Monitoring Gaseous Emission From Terrain Through Tomographic Techniques In The Infrared Spectral Region

F. Cuccoli[+], O. Vaselli[*], A. Minissale[§], D. Giuli[+], S. Tanelli[+], L. Facheris[+]

[+]Dipartimento di Ingegneria Elettronica, Università di Firenze, Via di Santa Marta, 3 50139 Firenze - Italy
[§]CNR- C.S. Minerogenesi Geochimica Applicata, Via G. La Pira, 4 50121 Firenze - Italy
[*]Dipartimento di Scienze della Terra, Università di Firenze, Via G. La Pira, 4 50121 Firenze - Italy
Tel: +390554796274; Fax: +39055488883; e-mail: facheris@ingfi1.ing.unifi.it

ABSTRACT – In this paper we propose a study about a system for measuring the flux of gaseous species of interest emitted by the terrain by means of a tomographic method operating in the infrared spectral region. The main components of this system are: a ground network of transmitters-retroreflectors-receivers for IR attenuation measurements, a data-processing both to retrieve the 2D-distribution of the molecular species and to estimate the emission flux by the terrain. CO_2 emission in the Rapolano Terme area (Italy) has been taken as case study.

INTRODUCTION

The Rapolano Terme area is located in the eastern part of the Siena Basin (central-northern Apennines, Italy) which follows the Mesozoic limestone outcrops belonging to the non-metamorphic Tuscan Succession. Thermal spring and gas discharges characterize the whole area which also contain presently-forming and recent travertine deposits. The Rapolano thermal waters (mainly Ca(Mg)-HCO_3 and Ca(Mg)-SO_4 in composition) have temperatures varying between 20° and 40 °C and pH<7 at which a gas phase is generally associated [2]. However, gas emissions are often found discharging from cold water pools. Gases are mainly composed by CO_2 (up to 99.8% by volume) and N_2 (up to 10% by vol.) with subordinate amounts of Ar, CH_4, He, H_2S, etc.(Table 1).

Table 1 - Representative gas analyses of the Rapolano Terme area [1]. All values are in % by volume. AB: Acqua Borra; BR: Bagni Freddi; TQ: Terme Querciolaie; B2: Bogliole 2; AM: Ambra.

	AB	BF	TQ	B2	AM
CO_2	99.56	99.44	99.57	97.91	89.98
N2	0.43	0.55	0.42	1.87	9.92
Ar	0.0015	0.012	0.0076	0.03	0.012
CH_4	0.107	0.003	0.002	0.011	2.47
He	0.0003	0.0001	0.0002	0.006	0.005
H_2S	<0.005	<0.005	0.005	0.005	0.01
O_2	0.0008	0.0018	0.001	0.187	0.009
H_2	0.00005	0.00001	0.074	0.00002	0.0002

Evaluating the amount of CO_2 emitted in the atmosphere by this kind of sources is important in several research fields, such as those involving the analysis of the atmospheric energetic balance, or the control of volcanic sites. For such an objective, it is necessary to estimate the emission flux by each source. Here we propose a simulated study concerning a non intrusive methodology based on the CO_2 concentration estimate on a 2D surface over the emission area by means of a tomographic approach.

The 2D concentration of CO_2, together the atmospheric conditions and the source locations, are used as input parameters in a minimization algorithm to find the best emission flux that validates the "measured" quantity on site.

THE MEASUREMENT SYSTEM

As shown in [3], by means of an IR transmitter-retroreflector-receiver network, it is possible to obtain a set of IR attenuation measurements that are directly dependent on the mean concentration of an atmospheric gaseous components. This direct dependence is connected to the choice of the emission wavelength of the transmitter. The IR spectral region is characterized by strong spectral absorption lines of the atmospheric gaseous components. So using wavelengths around these lines, the attenuation values are mainly due to the absorption effects of the molecular specie having those spectral absorption lines. The validity of this statement is greater, the higher the molecular concentration. Fig. 1 shows the attenuation coefficient in (2272, 2301) cm^{-1} range that is characterized by an absorption band of the CO_2 Notice that between 300 and 30000 ppm, CO_2 attenuation contribution is always dominant with respect to the others, obtained considering a standard model of atmospheric composition. Absorption characteristics have been obtained using HITRAN96 compilation [4].

