

# Hyperspectral Remote Sensing of Coral Reefs

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## Sensitivity Analysis of a Shallow Water Inverse Model

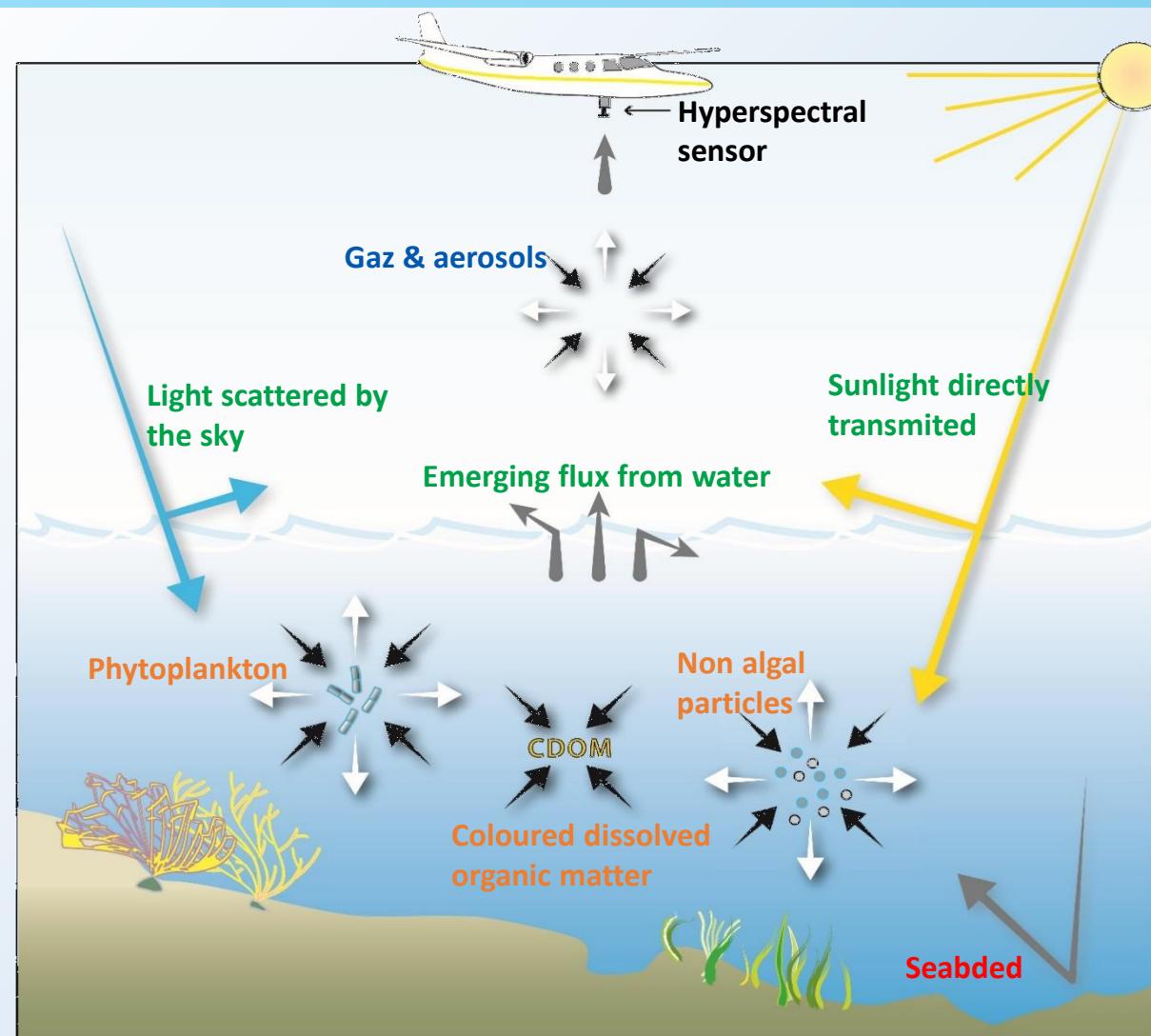
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Passive optical remote sensing in subtidal area : from sun to sensor ...



