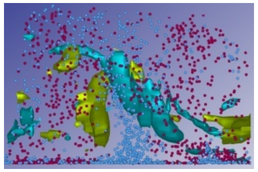
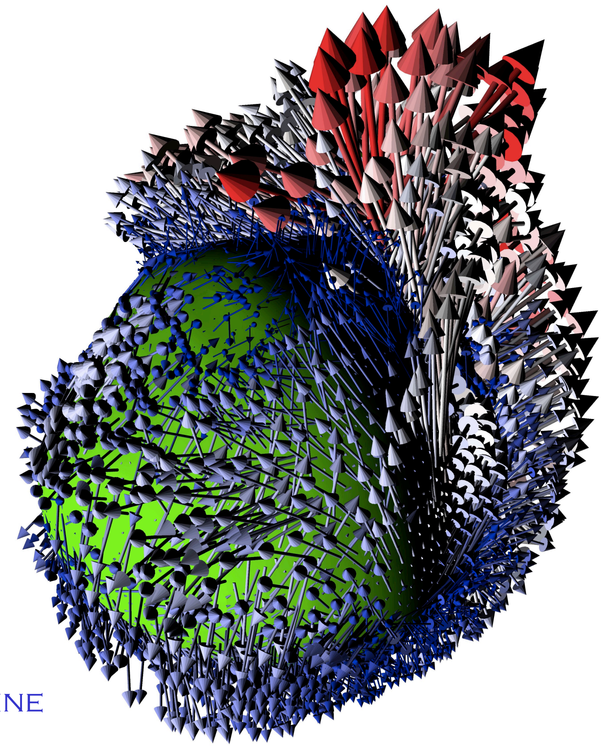


Environmental Transport Phenomena

Introductory Seminar To The Course



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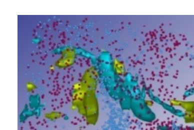


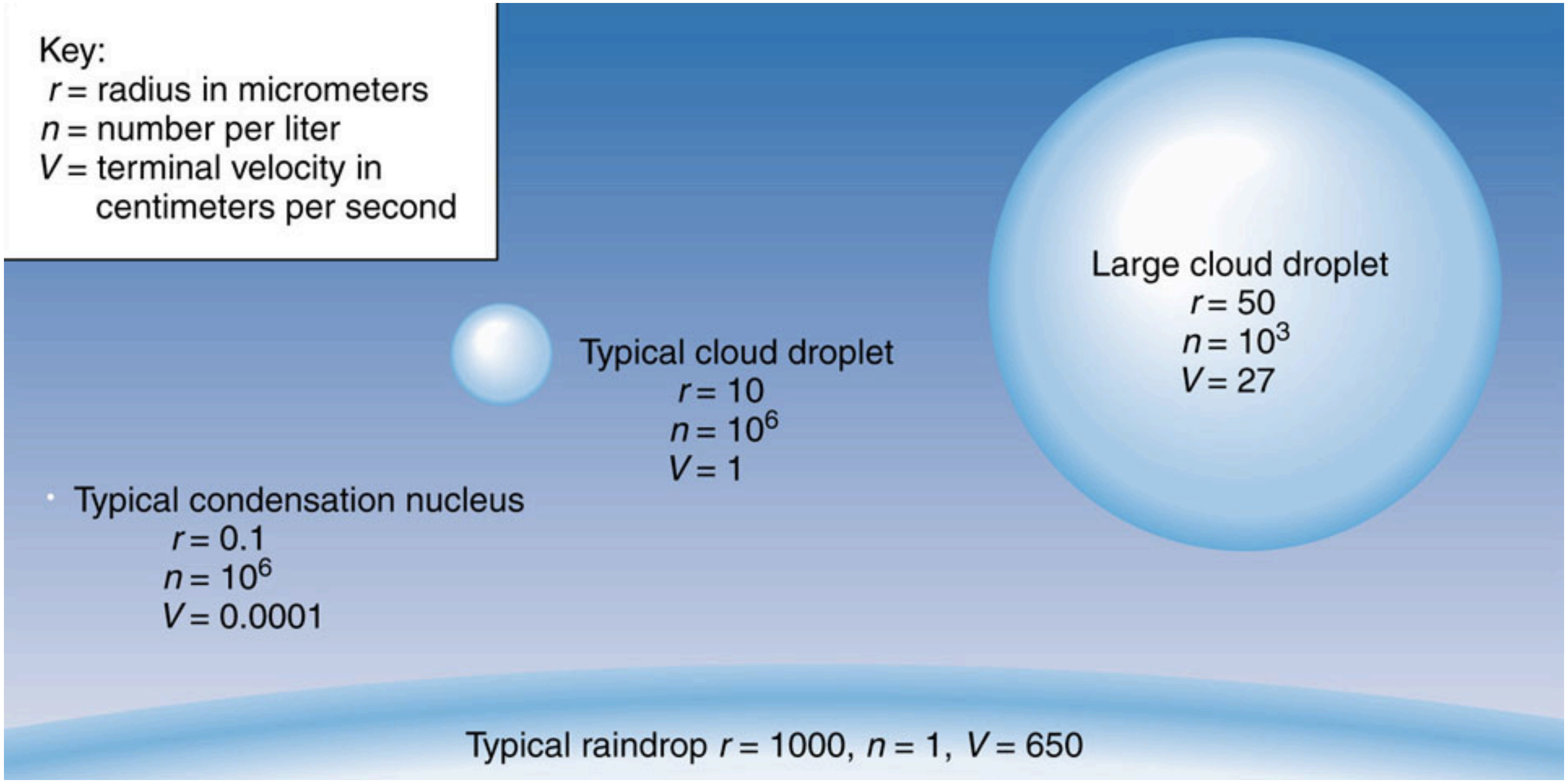
Environmental Applications:

