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Climatology of the winter Red Sea Trough

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ABSTRACT

In this study, a new and objective method for detecting the Red Sea Trough (RST) was developed using mean sea level pressure (SLP) data from NCEP/NCAR reanalysis dataset from the winters of 1956 to 2015 to identify the Sudan Low and its trough.

Approximately 96% of the winter RSTs were generated near two main sources, South Sudan and southeastern Sudan, and approximately 85% of these troughs were in four of the most outer areas surrounding the northern Red Sea.

Moreover, from west to east of the Red Sea, the RST was affected by the relationships between the Siberian High and Azores High. The RST was oriented to the west when the strength of the Siberian High increased and to the east when the strength of the Azores High increased. Furthermore, the synoptic features of the upper level of the RST emphasize the impacts of subtropical anticyclones at 850 hPa on the orientation of the RST, the impacts of the northern cyclone trough and the maximum wind at a pressure level of 250 hPa. The average static stability between 1000 hPa and 500 hPa demonstrated that the RST followed the northern areas of low static stability.

The results from previous studies were confirmed by a detailed case study of the RST that extended to its central outermost area. The results of a detailed case study of the short RST indicated that the trough becomes shorter with increasing static stability and that the Azores and Siberian high-pressure systems influence the northern region of the trough while the maximum upper wind shifts south of the climate position.

1. Introduction

The Red Sea Trough (RST) is a northward extension of the southern Red Sea low-pressure system that extends toward the eastern Mediterranean (EM) and Levant region at lower atmospheric levels (El-Fandy, 1948). The RST originates at the 'Sudan Monsoon Low' (Sudan Low), which is a part of the large-scale subtropical/equatorial low-pressure thermal system known as 'the intertropical convergence zone.' The center of the Sudan Low oscillates annually from Ethiopia and Sudan in winter to Saudi Arabia in spring and India in summer, and back to Ethiopia and Sudan during autumn (El-Fandy, 1950; Solot, 1950). Tsvieli and Zangvil (2005) demonstrated that the RST oscillated from west to east, shifting westward from September to January and eastward from February to May.

Alpert et al. (2004) semi-objectively classified daily synoptic systems in the EM and demonstrated that the RST is one of the main systems affected in the EM. Additionally, Mashat and Awad (2015) indicated the importance of the Sudan Low in the development of widespread dust across the northern Arabian Peninsula. Generally, the RST is associated with hot and dry weather that results from east-southeasterly flows in the lower troposphere. In active cases, the RST is accompanied by an upper-tropospheric trough that extends from the north over the EM (Saaroni et al., 1998; Tsvieli and Zangvil, 2005). In these active cases, the RST phenomenon represents a serious threat to human society in the northeastern Africa–EM region and is sometimes associated with devastating floods (El-Fandy, 1948; Dayan and Abramski, 1983; Krichak et al., 2000, 2012; Kahana et al., 2002, de Vries et al., 2013; Yair et al., 2015). For example, Dayan and Abramski (1983) studied exceptionally heavy rainfall in the Middle East, where the RST and an unusual jet stream were mainly responsible for heavy rainfall. In addition, Rubin et al. (2007) studied the effects of the RST on precipitation in the southeastern Mediterranean region, de Vries et al. (2013) studied the influences of the RST on extreme precipitation events in the Middle East, and Haggag and El-Badry (2013) used a numerical method to study the influences of the RST on flash floods in Saudi Arabia in November 2009.

Several researchers have attempted to identify and investigate the characteristics of the RST. Krichak et al. (1997a) studied the interactions of topography and mid-tropospheric wind relative to the generation of the RST and found that the terrain surrounding the Red Sea plays a primary role in the development of the RST. Krichak et al. (1997b) used a numerical method to evaluate the effects of terrain, latent heat release and surface fluxes on the development of the RST and found that topography and sensible heat flux were dominant factors. De Vries et al. (2013) investigated the dynamics of the active RST and identified six dynamic factors involved in its active phase (the lower

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and upper troughs, the subtropical jet, moisture, the Arabian Peninsula and ascending motion).

This paper is organized as follows. The data and methods used in this study are described in Section 2, the statistical results, synoptic features of the RST, and synoptic features of the case studies are presented in Section 3, and the conclusions are presented in the last section.

2. Data and methodology

In this paper, the winter (December, January and February) RST is objectively identified using National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) 6-hourly mean sea level pressure (SLP) data, which is available as regular 2.5° × 2.5° latitude-longitude grids (Kistler et al., 2001; Kalnay et al., 1996), from the winter periods of 1956 to 2015. In addition, the geopotential height at 850 hPa, the wind components at 850 hPa and 250 hPa, and the temperature between 1000 hPa and 500 hPa are analyzed to evaluate the synoptic patterns associated with the RST oscillations. The study domain shown in Fig. 1 is located at 10°E–65°E longitude and 0°N–50°N latitude.

