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Evolution of carbon dioxide dynamics in alkaline volcanic lake Dziani Dzaha

J. Frère, A. Groleau, D. Jézéquel, B. Bénard, N. Assayag, G. Bardoux, G. Landais, R. Tchibinda, M. Ader

Introduction – Volcanic lakes

Lakes formed as a result of volcanic activity (caldera lakes, crater lakes, maar lakes…)

El Chichon

Nyos

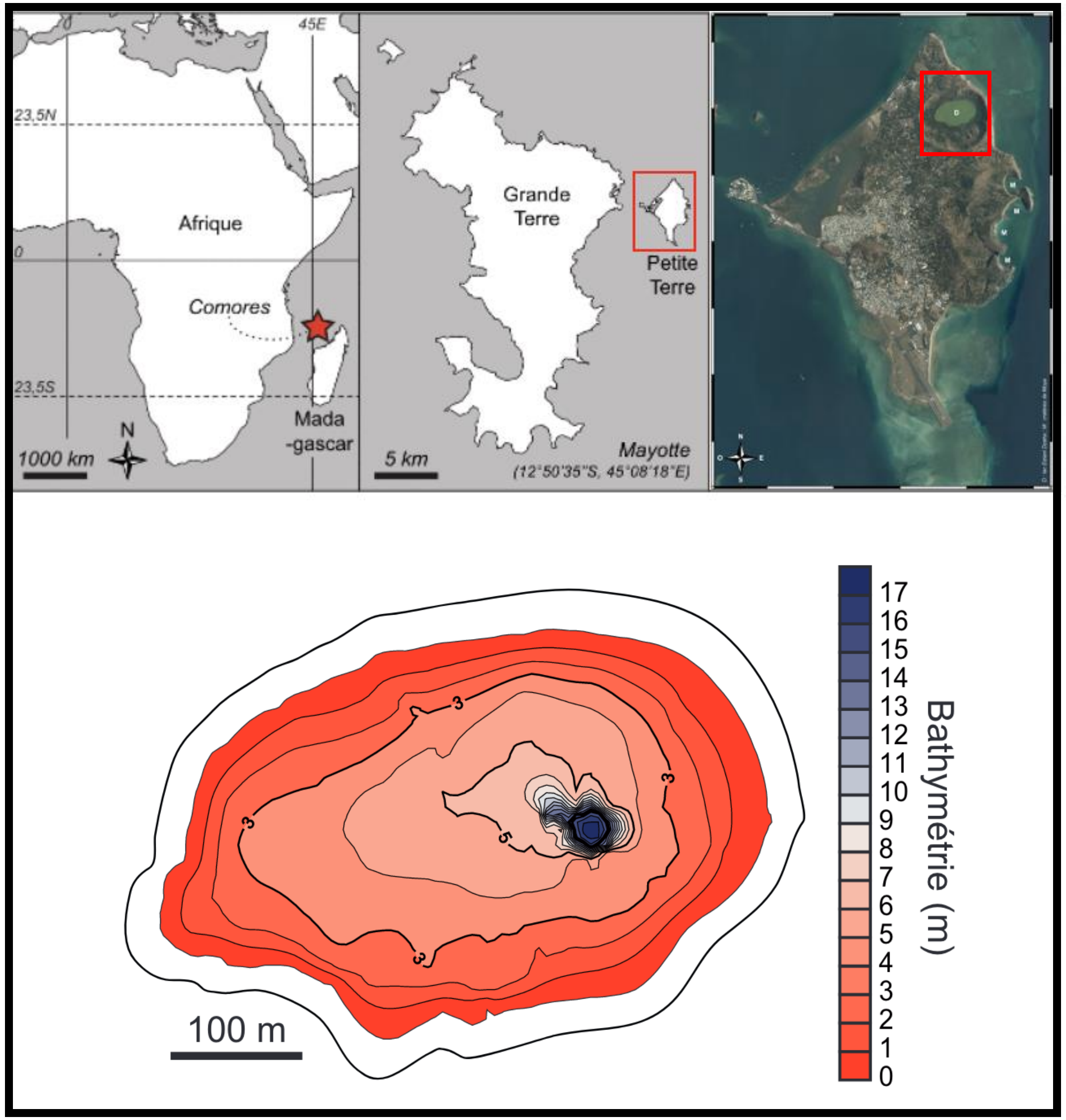
Taal

Wide range of volcanic lakes … from hot and superacidic to quiescent and alkaline

Source of hazards (phreatic, phreatomagmatic, limnic eruptions, lahars, *etc.*)

<u>But also **usefool tools** for volcanic activity monitoring !</u>

Introduction – Dziani Dzaha Lake



Jovovic (2021)

« Crater lake» in Shimaore

Tuff ring (Lacombe et al., 2024)

Intensively studied since 2010:

- Initially filled with seawater
- Up to twice as salty as seawater
- pH > 9 and alkalinity 100 x SW
- Magmatic CO_2 bubbling

Introduction – Dziani Dzaha Lake

2018 – 2020 : Fani Maore eruption
Since 2019 : volcanic surveillance (REVOSIMA)
+ very active submarine CO_2 vents (Horseshoe)

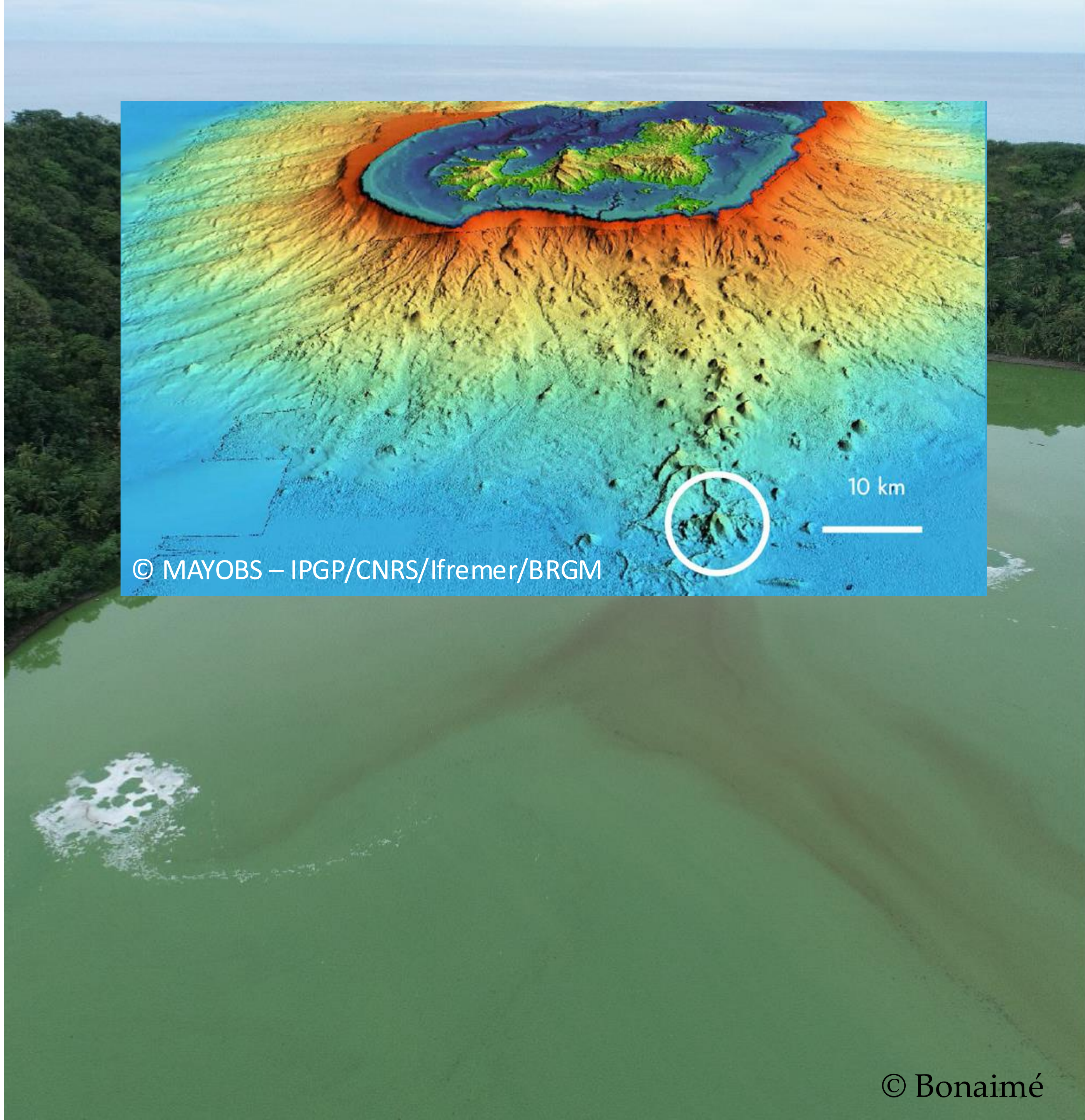
Dziani Dzaha:
Nov 2020 : bubbling intensification

Sept 2021 : physico-chemical changes
(pH decrease, DIC increase)

2022 - 2025 : 8 field surveys

What changes happened?

What insights can we get on volcanic activity and monitoring ?



