
# When and why does heavy rain occur?

## A retrospective analysis on climatic drivers and future projections

P. Hoffmann

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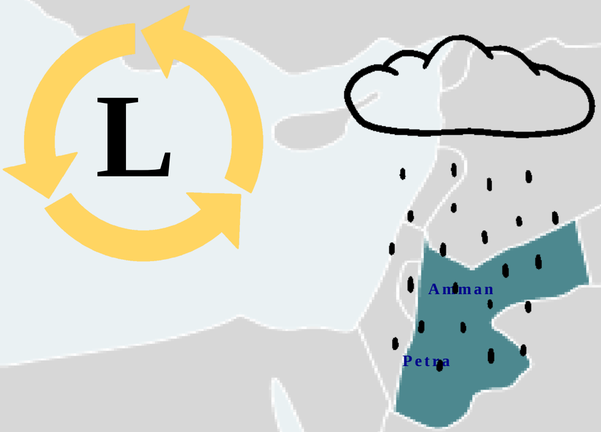
# Introduction

## WP2: Natural Hazard: Heavy Rainfall




# Heavy Rainfall Scenarios for Amman and Jordan

# Long-term Trends over the Mediterranean

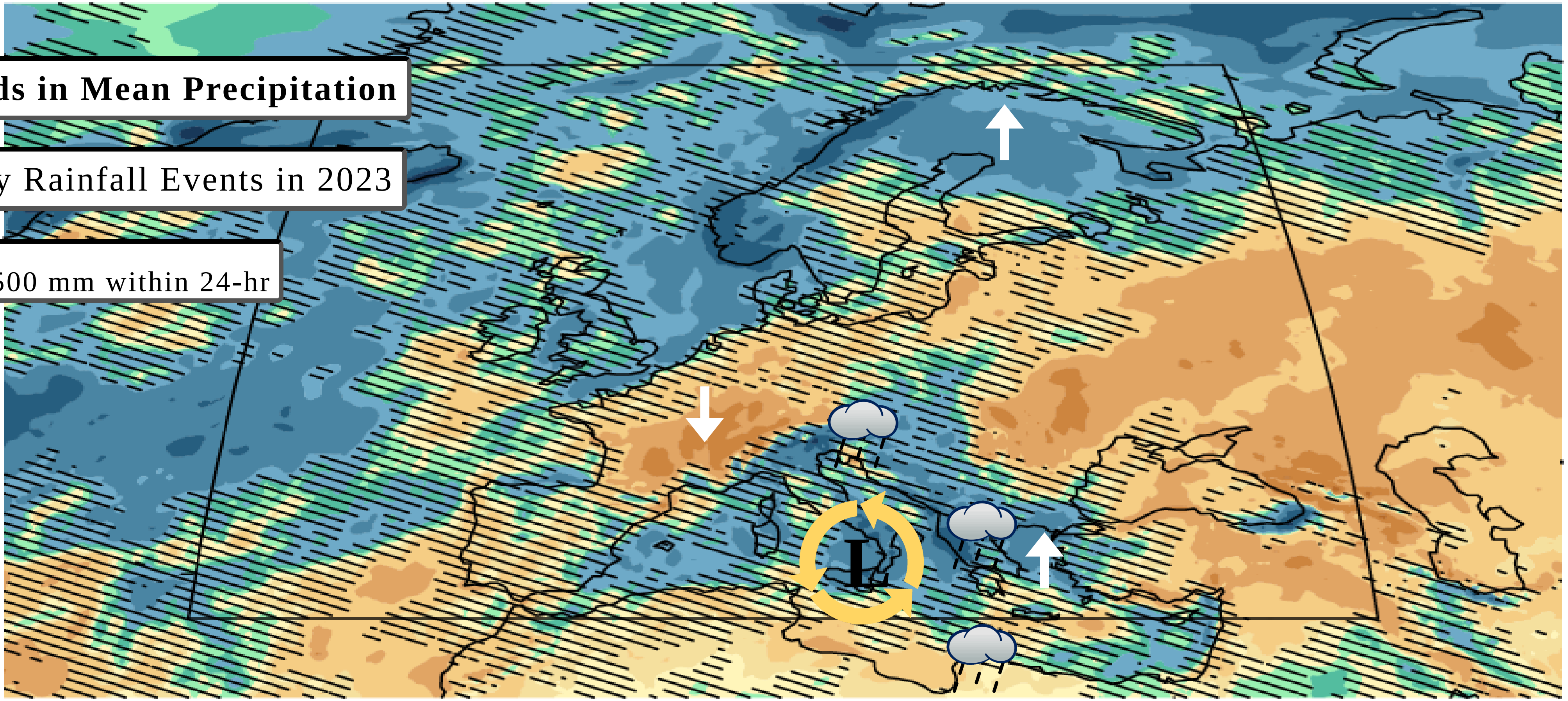
## Annual Precipitation

mean regression precipitation on time 1979-2022 Jan-Dec ERA5

## Trends in Mean Precipitation

Heavy Rainfall Events in 2023

up to 500 mm within 24-hr

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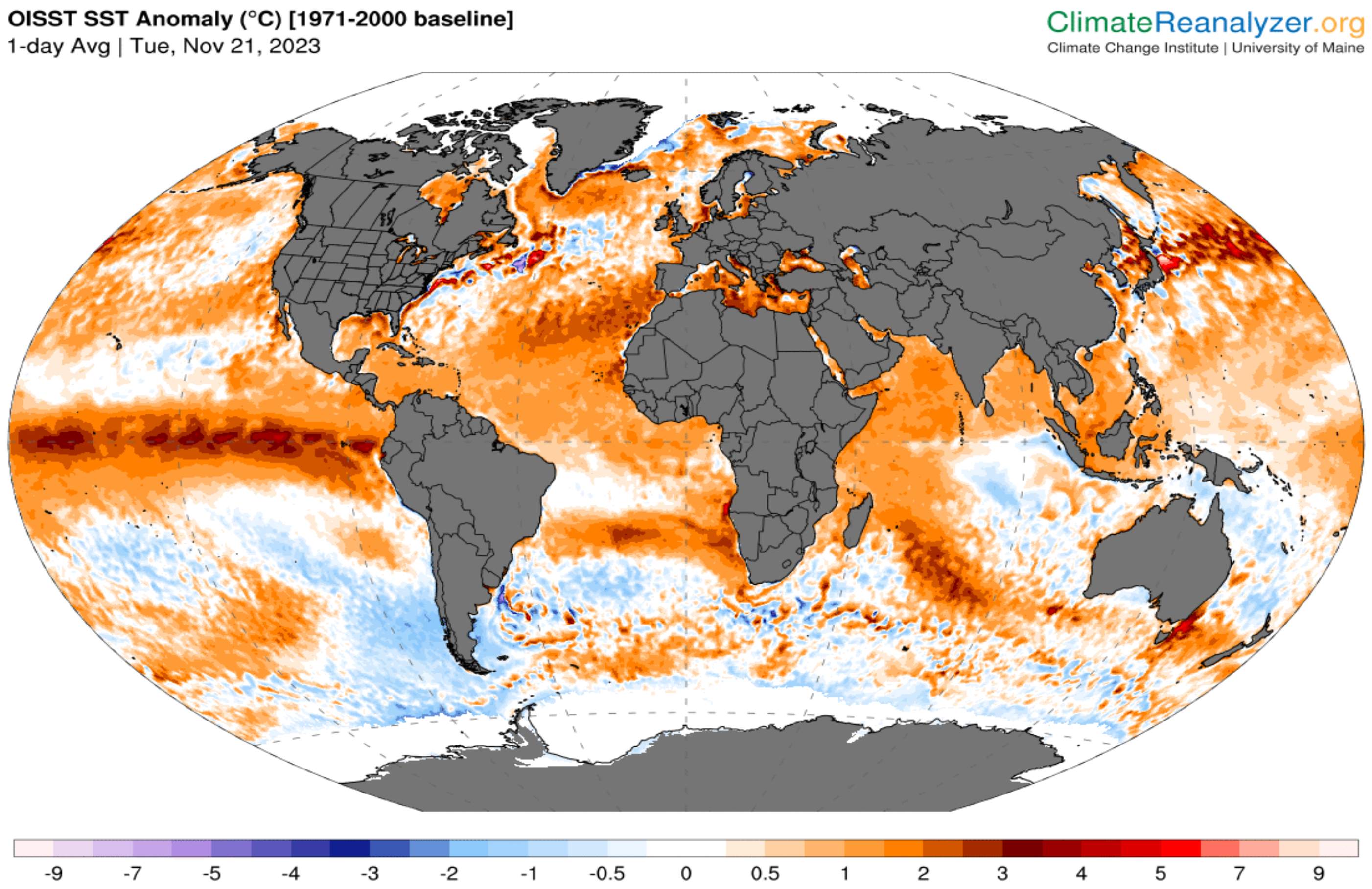
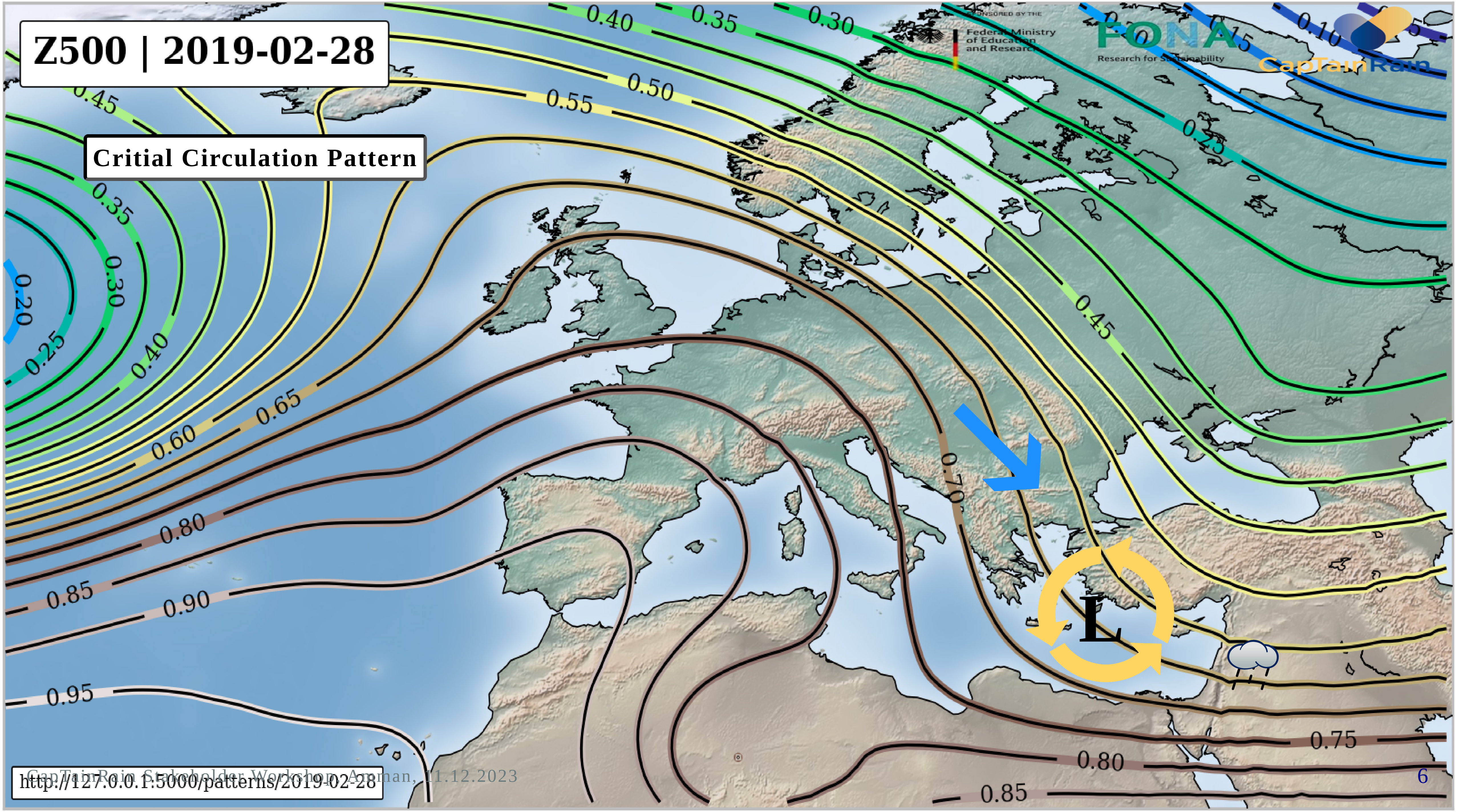
# Warmer Sea Surface Temperature Anomalies

