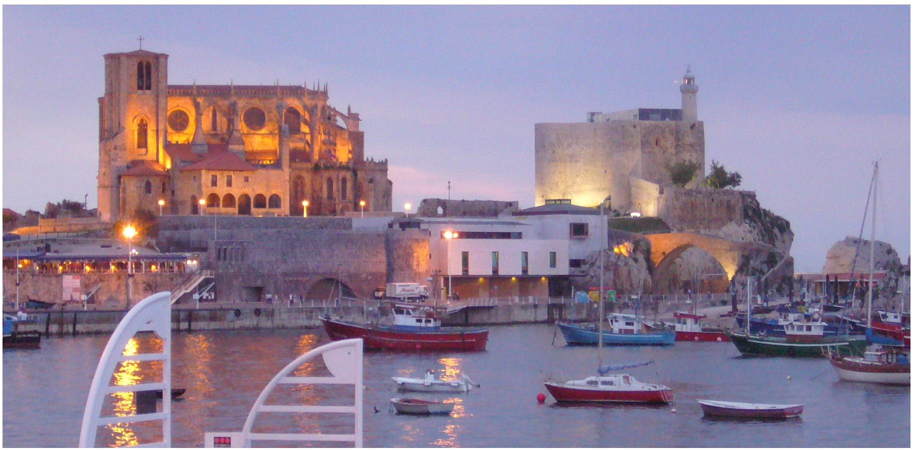
NLOA 2008

Nonlinear processes in oceanic and atmospheric flows



Castro Urdiales, July 2-4, 2008

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Horizontal dispersal and Southern Ocean blooms

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Co-authors: *Mathieu Mongin and Tom Trull*
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Production in the Southern Ocean is limited by the availability of iron. Southern Ocean chlorophyll concentrations are generally low. However there are persistent blooms associated with islands, such as Kerguelen in the southern Indian Ocean. While it is assumed that these blooms are supported by a locally increased iron supply, the origin of the iron is unclear. It has been suggested that enhanced vertical mixing, driven by an interaction between the circumpolar current and the bathymetry, is supplying the iron. In this talk, we present evidence for a contrary point of view, that the blooms are supported by horizontal advection of iron from the islands. This work has been carried out in collaboration with Mathieu Mongin and Tom Trull of the Antarctic Climate & Ecosystems Cooperative Research Centre (Australia).

Set Oriented Numerical Methods for the Approximation of Transport Phenomena

Michael Dellnitz
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Over the last years so-called *set oriented* numerical methods have been developed in the context of the numerical treatment of dynamical systems. The basic idea is to cover the objects of interest – for instance *invariant manifolds* or *invariant measures* – by outer approximations which are created via adaptive multilevel subdivision techniques. These schemes allow for an extremely memory and time efficient discretisation of the phase space and have the flexibility to be applied to several problem types.

In this talk it will be shown that these numerical techniques can particularly be useful for the approximation of *transport phenomena*. In this context we will mainly focus on two related applications: first we will analyze the transport of asteroids in the solar system – this work is mainly motivated by the explanation of the existence of the asteroid belt between Mars and Jupiter. Secondly we will show how to analyze (time dependent) transport phenomena in ocean dynamics. Here we will illustrate the strength of these techniques by a study of transport both in Monterey Bay and in the Antarctic Circumpolar Current.

A nonlinear theory of the bimodality of the Kuroshio Extension

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The bimodal behavior of the Kuroshio Extension (KE) in the North Pacific has fascinated physical oceanographers since indications of this phenomenon were found. Why would a western boundary current switch between a large-meander and a small- meander state and back in a few years time? Why does this phenomenon not appear in other western boundary currents, such as the Gulf Stream? For the Kuroshio, both large- and small meander states can persist over a period ranging from a few years to a decade. With the analysis of satellite data and those of in situ measurements, a quite detailed description of the different states and their transition behavior is now available. There is still, however, no consensus on which processes cause the low-frequency variability in the KE. It appears that direct interpretation of observations often has been based on mechanisms involving external causes (such as atmospheric forcing) and linear ocean dynamics while ocean modelers have tended to suggest mechanisms which involve elements of nonlinear ocean dynamics. A theory of the bimodality of the Kuroshio Extension should include a few essential ingredients. It should explain (i) why the KE can be in different states and also the origin of the spatial patterns of these states, (ii) the interannual time scale of the transition between the two states, and (iii) why there is much irregularity in the large-meander state while spatial and temporal variability are relatively low in the small-meander state. In this presentation we propose a nonlinear theory which is able to provide answers to the issues above.

Interplay between hydrodynamic motion and biological activity: Plankton blooms and marine aggregates.

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Spatio-temporal patterns in marine systems are a result of the interaction of biological and chemical processes with physical transport. In the water column advection is the dominant physical process. We study the influence of mesoscale hydrodynamic structures on biological growth processes in the wake of an island as well as aggregation and fragmentation of marine aggregates in hydrodynamic flows on small spatial scales. In both cases we restrict ourselves to two-dimensional flows and use a stream function approach for the velocity field. In the case of a horizontal flow in the wake of an island we show how the upwelling of nutrients away from the island affects the evolution of plankton close to the island. In particular we show that mesoscale vortices act as incubators for plankton growth leading to localized plankton blooms within vortices. In the case of vertical convection acting on marine aggregates we find that aggregation and fragmentation lead to a stationary size distribution for marine aggregates which depends crucially on the type of fragmentation assumed.

