Five years measurements of CO_2 air concentrations by DSA IR laser devices. Results and perspectives for laser remote sensing systems of gas emissions by critical areas.

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***Abstract*—In this work we summarize some of the results obtained using a portable IR laser device during measurement campaigns of CO_2 concentrations in air from different environmental sites characterized by gas emissions. The IR laser measurements for the remote sensing have been carried out in volcanic, geothermal, industrial and waste disposal areas. The measurement methods we are developing, based on gas concentration measurements in air by IR laser devices on optical links, seem to be particularly suitable when CO_2 gas emissions cannot be measured by means of other reliable methods.**

Keywords-component; IR laser, atmospheric gas remote sensing, CO_2 emission rate

I. INTRODUCTION

Direct and instantaneous measurements of gas concentrations of molecular species along air optical paths up to 1 km length can be made through DSA (Differential Spectroscopy Absorption) based IR portable laser systems [1] [2] [3] [4]

In situ measurements of integral concentration along rectilinear optical paths, where gases are emitted into the atmosphere (i.e. volcanic, geothermal, waste disposal and industrial sites), can thus be performed and collected in time-continuous mode. In this work CO_2 data have been gathered by a Gasfinder 2.0 that is a laser transmit-receive unit based on a NIR room temperature tunable diode laser operating around 1580 nm. Extensive campaigns in central Italy in different natural and anthropogenic environments, e.g. CO_2 wells, bubbling and dry vents, fumaroles from active volcanic areas and dumping areas have been carried out. Some information about the nature of natural emission of CO_2 in Italy can be found in [5] and [6]. Different measurement configurations and data processing procedures were tested, depending on the monitoring requirements. In this work the most significant case studies are reported in order to show how the laser remote measurements can be used to improve the knowledge of the spatial and temporal dynamics of CO_2 emissions in atmosphere.

II. VOLCANIC AREAS

The multi-optical link approach has been used to estimate the CO_2 concentration field over emission areas characterized by multiple sources such as volcanic and geothermal sites. In this case, laser data are processed by means of *ad hoc* tomographic algorithms for the estimation of the 2D concentration field related to air sections interested by optical link crossing [7],[8]. The main objective of 2D fields retrieval is estimating the position of the maximum emission spots within the monitored area and to evaluate the emitted CO_2 mass. Fig. 1 shows a picture of the Bocca Grande fumarole at "Solfatara di Pozzuoli", Pozzuoli (Naples, Italy), whereas Fig. 2 displays the 2D tomographic reconstruction of the CO_2 concentration over the emitting area [9]. The reconstruction is based on a subset of the CO_2 measurements gathered on the network of optical links shown in Fig. 1. All the CO_2 measurements in the subset are characterized by the same atmospheric conditions therefore, the reconstruction in Fig. 2 refers to that specific atmospheric status. The positions of the two maxima in the reconstructed CO_2 field are in agreement with the main emitting discharges within the monitored area and the dominating wind conditions.

Fig. 1 - Picture of the Bocca Grande fumarole at "Solfatara di Pozzuoli", Pozzuoli (Naples, Italy) with a representation of the optical links network used for the CO_2 measurements.

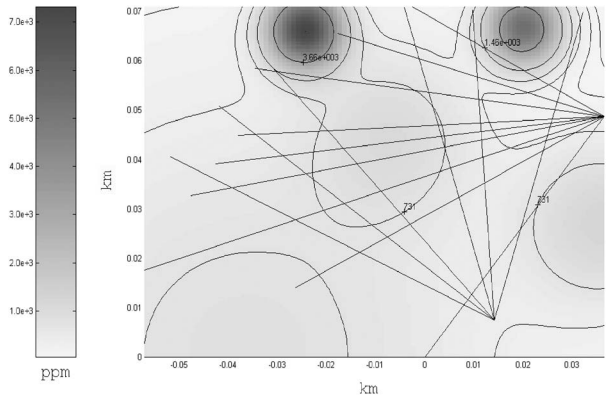

Fig. 2 - Tomographic reconstruction of the 2D mean concentration field of CO_2 based on concentration measurements of the network shown in Fig. 1

III. GEOTHERMAL AREAS (NATURAL EMISSIONS)

Single optical links with time-continuos measurements were used to investigate the mechanisms of discharge and diffusion of CO_2 in atmosphere from low-to-high CO_2 flux multiple manifestations. This is particularly useful for instance to check health hazard for human beings and animals, as CO_2 tends to accumulate at ground surface. The risk conditions in terms of meteorological parameters independently by the CO_2 discharge rate were consequently defined. In the presence of atmospheric conditions that impede air dispersion, even low emitting CO_2 vents tend to accumulate considerable amounts of CO_2, particularly if discharging in depressed areas [11].

