



Activity Report 2013

## **Project-Team GEOSTAT**

Geometry and Statistics in acquisition data

RESEARCH CENTER  
**Bordeaux - Sud-Ouest**

THEME  
**Optimization, machine learning and  
statistical methods**



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# Project-Team GEOSTAT

**Keywords:** Signal Processing, Multiscale Analysis, Complexity, Statistical Methods, Statistical Physics

*Creation of the Team:* 2009 November 01, *updated into Project-Team:* 2011 January 01.

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## 2. Overall Objectives

### 2.1. Overall objectives

**Singularity exponent** A measure of the unpredictability around a point in a complex signal. Based on local reconstruction around a point, singularity exponents can be evaluated in different ways and in different contexts (e.g. non-localized, through the consideration of moments and structure functions, through the computation of singularity spectra). In GEOSTAT we study approaches corresponding to *far from equilibrium* hypothesis (e.g. microcanonical) leading to geometrically localized singularity exponents.

**Singularity spectrum** The mapping from scaling exponents to Hausdorff dimensions. The singularity spectrum quantifies the degree of nonlinearity in a signal or process, and is used to characterize globally the complexity of a signal.

**Most Singular Manifold** The set of most unpredictable points in a signal, identified to the set of strongest transitions as defined by the singularity exponents. From that set the whole signal can be reconstructed.

**Adaptive Optics (AO)** This term refers to a set of methodologies used, notably in Astronomical observations, to compensate for the loss of spatial resolution in optical instruments caused by atmospheric turbulence.

**Compact Representation** Reduced representation of a complex signal (dimensionality reduction) from which the whole signal can be reconstructed. The reduced representation can correspond to points randomly chosen, such as in Compressive Sensing, or to geometric localization related to statistical information content (framework of reconstructible systems).

**MMF** Microcanonical Multiscale Formalism.

**Sparse representation** The representation of a signal as a linear combination of elements taken in a dictionary, with the aim of finding the most sparse possible one.

**Optimal wavelet (OW).** Wavelets whose associated multiresolution analysis optimizes inference along the scales in complex systems.

**Universality class** In theoretical physics, the observation of the coincidence of the critical exponents (behaviour near a second order phase transition) in different phenomena and systems is called universality. Universality is explained by the theory of the renormalization group, allowing for determination of the changes a physical system undergoes under different distance scales. As a consequence, different macroscopic phenomena displaying a multiscale structure (and their acquisition in the form of complex signals) can be grouped into different sets of universality classes.

GEOSTAT is a research project in **nonlinear digital signal processing**, with the fundamental distinction that it considers the signals as the realizations of complex dynamic systems. The driving approach is to understand the relations between complexity (or information content) and the geometric organization of information in a signal. For instance, for signals which are acquisitions of turbulent fluids, the organization of information is related to the effective presence of a multiscale hierarchy, of multifractal nature, which is strongly related to intermittency and multiplicative cascade phenomena; the determination of this geometric organization unlocks key nonlinear parameters and features associated to these signals; it helps understanding their dynamical properties and, as a consequence, their analysis. Specific advances are obtained in GEOSTAT in using this type of statistical/geometric approach to get validated dynamical information of signals acquired in Universe Sciences, e.g. Oceanography or Astronomy. The research in GEOSTAT encompasses nonlinear signal processing and the study of emergence in complex systems, with a strong emphasis on geometric approaches to complexity. Consequently, research in GEOSTAT is oriented towards the determination, in real signals, of quantities or phenomena, usually unattainable through linear methods, that are known to play an important role both in the evolution of dynamical systems whose acquisitions are the signals under study, and in the compact representations of the signals themselves. Hence we first mention:

- Singularity exponents,
- how singularity exponents can be related to *sparse representations* with reconstruction formulae,
- comparison with embedding techniques, such as the one provided by the classical theorem of Takens [59], [52].
- Lyapunov exponents, how they are related to intermittency, large deviations and singularity exponents,
- various forms of entropies,
- multiresolution analysis, specifically when performed on the singularity exponents,
- the cascading properties of associated random variables,
- persistence along the scales, *optimal wavelets*,
- the determination of subsets where statistical information is maximized, their relation to reconstruction and compact representation,
- comparison with other approaches such as Compressive Sensing,

and, above all, **the ways that lead to effective numerical and high precision determination of nonlinear characteristics in real signals**. The MMF (Multiscale Microcanonical Formalism) is one of the ways to partly unlock this type of analysis, most notably w.r.t. singularity exponents and reconstructible systems [11]. We presently concentrate our efforts on it, but GEOSTAT is intended to explore other ways [48]. Presently GEOSTAT explores new methods for analyzing and understanding complex signals in different applicative domains through the theoretical advances of the MMF, and the framework of **reconstructible systems** [60]. Derived from ideas in Statistical Physics, the methods developed in GEOSTAT provide new ways to relate and evaluate quantitatively the *local irregularity* in complex signals and systems, the statistical concepts of *information content* and *most informative subset*. That latter notion is developed through the notion of *transition front* and *Most Singular Manifold*. As a result, GEOSTAT is aimed at providing *radically new approaches* to the study of signals acquired from different complex systems (their analysis, their classification, the study of their dynamical properties etc.). A common characteristic of these signals, which is related to *universality classes* [55] [56] [53], being the existence of a *multiscale organization* of the systems. For instance, the classical notion of *edge* or *border*, which is of multiscale nature, and whose importance is well known in Computer Vision and Image Processing, receives profound and rigorous new definitions, in relation with the more physical notion of *transition* and fits adequately to the case of chaotic data. The description is analogous to the modeling of states far from equilibrium, that is to say, there is no stationarity assumption. From this formalism we derive methods able to determine geometrically the most informative part in a signal, which also defines its global properties and allows for *compact representation* in the wake of known problematics addressed, for instance, in *time-frequency analysis*. In this way, the MMF allows the reconstruction, at any prescribed quality threshold, of a signal from its most informative (i. e. most unpredictable) subset, and is able to quantitatively evaluate key features in complex signals (unavailable with classical methods in Image or Signal Processing). It appears that the notion of *transition front* in a signal is much more complex than previously expected and, most importantly, related to multiscale notions encountered in the study of nonlinearity [57]. For instance, we give new insights to the computation of dynamical properties in complex signals, in particular in signals for which the classical tools for analyzing dynamics give poor results (such as, for example, correlation methods or optical flow for determining motion in turbulent datasets). The problematics in GEOSTAT can be summarized in the following items:

- the accurate determination in any n-dimensional complex signal of singularity exponents (also called Local Predictability Exponents or LPEs) **at every point in the signal domain** [61][7].
- The geometrical determination and organization of *singular manifolds* associated to various transition fronts in complex signals, the study of their geometrical arrangement, and the relation of that arrangement with statistical properties or other global quantities associated to the signal, e.g. *cascading properties* [12].
- The study of the relationships between the dynamics in the signal and the distributions of singularity exponents [62][12].
- **Multiresolution analysis** and inference along the scales [12], [2].
- The study of the relationships between the distributions of singularity exponents and other formalisms associated to *predictability* in complex signals and systems, such as cascading variables, large deviations and Lyapunov exponents.
- The ability to compute *optimal wavelets* and relate such wavelets to the geometric arrangement of singular manifolds and cascading properties[5].
- The translation of *recognition, analysis* and *classification problems* in complex signals to simpler and more accurate determinations involving new operators acting on singular manifolds using the framework of reconstructible systems.

## 2.2. Highlights of the Year

- Hicham Badri, PhD student in GEOSTAT (thesis under way cosupervised by H. Yahia and D. Aboutajdine) received the University Mohammed V best Master student award.

