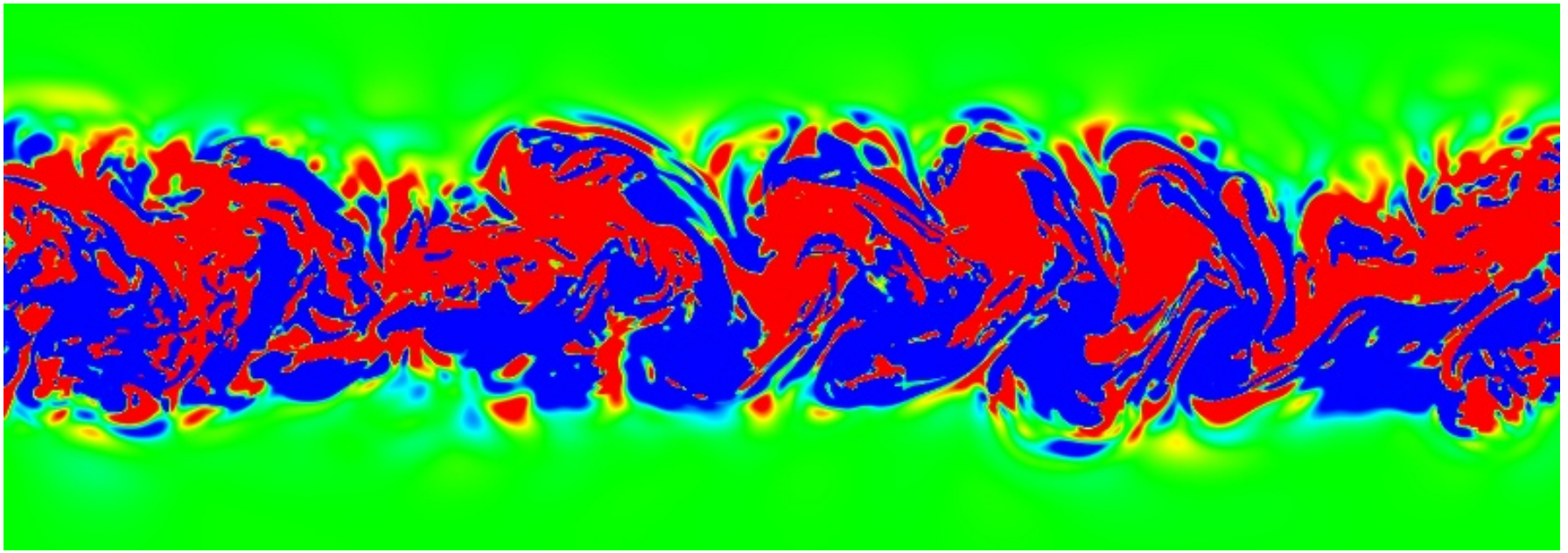


Welcome to the Computational Fluid Dynamics Laboratory

Matt de Stadler
Vamsi Chalamalla

What does the CFD Lab do?

We use numerical simulations to study turbulence and turbulent phenomena in the ocean and atmosphere

We try to understand how turbulence affects the natural environment and engineering applications

Wake behind Guadalupe island

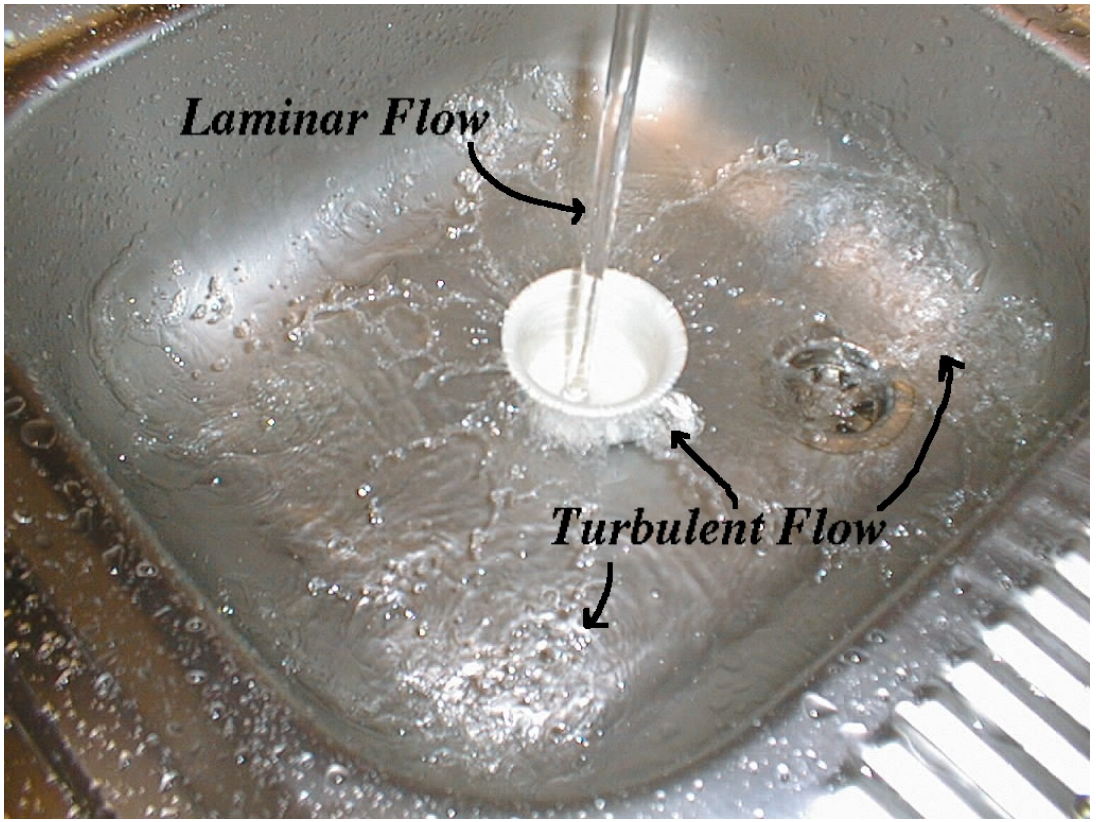
http://www.nasaimages.org/luna/servlet/detail/nasaNAS~10~10~84390~190735:Atmospheric-Vortices-near-Guadalupe

Turbulent jet in water

What is turbulence?

