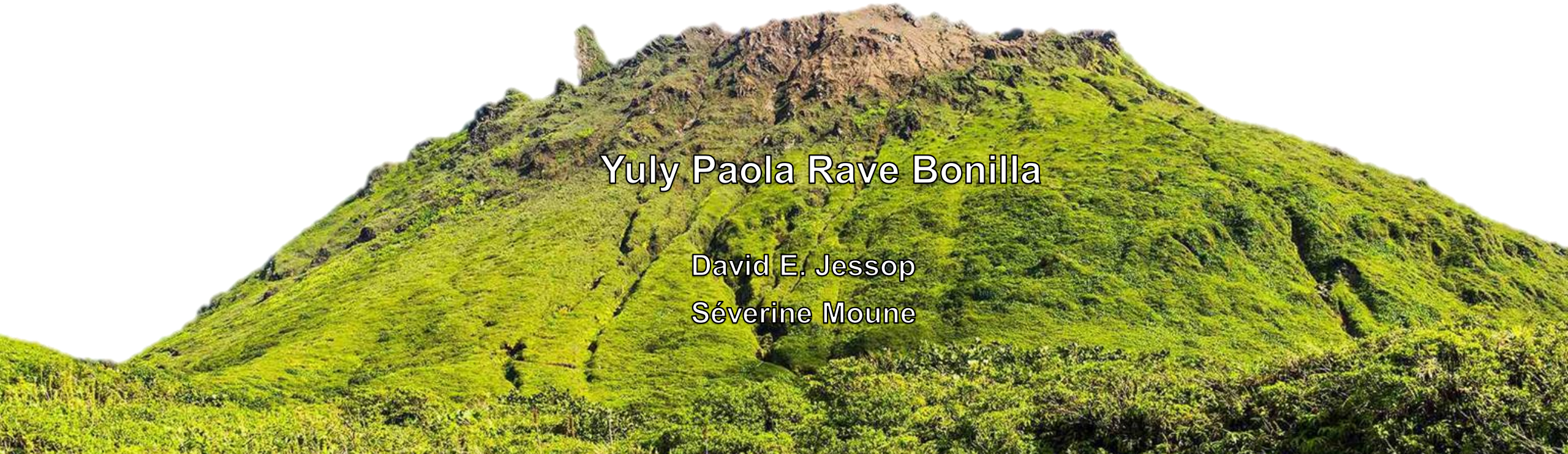
Numerical modelling of the volcanic emissions dispersion from La Soufrière de Guadeloupe

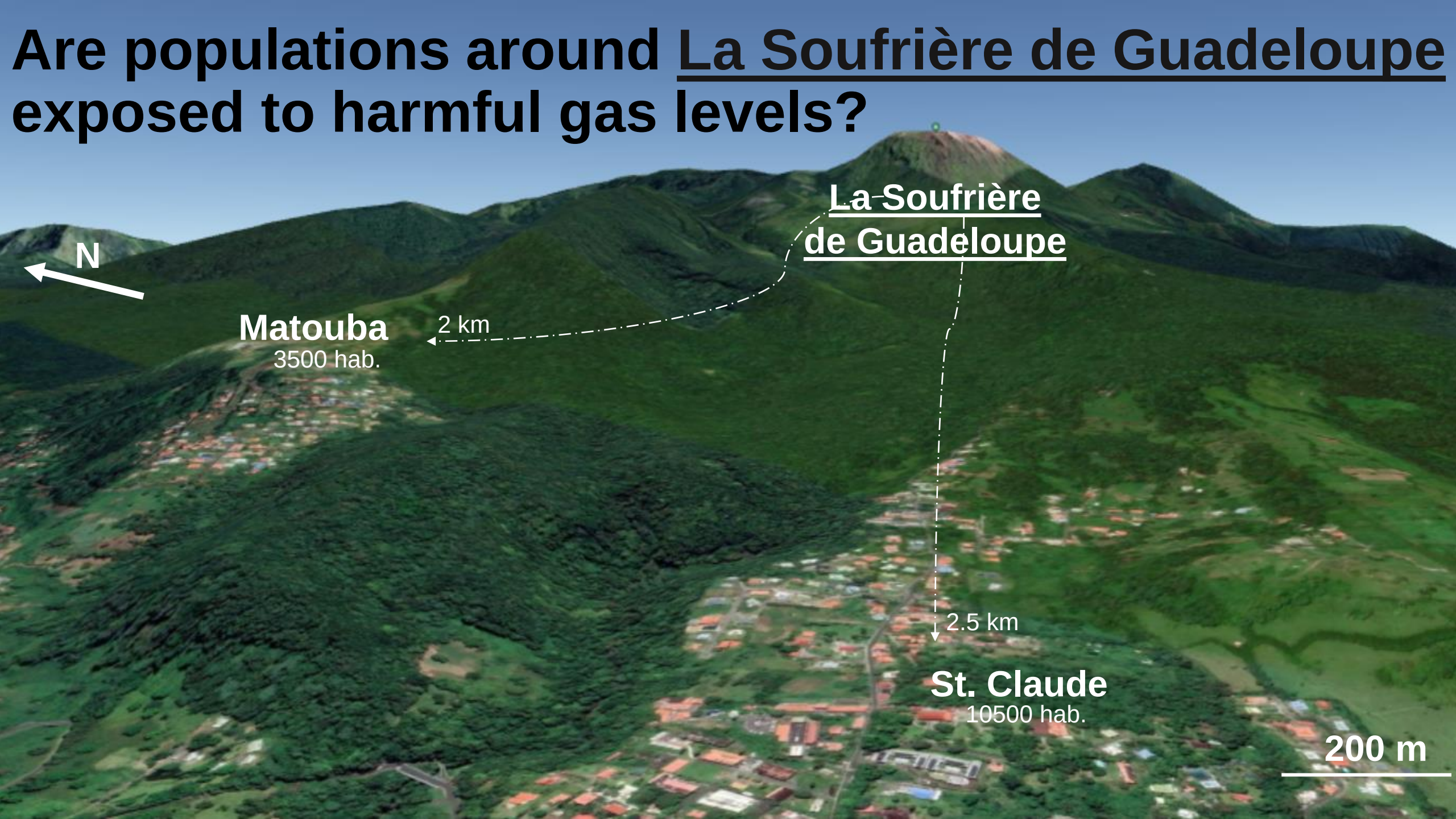


Yuly Paola Rave Bonilla

David E. Jessop

Séverine Moune

Are populations around La Soufrière de Guadeloupe exposed to harmful gas levels?

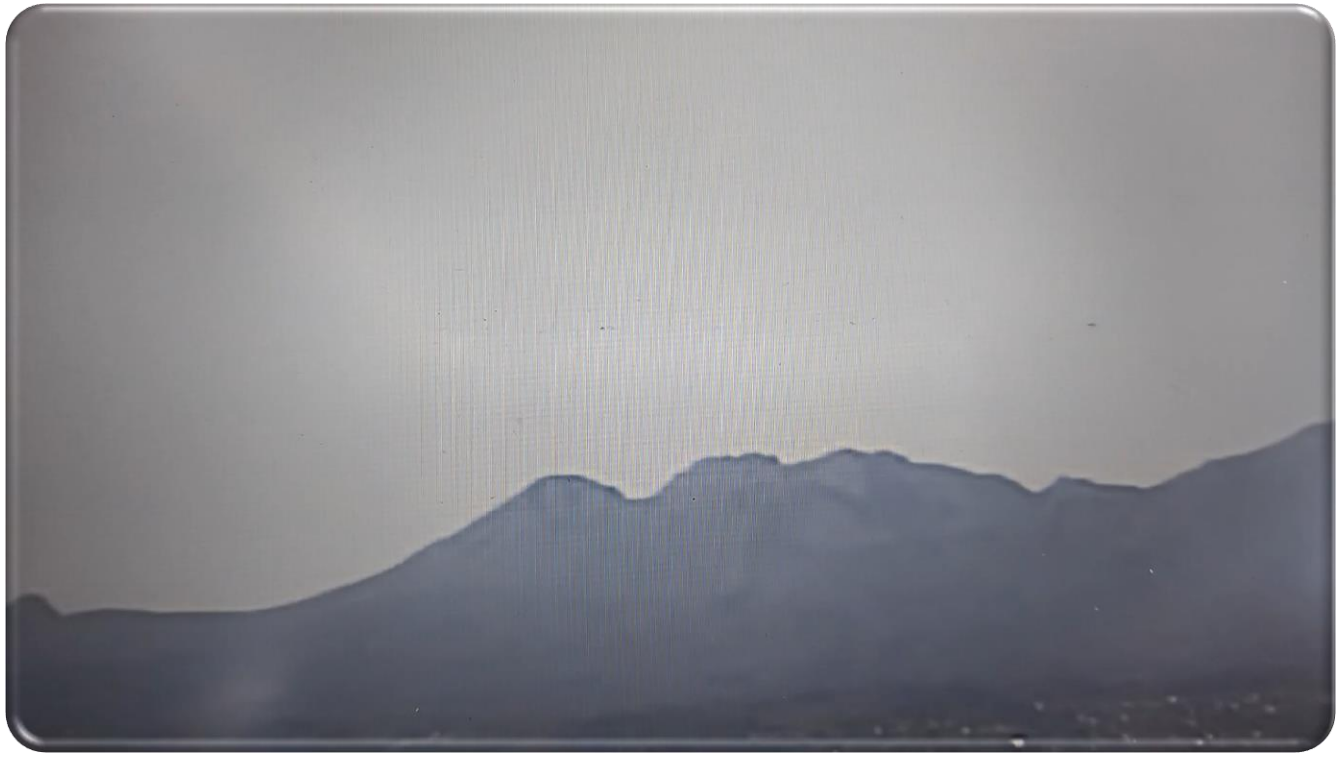


How to determine current gas exposure level of surrounding populations of the volcano?

La Soufrière is one of the largest gas emitters of the Lesser Antilles[1]

Passive degassing is as harmful as sporadic eruptions[2]

Long exposure to volcanic gases can induce breathing difficulties[3]



Images from IPGP

DISGAS 2.0.

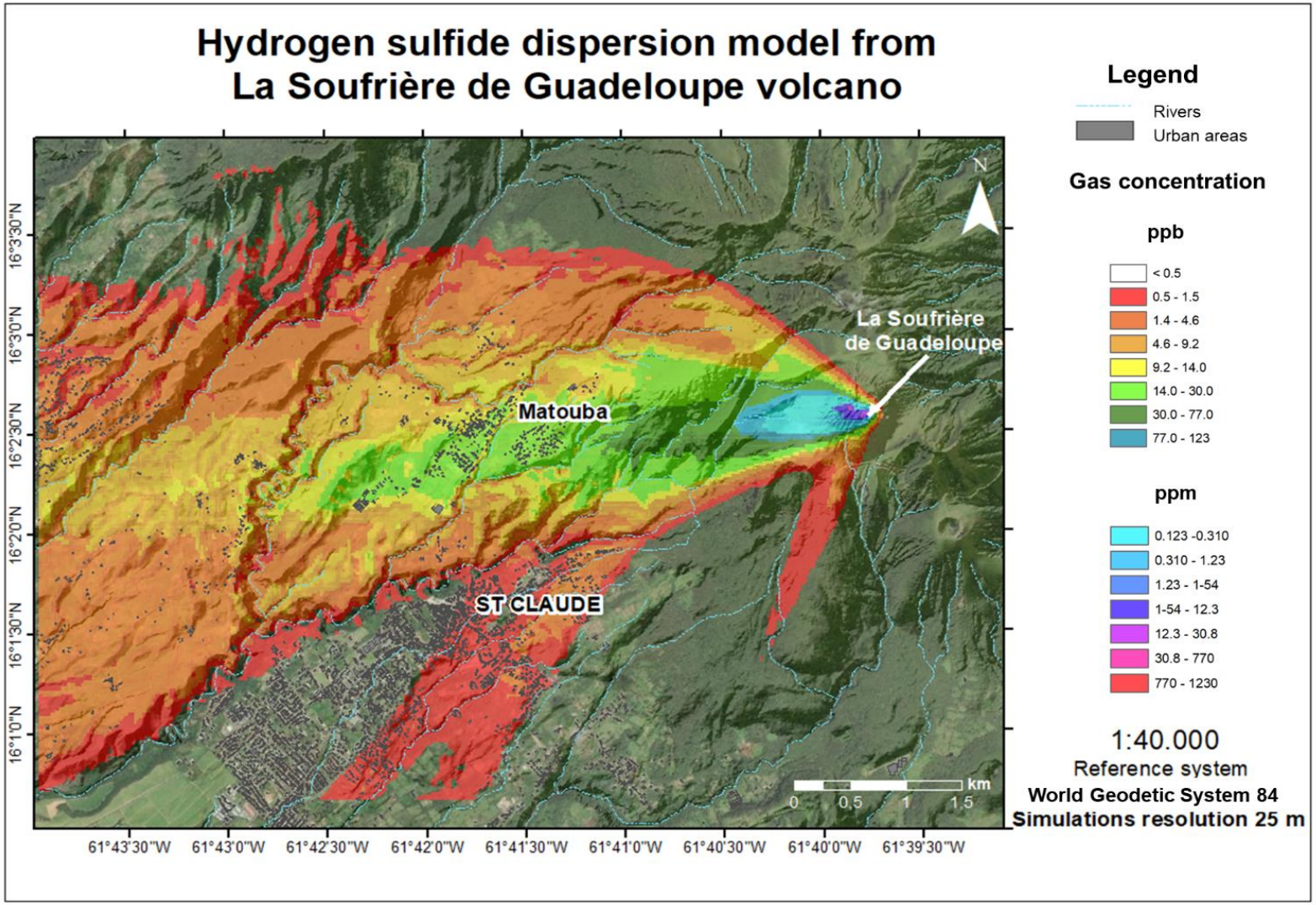
Eulerian numerical model[16]

Numerical models to simulate the most probable scenario of gas dispersion

[1] Massaro *et al.,* (2021)
[2] Oppenheimer *et al.*, (2013)
[3] Armstrong & Green, (2004)

Gas presence in nearby populations

H_2S presence in St. Claude and Matouba



H_2S dispersion model from La Soufrière de Guadeloupe.