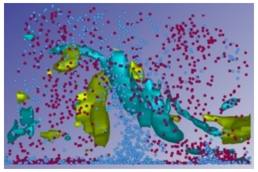
1. Rain Formation Mechanism

Environmental Applications:

1. Rain Formation Mechanism

Time required for Rain Formation





Environmental Applications:

1. Rain Formation Mechanism

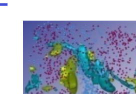
How does rain form?

The aerosol community believes that:

1. rain drops grow within the cloud due to condensation of water vapour around small condensation nuclei
2. when the drop is large (heavy) enough, it starts falling down to the Earth's surface (precipitation)
3. during its fall, the drop can accumulate more and more drops, thus becoming bigger and falling faster
4. Large-enough drops survive the fall through the air below the cloud, despite evaporation, and reach the ground as rain.

However, the time it takes for a drop to precipitate is much shorter than that allowed by condensation alone.

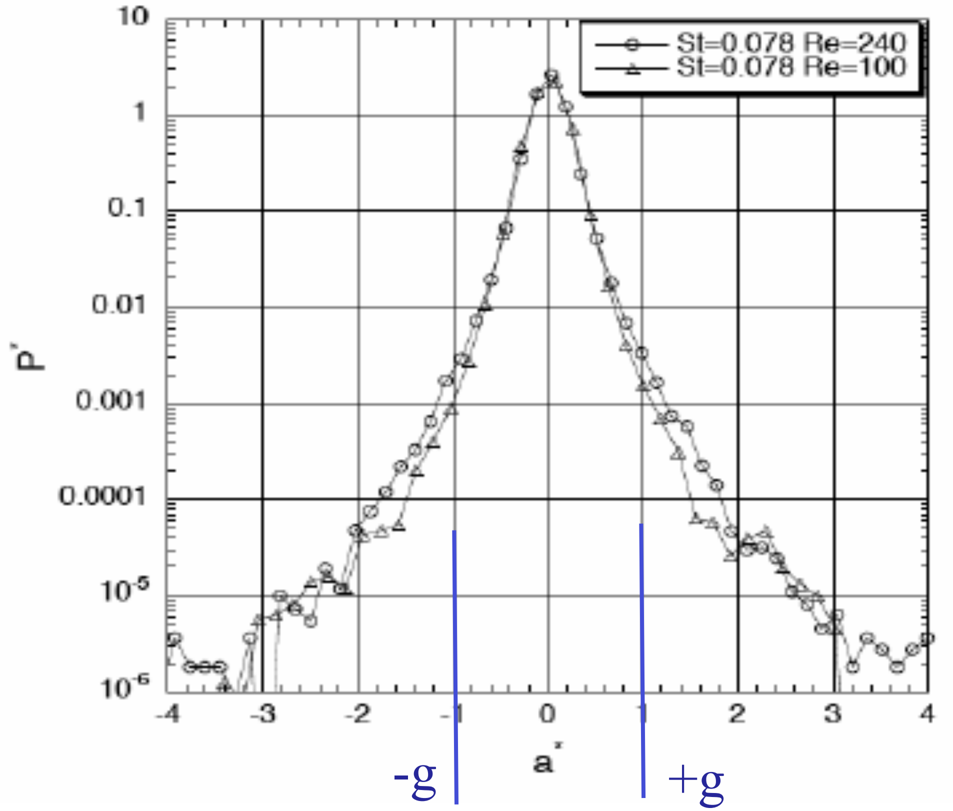
Is atmospheric turbulence playing a role?



