MONTHLY ISOTOPIC SIGNAL OF THE PRECIPITATED WATER IN THE PROVINCE OF TRENTO: LAGRANGIAN ANALYSIS AND DISCUSSION OF MEASUREMENTS

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Abstract: The present work has been performed in the framework of the research project AQUAPAST. The main focus of AQUAPAST is the reconstruction of past climate changes in the atmospheric circulation and in particular in the water vapour transport mechanism over the Mediterranean area starting from the analysis of the isotopic content of cave speleothemes in the Trentino Province (North-East of Italy). A Lagrangian methodology for the reconstruction and the analysis of the airstreams which govern the transport of water vapour has been applied to recent events. The average monthly isotopic signal of the precipitation water sampled in stations located in key geographic settings in the Province of Trento is used as tracer to infer the origin of the precipitating water and to validate the Lagrangian analysis. A comparison between the isotopic signal of November 2002 and November 2003 is here presented, as most of the yearly precipitation falls in November over the Eastern Alps. Hypotheses are proposed about the meteorological factors (e.g. monthly averaged sea surface temperature, atmospheric circulation, etc.) determining different isotopic signals in the two years.

Keywords – *Lagrangian Analysis, Atmospheric Circulation, Isotopic Signal*

1. INTRODUCTION AND ISOTOPIC SIGNAL

The present-day spatial patterns of $\delta^{18}O$ values of precipitated water ($\delta^{18}O_p$) are a consequence of the $\delta^{18}O$ of the source, which is commonly the Ocean ($\delta^{18}O$ water is equal to zero or slightly negative for the Atlantic Ocean, and about zero for the Mediterranean Sea), of the temperature of condensation along the trajectory of the cloud fronts, of the distance from the sea, of longitude and latitude and of the amount of precipitation (Gat, 1996).

Longinelli and Selmo (2003) showed that there is no latitudinal effect in Italy on the spatial variation of mean annual $\delta^{18}O_p$ observed over a time period of 1 to 8 years in the '90s. By contrast, the $\delta^{18}O_p$ depends on the orography of the Italian peninsula. This seems to confirm the dependence of the isotopic signal on the average height (and temperature) at which water vapour condensation occurs (Ayalon et al., 1998).

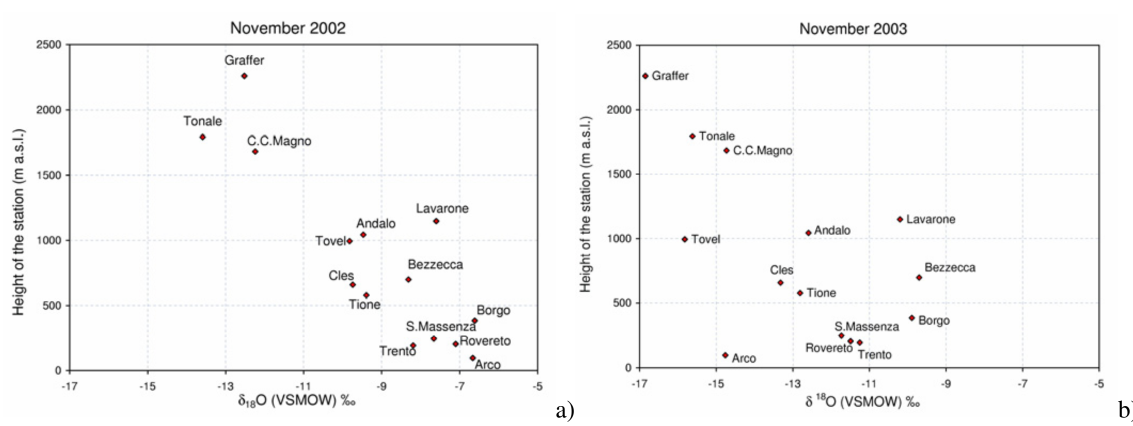

Figure 1. Plot of mean monthly $\delta^{18}O_p$ in precipitation vs. altitude of the meteorological stations in Trentino for (a) November 2002 and (b) November 2003 .

Fig. 1 shows the mean monthly $\delta^{18}O_p$ recorded in the selected meteorological stations of Trentino in November 2002 and November 2003. A clear $\delta^{18}O_p$ depletion with altitude can be observed. The average values of the $\delta^{18}O_p$ measured at all stations show a clear ^{18}O enrichment in the precipitation of November 2002 (mean $\delta^{18}O_p$ for all stations about -9 ‰) with respect to November 2003 (about -13 ‰). The oxygen isotopic composition for the November 2002 and 2003 rainfalls can be explained by the different large-scale atmospheric circulation governing the precipitation episodes which contributed to the mean $\delta^{18}O_p$ signal and drove the water vapour on Trentino from different source-areas. In November 2002 there was a major precipitation event which occurred from the 24th to the 26th of November. By contrast, in November 2003 two minor precipitation events occurred: a first one from the 31th of October to the 1st of November and a second one on the 8th of November.