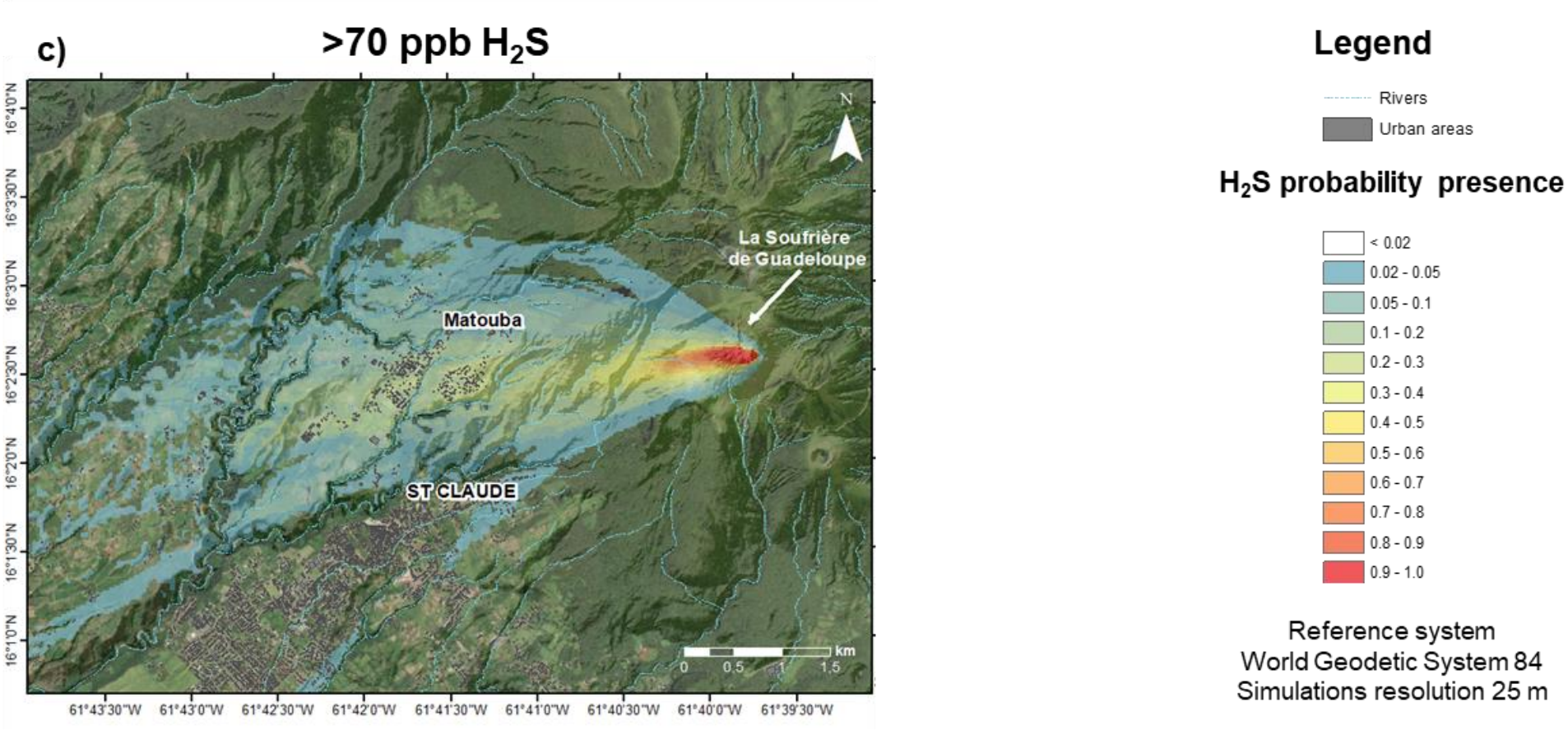
Most exposed zones are:

Matouba (14 - 30 ppb H_2S)

Highest areas of St. Claude (1.4 - 4.6 ppb H_2S)

Gas presence in nearby populations

Probability of longterm exposure and health implications



Probability map for H_2S reference values presence around La Soufrière de Guadeloupe volcano.

The probability of exceeding H_2S guideline for long-term gas exposure (70 ppb) is:

2 - 5% in St. Claude (7 – 18 d/y)

10 - 20% in Matouba (36 – 73 d/y)

La Soufrière location and geological context

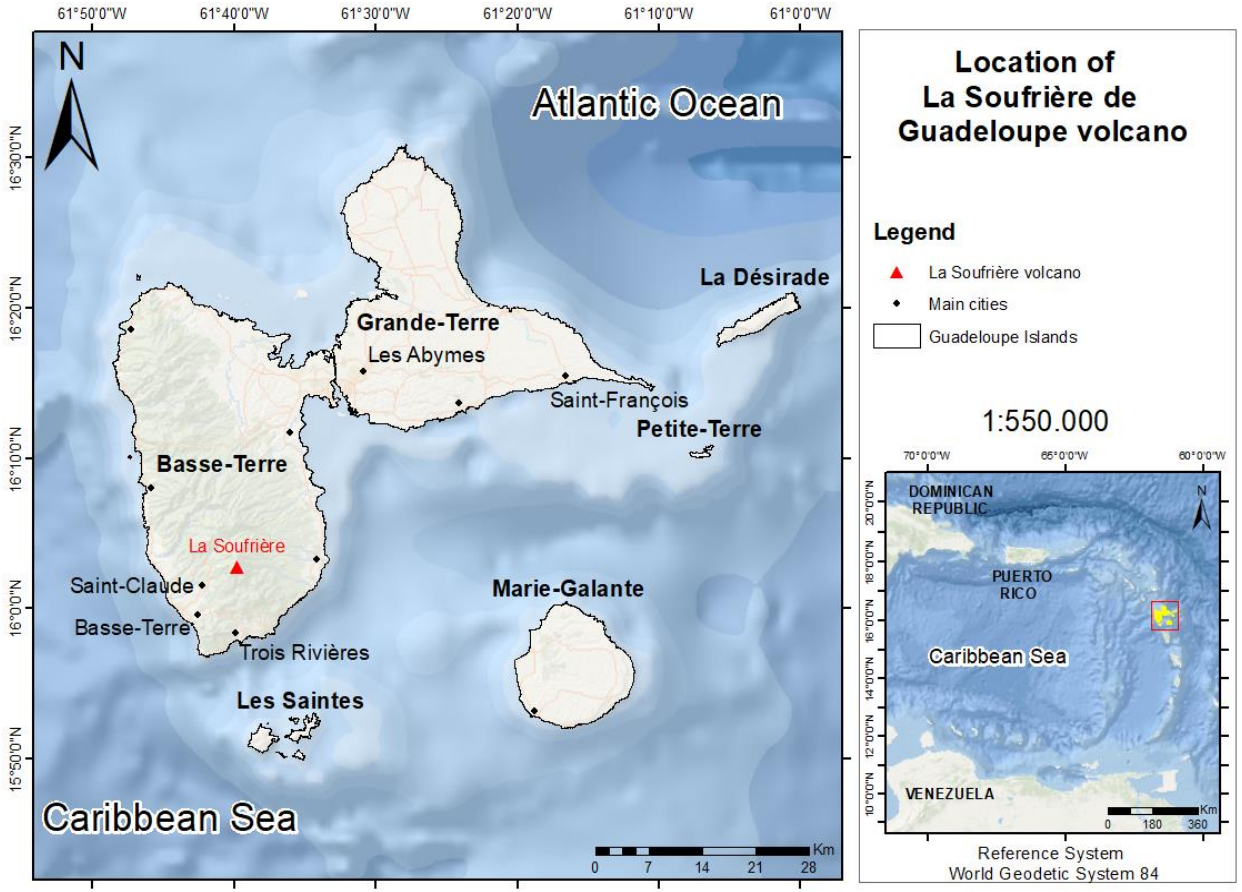


Fig. 1. La Soufrière de Guadeloupe location map.

-La Soufrière de Guadeloupe is located in the Guadeloupe Archipelago in the Lesser Antilles

-North American-Caribbean plates subduction zone volcanic arc[4].

-Andesitic volcanic dome (formed during last magmatic eruption 1530 AD).

-Current eruptive activity mainly hydrothermal. Unrest phase, **fumarolic** and seismic activity since 1992[5], with a peak in 2018[6].

[4] Feuillet *et al.,* (2002)
[5] Komorowski *et al.*, (2005)
[6] Moretti *et al.,* (2020)

Hydrothermal systems

La Soufrière de Guadeloupe case

Fig. 2. Surface degassing mainfestations from La Soufrière (Crátere Sud vent). From Allard *et al.,* (2014).

The supply of volatiles from the magma reservoir to shallow aquifers maintains a hydrothermal system within the volcanic edifice, better developed in tropical-climate rainfall regimes[7,8].

Surface degassing enriched in steam (~90%)[9,10] and less soluble gases such as (CO_2, H_2S, H_2, CH_4, CO)[11].

-Constant fumarolic activity [12,13]**:**

Temperature from 96 to 110°C

-Total dry flux[14]**:**

Crátere Sud (CS): 4.2 t/d

Gouffre-56 (G56): 2.4 t/d

Tarissan (TAS): 4 t/d

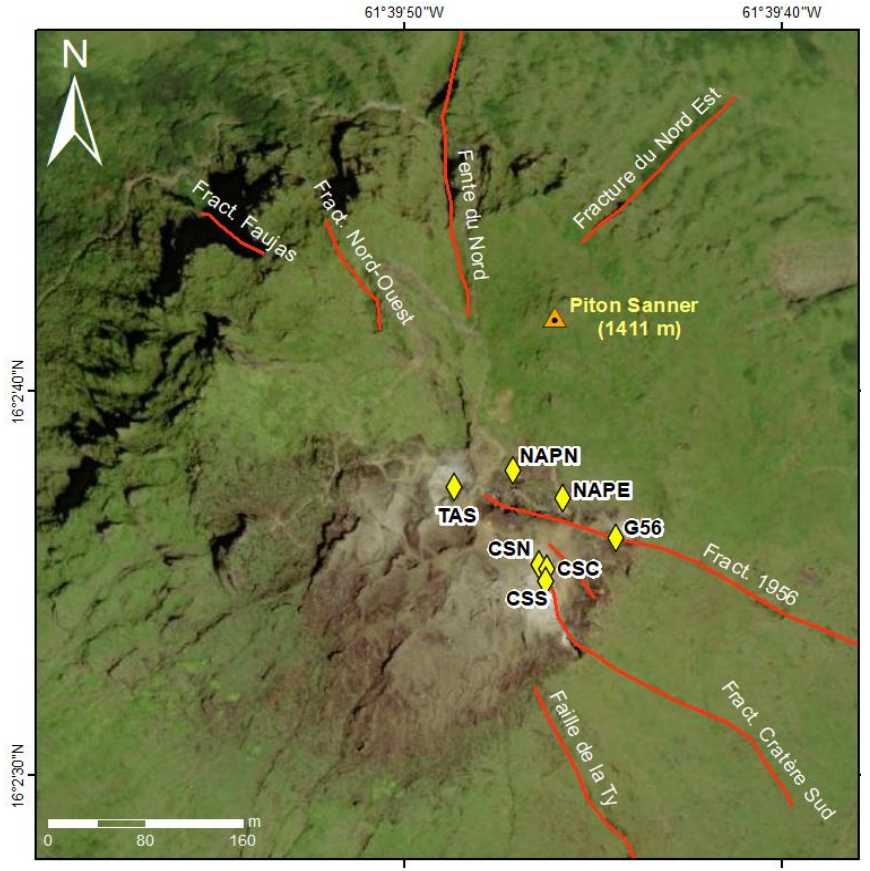


Fig. 3. Fumarole vents and fractures in the summit of La Soufrière de Guadeloupe

[7] Rye *et al.,* (1992, 2005)
[8] Fischer & Chiodini, (2015)
[9] Aiuppa, (2005)
[10] Moretti *et al.,* (2013)
[11] Symonds *et al.,* (2001
[12] Allard *et al.,* (2014)
[13] Tamburello *et al.*, (2019)
[14] Moune *et al.*, (2022)

