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Abstract

Atmospheric circulation provides permanent heat and humidity transfer between sea surface and the surrounding regions. Our study aims to identify the role of regional sea surface temperature anomalies on extreme precipitation in Romania. We used daily precipitation amounts from 104 Romanian stations to build a seasonal time series of extreme precipitation for the period 1961-2000. Canonical correlation analysis of observed extreme precipitation and sea surface temperatures (SSTs) over the Mediterranean and Black Seas suggests that local extreme precipitation is significantly affected by the Black Sea surface temperatures in winter. This result is confirmed by sensitivity experiments with a regional climate model in which Black Sea surface temperature is raised by 2 K.

Key words: Mediterranean cyclones, climate variability and change, regional modeling, sea surface temperature

1. Introduction

Extreme precipitation events often result in major societal and ecological impacts making their prediction particularly challenging on all time scales. Heavy precipitation prediction requires an improved understanding of the mechanisms involved in their generation. Precipitation is essentially local in nature. On regional and local scales, the Mediterranean and Black Seas are sources of heat and humidity for the surrounding regions. Mediterranean cyclones are important players in providing permanent heat and humidity transfer in southern Europe (Trigo et al., 1999). As for the Black Sea, even though it does not play a large role in generating cyclones, its surface properties (e.g. sea surface temperature (SST)) could influence the characteristics of passing cyclones.

Romania is situated near the northeastern limit of Mediterranean cyclone influences (Ion-Bordei, 1983), and its proximity to the Black Sea suggests that changes in Black Sea surface temperatures could have a substantial role in modulating local patterns of extreme precipitation, especially in winter. During the cold season, frontal precipitation related to sea-to-land moisture transport accounts for much of the precipitation falling over Romanian territory because moisture supplies available on land are negligible. In addition, local orography has an impact on the amount and distribution of precipitation - the mountains help to produce heavy precipitation through orographic lifting of potentially unstable air, provided favorable atmospheric circulation occurs (Ion-Bordei, 1988). As for the warm season, the situation seems to be more complex due to the diminished role of large-scale dynamics and the local interplay between soil hydrology and convection (Schäar et al., 1998). Our present study aims at identifying the role of winter SSTs over the Black Sea for extreme precipitation occurrence over Romanian territory.

2. Data and methodology

The observed data set consists of daily precipitation amounts from 104 Romanian stations and sea surface temperature (SST) anomalies over the Mediterranean and Black Seas taken from ERA 40 (Uppala et al., 2005) for the period 1961-2002. An index of extreme precipitation (R95) is obtained from daily data as the sum of daily amounts equal or above the 95% percentile computed from December to February as in Whalter (2004) and Zhang et al. (2005). Canonical correlation analysis (CCA) is applied to the R95 index and regional SSTs to identify common patterns of variability. The CCA selects a pair of spatial patterns of two variables such that their time evolution is optimally correlated (Preisendorfer 1988; Zorita et al. 1992; Bretherton, 1992; Kharin 1994; Von Storch 1995). Before CCA is performed, the original data are usually projected onto their Empirical Orthogonal Functions (EOFs), retaining only a limited number of them in order to minimize noise.

A main drawback of statistical techniques is that they cannot be used solely to infer causality and a physical framework is needed to support the conclusions drawn. Therefore, results from the statistical analysis of coupled precipitation and SST patterns are explored using numerical experiments with a regional climate model (RCM) (Pal et al. 2007). The experiments are based on selected cases with Mediterranean cyclones crossing Balkan regions, taken from a Mediterranean Cyclone Catalog (Ion-Bordei, 1997). These situations are known to lead to extreme precipitation over Romanian territory (Ion-Bordei, 1983).

3. Observed interdecadal variability of local precipitation and SST

We have identified the SST-related patterns in observed extreme precipitation over Romania by computing the CCA with the ERA 40 data of Mediterranean/Black Sea SST and the R95 index for the winters of the interval 1961–2000. Tests with different numbers of EOFs suggested that the best choice in terms of both highest correlation and explained variance is to retain the first five EOFs of SST and precipitation in the subsequent CCA. Figures 1a and 1b illustrate the leading CCA spatial patterns of extreme precipitation paired with winter-averaged SST anomalies, respectively. The correlation coefficient associated with the first CCA mode is 0.73 and the fraction of total variance represented is 0.25 for SST and 0.17 for extreme precipitation. The CCA spatial coefficients derived from the 104 stations were interpolated onto a 0.3 degree longitude-latitude grid by applying a Cressman procedure. Note that the observing stations cover only the Romanian territory and features outside the Romanian borders are solely due to the spatial interpolation procedure.

