LINKING DROUGHTY AND WET WEATHER IN THE JORDAN CATCHMENT WITH ATMOSPHERIC CIRCULATION PATTERNS

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RESUMEN
El alcance de este estudio es la identificación de patrones de circulación sobre el Mediterráneo oriental los cuales están relacionados de una manera significativa con la precipitación extrema en la cuenca hidrográfica del Jordan. A ese fin, un método multi-objetivo de clasificación a base de lógica fuzzy se pone en practica. El método condiciona los datos de la precipitación y patrones de circulación atmosférica a gran escala diariamente.
Para comenzar, se realiza la clasificación condicional de la precipitación para el período de 1961-1990 usando presión a nivel del mar y potencial geológico en 500hPa, dispuestos por el proyecto de reanálisis NCEP/NCAR. Se comprueba la plausibilidad de los patrones de circulación obtenidos para situaciones de sequia y humedas. Luego, se realiza un análisis de la frecuencia de su presencia a escala temporal de meses, años y décadas. Por último, se compara la distribución de frecuencia de los patrones de circulación para los años 1961-1990 con la distribución de frecuencia para los años 2011-2040 utilizando ECHAM5 impulsado por A1B. Se presenta y discuta el impacto del cambio climático al cambio de frecuencia en patrones de circulación en situaciones de sequia y humedas.

Palabras clave: Clasificación multi-objetivo a base de lógica fuzzy, clasificación de patrones de circulación, Mediterráneo oriental, cuenca hidrográfica del Jordan

ABSTRACT
The scope of this study is to identify *circulation patterns* (CPs) over the *Eastern Mediterranean* (EM), which are significantly linked to extreme rainfall events in the Jordan catchment. For this reason, a *multi objective fuzzy logic-based classification* (MOFRBC) method is applied, which conditions rainfall data to large-scale atmospheric circulation patterns on dthe aily time scale.
First, the rainfall conditional classification is performed for the period 1961-1990 using *Sea Level Pressure* (SLP) and *Geopotential Height* in 500hPa (GPH500), retrieved from the NCEP/NCAR reanalysis project. The obtained drought and wet circulation patterns are checked for plausibility and a frequency analysis of their occurrence is performed on monthly, interannual and decadal time scales. Second, the CP frequency distribution of the 1961-1990 time slice is then compared to the frequency distribution of the 2011-2040 time slice using the A1B driven ECHAM5. The impact of climate change on the frequency change of droughty and wet circulation patterns is presented and discussed.

Key words: Multi-objective fuzzy logic-based classification, Eastern Mediterranean, Jordan catchment

1. INTRODUCTION

The Eastern Mediterranean (EM) region is affected by relatively high interannual rainfall variations (Alpert et al., 2002): Simultaneously, this region is ranks among the countries with the lowest per capita water consumption levels in the world. In the past, rainfall deficiencies often led to water shortages in this region. Recent observation show that precipitation decreased in northern Israel and increased slightly in the southern part during the period 1961-1990 (e.g. Ben Gai et al., 1993, 1994, 1998). A more recent study of Freiwan and Kadioglu (2008) dealt with annual and seasonal trend analysis of rainfall. For the annual precipitation, no clear trend signal was detected. For the spring, summer and autumn season, a generally decreasing trend is reported, but just a few stations are significant. For the winter season, no trends were observed. The impact of expected climate change on water availability in the Near East and the Upper Jordan catchment (UJC) was investigated by Kunstmann et al. (2007). Running the mesoscale meteorological model MM5 driven by the global climate scenario B2 of ECHAM4, a decrease of the winter precipitation amount of 30% and a slightl increase of the spring precipitation amount in the Upper Jordan region is revealed for 2070-2099, compared to the 1961-1990.

