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Using Wind Data to Predict the Risk of Volcanic Eruption: An Example from Damavand Volcano, Iran

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Abstract

Damavand volcano is located 60 km to the East North- East of Tehran. It is a dormant stratovolcano outcrop in the Alborz Mountains of northern Iran and is the highest mountain (5670 m) in the Middle East and West Asia. Mazandaran Province, one of the most populous provinces by population density, Semnan and Gorgan provinces further east are neighbours of the Damavand. Volcanism in Damavand goes back to at least 1 Ma year ago and the latest eruption occurred 7000 years ago. Tephra dispersal in volcanoes strongly depends on atmospheric information in particular wind direction and velocity in stratospheric and tropospheric levels. We present an analysis of wind data to assess the hazards that would result from tephra fall in the cities and provinces neighbouring Damavand. Atmospheric data were provided from the Meteorological stations at Mehr-Abaad airport, Wyoming University and global data sets. We examine wind data from 17 standard pressure levels which cover from 5700 meter (Damavand peak) to 31 km above sea level. If Damavand moved into a state of unrest then a major explosive eruption is a plausible scenario that should be planned for. The results confirm that the area to the south and east of volcano will be affected by tephra. Communities around the southern and eastern flanks of the volcano also have high hazard. Wind data also shows the effects of season on dispersal of tephra from a 25 km high eruption column. Tephra dispersal is dominantly towards the east in all seasons for eruption columns up to 20 km above sea level. Mazandran, Semnan and Gorgan providence could be affected in this case. At 25 km- high eruption column and during the summer there are easterly winds; therefore, the tephra would disperse toward the east. In this case Tehran could experience a tephra fall deposit

Keywords: *Damavand Volcano, Explosive eruptions, Volcanic hazards, Pyroclastic units.*

1. Introduction

Damavand volcano is located 60 km to the ENE of Tehran, a capital megacity with a population of millions. The main highway connecting Tehran with the Caspian Sea passes down the Haraz valley on its southern flanks. Damavand is the highest mountain (5670 m) in the Middle East and west Asia located in the Alborz Mountains of northern Iran in the Mazandaran Province (Fig. 1). The Mazandaran Province is one of the wealthiest in Iran with diverse natural resources and one of the most populous provinces by population density which lies close to the volcano. As many as 50,000 people live on the flanks of the volcano in numerous villages and small towns and could face high direct risk from the volcano. Millions of tourists visit the region during the spring and summer. Further east, the neighbouring Golestan and Semnan Provinces also have large populations. The regional economy relies heavily on agriculture and fish farming and caviar production which is famous throughout Iran. There are no known historic eruptions of Damavand and the volcanism goes back to at least 1 Ma year ago; the latest eruption occurred 7000 years ago.

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Damavand volcanic products consist of many lava flows and pyroclastic fall, flow and surge deposits which cover an area up to 400 km^2 around the volcano. In 1979 a seismic swarm was experienced by local people and in 2007 mountain guides noticed that the summit fumaroles had become more active. Earthquakes have also been reported (2.9 magnitude-2007) close to the volcano.

2. Previous study

The geology of Damavand has been studied by many researchers. Most studies concentrated on general geology, petrography, petrology and geochemistry of lavas and volcanic rocks. Allenbach [1&2] did a systematic study on the geology of Damavand and Emami [5] did an important petrological and geochemical study on the volcanics and some pyroclastic rocks of Damavand. Geology of Damavand has also been the subject of a few MSc and PhD theses. Knowledge on pyroclastics and volcano-sedimentary rock units of Damavand is quite limited and confined to reconnaissance studies [3] and [6]. Darvishzadeh and Moradi [3] described young pyroclastic deposits that they concluded were formed by sub-Plinian explosive eruptions. Knowledge about the age and geochemistry was significantly enhanced by the study of Davidson et al. [4]. This study showed that the volcanism goes back to at least 1 Ma with on older sequence. The youngest known eruption is a lava flow on the western flanks with an age of 7.3 ka. Davidson et al. [4] also confirmed that the largely volcanic products are remarkably uniform in composition and petrology, being predominantly porphyritic trachyandesite. Alkaline basalts of Damavand are known to show early stages of volcanism.

