Islamic Republic of Afghanistan

National Environmental Protection Agency

AFGHANISTAN: CLIMATE CHANGE SCIENCE PERSPECTIVES

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First published in December 2016 by the National Environmental Protection Agency (NEPA)

This report was developed jointly by the National Environmental Protection Agency (NEPA) of the Islamic Republic of Afghanistan together with UN Environment, with funding from the Global Environment Facility's Least Developed Countries Fund (GEF LDCF), UKaid, Estonian Development Cooperation, and the European Union.

Suggested citation: NEPA & UN Environment. (2016). *Afghanistan: Climate Change Science Perspectives*. Kabul: National Environmental Protection Agency & UN Environment.

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Acknowledgements: Many thanks to the Indian Institute of Tropical Meteorology for providing the CORDEX data.

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CONTENT

EXECUTIVE SUMMARY

Global climate change will likely have severe impacts in Afghanistan. Even an “optimistic” scenario with limited Green House Gas (GHG) emissions (RCP 4.5) is projected to lead, with high certainty, to strong warming. Climate change projections for Afghanistan also show a temperature increase of around 1.4°C until 2050 and stabilization at the end of the century at around 2.6°C. Under a “pessimistic,” business-as-usual scenario with unchecked emissions, temperature rise is projected to become extreme with a mean increase of 2°C until 2050 and reaching more than 6°C by the end of the 21st century. The temperature increase shows regional differences with the strongest increases in the Central Highlands and the Hindukush regions. These findings are in line with historical temperate trends of over 1.8°C since the middle of the 20th century, though in the past the country’s South experienced the strongest warming.

Precipitation projections are more uncertain and the differences between scenarios is less distinct, with no clear trend for annual precipitation for the past and the future. However, most models predict a distinct decrease in precipitation during the spring season, which are the most important months for rain-fed agriculture. For the relevant regions in the East, North and Central Highlands, these precipitation decreases are estimated at around -30% to nearly -40 % for the past. Future projections show decreases in these relevant regions of around -20% until 2100. The trends for winter precipitation are also significant, but not systematic. Heavy precipitation (95th percentile) shows no statistically significant trend for the past and the future.

In sum, the climate signals for Afghanistan are alarming, particularly with regard to temperature increase. Even with limited GHG emissions, Afghanistan’s ecosystems, agriculture, economy, biodiversity, health, and food security will face big challenges. The changes caused by unchecked GHG emissions will be considerably more extreme and lead to unpredictable changes in the aforementioned systems and sectors in Afghanistan. In the face of an already existing adaptation deficit in the country, Afghanistan urgently needs enhancement of adaptation measures and strategies in all sectors, and a strong global effort to limit GHG emissions.

1

INTRODUCTION

1. INTRODUCTION

Afghanistan has a unique geography, ranging from the glaciered peaks of the Hindukush to the arid deserts of the South, covering altitudes from over 7,000 m.a.sl. down to under 250 m.a.sl. It is a landlocked country, located between 29-37° north, and its main geographical features are the very pronounced topography which are part of the Hindukush. These geographic features result in a generally dry and very characteristic continental climate. It is only influenced partly by the Indian sub-continent monsoon from the southeast, bringing moist maritime air in the summer. The majority of the country generally experiences cold winters and hot summers. Temperature ranges vary with elevation. This variation holds not only for the annual cycle but also within one day; temperatures often vary considerably from very cold nights to very hot days. Precipitation is mainly limited to the months between October and May, whereas the arid deserts receive less than 100 mm and in the mountains, mean annual precipitation is considerable above 1000 m.a.sl. In the mountains, most precipitation falls as snow during winter.

Afghanistan's variety of different climates has a large natural variability; however, over recent decades people are beginning to perceive climatological changes. There are very few scientific studies on climate change in Afghanistan. Analysis of past climate and future climate projections for Afghanistan only exist from a study of the Tyndell Center for UNDP and DFID country profiles[1,2] of which results are also published in a study of the Stockholm Environmental Institute (SEI)[3] on the socio-economic impacts on climate change from 2009. The analysis of the past is based on observations of station data which have large gaps, especially after 1970. The projections are based on the third generation of Global Climate Models (GCM) generated within the Coupled-Model Intercomparison Project (CMIP).[4] They have a grid size of 2.5°, which means that Afghanistan is covered by a total of 19 cells. Regional climate models (RCM) or statistically downscaled GCMs have not been evaluated for Afghanistan comprehensively. In regard of its distinguished topography, a finer grid might bring new insights on climate trends for the future.

This report intends to update the former findings and evaluate the consistency with a new generation of climate models. Due to the large gaps in the observation data, reanalysis data has been analyzed for different regions in Afghanistan (Figure 1) from 1950 to 2010. For future climate trends, seven different RCM GCM combinations generated from the CORDEX[5] project have been evaluated. Their grid size is 0.5° and Afghanistan is covered by over 300 cells in total, which permits a spatially detailed analysis.

2

OBSERVED CHANGES IN AFGHANISTAN´S CLIMATE

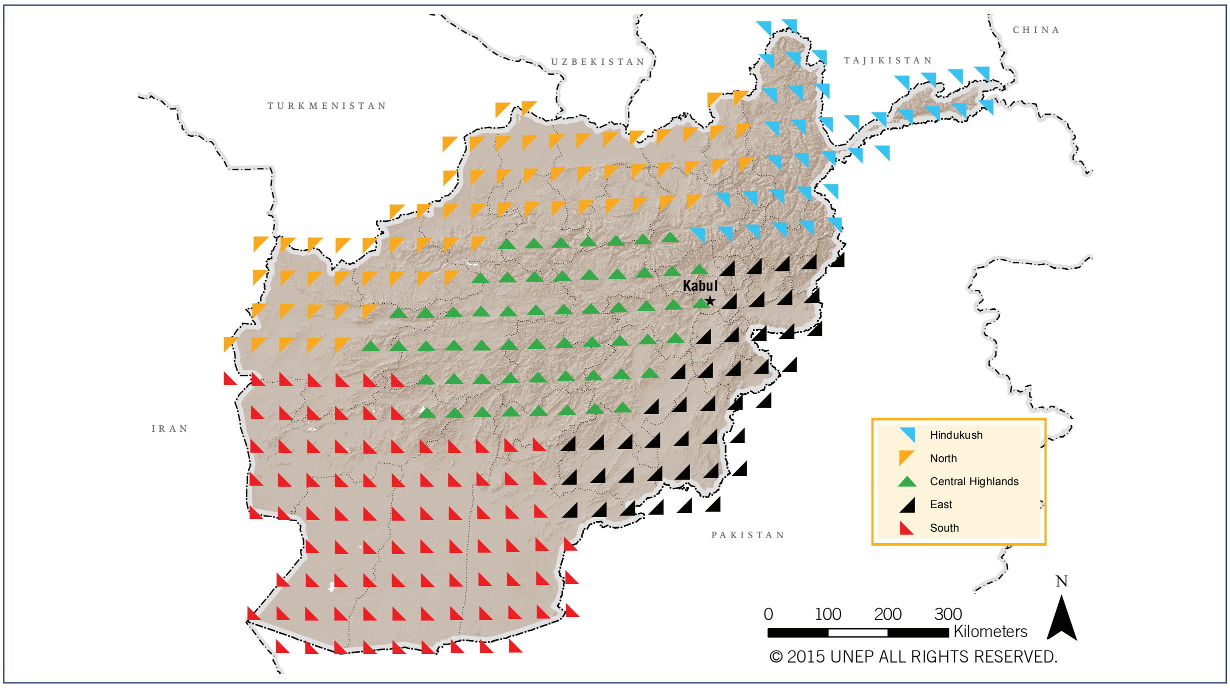
OBSERVED CHANGES IN AFGHANISTAN´S CLIMATE

Climate regions of Afghanistan:

Due to the geographic heterogeneity of Afghanistan, the country has been divided into five regions for this analysis (Figure 1):

1. *The Hindukush region in the Northwest mainly consists of Badakhshan province, which also comprises the Wakhan area, including parts of the Pamir and Karakoram regions. It is the highest and most mountainous part of Afghanistan. It receives the highest amount of precipitation and is therefore a major water source, feeding important rivers like the Amu Darya.*
2. *The Northern Plains (North) have a mean altitude of around 600m and are covered mainly by grasslands. Though the region is rather dry, it is important for agriculture, especially the almond trees and sheep and goat grazing.*
3. *The Central Highlands in the middle of Afghanistan is characterized by deep valleys and mountain ranges up to 6400m.*
4. *The Eastern Slopes (East) are influenced by the moist air masses of the Indian monsoon which get trapped at the high mountain slopes and bring rain. Therefore, it is covered by forests and allows agriculture. The rains, however, also can cause flooding and land/mud slides.*
5. *The Southern Plateau (South) is the largest region and mainly covered by arid desert. Only along the rivers and in the marshlands is agriculture possible. The Helmand River divides the region and nourishes Lake Helmand. This region is also prone to sand and dust storms, mainly associated with northerly winds.*

Figure 1: Climate Regions of Afghanistan Used for this Analysis.



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Reanalysis Data

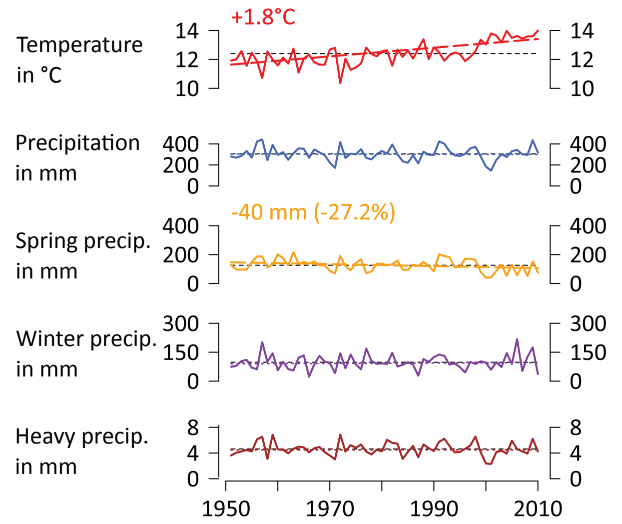
Climate reanalyses are numerical descriptions of the past climate. They are produced by combining model outputs with observations from weather stations, radiosondes, satellites, buoys, aircrafts and ship reports. They contain estimates of all main climatic parameters such as air temperature, wind at different altitudes, and precipitation. For this study, different reanalysis products have been evaluated against observation data (see Statistical Methods) for Afghanistan and finally the dataset from the Global Soil Wetness Project Phase 3 (GSWP3)[6] has been selected due to its performance over Afghanistan and its temporal coverage of the period from 1950 until 2010. It is generated globally on a 0.5° x 0.5° grid and provides all parameters at a daily time step.

2.1. TEMPERATURE

Afghanistan's mean annual temperature has increased significantly and pronouncedly since 1950 by 1.8°C (Figure 2). The map in Figure 3 shows the spatial distribution of the warming between the 30-year periods from 1951-1980 and 1981-2010 (see box *Weather and Climate*). A strong warming trend was experienced in the largest parts of the country, from the Central Highlands to the Southwest. Particularly in the South, this warming was extraordinarily strong at 2.4°C (Figure 12). In the Central Highlands and the North, it was still very distinct with 1.6°C and 1.7°C (Figures 9 and 10). In the Hindukush region, the warming was around 1°C; in the East, the warming is still significant, but with 0.6°C lower than in the rest of Afghanistan (Figure 11). In some sub-regions of the East there was also little or no warming, or even a slight decrease in temperature (Figure 8).

