“Make Our Planet Great Again” proposal for Short Stay

PROJECT TITLE:
Impact of the Loop Current variability on connectivity and dispersal across the Gulf of Mexico and the Caribbean

Proposed dates of stay:
Sep 15th – Dec 15th

Main Domain
Earth and Universe

Secondary Domain
Agronomy-Ecology

MOPGA DOMAIN
Earth System Sciences

Abstract:

In this study we will apply a cutting-edge methodology linking Network Theory and Lagrangian oceanographic modelling (Lagrangian Flow Networks, LFN; developed by Vincent Rossi of MIO laboratory, Marseille, France), that has been used extensively to study ocean connectivity in the Mediterranean Sea (Dubois et al., 2016; Monroy et al., 2017; Rossi et al., 2014; Ser-Giacomi et al., 2015), to investigate how the Loop Current connects the Gulf of Mexico (GoM) and the Caribbean. While both sub-basins have been studied separately, their joint connectivity is largely unknown. These regions, and more especially the GoM, are the subject of much current interest in the broader North American oceanographic community (cf. National Academies of Sciences, 2018), due to great uncertainties in the circulation and large impacts on various regional economies. In this project, we will identify how the dominant modes of variability of the Loop Current affect connectivity and dispersal across the GoM and the Caribbean, which are highly relevant for both ecosystem-based management (Olascoaga et al., 2008; Dubois et al., 2016; Rippe et al., 2017) and pollutant transport (e.g., Olascoaga and Haller, 2012; Rossi et al. 2013), the risk of which is high in these regions. **Our hypothesis is that the state of the Loop Current will strongly affect circulation and dispersal patterns in the GoM and the Caribbean, leading to regular connectivity patterns that depend on the Loop Current state.** The LFN methodology will allow us to robustly assess the impact of the Loop Current on regional dispersal patterns for a variety of applications, and how they depend on biological, physical and numerical factors. For this project, we propose to use ocean model outputs (Jouanno et al., 2012, 2016; Jouanno and

Sheinbaum, 2013) generated by Dr. Julien Jouanno of LEGOS laboratory (Toulouse, France) validated by drifter data (e.g., Gough et al., 2017) supplied by Dr. Josephina Olascoaga of University of Miami (Florida, USA), as well as satellite data that are freely available (Harrison and Glatzmaier, 2012; Jouanno et al., 2016). After completion of this short-visit, this project should deliver a validated bio-physical modelling platform to study transport and connectivity processes in this oceanic region at different scales, thus improving our ability to manage ecosystems and to assess risks of environmental pollution. Moreover, assessment of the Loop Current controls on transport and connectivity across the GoM and the Caribbean will provide a baseline for understanding regional impacts of climate change, which is predicted to strongly affect the Loop Current through a slowing down of the global overturning circulation (Liu et al., 2015). Drs. Harrison (CU Boulder & UCSB, USA) and Rossi will co-lead the study and the proposed project is for Harrison to work with Rossi and Jouanno in France to a first collaborative paper. The proposed short stay will expand and solidify collaborative ties between Harrison and Rossi, who recently co-convened a session at OSM 2018, and more broadly between French, American and Mexican oceanographic communities, as Jouanno and Olascoaga collaborate together (Gough et al., 2017) and with Mexican research labs. On the longer term, Dr. Harrison's short visit will favor the development of an international consortium that could be well positioned to build ambitious collaborative projects on the impacts of climate change in regional seas.

