WHAT KIND OF ENVIRONMENTAL TRANSITION FOR THE MEDITERRANEAN REGION?
OCTOBER 14-16 2019 Marseille Pharo

Groundwater processes in coastal Mediterranean lagoons

Fluxes and driving forces

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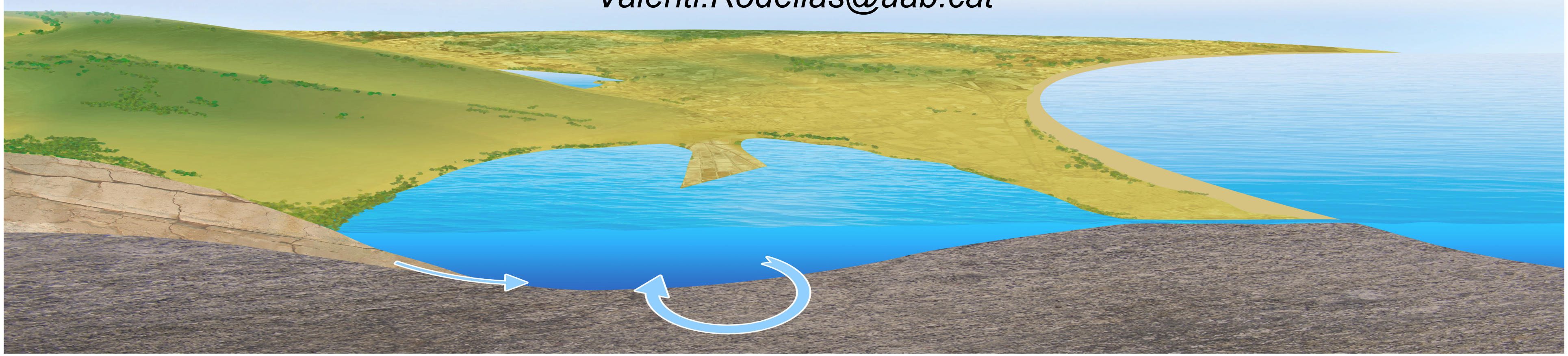


CONTENTS

- **Groundwater discharge to coastal lagoons**

1) Quantification of GROUNDWATER FLUXES

- Water inputs
- Nutrient inputs

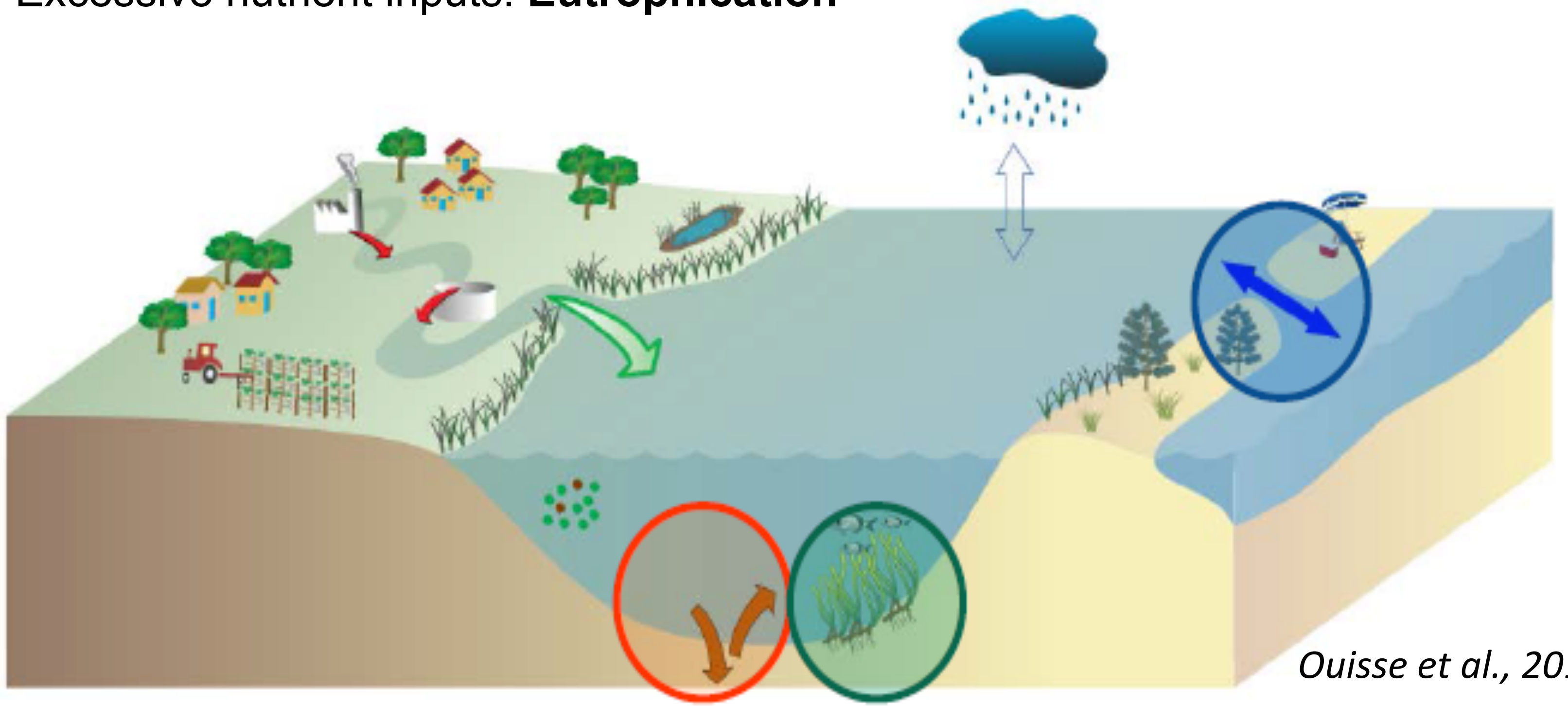
Radon

2) Identification of DRIVING FORCES

- Changes in lagoon water depths *Subsurface Salinity*
- Wind waves *Subsurface Temperature*

MEDITERRANEAN COASTAL LAGOONS

- ~400 coastal lagoons in the Mediterranean Sea
- Dynamic, diverse and **productive ecosystems**
- **Semi-enclosed water bodies**: accumulation of solutes
- Land-ocean interface: extremely **vulnerable** to anthropogenic and climatic pressures
- Excessive nutrient inputs: **Eutrophication**



Ouisse et al., 2013

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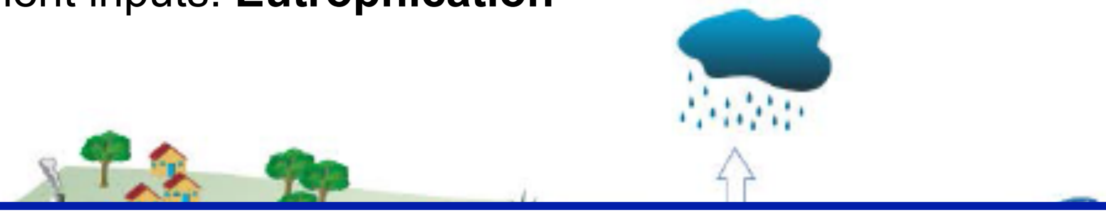
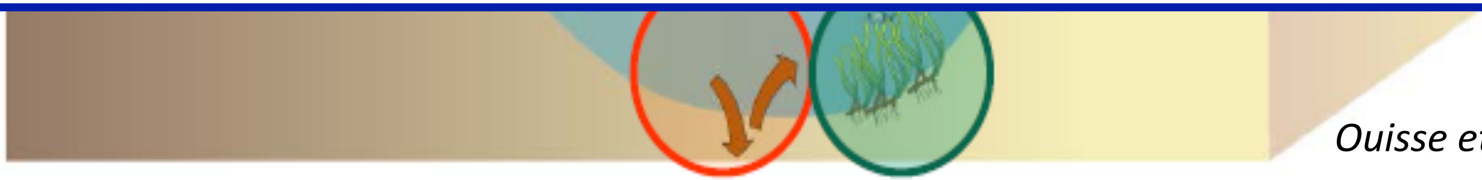


*Limited understanding on the **pathways delivering nutrients** to coastal lagoons*