2. LAGRANGIAN ANALYSIS

A Lagrangian analysis of three case studies was performed in order to shed light upon the relationship between atmospheric circulation and mean monthly $\delta^{18}O_p$.

2.1. Trajectory computation and cluster analysis

Five-day back-trajectories were computed by using the FLEXTRA Lagrangian model, which integrates fully 3D-trajectories by interpolating wind records to air current particle position. FLEXTRA interpolation of the wind field is linear in time, bi-cubic in the horizontal and polinomial in the vertical dimensions. The integration scheme is accurate to the second order. Representative ending points for the trajectories to be calculated have been selected as the grid-points of a 3D-grid with 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 was assumed that 460 ending points properly represent the thermodynamic state of the air masses producing precipitation over the target area. Subsequently, 460 back-trajectories arriving over Trentino were computed every 3 hours. Each parcel was tracked until it left the model domain. The (air) parcels were never backtracked for more than 5 days.

Afterward, refined techniques of trajectory cluster analysis helped to identify and characterize airstreams driving the water vapour from the respective source regions to the Alps. In particular, in the present work a new two-step agglomerative algorithm was adopted (*Bertò, 2005*).

2.2. Trajectory clusters in the three events

The computed trajectory clusters are shown in Fig. 2a and 3. From Fig 2, it can be seen that in the November 2002 event, the air masses were advected from the Tropical regions over Africa. They belonged to the WCB ahead of the cold front progressively moving from Spain and Morocco to Northern Africa and the Central Mediterranenan Sea. These air masses were moist (4-5 g kg^{-1}) in comparison with the typical values of specific humidity (2-3 g kg^{-1}) recorded along trajectories flowing over the desert, and gained further humidity from evaporation over the Mediterranean Sea.

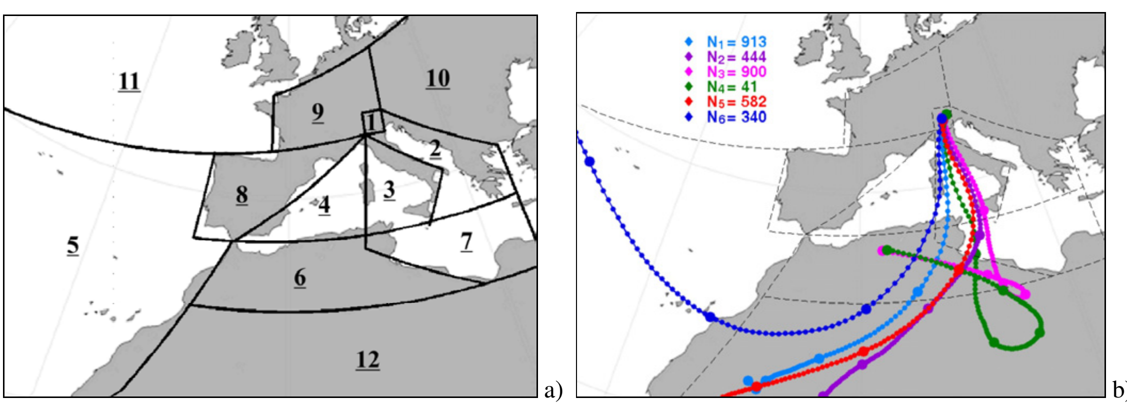

Figure 2. a) Subdivision of the computation domain in areas. b) Clusters of trajectories arriving over Trentino from 25/11/02 21 UTC to 26/11/02 15 UTC. Every curve is the average, in the physical space, of all trajectories belonging to that cluster. The average position every 1 hour is marked by a small circle, the position every 24 hours by a large circle. On the upper left corner the number of trajectories for each cluster is indicated.

During the final day, all trajectories entered an area of cyclonic ascent (over the North of Algeria, Tunisia, the Channel of Sicily and the Tyrrhenian Sea) which forced air masses to reach saturation.
In the first event of November 2003 (Fig. 3a) the atmospheric circulation was dominated by an intense zonal flow related to a deep low over Great Britain, driving a cold front from the Atlantic Ocean over Spain and over the South of France. The trajectory analysis confirms that the air masses gained specific humidity over the Ocean and that they experienced a weak vertical lifting in the last day. In the second event of November 2003 (Fig. 3b) the air masses showed a very peculiar path, with the higher trajectories originating over Russia and the Eastern Mediterranean basin and the lower trajectories originating over the North of Europe, approaching Italy from North-East (“Bora” wind) and only later turning and moving toward the Alps. So these air masses were almost dry at the origin, followed an easterly retrogade cold front, gained specific humidity while flowing over the North of Italy and over the Gulf of Genoa where an anomalous cyclogenesis occurred which suddenly drove the airmasses to the North.