For the purpose of this work it was important to choose the optimal emission wavelength, such that attenuation was mainly due to CO_2 absorption effects. Based on the plausible concentration values on the air volume in proximity of the emission points, we selected 2285cm^{-1} as the emission wavelength. For instance, 5 meters above an emission source emitting 70 Mg/day of CO_2, we estimated that CO_2

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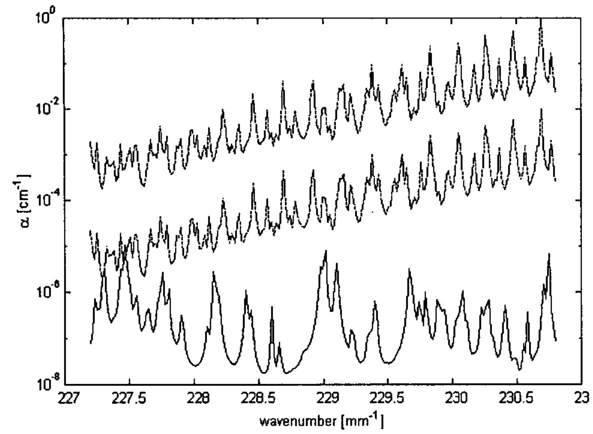

Fig. 1 – Absorption coefficients; Top curve: 30000 ppm CO_2; middle curve 300 ppm CO_2; bottom curve: remaining gaseous components considering a standard atmospheric model.

concentration ranges between 320 and 4000 ppm, depending on the turbulence conditions of the atmosphere.

THE 2D TOMOGRAPHIC CONCENTRATION ESTIMATE

For the objective of this work we considered a measurement network like that shown in Fig. 2. It is composed by two transmitter-receiver locations and a set of retroreflectors located around the area to be monitored. Under the hypothesis that the emission wavelength has been correctly selected, the attenuation measurements provide the CO_2 mean concentration along the network links. Starting from the network topology and the attenuation measurements, through tomographic data processing it is possible to retrieve the 2D distribution of the concentration on the atmospheric surface that is crossed by the network links. In this application we used the SRT (Stocasthic Reconstruction Technique) as tomographic technique. A full description of

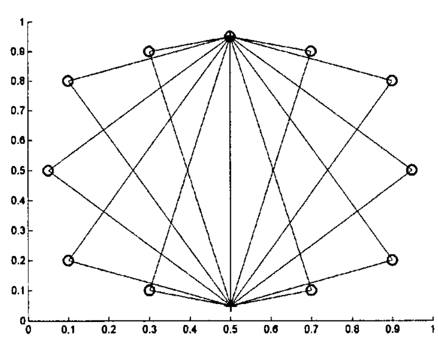

Fig. 2 – Measurement network O-retroreflector, + Transmitter-receiver. (normalized scale)

this technique is in [5]. Here we briefly recall that the retrieved 2D concentration is obtained by linear combination of 2D symmetrical Gaussian function such as to minimize a predefined functional error. Such functional error depends on the number of links of the network, on their length and on their attenuation measurements (hence on the total amount of molecular species, as well).

Fig. 3 shows an example of a tomographic reconstruction of a 2D concentration of a sample species. It is based on a set of simulated attenuation measurements pertinent to the the network links shown in Fig. 2, 5 m above ground. Such simulations are based on a 3D atmospheric composition obtained starting from a standard model of atmosphere adding the contribution of a gaseous substance emitted by a stationary point source.

THE EMISSION ESTIMATE

Starting from the assumption that the emission of the considered gaseous sources is time stationary, the approach we used to estimate the emission flux of the gaseous species (CO_2) of interest is based on the possibility to simulate the atmospheric composition near the emission point by means of atmospheric diffusion models. In this case, we used the