They also showed that the trace element geochemistry has affinities with intraplate volcanism rather than subduction-related volcanism. The tectonic setting of Damavand has been studied by Jackson et al. [8] and Tatar et al. [10]. It is located in a young and very active zone of compressional and strike-slip faulting. Deep thrust faults border the mountain range with large strike-slip faults towards the centre and south. Volcanoes located in regions of compression thrust faulting are uncommon, although there are some rare examples [8]. Volcanic hazards at Damavand were studied by Mortazavi et al. [9]. They published the results of a reconnaissance study on stratigraphy of young pyroclastic deposits and an initial assessment of related hazards. Their new data indicate that the volcano has had high intensity explosive eruptions, producing widespread pyroclastic fall and flow deposits. Mortazavi et al. [9] also describe the distribution and characteristics of three pyroclastic units and interpret them in terms of eruption style, likely magnitude, and hazardous effects. They then discuss the current state of the volcano and the likelihood of the next explosive eruption and discuss possible scenarios and impacts of future eruptions locally and regionally. Their new evidence points to three major explosive eruptions in the recent geological past.

3. Volcanic products

Volcanic products on Damavand consist of lava flows (Fig. 2) and pyroclastic deposits. The geology, petrography, petrology and geochemistry of lavas and volcanic rocks were studied by Allenbach [1, 2] and Emami [5]. Extrusive volcano erupting lavas are unlikely to cause major hazards therefore we do not attempt to explain the lavas here. Explosive eruptions have high hazard for the communities and produce widespread pyroclastic fall- and flow-deposits. Recent pumice deposits were recognised by Davidson et al. [4]. Mortazavi et al. [9] have described their stratigraphy in more detail and consider these deposits as evidences of explosive eruptions in the recent geological past.

4. Recent pyroclastic units on Damavand

Mortazavi et al. [9] identified three major pyroclastic deposits on the southern and western flanks of Damavand Volcano. The deposits were named after the most prominent localities and are, in stratigraphic order from oldest to youngest: Reyneh pumice deposits, Karam Poshteh pumice deposits, and Mallar pumice deposits.

Reyneh pumice deposits are found in local valley fills from Mallar adjacent to the Gezaneh valley to valleys due west of the Damavand summit. Exposures have been found up to 20 km from the volcano's summit. Reyneh pumice deposits consist of an amalgamated sequence of numerous thin pumice flows, deposits, 0.5 to 2 metres thick, and are commonly reversely graded thin horizons of pumice fall deposits intercalated with the pumice flow deposits. These deposits are overlain in most localities by coarse-grained lithic-rich lahar deposits.

Karam Poshteh pumice fall deposit is a young pumice fall deposit and distributed over much of the south-western and western flanks. Karam Poshteh pumice fall deposits can be usefully divided into thin, more distal unconsolidated pumice fall deposits and up to 10 m thick proximal welded pumice fall deposits.

Mallar pumice deposits are found from Mallar above the Gezaneh valley to the western flanks of the volcano and consist of basal pumice fall deposits which show thinning and fining to the west. The basal pumice fall deposits are overlain by a series of pumice flow deposits and flow deposits (Fig. 3). Mortazavi et al. [9] suggest that the Reyneh deposits and to a lesser extent the Mallar deposits show evidence of pulsatory activity with intraformational pumice fall in the Reyneh and minor reworked horizons in the Mallar. The lack of intra-formational reworked deposits thus suggests periods of hours or days rather than months for the pauses (Fig. 4) between the active phases.

5. Other pumice deposits on Damavand

Other pumice deposits have been on Damavand [4]. Axe ignimbrite, which is a widespread and thick (up to 100m) welded pumiceous pyroclastic flow deposit and is one of the most important pumice deposit recognised which has been assigned an age of 260 ka [4]. On the flanks of the volcano the ignimbrite forms a multiple package of numerous pumice flow deposits, which have similar appearance to the Reyne deposit. In the Haraz valley the ignimbrite is much thicker and massive in appearance. There also are pyroclastic deposits on the eastern rim of the Gazaneh valley. There are at least 6 pumice fall deposits alternating with paleosoils, two pumice flow deposits and reworked pumice and ash in that area. These are an older sequence of explosive eruptions that formed prior to the formation of Gazaneh valley and were deposited on a thick sequence of volcanoclastics and lavas that form the eastern wall of the valley (Fig. 5).

