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NON-NEGATIVE DECOMPOSITION OF GEOPHYSICAL DYNAMICS

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:

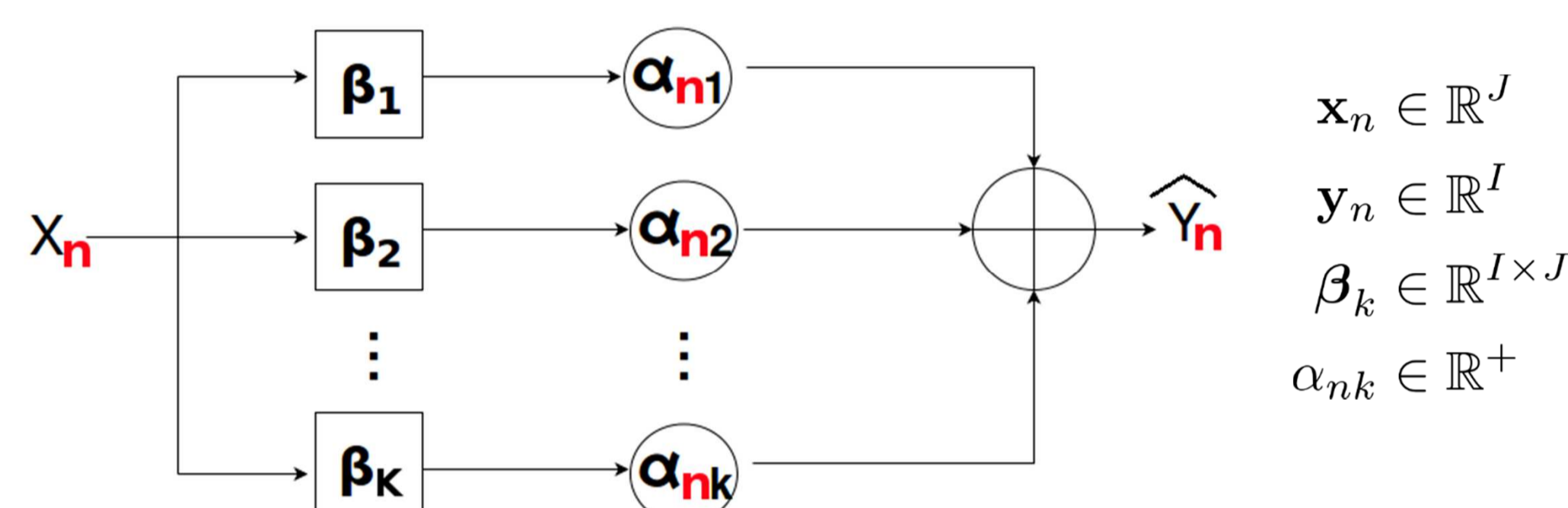


Fig. 1: Model block diagram

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 β_k are shared by all observation pairs.
- Non-negative mixing coefficients α_{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.

