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## Non-negative Decomposition of Geophysical Dynamics

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## 1. Abstract

The decomposition of geophysical processes into relevant modes is a key issue for characterization, forecasting and reconstruction problems in environmental sciences. Moreover, the blind separation of contributions associated with different sources is a classical problem in signal and image processing. Recently, significant advances have been reported with the introduction of non-negative and sparse formulations. In this work, we address the blind decomposition of linear operators or transfer functions between variables of interest, with an emphasis on a non-negative setting. We illustrate the relevance of these decompositions for the analysis, prediction and reconstruction of geophysical dynamics.

## 2. Context and motivation

**Satellite remote sensing:**

- ▶ Huge datasets exist.
- ▶ Largely under-exploited scientific potential.

**General objective:** Exploit satellite remote sensing datasets to improve our understanding of geophysical processes.

**Specific objective:** Characterization and decomposition of variable relationships from observations.

## 3. Model

**Non-negative linear decomposition:**

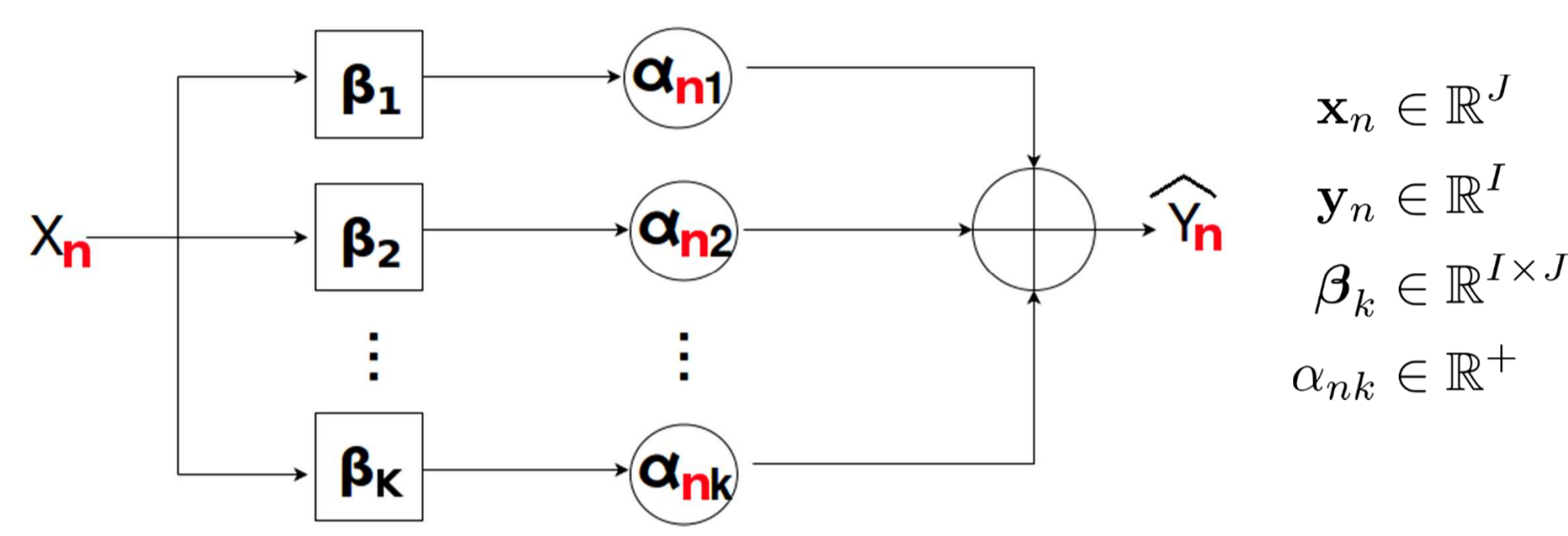


Fig. 1: Model block diagram

**Non-negative superposition of linear modes:**

$$y_n = \sum_{k=1}^K \alpha_{nk} \beta_k x_n + \omega_n$$

Subject to  $\begin{cases} \alpha_{nk} \geq 0, & \forall k \in [1, K], \forall n \in [1, N] \\ \|\beta_k\|_F = 1, & \forall k \in [1, K] \end{cases}$

- ▶ Linear modes  $\beta_k$  are shared by all observation pairs.
- ▶ Non-negative mixing coefficients  $\alpha_{nk}$  are specific to each observation pair.
- ▶ Model characterization can be reformulated as a dictionary learning problem.