Environmental Applications:

1. Rain Formation Mechanism

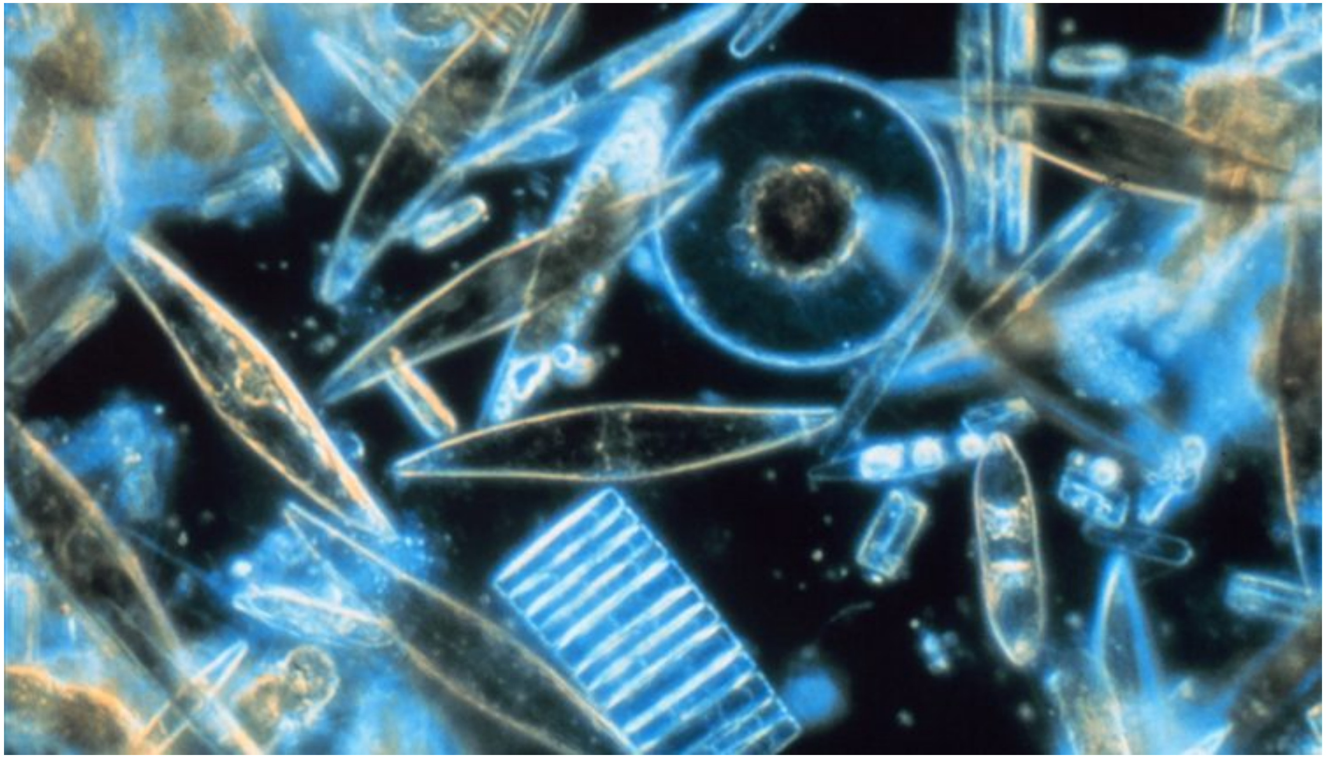
Probability distribution function of the acceleration of water droplets due to turbulence.