Scientific Context and Motivation

The Loop Current system (LC, Fig. 1) constitutes an apparently strong physical barrier separating the Gulf of Mexico (GoM, Fig. 1) on its western side from the Caribbean Sea to the east. Much recent oceanographic research has focused on the GoM on one hand (e.g. Duran et al. 2018) and on the Caribbean Sea on the other hand (e.g., Truelove et al., 2017). By considering both regions together, this project is the first, to our knowledge, to investigate the LC variability and its connecting role. This is highly relevant since both sub-basins house different biological communities (e.g. Rippe et al. 2017), with differences in physical function, anthropogenic activities, and pressures. Previous research examined the effects of mean ocean circulation and dispersal (Miron et al., 2017; Duran et al., 2018). However, the state of the Loop Current System is highly variable and exerts a strong impact on ocean circulation in both regions (Oey L.-Y. et al., 2013; National Academies of Sciences, 2018). What is yet to be done is understand how the extension of the Loop Current (LC), as well as the detachment and subsequent movement of the LC eddy, organizes ocean circulation, and in particular Lagrangian transport and connectivity across those two sub-basins. This Lagrangian analysis is critical for understanding biological connectivity, as well as pathways for pollutant dispersal and retention, all of which are of great concern in the region (e.g., Olascoaga M. J. et al., 2008; Olascoaga and Haller, 2012; Sanvicente-Añorve et al., 2018). Furthermore, the LC is projected to slow down in the future due to reduction in the Atlantic Meridional Overturning Circulation (Liu et al., 2012, 2015). The proposed new collaboration between Harrison and Rossi, strengthened by the short-term visit, will accomplish the research needed to explore effects of climate change in future projects, and we believe the methods that will tested and validated here are very promising for that application. Thus, the proposed short visit to Marseille is the first and necessary step to develop a robust methodology for the current climate and its future evolution. The validity of the proposed approach will be ensured by comparing model outputs to observed data sets (satellite, drifters). The resulting research products can be applied to assess issues under the current climate, and will also serve as a solid baseline for a subsequent study which will exploit dynamic downscaling of future climate over the region (Jouanno's expertise).

Our hypothesis is that the different states of the Loop Current determine persistent patterns of local connectivity throughout the Gulf of Mexico.

The Loop Current system has a number of intermittently persistent states (National Academies of Sciences, 2018; Fig 1):

S1) Retracted, where the Loop Current barely penetrates the GoM, and the connection between the Yucatan and Florida Currents is short

S2) Extended, where the Loop Current extends north, up to the Texas-Louisiana shelf break

S3) Detached, a transitional state where the Loop Current releases an anti-cyclonic warm-core eddy (containing Caribbean waters) that then travels westward into the GoM.

The mechanisms that cause the extension and detachment of the LC are uncertain and the subject of much current international research effort (e.g., Jouanno et al., 2016; National Academies of Sciences, 2018). In this study, we propose to study not the mechanisms, but instead the impact of these states on the overall transport and connectedness of both sub-basins, which are yet unknown. Limited regional studies of connectivity for specific species have been done for the GoM shelf (e.g., Sanvicente-Añorve et al., 2018), and for the Caribbean Sea (Rippe John P. et al., 2017; Truelove et al., 2017). However, the role of the LC in determining the connectivity between those two distinct regions has never been investigated. Moreover, a systematic understanding of GoM connectivity has only been done from a climatological perspective (Miron et al., 2017; Duran et al., 2018), ignoring the effects of the large spatio-temporal variability of the Loop Current (Donohue et al., 2016; Hall and Leben, 2016; Liu Yonggang et al., 2016; Vukovich, 2007), and not as a function of the biological, physical and numerical factors that could strongly affect the effective connectivity and residence time, which are critical for societally relevant applications (Harrison et al., 2013; Ser-Giacomi et al., 2015). Understanding how connectivity relates to the LC state and its variability gives us a conceptual framework for understanding connectivity and dispersal for all species distributed across the GoM and Caribbean, and for identifying persistent corridors of transport relevant for pollutant dispersal. Pollutant transport is a crucial concern in the region due to extensive offshore oil drilling along the Texas shelf (Olascoaga and Haller, 2012), as well as the prevalence of harmful algal blooms along the coast (Olascoaga M. J. et al., 2008). In this region, connectivity and dispersal represent serious impacts to the regional economies through beach closures as well as impacts on protected and endangered species, such as Loggerhead sea turtles (Harrison, Cheryl et al., in prep; Fig. 2).