- The paper *Reconstructing an image from its edge representation* by Suman K. Maji, H. Yahia and H. Badri [19] is ranked in the top ten entries in the list of most downloaded papers of Elsevier's Digital Signal Processing journal.
- The paper *An efficient solution to sparse linear prediction analysis of speech* by V. Khanagha and K. Daoudi [15] is ranked in the top ten entries, 13th over 100, in the list of most downloaded papers in 2013 of the EURASIP Journal on Audio, Speech, and Music Processing.
- GEOSTAT and DYNBIO (LEGOS, CNRS UMR 5566, Toulouse) teams have computed daily ocean dynamics at super resolution over a large area around the Agulhas current near South Africa using low resolution altimetry data and high resolution Sea Surface Temperature (SST) data for the year 2006. The computed ocean dynamics over a one year time interval is the result of the propagation of low resolution ocean dynamics derived from altimetry across the scales of a multiresolution analysis computed on the SST singularity exponents. The resulting turbulent ocean dynamics has been made into a movie with the help of Inria DIRCOM team (C. Blonz, P.-O. Gaumin) <sup>1</sup>.
- Researchers of GEOSTAT have been invited to two speaker sessions, firstly in one of the best international conference in computational biomedecine: EMBC 2013, [21], and second during the India-CEFIPRA workshop in ICST "Challenges in overcoming complexity, from big data to cyberphysical systems", April 4 - 5, 2013, New Delhi- India [22].
- Paper *Fast Multi-Scale Detail Decomposition via Accelerated Iterative Shrinkage* [24] accepted at SIGGRAPH ASIA 2013 conference (technical brief).

## 3. Research Program

### 3.1. Dynamics of complex systems

GEOSTAT is studying complex signals under the point of view of *nonlinear* methods, in the sense of *nonlinear physics* i.e. the methodologies developed to study complex systems, with a strong emphasis on multiresolution analysis. Linear methods in signal processing refer to the standard point of view under which operators are expressed by simple convolutions with impulse responses. Linear methods in signal processing are widely used, from least-square deconvolution methods in adaptive optics to source-filter models in speech processing. Because of the absence of localization of the Fourier transform, linear methods are not successful to unlock the multiscale structures and cascading properties of variables which are of primary importance as stated by the physics of the phenomena. This is the reason why new approaches, such as DFA (Detrended Fluctuation Analysis), Time-frequency analysis, variations on curvelets [58] etc. have appeared during the last decades. Recent advances in dimensionality reduction, and notably in Compressive Sensing, go beyond the Nyquist rate in sampling theory using nonlinear reconstruction, but data reduction occur at random places, independently of geometric localization of information content, which can be very useful for acquisition purposes, but of lower impact in signal analysis. One important result obtained in GEOSTAT is the effective use of multiresolution analysis associated to optimal inference along the scales of a complex system. The multiresolution analysis is performed on dimensionless quantities given by the *singularity exponents* which encode properly the geometrical structures associated to multiscale organization. This is applied successfully in the derivation of high resolution ocean dynamics, or the high resolution mapping of gaseous exchanges between the ocean and the atmosphere; the latter is of primary importance for a quantitative evaluation of global warming. Understanding the dynamics of complex systems is recognized as a new discipline, which makes use of theoretical and methodological foundations coming from nonlinear physics, the study of dynamical systems and many aspects of computer science. One of the challenges is related to the question of *emergence* in complex systems: large-scale effects measurable macroscopically from a system made of huge numbers of interactive agents [50], [47], [63], [54]. Some quantities related to nonlinearity, such as Lyapunov exponents, Kolmogorov-Sinai entropy etc. can be computed at least in the phase space [48]. Consequently, knowledge

<sup>1</sup> [http://geostat.bordeaux.inria.fr/exj1309/annee2006\\_SHORTER\\_2ipj.mov](http://geostat.bordeaux.inria.fr/exj1309/annee2006_SHORTER_2ipj.mov) (size ~ 800 Mo).



from acquisitions of complex systems (which include *complex signals*) could be obtained from information about the phase space. A result from F. Takens [59] about strange attractors in turbulence has motivated the determination of discrete dynamical systems associated to time series [52], and consequently the theoretical determination of nonlinear characteristics associated to complex acquisitions. Emergence phenomena can also be traced inside complex signals themselves, by trying to localize information content geometrically. Fundamentally, in the nonlinear analysis of complex signals there are broadly two approaches: characterization by attractors (embedding and bifurcation) and time-frequency, multiscale/multiresolution approaches. Time-frequency analysis [49] and multiscale/multiresolution are the subjects of intense research and are profoundly reshaping the analysis of complex signals by nonlinear approaches [46], [51]. In real situations, the phase space associated to the acquisition of a complex phenomenon is unknown. It is however possible to relate, inside the signal's domain, local predictability to local reconstruction and deduce from that singularity exponents (SEs) [11] [7]. The SEs are defined at any point in the signal's domain, they relate, but are different, to other kinds of exponents used in the nonlinear analysis of complex signals. We are working on their relation with:

- properties in universality classes,
- the geometric localization of multiscale properties in complex signals,
- cascading characteristics of physical variables,
- optimal wavelets and inference in multiresolution analysis.

The alternative approach taken in GEOSTAT is microscopical, or geometrical: the multiscale structures which have their "fingerprint" in complex signals are being isolated in a single realization of the complex system, i.e. using the data of the signal itself, as opposed to the consideration of grand ensembles or a wide set of realizations. This is much harder than the ergodic approaches, but it is possible because a reconstruction formula such as the one derived in [60] is local and reconstruction in the signal's domain is related to predictability. This approach is analogous to the consideration of "microcanonical ensembles" in statistical mechanics.

Nonlinear signal processing is making use of quantities related to predictability. For instance the first Lyapunov exponent  $\lambda_1$  is related, from Osedelec's theorem, to the limiting behaviour of the response, after a time  $t$ , to perturbation in the phase space  $\log R_\tau(t)$ :

$$\lambda_1 = \lim_{t \rightarrow \infty} \frac{1}{t} \langle \log R_\tau(t) \rangle \quad (1)$$

with  $\langle \cdot \rangle$  being time average and  $R_\tau$  the response to a perturbation [48]. In GEOSTAT our aim is to relate such classical quantities (among others) to the behaviour of SEs, which are defined by a limiting behaviour

$$\mu(\mathcal{B}_r(\mathbf{x})) = \alpha(\mathbf{x}) r^{d+h(\mathbf{x})} + o(r^{d+h(\mathbf{x})}) \quad (r \rightarrow 0) \quad (2)$$

( $d$ : dimension of the signal's domain,  $\mu$ : multiscale measure, typically whose density is the gradient's norm,  $\mathcal{B}_r(\mathbf{x})$ : ball of radius  $r$  centered at  $\mathbf{x}$ ). For precise computation, SEs can be smoothly interpolated by projecting wavelets:

$$\mathcal{J}_\Psi \mu(\mathbf{x}, r) = \int_{\mathbb{R}^d} d\mu(\mathbf{x}') \frac{1}{r^d} \Psi \left( \frac{\mathbf{x} - \mathbf{x}'}{r} \right) \quad (3)$$

( $\Psi$ : mother wavelet, admissible or not), but the best numerical method in computing singularity exponents lies in the definition of a measure related to predictability [20], [43]:

$$h(\mathbf{x}) = \frac{\log \mathcal{J}_\Psi \mu(\mathbf{x}, r_0) / \langle \mathcal{J}_\Psi \mu(\cdot, r_0) \rangle}{\log r_0} + o\left(\frac{1}{\log r_0}\right) \quad (4)$$

with:  $r_0$  is a scale chosen to diminish the amplitude of the correction term, and  $\langle \mathcal{J}_\Psi \mu(\cdot, r_0) \rangle$  is the average value of the wavelet projection (mother wavelet  $\Psi$ ) over the whole signal. Singularity exponents computed with this formula generalize the elementary "gradient's norm" in a very statistically coherent way across the scales.