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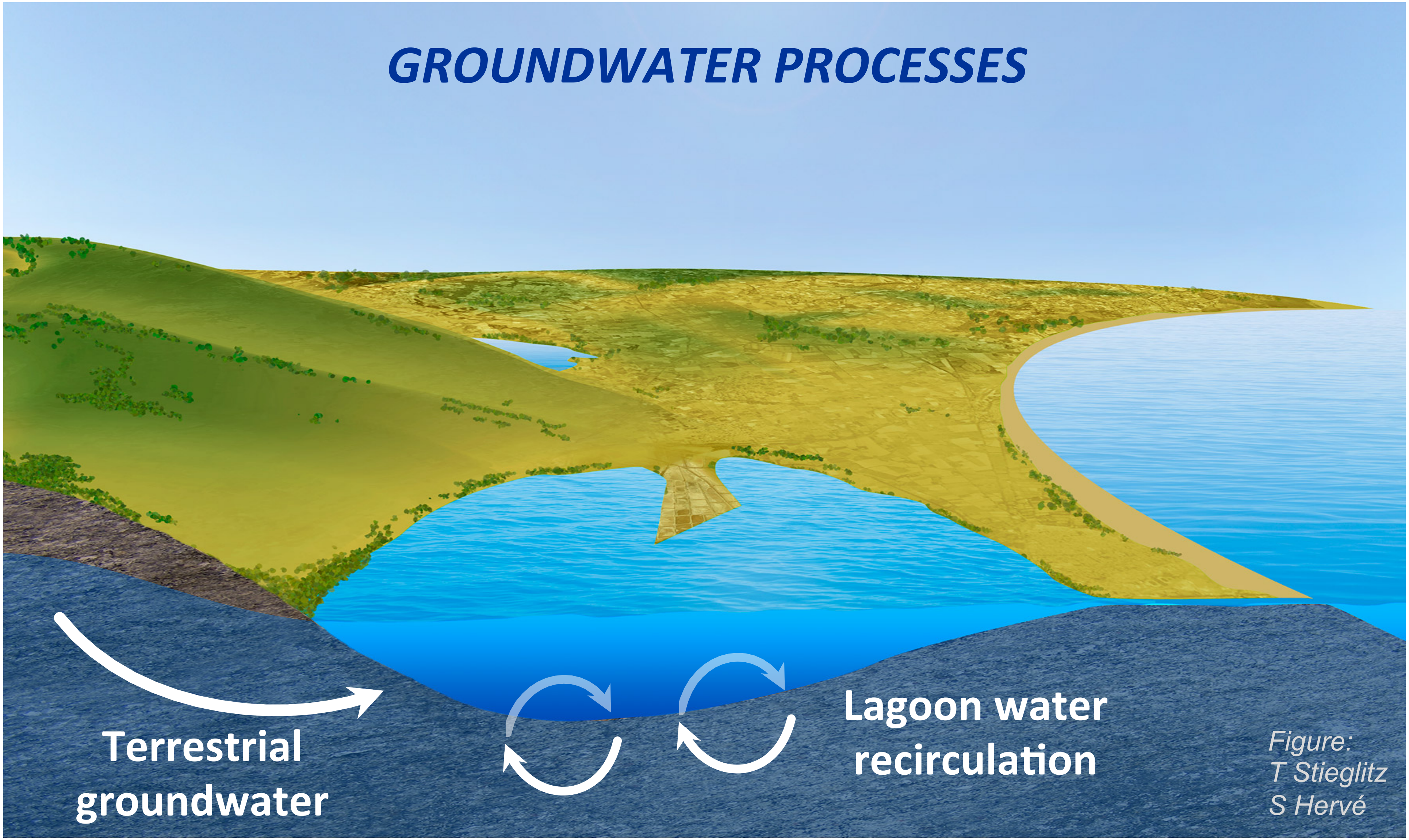
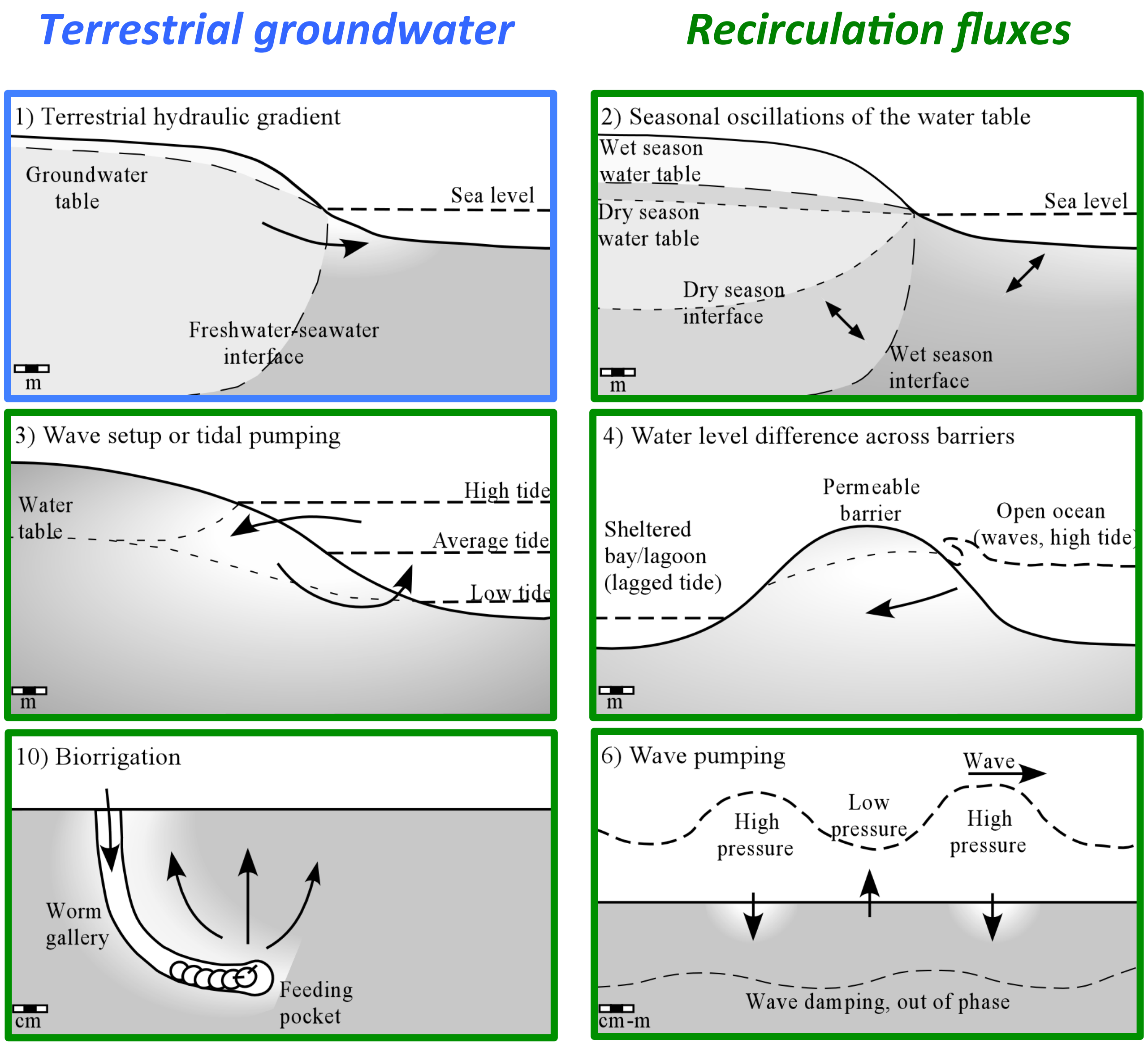

GROUNDWATER PROCESSES
Terrestrial groundwater
Lagoon water recirculation
Figure:
T Stieglitz
S Hervé

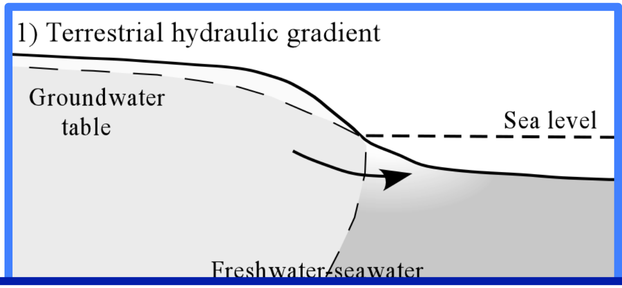
Mechanisms driving groundwater discharge