Turbulence is classified by the presence of seemingly random and disordered motion

Multi scale phenomena, flow at very large and very small scales



Turbulence in a kitchen sink

http://www.cora.nwra.com/~werne/eos/images/turbulent.jpg

Turbulence in smoke

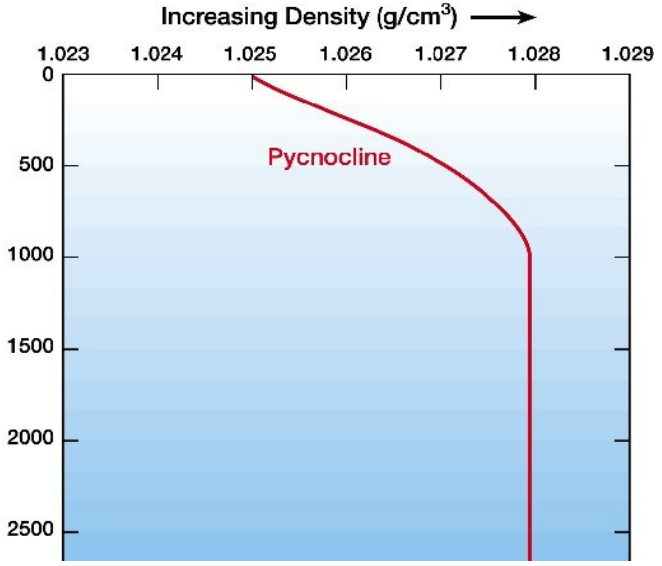
Turbulence in the ocean and atmosphere

Turbulence in the ocean and atmosphere introduces complexity due to stratification and rotation

Stratification: hot, light fluid on top of cold, heavy fluid

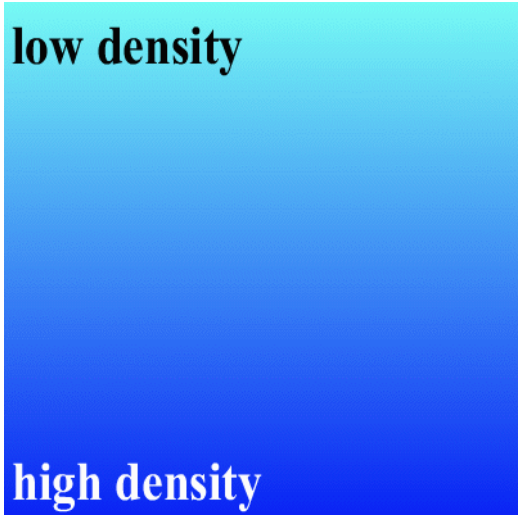
Buoyancy resists vertical motion

Rotation: The earth's rotation causes a Coriolis force to appear

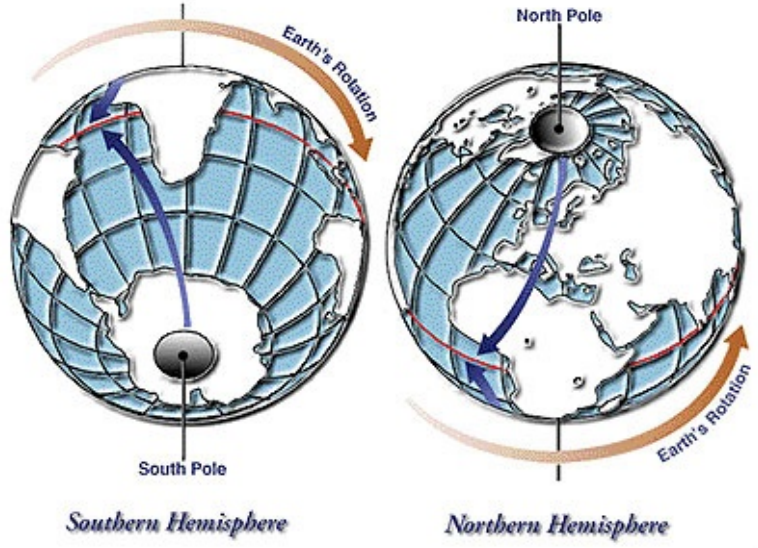


Ocean Density

http://www.windows2universe.org/earth/Water/images/density_depth.jpg



Movie courtesy of Kyle Brucker, PhD



Shooting a cannon from the poles

http://www.uwsp.edu/geo/faculty/ritter/geog101/textbook/images/atmosphere/circulation/coriolis-force_NASA_JPL.jpg