Methods

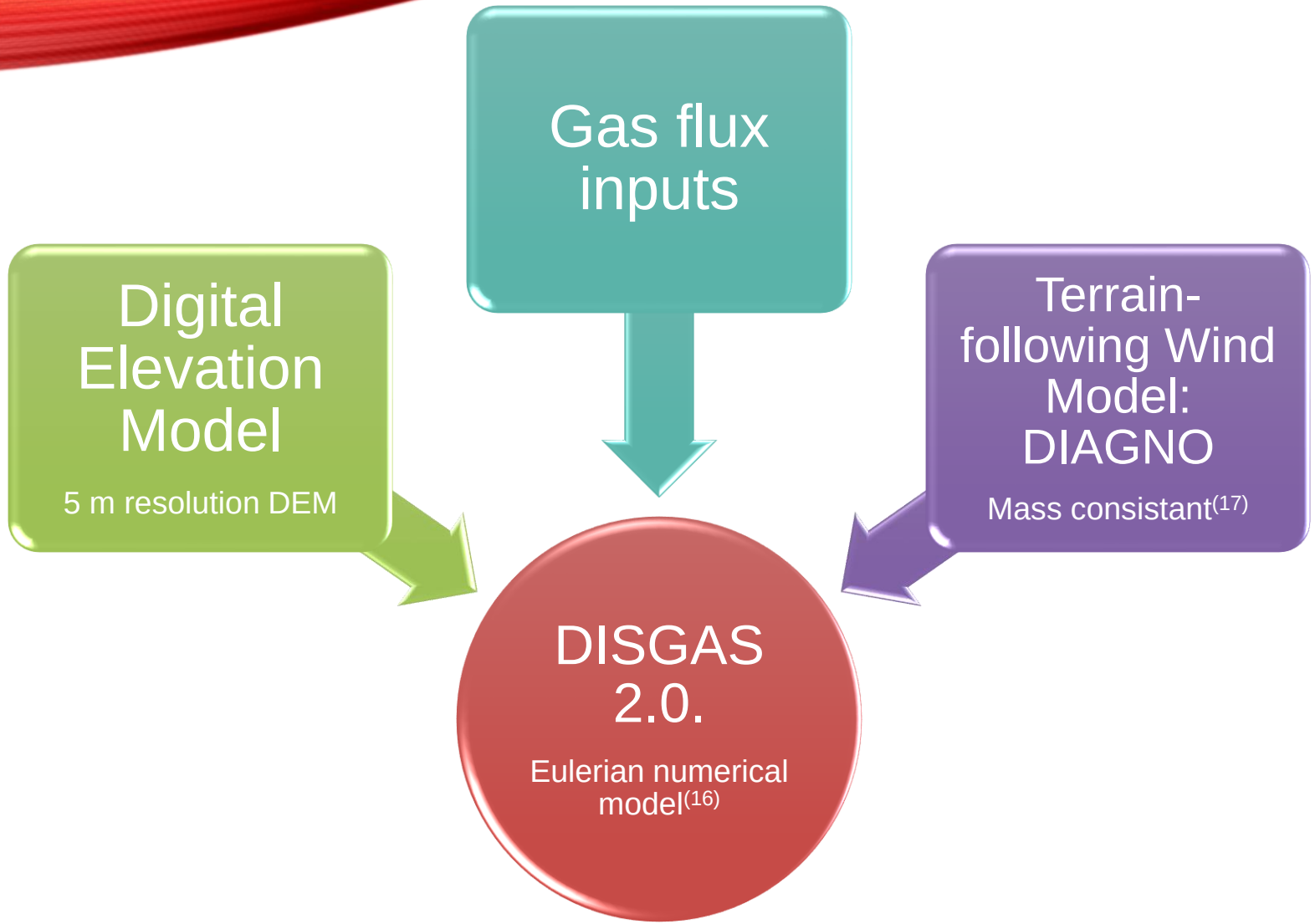


Fig. 4. DISGAS 2.0. numerical model requirements

Low density contrast

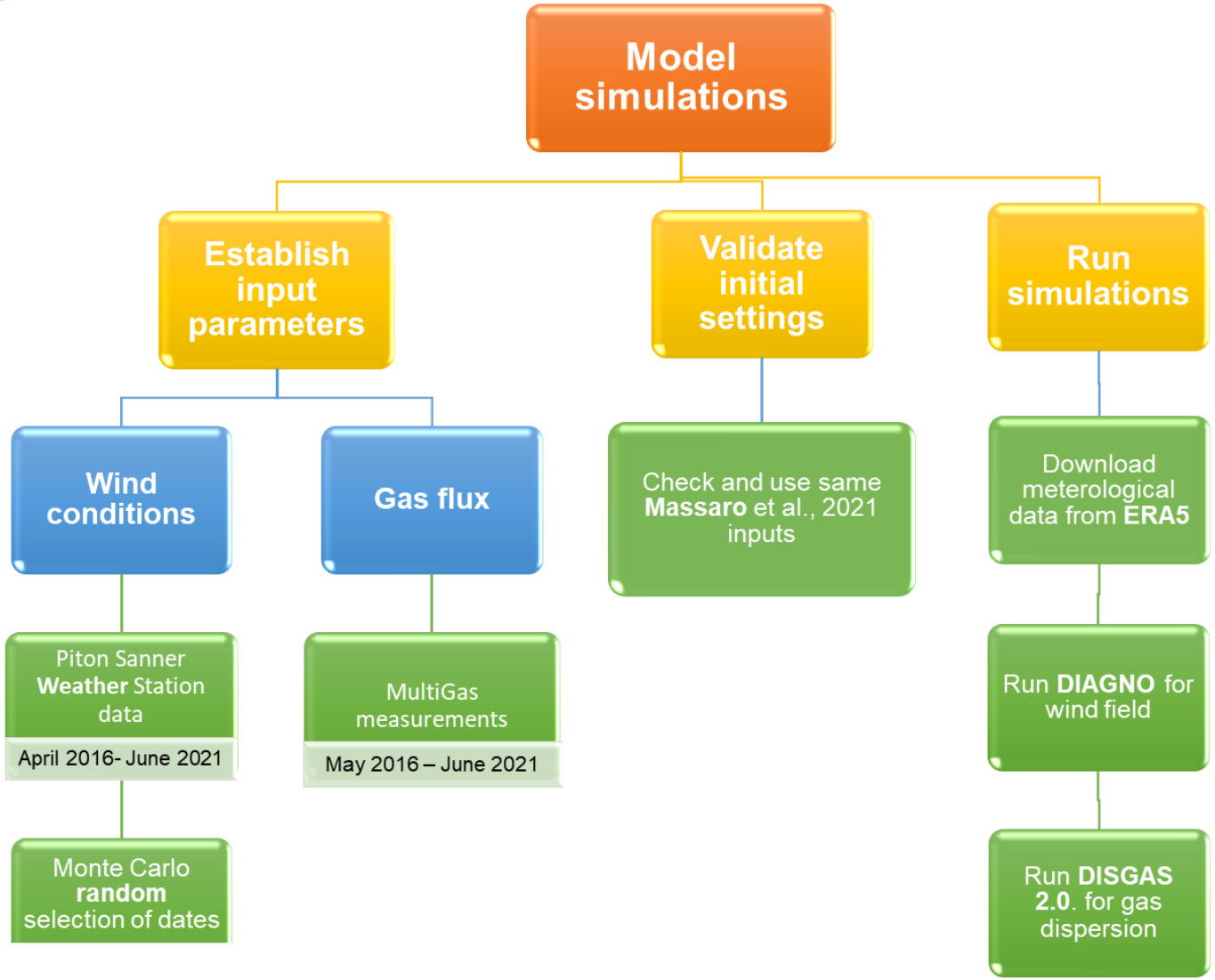
(plume vs atmosphere(15,16))

Passive gas dispersion

By atmospheric turbulence and wind advection(15,16)

(15) Cortis & Oldenburg, (2009)
(16) Costa & Macedonio, (2016)
(17) Douglas *et al.*, (1990)

Model simulations

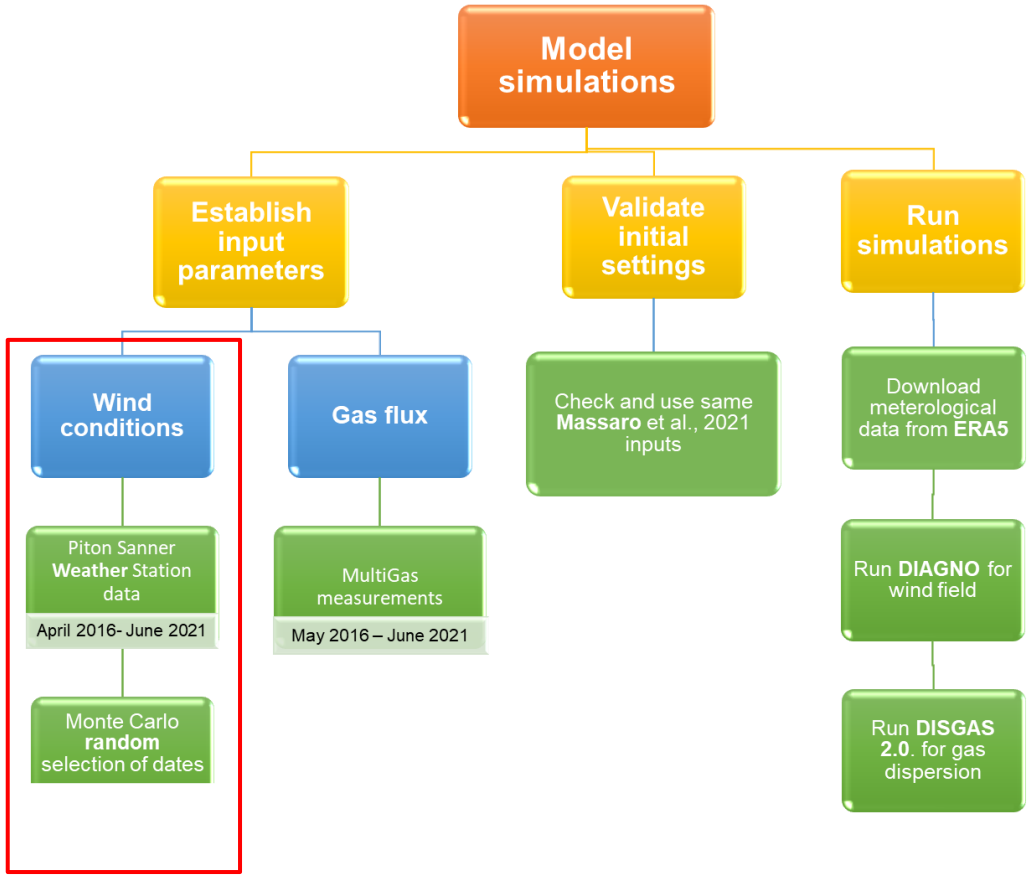


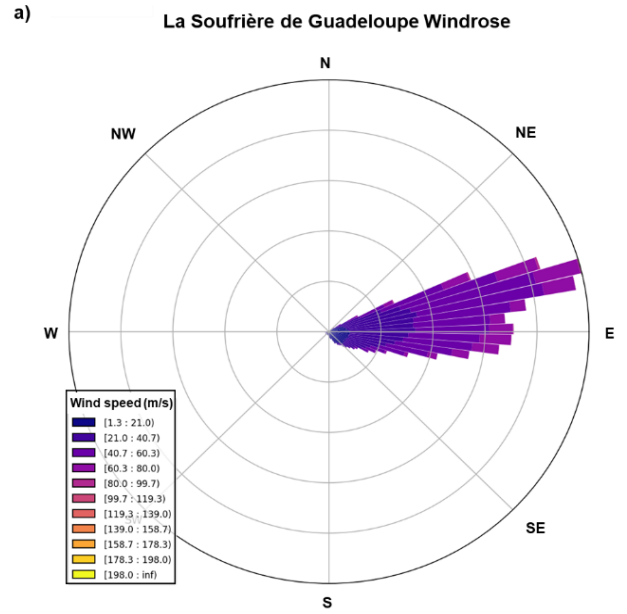
[1] Massaro *et al.,* (2021)
[14] Moune *et al.*, (2022)
[15] Costa & Macedonio, (2016)
[17] Douglas *et al.*, (1990)

Fig. 5. Methodology process, inputs and setting for model simulations.

