



Image-Based Forecast of the Surface Circulation of Black Sea

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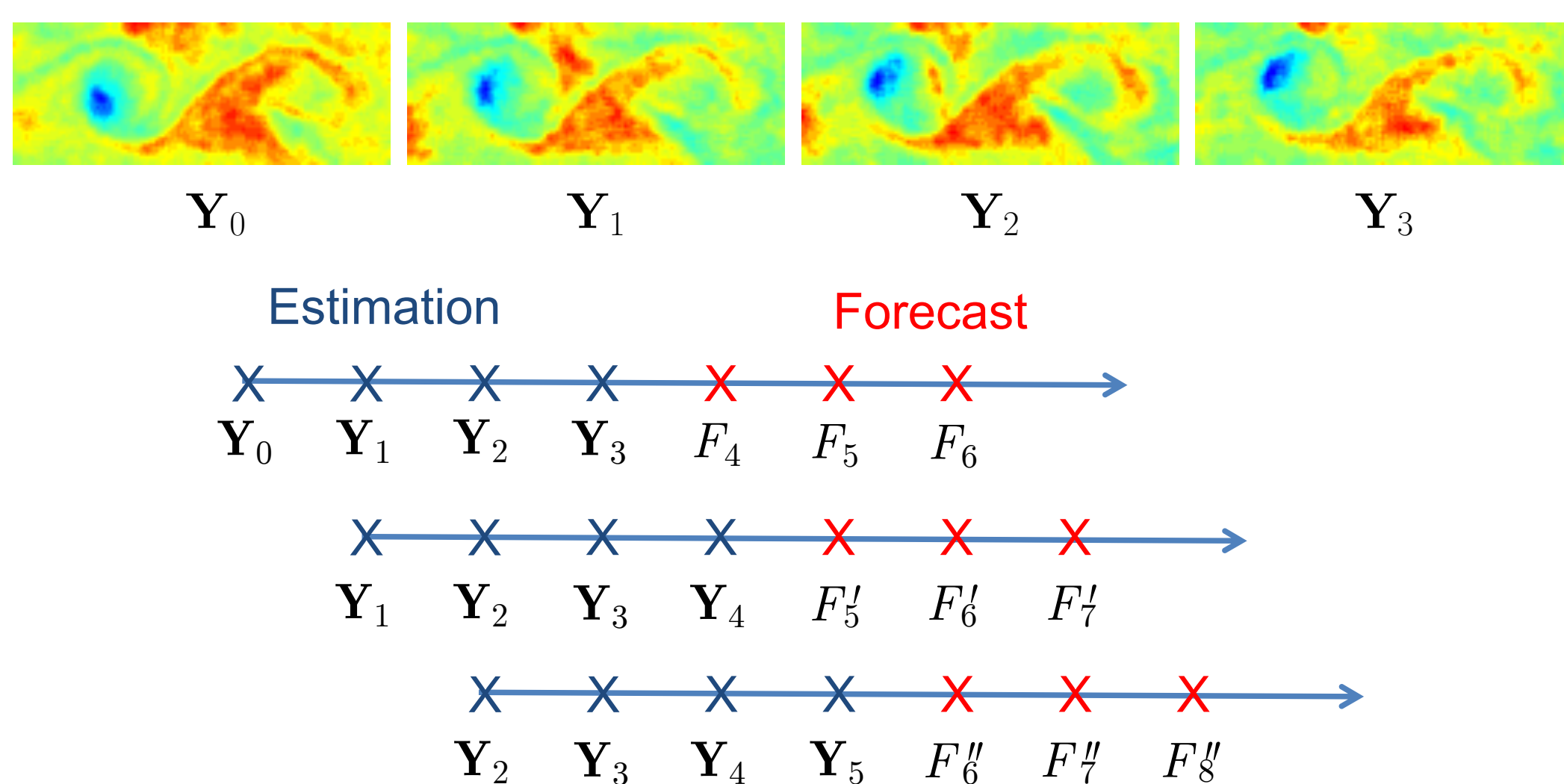
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ABSTRACT

Satellite data allow visualising the surface circulation and the meso-scale structures at the spatial resolution and time frequency of the sensor. These images provide continuous information at fine scale and permit analysing eddies, jets, filaments, mushroom-shaped vortices. Many applications, such as oil spill monitoring, also require the forecast of surface circulation at short temporal horizon. This nowcasting includes two main components: one in charge of estimating the surface dynamics and one of the forecast of future images at a given temporal horizon.

OBJECTIVES

A sliding-window technique processes the last 4 images:



The state vector \mathbf{X} is composed of motion \mathbf{w} and synthetic image I :

$$\mathbf{X}(\mathbf{x}, t) = (\mathbf{w}(\mathbf{x}, t) \ I(\mathbf{x}, t))^T$$

SURFACE DYNAMICS ESTIMATION

The surface dynamics is estimated with a data assimilation approach from four image acquisitions and the evolution laws of \mathbf{w} and I , summarized in the numerical model \mathbb{M}_e :

$$\begin{cases} \frac{\partial \mathbf{w}}{\partial t} = 0 \\ \frac{\partial I}{\partial t} + \mathbf{w} \cdot \nabla I = 0 \end{cases}$$

- Estimation is computed from the comparison between the satellite images $\mathbf{Y}(t)$ and the synthetic images $I(t)$.