De Ridder and Gallee (1998) detected trends in the past rainfall series and tried to explain precipitation trends by local land-use change. Other studies dealt with the connection of rainfall variability and large-scale atmospheric circulation (e.g. Kutiel and Paz, 1998; Ribera et al., 2000; Maheras et al., 2001; Zangvil et al., 2003; Ziv et al., 2006). Zangvil et al. (2003), for example, identified typical SLP distributions for four GPH500 prototype patterns, occurring predominantly on major rainy days. Ziv et al. (2006) identified an upper level trough extending from Eastern Europe towards the EM region linked with the December-February rainfall amount in the northern part of Israel. Many studies refer rainfall occurrence in the EM mainly to the passages of extratropical cyclones, the so called Cyprus Lows (e.g. Alpert et al., 1990). For this reason, diverse circulation patterns classification schemes (objective, semi-objective, subjective) were developed and carried out for the EM region. A comprehensive overview can be found in Alpert et al. (1990). The first classification for the EM was performed by Koplowitz (1973) using synoptic pressure field patterns. Ronberg (1984) used radiosonde and surface data for his classification over the southeastern EM coastal plain (Israel) for the October to April period. He identified 18 weather patterns using cluster analysis, which can be grouped together to the 4 types: *Red Sea Troughs* types, *transitional* types, *Sharav-like* types, and *stormy* types. A similar approach has been applied by Shafir et al. (1994). The results of the classification were linked to important hydro-meteorological features, such as. wind energy regimes (Alpert et al., 1987; Shafir et al., 1994), floods (Kahana et al., 2002), tropospheric ozone days (Dayan and Levy, 2002) or rainfall amount (Alpert et al., 2004). Performing frequency analysis on the obtained daily synoptic patterns, Alpert et al. (2004) blamed the Red Sea Trough for the decreasing rainfall trend in the EM region.

In this study, the results of an objective circulation pattern classification based on fuzzy rules are presented. No meteorological a-priori information about the research area is used, with exception of the number of CPs. 19 CPs were used following the approach of Alpert et al.

(2004). The CPs are derived using surface (SLP) and upper tropospheric data (GPH500). The CP classification is a conditional approach, optimizing the patterns on 26 rainfall observation stations in Israel and Jordan (
Figure **1**). The principle objectives of this study are:

- Identify CPs for the SLP and the GPH500, which are linked to wet and drought situations in the study area
- To assess the seasonal, interannual and decadal variability of the occurrence frequencies of the extreme CPs
- Assess the impact of CC on the occurrence frequency of the extreme CPs in the EM region. Therefore, the A1B driven ECHAM5 output of the SLP is used for the period 2011-2040

#	Station
1	Amman
2	Deirabisaid
3	Deirallaagr
4	Ennueiyime
5	Hartha
6	Irbidagr
7	Naur
8	Ramtha
9	Rihab
10	Qiryant-Anav
11	Jerusalem
12	Ramat-David
13	Kebutzat
14	Kefar Blum
15	Kefar Galad
16	Yiron
17	Eilon
18	Har Kenaan
19	Ainbisas
20	Hemud
21	Tafile
22	Beer-Sheva
23	Sed'e
24	Dorot
25	Qiryant-Shaut
26	Tel Aviv

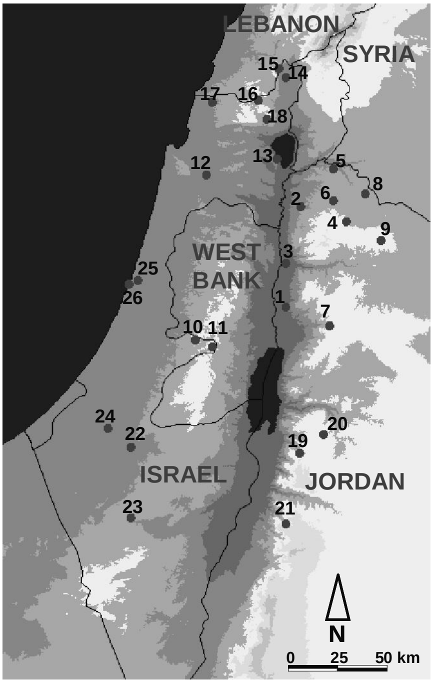


Figure 1: Location of the 26 rainfall observation stations in Israel and Jordan.

2. METHODOLGY

2.1 Multi objective fuzzy rule-based classification

The multi objective fuzzy rule-based classification is fully described in Bárdossy et al. (1995). Here only a brief description is given. As a first step the daily *Sea Level Pressure* (SLP) fields and the *Geopotential Height* (GPH) fields at 500hPa, both extracted from the National Centers for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) reanalysis project (Kistler et al., 2001), are transformed to standardized anomalies:

$$g(i,t) = \frac{h(i,t) - h(i,t')}{\sigma(i,t')}$$

with:
h(i,t): Observed variable at grid point i and time t
h(i,t'): Mean of variable at grid point i over annual cycle
σ(i,t'): Standard deviation of variable at grid point i over annual cycle