Marine ecosystem dynamics and horizontal stirring and mixing

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Eastern boundary upwelling zones constitute the largest contribution to the world ocean productivity. They include the Canary and Benguela upwelling systems in the Atlantic ocean and the California and Humboldt upwelling systems in the Pacific ocean. Upwelling areas are spatially heterogeneous, populated with a large variety of mesoscale and sub-mesoscale structures such as fronts, filaments, plumes and eddies. Exchange processes in the transitional area between the shelf and offshore areas are controlled by these sub- and mesoscale structures. They play a major role in modulating the biomass, rates and structure of marine ecosystems. These upwelling systems represent natural SOLAS laboratories. We will present here results from a lagrangian approach based on Finite Size Lyapunov Exponents (FSLE) using altimetric and scatterometric data to estimate the spatial and temporal variations in the lateral stirring and mixing of tracers in the upper ocean within the four upwelling systems. When investigating links with chlorophyll a concentration as a proxy for biological activity in these upwelling systems, results show that surface horizontal stirring and mixing vary inversely with chlorophyll standing stocks. FSLEs lead to a clear clustering of the systems suggesting that one may use them as integrated and comparative indices for characterizing horizontal dynamical features in all eastern boundary upwellings.

Local versus global control of mixing in smooth flows

Peter Haynes
University of Cambridge (UK)

There are now many theoretical descriptions of stirring and mixing in smooth flows (which are a good model for many atmospheric and oceanic flows) based on stretching histories following fluid particles. These 'Lagrangian stretching theories' can capture the effects of diffusive mixing as well as stirring and make many potentially useful predictions, such as decay rates, and spectra and structure functions of scalar concentration. The fact that, in the atmosphere at least, global meteorological datasets can be used to calculate the statistics of stretching rates, means that the prediction of Lagrangian stretching theories are potentially useful for interpreting data on atmospheric chemical fields.

However Lagrangian stretching theories are incomplete in the sense that they are 'local' – they take account only of the local structure of the velocity field. This talk will summarise results in Haynes and Vanneste (2005, Physics of Fluids) which clarify, for the case of a freely decaying scalar, when 'local' theories are adequate and when they are not. The important point is that the operator describing advection-diffusion may sometimes (in the limit of small diffusivity) have only a continuous spectrum (in which case 'local' theories work) but may sometimes have discrete eigenvalues (in which case they do not). In the former case the decay of a scalar is locally controlled and in the latter it is globally controlled. The dependence of decay rate on diffusivity on decay rate is quite different in the two cases (and the approach to the limiting value for very small diffusivity is very slow in the locally controlled case).

Some results on the ability of Lagrangian stretching theories to capture the forced, rather than freely decaying problem, will be presented. Implications for studying atmospheric and oceanic flows will be discussed.

A review of relative dispersion in the ocean

Joseph H. Lacasce
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Results from recent experiments in which pair statistics were measured are reviewed. There are indications of exponential growth below the deformation radius, as has also been found with balloon measurements in the stratosphere. However, the behavior at larger scales is unsettled and evidently varies with region. Recent results from a surface drifter experiment in the Nordic Seas are also examined.

Atmospheric complexity or scale by scale simplicity?

Shaun Lovejoy
McGill University (Canada)

In 1922, Lewis Fry Richardson published the now celebrated book "Weather forecasting by numerical process" in which he daringly proposed that the weather could be forecast by brute force numerical integration of coupled nonlinear partial differential equations. But the father of numerical weather prediction was Janus-faced: his book contains a famous passage in which he proposed that the complex nonlinear atmospheric dynamics cascaded scale after scale from planetary down to small viscous scales: he is also the grandfather of modern cascade models. The idea of scale by scale simplicity embodied in cascades is in tune with the history of science that shows that once the fundamentals are correctly grasped, that messy complexity generally gives way to simplicity and that simplicity points the way to the future. But are cascades correct? Over the last five years, profiting from "golden age" of atmospheric data and models of unprecedented quality and quantity, my colleagues and I have used state of the art satellite, lidar and "drop sonde" data to decisively show that over the entire range of meteorologically significant scales that the atmosphere accurately follows the predictions of cascade models. So which Richardson is right? The father of numerical weather prediction or the grandfather of cascades? The answer may be both. This is possible because cascade models are specifically designed as phenomenological models of the equations. It turns out that typical numerical models (General Circulation Models, GCMs) do indeed catch a glimpse of the cascade: todays models apparently capture the first factor of ~ 30 in scale of a cascade which starts near planetary scales and apparently continues down to millimetres (a factor of ~ 1010). Yet even if the GCM's are consistent with cascades, in time they will receive competition from a new potentially more powerful class of cascade models which directly exploit the scale by - scale cascade simplicity allowing them to handle a far larger ranges of scale than is currently possible.

Dynamical Systems and Geophysical Fluid Dynamics: A historical perspective of recent analytical and computational progress

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This talk will be in two parts. In the first part I will review some of the salient work supported by the Office of Naval Research since 1993 in the area of dynamical systems where the emphasis has been in developing computational tools for understanding ocean currents and the atmosphere based on rigorous and foundational mathematics. Certain results on hierarchical models as well as data assimilation will be presented. In the second part of the talk I will elaborate on a new method for solving the three-dimensional Shallow Water equations, which is Lagrangian in essence and is parallelizable. The main details of the program, which is implemented in MATLAB's Distributed Toolbox, will be discussed.

