Evaluation of uncertainties on the surface mass balance (SMB) of Antarctica and related contribution to sea-level

A contribution of WP2.4 to WP6

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Uncertainties on precipitation

Precipitation is the single most important term of the SMB of Antarctica. It is also the only significant positive term of the mass balance of the ice sheet. Yet it is very poorly known because it cannot be measured in the field or by satellite (so far at least). An uncertainty on the the contribution of Antarctic precipitation to future sea-level may be approximated by comparing the precipitation reconstructions and predictions by various climate models of the CMIP5 (Climate Model Intercomparison project 5) and the ICE2SEA predictions. An evaluation was already provided on the basis of the CMIP3 / IPPC4 model predictions (Genthon et al., 2009).

The "standard" greenhouse gas scenario for CMIP5 / IPCC5 is RCP4.5. In principle, all models participating in the CMIP5 intercomparison project should run the RCP4.5 scenario, although monthly mean output could only be found for 8 models on the PCMDI / CMIP5 archive (accessing the CMIP5 archive proves more tricky than CMIP3 was, obviously because the number of models and scenarios has considerably increased). Figure 1 shows the simulated / predicted integrated SMB by the 8 models, separately for that part of the grounded ice sheet surface that is below and above 2250 m. About half of the surface of the grounded ice sheet is below (and thus above) this elevation. Table 1 summarizes essential means and intermodel statistics.

According to the models, precipitation is more than 3 times larger over the lower than over the higher part of the ice sheet, yet the intermodel variance of model estimates for present Antarctic precipitation is about the same on the 2 parts of the ice sheets (table 1). All models predict and increase of the integrated precipitation. In the CMIP3 / IPCC4 archive, all models but one predicted a precipitation increase in the SRESA1B greenhouse gas scenario. The outlying model predicted a small decrease, in fact close to no change at all Genthon et al. 2009). In CMIP5, the predicted increase of precipitation is also about 3 times more over the lower than over the higher part of the ice sheet, but here the intermodel variance (uncertainty) is also 3 times more over the lower part.

An increase of the Antarctic precipitation implies a negative contribution to sea-leverl rise. Considering the intermodel statistics, a 15.4 +/- 9.9 mm.yr^{-1} precipitation increase results in approximately -0.5 +/- 0.3 mm.yr^{-1} sea-level change at the end of the century. Considering the extremes, 37.4 mm.yr^{-1} (CNRM-CM5) converts into ~1 mm/yr sea level change, 6.3 mm.yr^{-1} (MIROC5) into ~-0.2 mm/yr sea-level change. There is no a priori reason to believe that one model is more reliable than an other with respect to Antarctic precipitation, thus these numbers define error bars that should be used on sea-level rise predictions. The error bars are somewhat narrower than in the CMIP3 models (2-3 mm.y^{-1}, Genthon et al. 2009), yet still significant.

