Burgers Lecture: Concepts of dynamical systems theory in environmental science.

Ulrike Feudel
Theoretical Physics/Complex Systems
Institute for Chemistry and Biology of the Marine Environment
Carl von Ossietzky University
Oldenburg, Germany.

The dynamics of our environment are, in general, characterized by complex patterns which evolve in space and time, such as circulation patterns in the oceans, weather patterns in the atmosphere and biodiversity patterns in the biosphere. The methodology of dynamical systems theory is focused, on the one hand, on characterizing spatio-temporal patterns and, on the other hand, on studying transitions between such patterns when environmental parameters or forcings are varied. We will discuss several approaches originating from dynamical systems theory and their extension to environmental science. As one example, we will demonstrate how the concept of Lagrangian Coherent Structures and Finite Time/Size Lyapunov Exponents can be used to study the organization of ocean flows and its impact on marine biology. Furthermore, we will examine the notion of tipping points and their relation to transitions between patterns, e.g. alternative states of vegetation in arid areas, species dominance in oceans, and lakes and sediments in the context of climate change. However, tipping points can also correspond to switches between states due to changing long-term trends or changing variability. Climate change is not only related to changes in mean value like, for example, the increase of mean temperatures in the ocean and atmosphere, but also to a variation of the characteristics of fluctuations (noise) with, for example, an increasing number of extreme events. We will discuss various examples from different fields of environmental science to shed some light on the study of conceptual models using dynamical systems theory to understand basic principles of transitions in the earth system resulting from changing environmental conditions and the challenges to identify those transitions in complex models and natural systems.

Investigation of turbulent pressure fluctuations by time-resolved tomographic particle image velocimetry.

Fulvio Scarano
Department of Aerospace Engineering
Delft Technical University
The Netherlands

A measurement approach is examined to obtain spatio-temporal pressure fluctuations generated by turbulent flows interacting with solid objects. This experimental method is based on a three-dimensional time-resolved variant of the particle image velocimetry technique (4D-PIV, Tomographic-PIV). The working principle invokes the Navier-Stokes equations and is based on the evaluation of the instantaneous pressure gradient from the measurement of the acceleration of fluid particles, with the assumption of incompressible flow. Experiments are conducted at measurement rates up to 10 kHz demonstrating the applicability of the PIV-based pressure imaging to broadband pressure fluctuations from a fully developed turbulent boundary layer at outer velocity of 10 m/s, under zero-pressure gradient. The work includes applications of PIV-based pressure visualization to rod-airfoil interaction and within turbulent jets.

Stability analysis of parallel two-phase flow in channels.

Amir Riaz
Department of Mechanical Engineering
University of Maryland

Parallel flow of two immiscible fluids in channels is subject to two different mechanisms of hydrodynamic instability. The velocity gradients normal to the mean flow give rise to the classical shear driven instability. For this case, destabilizing inertial effects are balanced by viscous damping. In the second mechanism, the viscosity difference between the liquid and the vapor phase leads to interfacial instability. This mode of instability is driven by the discontinuity in the normal viscous stress across the interface and is damped by both interfacial tension and viscous damping. These two instability mechanisms amplify small-scale disturbances, giving rise to finite amplitude nonlinear waves observed in the experiments. With the help of linear stability analysis and direct numerical simulation, we examine the interaction of the two instability modes as a function of the viscosity contrast, interfacial tension and density difference.
The role of the Antarctic polar vortex and Rossby wave breaking on large-scale stirring in the lower stratosphere.

Kayo Ide
Weather-Chaos Research Group
Department of Atmospheric and Oceanic Sciences, AOSC/CSCAMM/ESSIC/IPST
University of Maryland

The most prominent feature of the stratospheric circulation is the seasonal formation and decay of an intense cyclonic vortex that forms in the fall, reaches maximum strength in midwinter, and decays in later winter to spring. The structure and dynamics of the polar vortex thus play a dominant role in the winter and spring stratospheric circulation and are key to determining distributions of trace gases. The trajectories of isopycnic balloons in the lower stratosphere released by the international field campaigns during the southern springs of 2005 and 2010 showed events of latitudinal transport inside the vortex, both away and towards the poleward flank of the polar jet. We apply trajectory-based diagnostic techniques to the ECMWF ERA-Intrim data set and examine mechanisms at work during such events. The Antarctic polar vortex edge is an effective transport barrier. Rossby wave breaking inside the vortex, however, can contribute to mixing inside the vortex and to occasional air crossings of the barrier.