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CHANGES OF OZONE CONCENTRATION AT THE KISLOVODSK MOUNTAIN OBSERVATORY DURING THE FOEHNS CAUSED BY THE AIR CROSSING OF THE GREAT CAUCASIAN RIDGE

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Abstract The results of ozone concentration measurements at Kislovodsk mountain scientific station of the Institute of Atmospheric Physics (2070 m asl, the Shadzhatmaz Plateau, Caucasus) during a foehn caused by air crossing of Great Caucasian ridge are presented. The analysis shows that the foehn occurrence, indicated by meteorological parameters, is accompanied by a synchronous increase in the ozone concentration by 15-25 ppb. The increase results from the air, enriched with ozone, coming from the upper layers of the atmosphere.

Introduction

The foehn is a warm and dry downslope wind, which occurs on the leeward side. The classical mechanism used to explain the foehn effect suggests a forced rise (orographic lifting) of the air along the windward slope of mountain ridge and lowering along the leeward slope [1,2]. This confirms that foehn transports air masses from high altitudes above the mountains down into the lower boundary layer.

As the wind moves upslope, it expands and cools, causing water vapor to precipitate out. This dehydrated air then passes over the crest and begins to move downslope. As the wind descends to lower levels on the leeward side of the mountains, the air heats as it comes under greater atmospheric pressure creating strong, gusty, warm and dry winds. This ability is based not only on high temperature, but also the low relative humidity of the air mass.

Foehns in the Caucasus mountains

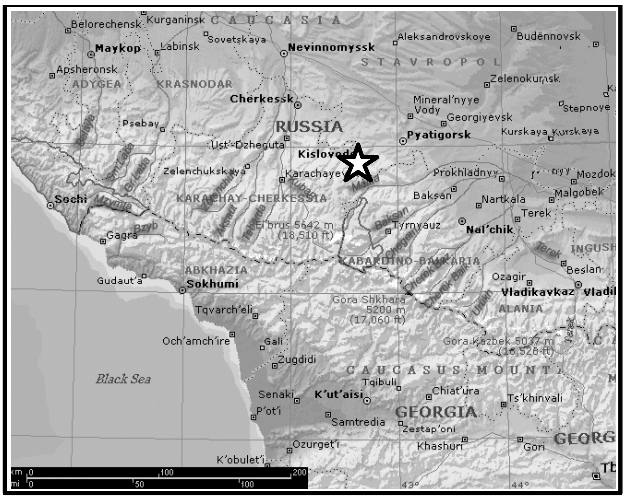

Fig. 1 Map of North-West Caucasus and location of the Kislovodsk mountain scientific station (KVNS)

The Great Caucasian ridge is stretched hundreds kilometers from the North-West to the South-East. The large extent and significant altitudes make difficult a horizontal airflow of the mountain range and the air is forced to cross over the ridge.

The Kislovodsk mountain observatory of the Institute of Atmospheric Physics (KVNS) is located in the northern part of the Caucasus (the Shadzhatmaz Plateau) and has an altitude of 2070 m (fig. 1). Foehn winds occur frequently at northern sites of the Caucasus Mountains.

The typical foehn synoptic situation in northern sites of the Caucasus is the following: the passage of cyclone to the north and north-west of the Caucasian Mountains. In this situation the southern air currents run into a mountain obstacle. This forces the air to flow across the ridges. This flow has the descending contribution on the northern (leeward) slope of the mountain ridge.

The air crossing of the Great Caucasian ridge and the subsequent lowering was detected by the technique of the backward trajectories [http://www.arl.noaa.gov] also.

Various criteria of foehns in the Caucasian mountains have been proposed in [1-4]. The whole complex of meteorological factors is taken into consideration: the direction and speed of the wind, the total and low-level cloudiness, the cloud forms, air temperature and humidity and atmospheric phenomena. It is known, for example, that the foehn phenomena imply the foehn synoptic situation, a definite direction of the wind (from the mountains) in the lower troposphere, an increase in the air temperature, a simultaneous decrease in the relative humidity lower 40% and the absence of low-level clouds and precipitation.

It is common knowledge that the ozone concentration in the troposphere increases with altitude. The rising air is enriched with ozone in the upper atmosphere levels. This air causes the increase of ozone concentration in the foothill regions when it is lowering.

However, if a monitoring station gets into the layer of intense descending motions, a foehn emerges. Thus, the foehn effects, well-known in meteorology, can serve an indicator of the katabatic mechanism of changes in the ground-level ozone concentration in the foothill regions.
The time of the lowering air appearance at the station level can be detected by the characteristic foehn feature.