Environmental intermittency versus behavioral intermittency: evolutionary perspectives

Laurent Seuront
CNRS (France) & Flinders U. (New Zealand)

The intermittent nature of the marine environment is considered from both physical and biological perspectives through investigations of the highly nonlinear properties of (i) turbulent velocity, temperature and salinity, and (ii) nutrient, phytoplankton and zooplankton concentrations as a function of turbulent kinetic energy dissipation rates. Turbulent velocity, temperature and salinity exhibit a universal signature independent of turbulence intensity. In contrast, biological scalars exhibit a far more complex structure which can be very distinct from the one of a passive scalar, and suggest that the biological activity of minute plankton organisms might significantly alter the effect of turbulent diffusion. The swimming behaviors of invertebrates and vertebrates are shown to exhibit very similar intermittent patterns that are reminiscent of the patterns observed in their surrounding fluid environments for scales ranging from millimeters to kilometers. The swimming behaviors of both invertebrate and vertebrate organisms considered here, the copepod Temora longicornis and the sunfish Mola mola, belong to the class of multifractal random walks (MRW), characterized by a nonlinear moment scaling function for distance versus time. This clearly differs from the traditional Brownian and fractional Brownian walks expected or previously detected in animal behaviors. The divergence between MRW and Lévy flight and walk is also discussed. The similarities between MRW and the properties of turbulence and plankton distributions are discussed, and the existence of a universal class of intermittent patterns is discussed from an evolutionary perspective.

The Fluctuation-Response relation in Geophysical Systems

Angelo Vulpiani
U. La Sapienza, Roma (Italy)

We show how a general formulation of the Fluctuation-Response Relation is able to describe in detail the connection between response properties to external perturbations and spontaneous fluctuations in systems with fast and slow variables. Numerical computations on systems with many characteristic times show the relevance of the above relation in realistic cases.

Stirring in the Global Surface Ocean from Altimetry

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Global variations in lateral stirring in the surface ocean are examined by calculating finite-time Lyapunov exponents (FTLEs) from surface geostrophic currents derived from satellite-altimeter measurements. These calculations show that stirring in the surface ocean is highly non-uniform, and vary on a wide range of scales. The probability distribution functions (PDFs) of the FTLEs are broad, asymmetric, and have long high-stretch tails. The mean FTLEs and widths of the PDFs vary with the level of mesoscale activity: There are large mean values and very broad distributions in regions of high strain rates and eddy kinetic energy (EKE), e.g., western boundary currents and the Antarctic circumpolar current, and weak mean values and narrower distributions in low strain and EKE regions, e.g. eastern subtropical oceans. The FTLEs also vary at smaller (10 km) scales, with these variations are related to the characteristics of coherent vortex structures. There are low FTLES inside vortices and filaments of high FTLEs in strain-dominated regions surrounding these vortices.

The Dynamical Systems Approach to Transport Associated with Fronts and Eddies in a Realistic Numerical Model of Flow in the Northwest Mediterranean

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Advances in observational methods and computational resources have revealed a variety of flow structures in the ocean, such as jets, fronts, and eddies, whose spatial and temporal dynamics influence transport in a variety of complex ways. Over the past 15 years the global, geometrical approach to dynamical systems theory has been developed to deal with the complexity exhibited by these new data sets. This has required the development of the notion of a ”finite time dynamical system”, which has necessitated the creation of new theoretical and computational techniques. In this talk I will illustrate the merging of these areas by considering transport associated with a front and eddy system in the North Western Mediterranean Sea. The velocity field is obtained from a realistic computational model of the Mediterranean Sea. Dynamical systems theory provides the techniques to give a Lagrangian characterization of the front in a way that allows a detailed and quantitative description of the spatio-temporal structure of transport associated with the front. We extend this further by considering ”interaction” of the front with one, or two, nearby eddies. The notion of a ”Lagrangian eddy” is somewhat novel on its own, and we describe some of the associated issues. We show how dynamical systems techniques can be used to describe the spatio-temporal transport routes associated with the front-eddy system. Finally, we describe the outlook and future problems for analysis of oceanographic data sets in the same manner.

This work has been supported by the US Office of Naval Research.

Energy injection and the inverse cascade of body-forced, two-dimensional turbulence

William R. Young
Scripps Institution of Oceanography (USA)

I'll review theoretical and numerical work in support of the Kraichnan scenario of statistically steady forced-dissipative two-dimensional turbulence. According to Kraichnan's hypothesis, a direct cascade of enstrophy and an inverse cascade of energy coexist provided that dissipative drag (due, for example, to an Ekman layer) is strong enough to halt the inverse cascade before significant energy accumulates at the domain scale. This drag does steepen the slope of the enstrophy cascading spectrum below minus three. But the steeper slope at high wavenumbers might be regarded as only a small modification of Kraichnan's vision. A more significant issue is that if the turbulence is maintained by an applied body force (the most common experimental protocol) then the cascade rate (watts per kilogram injected by the body force) is unknown a priori. So a main open problem is to understand the dependence of the time-mean energy injection, and the strength of its unsteady fluctuations, on the control parameters. This is important because the mean-injection rate determines the overall energy level and thus large-scale flow properties such as eddy diffusivities. Direct numerical simulation indicates that the strength of the drag is the most decisive parameter controlling mean injection. I'll show that variational method provide generously small lower bound on the mean injection and discuss various "phenomenological" models of the energy injection.

Contributed talks

Zonal jets as transport barriers in planetary atmospheres

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The connection between transport barriers and potential vorticity (PV) barriers in PV-conserving flows is investigated with a focus on zonal jets in planetary atmospheres. A perturbed PV-staircase model is used to illustrate important concepts. This flow consists of a sequence of narrow eastward and broad westward zonal jets with a staircase PV structure; the PV-steps are at the latitudes of the cores of the eastward jets. Numerically simulated solutions to the quasigeostrophic PV conservation equation in a perturbed PV-staircase flow are presented. These simulations reveal that both eastward and westward zonal jets serve as robust meridional transport barriers. The surprise is that westward jets, across which the background PV gradient vanishes, serve as robust transport barriers. A theoretical explanation of the underlying barrier mechanism is provided. It is argued that transport barriers near the cores of westward zonal jets, across which the background PV gradient is small, are found in Jupiter's midlatitude weather layer and in the Earth's summer hemisphere subtropical stratosphere.