Uncertainty: The temperature trend results are robust even though they do not rely on weather observations but rather reanalysis data (see box *Reanalysis Data*). The performance of the dataset has been tested against observed station data and proved to be reliable (section 4.2, below). In addition, the warming trends are in line with results of global analysis the NASA[9,10] and former findings of a temperature increase for Afghanistan, though the formerly found temperature increase of 0.6 °C between 1960 and 2008 for Afghanistan is distinctly higher for most of Afghanistan.

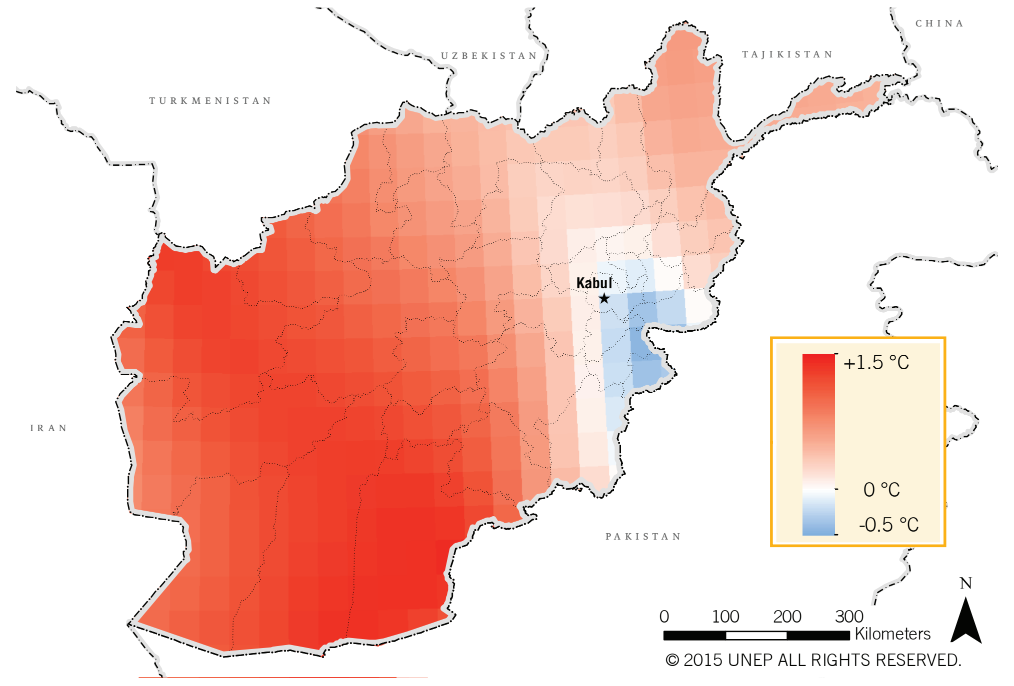
Figure 2: Trends for Temperature, Annual Precipitation, Spring Precipitation (March-May), Winter Precipitation (November-January), and Heavy Precipitation (95th percentile) for Afghanistan from 1951-2010 Derived from Reanalysis Data (GSWP3). If Trends are Statistically Significant (□=0.5), They are Plotted as Dashed Line and the Magnitude is Added.



Observations and Weather Stations in Afghanistan

Observed weather data is scarce in Afghanistan due the limited meteorological stations and the political instability in the last decades, particularly under the Taliban regime, when data records were lost and observation ceased. Historic data sets have been restored by the PEACE project[7] and are publicly available. Recent weather observations are beside other sources available from the Global Summary of the Day (GSOD).[8]

Figure 3: Change in Temperature Between 1981-2010 and 1951-1980 in Afghanistan Derived from Reanalysis Data (GSWP3)



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Weather and Climate

Weather is commonly defined as the state of the atmosphere at a given time and place with respect to variables such as temperatures, moisture, wind velocity, and barometric pressure. Climate in contrast is the "average weather," and is defined as the measurement of the mean and variability of the weather over a period of time, ranging from months to thousands or millions of years. The classic period of measurement is 30 years, as defined by the World Meteorological Organization (WMO). Climate in a wider sense is the state, including a statistical description, of the climate system. Hence, when we compare two 30-year periods of weather observations, we compare the climate and if there are changes, we may refer to them as climatic changes.

2.2. PRECIPITATION

Precipitation has not changed significantly when considered over the whole of Afghanistan and for all months (Figures 2 and 4). However, the detailed analysis for spring and winter precipitation reveals that the changes are simply levelled out since spring precipitation has significantly decreased by almost a third and winter precipitation has slightly increased, though not by a statistically significant amount. The decrease in spring (March-May) is particularly relevant for agriculture, since spring crops are typically rain-fed and dependent on sufficient rainfall during this period. Figure 5 shows that the regions with most significant agriculture (East, Central Highlands, and North) are affected by the decrease in spring precipitation. Figures 8, 9, and 10 show the trends in detail for these regions, with the strongest decrease in the Central Highlands of almost 40% from 1950 until 2010. In the Hindukush and the South, the decrease is less distinct during these months and there is even a slight increase in the Wakhan and the far South (Figure 5).

Winter precipitation, contrastingly, has increased in most parts of the countries (Figure 6), or only slightly decreased, and none of the regional trends is significant.

Heavy precipitation has often been reported to have increased during the last decades, leading to more frequent and intense flooding, landslides and other related hazards. In contrast, this study could not find an increase in heavy precipitation (defined as 95th percentile of annual rainfall) between 1950 and 2010 (Figures 2 and 7). However, an increase in heavy precipitation is just one reason amongst many that can lead to these aforementioned catastrophes. For example, rising temperatures might lead to more rapid and earlier spring snow melt, causing an increased risk of flash flooding. Also, droughts can exacerbate the impact of heavy precipitation by hardening soils and reducing their permeability, which can cause flash floods or landslides. In addition, increasing exposure and/or vulnerability against certain hazards might have increased the risk.

Uncertainty: The uncertainty of precipitation trends is higher than temperatures due to the greater spatial variability and the complexity of processes that lead to precipitation. neverthless the validation of the reanalysis precipitation data has shown good results when compared with observations. Mainly in the spring, there are deficits of the re-analysis precipitation data, but the general pattern is well represented. Heavy precipitation is by definition a rare event and therefore connected with more statistical uncertainty, also in the representation of the reanalysis data.

Figure 4: Change in Annual Precipitation Between 1981-2010 and 1951-1980 in Afghanistan Derived from Reanalysis data (GSWP3)

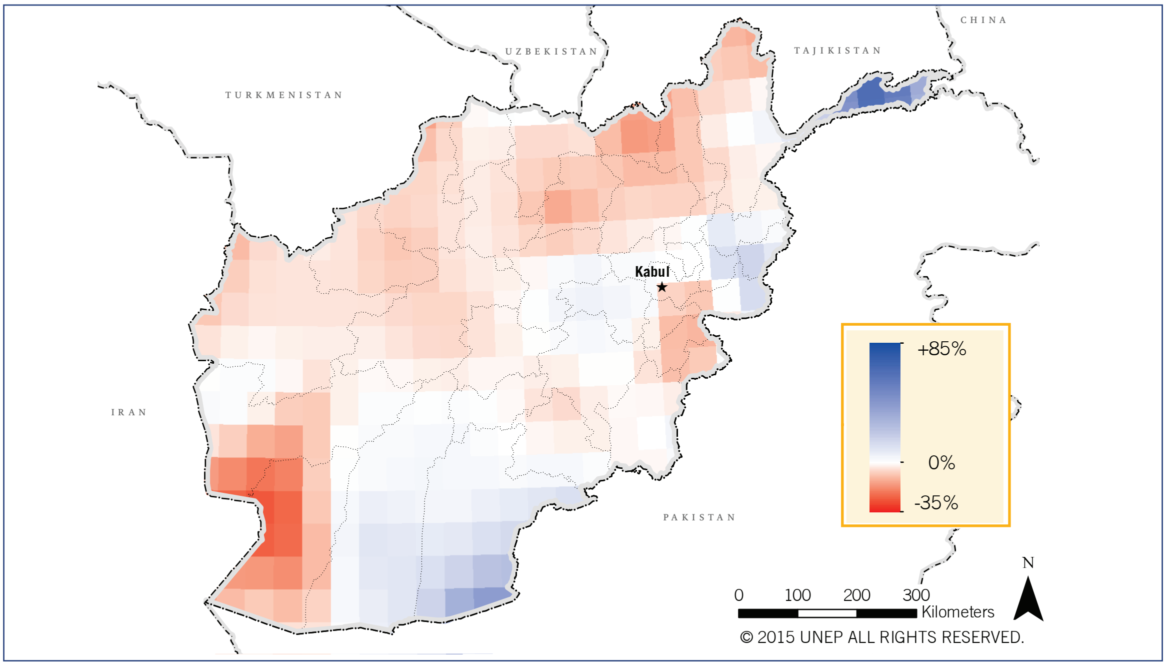


Figure 5: Change in Spring Precipitation (March-May) Between 1981-2010 and 1951-1980 in Afghanistan Derived from Reanalysis Data (GSWP3)

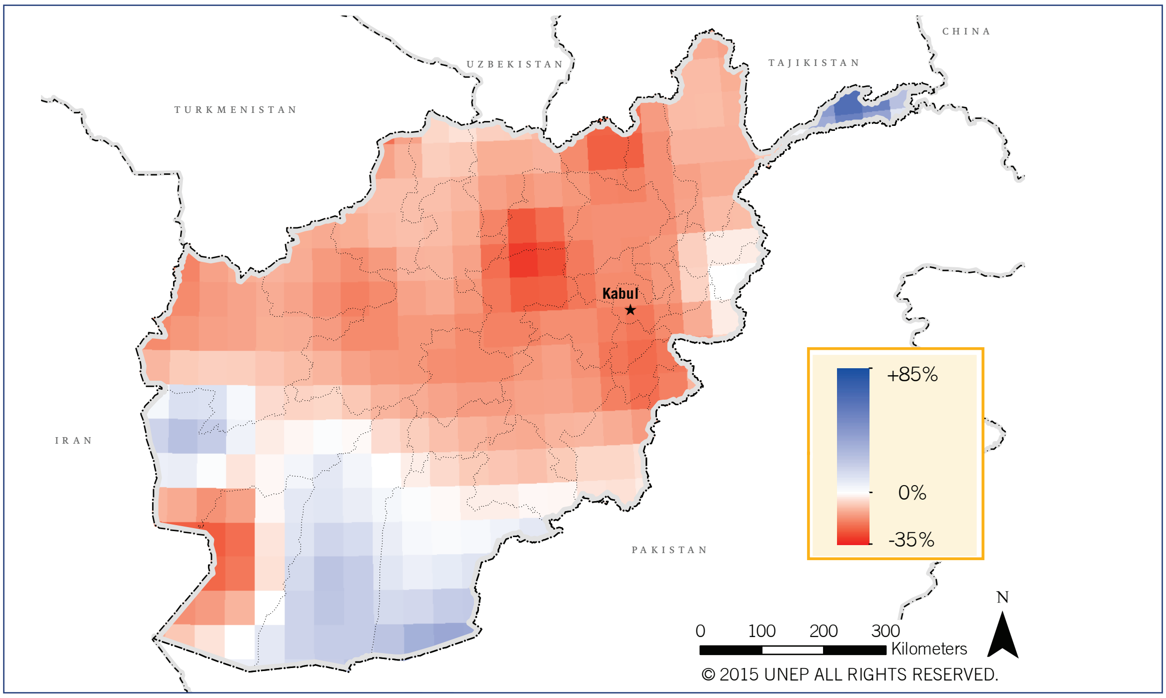


Figure 6: Change in Winter Precipitation (November - January) Between 1981-2010 and 1951-1980 in Afghanistan Derived from Reanalysis Data (GSWP3)

