Data assimilation of velocity fields coming from image processing

29-Jun-05

INSTITUT NATIONAL
DE RECHERCHE
EN INFORMATIQUE
ET EN AUTOMATIQUE

INRIA

Context: ASSIMAGE

ACI ASSIMAGE

- ACI: national research collaboration framework
- Collaboration between 8 French laboratories:
  - INRIA
    - IDOPT (Grenoble) – Data assimilation
    - CLIME (Paris) – Image processing and data assimilation
    - VISTA (Rennes) – Image processing
  - CEMAGREF
    - ETNA (Grenoble) – Snow avalanches
    - ENGREF (Montpellier) – Hydrology
    - Aerobio (Rennes) – Aerology and fluid mechanic
  - CNRS
    - LGGE (Grenoble) – Glaciology
    - LEGI (Grenoble) – Oceanography

- Extra-collaboration with MHI (Sevastopol) – Oceanography

Objectives of ASSIMAGE

- Study the feasibility and potentiality of assimilation of image data
- Application to geophysical simulation models
- Focus on oceanographic application

General objectives: image assimilation

Summary of Data Assimilation

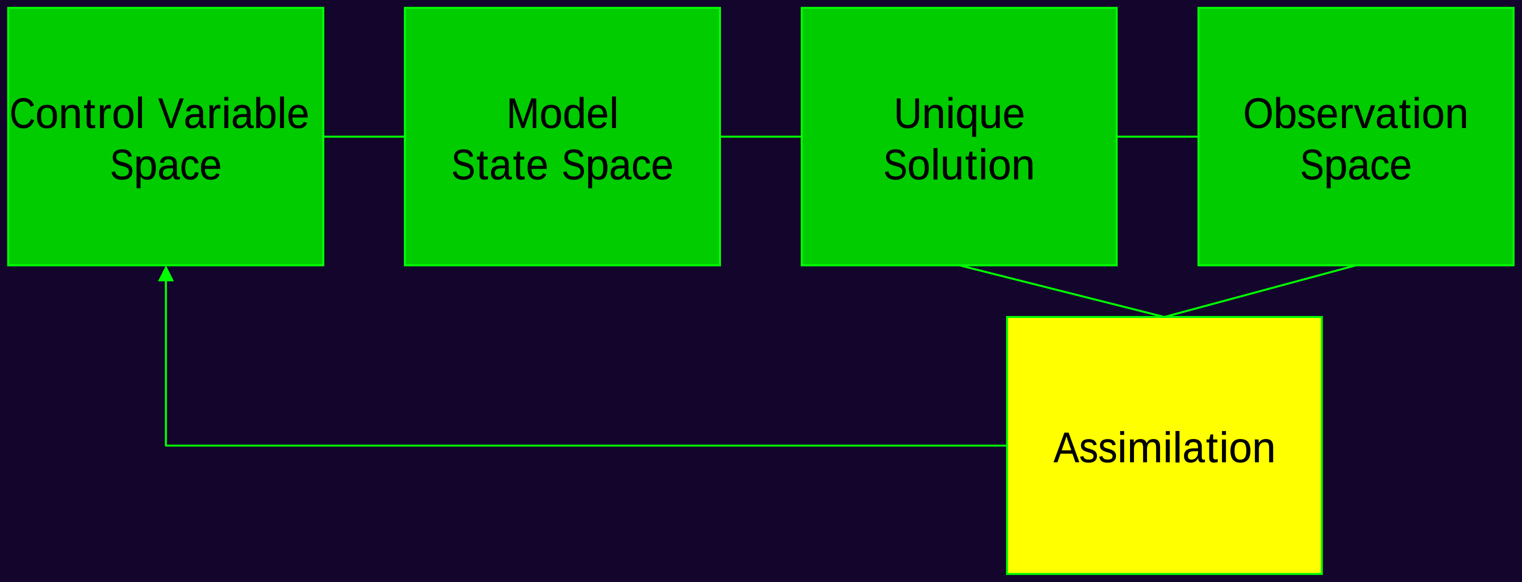
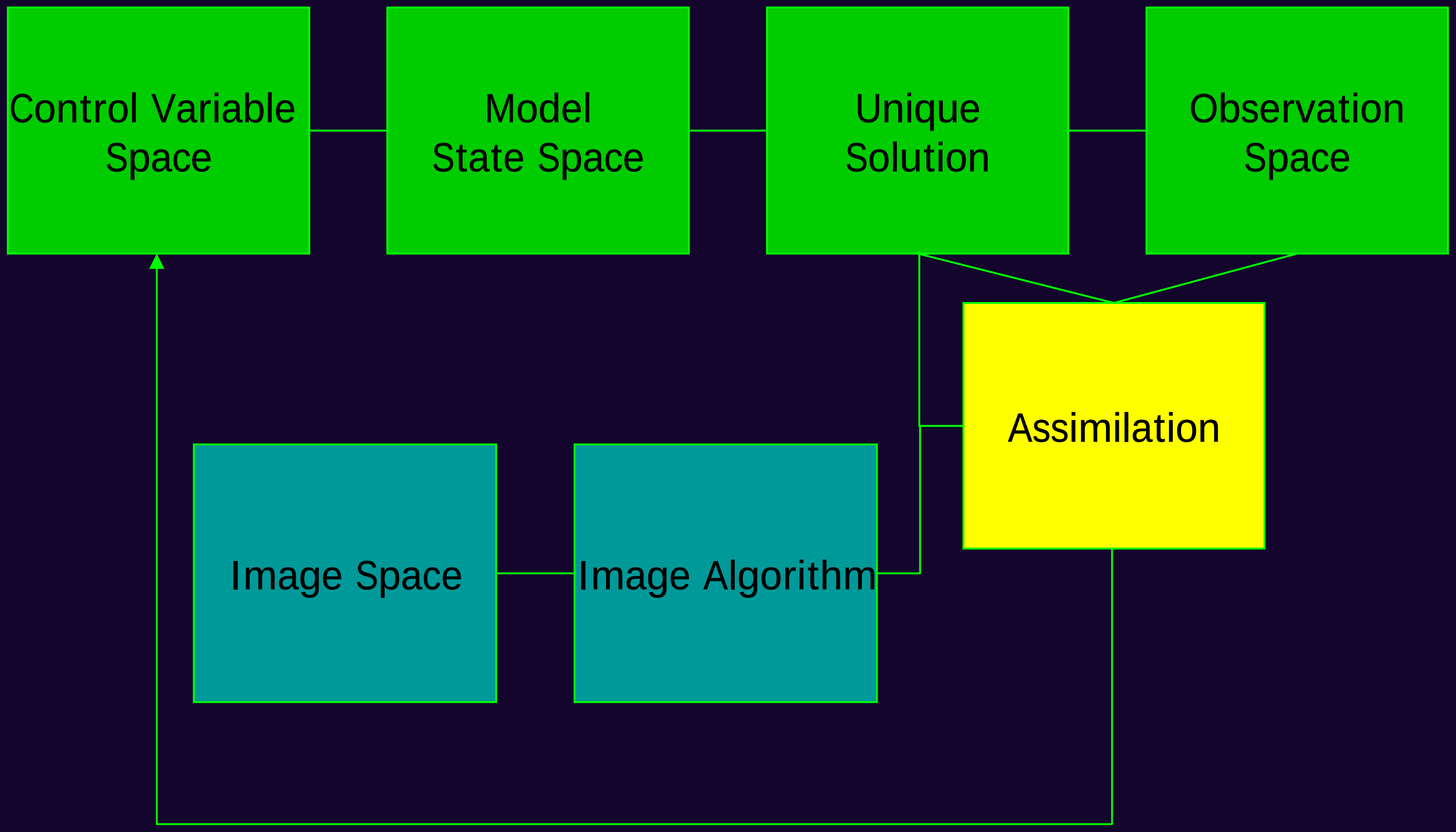