The evolution of tracer patches

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Co-authors: *William R. Young*
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We use explicit solutions of the advection-diffusion equation to examine the evolution of a patch of a passive tracer subject to vertical shear, horizontal strain, and diffusion. We are especially interested in the evolution of the patch's vertical thickness, horizontal extent, slope, and intensity. In the case of steady shear with no strain, the patch forms a layer with a minimum layer thickness determined by the shear, vertical diffusivity, and the initial horizontal scale of the patch. The initial thickness of the patch is irrelevent. Furthermore, the patch's thickness, extent, and intensity all evolve algebraically in time. The addition of non-zero horizontal strain causes the evolution of the patch properties to become exponential in time. Furthermore, steady horizontal strain causes the patch to tend towards a steady-state vertical thickness. This is in contrast to the case with zero strain, in which the patch thickness grows diffusively with time. Finally, we supplement the steady-flow models with Monte Carlo simulations of time-dependent flow models.

On the importance of mesoscale eddies in the general circulation of the ocean

Paola Cessi
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High resolution computations in a semi-enclosed, idealized, large-scale basin reveal a richness of new phenomena. Firstly, mesoscale eddies lead to qualitative differences in the mean stratification and the MOC compared to laminar (i.e., eddy-free) models. For example, the spreading of fluid across the models representation of the Antarctic Circumpolar Current (ACC) no longer relies on the existence of a sill in the ACC. Secondly, eddy-fluxes of heat, rather than the mean overturn, prominently balance the irreversible heat mixing due to microstrure. Thirdly, in localized but important regions, eddies flux heat upgradient on average. Finally, eddy-fluxes of heat mantain substantial buoyancy gradients along the eastern boundary, breaking the classical constraint that pressure must be constant on a boundary to fulfill the no-flow condition. A simple semi-analytic theory provides a quantitave framework of this result.

Mesoscale, open-ocean anticyclones, vortex Rossby waves and strong vertical velocities

Inga Koszalka
University of Oslo (Norway)

I study numerically the dynamics of mesoscale vortices by using a high-resolution, primitive-equation circulation model (Regional Ocean Modelling System, ROMS) in the context of a wind-forced, stably-stratified, open ocean on a f-plane and in the regime of a small internal Rossby deformation radius. Many properties of the simulated flow, in terms of wavenumber spectra, topology, velocity distributions and dispersion statistics, are found to be similar to these of two-dimensional turbulence. In contrast to quasi-geostrophic approximation, the dynamics features a strong cyclone-anticyclone asymmetry and an unexpectedly complex structure of the vertical velocity field related to the presence of vortices, filaments, vortex Rossby waves, as well as their interactions with Ekman circulation and inertial-internal waves. The vertical motions reach up to 100 m/day in magnitude and are responsible for large vertical excursions of Lagrangian tracers.

The structure of predictability in a quasigeostrophic atmospheric model

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The local predictability of planetary atmospheric flow is investigated in the framework of a three-level quasigeostrophic (QG) model with realistic climatological mean state and variance pattern as well as Pacific/North America and North Atlantic Oscillation teleconnection patterns. Local predictability is quantified by instantaneous and finite-time Lyapunov exponents and vectors. The variation of local predictability across state space is examined. The study also aims to infer predictability information in geographical rather than spectral space. To this end, local growth exponents are calculated from the Lyapunov vectors and their time evolution. Moreover, a local Lyapunov vector dimension is introduced to measure the dimension of the space spanned by the leading Lyapunov vectors locally in geographical space. The methodology of cluster-weighted modelling is used to derive a probabilistic model of the first Lyapunov exponent conditioned on the leading empirical orthogonal functions (EOFs) of the QG model. This approach allows the identification of regimes in the large-scale circulation that tend to be associated with large or small finite-time Lyapunov exponents as quantified by a regime-weighted mean Lyapunov exponent.

Simulation of the Spanish coast currents

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In order to study the exchange of North Atlantic Ocean and Mediterranean Sea water around the Iberian Peninsula through the Strait of Gibraltar and the associated currents, including the MOW density current, a model is required. Therefore, an ocean model called MEDiNA, which comes from the DieCAST model (Dietrich et al.,1987), has been developed. The MEDiNA model has six different grids. A z-level, 4th-order-accurate ocean model is applied in six two-way-coupled grids spanning the model domain. Resolutions vary from 1/4^o in central North Atlantic to 1/24^o in the Strait of Gibraltar region. This allows the MEDiNA model to efficiently resolve small features in a multi-basin model. The wind forcing of MEDiNA is obtained from interpolated monthly Hellerman winds. The World Ocean Atlas climatology database is used to initialize MEDiNA. The 1/8^o Mediterranean Sea grid forms deep water by resolved flow that emulates subgrid-scale processes directly, avoiding watermass drift. No excessively watermass-diluting process allows advection to realistically dominate downslope migration of dense MOW. This and the model's higher order numerics allow simulation of the narrow, thin MOW downslope migration with little dilution. The model results show realistic MOW migration to the observed equilibrium depth, consistent with the climatology (Dietrich et al., 2008)

Currently, the model is running and temporal series of temperature, salinity and current velocity are being obtained. All the results are being studied, through statistic techniques such as EOF (Tomás, et al., 2005) and SOM (Gutiérrez, et al., 2004), to precisely analyse variable behaviour and trends.

References

Dietrich, D., et al.,(1987). DieCAST ocean modeling system programmers guide and users manual.