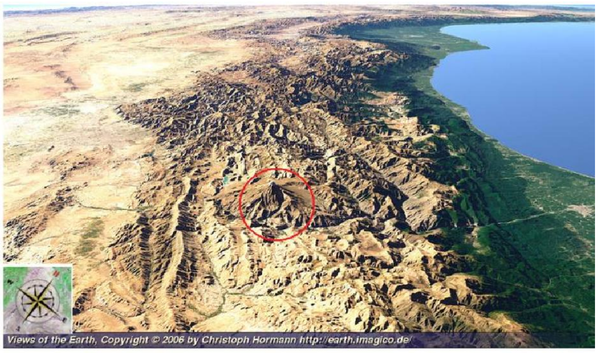

Fig. 1. Satellite image of Alborz Mountains showing location of Damavand volcano located on the crest of the mountain range with Tehran to the west-south-west and the Caspian Sea to the north.

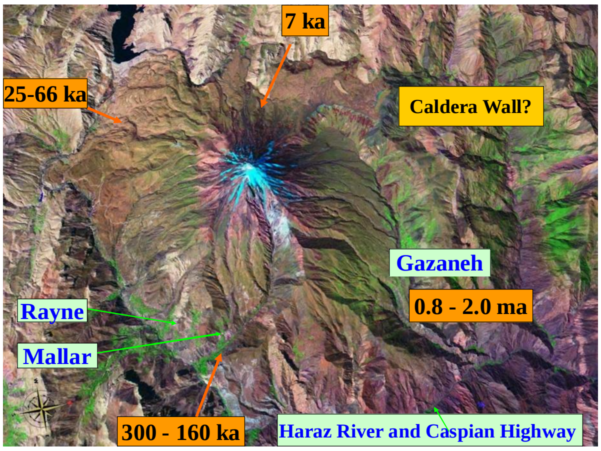

Fig. 2. Satellite image of Damavand showing lava flow erupted in different stage of Damavand activity.

Late Quaternary explosive eruptions

>7 ka and <25 ka VEI 4

Young

Mallar pumice deposit
Pumice fall and multiple pumice flow deposits
Dispersal to east

Karam Poshteh pumice deposit
Pumice fall with proximal welded facies
Dispersal to west (towards Tehran)

Reyne pumice deposit
Pumice fall with multiple pumice flow deposits
Dispersal to the east

Old

Fig. 3. Lithostratigraphic section through the recent three major deposits on Damavand. The deposits were named after the most prominent localities and are, in stratigraphic order from oldest to youngest: Reyneh pumice deposits, Karam Poshteh pumice deposits, and Mallar pumice deposits.