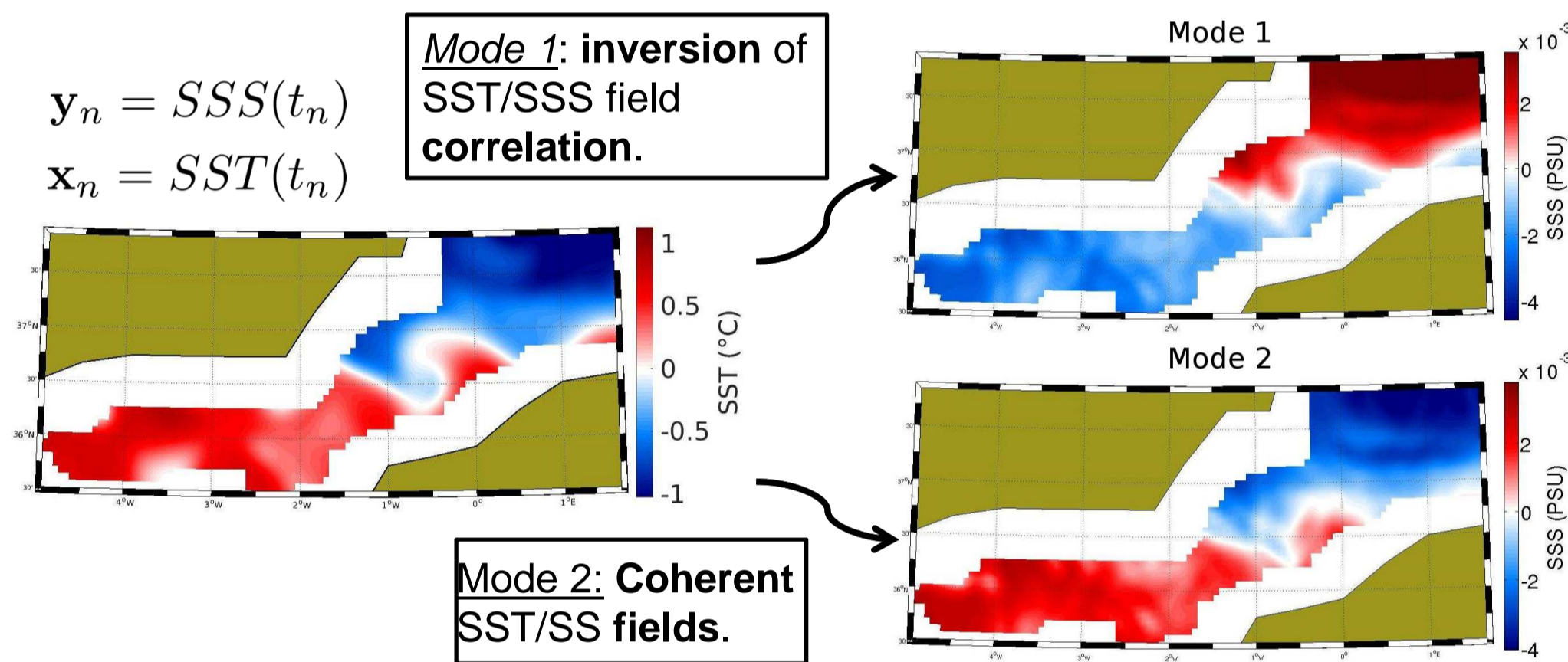


Fig. 2: Modal predictions of SSS from SST for a bi-modal non-negative decomposition model.

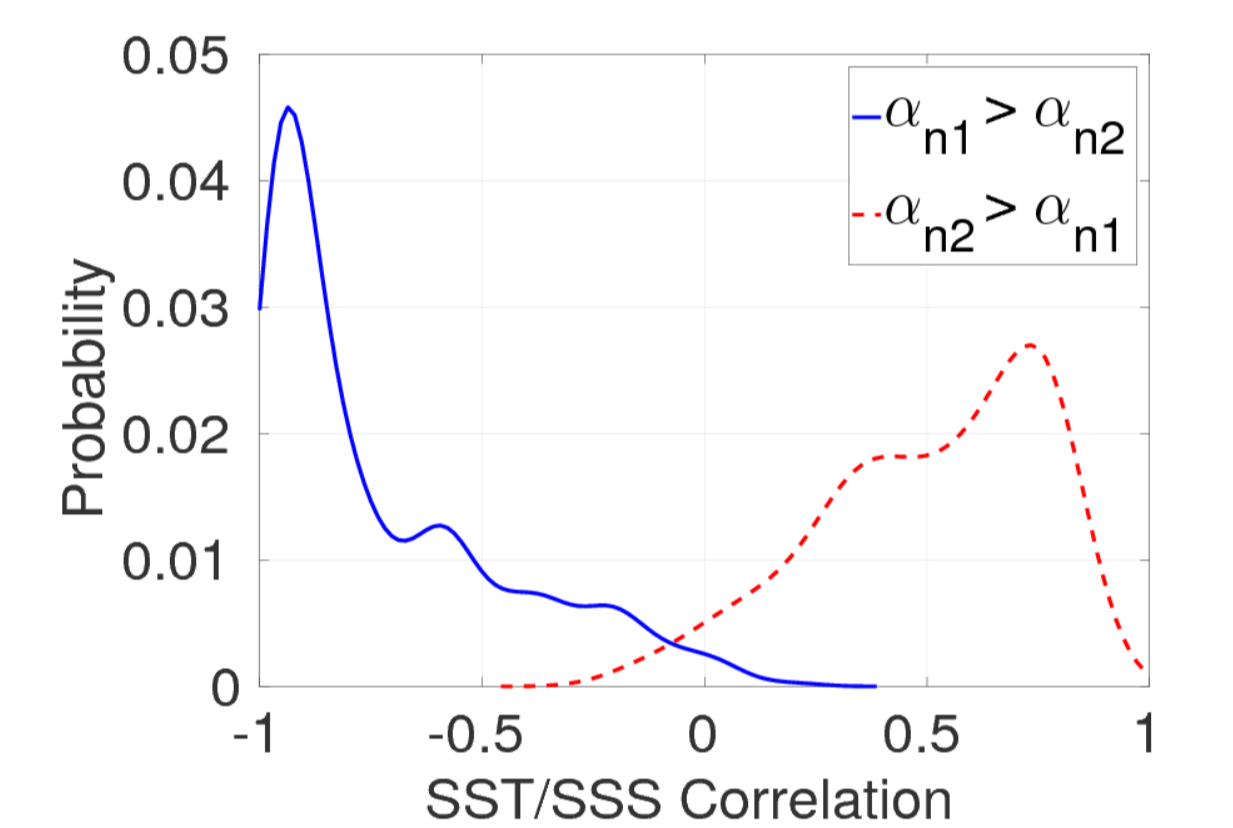


Fig. 3: SST/SSS field correlation coefficient distribution.