## 4. Applications

### I. Upper ocean dynamics segmentation

**Case study:** Alboran Sea (35°N - 38°N, 0°W - 5°W).

▶ Daily synthetic images (2009- 2012):

- Sea surface temperature (SST).
- Sea surface salinity (SSS).

▶ Cold water intake from the Atlantic through the Gibraltar Strait:

- Strong seasonal patterns.
- Inversion of SST/SSS correlation.

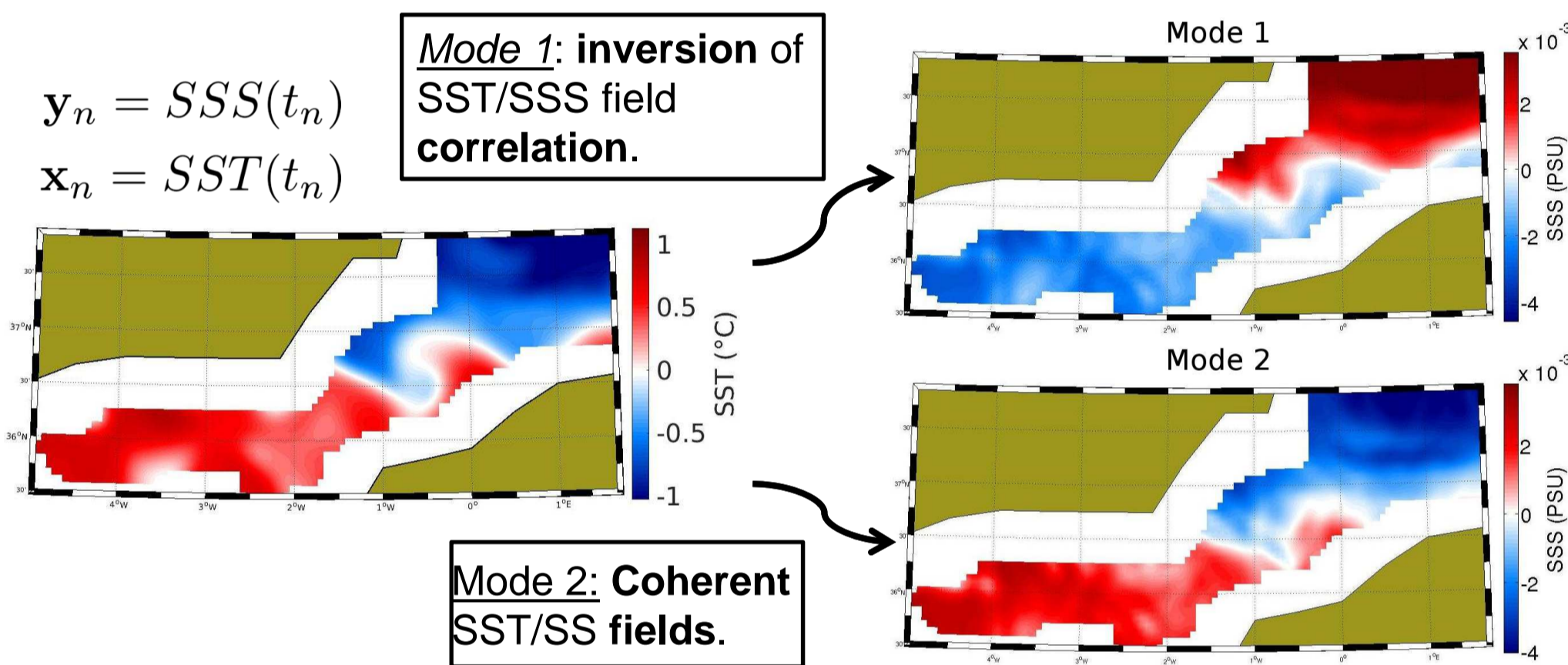


Fig. 2: Modal predictions of SSS from SST for a bi-modal non-negative decomposition model.