The SLP data are transformed to a finer grid (0.5° × 0.5°) to identify the cyclone centers at sub-positions between the coarse grid points (Pinto et al., 2005; Hannachi et al., 2011; Almazroui et al., 2015) and trough lines. The center of the cyclone is defined by the following conditions:

1- The center of the cyclone is located at a grid point if the grid has a lower SLP value than the SLP of each of its eight neighboring grid points.
2- The pressure differences between the designated center and the neighboring eight grid points range from 0.8 hPa to 3.8 hPa. A pressure of less than 4 hPa was considered as the threshold value for low-resolution (5° × 5°) data by Ziv et al. (2013).
3- The designated center has an SLP value of less than 1008.8 hPa, which is adequate for detecting the initial stages of the cyclones. For the synoptic scale, Bartholy et al. (2006) used 1012 hPa as the upper pressure limit to detect cyclones over the North Atlantic-European region.

Moreover, the cyclone troughs are determined in a manner similar to Hannachi et al. (2011) and Almazroui et al. (2015) as follows:

1- The initial search area is bounded by 5.0°–22°N and 22.5°–45.0°E, which represents the expected area of the Sudan Low or 'African portion of the intertropical convergence zone' (Krichak et al., 2012), and the outermost extent of the search for the trough is at 55°E or 47°N.
2- The location of the deepened cyclone center detected within the initial area is considered as the starting point for determining the subsequent point on the trough line. A box surrounding the defined point and containing 20 fine grid points situated to the north, south, northeast and southeast of the initial state is used to search for a new location of the open center, i.e., the SLP grid point lower than only 5 of its neighbor grid points.
3- After determining the location of the next center, step 2 is repeated for this new location.
4- The detected center is terminated if:

a) no open cyclone center is detected in a subsequent step;
b) the current center is located beyond 55°E or 47°N;
c) the pressure of the detected center is greater than 1018.5 hPa (adapted manually); and
d) the pressure difference between two sequential centers is greater than 0.9 hPa (i.e., the trough line extends inside a high-pressure system) or less than −0.25 hPa (i.e., the trough line extends inside a new low-pressure system).

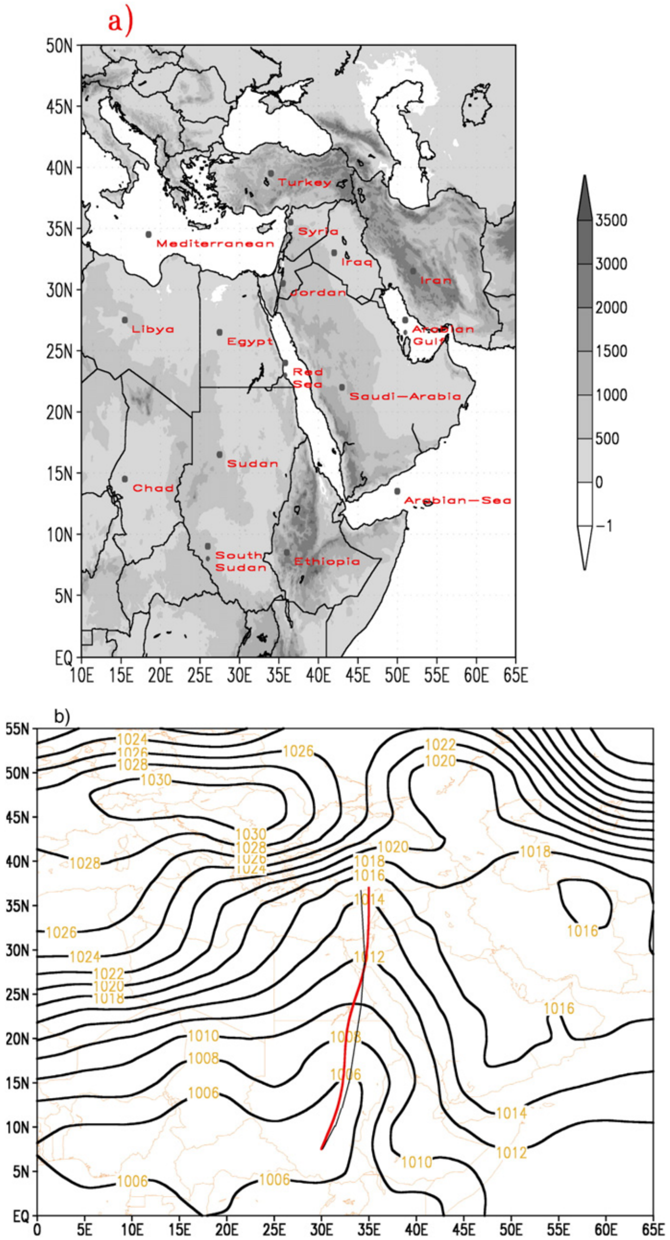

Fig. 1. a) Geographic map and topography of the Red Sea and the study area (elevation scale in meters). b) Example of the manual trough (black) and objective trough (red) for 00 2 Jan 2000. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3. Results

The procedure was tested by comparing the objective troughs with the manual troughs for the same dates. The troughs for 1970, 1980, 1990, 2000 and 2010 were selected and used to validate the procedure. The agreement (92%) is presented in terms of the features of the cyclone center and the trough position (especially for long troughs). Small differences (negligible error) between the manual and automated troughs result from the manner in which the cyclone center and trough positions are specified. The visual trough uses a cursor on the map to specify the position of the cyclone trough, and the automated routine determines the minimum value of the field at each grid point, as shown in the example in Fig. 1b.