## Higher Potential Risk for Extreme Rainfall




# Z500 | 2019-02-28

**Critial Circulation Pattern**




http://127.0.0.1:5000/patterns/2019-02-28

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# Local Extreme Events

## Heavy Rainfall in Amman: 28. Feb. 2019 (~60mm/3hr & ~140mm/d | ~25-yr event)

### Rain Gauges

| Year | Month | Day | Hour | Hussien Garden | Jubiha | Quiesmeh | Amman Downtown | Amman Civil Airport |
|---|---|---|---|---|---|---|---|---|
| 2019 | 2 | 28 | 0 | 3.5 | 5.0 | 1.0 | 1.5 | 3.0 |
| 2019 | 2 | 28 | 1 | 10.5 | 4.5 | 2.5 | 4.0 | 5.5 |
| 2019 | 2 | 28 | 2 | 8.5 | 7.0 | 9.0 | 9.0 | 11.0 |
| 2019 | 2 | 28 | 3 | 1.0 | 0.5 | 5.5 | 5.5 | 6.0 |
| 2019 | 2 | 28 | 4 | 4.0 | 4.0 | 5.5 | 5.5 | 6.5 |
| 2019 | 2 | 28 | 5 | 7.5 | 3.5 | 7.0 | 8.0 | 11.5 |
| 2019 | 2 | 28 | 6 | 0.0 | 0.5 | 5.0 | 5.0 | 7.5 |
| 2019 | 2 | 28 | 7 | 1.5 | 0.5 | 3.5 | 4.0 | 5.0 |
| 2019 | 2 | 28 | 8 | 1.0 | 1.0 | 4.5 | 3.5 | 6.0 |
| 2019 | 2 | 28 | 9 | 2.0 | 2.0 | 1.5 | 2.0 | 2.0 |
| 2019 | 2 | 28 | 10 | 12.0 | 7.0 | 8.5 | 10.0 | 18.0 |
| 2019 | 2 | 28 | 11 | 9.5 | 3.5 | 10.0 | 11.5 | 18.5 |
| 2019 | 2 | 28 | 12 | 8.0 | 4.0 | 6.5 | 8.0 | 11.5 |
| 2019 | 2 | 28 | 13 | 3.0 | 1.0 | 4.5 | 5.0 | 9.5 |
| 2019 | 2 | 28 | 14 | 1.0 | 1.5 | 7.0 | 3.0 | 5.0 |
| 2019 | 2 | 28 | 15 | 0.5 | 0.0 | 0.5 | 0.0 | 0.0 |
| 2019 | 2 | 28 | 16 | 0.0 | 0.0 | 0.0 | 0.5 | 0.5 |
| 2019 | 2 | 28 | 17 | 0.5 | 2.0 | 1.0 | 0.0 | 0.0 |
| 2019 | 2 | 28 | 18 | 2.0 | 1.5 | 1.5 | 1.5 | 2.0 |
| 2019 | 2 | 28 | 19 | 0.5 | 1.0 | 0.0 | 0.0 | 0.0 |
| 2019 | 2 | 28 | 20 | 2.0 | 0.5 | 2.0 | 2.0 | 1.0 |
| 2019 | 2 | 28 | 21 | 2.0 | 0.5 | 3.0 | 3.0 | 2.0 |
| 2019 | 2 | 28 | 22 | 0.5 | 0.0 | 0.5 | 0.5 | 0.0 |
| 2019 | 2 | 28 | 23 | 0.0 | 0.0 | 0.5 | 0.5 | 0.0 |

### Return Levels/Periods

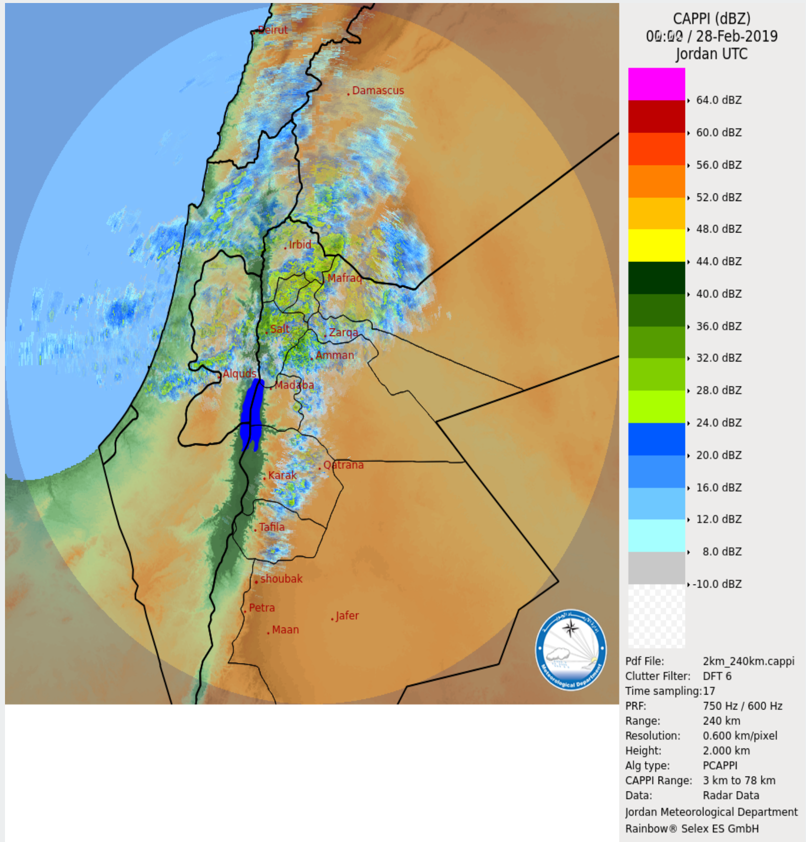
*Table 6: Regional Depth-Duration-Frequency (DDF) values for the study region.*

