SCAR Fellowship Report

High-resolution atmospheric and glaciological modelling for the South Shetland Islands on the northern Antarctic Peninsula

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Dates of Activity 01/04/2023 - 30/11/2023

Introduction

Since the 1950s, the Antarctic Peninsula (AP) has experienced one of the most significant warming trends on Earth causing abrupt changes in the cryosphere of this region. However, there are a few detailed studies investigating atmosphere-cryosphere interactions on the small island glaciers like those found on the South Shetland Islands (SSI), due to the harsh environmental conditions, which impose a limitation on the field data collection. In addition, due to the insufficient observational network and complex topographical features, precipitation—a crucial variable in determining glacier surface mass balance (SMB)—over these small regions are poorly represented in global reanalysis and climate models (e.g., ERA5, CMIP5 and CMIP6). In this context, regional climate models (RCM) can be used to provide climatological variables at a high-spatiotemporal resolution with more accuracy over these small regions.

Project Objectives

The objectives of this study were threefold: (1) to analyse the capability of the Polar version of the Weather Research and Forecasting (PWRF) model in producing accurate high resolution datasets of atmospheric variables, particularly the total precipitation and solar radiation, for the SSI on the northern AP; (2) to force the new COupled Snowpack and Ice surface energy and mass-balance model in PYthon (COSIPY) with PWRF and to evaluate its ability to simulate the glacier SMB; and (3) to describe the local scale atmospheric (precipitation and solar radiation) and glaciological (SMB) characteristics on the SSI obtain a more spatially detailed.

Methods, Execution and Results

We utilised the PWRF model, version 3.9.1, to generate high-resolution atmospheric data for the SSI. Our setup consists of three nested domains spatial resolutions of 15, 5 and 1 km with a one-way nesting approach on a polar stereographic projection. For our simulation domain, we incorporated the updated Reference Elevation Model of Antarctica (REMA) from Howat et al. (2019). The modelling experiment was tested for both one summer (January) and winter (July) month in 2013. The ERA5 reanalysis released by ECMWF was used for the PWRF model initialization and input of the boundary conditions at six-hours intervals. The physics options used in this study were obtained from Bozkurt et al. (2020). Additionally, we conducted sensitivity experiments for both microphysics and cumulus schemes.

To assess the accuracy of PWRF simulations, we compared them with observational data from two stations: one situated on a glacier surface (Fourcade and Polar Club Glacier) and another on a bare ground surface (King Sejong Station). The results of the PWRF sensitivity experiments revealed that employing the Morrison 2 moment microphysics and Grell Freitas cumulus schemes enhanced the accuracy and reduced bias in temperature, surface pressure, wind, and solar radiation variables. However, longwave atmospheric radiation was only moderately represented by different PWRF configurations. Furthermore, the high-resolution PWRF outputs exhibited improved representation of precipitation, attributed to orthographic influence.

For the meteorological fields, we used the best high-resolution PWRF output to force the COSIPY model for the same period (January and July 2013). The glaciological modelling results demonstrated a more accurate spatial representation of the SMB for these small glaciers. In summer, the SMB exhibited a strongly negative trend in the lower parts and a moderately positive trend in the upper parts of the glaciers. Conversely, during winter, the SMB was highly positive across almost the entire glacier area. These findings offer valuable insights into the spatial distribution of energy and mass fluxes within the small glaciers situated on the SSI.

Project Outcomes

The PWRF atmospheric model provides multiple options for parameterization of selected physical processes, e.g., cloud microphysics, cumulus, radiation or boundary layer turbulence. One of the main outcomes of this project was to find an optimised configuration for cloud microphysics and cumulus schemes to acquire high-resolution climatic data over the small islands region like those found on the SSI, northern AP. This optimal PWRF configuration tested and verified over this region can be used over small islands for long-term climate simulations, case study analyses, etc. In addition, the utilisation of this model (i.e., PWRF) empowered us to acquire high-resolution meteorological fields for both one summer (January) and winter month (July) in 2013. These substantial data, totaling around 28GB, were efficiently stored in netCDF files for user-friendly availability. Subsequently, we used these high-resolution atmospheric datasets to force the COSIPY model, generating energy and mass balance data with more detail for small glaciers within the SSI. These datasets, comprising approximately 1GB, were also stored into netCDF files for user-friendly dissemination. The enhanced spatial resolution allowed a more understanding of local atmospheric and glaciological processes in this region. For instance, on January 7, 2013, a low-pressure system was identified to the east of the SSI. This cyclonic system, coupled with the intricate local orography of the northern AP, induced strong southward winds at the SSI. This meteorological event aligns with findings from a previous study by Kwon et al. (2019). Additionally, the intensified winds coincided with minor surface temperature and substantial snowfall over the SSI, as corroborated by our PWRF outputs. This event contributed to the SMB of the small glaciers within the SSI. I am very satisfied with these new results that can surely be published in an international journal.

