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Variation of nitric oxide concentration before the Kobe earthquake, Japan

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Abstract

The variation and spatial distribution of the atmospheric concentration of nitric oxide (NO) near the epicenter of the Kobe earthquake at local time 5:46, 17 January 1995 have been studied using data at monitoring stations of the local environmental protection agencies. The concentration of NO 8 days before the earthquake was 199 ppb, about ten times larger than the average peak level of 19 ppb, accompanying the retrospectively reported precursory earthquake lightning, increase of radon concentration in well water and of the counts of electromagnetic (EM) signals. The reported thunderstorm over the Japan Sea about 150 km away was too far for the thunder-generated NO to reach the epicenter area. The concentration of NO was also found to have increased before other major earthquakes (Magnitude > 5.0) in Japan. Atmospheric discharges by electric charges or EM waves before earthquakes may have generated NO. However, the generation of NO by human activities of fuel combustion soon after holidays is enormously high every year, which makes it difficult to clearly link the increase with the earthquakes. The increase soon after the earthquake due to traffic jams is clear. The concentration of NO should be monitored at a several sites away from human activities as background data of natural variation and to study its generation at a seismic area before a large earthquake.

Keywords: Nitrogen oxides; Seismic electromagnetic signals (SEMS); Lightning; Radon; Environment

1. Introduction

There were many retrospective reports of preseismic phenomena (Ikeya et al., 1998; Ikeya and Matsumoto, 1997; Ikeya et al., 1997) such as the increase of radon (Rn) activity and dissolved ions in well water before the Kobe earthquake with the magnitude 7.2 (M7.2) at 5:46 a.m. 17 January 1995 (Silver and Wakita, 1996; Igarashi et al., 1995). Clouds brightened by earthquake lightning (EQL) (Takaki and Ikeya, 1998) were photographed before the earthquake (Wadatsumi, 1995a; Wadatsumi, 1995b). Earthquake clouds (EQCs) ascribed to the vapor condensation by an intense electric field of electromagnetic (EM) waves (Teramoto and Ikeya, 2000) were also photographed 8 days and 13 h before the earthquake. Seismic electromagnetic signals (SEMS) at various frequencies were observed 8 days as well as several hours before the earthquake (Yamada and Oike, 1996; Maeda and Tokimasa, 1996; Nagao and Uyeda, 2001). The increase of ultra low frequency (ULF) noise was also observed peaking 8 days and a few hours before the Loma Prieta earthquake around San Francisco in 1989 (Fraser-Smith et al., 1990).

If the EQL before the Kobe earthquake, which was extensively studied from the information provided by lay citizens (Tsukuda, 1997), is due to atmospheric discharges caused by an intense electric field, molecules of nitric oxide (NO) might also be produced. A single natural lightning produces the 1000 mol molecules of

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NO (Franzblau and Popp, 1989). The lifetime of NO is about one day due to the chemical reaction with ozone, O_3. Hence, the local atmospheric NO anomaly may be detected before the earthquake by routinely monitored concentration of NO. Emanation of NO from the ground might also be expected before the earthquake if active oxygen called peroxy radicals were formed underground by the fracture of rocks (Freund, 2000) and reacted with NO_3^- in nature.

In this paper, the variation and spatial distribution of NO concentration before the Kobe earthquake have been analyzed using the data stored at local environmental protection agencies (EPAs). The unusual increase of NO concentration 8 days before the earthquake coincides with other phenomena such as Rn emanation, lightning and EM noises.

2. Experimental

The concentration of atmospheric ingredients, especially NO, was measured at two different types of monitoring stations operated by local EPAs around the epicenter of the Kobe earthquake. One is the traffic pollutant monitoring station (indicated as TP hereafter), which monitors both traffic volume and concentration of atmospheric ingredients beside the heavy traffic road, at 21 sites in Kobe and 12 sites in Osaka. The other is the general atmosphere monitoring station in a residential area, indicated as AM station hereafter, which measures only the concentration of atmospheric ingredients, at 35 sites in Kobe and 18 sites in Osaka. The average concentration of NO for every hour is measured with the Saltzman reagent method at these stations.

