The Assessment of Marine Oil Spills with Lagrangian Descriptors and Remote Sensing

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3^{rd} **International Workshop on Nonlinear Processes in Oceanic and Atmospheric Flows**

6 - 8 July 2016

INSTITUTO DE CIENCIAS MATEMÁTICAS

EXCELENCIA SEVERO OCHOA

Introduction

Study oil spill due to the **sinkage** of the **Oleg Naydenov** fishing trawler off the coast of **Gran Canaria** on 14th April 2015

Objectives

Use **Lagrangian Descriptors** and **Remote Sensing** to:

- **Understand currents and transport in the Canary Islands.**
- **Address potential risk of the oil spill and its fate.**

Provide an interdisciplinary framework for the assessment and effective management of future spills

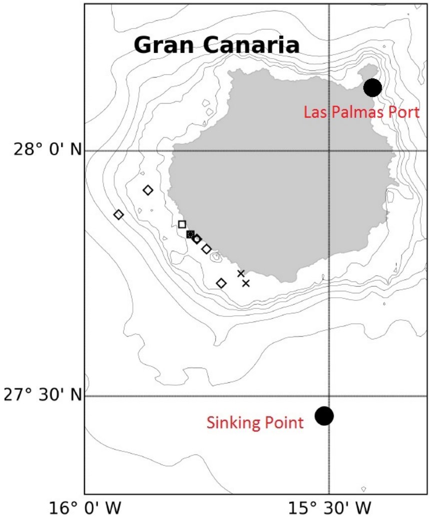
Methodology

- Determine Lagrangian skeleton in phase space (the ocean).
- Evolve oil spills with a contour advection algorithm.
- Validate with Satellite Imagery and Emergency Services sightings.

Event

Oleg Naydenov caught fire on
11th April 2015 in Port of Las Palmas

(with 1500 tons of IFO 380 fuel)



Spanish authorities **towed** the ship **out of the port** and it **sank** on the night of the 14th April

Oil slicks were spotted at sea on the 16th April

Air-Sea Operatives and Ground Emergency Services Monitor the Spill Evolution in SW Gran Canaria

On 23rd April spill hits the coast

Search & Rescue Aircraft Paths

(23rd April - 10th May)

