**2022 CliC Fellowship: FINAL REPORT**

**Project title:** Developing meteorological forecasts for the early warning of hazards in the glacierized catchments of Central Asia

**Period:** 5.07.2022 – 31.01.2023

**Grantee:** Gavkhar Mamadjanova, Hydrometeorological Research Institute, Center of Hydrometeorological Service of Uzbekistan, Tashkent, Uzbekistan.

E: g.mamadjanova@reading.ac.uk

Private-E: gavkhar.mamadjanova@gmail.com; gavhar1402@mail.ru

**Objectives**

1. To build on the existing extensive database of Glacier Lake Outburst Floods (GLOF) and precipitation-induced (pluvial) DF for Central Asia (CA) with focus on Uzbekistan and Kazakhstan, expand the database to include variables relevant to the forecast of GLOF and DF.

2. To examine statistics of DF occurrences and quantify meteorological conditions of their formation focusing on positive air temperature and precipitation.

3. To derive the selected ECMWF forecast products for the past years for the glacierized catchments of CA and verify against the observations.

4. To compare the performance of two methods of precipitation forecast: standard ensemble forecast and the state-of-the-art ECMWF ecPoint-Rainfall product.

5. To apply the selected forecast products to hindcast GLOF and pluvial DF and verify the outcomes.

6. To disseminate the outcomes of the newly developed forecast method to stakeholders in Uzbekistan and Kazakhstan aiming to implement it into the operational practices of the State Hydrometeorological Services of both countries.

**Background and rationale**

In glacierized regions of CA, climatic warming is leading to the earlier onset of snow melt and liquid precipitation, intensifying melt of glacier ice and ice contained in moraines. This directly increases the risk of GLOF. A combination of saturation of soil and sediment with meltwater and extreme precipitation leads to a higher risk of slope instability and occurrence of pluvial DF. The upper limit of DF formation increased recently in CA reaching glacier-tongue elevation (Barandun et al., 2020).

A database of GLOF and DF events observed in Uzbekistan has been compiled as a part of the recently completed PhD project (Mamadjanova, 2019) and analysed with regard to the current meteorological conditions (Mamadjanova et al., 2018) and future climate change (Mamadjanova & Leckebusch, 2022). A similar database is available for Kazakhstan developed by the University of Reading. The proposed project will be based at the University of Reading, UK who works in close collaboration with the ECMWF on the development of novel methods of forecast including ecPoint rainfall (Hewson & Pillosu, 2021) and its application to the forecast of extreme events.
Guidelines:
• Please fill in the template report below.
• Send the completed template, illustrations, and scanned proof (receipts, etc) of expenditures to info@climate-cryosphere.org not later than 31 January 2023

I. Science report

1. Results/deliverables/outcomes

1.1. Give an account of whether the objectives have been achieved.

1.1.1. Database of Glacier Lake Outburst Floods (GLOF) and precipitation-induced (pluvial) DF for Central Asia (CA) with focus on Uzbekistan and Kazakhstan

This objective has been achieved in close collaboration with the Hydrometeorological Service of Uzbekistan (Uzhydromet) and the previously available data on precipitation induced debris (mainly mud type) flows (Mamadjanova et al., 2018)[1] in the country (1870-2014) was extended up to 2022 (Figure 1). The highest number of events was observed in 1930 with 167 events for the history of DF records, however, due to the excessive rainfall for the last 5 years the number of events gradually increased, and the record number was updated by 173 events in 2022. Precipitation is an important debris flows trigger in Uzbekistan; however, snow cover and glaciers in mountain regions (Petrov et al., 2017)[2], slope instability and temperature are additional factors. These phenomena typically occur between the months of March and July; however, data shows that the event can occur during the year with minor rates.