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Methods

Fieldwork ≈ twice a year

In-situ measurements:

CO_2/CH_4 diffusive fluxes, probe profiles (pH, T, Salinity…)

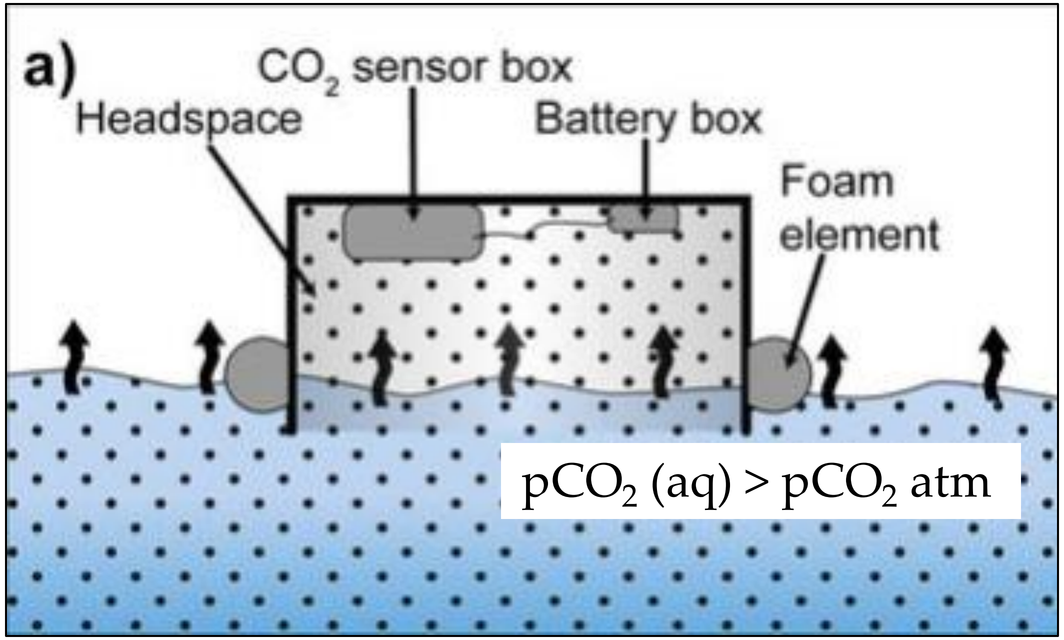
Water sampling:

DIC, alkalinity, ions (ICP-MS, acid titration, ICP-OES…)

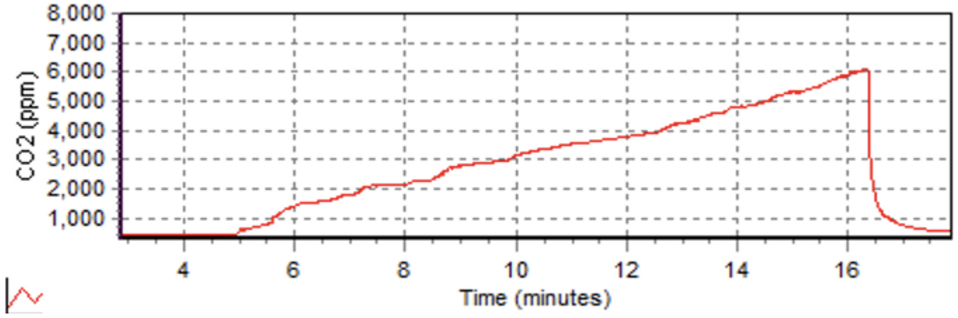
« Niskin » type sampling bottle

@SURUNEILE

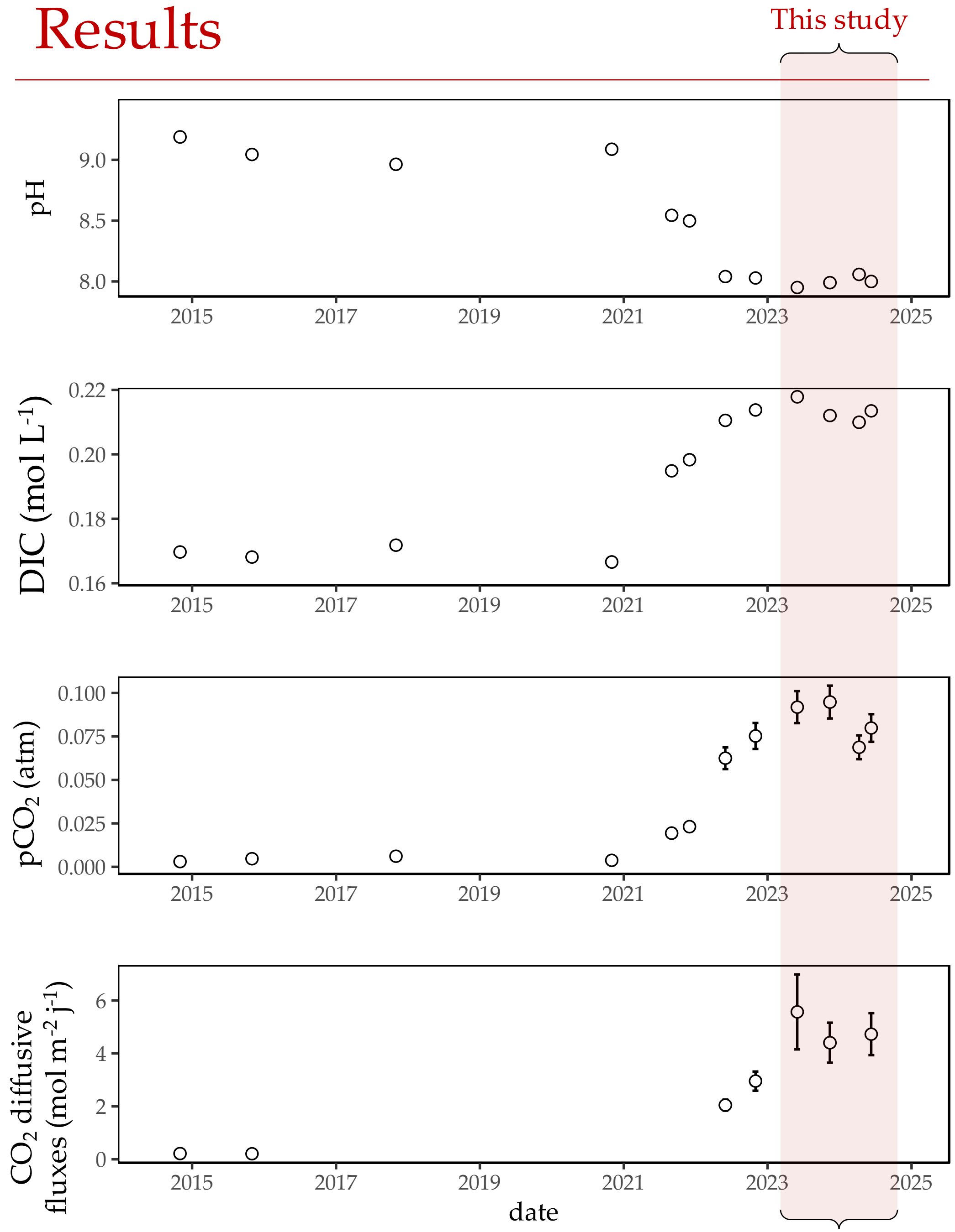
Methods



Measurement of CO_2/CH_4 diffusive fluxes at the water-air interface, with home-made floating accumulation chamber



Results



Older data from Cadeau et al., 2020 & Sarazin et al., 2020

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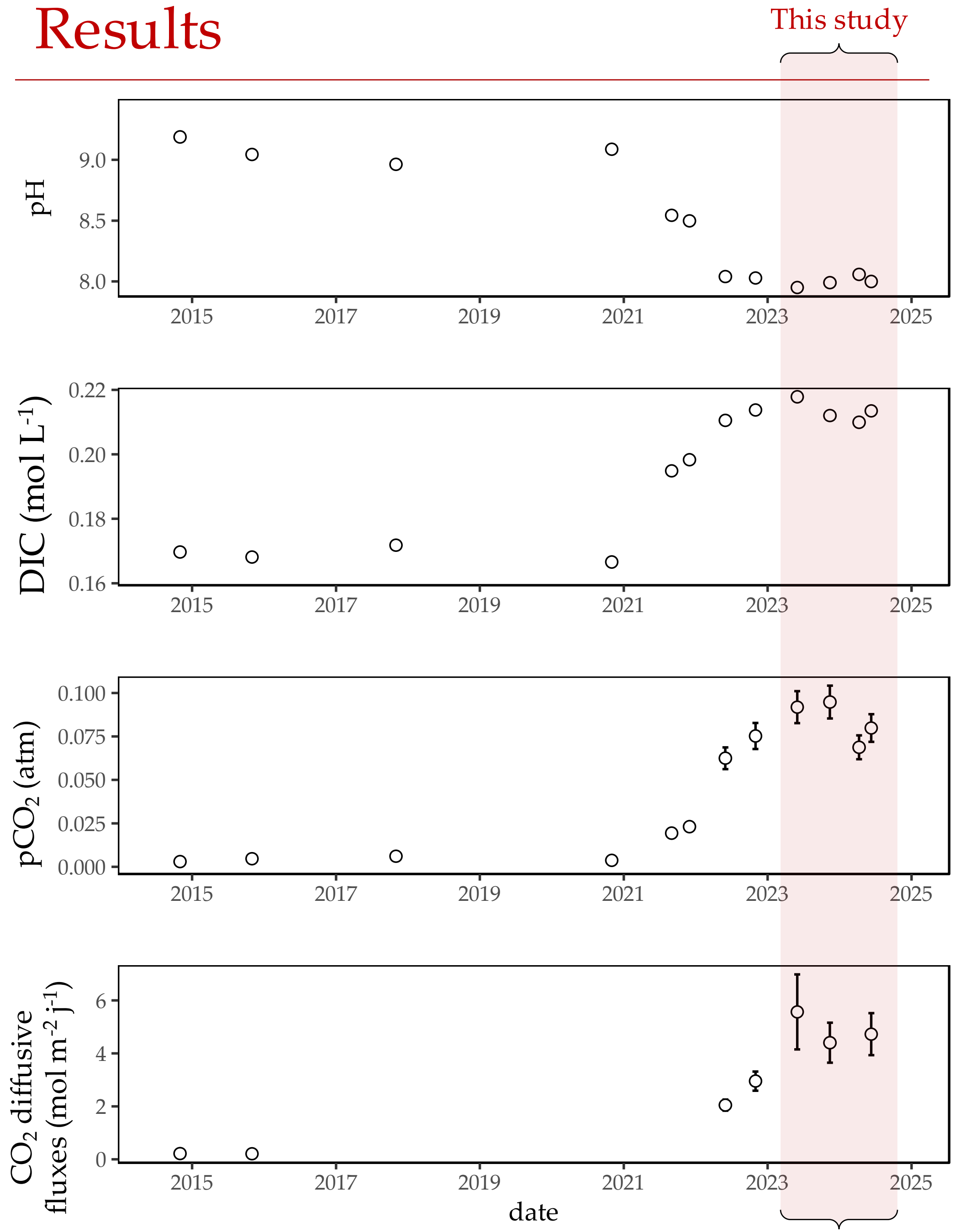