II. Analog forecasting of dynamical systems

Case study: Lorenz '96 dynamical system

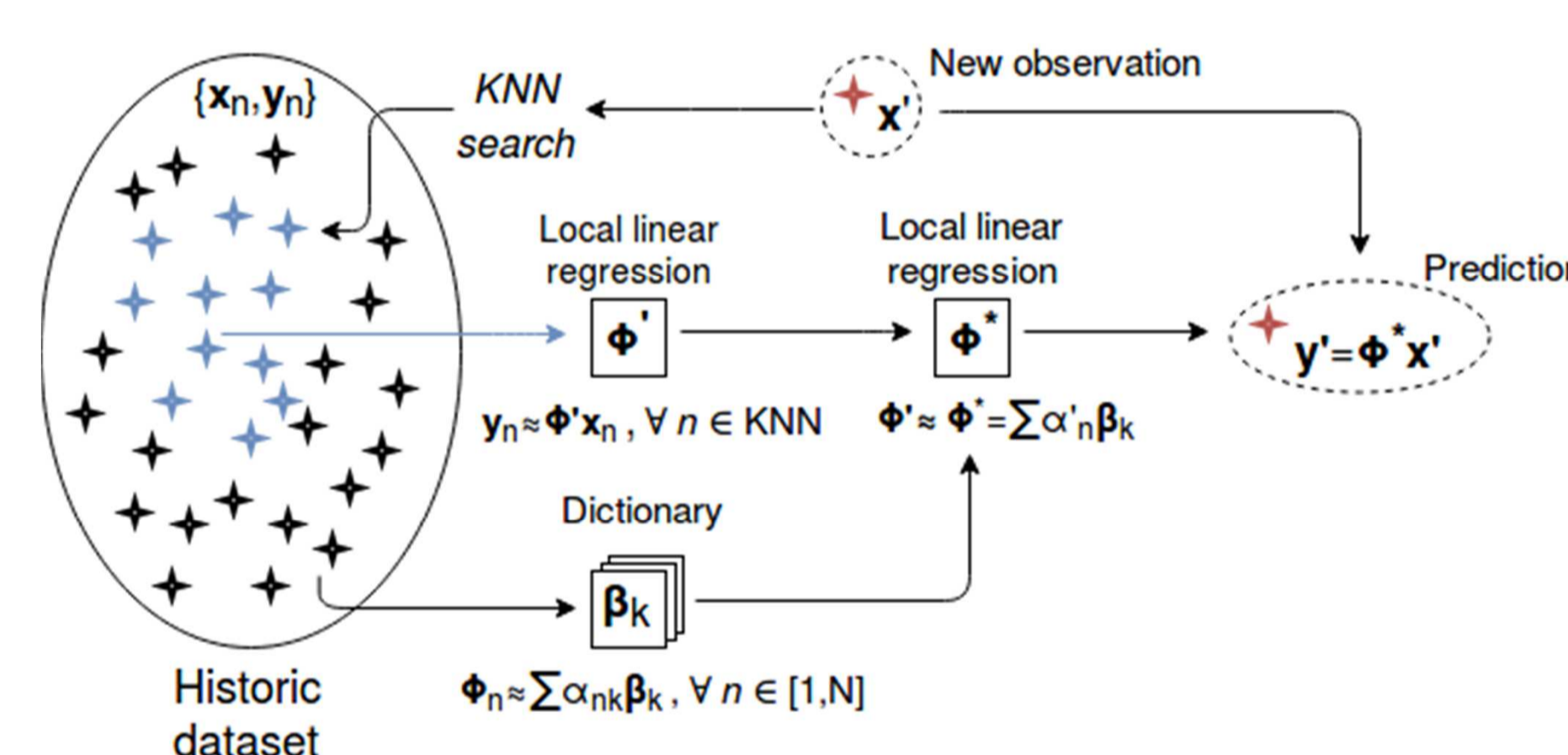


Fig. 4: Analog forecasting with non-negative decomposition.