![Figure 1. Precipitation induced debris flows (DF) in Uzbekistan (1870–2022). Vertical bars present the observations for each year. The mean annual DF count (21) is indicated in a solid continuous horizontal line (pink). Curves (red, blue, green) have been fitted to the distribution for illustrative purposes and indicate the 5-, 11- and 21-year rates of occurrences.](image)

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The database of GLOF\textsuperscript{3} and DF in Kazakhstan was developed at the University of Reading as part of the ‘Climate Change, Water Resources and Food Security in Kazakhstan’ project funded by Newton&Sal-Farabi Fund, and UKRI project ‘Bridging over troubled waters: Improving preparedness and reducing vulnerability to debris flow in Central Asia’ (Figure 2) in collaboration with Kazakhstan previously. According to available data, the main sources of debris flow in the country are:

- Glacier Lake Outburst Floods (low frequency due to lake management)
- Extreme and/or prolonged precipitation
- Snowmelt
- Glacier melt

Similar in Uzbekistan, the pluvial debris flows in Kazakhstan can occur in a warm period of the year mainly from March till September (Figure 3), however, GLOF risk which is dependent on strongly positive temperature anomalies needs more comprehensive investigation. Available data since 1938 shows that more than 75 GLOF events observed in Kazakhstan.

\textbf{Figure 2.} Information platform on GLOF and debris flows over Central Asia developed by Shahgedanova et al., 2023 (in preparation) at the University of Reading in collaboration with Kazakhstan and Uzbekistan.

\textbf{Figure 3.} Debris flows in Central Ile-Alatau, Kazakhstan. Source: Shahgedanova et al., 2023 (in preparation).

\textsuperscript{3} Kapitsa, V. et al., 2017. Assessment of evolution and risks of glacier lake outbursts in the Djungarskiy Alatau, Central Asia, using Landsat imagery and glacier bed topography modelling, Nat. Hazards Earth Syst. Sci., 17, 1837–1856, \url{https://doi.org/10.5194/nhess-17-1837-2017}
1.1.2. ECMWF forecast products for the glacierized catchments of CA and its verification against the observations.

Probabilistic forecasts developed by European Centre for Medium Range Weather Forecast (ECWMF) have been evaluated and compared for the Central Asian region (Figure 4) within this pilot study: Standard Ensemble Forecasts (ENS)\(^4\) which consist of an ensemble of 51 members and ecPoint Rainfall\(^5\) produced by statistical post-processing of the ENS and delivers probabilistic forecasts of rainfall totals for points within a model gridbox (18 km resolution) which is particularly useful in the mountains. Skills of both types of forecasts were assessed in relation to the forecast of debris flows in Central Asia.

![Figure 4. Map of investigation area 35-50 N and 50-80 E mainly focused on the mountain region for which ECMWF forecast products and SYNOP observations have been derived.](image)

Cumulative Distribution Function analysis shows that ecPoint defines the typical rainfall event that can cause DF when no point rainfall observations (e.g., rain gauges) are available in the study area. The 75\(^{th}\) percentile of ecPoint is usually less in the point rainfall particularly in mountain areas and the percentile where point rainfall tends to be around 90% while the values for high percentiles (e.g. 95+) are often much greater in the point rainfall (Figure 5).

![Figure 5. CDFs of ecPoint values and station data for Tashkent (477 m), Pskem (1256 m) and Oygaing (2162 m) in Uzbekistan for the forecast period of T+12hr in 2021.](image)


The ecPoint forecast product was verified against SYNOP (surface synoptic observations) data for stations over Central Asia for October 2022. In the first step, the rainfall amounts from forecast product have been derived for each available stations over Central Asia (Figure 4) by application of nearest neighbour algorithm. Therefore, a popular verification method Receiver Operating Characteristics (ROC) diagram for the exceedance of precipitation thresholds of 10 mm was built after the defining of contingency table for the binary events (e.g., yes and no event). Figure 6 shows the ROC curves with lead time for Central Asia computed are generally high suggesting that ecPoint-Rainfall forecasts can be a proxy for point rainfall observations and can be used to define warning areas of DF risk.

Figure 6. ROC diagrams for the ecPoint VRE99 corresponding to the probability threshold of >10 mm during October 2022

1.1.3. Compare the performance of ENS and ecPoint in identifying areas at DF risk
Out of verification period and available data for 2022, two case studies have been examined for pluvial debris flows over Uzbekistan, Central Asia. By this way, the skills of ENS and ecPoint Rainfall have been compared based on forecast charts and SYNOP observations as a first experimental trial.

