PROCEEDINGS OF THE TRAINING ON

Spatial and temporal climate change analysis using CORDEX regional climate models over South Asia

7–11 June 2021 | Platform: Microsoft Teams

Executive summary

Regional climate models are gaining increasing prominence in climate change science and literature. More finely grained regional projections are crucial to adaptation planning and policy. In this context, ICIMOD, the United Kingdom's Met Office, the World Climate Research Programme (WCRP), and the Coordinated Regional Climate Downscaling Experiment (CORDEX) office organized a five-day training event on spatial and temporal climate change analysis using CORDEX regional climate models for South Asia. It was conducted under the Asia Regional Resilience to a Changing Climate (ARRCC) programme in June 2021 for the Department of Hydrology and Meteorology, Nepal and related organizations. Nine participants, including four women, attended.

The training programme, organized virtually over the Microsoft Teams platform, focused on imparting knowledge and skills in analysing regional climate change projections using the CORDEX climate models. It covered relevant aspects of climate change science, and showed participants how to access and analyse CORDEX data sets. Through hands-on exercises, resource persons from ICIMOD, the Met Office, and the Indian Institute of Tropical Meteorology (IITM)–Pune guided the participants on how to use these climate models to carry out spatial and temporal analysis of climate change over South Asia. The training focused on bias calculation in CORDEX regional climate model (RCM) data measured against reference data sets for the historic period and the selection of a few representative RCM simulations for a defined area of interest. The training also delved deeply into how R-based tools could be used to analyse and visualize climate change projections spatially at different time scales.

Before the training, about 70 per cent of the participants said they had poor-to-average knowledge about future climate scenarios. Following the training, this percentage dropped to zero, with 29 per cent stating that they now had excellent knowledge of these issues, and 57 per cent stating that they had good knowledge about future scenarios.

The participants were asked to work on two projects. The two teams presented their experiences and learning, and future plans to translate the learning into action. They proposed having more advanced training in order to analyse future projected data and to produce relevant information that would meet institutional needs and be used in different sectors.

ICIMOD, the Met Office, and their partners plan to organize further training workshops in 2022 to build institutional capacities regarding climate projections in the region.

SECTION 1

Background

South Asia and the Hindu Kush Himalaya are highly vulnerable to a changing climate. Rising temperatures, extreme events, glacier melt, erratic rainfall, and other impacts are having a range of harmful effects in this region. Planning for, and adapting to such impacts needs a robust understanding of regional climate change projections for the decades ahead.

An institutional capacity-building approach

It was felt that the knowledge and capabilities of those working in key national and regional institutions that deliver climate services needed to be enhanced, to enable appropriate and timely climate change responses in South Asia. A series of training programmes was planned for 2020–2022 to strengthen the capacities of individuals in these institutions to analyse climate projections and produce the information needed for application in different sectors. The training has been jointly developed and is being delivered by ICIMOD and the Met Office (the UK's national meteorological agency), with the support of other organizations, including the World Climate Research Programme (WCRP), the Swedish Meteorological and Hydrological Institute (SMHI), and the Indian Institute of Tropical Meteorology (IITM) – Pune.

The training events are organized under the Asia Regional Resilience to a Changing Climate (ARRCC) programme, which is supported by the UK's Foreign, Commonwealth and Development Office (FCDO). They are part of ARRCC's institutional capacity-building approach to regional climate projections. This approach targets national meteorological and hydrological services (NMHSs) and other organizations in ARRCC focal countries (Afghanistan, Bangladesh, Nepal, and Pakistan) that provide climate services and related information to government departments, non-governmental organizations, communities, and varied sectors vulnerable to climatic impacts to enable informed climate change responses in the region.

As part of this, in October 2020, ICIMOD and the Met Office, along with WCRP, SMHI, and IITM–Pune, organized a training programme on Regional climate change projections: Climate change analysis using CORDEX regional climate models over South Asia. As a follow-up activity, country-focused training programmes were planned for professionals from different NMHSs in Afghanistan, Bangladesh, Nepal, and Pakistan under ICIMOD's Climate Services Initiative (CSI). However, with the region experiencing a second wave of COVID-19 in 2021, and with the sudden surge in Covid-19 cases, the training had to be scaled down.

The training event in 2021 was restricted to institutions and individuals in Nepal. It focused on using CORDEX regional climate models (RCMs) to carry out spatial and temporal analysis of climate change in South Asia. This training programme introduced climate change science, examined bias calculation, and enabled the selection of representative models for a defined area of interest. It also delved deeply into how programming language R-based tools can be used to analyse and visualize climate change projections spatially at different time scales.

Objectives and outcomes

Overall, the training aims at building the knowledge and skills of the relevant personnel in analysing climate change projections using CORDEX regional climate model simulations. The June 2021 training programme helped participants develop their understanding of climate model projections by using 17 simulations from two RCMs (see Table 1), selecting the representative simulations that are best able to replicate historical climate cycles, and assessing the spatial and temporal variability of climate change in the present and future over a defined geographical area of interest.

In addition to gaining an overall understanding of climate modelling and downscaling, the participants were able to:

- Prepare CORDEX data sets in areas of interest and compare them with reference data sets
- Generate annual and monthly data plots using CORDEX and APHRODITE data
- Visualize spatial and temporal variations in climate change projections
- Interpret uncertainty in model results

Participation

In its current iteration, training was offered to professionals from the Department of Hydrology and Meteorology (DHM) and other relevant institutions in Nepal. Nine representatives from four organizations attended, of which four were from DHM, three from Tribhuvan University (TU), one from Real Time Solutions Pvt. Ltd (RTS), a private sector entity, and one from World Food Programme (WFP). Four of the nine participants were women. The training had to be organized virtually on the Microsoft Teams platform due to constraints imposed by the Covid–19 pandemic. As the training had only Nepali participants, a major part of it was conducted in Nepali barring those sessions in which the Met Office staff led the discussion.

TABLE 1 DETAILS OF THE 17 CORDEX SOUTH ASIA REGIONAL CLIMATE MODELS USED

CORDEX South Asia RCM	RCM description	Contributing CORDEX modelling centre	Driving CMIP5 AOGCM (details)	Contributing CMIP5 modelling centre
IITM-RegCM4 (6 ensemble members)	The Abdus Salam International Centre for Theoretical Physics (ICTP) Regional Climatic Model version 4.4.5 (RegCM4; Giorgi et al. 2012[1])	CCCR, IITM–Pune, India	CanESM2	Canadian Centre for Climate Modelling and Analysis (CCCma), Canada
			GFDL-ESM2M	National Oceanic and Atmospheric Administration (NOAA), Geophysical Fluid Dynamics Laboratory (GFDL), USA
			CNRM-CM5	Centre National de Recherches Météorologiques (CNRM), France
			MPI-ESM-MR	Max Planck Institute for Meteorology (MPI-M), Germany
			IPSL-CM5A-LR	Institut Pierre-Simon Laplace (IPSL), France
			CSIRO-Mk3.6	Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia
SMHI-RCA4 (10 ensemble members)	Rossby Centre Regional Atmospheric Model version 4 (RCA4; Samuelsson et al. 2011[2])	Rosssy Centre, SMHI, Sweden	EC-EARTH	Irish Centre for High-End Computing (ICHEC), European Consortium (EC)
			MIROC5	Model for Interdisciplinary Research On Climate (MIROC), Japan Agency for Marine-Earth Science and Technology, Japan
			NorESM1-M	Norwegian Climate Centre (NCC), Norway
			HadGEM2-ES	Met Office Hadley Centre for Climate Science and Services (MOHC), United Kingdom
			CanESM2	CCCma, Canada
			GFDL-ESM2M	NOAA, GFDL, USA
			CNRM-CM5	CNRM, France
			MPI-ESM-LR	MPI-M, Germany
			IPSL-CM5A-MR	IPSL, France
			CSIRO-Mk3.6	CSIRO, Australia
MPI-CSC-REMO2009 (1 ensemble member)	MPI Regional Model 2009 (REMO2009; Teichmann et al. 2013)[3]	Climate Service Center (CSC), Germany	MPI-ESM-LR	MPI-M, Germany