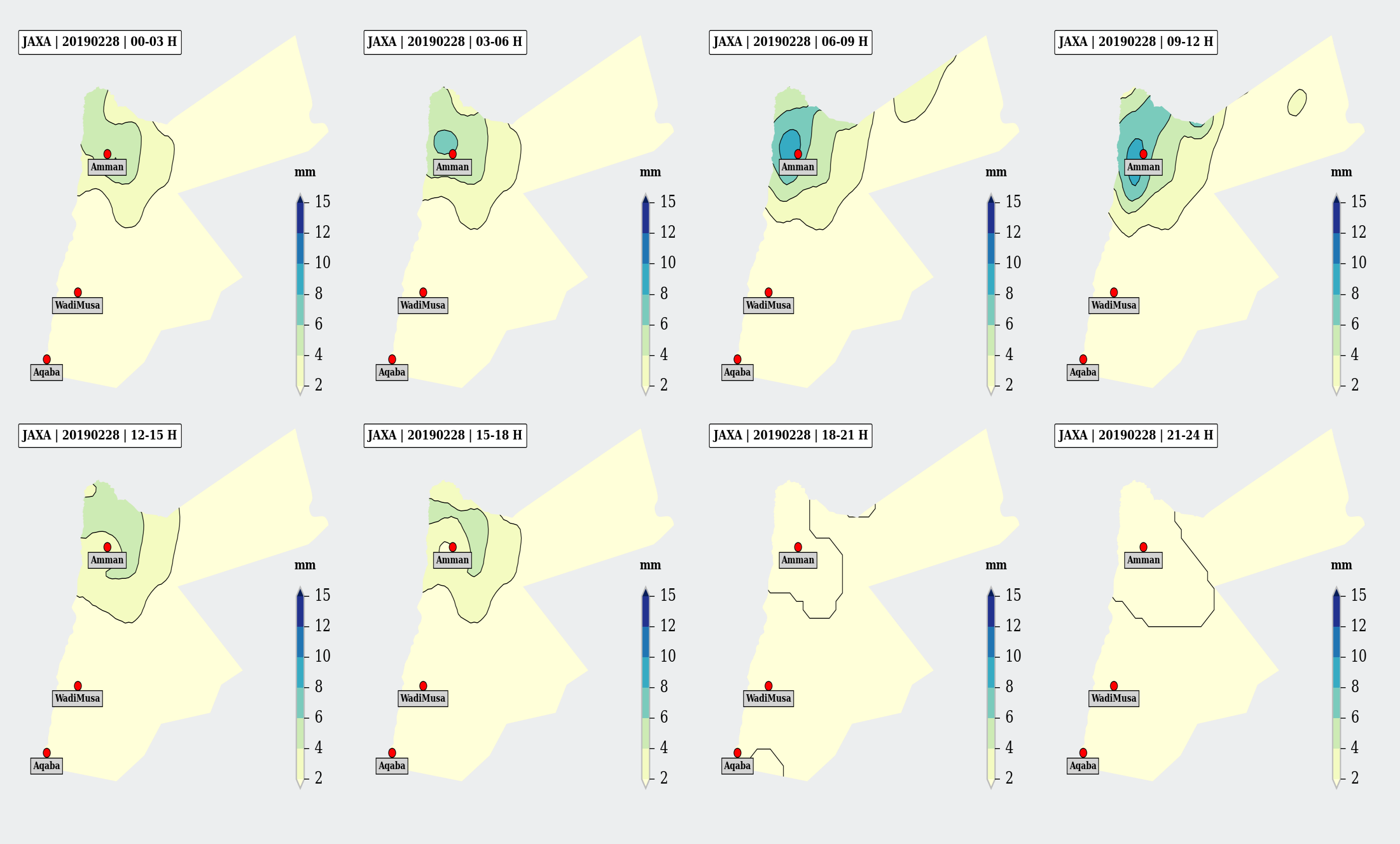
| Return Period | Rainfall Depth (mm) for Different Durations (minutes) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 10 | 15 | 30 | 60 | 120 | 180 | 360 | 720 | 1440 |
| 2 | 3.8 | 5.5 | 7.3 | 11.3 | 17 | 25.5 | 31.2 | 44.8 | 60.1 | 66.7 |
| 5 | 5.2 | 7.6 | 10 | 15.5 | 23.3 | 35 | 42.8 | 61.5 | 82.5 | 91.6 |
| 10 | 6.1 | 8.9 | 11.7 | 18.1 | 27.3 | 40.9 | 50.1 | 71.9 | 96.4 | 107 |
| 25 | 7.1 | 10.4 | 13.7 | 21.2 | 32 | 47.9 | 58.7 | 84.3 | 113 | 125.4 |
| 50 | 7.9 | 11.5 | 15.1 | 23.4 | 35.3 | 52.8 | 64.7 | 92.9 | 124.6 | 138.3 |
| 100 | 8.6 | 12.5 | 16.4 | 25.4 | 38.4 | 57.5 | 70.4 | 101.1 | 135.6 | 150.5 |

# RADAR vs GSMaP

## Heavy Rainfall in Amman: 28. Feb. 2019

| 12 min RADAR Loop | 3-hr aggregated GSMaPs |
| --- | --- |



# Regional Reanalysis Data

## UERRA 1961-2019

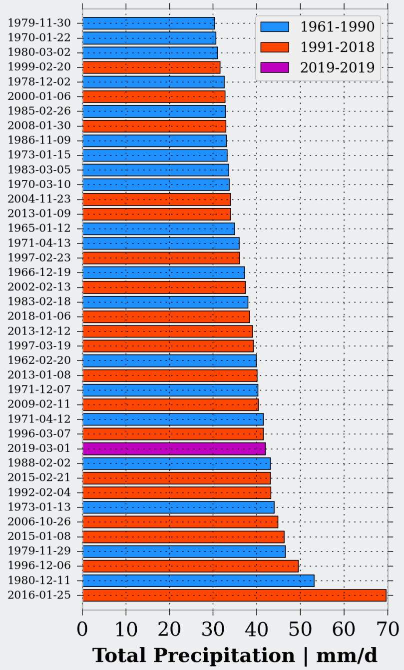
*gridded data*

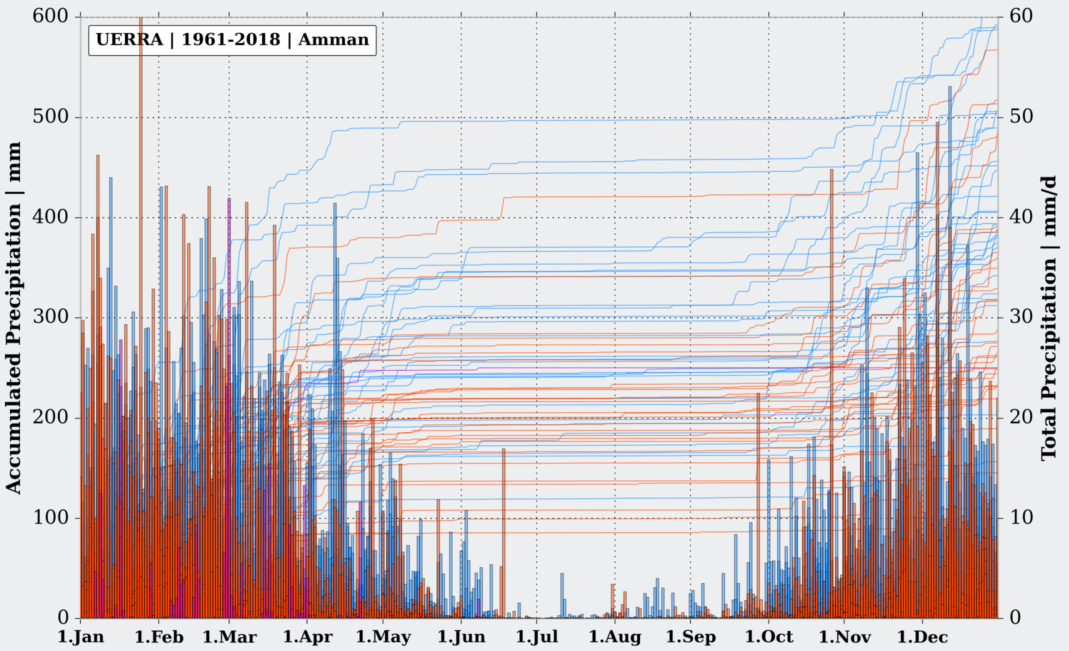
https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-uerra-europe-single-levels?tab=overview