Foehns and variation in the ozone concentration at the mountain stations

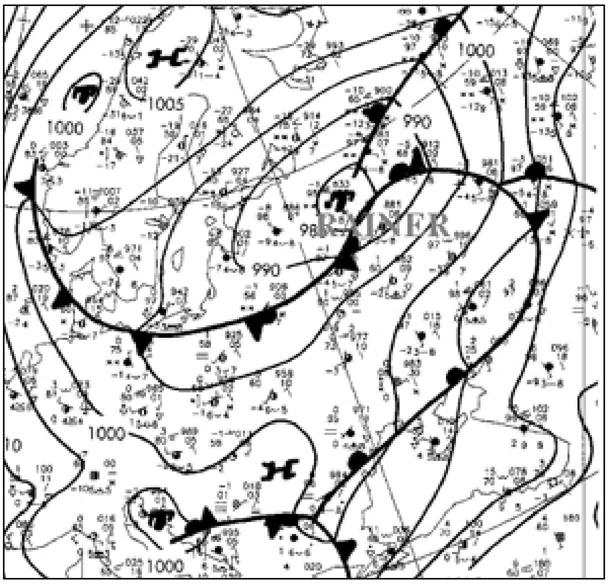

Fig. 2 Surface analysis at 00 UT 30.01.2003

We discover foehns and their effects in the ground-level ozone concentration at the KVNS in the southern and southwest air currents. We can demonstrate this with some examples.
January, 29-30 2003. The synoptic situation in this period is presented in fig. 2. The cyclone moved above the center, and an anticyclone was located above Transcaucasia. The inflow of air into the cyclonic circulation caused the flow across the Caucasus ridge. The southern and southwest air currents intensified in the afternoon on January, 29.
The relative humidity decreased from 80 to 26 %. The temperature of air increased at night hours therefore could not be caused by the radiation heating (table 1). These changes took place in condition of full absence of low cloudiness, but there were Ci and Ac.
Thus, the synoptic situation and the character of meteorological parameters variations satisfied the rigid requirements of the foehn.
The construction of air return trajectory indicated also that the south air currents flowed across the Great Caucasian ridge (fig. 3).

Table 1. Values of meteorological parameters at the KVNS on January, 29-30 2003 (air temperature T°C, relative humidity f%, dew point Td°C, wind direction dd°, wind velocity V ms^{-1}, pressure PgPa, level of H850, total cloud amount Ntotal, lower cloud amount Nlow, cloud forms).

Date	UT	T°C	f%	Td°C	dd°	V ms-1	P gPa	H850	Ntotal	Nlow	Cloud forms		
29	0	-9.8	88	-11.5	180	2	780	1386	10	0	Ci	Ac	-
29	3	-9.1	55	-16.5	225	2	780.4	1391	4	0	Ci	-	-
29	6	-7.4	54	-15	225	2	780.5	1386	10	0	Ci	Ac	-
29	9	-2.5	38	-14.9	180	2	781	1381	10	0	Ci	Ac	-
29	12	-3.5	47	-13.1	45	2	781.1	1381	8	0	Ci	Ac	-
29	15	-6.6	49	-15.6	180	2	782.6	1406	8	0	Ci	Ac	-
29	18	-4.4	35	-17.4	180	2	782.9	1401	8	0	Ci	Ac	-
29	21	-4	26	-20.7	180	2	783	1406	9	0	Ci	Ac	-
30	0	-3.7	34	-17.4	202	2	783.1	1406	10	0	Ci	Ac	-
30	3	-2.8	35	-16.1	202	2	783.3	1401	10	0	Ci	Ac	-
30	6	-2	34	-15.7	337	2	783.6	1406	10	9	Ci	Ac	Sc
30	9	1.9	26	-15.5	90	2	784.2	1401	8	0	Ci	Ac	-
30	12	2.4	28	-14.3	225	4	783.7	1396	10	8	Ci	Ac	Sc
30	15	0.7	36	-12.3	270	6	784.6	1401	10	10	-	-	Sc
30	18	0.1	42	-11.4	270	4	786.7	1431	10	4	-	AcAs	Ns
30	21	-0.6	45	-11	225	2	788.1	1446	8	0	Ci	Ac	-

During the foehn at the KVNS the ozone concentration increased from 36 to 47 ppb (fig. 4). We cannot exclude, that the given increase could be caused by descending movements which caused a foehn also. At least, the periods of the lowered relative humidity and the ozone concentration increase coincided. The instability of the vertical speed in the foehn zone caused time-dependent character of ozone concentration variations [2].
March, 29-30-31 and April, 1 2003 The ground-level ozone concentration at the KVNS was about 50-55 ppb. The extensive anticyclone was located above the Caucasus. The barical low moved above the central regions of Russia.

