Modelling of present and future climate and surface mass balance of Svalbard with the regional climate model MAR

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1. Simulations

- **Model: MAR** (**M**odèle **A**tmosphérique **R**égional, Gallée and Schayes, 1994)

  Regional climate model fully coupled with a snow energy balance model (SISVAT)

  SISVAT = Soil **I**ce **S**now **V**egetation **A**tmosphere **T**ransfer

  → Modelling of the climate and surface mass balance (SMB) of Svalbard

- Three experiments

	Forcings	Period	Resolution
1	ERA-Interim	1979-2012	10 km
2	MIROC5*	1979-2005	10 km
3	MIROC5	2010-2099	10 km

Present climate and SMB: MAR forced by ERA-Interim (MAR_{ERA}) and MIROC5 (MAR_{MIROC})

Future projections by MAR forced by MIROC5 (scenario RCP 8.5) ($MAR_{RCP8.5}$)

* Fettweis et al, 2013b

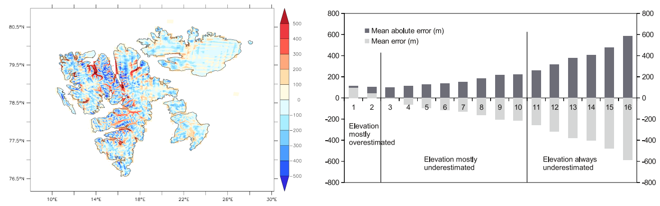


Figure 1: Left: Elevation difference between the 10km MAR topography and topography from the NPI (interpolated on the 250m grid). Right: Mean (absolute) elevation error for the 10-kilometre MAR topography compared to the 250-metre NPI topography for different classes of elevation (0 - 100 m, 100 - 200m, …, >1500m).

The elevation of the 10-km MAR grid is mostly underestimated compared to the Norsk Polarinstitutt topography (interpolation on a 250-m grid, figure 1), especially on both sides of Wijdefjorden (Northern Spisbergen) where the difference is greater than 500 metres due to a very steep topography.

→ A lot of glaciers will lie much lower than in reality and some could lie at such low elevations that they should not even exist in the 10-kilometre grid. The melt will be overestimated, which will introduce a surface mass balance but the interannual variability of the SMB should not significantly be affected.

Svalbard is also covered by a lot of small glacier that can not be represented with a 10-km resolution. This resolution is clearly not high enough to resolve the complex topography of Spitsbergen.

2. MAR forced by ERA-Interim

In order to validate MAR forced by the ERA-Interim reanalysis, we have compared the model results to daily near-surface measurements (temperature and precipitation) coming from weather stations as well SMB measurements. MAR is too cold compared to the weather stations data but able to improve the reanalysis outputs in some places. There is no systematic SMB bias and the modelled SMB is closed to the measured SMB in smooth topography areas (e.g. Austfonna) where a resolution of 10 km is enough. On Spitsbergen, where the topography is steep, there are huge elevation biases and therefore, the complex precipitation pattern can not be represented, leading to much bigger SMB biases.

The SMB (green curve, mean value of -4.9 Gt) has a huge interannual variability due to the variability of the meltwater runoff (blue) but there is no temporal trend over the last 30 years (no acceleration or deceleration of the ice loss).

No records of melt have been modelled in the last years like in Greenland. This is due to a recent change in atmospheric flow frequencies (more northerly flows over Svalbard, Fettweis et al., 2013a).

The precipitation is much more constant from year to year then runoff.

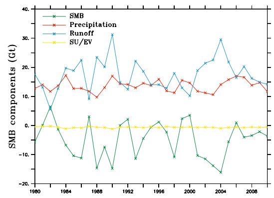
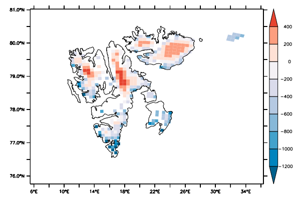
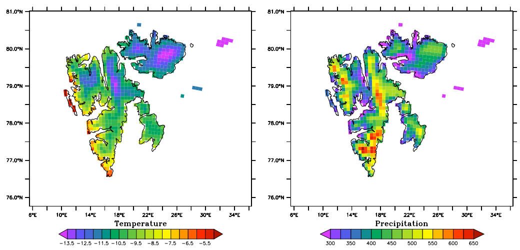


Figure 2: Evolution of the total SMB and its components (solid and liquid precipitation, meltwater runoff and sublimation and evaporation) of Svalbard over 1980-2010.



The surface mass balance is positive only on the ice caps on Nordaustlandet and in high elevation zones (Northwestern and Norteastern Spitsbergen and to a smaller extent in Southern Spitsbergen) where temperatures are low or precipitation high or both (see figure 4).

Figure 3: 1980-2010 surface mass balance annual mean (mm).



The mean annual temperature goes from -5°C on the Western coast of Spitsbergen to almost -15° in the centre of the ice caps and in Newtontoppen region (highest elevations). There is a West-to-East gradient showing the effect of the North Atlantic Drift bringing warmth on the West coast of the archipelago.