SEs are related to the framework of reconstructible systems, and consequently to predictability. They unlock the geometric localization of a multiscale structure in a complex signal:

$$\mathcal{F}_h = \{\mathbf{x} \in \Omega \mid h(\mathbf{x}) = h\}, \quad (5)$$

( $\Omega$ : signal's domain). This multiscale structure is a fundamental feature of a complex system. Indeed, let us take the explicit example of a signal which is an acquisition of a 3D turbulent fluid. The velocity field of the flow,  $\mathbf{v}(\mathbf{x}, t)$ , is a solution of the Navier-Stokes equations. Fully Developed Turbulence (FDT) is defined as the regime observed when the Reynolds number  $R \rightarrow \infty$ ,  $R$  being defined as the ratio of "viscous diffusion time" by "circulation time":  $R = \frac{LV}{\nu}$ ,  $L$  and  $V$  being respectively characteristic length and velocity of the flow. The phase space of the associated dynamical system is infinite dimensional, while the dynamics of the flow possess one or more finite dimensional attractors. In the case of FDT, particles of the fluid in the continuum which are trapped around KAM invariant manifolds undergo random perturbations in their motion which accounts for the "boost" observed in turbulent diffusion. From there comes the observed behaviour for the energy spectrum (the law  $\mathcal{E}(\mathbf{k}) \sim |\mathbf{k}|^{-5/3}$  within the inertial range), an observation that was the starting point of the Kolmogorov K41 theory, but is still not directly mathematically related from the Navier-Stokes equations. Intermittency is observed within the inertial range and is related to the fact that, in the case of FDT, symmetry is restored only in a statistical sense, a fact that has consequences on the quality of any nonlinear signal representation by frames or dictionaries.

The example of FDT as a standard "template" for developing general methods that apply to a vast class of complex systems and signals is of fundamental interest because, in FDT, the existence of a multiscale hierarchy (i.e. the collection of sets  $\mathcal{F}_h$  of equation 5) which is of multifractal nature and geometrically localized can be derived from physical considerations. This geometric hierarchy of sets is responsible for the shape of the computed singularity spectra, which in turn is related to the statistical organization of information content in a signal. It explains scale invariance, a characteristic feature of complex signals. The analogy from statistical physics comes from the fact that singularity exponents are direct generalizations of *critical exponents* which explain the macroscopic properties of a system around critical points, and the quantitative characterization of *universality classes*, which allow the definition of methods and algorithms that apply to general complex signals and systems, and not only turbulent signals: signals which belong to a same universality class share common statistical organization. In GEOSTAT, the approach to singularity exponents is done within a microcanonical setting, which can interestingly be compared with other approaches such that wavelet leaders, WTMM or DFA. During the past decades, classical approaches (here called "canonical" because they use the analogy taken from the consideration of "canonical ensembles" in statistical mechanics) permitted the development of a well-established analogy taken from thermodynamics in the analysis of complex signals: if  $\mathcal{F}$  is the free energy,  $\mathcal{T}$  the temperature measured in energy units,  $\mathcal{U}$  the internal energy per volume unit  $\mathcal{S}$  the entropy and  $\hat{\beta} = 1/\mathcal{T}$ , then the scaling exponents associated to moments of intensive variables  $p \rightarrow \tau_p$  corresponds to  $\hat{\beta}\mathcal{F}$ ,  $\mathcal{U}(\hat{\beta})$  corresponds to the singularity exponents values, and  $\mathcal{S}(\mathcal{U})$  to the singularity spectrum.

The singularity exponents belong to a universality class, independently of microscopic properties in the phase space of various complex systems, and beyond the particular case of turbulent data (where the existence of a multiscale hierarchy, of multifractal nature, can be inferred directly from physical considerations). They describe common multiscale statistical organizations in different complex systems [57], and this is why GEOSTAT is working on nonlinear signal processing tools that are applied to very different types of signals. The methodological framework used in GEOSTAT for analyzing complex signals is different from, but related to, the "canonical" apparatus developed in recent years (WTMM method, wavelet leaders etc.). In the microcanonical approach developed, geometrically localized singularity exponents relate to a

"microcanonical" description of multiplicative cascades observed in complex systems. Indeed, it can be shown that  $p$ -dissipation at scale  $r$  associated to a fixed interval  $]p, p + \Delta p[$ ,  $\epsilon_r^{(p, \Delta p)}$ , behaves in the limit  $\Delta p \rightarrow 0$  as

$$\epsilon_r^{(p)} = \lim_{\Delta p \rightarrow 0} \epsilon_r^{(p, \Delta p)} = (\epsilon_r^{(\infty)})^{h(p)/h_\infty} \quad (6)$$

which indicates the existence of a relation between the multiscale hierarchy and the geometric localization of the cascade in complex systems.

The GEOSTAT team is working particularly on the very important subject of *optimal wavelets* which are wavelets  $\psi$  that "split" the signal projections between two different scales  $\mathbf{r}_1 < \mathbf{r}_2$  in such a way that there exists an injection term  $\zeta_{r_1/r_2}(\mathbf{x})$ , independent of the process  $\mathcal{T}_\psi[\mathbf{s}](\mathbf{x}, \mathbf{r})$  with:

$$\mathcal{T}_\psi[\mathbf{s}](\mathbf{x}, \mathbf{r}_1) = \zeta_{r_1/r_2}(\mathbf{x}) \mathcal{T}_\psi[\mathbf{s}](\mathbf{x}, \mathbf{r}_2) \quad (7)$$

( $\mathbf{r}_1 < \mathbf{r}_2$ : two scales of observation,  $\zeta$ : injection variable between the scales,  $\psi$ : optimal wavelet). The **multiresolution analysis** associated to optimal wavelets is particularly interesting because it reflects, in an optimal way, the cross-scale information transfer in a complex system. These wavelets are related to persistence along the scales and lead to multiresolution analysis whose coefficients verify

$$\alpha_s = \eta_1 \alpha_f + \eta_2 \quad (8)$$

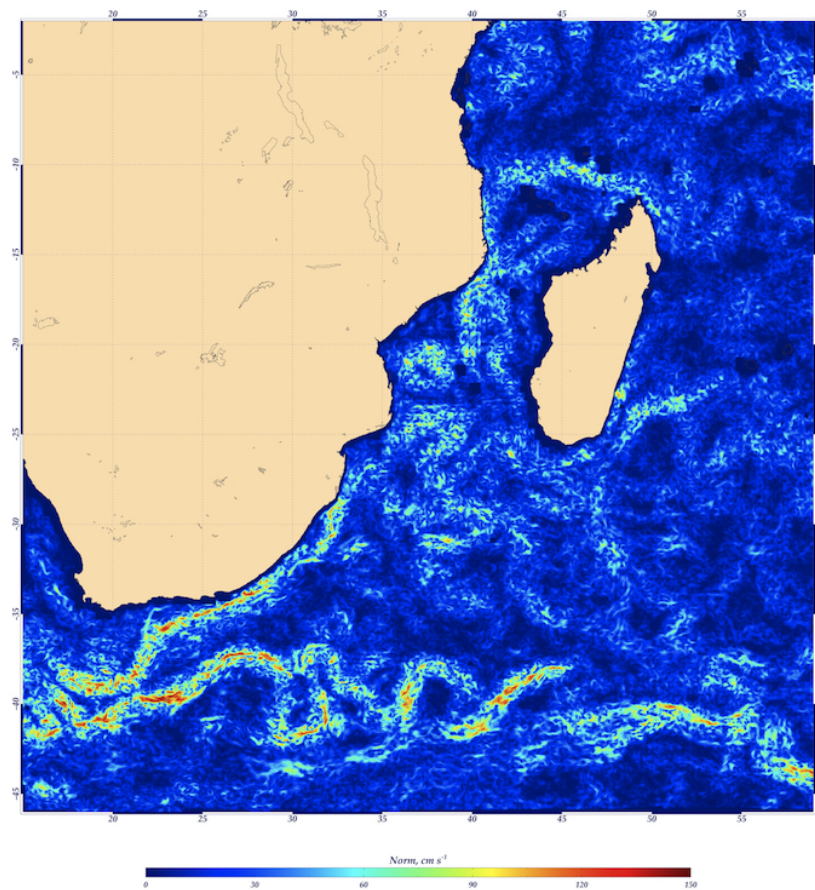
with  $\alpha_s$  and  $\alpha_f$  referring to child and parent coefficients,  $\eta_1$  and  $\eta_2$  are random variables independent of  $\alpha_s$  and  $\alpha_f$  and also independent of each other.

