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Integrating water column effects and bottom neighbor influence for a specific NMF seabed unmixing method

M. Guillaume¹, L. Juste¹, Y. Deville², X. Lenot³, A. Minghelli⁴, B. Lafrance³, M. Chami⁵, S. Jay⁶, X. Briottet⁷, V. Serfaty⁸

¹ Aix Marseille Univ., CNRS, Centrale Marseille, Institut Fresnel UMR 7249, 13013 Marseille, France ; ² IRAP, OMP, Univ. Paul Sabatier Toulouse 3, 14 Av. Edouard Belin, 31400 Toulouse, France ³ C-S SI, rue brindejonc des moulinais 31500 Toulouse ; ⁴ Univ. de Toulon, Seatech, LISIS UMR 7296, 83041 Toulon, France; ⁵ LATMOS, Univ. Pierre et Marie Curie - UMR CNRS 8190, OCA de Nice, Boulevard de l'Observatoire CS 34229 06304 Nice Cedex 4, France, ⁶ ONERA.DOTA, Université de Toulouse, France ; ⁷ DGA, MRIS, 60 boulevard Martial Valin - CS 21623 75509 PARIS Cedex 15



Objective

Develop an advanced method for unmixing the seabed in coastal areas

Mixing model

The mixing model is ⁽¹⁾

$$\tilde{\mathbf{R}} = \mathbf{K}_1 \odot (\mathbf{S} \mathbf{A}) + \mathbf{K}_2 \odot (\mathbf{S} \mathbf{A} \mathbf{P})$$

$\tilde{\mathbf{R}}$: $\mathbf{R} - (\frac{L_{up}}{E(0-)})$; observed reflectance - water reflectance (L wavelengths X N pixels)

\mathbf{K}_1 : water direct attenuation; \mathbf{K}_2 : water diffuse attenuation (L X N);

\odot : pointwise product (Hadamard)

\mathbf{S} : bottom endmembers matrix (L X J endmembers)

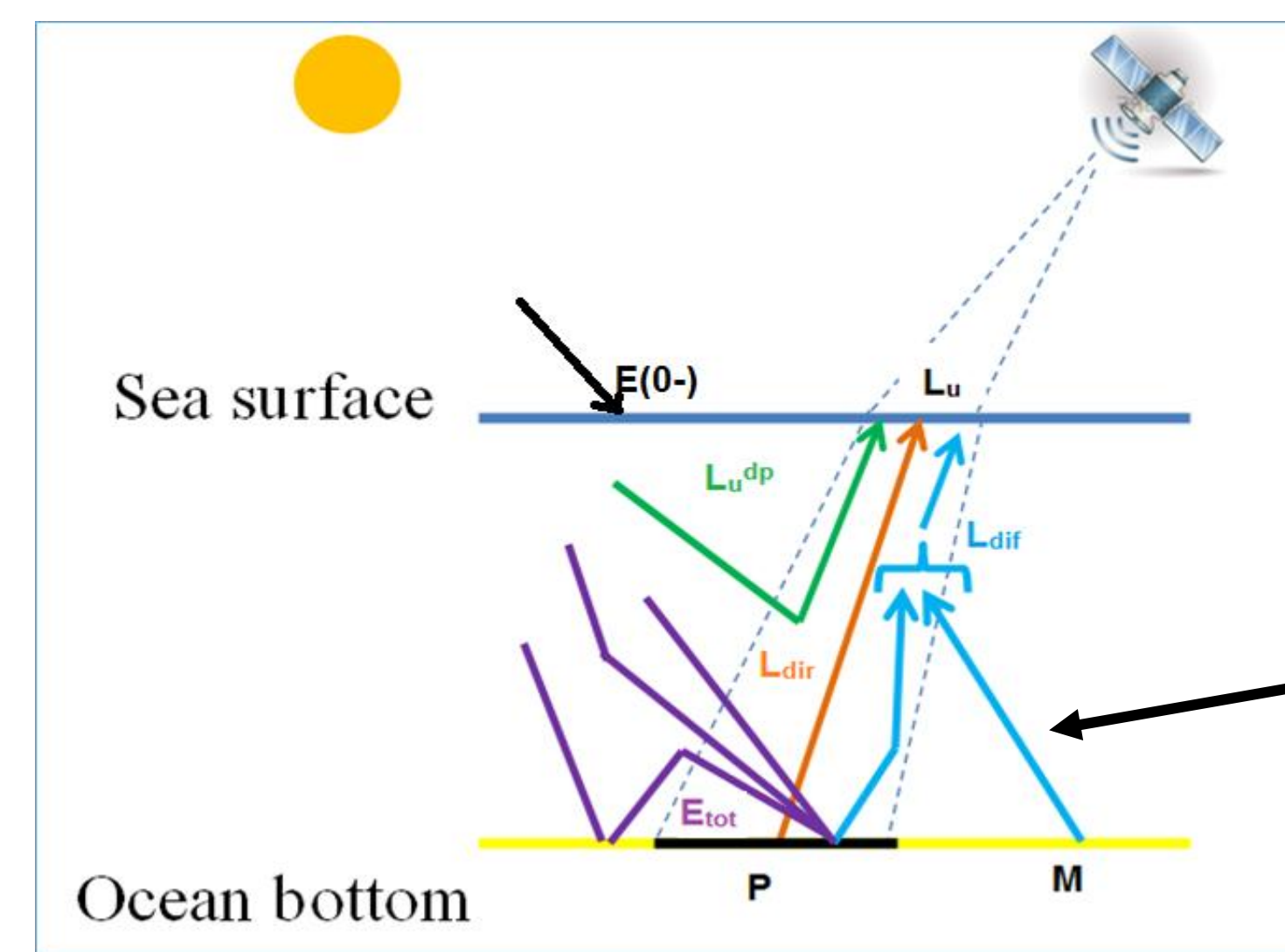
\mathbf{A} : bottom abundances matrix (J X N)