- Three optical phenomena

1. Reflexion
2. Absorption
3. Scattering

- Four levels

1. Atmosphere
2. Sea surface
3. Water column
4. Seabed

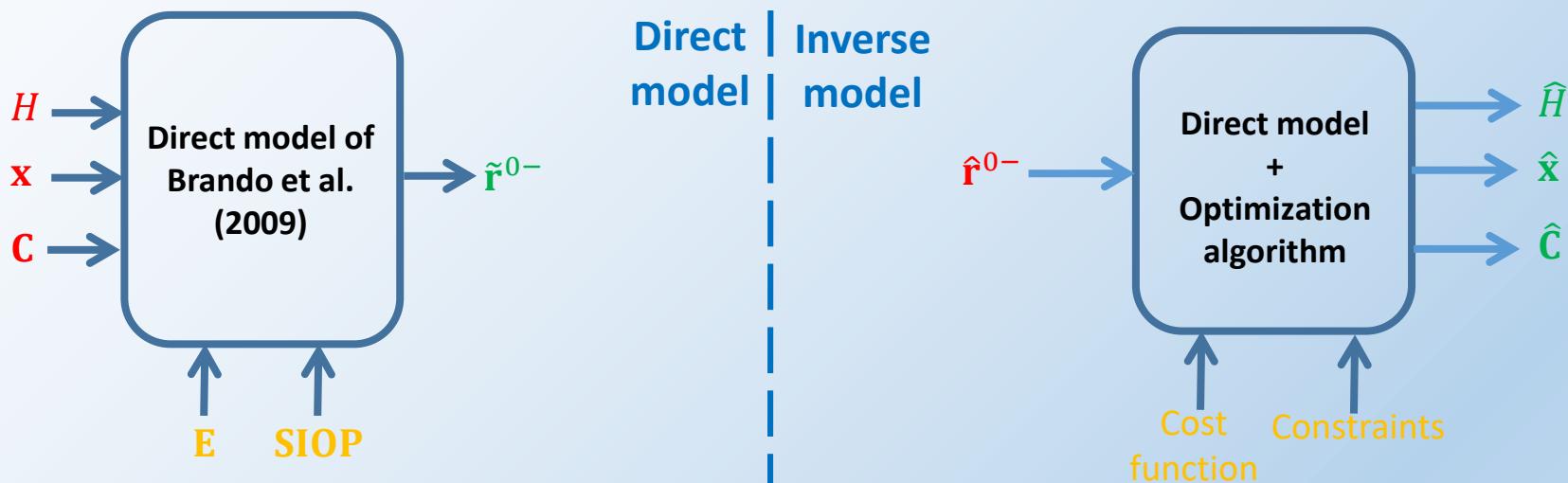
+ Seabed types characterization

+ Water column characterization  
(concentrations + bathymetry)

- Complex radiometric processing

→ In the following : Preprocessing steps (atmosphere + sea surface) already performed

## Water column correction by semi-analytical model inversion



<b>Input (variable)</b>	$H$ : Bottom depth $x$ : Seabed abundances $C = [C_{phy}, C_{NAP}, C_{CDOM}]$ : Phytoplankton, NAP and CDOM concentrations	$\hat{r}^{0-}$ : Observed reflectance
<b>Output</b>	$\tilde{r}^{0-}$ : Modeled reflectance	$\hat{H}$ : Estimated bottom depth $\hat{x}$ : Estimated seabed abundances $\hat{C}$ : Estimated concentrations
<b>Parameter (constant)</b>	$E$ : Bottom endmember matrix SIOP : Water Specific Inherent Optical Properties	Cost function : Distance metric Constraints : Physical constraints

## Difficulties to be addressed & degrees of freedom

Difficulties	Degrees of freedom
• Noise in observed reflectance $\hat{r}^{0-}$ (sensor + atmosphere + sea surface)	• SIOP tuning : in-situ measurements during hyperspectral acquisition
• Endmembers spectral variability (amplitude + shape)	• Inversion setup (cost function + constraints)
• SIOP parameterized from literature while depending on environmental conditions	

## Associated scientific questions (and answers ?)

**Q1: Does inversion setup play a role in the accuracy and robustness of the estimations ?**

**Q2: Is it necessary to parameterize locally the SIOP ?**

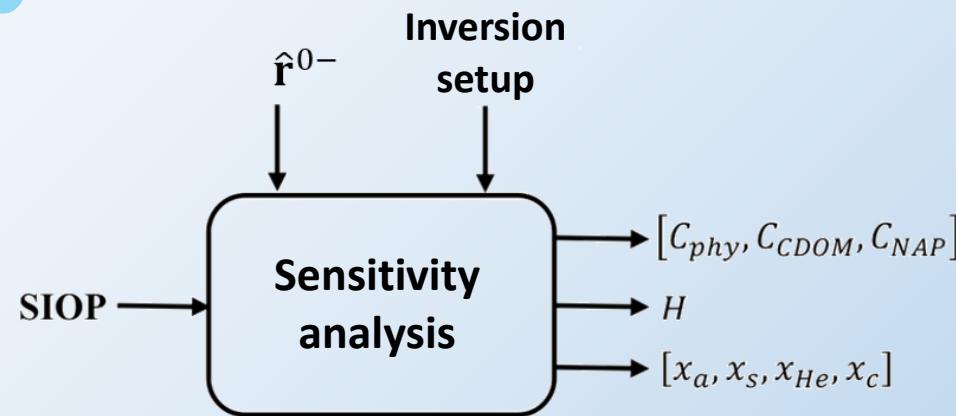
**Q3: What are the relative importance of the direct and inverse model setup ?**

**Answer to Q1: Yes** (Petit et al. "Hyperspectral remote sensing of coral reefs by semi-analytical model inversion–Comparison of different inversion setups." *Remote Sensing of Environment* 190 (2017): 348-365.)