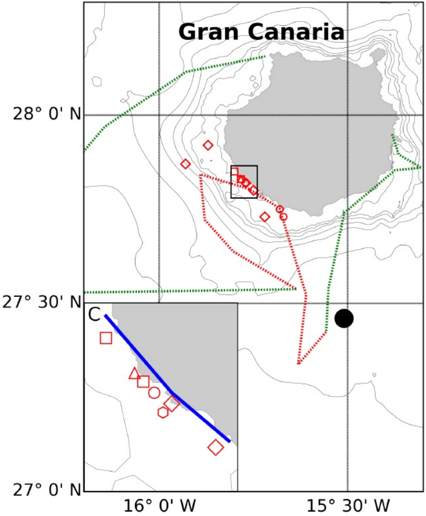
Green Sections - No Oil Reported

Red Sections - Reported Oil

Coast Guard Helicopter Track

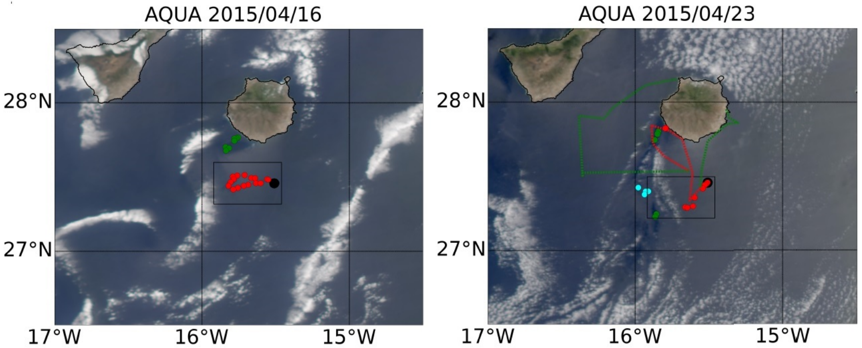
(23rd April - 10th May) Blue line

Symbols: Confirmed Oil Sightings



Remote Sensing

MODIS Aqua and Terra Quasi-True Color Images



Remote Sensing Reflectance (Rrs) Spectra

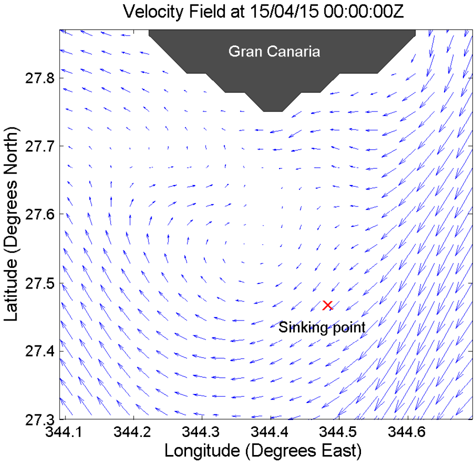
- Red Points - Confirmed Oil Spill (short wavelengths with Rrs < 0.005)
- Green Points - Clean Water
- Cyan Points - Doubts

Dynamical Systems Approach

Potential risk of sinking point and fuel arrival to the coast

Instantaneous velocity fields provide **incomplete picture**

Dynamical Systems Tools **reveal a template** to understand ocean transport **(Oil spill evolution)**



Model Fuel slicks:

- Release (radius 6km) every 24h.
- From Satellite Imagery.

Dynamical System (Passive Tracer Advection)

Daily velocity field with 2 km resolution obtained from COPERNICUS IBI:

$$\frac{d\mathbf{x}}{dt} = \mathbf{v}(\mathbf{x}(t), t)$$

On a sphere of radius R this yields:

$$\frac{d\lambda}{dt} = \frac{u(\lambda, \phi, t)}{R\cos\phi} \quad , \quad \frac{d\phi}{dt} = \frac{v(\lambda, \phi, t)}{R}$$

- λ is longitude and ϕ latitude.
- u and v are the zonal and meridional components of the velocity respectively.

Dynamical System defined on a finite space-time grid

- Bicubic Spatial Interpolation, Third order Lagrange Polynomials in time.
- Trajectory evolution with Cash-Karp Runge-Kutta 4(5) scheme.
- Advection algortihm to evolve sets of initial conditions.

  (Dritschel (1989) , Mancho et al. (2003))

Poincaré's idea

Find geometrical structures that divide phase space into regions of trajectories with qualitatively distinct dynamical behaviors

Lagrangian Decriptors ($\mathcal{M}$ function)

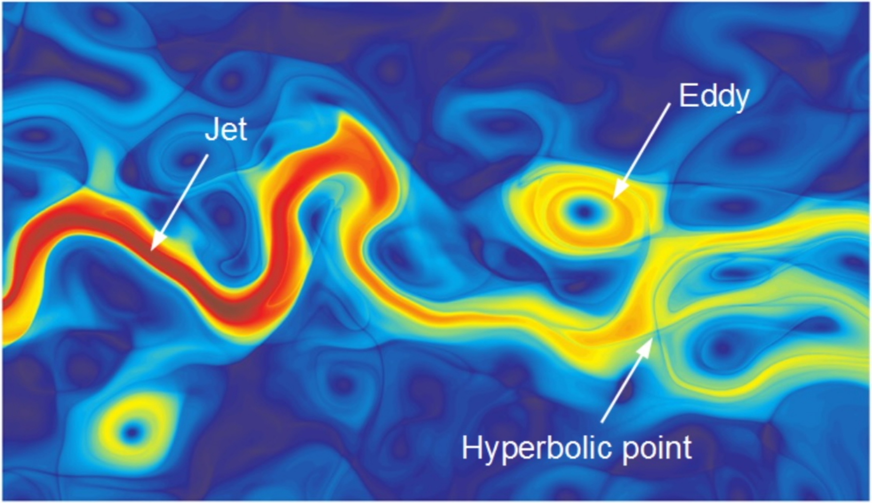
$$\mathcal{M}(\mathbf{x}_0, t_0, \tau) = \int_{t_0-\tau}^{t_0+\tau} ||\mathbf{v}(\mathbf{x}(t;\mathbf{x}_0), t)|| \, dt$$

For any initial condition $\mathbf{x}_0 = \mathbf{x}(t_0)$, computes the arc length of the trajectory as it evolves backwards and forwards in time for a period τ.