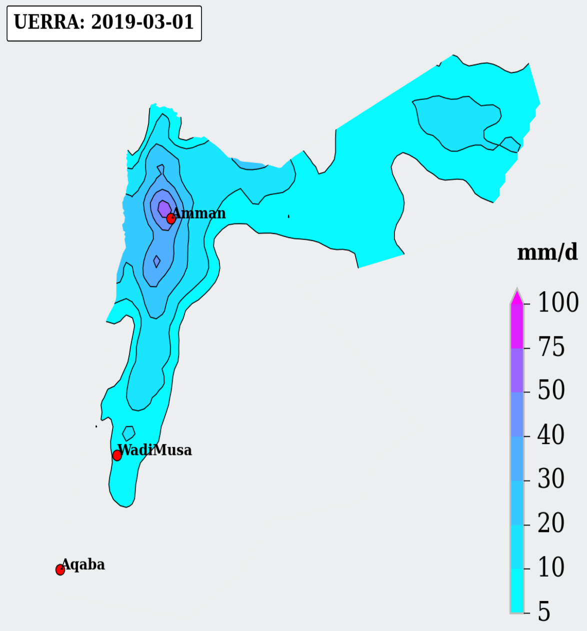
# UERRA Reanalysis Data

## Daily Precipitation in Amman 1961-2019

| Chart | Pattern |
|---|---|



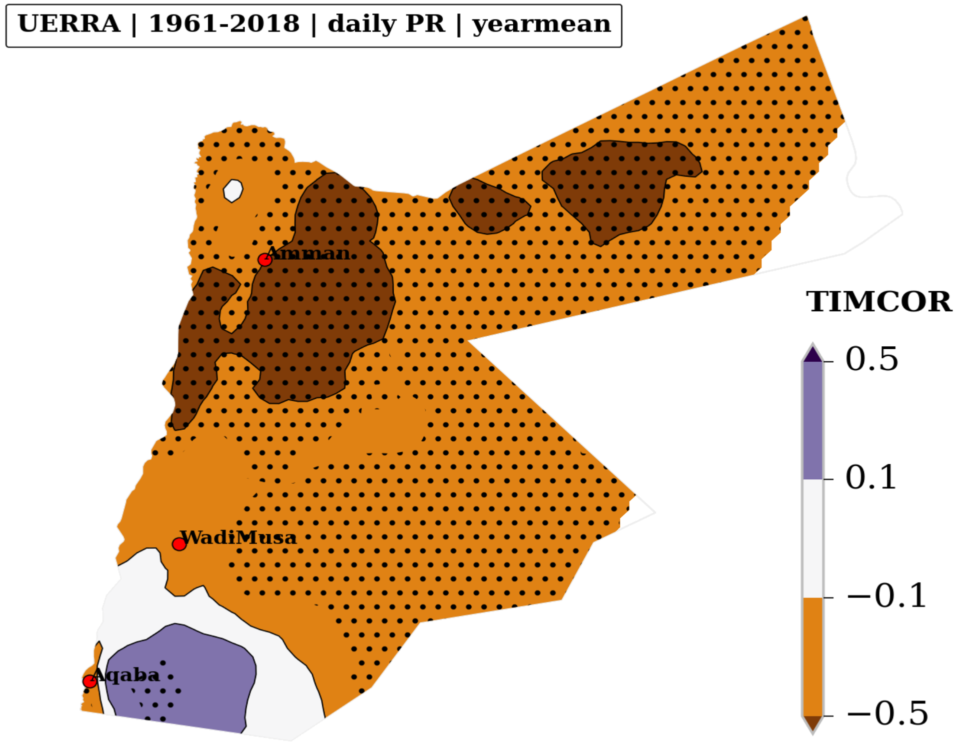



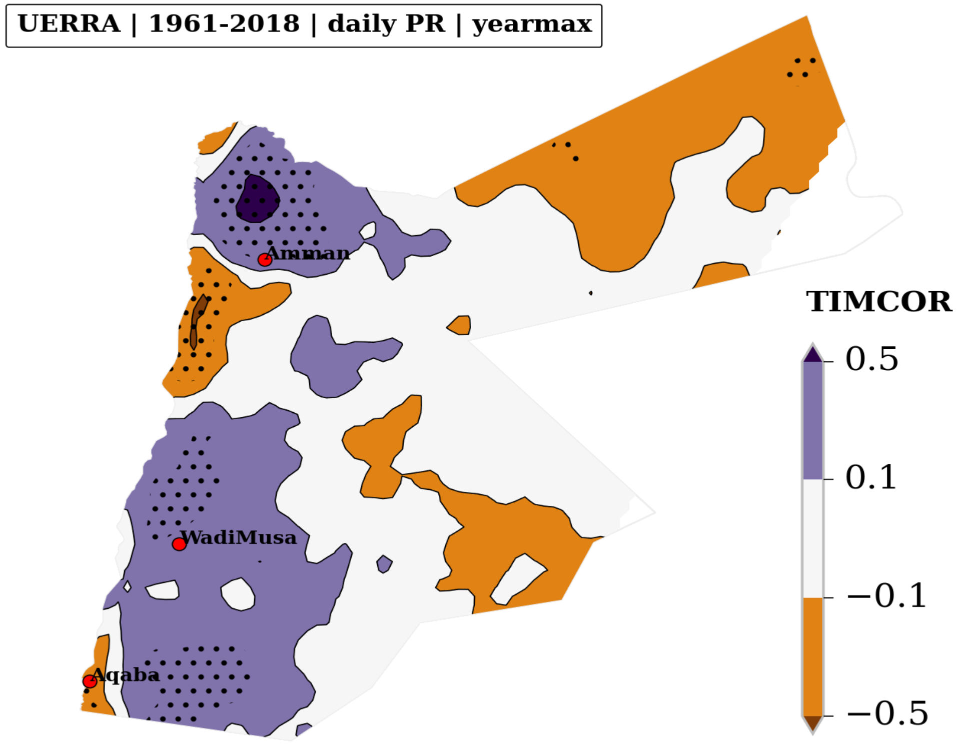

| **Seasonality:** Absolute/Accumulated, past/present, high/low | critical rainfall pattern |
|---|---|

station data can reach higher values

# UERRA Reanalysis Data

## Time Correlation of the Annual Mean/Maximum of Daily Precipitation




Decreasing/Increasing Trends of Mean/Maximum

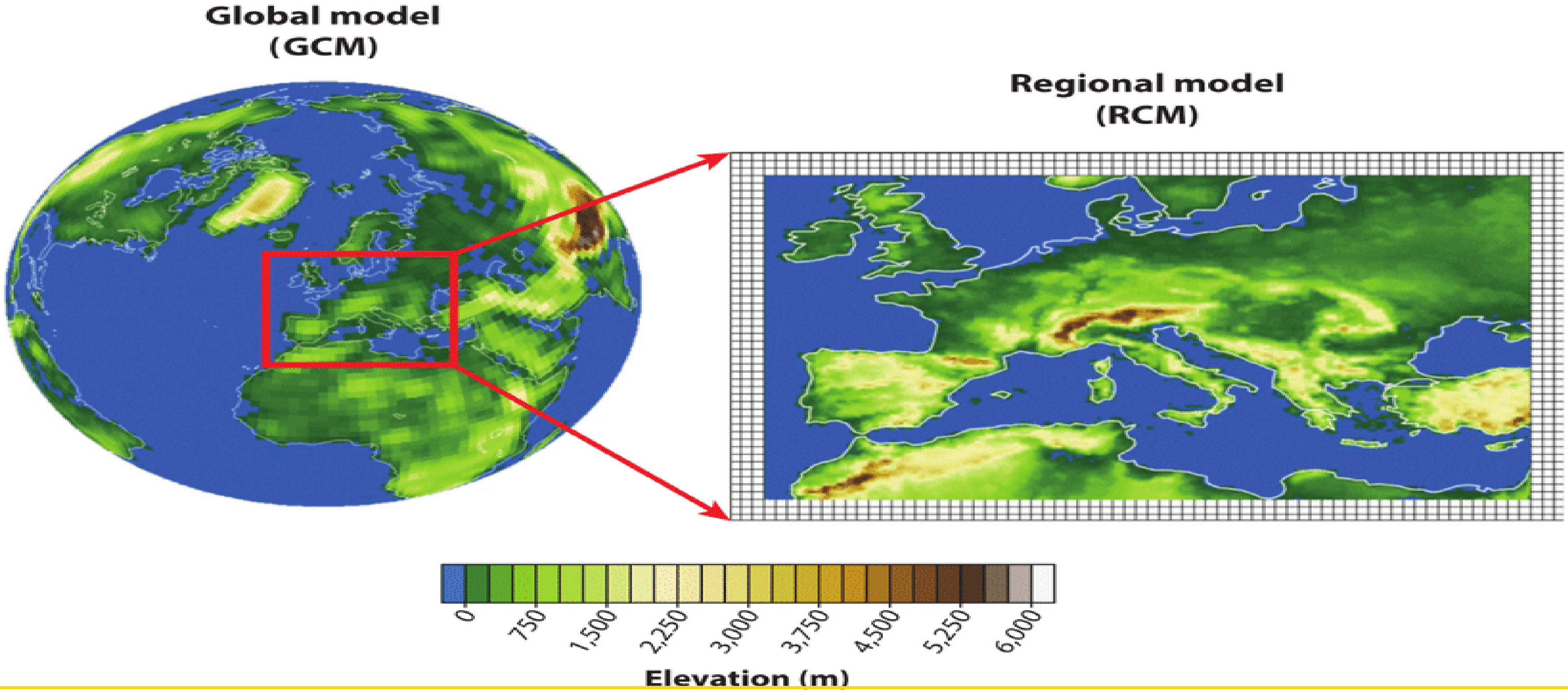
# Research Question:

## How sensitive is heavy rainfall in Jordan to global warming?

***Data - Methods - Results***

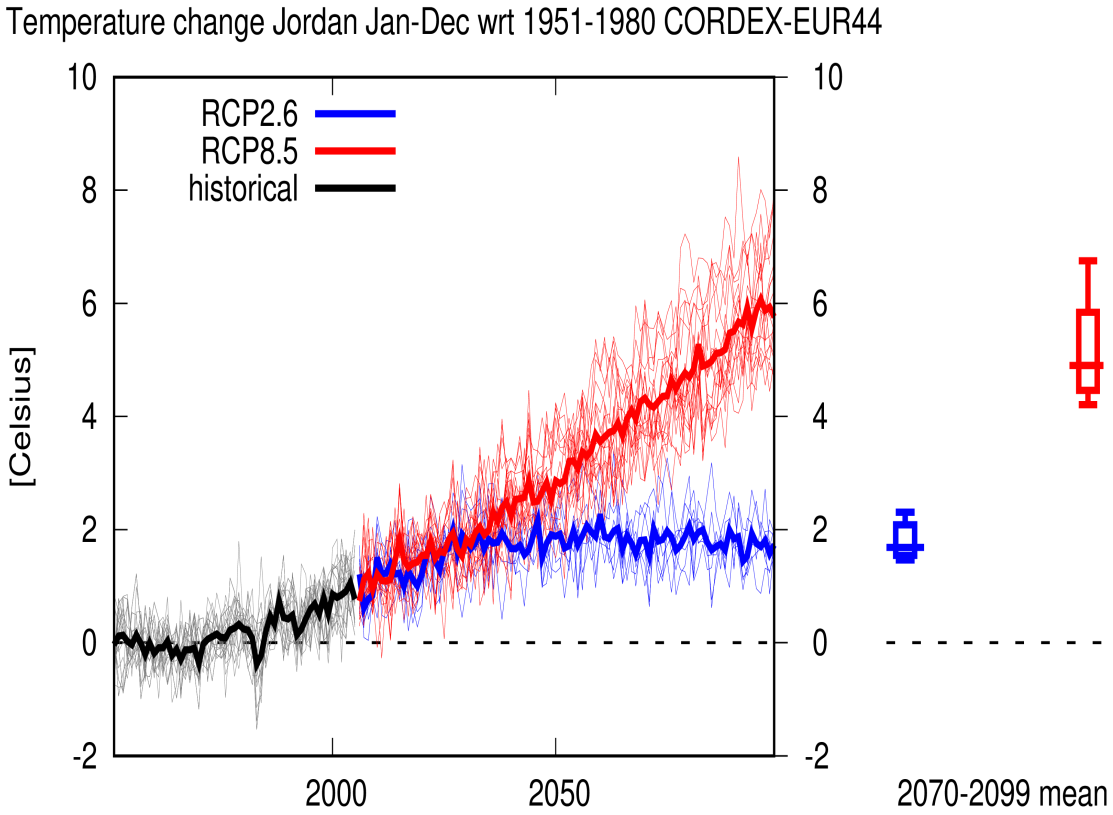
# Dynamical Downscaling

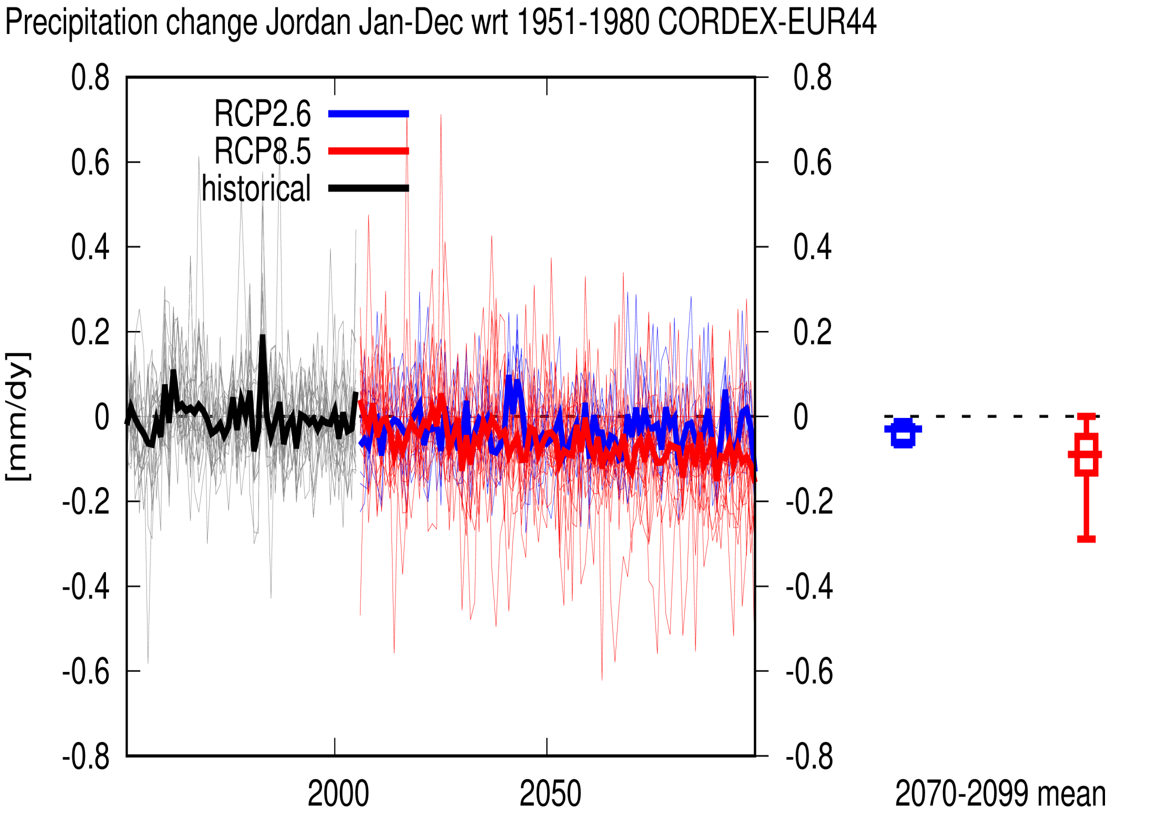
## High-Resolution Climate Scenarios (CORDEX)



# Mean Temperature/Precipitation Changes

## RCP8.5/RCP2.6 | CMIP5 | CORDEX-EUR44 | JORDAN






**RCP8.5:** temperature rise up to +5°C until 2100 (+3°C compared to **RCP2.6**)

# Regional Climate Model Ensemble

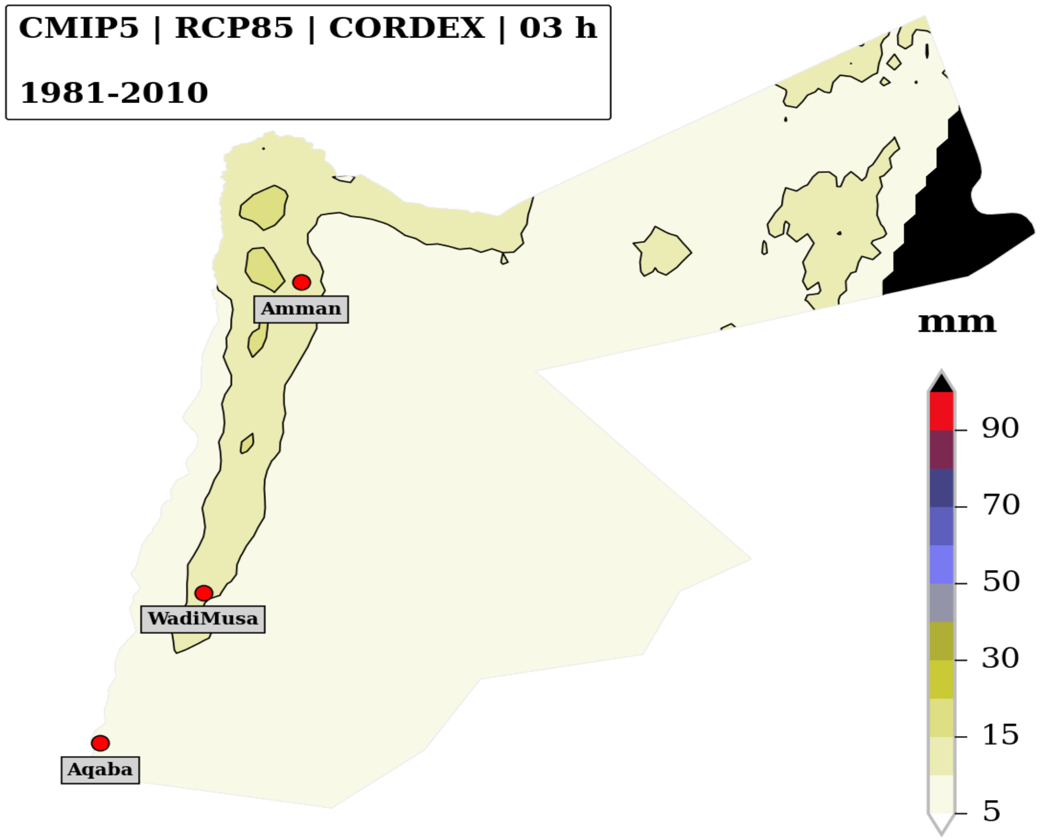
**RCP: 8.5 | Members:10 | Time:1981-2100 | Space:12x12km | Precipitation: 3-hr**

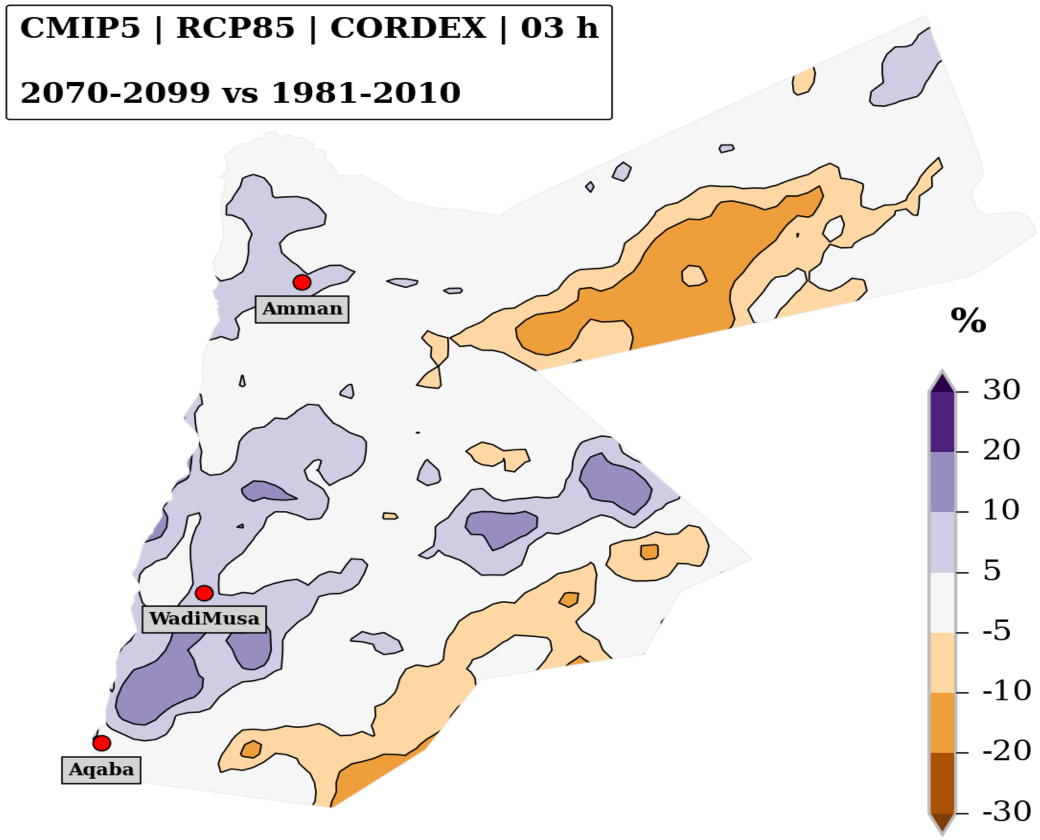
# 2061-2090 vs 1981-2010

## - Relative Changes of Return Levels -

# Ensemble Mean: CORDEX-EUR-RCP8.5

## Annual Maximum of 3-hr Precipitation | Mean/Trend



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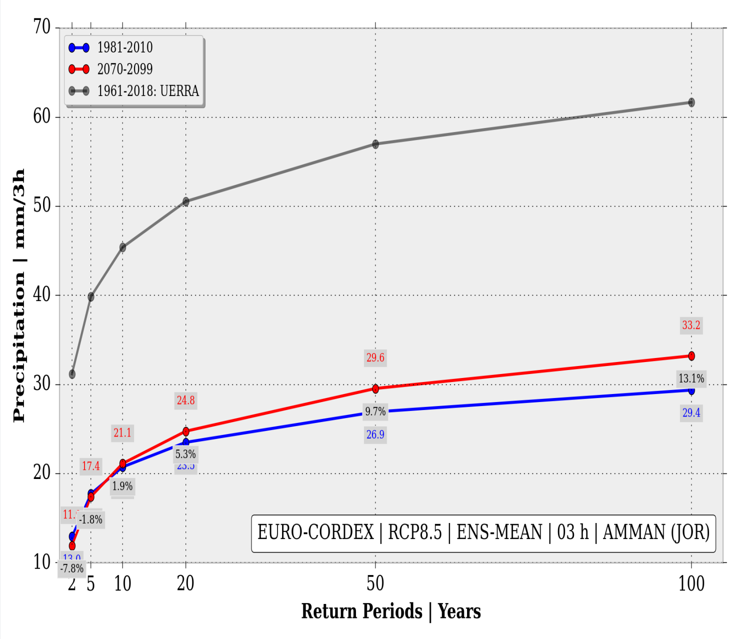
# Return Levels | Amman