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Decrease in pH (9.2 to 8)

$[CO_2]_{(aq)} + [HCO_3^-] + [CO_3^{2-}]$

DIC increase (0.17 to 0.21 M)

pCO_2 calculated with alkalinity and pH

pCO_2 increase (2000 to ≈ 80 000 ppm)

Diffusive fluxes increase (0.2 to ≈ 4 mol m^{-2} d^{-1})

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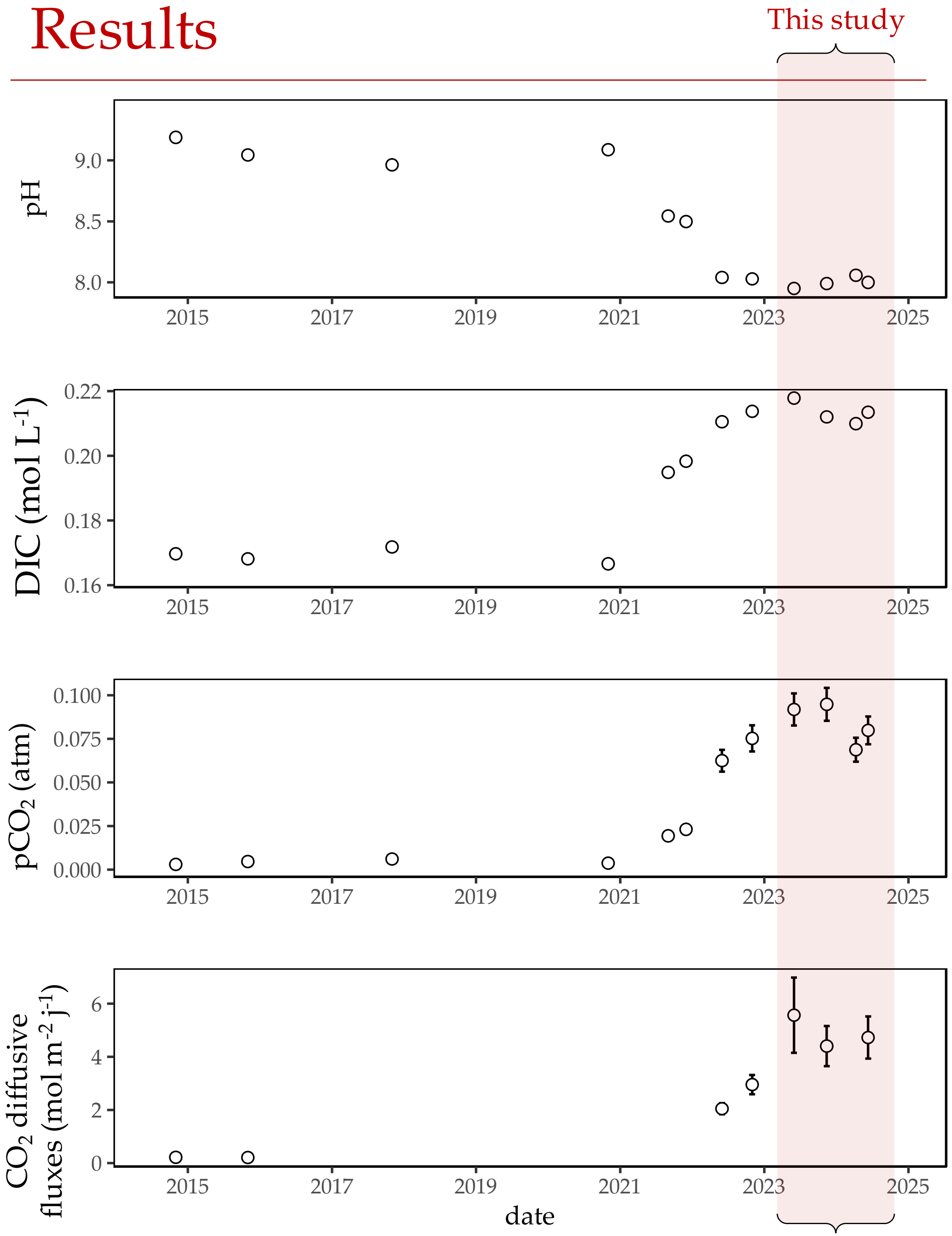

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CO_2 invasion
(similar chemistry as ocean acidification)

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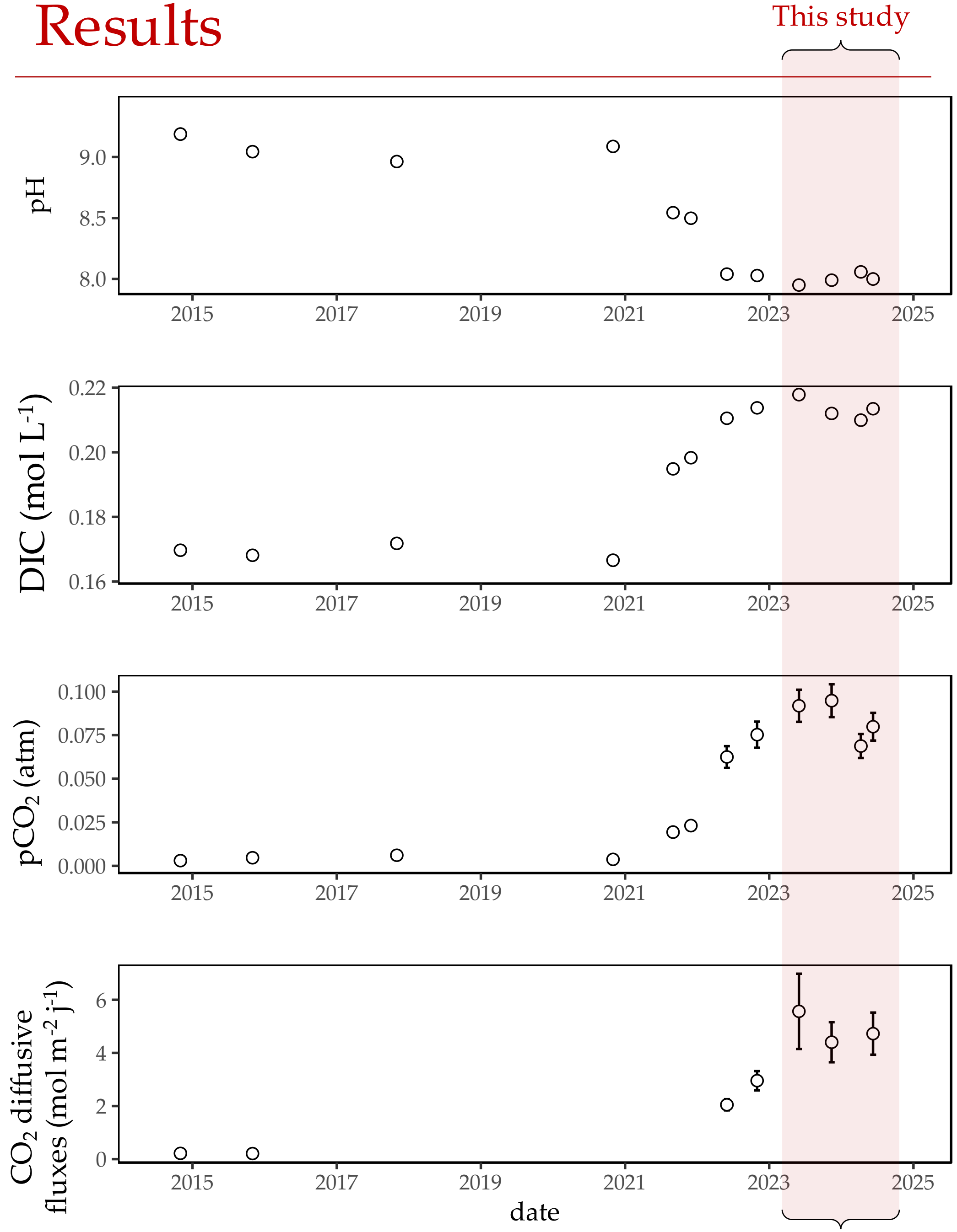

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Input of CO_2 through increased magmatic degassing