This method reveals the geometrical skeleton of structures that govern transport and mixing processes in phase space (in this case, the ocean)

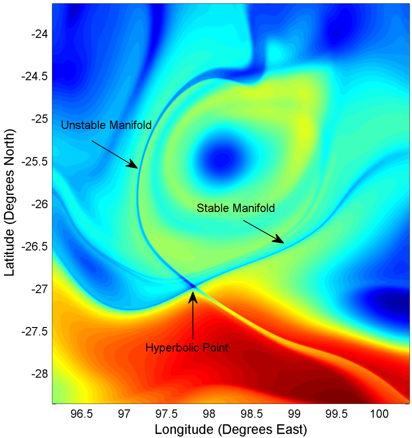
References:

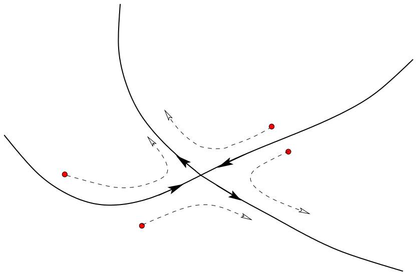
- A. M. Mancho, S. Wiggins, J. Curbelo, and C. Mendoza. Lagrangian descriptors: A method for revealing phase space structures of general time dependent dynamical systems. Commun. Nonlinear Sci. Numer. Simul., 755 18(12), 3530-557, 2013.



$\mathcal{M}$ **draws the global dynamics** of Geophysical Flows, detecting simultaneously **hyperbolic regions** defined by the invariant stable and unstable manifolds, **elliptic regions** corresponding to vortices, and **parabolic regions** related to jet-like structures.

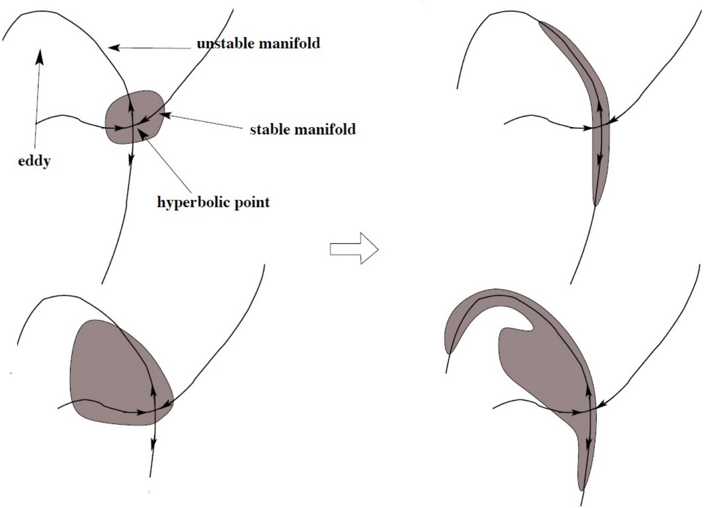
- **Singular features of $\mathcal{M}$ (Stable and Unstable Manifolds).**
- **Increasing τ correlated with richer phase space structure.**