Model simulations

Wind conditions





Most frequent conditions:

90 – 105°

40 – 60 km/h

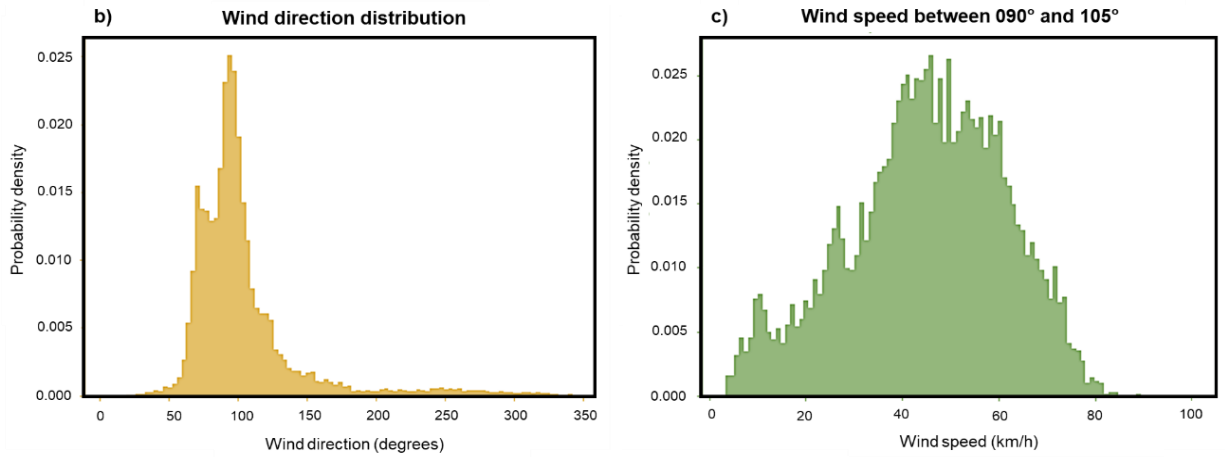
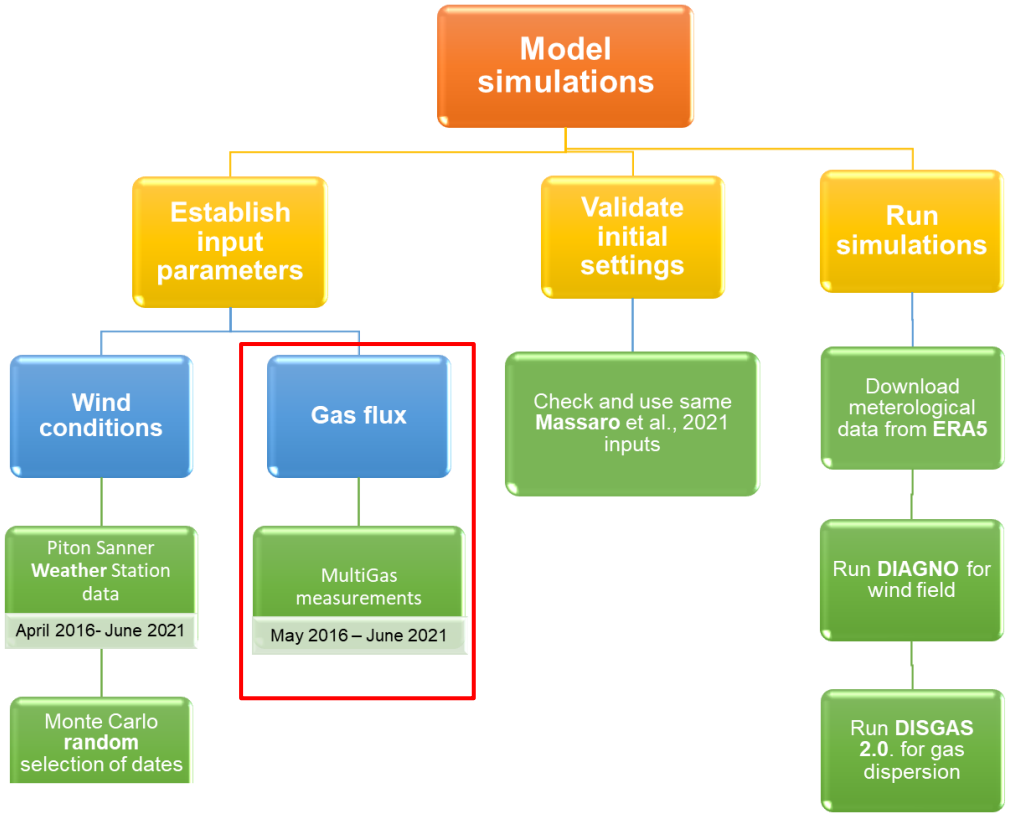


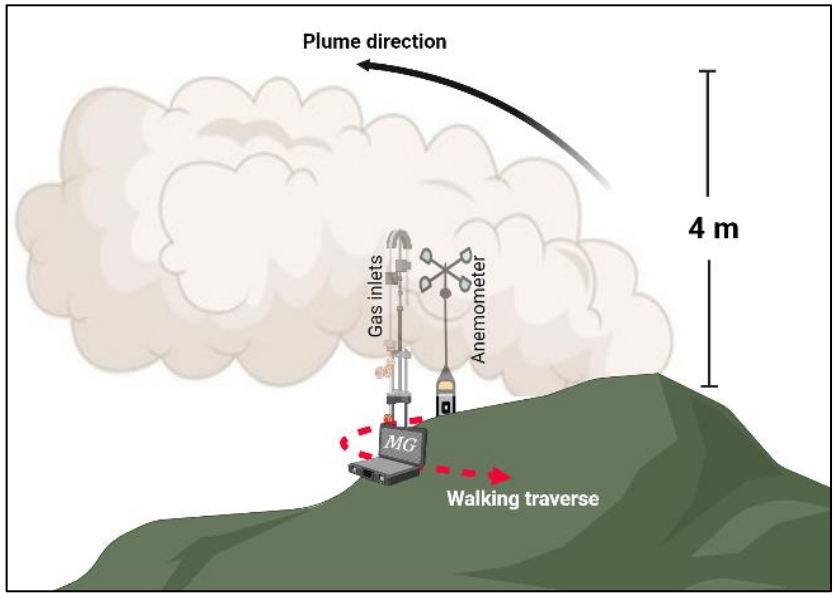
Fig. 6. a) Wind rose indicating the typical wind conditions in the top of La Soufrière. **b)** Frequency distribution of wind directions in the top of La Soufrière **c)** Wind speed frequency distribution in the most frequent acquired range.

Model simulations



CO_2 flux inputs (kg/s)
CS: 0.0496
G65: 0.0289
TA: 0.0347

Gas flux



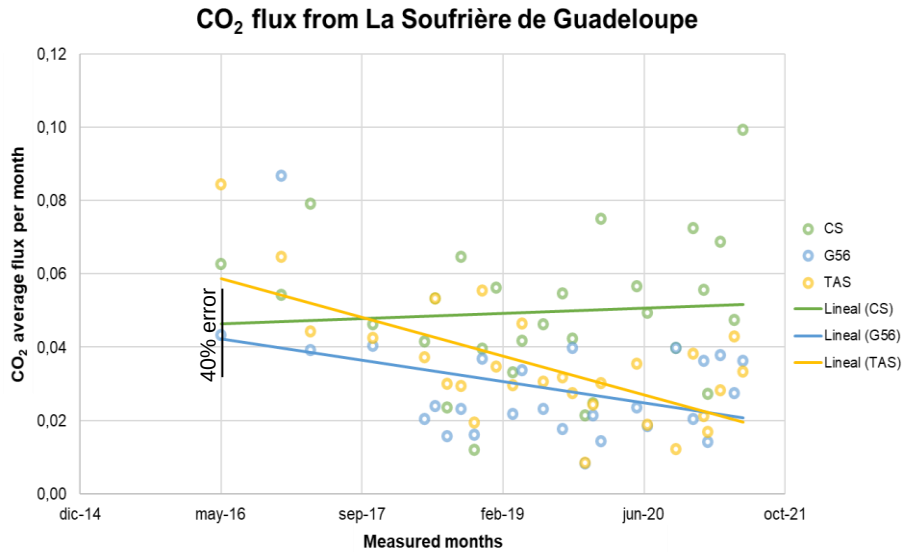
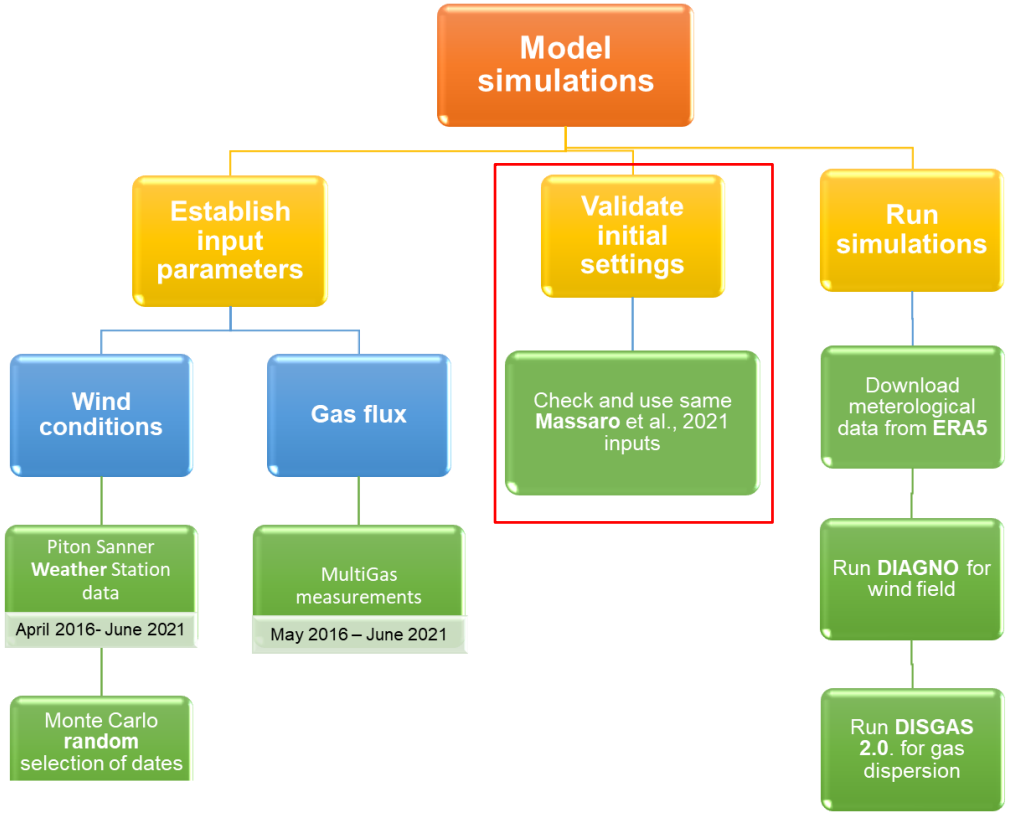


Fig. 7. a) Setting for MultiGAS measurements **b)** CO_2 flux measured with MultiGas from the three main fumarole vents in the top of La Soufrière. Data from (Moune *et al.*, 2022).

