A WARM CONVEYOR BELT MECHANISM ACCOMPANYING EXTREME PRECIPITATION EVENTS OVER NORTH-EASTERN ITALY

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Abstract: A Lagrangian methodology for the reconstruction and the analysis of the airstreams governing the transport of water vapour has been applied to analyse three recent extreme precipitation events over the Alps (3-5 November 1966, 16-18 November 2000 and 24-26 November 2002). The analysis outlines that the precipitation over the North-East of Italy is strongly conditioned by the evaporation rate and by properties of airmasses over the Central Mediterranean area. In particular most of the water vapour contributing to the precipitation ending over the Alps originates over Tunisia, the coastal regions in the western Lybia, the Channel of Sicilia, the Gulf of Gabes and the southerly Thyrrenian Sea. A simplified conceptual model is also proposed to visualize the traits of the moist airstreams inside the Mediterranean cyclones. Two patterns of airstreams can be identified, according to the scheme proposed by *Browning and Roberts, 1994*. The trajectory population of the two portions of WCB is a crucial factor controlling the precipitation production.

Keywords - *Warm Conveyor Belt (WCB), Extreme Precipitation, Evaporation areas, Trajectory clusters*

1. INTRODUCTION

The origin of water vapour producing precipitation events at specific target areas is a crucial step in the understanding of precipitation mechanisms over the Alps. In the 90s much work was devoted to investigate the structure and dynamics of extratropical cyclones. *Browning and Roberts (1994)* proposed a synthetic analysis scheme (Fig. 1), which was obtained from the diagnosis of a mid-latitude cyclone over the Eastern Atlantic Ocean. The Warm Conveyor Belt (WCB) is a warm and moist airstream within the cyclones which plays a major role in the transport of water vapour: a main core (labelled with W1) and a secondary lower level airstream (labelled with W2) producing the most precipitation can be detected.

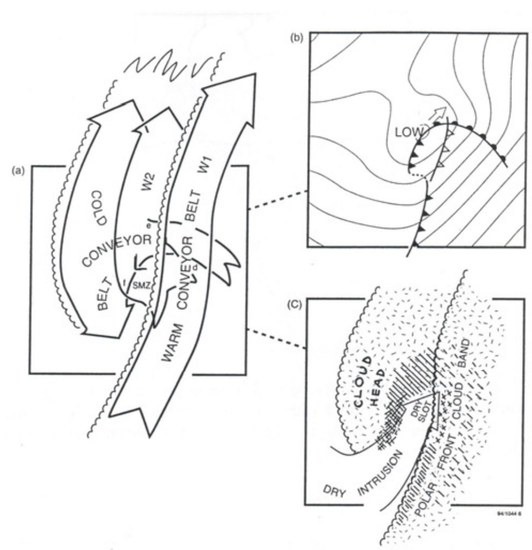

Figure 1. Airflow and precipitation within a developing extratropical frontal cyclone (based on *Browning and Roberts, 1994*). The main warm conveyor belt is labelled W1. The lowest part of the warm conveyor belt is labelled W2: it peels off and ascends in the top part of the cloud head.

The present work aims to analyze the water vapour transport mechanisms inside the Mediterranean cyclones. So a methodology for both the Lagrangian trajectory reconstruction and the analysis of the typical WCB occurring during precipitation events over Trentino (in the North-East of Italy) was developed.
A testing phase was necessary whereby the methodology had to be applied to three strong precipitation events affecting Trentino: 3-5 November 1966 (16 mm h^{-1} average precipitation for 30 h), 16-18 November 2000 (7 mm h^{-1} average precipitation for 30 h) and 24-26 November 2002 (7 mm h^{-1} average precipitation for 36 h).

2. LAGRANGIAN ANALYSIS

2.1. Trajectory computation

For each event five-day back-trajectories were computed. Representative ending points for the trajectories to be calculated were selected as the gridpoints of a 3D-grid with a 0.5° × 0.5° horizontal resolution and 200m vertical resolution (from 1500m to 5900m above sea level). This implies a total number of $N_z = 23$ horizontal levels; on each of them $N_x \times N_y = 5 \times 4$ grid points are set, resulting in an overall number of $N_T = 460$ endpoints over Trentino (for more details, *Bertò et al., 2004*). It is implicitly assumed that 460 ending points properly represent the thermodynamic state of the air masses producing precipitation over the target area.
Then 460 back-trajectories arriving over Trentino have been computed every 3 hours: each parcel was tracked until it left the model domain. In any case the parcels are never backtracked for more than 5 days.

2.2. Water vapour budget

To provide possible quantitative criteria consistent with a back-trajectory approach, the whole surface domain, flown over by computed airflows, was subdivided into 12 macroareas covering the European and Mediterranean regions (Fig. 2a):

1. the target area,
2. the Adriatic and Ionic Sea,
3. the Tyrrhenian Sea,
4. the West Mediterranean,
5. the central Atlantic Ocean,
6. the Atlas chain and the northern side of Sahara,
7. the central Mediterranean Sea,
8. Spain,
9. the central Europe,
10. the eastern Europe,
11. the northern Atlantic Ocean,
12. the rest of Sahara.