Image Data Assimilation



Problems

- **Which images:** static or dynamic.

- **Image space:** adapted to edge representation of particular structures, Lagrangian trajectories, vector field, *etc*.

- **Image operator:** to project the image space into state variable space.

- **Regularity constraint:** to extract information from images generally rely on a regularity constraint since such problem are often ill-posed.

Application to oceanography

Interesting problems

- Assimilation of:
  - **Circulation velocity**
  - **Lagrangian trajectories**
    - Coming from detection and tracking of structures
    - Velocity field integration
  - Matching of structures coming from image space and model space

Our goal

- Estimation of surface velocity circulation using satellite images

- Assimilation of estimated speed within a circulation model.

  ➔ We need to define the most appropriate method to estimate velocity.

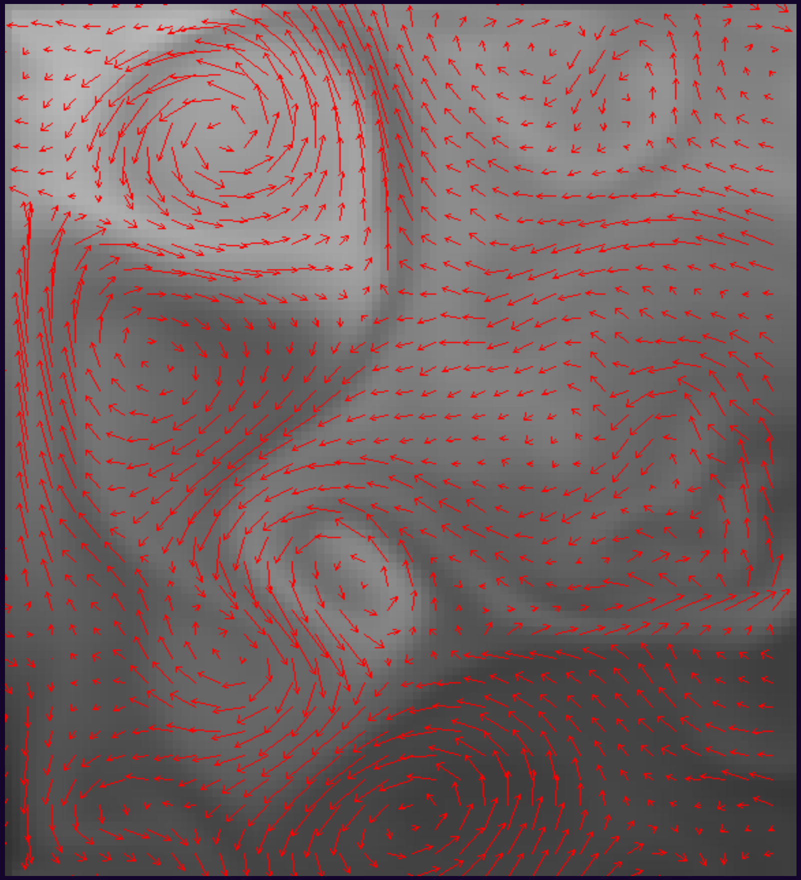
Simulated data

- OPA: 3D circulation model
- SST
- Velocity field
- Spatial resolution 5km²
- Temporal 24h
- Sample test 500km²

Données simulées

SST

Données simulées



SST et Champ de vitesses

Image processing

Motion estimation

- Conservation equation:

$$\frac{dI}{dt}(x, y, t) = \frac{\partial I}{\partial t} + \nabla I \cdot \mathbf{w} + I_t = 0$$

- Regularity constraint to solve the aperture problem

Which conservation equation?

- Luminance conservation applied to temperature

$$\frac{\partial T}{\partial t} + \nabla T \cdot \mathbf{w} = 0$$

- Temperature conservation

$$\frac{\partial T}{\partial t} + \nabla T \cdot \mathbf{w} = K_T \Delta T$$

Conclusion

- Luminance Conservation: not so bad!

  But not respected everywhere

- Temperature conservation: equivalent to luminance conservation since horizontal diffusivity is weak.

Which regularity?