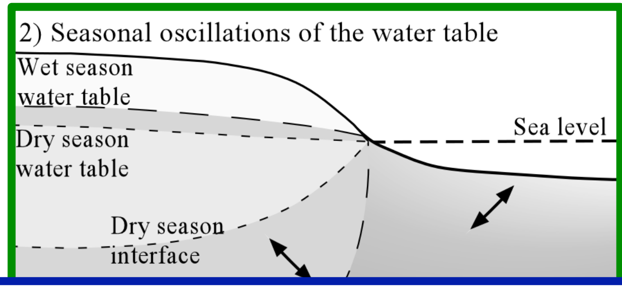
Santos et al., 2012, ECSS

Mechanisms driving groundwater discharge

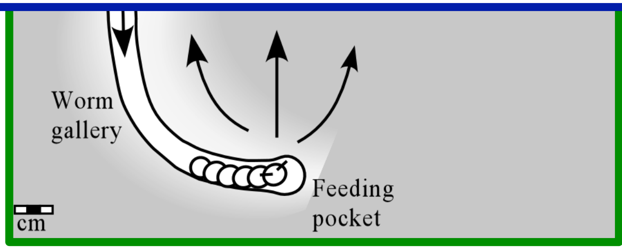
Terrestrial groundwater

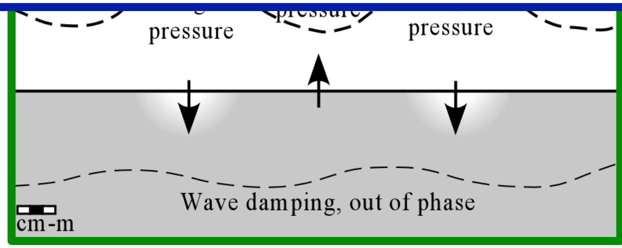


Recirculation fluxes



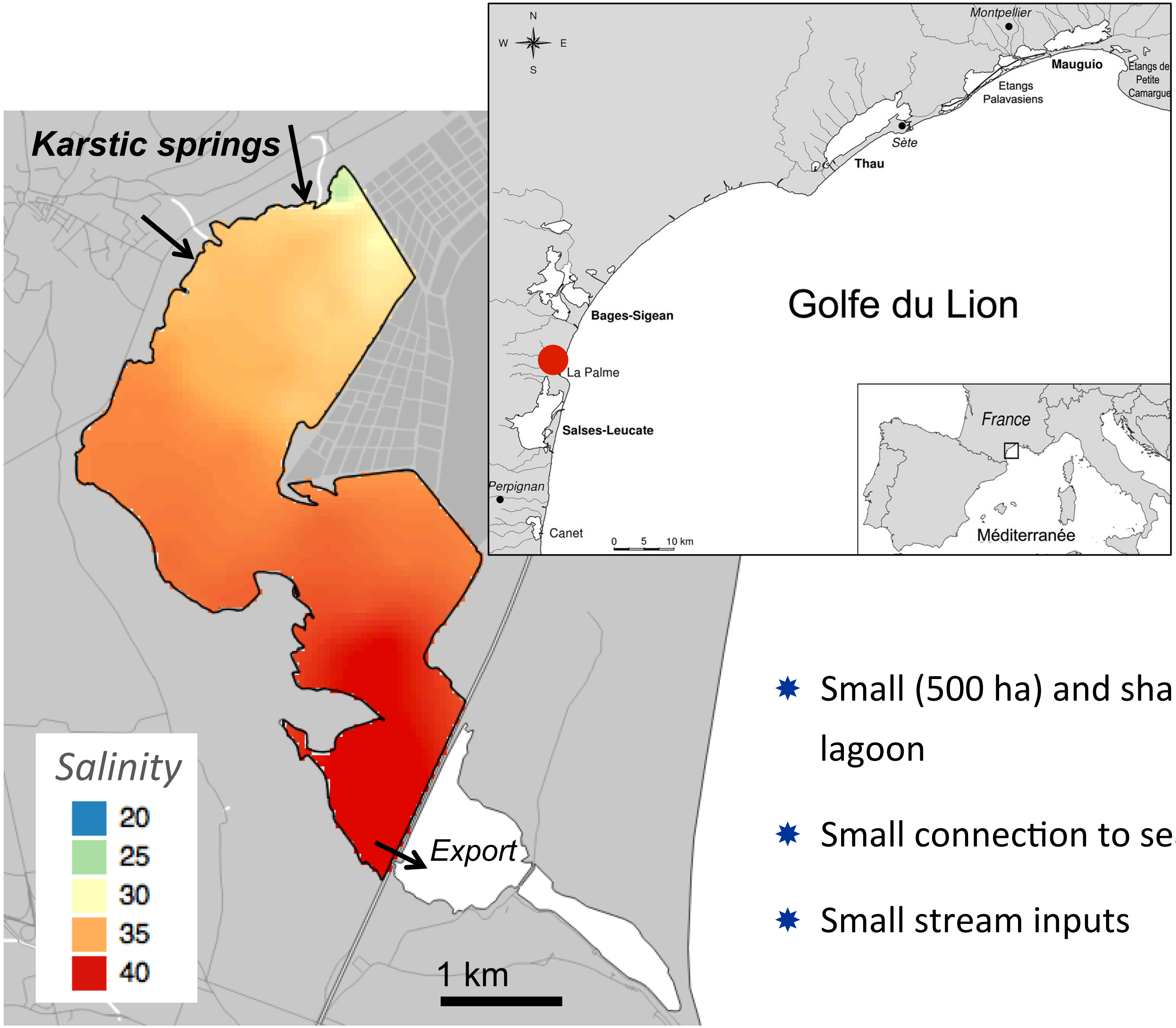
*Understand the **driving forces** of groundwater fluxes to better predict the **effects of increasing stressors** and to inform **sustainable management strategies***





Santos et al., 2012, ECSS

LA PALME LAGOON



- Small (500 ha) and shallow (<1 m) coastal lagoon
- Small connection to sea
- Small stream inputs

1) Quantification of GROUNDWATER FLUXES

Water & Radon lagoon mass balances

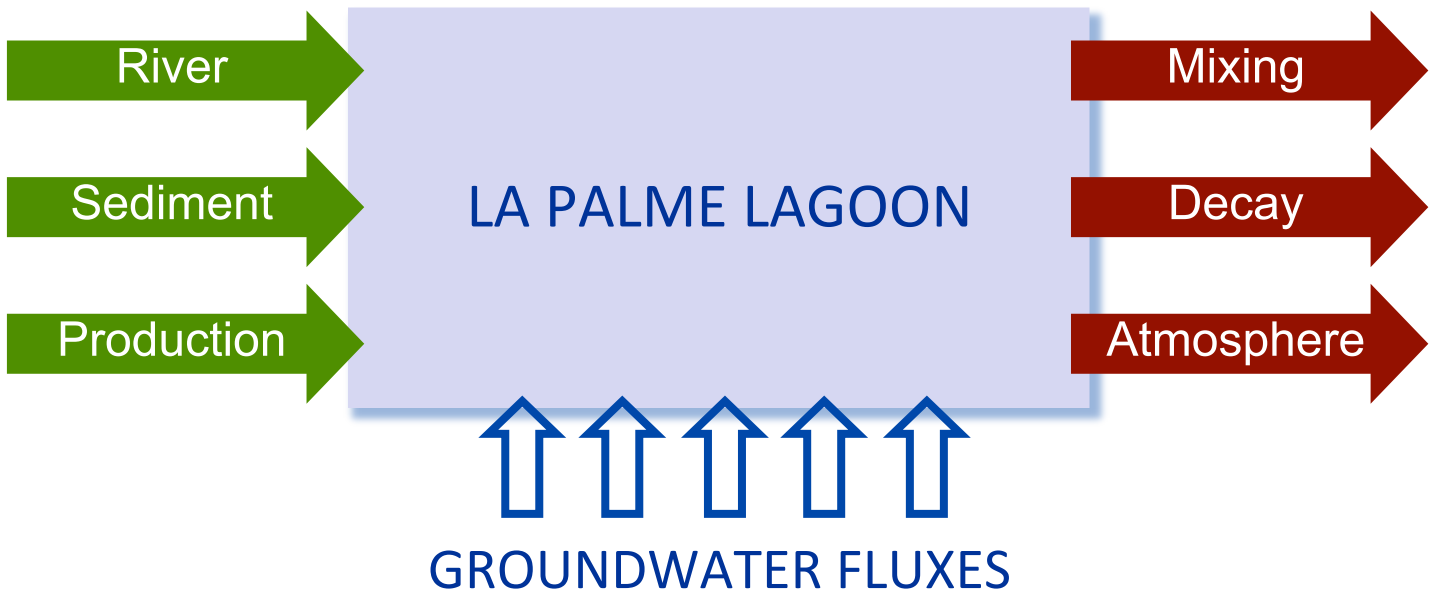
Why???

WATER: evaluation of water inputs (karstic groundwater)

RADON: tracer of groundwater and recirculation inputs

Water
$$\frac{\partial V_N}{\partial t} = Q_g + PA_N - EA_N - J_{NS}$$

Radon
$$\frac{\partial CV_N}{\partial t} = Q_g C_g + P_{Ra226} + (F_{diffusion} + F_{recirculation}) A_N - kA_N C - \lambda V_N C - J_{NS} C + D_{NS} \Delta C_{NS}$$



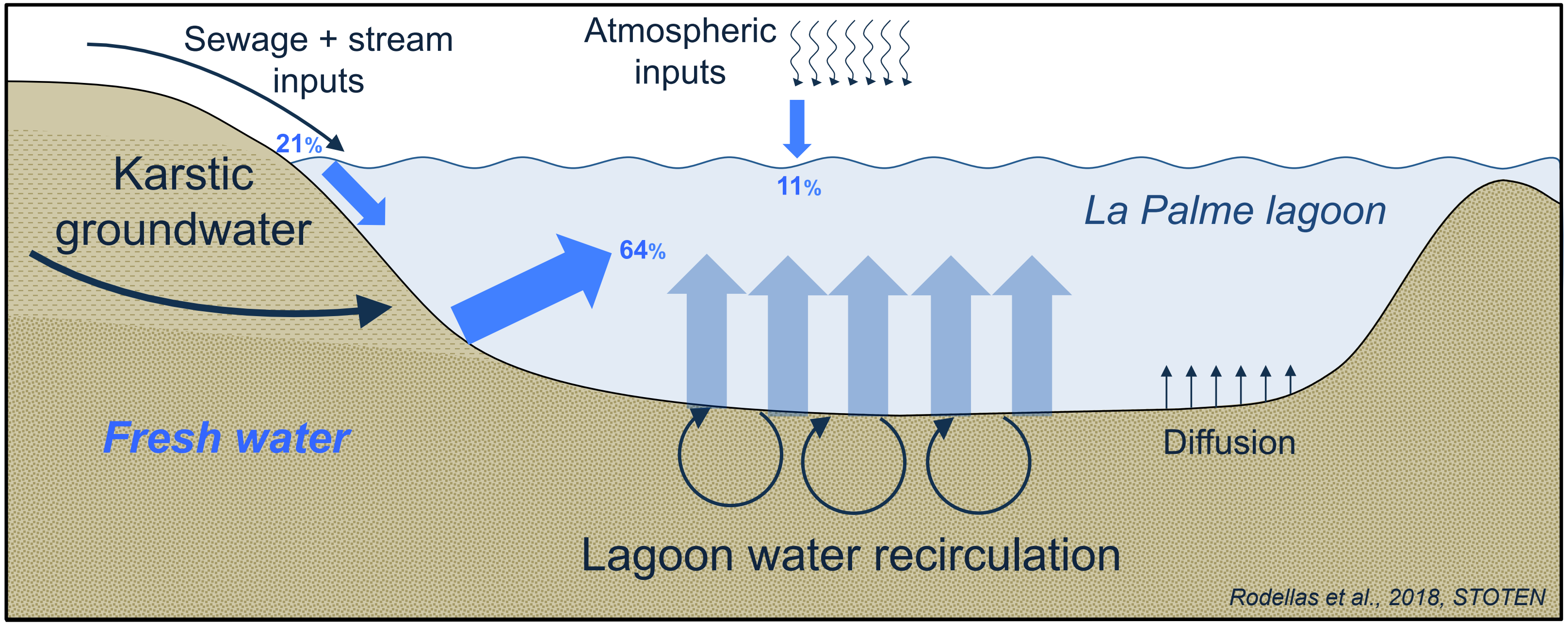
Importance of Groundwater: **WATER INPUTS**