Fig. 3 - CO_2 emission areas in Campiglia d'Orcia, (Siena, Italy). The white link is the optical link located 1.5 m above ground over the mountain road.

The area of Campiglia d'Orcia (Siena, central Italy) is characterized by a series of poorly signed multiple manifestations in a small valley cut by a mountain road. Here, people can freely access to the degassing spots whose CO_2 contents reaches up to 97 % by vol. and some of them have up to few ton/day CO_2 discharge rate. In Fig. 3 one of main CO_2 emission areas is reported, whereas in Fig. 4 the 24 hours measurements, carried out on June 8 and 9, 2006 and related to the single optical link shown in Fig. 3, are reported.

It is worthwhile to mention the high correlation between the atmospheric conditions (wind and temperature) and the CO_2 concentration in air. Almost instantaneously the CO_2 content in atmosphere at the height of 1.5 m varies from about 400 ppm to 15.000 ppm and viceversa, on sunrise and sunset.

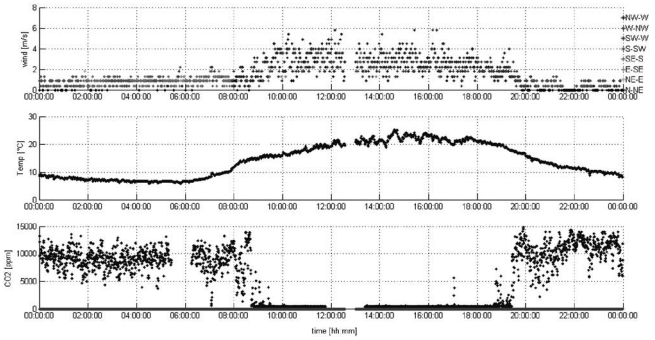

Fig. 4 - 24 hours measurements on June 8 and 9 2006 along the single link shown in Fig. 3. From top to down: wind speed and its direction, temperature, CO_2 concentration.

Multi-optical link measurement networks have also been used to estimate the CO_2 flux by natural sources located in the Ambra riverbed and in the surrounding areas (Fig. 5), i.e. in presence of water. Combining the air concentration measurements with 3D atmospheric diffusion models, the discharge rate from CO_2 sources has been estimated [11]. Measurements were performed in two days and about 40 optical links were used, whose distribution is schematically plotted in Fig. 5.

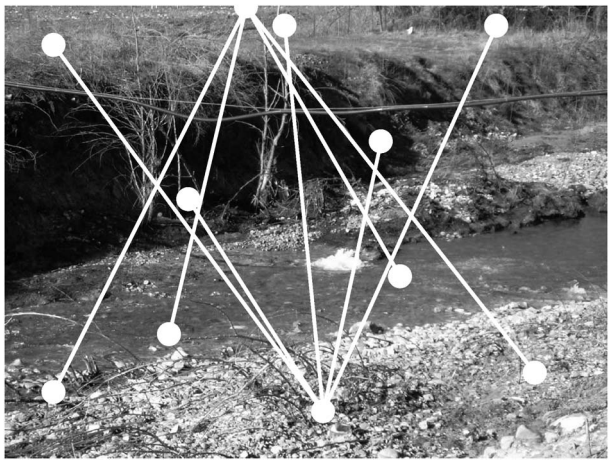

Fig. 5 - CO_2 Emission area (white eddy on the river) along the Ambra riverbed (Siena, Italy) and surrounding areas, with a schematic representation of the optical links network used for the CO_2 measurements

Fig. 6 summarizes the CO_2 measurements in terms of mean, maximum, minimum and standard deviation for each of the considered optical links. The data are a subset of the whole collected set, since they refer those taken in the same atmospheric conditions. By applying a Gaussian model of atmospheric diffusion we estimated a CO_2 emission rate of about 50 ton/day [1].

