CLUSTERING OF THE HIGH RESOLUTION BACKWARD TRAJECTORIES FOR SLOVENIA

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Abstract: High resolution backward air trajectories arriving at four measuring sites in Slovenia were calculated for months April to September of years 2003 and 2004. K-means clustering methodology was used for classification of trajectories into groups with similar curvature, length and direction. We investigated how different meteorological variables at trajectory receptor points differ between groups of similar trajectories (clusters). Analyses of trajectories reveal the most typical flow patterns and effects of alpine barrier on air mass travelling. Their influence on precipitation accumulation is discussed in more detail.

Keywords: *trajectory, clustering, climatology*

1. INTRODUCTION

The study of episodes of high ozone concentrations in Slovenia was the primary motivation for computing the backward trajectories on high resolution meteorological fields. The trajectories were calculated for the warm halves of two years and analyzed from the air quality point of view. Regarding high ozone concentrations, trajectories can be used to estimate pollutant source regions and to identify meteorological regimes that lead to high ozone concentrations on selected locations in Slovenia. Such trajectories help to better understand some other meteorological phenomena, as well. Groups of trajectories associated with significantly lower and higher value of several meteorological variables were identified with clustering methodology. The clusters of high resolution trajectories were analyzed and results related to precipitation, temperature, and ozone are presented.

2. DATA

Meteorological fields computed with ALADIN/SI model (ALADIN IT, 2003) with 9.5 km spatial and 1 hour temporal resolution were used for trajectory calculations for the warm parts (April - September) of years 2003 and 2004.

Three-dimensional trajectories were computed with the FLEXTRA trajectory model (Stohl et al., 1995) for 4 receptor points in Slovenia (Ljubljana, Nova Gorica, Krvavec, Iskrba) at 3 different arrival levels (50 meters a.g.l., and 1500 and 5500 meters a.s.l.). Trajectories were calculated 96 hours backward in time every 3 hours for arrival levels 50 meters a.g.l. and every 12 hours for remaining two arrival levels. Their positions were recorded each hour, though for clustering, only horizontal coordinates of last 24 hours were taken into account. The classifications were done also for 48, 72 and 96-hour trajectory lengths, but results of 24-hour trajectories clustering are most representative and interpretable.

Ground level measurements of meteorological parameters (temperature, pressure, relative humidity, solar radiation, wind speed and precipitation) at all trajectory receptor points were provided by Environmental Agency of the Republic of Slovenia.

2. CLUSTERING

Clustering algorithms (Everitt, 1993) are a set of multivariate analysis techniques that seek to discover natural groupings among a set of *N* objects for which the same set of variables is observed. In our study, k-means clustering algorithm was used, which is probably the most common technique among many different clustering algorithms (Hand et al, 2005). This algorithm iteratively minimizes the sum of distances from each object (trajectory in our case) to its cluster centroid, over all clusters, by moving objects between clusters until the sum cannot be decreased further. The result is a set of clusters that are as compact and well-separated as possible.

Like many other types of numerical minimizations, the solution that k-means reaches, often depends on the starting points, i.e. the initial cluster centroids. Hence, the minimum that is found by k-means can be merely a local minimum. To avoid reaching the local minima we used the multiple random starts procedure. We repeated the clustering 800-times with random initial cluster centroids and then selected the solution with a minimum sum of distance from final cluster centroids. For calculating the distances between trajectories, the Euclidean similarity measure was used.

3. RESULTS

Figure 1 shows the number density of the entire trajectory data arriving to Ljubljana on two levels: 50 m a.g.l. and 5500 m a.s.l. In contrast to homogeneous flow pattern with predominating western flow at 5500 meters, there are some characteristic pathways at lower levels, that are influenced by the very complex topography. Some significant pathways were determined by grouping similar trajectories into clusters. Cluster centroids for three final levels are presented in Figures 3 and 4. They are consistent with flow patterns shown in Figure 1. The connections between meteorological variables measured at final trajectory points and the 50 m trajectory clusters were studied and are shown in Table 1. Kruskal-Wallis test was used for testing the significance of inter-cluster variation in variables, while Turkey-Kramer criterion was used to determine significant differences in measured variables for pairs of clusters (Hochberg and Tamhane, 1987).

