## TIME TABLE

| TIME | Monday | Tuesday | Wednesday | Thursday | Friday |
|---|---|---|---|---|---|
| | **June 25** | **June 26** | **June 27** | **June 28** | **June 29** |
| 9.00 - 9.45 | Registration | Chomaz | Chomaz | Legg | Rieutord |
| 9.45 - 10.30 | Chomaz | Linden | Linden | Rieutord | Legg |
| 11.00 - 11.45 | Linden | Staquet | Dalziel | Staquet | Staquet |
| 11.45 - 12.30 | Dalziel | Dalziel | Legg | Chomaz | Rieutord |
| 14.00 - 14.45 | Chomaz | Legg | Rieutord | Dalziel | |
| 14.45 - 15.30 | Linden | Rieutord | Staquet | Legg | |
| 16.00 - 16.45 | Dalziel | Chomaz | Legg | Rieutord | |
| 16.45 - 17.30 | Staquet | Linden | Dalziel | Staquet | |
| 18.00 | Welcome Aperitif | | | | |

## ADMISSION AND ACCOMMODATION

The registration fee is 600.00 Euro + VAT*, where applicable (bank charges are not included). The registration fee includes a complimentary bag, four fixed menu buffet lunches (on Friday upon request), hot beverages, downloadable lecture notes and wi-fi internet access.

Applicants must apply at least one month before the beginning of the course. Application forms should be sent on-line through the following web site: http://www.cism.it. A message of confirmation will be sent to accepted participants. Applicants requiring assistance with the registration should contact the secretariat at the following email address cism@cism.it.

Applicants may cancel their course registration and receive a full refund by notifying CISM Secretariat in writing (by email to cism@cism.it) no later than two weeks prior to the start of the course.

Cancellation requests received during the two weeks prior to the start of the course will be charged a 50.00 Euro handling fee. Incorrect payments are also subject to a 50.00 Euro handling fee.

A limited number of participants from universities and research centres who are not supported by their own institutions can be offered lodging and/or board, if available, in a reasonably priced hotel or student guest house.

Requests should be sent to CISM Secretariat by **April 25, 2018** along with the applicant's curriculum and a letter of recommendation by the head of the department or a supervisor confirming that the institute cannot provide funding. Preference will be given to applicants from countries that sponsor CISM.

Information about travel and accommodation is available on the web site www.cism.it, or can be mailed upon request.

* Italian VAT is 22%.

*For further information please contact:*
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ACADEMIC YEAR 2018
The Cowin Session

Centre International des Sciences Mécaniques
International Centre for Mechanical Sciences

# TURBULENT MIXING IN STRATIFIED FLOWS

Advanced School
coordinated by

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Ecole Polytechnique, Paris
France

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University of Cambridge
UK

**Udine** ***June 25 - 29*** **2018**

## TURBULENT MIXING IN STRATIFIED FLOWS

The world's oceans, lakes and atmospheres and many astrophysical bodies are stably stratified, in that the density of the fluid increases in the direction of the gravitational force. A fluid particle displaced from its equilibrium position is then subject to a restoring buoyancy force that tends to return it to its equilibrium position. On Earth, this means that vertical motions are inhibited by the stratification, providing an impediment to vertical exchanges of mass. However, these vertical exchanges and any consequent mixing are critical determinants of the structure of these natural fluid bodies. For example, the uptake of heat and carbon dioxide into the ocean from the surface depends critically on how these quantities are mixed down into the ocean interior, an essential aspect of the climate system. This mixing is caused predominantly by turbulent motions generated by shear flows, breaking internal waves and other forcing mechanisms interacting with large scale motions.

Over the past ten years or so there have been major advances in our understanding of stratified turbulence. This has been largely brought about by improved computational capabilities that allow direct numerical and large eddy simulations of stratified flows, coupled with significantly improved experimental diagnostics. In addition field measurements have provided new data at geophysical scales that have caused a re-evaluation of the extrapolations of data from numerical and laboratory studies. There has also been significant progress in understanding transitions from stratified laminar to turbulent flows through the application of modal as well as non-modal analysis.

