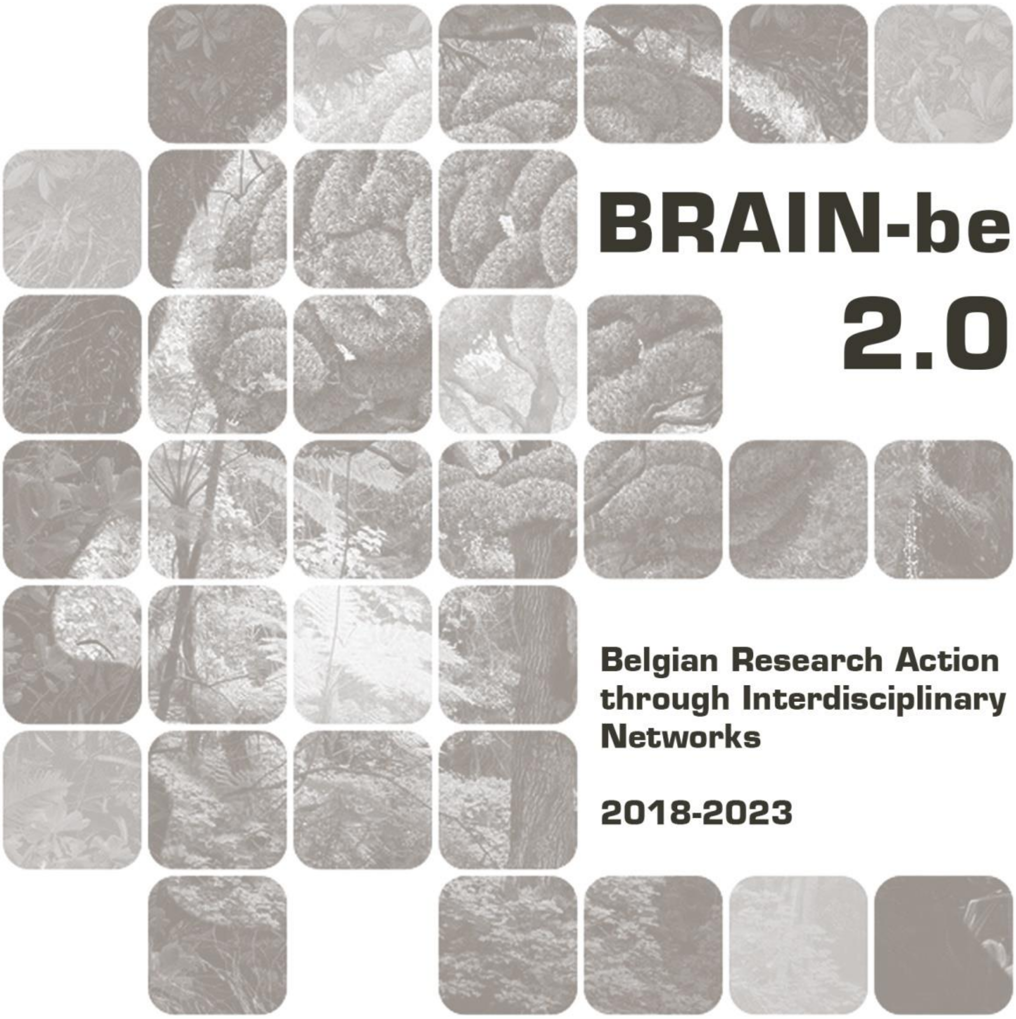

CLIMB

How do aerosol-CLoud Interactions influence the surface Mass Balance in East Antarctica?

Alexander Mangold (RMI) – Andy Delcloo (RMI) – Nicole van Lipzig (KUL) – Florian Sauerland (KUM) – Michel Van Roozendael (BIRA-IASB) – Alexis Merlaud (BIRA-IASB) – Martina M. Friedrich (BIRA-IASB) – Christophe Walgraeve (UGent) – Preben Van Overmeiren (UGent)

Pillar 1: Challenges and knowledge of the living and non-living world

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NETWORK PROJECT

CLIMB

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PROMOTORS: Dr. Alexander Mangold, Royal Meteorological Institute of Belgium (RMI)
Prof. Dr. Nicole van Lipzig, Katholieke Universiteit Leuven (KUL)
Dr. Michel Van Roozendael, Royal Belgian Institute for Space Aeronomy (BIRA-IASB)
Prof. Dr. Christophe Walgraeve, Universiteit Gent (UGent)

