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"Measurements of Volcanic SO_2 in the Atmosphere by Dial Remote Sensing Technqiues"

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MEASUREMENTS OF VOLCANIC SO_2 IN THE ATMOSPHERE BY DIAL REMOTE SENSING TECHNIQUES. Results obtained in the Vulcano Island survey.

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SUMMARY

The paper refers to one of the first feasibility study in the world on the analysis of the SO_2 released in the atmosphere by volcanic activity, using the advanced DIAL remote sensing technologies. Relevant progress has been made in recent years in devicing and using these advanced systems for the remote sensing of gaseous pollutants in the atmosphere. Such systems were set-up, primarly and almost exclusively, for the study and control of the man-caused atmospheric pollution.

The results achieved in the Vulcano Island survey point out that the SO_2 plumes from a small volcano were easily detected and measured. DIAL techniques can be, therefore, succesfully applied to volcanological studies, in both the fields of the volcanic risk surveillance and of the estimate of input of these pollutants into the atmosphere under undisturbed conditions.

1. FOREWORD

Present knowledge on natural systems and processes is lacking and incomplete, particularly as far as the natural fluxes of matter, chemical species and energy among and inside the geochemical spheres --i.e. lithosphere, hydrosphere, atmosphere, pedosphere and biosphere-- are concerned on a quantitative basis. And such knowledge proves to be really necessary to get a reliable and quantitative evaluation of the man induced alterations. Human activities cause, in fact, primarly an increase of flow pattern exchange of matter, species and energy with the environment as a whole, and inside its systems; and, secondarly, input of new products to the environment. These exchanges occur in the two directions, i.e. from mankind to the environment and viceversa, because they involve both energy and raw material supplies (natural waters, fossil fuels, minerals, hydroelectric, geothermal, solar, wind energies), and also wastes made of degraded energy and matter. Such anthropic fluxes become added to, and interact with, these ones already occurring in the environment under undisturbed conditions.

It is necessary to not significantly and irreversibly alterate the flow pattern of energy and matter that occur in nature on the basis of dynamic equilibria that have become established over the course of millions years. This is the only approach to the responsible management of the environment, which is acceptable from an ethic view point with particular regard to future generations.

These criteria must be applied on the basis of an indeep knowledge of the matter and energy fluxes -with their variability in space and time- under undisturbed conditions.

A pertinent example of lack of information is the estimate of natural emissions of sulfur and carbon compounds from volcanic and geothermal areas. These same compounds are released into the environment by fossil-fuelled power plants and other industrial and human activities.

The study of natural inputs of these same compounds can provide the basis for a reliable estimate of the anthropic to natural emissions ratio, which represents the reference point in order to evaluate the man induced alteration of geochemical cycles, on a global as well as on a regional basis. The study of the pathways of circulation and fate of these compounds naturally emitted can, moreover, get reliable information in order to predict the circulation and fate of the selfsame compounds put into the environment by human activities, and viceversa.

An equally important aspect refers to the volcanic risk surveillance. It is well established that

relevant variations in the sulphur chemical species flow patterns occur before volcanic eruptions and/or explosions. Their trend, with the real time control, can give an useful aid in volcanic surveillance.

This paper refers to the field experiment carried out in the Vulcano Island on the use of DIAL systems for the SO_2 atmospheric measurements from volcanic emissions.

2. EXPERIMENTAL

2.1. General

The DIAL (Differential Absorption Lidar) techniques make it possible -only from few years- to set-up analytical instruments capable of carrying out measurements of various kinds of pollutants directly in the field (1-2).

From an operational view point DIAL systems can be grouped into three main categories:

-bistatic systems that require two stations, one transmitting and the other receiving.
The average gaseous concentration between the two stations can be measured by means of such systems. It has the advantage of being able to utilize low power lasers and a simple receiving system.

-Monostatic systems which utilize a single transmitting and receiving station in which the signal is reflected, in general, from topographic reflectors (leaves, houses, hills, chimneys, etc.)

-Monostatic systems that utilize a single station to invoice the laser beam and to collect and analyze the signal backscattered by aerosols dispersed in the atmosphere. This is the only system capable of carrying out range-resolved measurements (3).

The DIAL system used in the Vulcano Island test is of the last type.

The block diagram of the DIAL system used is shown in **Figure 1**.