\mathbf{P} : neighbor matrix (with environment parameter included) (N X N)

Bottom: linear mixing model $\mathbf{X} = \mathbf{S} \mathbf{A}$

The water attenuates and diffuses the photons reflected by the bottom.

The photons diffused after interaction with pixels adjacent to the target one participate in the diffused light L_{dif} ⁽²⁾. The matrix \mathbf{P} selects the neighbor pixels to account for the diffusion.



Adjacency effect

$$\mathbf{K}_1 = \frac{L_{dif}}{E(0-)}, \quad \mathbf{K}_2 = \frac{L_{dir}}{E(0-)},$$

water reflectance

Unmixing

Unmixing is performed by minimizing the cost function J :

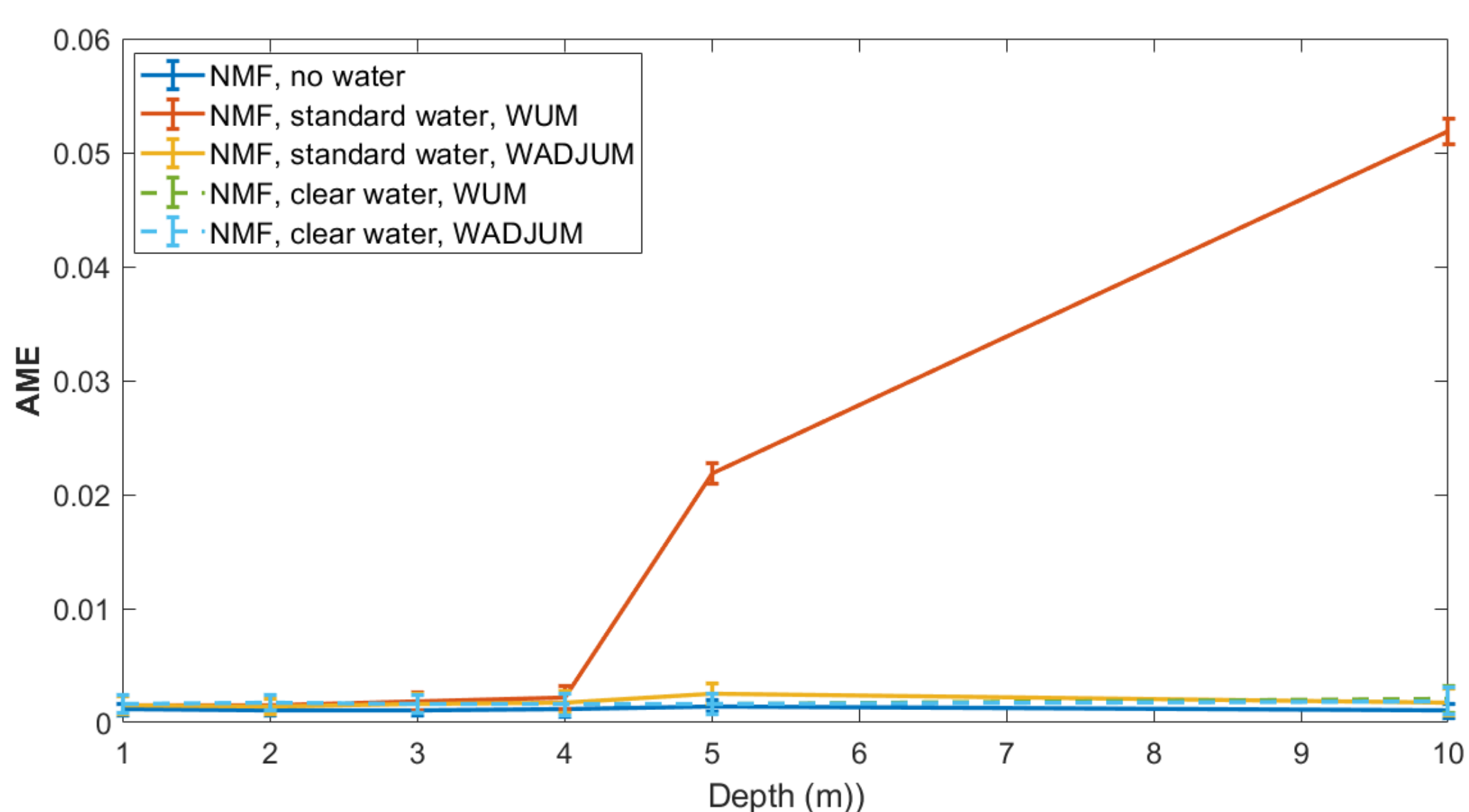
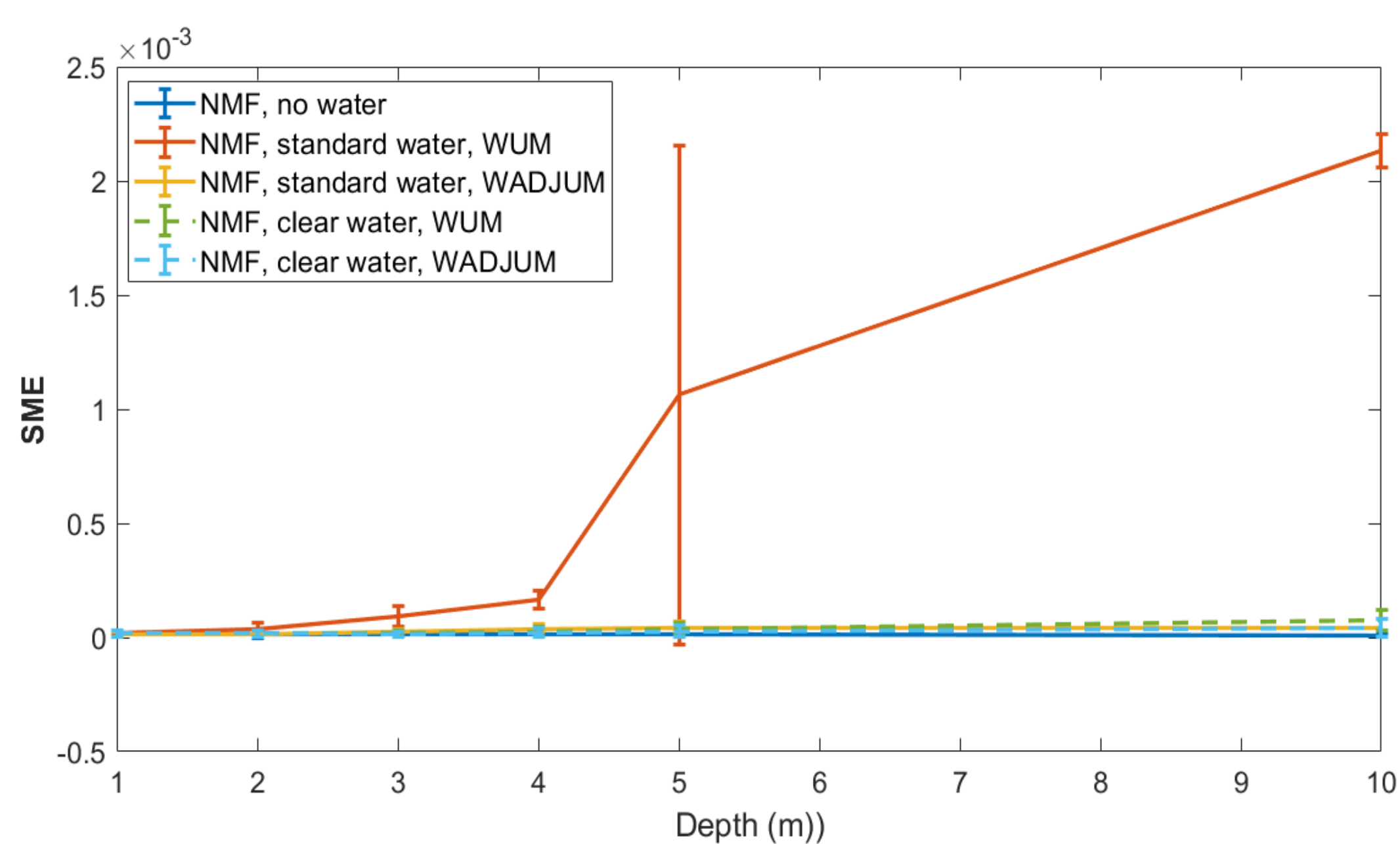
$$J = \arg \min_{\mathbf{S}, \mathbf{A}} \|\tilde{\mathbf{R}} - \mathbf{K}_1 \odot (\mathbf{S} \mathbf{A}) - \mathbf{K}_2 \odot (\mathbf{S} \mathbf{A} \mathbf{P})\|_F^2 + \text{reg}(\mathbf{S}, \mathbf{A})$$

