Proposition of PhD

LEGI, Grenoble - DAP, UPC Barcelona

Görtler vortices and induced mixing in gravity currents over curved boundaries

Numerical, theoretical and experimental approaches.

Gravity currents are relevant to many geophysical and environmental flows such as salt intrusions into lakes, reservoirs and estuaries, glacial runoff into the ocean, or cold downhill airflows in mountain areas. On a larger scale they play an important role for the transport of water masses in the oceans and the understanding of their dynamics is therefore important for ocean circulation models and climate models. The correct parametrization of sub-grid turbulent processes related to gravity flows over complex topography (sudden slope changes and curved slopes) are a problem of growing concern since predictions are often unreliable when the overflows themselves and the turbulent and mixing processes are not correctly included in atmospheric, coastal and oceanic circulation models.

While previous research on gravity currents have focused on dense currents descending a flat or uniform sloping bottom, where the dominant instability mechanism at the interface is given by the Kelvin-Helmholtz instability (KHI), this project aims at exploring the conditions of existence and amplification of centrifugal instabilities (Görtler instability GI) which may originate on curved boundaries (Saric, Ann Rev 1994). The novelty is brought by the presence of a background density stratification: its influence on their development and the and the interplay with the KHI are still open questions and deserve further study. At the present state, very few evidence is given of these instabilities within a stratified fluid (Brun, JGR 2017). The importance of the eventual existence of such instabilities is crucial for the dynamics of oceanic overflows, for katabatic flows, turbidity currents and snow avalanches as their induced entrainment/detrainment [Albayrak et al., 2008] modifies their mean properties significantly and the turbulent fluxes (Brun, JGR 2017).

The goal of this PhD thesis is thus to deeply understand these processes and to improve their modelization. For this, a fundamental understanding of the involved hydrodynamic instabilities is needed, which are finally responsible of most of the mixing mechanisms and properties. This will be realized using numerical, theoretical and experimental approaches. The PhD program is thus based on the four methods:

1. Direct numerical simulations (40%): DNS of boundary layers, of wall jets and gravity currents along a curved boundary using the numerical tools of LEGI/MoST (see GI visualizations in figure 1a) and of the group of F Marques at UPC, Barcelona (SPAIN).

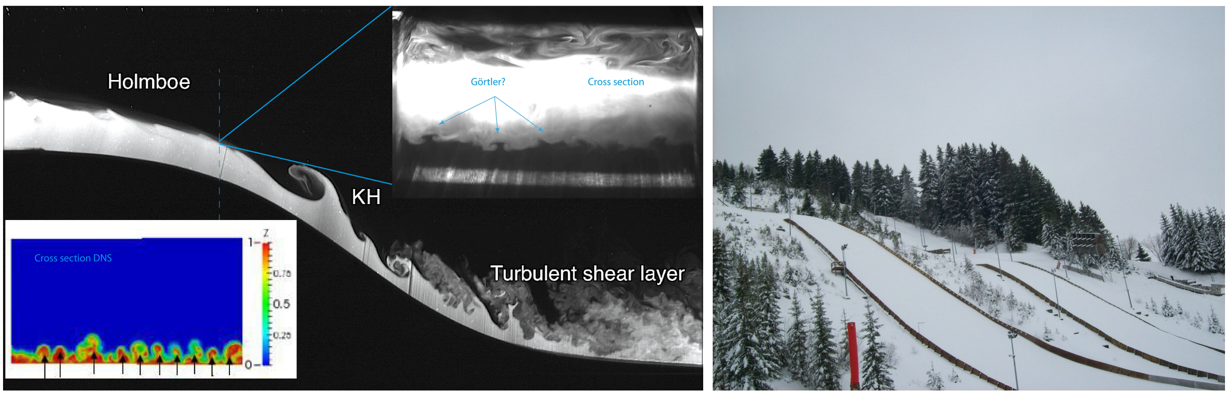

Figure 1: a) Visualizations from laboratory experiments of a gravity current with zoomed views of cross sectional areas from experiments (black and white square) and from DNS (colored square); (b) the ski springboard in St Nizier of Vercors, to be used for field experiments of katabatic winds over curved slopes.