The daily anomalies g(i,t) are then classified into the categories 1) high $(0.2, 1.0, \infty)_T$, medium high $(0, 0.6, 1.4)_T$, 3) medium low $(-1.4, -0.6, 0)_T$, 4), low (-∞, -1, -0.2) and 5) indifferent for the circulation patterns using triangular fuzzy membership functions (subscript T). Usually most of the grid-points belong to class number 5, since only characteristic ones are assigned to other classes. For a given time t and location i, the membership corresponding to rule k is defined as:

$$\mu_{(i,k)} = \mu_{v(i)^{(k)}}(g(i,t))$$

Thus, a circulation pattern CP_k is fully characterized by an index vector $v(k)=\{v(1)^{(k)}\ldots v(n)^{(k)}\}$, which defines the location of the five anomaly classes in the target area. After that, classification of daily fields is carried out by calculating the degree of fulfilment (DOF) for each rule based on the membership values μ:

$$DOF(k,t) = \prod_{l=1}^{4} \left(\frac{1}{N(v(i)^{(k)} = l)} \sum_{v(i)^{(k)}=l} \mu(i,k)^{P_l} \right)^{\frac{1}{P_l}}$$

with:
N: Number of grid points classified as class I
Pl: Parameter, which is modifying the influence of selected classes towards the DOF

Finally, the rule k, where DOF (k, t) is maximal, is selected as CP for the day t and the result is a vector with one objective circulation pattern per selected day.

2.2 Optimization

Two types of objective functions are defined. The first one deals with the probability of the occurrence of each class on a given day:

$$O_1 = \sum_{i=1}^{S} \sqrt{\frac{1}{T} \sum_{i=1}^{T} (p(CP(t))_i - \overline{p_i})^2}$$

where S is the number of stations within a region with rainfall observations, T is the number of days in the time series and $p(CP(t))_i$ is the CP-conditional probability of the class occurrence at station i within one region. A second objective function is additionally introduced to account for the conditional rainfall amounts:

$$O_2 = \sum_{i=1}^{S} \frac{1}{T} \sum_{t=1}^{T} \left| \left(\frac{z(CP(t))_i}{\overline{z}_i} \right)^{1.5} \right|$$

where $\overline{z}_i$ is the overall average of the class values at station i within one region. High values of O_2 indicate that the conditional class amount of a CP differs clearly from the average value. Optimization was performed using a simulated annealing algorithm and the sum of O_1 and O_2 as overall objective function O. The optimization starts with an arbitrary set of fuzzy rules, which classifies the daily anomalies of the reanalysis field into a CP time series, determines p(CP) and z(CP) by frequency analysis and calculates the overall objective function O. Then a rule is randomly selected and one of the five categories v is randomly assigned to a randomly chosen grid point. A new classification is performed and O is calculated again. If O exceeds the corresponding value of the old classification, then the change is accepted. If not the change is accepted with a probability that decreases exponentially with decreasing annealing temperature. More details on the optimization scheme are given in Bárdossy et al. (2002).

2.3 The quality of the CP classification

In order to judge the quality of the MOFRBC results for the EM, it is advisable to compare the obtained patterns with results of a different classification scheme. This can be either a subjective, semi-objective but also a different objective classification methodology. According to Alpert et al. (2004), six main groups can be identified for the EM region:

i) *Red Sea Troughs* (RSTs): They occur predominantly in fall and winter and are related to dry desert air in the EM region. Rarely, RSTs are deep enough over the Red Sea to bring moisture into the southern part of the EM region.
ii) *Mediterranean winter Lows* (MWLs): They are responsible for the bulk of rainfall over the continental part of the EM. When the Lows are positioned close to Cyprus, they are entitled *Cyprus Lows* (CLs).
iii) *Sharav Lows* (SLs): They occur predominantly during the transition seasons and bring hot and dusty air from the Sahara and the Arabian Desert to the EM region.
iv) *Persian Troughs* (PTs): originate from the east and reach West Turkey. PTs bring relatively warm and moist air to the EM region.
v) *Winter Highs* (WHs): High pressure pattern, which comes from the north, north-east or north-west.
vi) *Summer Highs* (SHs): High pressure pattern, which is coming from the west.

