ATMOSPHERIC INPUT OF INORGANIC NITROGEN TO THE ADRIATIC SEA

Vesna Duricic

Meteorological and Hydrological Service of Croatia, Zagreb, Croatia - Vesna.Djuricic@cirus.dhz.hr

Abstract

In order to study atmospheric transport of pollution to the Croatian Adriatic coast, cluster analyses of isenthropic backward trajectories, together with mean pH and nitrogen compounds precipitation concentration and wet deposition, for one-year period were calculated. In that particular year west flow was predominant. Adriatic coast is under the combined influence of local, regional and long distant pollution sources. The influence of local and regional pollution sources prevail on average, but the influence of long distant sources can not be neglected.

Keywords: Adriatic Sea, eutrophication, trajectory analyses.

The influx of man-made nutrients in the form of inorganic nitrogen compounds to coastal areas may result in the long-term decline of marine life. Some undesirable events occurred in the Adriatic Sea in the past decades: invasions of jellyfish and other species, hypertrophic formations of mucilaginous aggregates, and an increased frequency of toxic dynoflagellate appearance (1). Atmospherically derived dissolved inorganic nitrogen ($NO_3^- + NH_4^+$, components of acid rain) contributes 25-35% of total loading of this primary nutrient (2,3,4). Model calculations show that approximately 80% of nitrogen compounds comes to Croatia from neighbouring countries, while about 70% of nitrogen from Croatian sources is deposited in Croatia (5,6).

Computation of air parcel trajectories is a very powerful tool to estimate the long-range transport of substances. To study atmospheric transport to the northern, mid and southern Adriatic coast, 72-hours backward isentropic trajectories were computed for three locations, from 10 m asl once a day, beginning at 00 UTC, for the one year period October 1998 - September 1999. HYSPLIT4 (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model (7), developed in NOAA Air Resources Laboratory (http://www. arl.noaa.gov/ready/hysplit4.html) was used. Cluster analyses of trajectories in days with precipitation was made using cluster program developed by Stunder (8). For each cluster volume-weighted average pH value, nitrate and ammonium concentrations and wet deposition were calculated.

The main differences between cluster-mean trajectories are in their length and direction, depending specially if trajectories come from inland or sea. At all three stations there are short (50-400 km), medium (50-400 km), long (1500-2500 km) and very long (2000-5000 km) cluster-mean trajectories. Short trajectories, representing local and regional pollution transport, are very frequent (about 50% of all) during all seasons. They are connected with zero pressure gradient field, typical for summer, or the case of stationary low pressure field over the north Adriatic. Characteristics of those situations are weak winds of variable direction, maximum turbulent vertical exchange in summer, but very stable conditions with temperature inversions and no mixing in winter. Direction of short trajectories depends on location, but more frequently they come from inland in warm part of the year and from the sea in cold part of the year. The main characteristic of SW and W cluster-mean trajectories is crossing over the Mediterranean Sea and coming to the measurement site from the sea side. They are connected mostly with Genoa low pressure field. The region they cross over is not very polluted, so they do not bring a lot of anthropogenic air pollution. Those clusters contain sometimes several trajectories from Sahara, bringing Saharan dust to the Adriatic.

From NW-W come long and very long trajectories. In those situation southwest Europe is under the high pressure field, while northeast under the low pressure. Strong wind is mainly connected with frontal passages and fast advection of cold air over the warm land. Trajectories cross over the sea with natural sulphur emission (affecting chemical composition of precipitation, specially pH) with significant part of their length. They also cross over the west and northwest Europe with high anthropogenic pollution emission.

Most of trajectories are curved and very often the main direction of the cluster differs from the direction of its incoming to the site. Local and regional conditions (meteorological, and specially orographic) cause turning of general west and northwest airflow, which is the most common for Croatia, to local northeast. This analyses is made for one particular year. The conclusions cannot be generalised. However, they agree with similar investigation for the GAW regional station Zavizan (9) and for several other stations in Croatia (10).

In precipitation days about 65% o trajectories on the northern, 71% on the mid and 78% on the southern Adriatic come from western quadrant (Fig. 1). On average the most acid is precipitation connected with short or medium

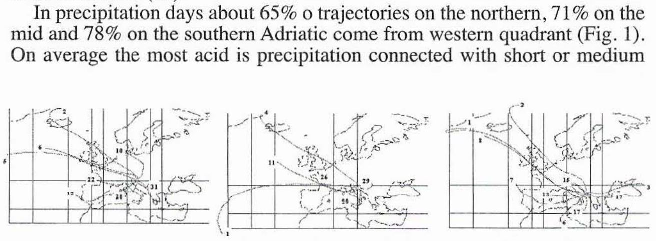

Fig 1. Cluster mean trajectories in days with precipitation to the northern, mid and southern Adriatic coast, in the period October 1998 – September 1999 (number at the end of cluster-mean trajectory indicates the number of belonging single trajectories).