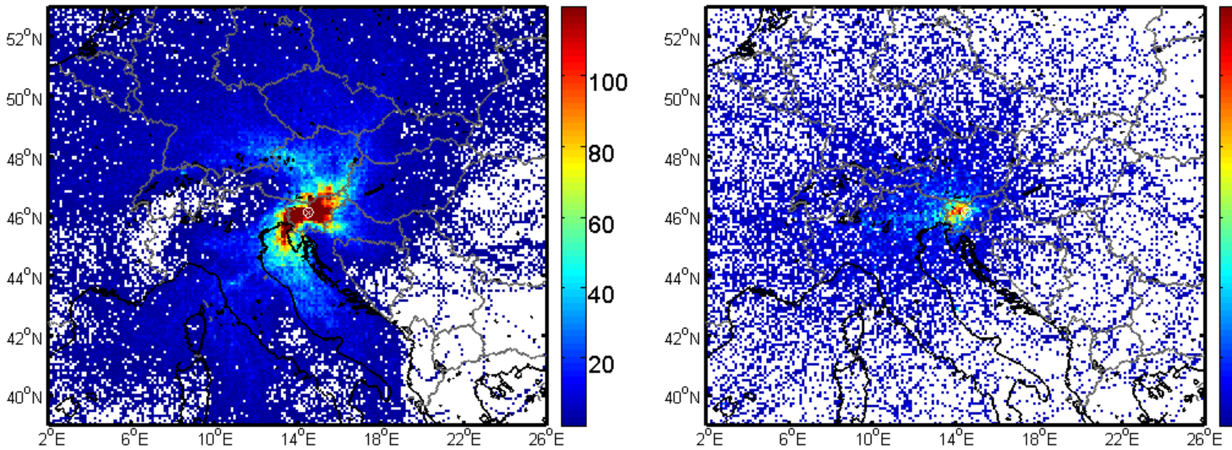

Figure 1: Number density of trajectories for Ljubljana. Left: final trajectory points are located 50 meters above ground level. Right: final trajectory points are located 5500 meters above mean sea level.

Among meteorological variables measured at ground level, precipitation depends mostly on air flow in higher level. For 1500 m and 5500 m, trajectory clusters are presented in Figure 3 and results of precipitation analysis are shown as well. Number density of 50 m trajectories for precipitation days, hot days and for days with maximum ozone concentrations above 150 µg/m^3 is shown in Figure 2. As we expected, flow patterns of ozone days correspond highly to hot days flow patterns, only that there is more south-westerly flow in ozone days which indicates possible sources of ozone precursors.

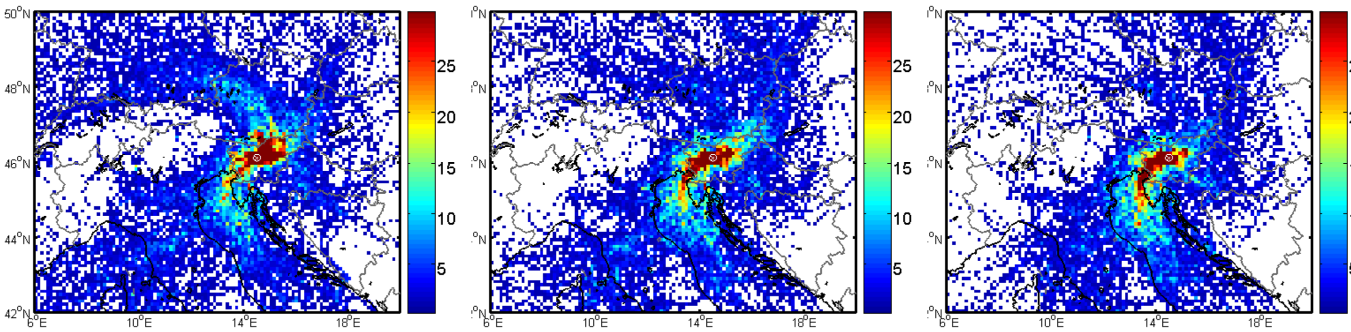

Figure 2: Number density of selected trajectories 50 m above ground level for Ljubljana. Left: days with measured precipitation above 5 mm. Centre: days with maximum daily temperature above 30 °C. Right: days with maximum ozone concentrations above 150 µg/m^3.

