A Multifractal approach for sun glint in medium resolution satelite imagery

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A MULTIFRACTAL APPROACH FOR SUN GLINT IN MEDIUM RESOLUTION SATELITE IMAGERY

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ABSTRACT

Sun glint, the specular reflection of sunlight off the ocean surface and into the satellite sensor, compromises data processing in ocean remote sensing imagery. Several correcting algorithms and models have been developed to improve satellite high-level products quality in glint-contaminated areas. Some rely on radiative transfer equations and others on in-scene information analysis, but most of these methods are based on an estimation of the sun glint contribution in terms of radiance.

In this paper, we introduce a new approach for sun glint study in medium resolution satellite images, derived from multiscale/multifractal techniques. Since sun glint introduces long range effects and occurs at a scale much smaller than pixel dimensions, multiscale techniques are well suited to analyse such complex signals and are able to extract features related to the oceanic flows. First, we apply a multifractal decomposition scheme to generate the signal singularity exponents and retrieve the so-called "most singular manifold". Using the main streamlines of the signal, we compute a reduced image containing the same multiscale structures as the original one but a naive distribution of the gradient.

We will then show that the correlation between the original image and the reduced one, also known as the source field in the microcanonical multiscale formalism, displays a signature related to the presence of sun glint.

INTRODUCTION

The revolution introduced by remote sensing and the increasing amount of data collected by earth observing satellites are expected to deliver major advances in earth observational geophysical sciences. In a socio-political context where global warming and climate changes have become a priority, cooperations between different scientific communities are quickly gearing towards a better understanding of the Atmosphere/Ocean interactions. Although products from medium resolution satellites provided great success in the fields of geophysical phenomena and ocean processes modelling, many issues currently persist and are yet to be solved. Among these issues, sun glint is the most recurrent one.

Since Cox/Munk's model [1] established more that a half century ago, many different approaches have been suggested in the literature to deal with the sun glint issue, however, most of them rely on a sun glint radiance estimation through complex radiative transfer modelling [2-3] or in-scene information analysis [4-5]. Given the huge multidisciplinary interest in the study of ocean tracers dynamics, the exact value of a given pixel radiance is of poor interest compared to the local variations that can be observed within a specific geophysical signal. In medium resolution imagery, suffice it to notice the small-scale effect associated with sun glint, to immediately invoque multiscale techniques.

In this paper, we make use of the most known "microcanonical multiscale formalism" (MMF) as a new approach for sun glint in medium resolution images. On the assumption that sun glint and atmospheric effects have little impact on the signal local behaviour, multiscale techniques should be able to detect many sharp transitions that correspond to oceanic features such as sea surface temperature or water-leaving radiance streamlines.

This paper is organised as follows: In section 2, we present the basis of the multifractal decomposition scheme used to generate the singularity exponents and retrieve the "most singular manifold". In section 3, we illustrate the results obtained on MODIS images. The chromatically reduced signal and source field framework will also be presented in this section. Discussion, conclusion and future work are given in section 4.

SECTION II: MICROCANONICAL MULTISCALE FORMALISM

In the following sub-section, we outline the main concepts of our approach. However, the reader is invited to read [6-7] for a complete presentation of the theoretical background and experimental results obtained with the MMF.

Singularity Exponents

The fundamental idea of the MMF consists in defining a local singularity exponent for each pixel of an acquired signal.

In the following, we denote $I(\vec{x})$ the signal associated to the image, where $\vec{x}$ represents the two-spatial coordinates of a pixel. Using the modulus of the image spatial gradient $\|\nabla I\|(\vec{x})$, we define the density measure μ as:

$$d\mu = \|\nabla I\| d\vec{x} \tag{1}$$

Since I is defined over a compact subset $A \subset \mathbb{R}^2$

$$\mu(A) = \int_A d\vec{x} \|\nabla I\|(\vec{x}) \tag{2}$$

For a wide variety of geophysical signals [8-9], the measure μ behaves in such a way that every pixel $\vec{x}$ of the image satisfies the following power-law behaviour equation:

$$\mu\left(B_r\left(\vec{x}\right)\right) = \alpha\left(\vec{x}\right) r^{d+h(\vec{x})} + o\left(r^{d+h(\vec{x})}\right) \tag{3}$$

where B_r is a ball of radius r centred at $\vec{x}$ and d the space dimension (d=2).