Case study 1 (20 April 2022)
During the midday of 20 April 2022, excessive rainfall and associated flash flooding across Forish District in Uzbekistan resulted in five fatalities and extensive damages in the area. According to the media, an exceptional amount of rain fell over two hours in five local streams and the surrounding hillside and resulted the water to gush rapidly down the slopes into the village of Egizbulog in Forish District which experienced one of the destructive events with the return period of 50 years. In general, rainfall amounts exceeding 15 mm within 12 hours is a lower threshold for precipitation induced natural hazards in the local area. However, during the storm, an official 2 hourly total rainfall of 31.5 mm was recorded near the town of Gallaorol about 100

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km southeast of Forish District centre (Figure 8), and daily accumulated rainfall up to 80 mm was estimated by satellite observations of the Global Precipitation Measurement (GPM) over the area (Figure 9). Synoptic environment responsible for initiating and maintaining the Forish flash flood (Figure 11) is supported by satellite imagery (Figure 7), suggesting that the rainfall resulted from a combination of forcing factors including transport of moist air (Figure 10) towards the topographic complex area (Figure 8).

ECMWF operational analysis applied to address the question of precipitation characteristics in the context of meteorological analysis and operational response to the hazards. Figure 13 shows ENS and ecPoint forecasts from the 00 UTC run for day 2 with the forecast lead time t+42 hours of accumulation 12 hourly precipitation. 95% of ENS and ecPoint with 10 mm threshold can capture the area of extreme flash flood events, however, when threshold increased up to 25 mm ecPoint predict the event while the ENS missing the extreme rainfall. SYNOP observation (Figure 12) also confirms that 95th percentile of ecPoint reached values more than 30mm/12h in the area where the deadly extreme event occurred.

**Figure 7.** Clouds over Uzbekistan on April 20, 2022, is obtained from NASA Worldview.

**Figure 8.** Map showing the topography (SRTM) of the regions in Uzbekistan (left panel) and the domain (right panel) where the flash flood event occurred on 20 April 2022. Accumulated precipitation from rain gauge observations (SYNOP) used for precipitation analysis.

https://worldview.earthdata.nasa.gov/
Figure 9. Multi-satellite precipitation estimates with climatological gauge calibration—late Run (GPM_3IMERGDLv06)9 over Uzbekistan (left panel) and the domain (right panel) on the day with flash flood event 22 Apr 2022 (res: 0.1x0.1)

Figure 10. Panel shows ECMWF ERA5 MSLP and moisture flux at 700 hPa over the study region for 0000 UTC, 0600 UTC, 1200 UTC and 1800 UTC 20 April 2022.

9 https://giovanni.gsfc.nasa.gov/giovanni/
**Figure 11.** Time evolution of the area (67.6 x 40.0) averaged ECMWF precipitation ERA5 land and ERA5 (top), specific humidity and temperature at 850 hPa (center) and relative humidity at 850 hPa (bottom).

**Figure 12.** SYNOP rainfall observation at 18 UTC on 20 April 2022.
Figure 13. Day 2 (00 UTC t+42) for 20 April 2022 18 UTC 95th percentile of ENS and ecPoint forecast charts with threshold >10mm and >25mm.

Case study 2 (19 October 2022)

After long and dry summer period, the October was one of the wettest months in 2022 in Uzbekistan. As a result of numerous of heavy rainfall events with extreme debris flows and flash floods observed in many different parts of the country. The 19th October was one of the wettest days resulted mainly in the highly populated foothill area of Djizakh region where more than 10 flash flood and debris flows were reported within a day. Figure 14 shows the ENS and ecPoint forecast from the 00 UTC run for day 2 (t+30hr) lead time for the 12-hourly accumulation period between 18 October 18 pm and 19 October 06 am when the majority of rainfall amount fell over the area. Both forecast products predict the area of debris flows in day 1 leading time. However, ecPoint Rainfall predicts more accurate the area of warning especially in a day 3 (t+54hr) leading time forecast starting from the 75th percentile and making it stronger in 95th percentile with threshold more than 25mm/12hr (Figure 15). SYNOP 12 UTC observation confirms that in a day of extreme event the rainfall amounts exceeded 20 mm in 12 hours (Figure 16).