1. Gradient norm:

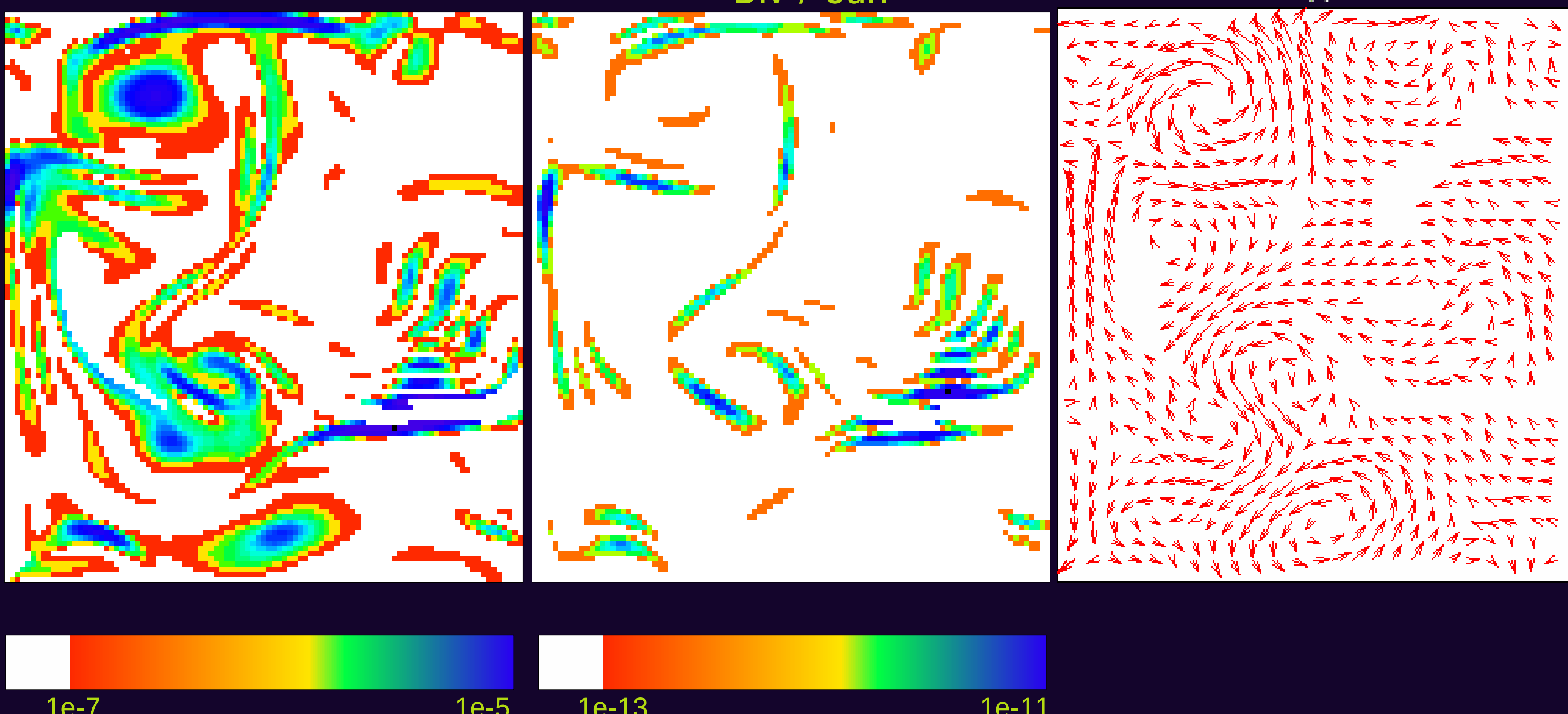
$$\min \int_{image} |\nabla \mathbf{w}|^2$$

2. Div/Curl:

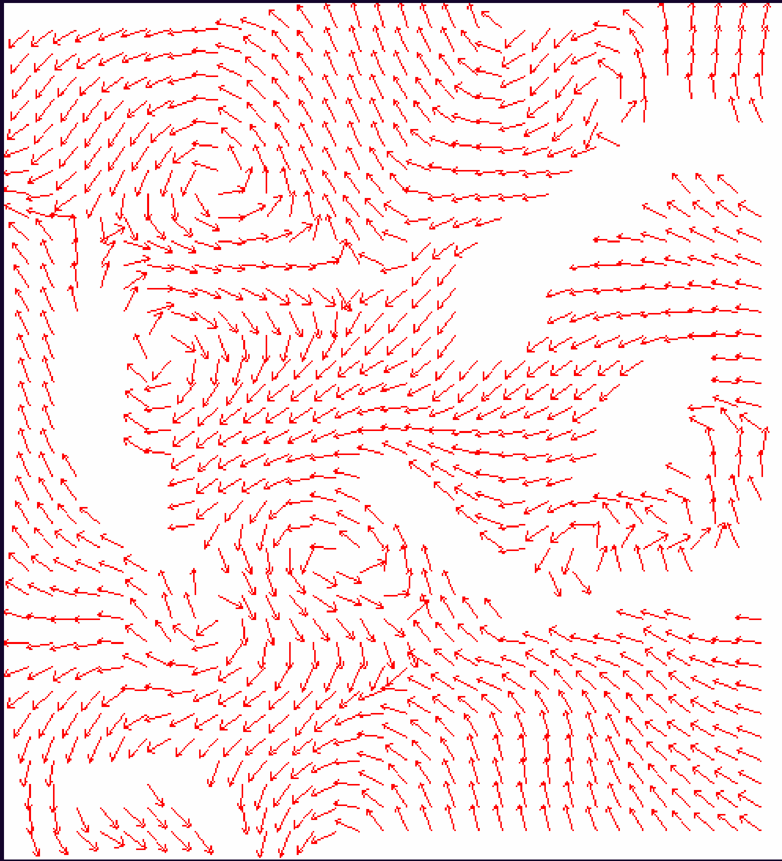
$$\min \int_{image} \alpha \|\nabla \mathrm{div} \mathbf{w}\|^2 + \beta \|\nabla \mathrm{curl} \mathbf{w}\|^2$$