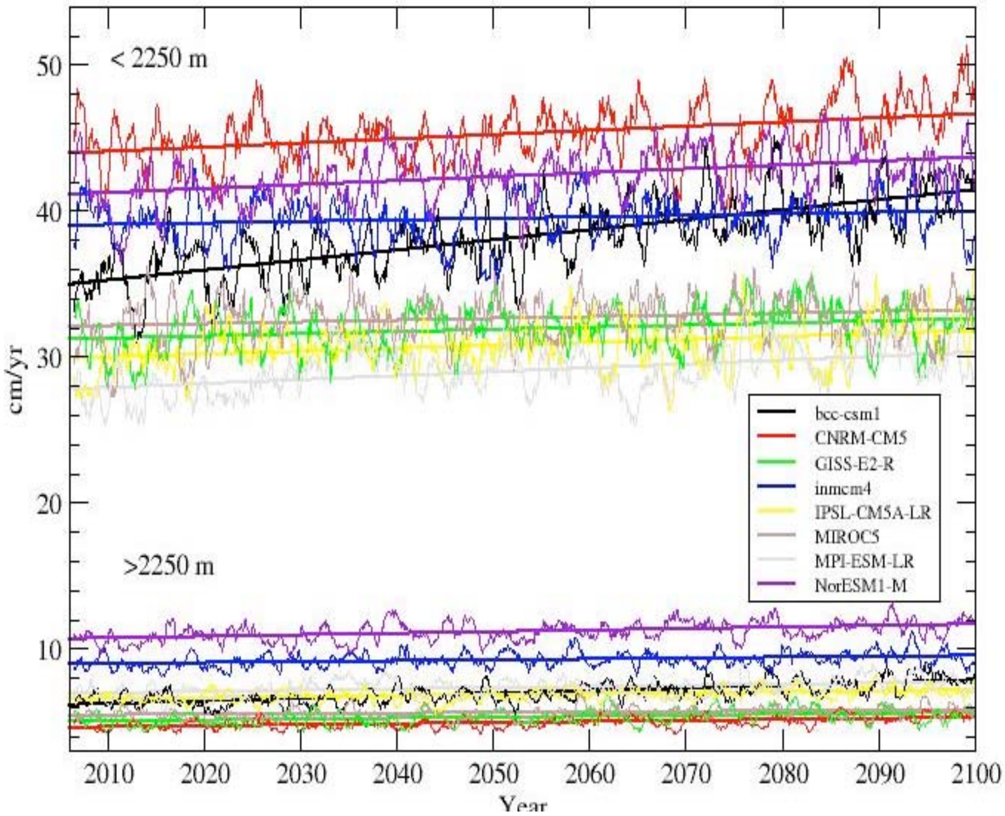


Figure 1: Integrated precipitation over the grounded Antarctic ice sheet from 8 models running the RCP4.5 IPCC5 scenario, series of annual (12-month running) mean and linear regression, for the ice sheet surface above and below 2250 m.

Model / precipitation	AMIP, mm/yr, total / above 2250 m	RCP4.5 2010 /2100, mm/yr	Change century RCP4.5, mm/yr	Regression century RCP4.5 <2250 m, mm/yr/yr	Regression century RCP4.5 >2250 m, mm/yr/yr
bcc-csm1	195 / 66	188 / 205	17.4	0.57	0.15
CNRM-CM5	157 / 46	208 /246	37.6	0.24	0.06
GISS-E2-R	190 / 34	247 / 164	17.5	0.12	0.05
inmcm4	186 / 69	246 /2 61	14.5	0.09	0.05
IPSL-CM5A-LR	176 / 53	178 / 187	8.9	0.16	0.05
MIROC5	178 / 61	246 / 252	6.3	0.10	0.03
MPI-ESM-LR	174 / 62	178 / 196	13.7	0.22	0.07
NorESM1-M	183 / 49	194 / 201	7.1	0.22	0.09
Mean	180 / 55	211 / 227	15.4	0.22	0.07
StD	12 / 12	31 / 32	9.9	0.15	0.04

Table 1: Mean and statistics of model simulation and prediction of integrated precipitation over the grounded Antarctic ice sheet.

Unfortunately, due to timing constrains, the ICE2SEA SMB predictions (WP4.2) were run using the “old” SRES1AB IPCC4 greenhouse gas scenario rather then the IPCC5 RCP4.5 scenario, a fact that may slightly limit the significance of comparing the CMIP5 and ICE2SEA predictions. On the other hand, it was suggested that model spatial resolution is a factor in the accuracy of model depiction and prediction of Antarctic precipitation (Genthon et al. 2009). The ICE2SEA predictions typically have much higher spatial resolution than the CMIP5. The LGGE contribution to WP4.2 is a downscaling of a streched-grid climate model prediction, using a physically-based downscaling model of precipitation and other components of the SMB (yet ignoring blowing snow, see below). The downscaling resolution is an unprecedented 15 km. The early century average precipitation over the grounded ice sheet is 229 mm.yr^{-1}, on the higher end of the CMIP5 models (table 1). By the end of the century, this has increased by more than 35 mm.yr^{-1}. This is also at the higher en of the CMIP5 models and converts into ~ -1 mm.yr^{-1} sea-level.

