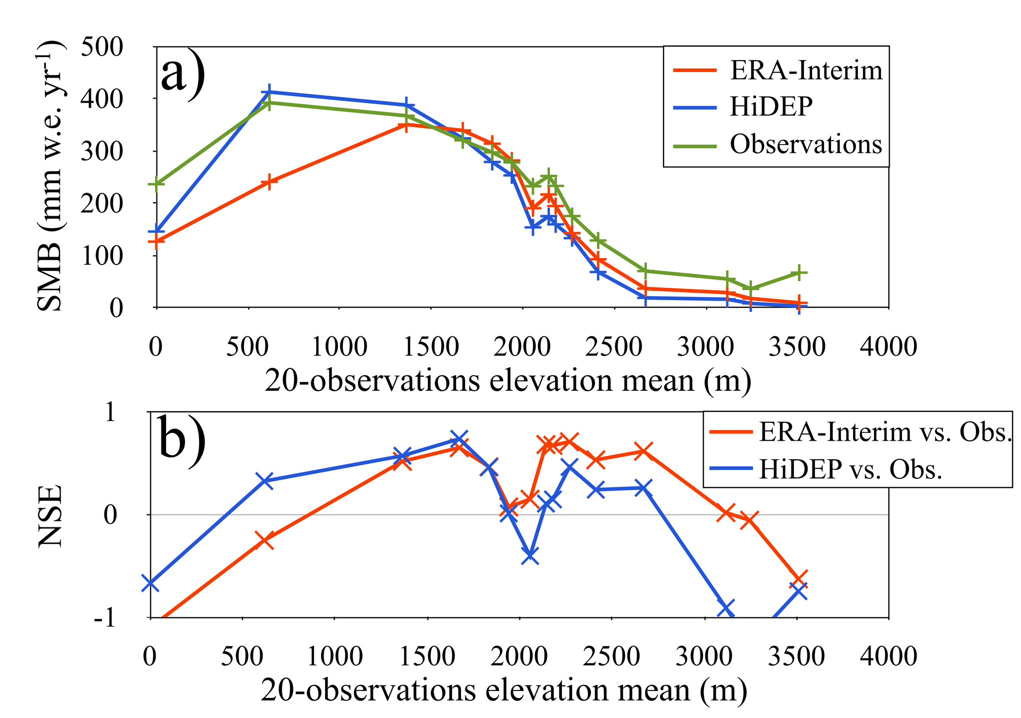

***Figure 3** : a) SMB from ERA-Interim, HiDEP forced by ERA-Interim and Observation for each 20-observations bins b) Nash-Sutcliff Efficiency (NSE) between modeled and measured SMB values before and after downscaling step*

Our results reflect that the SMB distribution is mainly caused by the orographic forcing on precipitation even if snowdrift is an important variable in strong katabatic wind areas. However, the SMB lapse rate across mountain ranges is not as pronounced as in observation, suggesting that including humidity advection is necessary when Fœhn effect is strong.

21^{st} century SMB forecast : improvements obtained with the downscaling step

HiDEP suggests a larger SMB increase of about 0.15 mm s.l.e. a^{-1} than in the low resolution GCM simulations (Figure 4). SMB increase is mainly due to an important increase in solid precipitation in intermediate elevation regions, between the coast and the plateau (Figure 5).