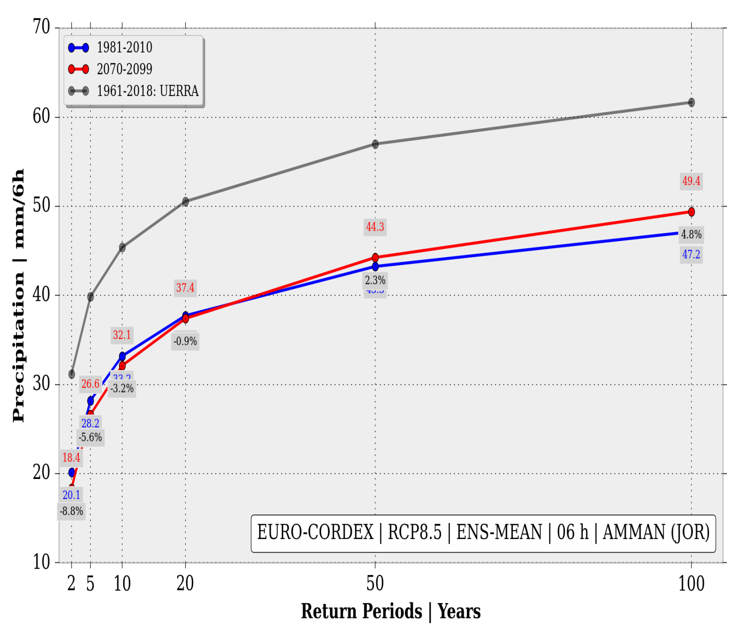
## Event Lengths

**3-hr**



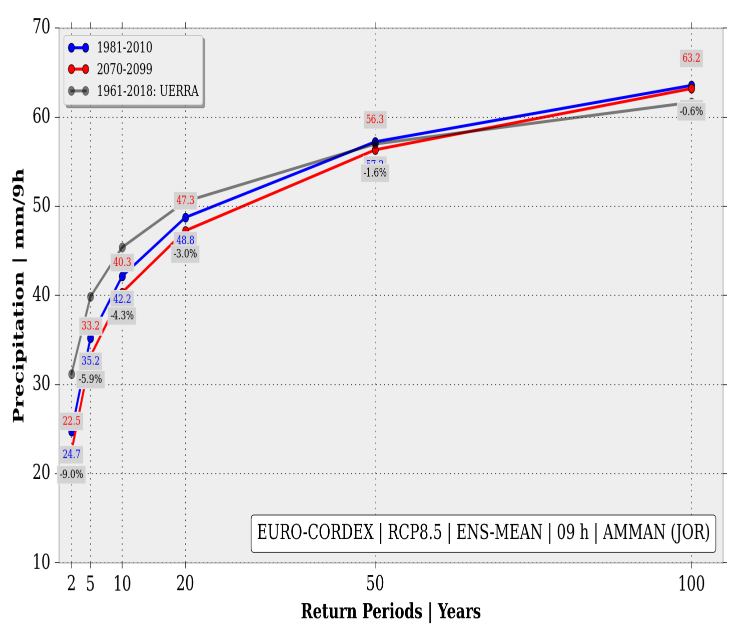

$$\Delta_{100} = +13.1\%$$

**6-hr**




$$\Delta_{100} = +4.8\%$$

**9-hr**

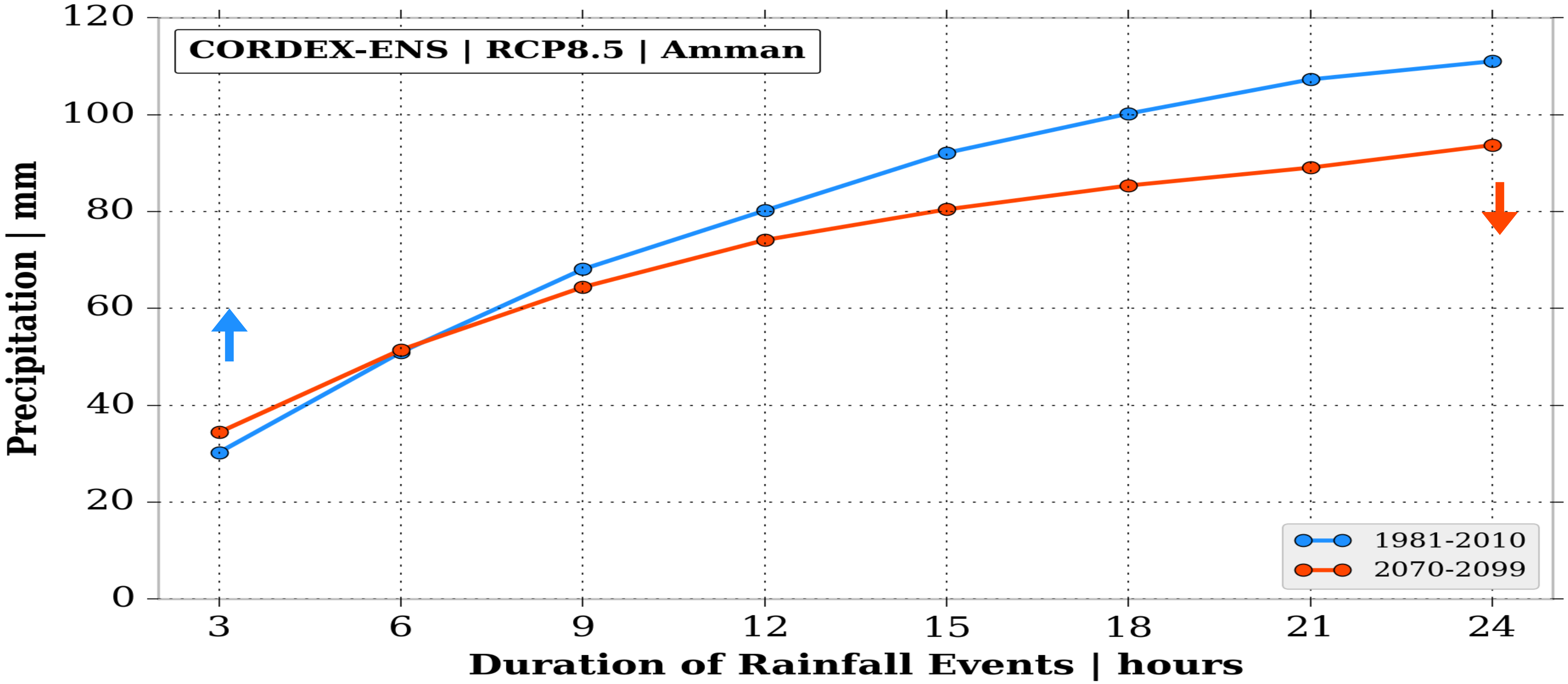



$$\Delta_{100} = -0.6\%$$

Intensification of short-term heavy rainfall events <6-hr up to 15%

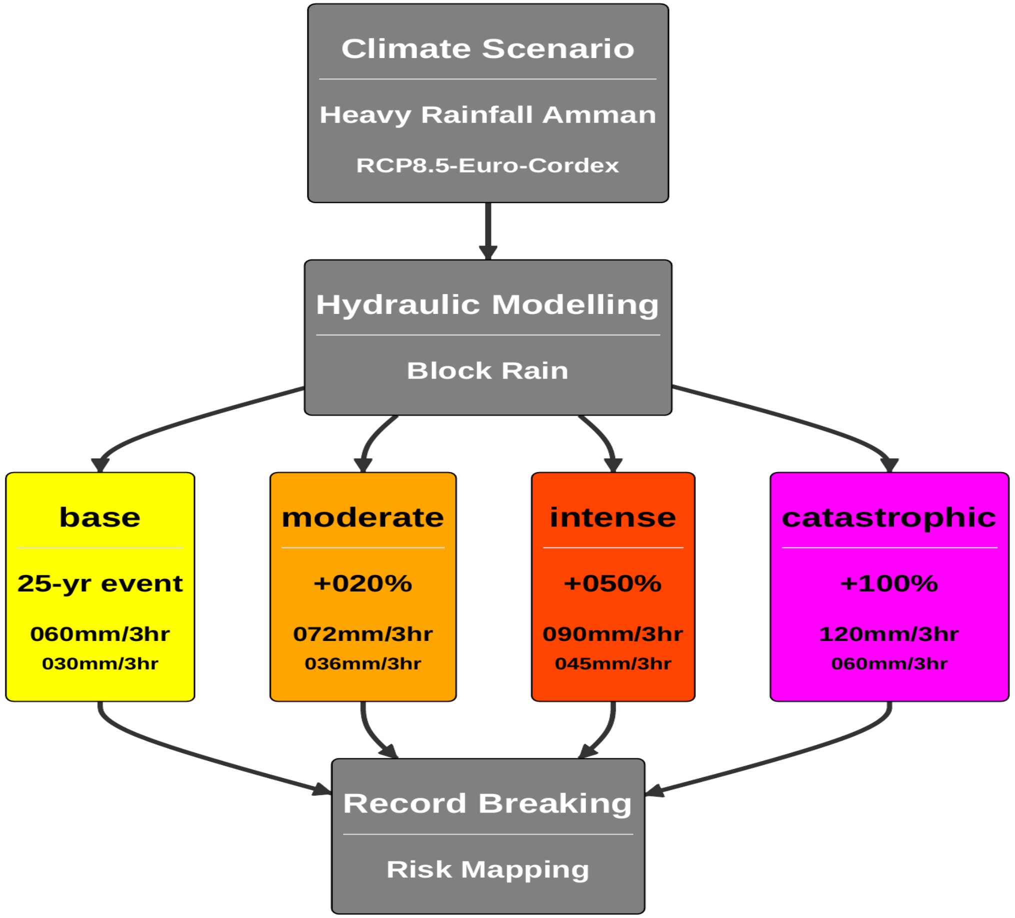
# 100-yr Return Levels | Amman

## Intensity over Length



# Heavy Rainfall Scenario Design

## Relative Changes to the Baseline Scenario




**Analysis of 1200 model years (1981-2100,rcp85)**

- whole Jordan (from Amman to Aqaba)
- Events from 3-hr to 24-hr
- Risk Maps

## Location: Amman

| Scenario | Intensity | Comment |
|---|---|---|
| baseline | 060$_{030}$ mm/3hr | Event: 2019-02-28 |
| | Airport$_{Downtown}$ | |
| moderate | 072$_{036}$ mm/3hr | +20% |
| intense | 090$_{045}$ mm/3hr | +50% |
| catastrophic | 120$_{090}$ mm/3hr | +100% |