To capture the impact of a CP on precipitation in the Jordan catchment, the following performance parameters are calculated:

i) The *conditional occurrence probability* (in %) of a CP for a given time period
ii) The conditional *precipitation amount* (in mm) on a wet day for a given CP
iii) The *wetness index* I_{wet} (nondimensional), which is defined as the ratio of the percentage of annual precipitation total for a given CP and its appearance rate ($I_{wet} > 1$ indicates 'wet' CPs, $I_{wet} < 1$ indicates 'dry' CPs)
iv) The relative contribution (in %) of each CP to the total rainfall amount

3. RESULTS

An objective CP classification of 20 CPs (19 defined CPs and 1 undefined CP) is performed for 1961-1990 using SLP and GPH500 as predictor variables. The NCEP/NCAR reanalysis data are used for this purpose. No meteorological a-priori information is used for the classification procedure. The classification is optimized jointly for the rainfall occurrence probabilities and the rainfall amounts of 26 stations in the Jordan catchment. For both, the SLP and the GPH500 driven classification, a good discrimination between drought and wet patterns is achieved. The calculated performance parameters are illustrated in Figure 2 and Figure 4. For the SLP, the mean wetness index of the 26 stations is ranging between 0.1 and 3.4. Comparing the wetness indices of the single station, no remarkable differences are observed (not shown here). This indicates for a very robust circulation pattern classification for the EM region. The droughty patterns are CP1, CP4, CP6, CP7, CP9, CP12, CP14, CP15, CP16 and CP17, and wet patterns are CP2, CP5, CP10 and CP19.

CP5 is holding the highest mean precipitation amount with > 4mm and the highest conditional occurrence probability of 35.2% (Figure 2, left). Its contribution to the rainfall in the EM is 21%, and the wetness index is highest with approximately 3.4 (Figure 2, right). CP12 is an instance of a very dry CP. Its occurrence probability is 3.6% and the mean precipitation amount is 0.1mm (Figure 2, left). The wetness index is about 0.1 and the contribution to the rainfall in the EM is 0.4% (Figure 2, right).

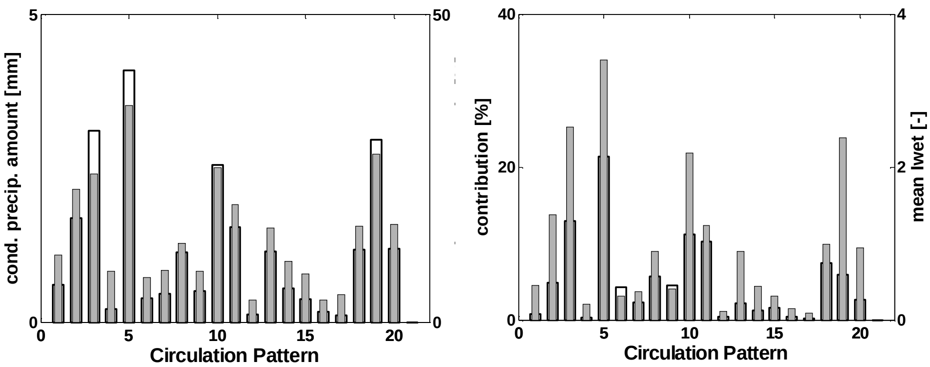


Figure 2: (Left) Mean CP conditional precipitation amount [mm] (white bars) and mean conditional rainfall occurrence probability [%] (grey bars) and (right) mean CP conditional contribution [%] (white bars) and mean conditional wetness index [-] (grey bars) of the 26 stations using the SLP.

Figure 3 show the composite of the mean anomalies for the wettest pattern CP5 and driest pattern CP12. CP5 shows a strong negative anomaly (Low) with its centre eastward of the Red Sea and a very strong positive anomaly over Libya. Due to its occurrence, moist air masses can penetrate into the EM region. The mean anomalies of CP3, CP10, and CP19 are very similar to CP5. They show slightly different positions of the Lows and are also wet (not presented here). CP12 involvesa negative anomaly over the Mediterranean and a positive anomaly over the Red Sea and Saudi Arabia.