The intensification of barical gradient caused the occurrence of southern currents and the foehn in northern sites of the Caucasus and at the KVNS. The return trajectories showed that the air flowed across the Great Caucasian ridge before an outlet at the Shadzhatmaz plateau. The ozone concentration increased to 60 and to 65-69 ppb at separate moments.

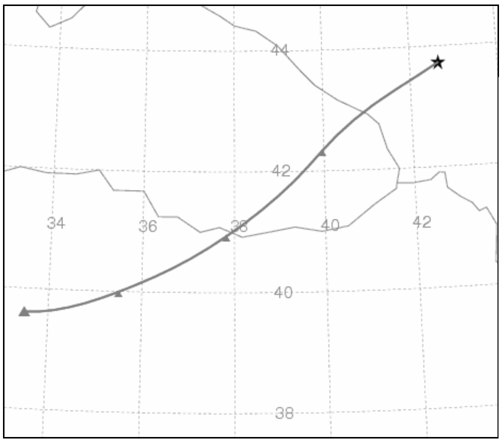

Fig. 3 Backward trajectory ending at 00 UT 30 January 2003 [http://www.arl.noaa.gov]

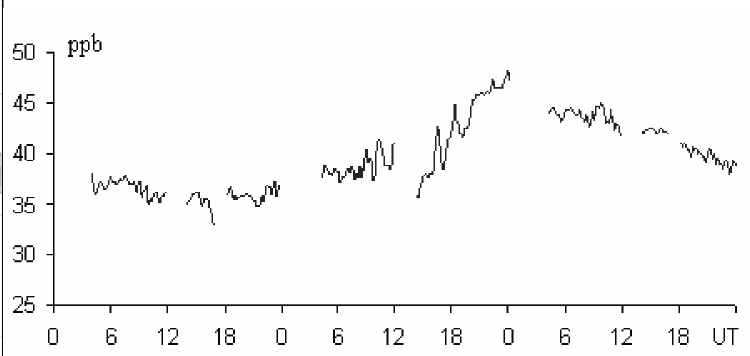

Fig. 4 Time series of ground-level ozone concentration (ppb) at KVNS on January, 29-30 2003

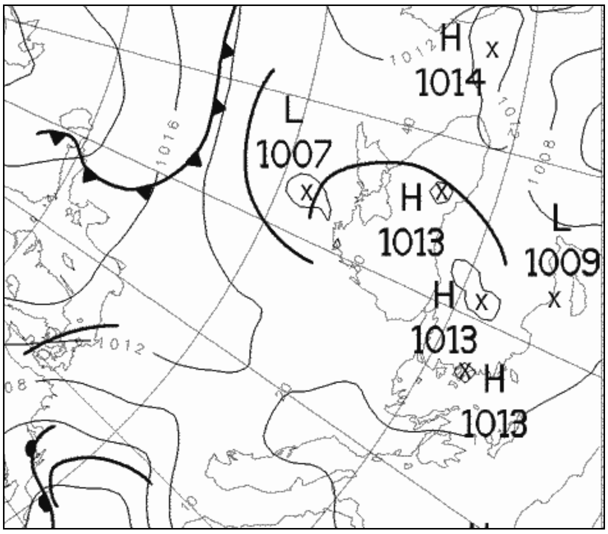

Fig. 5 Surface analysis at 00 UT 5.06.2002

The foehn effects in summer time are expressed unpronounced as the stratification in the planetary boundary layer was unstable [2]. In this connection separate episodes look impressive.

June, 5 2002 The synoptic situation is presented in fig. 5. The relative humidity decrease to 33 % in the afternoon on June, 4 2002 and at night on June, 5 is a foehn indicator (tab. 2). It is impossible to detect the foehn temperature effect as there was usual diurnal course. However, the air temperature at night was 3-5°C higher, than usually. It is an evidence that there was a mechanism of additional heating air (for example, due to lowering).

The ground-level ozone concentration increased from 35-38 up to 60 ppb (fig. 6). This increase of ozone concentration occured at night therefore it cannot be explained by photochemical generation. However, we can surmise, that ozone variation could be caused by air coming which was enriched with ozone under descending movements on the northern slope of the Great Caucasian ridge as the air current was directed northward.

In fact, as for previous examples, there is an air flow across the mountain ridge (fig. 7).

Thus, there were identified all basic attributes of foehn.