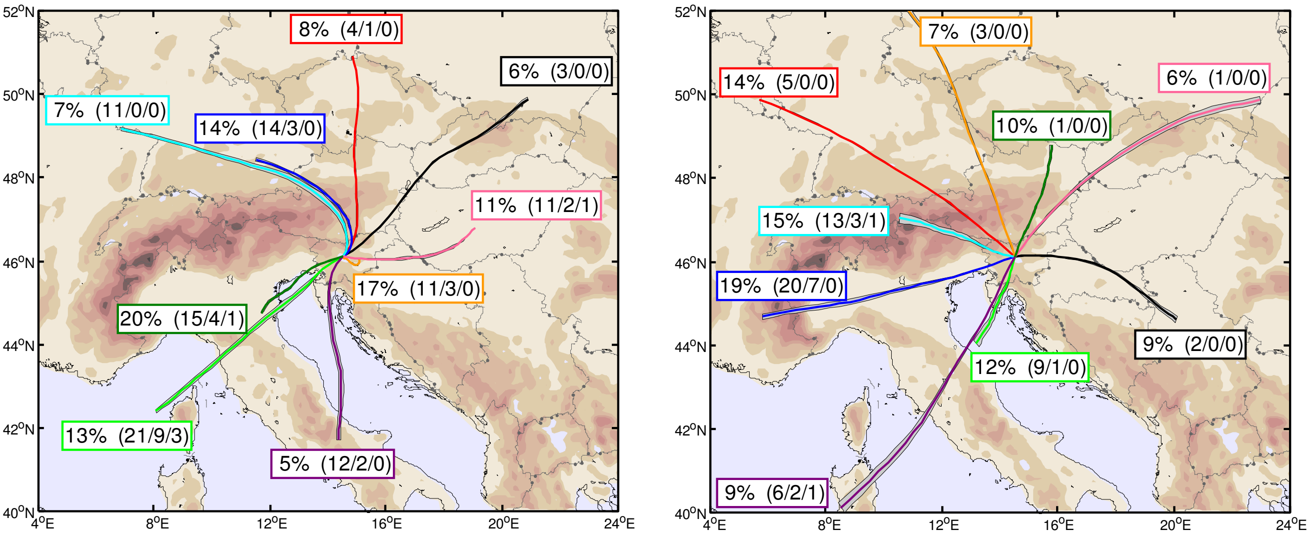

Figure 3: Trajectory cluster centroids for Ljubljana according to precipitation amount. Final trajectory points are located 1500 meters (left) and 5500 meters (right) above sea level. Text in the boxes has the following form: *a* (*b/c/d*), where *a* stands for percentage of trajectories in a cluster, and *b*,*c* and *d* stand for the number of days with precipitation above a certain threshold: *b* above 1 mm, *c* above 20 mm and *d* above 40 mm.

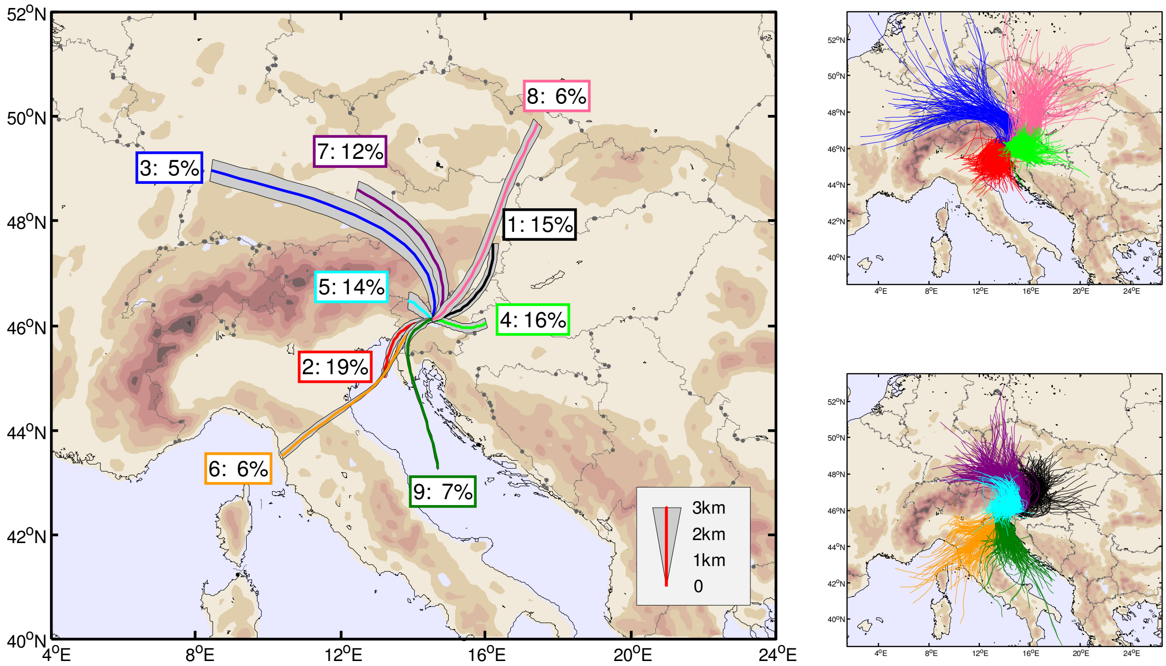

Figure 4: Left: trajectory cluster centroids for Ljubljana. Final trajectory points are located 50 meters above ground level. Beside cluster number the percentages of complete trajectories occurring in that cluster are stated. Right: all cluster members for the clusters on the left side.