At current state ecPoint performs accurate prediction of extreme rainfall induced debris flows in the area of investigation, however, long-term verification of the performance of ENS and ecPoint rainfall forecasts at predicting areas at debris flow risk needs to be finalised in order to make a strong conclusion. Since ecPoint-Rainfall forecasts are global and the ability to create debris flow warnings is a high priority for the community of CA.
Figure 14. Day 2 (00 UTC t+30) for 19 October 2022 95th percentile of ENS and ecPoint forecast charts including thresholds >10mm and >25mm in 12 hour.

Figure 15. 75th, 90th, 95th percentile of ecPoint Rainfall forecast for 19 October 2022 (t+54) with the threshold more 25mm/12hr

Figure 16. SYNOP rainfall observation at 06 UTC 19/10/2022
1.2. Give account of deliverables achieved and outcomes described in the original project description.

Project milestones (Table 1) confirms that majority of tasks are completed and some of research activities still going on and following deliverables and outcomes have been achieved in this project.

**Deliverables:**

- An extended and improved database of DF and accompanying meteorological conditions have been completed.

- Verification trials over the 2022 debris flow season in Central Asia showed that performance of ecPoint Rainfall depending on the forecast lead-time can be a good proxy for the range of point rainfall values to define the warning areas of debris flow risk over the study area. The ecPoint Rainfall is recommended for the operational application of heavy rainfall leading to debris flow formation which can support impact-orientated forecasting and early warning systems in Central Asia.

- 3 conference contributions (AGU 2022, ECMWF annual seminar 2022, Almaty conference 2022), 1 invited departmental talk at the University of Reading have been delivered; 1 conference presentation (EGU 2023) and 2 research paper are due to be delivered in 2023.

**Outcomes:**

- Improved research capacity in Uzbekistan and new and links between Hydrometeorological Research Institute in Uzbekistan, University Reading in the UK and international organisations such as the ECMWF have been launched.

- Workshops on ecPoint Rainfall will be delivered to the Hydrometeorological Services of Uzbekistan and Kazakhstan in June 2023 and the findings will be presented for the implementation in decision-making in collaboration with the Central Asian Regional Glaciological Centre (CARGC), Kazakhstan State Agency for Mudflow Protection (KSAMP), representers from the educational system (National University of Uzbekistan, Al-Farabi Kazakh National University), and local authorities. Recommendations for the national decision-makers on the implementation of the new method of meteorological forecast in risk reduction and hazard control will be delivered.
Table 1. CliC fellowship project milestone and completed tasks.

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Colour code:
- CliC Fellowship period
- Project activities
- Completed works
- Ongoing
- Planned activities
1.3. Explain any deviation from the original plan.

The original plan of this pilot project has been affected by two major issues (UK visa and data access) that obviously contributed to the delay in the completion all research objectives within the deadline.

1. **Delayed UK visa.** The evidence of experiencing a delay in processing UK Visa due to the Ukraine war and the corresponding letter with the UK Visas and Immigration (UKVI) has been reported to the project coordinator via email on 9 June 2022. Decision on UK visa has changed the original visit to the University of Reading (April 2022 - January 2023), and did contribute to rescheduling all research activities for the later and relatively short timeframe (July 2022 - January 2023).

2. **Data access.** I was appointed as a Visiting Scientist at ECMWF in Reading in November 2022 to get access to the standard ensemble forecast and ecPoint product independently which I needed to apply in the project. Unfortunately, the status request has come at a very critical moment for ECMWF in Reading, UK as all Data centre has been migrated to Bologna, Italy. All data archive has to be moved from Reading to Bologna between the period of June-October 2022. The physical transfer has been completed, but the data including ecPoint product was not fully functioned for some time after the migration. Due to these issues my computational work to analyse ecPoint and ENS forecast including download and handle the ECMWF data, scripting and running the necessary codes in unix-based HPC (High Performance Computing) environment got impacted massively and delayed my work significantly as many other ECMWF users. Information on ECMWF data transition can be found via the following links:

   - [https://confluence.ecmwf.int/pages/viewpage.action?pageId=226501261](https://confluence.ecmwf.int/pages/viewpage.action?pageId=226501261)

Overall, the delay in original work plans caused difficulties out of my control that impacted my progress to fully complete the verification process of ecPoint Rainfall and ENS forecast for a longer time period (e.g., for the period 2019-2022) and assess temperature impact on GLOF events in Central Asia. However, the research work is still ongoing, and the University of Reading has agreed to finance the completion of research activities by June 2023.