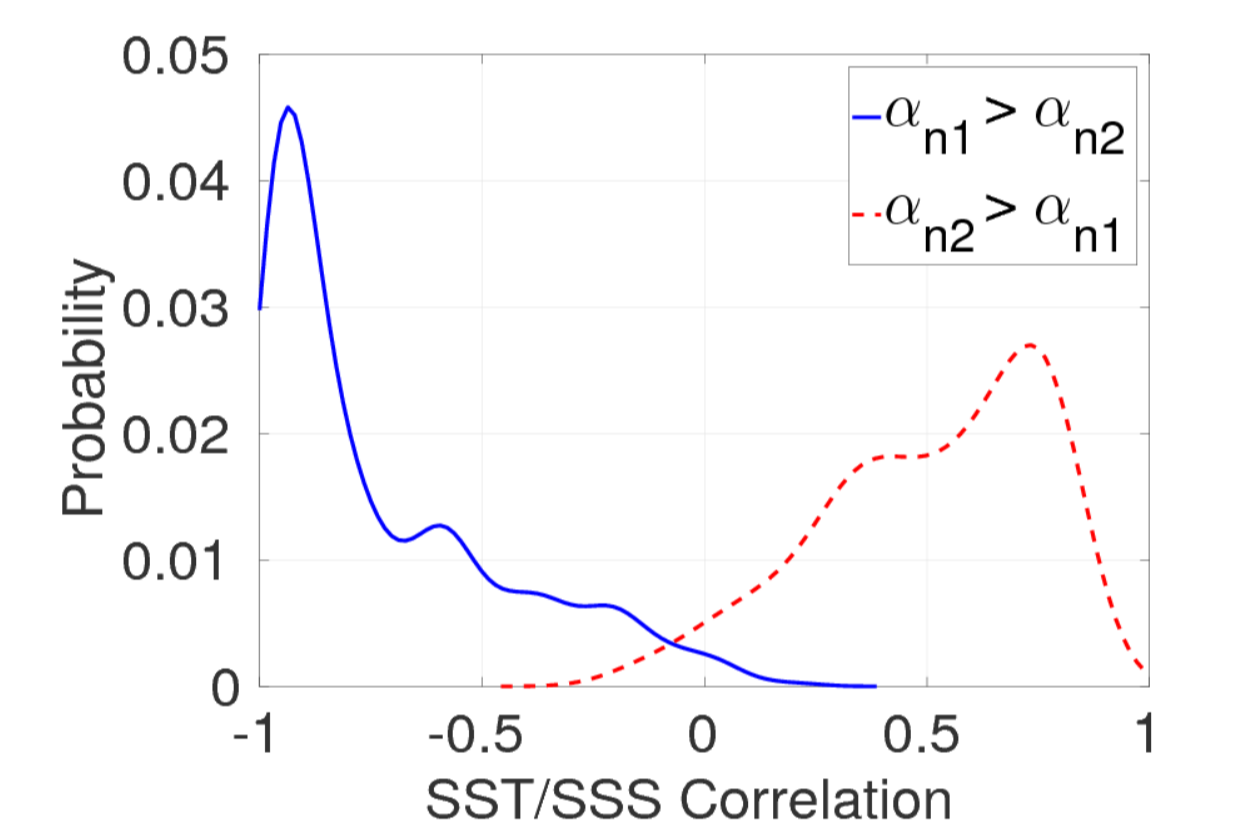


Fig. 3: SST/SSS field correlation coefficient distribution.