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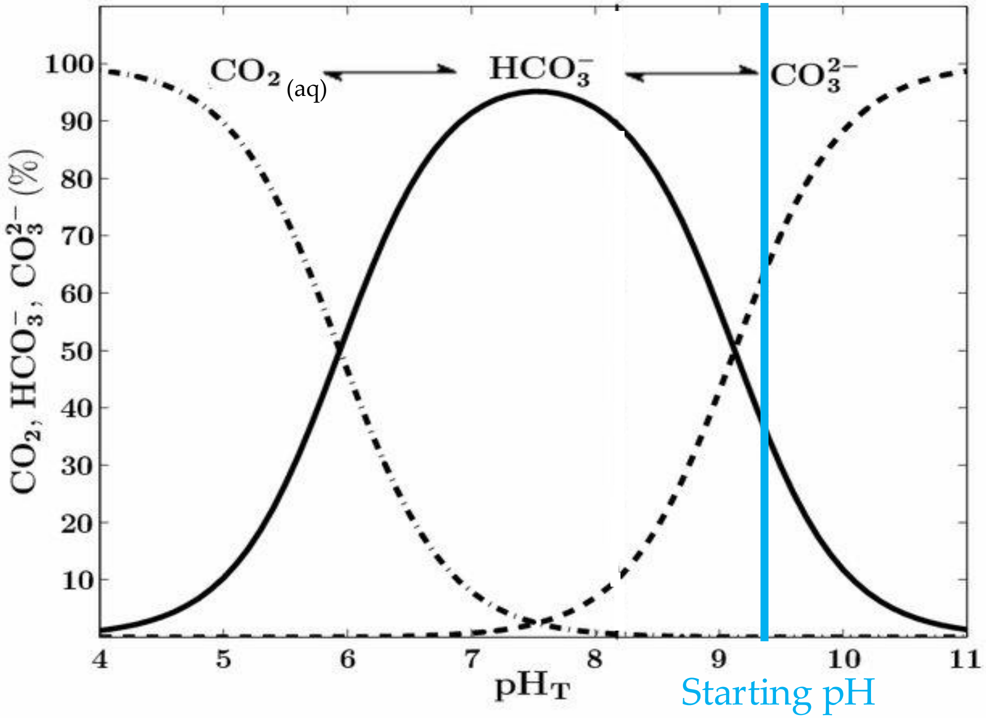
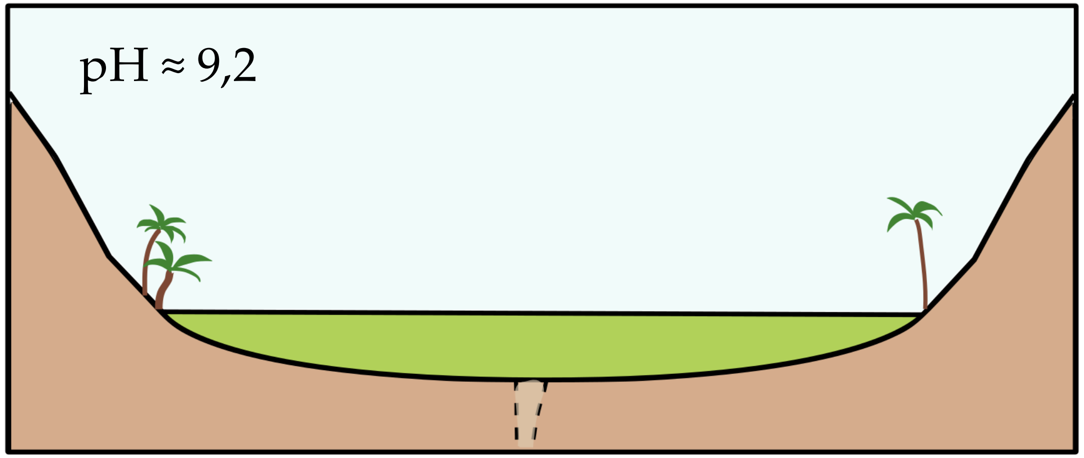
Effects of CO_2 inputs





Carbonate system : three species
$[CO_2]_{(aq)}$ $[HCO_3^-]$ $[CO_3^{2-}]$
whose relative abundances depend on pH

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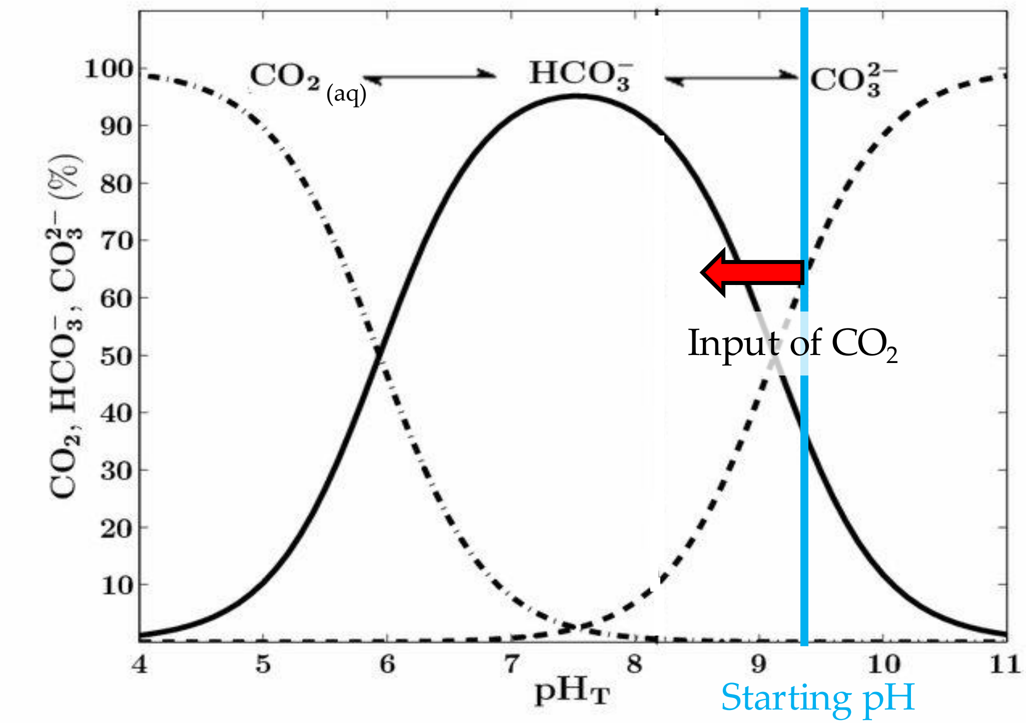

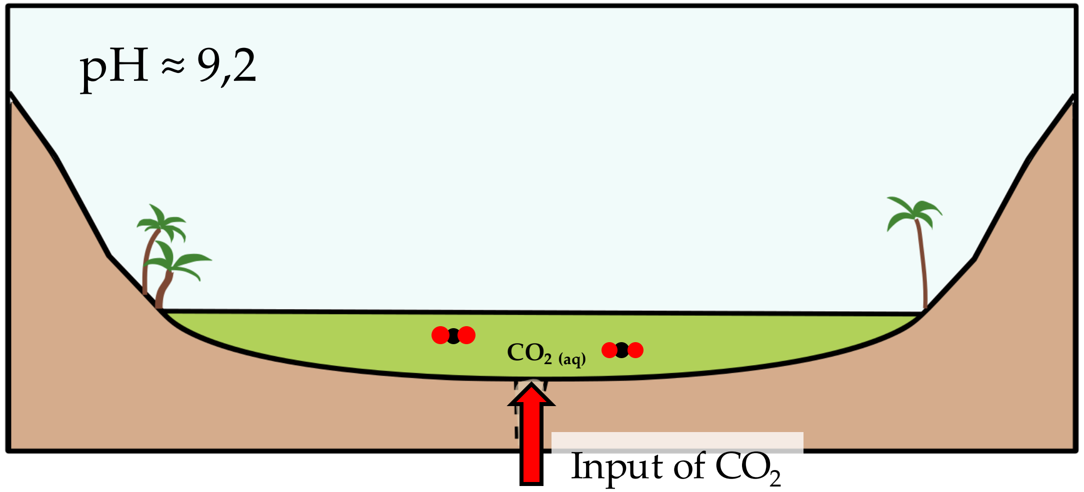

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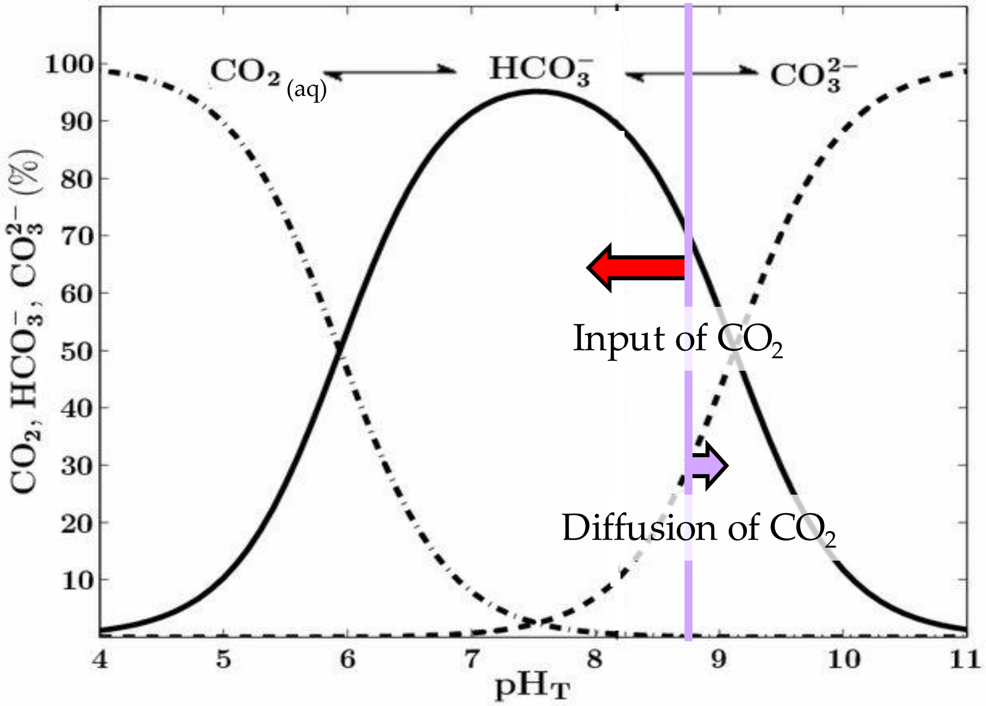