Table 1. Characteristics of wet deposition in different trajectory clusters on the Adriatic coast, for the period Oct. 1998. to Sept. 1999. (N = number of trajectories; Σ RR = total precipitation amount in cluster (mm); pH_{vw} = prec. volume-weighted average pH; $(NO_3^- \text{-} N)_{vw}$ = prec. volume-weighted nitrate concentration (mg/l); $(NH_4^+ \text{-} N)_{vw}$ = prec. volume-weighted ammonium concentration (mg/l); Dep.NO_3 = nitrogen wet deposition from nitrates (g/m²); Dep. NH_4 = nitrogen wet deposition from ammonia (g/m²); numbers in brackets indicates only one or two samples).

	Northern Adriatic								Mid - Adriatic					
Cluster	short	S	W	SW	NW_l	NW	N	NW_{vl}	short NE	short SW	NW_l	NW	NW_{vl}	W
N	31	28	22	12	5	6	10	2	29	29	11	26	4	1
S RR (mm)	428.3	500.9	223.9	157.3	54.1	13.6	38.6	3.8	108.8	227.6	127.3	293.2	15.8	0.4
pHvw	5.39	4.98	5.47	5.41	5.33	6.70	6.10	6.10	6.4	6.3	6.1	5.7	6.7	7.8
$(NO_3^-\text{-}N)vw$	0.86	1.06	0.68	0.75	0.70	(2.2)	0.79	(1.4)	0.94	0.85	0.72	0.74	0.70	/
$(NH_4^+\text{-}N)vw$	0.91	0.67	0.87	0.61	0.48	(2.2)	0.81	(1.2)	0.48	0.57	0.73	0.40	0.54	/
Dep. NO_3 (g/m²)	0.37	0.53	0.15	0.12	0.04	0.03	0.03	0.005	0.10	0.19	0.09	0.22	0.01	/
Dep. NH_4 (g/m²)	0.39	0.33	0.20	0.10	0.03	0.03	0.03	0.004	0.05	0.13	0.09	0.12	0.01	/
	Southern Adriatic													
Cluster	short NW	short S	E	E_l	W	SW	NW	NW_l	$NW\text{-}N_{vl}$					
N	15	17	17	3	13	6	7	8	3					
S RR (mm)	143.9	164.6	203.9	34.2	151.5	107.4	58.3	55.4	15.3					
pHvw	6.06	6.23	5.76	5.85	5.74	6.50	5.97	6.38	6.38					
$(NO_3^-\text{-}N)vw$	1.28	0.95	0.41	(0.4)	0.75	0.92	1.07	0.76	1.51					
$(NH_4^+\text{-}N)vw$	3.79	0.82	0.47	(0.2)	0.66	1.12	1.66	0.42	1.12					
Dep. NO_3 (g/m²)	0.184	0.156	0.084	0.014	0.114	0.099	0.062	0.042	0.023					
Dep. NH_4 (g/m²)	0.545	0.135	0.096	0.006	0.099	0.120	0.097	0.023	0.018					

long trajectories from west, which are more or less curved before reaching the monitoring station (Tab. 1). Those trajectories bring the greatest amount of nitrate wet deposition to the northern and mid Adriatic coast. Air mass belonging to those cluster-mean trajectories circulates over industrial developed, anthropogenic and natural polluted European regions, northern Italy, Mediterranean and northern Adriatic (Kvarner Bay). The highest ammonium wet deposition at the northern Adriatic is connected with short trajectories from SE (inland sources), while at the mid Adriatic from S-SW (across the sea). On the southern Adriatic wet deposition of both nitrogen compounds is the greatest connected with short NW trajectories (inland), although they bring only 15% of total precipitation amount. Concentration of nitrate and ammonium ions could be very high in precipitation coming from very distant sources from NW or N, because of the high anthropogenic pollution in NW Europe (11). It seems that Adriatic coast is under the combined influence of local, regional and long-distant pollution sources. On average, higher nitrogen concentrations were found in weather situations reflecting local and regional pollution source influence, with frequency of about 20% of time giving cca 20% of total precipitation amount. However, higher individually concentrations were connected with weather situations reflecting mainly distant source influence which frequency is about 45% of time and gives 60% of total precipitation amount.

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