The variability center located near the coast can be explained mainly by the direct influences of higher SSTs which lead to increased air instability and precipitation intensity along the shoreline, due to the land-sea contrast. A similar effect was revealed for the Netherlands and the North Sea by Lenderink et al. (2008) who showed that in summer, SST influences are particularly strong in the area less than 30-50 km from the Netherlands coastline. This effect seems to act similarly in winter, due to the negligible effect of soil moisture Lenderink et al. (2008) detected for their summer case study. The location of higher variability near northern part of the Romanian coast is related to the concave shape of the shoreline that results in confluent flow and and exposes that area to enhanced sea-land transport of humidity provided favorable atmospheric circulation conditions (in our case - the southerly flow) occur. Other features such as extreme precipitation variability over certain southern, eastern, and north-western Romanian regions seem to be related to the interaction of Mediterranean cyclones passing over a warmer Black Sea, in the vicinity of Romanian territory, and local topography (the Carpathian arch).

The time evolution of leading CCA mode (Fig. 2) shows an interdecadal pattern with higher (lower) SST anomalies over the Black Sea for the period 1961-1979 (1980-1995), corresponding to the warm (cold) phase of Black Sea surface temperatures defined by Oguz et al. (2006). It is interesting to note that a similar CCA procedure applied to SST and total winter precipitation (instead of extreme precipitation) reveals a leading mode with similar patterns but the fraction of total variance associated with total precipitation field is substantially lower (0.04).

4. Regional numerical experiments

Our CCA results suggest that the Black Sea surface temperatures seem to affect heavy precipitation. This suggests we may have a “moisture effect” similar to that identified by Frei et al. (1998) in their numerical experiments carried out over Europe for the fall season. Through sensitivity experiments they found that a uniform temperature increase in the RCM initial and lateral boundaries resulted in more frequent events of heavy precipitation in regions dominated by sea-to-land moisture transport. This effect was attributed an increase in atmospheric moisture content due to the imposed higher temperatures. In our particular situation, consistent with the CCA mode previously identified in the observed data, we suspect the warming of the Black Sea surface would have similar effects on the local hydrological cycle. However, one may argue that beside Black Sea affecting extreme precipitation, it cannot be ruled out the possibility of large - scale atmospheric processes leading both Black Sea SST and extreme precipitation increases. The use of a RCM can help us to determine if the Black Sea warming is really a main cause of local increases in extreme precipitation during the cold season, as statistical results are suggesting.

The climate model is the version 3 of RegCM, a 3-dimensional, sigma-coordinate, primitive equation model (Pal et al. 2007). The model horizontal grid interval is 30 km and it uses a Lambert conformal projection. The selected domain consists of Black Sea and riparian regions (Fig. 3) but also including key Mediterranean areas from the standpoint of cyclogenesis-related processes (Trigo et al., 1999). The ERA-40 reanalysis data were used as initial and lateral boundary conditions for all experiments (Uppala et al., 2005). The SST forcing consists of observed SSTs from NOAA Optimum Interpolation (OI) Sea Surface Temperature (SST) V2 data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA (Reynolds et al., 2002).

For the simulations, nine observed cases of Meditteranean cyclones occurring during the winter season (DJF) with trans-Balkan paths were chosen. These observed cases are listed in Table 1. For the control simulations (CTRL), these nine cases were run with the observed SSTs. In a second set of simulations (referred to as WSEA), the surface temperature of the Black Sea was modified by an uniform temperature increase of 2 K, but the lateral boundary conditions and sea surface temperature elsewhere are left unchanged for the same nine cases. In both sets of simulations (CTRL and WSEA), each case was run for two months, with one month for spin-up. This is sufficient time for a balance to be reached between the lateral boundary forcing and the regional climate model dynamics (Qian et al. 2003).

The WSEA experiment allows us to separate the local effect of the Black Sea SST from large scale effects related to other influences. The 2 K change in the Black Sea SST is consistent with what happens in the real world, knowing that Black Sea SSTs have significant interdecadal variability. Oguz et al. (2006) show that temperature drop (i.e. the average difference between the cold phase and the warm phase) between the warm phase from early 1960s to 1980 and the following cold one (from 1980 to 1995) is of about 1.7 K. All nine cases simulated in the numerical experiments are from the cold SST phase of 1980 -1995 (Table 1).