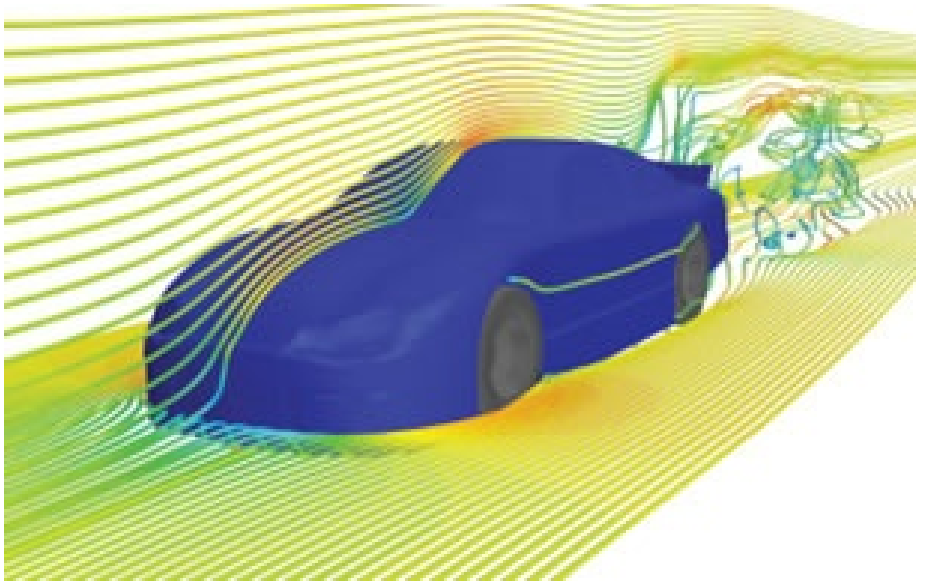
Why are we interested in turbulence?

Turbulence is all around us, it is the rule rather than the exception

We would like to be able to predict and subsequently control turbulence to take advantage of its good properties (higher mixing) and avoid its bad properties (more drag)

Prediction of turbulent mixing/transport is important to prediction of weather and climate change

Milk in coffee
From http://www.gettyimages.com/detail/72724325/Riser



Flow past a NASCAR car
From http://www.deskeng.com/articles/aaafsg.htm

How do people study turbulence

There are three ways people study turbulence

1. Theory

advantage:	powerful results that explain experiments, no costs
disadvantage:	can only be used for idealized problems if at all

2. Physical experiment

advantage:	easy to visualize flow behavior
disadvantage:	measurements affect experiment, cost

3. Numerical experiment

advantage:	only requires computer access, gives lots of information
disadvantage:	complicated to set up, numerical issues affect accuracy

We know the governing equations

The good news: We know the governing equations

The bad news: Solutions exist only for very simple cases

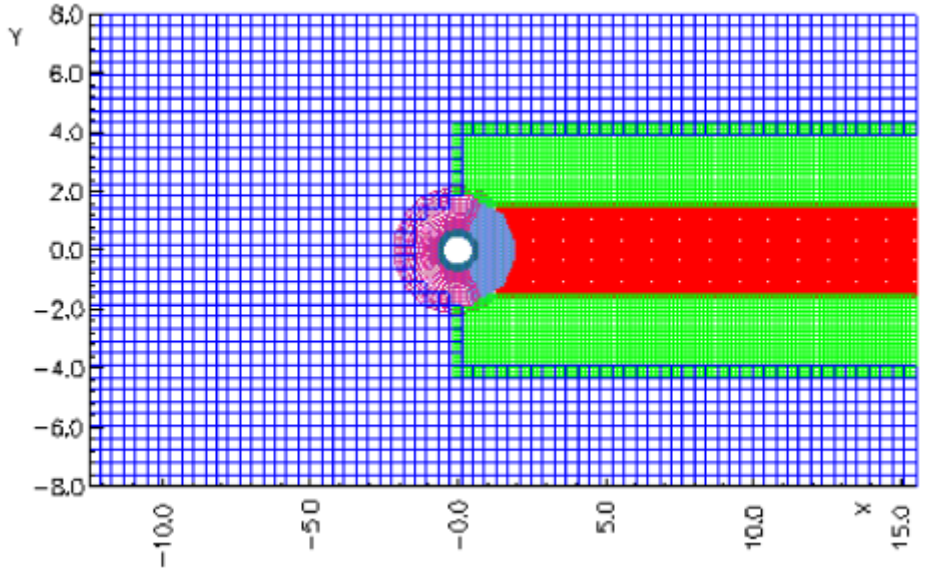
- They are very expensive to solve accurately
- Modeling the equations is difficult

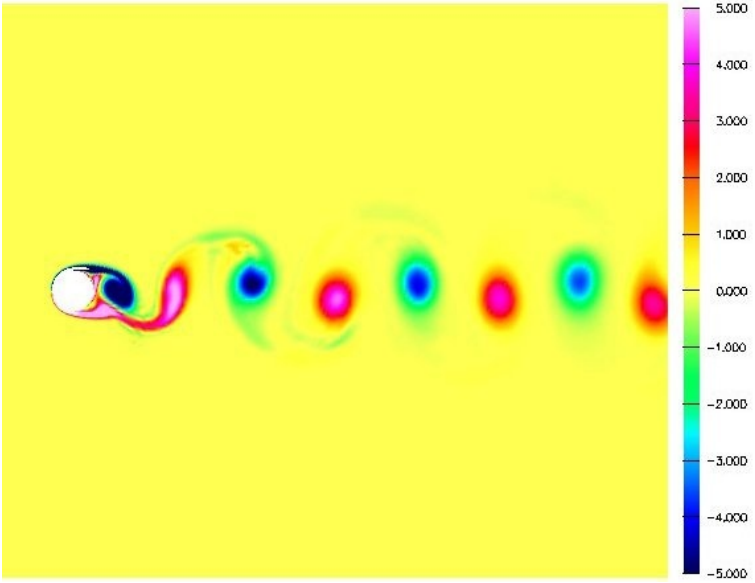
Different effects dominate under different flow conditions

- We quantify this using non-dimensional numbers which are ratios of effects. Common examples: *Re*, *Pr* and *Fr*
- How does the flow depend on *Re, Pr and Fr?*

Solving equations on a computer

1. Put a large “box” around our area of interest
2. Break the large box into many small boxes
3. Write an approximation to the governing equations in each box
4. Solve the approximation to the governing equations in each box
5. Advance in time
6. Repeat steps 4 and 5 until solution is obtained