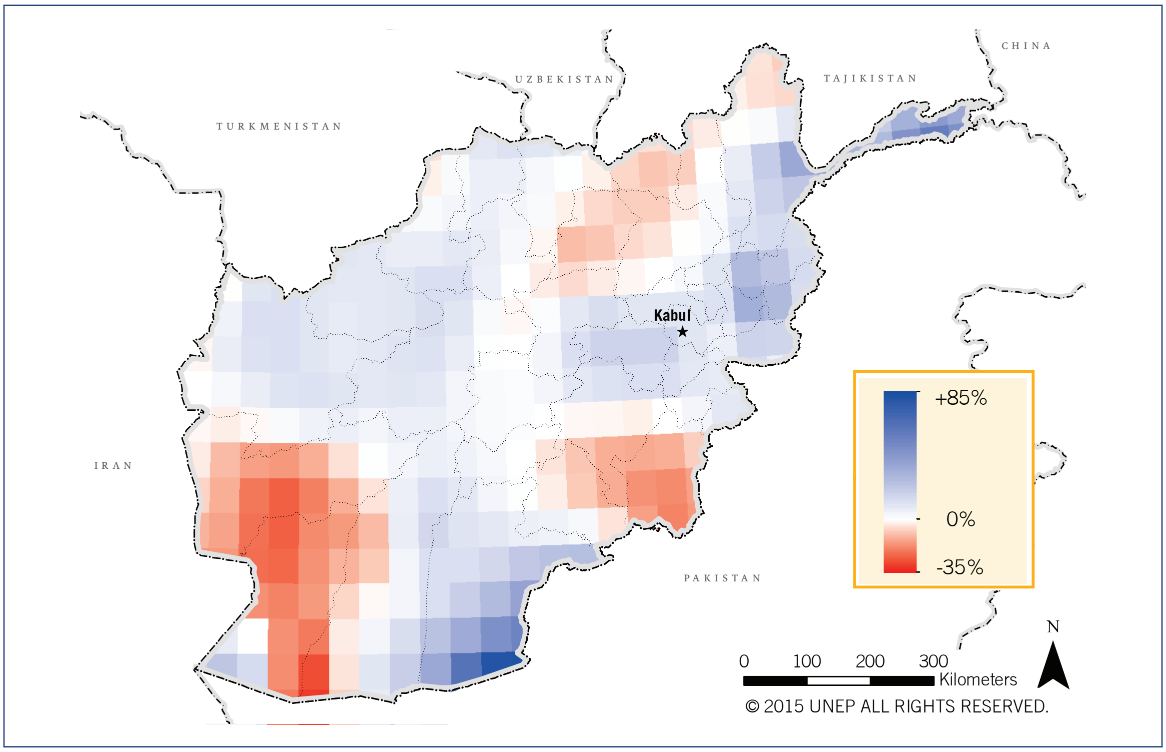


Figure 7: Change in Heavy Precipitation (95th percentile) Between 1981-2010 and 1951-1980 in Afghanistan Derived from Reanalysis Data (GSWP3)

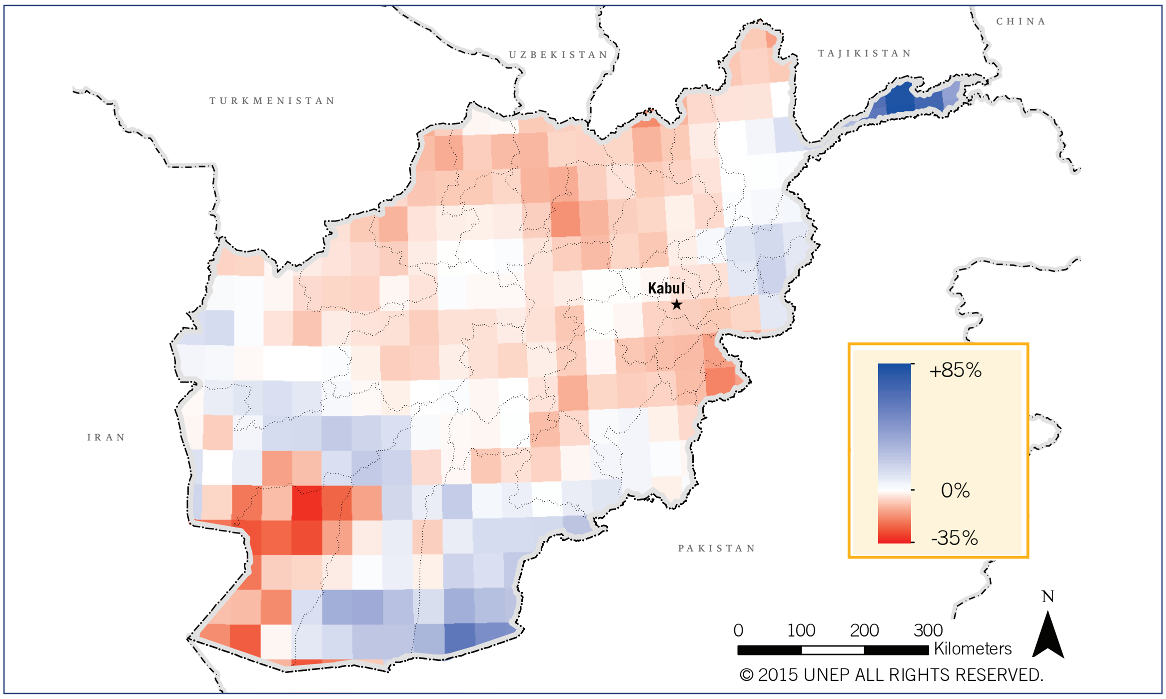


Figure 8: Similar to Figure 2 but for the Hindukush of Afghanistan (see Figure 1)

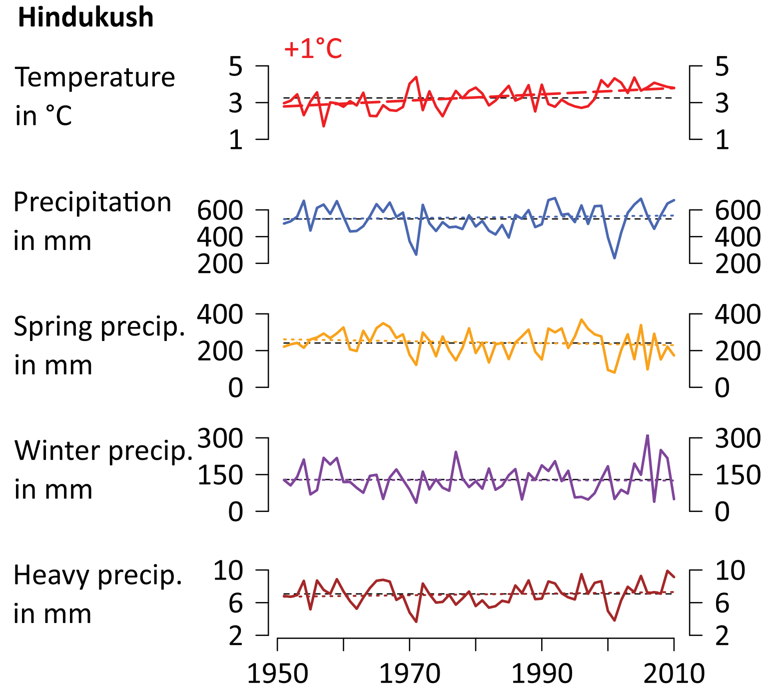


Figure 9: Similar to Figure 2 but for the North of Afghanistan (see Figure 1)

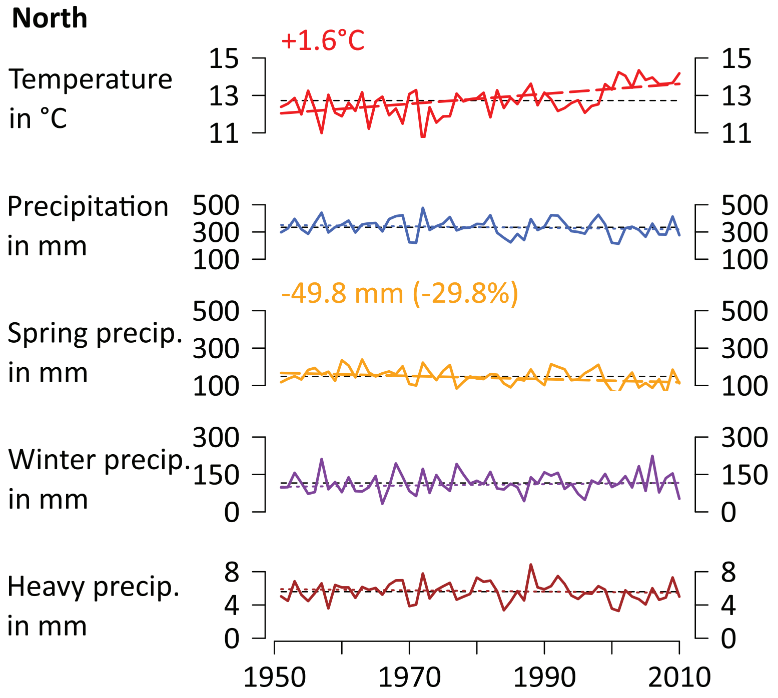


Figure 10: Similar to Figure 2 but for Central Highlands of Afghanistan (see Figure 1)

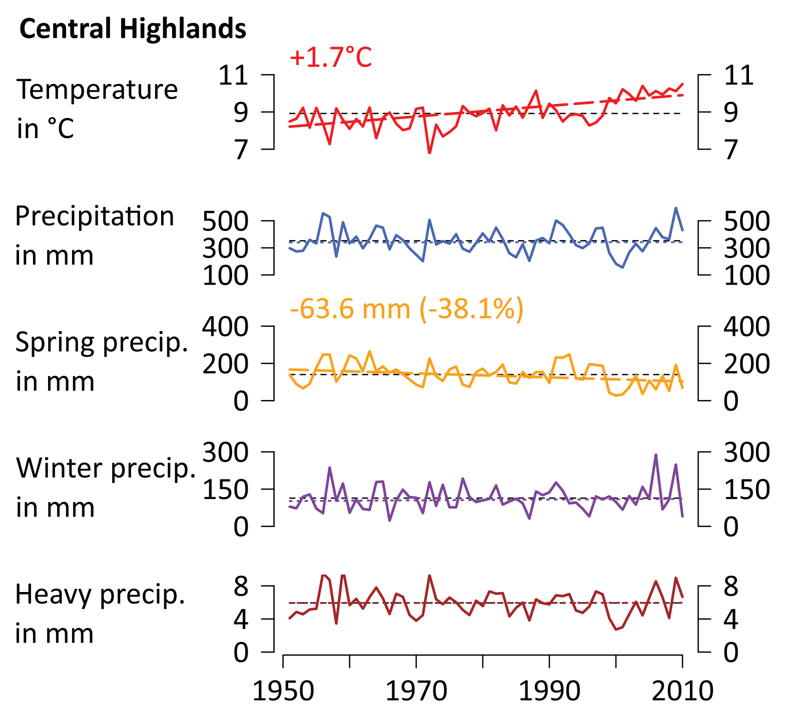


Figure 11: Similar to Figure 2 but for the East of Afghanistan (see Figure 1)