As in previous analysis, the observed precipitation derived from the 104 stations was interpolated onto a 0.3 degree longitude-latitude grid by applying a Cressman procedure. Features outside the Romanian borders are solely due to the spatial interpolation technique. The RegCM CTRL composite shows a tendency to underestimate precipitation over Southern Carpathian upslopes and overestimate it over intra-Carpathian areas and northward, probably due to the simplified model topography. However, CTRL composite exhibits similar spatial features as the observations, with the exception of a near-coast maximum unrealistically simulated by the RegCM (Fig. 4 a, b). The pronounced near-coast feature in the CTRL simulations is caused by unrealistically strong air-instability associated with the enhanced sea-land thermal gradient causing an artificially inland shifted sea-breeze front. Other small spatial features captured by the simulations are mainly due to the interaction between the Carpathian

Mountains and low pressure systems passing Romanian territory. In mountainous areas, upslope conditions are wetter, while downslope are drier, sometimes enhanced by foehn - type winds. The signature retrograde movement of Mediterranean cyclones (i.e. cyclones that move east to west), reinforced over the Black Sea, is also present over northwestern Romanian regions, in both observed and simulated precipitation fields, even though the exact locations are not exactly reproduced by the model, probably due to its simplified topography.

The composite for the WSEA experiments (Fig. 4 c) reveals an intensification of precipitation onto upslope areas of Carpathian Mountains and near Black Sea coast. An eastward shift of precipitation bordering the southern part of Romanian Carpathians is also apparent together with a stronger northwestern signature of the retrograde Mediterranean cyclones passing Romanian territory. When the difference between CTRL and WSEA composite precipitation fields for the nine cases is represented, we can see that this pattern has common features with the difference map obtained subtracting winter extreme precipitation observed in the interval 1961-1979 from the same field observed in the interval 1980-1995 (Fig. 5a, b). Also, the difference maps resemble reasonably well the CCA spatial pattern of observed extreme precipitation over Romania and Black Sea SSTs, presented in section 3. Warmer SSTs over the Black Sea in winter are associated with heavier precipitation near the coast and on Carpathian upslopes, and with stronger retrograde movement of reinforced Mediterranean cyclones passing Romania. Figure 6 shows difference composites (WSEA minus CTRL) of total column precipitable water and SLP. The results show that the increase in local atmospheric moisture content due to a warmer Black Sea surface (Fig. 6 a) has only slightly affected the spatial extent and paths of simulated low pressure systems (Fig. 6 b). However, the higher SSTs cause an increase of precipitation in certain regions (Fig. 5 b). This result is consistent with Frei et al. (1998), suggesting we are dealing with the “moisture effect” mechanism controlled by the temperature dependence of atmospheric water holding capacity (the Clausius-Clapeyron relationship) (e.g. Trenberth et al., 2003).

Thus, we can conclude that the observed interdecadal behaviour of extreme precipitation in winter, over Romanian territory, is strongly related to the interdecadal variability of Black Sea SST. In this study we focused on winter (December to February), but similar results can be expected for other months provided there are similar sea-land thermal gradient and dominant sea-land moisture transports by synoptic systems (e.g. October, November, and March).

5. Discussion

Our observational analysis and model results show that extreme precipitation variability in Romania has a strong interdecadal component which is modulated by the Black Sea SSTs in the cold season. This cold season signal is robust and could be used in predictive methodologies on seasonal, interannual and decadal time scales. An interesting issue is what causes the interdecadal variability of the Black Sea SSTs. Oguz et al. (2006) claim that these interdecadal variations are governed by the interplay of two atmospheric teleconnection patterns: the North Atlantic Oscillation (NAO) and East Atlantic-West Russia (EAWR). Extremely cold (mild) and dry (wet) winters occur over the Black Sea during strong positive (negative) NAO and EAWR phase. The cooling of the Black Sea during 1980-1995 is therefore consistent with the observed trend towards its positive phase in the second half of the 20th century (e.g., Hoerling et al., 2001; Hurrell, 1995; Hurrell et al., 2004). Oguz et al. (2006) relate warmer (colder) winter SSTs to stronger (weaker) wind stress and higher (lower) surface air pressures and evaporation minus precipitation values. Warm-moist advection process driven by passing low pressure systems originating in Mediterranean could partially explain the signal.