Karstic groundwater ~10^4 m^3 d^{-1}

- Main source of freshwater
- **Maintains brackish conditions in lagoon waters**

Recirculation ~$5 \cdot 10^4$ m^3 d^{-1}

- Large volumes of water recirculating through sediments



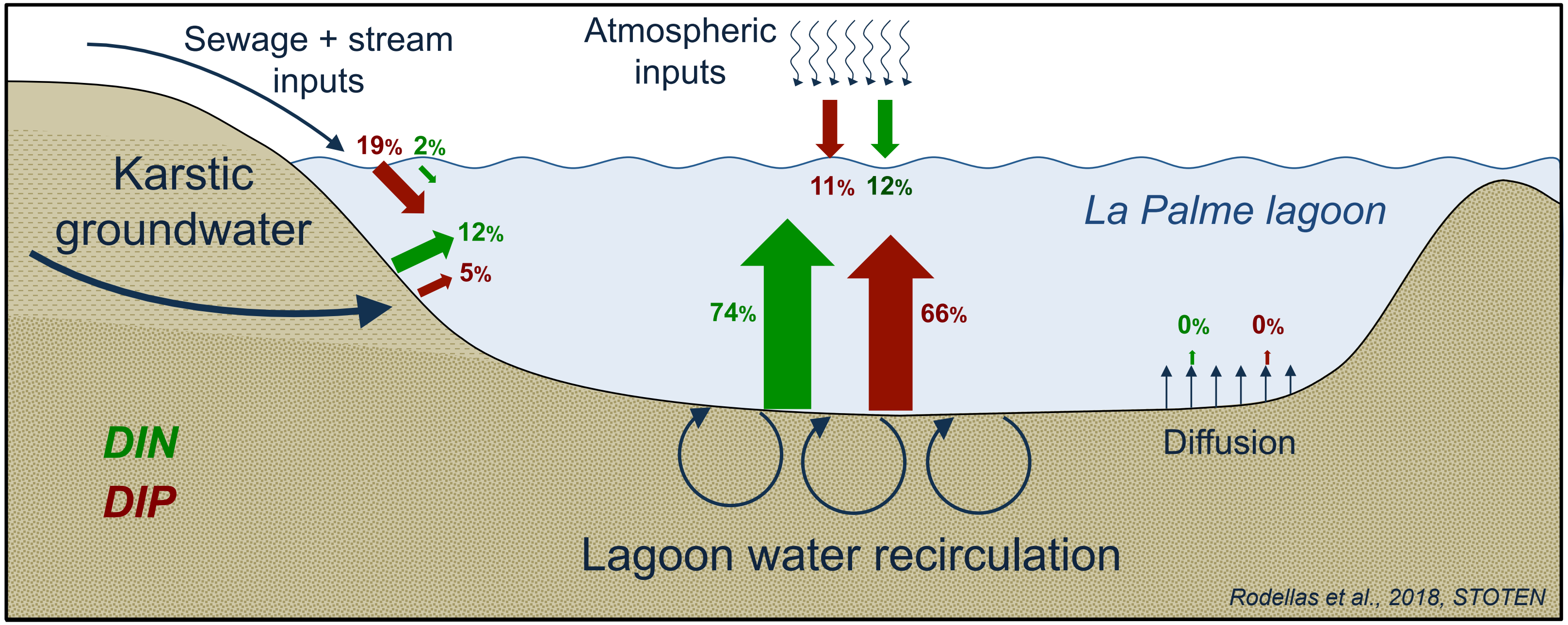
Importance of Groundwater: **NUTRIENT INPUTS**

Karstic groundwater ~10^4 m^3 d^{-1}

- Main source of freshwater
- **Maintains brackish conditions in lagoon waters**

Recirculation ~$5 \cdot 10^4$ m^3 d^{-1}

- Large volumes of water recirculating through sediments
- Main source of DIN and DIP
- **Impact on lagoon primary production**



2) Identification of **DRIVING FORCES**

*What **physical force** is driving the recirculation of lagoon water **???***

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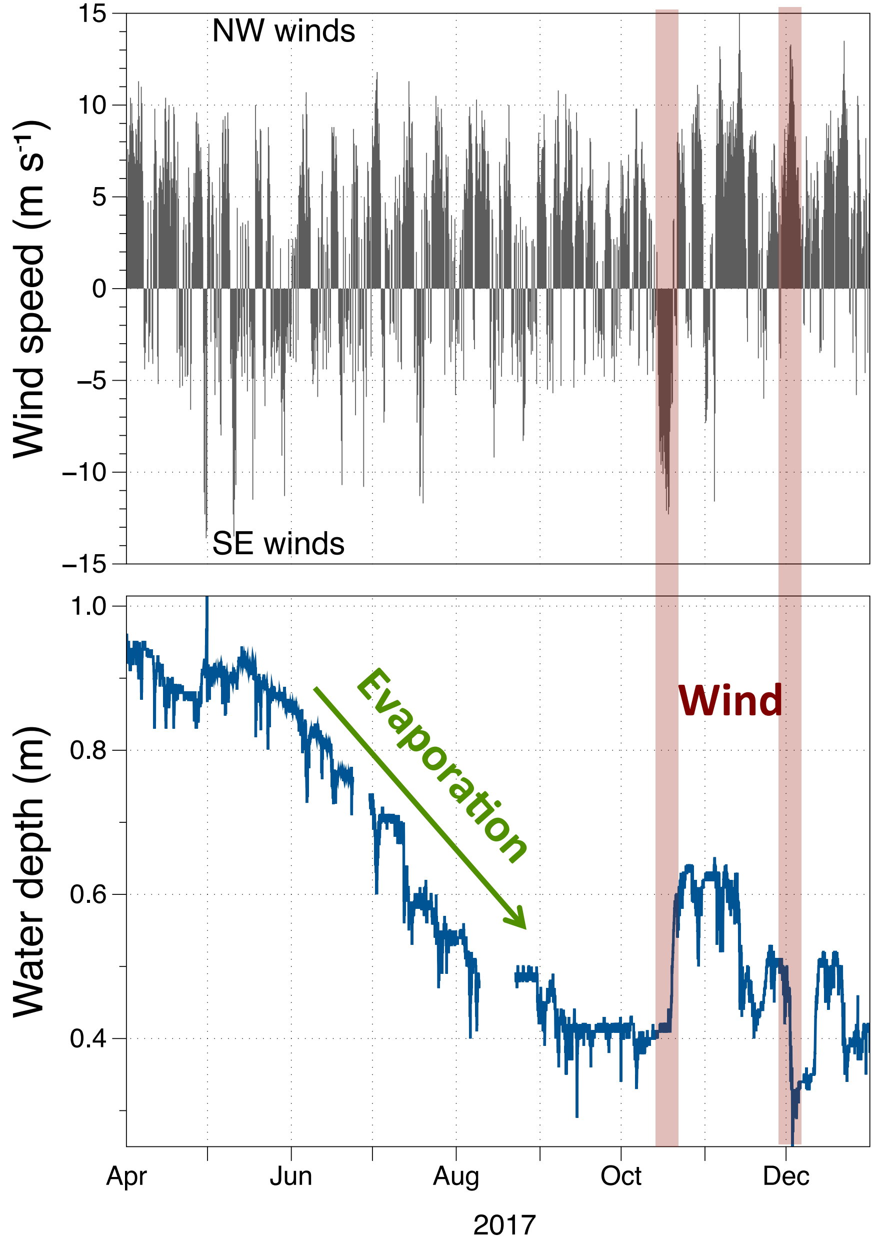
Two potential driving forces:

- **Changes in lagoon water depths**



2) Identification of **DRIVING FORCES**

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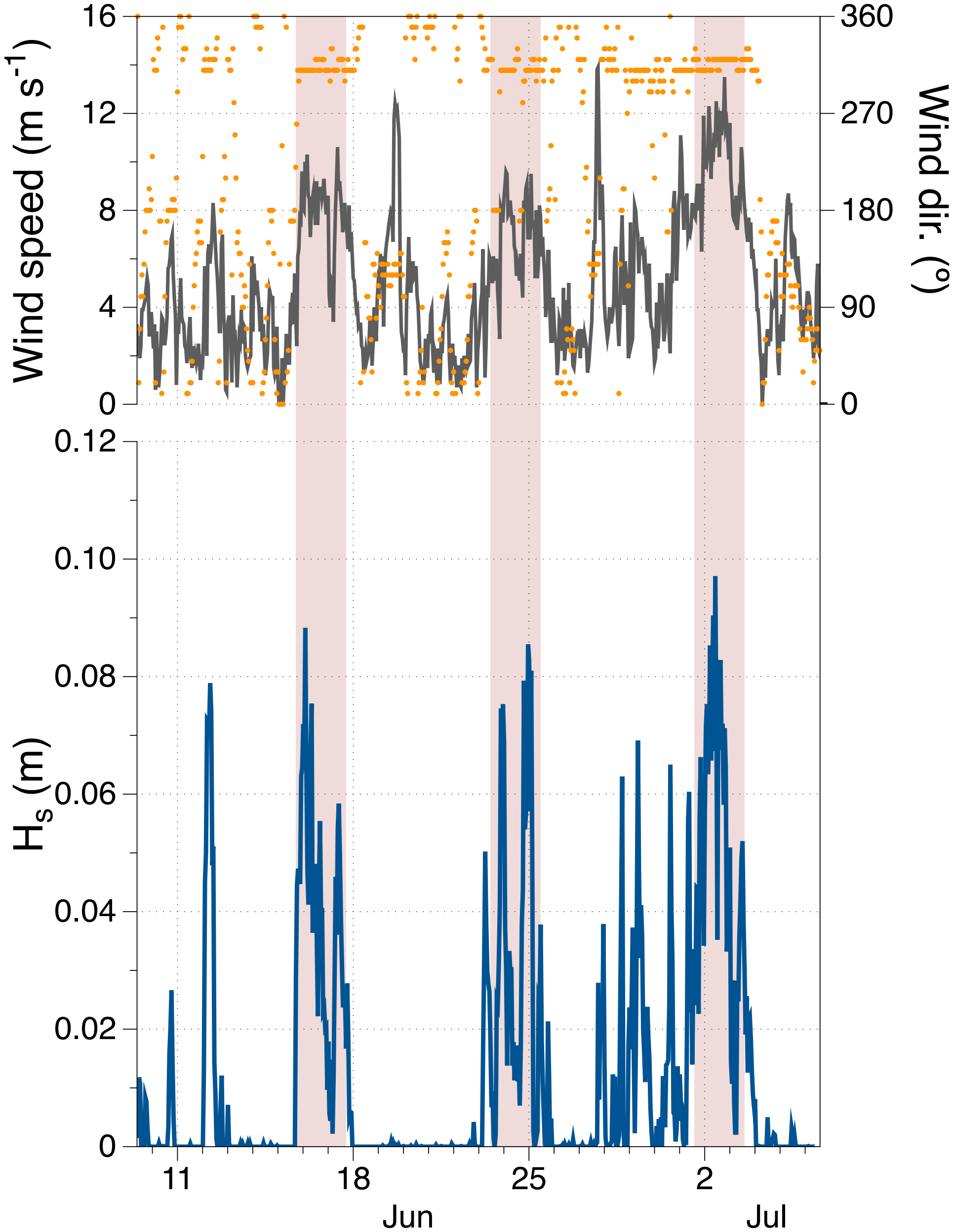
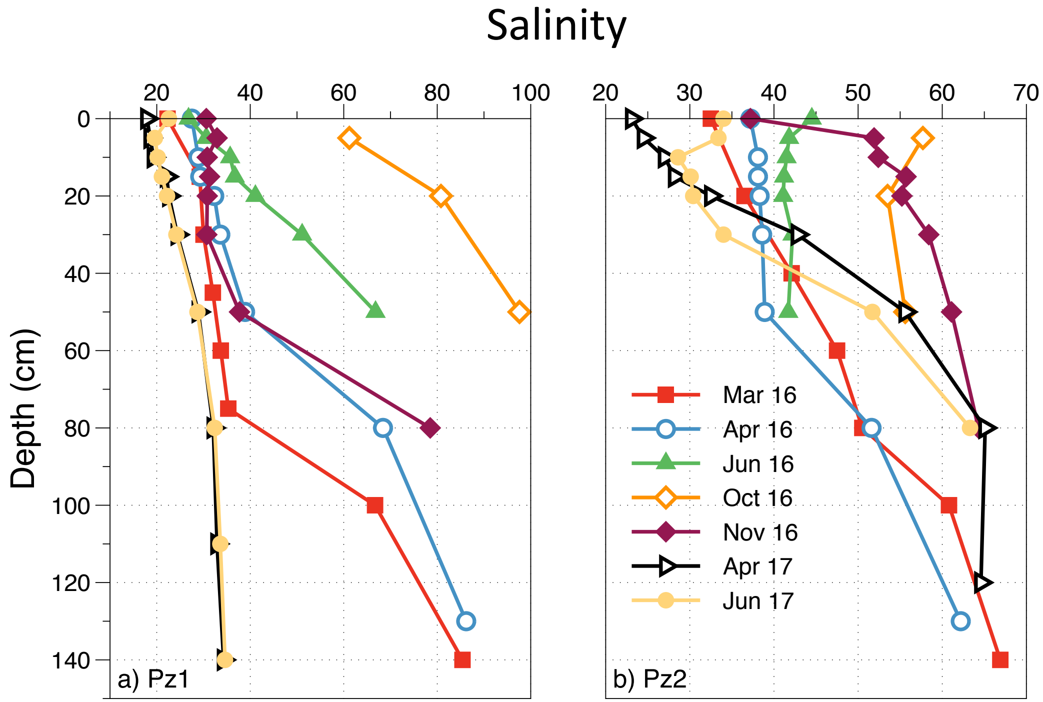
Two potential driving forces:

- **Changes in lagoon water depths**
- **Wind waves**



Subsurface salinities: Fluxes driven by **changes in lagoon water depths**

Why??? ✷ **Subsurface salinities:** Different salinities between lagoon waters and subsurface porewaters



Periodic collection of porewater profiles

(5 – 150 cm below sediment-water interface)

Subsurface salinities: Fluxes driven by **changes in lagoon water depths**

Water transport ⟶ $\rho S_{op} \frac{\partial p}{\partial t} + \theta \frac{\partial \rho}{\partial C} \frac{\partial C}{\partial t} + \frac{\partial}{\partial z}(\theta \rho v) = Q_p$

Salt transport ⟶ $\theta \rho \frac{\partial C}{\partial t} + \frac{\partial}{\partial z} \theta \rho v C - \frac{\partial}{\partial z}\left(\theta \rho D \frac{\partial C}{\partial z}\right) = Q_p(C_p - C)$