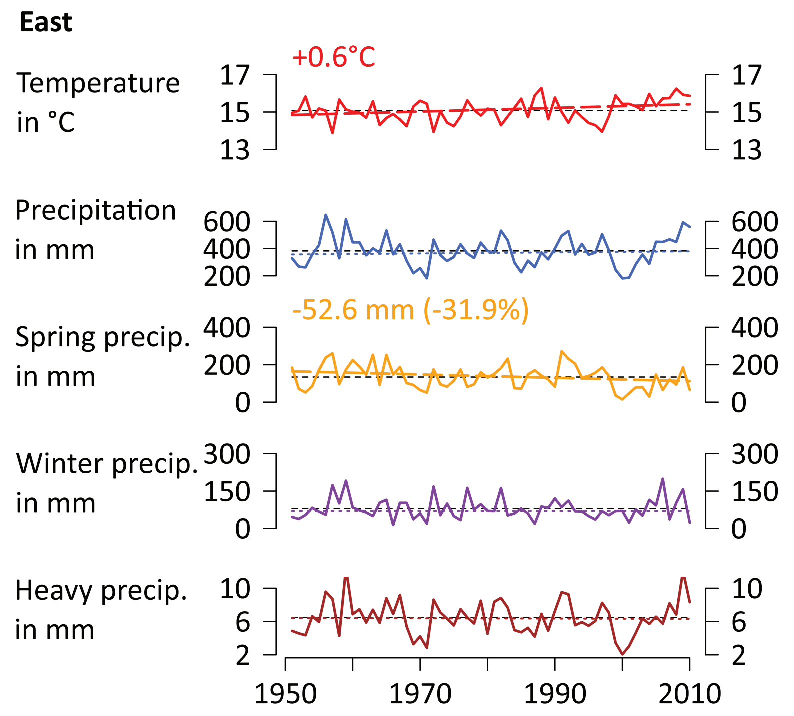
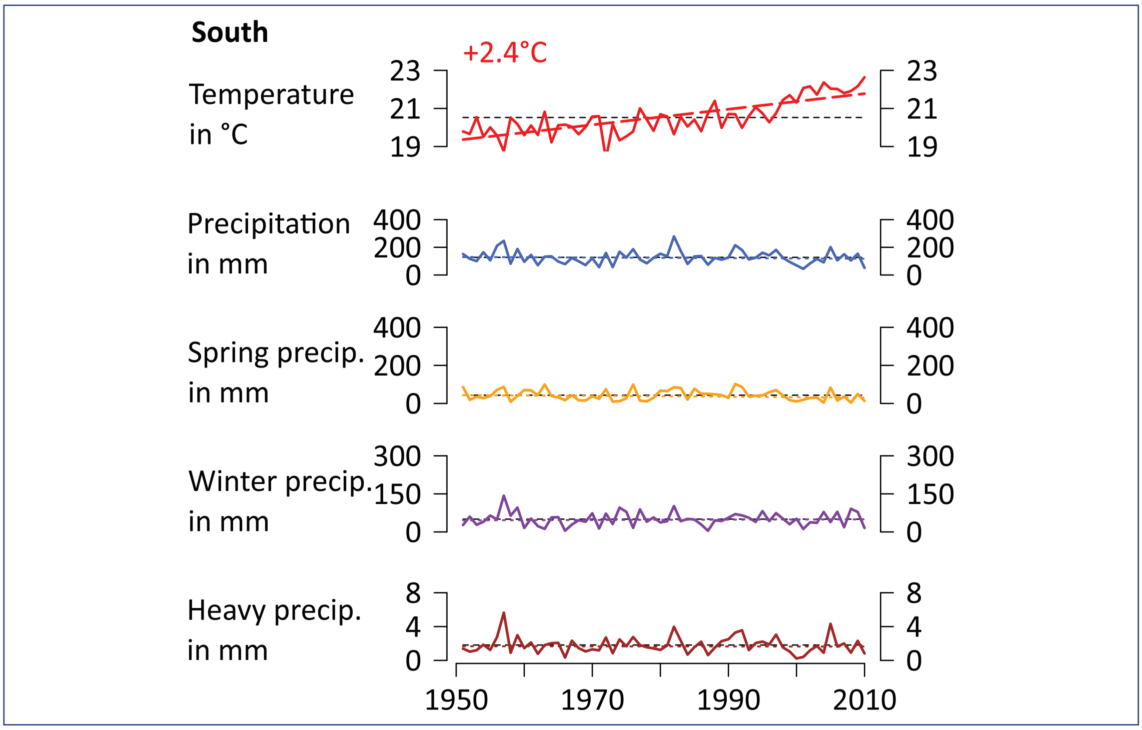


Figure 12: Similar to Figure 2 but for the South of Afghanistan (see Figure 1)



3

CLIMATE PROJECTIONS FOR AFGHANISTAN

CLIMATE PROJECTIONS FOR AFGHANISTAN

CORDEX Regional Climate Model:

CORDEX is an international coordinated framework to produce an improved generation of regional climate change projections world-wide for input into impact and adaptation studies. It covers different domains and Afghanistan is part of the South Asian domain. The regional climate projections are generated by different physical Regional Climate Models (RCM) (see Table 1). These RCMs are nested into General Circulation Models (GCM). This means, at the edges of the regional domain, in this case the South Asia domain, the RCM receives information from the GCM. The RCM has a higher temporal and spatial resolution and can therefore include processes which are not represented by GCMs. Especially extreme events and regional trends in mountainous areas are modelled with a higher efficiency. In the CORDEX project, domains on continental or sub-continental scale are modelled by all major regional climate modelling groups of the world. They are the state-of-art in regard of regional climate modelling and since all models are run under the same conditions, estimating the robustness of the results and the connected uncertainty is possible. For the South Asia domain, 11 model combinations are currently available and the data has been validated for the Central Himalayan region with satisfying results.[11] Some of the model runs are corrupt for a certain parameter or not available for the analyzed period and finally seven models have been used consistently (see Table 1). Therefore, not all model combinations could be used for the analysis. The CORDEX data is on a 0.5° mash and for Afghanistan it comprises over 300 tiles, which allows a detailed spatial analysis, especially for the mountainous areas of Afghanistan.

3.1 TEMPERATURE

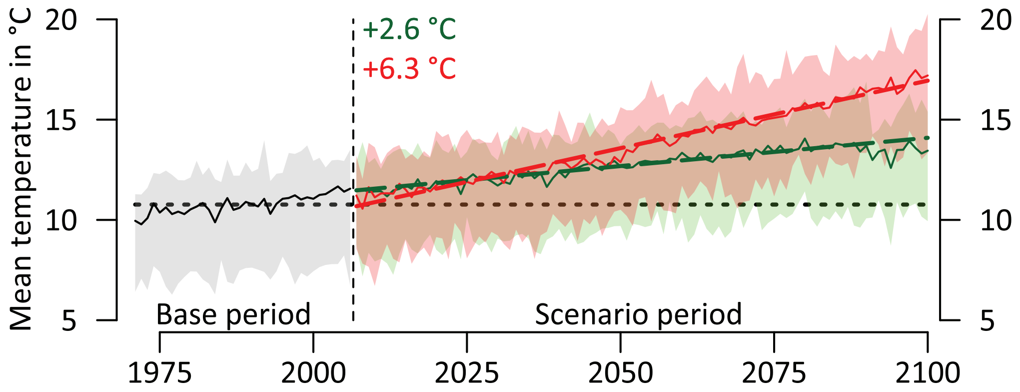
The trends for the mean temperature increase over Afghanistan are significant and very distinct for both scenarios and all models. For the “pessimistic” business-as-usual scenario (RCP 8.5), the mean warming is extreme and model mean projects an increase of around 2°C until 2050 and of 6.3° C until the end of the century. For the “optimistic” scenario (RCP 2.6) the projections show a warming around 1.4°C until 2050 and a stabilization afterwards, with a warming around 2.6°C until 2100.

The maps of Figure 14 show that the spatial distribution of the warming, when comparing the future periods from 2021-2050 with the base period (1976-2005), is projected to be most severe under both scenarios in the Central Highlands and the Hindukush, particularly in the Wakhan, where the model mean reaches even 3°C in the near future. This pattern is also confirmed by the regional trend analysis shown in Figure 15.

The implications of the warming for both scenarios are drastic. Even under the optimistic scenario, the warming in Afghanistan is above the global mean warming (see box *Scenarios*). Warming of 1.5°C until 2050 will have severe impacts on ecosystems, agriculture, water resources, food security, economy, health, energy, and other sectors. The extreme warming of the pessimistic scenario will lead most probably to complete changes of the environment and the current ecosystems. It is unlikely, that ecosystems can adapt to these changes in less than 100 years, e.g. via emigration to higher altitudes and the extinction of endemic species is very likely. In addition, it is likely that it will not be possible to adapt the current agricultural system to the projected severe temperature increase and further economic decay and its associated implications become likely. Even the optimistic scenario will pose difficult challenges to adaptation in Afghanistan in terms of temperature, but a warming as projected by the pessimistic scenario should be avoided since the consequence of a complete and radical change of the environment and socio-cultural is likely.

Uncertainty: The validation of the temperature of the models during the base period has shown that the RCMs used in his study are generally capable of reproducing the temperature dynamics of all regions of Afghanistan well (see section 4.1.2, below). The model spread, also called the band of uncertainty, of the projections is around +/-2 °C and all model runs show the same increasing tendency. This means, taking into account the different starting levels of the models, all RCMs project similar degrees of warming for both scenarios. This implies robust results, which also confirm the projections of the former GCM results of warming levels between 2°C to over 6°C.[2]

Figure 13: Mean Annual Temperature for Afghanistan for Seven Regional Climate Models for a Base Period (grey, 1970-2005) and a Scenario Period (2006-2100) with Limited GHG Emissions (green, RCP 4.5) and Uncontrolled GHG Emissions (red, RCP 8.5). The Spread of the Models are Depicted as Transparent Areas and the Means as Lines. Both Trends are Statistically Significant and Depicted as Dashed Line. The Magnitudes of the Trends are Plotted in the Relative Colors.



Scenarios

Climate change is included in the climate models via emission scenarios. The latest generations of scenarios, which are also used in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) are the Representative Concentration Pathways (RCP). Differently from the projections described in the previous Special Report on Emission Scenarios (SRES), RCPs do not imply a unique framework for evaluating the impact of socio-economic assumptions such as population growth, economic development and technology. Instead, each RCP is the result of a different set of modelling assumptions. Each RCP is named after the level of additional radiative forcing achieved by 2100, with respect to the pre-industrial value. The RCP 4.5 adopted in this study corresponds to a low stabilization scenario, whereby in 2100 the radiative forcing is 4.5 W above the pre-industrial level. On the other hand, the RCP 8.5 corresponds to a high-end stabilization scenario, mainly driven by a sustained population growth, whereby in 2100 the radiative forcing is 8.5 W above the pre-industrial level. The RCP 4.5 corresponds likely to a warming between 1.1°C to 2.6°C increase of global temperature above the pre-industrial level until the end of this century and the RCP 8.5 to a likely increase of 2.6°C to 4.8°C.[12]

Figure 14: Projected Changes in Temperature in °C for Afghanistan as Mean of Seven Regional Climate Models Between a Scenario Period (2021-2050) and a Base Period (1976-2005) Under Limited GHG Emissions (left, RCP 4.5) and Uncontrolled GHG Emission (right, RCP 8.5)

