Statistical analysis of geogenic CO_2 dispersion in lower atmospheric layers using an integrated approach

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Congrès des Doctorants (23/05/2025)

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CO_2 emissions across the globe

Origin of CO_2

- Natural : volcanic and non-volcanic
- Anthropogenic

→ Widely spread phenomenon across the globe, often impacting highly populated places

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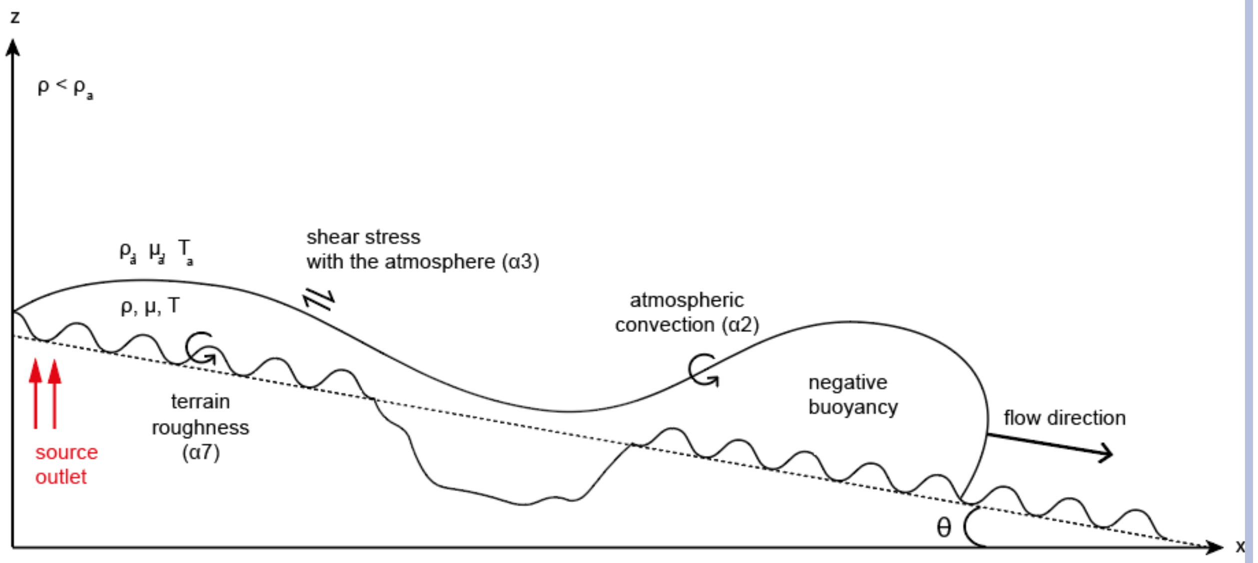
« CO2 rivers »



- Dense flow
- 4 main physical contributions:
  - Shear stress with the atmosphere
  - Terrain roughness effects
  - Atmospheric convection
  - Negative buoyancy
- Low-lying geometry

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- Located at human height (denser than air)
- Poorly detected (odorless and colorless)

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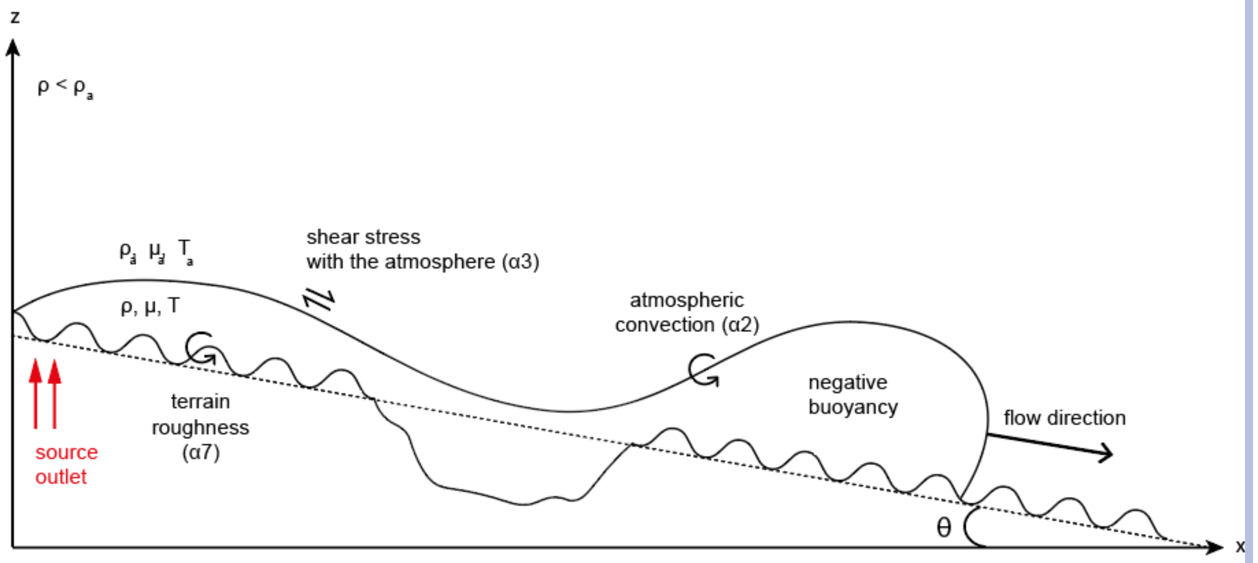

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Many recorded cases around the world

e.g. : Lake Nyos lymnic eruption (Cameroun, 1986)
<1700 fatalities

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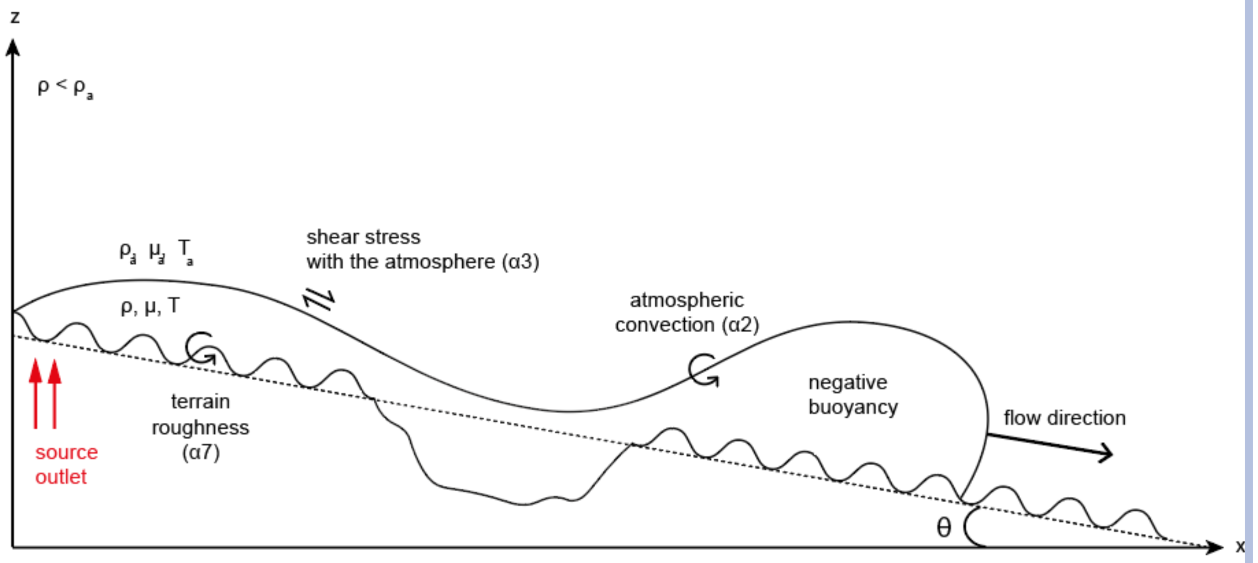

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- Poorly constrained parameters of current numerical codes

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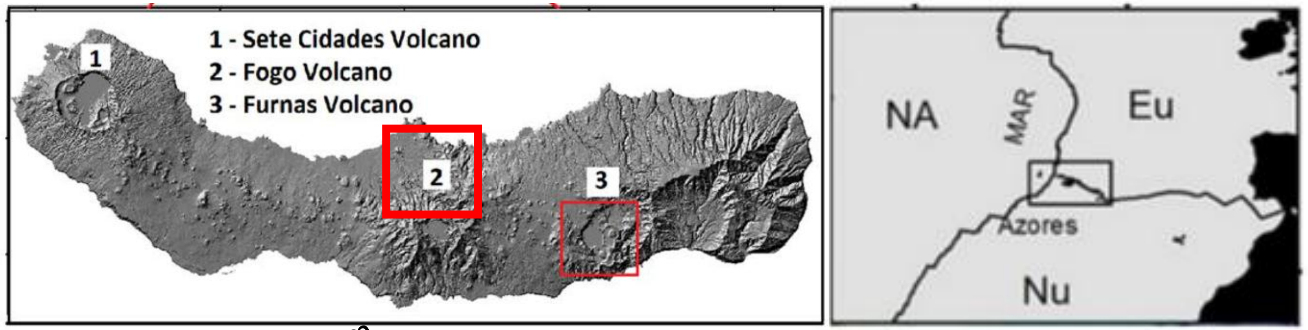
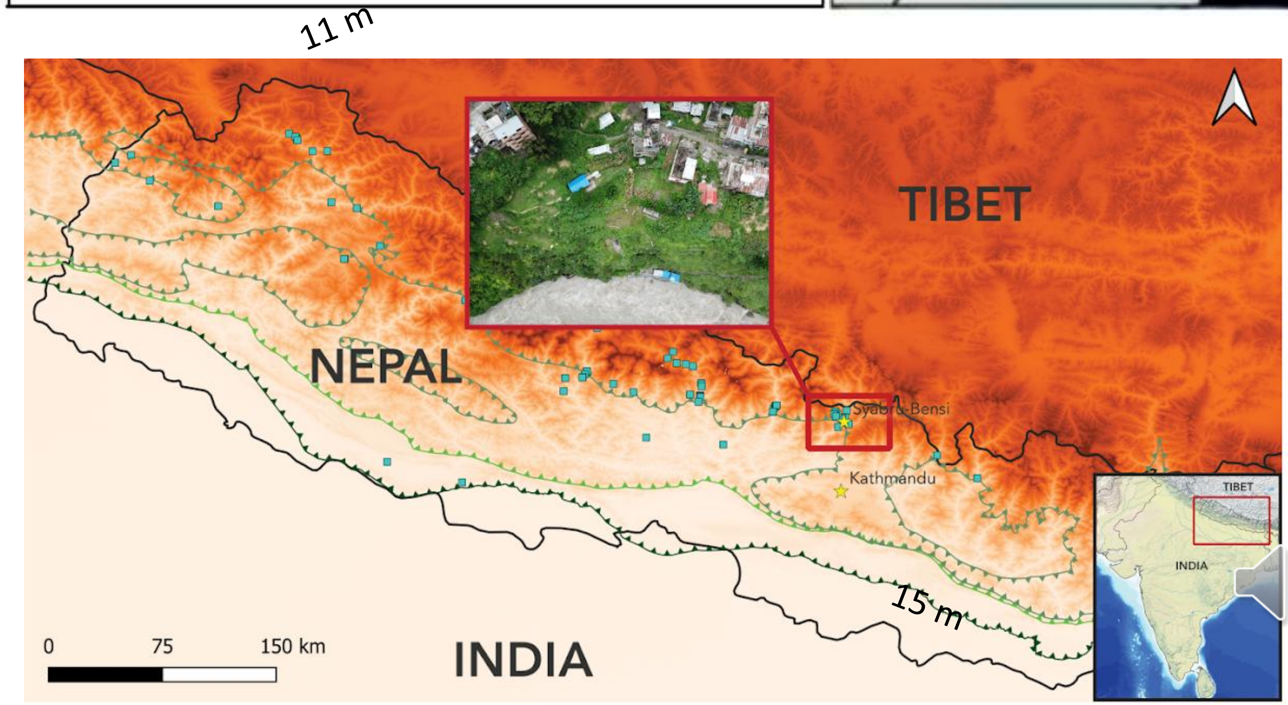
1 - Where and how to acquire more field data?
2 - How to recreate CO_2 rivers in a laboratory?
3 - What model to choose and how to improve it?