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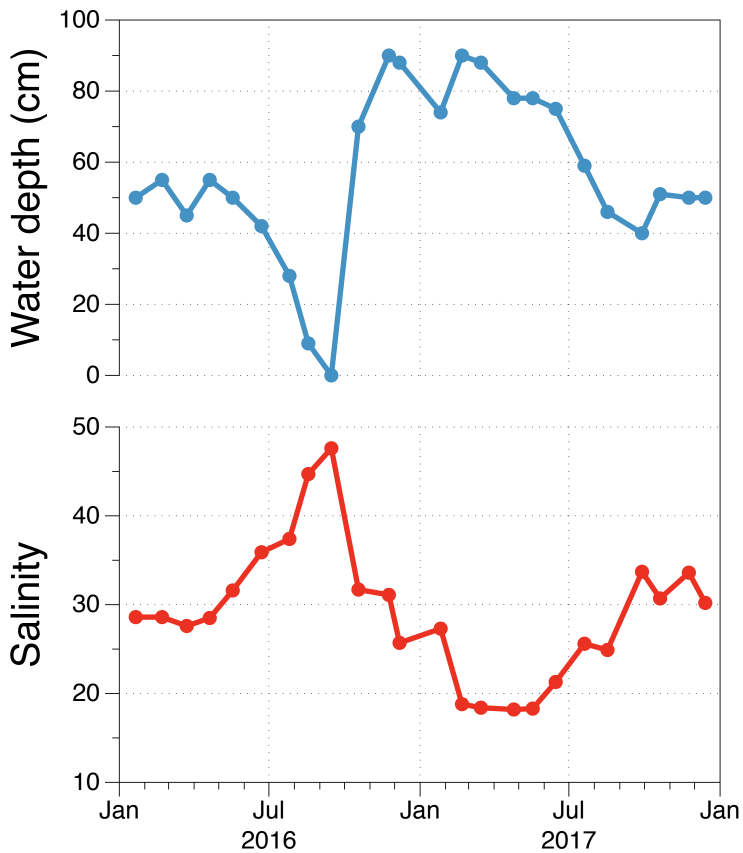
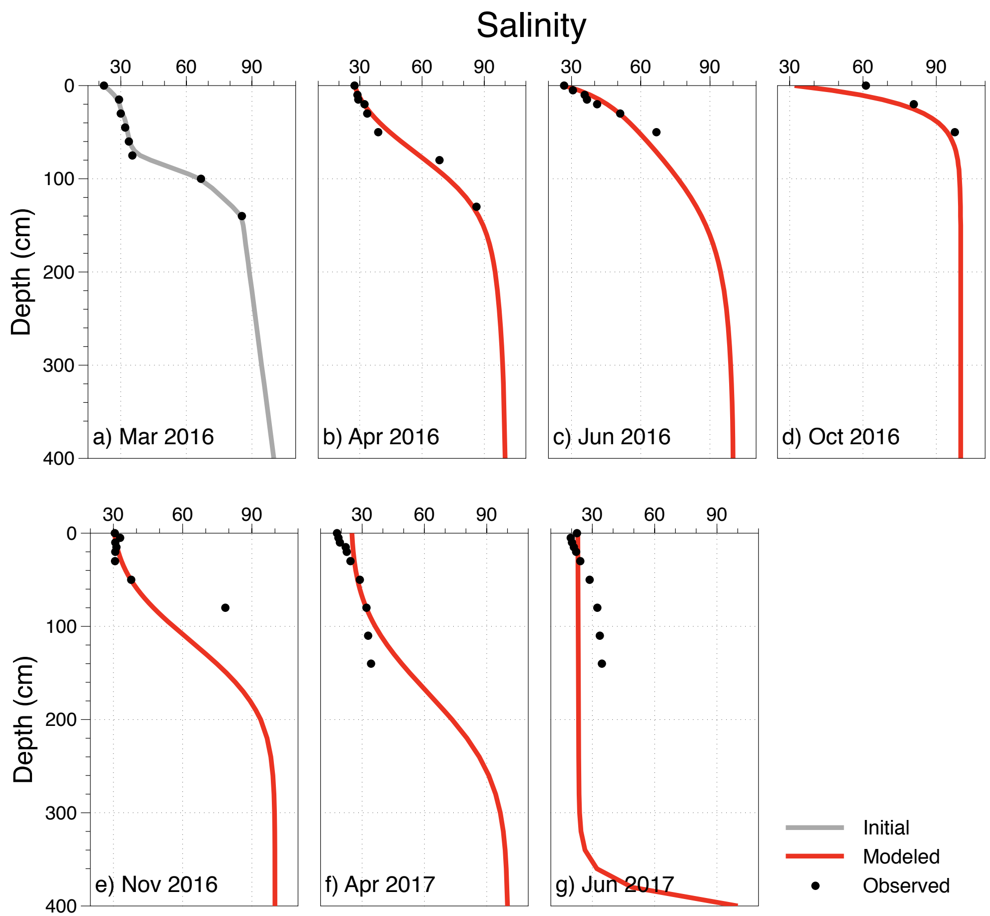
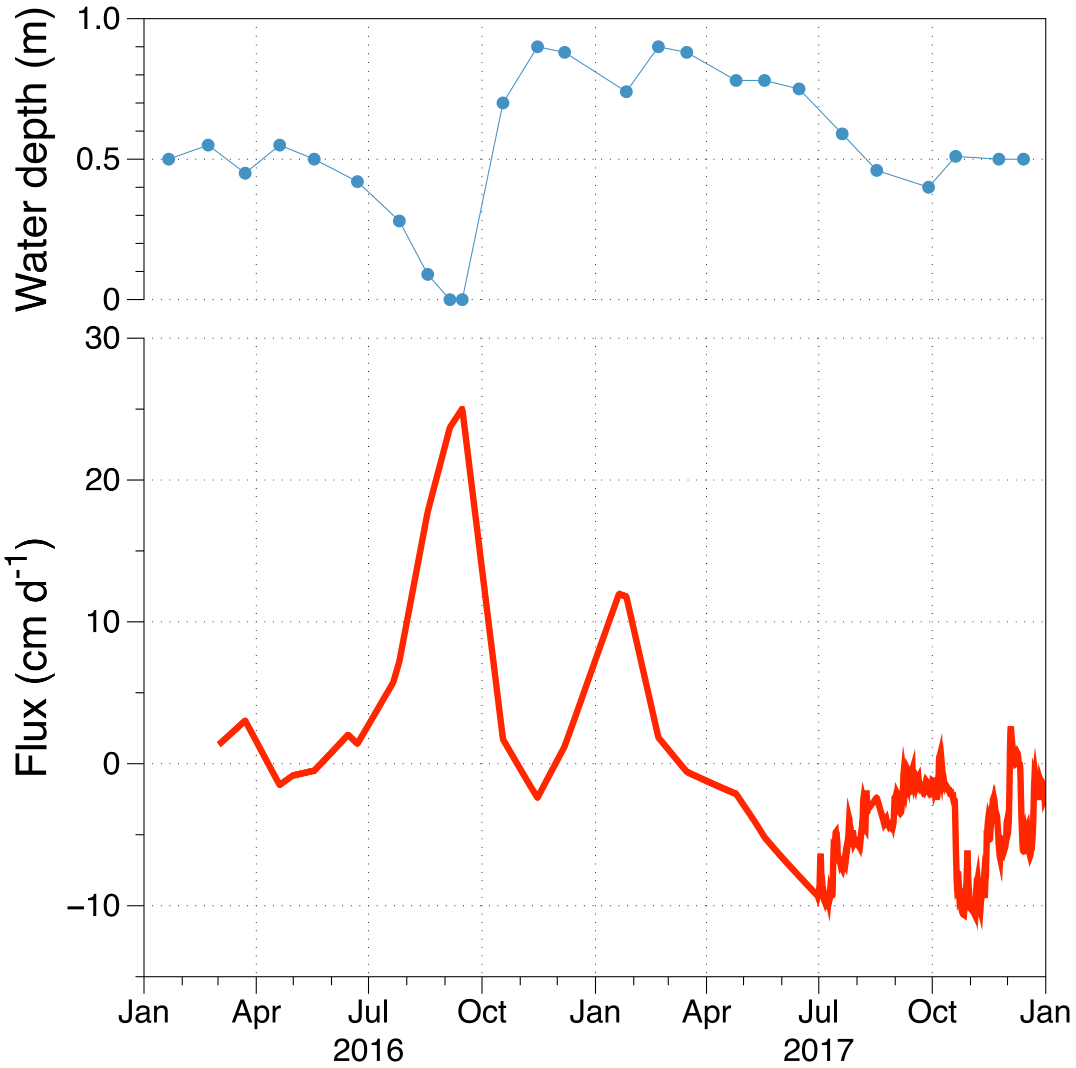


Boundary conditions



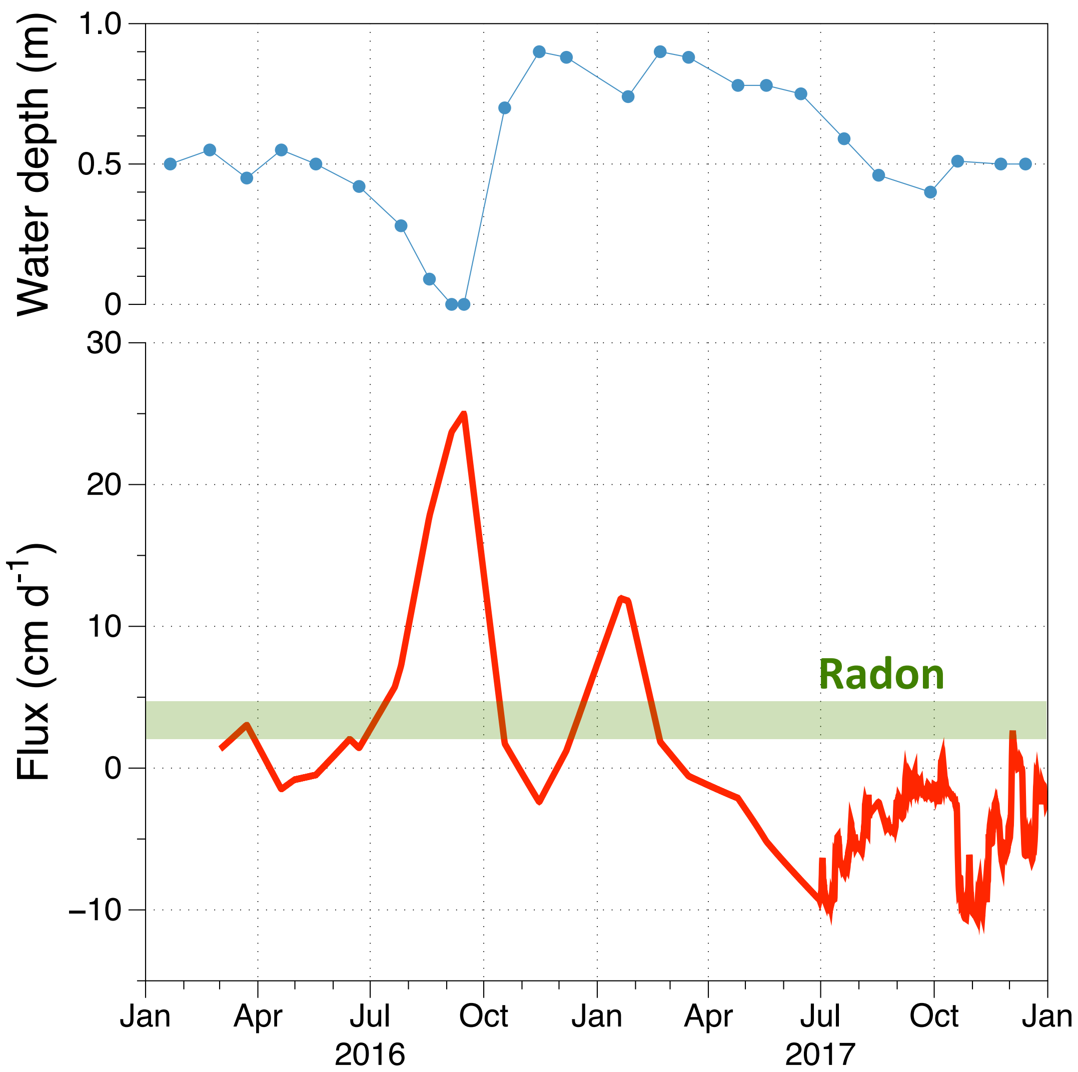
Fitting model results to observed profiles

Subsurface salinities: Fluxes driven by **changes in lagoon water depths**



- Changes in lagoon water depths (i.e. **hydraulic gradient**) control recirculation fluxes

Subsurface salinities: Fluxes driven by **changes in lagoon water depths**

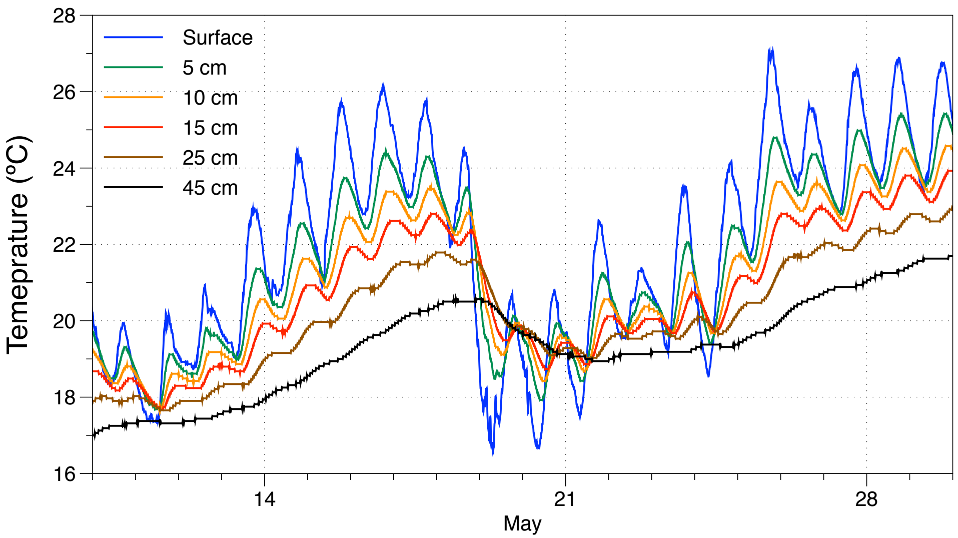


- Changes in lagoon water depths (i.e. **hydraulic gradient**) control recirculation fluxes
- **Agreement** between estimates derived from whole-of-lagoon **radon mass balances** and **subsurface salinities**