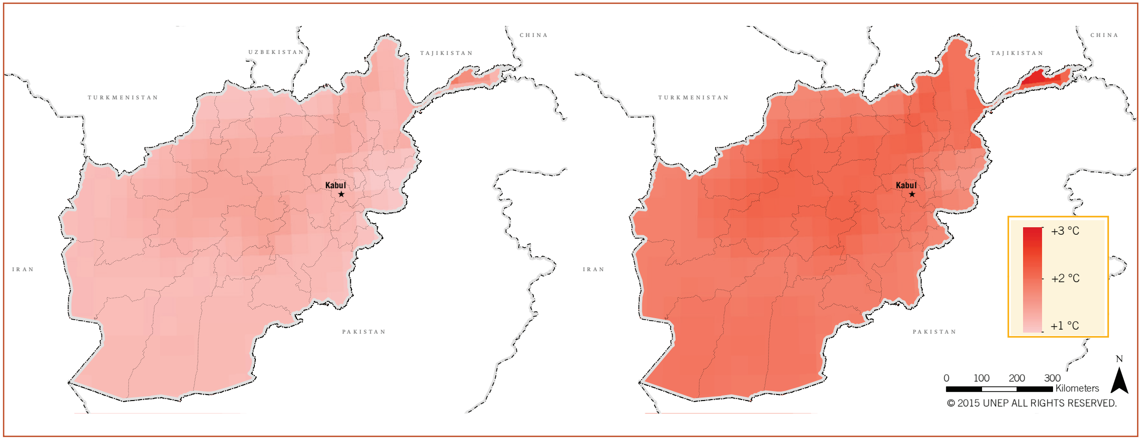
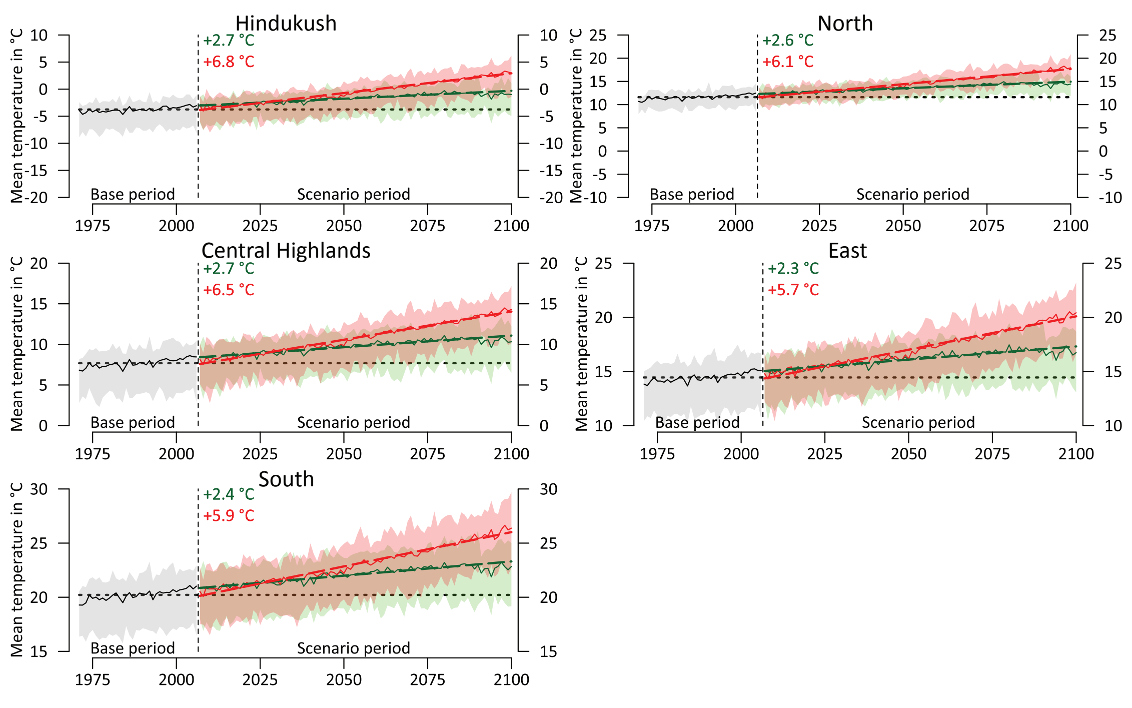


Figure 15: Similar to Figure 14 but for the Climate Regions of Afghanistan (see Figure 1): Hindukush, North, Central Highlands, East, and South



3.2. PRECIPITATION

3.2.1 ANNUAL PRECIPITATION

For annual precipitation, the pattern is similar to the pattern in the past. There is no significant trend but rather a slight decrease until 2100. The internal variability is high during the whole period. The maps of Figure 17 show a slight decrease in the near future period from 2021-2050 for most of the area which is slightly more distinct in the optimistic GHG emission scenario. For the different regions, as shown in Figure 18, there are only slight trends around in- or decreases of approximately 10% until 2100. Only for the South the projections of the optimistic scenario show an increase of 20%. This trend can, however, be explained by a decrease before 2050 and a subsequent increase. This pattern holds also for the relatively smaller increases in the East and Hindukush of around 10%. In the Central Highlands and the North, the annual precipitation is projected to decrease to a small extent.

Uncertainty: Precipitation is generally connected with higher uncertainties than temperatures in climate modelling. As shown in the validation (see section 4.1.2, below) and by the study of Ghimire et al.,[11] the general performance is satisfying but uncertainty is considerably high, since the models do not agree on the director of the trend. Only during spring, the models seem to underestimate the amount of precipitation as a general bias. Since the overall trends seem to be reflected by the models, and results are analyzed as changes from the base period of the same models, the relative changes of the model are still expected to be still satisfyingly reliable. However, for the interpretation it should be taken into account, that the results are considerably uncertain, especially when it comes to absolute magnitudes of precipitation.

Figure 16: Annual Precipitation for Afghanistan for Seven Regional Climate Models for a Base Period (grey, 1970-2005) and a Scenario Period (2006-2100) with Limited GHG Emissions (green, RCP 4.5) and Uncontrolled GHG Emissions (red, RCP 8.5). The Spread of the Models are Depicted as Transparent Areas and the Means as Lines. The Statistically Significant Trend of RCP 4.5 is Depicted as Dashed Line and its Magnitude is Plotted in Green.

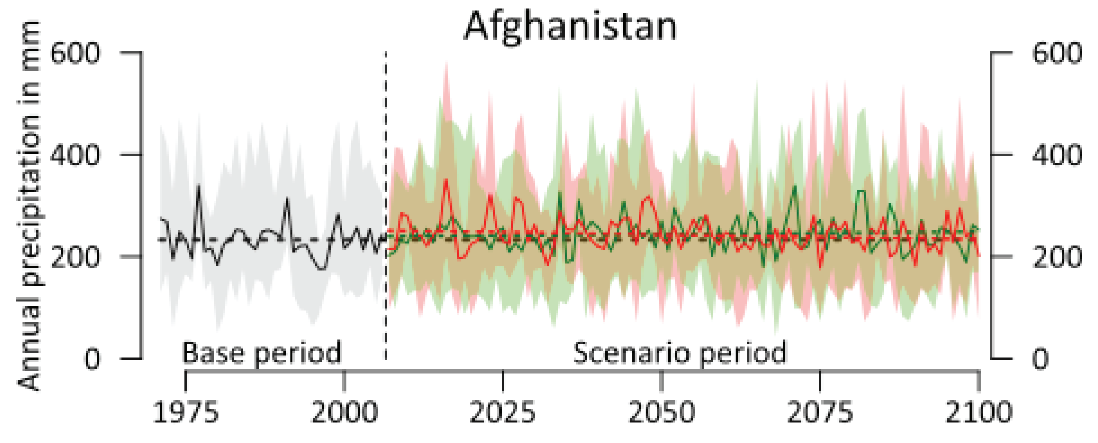


Figure 17: Projected Changes of Annual Precipitation in % for Afghanistan as Mean of Seven Regional Climate Models Between a Scenario Period (2021-2050) and a Base Period (1976-2005) Under Limited GHG Emissions (left, RCP 4.5) and Uncontrolled GHG Emission (right, RCP 8.5).

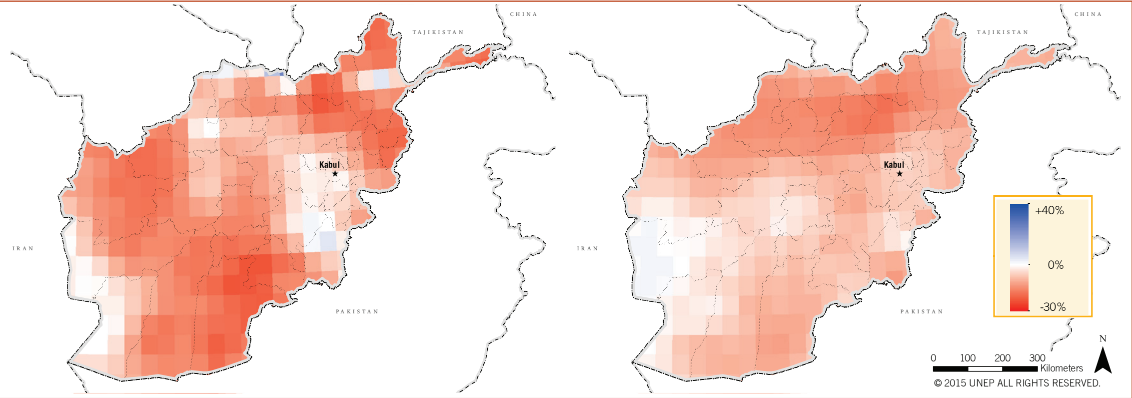


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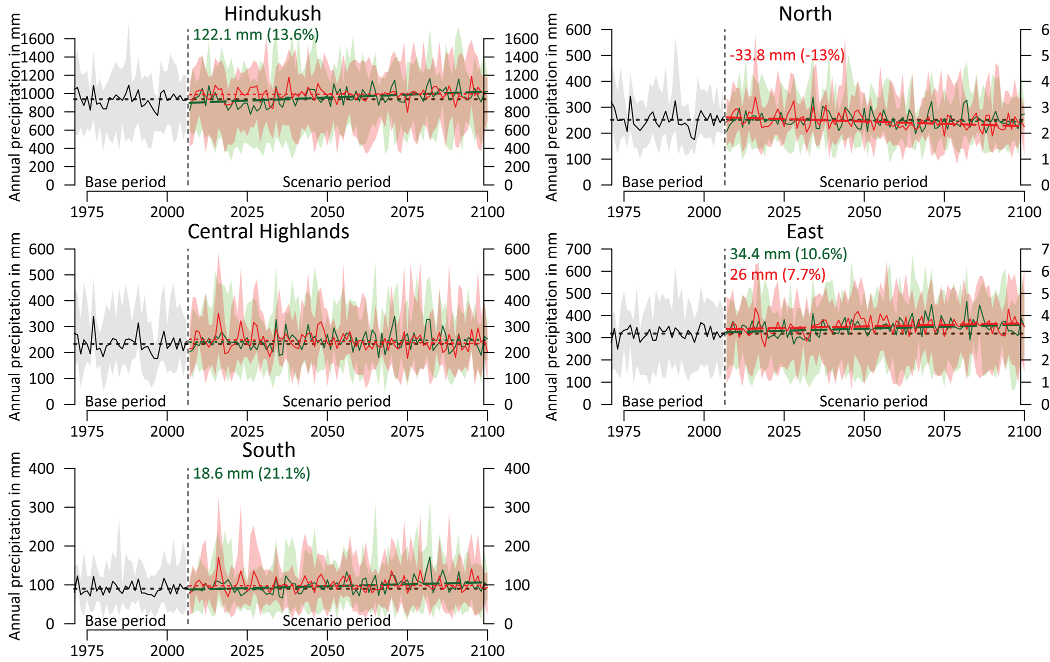
Figure 18: Similar to Figure 16 but for the Climate Regions of Afghanistan (see Figure 1): Hindukush, North, Central Highlands, East, and South. Statistically Significant Trends are Depicted as Dashed line and their Magnitude is Plotted in the Relative Color.



3.2.2. SPRING PRECIPITATION

In contrast to annual precipitation, there is a distinct and statistically significant decrease of precipitation during the months from March to May (Figure 19), especially for the “pessimistic” scenario. Figure 20, shows that in the near future period this decrease in spring precipitation is most pronounced in the North, the Central Highlands and the eastern part of the South regions. In the central East and the far South, the models project no trend for the business as usual scenario and even an increase for the “optimistic” scenario. The regional trends until 2100 (Figure 21) confirm these trends of decreases in the North, Central Highlands, and East. These are also the regions with most of Afghanistan´s agricultural production, for which the spring precipitation is very important. In combination with the increasing temperatures and connected increase in evapotranspiration, this will challenge the current rain-fed agriculture and enhance the need for irrigation.