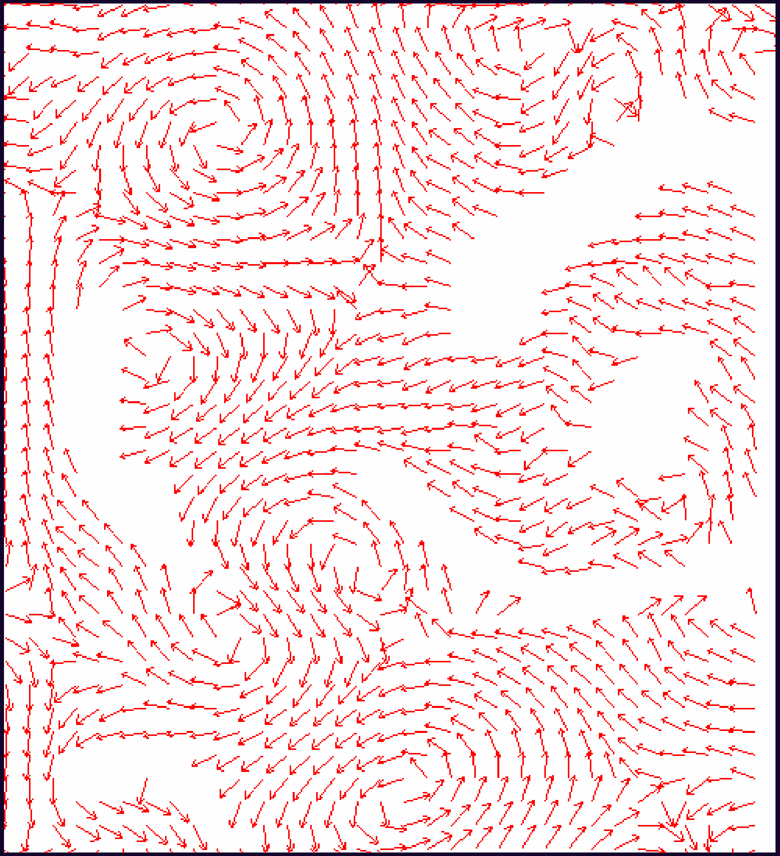
Regularity Constraints

Gradient norm | Div / Curl | w



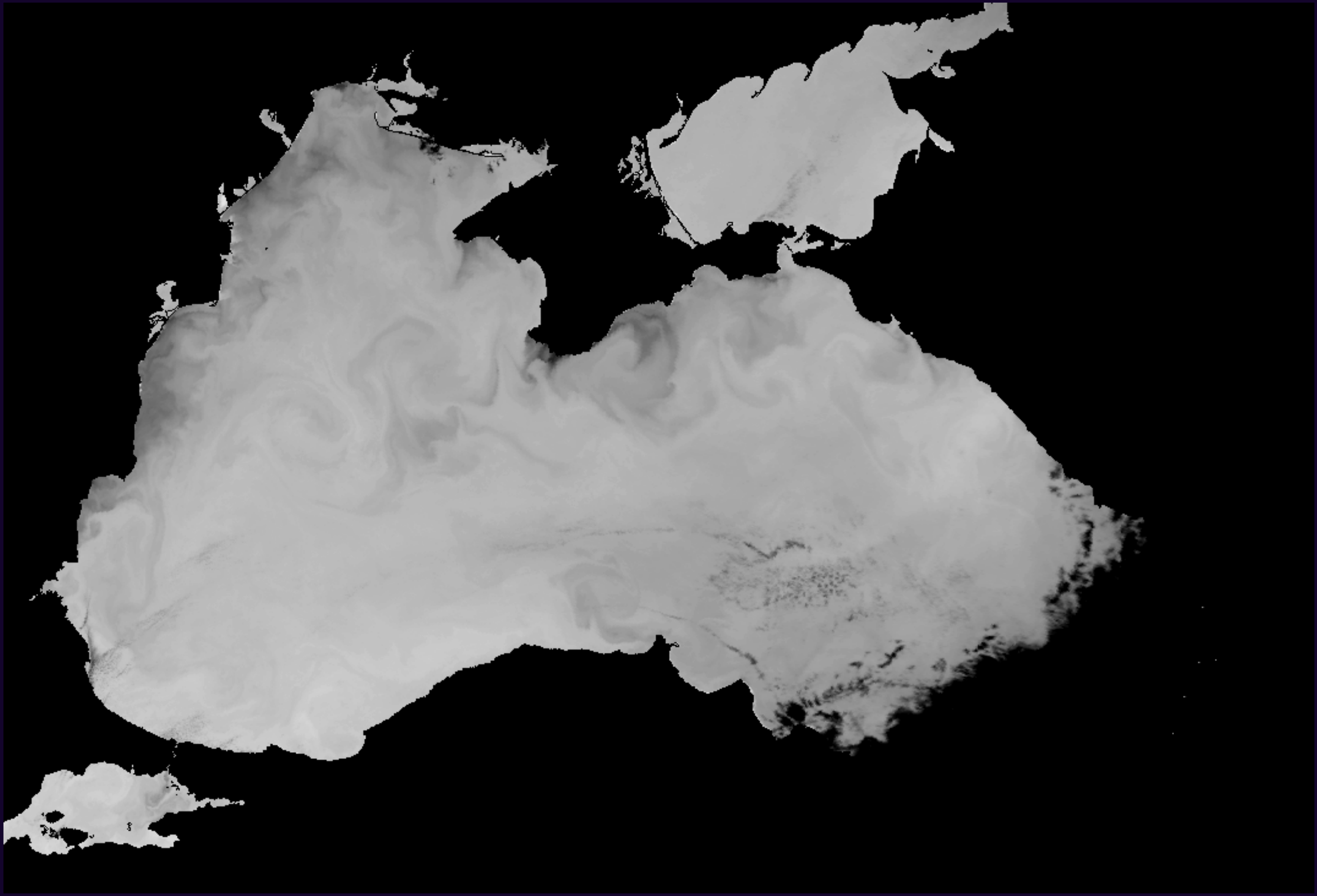
Results



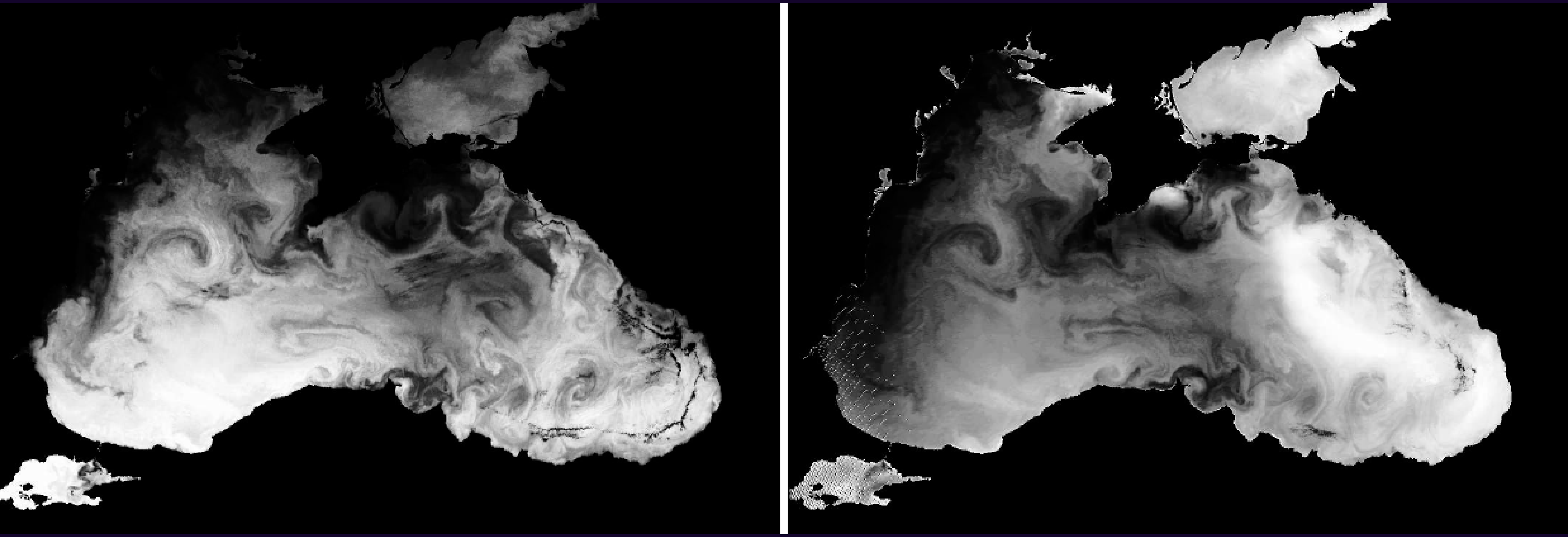


Dealing with real satellite data

NOAA-AVHRR images of the Black Sea



Two consecutive frames in the sequence



List of problems

- Clouds
- Geometry of the acquisition