Changes in lagoon water depths are a major driver of recirculation fluxes

Subsurface temperatures: **Wave**-driven recirculation

Why??? ✸ **Subsurface temperatures**: continuous information on shallow recirculation in response to temporally variable forcings



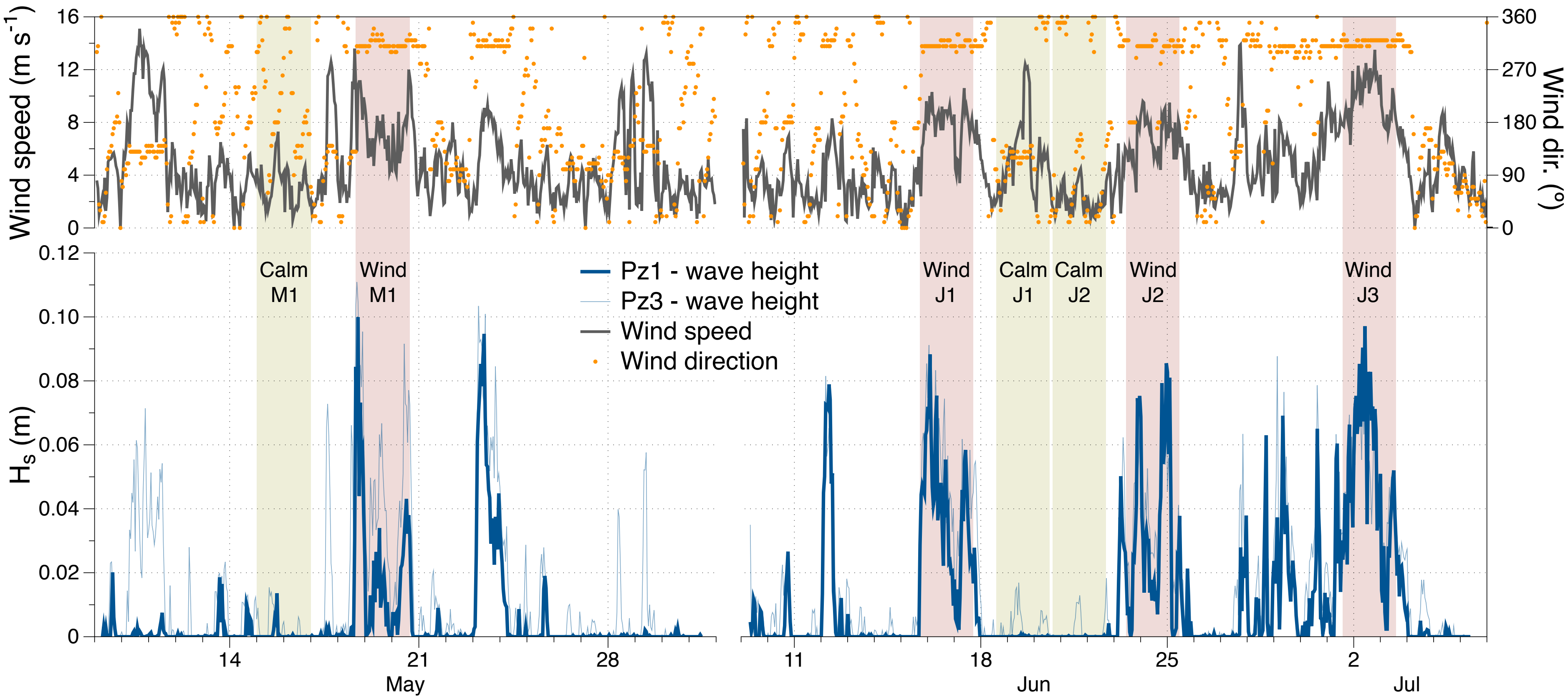
Continuous measurements of subsurface temperatures

(5 – 45 cm below sediment-water interface)

Subsurface temperatures: **Wave**-driven recirculation

Heat transport →

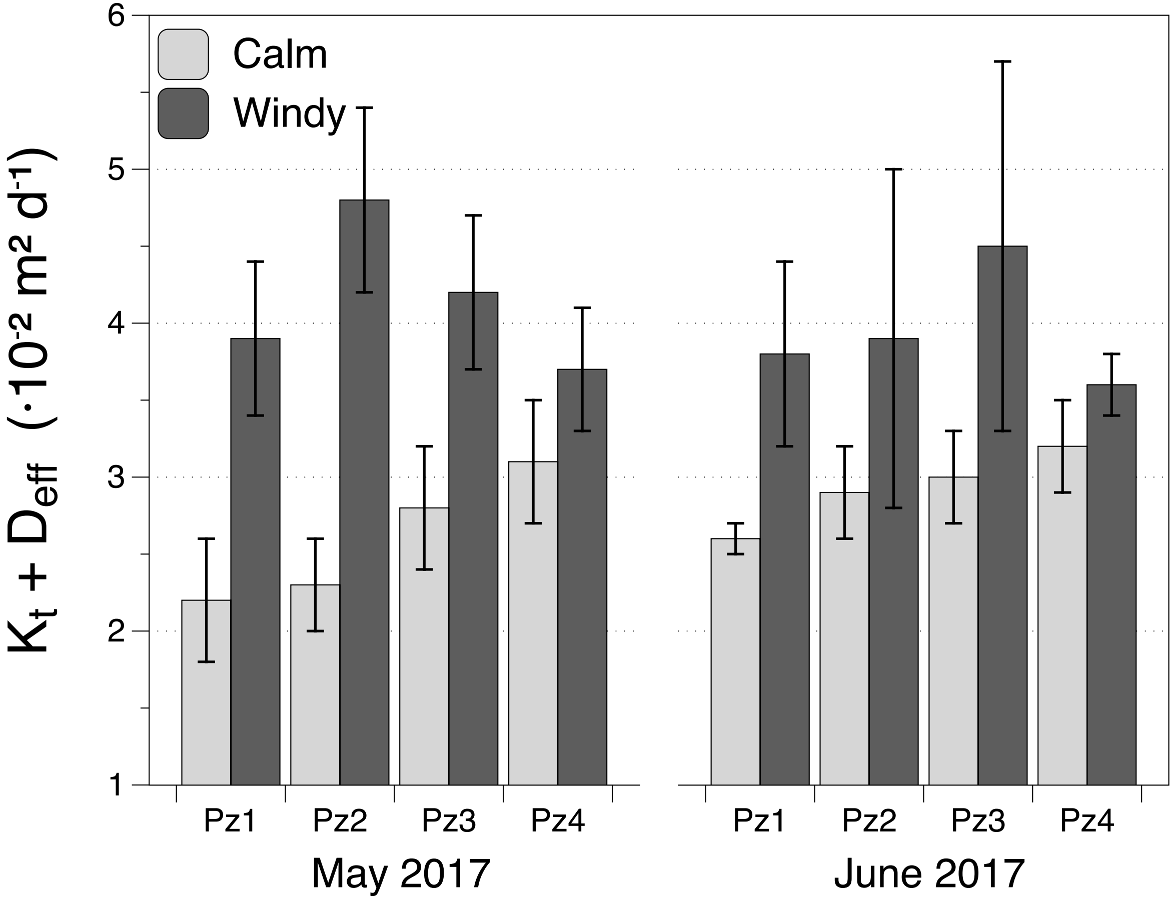
$$\frac{\partial T}{\partial t} = (K_t + D_{eff})\frac{\partial^2 T}{\partial z^2} - v\frac{\phi \rho_w c_w}{C}\frac{\partial T}{\partial z}$$