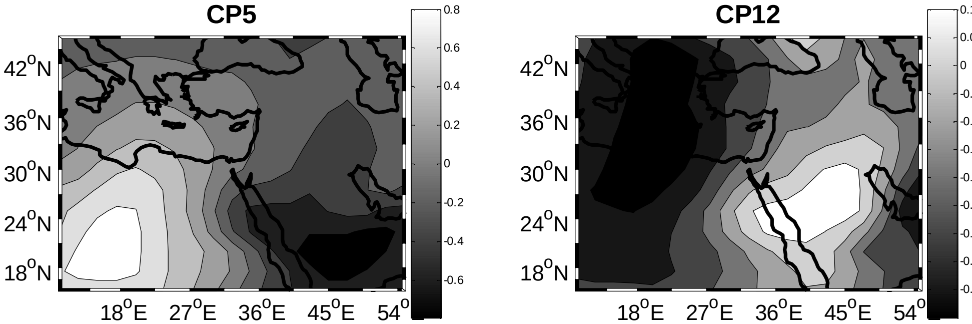


Figure 3: Composites of the mean SLP anomalies for the wettest pattern CP5 (left) and the driest pattern CP12 (right) for the period 1961-1990.

Figure 4 is presents the results of the circulation pattern analysis for the GPH500. Similar to the SLP driven classification, the results reveal diversified performance parameters. Wet and drought CPs could be classified. Instances for wet patterns are CP2, CP7, CP8 and CP16. Very dry patterns are CP1, CP3, CP6, CP11, CP15 and CP18.

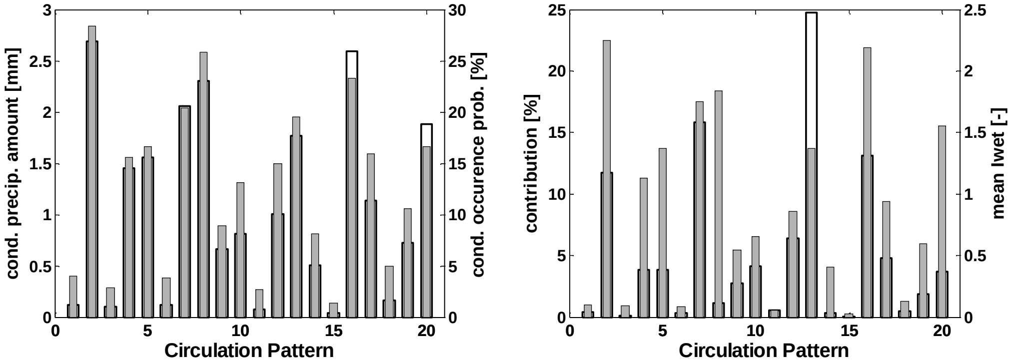


Figure 4: (Left) Mean CP conditional precipitation amount [mm] (white bars) and mean conditional rainfall occurrence probability [%] (grey bars) and (right) mean CP conditional contribution [%] (white bars) and mean conditional wetness index [-] (grey bars) of the 26 stations using the GPH500.

Figure 5 (left) is illustrates the wettest patterns using GPH500. A negative anomaly can be found over the Red Sea, whereas a strong positive anomaly over the Red Sea and a minimum over Libya can be observed for the driest pattern CP15 (Figure 5, right).

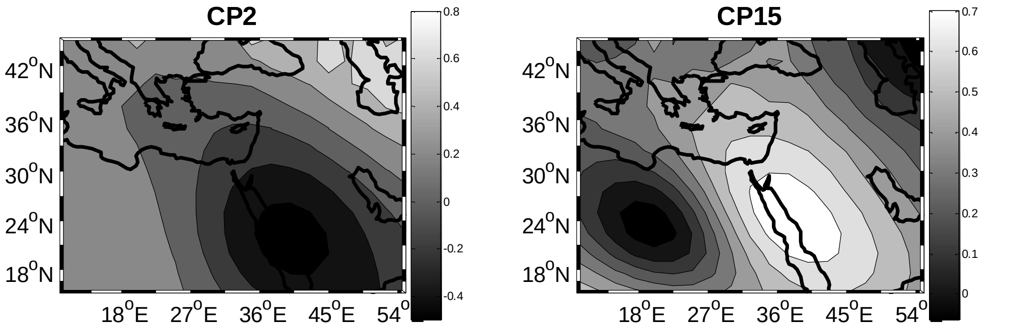


Figure 5: Composites of the mean GPH500 anomalies for the wettest pattern CP2 (left) and the driest pattern CP15 (right) for the period 1961-1990.