In a first example we give some insight about the collaboration with LEGOS Dynbio team <sup>2</sup> about high-resolution ocean dynamics from microcanonical formulations in nonlinear complex signal analysis. LPEs relate to the geometric structures linked with the cascading properties of indefinitely divisible variables in turbulent flows. Cascading properties can be represented by optimal wavelets (OWs); this opens new and fascinating directions of research for the determination of ocean motion field at high spatial resolution. OWs in a microcanonical sense pave the way for the determination of the energy injection mechanisms between the scales. From this results a new method for the complete evaluation of oceanic motion field; it consists in propagating along the scales the norm and the orientation of ocean dynamics deduced at low spatial resolution (geostrophic from altimetry and a part of ageostrophic from wind stress products). Using this approach, there is no need to use several temporal occurrences. Instead, the proper determination of the turbulent cascading and energy injection mechanisms in oceanographic signals allows the determination of oceanic motion field at the SST or Ocean colour spatial resolution (pixel size: 4 kms). We use the Regional Ocean Modelling System (ROMS) to validate the results on simulated data and compare the motion fields obtained with other techniques. See figure 1.

In a second example, we show in figure 2 the highly promising results obtained in the application of nonlinear signal processing and multiscale techniques to the localization of heart fibrillation phenomenon acquired from a real patient and mapped over a reconstructed 3D surface of the heart. The notion of *source field*, defined in GEOSTAT from the computation of derivative measures related to the singularity exponents allows the localization of arrhythmic phenomena inside the heart [8].

In a third example, we show in figure 3 the result of a new nonlinear method based on singularity exponents for optical phase reconstruction in adaptive optics (PhD of Suman Kumar Maji, defended November 2013). The method is very robust to noise. It consists in propagating subgradient information of acquired phase at low resolution across the scales of a multiresolution analysis computed on singularity exponents.

<sup>2</sup><http://www.legos.obs-mip.fr/recherches/equipements/dynbio>.



*Figure 1. Visualization of the motion field computed at high spatial resolution (pixel size: 4kms) over a wide area around South Africa. The ocean dynamics is computed by propagating low resolution information coming from altimetry data (pixel size: 24 kms) along approximated optimal multiresolution analysis computed over the singularity exponents of Sea Surface Temperature data obtained from MODIS AQUA and OSTIA. Common work between GEOSTAT and DYNBIO (LEGOS, CNRS UMR 55 66, Toulouse).*

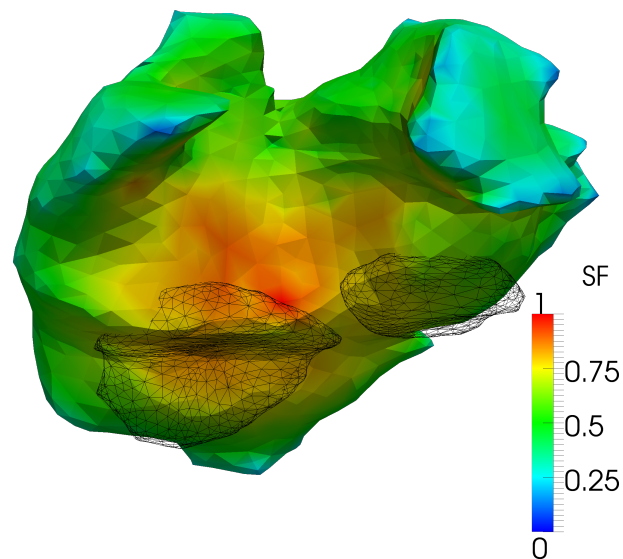


Figure 2. Result of the computation of a normalized source field over the 3D epicardial surface of the atria, from electric potential data acquired on a regular grid of electrodes placed on a patient's chest. There is a strong correlation between the red parts of the source field and the locations inside the heart where fibrillation occurs. Inputted data courtesy of IHU LIRYC.

Our last example is about speech. In speech analysis, we use the concept of the Most Singular Manifold (MSM) to localize critical events in domain of this signal. We show that in case of voiced speech signals, the MSM coincides with the instants of significant excitation of the vocal tract system. It is known that these major excitations occur when the glottis is closed, and hence, they are called the Glottal Closure Instants (GCI). We use the MSM to develop a reliable and noise robust GCI detection algorithm and we evaluate our algorithm using contemporaneous Electro-Glotto-Graph (EGG) recordings. See figure 4.

## 4. Application Domains

### 4.1. Application Domains

In GEOSTAT, the development of nonlinear methods for the study of complex systems and signals is conducted on four broad types of complex signals:

- Ocean dynamics and ocean/atmosphere interactions: generation of high-resolution maps from cascading properties and the determination of optimal wavelets [12], geostrophic or non-geostrophic complex oceanic dynamics, mixing phenomena.
- Speech signal (analysis, recognition, classification) [15], [17].
- Optimal wavelets for phase reconstruction in adaptive optics [20], [28], [14].
- Heartbeat signals, in cooperation with IHU LIRYC and Professor M. Haissaguerre (INSERM EA 2668 Electrophysiology and Cardiac Stimulation) [34], [21].