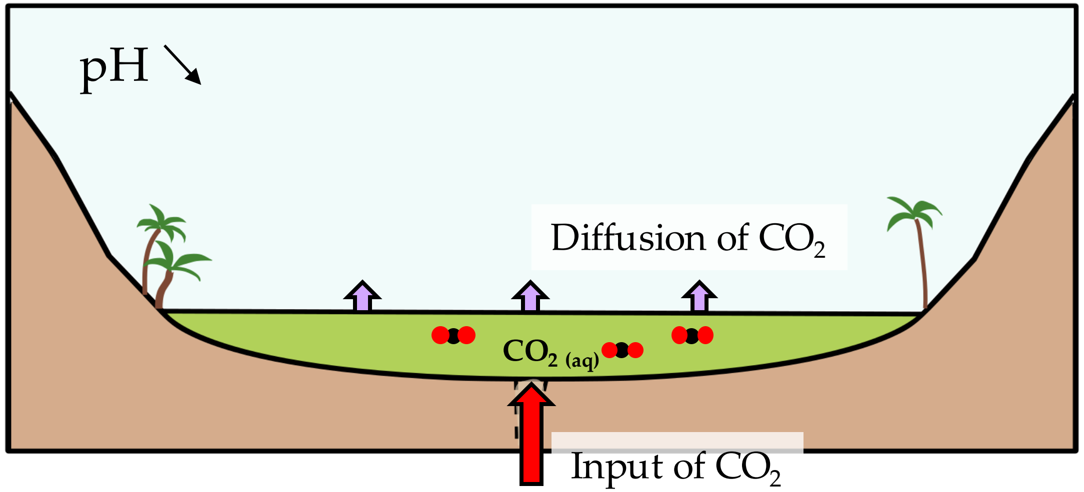

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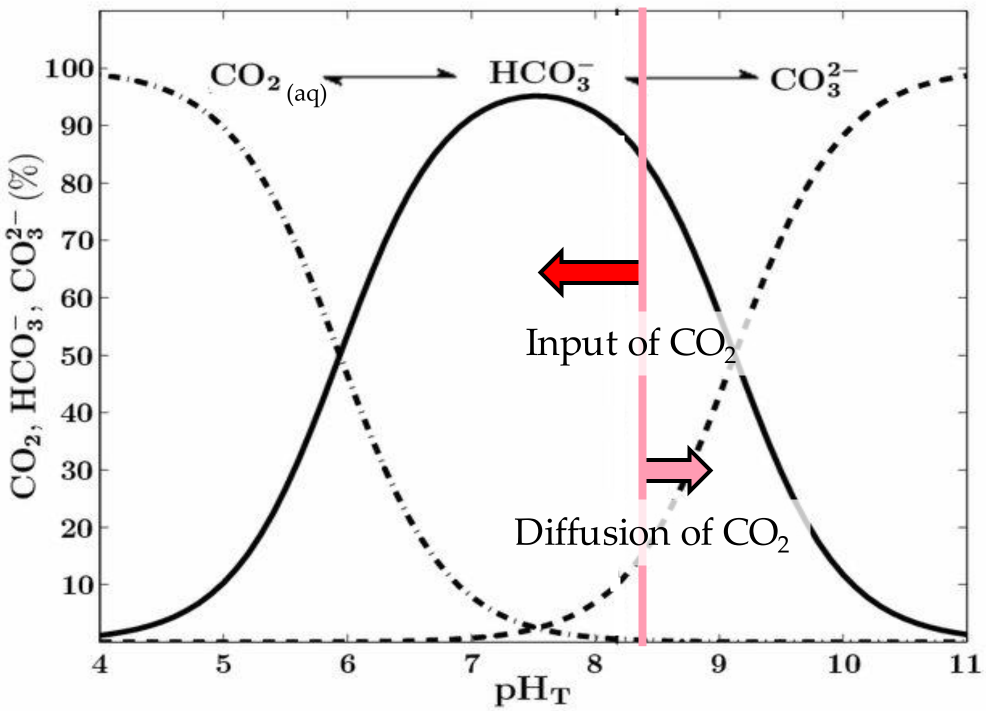

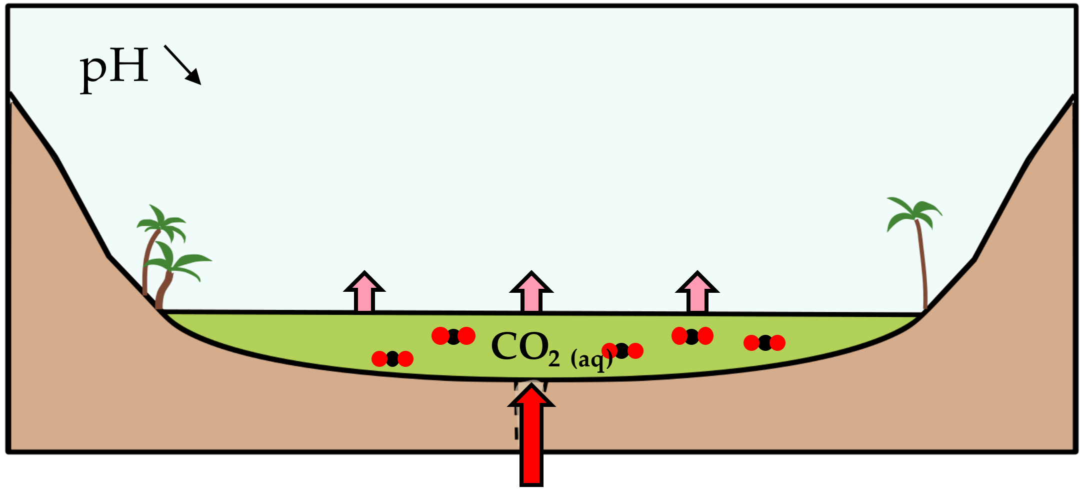

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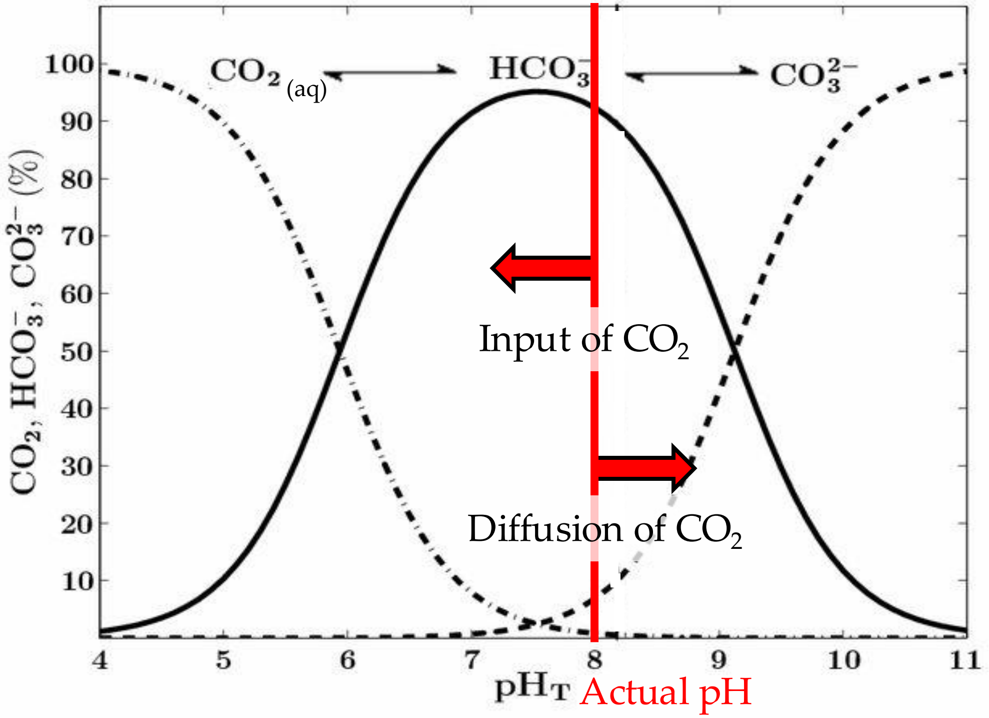

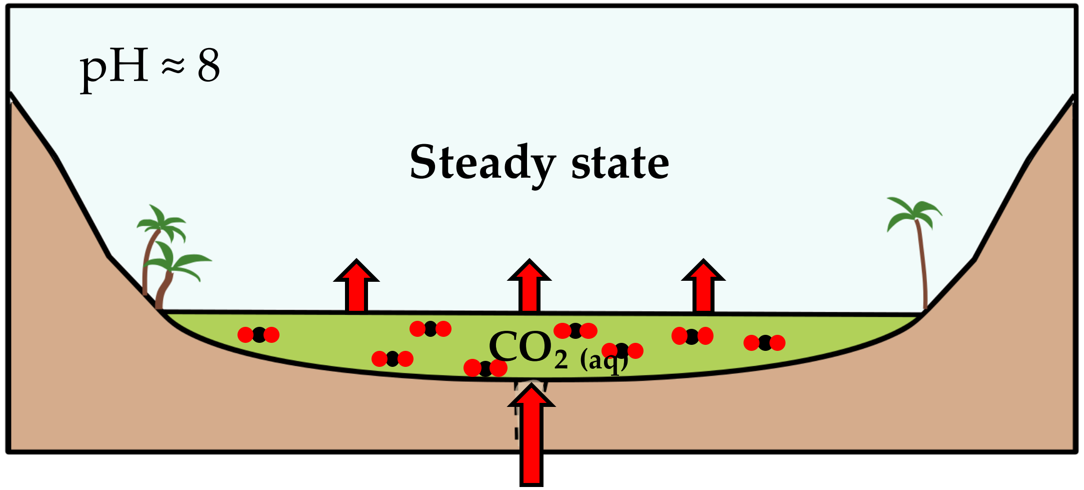

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Steady state is reached when input and output balance each other