However, it is intriguing that such strong interdecadal signature may arise solely from the atmospheric forcing, knowing the short time scales involved in atmospheric processes. It’s also interesting to note that over land areas near the coast - one of the key regions characterized by this interdecadal behaviour - the correlations between precipitation, temperature and NAO index are weak in winter (e.g. Bojariu and Paliu, 2001). On the other hand, warmer SST associated with increased water content in the atmosphere is consistent with the mechanism of a local SST forcing which drives the atmosphere (e.g. Trenberth and Shea, 2005) like what we have seen in the WSEA simulation (Fig. 6). That is why interdecadal Black Sea forcing might be due to processes related to water masses, rather than to pure atmospheric phenomena.

Another issue is that of future climate change which raises the problem of climate projection on local and regional scales. Many studies suggest significant precipitation changes over northwestern Europe and Mediterranean basin under different climate conditions (e.g. Deque et al., 2007). In general, precipitation is projected to become diminished over the eastern Mediterranean and enhanced in the northwestern European areas. Romania is situated in a region where the influence of storm track changes is not particularly strong and the signal-to-noise ratio reveled by large scale projections is small. In this context, local mechanisms such as that related to Black Sea moisture enhancement, due to the progressive warming of almost land-locked water basin will make the difference under climate change conditions. On centennial time scales, the fact that Black Sea warming contributes to extreme precipitation in Romania implies that more extreme events such as flash floods are expected in cold season, in certain regions (mainly near the coast and in southern, eastern and selected northwestern areas of the country) under global warming conditions. On the other hand, the strong interdecadal variability of Black Sea SST seems to be a natural phenomenon which should be taken into account when the global change signal is projected on Romanian territory on shorter than centennial time scales. Further investigation is needed using both observed data and results from regional climate models to find other regional mechanisms responsible for extreme precipitation, including those for warm season.

The results presented in this work were carried out by R. Bojariu (Administratia Nationala de Meteorologie, Bucharest) in collaboration with F. Giorgi, S. A. Rauscher, and X. Bi (International Centre for Theoretical Physics, Trieste). In addition, the 9 case studies were chosen with the help of E. Ion-Bordei (Ecological University, Bucharest).

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Table 1. Selected cases with Mediterranean cyclones crossing Balkan regions.
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Nr.	Cases
1.	**25-29.12.1981**
2.	**18-22.12.1982**
3.	**20-23.01.1984**
4.	**24-28.02.1984**
5.	**06-10.01.1986**
6.	**07-08.12.1990**
7.	**12-14.12.1990**
8.	**12-14.02.1991**
9.	**20-25.02.1993**

Figure Captions

Figure 1. RegCM domain and orography (shaded, in m).

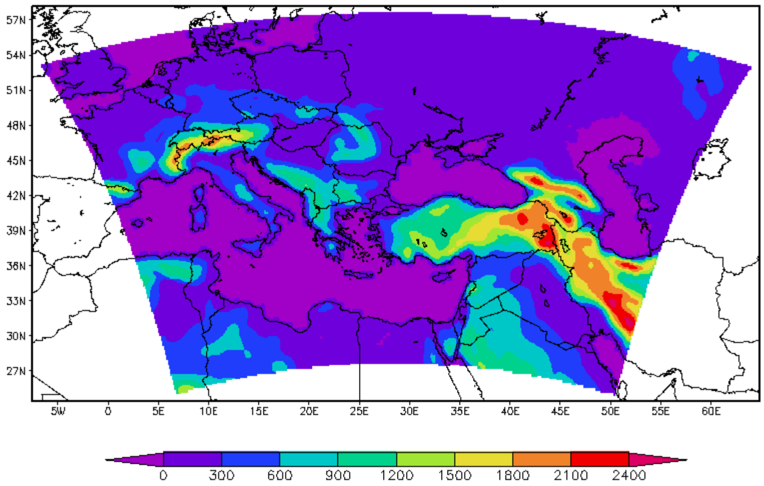
Figure 2. Lead CCA spatial pattern of winter (DJF) SST (a) and extreme precipitation (b). SSTs are in K and precipitation in mm.

Figure 3. Time evolution associated with the CCA spatial patterns represented in figure 2.

Figure 4. Observed (a) and modeled (b) composite of precipitation (in mm/day) from 9 cases of Mediterranean cyclones passing Romanian territory. White contours (500 m intervals) represent the topography.