From Figure 4 and Table 1 some conclusions for 50 m trajectories can be drawn. Since they are originating from the north, air masses in clusters 3, 7 and 8 have significantly lower temperatures. All three clusters have only a few precipitation days, which is partly due to Foehn effect. Clusters 7 and 8 are associated with high amount of direct solar radiation, while cluster 3 is associated with a significantly higher relative humidity and the lowest average value of measured direct solar radiation. There are cold and cloudy days in this cluster, but without precipitation.

Table 1: Average values of meteorological variables measured in Ljubljana for 9 clusters of trajectories with final points 50 m above ground level (Figure 4). Precipitation averages are calculated over days with precipitations above 1 mm and above 20 mm – numbers of those days are stated in brackets. Bold numbers indicate groups that significantly differ in the value of the variable from other clusters (Tukey-Kramer significant difference criterion, significance level α=0.05).

Parameter\Cluster	1	2	3	4	5	6	7	8	9
Temperature (°C)	18.8	18.5	**10.9**	18.5	20.0	18.2	**15.6**	**14.5**	18.3
Max temperature (°C)	23.5	24.8	14.9	24.7	25.7	22.7	20.7	21.4	23.6
Solar radiation (W/m^2)	362	435	265	376	405	271	416	391	312
Relative humidity (%)	70	70	**84**	72	68	69	71	70	71
Pressure (hPa)	981	979	980	981	979	**976**	981	**984**	**975**
Wind speed (m/s)	1.7	2.0	2.1	**1.3**	1.6	2.5	1.7	2.2	2.5
Precipitation (mm)	14.9 (**14**)	15.6 (**25**)	11.0 (4)	9.0 (9)	12.0 (**20**)	13.6 (6)	7.7 (9)	**4.0** (5)	19.2 (**13**)
Precip. above 20mm	38.4 (**4**)	38.2 (**7**)	20.1 (1)	21.9 (1)	35.2 (**4**)	25.5 (2)	25.4 (1)	- (0)	40.5 (**5**)

In clusters 2, 4 and 5, there is a slow movement near the ground, indicating situations with weak pressure gradient. A high amount of direct solar radiation accounts for stagnant anticyclone situations. But in clusters 2 and 5, there is also considerable amount of precipitation days. Precipitation in cluster 5 is due to the front from NW which is stationary at the alpine barrier. Precipitation in cluster 2 (and also in clusters 9 and 6) correspond to the Mediterranean cyclone, formed at the western edge of the Alps, when the southern flow of warm and wet air from the Adriatic sea following the front passage leads to precipitation.

From previous studies we know that most precipitation in the SE Alps accumulates in the prefrontal stage of the Mediterranean cyclone with strong SW conveyor belt within warm sector. Additionally, precipitation is enhanced ageostrophically, when cold air moves around the Alps and invades the SE slopes of the Alps from East. This flow can be detected with strong wind shearing at low levels: S – SSW winds above and E – NE below (Vrhovec et al. 2001, Vrhovec et al. 2004). This may explain a great part of precipitation of cluster 1. Analysis of precipitation for higher level trajectory clusters in Figure 3 confirms that precipitation is correlated to western and south-western flow in higher altitudes.

4. CONCLUSION

K-means clustering proved to be a successful tool for identifying the typical pathways of air masses. Analyses of meteorological parameters for trajectory clusters show some distinct characteristics of air masses approaching Slovenia from different origins. The relations between clusters and precipitation were studied in greater detail and our results correspondent to the results of previous studies. In our study, only clustering of trajectories at one final level at once was performed. To identify both the typical pathways at different levels and also the synoptic regimes, trajectories at different final heights should be studied at once and the trajectories approaching final points at different levels should be clustered at the same time.

Acknowledgements: The authors would like to thank dr. Mark Žagar for providing ALADIN meteorological fields and dr. Saša Gaberšek for the calculation of trajectories with FLEXTRA model. This study has been carried out with the support of Environmental Agency of the Republic of Slovenia, which provided us with all the measured data.

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