Source: http://cccr.tropmet.res.in/home/esgf_data.jsp
Note: The four selected models are highlighted in bold

[1] Giorgi, F. and Coauthors (2012) RegCM4: model description and preliminary tests over multiple CORDEX domains. Clim Res 52:7–29.
[2] Samuelsson, P. and Coauthors (2011) The Rossby Centre regional climate model RCA3: Model description and performance. Tellus, 63A, 4–23.
[3] Teichmann C, Eggert B, Elizalde A, Haensler A, Jacob D, Kumar P, Moseley C, Pfeifer S, Rechid D, Remedio A, Ries H, Petersen J, Preuschmann S, Raub T, Saeed F, Sieck K, Weber T (2013) "How does a regional climate model modify the projected climate change signal of the driving GCM: A study over different CORDEX regions using REMO", Atmosphere, 4(2), 214-236.

SECTION 2

Day 1

7 June 2021

Opening presentations and software installation

Opening session

Ghulam Rasul, ICIMOD chaired the opening session.

Mandira Singh Shrestha, ICIMOD welcomed the participants. She stated that the training event was specific to Nepal, was being organized for officials from DHM, and was a follow-on activity to the CORDEX training programme held in October 2020.

Ghulam Rasul thanked the Met Office, the WCRP, the SMHI, and IITM–Pune for collaborating in the training. Outlining some of its key objectives, he said the training would enhance knowledge about different facets of climate change analysis, including an improved understanding of climate modelling and downscaling, preparation of climate change data and comparison processes, uncertainty analysis. and bias calculation. The training programme, he said, would also briefly touch upon extreme climate indices for sectoral applications.

Daniel Ryan, Met Office said the training was being organized as part of the Climate Analysis for Risk Information & Services in South Asia (CARISSA) project of the ARRCC programme. The ARRCC, he said, collaborates with DHM and other institutions in Nepal to develop a collective understanding of climate science. It is helping enhance the resilience of vulnerable communities to current and future climate impacts by analysing, using, and communicating climatic projections for the future in the region.

Santosh Nepal, ICIMOD provided a brief overview of the training's content and broad objectives. The training, he said, aims at building the knowledge and skills needed to analyse regional climate change projections using CORDEX regional climate model simulations. Quantitative climate information, Nepal noted, plays a significant role in understanding changes in climatic variables. The training programme enables spatial and temporal climatic change analysis through the use of CORDEX data. Using regional climate data, he said, helps us understand regional climates better. Building the capacities of the national meteorological and hydrological services in the region to interpret and use climate information would aid informed decision-making.

Mandira Singh Shrestha made a presentation on climate services in the Hindu Kush Himalaya (HKH) region and their role in informed decision-making. She drew the audience's attention to the capacity-building approach adopted by ICIMOD's Climate Services Initiative to support NMHSs in the region. The CSI's aim is to improve the lives and livelihoods of people in the region, enhance their resilience, and reduce risks and vulnerabilities through the dissemination of relevant and timely climate information. It seeks to build the institutional capacities to do with climate change projections and harness the information for societal benefits. A series of training events had been planned, she said, to augment the capacities of partners. An expected outcome was that the learning from the trainings would be used for appropriate decision-making at various levels.

Mountains constitute a multi-hazard environment and are extremely vulnerable to climate change and variability, addressing which needs adequate data. Whereas climate services provide science-based information and forecasts that can empower decision-makers at different levels, both challenges and opportunities exist in the HKH in terms of their utilization. In this context, the implementation of the Global Framework of Climate Services (GFCS) becomes important, she said, especially for climate-sensitive sectors and areas such as agriculture, tourism, water, energy, health, and disaster risk reduction.

The opening session concluded with short introductions by the participants followed by them sharing their expectations from the training programme.

Fundamental concepts of climate change science and prediction

Cathryn Fox, Met Office made a presentation on climate modelling and the approaches used in regional and local downscaling of general circulation models (GCMs). She discussed the designing and production of simulations using RCMs, like in CORDEX; methods to downscale the GCMs; the suitability of different downscaling methods; and RCM evaluation techniques. She underlined the importance of the spatial and temporal resolution of data: GCMs have their limitations; for instance, they cannot, she said, represent small-scale atmospheric processes such as thunderstorms, which last for only a few hours and occur on sub-grid spatial scales. Hence GCMs need to be downscaled to RCMs that give climate information at a finer resolution and can help in assessing vulnerability and devising adaptation strategies. The optimum simulation duration to observe changes in climate is about 30 years, as it helps capture natural multi-year variability such as ENSO events. Statistical downscaling and dynamical downscaling are the two primary techniques used in downscaling GCMs. CORDEX models use dynamical downscaling, with spatial resolutions of about 25–50 kilometres (km). She cautioned the participants that errors in the GCMs are sometimes carried down to RCMs as well while downscaling. She underlined the importance of lateral boundary conditions (LBCs) – meteorological boundary conditions at the lateral boundaries – for RCMs, whose inputs can be provided through GCMs and reanalysis data. Model evaluation informs us how well the model can simulate the present-day climate. It helps one gain familiarity with the model characteristics, and indicates how to use the model for analysis. A non-prescriptive model evaluation framework, she said, helps users understand the purposes for which the models are being used. It provides a baseline for assessing the credibility of future projections, provides information about errors and uncertainties in the models, and helps users understand how RCMs work for a particular application.

Arun B. Shrestha and Santosh Nepal, ICIMOD spoke on climate change and predicted impacts in the HKH region. The region, said Shrestha, is a global asset for food, energy, water, and cultural and biological diversity, and the source for 10 major river basins. The region's climatic system is very important to sustaining these resources. The changing climate, he said, is of grave concern and its impacts on different sectors needed to be understood better. Understanding how the climate would evolve in the future – using different tools – can help inform how different sectors would be impacted. Despite having low average emissions, mountainous areas in the HKH region are likely to be the most affected. Both temperature and precipitation extremes are increasing in the region. Data from phase 5 of the Coupled Model Inter-comparison Project (CMIP) showed a projected temperature rise of 2.5 ± 1.5°C for the representative concentration pathway (RCP)4.5 and 5.5 ± 1.5°C for RCP8.5 by the end of the century. Precipitation would increase by 2 per cent in the near future and by 20 per cent in the long term. An average global temperature rise of 1.5°C would mean a temperature increase by 1.8 ± 0.4°C on average for the HKH region. A complex topography and coarse global models may have resulted in a weak consensus among the different climate models for the region, Shrestha cautioned.