AUTHORS: Dr. Alexander Mangold (RMI) – Dr. Andy Delcloo (RMI)
Prof. Dr. Nicole van Lipzig (KUL) – MSc Florian Sauerland (KUL)
Dr. Michel Van Roozendael (BIRA-IASB) – Dr. Alexis Merlaud (BIRA-IASB)
Dr. Martina M. Friedrich (BIRA-IASB) – Prof. Dr. Christophe Walgraeve (UGent)
MSc Preben Van Overmeiren (UGent)

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WTCIII
Simon Bolivarlaan 30 bus 7
Boulevard Simon Bolivar 30 bte 7
B-1000 Brussels
Belgium
Tel: +32 (0)2 238 34 11
http://www.belspo.be
http://www.belspo.be/brain-be

Contact person: Maaike Vancauwenberghe
Tel: +32 (0)2 238 36 78

MANGOLD, A., DELCLOO, A., VAN LIPZIG, N., SAUERLAND, F., VAN ROOZENDAEL, M., MERLAUD, A., FRIEDRICH, M. M., WALGRAEVE, C., VAN OVERMEIREN, P. ***How do aerosol-CLoud Interactions influence the surface Mass Balance in East Antarctica? – CLIMB.*** Final Report. Brussels: Belgian Science Policy Office 2023 – 7 p. (BRAIN-be 2.0 - (Belgian Research Action through Interdisciplinary Networks))

ABSTRACT

Context

The water cycle, cloud microphysics and cloud-aerosol-interactions are recognized as key elements of the Antarctic climate system by several international consortia, such as the International Panel on Climate Change (IPCC). Clouds and aerosols play a significant role in the radiative energy budget and aerosols impact cloud microphysics because they are cloud condensation and ice nuclei. In addition, clouds are an important part of the hydrological cycle serving as the agent linking water vapour transport into Antarctica with precipitation. Because precipitation is the only source term in the surface mass balance (SMB) of the Antarctic ice sheet, it is one of the key factors affecting sea level. However, current knowledge on the interaction between clouds, precipitation and aerosol in the Antarctic is still limited, both from direct observations and from regional climate models.

CLIMB relied on an interdisciplinary research team, bringing together scientists with complementary expertise in long-term experimental work related to atmospheric chemistry and physics, expertise in Antarctic research campaigns, regional climate modelling, radiative transfer processes, and expertise in state-of-the-art chemical analyses.

CLIMB performed measurements of meteorological, aerosol, cloud and precipitation characteristics, both in the vicinity of Princess Elisabeth Antarctica station (PEA), and at an altitude which was high enough and exposed to easterly winds to be often within cloud level. In addition to extended ice nuclei particle (INP) filter sampling at PEA, there were (i) a vertically resolved profile of temperature, relative humidity and pressure for three heights: at PEA (1390 m asl), on the Utsteinen nunatak summit (around 1600 m asl) and in the Vikinghogda mountains (2350 m asl); (ii) measurements of precipitation type and intensity by a disdrometer; (iii) measurements of aerosol particle size in the Vikinghogda mountains; and (iv) an automated sampling system for Volatile Organic Compounds (VOC), also in the remote Vikinghogda mountains. The results were used to improving the aerosol-cloud-precipitation parameterisation in a regional climate model for East Antarctica.

Objectives

The objectives of CLIMB were:

- to deliver a unique data set of in-cloud meteorological, aerosol and cloud characteristics, combined with simultaneous boundary layer and ground-based remote sensing measurements;
- to establish a data set with a detailed mapping of air mass origins and transport pathways into East Antarctica;
- to generate an improved COSMO-CLM² regional climate model for Antarctica;
- to improve the understanding of the climatological effect of cloud condensation and ice nuclei particles on clouds, precipitation, radiation and the surface mass balance in East Antarctica;
- to strengthen the role of Belgium in the Antarctic research community;
- to valorise the results by scientific publications and workshops, open data access, lectures to the general public and press contributions.