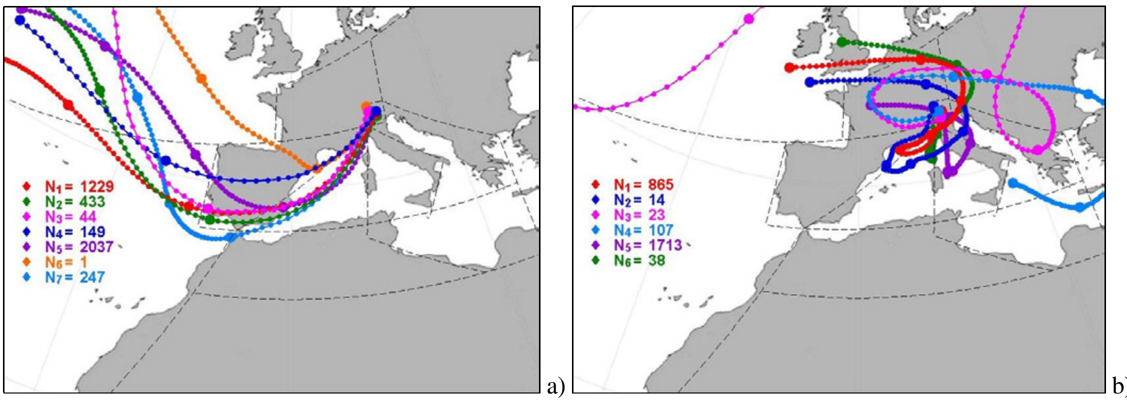

Figure 3. Clusters of trajectories arriving over Trentino in the period from 31/10/03 12 UTC to 01/11/03 12 UTC (a) and in the period from 08/11/03 06 UTC to 08/11/03 21 UTC (b). Every curve is the average, in the physical space, of all trajectories belonging to that cluster. The average position every 1 hour is marked by a small circle, the position every 24 hours by a big one. The number of trajectories for each cluster is indicated.

2.3. Origin of water vapour

The whole surface domain was subdivided into 12 macroareas covering the European and Mediterranean regions (Fig. 2a) to estimate, as best as we could, the amount of water vapour generated over each area.

Area	2002 [%]	2003_1 [%]	2003_2 [%]
2	12	-3	18
3	**72**	-	-53
4	6	-9	**116**
5	4	**108**	-
6	-20	16	16
7	**45**	1	5
8	-2	3	3
9	-4	-17	5
10	-	-	-14
11	-19	10	-2
12	-9	-	-

Table 1. Lagrangian estimation of the amount of water vapour which originated over each macroarea (see Fig. 2 for their definition) and contributed to the precipitation over the target area (Trentino) on 25-26 November 2002 (column header 2002), on 31 October – 1 November 2003 (column header 2003_1) and on 8 November 2003 (column header 2003_2). The estimation is expressed as a volume percentage of the total amount of precipitation fallen during each event. The value is positive if trajectories gain specific humidity over the considered macro-area.

Such choice allows for summarizing most of information in a 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. For example in Tab. 1 the Lagrangian estimation is reported of the amount of water vapour which originated over each macro-area and contributed to the precipitation over the target area (Trentino) during the three case studies.

The analysis confirms that in November 2002 most of the water vapour producing precipitation originated over the Central Mediterranean Sea, while in November 2003 it originated over the easterly Atlantic Ocean, the Gulf of Genoa or even over the North of Italy. Moreover the height at which condensation occured was higher in 2003 than in 2002 since the starting relative humidity along trajectories was quite low. The Atlantic provenance and the higher altitude of condensation for the 2003 events are consistent with the depleted mean monthly $\delta^{18}O_p$ values measured at all stations in Trentino. Thus, the $\delta^{18}O_p$ values validate our reconstructed area of origin for the water vapour. Our reconstruction, also, stresses the importance of the source areas contribution to the $\delta^{18}O_p$ signal, which may vary for the same month in different years. This might be a possible explanation for the observed lack of latitudinal effects in Longinelli & Selmo's 2003 map.

3. CONCLUSIONS

Different mean monthly $\delta^{18}O_p$ values measured in several stations for the same month in two successive years can be ascribed to several meteorological factors, which were reconstructed by Lagrangian analysis. Even though only three cases were considered, the present study confirms that the meteorological scenario, and in particular the large scale circulation, largely influence the $\delta^{18}O_p$ signal in a target region. This has important implications in past climate reconstructions from $\delta^{18}O$ values of climate archives, such as cave calcite (stalagmites).

The $\delta^{18}O$ value measured in the annual layers of stalagmites can be potentially used as a tracer of the water vapour tracks in the past decades in order to reconstruct changes in atmospheric circulation and in particular in the water vapour transport mechanisms and possibly link these changes to climate forcing (solar) and climate phenomena (NAO) that are well preserved in these climate archives.

Acknowledgement: *This work was supported by the Provincia Autonoma of Trento under the research project AQUAPAST.*

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