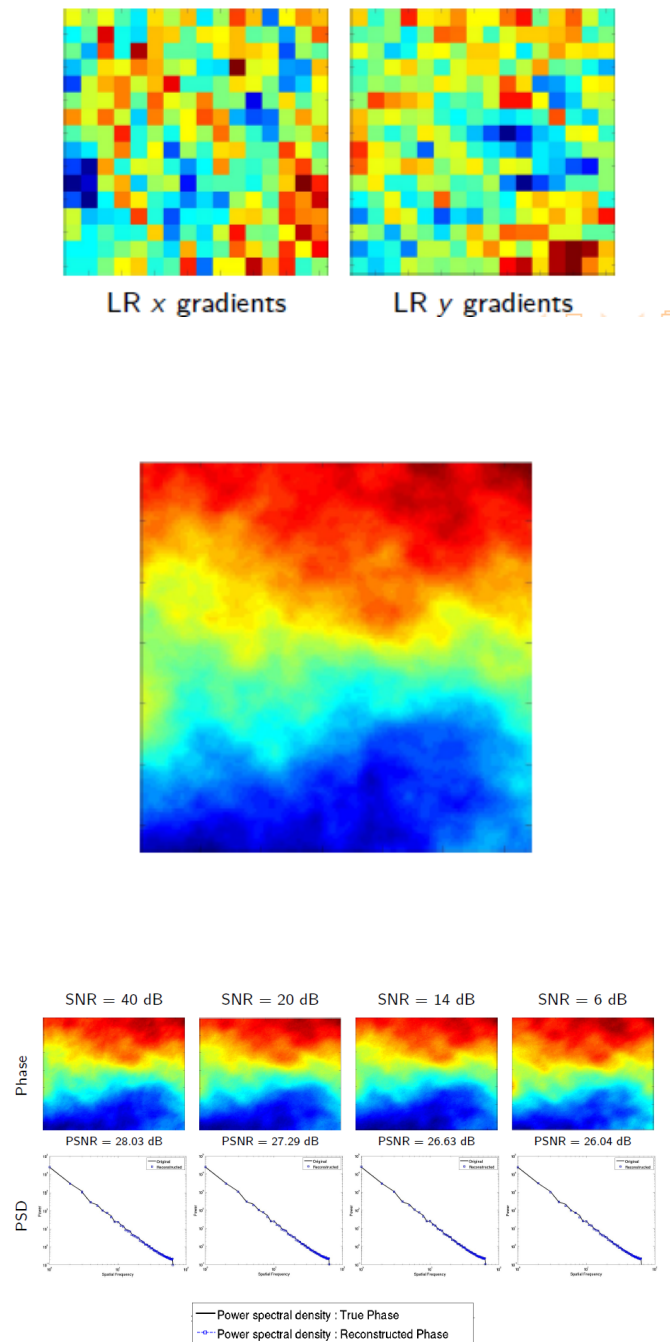


Figure 3. Nonlinear method for reconstructing the phase in adaptive optics (PhD thesis of Suman Kumar Maji, defended November 2013). Top: image of  $x$  and  $y$  subgradients of acquired turbulent optical phase at low resolution ( $16 \times 16$ ) pixels. Middle: "true" phase at resolution  $128 \times 128$  shown here for visual verification. Bottom: reconstruction of the high resolution phase  $128 \times 128$  from the low resolution subgradients of top image using multiresolution analysis computed on singularity exponents under various conditions of noise and associated power spectral densities (PSDs). Data courtesy T. Fusco (ONERA)

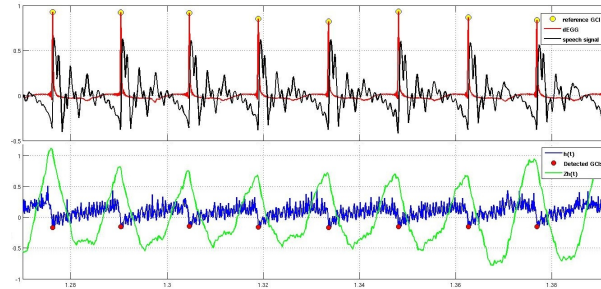


Figure 4. Top: A segment of a voiced speech signal (in black) along with the differentiated EGG (dEGG) recording (in red). Local maxima of dEGG shows the reference GCIs (yellow circles). Bottom: The singularity exponents (in blue) along with an auxiliary functional (in green) defined as  $Zh(t) = \sum_{u=t-T_L}^{t-\delta t} h(u) - \sum_{u=t}^{t+T_L} h(u)$  ( $h(t)$ : singularity exponent at  $t$ ). In each positive half-period of  $Zh(t)$ , the minimum of singularity exponents is taken as the GCI (red circle).

## 5. Software and Platforms

### 5.1. Fluex

**Participants:** Denis Arrivault [correspondant], Rémi Paties, Hussein Yahia, Joel Sudre.

- Denis Arrivault has joined the team for a complete refoundation, rewriting, generalization and diffusion of the FluidExponents software, now called Fluex. FluidExponents is a software implementation of the MMF, presently written in Java, in a cooperative development mode on the Inria GForge, deposited at APP in 2010. Denis Arrivault has delivered the first Fluex package in December 2013, consisting of a core implementation under Gforge of the Microcanonical Multiscale Formalism in the form of C++ classes, for 1D, 2D 3D and 3D+t general signals. Fluex is in the process of being deposited in 2014. The Fluex project is carried on in 2014 by Rémi Paties. Contact: denis.arrivault@inria.fr, remi.paties@inria.fr
- A matlab code for the speech GCI detection algorithm has been made publicly available on the GeoStat website.

## 6. New Results

### 6.1. Nonlinear dynamics and Mild Therapeutic Hypothermia (MTH)

**Participants:** Binbin Xu [correspondant], Oriol Pont, Hussein Yahia, Ihu Liryc.

The neurological damage after cardiac arrest constitutes a big challenge of hospital discharge. The mild therapeutic hypothermia (MTH) ( $34^{\circ}\text{C}$  -  $32^{\circ}\text{C}$ ) has shown its benefit to reduce this type of damage. However, it can have many adverse effects, among which the cardiac-arrhythmia-generation-a-posteriori (CAGP) can represent up to 34%. So it's important to understand the mechanism of CAGP in order to improve this therapy. Our study with a cardiac culture in vitro showed that at  $35^{\circ}\text{C}$  the CAGP can be induced. Spiral waves, commonly considered as a sign of cardiac arrhythmia, are observed. The process of MTH can be represented by a Pitchfork bifurcation, which could explain the different ratio of arrhythmia among the adverse effects after this therapy. This nonlinear dynamics suggests that a variable speed of cooling / rewarming, especially when passing  $35^{\circ}\text{C}$ , would help to decrease the ratio of post-hypothermia arrhythmia and then improve the hospital output. See figures 5, 6.

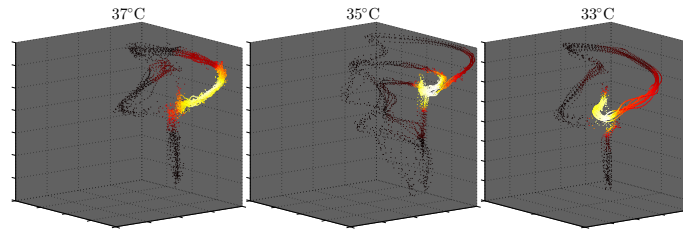


Figure 5. Phase space reconstruction for extracellular potential signals at 37°C, 35°C and 33°C.

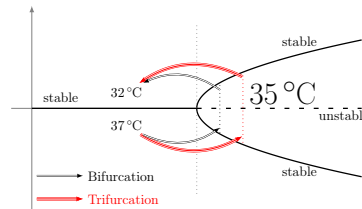


Figure 6. Illustration of Bifurcation or Trifurcation (type Pitchfork) of hypothermia effect.

Publications: [33], [35], [39].

## 6.2. Characterizing cardiac arrhythmias and their mechanisms by means of nonlinear and robust methods

**Participants:** Oriol Pont [correspondant], Binbin Xu, Hussein Yahia, Ihu Liryc.

Nonlinear analysis provides appropriate tools to characterize cardiac dynamics. Singularity analysis and phase-space reconstruction are physically meaningful complexity measures with minimal assumptions on the underlying models. These methods are based on effective descriptions derived from first principles, and as a consequence, parameters are robustly estimated. We have validated this approach on ECG, endocavitary catheter measures and electrocardiographic maps.

Key parameters vary infrequently and exhibit sharp transitions, which show where information concentrates and correspond to actual dynamical regime changes. Singularity exponents sift a simple fast dynamics from its slow modulation. In space domain, extreme values highlight arrhythmogenic areas. We observe a correspondence of time lag fluctuations of phase-space reconstructions with atrial fibrillation episodes in the same way as with the dynamical changes coming from singularity exponents. This characterization of information transitions could be used in the regularization of inverse-problem mapping of electrocardiographic epicardial maps. Furthermore, this opens the way for improved model-independent complexity descriptors to be used in non-invasive, automatic diagnosis support and ablation guide for electrical insulation therapy, in cases of arrhythmias such as atrial flutter and fibrillation.