Images $I(t)$ are obtained from the integration of the evolution model \mathbb{M}_e .

The discrepancy between $\mathbf{Y}(t)$ and $I(t)$ is equal to $\varepsilon_I(\mathbf{x}, t)$:

$$\varepsilon_I(\mathbf{x}, t) = \mathbf{Y}(\mathbf{x}, t) - I(\mathbf{x}, t)$$

- The minimization of the discrepancy ε_I is obtained through the minimization of the energy:

$$J(\mathbf{X}(0)) = \iint \frac{\varepsilon_I(\mathbf{x}, t)^2}{R_I(\mathbf{x}, t)} d\mathbf{x} dt + \text{additional terms}$$

and a steepest descent method (L-BFGS algorithm).

R_I is taken as the variance of the acquisition error.

- The issue of missing data, due to the cloud cover for instance, is solved with $R_I(\mathbf{x}, t) = 10^8$, which excludes these pixels from the energy J .

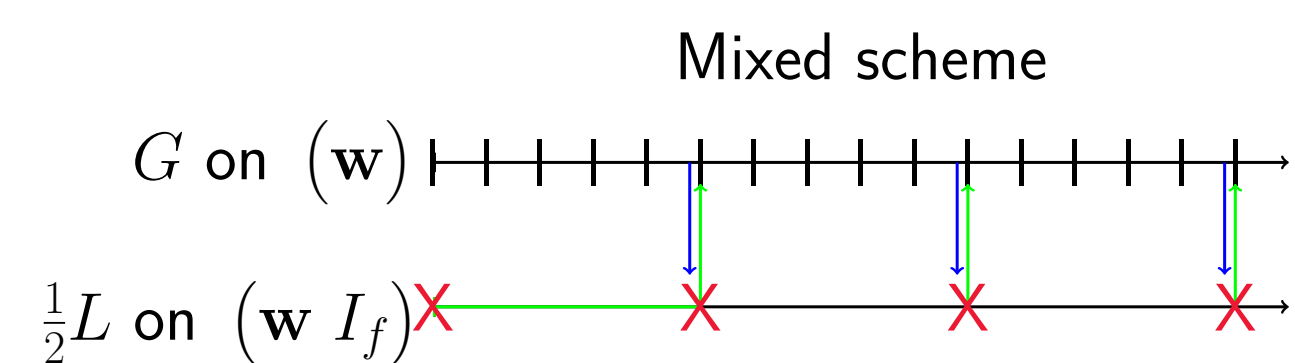
FORECAST

The forecast synthesizes future images based on the estimated dynamics and on the last acquisition with the numerical model \mathbb{M}_f :

$$\begin{cases} \frac{\partial \mathbf{w}}{\partial t} + \mathbf{w} \cdot \nabla \mathbf{w} = 0 \\ \frac{\partial I}{\partial t} + \mathbf{w} \cdot \nabla I = 0 \end{cases}$$

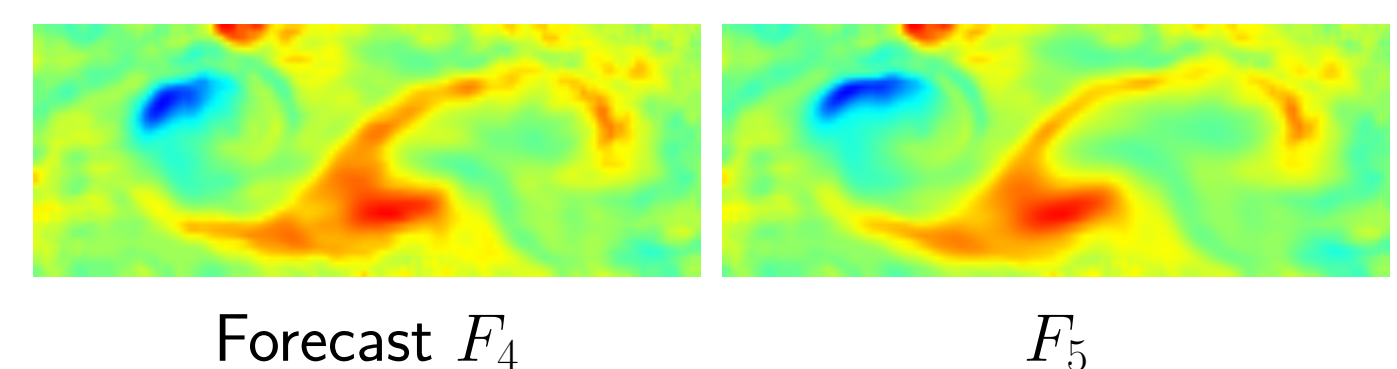
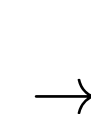
The numerical accuracy of the synthesized images is crucial for the effective exploitation of the forecasts. Two spatial discretization schemes are combined during the temporal integration:

- A semi-Lagrangian scheme, denoted $\frac{1}{2}L$, which is unconditionally stable and allows a large time step.
- A Godunov scheme, denoted G , which solves the Riemann problem at each inter-pixels boundary. It is adapted for an accurate advection of functions with high spatial gradient values (but CFL conditions).



