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# Colloquium n. 619 – Oberbeck - Boussinesq hypothesis and beyond in stratified turbulence

## Dates and location

4 July — 8 July 2022, Wien, Austria

## Chairperson

Francesco Zonta

## Co-chairperson

Sergio Pirozzoli and Francesca Chillà

## Conference fees

- Late Registration: **500.00 €**
- Online SPEAKER early-bird registration: **200.00 €**
- Online SPEAKER late Registration: **300.00 €**
- Online attendees: **100.00 €**
- Early-bird registration: **450.00 €**
- Accompanying person: **150.00 €**

## What other funding was obtained?

No other funding

## What were the participants offered?

Book of Abstracts and Program of the colloquium; Stationery and other colloquium material; Three lunches, Six coffee/Tea breaks, two dinners (a welcome dinner and a social dinner); Access to a fully-equipped room, exclusively reserved for the conference, for the three days.

## Applicants (members)

1. Pierre Augier
2. Elian Bernard
3. Shashwat Bhattacharya
4. Marco De Paoli
5. George Giamagas
6. Markus Holzner
7. Vincent Labarre
8. Detlef Lohse
9. Cristian Marchioli
10. Lucas Méthivier
11. Věra Musilová
12. Ambrish Pandey
13. Nicolaos Petropoulos
14. Julien Salort
15. Wilhelm Schneider
16. Olga Shishkina
17. Alfredo Soldati
18. Valentina Valori
19. Yantao Yang
20. Matthew Xinchen Zhang

## Applicants (non members)

1. Mohammad Anas
2. Stefano Brizzolara
3. Katherine Grayson
4. Robert Hartmann

5. Yonghuang Hu
6. Xianyang Jiang
7. Robert Kunz
8. Chang Liu
9. Visakh M G
10. Ziad Ntarmouchant
11. Roshan Samuel
12. KASTURI VENKATA SAI SRIKANTH
13. Yin Wang
14. Jin-Han Xie
15. Yi-Chao Xie
16. Xianfei Zhang
17. Lu Zhu

## Scientific report

A turbulent flow in which density gradients exist is bound to be subject to vertical buoyancy force, which modifies the physics of mass, momentum and energy transport. Density stratification can be either of stable type (i.e. light fluid lying on top of heavy fluid) or of unstable type (heavy fluid lying on top of light fluid) and is often affected by the presence of boundaries, thus yielding wall-bounded turbulent stratified flows. Examples of such flows can be found in industrial and geophysical/environmental applications and include heat exchangers, chemical/nuclear reactors and atmospheric/oceanic boundary layers. Experimental, computational, and theoretical methodologies have provided plenty of data and insights into the complex intertwined phenomena typical of stably and unstably stratified turbulence, yet the field remains rich in future challenges.

One of such challenges is the need for accurate numerical and experimental results at large Reynolds and Rayleigh number. Although DNS (Direct Numerical Simulation) has produced a huge amount of information on stratified turbulence, the Reynolds/Rayleigh number in most available studies is too low to satisfactorily address full-scale environmental and industrial phenomena. In fact, it is far from clear that information obtained from low-Reynolds/Rayleigh-number simulations can be confidently extrapolated to the scales relevant of real-world phenomena, especially in the oceanic and atmospheric context. In this respect, the capability of carrying out large exa-scale DNS on next-generation supercomputers will allow for systematic investigation of a broader range of the governing parameters. These large-scale databases will certainly also help LES (Large Eddy Simulation) to design high-fidelity subgrid-scale models, as well as RANS (Reynolds-Averaged Navies Stokes) to develop reliably buoyancy-sensitive turbulence closures.

A further important issue is encountered in environmental and industrial applications, in which vertical length scales are large (for example, the atmospheric/oceanic boundary layer) and fluid temperature gradients are large (for example, nuclear reactors). In such instances, the classical Oberbeck-Boussinesq (OB) linearization is questionable. Although the OB model has been of utmost use in gaining fundamental insight into stratified flows, it can no longer be maintained whenever temperature gradients are large and/or when the focus is on phenomena occurring at large vertical scales. As a consequence, suitable modeling approaches including non-Oberbeck-Boussinesq effects should be adopted/developed to accurately capture the physics of stratified turbulence at large Reynolds/Rayleigh numbers.

