A dynamical identification of the sources of moisture over the Mediterranean Region

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I. MOTIVATION AND OBJECTIVES

The Mediterranean is positioned at the border between the tropical climate zone and the mid latitude climate belt. The temperate climate of this region is characterized by mild and humid winter months and hot and most dry summer months. The hydrological cycle is specially sensitive to the timing and the location of the winter storms as they move into the region [Trigo et al., 2002]. Studies have showed a relationship between a few major large-scale atmospheric circulation modes such as the NAO and precipitation over this area, specially at lower frequencies [e.g.Trigo et al., 2004].

Many previous studies were published identifying geographical sources or sinks of moisture over this region based on different methodologies (most of them Eulerian) and input data with results varying significantly among authors [Mariotti et al., 2002]. In this work the FLEXPART 3-D Lagrangian method is used to investigate the sources of moisture over the Mediterranean basin. In comparison to the traditional Eulerian techniques, we believe that the Lagrangian method can give more precise information concerning the trajectories of air masses and the their moisture variability.

II. METHODOLOGY

This study is based on the method developed by Stohl and James [2004, 2005], which uses the Lagrangian particle dispersion model FLEXPART.

The atmosphere is divided homogeneously into a large number of so-called particles and then these particles are transported by the model using three-dimensional winds, with their positions and specific humidity (q) being recorded every six hours. The increases (evaporation, e) and decreases (precipitation, p) in moisture along the trajectory can be calculated through changes in (q) with time (e-p = m dq/dt), (m) being the mass of the particle. When adding (e-p) for all the particles residing in the atmospheric column over an area, we can obtain (E-P), where the surface freshwater flux (E) is the evaporation and (P) is the precipitation rate per unit area. The method can also track (E-P) from a region backward in time along the trajectories, choosing appropriate particles and finding sources of moisture and precipitation.

In the work reported here we used the tracks of 1,398,801 particles over a five-year period (2000–2004) computed using ECMWF operational analysis available every six hours (00, 06, 12 and 18 UTC) with a 1ºx1º resolution and all 60 vertical levels of the analysis [ECMWF, 2002] [P. W. White (Ed.), IFS documentation, European Centre for Medium-Range Weather Forecasts, Reading, UK, 2002, available at http://www.ecmwf.int].

We traced (E-P) climatological winter (DJF) and summer (JJA) forwards trajectories over 3 areas in the Mediterranean Sea, selected according to the climatological atmospheric moisture flux and moisture divergence analysis [Mariotti et al., 2002] (see boxes figure 1). The transport time is limited to 10 days, which is the average time that water vapour resides in the atmosphere [Numaguti, 1999]. For the first trajectory time step, all the target particles resided over the defined region and (E-P) is the region-integrated net freshwater flux. For subsequent trajectory time steps, (E-P) represents the net freshwater flux into the air mass travelling from each region.

This methodology follows the same one applied by Nieto et al [2006], [2007] for Sahel and Iceland.

How to interpret the figures?

The air masses residing over the region of interest can be tracked forward in time to see where the particles gained or lost moisture. The figures show the average over the 10-day period $(E-P)^{10}$.

Results corresponding to regions characterised by E-P>0 are represented by reddish colours. Evaporation dominates over precipitation, which indicates that air particles located within that vertical column and in transit from the analyzed area gain moisture. These regions are therefore identified as moisture source regions.

and E-P<0 by bluish ones, revealing regions where precipitation dominates over evaporation. Consequently, air masses located over these regions in transit from the analysed area display a net loss of moisture, and these regions are identified as moisture sink regions.

III. RESULTS

The winter means of vertically integrated atmospheric water vapour divergence (figure 1a) shows maximum moisture divergence (indicating a local net water flux from the ocean to the atmosphere) over three regions: Gulf of Lions (red box, hereafter referred as Region 1), the southern Ionian Sea (blue box, Region 2), and the Levantine Sea (green box, Region 3). According to Mariotti et al. [2002], these areas provide maximum water supply to the atmosphere during this season. In the summer the divergence over the Mediterranean intensifies and its domains covers almost all the basin.