Projects going on in the CFD Lab

Underwater jet at the equator from North America to Asia

Tidal flow on the bottom of the ocean

Flow past underwater mountains

The horizontal shear layer

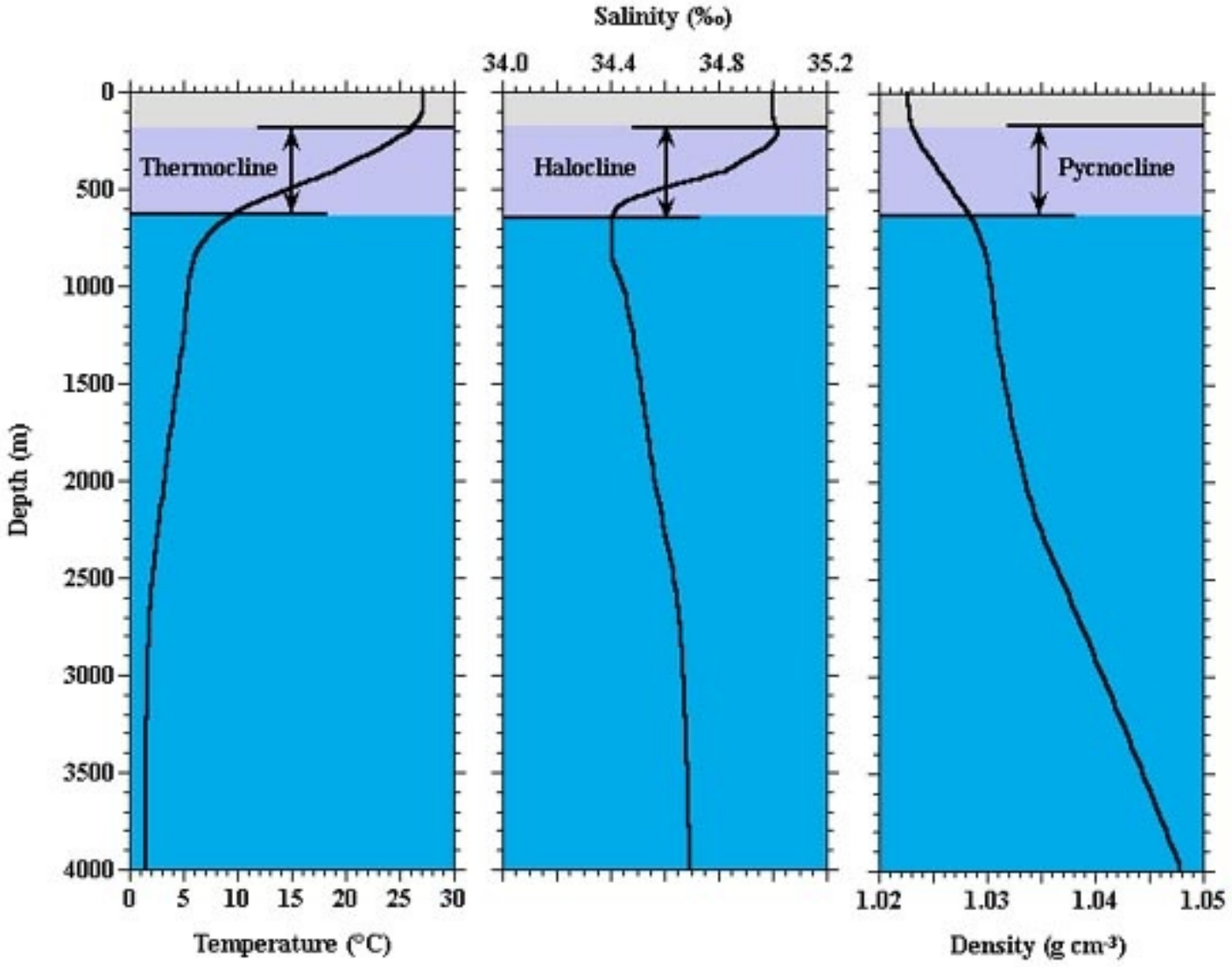
The turbulent wake behind a bluff body in a stratified fluid