1.4. Explain how results will be published/communicated to the scientific community and to pertinent stakeholder/local communities (if applicable).

During the fellowship period the following **conference and workshop contributions (poster & presentations)** have been made.

1. **Mamadjanova G.,** Pillosu F.M., Shahgedanova M.: Evaluation of convective scale flow patterns initiating flash floods over Forish District of Uzbekistan in April 2022. ECMWF Annual Seminar on Challenging physics in seamless predictions. 12-16 September 2022, Reading, United Kingdom, [https://events.ecmwf.int/event/300/contributions/3376/](https://events.ecmwf.int/event/300/contributions/3376/), 2022.


**In preparation:**

2. Mamadjanova et al., 2023. The role of upper-level atmospheric flows and surface processes for the Forish flash flood of April 2022 in Uzbekistan.

**Invited talk:**


**Planned workshops:**

1. **Workshop in Uzbekistan** to train scientists and practitioners in application of ecPoint Rainfall to forecast flash floods and debris flows in mountain areas of Uzbekistan.  
   **Local partners, stakeholders and scientific community:** Hydrometeorological Service of Uzbekistan (Forecast Department, Natural Hazards Department), Hydrometeorological Research Institute, National University of Uzbekistan (Department of Hydrometeorology), Ministry of Emergency Situations of Uzbekistan.  
   Date: June 2023 (TBC).
2. **Workshop in Kazakhstan** to train scientists and practitioners in application of ecPoint Rainfall to forecast debris flows in glacierised catchments of Kazakhstan.  
   **Local partners, stakeholders and scientific community:** Hydrometeorological Service of Kazakhstan, Kazakhstan State Agency for Mudflow Protection, Central Asian Regional Glaciological Centre under UNESCO, Al-Farabi Kazakh National University.  
   Date: June 2023 (TBC).

*Include illustrations (pictures, figures, links to videos, etc) of the project to publish in the CliC webpage. The originals shall be sent as attachments to an email to info@climate-cryosphere.org*
Figure 17. Giving a talk at the Geography and Environmental Science (GES) Departmental Seminar, University of Reading on 12 January 2023.

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

Describe how the project contributed to CliC. Is there anything to add from what you described in the project description?

The project addressed CliC Strategic Priority 4 ‘System description of the cryosphere regions’ as it focuses on the mountainous glacierized catchments of CA aiming to improve understanding of integrated functioning and prediction of the cryospheric system under the observed climatic warming. It provided a pathway from physical science to the improvements in adaptation practices via the implementation of the new method of forecast. This is particularly important in the face of climate change, which is likely to increase the frequency of DF and GLOF and vulnerability population in mountain areas.

The joint investigation (UK and Uzbekistan) assisted capacity building. Research activities relevant to extending local data have been conducted in close collaboration with stakeholders in Uzbekistan (Centre of Hydrometeorological Service of the Republic of Uzbekistan) and Kazakhstan (Kazakhstan Hydrometeorological Service, Kazakhstan State Agency for Mudflow Protection). Achieved scientific results within the CliC fellowship period and after at the University of Reading & ECMWF will be delivered to the local stakeholders in Central Asia in planned workshops in June 2023 which addresses CliC Strategic Priority 5 Knowledge syntheses and communication to stakeholders.
3. Future plans

What’s next? Do you see this activity becoming part of CliC in the future? If so, how?

CliC fellowship project results show a considerable improvement in the precipitation forecast skill in complex terrain area which can be applied to all CA countries to predict extreme rainfall and debris flows. During the CliC project, the preparatory work associated with the management and analyses of large and complex ECMWF dataset was completed and codes for data analysis were scripted by me in collaboration with ECMWF and the University of Reading which enables to continue the research activities from February 2023 completing it by July 2023 using funding from the UKRI Rapid Response Policy Engagement Fund which prof Maria Shahgedanova and myself have secured on the strengths of the CliC Fellowship outcomes. This new project aims to complete the development of forecast of extreme rainfall for the early warning of debris flow (DF) events which is started as pilot project funded by CliC, and initiate the development of the Early Action Protocols (EAP) in Central Asia (CA) in collaboration with local authorities and Red Cross Red Crescent Climate Centre at the University of Reading. This work will contribute to the development of national and regional policies on hazard control and risk reduction in mountain areas which is a part of CliC Strategic Priorities (5) ‘Knowledge syntheses and communication to stakeholders’.