In his presentation, Santosh Nepal, ICIMOD said that changes in temperature, precipitation, wind patterns, and radiation would adversely affect the cryosphere, in turn the hydrological regime, and eventually various sectors, human society, and ecosystem services. Changes at higher altitudes directly influence downstream areas, suggestive of strong upstream–downstream linkages in mountainous regions. Citing the landmark 2019 report, The Hindu Kush Himalaya Assessment, he said that one-third of the ice in the Himalaya would disappear by 2100, and as much as two-thirds in business-as-usual scenarios. Already, Nepal's glaciated area had decreased by 25 per cent between 1980 to 2010. The Panjshir basin in the western Himalaya – which experienced only two snow-free months a year during the reference period 1981–2010 – is likely to have 5–6 months a year without snow by the end of the century under high-emission pathways. This would seriously impact agricultural systems in downstream areas dependent on snowmelt. The frequency and magnitude of hydrological disasters are likely to increase. Extreme events such as glacial lake outburst floods (GLOFs) can damage infrastructure downstream, such as a GLOF in Tibet in 2016 that damaged a Bhote Koshi hydropower project in the Koshi River basin (KRB). Droughts, which affected 330 million people in India in 2016, are also a serious issue, affecting farmers and triggering seasonal and permanent migration. Climate change is likely to disproportionally impact women, and poor and marginalized communities, Nepal said. A better understanding of climate change was required, he emphasized, to design proper adaptation strategies.

In his presentation, J. Sanjay, IITM-Pune introduced the high-resolution climate projections available for South Asia from the World Climate Research Program (WCRP)'s regional activity – Coordinated Regional climate Downscaling Experiment (CORDEX).

CORDEX's vision, he stated, is to advance and coordinate the science and application of regional climate downscaling through global partnerships. CORDEX's primary focus is to downscale WCRP Coupled Model Intercomparison Project (CMIP) global climate projections to generate higher resolution data at regional scales. The CORDEX models are customized for different regions; models tend to differ depending on the different types of physical processes, boundary layer processes, and land surface processes. The CORDEX activity under the WCRP seeks to coordinate a single experiment framework that would enable comparisons between different climate models. The dynamical downscaling of CMIP5 projections to 50 km spatial resolution has been carried out. More recently, the CORDEX-CORE simulations with 25 km spatial resolution have also been generated by the CORDEX South Asia modelling partners, which has been used in the latest IPCC report, the Sixth Assessment Report (AR6).

He then spoke about related work being done in the Centre for Climate Change Research (CCCR) at IITM-Pune. The centre's work focuses on generating regional climate information for impact assessment studies in the South Asian region. The CCCR is currently developing a global high-resolution (27-km) atmospheric version of the IITM Earth System Model (IITM-ESM). The IITM-ESM has contributed to the WCRP CMIP6 experiments. He showed some results of the assessment done using CORDEX data from The Hindukush Himalaya Assessment. Finally, he drew attention to the centre's climate data portal that allows users to subset and download CORDEX South Asia data pertaining to their area of interest.

This concluded the presentations for the first day. After which, ICIMOD's resource persons addressed problems faced by the participants while installing the software and downloading the data needed for the hands-on session the following day.

Day 2

8 June 2021

CORDEX data extraction and management for the analysis

The second day of the training programme focused on presentations and hands-on training regarding data extraction and generating annual and monthly data plots using CORDEX and APHRODITE data. APRHRODITE comprises long-term gridded data at a continental scale that is based on data from a dense network of rain gauges for Asia.

The resource persons first ensured that the participants had downloaded all the data and tools required. Participants carried out a spatial and temporal analysis of the data, having defined the Koshi River basin in Nepal as the area of interest. Data from two representative concentration pathways (RCPs) – RCP4.5 and RCP8.5 – was used for the practical sessions. RCPs, used in IPCC's *Fifth Assessment Report*, reflect socioeconomic trajectories and represent greenhouse gas (GHG) concentrations that result in a certain radiative forcing, or energy imbalance, by 2100, measured in watts per metre squared (W/m^2). Hence, RCP4.5 refers to a radiative forcing of 4.5 W/m^2 in 2100. Expectedly, RCP8.5 is a high-emissions scenario that will result in greater temperature increases, impacts, and costs. RCP2.6 is a rather optimistic, low-emissions scenario. The training used data from all 17 CORDEX model simulations for the RCP4.5 and RCP8.5 scenarios.

Saurav Pradhananga, ICIMOD demonstrated in detail the steps needed to extract and clip CORDEX data sets pertaining to precipitation and temperature for a defined area of interest. Extracting CORDEX data consumes a lot of time and computing resources – the uncompressed and unclipped data from 17 model simulations amounts to around 350 gigabytes.

For the training exercise, ICIMOD resource persons made available processed data sets – data from all 17 model simulations for the Koshi River basin clipped from the South Asia domain. The participants were given material how to download data from the Earth System Grid Federation (ESGF) and IITM–Pune.

The training adopted APHRODITE data pertaining to precipitation and temperature for 1976–2005 as the reference data set for analysis. APHRODITE data has a resolution of 0.25°, and was chosen as the reference data set because it is widely used. It can be replaced by other data sets; however, the temporal and spatial extent of the selected data – reference and model – must be comparable.

At first, the monthly values for both the variables – temperature and precipitation – were calculated to check whether APHRODITE data represented the climate of the Koshi River basin. The graph plotted from the monthly averaged APHRODITE data successfully represents the monsoon cycle in the Koshi River basin, and can be compared with climate change data; almost 80 per cent of the precipitation occurs between June to September. The lowest precipitation is received in winter months.

Then, the annual averages of temperature and precipitation were computed for the reference period and plotted. Graphs were generated for all 17 CORDEX model simulations, and would be used in bias calculation for the comparison and selection of representative model simulations from these seventeen. By also examining the annual precipitation patterns visually, a general subjective analysis of the model simulations can be carried out to see which model may be more representative of the KRB. Some model simulations successfully represent the monsoon system in the plots while some do not. The annual plots for temperature have similar variations.

All the participants were able to generate graphs and spatial plots with the codes provided. The session, and the day, concluded with feedback from the participants regarding the content of the training, and the pace at which it was conducted.

Day 3

9 June 2021

Selection of representative model simulations from the 17 CORDEX model runs

The third day began with the participants providing a brief recap of the previous session and a discussion of the problems they had faced. They were then provided information on the workflow for the day.

On the third day, the bias in the 17 CORDEX model simulations was calculated, using the APHRODITE reference data set. The average monthly data for both precipitation and temperature were generated for bias calculation. Using this method, participants selected eight of the 17 model simulations that were able to accurately represent the seasonal bias. They then carried out a second round of bias calculation using the annual averages of precipitation and temperature to finally narrow the field to four model simulations. The difference between the reference data set and model data for the future was also plotted spatially to visualize the difference. Then, the ensemble mean of the four models was used to chart future climatic projections.

Day 3 included the following steps:

- Loading the required libraries and setting up working directories

- Monthly data extraction for all model simulations for both RCPs
- Annual data extraction for all model simulations for both RCPs and trend analysis
- Seasonal bias calculation for selecting model simulations
- Annual bias calculation for further model selection
- Plotting the selected model for precipitation and temperature

Comparing the CORDEX data sets with APHRODITE reference data sets

Monthly and annual data pertaining to temperature and precipitation was extracted for RCP4.5 and RCP8.5. The participants carried out a trend analysis for these two variables. The temperature trends showed a consistent rise for both RCPs in all 17 model simulations. However, in the case of precipitation, some years showed a decreasing trend.

STEP 1: CALCULATING THE SEASONAL BIAS

The monthly averages from the APHRODITE data set were used to calculate the seasonal bias for the reference period 1976–2005. First, participants extracted the monthly average data for both temperature and precipitation for all 17 model simulations. The monthly data was categorized into the four seasons: pre-monsoon (March–May), monsoon (June-September), post-monsoon (October–November), and winter (December–February). They plotted the monthly average values for the 17 model simulations and the APHRODITE data and separated them by season. The percentage difference in the various seasons between all the model simulations and the APHRODITE data was calculated as bias, which was then ranked jointly for both variables. Model simulations with the highest bias were identified. Four model simulations did not show the effects of the monsoon, the dominant weather system in the Koshi basin, and were hence considered non-behavioural model simulations. Using this seasonal bias, 17 model simulations were narrowed down to eight for RCP4.5 and RCP8.5. One must point out that equal weightage is given for all seasons; for a sector-specific study, weightage can be allocated according to the user's needs.