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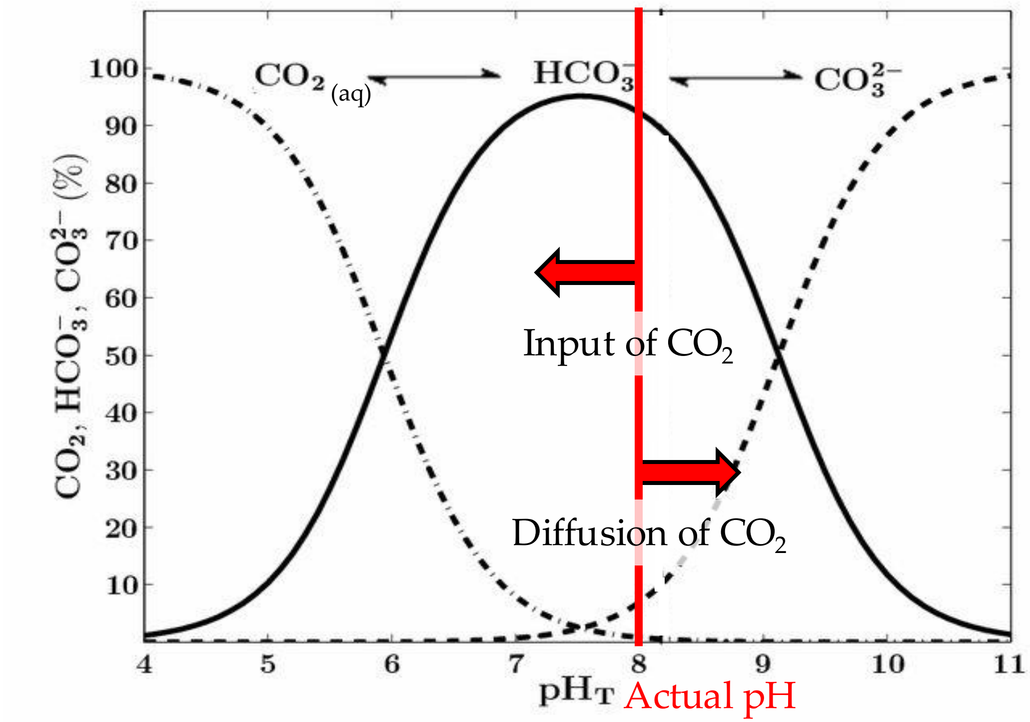

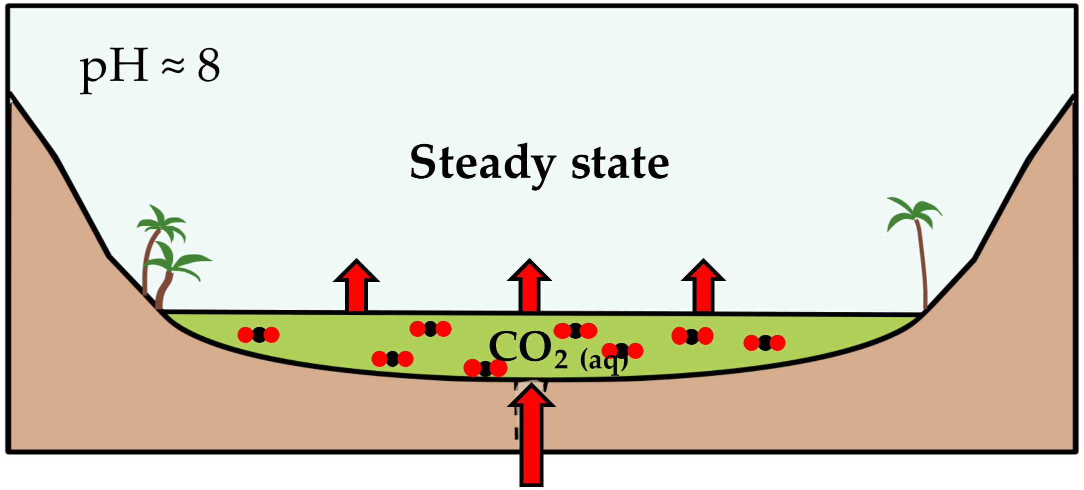

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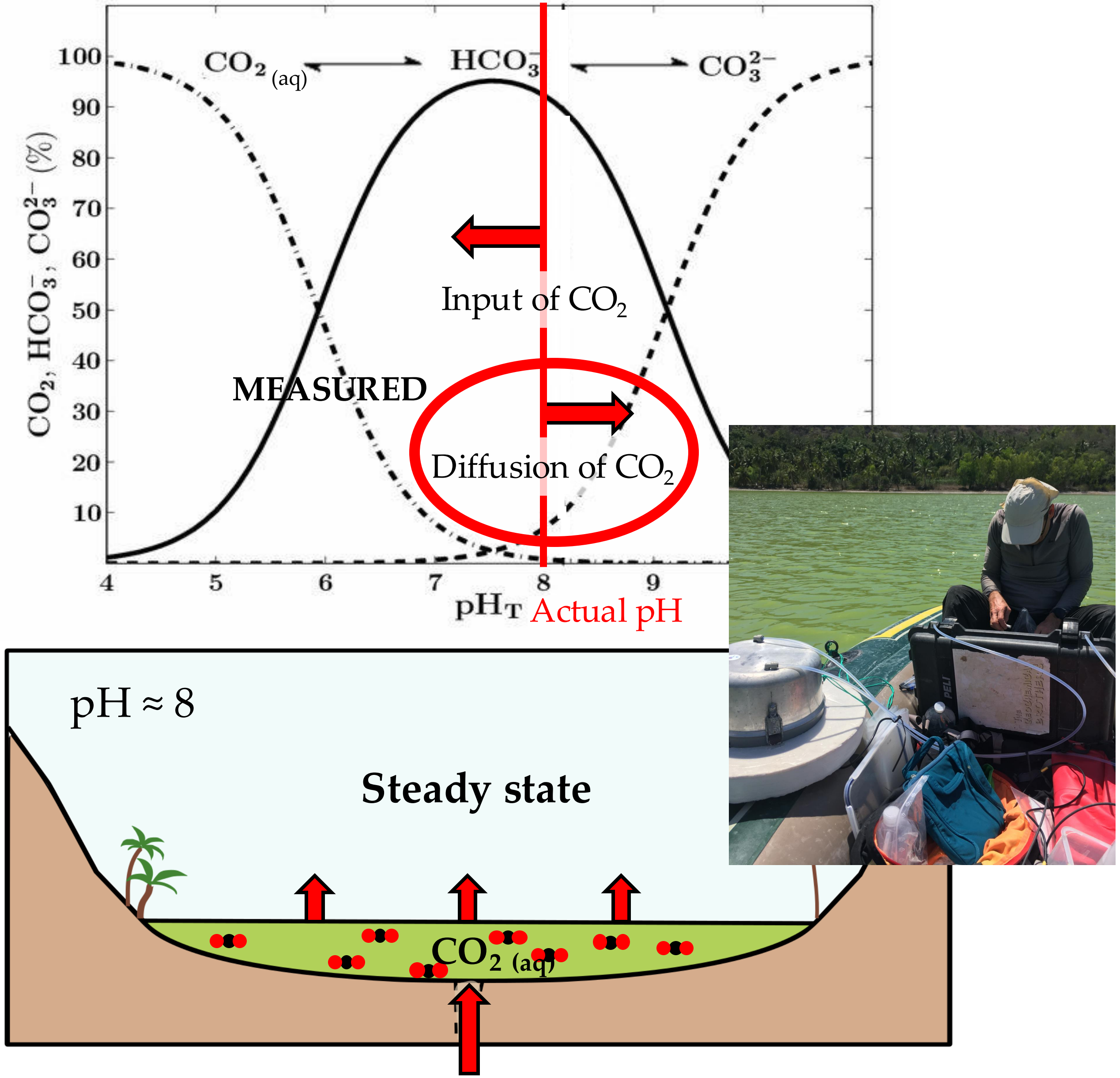

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- Magmatic CO_2 dissolution ≈ **39 ± 15 tons day^{-1}**

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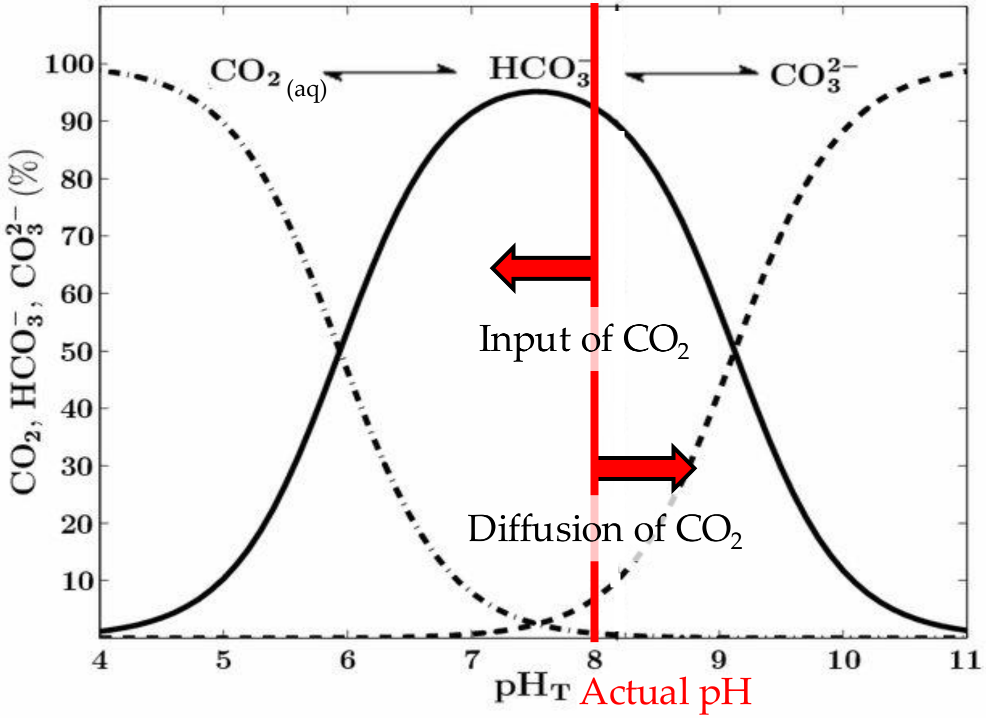