Figure 6 (left) presents the decadal variations of the CP occurrence frequencies using SLP as predictor variable. On decadal time scales, the absolute number of wet patterns is generally decreasing from 1961-1990. Depending on the CP, some frequencies are decreasing (CP5, CP10), whereas some are slightly increasing (CP2, CP19). Diversified decadal trends could also be detected for the drought patterns. The occurrence frequencies are increasing for CP6, CP7, CP14 and CP16, and decreasing for CP1, CP4, CP9, CP12, CP15 and CP17. For the GPH500 driven classification, positive as well as negative trends were found for the droughty as well as wet patterns (Figure 6, right).

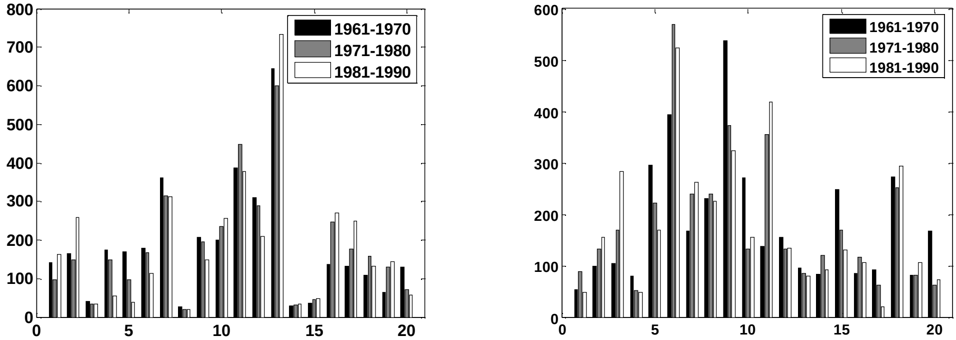


Figure 6: Decadal variations of the CP occurrence frequencies for the SLP classification (left) and the GPH500 classification (right)

Figure 7 show the interannual variability of the wettest and driest CPs for the SLP and the GPH500 classification. For the SLP, a very strong negative trend can be found for the wettest CP5. The frequency for the driest CP12 is increasing strongly from 1961-1973, decreasing rapidly until 1975, and increasing again until 1990. For the GPH500, a positive trend is detected for the wettest CP2, showing a break around 1970. No trend can be found for the driest CP15.

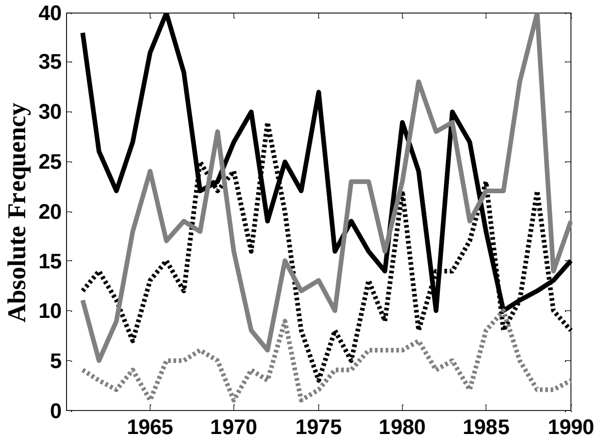
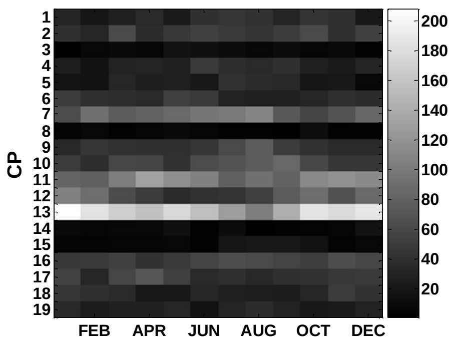


Figure 7: Interannual variability of wettest (solid line) and driest (dashed line) CPs for the SLP (black line) and the GPH500 (grey line).

Figure 8 shows the intra-annual CP variability of the SLP and the GPH500 driven classifications in terms of monthly occurrence frequencies. For both classification approaches, typical summer and winter patterns can be observed.



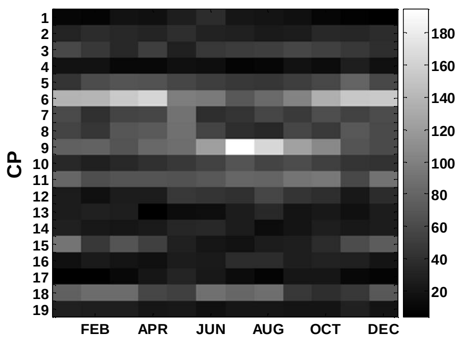


Figure 8: Intraannual variations of the CP occurrence frequencies for the SLP classification (left) and the GPH500 classification (right).