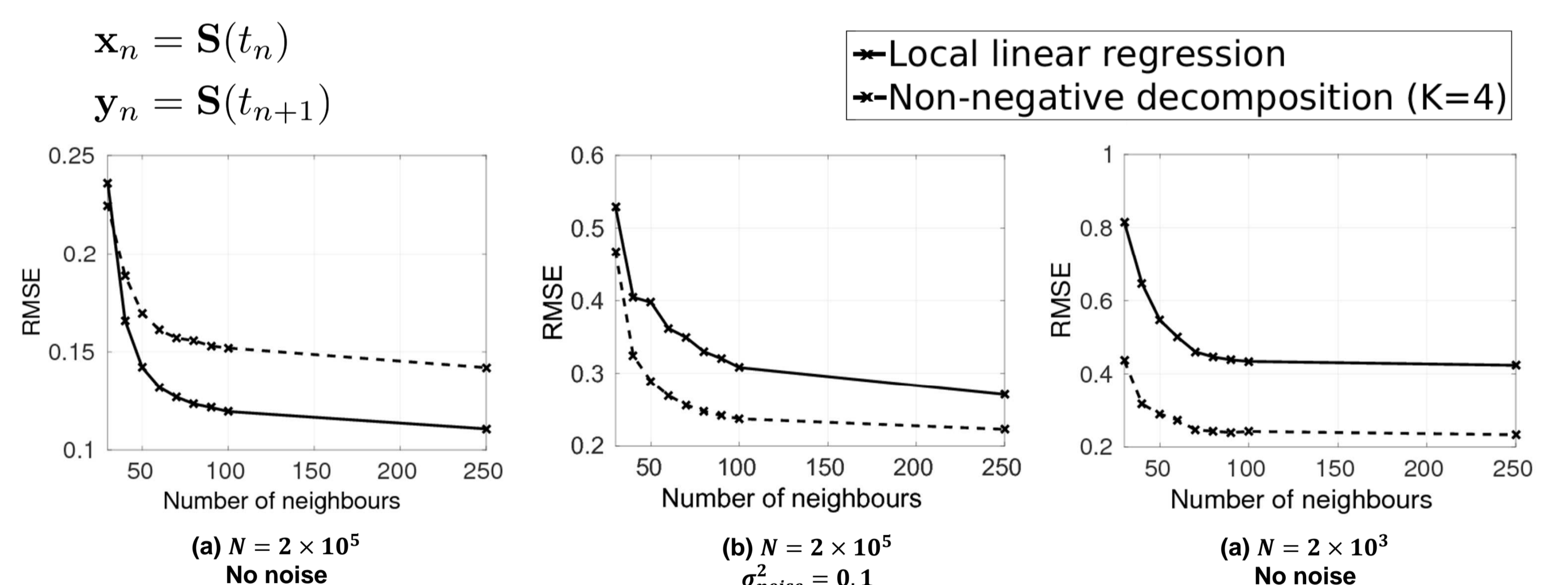


Fig. 5: Normalized forecasting RMSE vs. number of analogs used to estimate locally-linear forecasting operators.

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).