The coefficient $h(\vec{x})$ in the previous equation is the local singularity exponent. This exponent quantifies the local transition of grey level values in each pixel of the image. In practice, a direct log-log linear regression on the previous formula will provide inaccurate numerical results for the exponents due to the discretization of the radius r. To overcome this issue, we take advantage of the fact that a wavelet projection of the measure defined in (2) also scales as a power law in r, with the same parameter $h(\vec{x})$. Let ψ be an appropriate wavelet. The projection of μ over ψ at the point $\vec{x}$ is given by:

$$\mathrm{T}_\psi \mu\left(\vec{x}, r\right) \equiv \int d\mu\left(\vec{y}\right) \frac{1}{r^d} \psi\left(\frac{\vec{x}-\vec{y}}{r}\right) \tag{4}$$

and satisfies the following law:

$$\mathrm{T}_\psi \mu\left(\vec{x}, r\right) = \alpha_\psi\left(\vec{x}\right) r^{d+h(\vec{x})} + o\left(r^{d+h(\vec{x})}\right) \tag{5}$$

The singularity coefficients $h(\vec{x})$ are then obtained with a linear regression between $\log\left(\mathrm{T}_\psi \mu\left(\vec{x}, r\right)\right)$ and $\log r$.

In the MMF, the singularity exponents have proven to hold a very good description of the thermodynamic power-law behaviour associated with turbulent phenomena in sea surface temperature [8].

Most Singular Manifold

According to [11], the existence of a multifractal measure implies an organisation of the signal in multifractal sets which dimensions can be predicted by its statistical properties. By assigning to each a singularity exponent, the image can be decomposed into several hierarchical sets that correspond to superstructures with the same geometrical and statistical properties.

In the MMF theory, experimentation shows that the singularity spectrum is bounded and that there exists a specific exponent h_∞, called the most singular exponent that characterizes the strongest irregularities of the signal.

We define the Most Singular Manifold (also denoted $\tilde{F}_\infty$) as the following set of pixels:

$$\tilde{F}_\infty \equiv \left\{ \vec{x} : h\left(\vec{x}\right) = h_\infty \right\} \tag{6}$$

In the implementation process, we also take into consideration the parameter Δh that allows us to define the range of values retained for $\tilde{F}_\infty$. In other words, the level-set $\tilde{F}_\infty$ contains all the pixels which singularity exponent lays in the interval $\left[h_\infty - \Delta h \ ; \ h_\infty + \Delta h\right]$. From a statistical point of view, the MSM will contain most of the signal's information. Therefore using only the spatial gradient over pixels of the MSM, it is possible to estimate the intensity field of every pixel and to compute the fully reconstructed image (FRI) with the following reconstruction formula:

$$I\left(\vec{x}\right) = \vec{g} \otimes \overrightarrow{\nabla I_\infty}\left(\vec{x}\right) \tag{7}$$

where $\otimes$ is the convolution symbol, $\overrightarrow{\nabla I_\infty}$ is the essential gradient (equals $\overrightarrow{\nabla I}\left(\vec{x}\right)$ over the MSM and 0 elsewhere) and $\vec{g}$ is the universal reconstruction kernel. In Fourier space, the kernel propagator can be expressed as:

$$\hat{\vec{g}}\left(\vec{f}\right) = i\frac{\vec{f}}{\left|\vec{f}\right|^2} \tag{8}$$

leading to the following reconstruction formula in Fourier space:

$$\hat{I}\left(\vec{f}\right) = \frac{i\,\vec{f}.\overrightarrow{\nabla I_\infty}\left(\vec{f}\right)}{f^2} \tag{9}$$

where $\vec{f}$ is the frequency vector and i the imaginary unit ($i = \sqrt{-1}$).