D. Dietrich, Y-H. Tseng, R. Medina, M. Liste , M. Olabarrieta, S. Piacsek .Mediterranean Overflow Water (MOW) simulation using a coupled multiple-grid Mediterranean Sea/North Atlantic Ocean model. Journal of Geophysical Research. In press.

Gutiérrez, J.M., et al.,(2004). Redes Probabilísticas y Neuronales en la Ciencias Atmosféricas.

Soares ,et al.,(2002). A 40 years hindcast of wind, sea level and waves in European waters.

Tomás, A., et al.,(2005). Metodología de calibración espacial de bases de datos de modelos de reanálisis.

Zonal jet growth as a phase instability

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We study the linear instability of plane Rossby waves to zonal perturbations (jets). Using a phase dynamics formalism, we derive simple equations describing the interactions between the jets and waves. We show that the growth of the jets can be easily understood as a phase instability of the waves, for which different mechanisms can be isolated depending on the various parameters. The accuracy of the asymptotic results is satisfactorily checked against numerical simulations.

Self-organization and criticality in hurricanes

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Self-organization and criticality in hurricanes Tropical cyclones, or, roughly speaking, hurricanes, are complex structures that have been studied for a long time; nevertheless, many aspects of the physics of hurricanes remain unknown. For instance, although there have been substantial improvements on the prediction of their trajectories, the sudden intensifications that they experience preclude the possibility of obtaining reliable forecasts. We analyze different measures of hurricane size, trying to establish connections with out-of equilibrium critical phenomena. Moreover, this new perspective can help to understand the complexity of climate-change processes.

Dynamical response characteristics of the Turkish Straits and Black Sea system

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The Turkish Straits System consists of the Dardanelles and Bosphorus Straits and the Marmara Sea, connecting the Aegean Sea to the Black Sea. This coupled system responds to hydro-meteorological forcing at a wide range of time and space scales. The response is determined by the geometrical characteristics of the interconnected basins, and the connecting channels, where hydraulic controls, separated plumes and jets, bottom and interfacial friction, mixing, and inertial effects all play significant roles. Because the flow has layered stratification, the response also depends on complex internal dynamics, which can not be parameterized with ease. Further, the individual responses of the coupled basins under the action of the hydrometeorological forcing also influence the outcome. Applications of a series of simple models are discussed to characterize scale dependent behaviour of the coupled system. Observations are then used to interpret model results. Other results from ongoing high resolution model studies of strait flows are reported to compare observations with predictions, as well to provide guidance for further studies. Application to problems of transport of passive substances as well as to biogeochemical reactions are also discussed.

Microstructure measurements: Lakes, coastal zone, deep ocean

Elena Roget
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The analysis of microstructure measurements is based on various statistical methods that are conceptually helpful for correct description and better understanding of the processes that govern small-scale dynamics in natural aquatic systems. In the talk, we discuss a) shear induced turbulence in the ocean surface layer, b) double diffusive interface generated by geothermal convection at the bottom of a lake, and c) a bottom boundary layer in a littoral costal zone. The importance of the feedback between theoretical and experimental research will be illustrated.

Transport and mixing in oceanic surface flows

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Theoretical results (the Kolmogorov-Arnold-Moser theorem, and results relating to stable and unstable manifolds and lobe dynamics) and numerical methods (especially the computation of Finite-Time Lyapunov Exponents) from dynamical systems theory are used to study mixing and transport in oceanic flows, with an emphasis on surface flows in the Adriatic Sea and in the Philippines region. Much of the work focuses on the role of transport barriers in non-steady two-dimensional and incompressible flows, their dynamics and methods of their identification. Motivated by observations of surface drifters in the Adriatic Sea, transport in a three-gyre system is studied in some detail. Particular attention is paid to the issue of intergyre transport. The velocity field is assumed to be two-dimensional and incompressible, and composed of a steady three-gyre background flow on which a time-dependent perturbation is superimposed. Two systems of this type are considered: 1) an analytical model of the Adriatic Sea; and 2) an observationally-based altimetry-derived model of the Adriatic Sea. It is shown that for a small perturbation to the steady three-gyre background flow two of the gyres exchange no fluid with the third gyre. When the perturbation strength exceeds a certain threshold transport between all three gyres occurs. This behavior is described theoretically, illustrated using the analytic model and shown to be consistent with the observationally-based model of the Adriatic Sea.

Baroclinic Eddy Fluxes in Quasi-Geostrophic Turbulence with Simple Topography

Andrew F. Thompson
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Jets are a well-known feature of the Southern Ocean's Antarctic Circumpolar Current. Recent evidence from satellite altimetry and numerical models suggests that zonal jets are also a robust feature of the mid-latitude ocean basins. The characteristics of these jets differ, however, with satellite altimetry indicating that Southern Ocean jets have a narrower, ribbon-like appearance and a greater tendency to meander. Topographical features, continental boundaries, and differences in the strength and vertical structure of mean flows may all contribute to the dissimilarity of mid-latitude and Southern Ocean jets. This study considers the influence of simple topography on both the formation and transport properties of coherent structures (jets and eddies) in forced-dissipative, quasi-geostrophic turbulence. The experimental framework is a series of two-layer, baroclinically-unstable simulations in a doubly-periodic domain forced by an imposed vertical shear. These large-domain simulations allow the turbulence to achieve statistically-steady equilibrium states with multiple jets. The sensitivity of the jet structure to topographical slopes, sinusoidal ridges and bumps is explored. Besides providing a mechanism for steering through potential vorticity conservation, topography can also alter the equilibrated energy levels and eddy heat transport. Effective diffusivity calculations are presented to provide insight into how jets and eddies enable or inhibit mixing.