Conclusions

- The aerosol optical depth was determined by both CIMEL sunphotometer and MAX-DOAS measurements. For three austral summer seasons, overlapping data exists. Typical AOD values in the UV and visible range of 0.02 to 0.04 were found, close to those previously reported in the literature for pristine Antarctica.
- Ground-based MAX-DOAS measurements were exploited to infer the abundance of stratospheric ozone, the NO_2 vertical column, and the OClO slant column – key chemical species involved in the processes leading to the ozone hole. Measurements for 2022 showed the OClO build-up during July-August, the polar stratospheric clouds induced denoxification/denitrification, and the corresponding ozone depletion, reaching a minimum total ozone value of 126 DU by end of October.
- A high variation of the temperature difference between the Utsteinen nunatak and ridge (around 200 m altitude difference) was found, higher than could be explained by the mere difference in height. This feature of local meteorology needs further investigation.
- The analysis of the cloud phase showed that liquid-containing clouds were much more frequent during austral summer, when in about a third of all clouds, liquid water has been detected, compared to other seasons. These events were found to correlate to more northerly winds in the upper atmosphere.
- The purpose-built automated sampler for VOCs proved capable of taking multiple samples from December 2019 to October 2020. This led to the first ever year-round dataset of 66 (oxygenated)VOCs reported for East-Antarctica and marks the first time that these compounds were successfully sampled in an automated sequential manner in Antarctica for later, off-line analysis. The laboratory analyses led to a dataset, spanning across different groups of organic compounds (like aromatic, halocarbons), from very reactive to very persistent, and molecular weights from 46 to 253 g/mol. Concentration ranges from 0.5 ng/m³ (methylbenzoate) to 20 µg/m³ (benzoic acid) were found. Almost half of the detected species in the samples were oxygenated compounds.
- During two austral summer seasons, samples were collected for the analysis on the concentration of ice nucleating particles (INP). Compared to studies in other regions of Antarctica, the found INP numbers for PEA are at the lower limit. This is an important finding, in particular for modelling studies on the aerosol influence on cloud formation and precipitation. The measurements of the optical particle sizer indicated that the concentration of particles larger than 500 nm (sizes relevant for INP) was very low. Overall, the Antarctic continent itself seemed to be no important contributor to INP.
- The regional climate model COSMO-CLM2 was adapted and improved to investigate the effect of INP on clouds and the climate of East Antarctica. The model was found to represent accurately cloud height and occurrence. A strong anti-correlation between INP concentration and liquid water content was found, including INP concentrations representative for the region around PEA. Overall, CLIMB results indicate that the exact concentration of INPs, as long as it is within a realistic range for the region, is not strictly

required for a good model performance. However, low INP concentration caused an increase in the cloud radiative effect both for short- and longwave radiation. These opposing effects mostly cancelled out in the austral summer, while during the winter, the lack of incoming shortwave radiation meant a stronger warming effect through the increase in reflected longwave radiation.

- A climatology of backward air mass trajectories has been established for the region of East Antarctica around PEA, covering a period of 11 years (2010-2020). A k-means cluster analysis has been performed and four clusters of air mass origin were found. The results show that air masses of Antarctic continental origin dominated the potential source regions, followed by the Southern Ocean. Contributions from other continents were found to be marginal. Over all seasons, the Antarctic continent with air masses between 1400 m and 8000 m was the dominant source region, with mainly the altitude level between 1400 and 4000 m. The Antarctic continental source was most prominent during austral summer with more than 80% share of origin. Air masses with maritime origin had the highest share during austral winter. It illustrates the importance of the sources of the Antarctic continent itself, related also to the subsidence of cold air masses also during austral summer, and the importance of synoptic weather patterns like cyclones during austral winter.

These findings clearly demonstrate the value of the inter-disciplinary approach of the CLIMB project, combining expertise in long-term experimental work related to atmospheric chemistry and physics, expertise in Antarctic research campaigns, regional climate modelling, radiative transfer processes, and expertise in state-of-the-art chemical analyses. Although much progress has been made, some gaps have been identified that need to be addressed in future research. In order to discriminate potential source regions even better, more samples would be required, covering several years and with higher temporal resolution, in particular during winter. Measurement sites near the coast have the advantage that these locations are more often impacted by transport from the Southern Ocean and potentially lower latitudes than sites in the Antarctic interior. Simulations of current atmospheric transport models have large uncertainties when simulating many weeks of atmospheric transport what however seems to be necessary. Therefore, more elucidated modelling and input from measurements would be required to disentangle how atmospheric compounds from lower latitudes reach East Antarctica. The regional climate model COSMO-CLM2 was adapted and improved and was found to represent accurately cloud height and occurrence. With respect to cloud ice formation, secondary ice formation, which was not fully implemented in the modified model, is a topic that is mostly unexplored, but which is known to have important effects on cloud structure and cloud phase. Further investigation is also needed to differentiate the effects from the change in cloud phase on the radiative effects from the effects of the change in total water content.

Keywords

Aerosol-clouds-precipitation interaction / Ice nucleating particles / Regional Climate Modelling / East Antarctic Climate / Volatile Organic Compounds