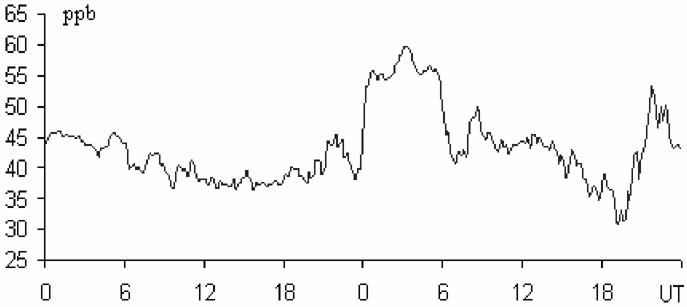

Fig. 6 Time series of ground-level ozone concentration (ppb) at KVNS on June, 4-5 2002

The ozone concentration increased from 40-45 to 60 ppb in the afternoon on July, 21, 2002. The relative humidity decreased to 36 %. The absence of the lower overcast, the decrease of the relative humidity, warm advection, southern component of air currents in the lower troposphere (from mountains) and characteristic synoptic situation indicate the foehn character of the weather. Hence, the increase of ozone concentration could be caused by the vertical transport under descending movements of the air.

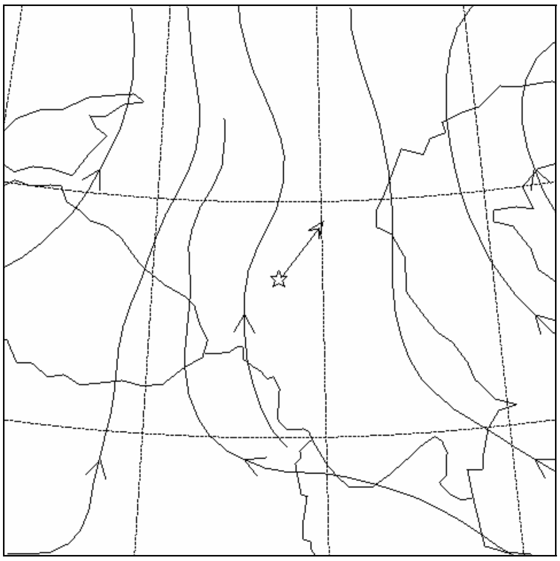

Fig. 7 Streamlines on H850 level at 00 UT 5 June 2002 [http://www.arl.noaa.gov]

Table 2. Values of meteorological parameters at the KVNS on June, 3-5 2002

Date	UT	T°C	f%	Td°C	dd°	V ms-1	PgPa	H850	Ntotal	Nlow	Cloud forms		
3	15	7.6	81	4.5	157	2	793.3	1481	10	0	Ci	Ac	-
3	18	5.6	95	4.9	0	0	794.5	1502	6	0	Ci	Ac	-
3	21	5.3	83	2.6	157	2	794.1	1496	3	0	Ci	-	-
4	0	5.2	87	3.3	157	2	793.7	1491	2	0	Ci	-	-
4	3	5.8	77	2.1	180	2	793.6	1491	2	0	Ci	-	-
4	6	10.4	57	2.1	135	2	793.8	1481	6	0	Ci	Ac	-
4	9	12.9	44	0.9	135	2	793.4	1476	7	2	Ci	Ac	Cu
4	12	13.6	36	-1.2	67	2	793.3	1471	9	7	Ci	Ac	Cu
4	15	12.3	35	-2.7	112	2	793.6	1476	9	7	Ci	Ac	Cu
4	18	10.6	34	-4.4	135	2	793.9	1486	8	0	Ci	Ac	-
4	21	10.8	33	-5	180	2	793.5	1481	7	0	Ci	Ac	-
5	0	9	34	-6	135	2	793.3	1481	6	0	Ci	Ac	-
5	3	9.2	39	-4.1	247	2	793.1	1481	10	4	Ci	Ac	Cu
5	6	9.6	58	1.7	22	2	792.8	1471	10	6	Ci	Ac	Cu
5	9	11.2	62	4.3	360	2	792.5	1466	10	7	-	Ac	CuCb

It is important, that foehns caused by air crossing of the Great Caucasian ridge are accompanied by significant advection. For this reason we can not segregate the absolute value of the ozone concentration increase which is caused by vertical transport from the advective change increase.

Summary

The analysis of ozone concentration dynamics during foehn events at the Kislovodsk mountain scientific station (2070 m, the Shadzhatmaz Plateau, the Caucasus) has been performed. It is shown that the occurrence of the foehn at the level of the observatory is accompanied by simultaneous increase in the ozone concentration by 15-25 ppb. The increase can be caused by descending motions and reception of the air enriched with ozone from higher atmospheric layers. The ozone concentration increases are 15-25 ppb in the present state.

It follows that foehns are an important process for ozone concentrations at the Kislovodsk mountain observatory and other foothill regions.

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