2022 CliC Fellowship: FINAL REPORT

Project title: *Analysing snowpack characteristics in the Karakoram mountains via in-situ measurements and surface modelling*

Period: 1 March 2022- 31 March 2023

Fellow: Jawairia Ashfaq Ahmad, Centre for Water Informatics and Technology (WIT), LUMS, Pakistan

Objectives

1. Conduct fieldwork to collect (the first) in-situ snowpack measurements at two locations: Gabin Jabba (Khyber Pakhtunkhwa), and Skardu (Gilgit Baltistan)
2. Analysis of in-situ collected data and the subsequent spatiotemporal modelling of regional snow using models developed by the Institute for Snow and Avalanche Research SLF (SNOWPACK and Alpine3D)
3. Development and dissemination of the first publicly available, in-situ snowpack characterizing dataset in the Karakoram mountains of Pakistan

1. Results/deliverables/outcomes

1.1. Objectives

The objectives have primarily been achieved successfully.

Obj. 1: Fieldwork to collect in-situ snowpack measurements at Gabin Jabba and Skardu

Fieldwork in Gabin Jabba, Swat was conducted from 5th to 8th March 2022. The team included Jawairia Ahmad, Amna Ijaz, Muhammad Sohail, and Zahoor Khan. The delay in the transfer of fellowship funds (funds received in May 2022) caused a delay in the fieldwork timeline. We finally visited Swat in early March 2022. However, by early March the temperatures start increasing in Swat and precipitation reaches the ground as rain instead of snow. The rain-on-snow events cut our trip short as it raised safety concerns for the team and we returned after just two days in the field. However, the team was able to measure snowpack characterizing variables at two locations at elevations between 8000 and 9000ft. In addition, maintenance

operations of several telemetry-based sensors already deployed in Swat were performed. These sensors are still collecting snow depth data used for model validation.

Fieldwork in Skardu, Gilgit Baltistan was conducted from 10th to 13th February 2023. The team included Jawairia Ahmad, Muhammad Sohail, Zahoor Khan, and Soban Hameed. Dr. Edward Bair and Alex Mitchell from University of California Santa Barbara were also supposed to join the team in Skardu. However, due to the cancellation of flights caused by inclement weather, they were unable to travel with the team. Snowpack measurements from different areas across Skardu were collected. The area is prone to landsliding. The road to Sadpara catchment, which is one of the main study areas, was closed due to landsliding. The team improvised the field plan and collected measurements near the Sadpara reservoir and the Chunda valley near Skardu.

Obj. 2: Spatiotemporal modelling of regional snow

Spatiotemporal modelling of snow was implemented using two models at point and catchment scales. SNOWPACK and Alpine3D are energy balance based models developed at WSL Institute of Snow and Avalanche Research SLF to model the accumulation and ablation of snow. During the research visit to SLF, I learned about the basic features of both models, the datasets required to run them, and analysis of modelled results.

SNOWPACK was used to model snow depth at point scale for five station locations in Gabin Jabba, 31 station locations in the Chitral region, and 5 station locations in Skardu. Decadal timeseries show a decreasing trend in snow depth in Swat (see Fig. 1). There is considerable bias in the modelled snow depth in Chitral. Due to the bias in the model forcing temperature (ERA5), the modelled snow depth is considerably higher than the in-situ measurements.