3. Results and discussion

3.1. Variation of NO concentration

Fig. 1(a) and (b) indicates the daily variations of traffic volume and concentration of NO in January 1995 and January 1994 at the Tarumi TP monitoring station 5 km away from the epicenter. The concentration of NO is high during daytime, and low at night, which is almost synchronous to the change of the traffic volume. However, the peak values of NO concentration do not necessarily coincide with those of the daily traffic in Fig. 1(b).

The wind velocity and its direction are known as important factors that affect the NO variation in the atmosphere. Positive correlation between the inversion of wind velocity and concentration of NO is clear as shown in Fig. 1(c). The concentration of NO has a peak (an arrow in Fig. 1(a)) of 279 ppb 8 days before the earthquake; this is the highest value in January in 1995, while the traffic volume is normal. The concentration was reduced to the normal level after the earthquake.

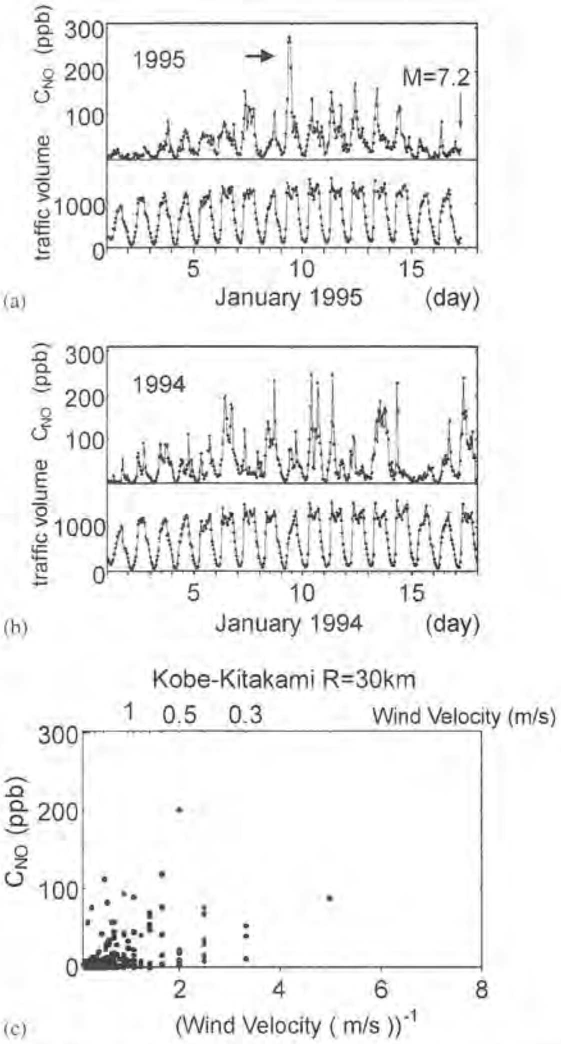

Fig. 1. The variations of NO and traffic volume from 1 January to 18 January 1995 (a), 1994 (b) at Tarumi roadside station (TP) 5 km away from the epicenter of the Kobe earthquake and correlation between inversion of wind velocity and concentration of NO at Kitakami AM station 30 km away from the epicenter (c).

Fig. 2 shows the correlation between the concentration of NO and thunder (natural atmospheric discharge). Fig. 2(a) shows the time variation of NO concentration before the earthquake at an elementary school AM station in the residential area of Nishinomiya, 30 km away from the epicenter. The highest peak of 257 ppb 8 days before and another dominant peak of 83 ppb 5 h before the earthquake are noted in agreement with the increased Rn concentration in well water also 8 days before as shown in Fig. 2(b) (Igarashi et al., 1995).

