Topological analysis of bio-sampled oceanographic time series

3-year doctoral position at IFAECI, Buenos Aires

Planned start in 2020

An international scholarship is launched to cover a single three-year doctoral position at the FCEN, Universidad de Buenos Aires, to work at the *Institut Franco-Argentin pour les Études du Climat et ses Impacts* IFAECI (CNRS-CONICET-UBA-IRD). The scholarship is funded by the *Mission pour les initiatives transverses et interdisciplinaires* (MITI) of the Centre National de la Recherche Scientifique (CNRS, France) according to an agreement established between CNRS and UBA to be completed once the beneficiary of the scholarship has been accepted as a PhD candidate at FCEN-UBA.

Thesis Director: Denisse Sciamarella (IFAECI/CNRS)
Co-directors: Martín Saraceno (CIMA/CONICET-UBA) / Christophe Guinet (CEBC/CNRS)

Context: Along the Patagonian shelf break, color images show chlorophyll-a concentration as high as that present in the eastern boundary upwelling systems. This productivity spreads through the food web, reaching top predators and significant fisheries. Along the continental slope flows the Malvinas Current (MC), the northernmost extension of the Antarctic Circumpolar Current that carries cold and nutrient-rich waters. The MC is thought to be a major source of nutrients for the southwestern South Atlantic. The interaction of the MC with the sloping bottom is presumably responsible for sustaining upwelling along the shelf break. Three main mechanisms have been proposed to explain the observed high concentration of chlorophyll-a: (i) numerical and analytical models indicate that the intensity of upwelling is modulated by the MC transport; (ii) the propagation of internal waves along the shelf break could regularly supply nutrients to the euphotic layer and (iii) wind stress could cause divergence and thus induce vertical currents which bring the necessary nutrients to the surface. Apart from numerical models and the use of satellite data, quantification of the above mechanism with *in situ* data has been elusive so far. The current PhD subject proposes to use a dataset collected by elephant seals equipped with a new unique set of satellite relayed data loggers that allow real-time transmission of oceanographic data and continuous (0.5 Hz) sampling of pressure, temperature, salinity, chlorophyll-a concentration and acceleration. In addition, high frequency (1,5 MHz), low energy active micro-sonars were deployed to assess zooplankton and micro-nekton density in the water column, while bioluminescence events are detected using highly sensitive high-frequency light sensors. Furthermore, acoustic tags fitted with a pressure sensor, accelerometers and a magnetometer were deployed for two seals, allowing the estimation of wind strength and direction as well as swell frequency and amplitude. The real time, low-resolution CTDF data are acquired via the Argos system while the high-resolution data will be available after the instruments are recovered.

Objectives: The main scientific objective is to (1) untangle the physical forcing that may drive the high biological productivity observed on the Patagonian Shelf Break (PSB), and (2) assess differences in the occurrence of elephant seal preys based on oceanographic features and the foraging success of female elephant seals in relation to their foraging habitat (PSB versus oceanic waters). These objectives involve the processing of complex time series that require going beyond the application of standard data analysis techniques. The contributions of Chaos Topology (CT) to Nonlinear Science provide a powerful way of accessing the nonlinear processes at work in geophysical and other flows and phenomena, from biology to society. The so-called topological program is specifically designed to provide a route from time series data to low-dimensional models, with methods that allow model validation and emulation, model-to-model and data-to-data comparison in a nonlinear perspective. Recent advances in computer science, brought about by a millennial discipline, Topological Data Analysis (TDA), are giving new thrust to this kind of approach. Although the geosciences constitute a natural and fertile ground for the application of these concepts, the challenge remains almost unexplored, mostly because of the interdisciplinary nature of a task that involves some knowledge of topology, nonlinear dynamics and fluid mechanics. A first step in this direction has been taken at IFAECI, with the introduction of a topological method for the diagnosis of Lagrangian dynamical diversity, based on sparse data, to unravel transport and mixing processes in geophysics. The technique, called Branched Manifold Analysis through Homologies (BraMAH), allows the topology associated with a dynamical reconstruction to be computed from a scalar time series. It has been successfully applied to data generated by canonical flow models inspired by oceanic and atmospheric flow patterns, and to data from Computational Fluid Dynamics (CFD) simulations of flows with transport barriers. Preliminary tests carried out with these algorithms on time series collected by elephant seals during previous campaigns show that such analytical efforts have the potential to achieve the scientific objectives of the thesis.