Uncertainty: see annual precipitation.

Figure 19: Similar to Figure 16 but for Spring Precipitation (March-May).

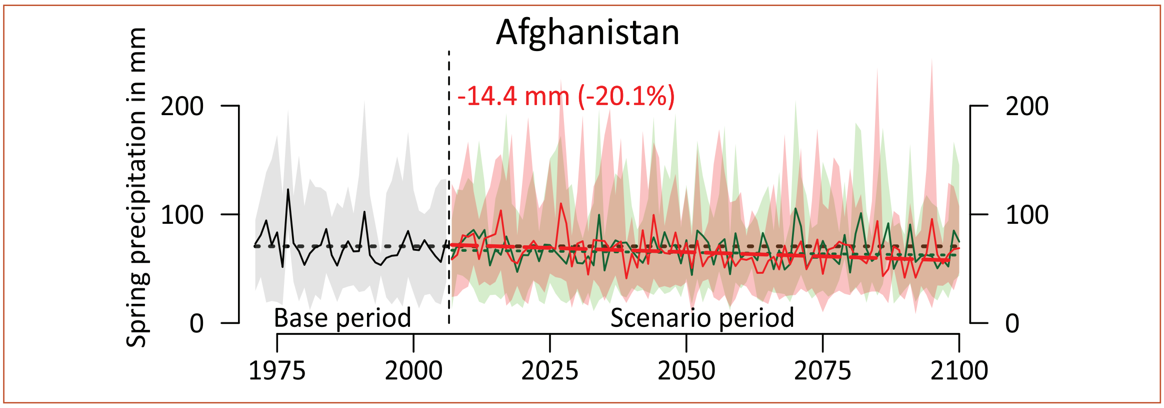


Figure 20: Projected Changes of Spring Precipitation (March-May) in % for Afghanistan as mean of Seven Regional Climate Models Between a Scenario Period (2021-2050) and a Base Period (1976-2005) Under Limited GHG Emissions (left, RCP 4.5) and Uncontrolled GHG Emission (right, RCP 8.5).

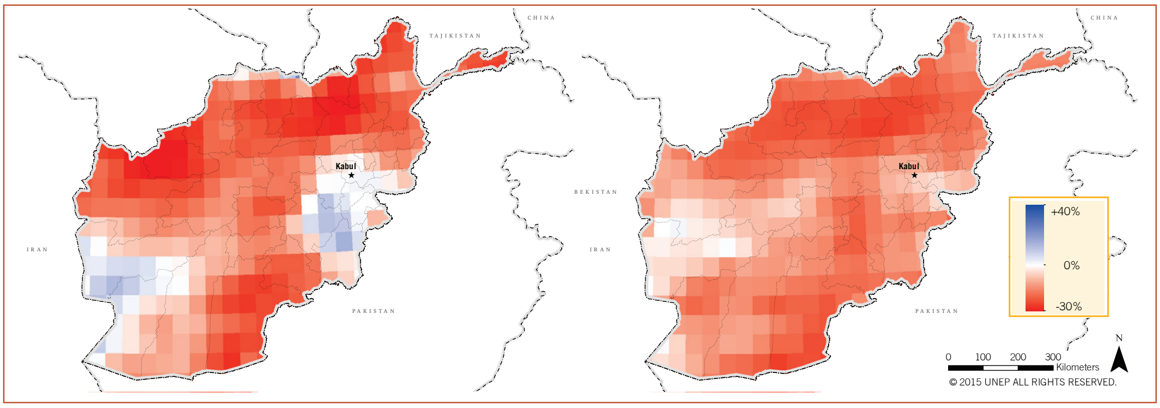
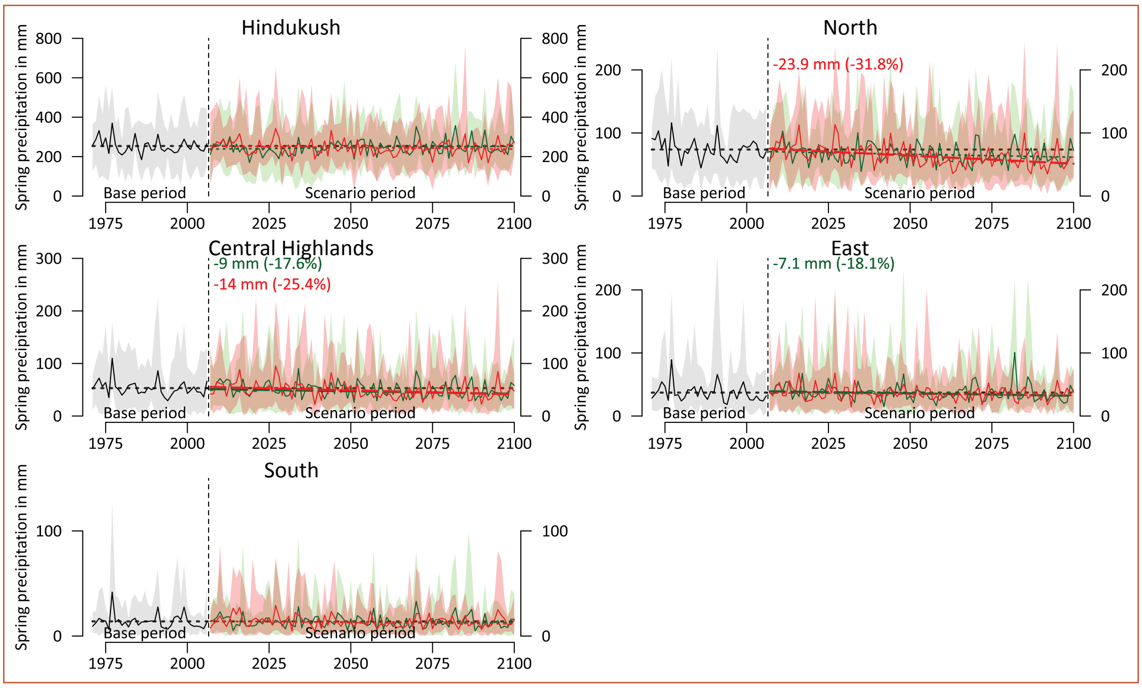


Figure 21: Similar to Figure 18 but for Spring Precipitation (March-May).



3.2.3. WINTER PRECIPITATION

The precipitation in the winter months from November to January, which in large parts of Afghanistan falls as snow, shows different trends for the scenarios, with a slight increase under the “optimistic” GHG scenario (RCP 4.5) and a slight decrease under the “pessimistic” GHG emission scenario (RCP 8.5) (Figure 22). However, the positive trend of the RCP 4.5 is due a decrease in the first half of the century, which can be also seen in the map of Figure 23. Until 2050, most of the country is projected to experience a decrease in winter precipitation. This trend continues for the RCP 8.5 scenario but turns in the other direction for the RCP 4.5. In the figure of the regional trend, this development can be seen more distinct (Figure 23). Until 2010, especially in the Hindukush, there is a substantial and significant increase under both scenarios. For the South, Central Highlands, and East, the decrease of the “pessimistic” scenario is distinct and also statistically significant. The partial increase in the Hindukush and the stable situation in the North in regard of winter precipitation can partly equal out the decreases of the spring precipitation, which consequently appears in sum over the whole year as no trend. This has to be taken into account when interpreting annual precipitation (see section 3.2.1, above).

Uncertainty: See annual precipitation.

Figure 22: Similar to Figure 16 but for Winter Precipitation (November-January)

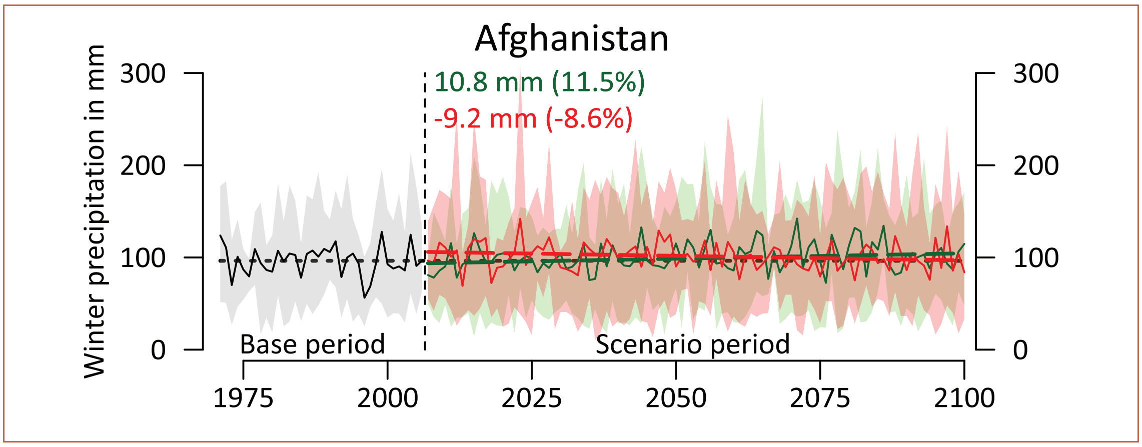


Figure 23: Projected Changes of Winter Precipitation (November-January) in % for Afghanistan as Mean of Seven Regional Climate Models Between a Scenario Period (2021-2050) and a Base Period (1976-2005) Under Limited GHG Emissions (left, RCP 4.5) and Uncontrolled GHG Emission (right, RCP 8.5).

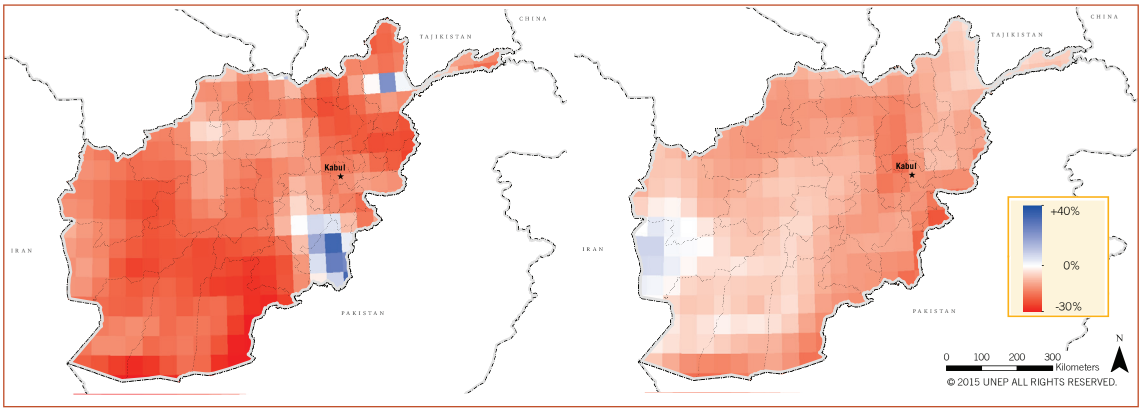
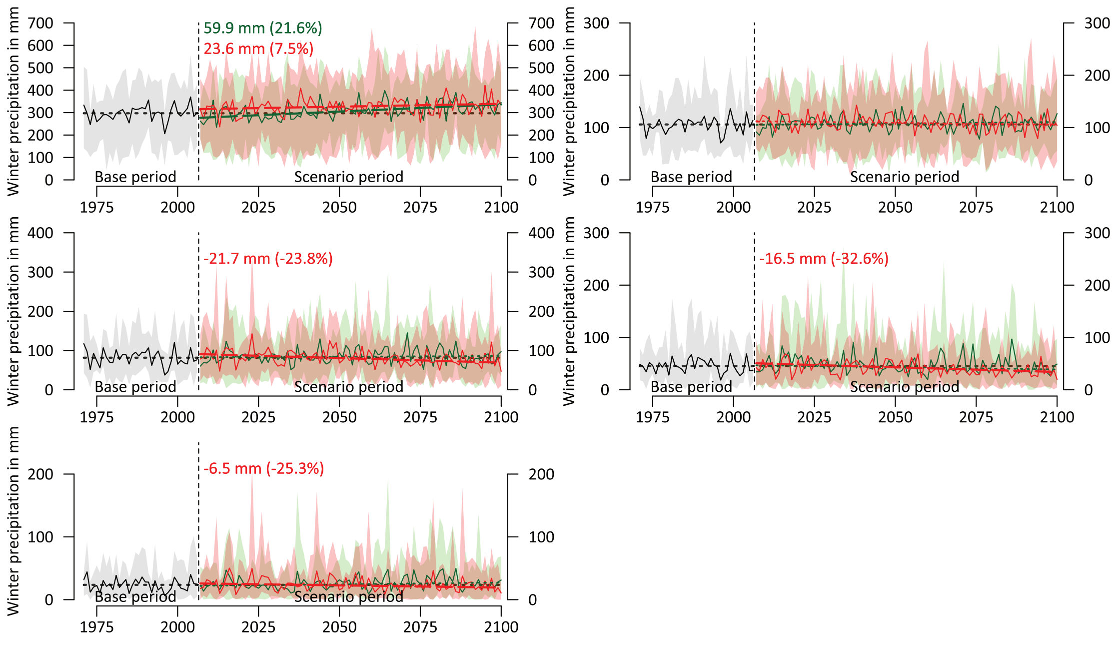


Figure 24: Similar to Figure 18 but for Winter Precipitation (November-January).