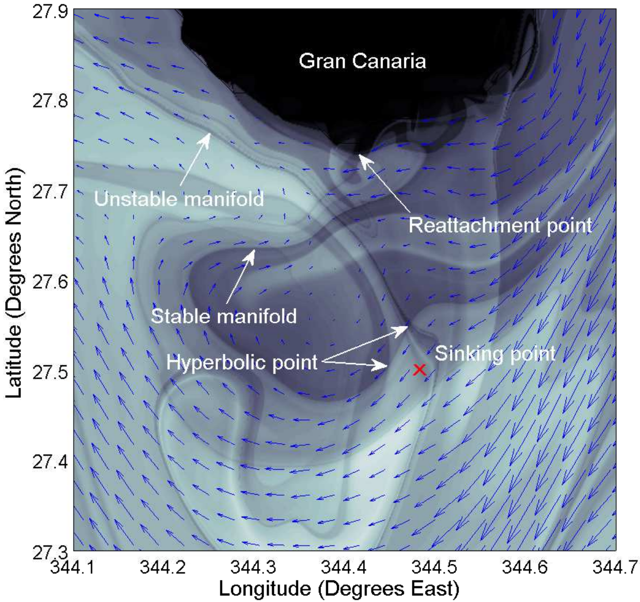


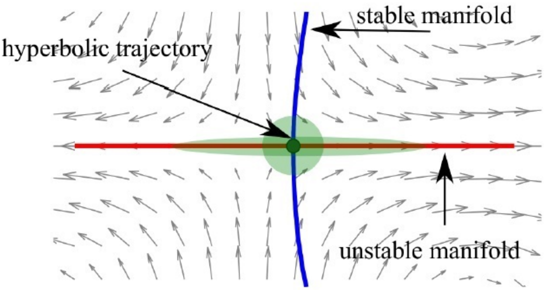
Dynamics of fuel slicks:

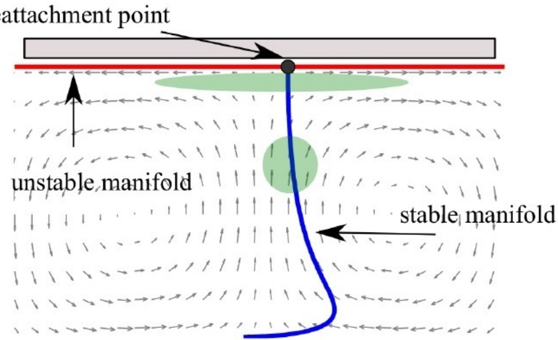
- Stretching along the unstable manifolds.
- Contraction along the stable manifolds.
- Circulation around vortices.



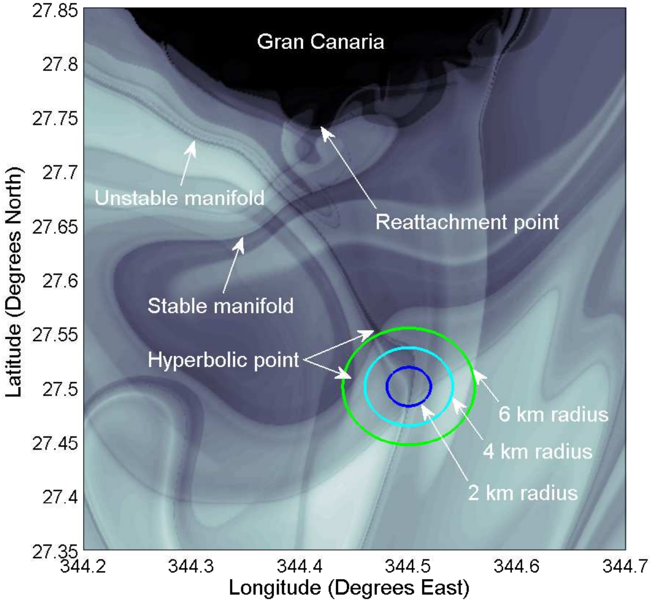
$\mathcal{M}$ function for $\tau = 15$ days on the 15th April 2015