The main goal of the 619 Euromech colloquium was to gather together a group of world-wide experts in the study of turbulent stratified flows, to highlight the main physical, experimental and computational challenges standing before us, and devise avenues for effective physical and technological advancement.

About 45 participants attended the colloquium, which was held in hybrid form (online+presence). The colloquium was subdivided into 6 main blocks, each introduced by a specific keynote lecture. A brief summary of the addressed topics and of the discussions is given below:

DAY 1. The morning of day 1 has been focused on stably stratified turbulence. The discussion has been opened by the keynote lecture of Prof. Caulfield ("Mixing up the climate? How the mystery of stratified turbulence is controlling all our futures") on the role of stratified turbulence on climate prediction.
The discussion has then continued touching other extremely important aspects of stratified turbulence, including the dynamics of internal waves, the origin/disruption of flow layering, and the role of boundaries in the development of the stratified flow.
In the afternoon, the attention was been switched to the problem of buoyancy influenced flows in high-Prandtl number and porous media flows. The discussion was been opened by the keynote lecture of Prof. Hansen on "Thermal and double diffusive convection in the earth's mantle", and has continued focusing on Rayleigh-Darcy flows, Rayleigh-Taylor convection (also in porous media), fingering and double diffusion. All subjects of great importance in geophysical/environmental contexts.

DAY 2. In day 2, the attention has moved to thermal convection. In the morning, the discussion has started by the keynote lecture of Prof. Schumacher on "Order at the mesoscale: turbulent convection in horizontally extended domains". The discussion on thermal convection has then continued focusing in particular on extreme events and thermal plumes in thermal convection, and on the available approaches to measure/simulate/model these kind of flows. The role of additional effects, including rotation and magnetic forces was also discussed.
The afternoon session has been completely devoted to Non-Oberbeck-Boussinesq effects in flows dominated by buoyancy. The discussion has started with the keynote lecture of Prof. Pecnik on "Scaling laws for density and viscosity stratified turbulent flows", and has continued with several talks on Non-Oberbeck-Boussinesq effects in liquids and gases, in particular for high-Rayleigh number thermal convection.

DAY 3. In day 3, an additional ingredient has been added to our discussion: the presence of more than one phase within the flow (multiphase flow). The morning session has been opened by the keynote lecture of Prof. Verzicco on "Multiphase Rayleigh-Benard convection", and has continued with talks on moist convection and on liquid-liquid flows inside channels. The discussion has also explored more general aspects of buoyancy influenced flows, like the role of smooth/rough walls, or the spectral flow properties.
In the afternoon session, the attention has moved to a very applied aspect of stratified flows, that is the mixing and dispersion of organisms and particles in stably stratified environments. The session has started with the keynote lecture of Prof. Dijkstra on "Intermittent mixing events in deep stratified lakes", and has continued focusing on the dispersion of inertial and neutrally-buoyant particles (including also the case of gyrotactic, swimming, microorganisms, like plancton) in mixing layers and in confined and free-surface flows (mimicking the case of rivers or lakes).

For all three days of colloquium, there was a lot of time for discussions, after the single presentations, but also during coffee breaks, lunches and dinners.
Discussions on Oberbeck and Non-Oberbeck-Boussinesq effects in buoyancy driven and buoyancy influenced flows were so vivid and engaging that brought the involved participants, after years of debate on these subjects, to a general agreement/unified picture on most of the crucial aspects.
Participants were all extremely supportive and active for the entire duration of the colloquium.

A sincere, huge, thank to all participants!

And a final special thank to Euromech for making this meeting possible and for financial and organizational support.

## Number of participants from each country

| Country | Participants |
| --- | --- |
| France | 6 |
| China | 5 |
| India | 4 |
| United Kingdom | 4 |
| Germany | 3 |
| Austria | 3 |
| United States | 3 |
| Switzerland | 2 |
| Netherlands | 2 |
| Italy | 2 |
| Czech Republic | 1 |
| United Arab Emirates | 1 |
| Australia | 1 |
| **Total** | **37** |