Model simulations

Settings validation



Simulations models the with same Massaro et al., (2021) inputs

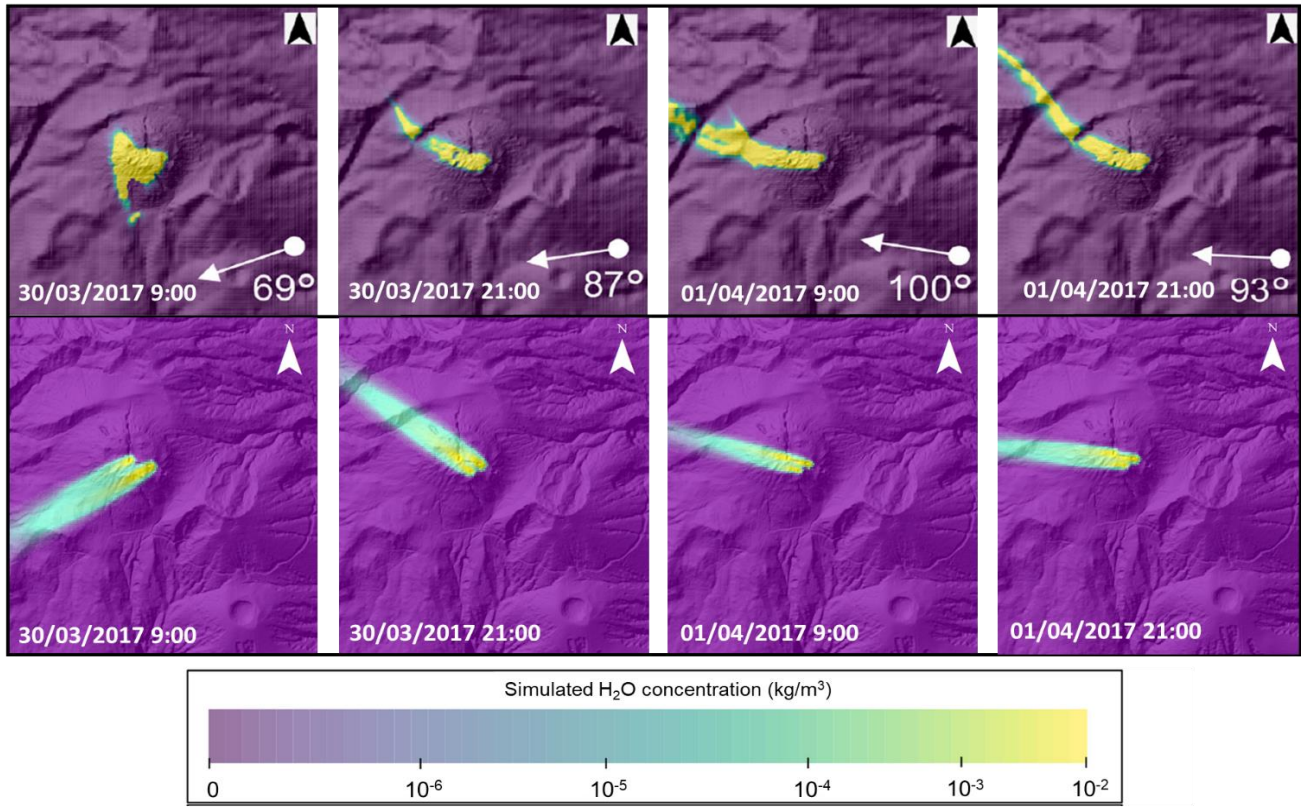
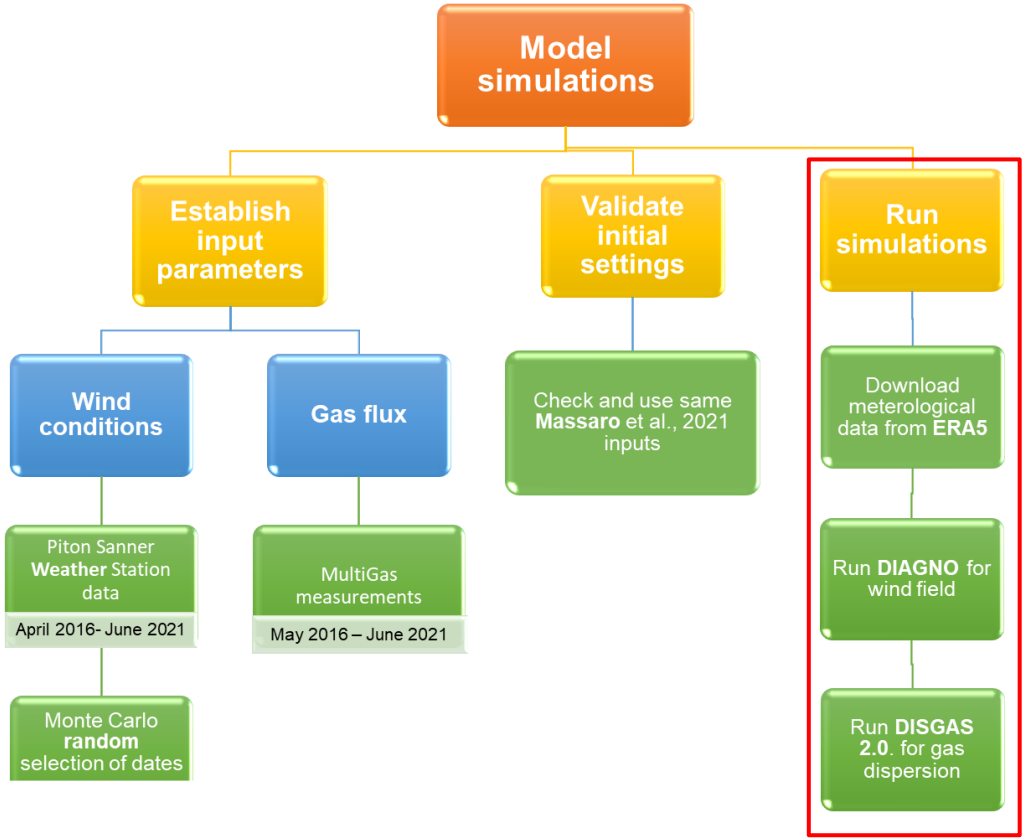


Fig. 8. Comparison simulations to test DIAGNO and DISGAS 2.0. setting according with Massaro *et al.*, (2021) input parameters. In the upper part Massaro's results and in the lower part the results of this study.

Model simulations

Terrain models



We ran ~100 simulations (supercomputer facilities of the Mésocentre UCA)

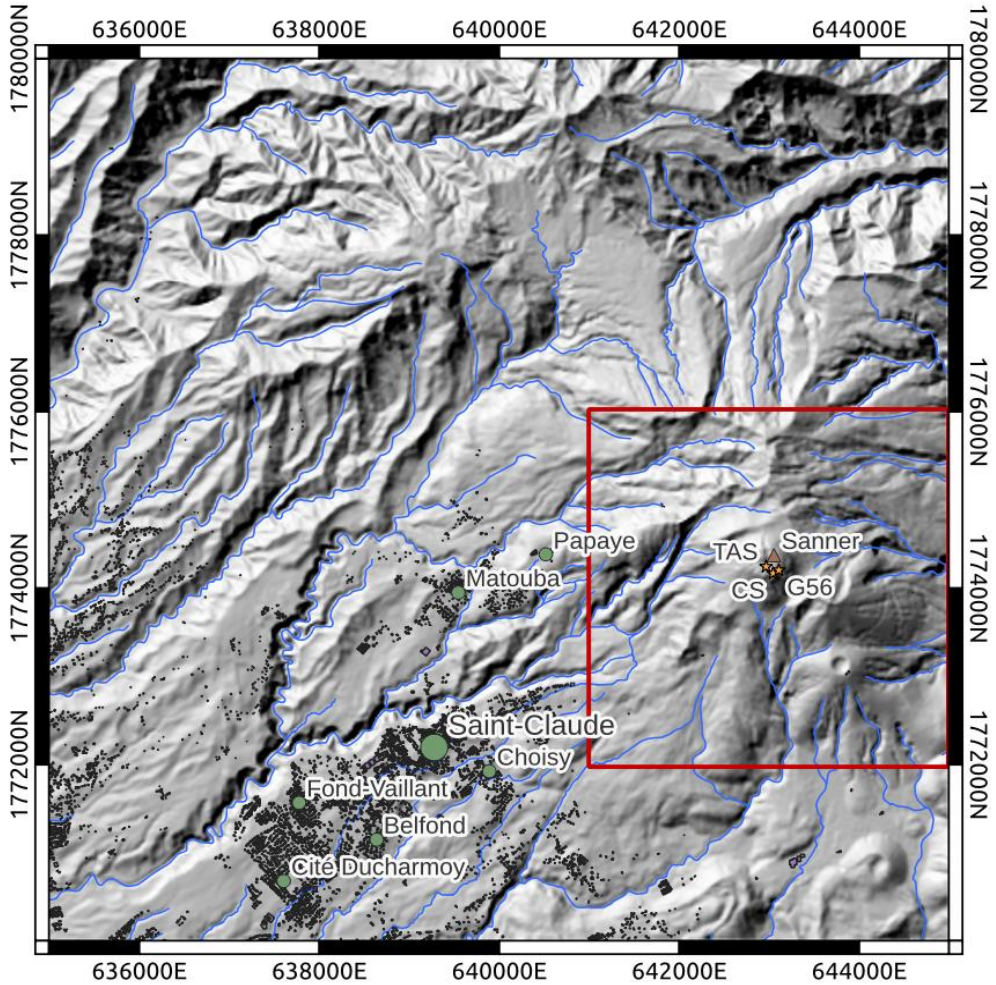


Fig. 9. 5 m resolution DEM for the area covered by the 25 m resolution simulations. Red box is the area of 5 m resolution simulations.

ERA5: European Centre for Medium-Range Weather Forecasts
→ Climate reanalysed data

Simulation results

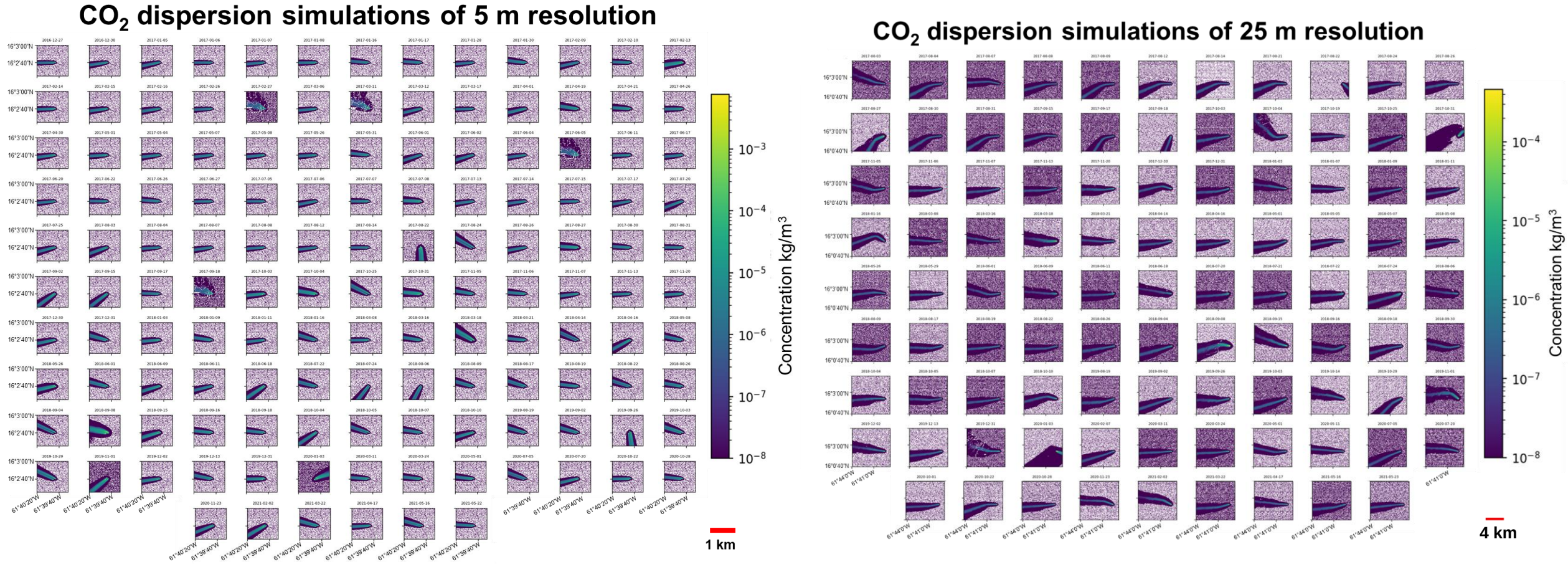


Fig. 10. Resulting simulations of 5 m and 25 m resolution (136 for 5 m resolution and 97 for 25 m resolution).

Gas plume is dispersed westward around 255° - 270° from the volcano summit.