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

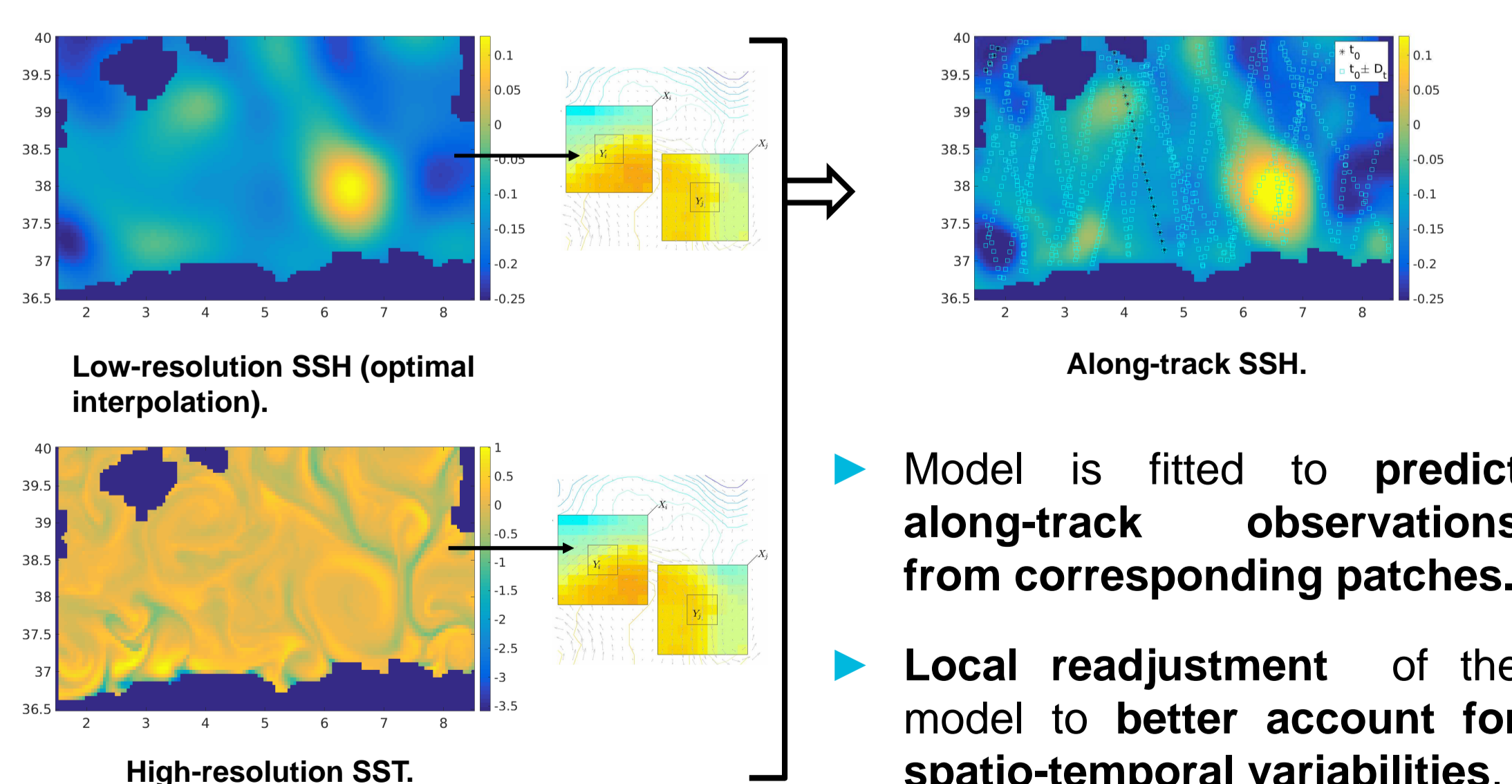


Fig. 6: Patch-based super-resolution of SSH fields from OI-SSH, SST and along-track SSH.

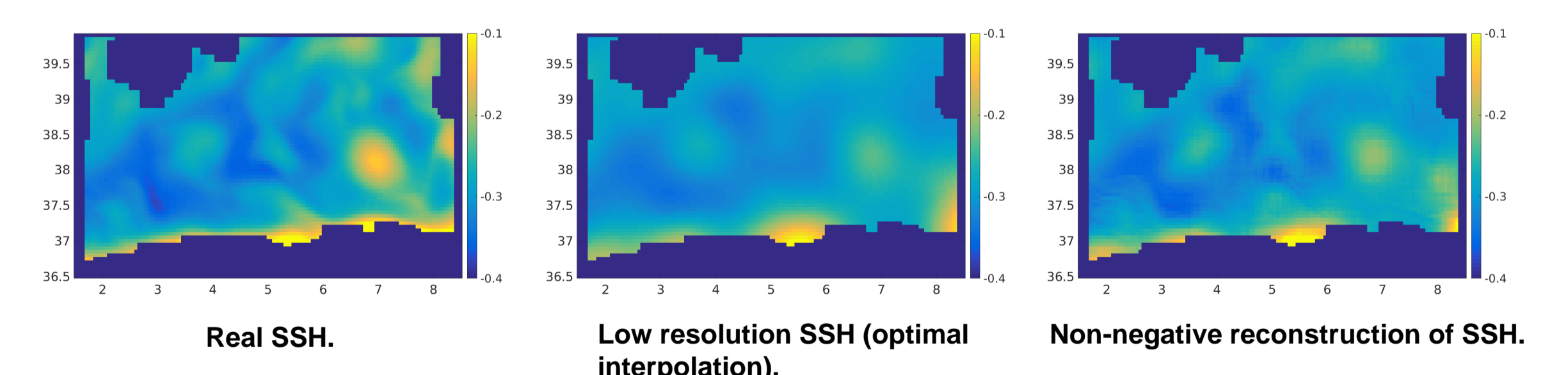


Fig. 7: High-resolution SSH image reconstruction, April 20th, 2012

	$K=2$	$K=5$	$K=10$
PCA	0.1807	0.1734	0.1680
KSVD	0.2228	0.2228	0.2228
NN	0.1807	0.1734	0.1666
Global model			0.1755
SSH_{LR}			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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