3.2.4. HEAVY PRECIPITATION

Heavy precipitation (95th percentile) increases slightly under the limited emission scenario (RCP 4.5), and decreases slightly under the unchecked emission scenario (RCP 8.5) (Figure 25). The regional pattern of the heavy precipitation trend is similar to annual precipitation until 2050 (Figure 26, compare to annual precipitation Figure 17). The further regional trends until 2100 show again a strong regional heterogeneity. Especially in the Hindukush and East, the projected increase might have negative implications for erosion and hazards like floods and landslides. However, an increase in heavy precipitation is just one possible reason that can lead to the aforementioned natural hazards.

Uncertainty: See annual precipitation. Besides the general uncertainty of precipitation projections, heavy precipitation comes even with higher uncertainty. This additional uncertainty is due to the rare statistical character of these rainfall events and to the complex processes that can cause heavy precipitation. Models are limited to a certain time step and spatial grid, which often cannot reflect heavy precipitation events that lead to flash floods. Locally limited convective systems with strong rains or short downpours are therefore not detectable. Warmer air can hold more moisture than cold air. Therefore, it is possible that even under a stable or decreasing precipitation trends a warming can lead to more extreme rainfalls. This process might not be reflected in the modelling and this overall high uncertainty should be taken into account when interpreting the scenarios results for heavy precipitation.

Figure 25: Similar to Figure 16 but for Heavy Precipitation (95th percentile)

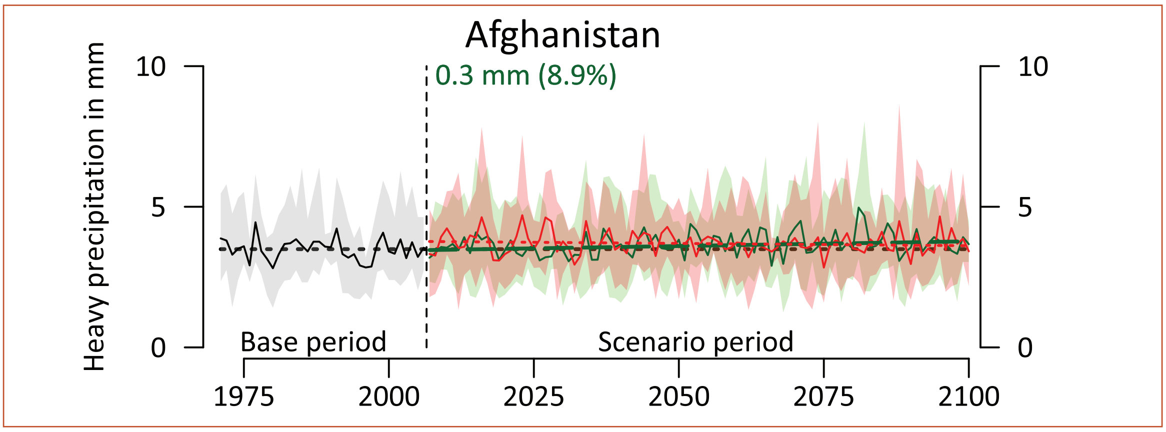


Figure 26: Projected Changes of Heavy Precipitation (95th percentile) in % for Afghanistan as Mean of seven Regional Climate Models Between a Scenario Period (2021-2050) and a Base Period (1976-2005) Under Limited GHG Emissions (left, RCP 4.5) and Uncontrolled GHG emission (right, RCP 8.5).

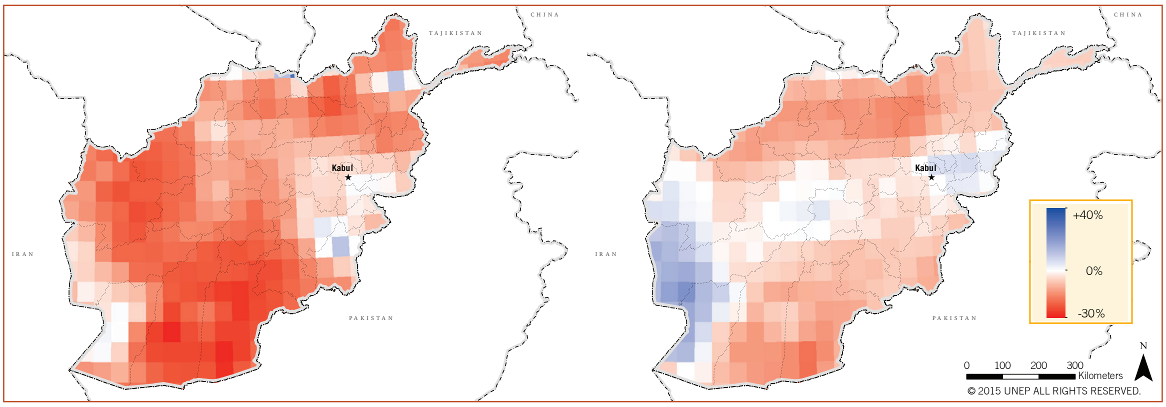
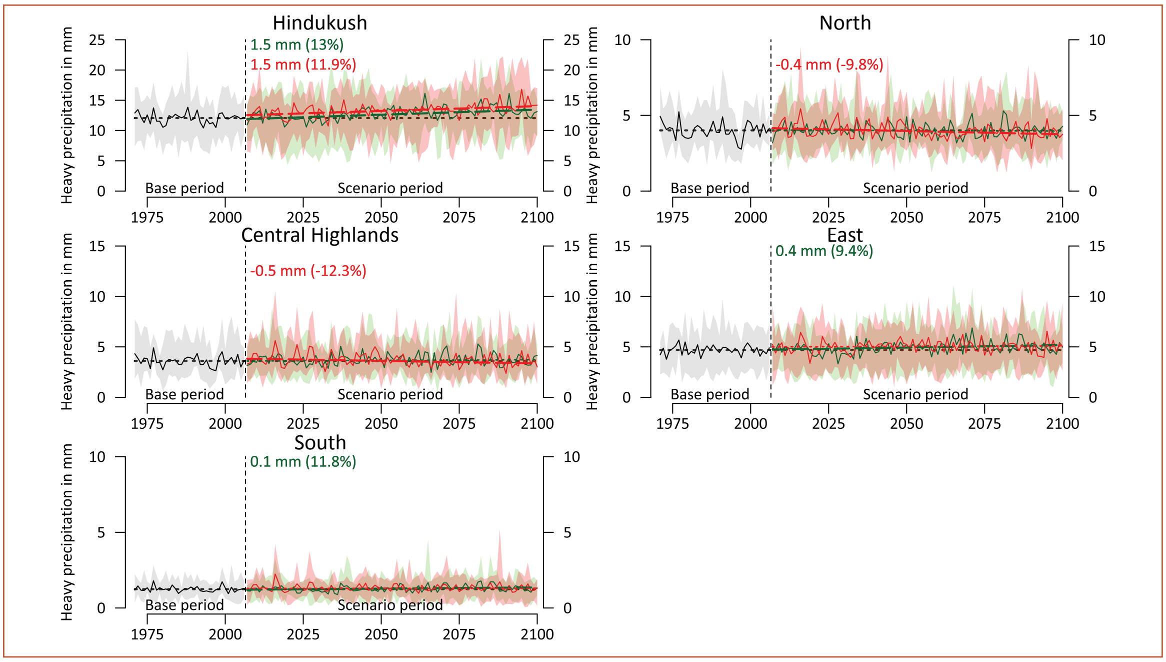


Figure 27: Similar to Figure 18 but for Heavy Precipitation (95th percentile)



4

VALIDATION

VALIDATION

Table 1: List of Global (GCM) and Regional (RCM) Climate Model Combinations of CORDEX South Asia used in this Analysis

General Circulation Models (GCM) / Institute		Regional Climate Models (RCM) / Institute
1	ACCESS / Bureau of Meteorology, Australia	CCAM / Commonwealth Scientific and Industrial Research Organisation, Australia
2	NorESM / Bjerknes Centre for climate research, Norway	CCAM
3	CCSM / National Center for Atmospheric Research in Boulder, USA	CCAM
4	CNRM / Centre National de Recherches Météorologiques, France	CCAM
5	ECHAM / Max Planck Institute für Meteorologie, Germany	CCAM
6	SMHI / Swedish Meteorological and Hydrological Institute, Sweden	ICHEC / Irish Centre for High-End Computing, Ireland
7	ECHAM	REMO / Max Planck Institut für Meteorologie, Germany

Figure 28: Weather Stations of Afghanistan used for the Validation of the Re-analysis Data and the Climate Projections. For Time Periods of Observations see Table 2.

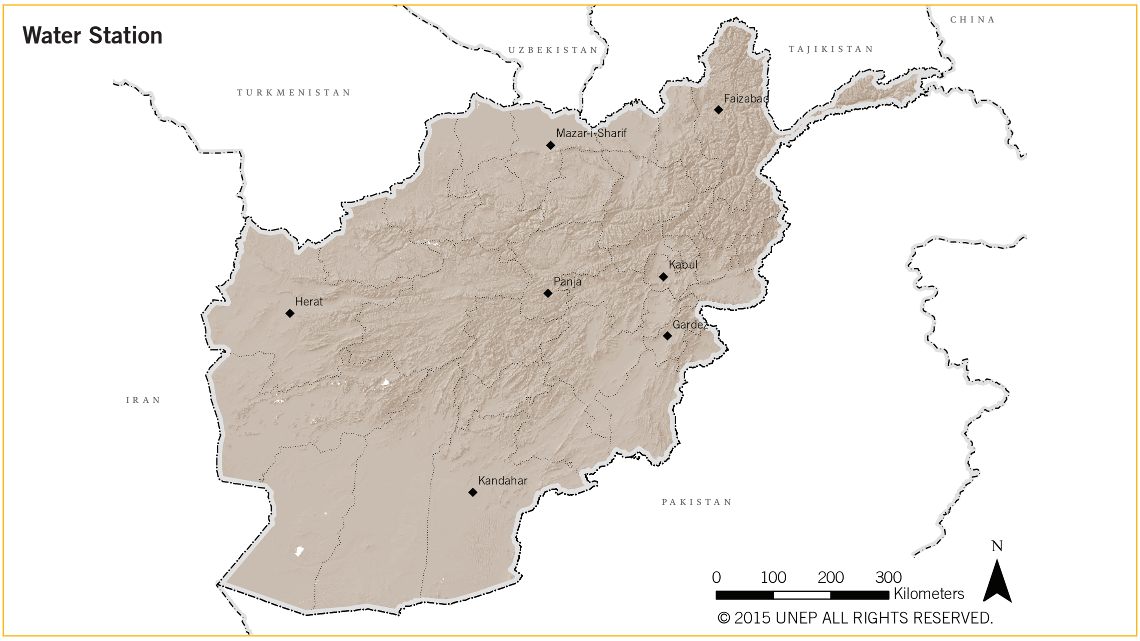


Table 2: Periods of Available Monthly Weather Data used for the Validation of Reanalysis and Regional Climate Models.