Energy-Enstrophy Stability of beta-plane Kolmogorov Flow with Drag

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We develop a new nonlinear stability method, the Energy-Enstrophy (EZ) method, that is specialized to two-dimensional hydrodynamics; the method is applied to a beta-plane flow driven by a sinusoidal body force, and retarded by drag with damping time-scale μ^{-1}. The standard energy method (Fukuta and Murakami, J. Phys. Soc. Japan, 64, 1995, pp 3725) shows that the laminar solution is monotonically and globally stable in a certain portion of the (mu,beta)-parameter space. The EZ method proves nonlinear stability in a larger portion of the (μ,β)-parameter space. And by penalizing high wavenumbers, the EZ method identifies a most strongly amplifying disturbance that is more physically realistic than that delivered by the energy method. Linear instability calculations are used to determine the region of the (μ,β)-parameter space where the flow is unstable to infinitesimal perturbations. There is only a small gap between the linearly unstable region and the nonlinearly stable region, and full numerical solutions show only small transient amplification in that gap.

Small-scale spatial structure in plankton distributions: The role of a maturation time introduced into the biology

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The observed filamental nature of plankton populations suggests that stirring plays an important role in determining their spatial structure. In a flow where the fluid parcels follow chaotic trajectories and in a regime where diffusion can be neglected, the concentration within a fluid parcel is given by its time history. The spatial structure of the biological concentration fields has been shown to be a result of competition between the rate of convergence of the biological processes involved and the rate of divergence of the distance of neighbouring fluid parcels. It has also been argued (except under rather special conditions), that the small scale behaviour should be the same for all interacting species (Neufeld et al. (1999)). However, a set of numerical results presented by Abraham et al. (1998), in which a maturation time is introduced into the predator evolution equation, shows that the spatial structure of different species decouples (specifically the phytoplankton and zooplankton have different spatial structures at small scales). In this talk a class of models involving a nutrient, a predator and a prey and coupled to a Batchelor-regime chaotic flow are examined. Theoretical and numerical investigations show that the addition of a maturation time does not decouple the spatial structures of the interacting fields, provided sufficiently small spatial scales are considered. However, the same investigations also show that for scales larger than a characteristic lengthscale, a second scaling regime within which the spatial structure of the zooplankton decouples from that of the phytoplankton and nutrient, may appear. The factors that control the appearance of this second scaling regime will be discussed. The fields' scaling behaviour will be explained and shown to essentially be determined by a reduced reaction system in which all terms that include a maturation time are ignored. Finally, an estimate for the magnitude of the characteristic lengthscale will be deduced to depend on both the flow's stirring strength and the magnitude of the maturation time.

Posters

The non-stationary and non-Gaussian nature of ENSO: the role of climate shifts and nonlinearities.

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ENSO is the dominant climate mode of variability in the Pacific, impacting surrounding regions with large socio-economical aspects. ENSO exhibits a significant modulation at interdecadal timescales, also associated to changes of its characteristics. Among these characteristics, some of them are generally ignored in ENSO studies, such as asymmetry and deviation of its statistics from those of an assumed Gaussian distribution. Here, statistical tests are performed to quantify the non-Gaussian nature and asymmetry of typical ENSO indices from long in situ records and intermediate complexity models. A low frequency modulation, dominated by climate shifts, is evidenced in the statistical distribution of the phenomenon, which oscillate between warm heavy-tailed periods (α-stable distribution) and cool Gaussian phases. This supports the mechanism of ENSO rectification by the change in mean state to produce decadal variability. We highlight the role of nonlinearities in the process leading to change in statistical properties. During periods characterized by a warm ocean background, nonlinearities emphasize phase relationships between temperature and currents fields which facilitate the growth of extreme events responsible for the variance burst and thus the switch of representative statistics. Conversely, this nonlinear activity is almost inhibited throughout cool mean state phases, giving back a more Gaussian nature to ENSO proxies.

An adaptive method for computing invariant manifolds in unsteady, three-dimensional flows

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Invariant manifolds have been widely used within the past two decades to study and visualise the processes of Lagrangian transport in two-dimensional, unsteady, advection-dominated fluid flows. In the 2D setting, the (invariant) stable and unstable manifolds of hyperbolic flow trajectories are given by material curves and the powerful (topological in nature) technique of 'lobe dynamics' can be implemented relatively easily. In this work we discuss a non-trivial extension of the 'invariant manifold' approach to the Lagrangian transport and present a method for computing two-dimensional invariant manifolds in 3D, aperiodically time-dependent flows. The presented method is adaptive in space which allows for detailed, computationally efficient determination of highly convoluted geometry of time-dependent invariant manifolds in unsteady 3D flows. We apply this procedure to compute the stable and unstable manifolds of relevant hyperbolic trajectories in a number of examples and study the associated Lagrangian transport processes using the 3D lobe dynamics. We show that the method is capable of providing detailed information on the evolving Lagrangian flow structure for long periods of time. The developed tools can be potentially very useful in providing a much needed insight into transport processes in 3D oceanic flows, obtained from 3D ocean models or from 3D data assimilation, including transport mechanisms due to the vertical coupling of the upper-and-deep ocean eddies.

Hurricanes, Homoclinic Tangles, and Horseshoes

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Recently, Lagrangian methods using Finite Time Liapunov Exponents (FTLE) have been developed to uncover the underlying skeletal structure that dictates how transport occurs in aperiodic flows. Interestingly, these Lagrangian methods reveal well-defined surfaces in the flow that act as barriers to transport and separate regions of different dynamical behavior. In this study, we apply this method of using FTLE to extract Lagrangian Coherent Structures (LCS) to both ocean flows and the manifestly turbulent wind field data for hurricanes. A main result is the discovery of sharply defined surfaces in the flow surrounding the hurricane that govern transport both into and out of the storm. Furthermore, the evolution of these surfaces indicate very plainly that transport in the large-scale flow occurs via the mechanism of lobe dynamics associated with a homoclinic tangle, a process well-understood in classical geometric dynamics. The LCS method reveals that transport in hurricanes is a low-dimensional process whose salient features are adequately described by a very simple two-dimensional dynamical system that exhibits a chaotic tangle concomitant with a perturbed homoclinic connection. Results for the simple model not only provide an insightful comparison with the LCS results for the full hurricane data set, but also illustrate the utility of the LCS method for identifying homoclinic tangles in aperiodic flows.

