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

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Objective

Develop an advanced method for unmixing the seabed in coastal areas

Mixing model

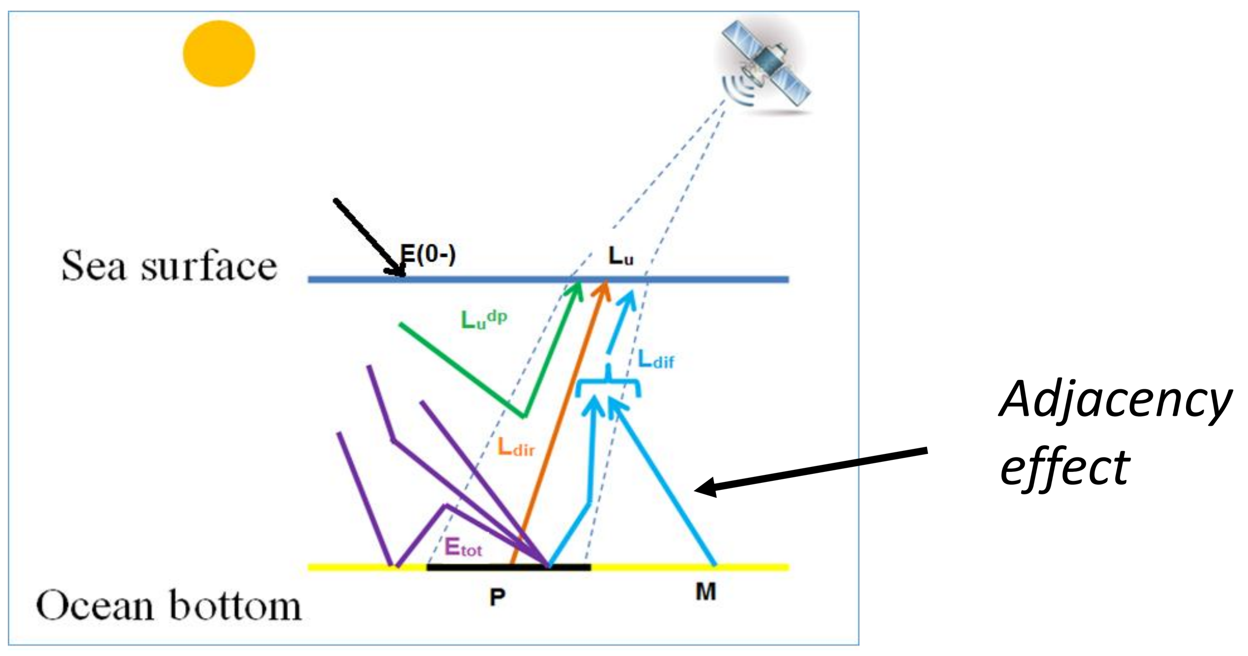
The mixing model is [1]

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

$\tilde{\mathbf{R}}$: $\mathbf{R}$ - $\left(\frac{L_u^{dp}}{E(0-)}\right)$; observed reflectance – water reflectance (L wavelengths X N pixels)
$\mathbf{K}_1$: water direct attenuation ; $\mathbf{K}_2$: water diffuse attenuation (L X N) ;
$\odot$: pointwize 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.



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

$water\ reflectance$

Unmixing

Unmixing is performed by minimizing the cost function J :

