ÉCOLE DOCTORALE
SCIENCES DE LA TERRE ET DE L'ENVIRONNEMENT
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Subject title: Quantifying carbon dioxide emissions and atmospheric dispersion at volcanic and non-volcanic sites using an integrated approach

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Host lab/Team: **IPGP-Physics of Natural Sites – UMR7154**

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Presentation of the subject:

Significant geological carbon dioxide (CO_2) emissions have been reported worldwide at plate boundaries in both volcanic and non-volcanic contexts. Understanding their temporal variations, possibly related to tectonic deformation and earthquakes, is crucial to mitigate associated hazard and risk to the population. This objective requires a good knowledge of the deep source of the CO_2, its transport through the Earth's crust, its emission at the surface and its dispersion in the first atmospheric layers. This thesis is part of a global effort to better understand the spatial and temporal variations of geological CO_2 emissions at increasing spatial scales in different geodynamic contexts.

Specific hydrothermal manifestations observed at the surface, such as CO_2 rivers in the form of fumaroles or mofettes, show large CO_2 emissions that are still difficult to quantify precisely [1]. These rivers are turbulent, negatively-buoyant flows that propagate near the surface following the topography and can entrain large amounts of air due to wind shear. In some cases, the air flow is so weak that CO_2 accumulates, forming a "lake" with volumetric CO_2 concentrations in the air above 10%. These CO_2 rivers, with characteristic length ranging from a few metres to several kilometres, have been reported in numerous volcanic and non-volcanic contexts and represent a major health hazard to the population. The limnic eruption at Lake Nyos (Cameroon) in 1986 is a tragic example of the impact of such CO_2 rivers with the death of ~1,800 people and ~3,500 livestock by asphyxiation [2].

The aim of this thesis is to improve the quantification of CO_2 rivers atmospheric dispersion in different geodynamic contexts using an integrated approach recently developed at the IPGP, which combines direct measurements in the field, analogue experiments and numerical modelling.

First, the PhD candidate will collect new data at three different geodynamic contexts: a hotspot with a magmatic and mantellic CO_2 source (the Caldeiras da Ribeira Grande, Azores, Portugal), a subduction with a magmatic CO_2 source (Saint-Vincent, West Indies) and an orogen with a metamorphic CO_2 source (Upper Trisuli Valley, Central Nepal). At these sites, measurements of CO_2 flux using the accumulation chamber method [3-4] and of CO_2 concentration in the first metres of the atmospheric layer above the ground using a portable sensor will provide an unprecedented data set. Complementary data including atmospheric temperature, temporal variations of wind speed and direction, and ground topography and roughness will also be acquired.

Second, analogue experiments will be designed and performed in the laboratory under controlled conditions to reproduce a hot turbulent flow of dense gas. The entrainment of turbulent air in the CO_2 flow [5-6] will be constrained using state-of-the-art techniques (PIV and LIF) to continuously follow the evolution of velocity and concentration fields as a function of time. The effects of gas temperature, gas composition, topography, surface roughness and convective atmosphere will be tested in the controlled conditions of the laboratory. Possibly, a large-scale field experiment will be designed to test mitigation strategies to reduce population exposure.

Finally, interpretation will be based on a numerical code with a recently improved interface and a better description of air entrainment (an improved version of the TWODEE-2.6 code; [7]). This physical model, validated by preliminary laboratory experiments and field data, will be applied to the three different geodynamic sites in order to interpret the field measurements in terms of flow dynamics and better quantify the atmospheric dispersion. The new laboratory results will provide a stringent test to fully validate the physical model, which will then be used to interpret the field data.

This work will provide critical constraints to better understand the dispersion of a dense gas in the first atmospheric layers, and to quantify the budget of CO_2 rivers in different geodynamic contexts. This newly developed framework will also provide a robust tool for hazard assessment at active volcanoes such as La Soufrière de Guadeloupe or Montagne Pelée in Martinique. The results will thus be of great interest for volcanological observatories worldwide. Further applications of this work include risk assessment in other contexts (pollution, underground environment), and industrial processes involving the dispersion of gas (artificial ventilation, geothermal plants).

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Collaborative framework:

- IVAR (Azores)
- DMG (Nepal)
- SRC-UWI (Trinidad-and-Tobago)

References:

[1] Chiodini, G., Granieri, D., Avino, R., Caliro, S., Costa, A., Minopoli, C., Vilardo, G., 2010. Non- volcanic CO_2 Earth degassing: Case of Mefite d'Ansanto (southern Apennines), Italy. *Geophys. Res. Lett.* 37, L11303.

[2] Kling, G.W., Clark M.A., Wagner, G.N., Compton H.R., Humphrey, A.M., Devine, J.D., Evans, W.C., Lockwood, J.P. et al., 1987. The 1986 Lake Nyos gas disaster in Cameroon, West Africa. *Science* 236 (4798), 169-175.

[3] Girault, F., Adhikari, L.B., France-Lanord, C., Agrinier, P., Koirala, B.P., Bhattarai, M., Mahat, S.S., Groppo, C., Rolfo, F., Bollinger, L., Perrier, F., 2018. Persistent CO_2 emissions and hydrothermal unrest following the 2015 earthquake in Nepal. *Nat. Comm.* 9, 2956.

[4] Girault, F., Viveiros, F., Silva, C., Thapa, S., Pacheco, J.E., Adhikari, L.B., Bhattarai, M., Koirala, B.P., Agrinier, P., France-Lanord, C., Zanon, V., Vandemeulebrouck, J., Byrdina, S., Perrier, F., 2022. Radon signature of CO_2 flux constrains the depth of degassing: Furnas volcano (Azores, Portugal) versus Syabru-Bensi (Nepal Himalayas). *Sci. Rep.* 12, 10837.

[5] Kaminski, E., Tait, S., Carazzo, G., 2005. Turbulent entrainment in jets with arbitrary buoyancy. *J. Fluid Mech.* 526, 361-376.

[6] Carazzo, G., Kaminski, E., Tait, S., 2006. The route to self-similarity in turbulent jets and plumes. *J. Fluid Mech.* 547, 137-148.

[7] Folch, A., Costa, A., Hankin, R.K.S., 2009. TWODEE-2: A shallow layer model for dense gas dispersion on complex topography. *Comput. Geosci.* 35, 667-674.