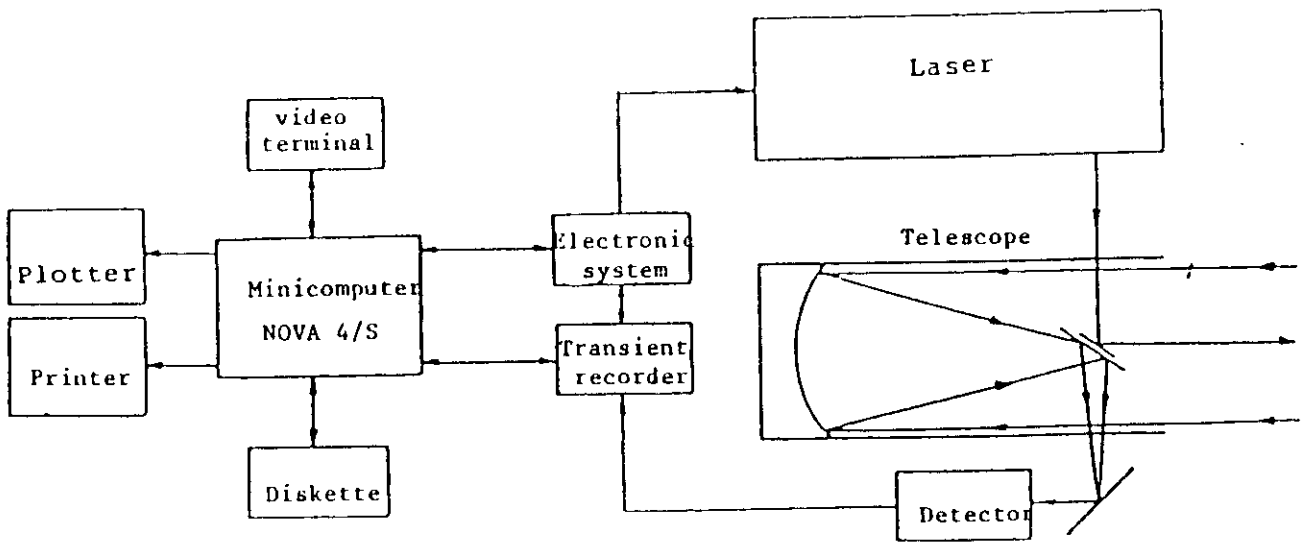

Figure 1.- Block diagram of the DIAL system.

Performances of such a system are good enough to gather data, on real time, on the spatial distribution of the chosen compound in the atmosphere. It is usual, in fact, to obtain SO_2 concentration maps over an approximately ten square kilometers section in a short time (i.e. less than half hour).

2.2. Instrumentation

The system utilizes a double dye laser pumped by the second harmonic of a Nd-YAG laser with 20 Hz repetition rate. The laser emission occurs at λ_1 and λ_2 alternated shot by shot; this is obtained by deflecting the laser beam on the grating of the dye laser oscillator cavity with the insertion of a prism in the optical path. λ_1 and λ_2 are the wavelengths corresponding respectively to a minimum and a maximum SO_2 absorption value.

Figure 2 shows the two wavelengths used in the SO_2 analysis.

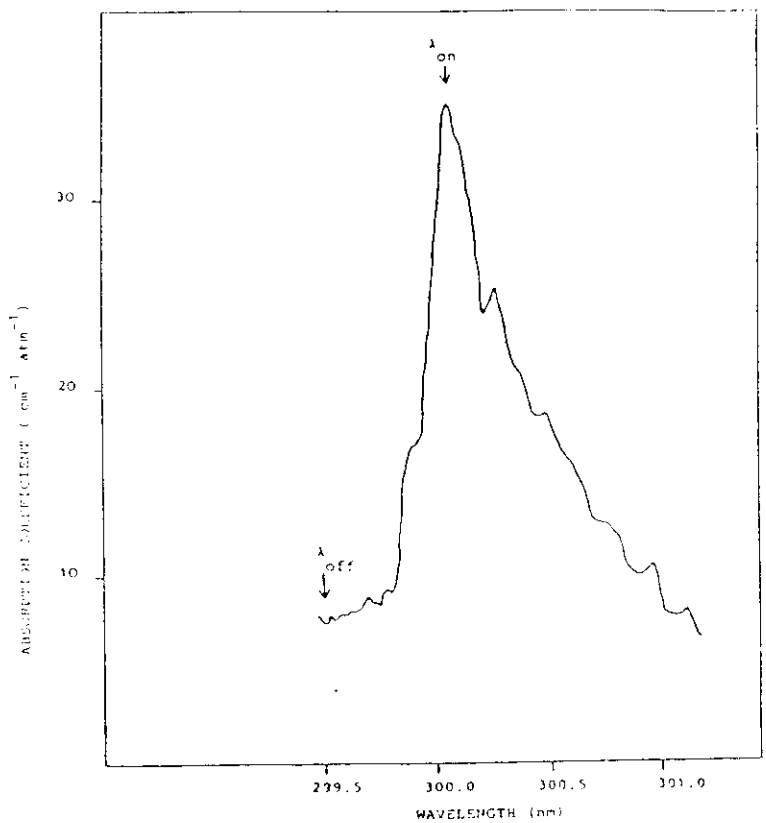

Figure 2.- SO_2 absorption spectrum.