Statistical properties and robustness of dispersion from surface velocity data

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We have analyzed surface velocity data of the Mediterranean Sea as obtained from a primitive equation circulation model. We have computed the Finite Size Lyapunov Exponents (FSLEs) from this data set, which provides a measure of oceanic horizontal stirring. In order to study their robustness and other statistical properties, the FSLEs are computed at different spatial resolutions, both above and below that of the velocity field. In particular we have analyzed: i) the robustness of the FSLEs by introducing a small error in the velocity data, ii) the influence of the eddy diffusivity in the filamental and vortex structures, and iii) the multifractal character of the spatial distribution of the FSLEs.

Mixing, Lyapunov exponents, and biological activity in the Benguela and the Canary upwelling systems

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A comparative study of the horizontal mixing properties of the two eastern boundary Canary and Benguela upwelling systems is presented. It is based on Finite Size Lyapunov Exponents obtained from satellite-derived velocity fields. Each of the systems is subdivided into two regions attending to their mixing activity values, which coincide nicely with distinct biological activity. Surface horizontal stirring and mixing are inversely correlated with chlorophyll standing stocks. On the other hand, Ekman-transport induced upwelling exhibits a positive correlation with chlorophyll.

Generalizing fixed points to aperiodic dynamical systems

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In the context of stationary flows the idea of fixed point is a keystone to describe geometrically the solutions of the dynamical system. It is extended to time periodic flows by means of the Poincaré map, as periodic orbits become fixed points on the Poincare map. Recent articles provide an important step-forwards to extend the concept of hyperbolic fixed point to aperiodic dynamical systems. In this presentation, we propose a new formal definition of Distinguished trajectory (DT) in aperiodic flows. We numerically test this definition in forced Duffing type flows with known exact distinguished trajectories. The definition accurately locates these trajectories. We also check the definition for examples of aperiodic flows in oceanographic contexts and we find that it overcomes some technical difficulties of other approaches. Also, this definition of distinguished trajectory is valid both for hyperbolic and non-hyperbolic type of stabilities and does not depend on the dimension n of the vector field.

Identification of Cusp Catastrophe in Gap Leaping Western Boundary Current Problem

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The Luzon Strait is an example of a western boundary current which negotiates a gap in bathymetry. In the gap region, the currents can exhibit multiple steady states (leaping the gap or penetrating the gap) and hysteresis (dependence on past flow state). Laboratory experiments on such flows are presented in order to investigate the system behavior in a two-dimensional parameter space of varying flow rate and rotation rate of the platform. The experiments were preformed in a cylindrical tank on a one-meter rotating table. A semi-circular ridge with a gap was inserted over sloping bottom topography in the active region, and the flow was driven by pumping water through sponges. The flow was visualized with the Particle Image Velocimetry method. By varying the flow rate (strength of current), we were able to identify transitions between leaping and penetrating flow states. These transitions bound a region of multiple steady states where hysteresis is present. The dynamics of the system is shown to exhibit a cusp catastrophe classified as A3. The scaling dependencies of some critical properties of the flow were analyzed. This catastrophe may explain irregularities encountered when analyzing observational data of gap leaping flows. Preliminary results of two layer experiments indicate similar dynamics.

Lagrangian Stochastic Models for a sea-surface transport prediction system of the Catalan-Balearic Sea: A first stage test of some LSM's with stochastic flows and a first evaluation of the sea dispers

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An adequate prediction of Lagrangian material transport at the first layer of the ocean (pollutants, shipwrecked persons, etc.) is one of the most important tasks of the Ocean Operational Systems. At sea surface, Lagrangian dynamics is due mainly to winds and currents. Operationally, the estimation of these forcings implies important simplifications which can produce important deviations in the Lagrangian prediction of the transport. Thus it is necessary to model, in some other way, the Lagrangian transport behaviours that can not be well described with available estimated forcings. Several stochastic models have shown good applicability in transport prediction at mesoscale open sea ranges, but operational systems have to respond questions at submesoscale ranges near to the coast. Towards to have more representative tools, it is necessary to evaluate the performance of this type of models in those environments and scales. Here it is conducted a first stage test of two specific types of the so-called Lagrangian Stochastic Models (LSM): Markovian single particle and multiparticle. Up to date the test has been carried out using two types of stochastic turbulent flows: homogeneous isotropic and anisotropic. The test has been mainly directed to learn about the ability of the LSM's to simulate some basic statistical dispersion and diffusion patterns exhibited by ensembles of numerical particles delivered in many realizations of those flows, for several levels of "turbulence".