This course brings together six leading researchers specializing in stratified turbulence and mixing to teach focused and highly original courses in this area. They will present the latest findings from stability theory on the laminar to turbulent transition, and discuss the recent progress in scaling stratified turbulent flows. The latest laboratory experiments will be presented and the impact of new highly-resolved three dimensional fields of velocity and density and the relation to the latest numerical simulations. Important quantities such as mixing efficiency and the relation to the underlying non-dimensional parameters and the molecular properties of the fluid involved will be highlighted. Lectures will also cover the role of stratified turbulence in the oceans, atmosphere and in astrophysics.

Learning skills in this interdisciplinary environment is challenging and rarely addressed to a sufficient level in standard graduate programs. The integrated presentation of theoretical, experimental and numerical research coupled with applications in geophysical and astrophysical fluid dynamics, provides a valuable opportunity to learn about this important field of fluid dynamics. The course is intended for doctoral and postdoctoral scholars in physics, applied mathematics, engineering, oceanography and meteorology.

## PRELIMINARY SUGGESTED READINGS


Balmforth, N. J., Llewellyn-Smith, S. G. & Young, W. R. 1998 Dynamics ofinterfaces and layers in a stratified turbulent fluid. J. Fluid Mech. 355, 329–358.

Fernando, H. J. S. 1991 Turbulent mixing in stratified fluids. Annu. Rev. Fluid Mech. 23, 455–493.

Linden, P. F. 1979 Mixing in stratified fluids. Geophys. Astro. Fluid Dyn. 13, 3–23.

Shih, L. H., Koseff, J. R., Ivey, G. N. & Ferziger, J. H. 2005 Parameterization of turbulent fluxes and scales using homogeneous sheared stably stratified turbulence simulations. J. Fluid Mech. 525, 193–214.

Turner, J. S. 1972 Buoyancy effects in fluids. CUP

Venayagamoorthy, S. K. & Koseff, J. R. 2016 On the flux Richardson number in stably stratified turbulence. J. Fluid Mech. 798, R1.


## LECTURES

All lectures will be given in English. Lecture notes can be downloaded from the CISM web site. Instructions will be sent to accepted

## INVITED LECTURERS

**Jean-Marc Chomaz** – Ecole Polytechnique, Paris, France
*6 lectures on:*
Stability of stratified shear flows and the application to the laminar turbulence transition. The role of internal waves and scaling analysis.

**Stuart Dalziel** – Cambridge University, UK
*6 lectures on:*
Advanced experimental techniques in stratified turbulence. Applications to the measurement of mixing efficiency and the roles of internal and external mixing processes.

**Sonya Legg** – Princeton University, USA
*6 lectures on:*
The generation of stratified turbulence in the ocean (breaking internal waves, gravity currents etc)? The representation of mixing in ocean models (parameterizations of internal-wave driven mixing and mixing in overflows). The impact of stratified turbulence-driven mixing on the large scale ocean circulation.

**Paul Linden** – Cambridge University, UK
*5 lectures on:*
General introduction and dimensional analysis applied to stratified turbulence. The form of the turbulent spectrum and the role of fluid properties in mixing.

**Michel Rieutord** - Université Paul Sabatier et Observatoire Midi-Pyrénées, Toulouse, France
*6 lectures on:*
The main questions raised by turbulent mixing in stratified turbulence in our quest to understand celestial bodies. This will bring us into the radiative zone of stars and accretion discs where the transport of angular momentum and/or chemical elements is still a difficulty of the models. We will consider wave mixing, overshooting, penetrative convection and stratified turbulence in the context of fluids characterised by a low Prandtl number, a strong density stratification and magnetic fields.

**Chantal Staquet** – LEGI, Grenoble, France
*6 lectures on:*
The importance of mixing in natural media, such as the Southern Ocean and the stable atmospheric boundary layer, as inferred from "advanced numerical modelling" in idealized or realistic conditions. An evaluation of the use of direct numerical and large eddy simulations of stratified turbulence.