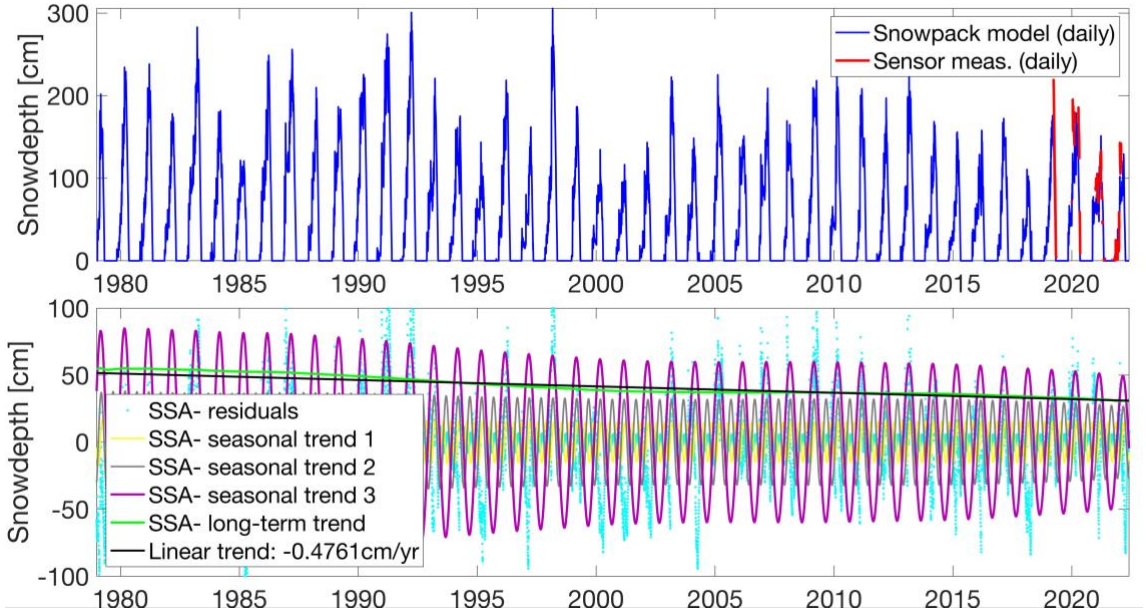

Fig. 1: *Singular spectrum analysis (SSA) is used to decompose the timeseries into additive trends (long-term + seasonal + residuals). SNOWPACK was able to model the start of accumulation and ablation seasons with differences in magnitude as compared to the station data. A decreasing long-term trend with reduced variation in the primary seasonal signal in snow depth is observed.*

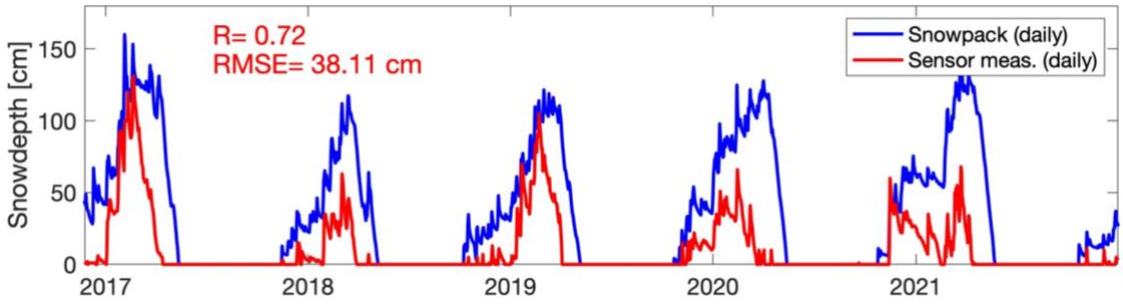

Fig. 2*: Timeseries comparison of modelled vs. measured snow depth at Parsan, Chitral. There is overestimation of snow depth across all the stations in Chitral due to temperature bias in ERA5.*

Alipne3D was used to model snow depth at the catchment scale for Gabin Jabba in Swat, Parsan in Chitral, and Sadpara in Skardu. The results for Gabin Jabba show bias in the modelled values when compared to the in-situ measurements from the field campaign (83.6 (Alpine3D) vs. 143 cm (measured) for a sloping location surrounded by trees and 93.8 vs. 131 cm for a relatively flat location on the side of a mountain). For both locations, the measured snow depth was higher than the modelled values. However, these are just two instances in time and space and cannot be taken to represent the model's behaviour throughout the spatiotemporal range.

In Parsan, snow accumulation in the high elevation areas begins in September and peak snow in elevated areas occurs after the snow melt has already started in the low elevation valleys. Similar results are observed for Sadpara in Skardu.

Obj. 3: Development and dissemination of in-situ snowpack data

The fieldwork described in Obj. 1 resulted in measurements collected in Gabin Jabba in 2022 and Skardu in 2023. This data has been digitized and is used to evaluate the modelled estimates (as discussed in Obj. 2). It has already been shared with the affiliated project members from UC Santa Barbara and will become publicly available once the ensuing paper is published. This data will be hosted on WIT's website for open dissemination.

1.2. Deliverables and Outcomes

The project outcomes include the in-situ snowpack measurements of snowpack characterizing variables at two locations (i.e., Gabin Jabba, Khyber Pakhtunkhwa and Skardu, Gilgit Baltistan). Details regarding the fieldwork planned and carried out to collect this data are provided above in Section 1.1 (Obj. 1). In addition to the originally planned two catchments in Swat and Skardu, a third catchment in Chitral was added to the study to increase the scope of the project. In-situ measurements collected by the Aga Khan Agency for Habitat were shared with WIT and provided supplemental data for evaluating the model performance. The third planned outcome was a peer-reviewed journal paper based on the analysis. The delay in the field visits subsequently delayed the paper writing process and the manuscript is currently under preparation.

1.3. Deviations from the original plan

The following list describes the deviations from the original plan that were caused by unforeseen circumstances:

- The original plan was to spend one week in Gabin Jabba in the end of Febryary 2022. However, due to the delay in the funds transfer, the fieldwork was pushed to March 2022 and had to be cut short by the start of rain-on-snow events.