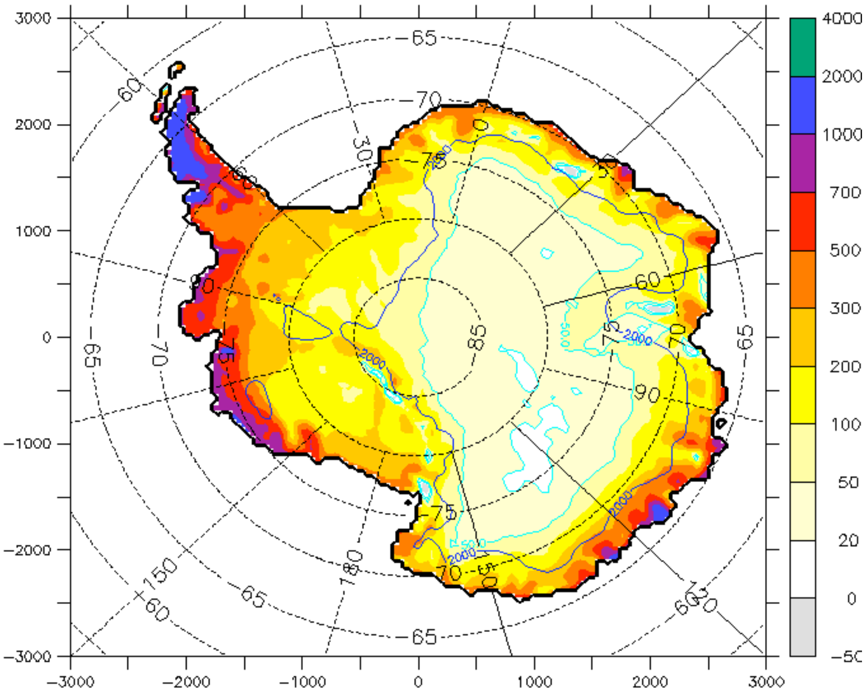
Uncertainties related to blowing snow

None of the climate models than have participated in the 4th IPCC assessment report, and apparently none of the models that participate in the 5th IPCC assessment report have a representation of blowing snow over Antarctica. The contribution of blowing snow to the SMB of Antarctica is unknown because 1) few models physically or even parametrically account for blowing snow, and 2) there are very few direct and reliable observations of blowing snow available in Antarctica. Most evaluation and validation of Antarctic blowing snow in models rely on a single observation campaign in the 1960s -(Budd et al., 1966) in West Antarctica. With financial support by the ICE2SEA program to acquire innovative instruments (and with logistical support by the French and Italian polar institutes) an extensive blowing snow observation campaign is being carried out in Adélie Land (Genthon et al., 2011), one of the most appropriate region to carry such a campaign because of particularly strong an persistent catabatic winds.

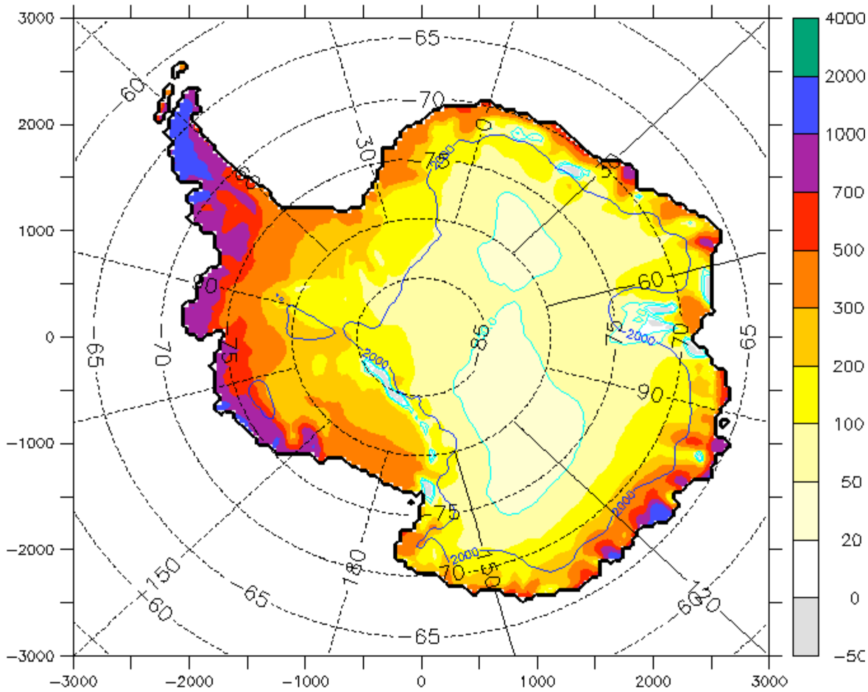
The MAR model is a Regional Climate Model developped by LGGE. It contains three sub-models, namely an atmospheric sub-model, a blowing snow sub-model and a detailled surface sub-model (SISVAT: Soil – Ice – Snow – Vegetation – Atmosphere – Transfer). Its ability to detect blowing snow events has been validated for January 2010 (Gallée et al., 2012). In short MAR set up over Adélie Land and it is able to simulate the observed blowing snow events, although the number of simulated events is underestimated.

This model has been applied over the Antarctic ice sheet with an horizontal resolution of 40 km. Two simulations have been made, differing by the activation or not of the blowing snow sub-model. Results are shown on Figure 2 for MAR nested in the ERA-Interim re-analysis (years 2003 – 2007).

Surface Mass Balance contributions to sea level are respectively 154 / 188 mm w.e. / year when the blowing snow sub-model is switched ON / OFF. Contribution of blowing snow to ASMB is thus larger than in previous estimates and it could be expected that it is still larger, since MAR seems to underestimate blowing snow events. Another consequence from our simulations is that MAR underestimate accumulation, although it may be qualified as a moist model over the Antarctic ice sheet.



MAR simulated 2003 – 2007 Antarctic Surface Mass Balance, with Blowing Snow



MAR simulated 2003 – 2007 Antarctic Surface Mass Balance, without Blowing Snow

Figure: MAR simulations. Period 2003 – 2007. Antarctic Surface Mass Balance. Top, bottom: respectively with, without activating blowing snow sub-model

References

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