They decay of a patch of turbulence in the ocean

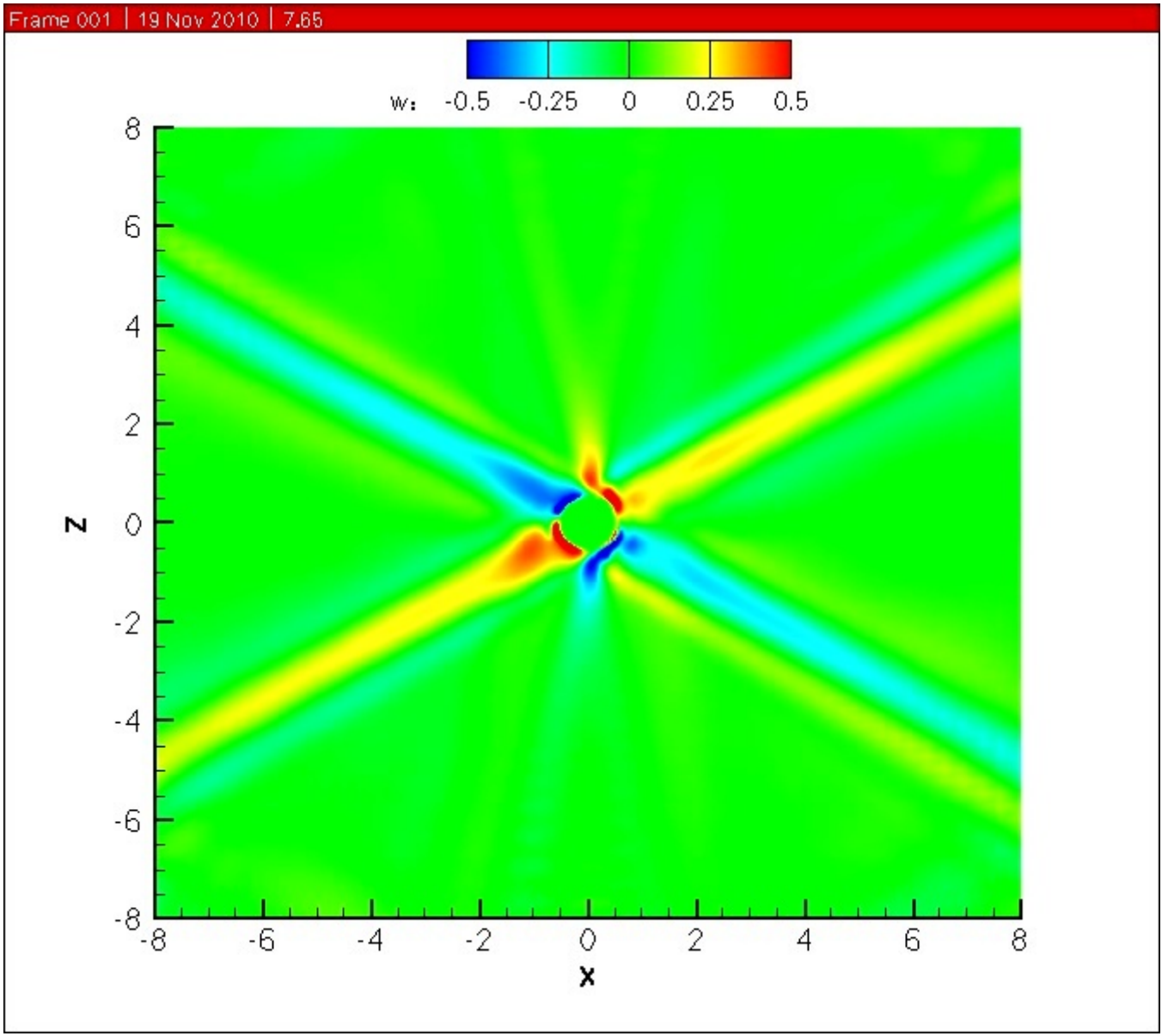
Ocean stratification

Light fluid over heavy fluid

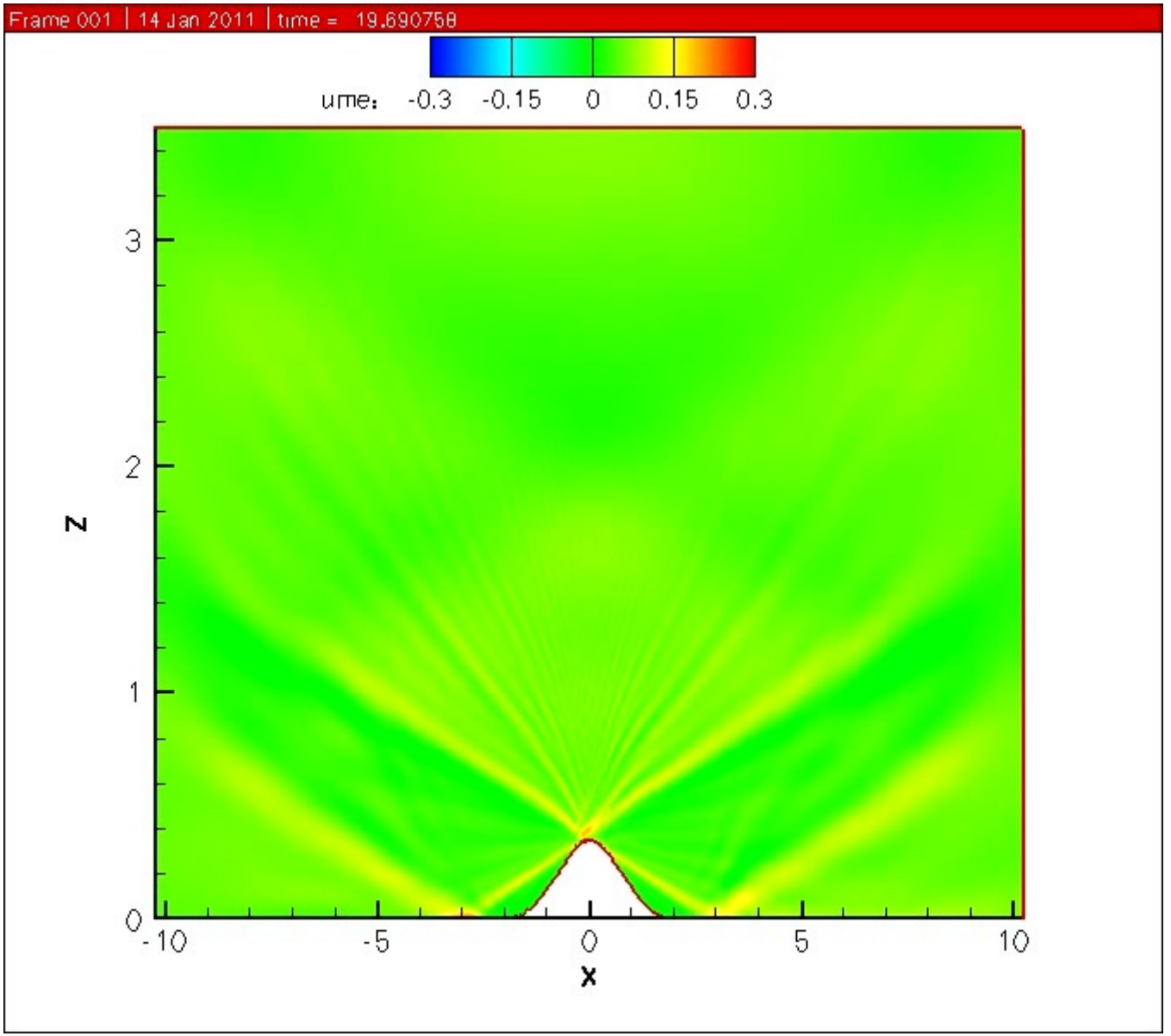
Region of sharp changes near the surface