Forecast results:

\mathbf{w} from $(\mathbf{Y}_0, \mathbf{Y}_1, \mathbf{Y}_2, \mathbf{Y}_3)$
Last Obs \mathbf{Y}_3

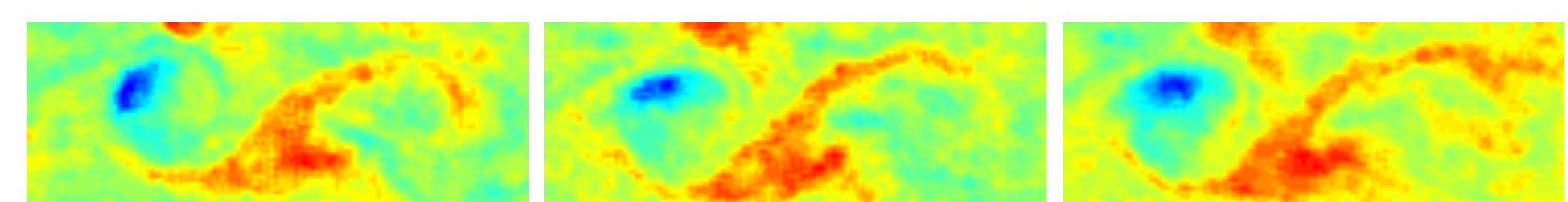


Forecast F_4

F_5

VALIDATION

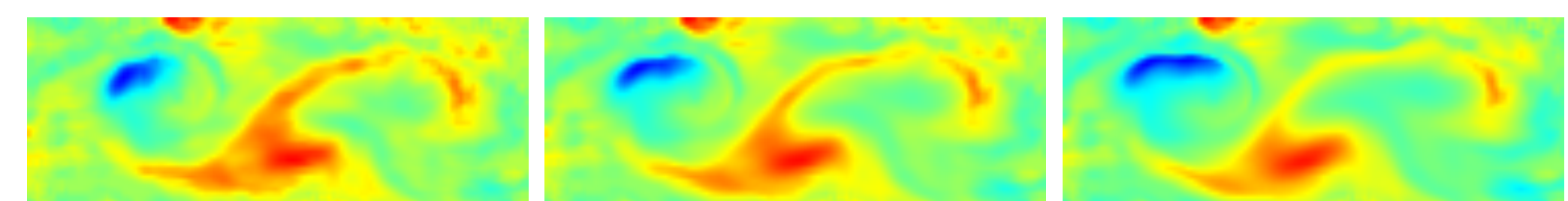
Comparison of the acquisitions \mathbf{Y}_i to the corresponding forecasts (at the same time) F_i, F'_i, F''_i :



Observations \mathbf{Y}_4

\mathbf{Y}_5

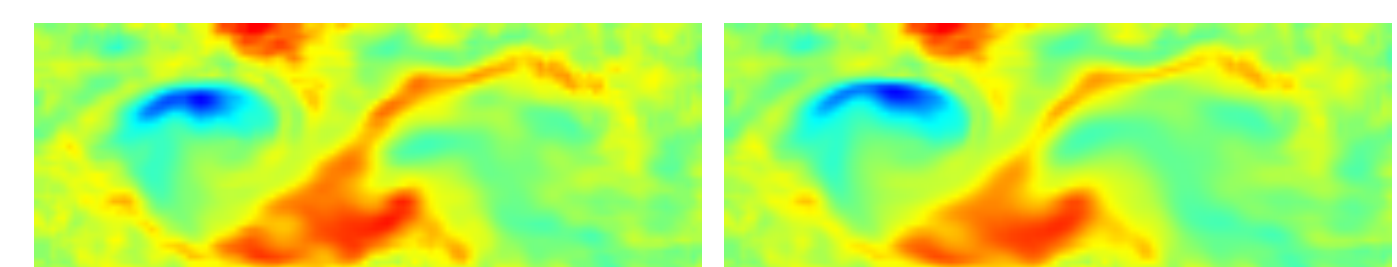
\mathbf{Y}_6



Forecast F_4

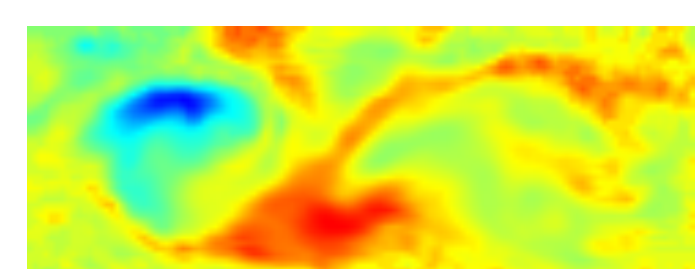
F_5

F_6



Forecast F_5'

F_6'



Forecast F_6''

Image courtesy: Gennady Korotaev, Marine Hydrophysical Institute, Sevastopol.