SCIENTIFIC OBJECTIVES

Our scientific objective is to determine the degree to which the LC state determines local connectivity throughout the GoM and regional exchange with the neighboring Caribbean Sea. To determine regions of persistent connectivity, we propose to apply the LFN methodology (Rossi et al., 2014; Ser-Giacomi et al., 2015; Fig. 3). This methodology allows us to examine the connectivity of water masses as a function of the LC state. The research objectives are as follows:

R1) Generate composite maps of the most pertinent physical variables for the GoM and Caribbean from both satellite and model data for the two relatively stable LC states (S1-2), and for the evolution of the loop current eddy (S3) over space and time.
R2) Apply the LFN methodology to the model and satellite-based velocity fields and examine the flow networks as a function of the LC state.
R3) Use existing drifter data, as well as biological estimates of realized connectivity, to validate the persistent connectivity regions found in (R2)

METHODOLOGY AND PLANNING

We will first use available satellite and model data (Harrison and Glatzmaier, 2012; Sudre Joël et al., 2013; Jouanno et al., 2016) to create composites of observed and modelled physical variables of the sea surface (e.g., Sea Surface Height, Eddy Kinetic Energy, Finite-Time Lyapunov Exponents, relative vorticity) as a function of the LC state (S1-3). The Loop Current states will be determined using the geometrical criteria (e.g., extension, the longitude and latitude of the maximum intrusion of a sea level contour at the core of the LC, etc.) following a methodology that has already proven to be useful to identify Loop Current eddy detachments (Leben, 2005). This first step will allow us to determine the extent to which S1-3 modify regional circulation, how regular these patterns of circulation are, and how well the model replicates the patterns observed by satellite (R1).

We will then apply the LFN framework to assess marine connectivity and ocean transport over the GoM and the wider Caribbean region (R2). The basic ingredients of the LFN methodology are:

- (i) the tracking of Lagrangian particles (simulating water parcels, and their passively transported constituents, e.g., larvae, pollutants) through the off-line integration of multi-year velocity fields generated by a high-resolution circulation model (Jouanno et al. 2012; 2013; 2016) and derived from satellite blended observations (Altimetry and Scatterometry, (e.g., Sudre Joël et al., 2013)).

- (ii) the construction and analysis of a flow network (Rossi et al. 2014; Ser-Giacomi et al. 2015) to derive connectivity through several complementary proxies.

For the model outputs, we will use the long-term simulations (1993-2015) generated by Dr. Jouanno; they have been validated for the region (Jouanno et al. 2012; 2013; 2016); in addition of having the adequate geographical extension, they are available at several horizontal resolutions (1/36; 1/12; 1/4), allowing us to test if resolution of fine-scale dynamics significantly impacts the local and regional connectivity.

The flow network is composed of an ensemble of nodes which are interconnected by directed and weighted links (water transport). It allows assessing connectivity in a robust manner (Monroy et al., 2017), providing results that can be easily interpreted by ecologists (Dubois et al. 2016). We will compute complementary metrics of connectivity and transport (including local retention, residence times, hydrodynamic provinces, Lagrangian coherent structures, preferential corridors of transport, etc.) to understand how the ocean circulation affects the transport and dispersal of tracers. While our results will primarily focus on the inter-annual variability of such dispersal patterns as function of the LC state, the time-scale in the Lagrangian experiments will be shorter (weeks, months) to match our processes of interests (i.e. biological connectivity and pollutant dispersal).

