Assimilation of SST Satellite Images for Estimation of Ocean Circulation Velocity

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1. INTRODUCTION

The objective of this study is to compute the surface circulation velocity from oceanographic satellite acquisitions. The problem of apparent motion estimation from a sequence of images has been addressed by the image processing community for a long time. It can be tackled by solving a PDEs system composed of a conservation equation and a regularity hypothesis. On the other hand, data assimilation provides a mathematical solution to combine optimally observations and models; oceanographers use circulation models and data assimilation to estimate and forecast ocean' state.

We recently proposed [1] a new method for velocity estimation using the data assimilation framework: the available satellite images constitute observations of Sea Surface Temperature (SST) to be assimilated within a dedicated *Image Model* (*IM*). The major drawback of this approach was the lack of physical meaning of the evolution equations used in the *IM*. To take into account the physic of underlying processes, it is possible to consider estimated velocities as pseudo-observations and, further assimilated in a physical circulation model [2].

In this paper we propose to define a new *Image Model* taking into account the physical knowledge of ocean processes. This so-called *Extended Image Model* (*EIM*) is based on both image evolution properties and some physical equations expressing the evolution of the ocean state. Variational data assimilation is used to assimilate SST observations into the *EIM* and estimate ocean surface velocity.

2. STATE OF THE ART

Ocean surface velocity can be estimated by image processing techniques applied to sequences of satellite images. Classical methods [3] rely on a conservation equation designed for rigid or fluid motion [4, 5, 6]. But the conservation equation relies on the spatial and temporal derivatives of the image sequence, missing data on the acquisition damage estimation results. This is crucial with SST data that can be significantly occluded by clouds. Recently, the image processing community has been interested in data assimilation approaches [2, 7, 8], which provides an optimal way to deal with missing data. According to the same idea, we introduced [1] an *Image Model*, expressed in the image space, that expresses a link between SST and surface velocity:

$$\begin{cases} \dfrac{\partial T}{\partial t} + \nabla T \cdot \mathbf{v} = K_T \Delta T \\[2mm] \dfrac{\partial u}{\partial t} = 0 \\[2mm] \dfrac{\partial v}{\partial t} = 0, \end{cases} \tag{1}$$

where the first equation is a simplification of the advection-diffusion formalism governing the transport of temperature of an uncompressible fluid; K_T stands for the temperature diffusivity parameter. The two other equations constrain the evolution of the two velocity components $\mathbf{v} = (u, v)$ through an hypothesis of a constant velocity field. SST satellite data are assimilated into the *IM* in order to estimate de surface velocity.

The major drawback of this approach is that the evolution equations of velocity have no physical interpretation.

3. EXTENDED IMAGE MODEL

To define an *Extended Image Model* with a physical meaning, it is necessary to address ocean modelizations done by oceanographers and numericians. As a first step, we are interested in shallow water models which link the 2D velocity of the merged layer of the ocean associated to the thickness h of this layer. The *EIM* definition is based on the same transport equation of temperature as the *IM* but the velocity evolution equations come from the shallow water model:

$$\begin{cases} \dfrac{\partial T}{\partial t} + \nabla T \cdot \mathbf{v} = K_T \Delta T \\[2mm] \dfrac{du}{dt} - fv = g' \dfrac{\partial h}{\partial x} + K_v \Delta u \\[2mm] \dfrac{dv}{dt} + fu = g' \dfrac{\partial h}{\partial y} + K_v \Delta v \\[2mm] \dfrac{\partial h}{\partial t} + \dfrac{\partial (uh)}{\partial x} + \dfrac{\partial (vh)}{\partial y} = 0, \end{cases} \tag{2}$$

where f is the Coriolis parameter; K_v the viscosity coefficient; $g' = g(\rho_0 - \rho_1)/\rho_0$ the reduced gravity, with ρ_0 corresponding to the reference density and ρ_1 to the average density of the mixed layer.

4. VARIATIONAL DATA ASSIMILATION

Estimation of surface velocity is performed using a variational 4DVAR data assimilation scheme. Satellite SST acquisition is an observation of the state variable T, and $\mathbf{v}$ is estimated minimizing the discrepancy between the model's outputs and the observations. This is formulated as:

$$\begin{cases} \dfrac{\partial X}{\partial t} + F(X) = \varepsilon_m \\ X(t_0) = X_0 + \varepsilon_b \\ Y = H(X) + \varepsilon_o \end{cases} \tag{3}$$

where the first equation is the evolution model (2), with state variable $X = (T, u, v, h)$; the second equation is the initial condition; and the third equation links the observations Y to the state variables X through the observation operator H. ε_m, ε_b, ε_o stands for errors on model, initialisation and observations respectively.

In order to deal with a simpler problem, we are considering several assumptions: the model is consider to be perfect $\varepsilon_m = 0$; we haven't any knowledge on the background $\varepsilon_b = 0$; and observation errors are uncorrelated.

The data assimilation procedure consists in minimizing the energy functional J, that depends upon the control X_0:

$$J(X_0) = \frac{1}{2} \int_{\Omega,t} (H(X) - Y)^{\mathrm{T}} \mathbf{R}^{-1} (H(X) - Y) dxdydt \tag{4}$$

Minimization is performed using a quasi-Newtown involving the adjoint of system (3).

5. CONCLUSION

This paper presents a velocity estimation method applied to oceanographic image sequences. It is based on variational assimilation of image information into a dedicated image model. The method has two major advantages: it can deal with missing data due to cloud occlusion, and it takes into account some physical knowledge of the ocean circulation.

6. REFERENCES

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7. ACKNOWLEDGEMENTS

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