Calm periods ***Windy periods***

Subsurface temperatures: **Wave**-driven recirculation

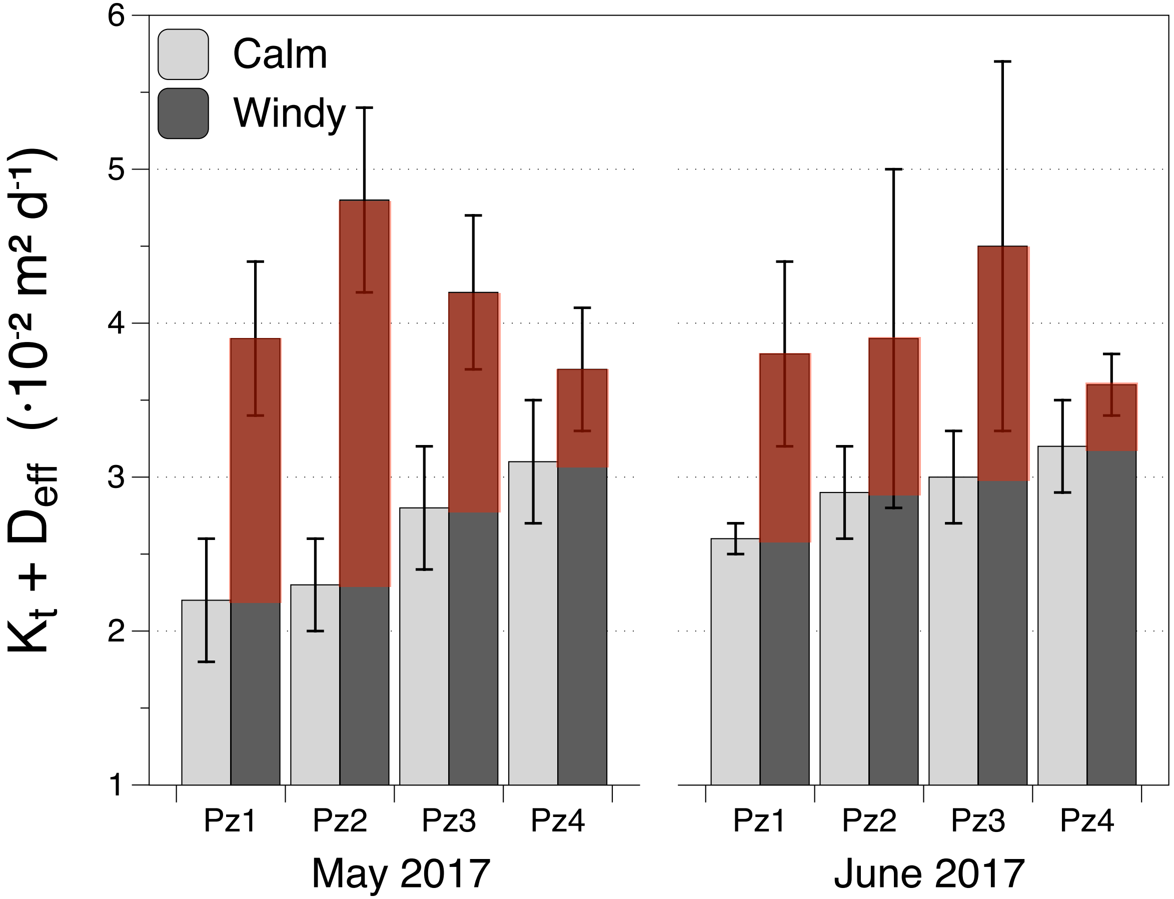
Comparison of heat transport in calm and windy periods



Subsurface temperatures: **Wave**-driven recirculation

Comparison of heat transport in calm and windy periods

- **Windy periods**: higher D_{eff} ; increase of the rate of heat transport driven by **wave-driven recirculation**



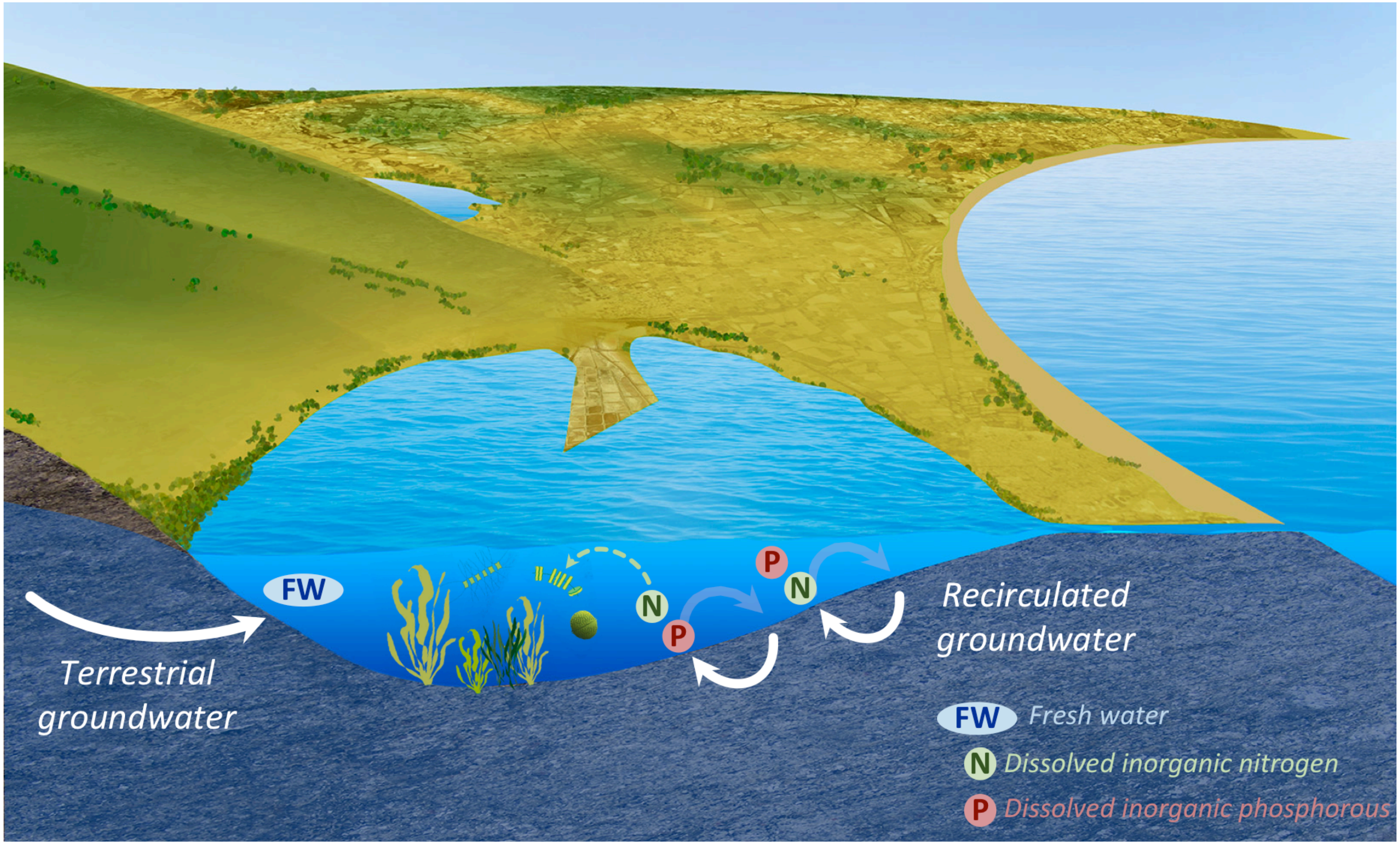
Wave-driven recirculation fluxes in windy periods of ≈ 20 cm d^{-1}

=

Lagoon volume can recirculate through sediments at each 3-5 day wind event

TAKE-HOME MESSAGE

1) Quantification of GROUNDWATER FLUXES ⇐ *Radon*



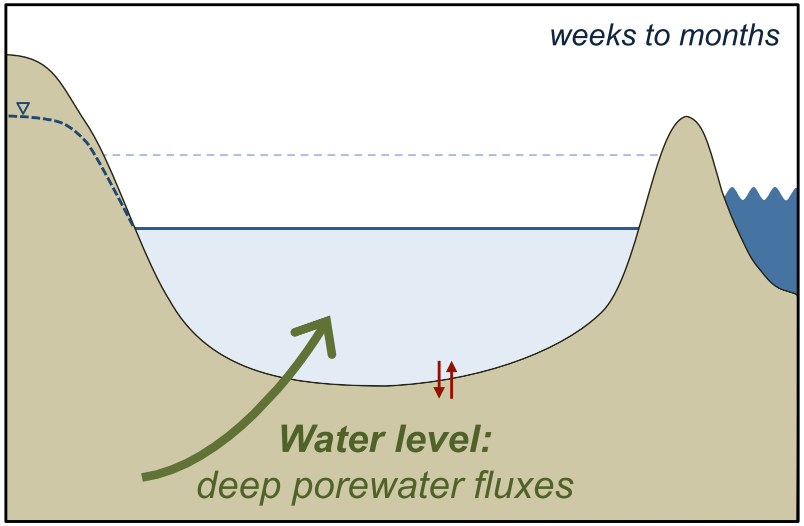
TAKE-HOME MESSAGE

2) Identification of DRIVING FORCES

Subsurface Salinity

↓

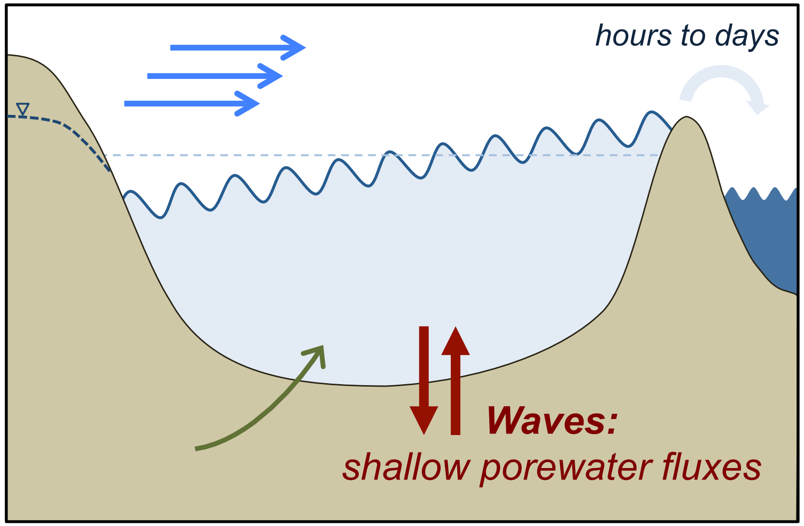
Changes of lagoon water depths



Subsurface Temperature

↓

Wind waves

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