- Sensor saturation
- Strong temporal variation between frames
- Large spatial variation of the local mean

Image pre-processing solutions

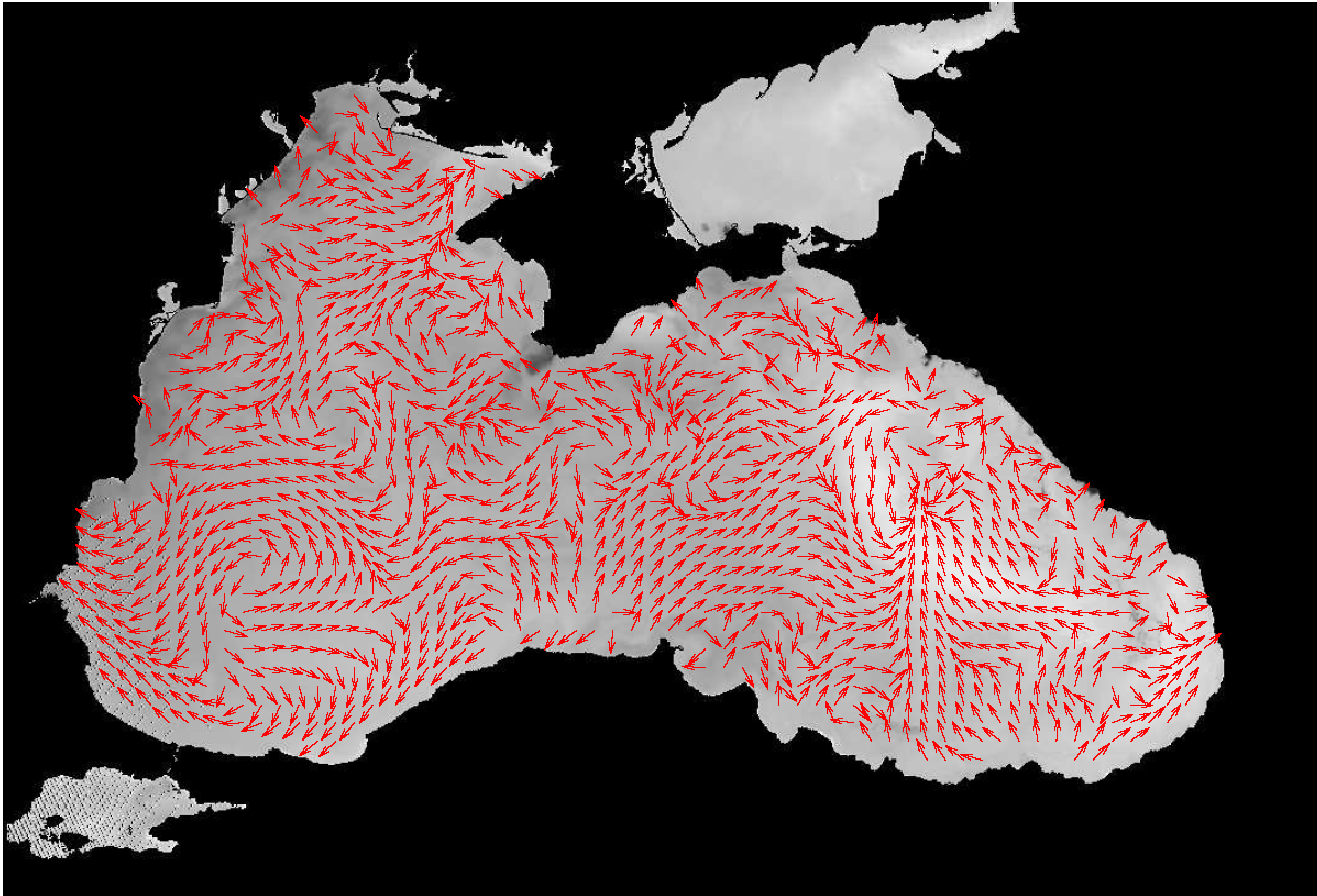
- Masks for earth, clouds and saturation
- Spatial filtering (correction of the local mean) frame by frame
- Correction of the global mean for the computation of temporal derivatives