Internal gravity waves [movie]



Oscillating flow over a ridge [movie]



Stratified turbulent wakes

Wakes are generated by every moving body and flow past any fixed body

Application sizes range from spray droplets to the wakes of mountains

Even simple geometries like spheres exhibit complex 3D behavior

Geophysical and naval applications

Significant source of mixing and transfer of energy

Detection and tracking of underwater vehicles

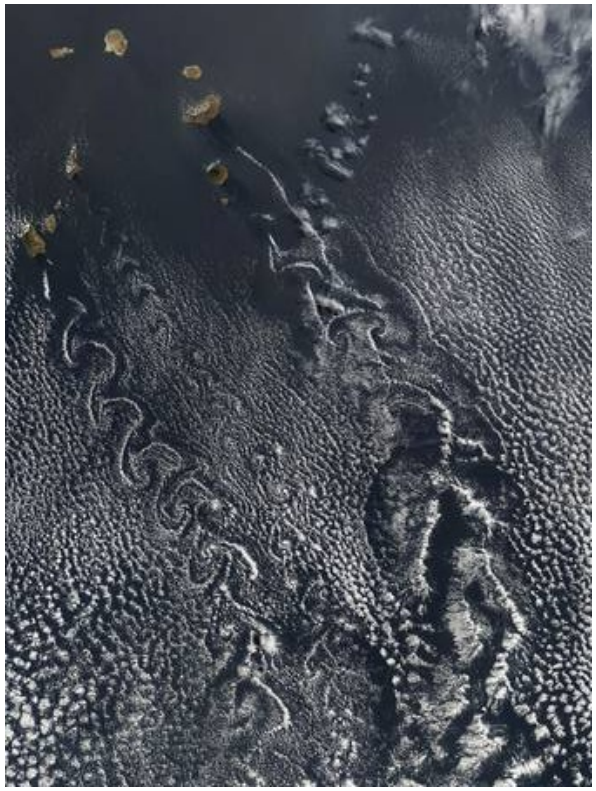
We want to understand and be able to predict

How does the wake evolve in time?

How long will the wake last?

How is the energy distributed?

What characteristic features emerge?



Low-level winds rushing over the Cape Verde Islands of northwestern Africa http://visibleeart

Features of turbulent wakes in stratified fluids

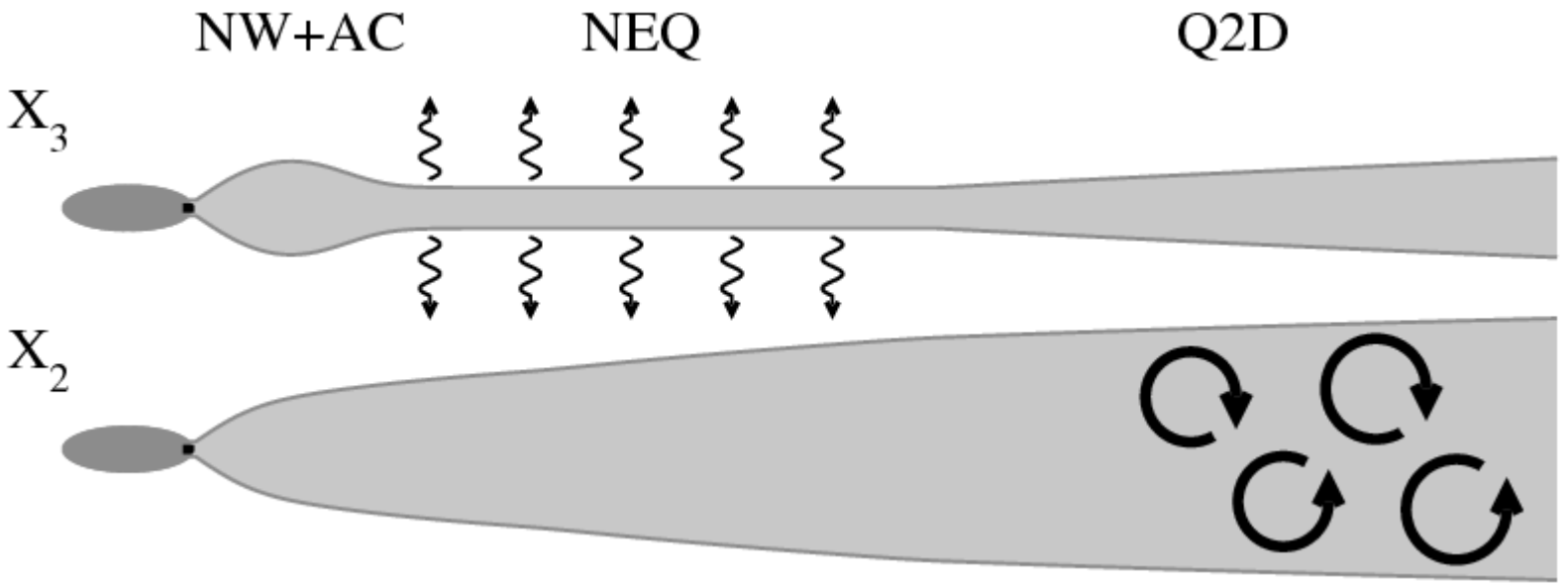
Stratification breaks radial symmetry: vertical motion inhibited