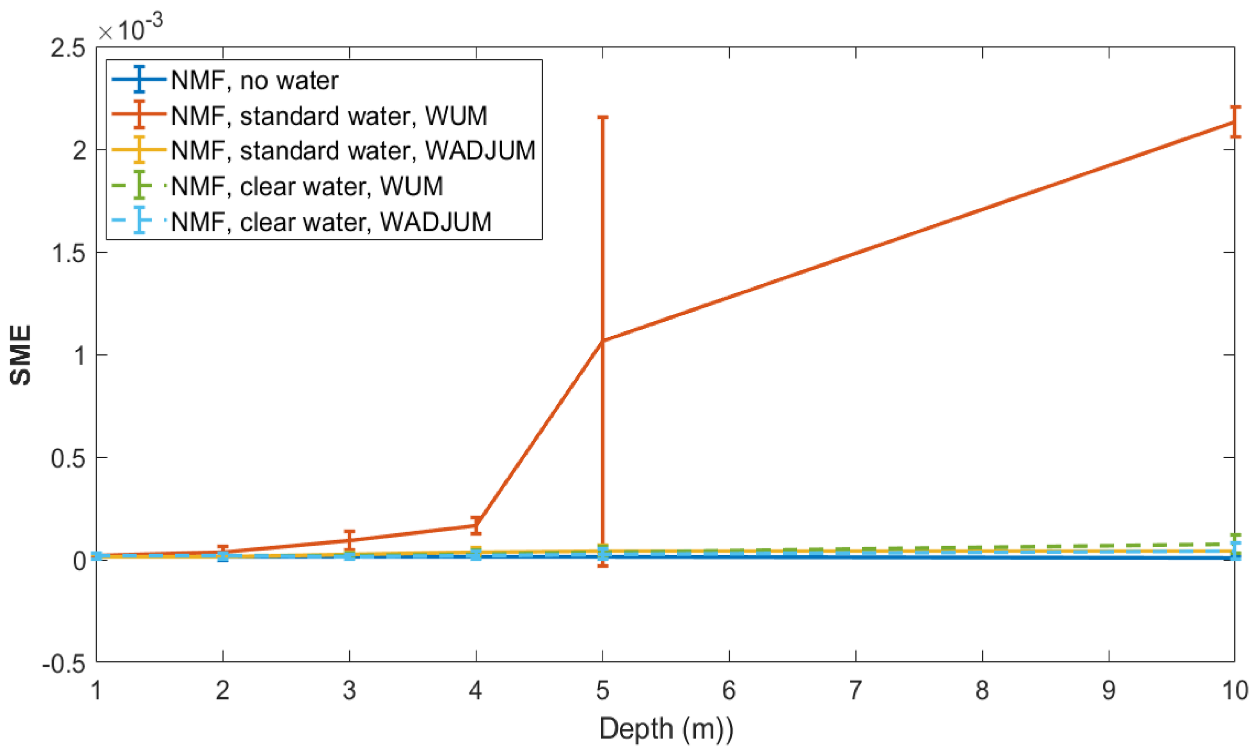
$$J = \arg\min_{S,A} \left\| \tilde{\mathbf{R}} - \mathbf{K}_1 \odot (\mathbf{S}\,\mathbf{A}) - \mathbf{K}_2 \odot (\mathbf{S}\,\mathbf{A}\,\mathbf{P}) \right\|_F^2 + \mathrm{reg}(\mathbf{S},\mathbf{A})$$

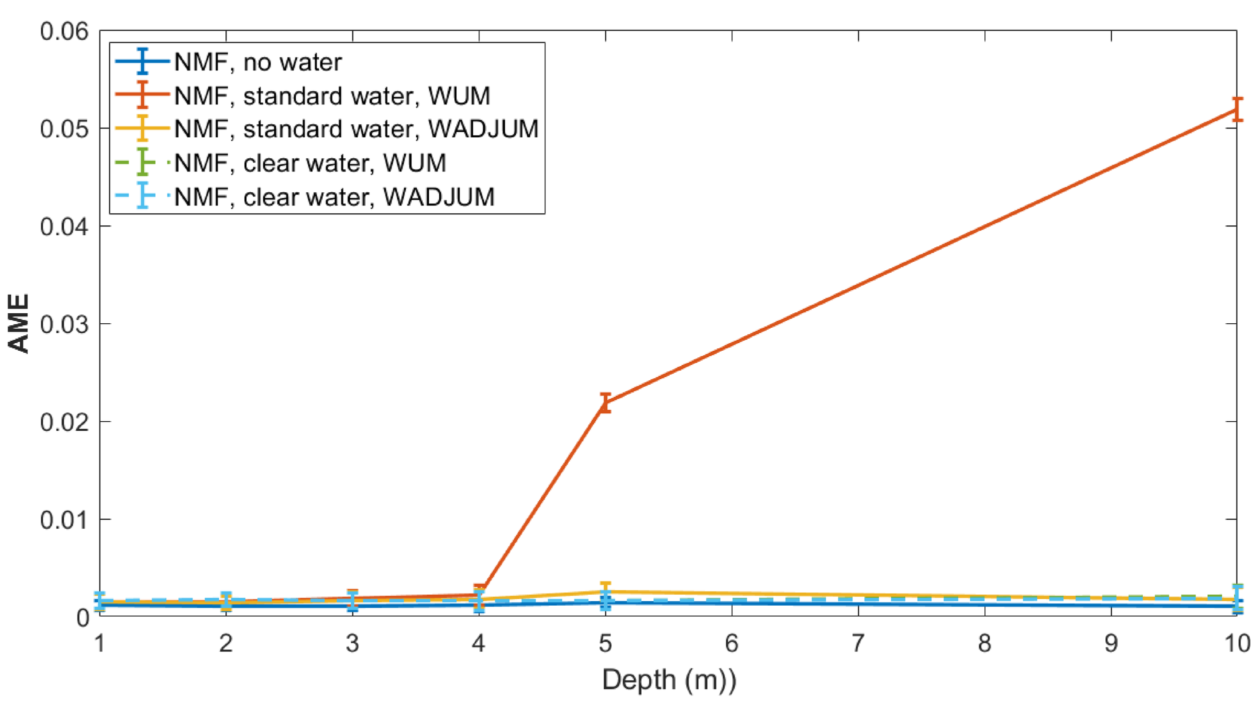
The regularization term reg(**S**,**A**) can be the abundance sum to one constraint or other.