1 – Field data acquisition

Regions of interest in different geodynamical contexts

Site	Ribeira Grande (Fogo volcano, Azores)	Upper Trisuli valley (central Nepal)
Origin of CO_2 emissions	Magmatic and mantellic (triple junction)	Metamorphic (orogen, continental collision)
Scale	$10^2 - 10^3$ m	$10^1 - 10^2$ m





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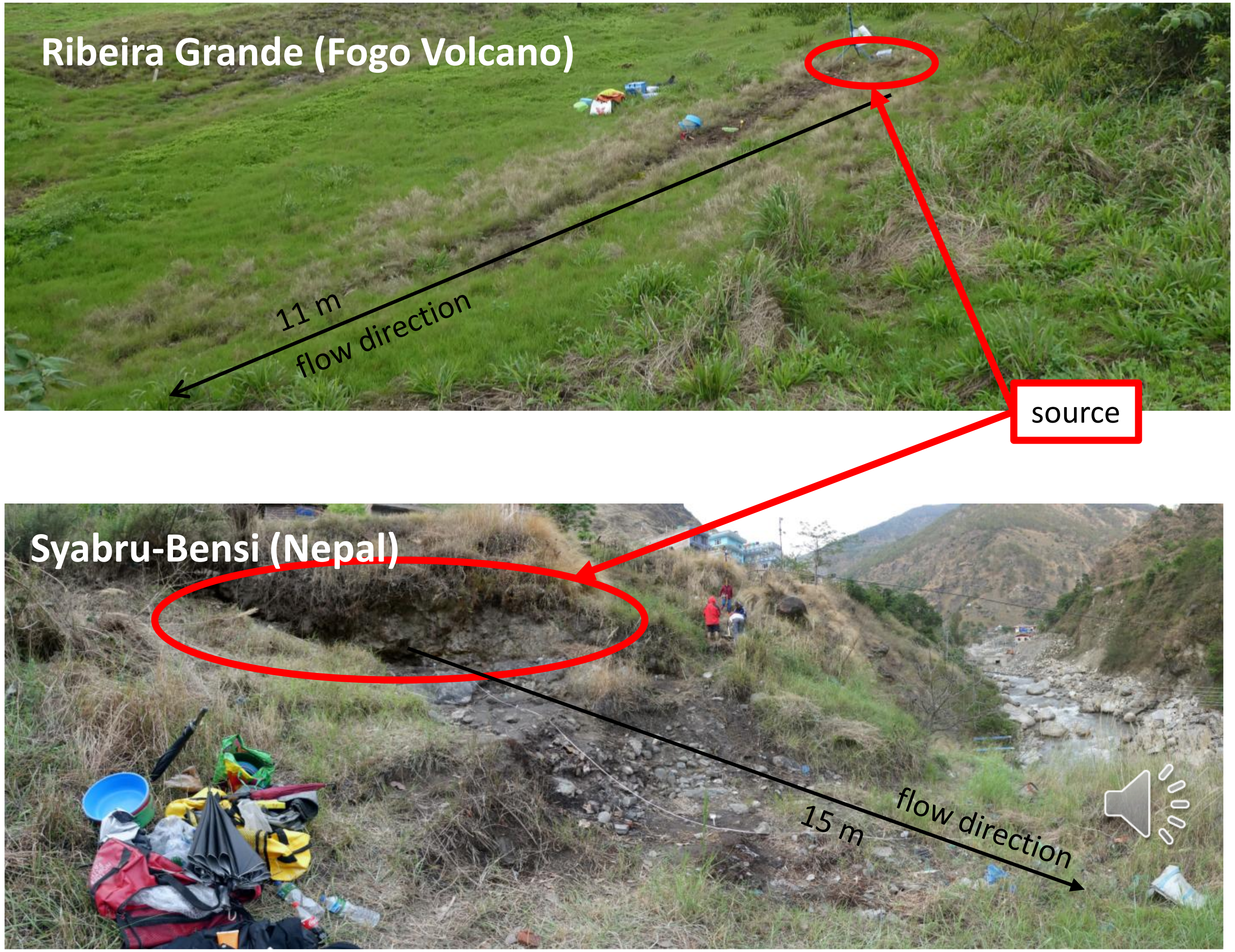
Area identification by **pervasive odor** (H_2S), **touch** (warm degassing) and **sight** (dead animals, absence of vegetation, fumaroles)



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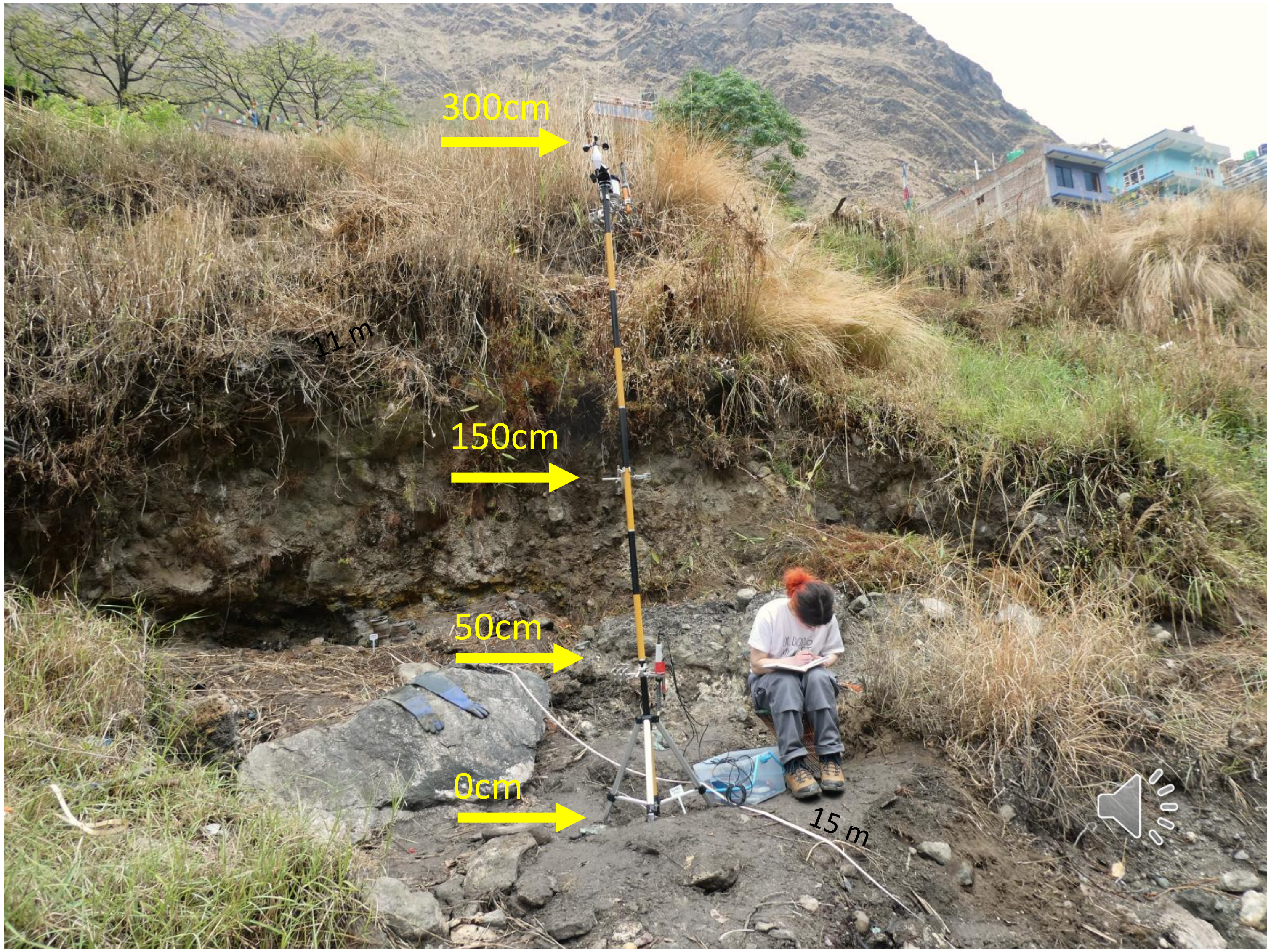
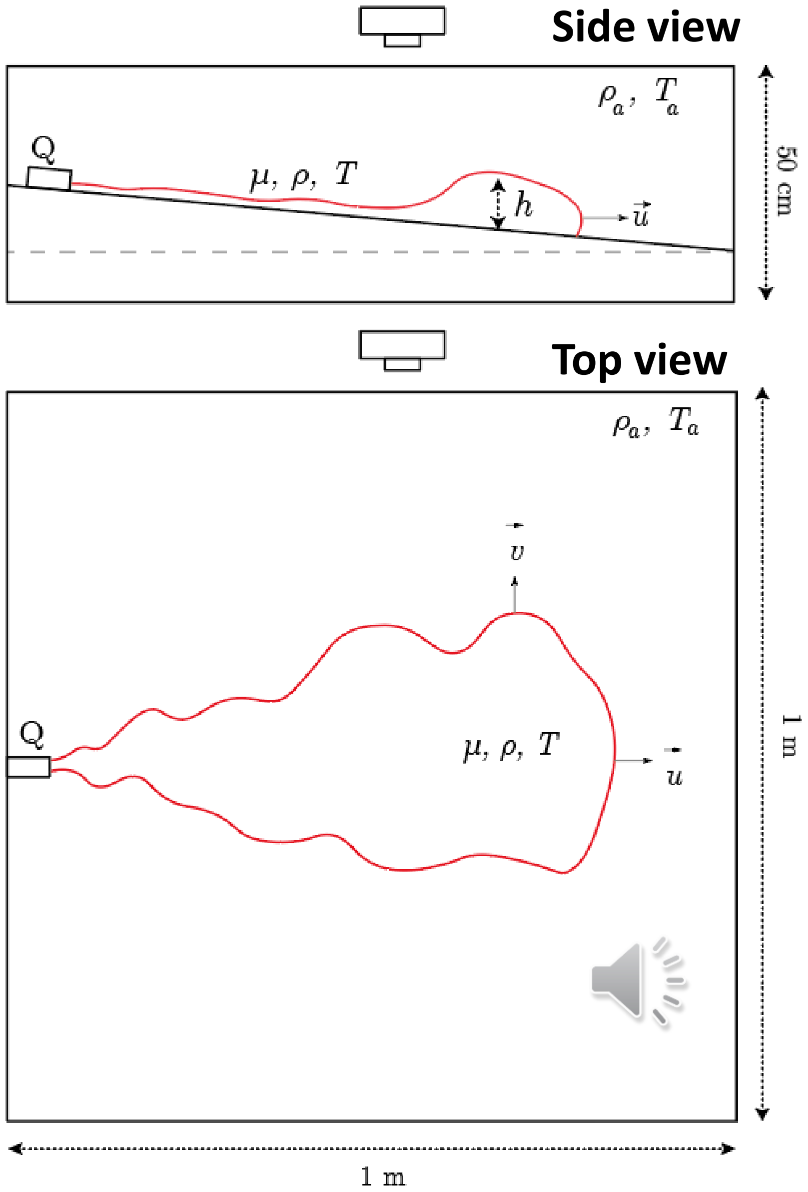
Variable	Measurement method
CO_2 flux	Accumulation chamber
Airborne CO_2 concentration	Infrared sensor
Wind (speed + direction)	Anemometer + permanent meteo station
Topography	Laser rangefinder, DEM by drone