Transfer between kinetic and potential energy

Internal waves radiated

Late time quasi-2 component flow

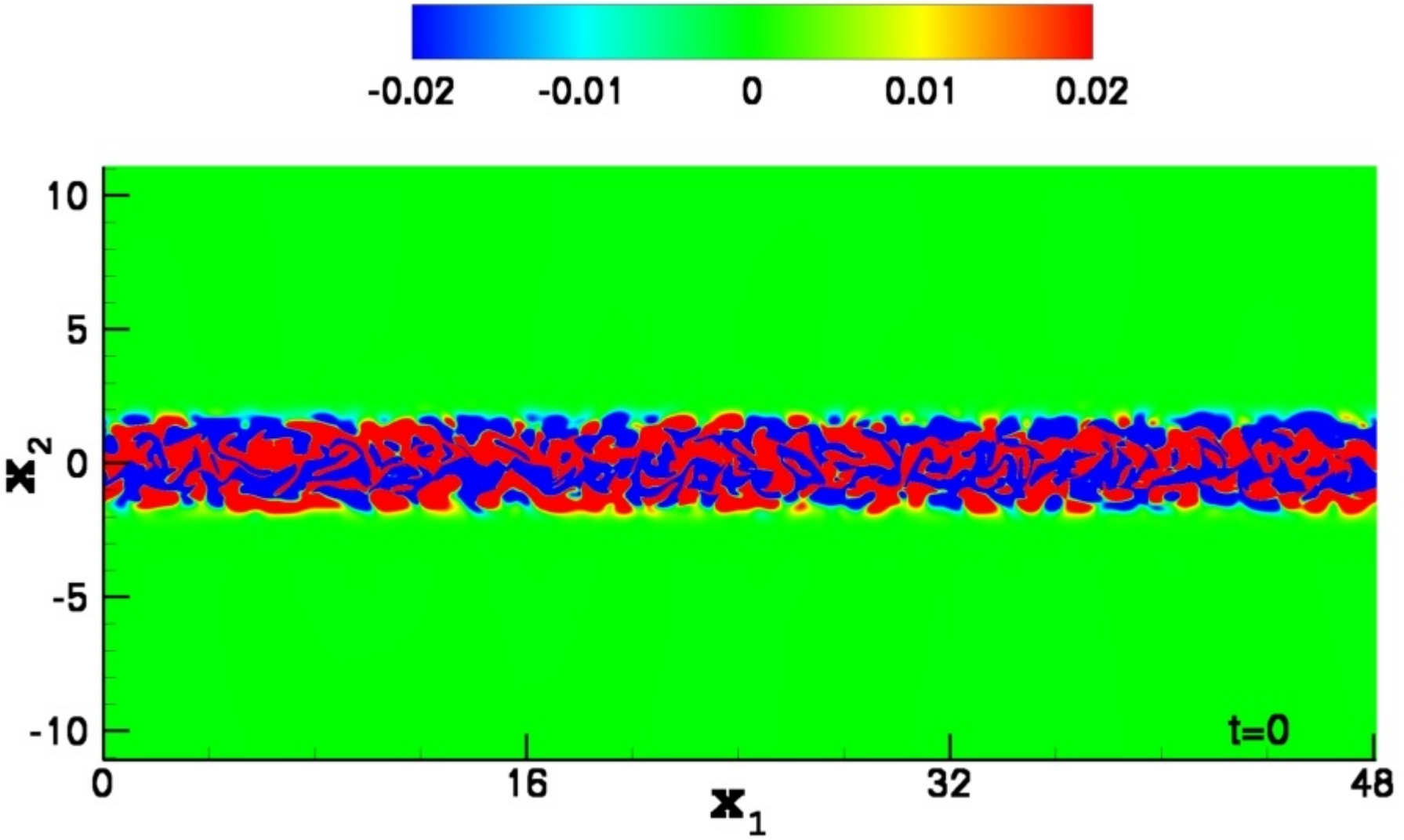
Very different than unstratified wake



The Stratified Turbulent Wake: Vorticity [movie]