CliC Fellowship study has demonstrated a strong potential of the proposed method for DF forecast by application of ecPoint Rainfall for glacierised catchments of Central Asia which was only a start of an important and challenging scientific project. This pilot study results enabled me to develop a new research proposal ‘Improving rainfall forecast for prediction of hazards in High Mountain Asia’ in collaboration with the University of Reading (Prof. Shahgedanova) and ECMWF. The proposal has been submitted to the Schlumberger Foundation Faculty for the Future Fellowship programme 2023 which supports STEM disciplines and funds female scientists from developing countries. Results will be announced by the end of March 2023. If successful, the new project (designed to last 24 months) will enable me to expand this work methodologically to High Mountain Asia (HMA) which could also address CliC Strategic Priorities (4) ‘System description of the cryosphere regions’ and (5) ‘Knowledge syntheses and communication to stakeholders’. Therefore, I will continue research activities on meteorological forecast of debris flow events in HMA region in collaboration with the University of Reading (host), ECMWF (host), University of Birmingham (host), Mountain Research Initiatives (planned) and ICIMOD (planned) in the near future.

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.

CliC Fellowship gave me the chance to collaborate with the University of Reading which is one of the global leaders in climate research (ranked 4th in the world for Atmospheric Science in 2022) and has very strong research links with ECMWF (global leader in weather forecasting). While this fellowship period in Reading, I was appointed Visiting Scientist at the ECMWF that gave me independent access to the ECMWF operational forecast products I used in my CliC pilot project. I also joined the Environmental Science Research Division and Water@Reading research group which brings together scientists from the University of Reading and ECMWF. I met successful
scientists and inventors in both institutions who are leaders in their fields that I will use my new network to facilitate future collaborations and research activities between UK and Central Asia.

During the CliC project, I made progress on management and analyses of large and complex ECMWF datasets and coding which enables to carry out research using the state-of-the-art data in my future projects and disseminate this knowledge to my colleagues in Uzbekistan. I also had a chance to share the research results with the international scientific community in conferences and workshops that could contribute to the development of national and regional policies on hazard control and risk reduction across Central Asia in the future.

CliC fellowship will result in significant improvements in my career prospects. The new research networks (University of Reading, ECMWF) planned scientific publications and international workshops will put me on a competitive footing at my home institution. The latter will enable me to develop a research group in home institution focusing on forecasting extreme hydrometeorological events, disaster management and developing resilience to climate change in glacierised catchments of Central Asia. As a climate scientist, I am passionate about sharing my experience, including my new knowledge on the state-of-the-art ECMWF forecast products and the practical and scientific opportunities they present with my colleagues and PGR students in my home institution.

CliC granted me not only the excellent opportunity to meet and collaborate with amazing scientists and academics at global institutions in the UK, but it also gave me the chance to explore more about Thames path and see the hydrological and other engineering structures built in the river, as well as the history of the country in which I was hosted while my fellowship period. More or less, I was able to do a walking across the river Thames for more than 120 miles between Benson Lock in Wallingford and Egypt Bay Beach (Hoo Peninsula), Kent (Figure 18) which was one of the longest paths I have ever done in my life.

For the CliC future, I would like to suggest launching a group of CliC fellows and grantees pursuing their pilot projects in research institutions and bring together both current grantees and alumni of the programme at annual forums or hybrid meetings (virtual, in person). These events help create a sense of community and collaboration, where networking with early carrier researchers, well-known CliC scientists, and other accomplished leaders is facilitated.

![Figure 18. Thames Path between Wallingford and Hoo Peninsula in Kent (left), and Thames Barrier in Woolwich (right) designed to prevent the floods in London zones.](image-url)