Boundaries of selected areas have been generally traced along meridians and parallels. Such a choice allows for condensing most of information in few parameters: this can be done when a detailed analysis is not necessary, as in the case of the study of water vapour source distribution.

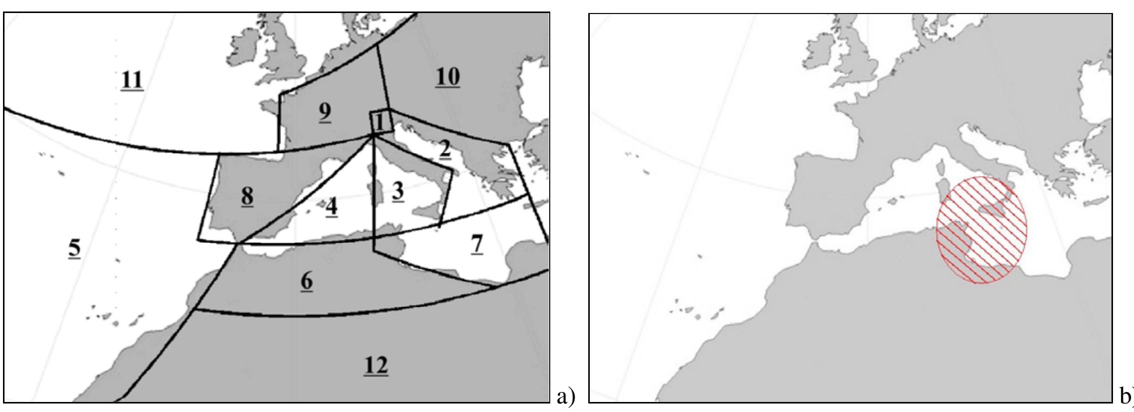

Figure 2. a) Subdivision of domain in areas. b) Geographical area where most of the evaporation contributing to precipitation over Trentino (during the extreme events of 3-5 November 1966, 16-18 November 2000 and 24-26 November 2002) occurred.

A simple statistical analysis of the meteorological variables along trajectories over various macro-areas allowed to point out the occurrence of interesting meteorological features (e.g. deep convection, intense latent heat fluxes, atmospheric instability or neutrality, ...). Although the analysis of singular meteorological events with a LAM model (i.e. from an Eulerian point of view) is generally more detailed and complete, the advantage of the lagrangian method consists in the capability of connecting them by airmass back trajectories. For example it can be noticed that on the 3rd of November 1966 deep convection occurring over the Tyrrhenian Sea contributed to reinforce water vapour fluxes to the lower atmospheric layer and to enhance the precipitation over Trentino.

The analysis of the three selected extreme precipitation events shows that precipitation over Trentino is strongly conditioned by the evaporation processes and by the airmasses properties determined over the Central Mediterranean area (Fig. 2b). In particular, most of the water vapour contributing to the precipitation ending over the Alps originates over Tunisia, the coastal regions in eastern Algeria and in western Lybia, the Channel of Sicily, the Gulf of Gabes and the southern Tyrrhenian Sea. A more detailed description of the water budget analysis and of the results can be found in *Bertò (2005)*.

3. FEATURES OF THE WCB IN MEDITERRANEAN CYCLONES

3.1. Trajectory clusters and analysis of the WCB in Mediterranean Cyclones

By gathering similar trajectories into representative clusters (see *Bertò et al., 2004* for details) airstreams driving the water vapour from the respective source regions to the Alps were identified and characterized. In particular, in the present work a two-step agglomerative algorithm has been adopted (*Bertò, 2005*). As an example, the trajectory clusters for the event of November 1966 is shown in Fig. 3.

A simplified conceptual model (Fig. 4) has been proposed to visualize the common traits of the moist airstreams within intense Mediterranean cyclones (*Bertò, 2005*).

Generally a surface low moves slowly over the Tyrrhenian Sea accompanied by a surface cold front, which is commonly meridionally oriented from North Africa to the low center. All the computed trajectories of air masses producing intense precipitation over the Alps result to belong to the WCB, which originates over Africa and the Central Mediterranean Sea, flows South to North over the Tyrrhenian Sea and crosses the Apennines and the Alps, forcing a pool of cold air to remain blocked in the Po Valley in front of the mountains. It is interesting to note that the airstreams ending at the lower levels over Trentino display the typical characters of a "W2" conveyor belt (*Browning and Roberts, 1994*): they originate over the Central Mediterranean Sea, are very moist and relatively cold; their lifting and precipitation production is generally enhanced by the Alpine chain (arrow B. in Fig. 4). The airstreams ending at higher levels over Trentino display typical characteristics of a "W1" conveyor belt, although their contribution to the precipitation over the Alps is moderate, as they are relatively drier: indeed they have flown for a long time over Sahara before reaching the target area (arrow A. in Fig. 4).