The regularization term $\text{reg}(\mathbf{S}, \mathbf{A})$ can be the abundance sum to one constraint or other.

Optimization: gradient descent on \mathbf{S} and \mathbf{A} , \mathbf{K}_1 and \mathbf{K}_2 are supposed known.

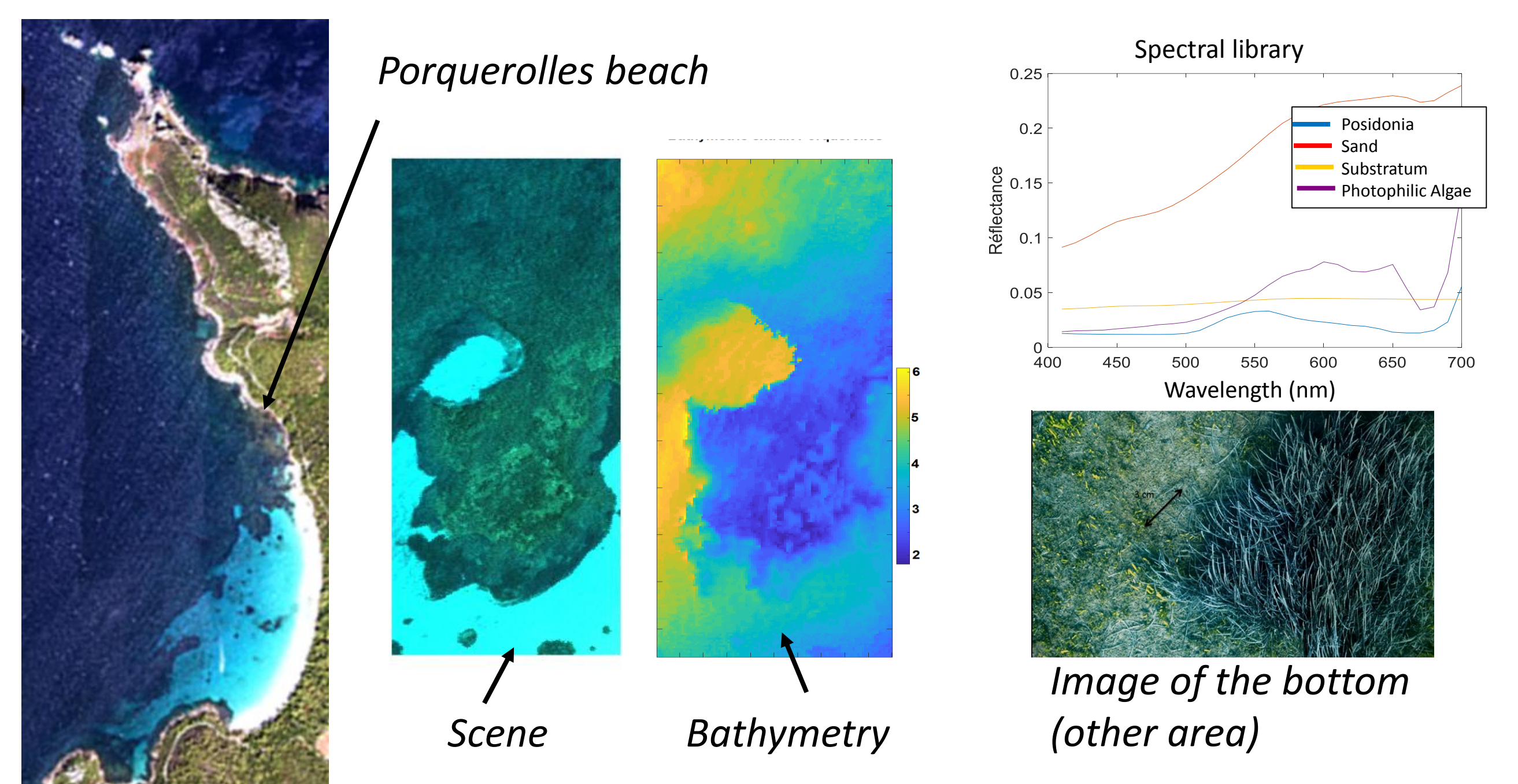
Results on simulated data

Comparison between NMF with no water, NMF for underwater data without modelling adjacency effects ($\mathbf{P}=\mathbf{I}$, algorithm WUM) and NMF for underwater data and modelling adjacency (algorithm WADJUM).