The laser beam is coaxially transmitted to the telescope by means of steering optics. The laser pointing covers a solid angle of 2π with a setting precision of 0.1° in zenith and 0.25° in azimuth.

The optical signal is detected by a photomultiplier whose gain is modulated in time with a quadratic law. In this way, the signal dynamic range is strongly reduced and a better precision in the digital conversion is obtained. The digitalized signals are then transmitted to a Data General NOVA 4/S minicomputer.

Fully automatized measurements can be made by means of a computer-controlled electronic system. It is possible to program telescope setting, laser firing, wavelength change and other functions. The software allows measurements over a fan of directions, with real time data processing. The results, i.e. the SO_2 range-resolved concentrations, are stored on a floppy disk and are subsequently recalled to get a concentration map using a plotter.

Table 1 summarizes the system specifications.

Table 1.- Technical specifications of the DIAL system.

TRANSMITTER	
Laser system	Nd-YAG pumped dye laser
Energy output	10 mJ at 300 nm
Laser bandwidth	0.1 cm^{-1}
Repetition rate	20 Hz
Pulse duration	10 ns
RECEIVER	
Telescope area	0.25 m^2
Optics efficiency	20%
Field of view	1 mrad
Detector	Photomultiplier PHILIPS XP-2020Q
Detector specifications	20% quantum efficiency
Transient recorder	BIOMATION 1010 - 10 bit, 10 Mhz
PERFORMANCES	
Range	up to 3 km
Detection limit	$\leq$ 50 ppb (SO_2)
Spatial resolution	15 to 200 m
Telescope angle resolution	0.1° in zenith
	0.25° in azimuth

The system is equipped with remote control of laser beam alignment. A TV camera is mounted on the telescope for eye safety and pointing control. The total time taken for the measurement in one direction, including telescope movement, is about 10 to 30 seconds; every measurement is obtained by averaging 100 shots at each wavelength.

The system is mounted on a truck and is equipped with a 50 kVA power generator. The set-up time is approximately two hours.

3. RESULTS

The Vulcano Island field test was carried out from the 7th to the 12th of November, 1983. Meteorological conditions were very severe. This created difficulties in carrying out the experiments because of storm conditions: rain and strong winds were predominating in that period. During rain the system can not operate and strong winds tend to disperse and dilute excessively the SO_2 plumes originating from the fumeroles at the top of the volcano.

It proved difficult to obtain reliable SO_2 flux estimates, also because of atmospheric turbolence downwind from the cone of the volcano, which is the only zone where it is possible to detect the plumes,

Figure 3 shows a SO_2 isoconcentration map obtained during the Vulcano Island survey.