### II. Analog forecasting of dynamical systems

**Case study:** Lorenz '96 dynamical system

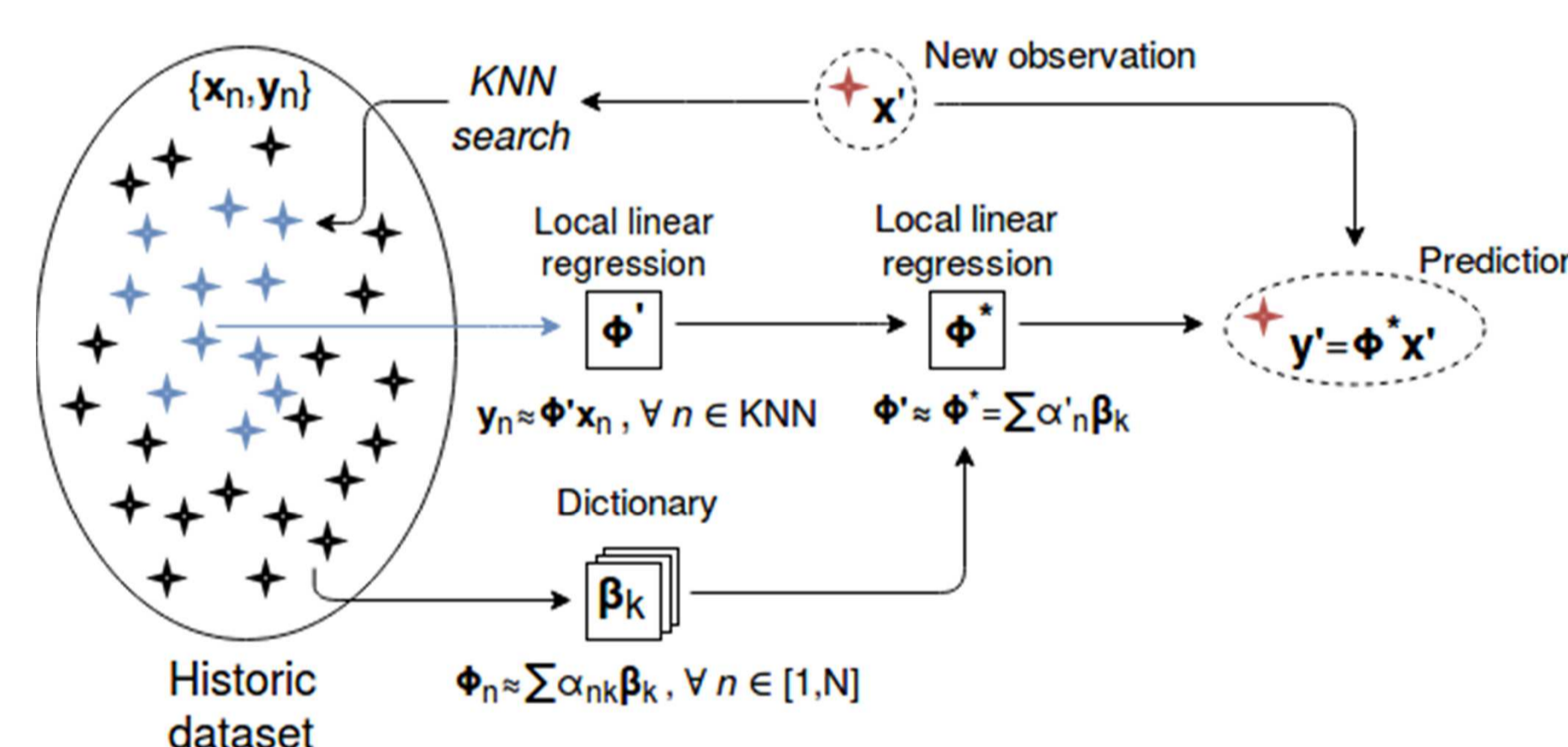


Fig. 4: Analog forecasting with non-negative decomposition.