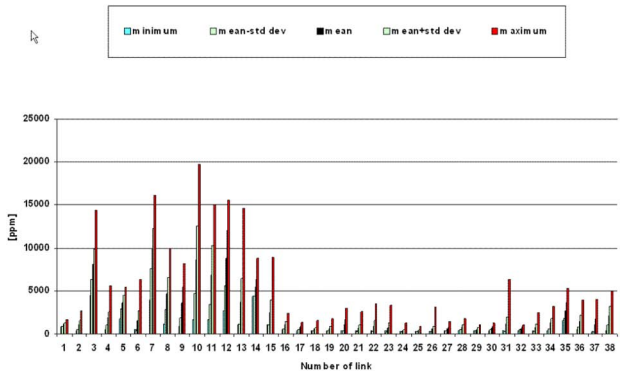

Fig. 6 – Report of the CO_2 concentration along 38 optical links arranged over the Ambra riverbed and surrounding areas as sketched in Fig. 5. The 1-20 links are those closest to the visible emission area and they can be interpreted as a sort of spatial gradient.

IV. SOLID WASTE DISPOSALS

A single optical link with time-continuos measurements was used to check the air emission rate of dumping areas for urban waste disposal. In this case long optical links allowed to record daily movement of the CO_2 gas mass close to the dumping area. Also in this case atmospheric diffusion models were applied in order to give a preliminary rough estimate of the CO_2 emission by the waste mass.

Fig. 7 – Air sight of a waste disposal close to the city of Firenze, Italy. The white line represents the 600m optical link crossing the active dumping area.

Fig. 7 shows an air sight of the dumping site close to the city of Florence (Italy) and Fig. 8 shows the 24 hours measurements on September 1, 2006 on a single 600 m optical link crossing the whole active dumping area. It is to note the high degree of correlation between the 0 speed wind conditions and the rise to the maximum concentration values during the nighttime. Such a behavior is similar to that of Campiglia d'Orcia in terms of time dynamics.

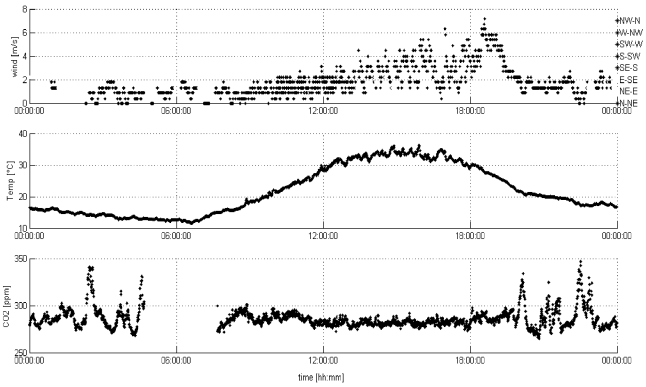

Fig. 8 – Report of the 24 hours measurements on September 1, 2006 along the single link shown in Fig. 7. From top to down: wind speed and its direction, temperature, CO_2 concentration

Therefore, it is likely that there are CO_2 sources close to the optical link allowing an increase of about 50-70 ppm over the whole 600 m optical link for those particular atmospheric conditions. Based on the number of these rising events in a day, and assuming that they are exclusively due to the waste disposal, its CO_2 emission rate could be estimated by inverting an atmospheric diffusion model following the same approach of the Ambra riverbed case. Nevertheless, the low CO_2 concentration values that have been measured in the single day need further measurement campaigns for understanding the possible contribution of the surrounding environment in the CO_2 production. A multilink approach able to cover the whole air volume above the waste disposal is the optimal choice for separating the CO_2 contribution of the surrounding environment with respect to that of the waste mass.

V. CONCLUSIONS

The high number of CO_2 measurement campaigns made in very different environmental sites allows to say that by processing air concentration measurements using IR laser systems and exploiting simultaneously measured meteorological parameters, remote sensing systems able to monitor CO_2 emissions by a limited area in real time can be realistically developed. In addition to CO_2, DSA (Differential Spectroscopy Absorption) based IR portable laser systems can be implemented by new sensors to simultaneously measure other gases fluxes, such as CH_4 and H_2S and to develop complete volumetric remote sensing system for the emission control in environmentally (natural and anthropogenic) sensitive areas.

The simultaneous measurements along optical links located on vertical and horizontal air sections, close to the emission point, would also allow to derive the real time diffusion atmospheric conditions. In [12] we proposed an approach to retrieve some parameters required to implement a Gaussian model for the atmospheric diffusion of gas emitted by point sources. The real time tuning of the diffusion parameters would allow to relate immediately the gas concentration in air to the emission rate of the gas sources.

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