Since the middle and the lower troposphere are expected not to behave completely independently due to the vertical transfer of mass and energy, the relative frequencies of simultaneous occurrence of SLP and GPH500 patterns are investigated. The results are given in Figure 9. A very clear relation between CP11 of the SLP classification and CP6 of the HGT500 classification is found. The relative frequency of the simultaneous occurrence is about 37%.

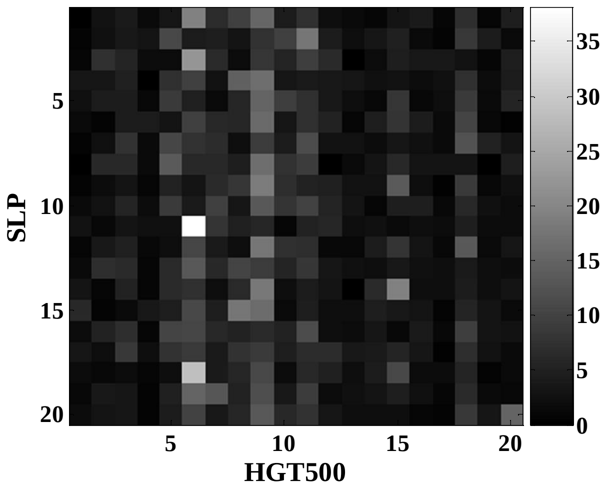


Figure 9: Relative frequencies [%] of simultaneous occurrence of SLP and GPH500 patterns.

Figure 10 shows the comparison of the absolute frequencies of the identified circulation patterns for the A1B ECHAM5 control run as well as the NCEP/NCAR reanalysis data for the baseline period 1961-1990, and the A1B ECHAM5 data for 2011-2040 using the SLP data. Comparing the CP occurrence frequencies of the ECHAM5 2011-2040 time slice with the ECHAM5 control run 1961-1990, no significant differences could be found. The differences in the CP occurrence frequencies between ECHAM5 control run and NCEP/NCAR reanalysis of the baseline period are larger than the differences between the ECHAM5 future scenario and the ECHAM5 control run.

4. SUMMARY

MOFRBC is a suitable methodology for CP classification in the EM region without considering any a-priori information of the meteorology. CPs, which are responsible for dry as well as wet weather, can be derived. The obtained CPs are similar to those identified by Alpert et al. (2003) using SLP as predictor variable. As the classification is conditioned to local precipitation in the Jordan catchment and optimized for the whole year, no exact accordance is expected with the non-conditional approach of Alpert et al. (2004). Although a seasonal variability in the occurrence frequency of some CPs is found, more similar results to the classified CPs of Alpert et al. (2003) are expected performing a seasonal optimized classification.

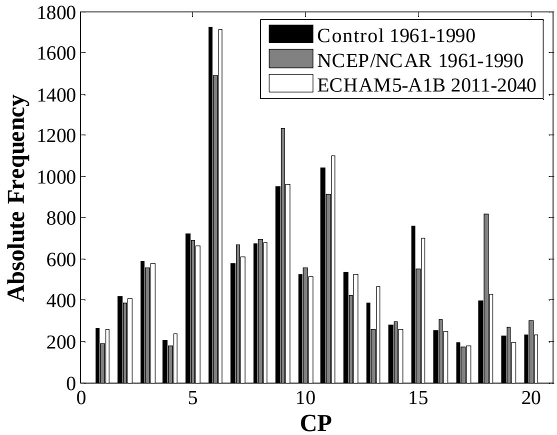


Figure 10: Comparison of the absolute frequencies of the identified CPs for the ECHAM5 control run (1961-1990), the NCEP/NCAR reanalysis (1961-1990) and the ECHAM5 (2011-2040) using SLP.

For the decadal and interannual frequencies, positive as well as negative trends for drought and wet CPs are found, but no general conclusions can be derived for the research area.

Comparing the results of the lower (SLP) and upper troposphere (GPH500) classification, correlations in terms of simultaneously occurrence frequencies are found.

For the future time slice 2011-2040, no big differences in the occurrence frequencies are expected.

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