Main related references:

Charó, G.D., Artana, G. & Sciamarella, D. Topology of dynamical reconstructions from Lagrangian data. Physica D, 405, 132371 (2020) https://doi.org/10.1016/j.physd.2020.132371

Hindell, M.A., et al. (including Guinet, C.). Tracking of marine predators to protect Southern Ocean ecosystems. Nature, 58, 87-92 (2020) https://doi.org/10.1038/s41586-020-2126-y

Beron-Vera, F.J., Bodnariuk, N., Saraceno, M., Olascoaga, M.J. & Simionato, C. Stability of the Malvinas Current. Chaos, 30, 013152 (2020) https://doi.org/10.1063/1.5129441

Charó, G.D., Sciamarella, D., Mangiarotti, S., Artana, G. & Letellier, C. Observability of laminar bidimensional fluid flows seen as autonomous chaotic systems. Chaos, 29, 123126 (2019) https://doi.org/10.1063/1.5120625

Goulet P., Guinet C., Swift R., Madsen P., Johnson M. A miniature biomimetic sonar and movement tag to study the biotic environment and predator-prey interactions in aquatic animals. Deep-Sea Research Part 1 (2019) https://doi.org/10.1016/j.dsr.2019.04.007

Saraceno, M., C. Provost and A. R. Piola. On the relationship of satellite retrieved surface temperature fronts and chlorophyll-a in the Western South Atlantic, J. Geophys. Res., 110, C11016 (2005) https://doi.org/10.1029/2004JC002736

Sciamarella, D. & Mindlin, G.B. Unveiling the topological structure of chaotic flows from data. Phys. Rev. E, 64, 036209 (2001) https://doi.org/10.1103/PhysRevE.64.036209

Sciamarella, D. & Mindlin, G.B. Topological structure of chaotic flows from human speech data. Phys. Rev. Lett., 82, 1450 (1999) https://doi.org/10.1103/PhysRevLett.82.1450

Sciamarella, D. Exploring state-space topology in the geosciences, Invited Speaker at CliMathParis 2019, Institut Henri Poincaré: https://youtu.be/RH2zzE8OkgE

Qualifications: At the time of appointment, the successful candidate will hold a Master of Science or equivalent degree in Mathematics, Physics, Engineering, Oceanography or a related scientific discipline. Preference will be given to candidates with a broad scientific background and a taste for applied mathematics in an interdisciplinary research context that will involve the integration of a team of physicists, mathematicians, biologists and oceanographers. Skills in R, MATLAB and/or Wolfram Mathematica programming will be acknowledged. Fluency in English is mandatory to ensure communication in an international context that will involve working in Spanish and/or French.

Workplace: *Instituto Franco-Argentino para el Estudio del Clima y sus Impactos* (IFAECI). IFAECI is an International Research Laboratory or *Unité Mixte Internationale* of CNRS located at the *Centro de Investigaciones del Mar y de la Atmósfera* (CIMA) Pabellón II, Ciudad Universitaria, Buenos Aires, Argentina (http://www.cima.fcen.uba.ar/UMI/). It is a joint research unit created in 2010 and sponsored by two French institutions (CNRS and IRD) and by two Argentine institutions (CONICET and UBA), with the scope of promoting a wide and multidisciplinary range of scientific interactions between the two countries. Its current director is Claudia Simionato, with a board of three deputy directors: Andrea Carril, François De Vleeschouwer and Denisse Sciamarella. The thesis may involve research stays at the *Centre d'Etudes Biologiques de Chizé* (CEBC - CNRS), and in this context a joint affiliation thesis (*co-tutela* in Spanish, *co-tutelle* in French) will be encouraged.

Contact: Interested candidates should contact Denisse.Sciamarella@cima.fcen.uba.ar and Bruno.Blanke@cnrs-dir.fr with a cover letter and an updated CV, to be sent no later than 31 May 2020.

Further information on the research project is available at http://mathgeo.cima.fcen.uba.ar. The timetable for the selection of candidates and the actual start of the PhD work will of course depend on the latest developments on the Covid-19 global pandemic.