Simulation results

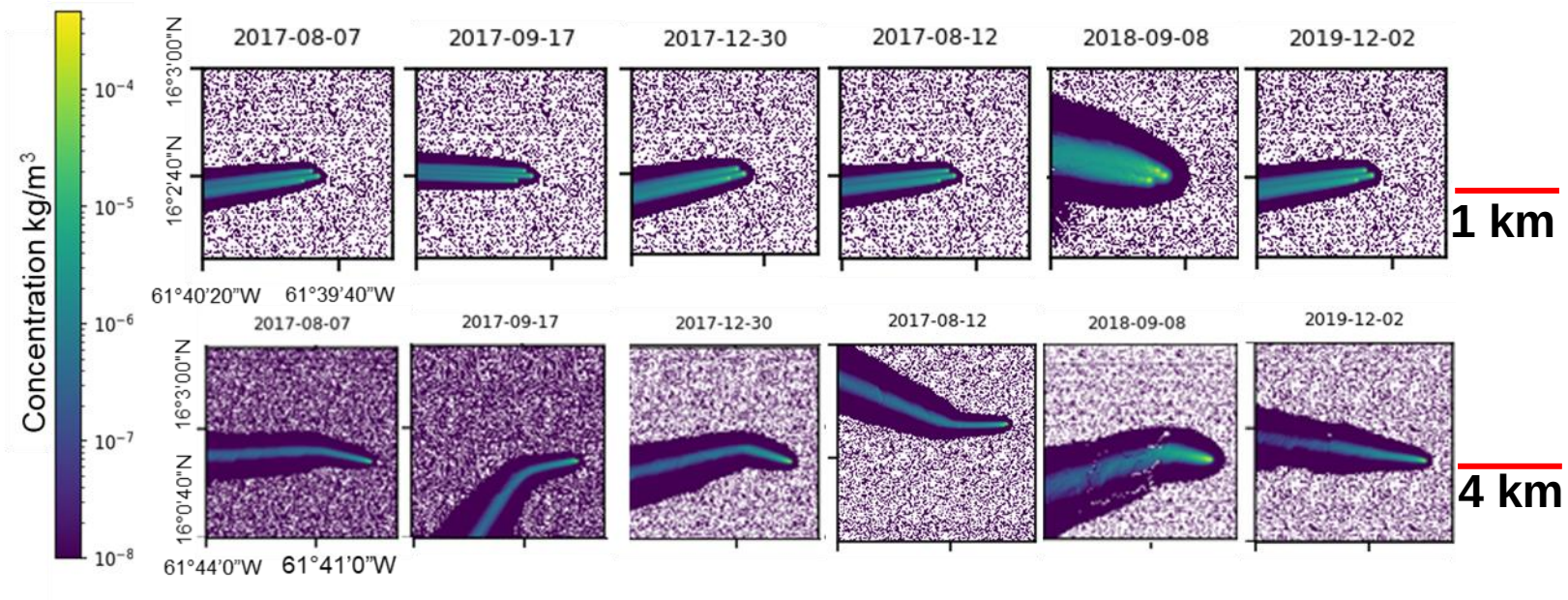


Fig. 11. Examples of 5 m resolution (upper) and 25 m resolution simulations (lower) of CO_2 dispersion

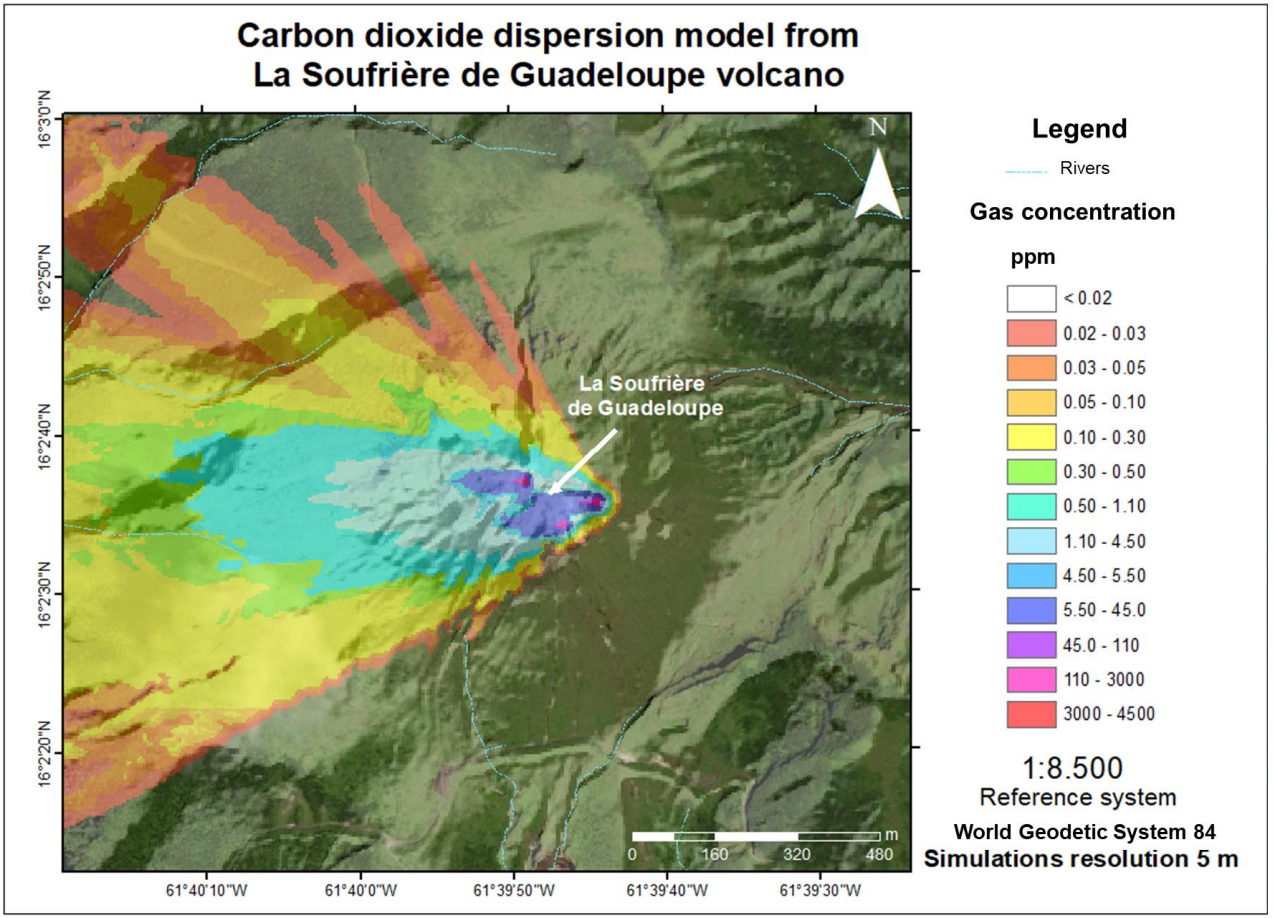
-Both 5 m and 25 m resolution are consistent

-Gas concentration decreases gradually as it flows westward

-In 25 m resolution simulations, direction variations are due to topography influence

Typical CO_2 dispersion

Average from resulting simulations



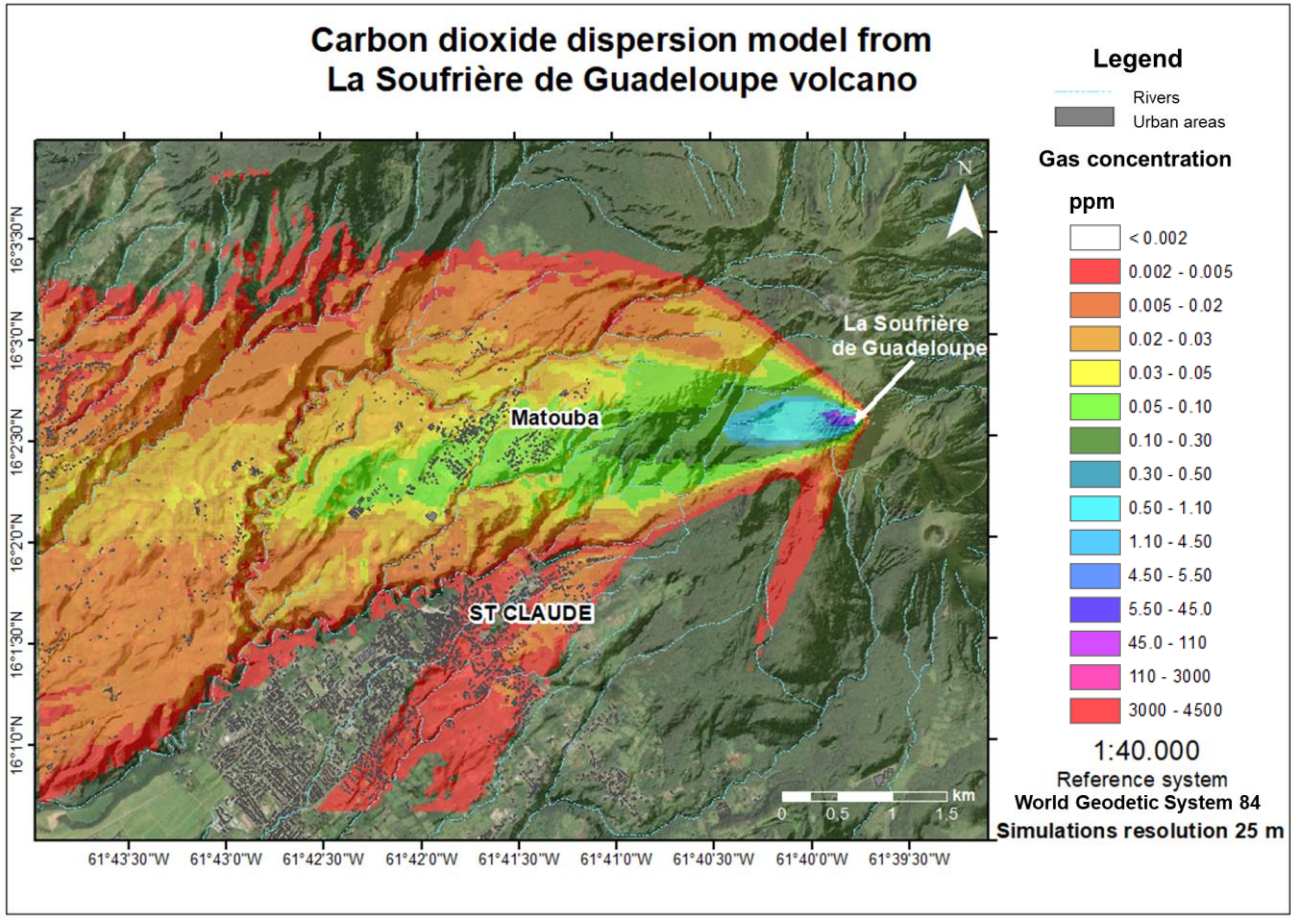


Fig. 12. CO_2 dispersion model from La Soufrière de Guadeloupe based on 5 m resolution and 25 m resolution simulations