Original image

Mask for saturation

Correction

Result for July 14th 1998



Data assimilation

Principle of data assimilation

- We can write the principle of data assimilation as:

$$\begin{cases} \dfrac{dX}{dt} = F(X, C) \\ \\ X(0) = V \end{cases}$$

where:

- X corresponds to the state variable of the model
- C is the control vector
- F is the forecast operator
- V is the initial value

Sequential data assimilation

- Kalman methods use the forecast value X and X_{obs} observation to compute the analyse:

$$a = \mathbf{K}[X_{obs} - \mathbf{H}X] + X$$

where $\mathbf{H}$ is the observation operator.

- Nudging method is a simplification, the Kalman gain matrix $\mathbf{K}$ is replaced by a constant term λ:

$$a = \lambda[X_{obs} - \mathbf{H}X] + X$$

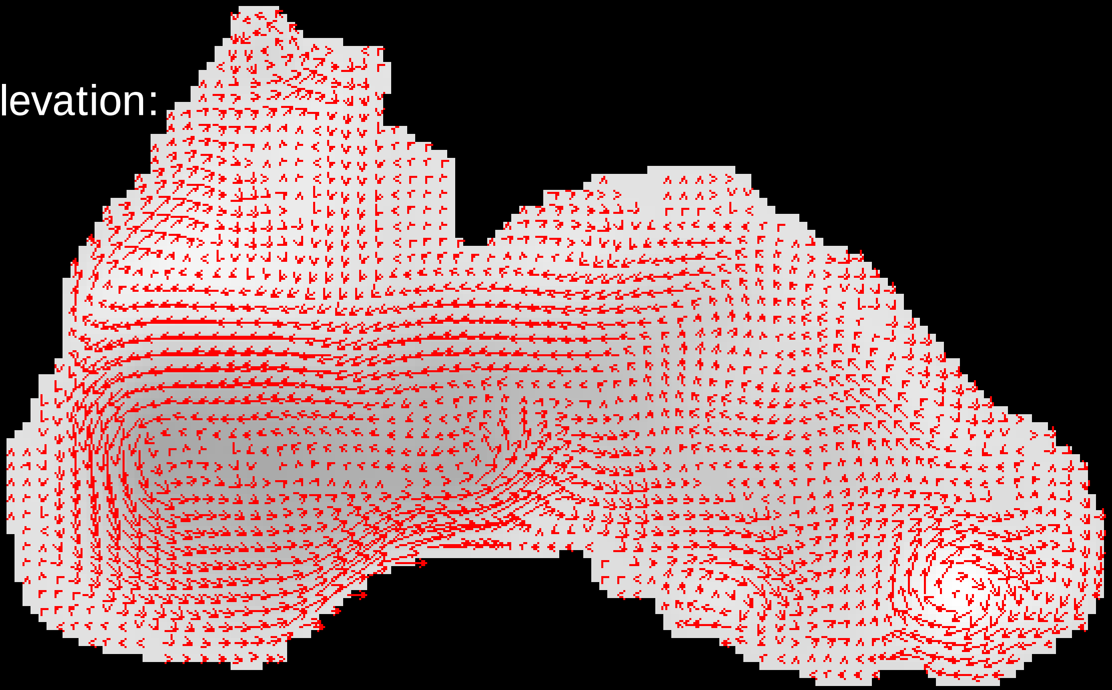
Shallow water model

$$\begin{cases} \dfrac{du}{dt} - fv = g'\dfrac{\partial h}{\partial x} + \dfrac{\tau^{(x)}}{\rho_0 h} + A_h \Delta u \\[2ex] \dfrac{dv}{dt} + fu = g'\dfrac{\partial h}{\partial y} + \dfrac{\tau^{(y)}}{\rho_0 h} + A_h \Delta v \\[2ex] \dfrac{\partial h}{\partial t} + \dfrac{\partial (uh)}{\partial x} + \dfrac{\partial (vh)}{\partial y} = 0. \end{cases}$$