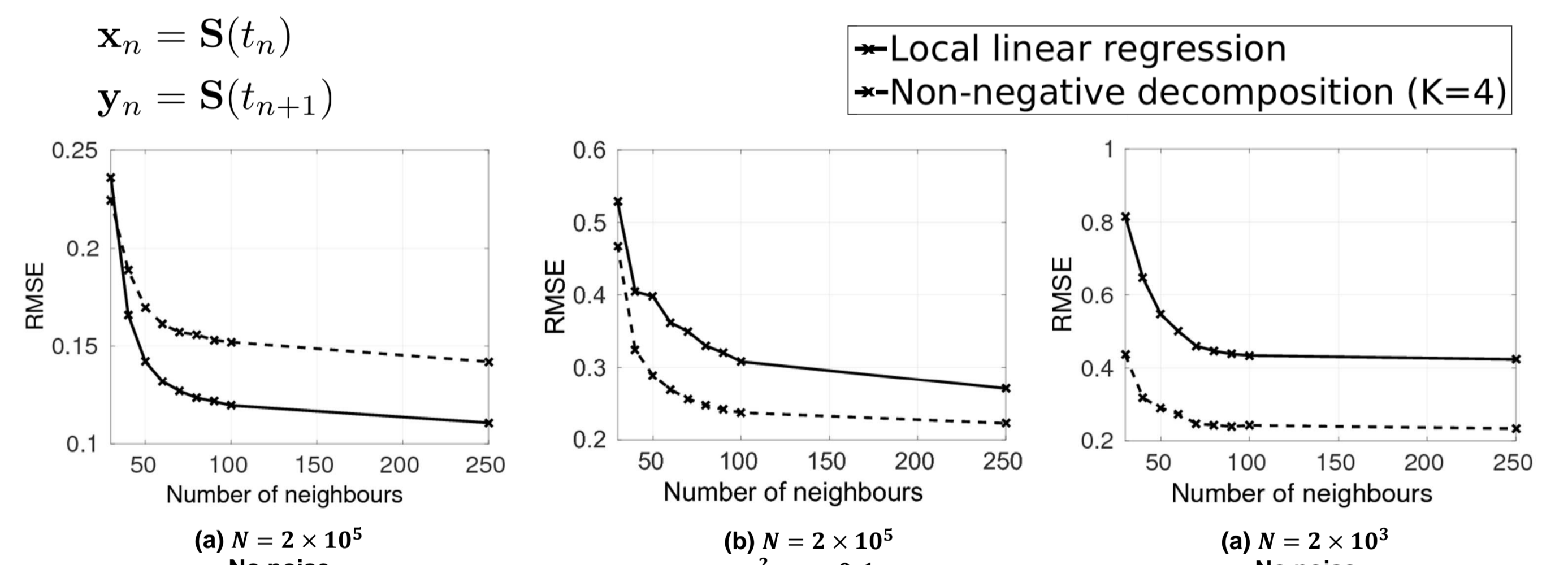


Fig. 5: Normalized forecasting RMSE vs. number of analogs used to estimate locally-linear forecasting operators.

### III. Super-resolution of sea surface height (SSH) fields

**Case study:** Western Mediterranean Sea (36.5°N - 40°N, 1.5°E - 8.5°E).

$$x_n = [SSH_{LR}(p_{s_n}, t_0), SST(p_{s_n}, t_0)] \quad y_n = SSH_{HR}(s_n, t_0)$$