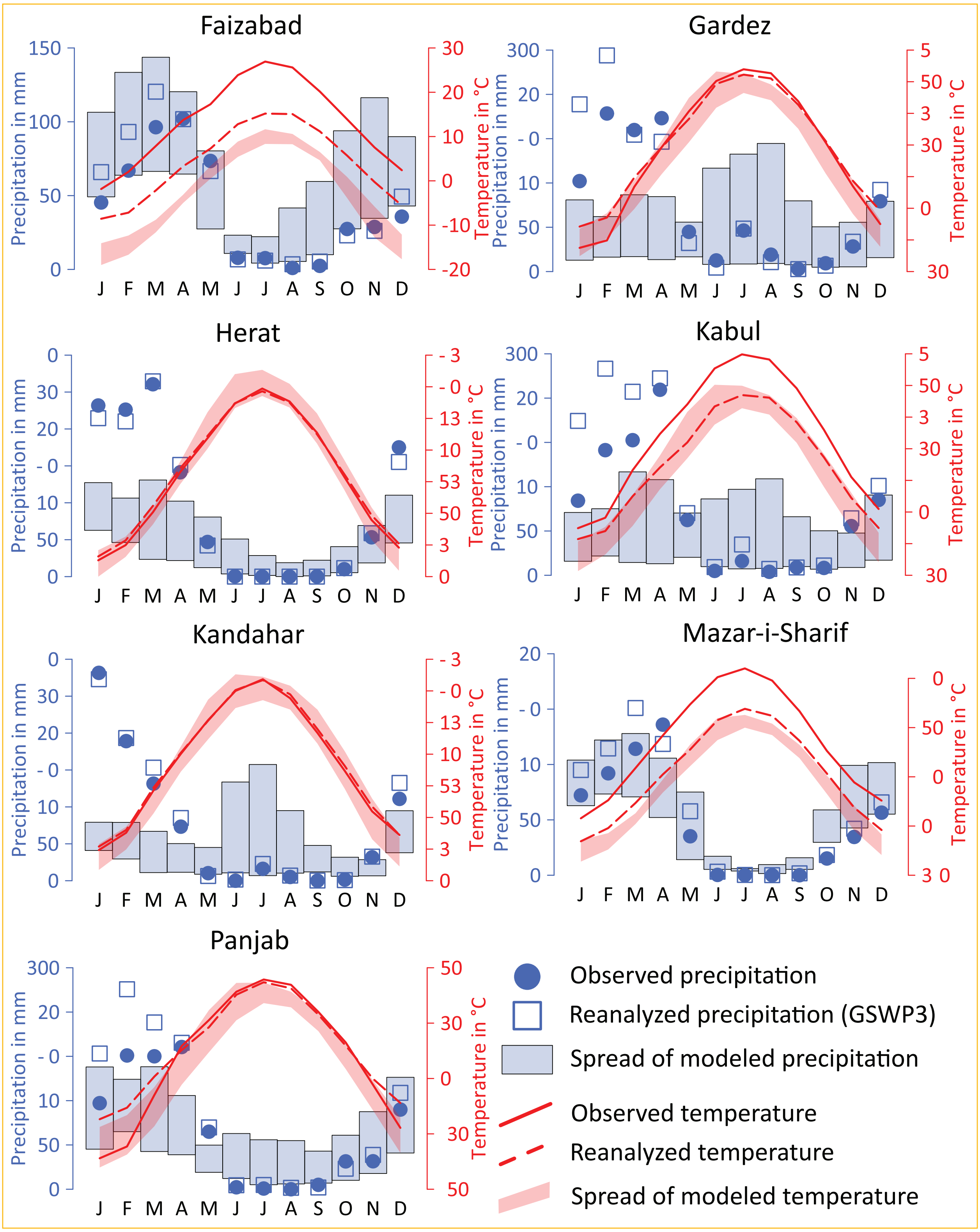
Station	Period
Faizabad	1963-1977
Mazar-i-Sharif	1958-1978
Kabul	1958-1977
Panjab	1965-1977
Herat	1958-1988
Gardez	1958-1978
Kandahar	1963-1977

4.1.1. REANALYSIS DATA

The reanalysis data from the Global Soil Wetness Project Phase 3 (GSWP3) (see textbox *Reanalysis Data*) has been validated against observed data in Figure 29. The data is on a 0.5° x 0.5° grid and in order to compare it with the point information of the different weather station, the nine nearest tiles around the point have been averaged (9-point filter). This is a standard procedure in order to avoid noise due to the minimum length wave of the signal.[13,14] The area of the compared data is therefore the mean of around 24,000km² and the regional geographical setting of the weather station, including its altitude, is therefore not reflected adequately. Still the general physical patterns should be reproduced by the reanalysis but the magnitudes of temperature and precipitation might differ. For example, Faizabad is located in the Kokcha valley (Figure 28), therefore its temperatures are distinctly warmer then then mean of the surrounding mountainous surrounding area. Thus, the temperature difference between the reanalysis and the measurements differ strongly, but still show the same seasonal cycle. For stations of which the altitude is similar to the mean of the surrounding gridboxes, like Kandahar, Herat and Gardez, the validation shows a more adequate performance and observed and reanalyzed temperature are almost equal. This means, that in regard of temperature, the reanalysis data is robust and reliable. For all stations, it shows the correct seasonal cycle and for stations with an altitude which is comparable with the mean of the surrounding grids, also the magnitude of the monthly temperature is correct.

With regard to precipitation, regional differences are larger and results are heterogeneous throughout the seasonal cycle. For all stations, the precipitation between April and December is well reproduced by the reanalysis data with medium deviations mainly in December and April. In contrast, the precipitation from January to March is overestimated for the stations Faizabad, Gardez, Kabul, Mazar-e Sharif and Panjab. All these stations are located in mountainous areas, where at the one hand, the described effect of the 9-point-filter is distinct. On the other hand, climate and weather models still have difficulties with high altitudes, since the spatial resolution of the cells is often too course to represent relevant processes that lead to rainfall. Still this bias holds for the whole period and since in the analysis for precipitation mainly relative changes are used, the data is also satisfying reliable and robust for these analyses. However, it should be kept in mind during the interpretation, that the precipitation from the reanalysis comes with uncertainty as mentioned in the chapter 2.2.

Figure 29: Climate Diagrams with Mean Monthly Temperature and Precipitation Used for the Validation of Reanalysis data (GSWP3) and Regional Climate Models for Seven Weather Stations of Afghanistan (see Figure 28). The Time Periods for the Observations and the Re-analysis Data is Given in Table 2. For the Climate Models, the Period from 1970-1999 has been Used.



4.1.2. CLIMATE MODEL PROJECTIONS

The performance of the CORDEX data of the South Asian domain has been checked for the Himalayan area, including the Hindukush and the Karakorum, in Ghimire et al. 2015.[11] They concluded that the data "facilitates precipitation evolution and structure over the Himalayan region with a certain degree of uncertainty." However, the study area does not cover all of Afghanistan; therefore, in order to check their performance and suitability for the region, the historical runs of the CORDEX project were validated against reanalysis data (see text box Re-analysis Data). Single model runs have not been evaluated but the spread of the whole ensemble. This is due to the fact, that the study of Ghimire et al. has shown that the mean of the whole model ensemble outperformances the individual models. In addition, also in the analysis only the whole ensemble is evaluated and not individual models. For the validation, the annual cycle of monthly values of temperature and precipitation has been compared similar to the reanalysis data (Figure 29). The selected time period of the models is from 1970 until 1999 and the modelled data has been evaluated for the same locations that have been used as in the validation of the reanalysis data.

With regard to temperature, the spread of the models for all stations, except Faizabad, include the curve for the reanalysis data. This means that the model ensemble is able to reproduce the general temperature patterns of the climate of Afghanistan. Around Faizabad, the models are still able to reproduce the annual cycle, but underestimate the magnitude by around 5°C. This deviation might be due to difficulties of the model in higher altitudes and pronounced topography.

The performance of the models on precipitation is considerably lower. The models' ability to reflect the seasonal cycle is satisfactory with deficits in the East, at the stations Kabul and Gardez, where the models hardly reflect the seasonal cycle. In terms of absolute values for most regions, especially the months from January to April, are largely underestimated by the models. In contrast to the temperature, the mountainous station of Faizabad, Mazar-e Sharif and Panjab show the best results during these months. From March to September, the spread of the models mostly covers the reanalysis data, but still the overall performance in regard of absolute is poor. In total, the performance in regard of precipitation is satisfactory. The principle climatological patterns seem to be reflected with deficits in the East. Absolute values, especially in spring should not be compared. These deficits might also be relevant for changes in the climatic system which is related to climate change. It can therefore not be excluded, that an important change in the climate system over Afghanistan is not reflected in the models. Therefore, the results should be interpreted carefully and the considerable large uncertainty should be taken into account.

5

STATISTICAL METHODS

STATISTICAL METHODS

Heavy precipitation is analyzed as 95th percentile of days above 1mm precipitation. This is a standard indicator for precipitation extremes and for example used by the European Union.[15]

Monotonic linear trends in precipitation and temperature time series were identified using the Mann-Kendall test.[16] It is a robust nonparametric test in which each element is compared with its successors and ranked as larger, equal or smaller. On this basis, it is possible to test the statistical significance of rejecting the null hypothesis (for all tests $\alpha = 0.05$).

Linear trends in the reanalysis data and the model projections have been quantified using the Theil-Sen estimator.[17,18] It is a method to estimate the slope of a trend without being sensitive against outliers. Since serial independence is a requirement of the test, the data was checked for autocorrelations using the Durbin-Watson statistic test.[19,20] It tests the null hypothesis that the residuals from an ordinary least-squares regression are not autocorrelated. If an autocorrelation of the first order was found, trend-free pre-whitening was applied according to the method proposed by Yue et al. (2002).[21] This method was applied using the “Kendall”[22] and the “zyp”[23] packages for the R statistical software.[24]

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ACRONYMS

AMA	Afghanistan Meteorological Authority
CMIP	Coupled-Model Intercomparison Project
GCM	General Circulation Model
GHG	Green House Gas
GSOD	Global Summary of the Day
GSWP3	Global Soil Wetness Project Phase 3
INC	Initial National Communication under the UNFCC
IPCC	Intergovernmental Panel on Climate Change
M.A.S.L.	Metres above sea level
MAIL	Ministry of Agriculture, Irrigation and Livestock
MEW	Ministry of Energy and Water
MRRD	Ministry of Rural Rehabilitation and Development
NAPA	National Adaptation Programme of Action
NEPA	National Environmental Protection Agency
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
SEI	Stockholm Environment Institute
SNC	Second National Communication under the UNFCC
SRES	Special Report on Emission Scenarios
UNEP	UN Environment
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organization

Building Environmental Resilience

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