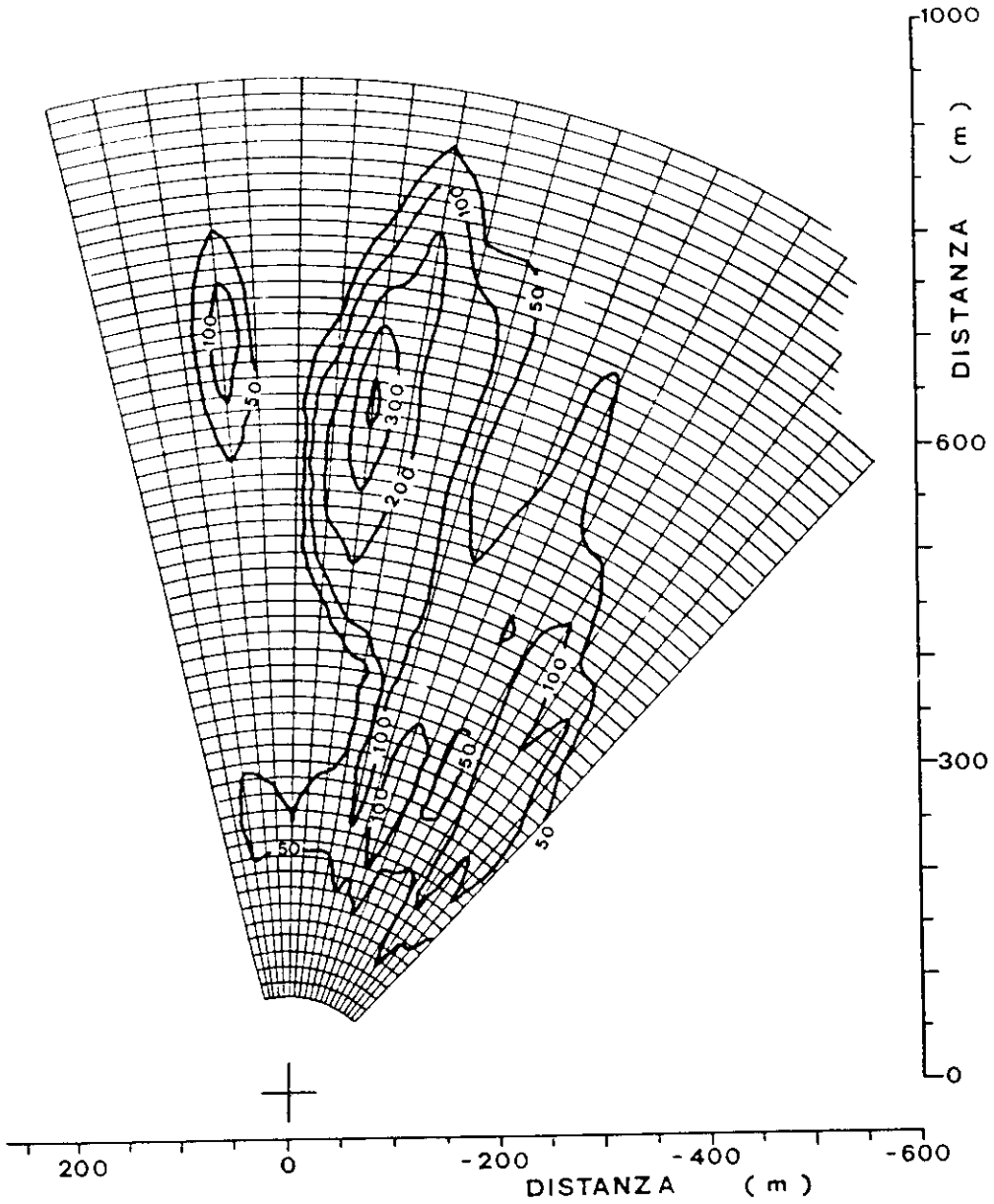

Figure 3.- SO_2 isoconcentration map obtained with an elevation angle of 20.5° from the site 500 m W to the volcano crater (wind speed = 5.5 m/s; wind direction E-NE)

4. CONCLUSIONS

The results achieved can be, nevertheless, considered very encouraging. The measurement system has in fact undergone a very severe test, considering:

- the long distance from Milan to the Vulcano Island, by road and by shipment,
- the unfavorable environmental conditions, mainly due to the adverse meteorological conditions during the test,
- the lack of electricity supply; a genset specifically set-up for operating in remote areas was utilized.

The Vulcano experiment, which is -as we know- the first in the world, as far as advanced remote sensing technologies applied to natural systems are concerned, has proven that such research project was successful. SO_2 volcanic plumes were in fact detected and measured even in not favorable environmental conditions.

The results achieved in this survey indicate that these techniques can be advantageously applied to the study of natural systems apart from the control of man induced pollution.

During spring time in 1988 a significant increase of volcanic activity was observed in the Vulcano Island. The National Group of Volcanology, which is responsible in Italy for the research and risk surveillance in this field, stated an emergency status, organizing gephysical and geochemical monitoring, as well as geological and volcanological studies.

A new survey based on DIAL SO_2 atmospheric analysis was planned in order to get relible information on flow pattern of this gas from fumeroles. Due to unexpected heavy malfunctions of the DIAL system, this survey can not be carried out till now. It will be conducted as soon as possible; at the same time a complete meteorological data set, necessary to ascertain the values of SO_2 flux from the volcano, will be collected.

In our opinion DIAL systems can give a powerful aid in volcanic risk surveillance due to the circumstance that they can get real-time information on SO_2 flow pattern, and in the next future of CO_2; the flux values of these gases can play the role of premonitory events of volcanic eruption and/or explosion.

REFERENCES

1 A. Egeback, K. A Fredriksson and H. M. Hertz, Applied Optics 23 (1984) 722-729

2 M. Alden, H. Edner and S. Svanberg, Optics Letters 7 (1982) 221-223

3 P. T. Woods and B. W. Jolliffe, Optics and Laser Technology 25 (1978)