Figure 5. Observed composite (a) of precipitation built as the difference between extreme precipitation from intervals 1961-1979 and 1980-1995 (in mm/day) and modeled composite of precipitation difference from 9 cases of Mediterranean cyclones passing Romanian territory in WSEA and CTRL simulations. White contours (500 m intervals) represent the topography.

Figure 6. Difference composites (WSEA minus CTRL) of SLP (color shaded, in hPa) for 9 cases of Mediterranean cyclones passing Romanian territory.



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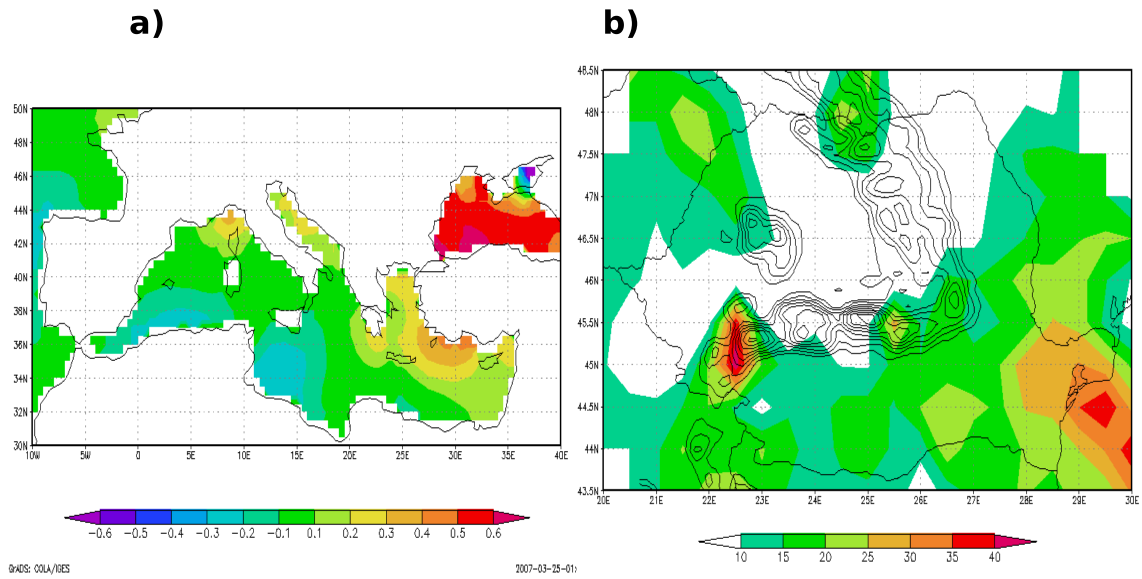

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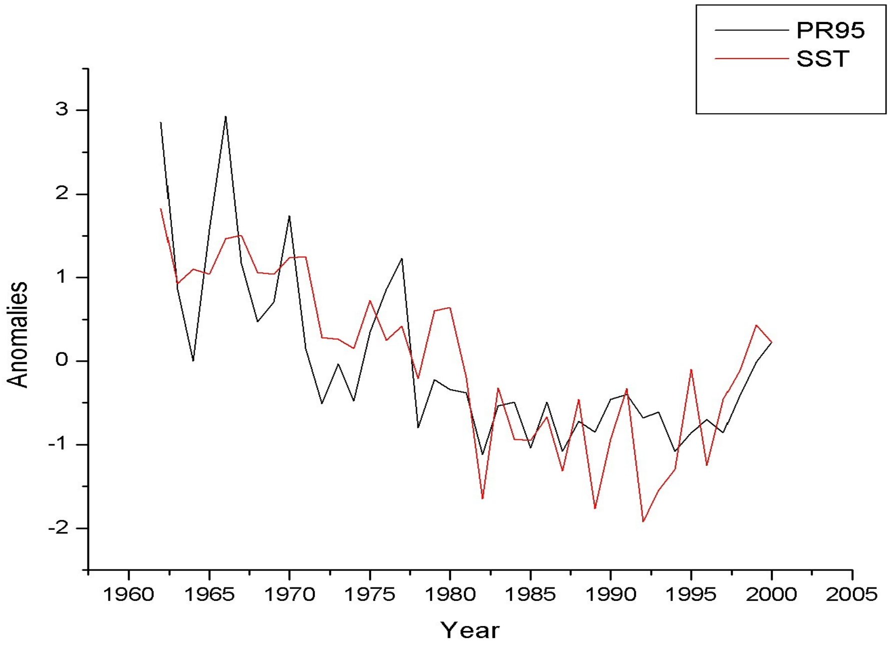