→ 6 inversion setups tested : 3 cost functions (LS, SAM, LSD) x 2 abundance sum constraints (ASC, RASC)

**Answers to Q2 & Q3: Let's see it through a sensitivity analysis !**

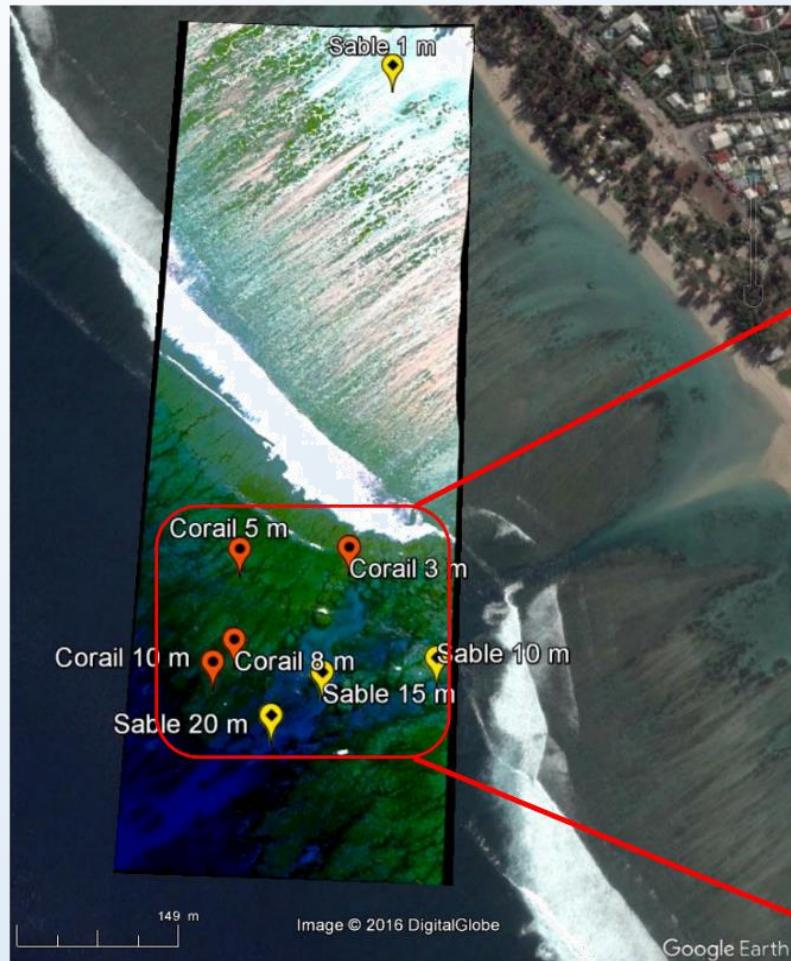
## Sensitivity analysis synoptic



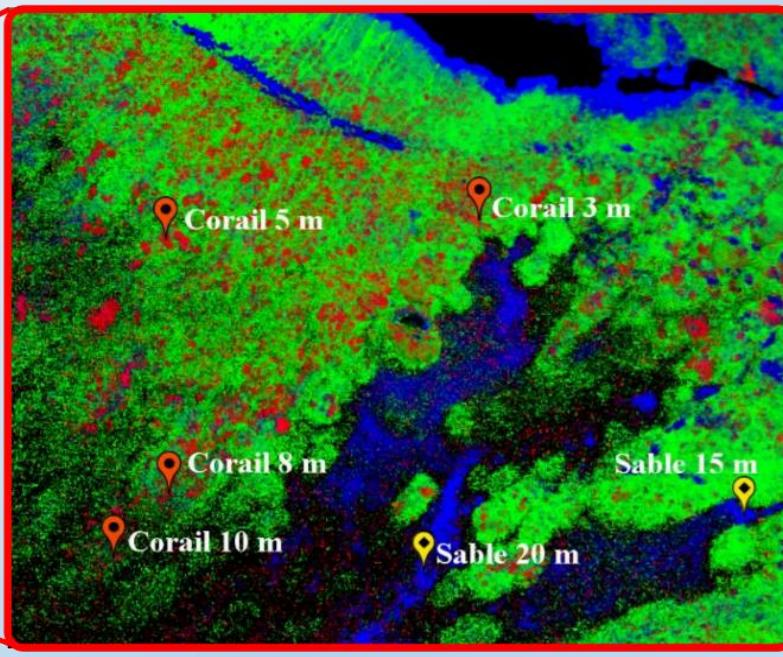
## Data acquisition at La Réunion Island (21-23 may 2015)