2 – Analogue experiments

Protocol : continuous injection of saltwater into a tank filled with freshwater, on an inclined slope (1x1x0.5m^3)

- Slope: 0°, 5°, 10°
- Roughness : 10^0 µm , 10^1 µm, 10^2 µm (glass beads)
- Approximately 12 input flux ranging between 0.6 and 1.6 L/min



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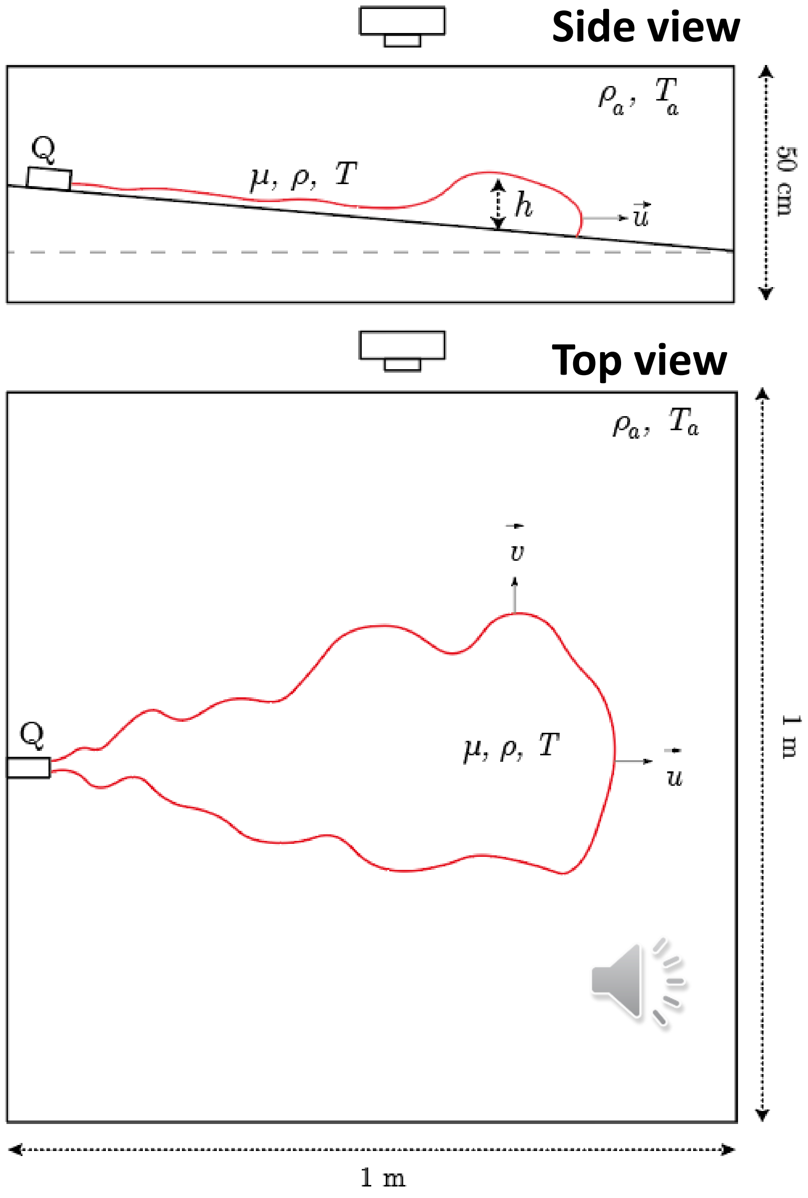
Scaling

- Data from the Mefite d'Ansanto *(Chiodini et al., 2010)*
- 3 adimensional parameters

Reynolds	Re	$\frac{\rho u h}{\mu}$	Flow regime
Froude	Fr	$\frac{u}{\sqrt{g' h}}$	Effects of buoyancy VS inertia (front)
Richardson	Ri	$\frac{g' h}{u^2}$	Effects of buoyancy VS inertia (internal)



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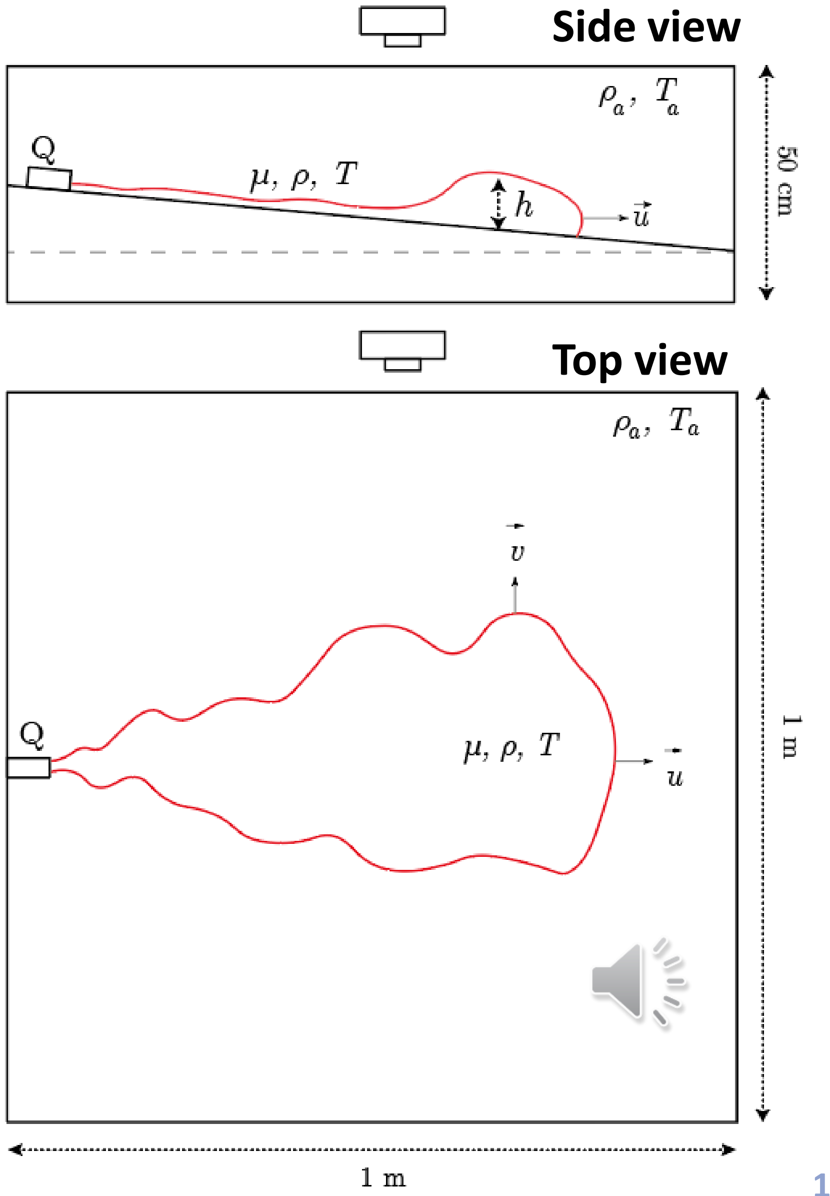
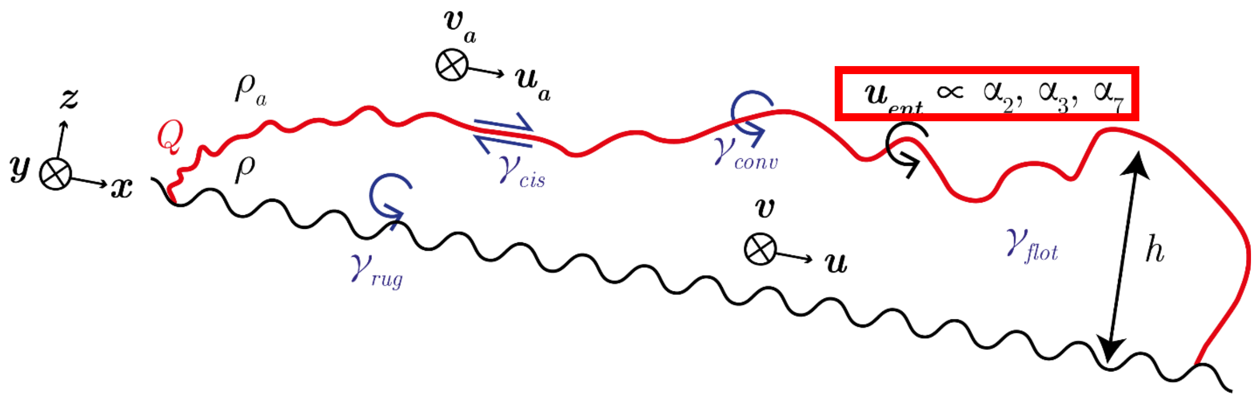
Analysis: video based analysis of the cloud lateral and front velocities, v and u