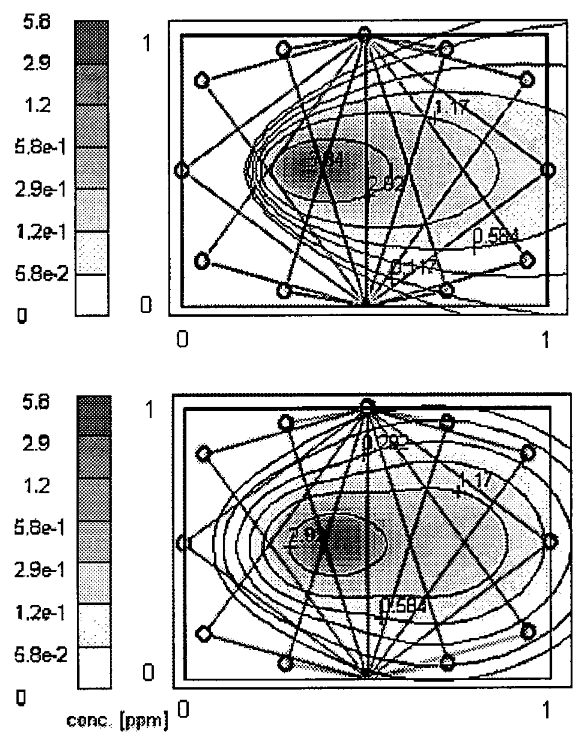

Fig. 3 – Top: 2D simulated concentration – Bottom: 2D retrieved concentration by tomographic data-processing. (normalized scale)

Table 2 – emission flux in Mg/daily.

	CO_2	N_2	Ar	CH_4	He	H_2S	O_2
Flux	70	7.7	$9\cdot10^{-3}$	1.92	$4\cdot10^{-3}$	$8\cdot10^{-3}$	$7\cdot10^{-3}$

slender plume model [3], that permits to simulate the diffusion of a gaseous species from a stationary point source knowing the atmospheric conditions (in terms of speed and direction of wind, temperature, pressure and turbulence state). We developed an iterative algorithm that, using as input parameters the atmospheric conditions and the source locations, estimates the flow F of the sources in order to approximate at best an a-priori known 2D concentration, $c_m(x,y)$, as obtainable by the tomographic approach discussed in the previous section. The main steps of the iterative procedure are:

1. start from a predefined flux value F_0,
2. compute the concentration $c_s(x,y)$ on the 2D surface using the diffusion model whose conditioning parameter is the turbulence state of the atmosphere
3. check an error functional based on the difference $c_m(x,y)$- $c_s(x,y)$: if a predefined acceptance threshold is not verified, the flux value is changed (based on a standard zero search iterative algorithm), then go to point 2, else stop.

SIMULATIONS AND RESULTS

The example we report below concerns the simulation of the emission of one source with the emission flux reported in Table 2.

The 3D atmospheric composition has been obtained through the Gaussian slender plume model considering the turbulence state of the atmosphere in class A with a speed of wind of 0.3 m/s. Considering 2285 cm^{-1} as emission wavelength and the network shown in Fig.2 located at 2 m above ground, we simulated 21 attenuation values (one for each network link). The network relative position with respect to the source is like that shown in Fig.3, but with an area of 1x1 km^2. Fig. 4 shows the specific attenuation values along the 21 links. They are attributable for 99% to CO_2 absorption effects. Processing these attenuation values, the tomographic reconstruction provides the 2D concentration of CO_2 above the emission source. Starting from this retrieved 2D concentration we estimated the best emission flux following the iterative procedure briefly described in the previous Section, using different turbulence states as input parameters. When the turbulence state is the same used to generate the 3D atmospheric composition, the flux is estimated with an error lower than 10%

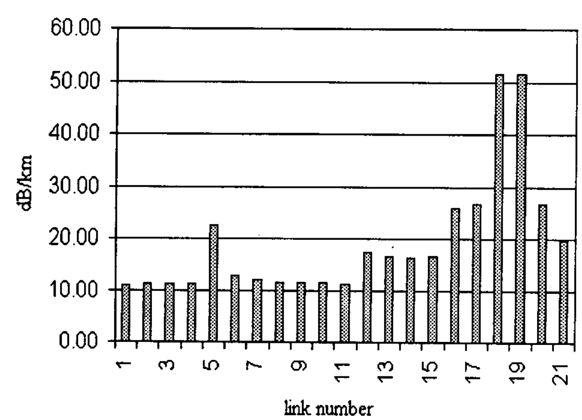

Fig. 4 – specific attenuation along the links of the network shown in Fig 2. Numbering of links is not significant.

CONCLUSIONS

The study carried out in this work shows the possibility to retrieve the emission flux of a gaseous source of CO_2 by means of a set of IR attenuation measurements opportunely processed. From a first analysis of the results, it seems that the most critical point is the knowledge of turbulence parameters given as input to the algorithm that estimates the emission flux. Small changes on these values may cause remarkable differences on the obtainable results. Further developments of this work will involve the study of diffused emission (multi-sources) and the analysis of problems related to the tomographic retrieval of 2D vertical concentration fields.

ACKNOWLEDGMENTS

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