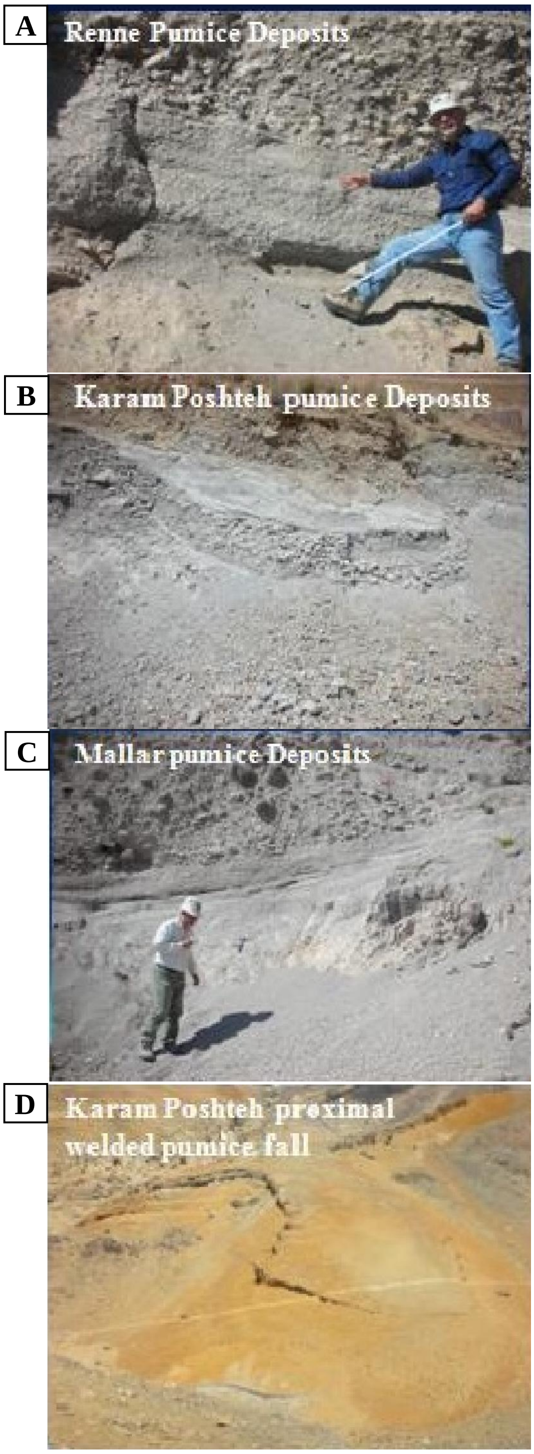

Fig. 4. (a) Reyneh pumice deposits at Mallar road in Gazaneh valley. Deposits consist of well-sorted thin pumice fall deposits intercalated with the pumice flow deposits. (b) Mallar Pumice deposits at Siyah Var Valley close to Mallar village. Avalanche bedding in pumice fall deposit with typical reversely graded and well-sorted sub-units horizon. (c) Karam Poshteh pumice deposit. It is a well-sorted pumice fall deposit at locality 15 km to the west of the summit of Damavand volcano. (d) View of the orange-coloured welded pumice fall deposit mantling the slopes of Damavand 0.5 km to the east of the Karam Poshteh quarry; two people on path indicate scale.

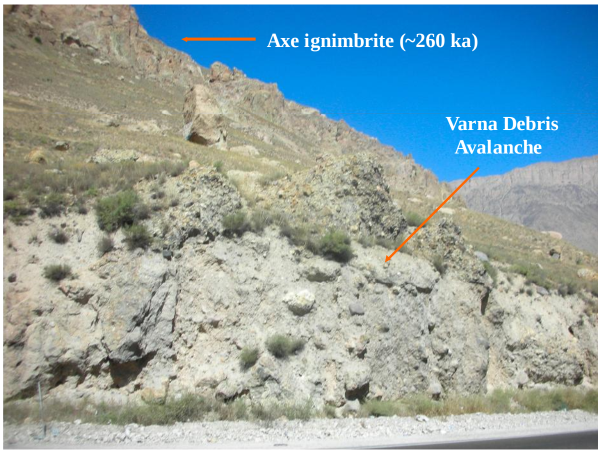

Fig. 5. One of the most important pumice deposit is Axe ignimbrite which is a widespread and thick (upto 100 m) welded pumiceous pyroclastic flow deposit.

The importance of the older deposits is that they demonstrate that the volcano has repeatedly been in phases where explosive eruptions were dominant.

6. Discussion

Patterns of activity at comparable stratovolcanoes, suggest that it is common for such volcanoes to have hundreds to thousands of years periods of dormancy prior to major explosive eruptions. Large explosive eruptions are commonly followed immediately by periods of enhanced lava flow of dome extrusion building up lava shields, lava cones or dome complexes. Such constructive activity then stops and a long period of dormancy then ensues before the next explosive eruption. The upper steep-sided cone of the young Damavand is the source of many young lava flows, so another lava eruption with limited or no hazardous consequences would not be a surprise. Given that Damavand has alternated between periods of lava extrusion and explosive eruptions and has had no eruptions for perhaps as long as a few thousand years, its behaviour could well conform to this common pattern.

Patterns of dispersal tephra and tephra fall in the cities and provinces neighbouring of Damavand depends on the wind direction and velocity. Wind data is a useful tool to capture atmospheric circulation patterns in a particular region, even where sparse conventional observations are available. Atmospheric information, in particular wind data, is crucial in order to perform tephra dispersal simulations.

To understand the hazard, wind data from 1990-2007 were analyzed. Meteorological stations that supply wind profiles at different altitudes are scarce throughout the study region. Due to this lack of information available, wind data from meteorological stations at Mehr-Abaad airport, Iran, Wyoming University and global data sets was used. We examined wind data from 17 standard pressure levels (1000 to 10 hPa). These pressure levels convert to height in meter and cover from 5700 meter (Damavand pick) to 31 km above sea level.

Temporal resolution varies from monthly averages to sub-daily data, typically at the synoptic hours of 00, 06, 12 and 18 UTC. Both wind direction (provenance) and velocity for four atmospheric levels were considered for consecutive years. The data shows tropospheric levels and the stratospheric ones (Table 1). The atmosphere is divided into horizontal layers characterized by uniform wind velocity and direction. Particles are transported by the wind specific to each layer; when they fall into a lower layer they are affected by a different wind. This process continues until the particles reach the ground. Tephra dispersal was simulated according to eruptive scenarios with column heights of 15, 20 and 25 km above the summit of the volcano which has a height of approximately 5 km.