3 – Numerical model: TWODEE

Approach

Depth-averaged variables over the characteristic height *h* of the flow
+ Shallow-water equations
+ Additional physical contributions



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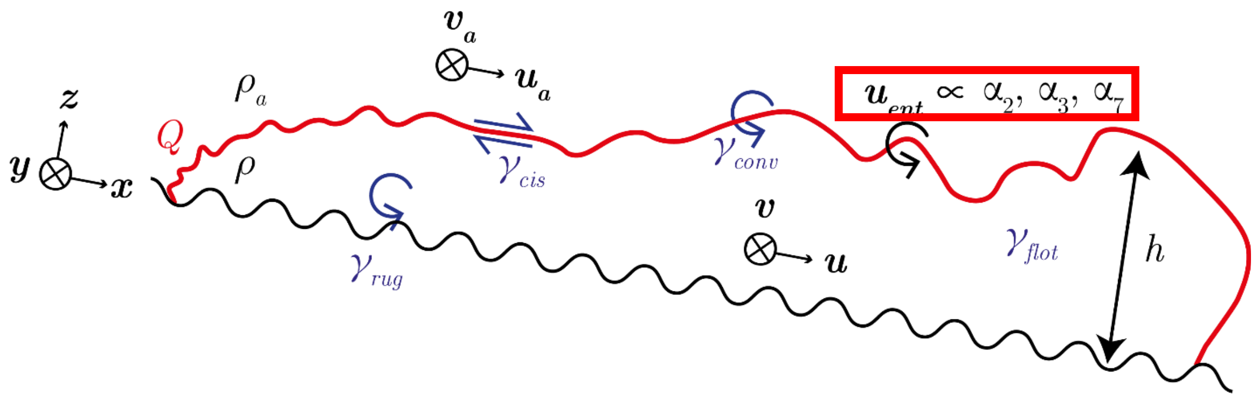

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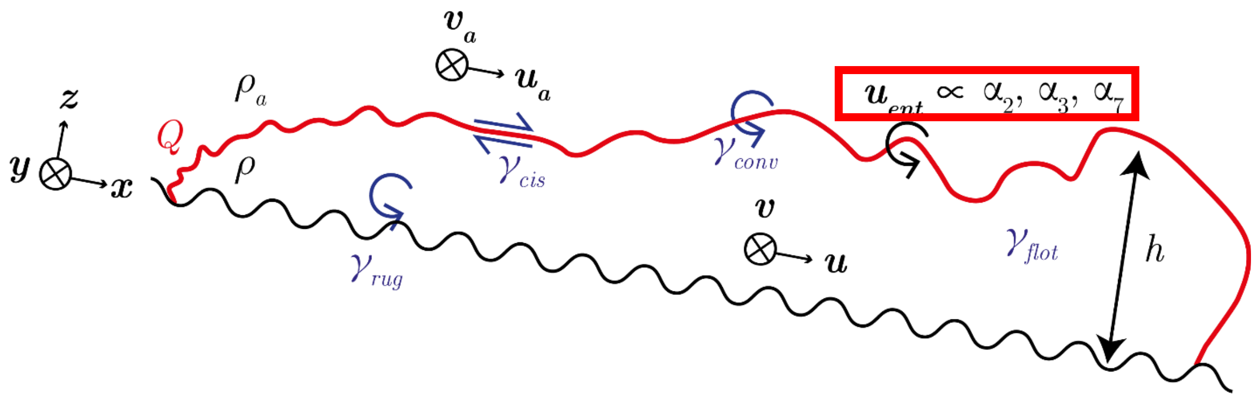

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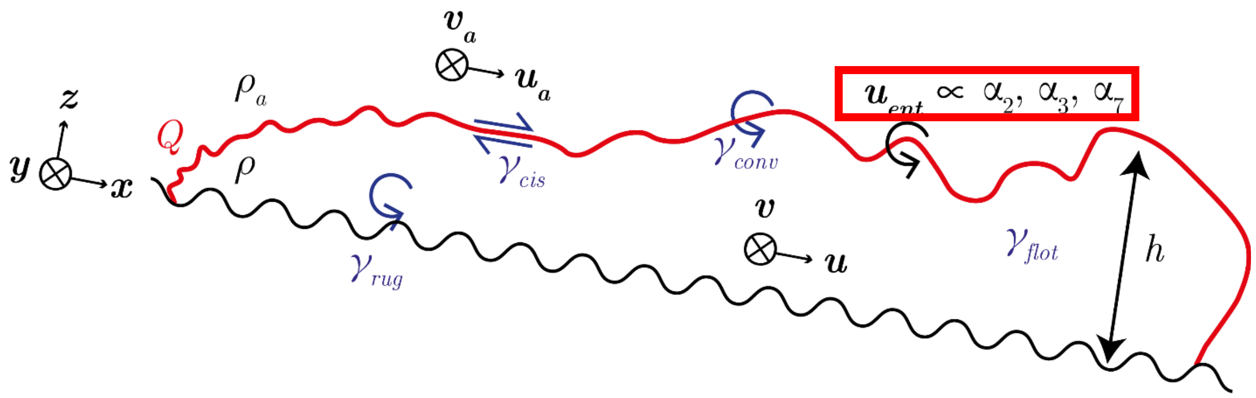

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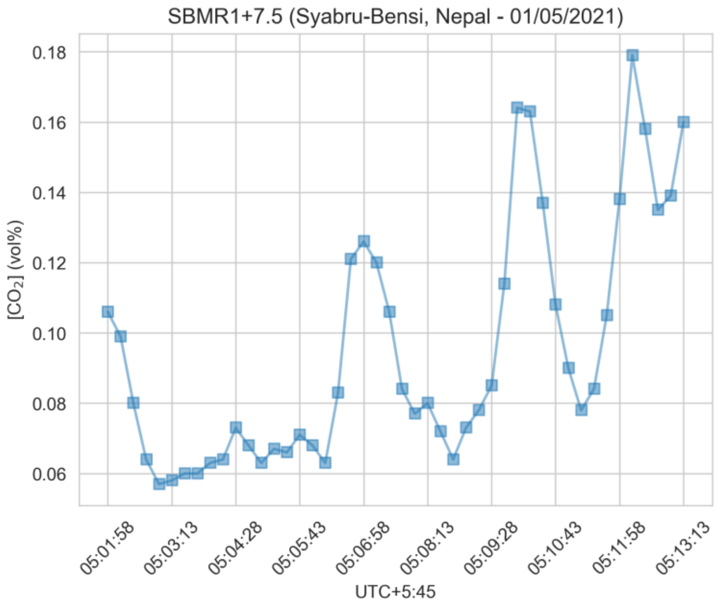
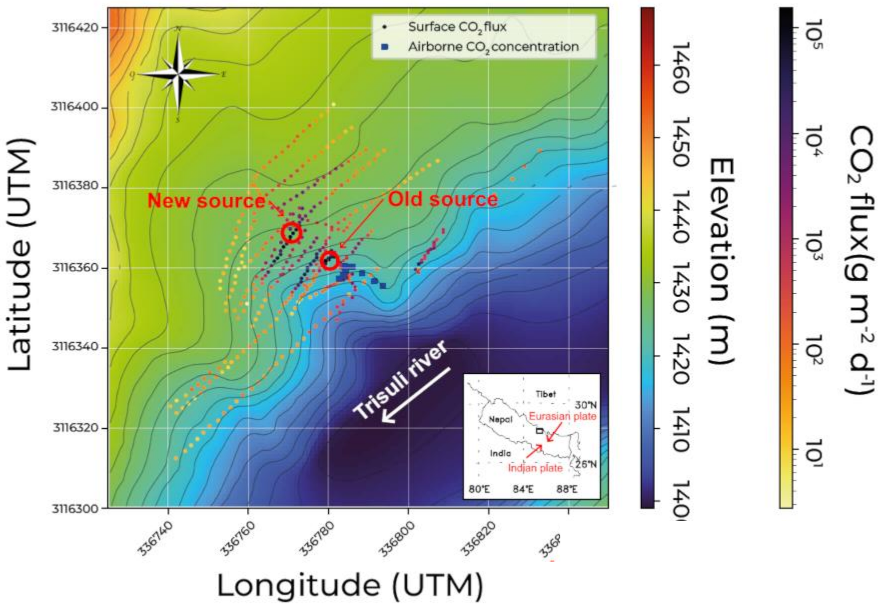
Simulations