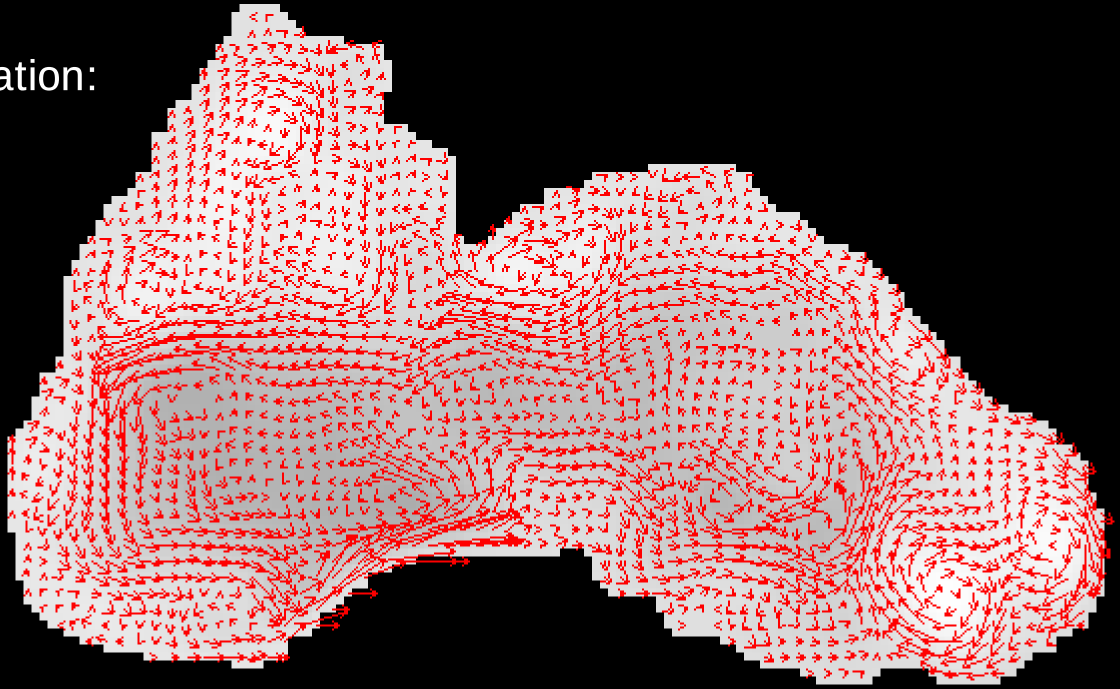
Assimilation of elevation

$$\begin{cases} \dfrac{du}{dt} - fv = g'\dfrac{\partial h}{\partial x} + \dfrac{\tau^{(x)}}{\rho_0 h} + A_h \Delta u \\[2em] \dfrac{dv}{dt} + fu = g'\dfrac{\partial h}{\partial y} + \dfrac{\tau^{(y)}}{\rho_0 h} + A_h \Delta v \\[2em] \dfrac{\partial h}{\partial t} + \dfrac{\partial (uh)}{\partial x} + \dfrac{\partial (vh)}{\partial y} = \lambda[\xi_d - \xi_m] \end{cases}$$

Without assimilation of elevation:



With assimilation of elevation:



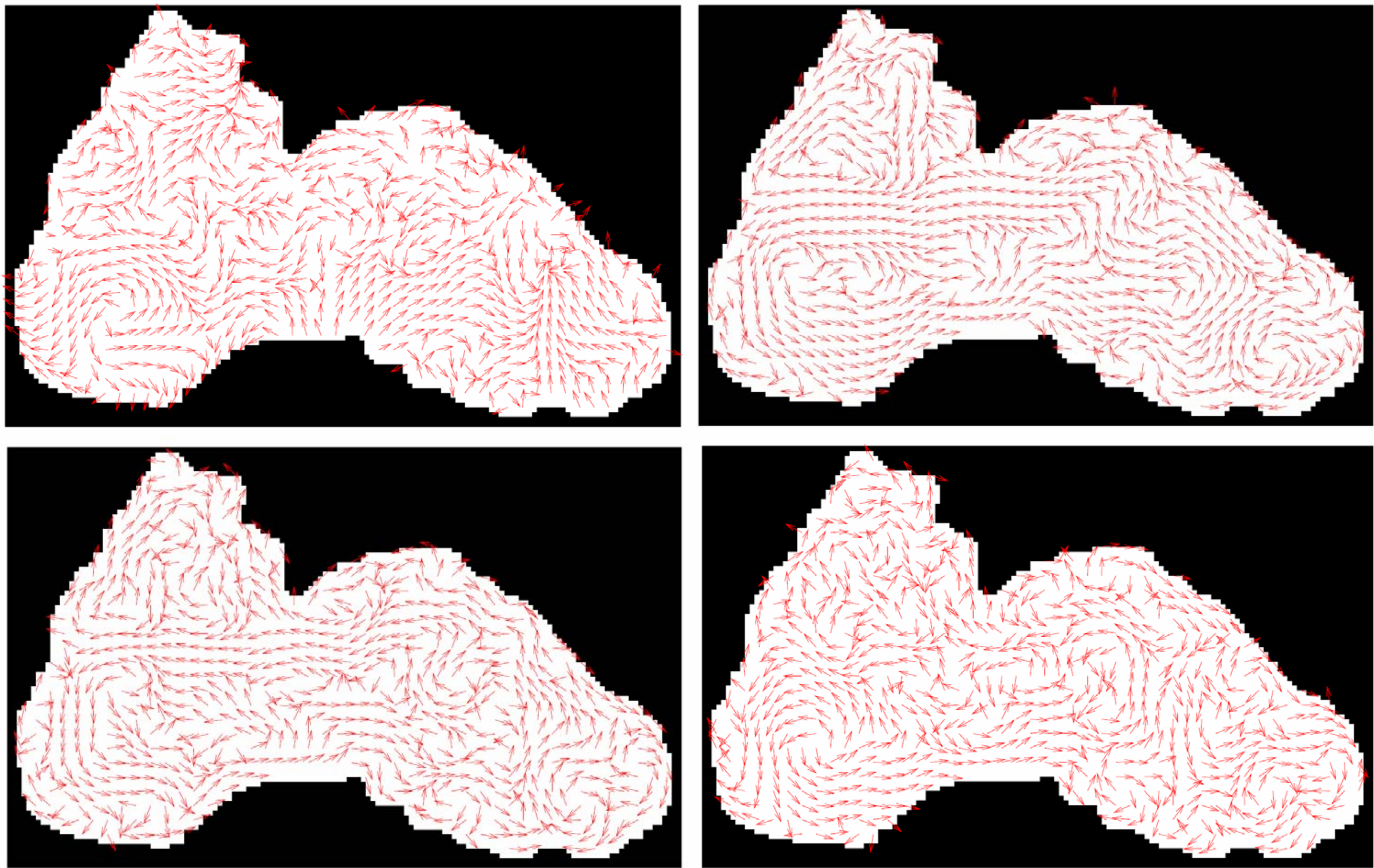
#28

Assimilation of estimated velocity

$$
\begin{cases}
\dfrac{du}{dt} \quad -fv = \quad g'\dfrac{\partial h}{\partial x} + \dfrac{\tau^{(x)}}{\rho_0 h} + A_h \Delta u \\
\qquad +\lambda \left[\dfrac{u_{obs}}{\sqrt{u_{obs}^2 + v_{obs}^2}} - \dfrac{u}{\sqrt{u^2+v^2}} \right] \times (\sqrt{u^2+v^2}) \\
\dfrac{dv}{dt} \quad +fu = \quad g'\dfrac{\partial h}{\partial y} + \dfrac{\tau^{(y)}}{\rho_0 h} + A_h \Delta v \\
\qquad +\lambda \left[\dfrac{v_{obs}}{\sqrt{u_{obs}^2 + v_{obs}^2}} - \dfrac{v}{\sqrt{u^2+v^2}} \right] \times (\sqrt{u^2+v^2}) \\
\dfrac{\partial h}{\partial t} + \dfrac{\partial (uh)}{\partial x} + \dfrac{\partial (vh)}{\partial y} = 0.
\end{cases}
$$