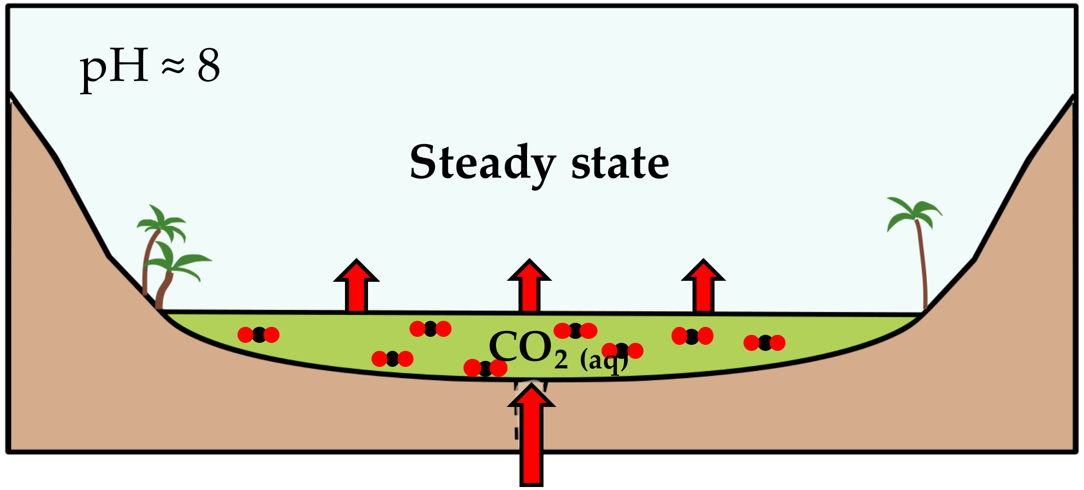

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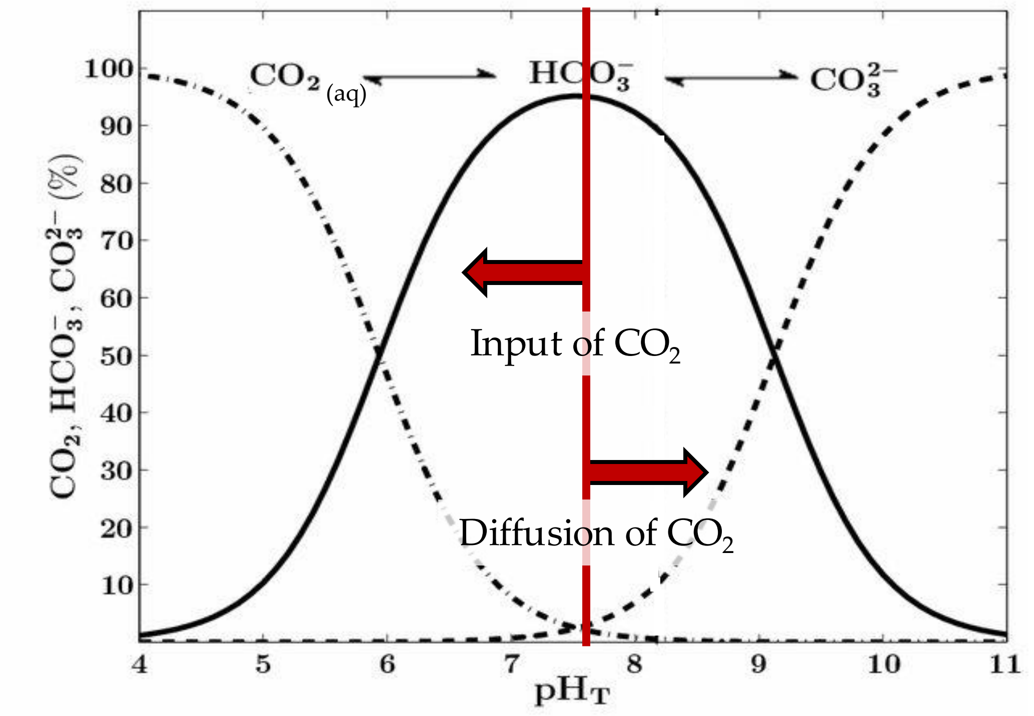

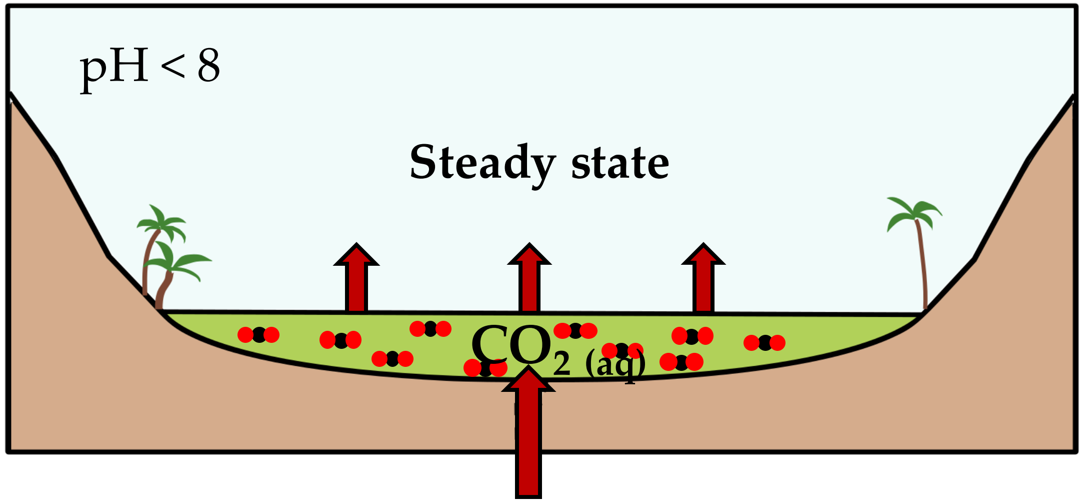

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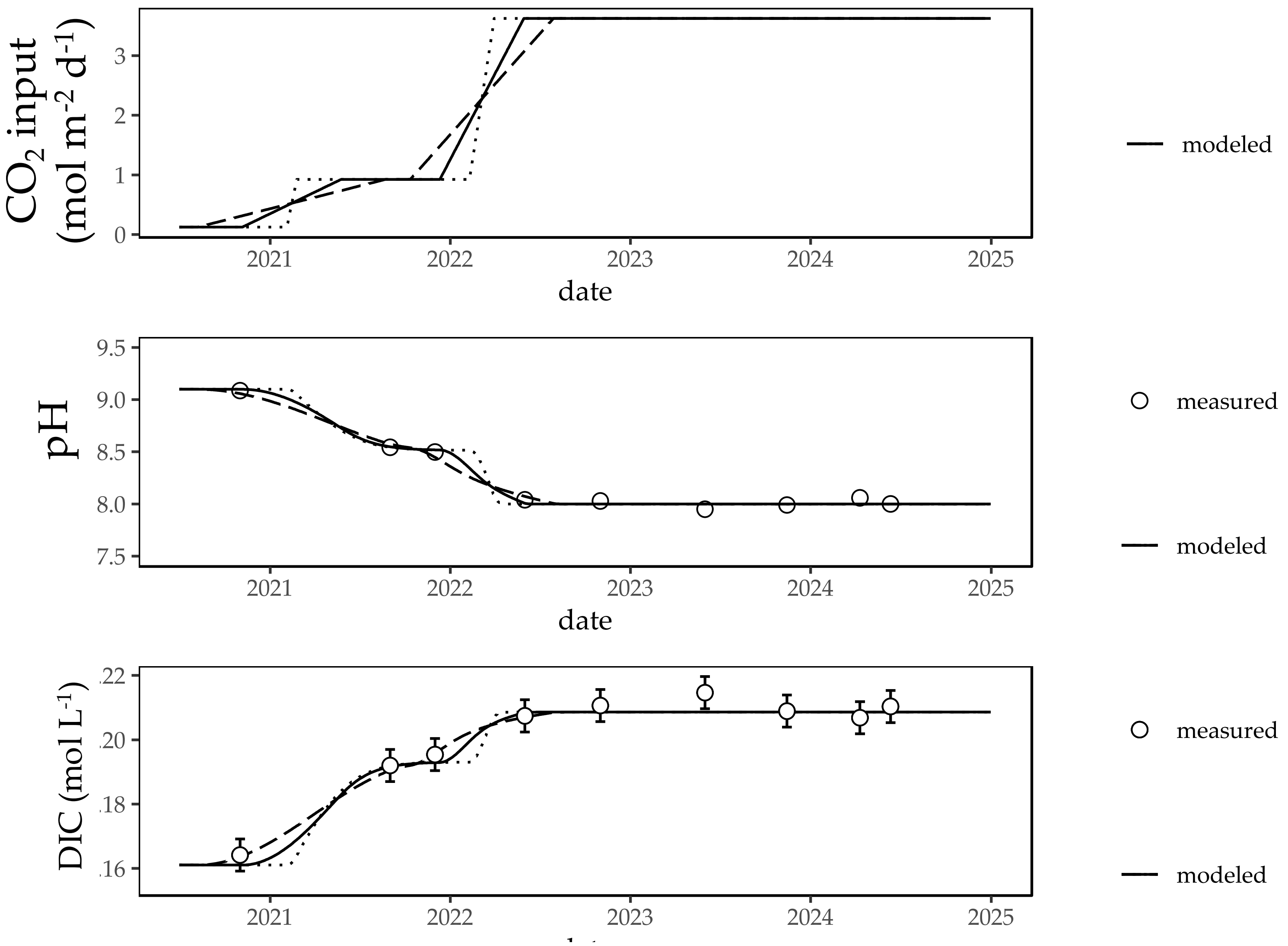
Modelisation