- Hyperspectral acquisitions (Hyscores project)
  - **Real subsurface reflectances**
- In-situ water optical properties measurements (with the help of Rüdiger Röttgers from HZG)
  - **SIOP variability**
  - **Creation of synthetic subsurface reflectances**

## Hyperspectral acquisitions – Visual selection of real spectra (Ermitage, St Gilles)



Hyperspectral image on Ermitage,  
atmospherically corrected by Onera (Cochise)



Abundance map (R = coral, G = algae, B = sand)  
obtained by model inversion

## In-situ measurements – Presentation

- Sampling design (yellow pins)

Boucan (6 stations)

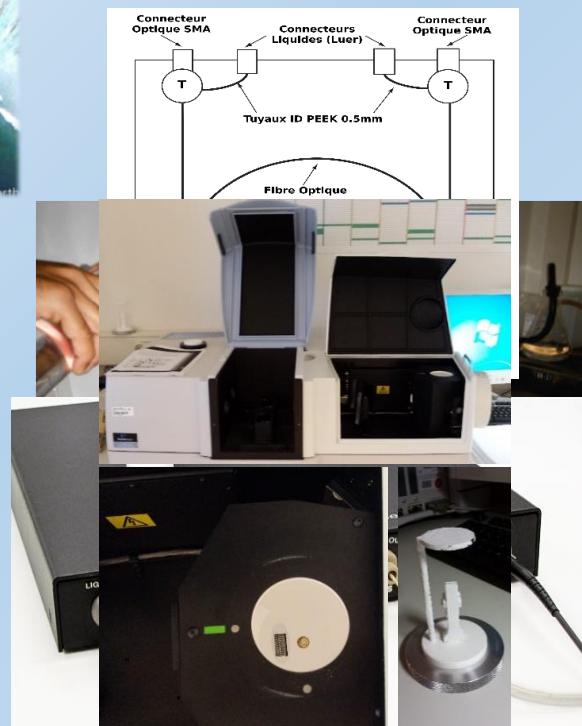


Ermitage (10 stations)



- Instruments used

- Fluorimeter Turner TD700 (chl<sub>a</sub> concentration)
- Precision weight (NAP concentration)
- Spectrometer LWCC-3250 (absorption by CDOM)
- Spectrometer Perkin Elmer Lambda 950 (particulate/detrital/phytoplanktonic absorption)



## In-situ measurements – Median concentrations of water optically active constituents

	$C_{CDOM}$ ( $\text{m}^{-1}$ )	$C_{phy}$ ( $\mu\text{g.L}^{-1}$ )	$C_{NAP}$ ( $\text{mg.L}^{-1}$ )
<b>Inner reef</b>	0.066	0.176	0.730
<b>Outer reef</b>	0.008	0.154	0.170
<b>Inner/Outer ratio</b>	<b>8,2</b>	<b>1,1</b>	<b>4,3</b>

## In-situ measurements – SIOP variability used as input of the sensitivity analysis

1. Constant SIOP : value used = median value measured
2. Variable SIOP : statistical distribution used =  $\sim \mathcal{U}([\text{quantile 0.1}, \text{quantile 0.9}])$

	<b>Absorption</b>	<b>Diffusion</b>
<b>CDOM</b>	$S_{CDOM} \sim \mathcal{U}([0.0146, 0.0210])$	-
<b>Phytoplankton</b>	$\alpha_{phy} \sim \mathcal{U}([0, 1])$	$b_{b_{phy}}^*(\lambda_1) = 3.8 \cdot 10^{-4}$ $Y_p \sim \mathcal{U}([0, 1])$
<b>NAP</b>	$a_{NAP}^*(\lambda_0) = 0.0254$ $S_{NAP} \sim \mathcal{U}([0.0074, 0.0109])$	$b_{b_{NAP}}^*(\lambda_1) = 5.4 \cdot 10^{-3}$ $Y_p \sim \mathcal{U}([0, 1])$

Tested scenario for the observed subsurface reflectance  $\tilde{r}^{0-}$

### Synthetic hyperspectral data

- 2 seabed types: coral, sand
- 2 water column types: inner & outer reef
- 5 bottom depths: 1, 5, 10, 15, 20m

$$\rightarrow 2 \times 2 \times 5 = 20 \text{ scenarios}$$

### Real hyperspectral data

- 2 seabed types: coral, sand
- 4 bottom depths: 1, 10, 15 and 20m (sand)  
3, 5, 8 and 10m (coral)

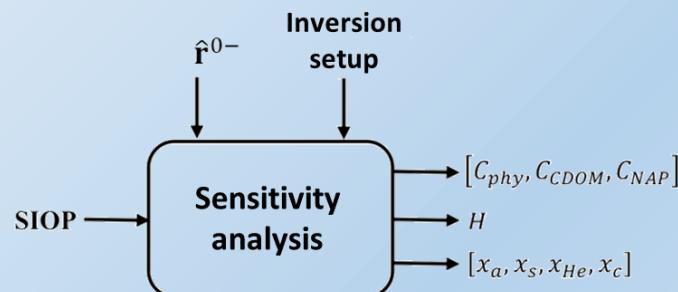
$$\rightarrow 2 \times 4 = 8 \text{ scénarios}$$