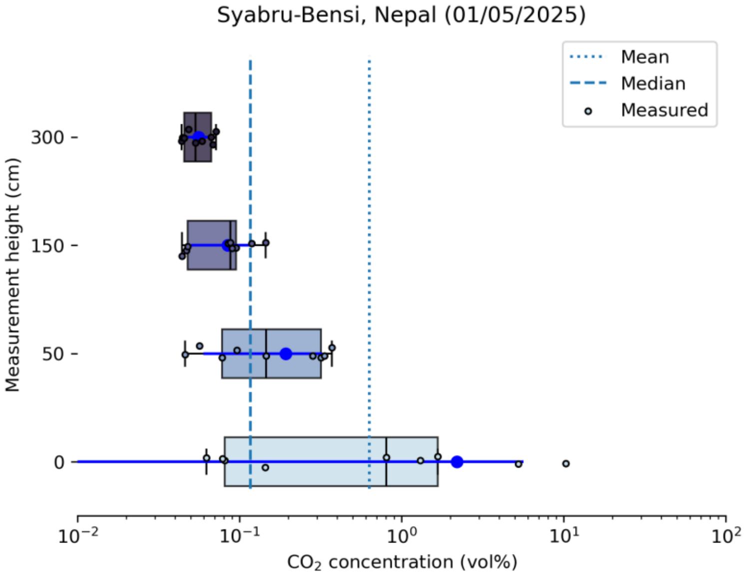
- Output: [CO_2] at every given elevation
- Analysis: calculation of statistical validation metrics which compare observed and simulated [CO_2]

1 – New extensive datasets obtained in the field

Region	Ribeira Grande (Azores)	Upper Trisuli Valley (Nepal)
Sites	1	4
Profiles	13	18
Measurement points	41 (164)	79 (316)
$[CO_2]$ > BG	in progress	92%



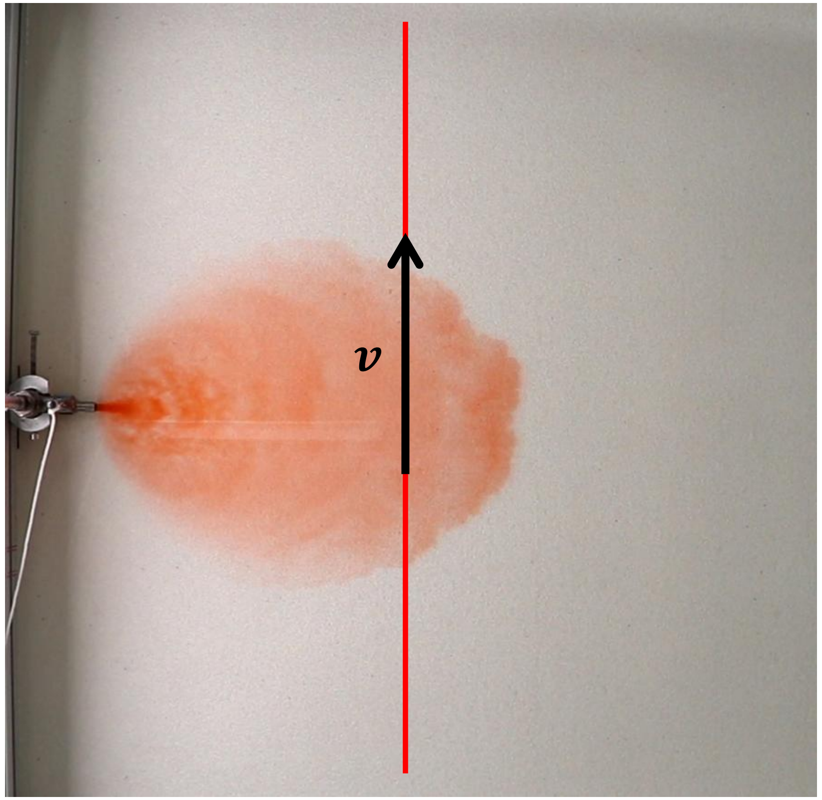




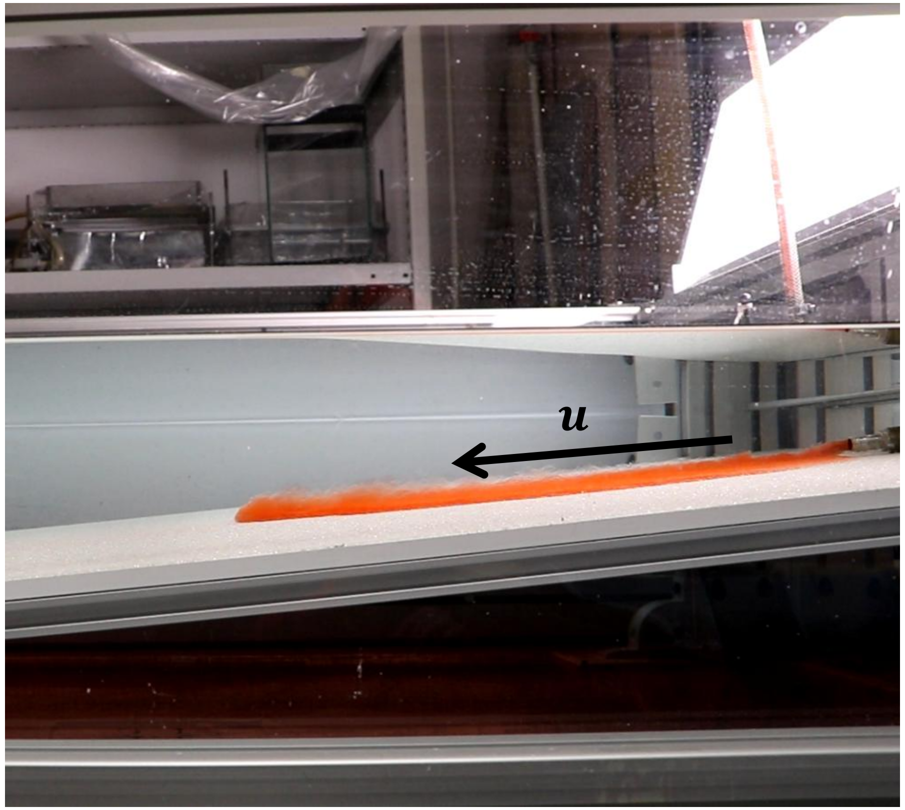
- ➢ Higher [CO2] levels in these areas, decreasing with elevation
- ➢ Points with highest [CO2] are compatible with the location of the sources that were previously identified
- ➢ Short-lived fluctuations in the form of pulses
  - ➡ Especially visible at high concentration levels

2 – Series of analogue experiments

34 experiments



Measurement of the lateral velocity v



Measurement of the front velocity u

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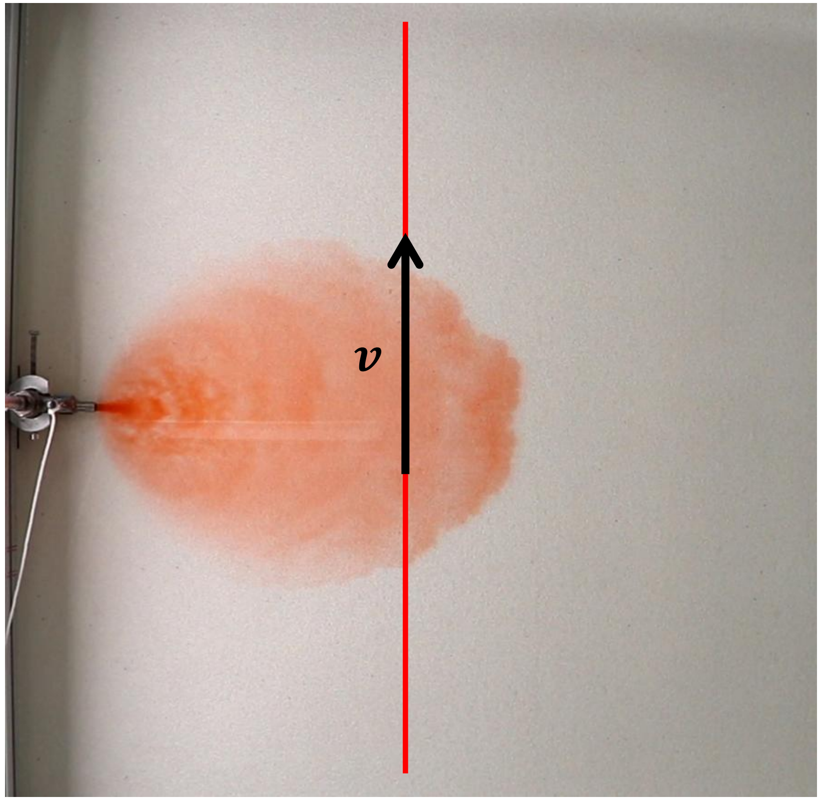
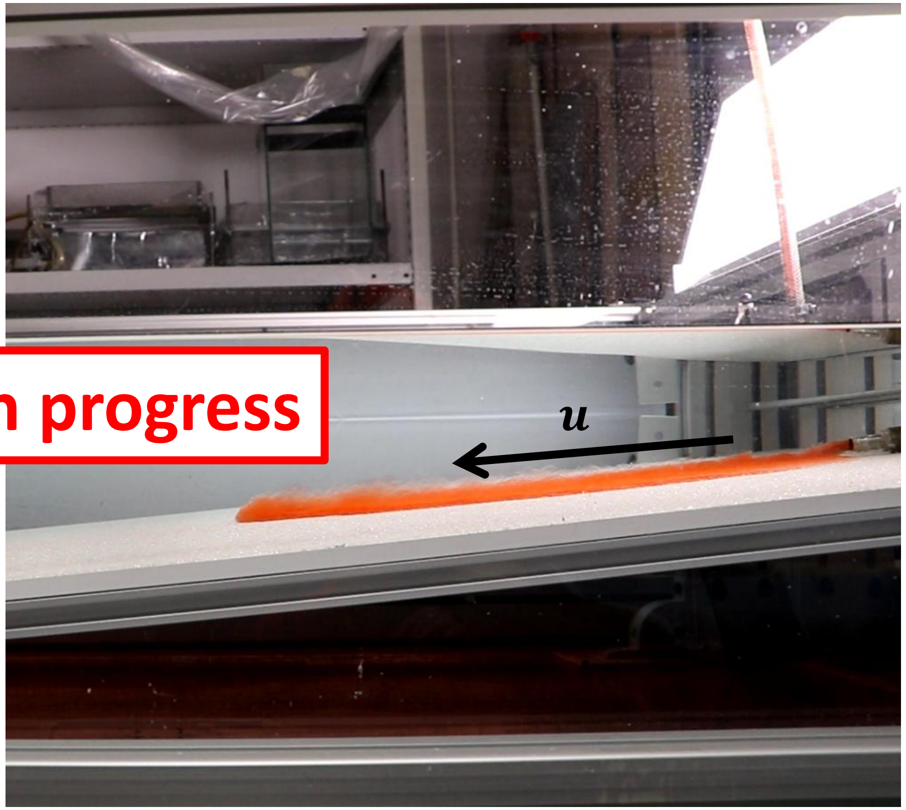