modelling the perturbation



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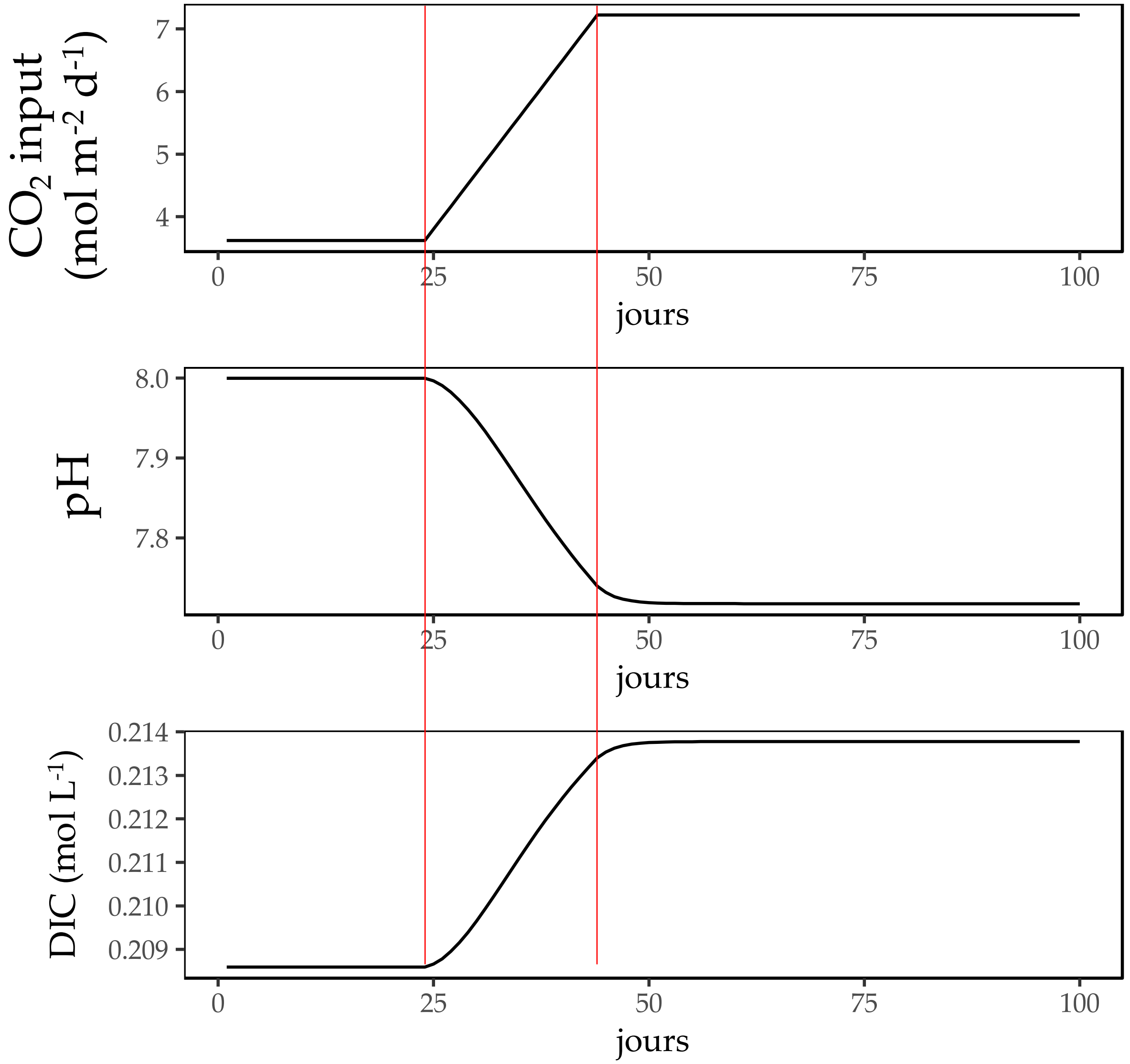
Modelisation

modelling a change in CO_2 flux



40 → 80 t CO_2 d^{-1}

Steady state is reached when the input equals the output

- Magmatic CO_2 dissolution ≈ **39 ± 15 tons day^{-1}**
- Change in flux → change in pH
- The perturbation likely occured in two phases
- The lake is **highly reactive** to change in flux (≈ days)

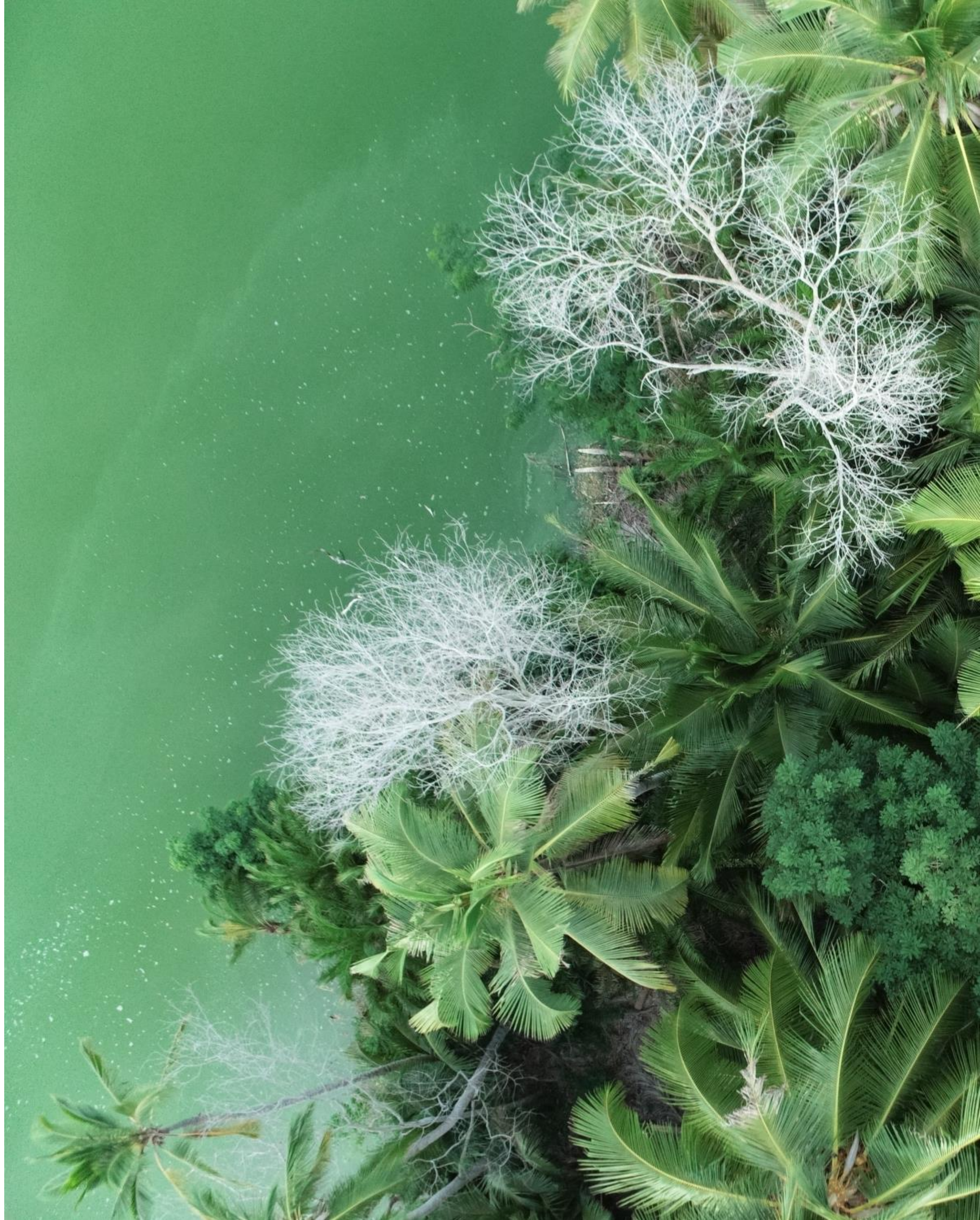
Conclusions

- The changes in the lake can be attributed to **the increase of CO_2 magmatic degassing → regional increase?**

- CO_2 dissolution (and diffusion) in the lake is ≈ **40 tons d^{-1}**

- The increase in degassing likely occured in **two phases** (1st between Nov 2020 and Sept 2021 and 2^{nd} between Dec 2021 and June 2022)

- change in flux is very quickly reflected in pH → simple parameter to measure for the monitoring **of the magmatic degassing** in Dziani Dzaha (proved crucial in other volcanic systems e.g Taal or Kelud volcanoes)



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Monitoring platform in Nov 2024… destroyed by Chido in December

Reconstruction planned for 2026