Publications: [34], [29], [32], [37], [21].

## 6.3. Multifractal Deep Convolutional Pooling for Robust Texture Discrimination

**Participants:** Hicham Badri [correspondant], Hussein Yahia, Khalid Daoudi.



A robust and fast affine invariant texture classification system is presented. The new approach consists first in filtering the input image with multiple wavelet filters of different scales and orientations followed by a dual-pooling operation to increase the local invariance. The process is repeated for different wavelet sets and multiple image resolutions. This can be seen as a deep convolutional network where the outputs correspond to the pooling responses. The next step consists in extracting a robust affine invariant descriptor based on the scale invariance prior observed in natural images ; a multifractal log exponent histogram is calculated for each output node of the network. These log- histograms are combined to form the main descriptor. The final step consists in features post-processing based on the sparse wavelet coefficients prior to reduce the influence of small perturbations. For the training, we propose a combination of the generative PCA classifier with multiclass SVMs which improves classification rates. We also propose to use multi-illumination and multi-scale training ; two simple strategies to significantly boost classification results when dealing with small and homogeneous training sets. Experiments demonstrate that the proposed solution outperforms existing methods on three challenging public benchmark datasets.

Work submitted to CVPR 2014.

#### 6.4. Nonlinear reconstruction of optical phase perturbed by atmospheric turbulence in Adaptive Optics

**Participants:** Suman Maji [correspondant], Hussein Yahia, Thierry Fusco.

A new approach to wavefront phase reconstruction in Adaptive Optics (AO) from the low-resolution gradient measurements provided by a wavefront sensor, using a nonlinear approach derived from the Microcanonical Multiscale Formalism (MMF). MMF comes from established concepts in statistical physics, it is naturally suited to the study of multiscale properties of complex natural signals, mainly due to the precise numerical estimate of geometrically localized critical exponents, called the singularity exponents. These exponents quantify the degree of predictability, locally, at each point of the signal domain, and they provide information on the dynamics of the associated system. We show that multiresolution analysis carried out on the singularity exponents of a high-resolution turbulent phase (obtained by model or from data) allows a propagation along the scales of the gradients in low-resolution (obtained from the wavefront sensor), to a higher resolution. We compare our results with those obtained by linear approaches, which allows us to offer an innovative approach to wavefront phase reconstruction in Adaptive Optics.

Supporting grant: Conseil Régional Aquitaine project and funding *OPTAD*.

PhD thesis defended: Suman Kumar Maji, *Multiscale Methods in Signal Processing for Adaptive Optics*, University Bordeaux-1, PhD defended on November 14th, 2013, supervisor: H. Yahia [14].

Publications: [19], [20], [28], [14].

#### 6.5. Nonlinear Speech Analysis

**Participants:** Vahid Khanagha [correspondant], Khalid Daoudi, Safa Mrad, Nicolas Vinuesa, Blaise Bertrac.

1. *MMF for speech analysis* : we continued our research on the adaptation and application of the MMF to speech analysis and started a research theme on pathological voice analysis. We proposed a novel compact representation of speech which consists in reconstructing a speech signal from its most singular manifold. This leads us to build a speech waveform coder which outperforms the G.726 standard. We then used our recently developed algorithm for Glottal Closure Instants (GCI) detection to improve the performance of our sparse linear prediction method. We also used this algorithm to develop new acoustic perturbation measures for normal/pathological voice classification.
2. *Matching pursuit for speech analysis* : we first showed that the Gabor dictionary is actually more efficient than the Gammatone dictionary for speech coding using the matching pursuit (MP) algorithm. This result mitigates some famous findings on the neural coding at the human auditory nerve. Second, we showed that one single parameter, derived from MP decomposition of speech, allows discrimination between normal and dysphonic voices with an accuracy which is significantly higher than all existing methods.

Supporting grant: Inria CORDIS.

PhD thesis defended: Vahid Khanagha *Novel Multiscale Methods for Nonlinear Speech Analysis*, University Bordeaux-1, PhD defended on January 16th, 2013, supervisors: K. Daoudi and H. Yahia [13].

Publications: [17], [27], [41], [40], [44].

## 6.6. Discriminative learning for Automatic speaker recognition

**Participants:** Khalid Daoudi [correspondant], Reda Jourani, Régine André Obrecht, Driss Aboutajdine.

We proposed a speaker identification which combines SVM and Large Margin Gaussian Mixture Models (LM-GMM) which outperforms the performance of our LM-GMM system.

Publication: [26].

## 6.7. Learning Multifractal Structures in Images

**Participants:** Hicham Badri [correspondant], Hussein Yahia, Driss Aboutajdine.

Learning dictionaries has become a powerful tool in many image processing applications. However, standard learning methods such as K-SVD and Online learning do not take into account the structure of the patches: each patch is expressed as a linear combination of atoms of one global dictionary. We present a new dictionary learning method which takes into account the nature of each patch by performing a multifractal decomposition of the image. As a result, each fractal set will have a specific dictionary and each dictionary contains atoms of a certain singularity degree. Each patch can therefore be expressed much more efficiently compared to global dictionary learning methods. Current experiments in image denoising show that the proposed method outperforms the global dictionary learning methods.

Work in progress.

## 6.8. Super resolution maps of partial pressure $pCO_2$ between the ocean and the atmosphere

**Participants:** Hussein Yahia [correspondant], Véronique Garçon (laboratoire d'Etudes En Géophysique Et Océanographie Spatiales (legos)), Joël Sudre (laboratoire d'Etudes En Géophysique Et Océanographie Spatiales (legos)), Christoph Garbe (university Of Heidelberg), Christophe Maes (laboratoire d'Etudes En Géophysique Et Océanographie Spatiales (legos)), André Butz (karlsruhe Institute Of Technology (kit)), Boris Dewitte (laboratoire d'Etudes En Géophysique Et Océanographie Spatiales (legos)), Isabelle Dadou (université Paul Sabatier).

Multiresolution analysis computed on singularity exponents estimated from physical variables is used to produce submesoscale (pixel size: 4 kms) of partial pressures  $pCO_2$  maps between the ocean and the atmosphere. Low resolution  $pCO_2$  information coming from models and data is propagated across the scale of the specific multiresolution analysis to infer super resolution  $pCO_2$  maps. Validation with model outputs and boat campaigns.

Supporting grant: OceanFlux project.

Publications: [30], [38].

## 6.9. Turbulent ocean dynamics at super resolution: validation

**Participants:** Hussein Yahia [correspondant], Véronique Garçon, Joël Sudre.

Synoptic determination of ocean circulation using data acquired from space, with a coherent depiction of its turbulent characteristics, from large scale ocean circulation down to super resolution of remote sensing optical sensors, remains a fundamental challenge in Oceanography. This determination has the potential of revealing all aspects of the ocean's dynamic variability on a wide range of spatio-temporal scales and will enhance our understanding of ocean-atmosphere exchanges at super resolution, as required in the present context of climate change. We show a 4-year time series of spatial super resolution (4 kms) turbulent ocean dynamics generated from satellite data using emerging nonlinear physics, low resolution dynamics and super resolution oceanic sea surface temperature data. The method at its core consists in propagating across the scales the low resolution dynamics in a multi resolution analysis computed on adimensional critical transition information. The resulting vector field is validated with Lagrangian buoy data at super resolution obtained from NASA Global Drifter Program.