# Products

## AP2 - Fact Sheets

# Fact Sheet: AP2a

## Contextualization of Extreme Rainfall
A case study for Amman in Jordan

*by Peter Hoffmann et al.*

### A Context

Day when local heavy rainfall occurs are often associated with critical atmosphere circulation patterns. They determine the large-scale transport of air masses across geographical regions and are part of the natural weather variability. Thus, a better knowledge of those structures and causal linkages to local weather phenomena can support to refine existing early warning systems and to better assess long-term changes in the context of global warming.
Extreme rainfall events are basically characterized by the intensity (mm per hour) and by the frequency (once per year). However, both are influenced in different ways by dynamic and thermodynamic factors. For instance, a decreasing number of events does not include a reduction of flash flood risks, because the rainfall intensity is determined by the availability of latent heat.
One work package of the CapTainRain project aims to better understand the essence of the natural hazard heavy rainfall in Jordan. Events can hit urban areas such as Amman but also wadi-systems (Petra) and the consequences are usually flash floods with dramatic effects for the local people and the critical infrastructure.
This fact sheet summarize part I of the study to detect critical weather patterns associated with heavy rainfall in Amman and to quantify long-term changes. The large-scale patterns are the context for days of local extreme rainfall.

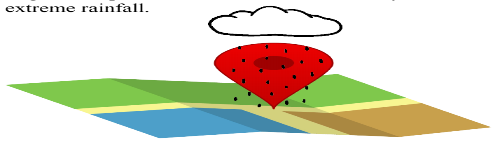


**Figure 1:** Illustration of the contextualization of extreme rainfall.

Using global observation data, existing connections between the large-scale cause (■) and the local effect (●) can be identified retrospectively (see scheme in Figure 1). Point information are translated to a map. The following sections briefly describe the used data (B), the methodology (C) and the main results (D).

**Research Question:** What are the critical atmosphere circulation patterns that can trigger heavy rainfall in Amman, and what changes does the current generation of climate simulations project by 2100?

### B Database

The meteorological quantity to characterize large scale atmosphere circulation conditions is the geopotential height at 500 hPa (Z500). Areas of high and low values are associated with High and Low pressure systems near surface. The global reanalysis dataset ERA5 (50 x 50 km) from 1961 to 2020 was used to retrospectively detect critical circulation patterns over the North-Atlantic and Europe associated local heavy rainfall events in Amman (grid point).
The same was done using 10 climate model simulations of the current CMIP6 ensemble for the SSP585 scenarios (ca. 100 x 100 km) in order to quantify the climate sensitivity. Each model run cover a simulation period from 1981 to 2100.
The respective fields of the Z500 and the daily precipitation (PR) were bilinearly interpolated onto a grid of 1° x 1° for a better comparability.

### C Methodology

The starting point are daily fields of precipitation (PR) and the geopotential height at 500 hPa (Z500). The respective context of the Z500 is mapped by filtering dates of extreme precipitation at the nearest grid point of Amman.
For the coordinate of Amman (lon/lat=35.9°E/31.9°N), a time series with daily precipitation values was extracted. For a climatological period of 30 years, days are identified when the 99th percentile is exceeded (N=110). The Z500 fields are scaled and averaged for the selected number days.
For the comparison of two climatic periods, we define the first one as the reference period. To derive differences in the frequency, the intensity and the spatial context, the 99th percentile threshold derived for the first period is also applied to the second period. In this way, global reanalyses and climate simulations are evaluated.

### D Maps and Charts

The results of the retrospective analysis of critical circulation patterns associated with heavy rainfall in Amman is shown in Figure 2. It shows the comparison between the periods 1961-1990 (left) and 1991-2020 (right). A trough can be seen over the Eastern Mediterranean. Cold air masses can penetrate far to the south. The cyclonic curvature (counter-clockwise) of

# Fact Sheet: AP2b

## Future Heavy Rainfall Scenario for Jordan

*by Peter Hoffmann*

### A Context

Jordan is a country located in eastern part Mediterranean area, where in recent years recurring heavy rainfall events have led to flash floods that caused enormous damages on critical infrastructure.
One prominent extreme rainfall event occurred on the 28th of February 2019. Within 3 hours rain gauges registered up to 60 mm close to Amman Civil Airport. Over 24 hour more than 100 mm total precipitation was measured. Retrospectively, this events could be statistically attributed to a 50-yr event. However, in general rainfall events in Jordan are clearly under balanced compared to the diversity of the meteorological phenomena. To what extent the climate change effect heavy rainfall events in Jordan will be assessed using regional climate model ensemble simulations. Those model scenarios simulate physically consistent historical and possible future weather developments and local rainfall patterns under changing climate conditions. The aim of the scenario analysis to quantify the climate sensitivity of heavy rainfall events for different return levels and event length.
The fact sheet AP2a already describes the approach to detect long-term changes of critical large-scale circulation patterns associated with heavy rainfall in Amman (Jordan) and how to quantify the existing climate sensitivity. The results show, that the number of events decreasing in number, however the magnitude of extreme precipitation can reach new records.

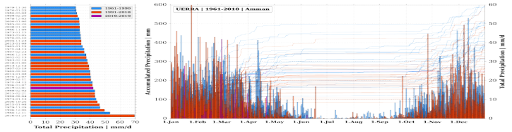



Figure 1: Seasonal variation of daily precipitation in Amman from 1961 to 2018 derived from the regional reanalysis product UERRA[1]: absolute values (bars) and accumulated values (lines) – before 1991 (blue) and after 1991 (red).

[1] UERRA

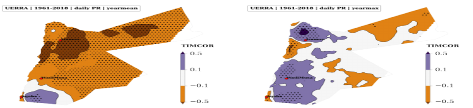



**Figure 2:** Comparison of the correlation in time from 1961 to 2018 for the annual mean precipitation (left) and the annual maximum of daily precipitation (right) derived from the regional reanalysis product UERRA.

**Research Question:** How sensitive respond heavy rainfall events in Jordan from 03-hours to 24-hours compared to the annual mean precipitation under a pessimistic future climate scenario of more than 4 degrees global warming until 2100.

### B Simulation Data

Our regional climate model ensemble includes 7 members with a spatial resolution of 12 x 12 km and a time step of 3-hours (EURO-CORDEX[2]). The simulation period covers the historical (1976-2005) and future (2006-2100) for the RCP8.5 scenario. In total 875 year were analysed. However, the values are not Bias adjusted, because only relative changes are relevant to estimate the climate sensitivity. The climate model ensembles simulate how possible weather condition will further develop under global warming.

| Global | Regional | Realisation |
|---|---|---|
| MPI-ESM-LR | RCA4 | |
| MPI-ESM-LR | CCLM | |
| HadGEM2-ES | RCA4 | |
| MIROC5 | CCLM | |
| IPSL-CM5A | RCA4 | |
| EC-EARTH | RCA4 | |
| NORESM1-M | RCA4 | |
| CanESM2 | CCLM | |
| CERFAS-CM5 | CCLM | |

**Table 1:** Overview of the used regional climate model ensemble (EURO-CORDEX).

### C Methodology

For the analysis of extreme rainfall events we first calculated running sum for 3-hours, 6-hours to 24-hours for each grid cell. Then we aggregated the fields to annual maxima, respectively. Finally, we extracted the time series for Amman from 1976 to 2100. For this location the estimate return levels for 2-yr events and up to 100-year events for the past (1981-2010) and future (2070-2099) by fitting the value to a GEV[3]. All model years are pooled.