Reduced Image

In this section, we go further in the multifractal analysis in order to characterise the sun glint.
The concept of chromatically reduced image has been initially introduced in [9] and applied to meteorological images to improve the detection of rainfall areas. It relies on the separation of the luminance distribution from the multifractal sets of the signal. The chromatically reduced image is computed so that it contains the same distribution of singularity exponents than the original image. Consequently, the reduced signal will display the same multifractal structures as the original one, but it will have a different distribution of the gradient over the MSM.

The reduced image essential gradient ∇I_R is computed so that:

- $\left|\overrightarrow{\nabla I_R}\right|\left(\vec{x}\right)=\begin{cases}1 & if\ \vec{x}\in \text{MSM}\\ 0 & otherwise\end{cases}$

- $\overrightarrow{\nabla I_R}\left(\vec{x}\right)\perp MSM$

- $\overrightarrow{\nabla I_R}\left(\vec{x}\right).\overrightarrow{\nabla I}\left(\vec{x}\right)>0$ ($\overrightarrow{\nabla I_R}\left(\vec{x}\right)$ and $\overrightarrow{\nabla I}\left(\vec{x}\right)$ have the same orientation)

The reduced image I_R is then obtained using the reconstruction formula (7) and replacing $\overrightarrow{\nabla I_\infty}$ by $\overrightarrow{\nabla I_R}$.

Source Field

The source field expresses the relationship existing between the original image and its reduced part.
Since these two images have exactly the same multifractal structure, the source field can be viewed as a non-multiscaling functional representative of the image dynamics.

To define the source field, we generalize the multifractal measures defined in equation (2) to vector valued measures $\overrightarrow{\mu_I}$ and $\overrightarrow{\mu_{I_R}}$ by integrating the gradient vector instead of its norm:

$$\overrightarrow{\mu_I}(A)=\int_A d\vec{x}\ \nabla I(\vec{x}) \tag{10}$$

and

$$\overrightarrow{\mu_{I_R}}(A)=\int_A d\vec{x}\ \nabla I_R(\vec{x}) \tag{11}$$

The complex vectorial source field is then defined as the Radon-Nykodin derivative:

$$\vec{\rho}\left(\vec{x}\right)=\lim_{r\to 0}\frac{\overrightarrow{\mu_I}\left(B_r\left(\vec{x}\right)\right)}{\overrightarrow{\mu_{I_R}}\left(B_r\left(\vec{x}\right)\right)} \tag{12}$$

Because the source field represents the ratio between two multifractal measures, it's reasonable to assume that it will contain an information independent of the ocean tracers turbulent character.

SECTION III: APPLICATION TO OCEANOGRAPHIC MODIS DATA

In this study, we have used both MODIS Terra and Aqua Level 1B data consisting of calibrated Top Of Atmosphere (TOA) radiances at 1km resolution, downloaded from http://ladsweb.nascom.nasa.gov/ and the corresponding level 2 products downloaded from http://oceancolor.gsfc.nasa.gov/.

Singularity Exponents and Sun Glint

The goal of this sub-section is to show that in spite of the long range effect introduced by sun glitter, some of the information related to oceanic tracers streamlines is yet accessible through multiscale techniques.

To illustrate this idea, we have selected a 512×512 sub-image with moderate sun glint, extracted from a Modis Aqua image captured on August 3 2007, in the Mediterranean Sea.

Figure 1 shows the singularity exponents computed on both band 23 (4 µm) and 31 (11µm).