A movie showing the evolution of turbulent ocean dynamics around South Africa in the Alguas current has been made with the help and support of Inria DIRCOM project (C. Blonz, P.-O. Gaumin).

Supporting grant: ICARODE project.

Publications: [30], [38].

## 6.10. Upwelling

**Participants:** Ayoub Tamim [correspondant], Khalid Daoudi, Hussein Yahia, Joël Sudre.

Based on fuzzy clustering, we developed a new algorithm for the segmentation of upwelling regions in the southern atlantic Moroccan coast using Sea Surface temperature images. This method has the advantage of being more efficient and more accurate than a state-of-the-art method. It is followed by a work under way of determining oriented contours using the MMF.

Publication: [31].

## 6.11. Combining Local and Non-Local Priors For Image Deconvolution

**Participants:** Hicham Badri [correspondant], Hussein Yahia.

Non-blind deconvolution consists in recovering a sharp latent image from a blurred image with a known kernel. Deconvolved images usually contain unpleasant artifacts due to the ill-posedness of the problem even when the kernel is known. Making use of natural sparse priors has shown to reduce ringing artifacts but handling noise remains limited. On the other hand, non-local priors have shown to give the best results in image denoising. We propose in this project to combine both local and non-local priors in one framework. By studying the distribution of the singularity exponents as well as the distribution of the eigenvalues of similar patches, we show that the blur increases the self-similarity within an image and thus makes the non-local prior a good choice for denoising blurred images. The blurred image is denoised using only the self-similarities within the image, without any prior specific to the blur, via low rank estimation. However, denoising introduces outliers which are not Gaussian and should be well modeled. Experiments show that our method produces a much better image reconstruction both visually and empirically compared to some popular methods. See figure 7.

Work in progress.

## 6.12. Fast Multi-Scale Detail Decomposition via Accelerated Iterative Shrinkage

**Participants:** Hicham Badri [correspondant], Hussein Yahia, Driss Aboutajdine.



(a) Blurred and Noisy,  $\sigma = 2\%$  (b) Krishnan (NIPS 2009) (c) Levin (SIGGRAPH 2007) (d) Proposed

Figure 7. Various deconvolution results. The proposed method produces a much better reconstruction ; note the background noise in the methods (b) and (c). The PSNR is higher with our method 29.56 dB compared to the methods (b) 27.22 dB and (c) 28.11 dB.

Edge-aware smoothing is one of the most important operations in computer graphics and vision. It is the building-block for a wide range of applications including : smoothing, detail manipulation, HDR tone-mapping, to cite a few. However, good quality edge-aware smoothing operators are relatively slow. We present a fast solution for performing high-quality edge-aware smoothing, particularly efficient for edge manipulation applications. Our strategy to perform smoothing consists in using a half-quadratic solver with a non-convex sparsity-inducing norm, accelerated using a first order approximation. First, we show how to solve optimization problems with complex non-convex norms using a first order proximal estimation. This step is of paramount importance not just for smoothing, but for many applications requiring the use non-convex norms. Secondly, we design two norms inspired by natural image statistics. We incorporate these norms with a first order proximal estimation to design the main smoothing operator. Finally, we propose a warm-start solution to accelerate the solver. Experiments show that our method produces high quality results, sometimes better than some state-of-the-art methods, with reduced processing time. We demonstrate the performance of the proposed approach on various applications such as smoothing, multi-scale detail manipulation of low and high dynamic range images as well as high definition video manipulation. See figure 8.

Work presented at SIGGRAPH Asia 2013 (technical brief), Hong Kong [24].



(a) (b) (c) (d)

Figure 8.

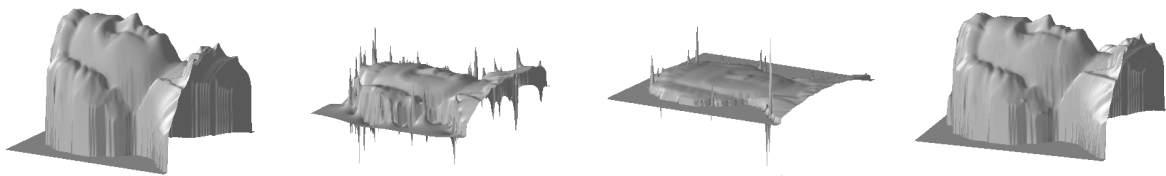
Detail manipulation example. The proposed method produces a high-quality result with reduced processing time. From left to right:(a) Input, (b) WLS, (c) EAW, (d) Proposed method.

### 6.13. Robust Surface Reconstruction via Triple Sparsity

**Participants:** Hicham Badri [correspondant], Hussein Yahia, Driss Aboutajdine.

Reconstructing a surface/image from corrupted gradient fields is a crucial step in many imaging applications where a gradient field is subject to both noise and unlocalized outliers, resulting typically in a non-integrable field. The methods presented so far can only handle a small amount of outliers and noise due to the limited performance of their models. We present in this project a powerful method for robust surface reconstruction. The proposed formulation is based on a triple sparsity prior : a sparse prior on the residual gradient field and a double sparse prior on the surface itself. A double prior corrects the outliers in the field, while the third sparsity prior smooths the surface to reduce the noise. We develop an efficient alternate minimization strategy to solve the proposed optimization problem. The method is able to recover a good quality surface from severely corrupted gradients thanks to its ability to handle both noise and outliers. We demonstrate the performance of the proposed method on synthetic and real data. Experiments show that the proposed solution outperforms some existing methods in the three possible cases : noise only, outliers only and mixed noise/outliers. See figure 9.

Work submitted to CVPR 2014.



(a) Ground-truth      (b) Diffusion (ECCV 2006)      (c)  $l_1$ -norm (CVPR09)      (d) Proposed

Figure 9. Photometric stereo reconstruction from noisy images. The proposed method produces a much better reconstruction compared to two state-of-the-art methods.

## 7. Partnerships and Cooperations

### 7.1. National Initiatives

- ICARODE [2013-2016]. Participants : Hussein Yahia, Oriol Pont, Véronique Garçon, Joel Sudre, Antonio Turiel, Christine Provost [ LOCEAN ]. 4-year contract, CNES-NASA funding, started 2013. Title: *ICARODE: Integration and cascading for high resolution ocean dynamics*. Project leader: H. Yahia.
- IHU LIRYC and CRA DIAFIL project [2012-2014]. Post-doctoral fellow: B. Xu. Project leaders H. Yahia and O. Bernus.
- REGION AQUITAINE PROJECT "OPTAD". Participants : H. Yahia, S. Kumar Maji. Project leader: H. Yahia.

### 7.2. European Initiatives

#### 7.2.1. Collaborations in European Programs, except FP7

Program: ESA (European Spatial Agency) Support to Science Element

Project acronym: OceanFlux

Project title: High resolution mapping of GHGs exchange fluxes.

Duration: 09/2011 - 09/2014

Coordinator: C. Garbe

Other partners: IWR (University of Heidelberg), LEGOS (CNRS DR-14), GEOSTAT (Inria), KIT (Karlsruher Institut für Technologie, Frankfurt), IRD, Université Paul Sabatier.