A body has just moved by us moving from right to left

We are watching a fixed place in space

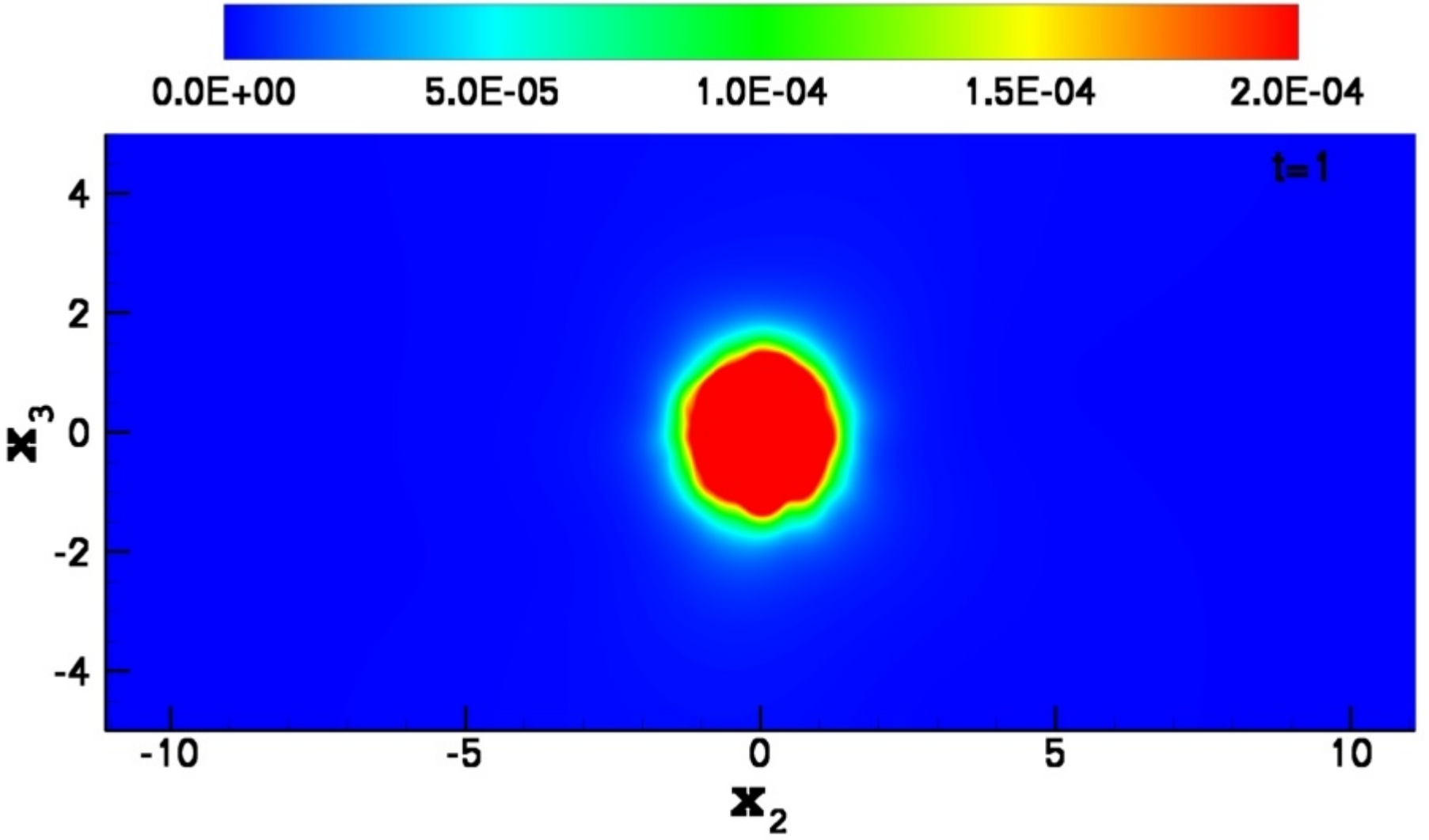


The Stratified Turbulent Wake: Internal waves [movie]

A body has just moved by us coming out of the page

We are watching a fixed place in space

Observe the transfer of energy from the wake to the background



Final Thoughts

There are many interesting problems in fluid mechanics

Turbulence will continue to be an important research area for a long time

Computational science will continue to grow in importance

There are still plenty of problems waiting for solutions

What do I need to do to join a group like the CFD Lab?

Study hard in your math and science courses, especially physics

Major in engineering, math or physics in college

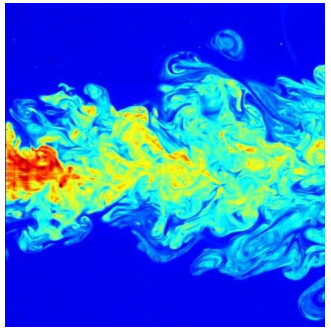
Enjoy solving hard problems

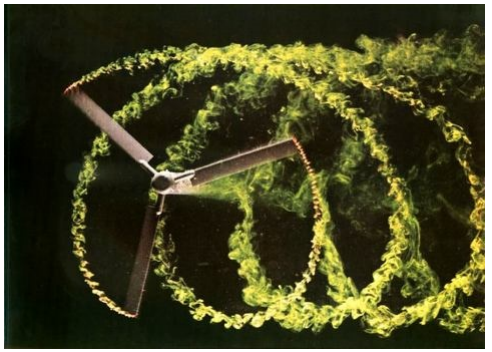
Have a drive to understand the world around you

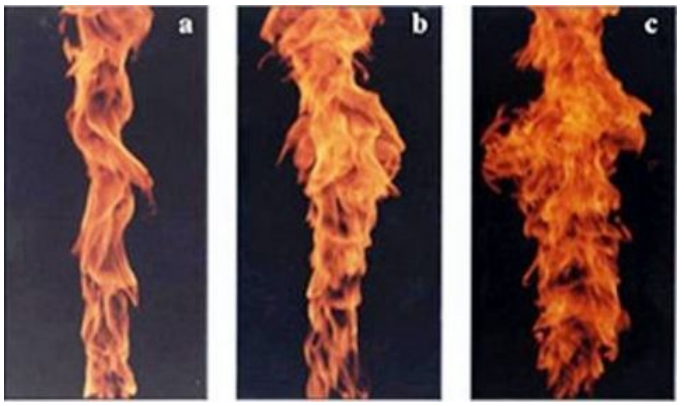
For more information

efluids.com video and movie galleries

http://media.efluids.com/galleries/turbulence

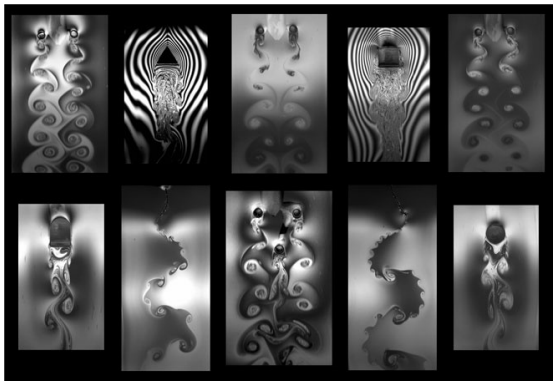






American Physical Society
Division of Fluid Dynamics
Gallery of Fluid Motion

http://pof.aip.org/gallery_of_fluid_motion



“Tackling Turbulence with Supercomputers”
Parviz Moin and John Kim.

http://www.stanford.edu/group/ctr/articles/tackle.html