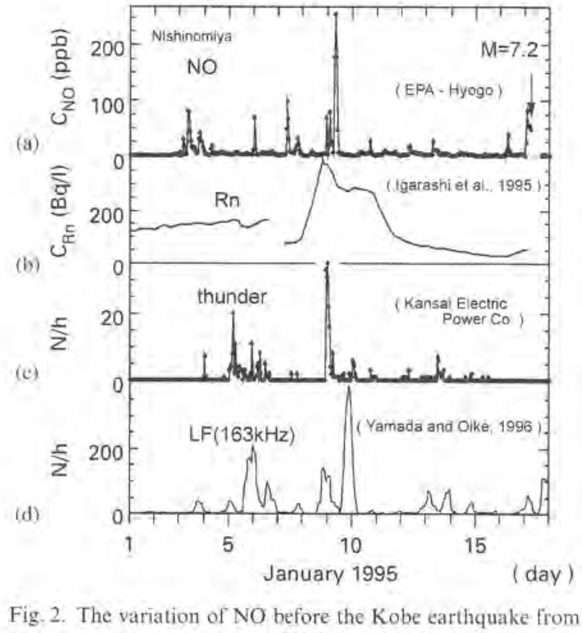

Fig. 2. The variation of NO before the Kobe earthquake from 1 January to 18 January 1995 (a) to indicate the unusual increases on 9 January together with anomalous Rn in well (b), lightning (c) and low frequency (LF) noises (d).

The SEMS, i.e., the increase of noises of EM waves at various frequencies, occurred 6–8 days before for island earthquakes and about 12 days before for plate-boundary earthquakes of M6–M7 in Japan (Kushida and Kushida, 1998). Noises at ULF (0.01 Hz) were reported before the Loma Prieta earthquake in USA in 1989 (Fraser-Smith et al., 1990). They started 12 days before, peaked 8 days before, decreased once and drastically increased a few hours before the earthquake. The concentration of NO peak seems to agree with the behavior of SEMS.

Falling of thunderbolts over the Japan Sea 150 km away from the monitoring station was observed by the Kansai Electric Power Co., about 10 h before the peak of NO concentration in Nishinomiya (Fig. 2(c)). The peak current of lightning is over 1 kA and produces 1000 mol molecules of NO in the atmosphere. The NO produced in nature by lightning was hard to reach from the source over the Japan Sea at the distance of 150 km from the monitoring stations because about 20 h are required for the travel at a wind velocity of about $7.2\,\mathrm{km\,h^{-1}}$ observed in Kobe. In addition, more than 1×10^4 lightning discharges were needed to fill the $50\,\mathrm{km} \times 50\,\mathrm{km} \times 10\,\mathrm{km}$ space with 30 ppb of produced NO by lightning. The detected number of the cloud-to-ground discharge was only 35 per hour, which is too small to account for the intense NO in the atmosphere. The number of intracloud discharges was reported to be about 3 times larger than that of the cloud-to-ground discharges around the Japan Sea (Brook et al., 1982).