Finally, patterns of Loop Current dependent circulation, connectivity and dispersal determined in R1-2 will be validated with two procedures. First, the LFN results obtained with the modelled velocity field will be compared to those obtained with the remote-sensed velocity fields. Secondly, connectivity patterns will be validated to the extent possible by the existing drifter data set, in coordination with Dr. Olascoaga and colleagues (e.g., Gough et al., 2017; Miron et al., 2017; Duran et al., 2018). These model-data comparison exercises will both assess the validity of the modeling results, but also if the existing spatio-temporal coverage of the drifter data set is sufficient for our goal. The findings here could also help inform what future observational campaigns are needed to better constrain societally-relevant ocean circulation features.

Planning: The proposed short stay is for Dr. Harrison to work mainly with Dr. Rossi, and marginally with Dr. Jouanno, over the period of 3 months, with the primary residence being at MIO in Marseille, housed by Dr. Rossi. During this time, I will benefit off daily interactions with V. Rossi for fruitful collaborative work and we will plan regular remote meeting with external collaborators (Jouanno, Olascoaga). In the first month, the model and satellite data sets Jouanno has experience with will be analyzed (R1). In month two, the methodology of Rossi will be applied to these data sets (R2). In month three results will be compared with observed drifter data in collaboration with Olascoaga and a manuscript will be prepared (R3). During this time, the four researchers will collaborate on writing a manuscript for a peer-reviewed international journal reporting the results of this project.

POSITION OF THE PROJECT IN RELATION WITH TO THE MAKE OUR PLANET GREAT AGAIN SCIENTIFIC DOMAINS

The proposed project sits squarely within the MOPGA research objective of **Earth System Sciences**, as we are developing **further understanding of processes** that control transport patterns in the region, including **interaction scales** of the Loop Current System variability with circulation and transport processes across the Gulf of Mexico and Caribbean Sea. After completion, this project will deliver a validated bio-physical modelling platform to study transport and connectivity processes in this oceanic region at different scales, thus improving our ability to manage ecosystems and to assess risks of environmental pollution. This baseline understanding will allow us to understand impacts of **future scenarios** in terms of climate change impacts on the Loop Current. Furthermore, this research addresses critical knowledge gaps in **Climate Change and Sustainability Sciences** in examining how climate variability impacts ecosystem services such as biological connectivity, needed for fisheries **management and sustainability (Marine Protected Areas).** Additionally, this research will extend a methodology developed by a French national (Rossi), indicating how it can be applied to other regions. Furthermore, the proposed short stay will expand and solidify collaborative ties between France, the US, and Mexican oceanography communities, as Jouanno and Olascoaga are both actively involved in projects with Mexican research labs.

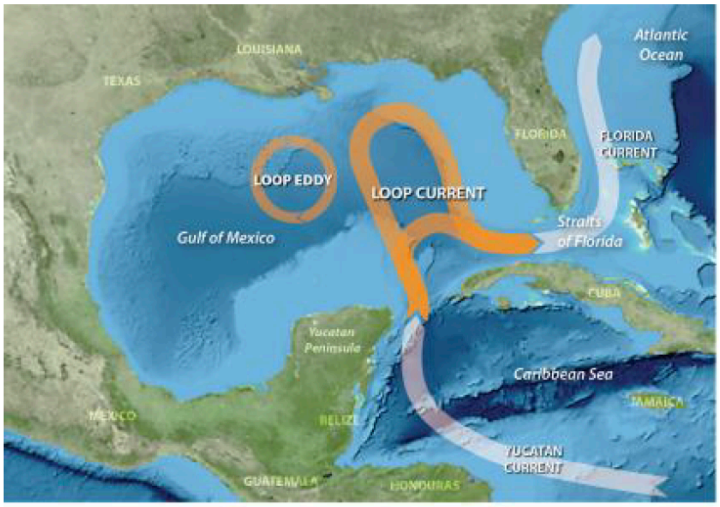

Fig 1. Loop Current System (LCS) showing the Loop Current (LC) in its (1) retracted state and (2) extended state, with (3) a typical Loop Current Eddy (LCE)
Sources: UCAR and NASA, National Academies Press