Gas presence in nearby populations

Gwad'air data

Fig. 13. Gwad'air air quality station in St. Claude. Measurement instrument

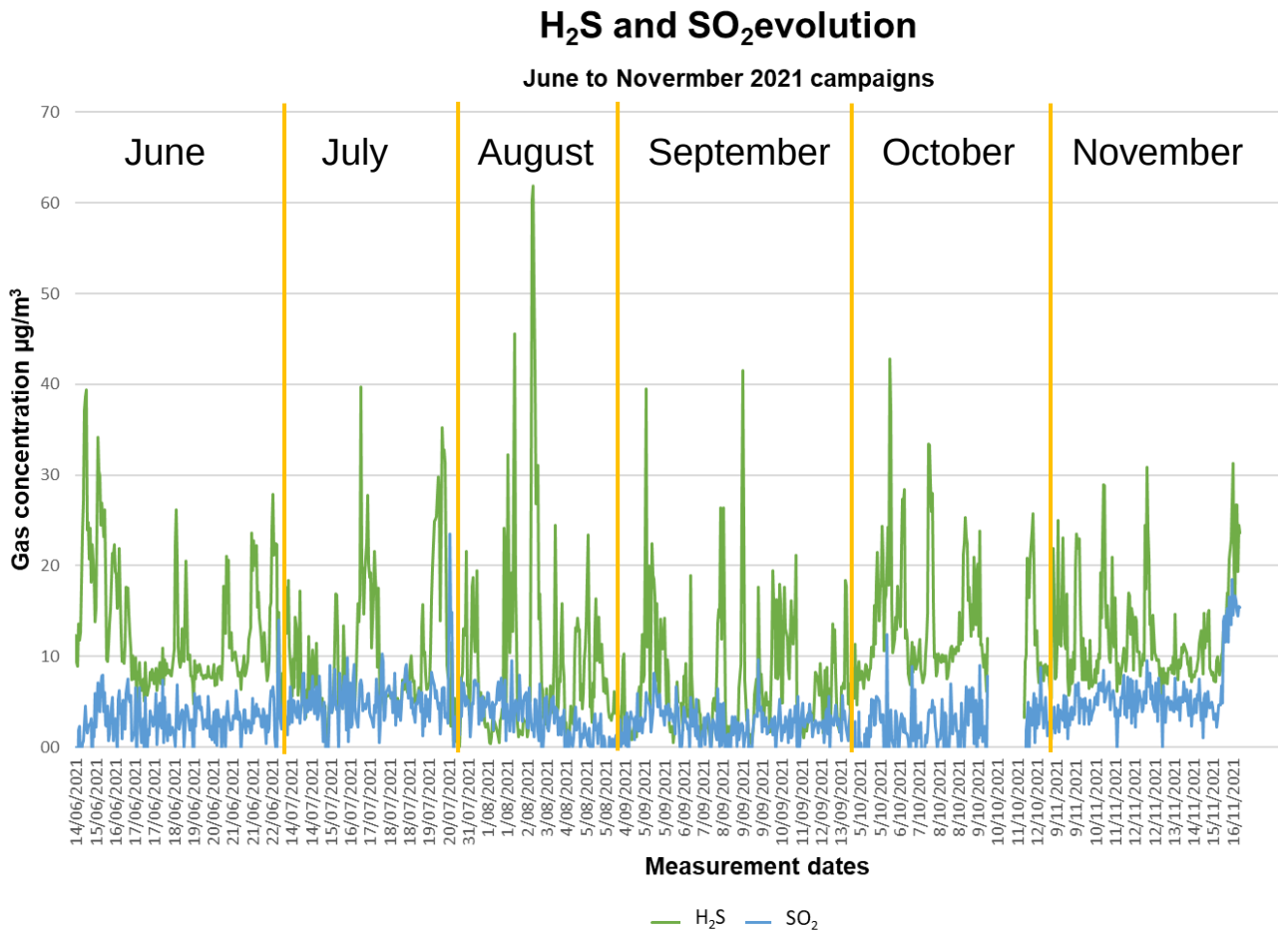


Fig. 14. General H_2S and SO_2 evolution from June to November 2021. These data include background values for both gas species .

Background

SO_2 ~4 µg/m³

H_2S ~6 µg/m³

H_2S values

up to 62 µg/m³

Mean: 11 µg/m³

Gas presence in nearby populations

Survey results

Fig. 15. Online surveys available to report sulphur odours perceived in populations around La Soufrière

Event date	Evet time	Survey site	Perceived odour	Zone	Health effects
29/09/2020	Not reported	Facebook	"Smell of sulfur"	Saint-Claude, "Prefecture"	None
27/10/2020	5:00 a. m.	Facebook	"Smell of sulfur"	Saint-Claude	None
29/10/2020	7:21 a. m.	Facebook	"Smell of sulfur"	Saint-Claude, "Prefecture"	None
12/11/2020	6:20 p. m.	Facebook	"Smell of sulfur"	Saint-Claude, "Morne Houël"	None
3/11/2020	6:35 p. m.	Facebook	"Smell of sulfur"	Saint-Claude	None
23/01/2021	Not reported	Facebook	"Smell of sulfur"	Saint-Claude, "Morne Houël"	None
5/02/2021	5:00 a. m.	Survey	"Rotten eggs"	Saint-Claude, "Centre-Ville"	None
27/05/2021	5:30 p. m.	Survey	"Fireworks"	Saint-Claude, "Choisy"	Respiratory allergy
6/06/2021	6:00 a. m.	Survey	"Rotten eggs"	Saint-Claude, "Choisy"	None
15/06/2021	7:45 a. m.	Survey	"Rotten eggs"	Saint-Claude, "Choisy"	None
3/07/2021	9:00 p. m.	Survey	"Rotten eggs"	Saint-Claude, "Choisy"	None
19/07/2021	6:15 p. m.	Survey	"Fireworks"	Saint-Claude, "Morne Houël"	None
16/08/2021	9:00 p. m.	Survey	"Rotten eggs"	Saint-Claude, "Choisy"	None
12/09/2021	Not reported	Facebook	"Smell of sulfur"	Saint-Claude, "Prefecture"	None
15/09/2021	2:00 p. m.	Survey	"Rotten eggs"	Saint-Claude, "Matouba"	Respiratory allergy
17/10/2021	5:00 a. m.	Survey	"Rotten eggs"	Saint-Claude, "Caféière"	Respiratory allergy
23/10/2021	9:00 p. m.	Survey	"Rotten eggs"	Saint-Claude, "Choisy"	None
28/10/2021	6:15 a. m.	Survey	"Rotten eggs"	Saint-Claude, "Choisy"	None
27/10/2021	6:30 a. m.	Survey	"Rotten eggs"	Saint-Claude, "La Diotte"	None
3/11/2021	8:25 a. m.	Survey	"Rotten eggs"	Saint-Claude, "Choisy"	None
5/11/2021	8:00 p. m.	Survey	"Rotten eggs"	Saint-Claude, "Choisy"	None
10/11/2021	2:00 p. m.	Survey	"Rotten eggs"	Farther, “Baillif”	None
14/11/2021	9:00 a. m.	Survey	"Rotten eggs"	Farther, “Basse-Terre”	Respiratory allergy
3/12/2021	9:00 p. m.	Survey	"Rotten eggs"	Saint-Claude, "Choisy"	None
11/01/2022	Not reported	Facebook	"Smell of sulfur"	Saint-Claude, "Gourbegre"	None

Table 1. Reported dates of perceived sulphur smells related to gas emissions

Gas presence in nearby populations

Survey results

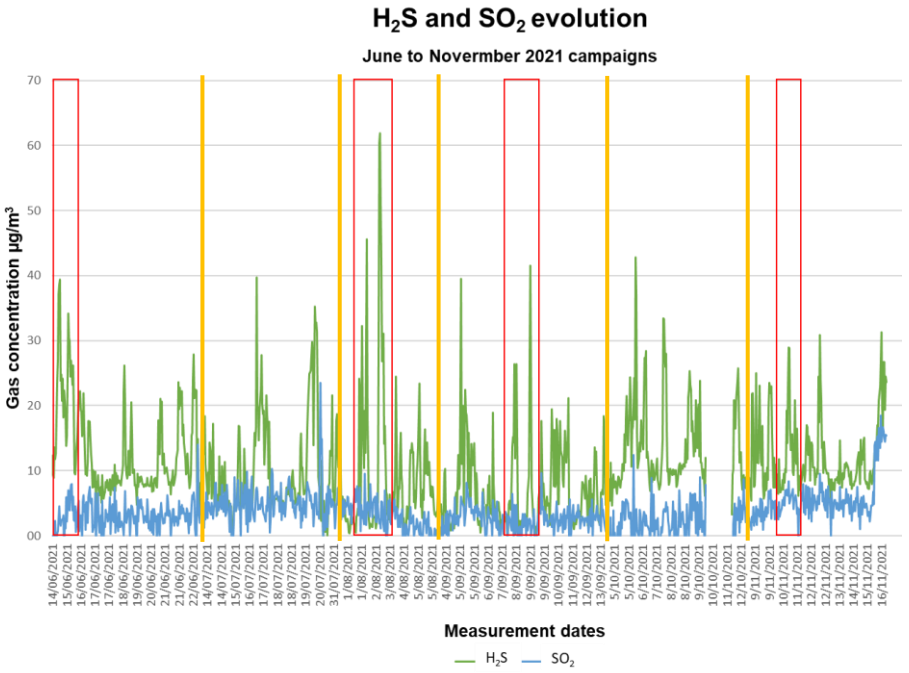


Fig. 16. Dates with H_2S peaks concident with surveys reports.

Event date	Evet time	Survey site	Perceived odour	Zone	Health effects
29/09/2020	Not reported	Facebook	"Smell of sulfur"	Saint-Claude, "Prefecture"	None
27/10/2020	5:00 a. m.	Facebook	"Smell of sulfur"	Saint-Claude	None
29/10/2020	7:21 a. m.	Facebook	"Smell of sulfur"	Saint-Claude, "Prefecture"	None
12/11/2020	6:20 p. m.	Facebook	"Smell of sulfur"	Saint-Claude, "Morne Houël"	None
3/11/2020	6:35 p. m.	Facebook	"Smell of sulfur"	Saint-Claude	None
23/01/2021	Not reported	Facebook	"Smell of sulfur"	Saint-Claude, "Morne Houël"	None
5/02/2021	5:00 a. m.	Survey	"Rotten eggs"	Saint-Claude, "Centre-Ville"	None
27/05/2021	5:30 p. m.	Survey	"Fireworks"	Saint-Claude, "Choisy"	Respiratory allergy
6/06/2021	6:00 a. m.	Survey	"Rotten eggs"	Saint-Claude, "Choisy"	None
15/06/2021	7:45 a. m.	Survey	"Rotten eggs"	Saint-Claude, "Choisy"	None
3/07/2021	9:00 p. m.	Survey	"Rotten eggs"	Saint-Claude, "Choisy"	None
19/07/2021	6:15 p. m.	Survey	"Fireworks"	Saint-Claude, "Morne Houël"	None
16/08/2021	9:00 p. m.	Survey	"Rotten eggs"	Saint-Claude, "Choisy"	None
12/09/2021	Not reported	Facebook	"Smell of sulfur"	Saint-Claude, "Prefecture"	None
15/09/2021	2:00 p. m.	Survey	"Rotten eggs"	Saint-Claude, "Matouba"	Respiratory allergy
17/10/2021	5:00 a. m.	Survey	"Rotten eggs"	Saint-Claude, "Caféière"	Respiratory allergy
23/10/2021	9:00 p. m.	Survey	"Rotten eggs"	Saint-Claude, "Choisy"	None
28/10/2021	6:15 a. m.	Survey	"Rotten eggs"	Saint-Claude, "Choisy"	None
27/10/2021	6:30 a. m.	Survey	"Rotten eggs"	Saint-Claude, "La Diotte"	None
3/11/2021	8:25 a. m.	Survey	"Rotten eggs"	Saint-Claude, "Choisy"	None
5/11/2021	8:00 p. m.	Survey	"Rotten eggs"	Saint-Claude, "Choisy"	None
10/11/2021	2:00 p. m.	Survey	"Rotten eggs"	Farther, “Baillif”	None
14/11/2021	9:00 a. m.	Survey	"Rotten eggs"	Farther, “Basse-Terre”	Respiratory allergy
3/12/2021	9:00 p. m.	Survey	"Rotten eggs"	Saint-Claude, "Choisy"	None
11/01/2022	Not reported	Facebook	"Smell of sulfur"	Saint-Claude, "Gourbegre"	None

Table 1. Reported dates of perceived sulphur smells related to gas emissions

Gas presence in nearby populations

H_2S model simulations for specific dates

Table 2. Gwad'air measurement vs simulated H_2S concentration of surveys dates. Background values are removed

Date	Wind speed (km/h)	Wind direction (degrees)	H_2S Gwadair station (µg/m³) average per day (± error)	Closest H_2S simulated to the reported place (µg/m³)	Closest H_2S simulated to the reported place (ppb)
15-06-21	15.90	063°	19.80 (±0.99)	1 - 10	0.7 - 7
02-08-21	3.10	079°	15.30 (±0.76)	1 - 10	0.7 - 7
07-10-21	18.50	079°	7.20 (±0.36)	1 - 10	0.7 - 7
10-11-21	12.80	069°	4.80 (±0.24)	1 - 10	0.7 - 7

Same gas dispersion direction

High correlation in gas concentration (<10 µg/m³ difference simulated vs measured)

