Atmospheric Research 161–162 (2015) 36–51

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

Atmospheric circulation patterns in the Arab region and its relationships with Saudi Arabian surface climate: A preliminary assessment

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ARTICLE INFO

Article history:
Received 9 February 2015
Received in revised form 17 March 2015
Accepted 18 March 2015
Available online 26 March 2015

Keywords:
Circulation
Climate patterns
Arabian Peninsula
Saudi Arabia

ABSTRACT

This paper establishes and analyses the principal circulation patterns in and around Saudi Arabia (domain: 10°E–70°E; 5°N–40°N) based on the daily mean sea-level pressure (MSLP) 0.75° × 0.75° gridded data derived from the European Centre for Medium-Range Weather Forecasts (ECMWF) re-analysis ERA-Interim for the period 1979–2012. Association of the circulation patterns to the local climate is investigated using observed daily temperature and rainfall data at 27 locations over Saudi Arabia for the period 1979–2010. Using the widely-used mathematical technique principal component analysis (PCA) we determine with MSLP data the principal patterns. We only analyse data for the wet season (October–May). The automated typing procedure establishes 12 circulation types, which represent all the main synoptic features especially those that originate from the Mediterranean, the European and African continents, Siberia, and also the Red and Arabian seas. There is a strong link between the circulation types and surface climate that is synoptically and spatially interpretable. Particular circulation types are associated with specific climatic conditions across the country: rainfall is linked with Types 9, 10 and 11, whilst warm days (nights) with 1, 2, 3, 9, 10, 11 and 12 (1, 2, 3, 10, 11 and 12), and cold days (nights) with 2, 3, 4, 5, 6, 7, 11 and 12 (2, 4, 5, 6, 7 and 8). In terms of regional influences, the circulation types also exhibit specific links between certain types and climatic divisions across Saudi Arabia.

1. Introduction

Circulation typing is often regarded as the fundamental analysis technique in synoptic climatology. Before computers and gridded datasets, climatologists looked for similarities and sequences in the weather, assessing manually many thousands of weather maps. Example of manual classifications are for Central Europe known as the Grosswetterlagen classification by Hess and Brezowsky (1977), for Greece by Maheras (1988, 1989), for the Northern Hemisphere extratropical latitudes by Dzerdzeevskii (1968), and for the United States by Krick (1943) and Elliott (1949). The first typing schemes were developed in the 1920s and 1930s with the principal aim to see if there was predictability in the system that might have potential use. From the 1950s, these typing schemes gained ground and climatologists began to use them to assess the relationships between weather patterns and the incidence of weather extremes. The advent of computer-based weather forecasts tended to move synoptic climatology onto the back burner, but it received a resurgence with the development of automated schemes for the classification of weather types (e.g. correlation-based by Lund (1963), Kirchhofer technique by Kirchhofer (1973) and eigenvector-based approaches by El-Kadi and Smithson (1992)).

In the context of Arabian region and specifically Saudi Arabia, pioneering efforts were initiated by Almazroui (2006). He made the first classification for atmospheric circulation in the region and analyzed the relationships between these circulation types (CTs) and surface climatic elements across Saudi Arabia. In his work, an objective map pattern classification method was employed for Saudi Arabia using observational and reanalysis datasets for the period up-to 2003. This latest study is an extension of the pioneering work of Almazroui (2006), which aims to provide a comprehensive catalogue of weather types and establish relationships with the local surface climate. Here we apply a similar approach (automated classification), which has been proven in previous studies (e.g. Almazroui, 2006; Dambul, 2005) which found the approach useful in diagnosing rainfall and temperature extremes under different seasons and climatic divisions in non-temperate regions. Worth mentioning that climate of the Arabian Peninsula particularly rainfall and temperature changes with the activities of desert dust (Islam and Almazroui, 2012).

As mentioned earlier, CT work across the Arabian Peninsula was pioneered by Almazroui (2006). This paper presents the updated work on CTs for this region using the latest reanalysis data currently available (such as ERA-Interim and 20CR). The established CTs are correlated with surface climate parameters i.e. temperature and rainfall,

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http://dx.doi.org/10.1016/j.atmosres.2015.03.014
0169-8095/

both for individual stations and the recently developed climatic divisions for Saudi Arabia by Almazroui et al. (2014a). This current work enhances the investigation of the relationships between the large-scale circulation patterns and the local climate, for both averages and extreme indices. It is worth mentioning that previous studies found that the climatic characteristics of the Arabian Peninsula in general and Saudi Arabia in particular are heavily influenced by seasonality and regional attributes (Almazroui, 2012a,b). Therefore, in this work it is relevant to revisit and reinforce those findings by specifically investigating the link between synoptic circulation patterns and the various surface atmospheric conditions.

Why is classification of circulation important? It can be translated into short-term and long-term forecasting of the surface impacts (especially the trends of weather extremes in different regions) based on the changes in weather patterns across Saudi Arabia. The understanding of these inter-relationships would enable stakeholders from various sectors to develop strategic actions for socio-economic planning. This can be used as the basis to document further study on weather extremes in future climate, impact studies due to climate change as well as the utilization of climate model data for the projection period.

2. Data and methodology

Daily mean sea-level pressure (MSLP) data gridded at a resolution of 0.75° × 0.75° derived from the European Centre for Medium-Range Weather Forecasts (ECMWF) re-analysis ERA-Interim (ECMWF, 2009) for the period 1979–2012 are used to establish the circulation typing. The analysis domain (10°E–70°E; 5°N–40°N) is considered large enough to allow circulation from north-western Mediterranean to north-eastern polar systems, and from south-western Sudan low to south-eastern Indian Ocean activities (see left panel, Fig. 1). All of these large-scale circulation features are potentially linked with the climatic behaviour across Saudi Arabia. Observed daily temperature and rainfall data at 27 locations over Saudi Arabia are utilized for the period 1979–2010 (see right panel, Fig. 1). These surface climate data are used as supporting data to evaluate the established circulation types to determine if they have any 'climatic meaning' when physically linked with various surface environmental conditions e.g. rainy days, extreme temperature, etc.