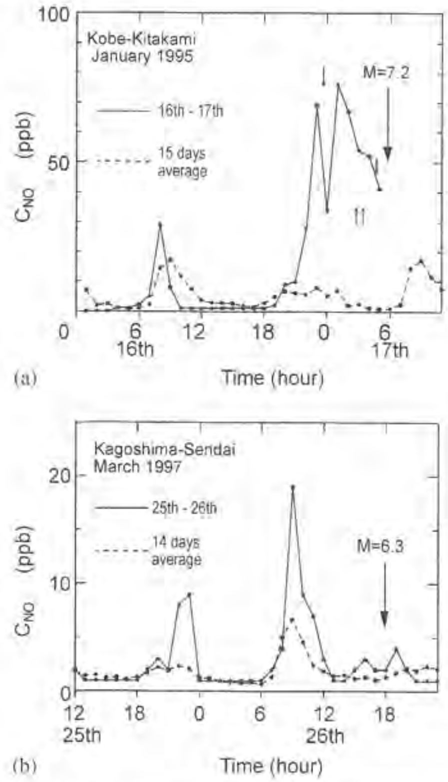

Fig. 3. The daily variation of atmospheric content of NO at Kitakami, 30 km away from the epicenter of the Kobe earthquake from 16 to 17 January 1995 (a) and at Sendai, 20 km away from the epicenter of another earthquake in Kagoshima (b). Unusual increase of NO of 20 ppb at midnight above the average content shown by a broken curve was observed. Arrows indicate the reported malfunctions of electric appliances.

Hence, the total number of lightning discharges would be too small to explain the high content of NO.

Yamada and Oike (1996) observed the increase of EM noises at low frequency (163 kHz) in the same period as shown in Fig. 2(d). The period of peak concentration of NO agrees well with those of the Rn and SEMS at low frequency. Some malfunctioning of electric appliances, such as the spontaneous switching of radio and TV, breakdown of remote controllers and radiowave-controlled clocks, 8 days before the Kobe earthquake were retrospectively reported by lay citizens (Ikeya, 2000; Wadatsumi, 1995b). Various preseismic phenomena were concentrated 8 days before the earthquake including the increase of NO concentration. These agreements may indicate that the phenomena are related with electric discharges of the atmosphere.

Fig. 3(a) shows a variation of NO at the day of the earthquake at Kitakami-AM station at a residential area 30 km away from the epicenter. The solid and broken lines indicate the concentration of NO just before, and that averaged over the 15 days before the earthquake at the station, respectively. Arrows indicate the reported malfunctioning of electric appliances in Kobe a few hours before the earthquake such as the spontaneous switching of electric appliances, radio noise and noises of TV (Matsumoto et al., 1998). The data for the day of the earthquake and 8 days before were not included to average the variations because the concentration showed the highest peak in January. The marked increase of NO and EM waves were clear on 0:00, 17 January, a few hours before the earthquake. There was no record of thunder from the informed data furnished by Kansai Electric Power Co.

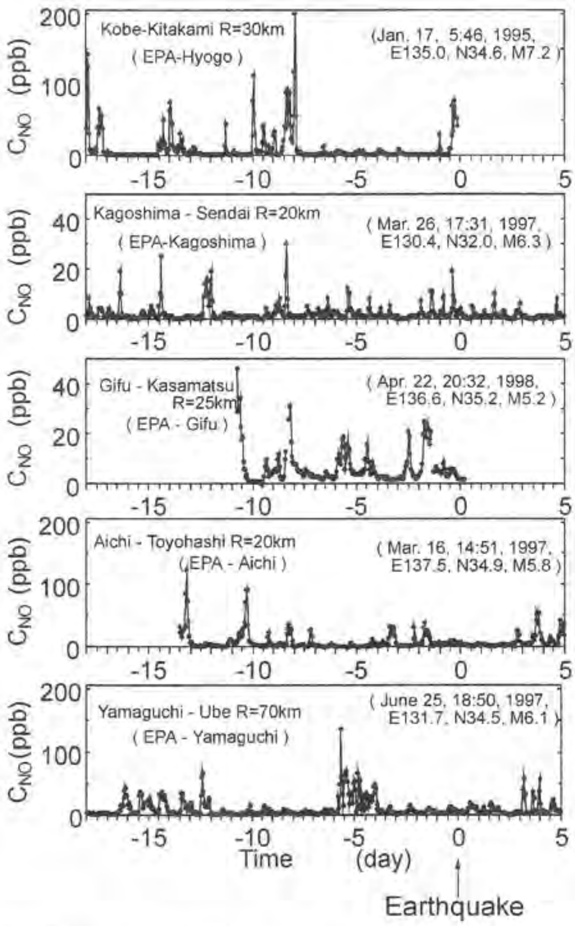

Fig. 4. Variations of NO concentration before five other major earthquakes larger than M5.0 in Japan. Comparisons with metrological lightning and other unusual phenomena are not made.