Measurement of the lateral velocity v

Work in progress

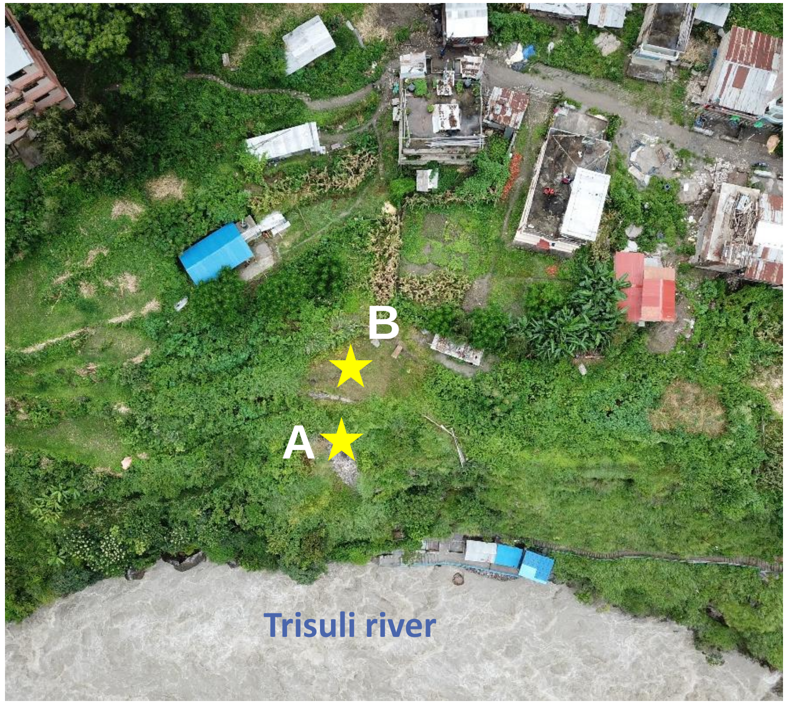


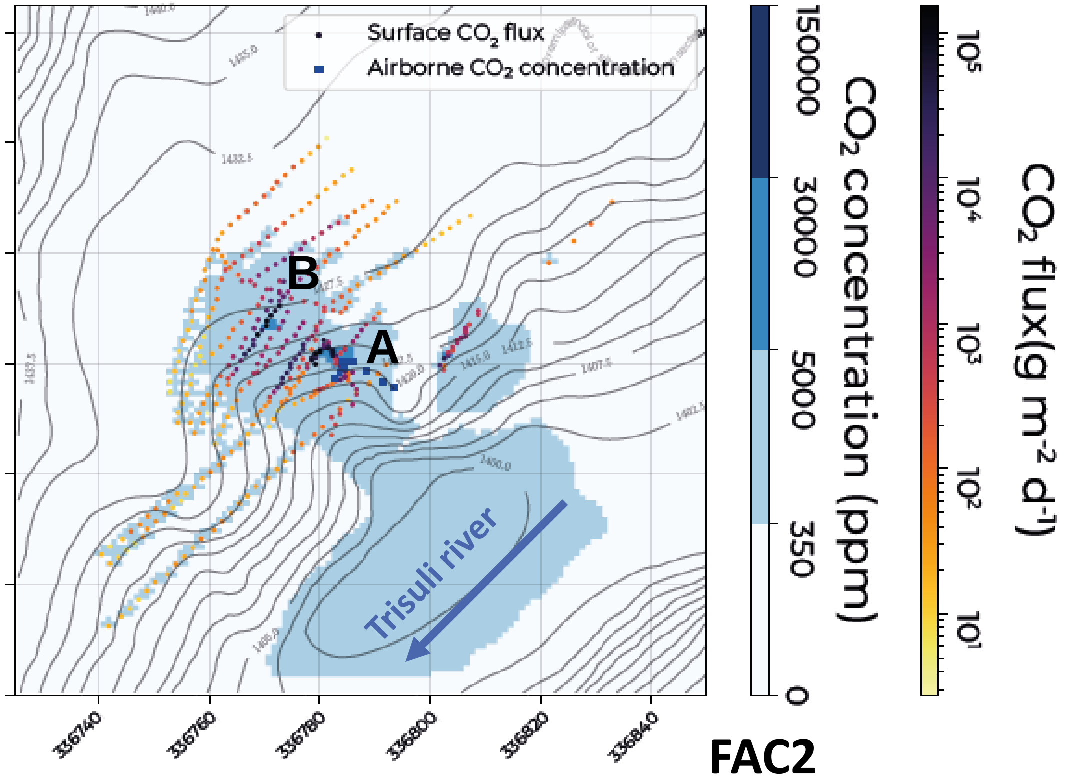
Measurement of the front velocity u

3 – Modelling of airborne CO_2 at Syabru-Bensi (Nepal)

Areas with high levels of CO_2 concentration near the village, compatible with observations

- 5 cm : 2.8%
- 150 cm : 0.6%





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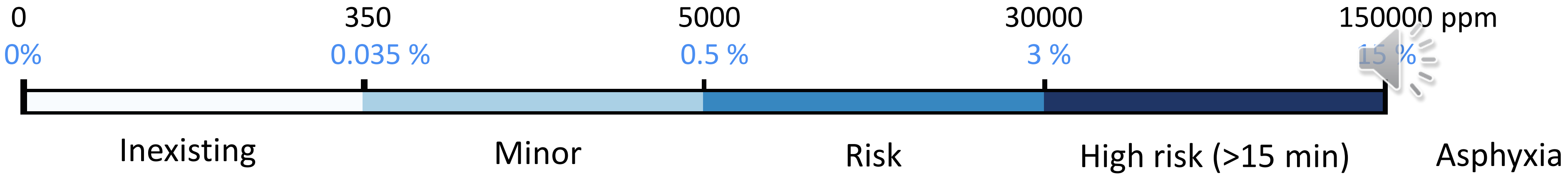

NIOSH (2007)

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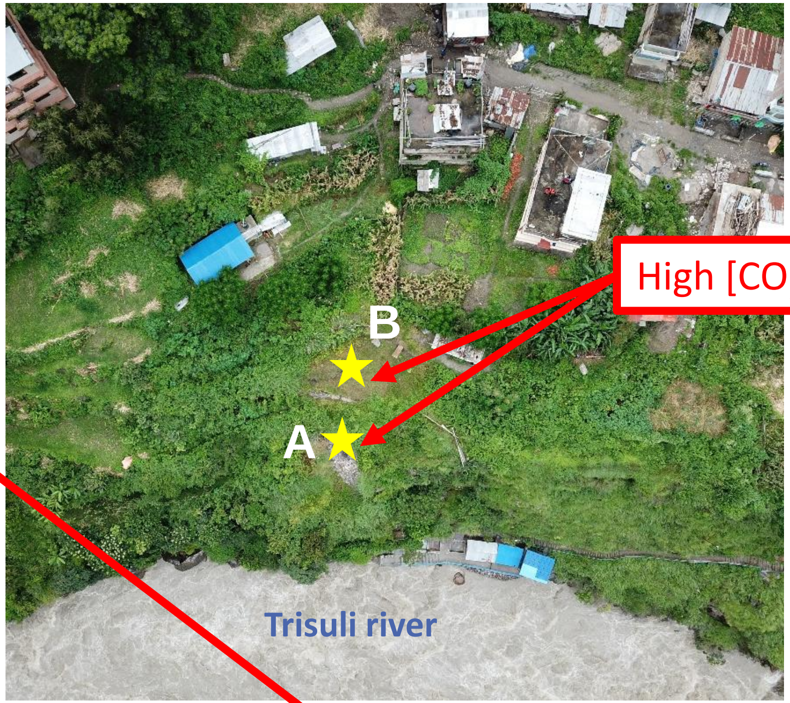