STEP 2: CALCULATING THE ANNUAL BIAS

In the second step, a similar process was carried out, but using an annual bias calculation. Annual averages were computed and compared against the reference data set for bias calculation of the eight model simulations selected in the first step. The aim was to select the four models most representative of the historical climate in the Koshi River basin. It is important to minimize uncertainty. As with step 1, it is preferable to discard the non-behavioural model simulations. For precipitation, the simulations that matched the monsoonal characteristics of the reference data set were selected.

Using the two-step method, the participants selected four model simulations which were found to be most representative of the Koshi basin – three simulations using the RCA4 regional model and one simulation using the RegCM4 regional model. They were:

- CCCma-CanESM2_SMHI-RCA4_v2
- CSIRO-QCCCE-CSIRO-Mk3-6-0_IITM-RegCM4-4_v5
- CSIRO-QCCCE-CSIRO-Mk3-6-0_SMHI-RCA4_v2
- IPSL-IPSL-CM5A-MR_SMHI-RCA4_v2

One should point out that the selection of future climate models is based on users' need; the criteria for their selection needs to be developed accordingly. In the case of Nepal's National Adaptation Plan (NAP) for instance, the selection of the most representative GCMs was done in three steps: the initial criterion used was changes in mean temperature and annual precipitation; then, four indices for climatic extremes; and the annual cycle of temperature and precipitation for the final selection.

Ensemble mean and ensemble range

The participants calculated the ensemble mean, or average, using the four selected model simulations listed above. It shows the average direction of change in the future across the model simulations. However, the ensemble range from the four model simulations is retained and considered rather than just their mean because it provides many possible scenarios for the future; the ensemble mean provides just one, which could be misleading.

At the participants' request, information on bias correction of data was briefly provided. They were told that the procedure followed for bias correction in the NAP could be used to correct the bias in the CORDEX data. The session ended with the resource persons addressing the problems faced by the participants during the hands-on exercises on Day 3.

Day 4

10 June 2021

Visualization of future scenarios based on selected model simulations

The morning session of Day 4 started with addressing the problems faced by participants the previous day. Some participants tried the previous day's codes for their area of interest and shared the challenges they faced. This was followed by a short demonstration on how to download CORDEX data from ICIMOD's regional database system (RDS).

The fourth day of the training event focused on the spatial visualization of future climate data based on the ensemble mean value from the four selected model simulations. The steps for the visualization of future scenarios based on selected model simulations in R platform are:

1. Loading the required library packages and setting up working folders
2. Plotting the annual data for the selected model simulations
3. Calculating the average and standard deviation for the ensemble mean of both temperature and rainfall
4. Plotting the ensemble values for both variables to view future climate projections
5. Calculating future climate change based on delta change for the selected model simulations with respect to the APHRODITE data set
6. Plotting spatial change maps for precipitation and temperature
7. Estimating future seasonal changes in both variables for the selected model simulations

Calculation of future scenarios of precipitation and temperature

The ensemble mean for the four selected CORDEX model simulations was calculated and plotted. Their standard deviation (SD) was also calculated to determine the errors bands for both the RCPs. The annual ensemble mean and error bands were plotted along with the historical reference data set to check future climate scenarios in the Koshi basin.

The annual ensemble band plot for precipitation didn't show much difference between RCP4.5 and RCP8.5. The annual data for the reference data set from 1976–2005 was also plotted alongside the historical and future values of the RCMs. The annual reference values agreed with the historical data of the models. The trend analysis of average annual temperatures showed a similar increasing trend until mid-century for both RCP4.5 and RCP8.5. However, after the mid-2040s, the annual temperature trend increased significantly under RCP8.5 as compared to RCP4.5. By the end of the century (defined as the period 2070–2099), the difference between the two RCPs was around 2°C. Then, the APHRODITE data was plotted along with the climate change data in a trend analysis graph. It was observed that all the RCMs had a cold bias of 2°C in the reference period when compared to APHRODITE data. This could be due to systematic bias in the model data. In such cases, bias correction of the data set is recommended.

Calculation of the annual and seasonal changes

Delta changes in precipitation and temperature between the reference period (1976–2005) and the future period (2070–2099) were calculated for both RCPs. Changes in precipitation were calculated as a percentage; for temperature, it was computed as the difference.

The participants then analysed these results spatially. The analysis showed precipitation in the upper reaches of the Koshi basin to be higher by almost 30 per cent under RCP4.5 and by almost 40–50 per cent under RCP8.5. Similarly, the temperature difference between the two periods was the highest in the upper basin, by 4.5°C under RCP4.5 and around 7°C for RCP8.5. The changes in the different seasons were also computed for both variables and RCPs. Monsoon precipitation showed increases ranging from 2.27 per cent to around 31 per cent in the different model simulations under RCP8.5. Temperatures were projected to increase in all seasons, with one of the model simulations showing an increase of as much as 7.78°C during the pre-monsoon period for RCP8.5. The seasonal analysis also showed that even if there is an increasing trend annually, some seasons may show a decreasing trend. The day concluded with an interactive session on the problems participants faced.

Day 5

11 June 2021

Uncertainty analysis

The last day of the training covered uncertainty analysis of the CORDEX data. It was pointed out that there will always be some uncertainty in future projections due to the uncertainties present in the RCMs and parent GCMs themselves. Hence, estimating the uncertainties in the models, before using the data, is important. The broader objective of uncertainty analysis is to provide decision makers the most precise data possible considering all possible aspects.

The team provided the codes to carry out the uncertainty analysis of models, which includes the following steps:

- Loading the library and setting the working directory
- Calculating the delta change for all model simulations for both variables – precipitation and temperature
- Reading the delta change of all model simulations for both variables for the uncertainty analysis
- Sub-setting the delta change of selected model simulations for comparison of uncertainty analyses
- Generating scatter plots with a max–min error bar of temperature and precipitation for both RCPs

The participants first calculated delta changes for all 17 model simulations. They compared the uncertainty analysis of all 17 model simulations and the four selected model simulations through the scatter plots for both RCPs. As expected, the scatter plots showed that the uncertainty in the selected model simulations was lower than in the 17 model simulations. Changes in the range of the model data could also be seen through the scatter plots. They demonstrated that uncertainty is higher in RCP8.5 than RCP4.5. Between the variables, temperature showed a smaller range of uncertainty than precipitation. Uncertainty analysis underlines the significance of model selection as its range decreased for the selected model simulations. The session ended with queries from the participants regarding uncertainty analysis and responses to them.

The training session shifted to a discussion on the dissemination of climate information. Indira Kandel, DHM made a presentation on existing climate services in Nepal and the DHM's future plans. Climate services, she began, helps people take improved decisions based on forecasts and aids policy makers in developing adaptation plans for climate variability and change. There are, she said, more than 500 meteorological and hydrological stations in operation throughout Nepal; data from all these stations are made available through online applications by users. The DHM monitors climate on a daily, seasonal, and annual basis and shares this information in the form of bulletins and reports. This information is also disseminated through websites, Twitter, Facebook, TV, etc.