We have also collected the data on NO before five other major earthquakes that occurred after the Kobe earthquake (Fig. 4, Table 1). All of the peaks were found to appear within 6–8 or 12–15 days before earthquakes, in agreement with the general tendency of the precedence of SEMS and Rn activity. The concentration of NO after the earthquake is not higher than the peak a few days before the earthquake. Unfortunately, the data on meteorological lightning and local traffic are not available. Hence, an extensive comparison could not be made as before the Kobe earthquake.

The increase of NO before the Kobe earthquake may indicate that NO is produced by an intense SEMS which led to EQL. There are several proposals for the generation of an intense electric field before earthquakes at the time of microfractures (Ikeya, 1998). The preseismic intense pulsed charges cause lightning, unusual animal behavior and the reported EM waves at ULF and other frequencies. Ground water then fills the microfractures in about 6–8 days for a large earthquake of M7 and makes the slip of the fault easy. When the fault moves, the presence of water changes the conductivity and reduces the intensity of EM waves (Ikeya, 1998).

3.2. Spatial distribution

Fig. 5 shows the spatial distribution of NO using rod height at 5:00 a.m. 17 January 1995. These are the last data before the Kobe earthquake at AM stations. Active faults were indicated as gray lines on the map (Active Fault Society, 1980). The star marks indicate the source sites of EQL observed as orange, red or lightning types by citizens (Tsukuda, 1997). The length and the direction of arrows indicate the wind velocities and its direction at the station.

If the fault plane is electrically conductive (for example, due to the existence of water), electric field

Table 1
The peaks of the concentration of NO measured at each monitoring station before the other earthquakes

Earthquake	M, Date	Station	R (km)	Peak (day)	C_{NO} (ppb)
Kobe	M7.2, 1995. 1. 17	Kitakami	30	8	199
Kagoshima	M6.3, 1997. 3. 26	Sendai	20	8	29
Gifu	M5.2, 1998. 4. 22	Kasamatsu	25	8, 11	31, 46
Aichi	M5.8, 1997. 3. 16	Toyohashi	20	12, 15	92, 124
Yamaguchi	M6.1, 1997. 6. 25	Ube	70	6	136

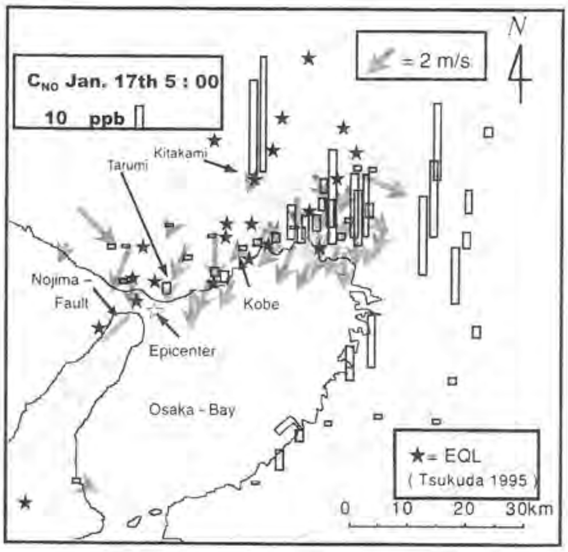

Fig. 5. The concentration of atmospheric NO at different AM stations around Kobe at 5 a.m. January 1995 with the active faults, reported source sites of EQL, wind velocities and directions indicated by gray arrows.

would be intense at the edge of the fault. Electric discharges causing EQL may have occurred and produced NO around the edge of the fault system before the earthquake. A prominent increase of NO was detected at the northern part of the Hyogo at the extrapolated edge of the Nojima fault early in the morning before the earthquake.