7. Results

The pumice fall deposit is not present on the western flanks, so the observations suggest an easterly dispersal. Fig. 6 shows wind provenance for tropospheric and stratospheric levels (5- 25 km) above sea level on Damavand volcano and Fig. 7 shows wind velocity for tropospheric and stratospheric levels in summer and winter. Four data points per day in August, July and December in 1999 and 2007 are examined. Westerly winds are persistent throughout the year, especially at 15 km above sea level. Wind velocities are higher during December (winter months) reaching on average around 80 and 90 knot for 10 and 15 km above sea level respectively. In contrast during summer months the velocity drops to around 20 m/s in both cases. At 25 km above sea level, summer easterlies winds reach a maximum during July, with 15 m/s on average. Wind velocity during the winter is higher than summer mainly due to the winter polar vortex, that is originated by the hemispheric temperature gradient. The most prominent features in the stratospheric circulation are a westerly jet in the winter hemisphere and low velocity easterly jet in the summer hemisphere. If Damavand moved into a state of unrest then a major explosive eruption is a plausible scenario that should be planned for. Here we consider the Mallar and Reyneh as the kind of likely eruptions so that the hazards are easy to identify.

According to tropospheric eruptive scenarios (column heights of 15, 20 km) above the summit of the volcano at approximately 5 km, tephra dispersal is dominantly towards the east in all seasons (Fig. 8).

Communities around the southern and eastern flanks of the volcano are in high hazard. A significant environmental disruption will occur to the east of the volcano with the major cities of Mazandaran Province.

Table1. Representative wind data (height, direction and velocity) during the summer and winter time.

July	**July**	**July**	**August**	**August**	**August**	**December**	**December**	**December**
Height	Deg	Velocity	Height	Deg	Velocity	Height	Deg	Velocity
10122	300	25	11020	295	29	10096	245	23
10196	280	27	10163	280	31	10136	280	111
10298	295	27	11050	270	31	10141	270	74
10325	299	27	10779	270	33	10145	280	29
10343	270	25	11030	280	33	10230	264	94
10407	280	23	11030	290	35	10262	261	63
10408	290	45	11444	276	35	10307	280	98
10427	294	26	11464	285	35	10362	250	78
10463	275	41	10990	280	37	10413	260	64
10729	280	57	11018	280	37	10430	250	113
10769	292	24	11070	285	37	10440	250	76
10881	305	68	10920	330	39	10446	270	31
10940	285	48	11100	285	39	10450	240	105
10950	305	41	11070	305	41	10456	250	113
10960	290	16	11637	275	44	10480	230	76
10960	280	27	10428	275	45	10480	285	29
10980	300	23	10631	280	45	10490	260	64
10990	295	49	11000	270	45	10494	255	64
11000	285	74	10890	277	46	10496	280	105
11042	295	33	10750	275	47	10510	345	51
11070	290	21	11000	275	47	10530	270	84
11070	295	33	11030	280	47	10538	280	107
11080	280	29	10398	277	49	10550	285	47
11154	277	26	10909	285	49	10550	320	45
11237	293	31	11020	285	49	10550	340	47
11287	270	29	10274	282	51	10554	239	104
11414	277	30	11010	280	51	10560	305	51
11464	290	27	10301	285	54	10570	260	105
11483	290	35	10990	285	54	10585	265	23
11722	288	45	11050	305	54	10590	220	47
11732	282	27	10800	270	56	10590	240	51
12003	285	27	10342	317	58	10600	280	103
12129	301	32	10810	285	60	10610	277	81
12225	286	26	10830	295	60	10620	270	91
12271	270	35	10870	305	62	10630	260	99
12351	305	33	11627	310	62	10640	251	110
12450	272	57	11741	283	62	10650	255	74
12460	300	29	11531	285	64	10670	280	105
12460	295	35	10301	305	66	10675	250	74
12470	285	33	10910	315	68	10690	260	111
12490	310	31	10900	305	70	10776	279	103
12500	285	43	11093	300	70	10858	255	78
12510	280	78	10245	313	79	10866	275	23
12520	315	12	10717	310	84	10892	260	111
12580	285	27	10990	308	86	10902	235	101