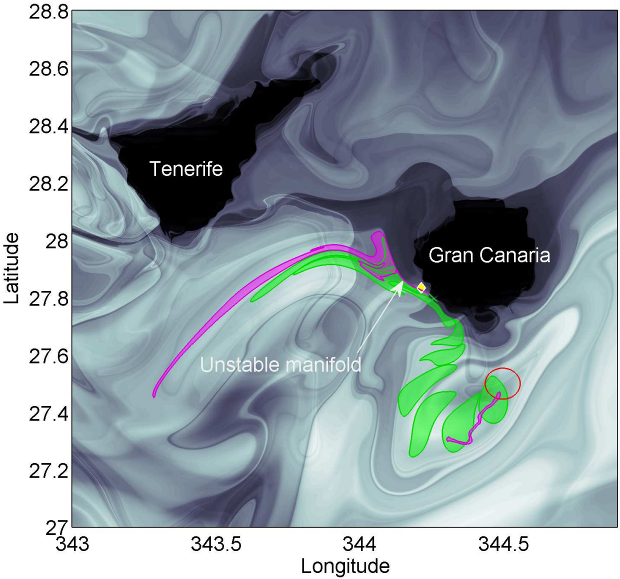

stable manifold
hyperbolic trajectory
unstable manifold


reattachment point
unstable manifold
stable manifold

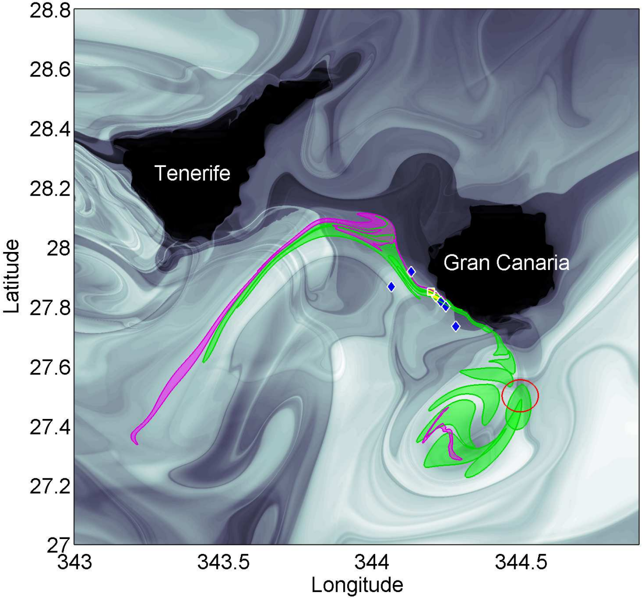
Model of Fuel Slicks (6km radius every 24h + Satellite Imagery)



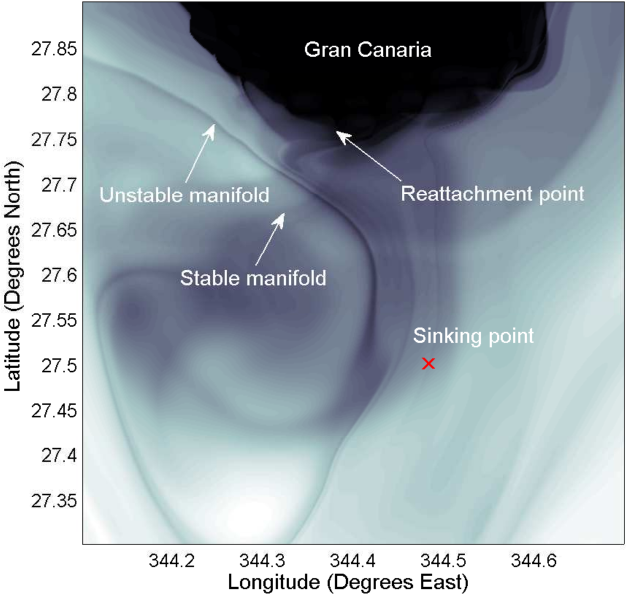
Fuel arrival to the coast of Gran Canaria on the 23rd April 2015



Comparison with Oil Sightings on the 25th April 2015



Operational Capability ($\mathcal{M}$ for $\tau = 5$ days on the 16th April 2015)



Conclusions

- **Oleg Naydenov oil spill is described from three perspectives:**
  - In Situ Observations.
  - Remote Sensing.
  - Dynamical Systems Theory.
- **Potential danger of the sinking point** highlighted by Dynamical Systems tools (reattachment point at the coast and a stable manifold close to the sinking point).
- The evolution of fuel spills confirms that the **stable manifold acts as a highway carrying the spill to the coast** of Gran Canaria.
- **In Situ observations and Remote Sensing oil detection are confirmed** by Dynamical Systems techniques.

Provide an interdisciplinary framework for the assessment and effective management of future spills

V. J. García-Garrido, A. Ramos, A. M. Mancho, J. Coca, S. Wiggins. An Interdisciplinary Approach for a Real-Time Response to a Marine Oil Spill. Preprint.

Thank you for your attention.

Questions?

Review of Lagrangian Techniques:

Distinguished Hyperbolic Trajectories (DHT)

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Lagrangian Descriptors (LD)

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Lagrangian Coherent Structures (LCS)

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Trajectory Complexity Measures

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Transfer Operator Methods and Almost-Invariant Sets

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