### Result analysis

$$\begin{aligned} \text{Nb stat. distri.} &= \text{Nb scenarios} \times \text{Nb inversion products} \times \text{Nb inversion setups} \\ &= (20 + 8) \quad \times \quad 8 \quad \times \quad 6 \end{aligned}$$

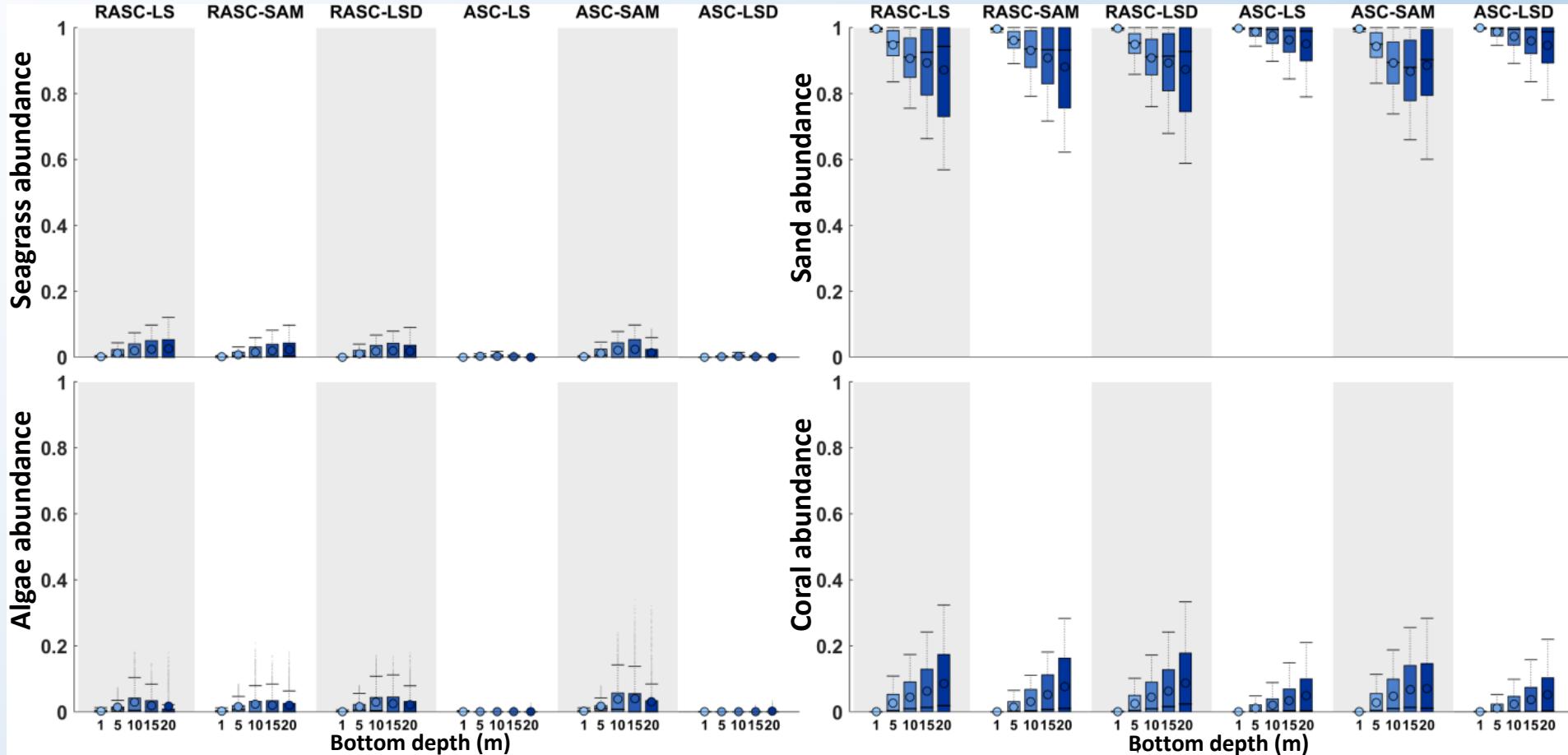