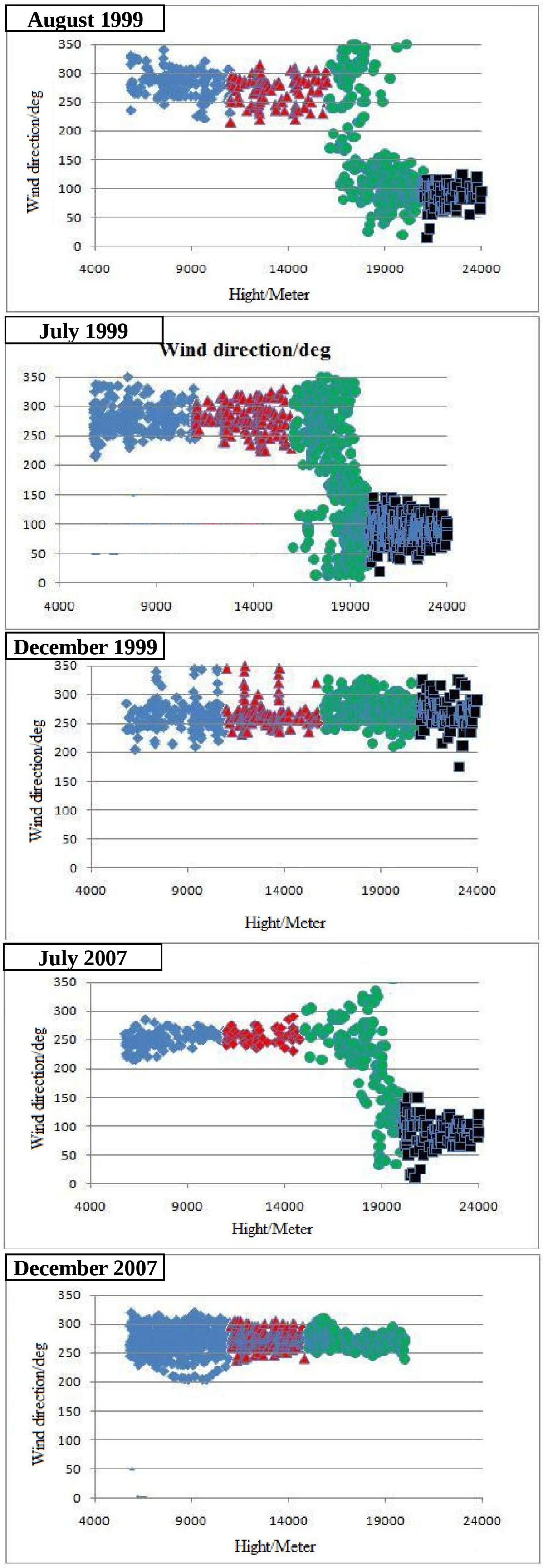

Fig. 6. Wind provenance for tropospheric and stratospheric levels in summer and winter highlighting seasonal variability.