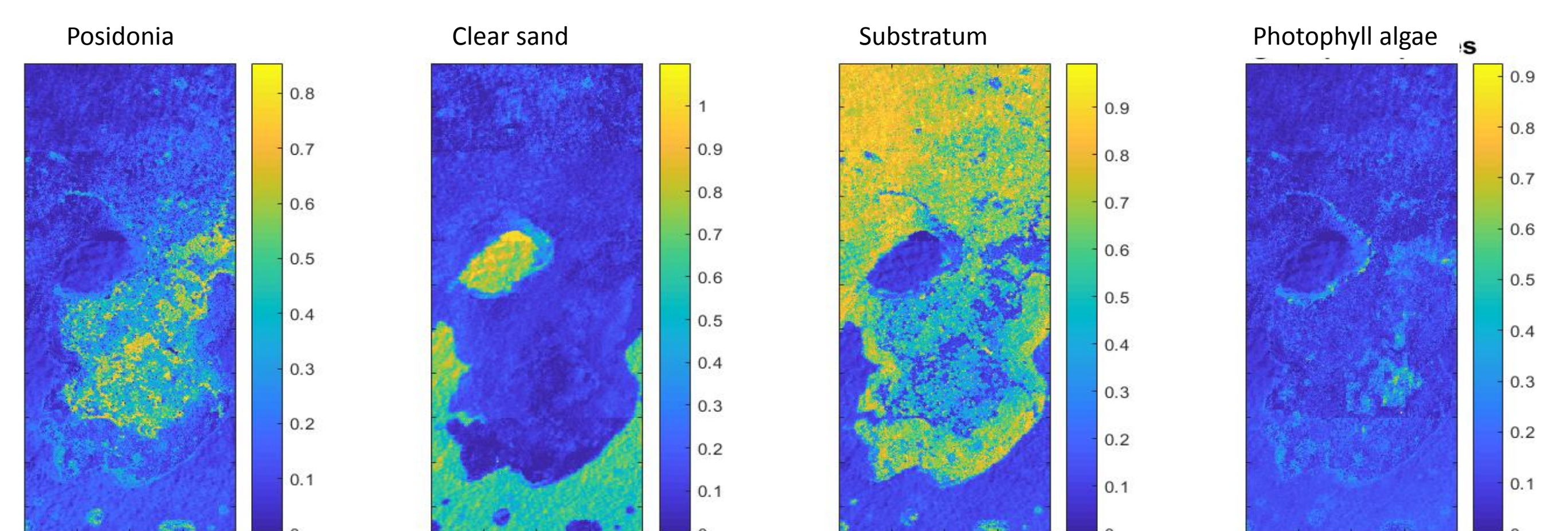
Spectral mean error (SME) and abundance mean error (AME) for clear water: $Chl = 0.03 \text{ mg m}^{-3}$, $SM = 0.01 \text{ mg L}^{-1}$, $C_{dom} = 0.01 \text{ m}^{-1}$, and moderately turbid (standard) water: $Chl = 1 \text{ mg m}^{-3}$, $SM = 1 \text{ mg L}^{-1}$, $C_{dom} = 0.1 \text{ m}^{-1}$

Real data



The scene is from the coastal zone of Porquerolles Island, France.

- The airborne images were acquired by Hytech Imaging
- Water quality measurements were conducted to calculate \mathbf{K}_1 , \mathbf{K}_2 : $Chl = 0.03 \text{ mg m}^{-3}$, $SM = 0.5 \text{ mg L}^{-1}$, $C_{dom} = 0.05 \text{ m}^{-1}$
- Bathymetry from Litto-3D was used



Abundance maps obtained with WADJUM. The spectral library is used for initialization of endmembers, abundances are initialized with estimated coefficients.

Conclusion

- We have developed a new NMF, taking into consideration the adjacency effect for underwater unmixing.
- Simulations show that the model is necessary to unmix sea bottom with moderately turbid water ($H > 3\text{m}$), and also improves the results for clear water ($H > 5\text{m}$)
- Results on real data
- Perspectives : study with unknown water quality

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(1) M. Guillaume, L. Juste, X. Lenot, Y. Deville, B. Lafrance, M. Chami, S. Jay, A. Minghelli, X. Briottet and V. Serfaty, «NMF hyperspectral unmixing of the sea bottom : influence of the adjacency effects, model and method,» *IEEE Whispers*, Amsterdam, 2018.
 (2) M. Chami, X. Lenot, M. Guillaume, B. Lafrance, X. Briottet, A. Minghelli, S. Jay, Y. Deville and V. Serfaty, «Analysis and quantification of seabed adjacency effects in the subsurface upward radiance in shallow waters,» *Optics Express*, Vol 7, n° 8, 2019, A319-A338.