$$\text{Nb stat. distri.} = 1344$$

$\rightarrow$  Adapted representation required



## Example of abundances statistical distributions – Synthetic hyperspectral data

- Scenario : sandy bottome and outer reef

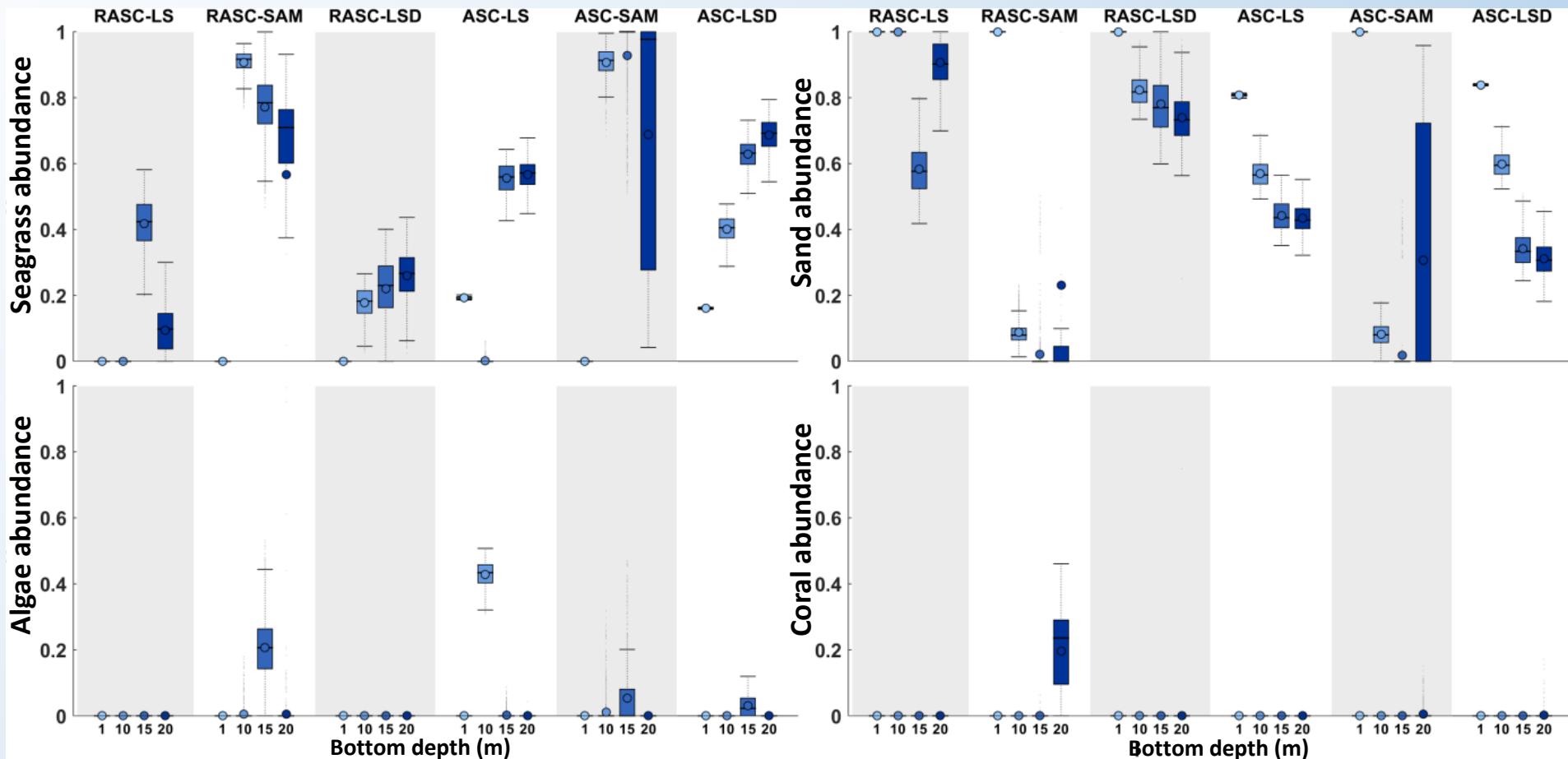