The precipitation is lower on the West coast of Spitsbergen than on the East coast due to winds bringing humid air from the East. Due to the underestimation of the topography, we expect precipitation to be lower than observed. With our 10-kilometre topography, the elevation is underestimated and so is the amount of clouds that form on top of the mountains. The precipitation is therefore underestimated and the lack of humidity in the atmosphere is also responsible in part for the cold bias through its influence on longwave radiation.

Figure 4: 1980-2010 annual temperature mean (°C) and total precipitation (mm)

4. Comparison of MAR_{ERA} and MAR_{MIROC}

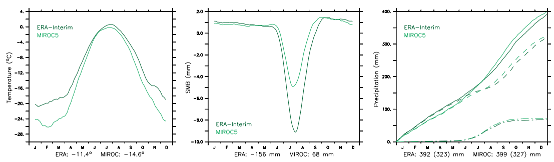


Figure 5: 30-days running mean of 2m temperature and SMB and cumulative precipitation averaged over 1980-2005 modelled by MAR_{ERA} (dark green) and MAR_{MIROC} (light green).

MAR_{MIROC} average temperature is lower than the MAR_{ERA} temperature, especially during winter. The SMB is positive for MAR_{MIROC} (+2.3 VS -5.4 Gt yr^{-1} for MAR_{ERA} over 1980-2005) and the melt season is shorter (62 versus 87 days). The amount of precipitation summed over all Svalbard is really similar for both runs but their spatial distribution is different (figure 6).

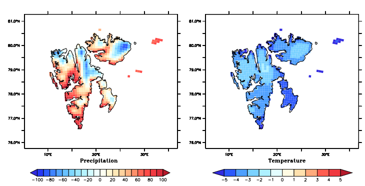


Figure 6: Annual precipitation (mm) and temperature difference (°) between MAR_{MIROC} and MAR_{ERA} averaged over 1980-2005.

The precipitation difference (figure 6, left) is caused by the difference in sea ice coverage (SIC) between ERA-Interim and MIROC5 which causes reduced exchanges of moisture between the ocean and the atmosphere in MIROC5.

The larger SIC in MIROC5 also causes MAR_{MIROC} to be colder than MAR_{ERA} (figure 6, right).

The MAR_{ERA} SMB is positive only in the central parts of NW and NE Spitsbergen and on the ice caps whereas MAR_{MIROC} still predicts a mass gain closer to the coastline (figure 7). Significant mass loss from year to year only happen on the West coast and the very Southern part of Spitsbergen. MAR_{ERA} predicts that only 35% of the area of Svalbard covered with ice has a positive SMB while with MAR_{MIROC}, 66% of this area gains mass on average.

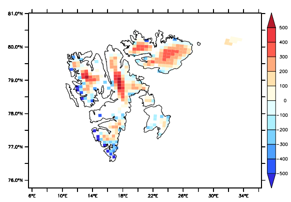


Figure 7: Annual SMB (mm) modelled by MAR_{MIROC} averaged over 1980-2005.

5. Future projections

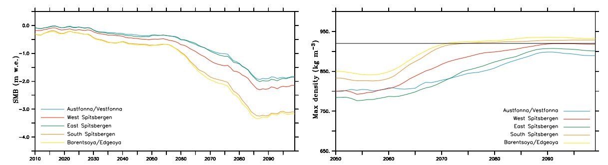
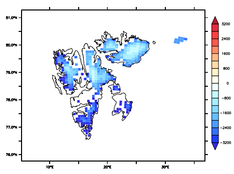


Figure 8: SMB (m w.e. left) and max ice/snow density (kg m^{-3}, right) 10-year running mean for 5 different zones.



The SMB is negative over the whole Svalbard and the greatest losses are mostly located in South Spitsbergen (figure 9). The evolution is similar for all the zones (figure 8) with a slight decrease up to 2055. After 2005, the melt accelerates with a more pronounced trend in the South. After 2080, the SMB stabilises for all the regions. This evolution is linked to the evolution of SIC and temperature.

The maximum ice/snow density (figure 8, right) shows that the ice will start to completely disappear shortly after 2075 in the South whereas, even at the end of the century, the ice caps and glaciers in NE Spitsbergen will still be present.

Figure 9: 2070-2099 annual SMB mean (mm).

6. Conclusion

Although MAR shows a negative temperature bias with respect to the measurements, it reproduces quite well the SMB where the resolution is high enough to represent the topography. However, given the steep topography of Spitsbergen, a resolution of 10 km is not enough.

MAR_{MIROC} is even colder than MAR_{ERA} and there is a precipitation deficit in the North due to an excessive SIC.

In the future, $MAR_{RCP8.5}$ predicts the SMB to be negative (2070-2099) with a different evolution for the North and the South of the archipelago. The relation between the evolution of the SMB and the temperature and SIC has still to be investigated. Finally, according to MAR, the ice will start to completely disappear in the South around 2075.

7. References

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[2] Fettweis X., Franco B., Tedesco M., van Angelen J.H., Lenaerts J.T.M., van den Broeke M.R., Gallée H., 2013b: *Estimating the Greenland ice sheet surface mass balance contribution to future sea level rise using the regional atmospheric climate model MAR*, The Cryosphere, **7**, 469–489, 2013

[3] Gallée H., Schayes G., 1994 : *Development of a three-dimensional meso-γ primitive equation model: katabatic winds simulation in the area of Terra Nova Bay, Antarctica*, Monthly Weather Review, **122**, 671-685

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