Our model is in agreement with measurements and reports

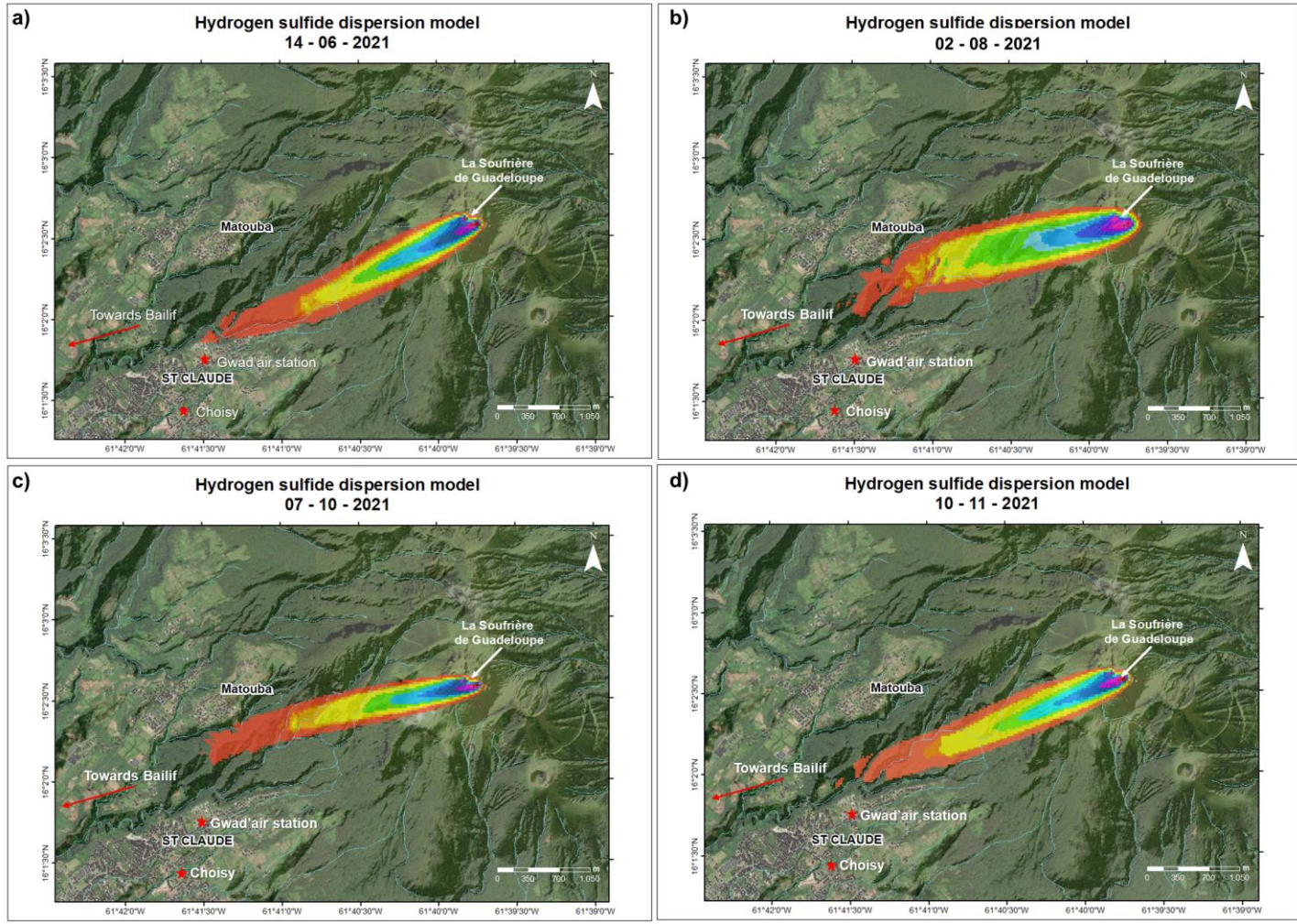


Fig. 17. Specific dates simulations to compare Gwad'air measurements with model results

Gas presence in nearby populations

H_2S presence in St. Claude and Matouba

Previous tests suggest our model is a useful tool for gas dispersion hazard assessment.

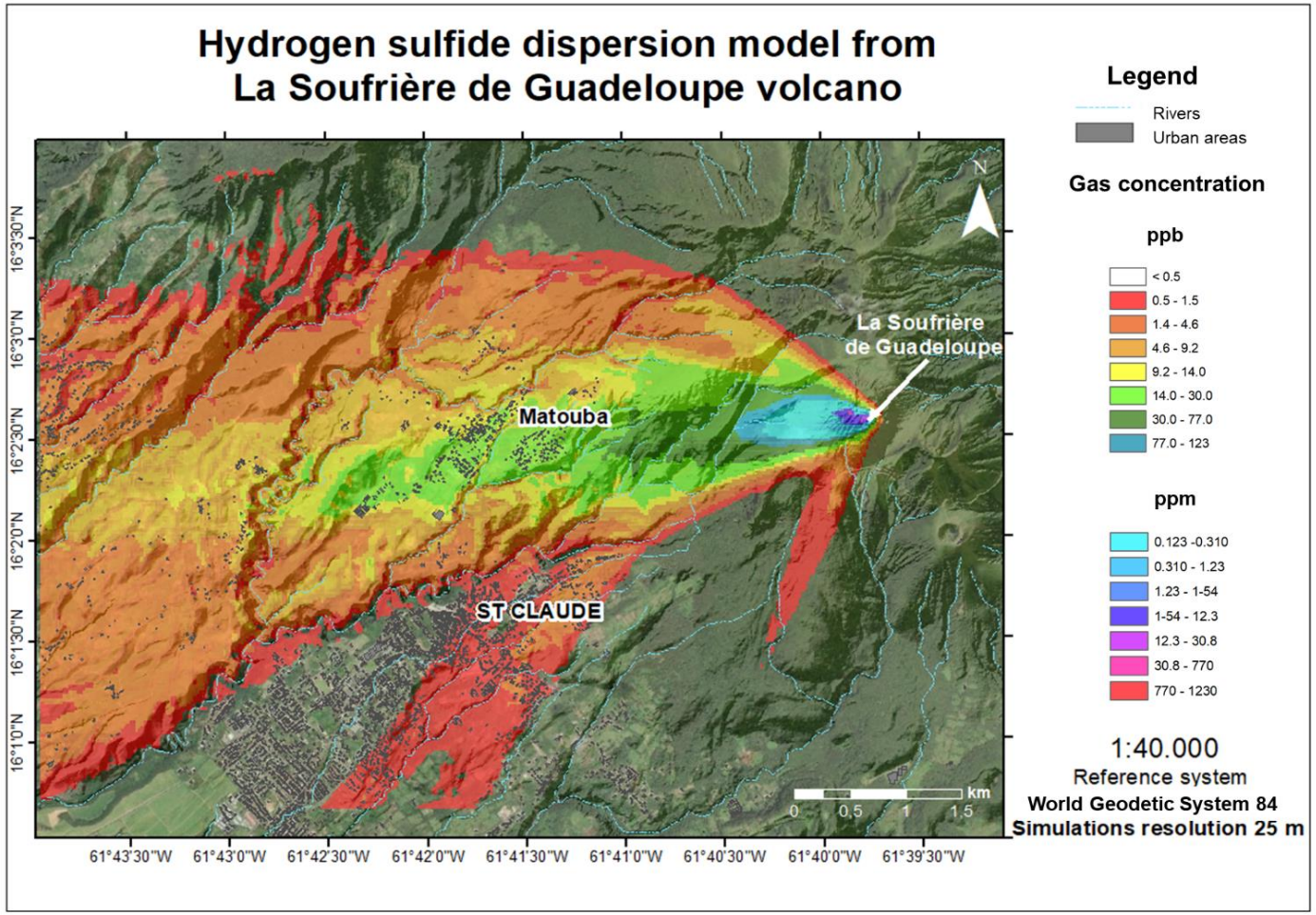


Fig. 18. H_2S dispersion model from La Soufrière de Guadeloupe.

We converted our CO_2 average dispersion model to H_2S concentrations using CO_2/H_2S molar ratio of 3.6[14]

Most exposed zones are:

Matouba (14 - 30 ppb H_2S)

Highest areas of St. Claude (1.4 - 4.6 ppb H_2S) (~3.5 ppb Gwad'air data)

[14]Moune *et al.*, (2022)

Gas presence in nearby populations

Probability of longterm exposure and health implications

Table 3. Low H_2S for long-term exposure recommendations for the general public (Armstrong & Green, 2004)

Reference value	Time exposure	Symptoms
1.5 ppb	Continuous, lifetime (i.e., 24/7)	No inflammation of nasal epithelium
8 ppb	Continuous, long term (i.e., 8 years)	No inflammation of nasal epithelium
70 ppb	Continuous, acute duration (up to 14 days)	Respiratory problems

The probability of exceeding H_2S guideline for long-term gas exposure (70 ppb) is:

2 - 5% in St. Claude (7 – 18 d/y)

10 - 20% in Matouba (36 – 73 d/y)

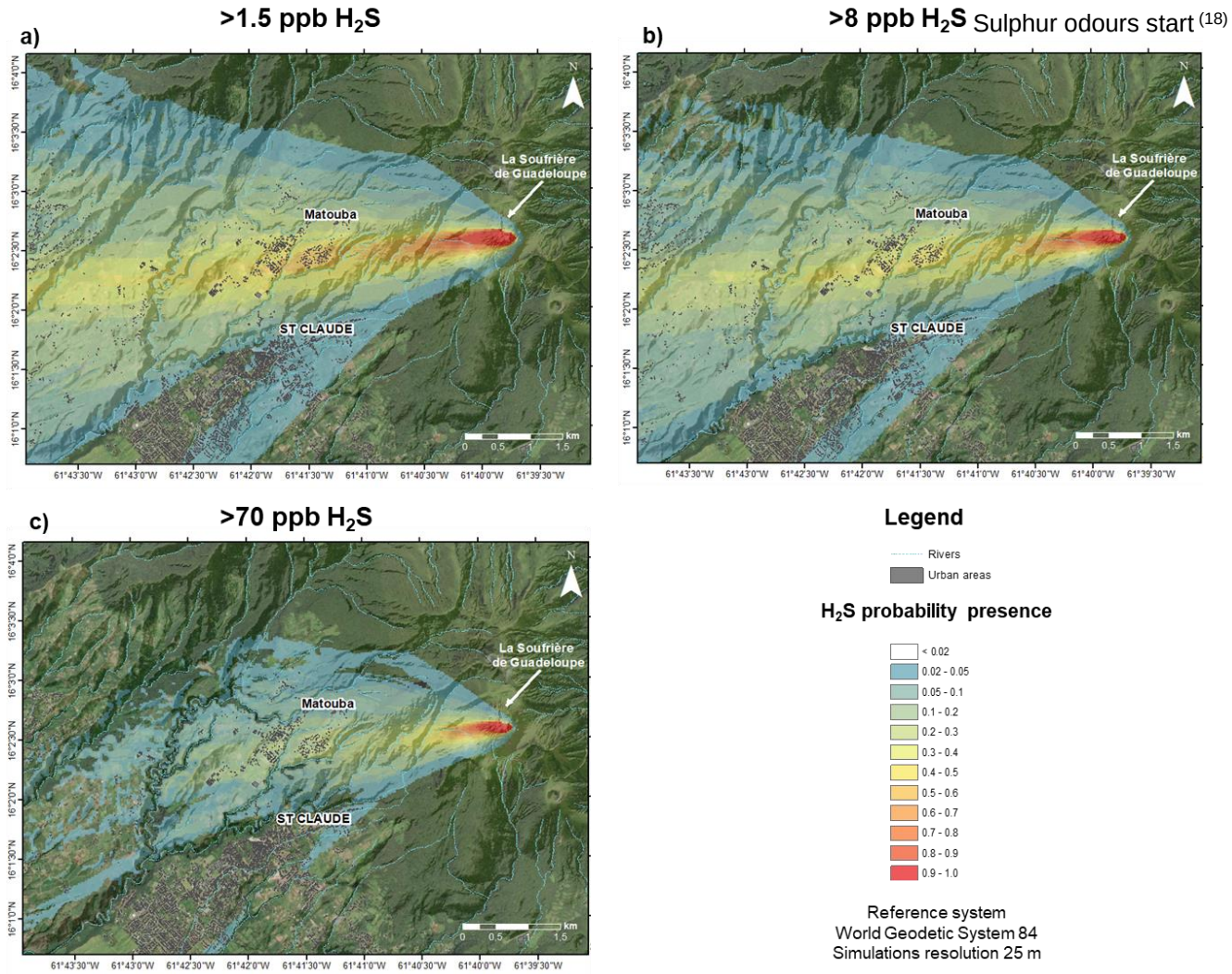


Fig. 19. Probability maps for H_2S reference values presence around La Soufrière de Guadeloupe volcano.

(18) WHO, (2000)

Conclusions and perspectives

- Our gas dispersion model simulations can be considered as a powerful tool to estimate quantitative hazard assessment of gas exposure

- The zones where gases from La Soufrière de Guadeloupe are predominantly dispersed are Matouba and the highest peripheric areas of St. Claude

- The probability of exceeding recommended acute H_2S exposure guidelines (70 ppb over 14 continuous days) in Matouba is 10 to 20%, i.e. 36 to 73 days per year.

-These model simulations can be improved considering soil degassing flux (2%)[(19)] and gas fluxes per day in the inputs

-Considering the simulated gas exposure in Matouba, it would be recommended to install another air quality station there

[(19)]Lebas, (2021)

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