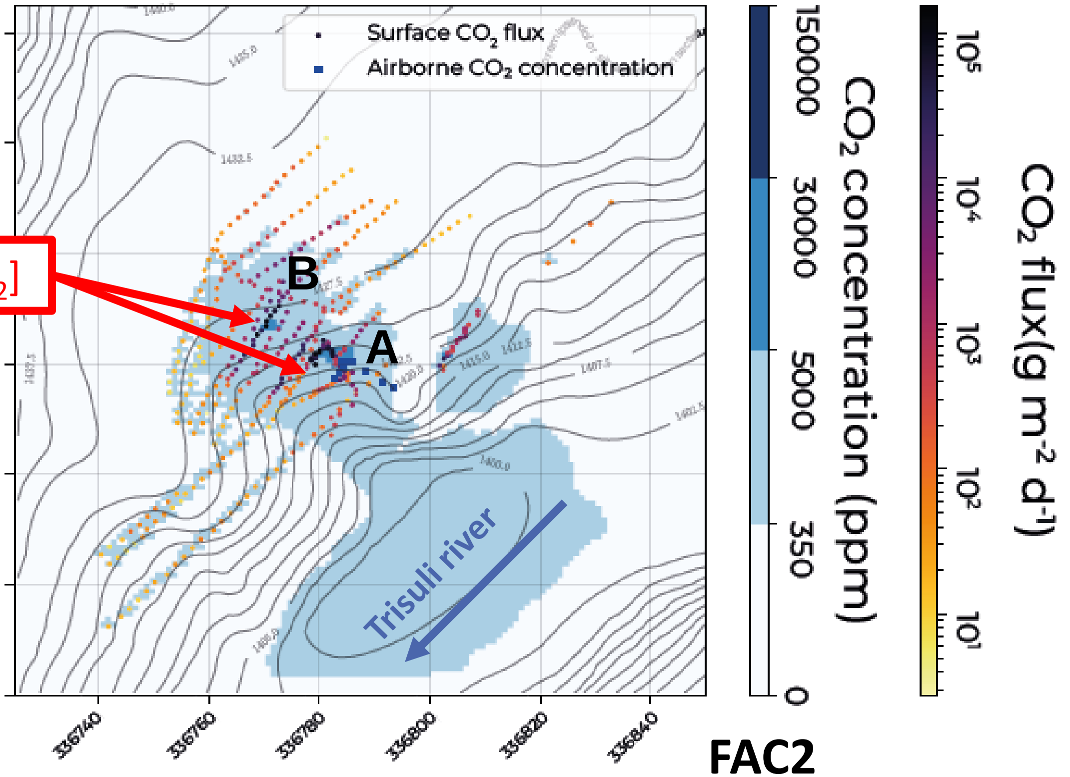

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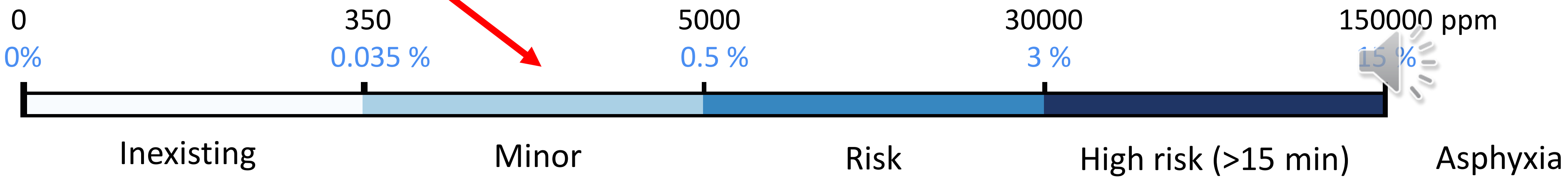

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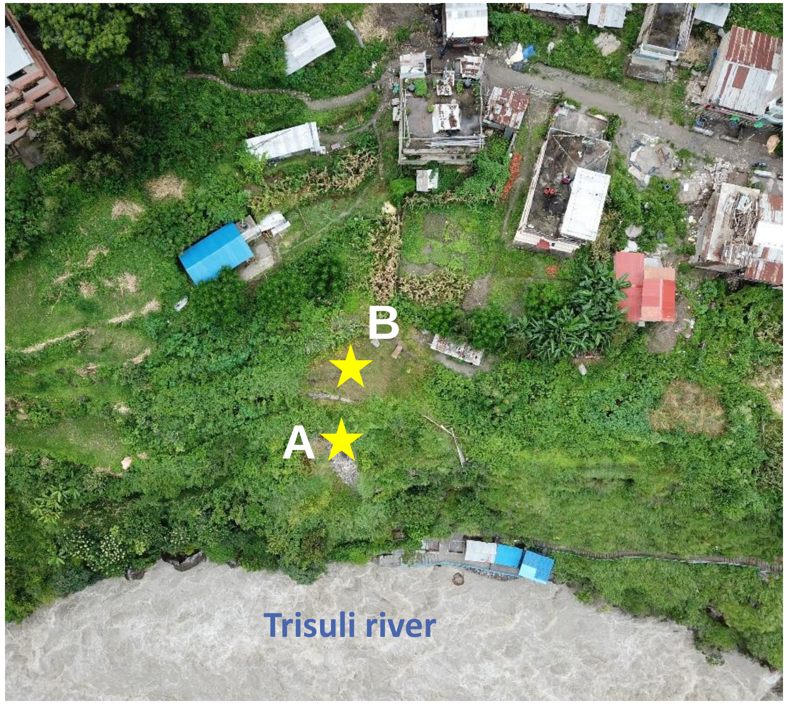
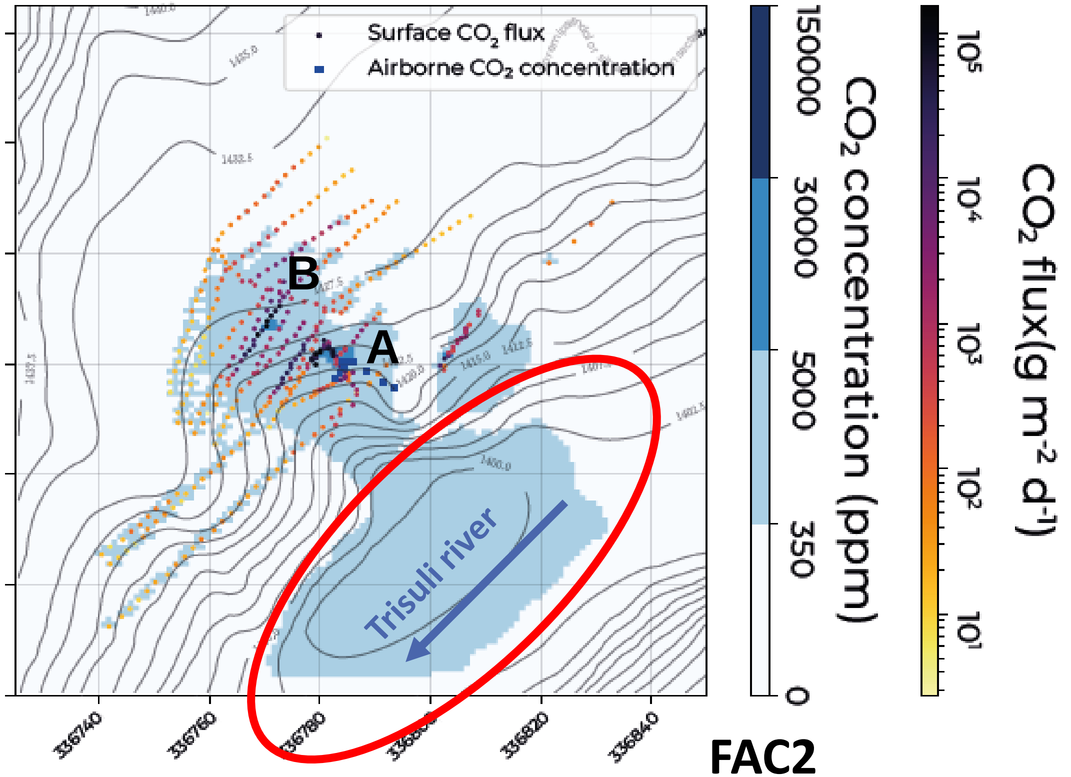
Risk of accumulation at the river surface

→ Airborne CO2 concentrations over the river?





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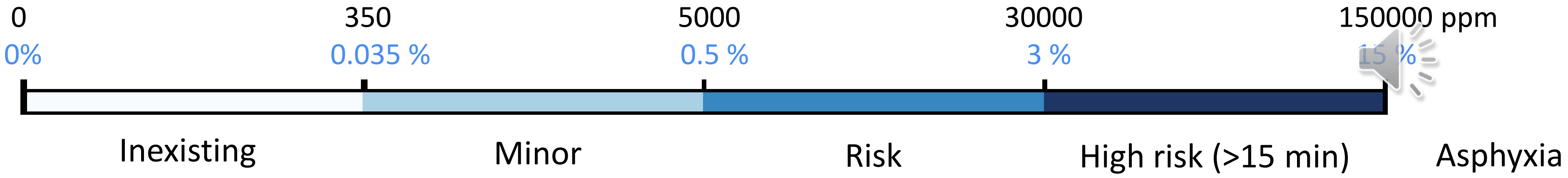

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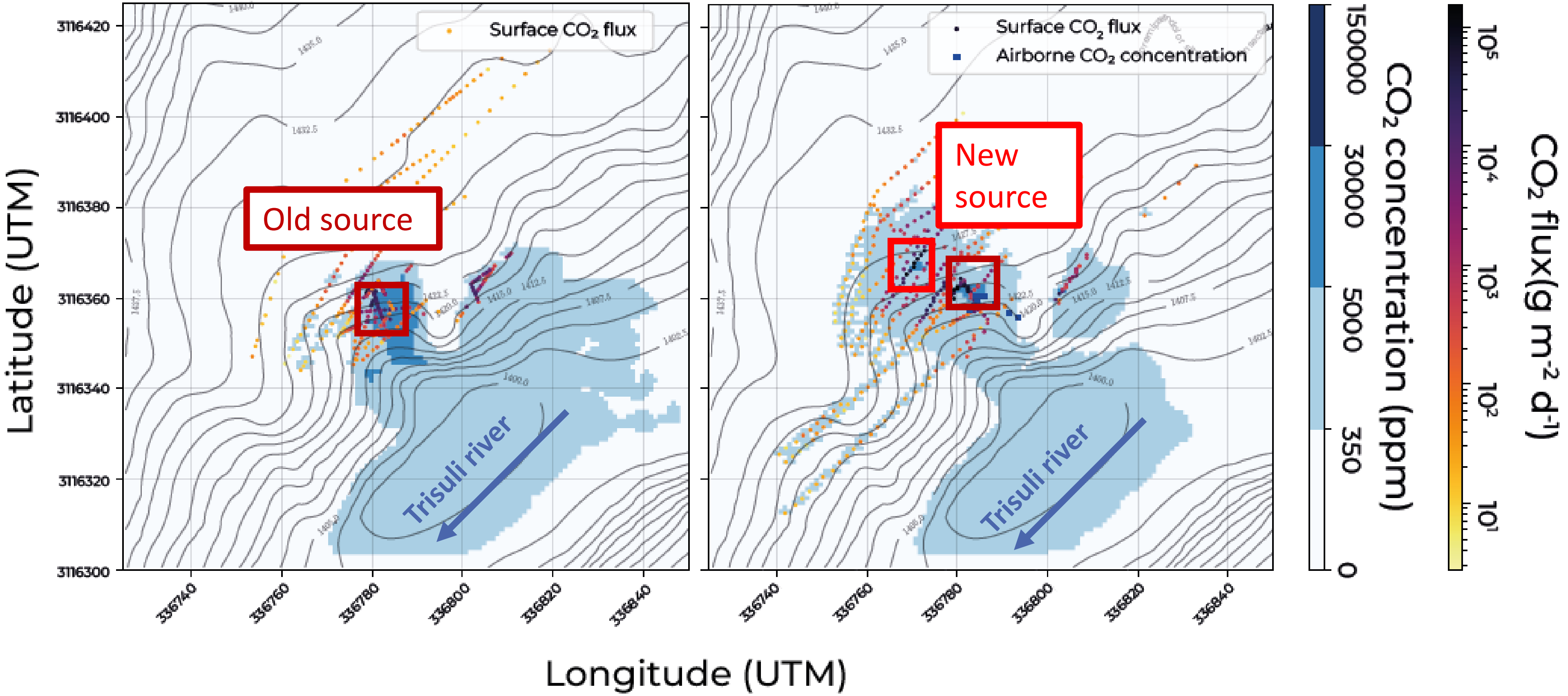
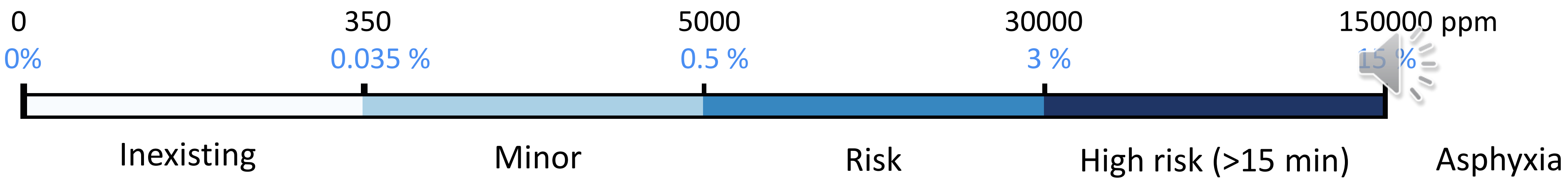
3 – Effects of the 2015 Gorkha earthquake