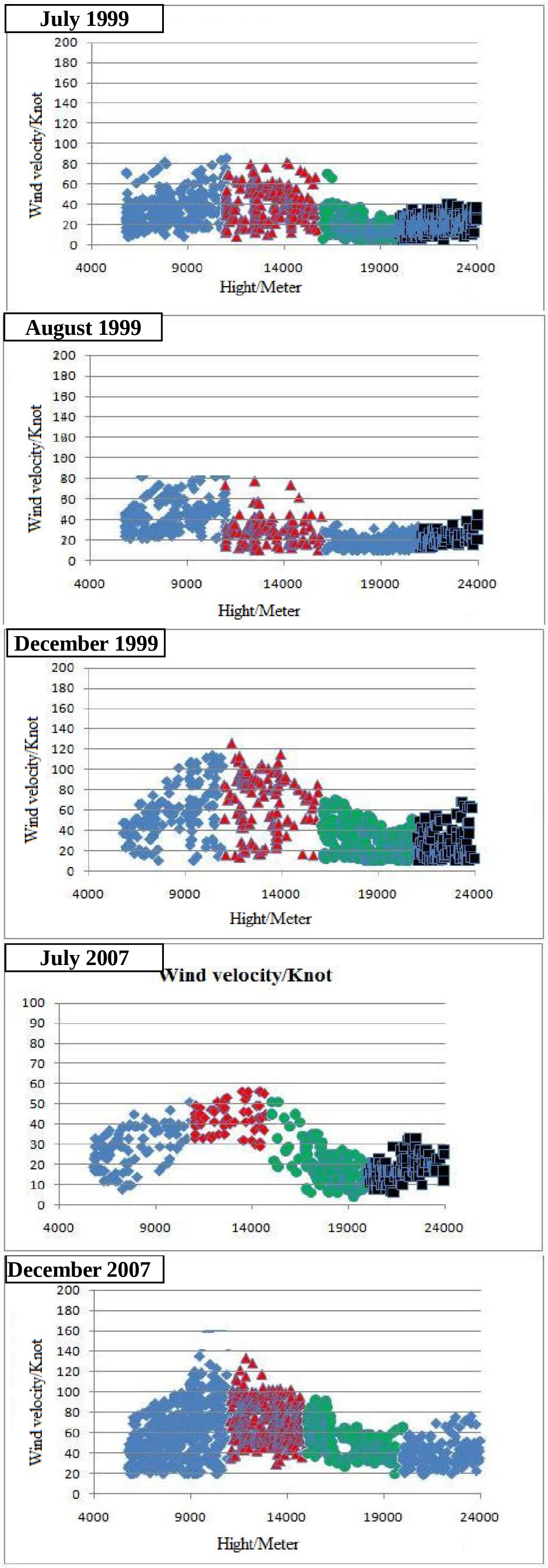

Fig. 7. Wind velocity for tropospheric and stratospheric levels in summer and winter.

The risk of the cities of Sari, Amol, Babol and Qaemshahr increases in the spring and early summer due to wind direction in troposphere and stratosphere. According to stratospheric eruptive scenarios (column heights of 25 km) above the summit of the volcano, tephra dispersal is dominantly towards the east in winter and is toward the west in summer time (Fig. 9). In this case tephra dispersal will be toward the west in high level (25 km) column. After a while and when particles fall down to tropospheric level, tephra dispersal would turn towards the east due to westerly tropospheric winds. The hazard in Tehran is low in tropospheric eruptive scenario during the year and stratospheric eruptive scenario in winter, because of the dominance of westerly winds. However, Tehran could experience tephra fall for high columns and during the summer.

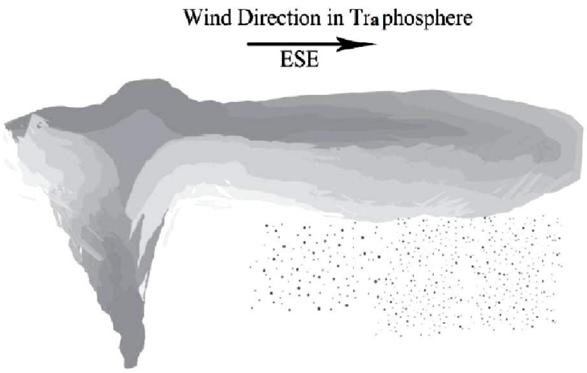

Fig. 8. Eruption column on Damavand in tropospheric eruptive scenarios. Tephra moved toward the east, south-east in all seasons. Cities located west of the volcano (Tehran, 60 km from the source) have low hazard and the cities towards the east (Sari, ca.110 km; Semnan, ca. 120km; and Gorgan, ca. 230 km) have high hazard. Hazard for Tehran is low in tropospheric eruptive scenarios

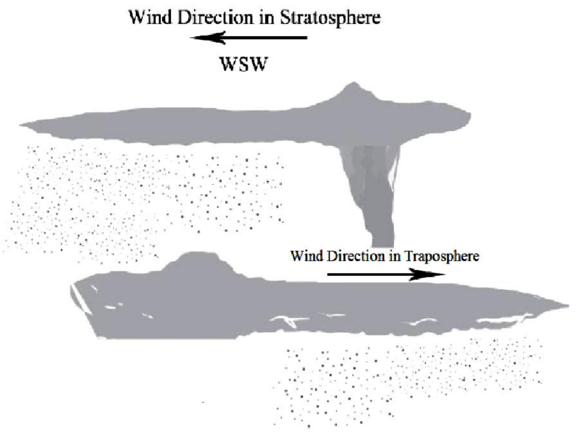

Fig. 9. Eruption column on Damavand in stratospheric eruptive scenarios: Tephra moves toward the west in summer time. Cities located west of the volcano (Tehran), could experience tephra fall for high columns and during the summer. Cities towards the east still have high hazard.

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