The DHM has recently started to issue a national seasonal climate outlook, starting with the 2020 monsoon. According to law, the DHM is mandated to produce climate change reports and update them every five years. It had jointly produced the National Adaptation Plan (NAP) report along with ICIMOD in 2019. It also collaborates with various national organizations – such as the National Disaster Risk Reduction and Management Authority (NDRRMA), the Ministry of Agriculture and Livestock Development (MoALD), and the National Agriculture Research Council (NARC) – for the dissemination of climate information. It is also seeking to enhance its capacities through ongoing collaborations with international or regional organizations such as ARRCC, the Finnish Meteorological Institute, and the World Meteorological Organization (WMO).

Based on the services provided, the WMO has categorized climate service providers into four categories. In the longer term, the DHM seeks to produce Category 4 services such as customized climate data products and develop various climate application tools targeting different sectors for enhanced communication. A limitation thus far, Kandel said, has been that DHM has not been able to take feedback from service users. It is planning to develop interactive web portals, produce advisories for various sectors, and set up feedback mechanisms for early warning systems. It plans to strengthen climate monitoring infrastructure at high altitudes. It also plans to establish data banks for climate-induced disasters, and produce risk maps for climate- and water-induced disasters on a regular basis.

Kandel concluded by emphasizing that there was an urgent need to enhance climate services in Nepal. This could be done through collaborations with partner agencies, which would fulfil the DHM's vision of making Nepal a climate-resilient nation.

Group work by participants

Following the 5-day training, participants were requested to work on a project based on what they had learnt and make a presentation. They were split into two groups for this exercise.

GROUP I: DHM

Team members: Nirmala Regmi, Lasakusa Shrestha, Sajina Shakya, Sudarshan Humagain

Nirmala Regmi presented the methods used in, and results of their project. The team had adapted steps in the spatial and temporal climate change analysis for the Koshi basin up to Chatara. A spatial plotting of the CORDEX data for all 17 model simulations for temperature and precipitation had been performed; she said that such an initial plotting could help filter out non-behavioural model simulations using a visual comparison. The group used APHRODITE data as the reference data set to select the most representative models of the 17 model simulations. Initially, using seasonal bias, eight model simulations were chosen from the seventeen. In the next step, the eight model simulations were filtered on the basis of the annual bias to finally get four representative model simulations. The changes in precipitation and temperature for RCP4.5 and RCP8.5 by the end of century were also shown and explained. The difference between the future period and the reference period was also calculated. She stated that precipitation showed lesser variability as compared to temperature for RCP4.5 and RCP8.5. Uncertainty analysis was also performed and compared for the 17 CORDEX model simulations and the four selected model simulations. The exercise showed that the range of uncertainty was lower for the selected model simulations.

Regmi then briefly talked about ways forward. This climate change analysis could be replicated in other basins as well. However, she said, more advanced training was needed to process data regarding future projections and to produce the relevant information to meet institutional needs. She concluded by emphasizing that this kind of training from partner organizations would greatly help in building the capacities of DHM's staff and benefit the organization.

GROUP II: TRIBHUVAN UNIVERSITY, REAL TIME SOLUTIONS PVT. LTD, WORLD FOOD PROGRAMME

Team members: Aarati Nepali, Arnab Singh, Deepa Pradhan, Dibash Shrestha, Nibesh Shrestha

Deepa Pradhan and Nibesh Shrestha made presentations on behalf of their group. They said they had found the first day of the training very helpful in understanding climate services, climate change and its impacts, climate modelling, and downscaling. The team carried out spatial and temporal climate change analysis for the Bagmati and Koshi basins up to Chatara. They extracted and plotted CORDEX data pertaining to precipitation and temperature for all 17 model simulations. APHRODITE data was used as the reference data to filter out four representative model simulations out of 17 model simulations by calculating the seasonal and annual biases. Even though the selected basins were sub-basins of the Koshi River basin, different sets of four selected model simulations were identified for the two regions. The team calculated future trends in temperature and rainfall using the 17 climatic model simulations for the Bagmati basin. Precipitation, they said, did not show much variation even for the end of the century but temperature rose for all models under both RCPs. Uncertainty analysis carried out for the 17 model simulations and the four selected model simulations showed that uncertainty greatly decreased for the latter. The team members said they planned to use what they had learnt in the training workshop in their field of work, such as for climate change analysis, disaster risk reduction, and enhancing food security. It would also be taught to first-semester students of the Central Department of Hydrology and Meteorology (CDHM), Tribhuvan University.

The participants were asked to assess the content of, and benefits from the training. They were asked to rate its overall content, its quality in specific areas, their knowledge of themes before the training, how much they had learnt overall, their knowledge of themes after the training, and how likely they were to apply this knowledge in their work. They were also asked to rate the quality of the training received (see Annexure 2).

Closing session

Joseph Daron, Met Office thanked the resource persons from ICIMOD for supporting and facilitating the worksh op. He praised the participants for their engagement throughout the training, and the effort they had put into the presentations. Understanding the significance of climate change analysis and information services is important for South Asia. There are many aspects to climate change analysis, he said, but the key aspect is the analysis of data that currently exists and will be available in the future. Exploring the CORDEX simulations provides a huge opportunity, he said.

Daron pointed out that the range of model results and the uncertainty analysis in the training had highlighted the uncertainties of future climates. We need to be cognizant of such uncertainties, he pointed out, when synthesizing and communicating such information. And whereas the focus of the training had been analysing model data, the human component was still critical, and hence regional expertise was needed for understanding the climate.

The IPCC's *Sixth Assessment Report*, he said, would be published this year, making available new sets of information. (Its first volume, of Working Group 1, was released on 9 August.) The challenge for the scientific community in the years ahead, Daren said, was how to incorporate CORDEX information along with the new information provided.

Indira Kandel, DHM expressed her happiness at seeing university students participating in the training workshop. CDHM is the only university department in Nepal, she said, producing human resources for DHM. By involving young students in the training, ICIMOD and the Met Office had helped broaden their knowledge and skills for climate change analysis. Kandel emphasized that further advanced training in the future would be more helpful. She concluded by requesting the participants to practice learning and training continually.

Ghulam Rasul, ICIMOD congratulated the participants on the successful completion of their training and said that the presentations by both teams had been very impressive. He recommended that the participants continue the learning process, apply the lessons learnt in their work, and reach out to the resource persons present for any additional support.

Mandira Singh Shrestha, ICIMOD said that the training had been successful in bringing together NMHSs and other relevant institutions working on climate change to learn and enhance skills of the individuals and across institutions. She expressed the hope that the good work would continue with the next phase of the ARRCC programme and that the learning from the training could be taken to the next level.

She thanked the key resource persons and all the presenters who had set the foundation regarding climate science before the hands-on training. She also thanked the FCDO, the Met Office, and the DHM for their support, and Indira Kandel for her engagement in building DHM staff capacities.

Arun Bhakta Shrestha, ICIMOD said that the participants' presentations had been very encouraging and that he was pleased with the outcome of the 5-day training workshop. He congratulated the trainers for being able to teach so well, and said it was encouraging to see future plans already being made to implement the learning from the training.

Santosh Nepal, ICIMOD acknowledged the efforts all key resource persons in designing the training module. He requested the participants to consult with the resource persons if they had any queries in the future. He concluded by thanking all the participants, resource persons, and partners.