Change in degassing dynamics since the Gorkha earthquake (2015)

- Appearance of a new source, uphill
- Smaller covered area
- High level of [CO_2] are still observed





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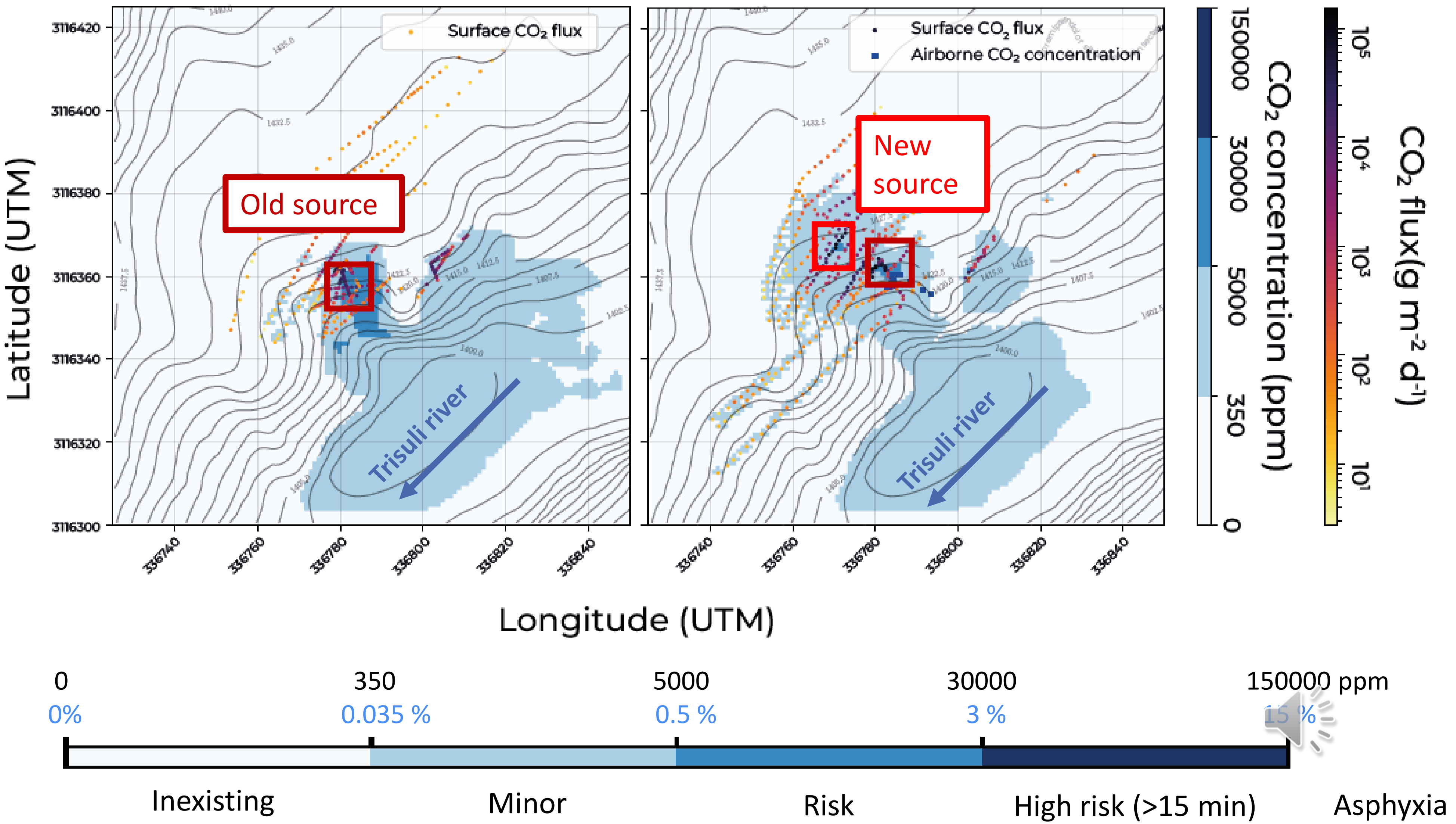

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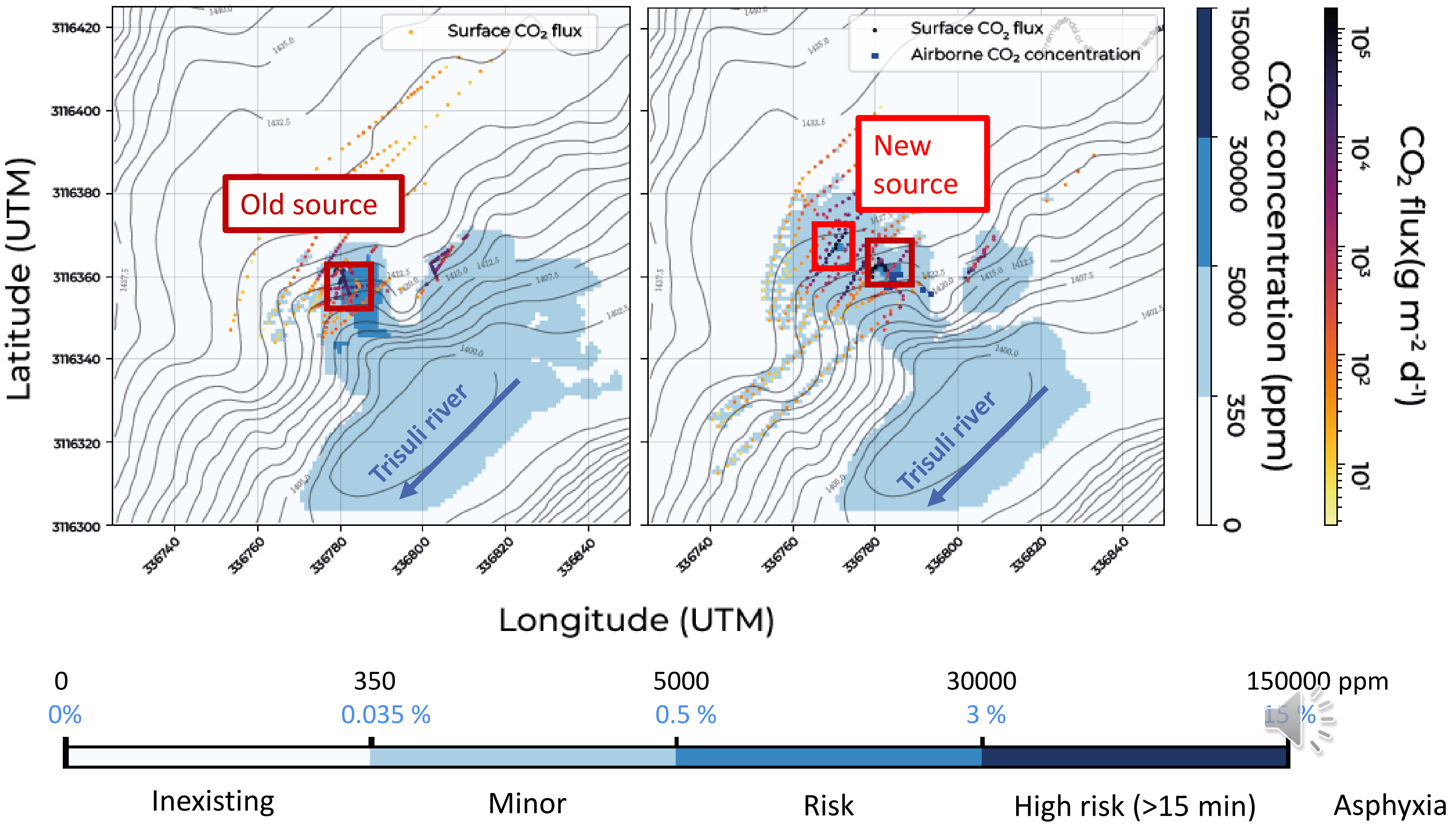
Longer simulations are required to account for the long-term effects of degassing!



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Conclusions

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- Reproduction of CO_2 rivers → More controlled data

Further analysis still needs to be done in order to properly reassess the model parameters

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By combining improved data sets and numerical modelling, this integrated approach helps **better understand the degassing dynamics of dense flows**

This paves the way for the **development of an operational tool for crisis management**