At the LEGI, the code YALES2 (success.coria-cfd.fr) will be used on massive parallel computers developed at IDRIS and CINES. High resolution computations at IDRIS and CINES (400,000 hCpu/year, DARI project) will be performed in the frame of DNS methods or well resolved LES, to avoid or reduce the need for subgrid-scale modeling. The simulations will reproduce some of the laboratory experiments. More than 1 billion grid points will be used to precisely solve the boundary layer spreading along the curved slope. Turbulent scalar flux and turbulent Reynolds stresses will be explicitly determined from the DNS. The validity of existing SGS models will be tested for stratified boundary layer (e.g. Mauritsen et al. 2007) in the context of a sloping boundary and specific laws of the wall to describe realistic boundary conditions for a gravity downslope flow will be tested.

2. Laboratory experiments (20%): a large database of laboratory gravity currents experiments over curved boundaries are already present at LEGI and additional experiments may be easily performed to complete the existent data (see flow visualizations in figure 1a) in an existent open channel flume at LEGI, where all the equipment for different initial conditions (buoyant fluxes and slope shapes) and for measurements of velocity and concentration fields (shadowgraph, PIV, PLIF) are available (Negretti et al., JFM 2017). New experiments are planned in an annular geometry of a lock-exchange configuration to support the theoretical analysis on the conditions of generation of the various types of instabilities, as detailed below.

3. Linear stability analysis (20%): A theoretical study on the linear stability of a lock-exchange flow within an annular geometry will be performed. Direct numerical simulations will be first performed to obtain the initial conditions (i.e. velocity and density profiles) needed to study in a second step the numerical three-dimensional stability analysis of an annular lock-exchange flow. A stability analysis will be performed in a second step using tangent hyperbolic profiles for both the velocity and density fields using a normal mode approach in cylindrical coordinates. The variation parameters will be the density difference which controls the relative strength of the exchange flow rate and the difference between the internal and the external radii. Finally, we will first consider the annular flow on a horizontal plane, where only the buoyancy difference will drive the flow, and then incline it of 90° with respect to the horizontal adding thus an additional gravity component to the forcings. Further experiments expressively designed to support this theoretical study are planned in an annular geometry with a mean diameter of $1,5m$ and a channel of $15x15cm^2$ cross sectional area. In this configuration GI are susceptible to appear both in the boundary layer of the heavier current and in the outer part of the velocity profile of the lighter, counter-flowing current. The stability conditions of the GI in the parameter space (e.g. Görtler and Richardson numbers, different geometrical parameters) will be obtained. Shadowgraph visualizations techniques as well as detailed PIV/LIF measurements in cross sectional areas of the channel at high frequencies will allow to detect the Görtler rolls and will produce detailed measurements of the velocity and its fluctuations (Negretti et al., Ph.Fl. 2008; Negretti and Billant, JFM 2013).

4. Field data analysis and design of field experiments on a ski-springboard (10%+10%): Measurement campains during stable winter conditions on the Grand Colon slopes on the Belledonne mountain chain are regularly performed since 2012 in collaboration with the IGE. The already available and new collected data will permit the validation of the recognition method of the Görtler vortices starting from the invariants of the Reynolds tensor, as proposed recently by Brun JGR, 2017).
An ideal configuration for field experiments on curved slopes of gravity flows (katabatic winds) is given by the ski-springboard in St Nizier of Vercors (see figure 1, right) 30m wide and 120m long. Measurements of katabatic winds will serve as elements for the validation of the numerical simulations and laboratory experiments. In a first step, the configuration will be studied numerically using the model MesoNH of Meteo France and the code YALES2, after the field measurements will be performed during stable anticyclonic conditions in winter time.

Support

For the numerical simulations all the calculation facilities based on the national and local computational center will be available. For the experiments, all the experimental facilities and for the measurements techniques based on PIV, PLIF, shadowgraph will be available. For the data processing, a PC equipped with MATLAB, inclusive with toolboxes, and all common scientific programs is available.

Supervision

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Fellowship

Starting date will be September 1st - November 1st, 2017. The net salary will be 1,500eu/months roughly. Candidates should contact one of the given supervisors for applications.