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

Results on simulated data

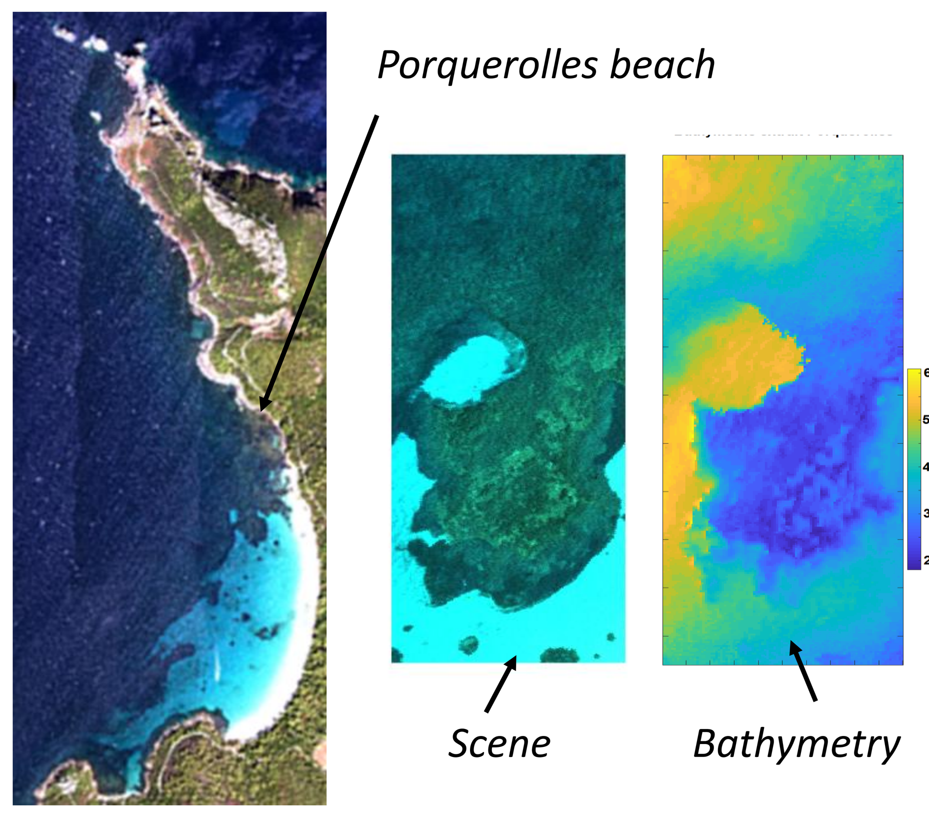
Comparison between NMF with no water, NMF for underwater data without modelling adjacency effects (P=**I**, algorithm WUM) and NMF for underwater data and modelling adjacency (algorithm WADJUM).