There is a rather large probability of having droplet acceleration significantly larger than gravity!

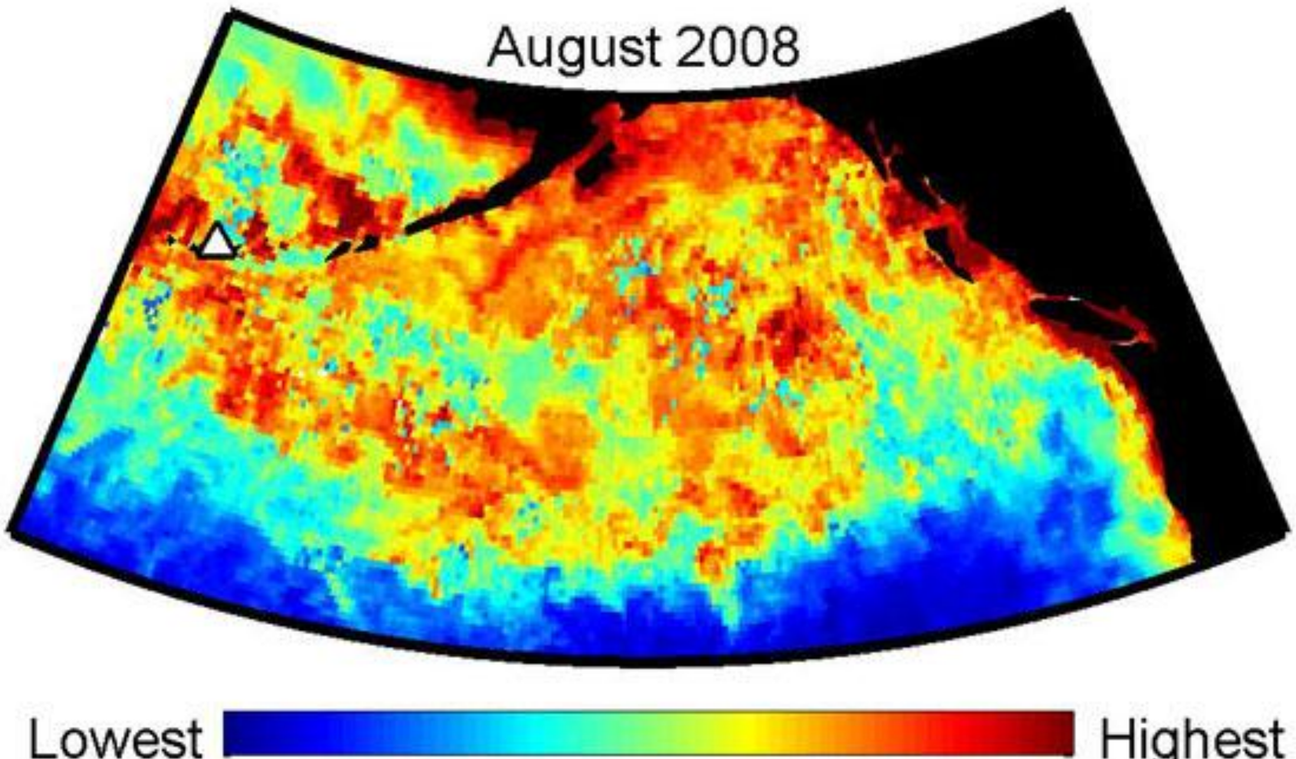
Environmental Sustenability

Crucial role of Phytoplankton