The reason why these bands have been chosen for our study relies on the fact that they are both used for the retrieval of Modis level 2 Sea Surface Temperature. Whereas the emissive bands 31 (11µm) and 32 (12µm) always provide a reliable SST, the computation of the STT with short wave bands 22 and 23, is generally discarded for day time measurements because of sun glint. However, as seen in figure (1), it is clear that despite the sun glitter effect, the MMF is still able to extract many significant superstructures that can be correlated with those extracted in long wave bands.

In figure (2), we have computed the singularity exponents on the level 2 SST and the 412 nm water-leaving radiance corresponding to the same time period and location as figure (1). Once again, several identical features can be identified through the multiscale singularity analysis, confirming the idea that sun glint and atmospheric effects do not significantly alter the multifractal character of the oceanic flows.

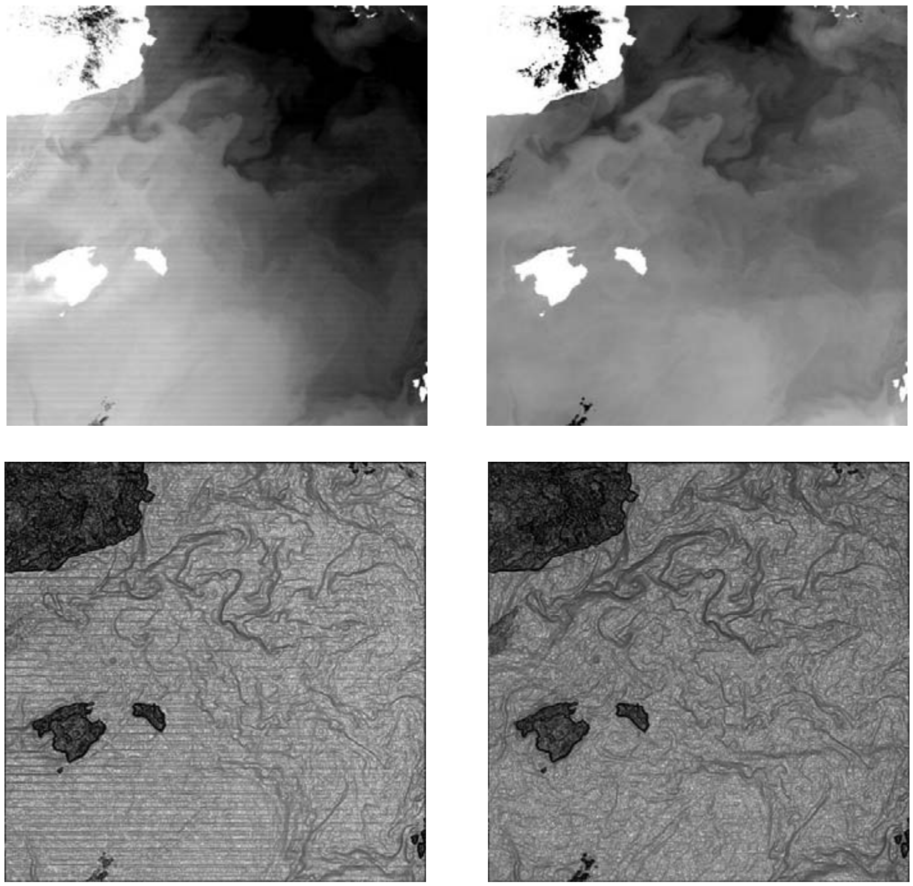

Figure 1. Top: Image from Modis Aqua band 23 (4.020-4.080 µm) captured on August 3 2007 in the Mediterranean Sea affected by sun glint. The sun glint intensity gradually decreases from left to right. The two islands in the middle left are Minorqua and Majorqua **(left)**; Image from Modis Aqua band 31 (10.780-11.280 µm). Modis band 31 is used to retrieve the day time SST and offers the advantage of glint free data **(right)**.
Bottom: Graylevel representation of the singularity exponents computed on band 23 **(left)** and band 31**(right)**;
The brighter the pixel, the greater the singularity at this point.