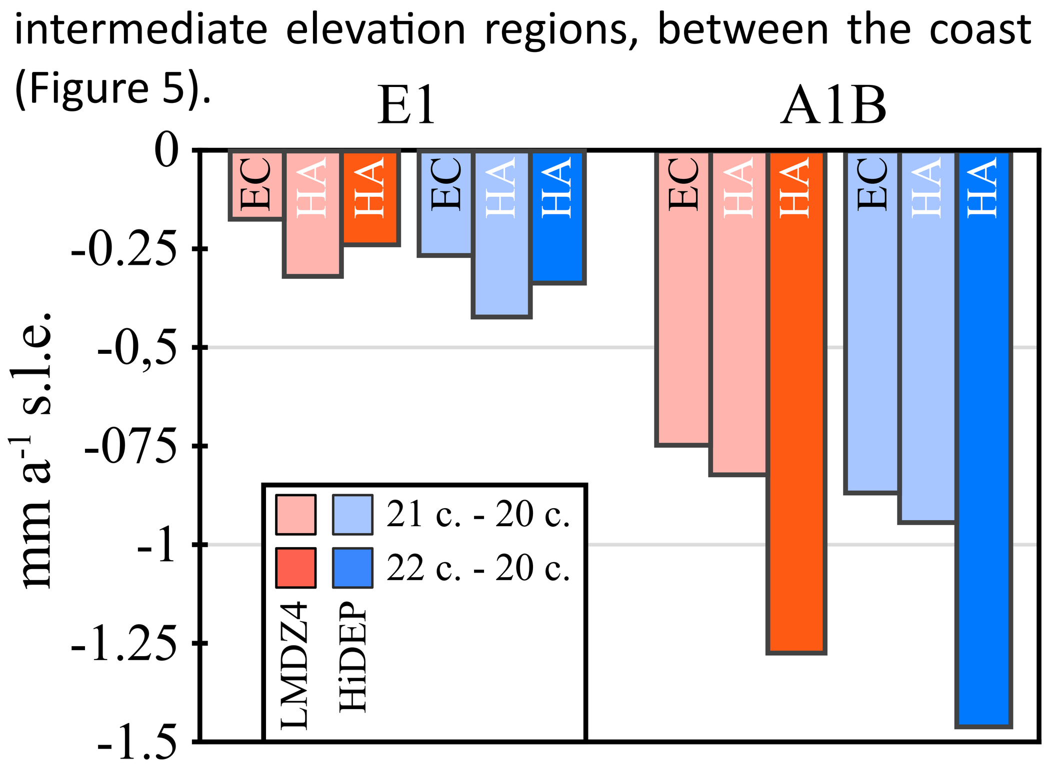

***Figure 4** : Sea level rise due to SMB difference between 1980-2007 and 2070-99 for E1 and A1B scenarios. Red bars show results for LMDZ4 simulations forced by the GCM sea surface characteristics and blue bars are results after downscaling step HiDEP. EC refers to ECHAM5, and HA refers to HadCM3.*

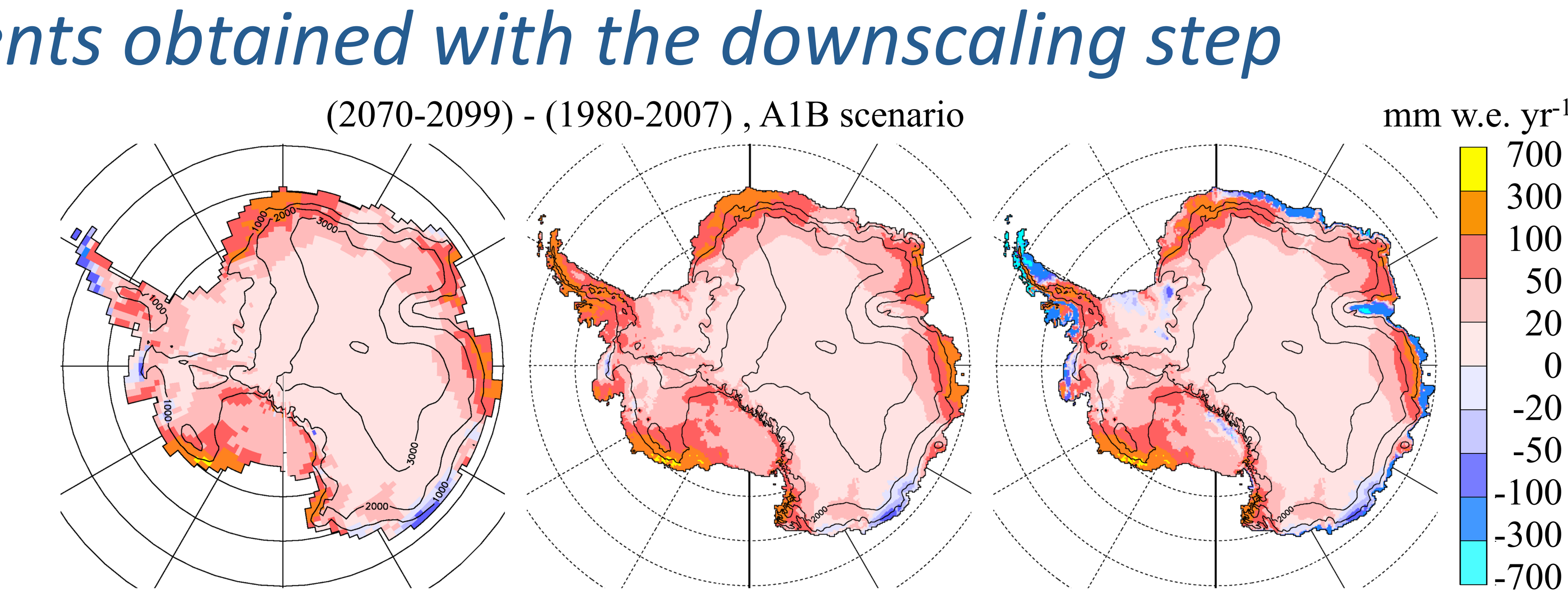

***Figure 5** : Difference of P-E (precipitation minus evaporation) and SMB between 1980-2007 and 2070-99 periods for A1B scenario for LMDZ4-HADCM3 and HiDEP forced by LMDZ4-HADCM3.*

However, more negative SMB are also observed in several regions, that limits the trend over the entire grounded ice sheet. Higher liquid precipitation amount and melting should be observed at low elevation in Adelie Land, on Lambert glacier the eastern part of Droning Maud Land, and on the Antarctic Peninsula (Figure 5). Results show that SMB will results from conflict between higher snow accumulation amounts and higher liquid precipitation and ablation rates. In such case, degree day approaches do not sufficiently represent physical processes and should be considered with caution due to the very poor data base used for precise calibration.

References : Gallée, H., et al. (2011), A downscaling approach towards high-resolution surface mass balance over Antarctica, Surveys in Geophysics.
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