→ Inversion setup impact on results = weak

→ SIOP impact on results = increasing with bottom depth

## Example of abundances statistical distributions – Real hyperspectral data

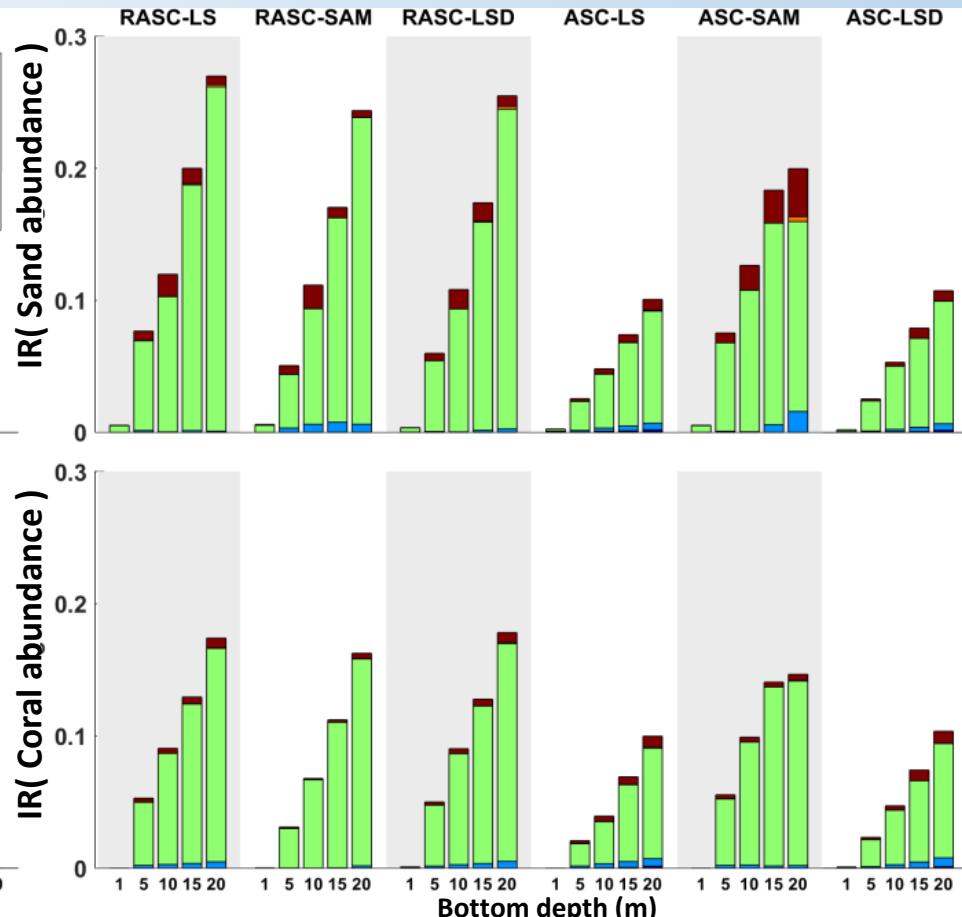
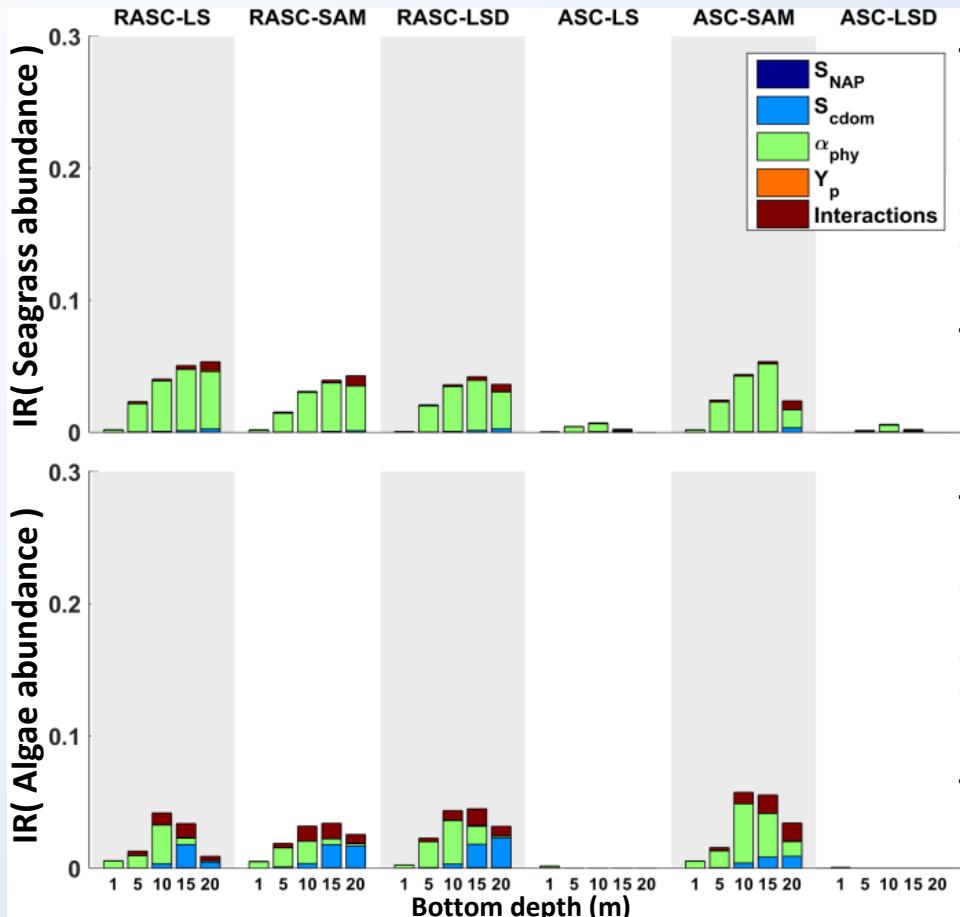
- Scenario : sandy bottom