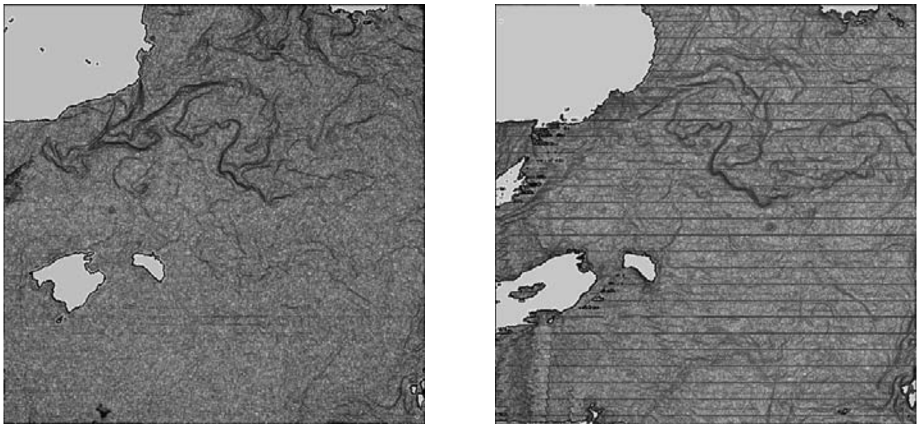

Figure 2. Graylevel representation of the singularity exponents computed on Modis level 2 SST **(left)** and 412 nm water-leaving radiance **(right)**.

Besides the numerous common filamentary structures observed in figure (1) and figure (2), it is interesting to point out that the singularity exponents are also contaminated with striping effect. The scan line noise due to imperfect detectors calibration introduces periodic lines in the singularity exponents that do not reflect any real geometrical irregularities and therefore harden the analysis of the signal dynamics.

Characterisation of Sun Glint

The source field framework, which theoretical content has been presented in section 2 is used here to characterize the presence of sun glint in images. The information contained in the source field illustrates the existing deviation between the original signal and its reduced part leading the later to act as a synthetic template containing all the multiscale features. Because the original image and the reduced one both share the same multifractality, strong deviations in the source field will be automatically associated with perturbations that do not hold any particular multiscale properties.

In figure (3), we illustrate the reduced image and source field framework on a 512×512 sub-image extracted from a Modis Terra image captured on August 1 2008, in the Mediterranean Sea, and heavily affected by sun glint. The island at the left top corner is Sicily.

A clear signature can be seen in the source field, in the middle of the glinted area. It appears as a concentration of poles and zeros in the modulus of the source field. To make sure that this signature is related to the sun glint, the source field has been also computed in the band 17 (890-920 nm), where the water leaving radiance is known to be very weak.

This characterization of sun glint with the source field framework is quite promising if we keep in mind the fact that any signal is reconstructable just knowing its reduced part and the source field.