- The fieldwork in Swat helped us better understand the shortcomings in our equipment and field gear. Therefore, additional funds were spent on buying the required gear and tools for the Skardu trip. Approval from CliC was granted prior to the change in expenses for the Skardu trip.
- A visa was required to enter Switzerland for my research trip to SLF. Due to a shortage of available appointments at the Swiss Visa Centers in Pakistan, the trip was delayed until I could get an appointment and be granted a visa. The research trip to SLF was originally planned for June 2022, but was eventually shifted to September 2022. The CliC representative was kept updated about the visa delay during this entire process.
- Originally, we had planned to take a flight from Islamabad to Skardu and spend one week collecting data in Skardu. Due to our flights being cancelled twice and landsliding on the Karakorum highway, we were delayed by four days and had only one day available for data collection. We also made multiple trips from Lahore to Islamabad for our flights which were eventually cancelled and we had to travel by road from Islamabad to Skardu. It took us 38 hours on the road to reach Skardu and 24 hours to return to Lahore. Multiple landsliding and construction events along the highway increased the total travel time.
- A third catchment and 31 stations in Chitral, Pakistan was added to the study domain and measurements collected by the Aga Khan Agency for Habitat were used for model performance evaluation.

1.4. Outreach an communication

The in-situ measurements collected from Swat and Skardu will be hosted on WIT's official website after the ensuing journal paper has been published. Currently, the manuscript is in preparation. The preliminary data was presented at the Himalayan University Consortium's Thematic Working Group on Cryosphere and Society Meeting at LUMS, Lahore in March 2022. In addition, the data and the modelling analysis was shared with the wider scientific community at the American Geophysical Union's Fall Meeting in December 2022 through an online presentation. Also, the authors were invited to share the key findings of the project with the participants of the Open Global Glacier Model workshop organized at WIT in Lahore in collaboration with scientists from University of Innsbruck and University of Bremen.

The snow modelling framework will be shared with the Aga Khan Agency for Habitat (AKAH) to enhance their cryospheric monitoring capacity in Pakistan. AKAH is a non-profit organization and works to provide the local mountain communities information regarding potential hazards. AKAH shared the ground measurements that have been collected by them during the last five years to improve this study and will be provided the necessary help in building their capacity to operationally run snow models.

1.5. Illustrations, figures, videos

Relevant illustrations of the project can be accessed through the following links.

- Shared drive containing media related to the field trips and figures (and videos) of modelled snow estimates:
  Illustrations

- Links related to the fellowship and other media

https://wit.lums.edu.pk/news/wit-faculty-wins-climate-and-cryosphere-clic-fellowship-2021
https://wit.lums.edu.pk/news/wit-conducts-expedition-collect-situ-snow-data-skardu
https://snow.ucsb.edu
https://sbasse.lums.edu.pk/snow-packed-north

2. Relevance of the project to the vision and objectives of CliC

The study aligned well with CliC's vision as it attempted to answer some of the core scientific questions that are a part of CliC's vision. The project revolved around enhancing scientific information about areas that have no precedence of cryospheric research. Seasonal snow in the Hindukush and Karakorum mountains has not been extensively studied. Considering its role in regional freshwater availability, it is critical that we know the amount of snow accumulated in the different mountainous catchments and the total volume of water it would contribute to the regional freshwater. This information is important for the sustainable advancement of the local communities. Collaborating with international partners, such as University of California Santa Barbara and the Institute for Snow and Avalanche Research SLF, on this project has connected WIT with the network of international groups that have similar research themes. In additions, the fieldwork has set up a precedence of in-situ snowpack observation and analysis across Pakistan and forms the basis for future similar investigations. The local communities are threatened by floods, avalanches, and elevation dependant warming. Partnering with regional organizations to continue this research theme will help in devising cryospheric hazard mitigation strategies, thereby enhancing the climate resilience of the local population.

3. Future plans

The funding provided by CliC helped in planning and implementing the first snow-based field campaign in Pakistan. I plan to continue these annual field campaigns to collect snowpack data. Continuous data is required to improve the modelling of seasonal snow. However, one obstacle is the lack of funding available for these scientific expeditions. This fieldwork aligns well with CliC's scientific vision and would be an ideal fit for the CliC activity grants in the future. In addition, I plan to continue improving the biases in the modelled snow by collaborating with SLF to devise bias correction strategies and AKAH to collect annual snow depth measurements.

4. Your personal comments

- *CliC grants aim at helping Early Career Scientists in their professional development and, hopefully, to get them engage and eventually taking leadership in CliC activities. Please describe how this particular grant can/will help you in the future career (either within or outside academia). We will also welcome suggestions on how to improve of this initiative.*

The CliC grants helped me in organizing the first snow-based field campaign in Pakistan. There are limited funds available for research in Pakistan. I was unable to find a single local platform that offered research funds to Post-docs or Early Career Scientists. Therefore, this fellowship provided vital support for my scientific career post-PhD. The funding helped us in procuring basic instruments that can be used in the years to come for snow measurements. It also helped start cryospheric research related to seasonal snow, which has a limited precedence in Pakistan, and develop connections with local hazard monitoring organizations.