[2] EURO-CORDEX
[3] GEV

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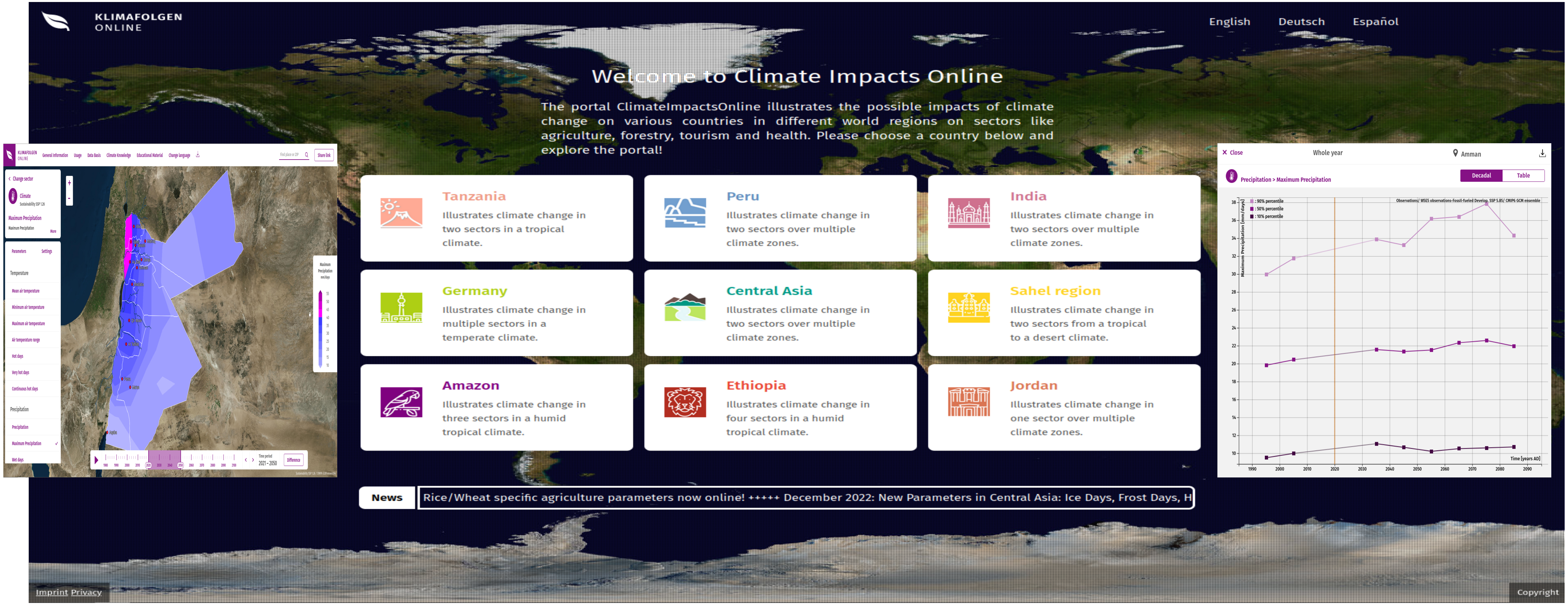
# Products

## Climate Service Portal for Jordan



# Products

## Weathering Risk Profile for Jordan (Report by Colleagues)

### Heavy precipitation events

In response to global warming, **heavy precipitation events are expected to become more intense and frequent** in many parts of the world due to the enhanced water vapour holding capacity of a warmer atmosphere [32]. In the case of Jordan, **the trend towards more frequent extreme precipitation events cannot be confirmed (Figure 7). All models agree on a declining trend in heavy precipitation,** though the projected decline is much higher in one model than in the others. Under RCP2.6, heavy precipitation days will slightly decrease from between 5.2 to 7 days in 2000 to between 5.1 to 6.6 days by 2030, and between 4.5 to 6.3 days by 2050. Under RCP6.0, heavy precipitation frequency will decline comparatively stronger. Heavy rainfall events are projected to go down to between 5 and 5.9 days a year by 2030. Due to a growing discrepancy between the models, modelling uncertainty strongly increases from 2030 onwards. Hence, while the best estimate projects 5.5 heavy precipitation days per year by 2050, the very likely range projects between 3.9 and 5.7 days. Projections for the year 2080 are similar (3.8 to 5.6 days/year).

Particularly under RCP2.6, geographically explicit projections of heavy precipitation events (Figure 8) are uncertain in many regions. Overall, regional variations will be rather small. Certainty is much higher under RCP6.0, with heavy precipitation events projected to decline across the entire country. The **strongest decrease can be expected for the arid east throughout all time frames, and for the very south of Jordan in the long term.** By 2080, the projected median decrease will be around 1.1 to 1.4 days in the populated Mountain Heights Plateau, 1.6 days in the northeast, and up to 2.2 days in the very south, in comparison to the year 2000.

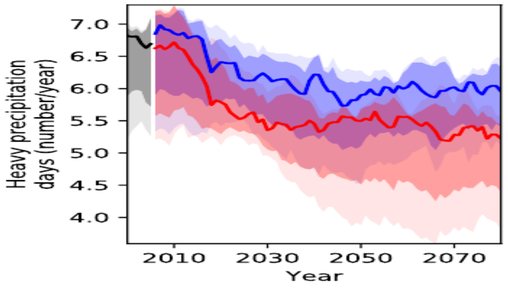



Figure 7: Projections of the number of days with heavy precipitation over Jordan for different GHG emissions scenarios, relative to the year 2000.

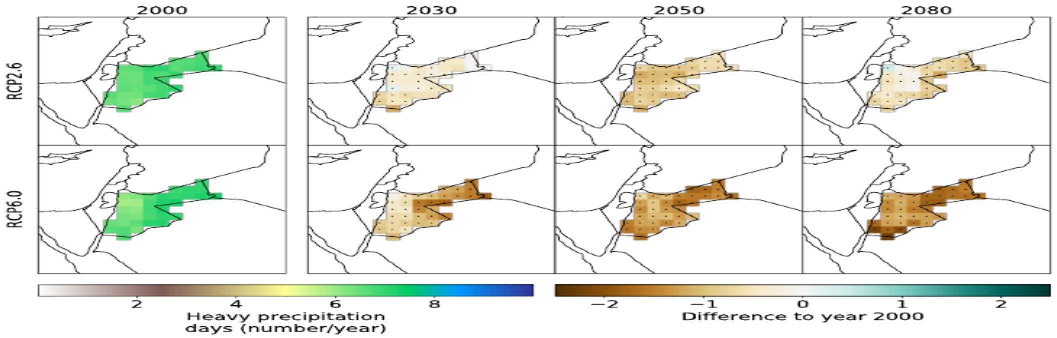
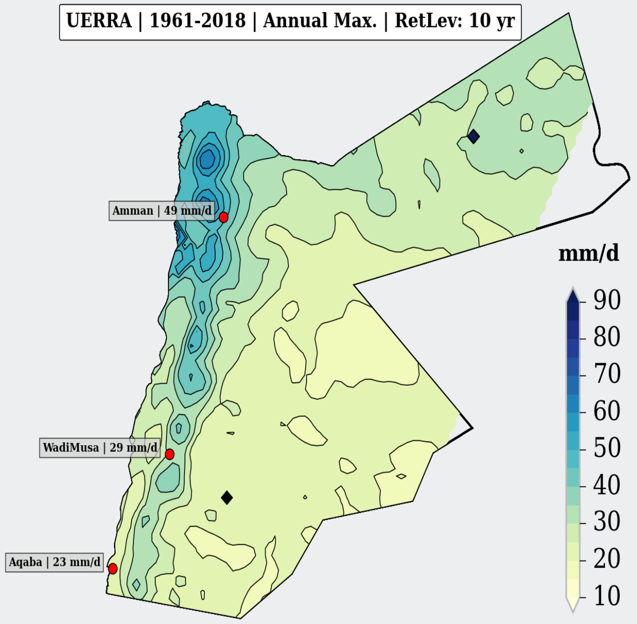
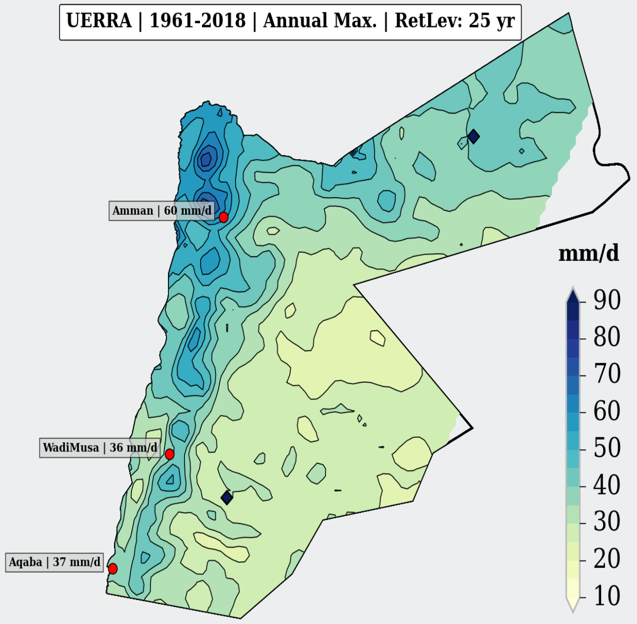
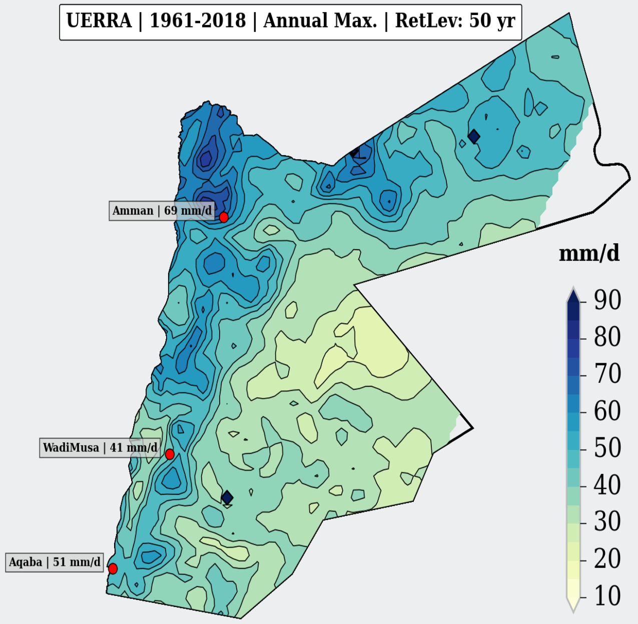



Figure 8: Projections of the number of days with heavy precipitation over Jordan for different GHG emissions, relative to the year 2000 (regional variations).

https://www.weatheringrisk.org/en/publication/climate-risk-profile-jordan

# Products

## Retrospective Risk Maps for Daily Precipitation

| 10-yr | 25-yr | 50-yr |
| --- | --- | --- |
|  |  |  |







Return Levels derived from UERRA Regional Reanalysis Data 1961-2018

# Further Steps

## Main Findings

1. Opposite trends between mean and extreme precipitation
2. Short-term heavy rainfall events (a few hours) will **very likely intensify** under global warming
3. The occurance frequency of critical weather patterns will **likely decrease** under global warming
4. **Likely:** less extreme rainfall events but more intense
5. Integration of risk maps and further reports and materials in the Climate Service Portal for Jordan (**ClimateImpactsOnline**)


# Dankeschön / شكرًا

## Feedback and Questions?