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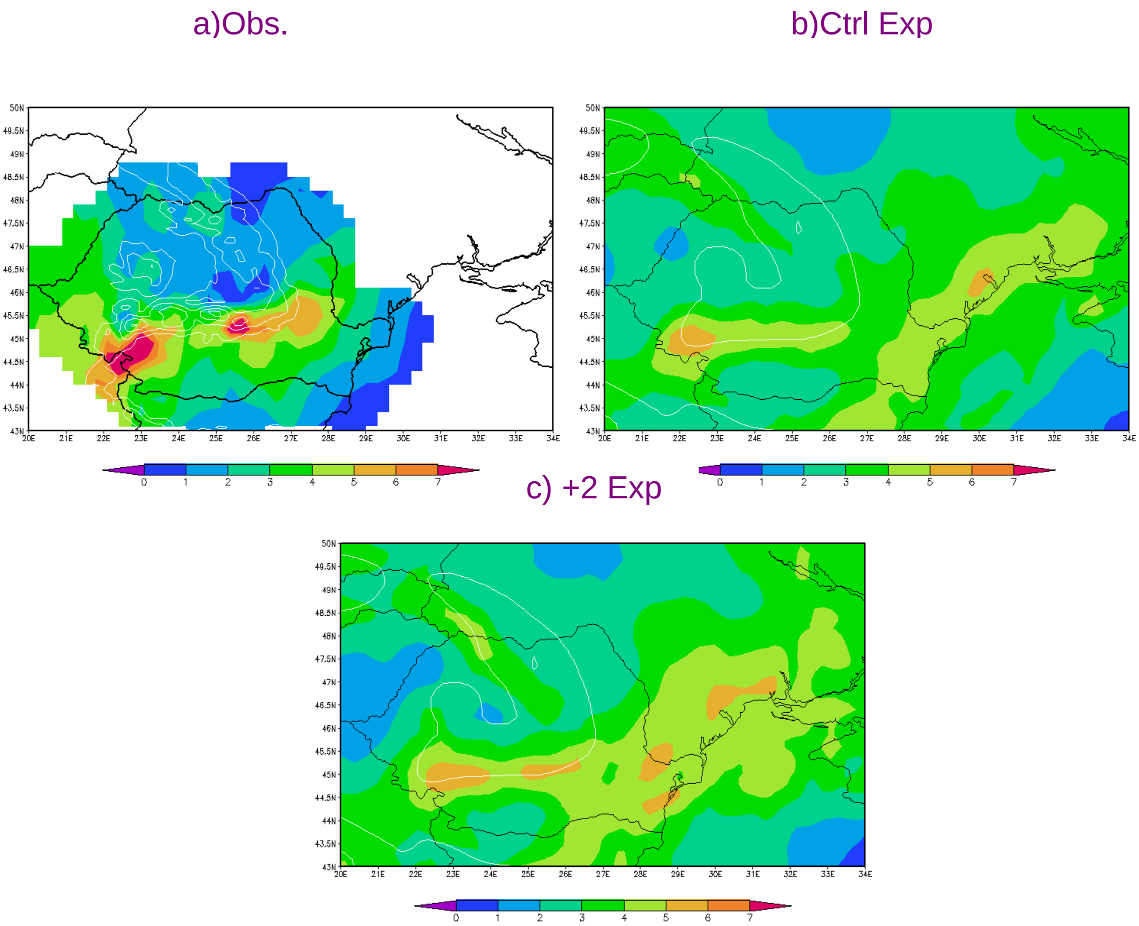
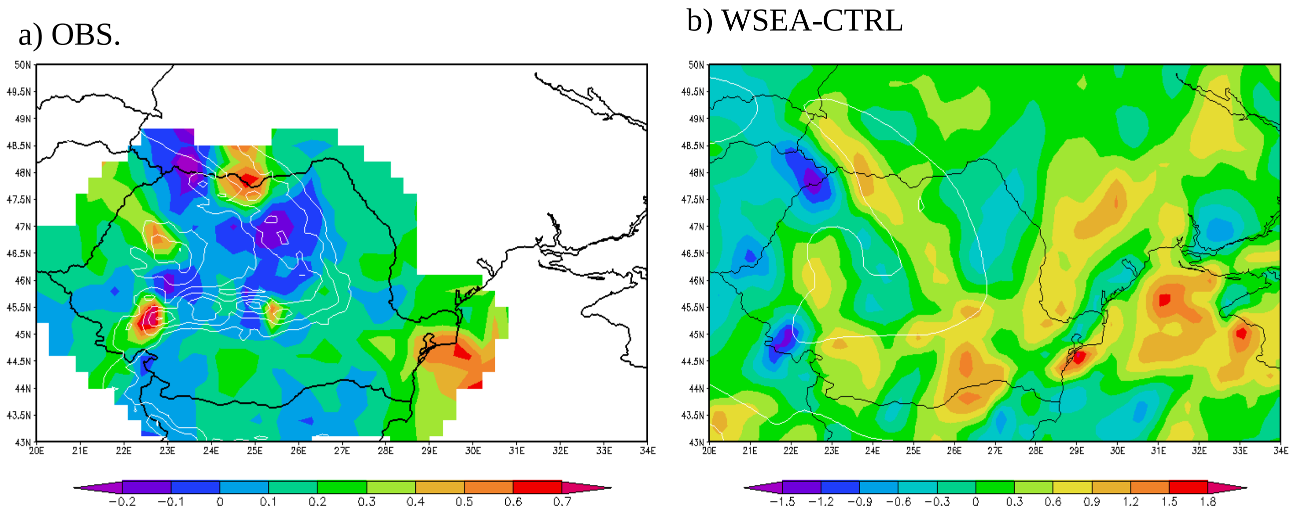