Results:

Comparison of results with and without assimilation



Measure of difference between fields

To quantify the difference between two fields we use two parameters:

- Average angular error: $\psi = \arccos(\mathbf{w}_1 \cdot \mathbf{w}_2)$

- Quadratic vorticity error: $\zeta = \sqrt{(\zeta_1 - \zeta_2)^2}$

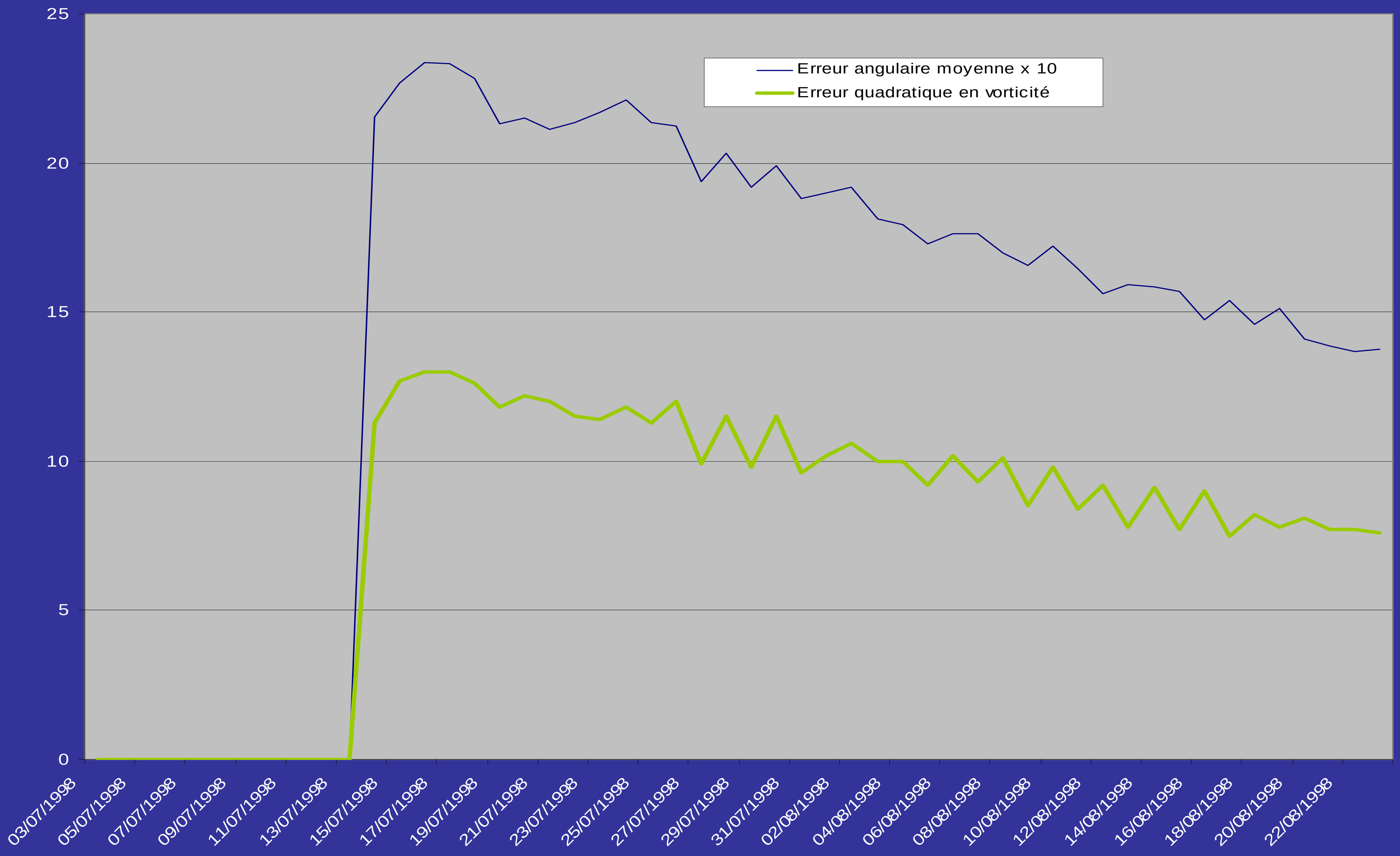
where ζ_1 and ζ_2 stands for the curl of the two fields.

Comparison of errors field to field

July 15th 1998		Forecast	Assimilation of elevation	Assimilation of velocity
Observations	ψ	28,26	28,74	22,51
	ζ	1,41	1,42	1,16
Forecast	ψ		15,76	22,4
	ζ		0,92	1,19
Assimilation	ψ			22,09
of elevation	ζ			1,12

INRIA

Evolution of errors along time



Perspectives

- Assimilation of both velocity and elevation
  - ➔ How to build the correlation matrix?
- Enhance assimilation technique
  - ➔ Kalman Filtering?
- The assimilation is made in the resolution of the model.
  - ➔ It should be better to do it in the image space.

List of questions

- What is the spatial coherence in the model?
- What the influence of holes?
- Why the vector field is so stable with no assimilation, and how explain it is not so stable with velocity assimilation?
- How much the comparison between estimated surface velocity and shallow-water velocity is realistic?
- How quantify error for model, image processing and other observation?