The identification of circulation types is based on principal component analysis (PCA; Jolliffe, 2005), a mathematical technique, which summarises the main modes of the variability in the MSLP dataset. PCA is widely used in meteorological and climatological research (Jolliffe, 1990) to identify large-scale atmospheric circulation patterns. It is primarily a data reduction technique, where a large number of variables are reduced into a dataset containing relatively few variables, but still reflecting the majority of the variance found in the original dataset. This eigenvector-based scheme employs the circulation-to-environment (local climate) approach to synoptic climatology (Yarnal, 1993). The identified types are verified for consistency with the recognised synoptic situations in the surrounding region.

Extracting the essential, or a specific number of circulation patterns of variation in a gridded dataset, such as an MSLP grid, can be carried out either by subjective (manual) or objective (automated) methods (Yarnal, 1993). Well-known subjective methods (see Fig. 2) include the Lamb weather type classification (Lamb, 1950, 1972) and the European Grosswetterlagen (Hess and Brezowsky, 1977). Automated techniques include classification based on correlation or eigenvector approaches, which have the advantage of being able to be repeated and also it is less time-consuming (Yarnal, 1993). The core objective of PCA in this analysis is to produce a map-pattern classification employing an automated eigenvector-based technique using the MSLP gridded dataset (based on ERA-Interim Reanalyses of Dee et al. (2011)).

One of the subjective decisions required in any application of PCA is how many retained components (PCs) to consider for further use. In practice, the number of PCs is decided based on the eigenvalues or characteristic root. Eigenvalues measure the amount of variation in the total sample (8422 time series grids in our case) accounted for by each factor. Various approaches have been suggested for determining the number to retain. The common rule of thumb for dropping the least important factors from the analysis is the Kaiser rule (K1 rule) that suggests omitting all factors with eigenvalues under 1.0. This rule usually overestimates the true number of PCs, sometimes severely so (Jolliffe, 2002; Lance et al., 2006). A similar and less used but more liberal rule of thumb is the Joliffe rule. According to this rule one can take all factors with eigenvalues under 0.7. Taking the number of retained component above the mean of eigenvalues is another technique of this kind of determining PCs. Another method of dropping components is the Cattell's scree test plot (components as the X axis and the corresponding eigenvalues as the Y axis). Moving from lower to higher components, the eigenvalues that drop above where the curve makes an elbow, however picking the elbow is a subjective matter. Keeping components to account for 90% (sometimes 80%) of the variation is known as variance explained criteria. This criterion could be used as low as 50% of the total variance. The normalized eigenvalues are used in assessing intermixing of eigenvectors (Quadrelli et al., 2005). Another approach named Parallel Analysis (PA) suggested by Henson and Roberts (2006) and Matsunaga

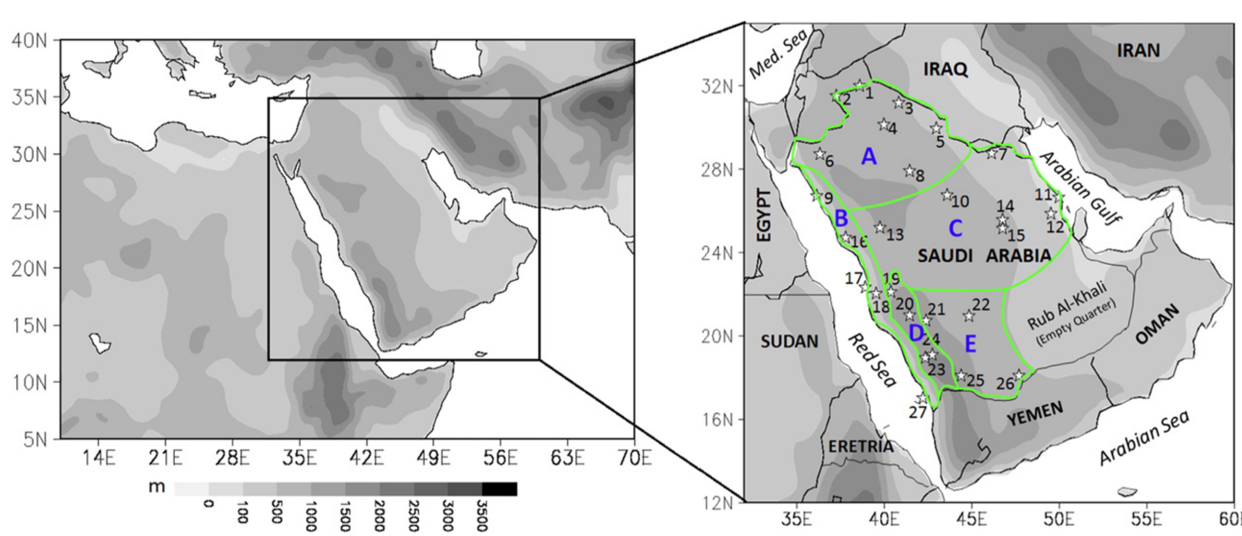

Fig. 1. Topography map of the Arabian Peninsula and its surroundings (left panel). The asterisks of the right panel represent the locations of 27 surface stations across Saudi Arabia where the numeric represents the station ID similar to Almazroui et al. (2014a). The five climatic divisions (Almazroui et al., 2014a) called Northern (A), Coastal (B), Interior (C), Highland (D) and Southern (E) are superimposed for use later on.