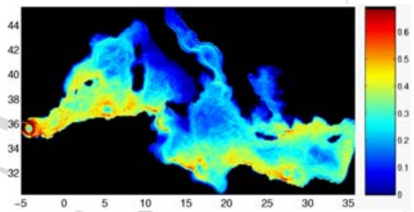
IFISC

FLUID DYNAMICS, BIOFLUIDS, AND GEOPHYSICAL FLUIDS

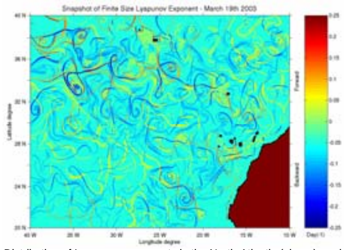
Fluid flow is a natural process occurring in a huge range of scales, from blood capillaries to atmospheric weather systems. It is also widely spread in technological settings, being its understanding crucial to aircraft design or materials production, for example. We concentrate in two research directions: on the one hand we study basic processes in fluid flow such as stirring, mixing, chemical or biological reactivity, instabilities, pattern formation, motion of non-ideal tracers, etc. The point of view of chaotic advection is a convenient starting point. On the other hand, we apply these concepts and methods to geophysical settings, mostly in ocean dynamics: transport modeling, plankton patchiness, ocean forecasting, stochastic forcing effects, etc. More recent topics include studies of biofluids, such as embryonic nodal flow, or plankton and bacterial swimming, and topics in microfluidics.

LYAPUNOV LINES IN THE OCEAN

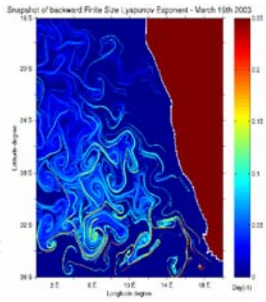
Characterizing the regions in the ocean with different turbulence, dispersion and mixing properties is essential to understand the physical, chemical and biological structure of the sea. The tools of chaotic fluid dynamics have been successfully developed to address such issues.
We have calculated Finite-Size Lyapunov Exponents in several ocean areas of the globe, in order to identify routes of surface transport, areas of intense horizontal mixing, and the interplay between biological and physical dynamics in the sea. Briefly, Finite-Size Lyapunov exponent values indicate the speed of separation between fluid particles closely released in a particular area. Their maximum values occur along lines which act as organizers of the fluid transport: a large accumulation of lines indicates intense mixing, and the lines themselves act as barriers thus indicating the directions along which fluid motion occurs.



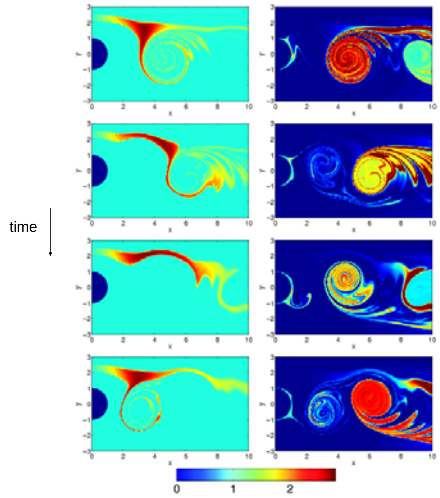
Intensity of mixing in the Mediterranean Sea, as calculated from Lyapunov techniques applied to the output of a computer simulation model of ocean circulation.



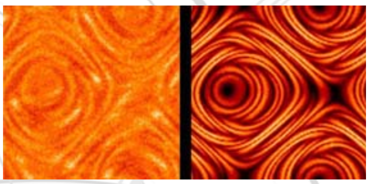
Distribution of Lyapunov exponents in the North-Atlantic (above), and the south-west of Africa (below) calculated from satellite altimetry.



PLANKTON DYNAMICS



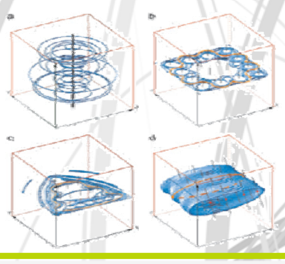
Plankton biology is strongly influenced by turbulent oceanic flows. The figures illustrate plankton dynamics in the wake of an island (blue semicircle at the left). There is a plankton bloom (right column) inside a vortex depending on the ratio of time scales for plankton and hydrodynamics.



DISTRIBUTIONS OF PARTICLES TRANSPORTED BY FLOWS

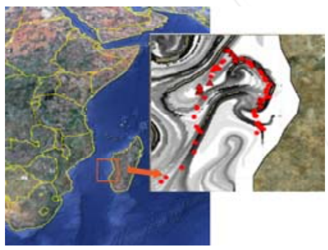
Particles transported by fluid flows may accumulate in particular areas and avoid others, following complex rules which involve the size, density or inertia of the particles and the properties of the fluid. The picture above shows an inhomogeneous distribution of neutrally buoyant particles produced by its evolution in a three-dimensional time-dependent chaotic flow, together with a theoretical calculation of the Lyapunov temperature indicating the regions of the flow that the particles tend to avoid.

EMBRIONIC NODAL FLOW



Left and right symmetry breaking in vertebrate development is linked to the flow direction in the embrio's node.
Comparison of possible flow patterns induced by cilia with the observed one implies cilia inclination of 5-20 º, nicely confirmed by recent experiments.

OCEAN STRUCTURES PROVIDE BIOLOGICAL CORRIDORS FOR MARINE SPECIES



Flying trajectory (red points) of a frigate-bird in the Mozambique channel, compared with filaments and lines that signal vortices and maximum deformation areas of the marine surface (ridges of FSLEs).

Meso- and submesoscales (fronts, eddies, filaments) in surface ocean flow have a crucial influence on marine ecosystems. Their dynamics partly control the foraging behaviour and the displacement of marine top predators (tuna, birds, turtles, and cetaceans). In collaboration with french scientists we focus on the role of submesoscale structures in the Mozambique Channel on the distribution of a marine predator, the Great Frigatebird. Using the Finite-Size Lyapunov Exponent (FSLE) technique, we have identified Lagrangian coherent structures present in the surface flow in the Channel over a 2-month observation period. By comparing seabirds´ satellite positions with the locations of the coherent structures, we demonstrate that frigatebirds track precisely these structures in the Mozambique Channel, *providing the first evidence that a top predator is able to track these FSLE ridges to locate food patches*. After comparing bird positions during long and short trips, and different parts of these trips, we propose several hypotheses to understand how frigatebirds can follow these LCSs. The birds might use visual and/or olfactory cues and/or atmospheric current changes over the structures to move along these biological corridors.