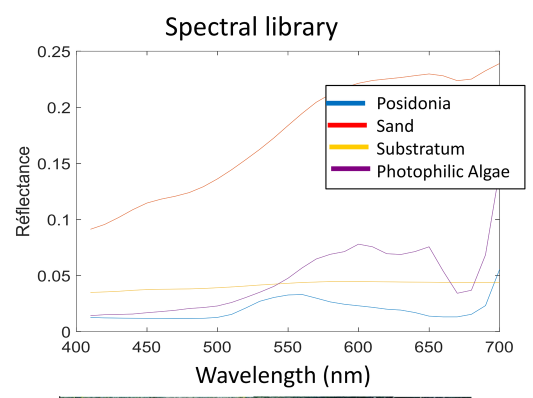




Spectral mean error (SME) and abundance mean error (AME) for clear water: Chl= 0.03 mg m⁻³, SM = 0.01 mg L⁻¹, Cdom = 0.01 m⁻¹, and moderately turbid (standard) water : Chl= 1 mg m⁻³, SM = 1 mg L⁻¹, Cdom = 0.1 m⁻¹

Real data





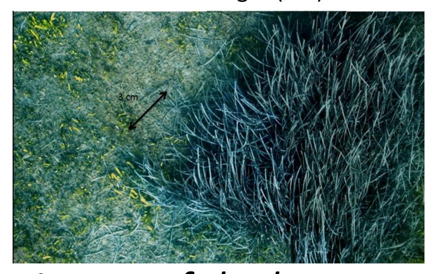
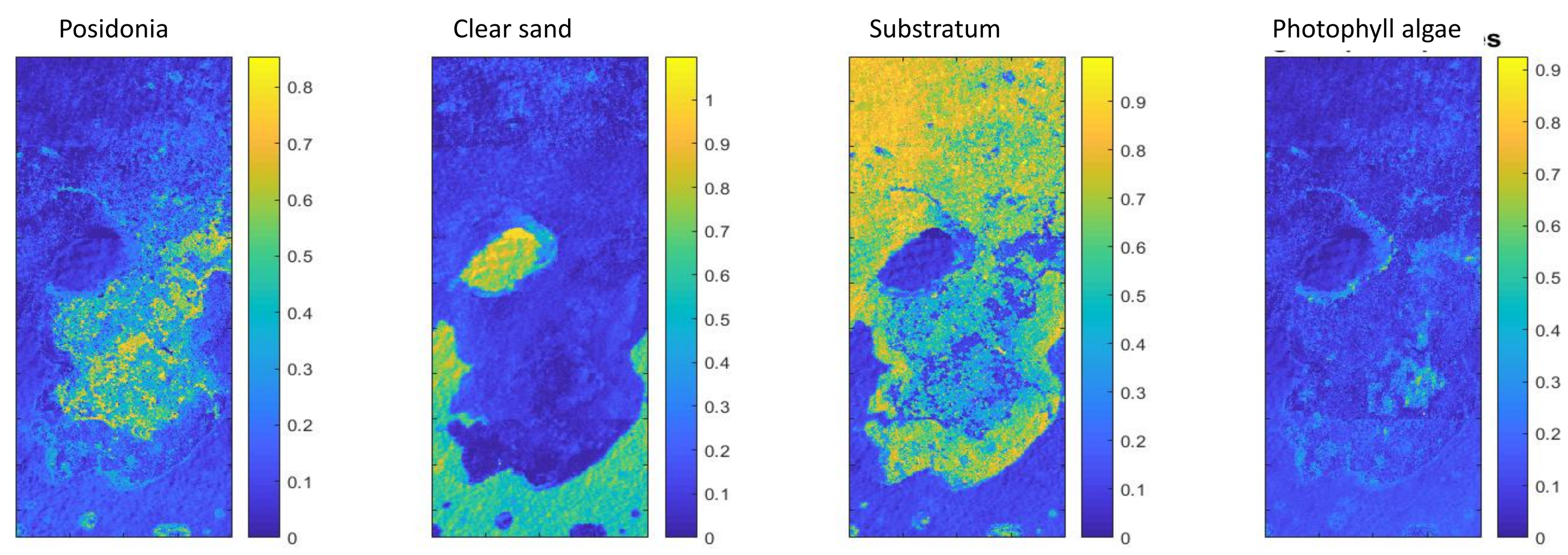


Image of the bottom (other area)

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 mg m⁻³, SM = 0.5 mg L⁻¹, Cdom = 0.05 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>3m), and also improves the results for clear water (H> 5m)
- 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 hyperspectal 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.