Additional event information and materials are available at:
https://www.icimod.org/event/spatial-and-temporal-climate-change-analysis-using-cordex-regional-climate-models-over-south-asia/

File links:
Agenda
List of participants

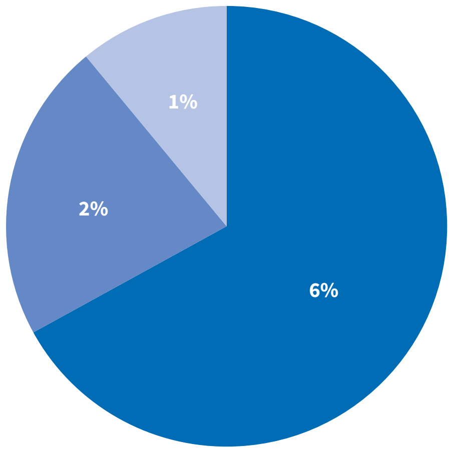
SECTION 3

Annexes

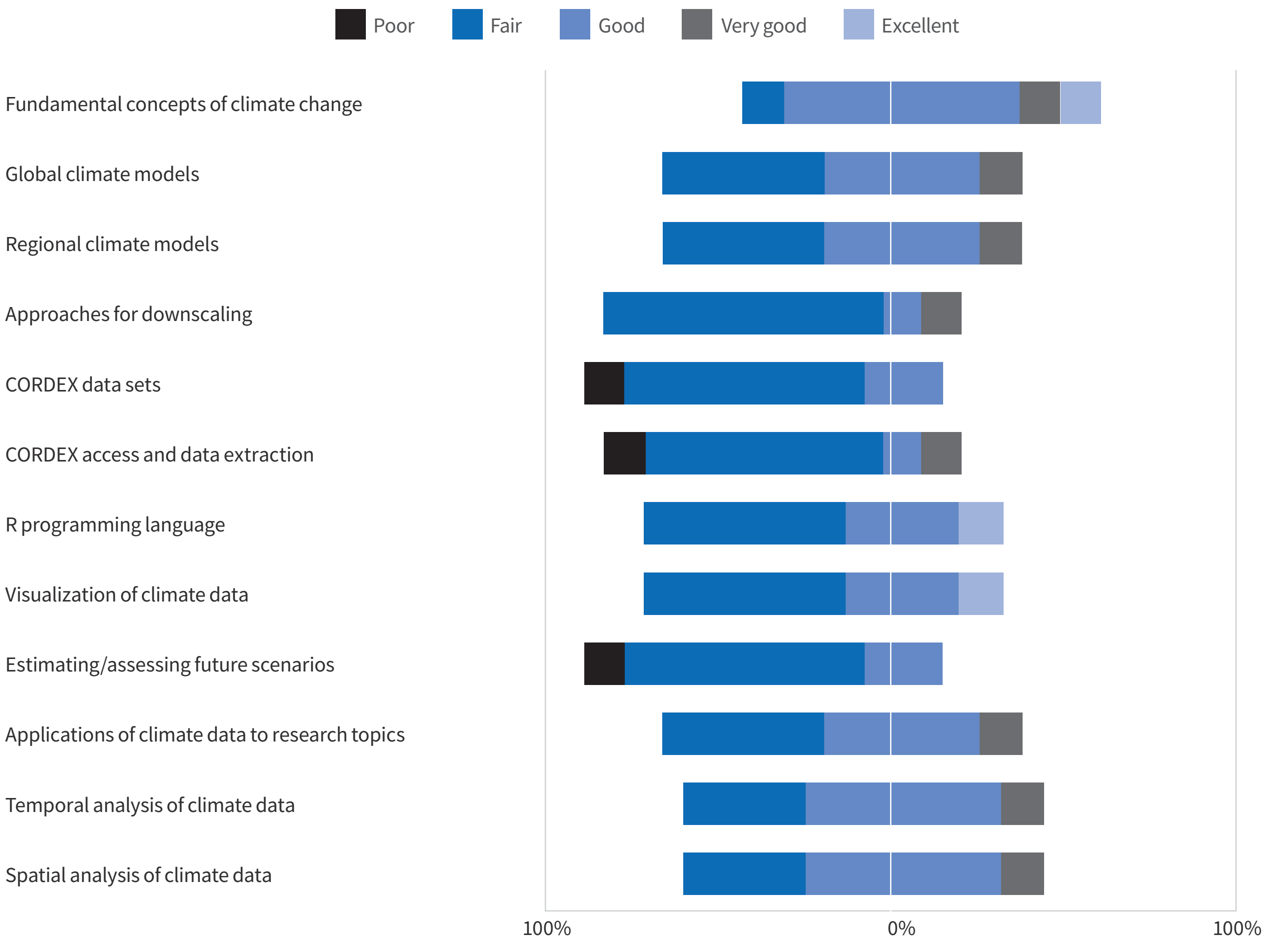
Annex I: Results of the pre-training assessment

Why did you choose to participate in this event? (Choose the most appropriate one)

This training is relevant to my job	6
To enhance my knowledge and skills to an advanced level	2
Exposure and professional networking	1
To build basic knowledge and skills on the subject	0
Others	6

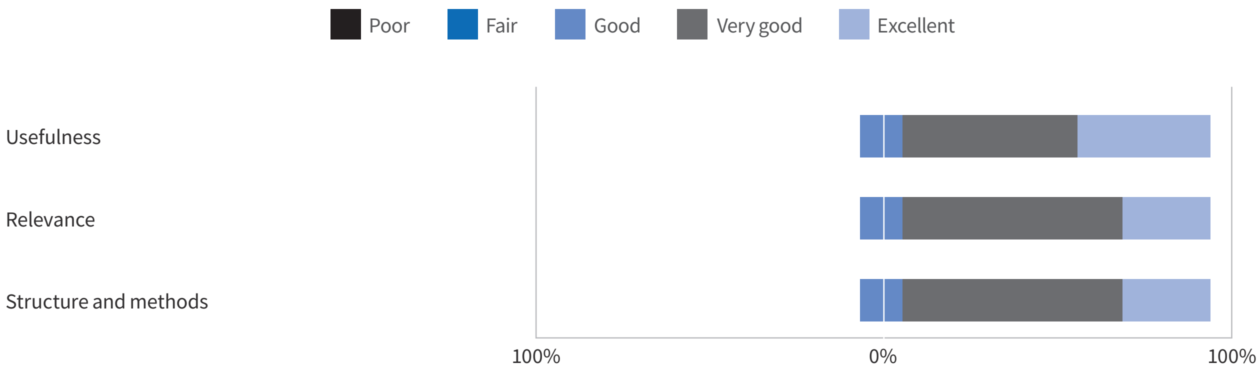


How would you rate your knowledge of the following topics?

