

Final report of the project MASS2ANT- East Antarctic surface mass balance in the Anthropocene: observations and multiscale modelling

Climate is changing rapidly at high southern latitudes. This has large consequences in the region but also globally as Antarctica and the Southern Ocean play a major role in the Earth's heat and carbon budget as well as in sea level variations. However, while some changes observed at high southern latitudes can unambiguously be related to human activities, the origin of others is less clear and this lack of understanding limits our ability to perform accurate projections of future changes.

The objective of Mass2Ant was to reduce our uncertainty on the drivers of the changes in the surface mass balance in Antarctica and, from this, on sea level rise. The specific focus was on the Princess Ragnhild Coast, East Antarctica, because of its complex topography and dynamics, taking advantage of the location of the Princess Elisabeth Station in the region. Large local to regional changes are observed there and we intended to determine how to connect them to the large-scale variations and thus have an integrated view of the contribution of the region to the mass balance of the Antarctic ice sheet.

One of the main achievements of the project is the collection and analysis of new data, including two new long ice core records, radar surveys on two ice rises, meteorological and snow observations. We were able to perform all the observations planned in the proposal, despite the strong constraints imposed at the beginning of the project by the cancellation of the first field campaign and later by the restrictions due to the COVID pandemic. We were even able to collect additional observations that were not initially planned thanks to collaborations, synergy with other projects and additional support from BELSPO for the 2021-2022 fieldwork season. Those data have been analyzed and compared to previously published ones and to provide input to models at different scales, from local snow models, to regional and global climate models. All those data are now archived in public, open access repositories and, in addition to our scientific results, will be one of the legacies of Mass2Ant.

The approach used during the course of the Mass2Ant project is unique as it used different types of observations and models, addressing very different spatial and temporal scales. It was only possible thanks to the strong and efficient collaboration between the partners and their combined expertise. This is well illustrated by the list of publications which include, for the large majority of them, authors from at least two groups among the partners.

The analysis of the ice core records and the reconstructions based on data assimilation have allowed us to put the recent changes in a longer-term perspective. It has shown that, in contrast to West Antarctica where relatively clear trends can be seen in many regions over the second half of the 20th century, with a warming and increased snow accumulation (in particular over the Antarctic Peninsula), the situation is more complex over East Antarctica. In the coastal regions of East Antarctica, trends in snow accumulation can be very different in relatively nearby places. Our results, including the explicit identification of causality between the observed changes, suggest that West Antarctica is more directly connected to global climate change and large-scale atmospheric variability than the Princess Ragnhild Coast. This does not mean that this connection with the larger scale does not exist for East Antarctica, but it can be often obscured in records by the effect of local to regional interactions between ocean, ice, topography and atmospheric circulation.

Past and future changes in Antarctica are also linked through the relative contributions of different processes to changes in snow precipitation. Snow precipitation and temperature tend to be connected at all temporal scales with a warming generally associated with more snow precipitation because of the increase of the water pressure at saturation in the air with temperature. This offers the opportunity to improve temperature reconstructions using snow accumulation records in data assimilation and to have a clear target to evaluate the behavior of regional climate models using observations. More precipitation is also expected in the future, mainly because of storms that will bring more moisture to Antarctica in a warmer world.

This link between temperature and precipitation due to storms that last a few days, trends over the 21st century and changes over the past centuries, illustrate well the interest of analyzing jointly the recent past, the more distant one and the future. Nevertheless, we have shown that models tend to overestimate the link between temperature and precipitation compared to observations. This may be due to their overestimation of the role of large-scale changes, arguing for an analysis of the link between local, regional and large-scale changes. This has been achieved in Mass2Ant both on the modelling side by comparing surface mass balance of regional and global models, using also statistical downscaling, and for the observations by comparing ice core records that sample the surface mass balance of individual locations separated by tens to hundreds of kilometers with radar derived surface mass balance that provides estimates over several square kilometers.

By comparing ice core records, local snow observations and ground penetrating radar data as well as model results, we have documented the strong spatial variability of snow accumulation over ice rises and the mechanisms responsible for that variability, in particular the influence of the topography on precipitation and the redistribution by the winds. This implies that the mean accumulation measured by the ice cores can be significantly different from the one at a scale of a few kilometers as estimated in regional models but ice cores generally provide a fair measure of the temporal variability of the accumulation. This large spatial variability imposes also care in the comparison between large-scale simulations and local records.

More generally, the project has shown the strong interest of a complementary approach using different tools to understand the complex changes in regions such as the Princess Ragnhild Coast. Thanks to exchanges within the group, we have been able to have two-way interactions between models and data, data being used to validate the models and models being essential to interpret the data and their limitations. The interest of different types of observations has been highlighted by comparing local snow measurements, ice core records and ground penetrating radar data and we strongly recommend to continue to make all those types of observations in future field work to be able to quantitatively estimate the uncertainties, in particular those of the ice core records, which are our main source of information for variations longer than a few decades. The joint use of models at different scales has underlined their common behaviors, the additional information brought by higher resolutions, and the interest of statistical downscaling to represent this regional variability using global models. Furthermore, the application of a recent method based on a causality approach on model results has unambiguously identified the dynamical dependences between the variables that could be obscure using simpler diagnostics.

The originality of the approach has allowed us to attract interest and partnerships without which we would not have been able to obtain all the results presented here. Furthermore, Mass2Ant has enabled new collaborations. Ice core records have been included in a data synthesis led

by the British Antarctic Survey (UK) and this new synthesis will be used in new reconstructions based on data assimilation. The local information obtained in the project will be a basis for the calibration of satellite data that will lead to better large-scale estimates of the surface mass balance of Antarctica. The GPR analyses resulted in the development of a new collaboration between UCLouvain, the Norwegian Polar Institute (in Tromsø, Norway) and the National Centre for Polar and Ocean Research (in Goa, India), to expand our analyses to many more coastal ice rises along the Dronning Maud Land coastal region.

Finally, in addition to the scientific results, the illustration of the added-value of common projects carried out by a complementary team and recommendations for future Antarctic projects, our results have been used in assessments that are important bases for decision-making, in particular for the latest assessment report of the Intergovernmental Panel on Climate Change (IPCC AR6). Ice cores are one of the main sources of in-situ surface mass balance data used to evaluate model simulations in Antarctica and assess Antarctic-wide mass balance, an exercise that allows us to determine present and future contributions of the ice sheet to sea level rise, with its worldwide coastal management policy impacts. Throughout the duration of Mass2Ant, we have widely disseminated our field work and results to the general public. We operated a blog on our website during the 2018/2019 deep ice core drilling seasons, we have participated in many radio and TV interviews about our fieldwork and the Antarctic climate in general (La Première, BX1, Le Soir, l'Avenir, RTBF La Une, LN24), we have created a vlog about the 2021/2022 field season (which was awarded the ULB Prix de la diffusion scientifique) and we have led a workshop in primary school.

Keywords: Antarctica, Princess Elisabeth Station, sea-level, surface mass balance, snow accumulation.