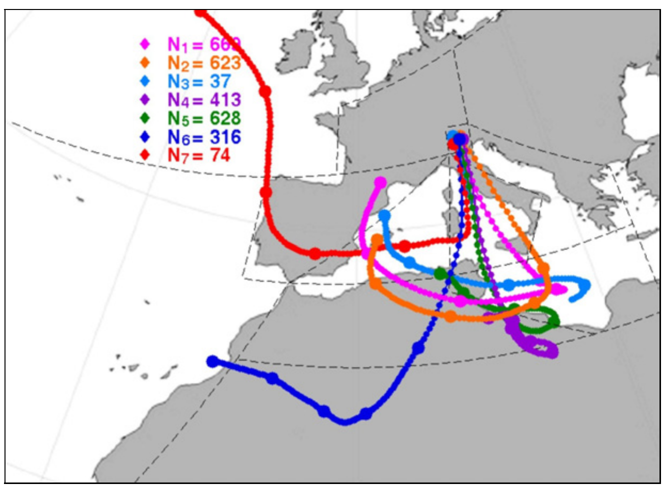

Figure 3. Clusters of airmass trajectories arriving over Trentino in the period from 03/11/66 21 UTC to 04/11/66 12 UTC. Every curve is the average, in the physical space, of all trajectories belonging to that cluster. Small circles denote position of the airmasses at 1 hour timesteps, big circles positions at 24 h timesteps. N_i denotes the number of trajectories in the i-th cluster.

In particular in the case of 2002 the 2/3 of trajectories belong to the airstream (arrow A.) flowing higher from Africa to the Alps (warm and relatively dry, moderately ascending), the remaining trajectories to the lower airstream (arrow B.) originating over the Central Mediterranean Sea (potentially colder, very moist and rapidly ascending).

On the contrary in the event of 1966 the first type of airstream (arrow A.) is essentially absent. Because of the high values of the vertical velocity in front of the Alps between 3 and 4 November, all the trajectories belong to W2 which causes the intense precipitations over the Alps.

This features suggest that the trajectory populations of the two portions of WCB can be a crucial point controlling the precipitation production: the higher the vertical lifting over the southerly slopes of Alps, the larger the amount of airmasses belonging to W2 (i.e. to the portion of WCB closer to the surface) and the larger the expected amount of precipitation.

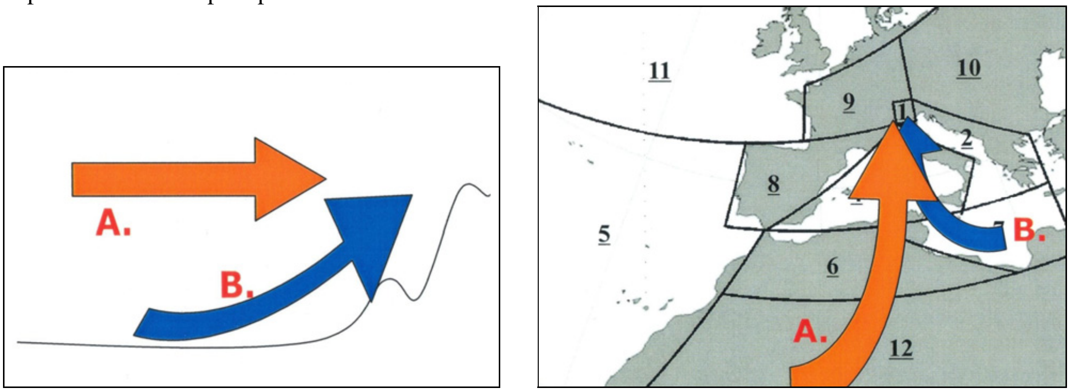

Figure 4. Conceptual model describing the main features of the WCB for extreme precipitation events occurring over the Alps. The airstreams ending at the higher (A.) / lower (B.) levels over Trentino have the characteristics of W1 / W2 conveyor belts.

3.2. Risk index

Following previous observation, a risk index of extreme precipitation over Trentino has been proposed, based on the path of the computed back trajectories:

$$i = \frac{N_{area7}}{N_{TOT}} \frac{1}{\bar{z}_{area7}} \tag{1}$$

where N_{TOT} is the total number of trajectories, N_{area7} is the number of trajectories flowing over area 7 and $\bar{z}_{area7}$ the average height of the trajectories while flowing over the same area. The idea behind this simple formula is that strong precipitation occurs when a high percentage of the total number of trajectories flows over area 7 at a relative low height. The formula has been tested over the 3 case studies: the linear regression between the risk index and the measured precipitation seems to confirm this idea. Of coarse the analysis should be extended to many more case studies to be tested conveniently.

4. CONCLUSIONS AND FUTURE DEVELOPMENTS

The present work proposes a method to investigate and estimate mechanisms of water vapour transport mechanisms over the Mediterranean area. The evaporation rate over the sea (related to the SST and to the surface wind speed) is one of the elements concurring to enhance the probability of precipitation. Nevertheless the results of the study show that the equation "higher evaporation = higher precipitation" is not always valid, and that the marking features of the WCB are much more crucial.
Anyway, so far, the methodology has been tested only on three selected events. In a near future it should be applied on a larger number of precipitation cases in order to reconstruct a climatology of both the WCBs and the evaporation areas contributing to the precipitation over the Alpine region.

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