Statistical properties of scale-invariance in satellite-derived variables

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Singularity analysis (SA), as part of the Microcanonical Multifractal Formalism (MMF), is an appropriate framework for the extraction of dynamic information from satellite-derived scalar variables [Turiel et al., Phys. Rev. Lett (2005); Isern-Fontanet et al., J. Geophys. Res. (2007)]. A strong scale invariance symmetry pervades the organization of a flow under Fully Developed Turbulent (FDT), as in oceans. In previous works it has been shown that i) emerging singularity patterns provide a description of the global oceanic currents [Turiel et al., Rem. Sen. Env. (2008)], and that ii) singularity-based statistical properties of different scalar tracers must coincide at any scale or region [Nieves et al., Geophys. Rev. Lett. (2007)]. In this work we will show that iii) scaling properties in the flow are fully described by Singularity Spectra (SS) derived from SA, while Probability Density Functions (PDFs) do not present this capability. SA is useful in order to measure and track mesoscale oceanic phenomena, opening the way to many operational and reanalysis applications. The common turbulent signature detected in different satellite images may allow e.g. to use temperature maps (which are more abundant than chlorophyll data, CC) for improve the inference of reasonable distributions of CC over data gaps.

Stirring and mixing in the West Florida Shelf

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Co-authors: *F. J. Beron-Vera*
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Application of dynamical systems tools has recently revealed in simulated surface ocean currents a persistent Lagrangian coherent structure (LCS) on the West Florida Shelf (WFS). Consistent with satellite-tracked drifter trajectories, this LCS constitutes a cross-shelf transport barrier which constrains pollutant dispersal and also has important biological consequences. More precisely, red tides occur most frequently on the shoreside of this barrier, which suggests that it provides favorable conditions for their development by allowing for nutrient and dinoflagellate buildup. Here we carry out a detailed study of the nature of the surface ocean Lagrangian motion in the WFS. Examination of several diagnostics suggests that chaotic stirring dominates over turbulent mixing on timescales of up to two months or so. For instance: 1) the large-scale traits of simulated LCSs remain fairly unaltered under spatiotemporal truncations of the advection field; 2) the kinetic energy spectrum has a nearly -3 slope, implying marginally nonlocal dynamics; 3) the PDFs of finite-time Lyapunov exponents exhibit Gaussian cores and long tails with several extrema that fall more slowly than Gaussian toward large stretching rates, indicating spatially inhomogeneous fluid particle dispersion; and 4) Eulerian autocorrelation times of the velocity gradient are shorter than Lagrangian autocorrelation times, suggesting that the Lagrangian evolution is more irregular than the driving Eulerian flow.

Influence of time and spatial scales on phytoplankton blooms

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Most of the hydrophysical factors controlling the functioning of the biological community, e.g. temperature, salinity, intensity of turbulent mixing, etc, are functions of time and space. This leads to a possibility of a spatial structure in the aquatic community induced by the heterogeneity of underlying hydrophysical and hydrochemical fields. Thus, for example, heterogeneity of the field of (horizontal) advection currents, usually caused by the wind among other factors, apparently leads to the formation of spatial structures in plankton communities. In the present work, we analyze the role of time and spatial scales of an advection field on pattern formation. Results will be shown with a simple nutrient-phytoplankton model coupled to (i) an advective field modelled by a Gaussian spatiotemporal distributed noise, and (ii) a real surface current field provided by ESEOAT model from Puertos del Estado for the western Iberian Peninsula with temporal and spatial scales naturally varying with time along one year simulation. The interplay between the biological and hydrodynamical time and spatial scales have been analyzed. Our results suggest high correlations between areas of strong vertical currents and plankton blooms. A minimum vortices size is needed to account for bloom formation.

Optimal wavelets for the realization of microcanonical multiplicative cascades in geophysical flows

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A growing evidence shows that turbulent flows develop cascade processes, which are intimately linked to the spatial arrangement and temporal evolution of the flow. In cascade processes, energy is successively transfered from large to small scales through a multiplicative relation. Classical approaches to turbulent cascading are based in global statistical descriptors. In this work, we propose a wavelet-based microcanonical approach in which cascades are characterized locally, i.e., at each position and scale. Wavelet bases provide a powerful scheme to represent cascade processes, explicitly separating the scales at which the cascade takes place. The kernel of these projections is called mother wavelet and it is a fast-decaying waveform. We show that any signal has an optimal mother wavelet for which the multiplicative relation between scales is locally verified. In this work we have processed time sequences of satellite daily maps of Sea Surface Temperature. We have shown that optimized wavelet bases evidence the locations, scales and times at which the heat cascade transfer is taking place on ocean surface. This allows identifying the precise pathway followed by turbulence-induced energy transfer.Technical applications of the presented methodology include data inference and fusion, and time forecasting. On the more fundamental side, our methods could be used to retrieve dynamical information of the flow such as stream lines, local diffusivities and energy transfer.

List of attendants

(in alphabetic order)

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54. **Young, William R.** (pages 16, 20 and 31)

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Schedule

	July 2	July 3	July 4
9:00-9:15	Opening		
9:15-10:00	Reza Malek-Madani	Laurent Seuront	Angelo Vulpiani
10:00-10:45	William R. Young	Véronique Garçon	Darryn W. Waugh
10:45-11:15	Coffee-break	Coffee-break	Coffee-break
11:15-12:00	Joseph H. Lacasce	Peter Haynes	Henk A. Dijkstra
12:00-12:20	Frank Kwasniok	Andrew F. Thompson	Paola Cessi
12:20-12:40	Alexandra Tzella	Albert Ossó	Emin Ozsoy
12:45-15:00	Lunch	Lunch	Lunch
15:00-15:45	Michael Dellnitz	Stephen Wiggins	Shaun Lovejoy
15:45-16:30	Ulrike Feudel	F.J. Beron-Vera Elena Roget	Edward Abraham
16:30-16:50	Daniel A. Birch	María Liste	Yue-Kin Tsang
16:50-17:10	Louis Marié	Irina I. Rypina	Inga Koszalka
17:10-18:00	Coffee, and poster viewing	Coffee, and poster viewing	Final remarks, coffee and poster viewing

Invited talks : 45 minutes; Contributed talks : 20 minutes