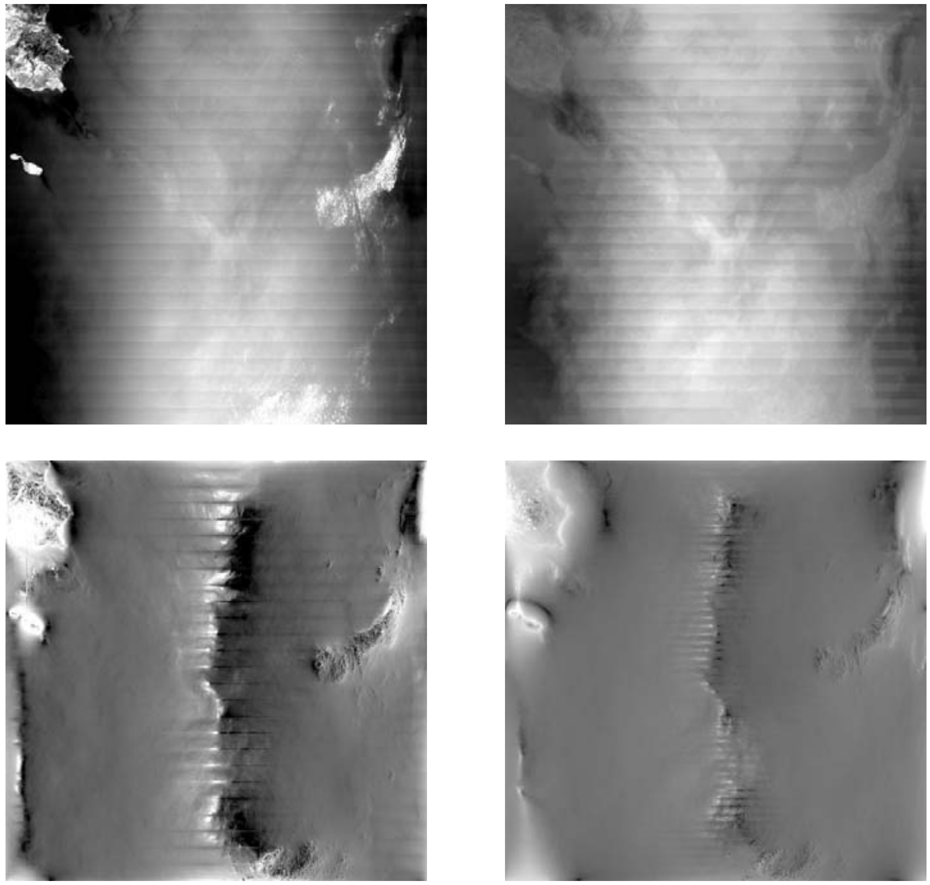

Figure 3. Top: Image from Modis Terra band 10 (483-493 nm), captured on August 1 2008, in the Mediterranean Sea; the island in the top right corner is Sicily **(left)**. Chromatically Reduced Image **(right)**.
Bottom: Modulus of the source field computed on band 10 **(left)** and band 17 (890-920 nm) **(right)**. The greater is the modulus, the brighter is the point according to a logarithmic scale. A clear vertical signature can be seen in the source field in both band 10 and 17.

SECTION IV: DISCUSSION AND CONCLUSION

In this paper we have introduced a new approach to analyse medium resolution images contaminated with sun glint.

The detection of filamentary structures within areas affected by sun glint underlines the potential of the MMF to process oceanographic data through singularity analysis and constitutes a preliminary result that deserves further work. Application of the MMF on Modis level 1B TOA radiances and level 2 products displayed many interesting similarities in the extracted streamlines. It is obvious that sun glint and atmospheric components have their own multifractal distribution, but their contribution to the TOA signal do not always mask the sharp transitions associated with water leaving radiance or SST features, which allows multiscale techniques such as the MMF to extract them.

The source field framework presented in section 2c and 2d offers an interesting decomposition of the image, in that a robust modification of the source field could reduce the effects of sun glint and therefore improve the detection and classification of the observed singularities. However, the manipulation of the source field is extremely sensitive and further research is being conducted to reconstruct an image with a modified source field without introducing any artefacts.

Also, with our multifractal approach, the detection of geometrical structures associated with ocean flow dynamics, relies on the assumption that the sun glint contribution to the signal can be considered as an additive smooth radiance without any strong geometrical irregularities.

However, we have noticed that in many cases, Modis images display anomalous features that appear as “glint gaps” within the characteristic white stripe. For instance, it is well know that in medium resolution satellite imagery, sun glint tends to highlight many phenomena such as oil slicks or internal waves [10].

Future improvement of our work consists in providing an accurate discrimination of the extracted features. A possible methodology could be to integrate in the MMF algorithms, additional data related to the sun glint spectral properties.

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