→ Low impact of SIOP compared to the one of the inversion setup

Example of abundances estimation sensitivity to SIOP – synthetic hyperspectral data

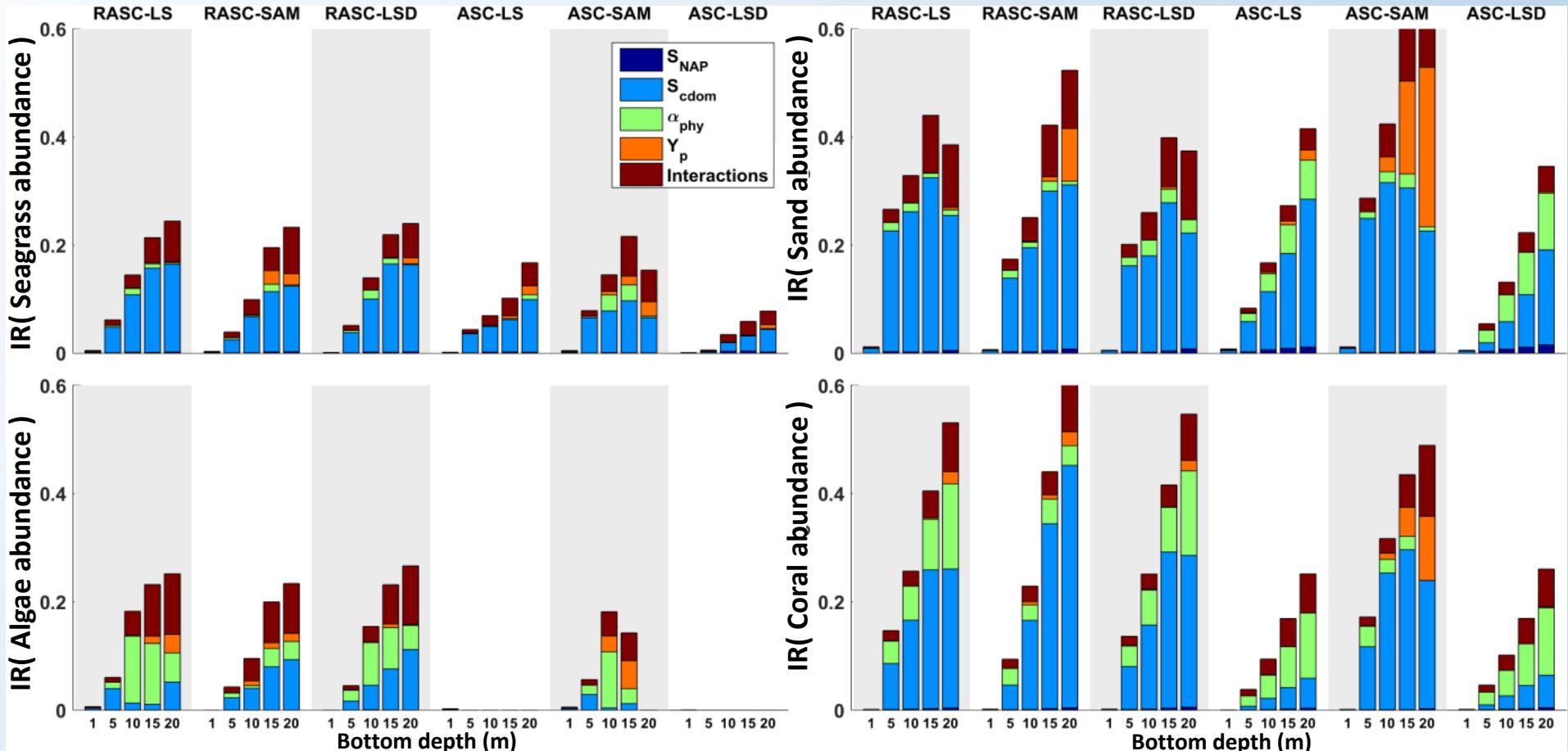
- Scenario : **sandy bottom** and **outer reef**



→ Abundances estimation (nearly) exclusively sensitive to  $\alpha_{phy}$

Example of abundances estimation sensitivity to SIOP – **synthetic** hyperspectral data

- Scénario : **sandy bottom** and **inner reef**



→ Abundances estimation mostly sensitive to  $S_{CDOM}$

## Conclusion

- **Synthetic hyperspectral data**
  - With clear water, SIOP tuning (by in-situ measurements during hyperspectral acquisitions) is not required for estimating seabed abundances and bottom depth
  - Sensitivity of the inversion outputs to each SIOP depends on the corresponding constituent concentration (low concentration = low sensitivity)
- A priori knowledge on environmental conditions is needed to determine how important it is to know precisely the SIOP values
- **Real hyperspectral data**
  - On our case studies : Impact of inversion setup >> Impact of SIOP accuracy

**Merci pour votre attention**