Figure 4. Observed (a) and modeled composite of precipitation (in mm/day) from 9 cases of Mediterranean cyclones passing Romanian territory. Modeled composites use results from CTRL (b) and WSEA (c) experiments. White contours (500 m intervals) represent the topography.



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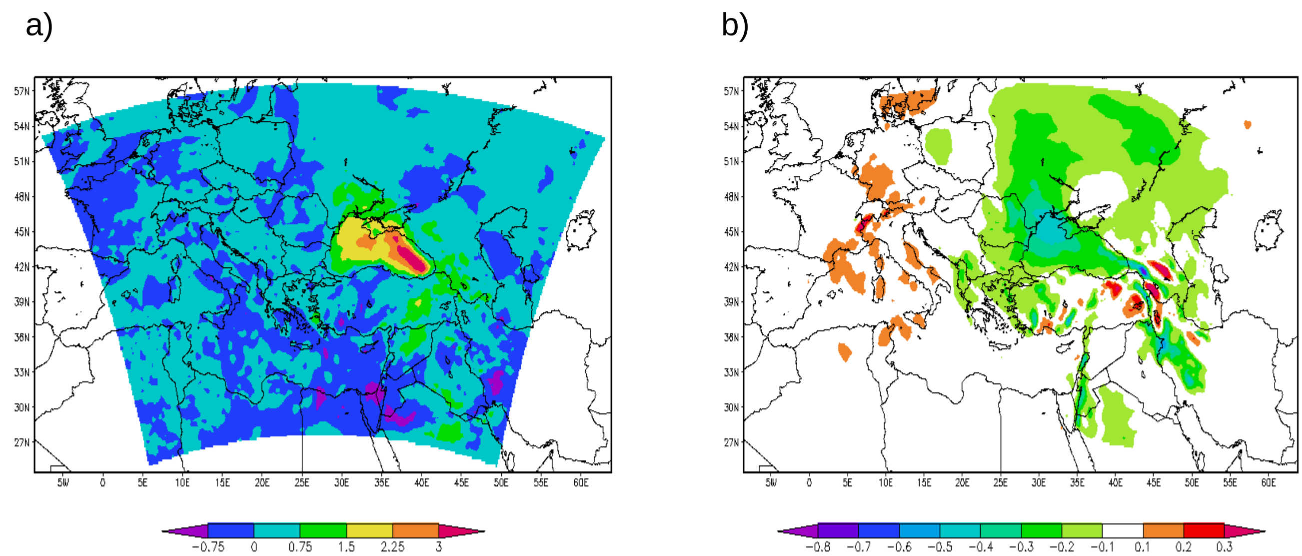

Figure 6. Difference composites (WSEA minus CTRL) of total column precipitable water (a, in g/m^2) and SLP (b, in hPa) for 9 cases of Mediterranean cyclones passing Romanian territory.