Publications, Presentations and Products

We are writing the results of the atmospheric and glaciological simulations in a single manuscript that will be submitted to an international journal in the coming months. Additionally, the results of this project will be presented next year at the SCAR Open Science Conference 2024 “Antarctic Science: Crossroads for a New Hope" in Pucón, Chile. We will also put the atmospheric and glaciological data, PWRF namalists and scripts files in a github repository to make it freely available to the scientific community. In this way, other researchers and students will be able to replicate it at their study sites. On the other hand, during the exchange I attended two international conferences (International Union of Geodesy and Geophysics-IUGG and Congreso de la Sociedad Chilena de la Criósfera-SOCHICRI) presenting preliminary results of my PhD and this project. In addition, preliminary results of the impact of Atmospheric Rivers on small glaciers located on the SSI were presented at the XI Antarctic Conference between 24 and 26 October in Punta Arenas, Chile. Complementary, a research proposal for the CLIMATE-AmSud (https://www.sticmathamsud.org/sitio/) programme was led and submitted by me during this exchange. This proposal aims at strengthening research networks from Peru, Chile, Bolivia, Ecuador, Brazil and France on topics related to machine learning, glaciology, climate and extreme weather events. Finally, during the exchange I took the opportunity to write and discuss with my host supervisor two manuscripts. One was accepted in November for publication in Annals of the Brazilian

Academy of Sciences and the other is under discussion by the co-authors for submission early January next year to Journal of Glaciology.

Capacity Building, Education and Outreach Activities

During the exchange, I introduced my SCAR project to researchers at the host institution, and their enthusiastic interest provided valuable feedback. This collaboration not only fostered a dynamic exchange of ideas, but also allowed me to substantially expand my research network, with a focus on climate change, meteorology and glaciology. I am currently in the process of planning to share my SCAR fellowship experience with both undergraduate and graduate students at my home institution. Numerous colleagues from my home institution are actively engaged in developing their research projects within the AP, concentrating on oceanographic and biological aspects. Therefore, sharing my experience can motivate my colleagues to apply to the SCAR fellowship program and they can do an exchange at another institution to increase their skills.

Future Plans and Follow-ups

Next year I will finish my PhD, then I plan to do a postdoc. I am in constant communication with my host supervisor to finalise the manuscript we are writing with the results of this SCAR-project. I will take advantage of these meetings to tell him about the possibility of applying for a postdoc fellowship in Chile. During this postdoc I will focus on the study of extreme events and their role in synoptic atmospheric circulation anomalies and their impacts on small glaciers in northern AP using the high-resolution glaciological and atmospheric data generated in this SCAR-project. During my participation in IUGG-2023 in Berlin, Germany, as part of my PhD activities, I met leading researchers from British Antarctic Survey, UK, and Masaryk University, Czech, whose work involves RCM in Antarctica. In the future, I plan to try to visit these research institutions too.

Personal Impact

I am an Environmental Engineer by education and my work is to analyse the impact of climate change on small glaciers located in the northern AP and the Peruvian Andes. However, analysing glacier-atmosphere-ocean interaction in these small glaciers is not an easy task due to the limited availability of data and coarse resolution global model outputs. Through this exchange, I acquired fundamental skills in RCM that are fundamental for a more detailed understanding of atmospheric processes at regional and local scales. This exchange definitely increased my skills for a successful career in the field of glaciology, meteorology and climatology. On the other hand, my scientific working group will also benefit from high-resolution atmospheric and glaciological datasets.

Financial Statement

The funds provided by the fellowship were used exclusively to sustain my own living expenses, which includes travel costs, accommodation, health insurance and groceries.

Acknowledgements and References:

I would like to thank Prof. Dr. Deniz Bozkurt for giving me support in RCM and also for the extensive conversations we had during this visit on scientific, cultural and social issues, which definitely allowed me to grow professionally and personally. I would also like to thank Prof. Dr. Jorge Arigony for having provided the facilities with my home institution to carry out this exchange in Chile. In addition, we would like to thank the National Laboratory for High Performance Computing (NLHPC) from the University of Chile, this project was partially supported by the supercomputing infrastructure of the NLHPC (ECM-02:Powered@NLHPC). Finally, the data (KOPRI-KPDC-00000960) from King Sejong Station used in this work was provided by the Korea Polar Research Institute and we are very grateful.

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