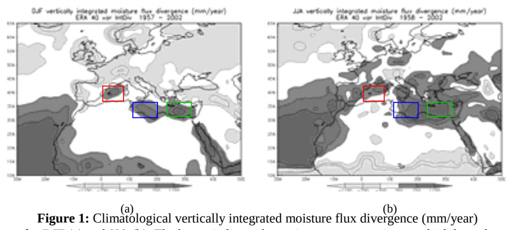

Figure 1: Climatological vertically integrated moisture flux divergence (mm/year) for DJF (a) and JJA (b). The boxes indicate the moisture source regions studied through the forward integrations.

The experiments aims to investigate the trajectories of the air masses emanating from the selected areas and where they gain or loose moisture through evaporation and precipitation, respectively. For each considered box, simulations were performed along the winter and the summer in order to analyse the inter seasonal variability.

A preliminary analysis suggests the different considered areas can contribute for the precipitation in distinct regions and even the contribution provided by the same area can vary along the year, as we can see from the forward trajectories maps presented in the Figure 2. For example, the air masses emanating from the Region 1 (Figure 2, top) can contribute for the precipitation in north western Africa and in the south western Mediterranean coast during the summer months, while its influence is observed on the Italian region along the winter. On the other hand, during the summer the maximum contribution for the precipitation from the Region 2 (Figure 2, centre) can be seen over north western Africa, while it becomes an important moisture source for the center-eastern Mediterranean in the winter. Finally, during the summer the region 3 (Figure 2, bottom) presents its maximum contribution for north eastern Africa and Middle East and in the winter its influence is displaced specially over eastern Mediterranean and north eastern Africa.

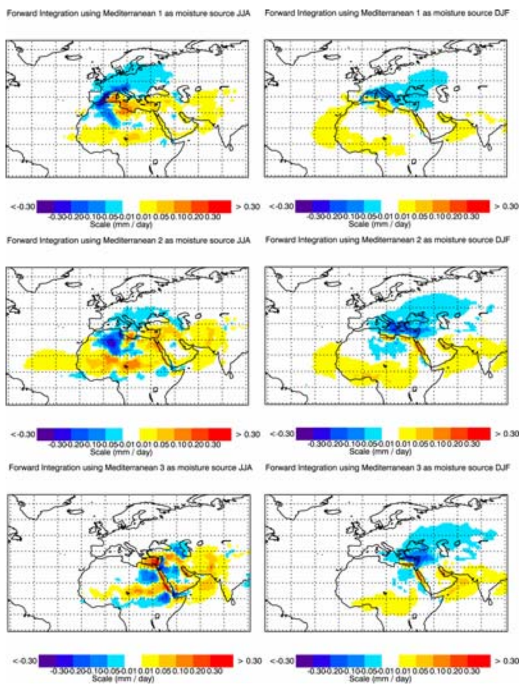

Figure 2: Seasonal average $(E-P)^{10}$ field of the Mediterranean (1), (2) and (3) regions (top, center and bottom panels) from the forward tracking (averaged over 10 days forward) for the summer and winter sesons (left and right panels, respectively) (mm/day).

IV. DISCUSSION

• The aim of this project is to identify the moisture sources over the Mediterranean region, their relative role and variations along the year, as well as their climatic variability.

• In this study, all air masses originated from three source regions selected according to the vertically integrated atmospheric water vapour divergence fields were tracked forward for the winter and summer seasons during the period 2000 – 2004, allowing to identify their seasonal variability.

• A preliminary analysis of the forward trajectories maps suggest that the different considered regions have some impact on different areas and this influence can vary along the year. For example, while the contribution from western Mediterranean is more important from this area, the eastern basin can have some influence on the Middle East. It can also be interesting to note that the considered sources can present some role on the precipitation even over Africa during the summer.

• Further studies including an analysis of SST and circulation fields will be performed in order to better understand the dynamics evolved.

• In addition, the climatic variability of the moisture sources will be investigated using ERA reanalysis dataset (e.g., through an EOF analysis) in order to identify how they change in the last decades.

• A 40-year FLEXPART experiment, which is being performed by our group, can be useful for these climatic variability studies.

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