Abstract: The EBUS (Eastern Boundary Upwelling Systems) and OMZs (Oxygen Minimum Zone) contribute very significantly to the gas exchange between the ocean and the atmosphere, notably with respect to the greenhouse gases (hereafter GHG). Invasion or outgassing fluxes of radiatively-active gases at the air-sea interface result in coupled or decoupled sink and source configurations. From in-situ ocean measurements, the uncertainty of the net global ocean-atmosphere CO<sub>2</sub> fluxes is between 20 and 30%, and could be much higher in the EBUS-OMZ. Off Peru, very few in-situ data are available presently, which justifies alternative approaches for assessing the fluxes. GHG vertical column densities (VCD) can be extracted from satellite spectrometers. The accuracy of these VCDs need to be very high in order to make extraction of sources feasible. To achieve this accuracy is extremely challenging, particularly above water bodies, as water strongly absorbs infra-red (IR) radiation. To increase the amount of reflected light, specular reflections (sun glint) can be used on some instruments such as GOSAT. Also, denoising techniques from image processing may be used for improving the signal-to-noise ratio (SNR). GHG air-sea fluxes determination can be inferred from inverse modeling applied to VCDs, using state of the art modeling, at low spatial resolution. For accurately linking sources of GHGs to EBUS and OMZs, the resolution of the source regions needs to be increased. This task develops on new non-linear and multiscale processing methods for complex signals to infer a higher spatial resolution mapping of the fluxes and the associated sinks and sources between the atmosphere and the ocean. Such an inference takes into account the cascading properties of physical variables across the scales in complex signals. The use of coupled satellite data (e.g. SST and/or Ocean colour) that carry turbulence information associated to ocean dynamics is taken into account at unprecedented detail level to incorporate turbulence effects in the evaluation of the air-sea fluxes. We will present a framework as described above for determining sources and sinks of GHG from satellite remote sensing. The approach includes resolutions enhancements from nonlinear and multiscale processing methods. The applicability is validated against ground truth observations and numerical model studies.

### 7.3. International Initiatives

- Project "Profilage à partir des données hétérogènes du Web pour la cybersécurité" funded by the Canadian CRSNG (3 years) is in its last year. The partners in this project are: Univ of Sherbrooke, Concordia Univ, Sûreté du Québec, the company E-Profile and GEOSTAT. related publication: [23].
- The Volubilis project "Study of Upwelling in the Moroccan coast by satellite imaging" led by K. Daoudi is in its last year. The partners in this project are: Faculté des sciences de Rabat (FSR), Centre Royal de Télédetection Spatiale (CRTS), LEGOS-CNRS (Toulouse) and GEOSTAT.

#### 7.3.1. Inria Associate Teams

A project of Associate Team with Indian Partner IIT Roorkee is submitted for 2014. This EA team project comes in conjunction with accepted IFCAM project (Indo-French Centre for Applied Mathematics) *Optimal inference in complex and turbulent data*.

#### 7.3.2. Inria International Partners

##### 7.3.2.1. Informal International Partners

IIT Roorkee: Indo-French Centre for Applied Mathematics (IFCAM) project [2014-2017] and submitted Associated Team project (2014).

### 7.3.3. Participation In other International Programs

- IFCAM (India): Indo-French Centre for Applied Mathematics (IFCAM) project [2014-2017]. Title: *Optimal inference in complex and turbulent data*. 3-year contract, IFCAM funding, started 2014. Partners: GEOSTAT and IIT ROORKEE (INDIA).

## 7.4. International Research Visitors

### 7.4.1. Visits of International Scientists

#### 7.4.1.1. Internships

##### Safa Mrad

Subject: Nonlinear speech analysis for pathological voice detection.

Date: from April 2013 until September 2013.

Report: [41].

Institution: Ecole Nationale d'Ingénieurs de Tunis (Tunisia)

##### Nicolas Vinuesa

Subject: Matching pursuit for efficient speech coding.

Date: from October 2012 until Avril 2013.

Report: [44]

Institution: Facultad de Ciencias Exactas, Ingenieria y Agrimensura (FCEIA), UNR (Rosario, Argentina)

##### Blaise Bertrac

Subject: Matching pursuit for pathological voice classification.

Date: June and July 2013.

Report: [40].

Institution: Université de Bordeaux-1.

## 8. Dissemination

### 8.1. Scientific Animation

- H. Badri has presented the Siggraph ASIA paper to Manao team seminar (Inria BSO) in November 2013.
- H. Badri has presentated his research projects to LRIT lab seminar (CNRST), December 2013, Rabat, Morocco.
- H. Badri is an invited speaker to the "Séminaire Signal-Image Bordeaux" organized by IMS, IMB and LaBRI, March 2014, Bordeaux.
- H. Yahia was an invited participant to the Workshop on "Global Systems Science: role of models and data" held at Brussels, February 7-8, 2013.
- H. Yahia was a member of the selection committee (February 25th, 2013) of the joint workshop in ICST held in Mumbai (India), 2013.
- H. Yahia participated in the CNU (Conseil national des Universités), section 61 selection meeting in January 2013.
- H. Yahia has presented the ICARODE project (*Integration and cascading for high resolution ocean dynamics*, CNES-NASA-OSTST) at the CNES meeting in September 2013 at LEGOS (UMR CNRS 5566), Toulouse.

- H. Yahia was an invited speaker at the India-CEFIPRA workshop in ICST "Challenges in overcoming complexity, from big data to cyberphysical systems", April 4 - 5, 2013, New Delhi- India, Bhagirathi Building - IIT Delhi. Title: *Advanced nonlinear approaches for handling complex datasets and acquisitions in Earth Observations and Universe Sciences* [22].
- O. Pont, B. Xu and H. Yahia were invited speakers at IEEE EMBC 2013: 35th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Osaka, July 3-7, 2013. Title: *Arrhythmic dynamics from singularity analysis of electrocardiographic maps* [21].
- H. Yahia is a member of Elsevier's Digital Processing editorial board (2010-2013), and of Frontiers in Fractal Physiology open journal editorial board.

## 8.2. Teaching - Supervision - Juries

### 8.2.1. Teaching

K. Daoudi was invited for the second time by the Moroccan CNRST within the FINCOME'2013 program (<http://www.fincome.cnrst.ma/>) to give a 20 hour set of lectures on speech processing at the Master2 InfoTelecom of the faculty of science of Rabat (<http://www.fsr.ac.ma/MIT/>).

### 8.2.2. Supervision

PhD : V. Khanagha, *Novel Multiscale Methods for Nonlinear Speech Analysis*, University Bordeaux-1, PhD defended on January 16th, 2013, supervisors: K. Daoudi and H. Yahia [13].

PhD : S. Kumar Maji, *Multiscale Methods in Signal Processing for Adaptive Optics*, University Bordeaux-1, PhD defended on November 14th, 2013, supervisor: H. Yahia [14].

PhD : J. Sudre, *Circulation submésoséchelle et comportements des prédateurs marins supérieurs : Apport de l'analyse multi-échelles et multi-capteurs*, University Toulouse-III Paul Sabatier, PhD defended on December 16th, 2013, supervisors: V. Garçon and H. Yahia [14].

### 8.2.3. Juries

- H. Yahia is a member of the jury ("reviewer") for the PhD of N. Navoret, defended on June 26th, 2013 at University of Bourgogne. Title: *Analyse et détection des électrogrammes complexes fractionnés en vue de soigner la fibrillation auriculaire à l'aide de techniques d'ablation par radiofréquence*. Jury: H. Yahia (reviewer), J.-M. Vesin (reviewer), A. Pumir (examiner), J.-M. Bilbault (examiner), G. Laurent (invited), S. Binczak (supervisor), S. Jacquir (co-supervisor).

## 8.3. Popularization

- H. Yahia made a presentation (title: *Dynamique océanique turbulente à super-résolution*. at the Unithé séminat, on September 2àth, 2013, Inria BSO).
- O. Pont participated to the "Ateliers de Médiation Scientifique" (Inria BSO).
- O. Pont did a radio interview with RFC radio station: "Que cherchent-ils ?".

# 9. Bibliography

## Major publications by the team in recent years

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