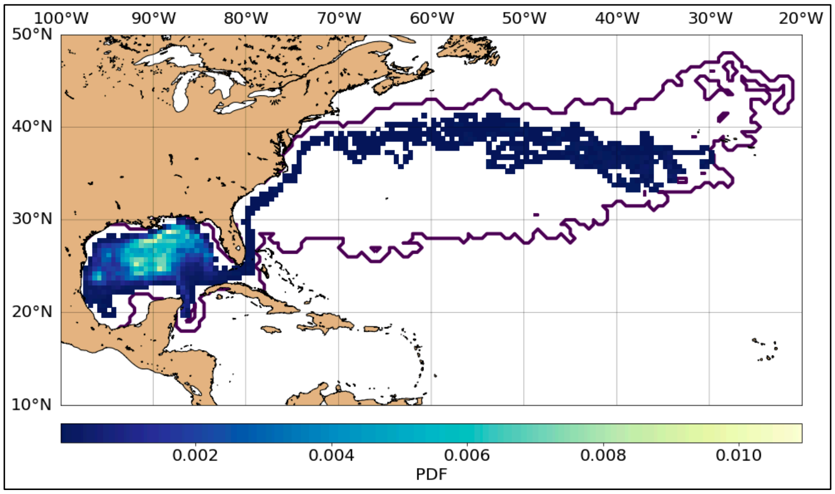

Fig 2. Probability distribution function (PDF) of top 10% best fed loggerhead turtle hatchling locations, originating from the Yucatan Peninsula nesting site (colormap), and the total dispersal range (contour). The Loop Current controls whether the hatchlings end up in the GoM or the North Atlantic. From (Harrison, Cheryl et al., in prep)

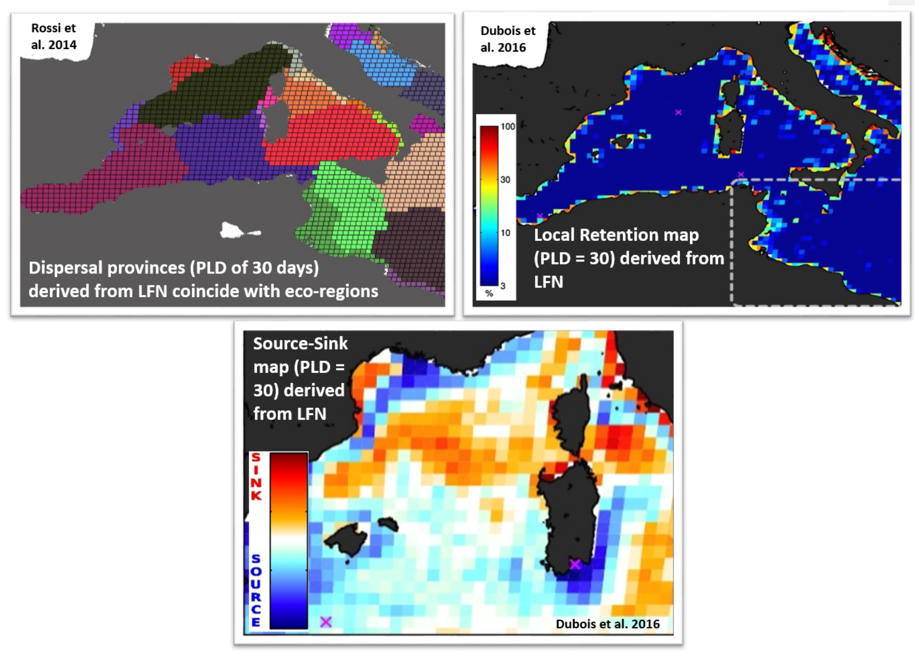

Fig 3. Lagrangian Flow Network results for the Mediterranean Sea. From Rossi et al. 2014 and Dubois et al. 2016.

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