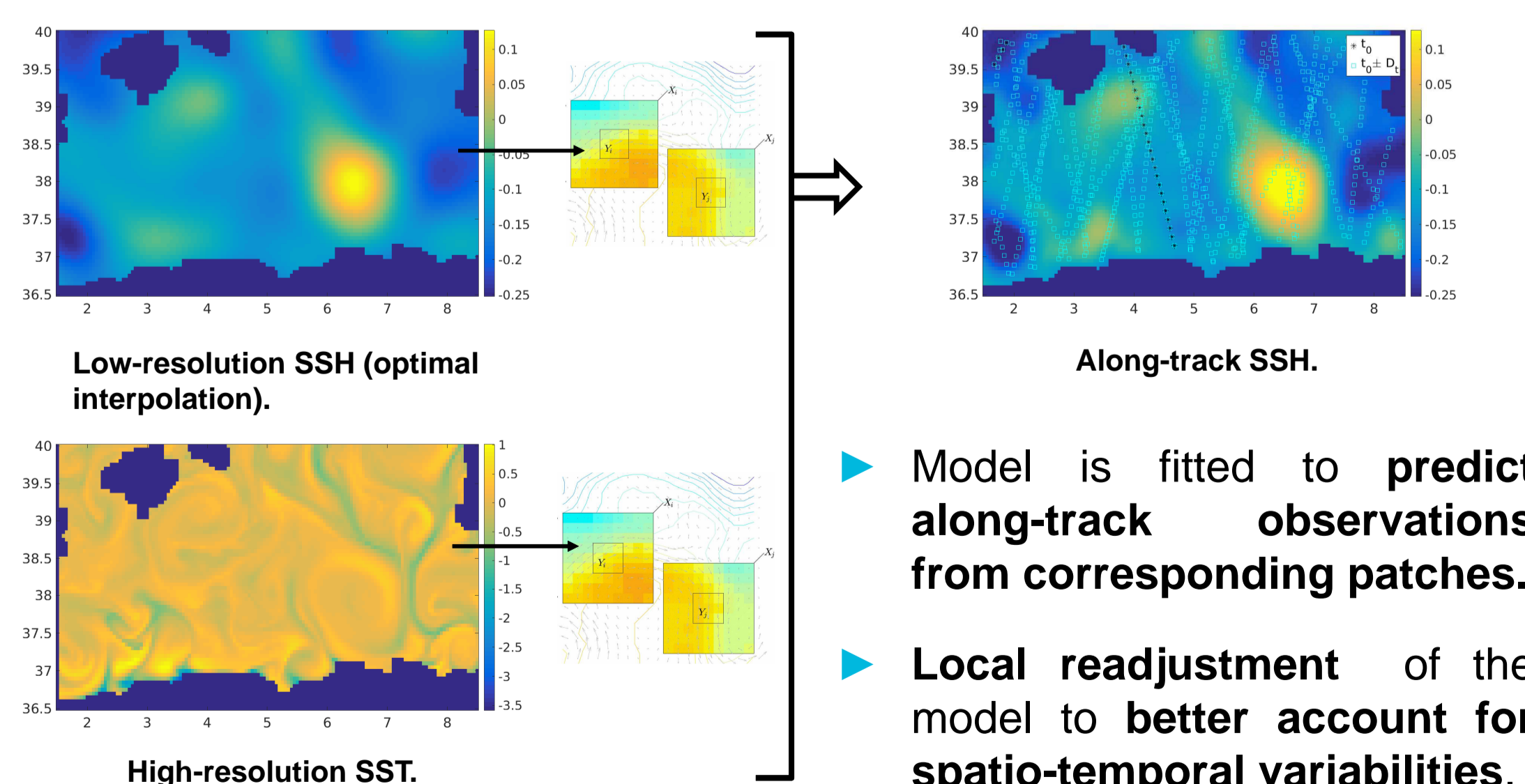


Fig. 6: Patch-based super-resolution of SSH fields from OI-SSH, SST and along-track SSH.

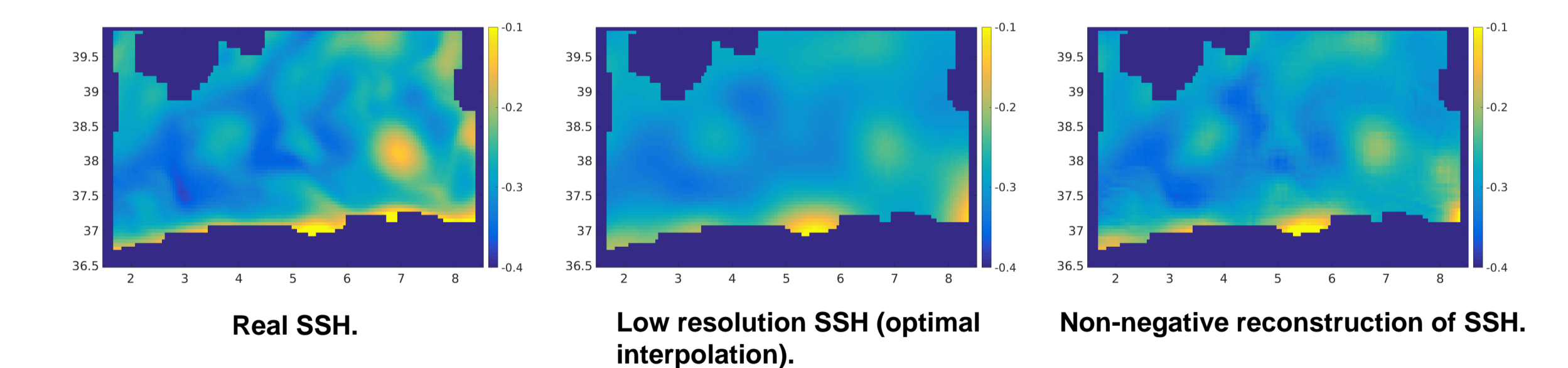


Fig. 7: High-resolution SSH image reconstruction, April 20th, 2012

|                   | K = 2  | K = 5         | K = 10        |
|-------------------|--------|---------------|---------------|
| PCA               | 0.1807 | <b>0.1734</b> | 0.1680        |
| KSVD              | 0.2228 | 0.2228        | 0.2228        |
| NN                | 0.1807 | <b>0.1734</b> | <b>0.1666</b> |
| Global model      |        |               | 0.1755        |
| SSH <sub>LR</sub> |        |               | 0.2228        |

Tab. 1: Mean high-resolution SSH field reconstruction error.

## 5. Conclusion

We introduced a new observation-based non-negative decomposition model and explored applications to the characterization and forecasting of geophysical dynamics. The proposed formulation exploits a dictionary-based formulation and has increased flexibility and adaptability, since it allows for the exploitation of alternative constraints. We illustrated the practicality and versatility of the proposed formulation by presenting applications to the analysis of geophysical processes, the prediction of dynamical systems and the super-resolution of altimetric fields. Future work will explore and evaluate alternative model constraints as well as the integration of the proposed approach in analog data assimilation methods. Moreover, an application to the super-resolution of SSH fields from wide-swath pseudo-SWOT observations, possibly enabling the modeling of higher-order geometrical details, is also considered.

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## Partners



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