EQL occurred not only around the end of the fault but also along the fault line in Kobe. However, NO concentration was minimum in Kobe city area where the traffic is heavy although EQL was frequently observed. The concentration in the eastern part of Osaka was also high. We have no clear interpretation of this fact. The site of the atmospheric discharges EQL responsible for the production of NO might have moved from the edge of the fault to the epicenter (Kobe city), where EPA stations were destroyed and gave no data.

3.3. Concentration of NO after the earthquake

Most monitoring stations were destroyed by the earthquake and subsequent fires around the epicenter. Hence, data were not available due to the termination of electricity. However, some stations survived and kept on taking data after the Kobe earthquake (Fig. 6). The suspected precursor peaks are indicated by P(?) and linked with the earthquake. A large number of aftershocks occurred after the earthquake, which might have caused the increase of NO, too. The artificial burning of destroyed houses may have also caused the increase of

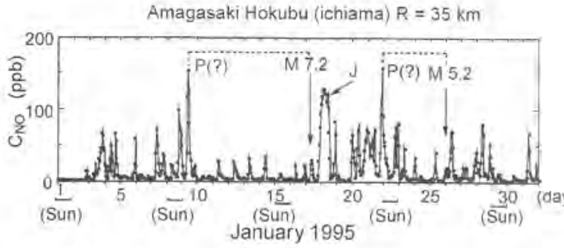

Fig. 6. The variation of NO after the Kobe earthquake from 15 January to 31 January 1995 at Amagasaki Hokubu station, which survived the earthquake 35 km away from the epicenter. The broad peak of an enormous increase (J) one day after the earthquake may be due to traffic jams for rescue operations. Unidentified unusual increases might be linked with the earthquake and its aftershock.

NO. Heavy traffic jams due to the destroyed highways would have caused the increase of NO. The decrease of the NO concentration to the normal level coincides with the day of the strict regulation of traffic at the epicenter area, 2 days after the earthquake. Artificial burning continued later. Hence, the enormous increase of NO one day after the earthquake would apparently be due to the fires and traffic jams.

3.4. Can one use the concentration of NO?

There is an increase of NO concentration on 22 January; which might be linked with the aftershock (M5.2) on 26 January. However, it is the first Sunday after the earthquake.

Traffic jams are reported although strict traffic regulation at the epicenter area was imposed. Human activities make it difficult to separate the increase of NO due to earthquake from that due to other reasons. The weather conditions must also be taken into account.

We have checked the data at 5 o'clock on 17 January 1994 and found the changes of almost the same level at the TP stations. Unfortunately, all the data at EPA are for the area where the environmental pollution by traffic is expected, indicating a high level of 200 ppm. Hence, the concentration of natural NO along active faults, where the human activities are not dominant, should also be monitored to obtain the data of natural background variation and to verify the increase of NO related to the rare phenomenon of a large earthquake. If either the emanation of NO from the ground or generation of NO by atmospheric discharges (earthquake lightning) at the fault zone is confirmed together with other unusual phenomena, such as Rn emanation, EM waves, lightning, clouds, fog and unusual animal behavior, the unusual increase of NO might be used to warn people about an impending earthquake for disaster prevention.

4. Summary

The concentration of NO in the data obtained from EPA showed peaks, a few hours and 8 days before the Kobe earthquake. The peaks agree well with those of the EM noises and increase of Rn concentration in well water. Similar increases were also confirmed before other major earthquakes. The increase of NO concentration two days after the Kobe earthquake was ascribed to the traffic jam. The effects of human activities and the weather conditions complicate the interpretation of the increase of NO 1 h before the earthquake. The measurement of NO should be made at a remote area to study the background variation of NO produced in nature and to distinguish NO generated by human activities. Naturally generated NO, if the effect of thunder can be separated, might arise from EQL, i.e., discharges related to seismic EM waves may be used for warning people about impending earthquakes.

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