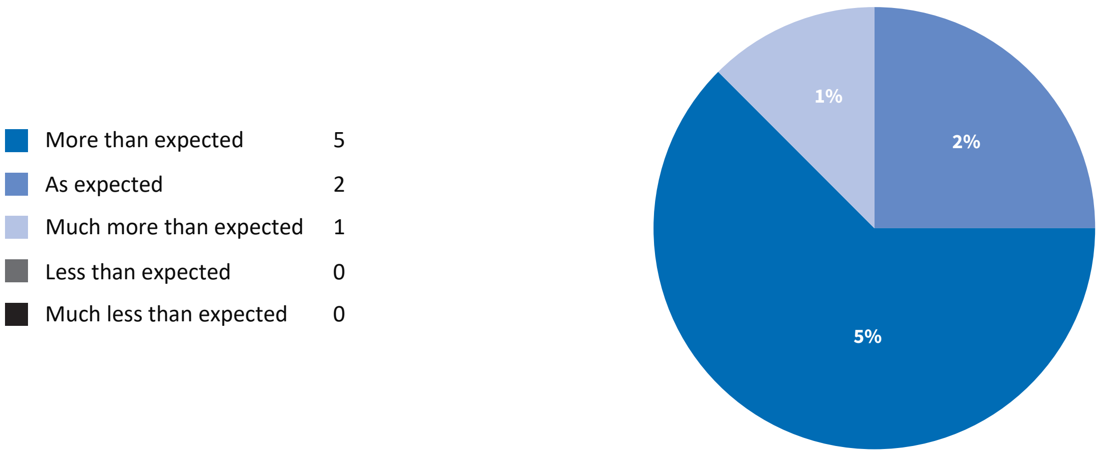


Annex II: Results of the post-training assessment

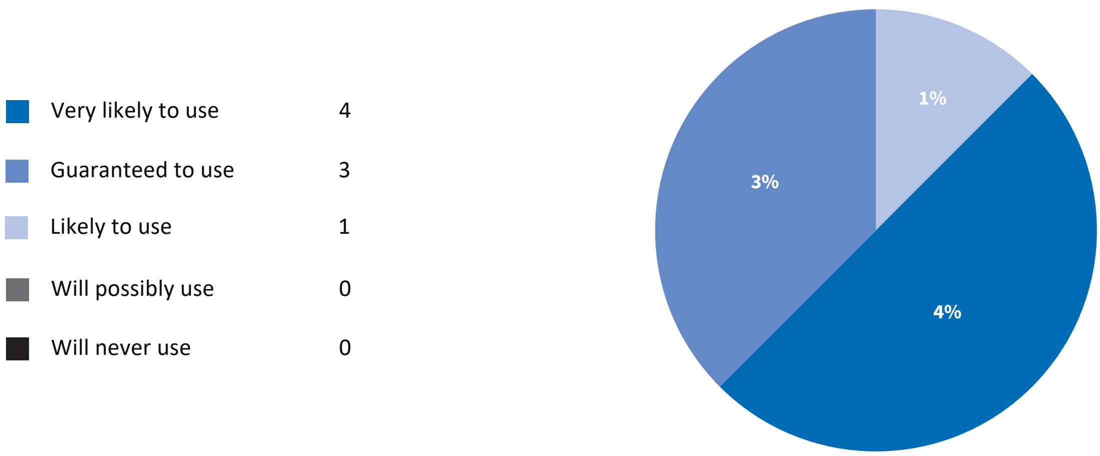
How would you rate the overall content of the training in the following areas?



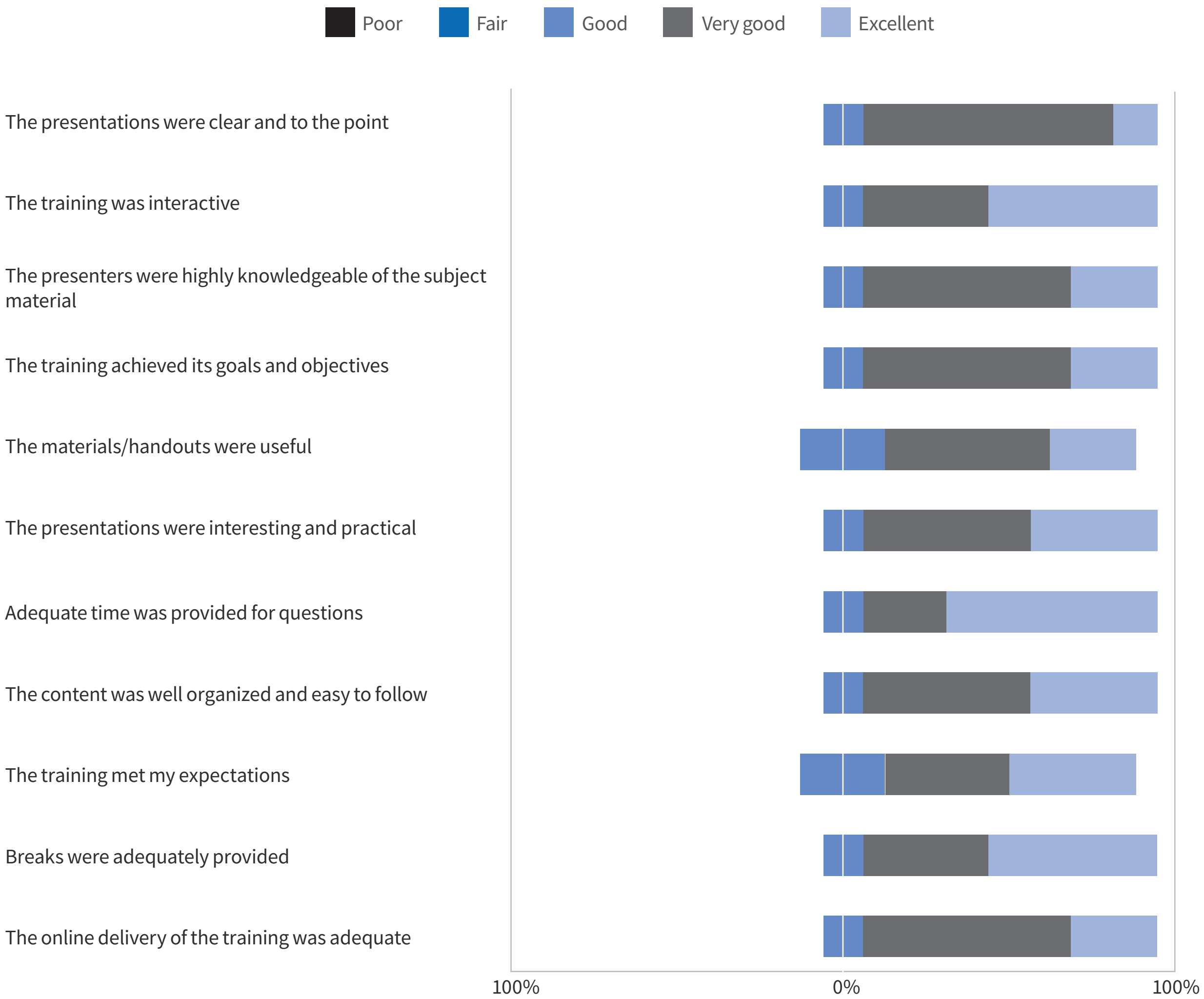
How much have you learnt about the overall topic of the training?



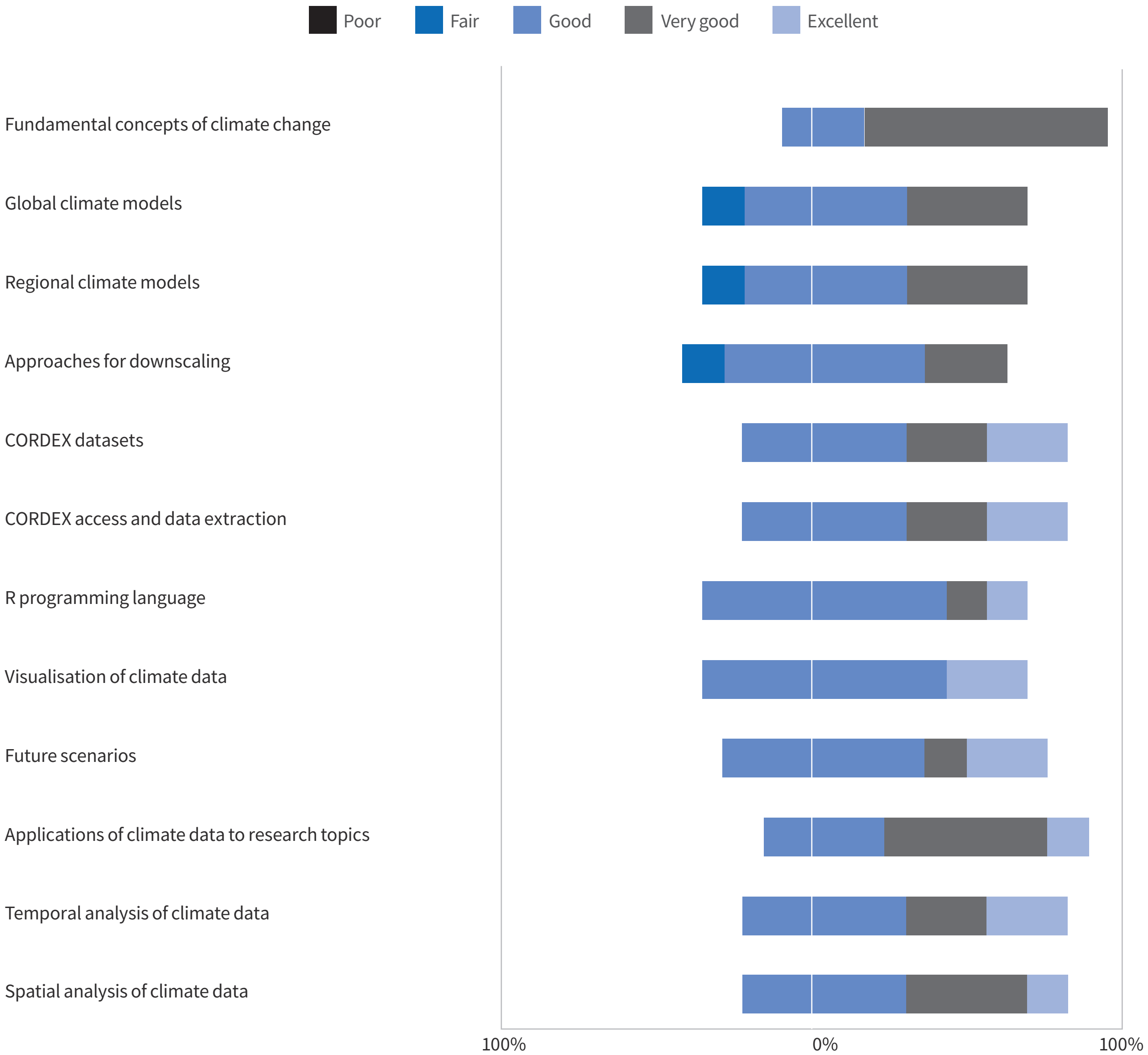
How likely are you to use the information or knowledge you gained in the training in your normal area of work?



How would you rate the quality of the training in the following areas?



How would you rate your knowledge of the following topics after the training?



Annex III: Pre-training assessment form

Training on
Spatial and temporal climate change analysis using CORDEX regional climate models over South Asia
7–11 June 2021 | Platform: Microsoft Teams

Thank you for your participation in this training. We would very much appreciate your support in responding to the questions below. Your contribution will help us in conducting an overall evaluation of our capacity-building efforts, update our training to meet participants' needs better, and inform our follow-up activities. Please respond as appropriate.

* Required

1. Name (optional):

2. Gender *

   - ○ Woman
   - ○ Man
   - ○ Other
   - ○ Prefer not to say

3. Organization/department affiliation *

4. Role/Job title *

5. Why did you choose to participate this event? (choose the most appropriate one) *

- ○ This training is relevant to my job
- ○ To build basic knowledge and skills on the subject
- ○ To enhance my knowledge and skills to an advanced level
- ○ Exposure and professional networking
- ○ Other

6. Was this event properly communicated to you on time? *

- ○ Yes
- ○ No

7. How would you rate your knowledge of the following topics? *

	Poor	Fair	Good	Very good	Excellent
Fundamental concepts of climate change	○	○	○	○	○
Global climate models	○	○	○	○	○
Regional climate models	○	○	○	○	○
Approaches for downscaling	○	○	○	○	○
CORDEX data sets	○	○	○	○	○
CORDEX access and data extraction	○	○	○	○	○
R programming language	○	○	○	○	○
Visualization of climate data	○	○	○	○	○
Estimating/assesssing future scenarios	○	○	○	○	○
Application of climate data to research topics	○	○	○	○	○
Temporal analysis of climate data	○	○	○	○	○
Spatial analysis of climate data	○	○	○	○	○

8. Please list your expectations from the training. *

9. Additional remarks *

10. Video/photo release

I grant permission to ICIMOD and its agents and employees the irrevocable and unrestricted right to reproduce the images taken of me for the purpose of publication, promotion, illustration, advertising, or trade, in any manner or in any medium. I hereby release ICIMOD and its legal representatives for all claims and liability relating to said images or video. Furthermore, I grant permission to use my statements that were given during an interview or guest lecture, with or without my name, for the purpose of advertising and publicity without restriction. I waive my right to any compensation. *

- ○ Yes
- ○ No

Annex IV: Post-training assessment form

Training on
Spatial and temporal climate change analysis using CORDEX regional climate models over South Asia
7–11 June 2021 | Platform: Microsoft Teams

Thank you for your participation in this training. We would very much appreciate your support in responding to the questions below. Your contribution will help us in conducting an overall evaluation of our capacity-building efforts, update our training to meet participants' needs better, and inform our follow-up activities. Please respond as appropriate.

* Required

1. Name (Optional)

2. Gender *

- ○ Woman
- ○ Man
- ○ Other
- ○ Prefer not to say

3. Organization/department affiliation *

4. Role/Job title *

5. How would you rate the overall content of the training in the following areas: *

	Poor	Fair	Good	Very good	Excellent
Usefulness	○	○	○	○	○
Relevance	○	○	○	○	○
Structure and methods	○	○	○	○	○

6. How much have you learned concerning the overall topic of the training? *

- ○ Much less than expected
- ○ Less than expected
- ○ As expected
- ○ More than expected
- ○ Much more than expected

7. How likely are you to use the information or knowledge you gained in the training in your normal area of work *

- ○ Will never use
- ○ Will possibly use
- ○ Likely to use
- ○ Very likely to use
- ○ Guaranteed to use

8. How would you rate the quality of the training in the following areas? *

	Poor	Fair	Good	Very good	Excellent
The presentations were clear and to the point	○	○	○	○	○
The training was interactive	○	○	○	○	○
The presenters were highly knowledgeable of the subject material	○	○	○	○	○
The training achieved its goals and objectives	○	○	○	○	○
The materials/handouts were useful	○	○	○	○	○
The presentations were interesting and practical	○	○	○	○	○
Adequate time was provided for attendee questions	○	○	○	○	○
The content was well organized and easy to follow	○	○	○	○	○
The training met my expectations	○	○	○	○	○
Breaks were adequately provided	○	○	○	○	○
The online delivery of the training was adequate	○	○	○	○	○

9. How would you rate your knowledge of the following topics after the training? *

	Poor	Fair	Good	Very good	Excellent
Fundamental concepts of climate change	○	○	○	○	○
Global climate models	○	○	○	○	○
Regional climate models	○	○	○	○	○
Approaches for downscaling	○	○	○	○	○
CORDEX data sets	○	○	○	○	○
CORDEX access and data extraction	○	○	○	○	○
R programming language	○	○	○	○	○
Visualization of climate data	○	○	○	○	○
Estimating/assessing future scenarios	○	○	○	○	○
Application of climate data to research topics	○	○	○	○	○
Temporal analysis of climate data	○	○	○	○	○
Spatial analysis of climate data	○	○	○	○	○

10. What did you find most useful in this training? Please elaborate *

11. Which aspect of the training could have been improved more? Please elaborate *

12. How do you plan to use the skill and knowledge from this training in your future work? Please elaborate *

13. What kind of advance training on climate change would be helpful for you/your work in the future? *

14. Additional remarks *

15. Video/photo release

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- ◯ Yes
- ◯ No

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