Environmental Sustenability

Crucial role of Phytoplankton

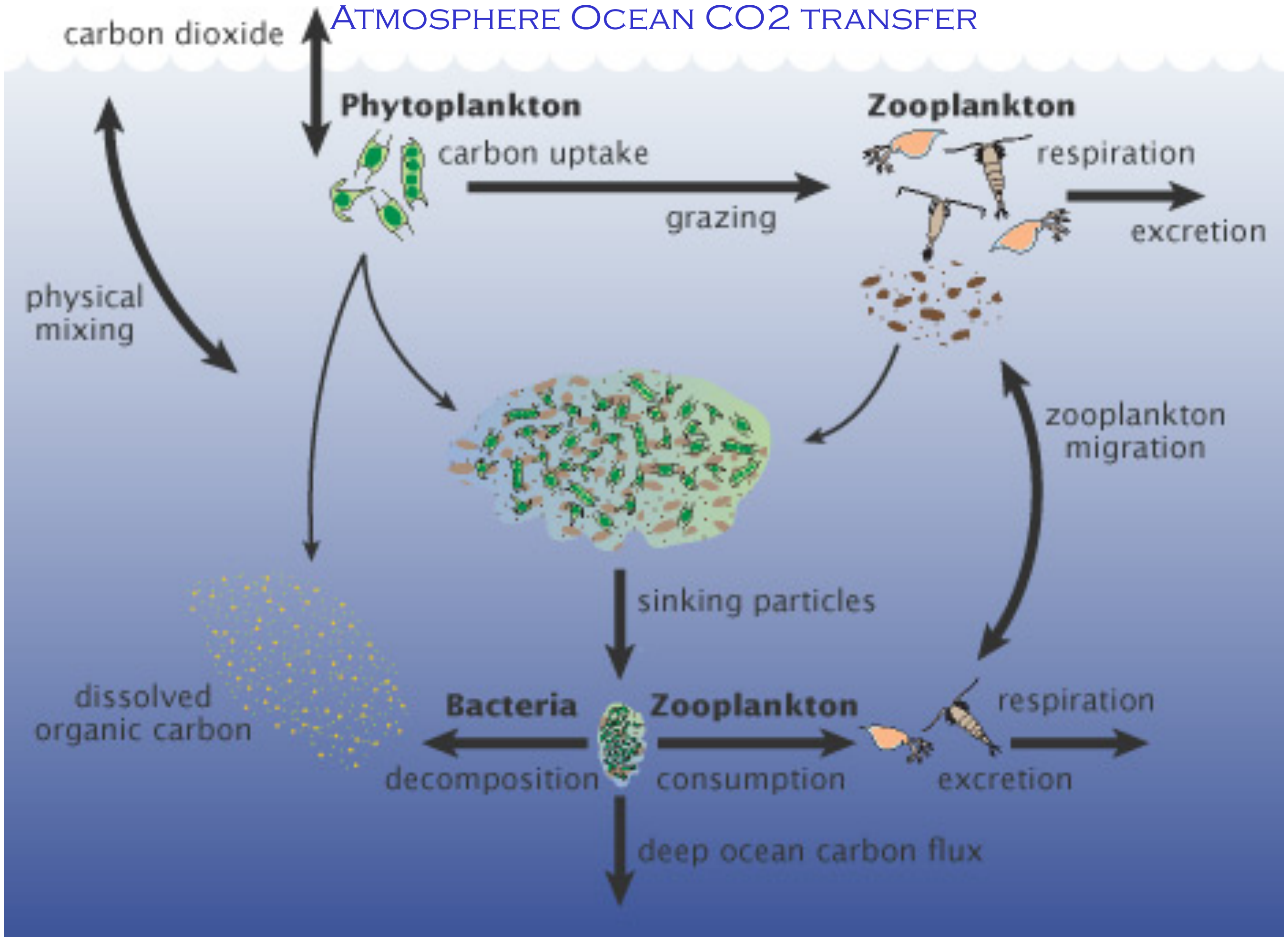


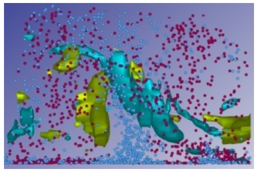
Satellite image of phytoplankton in North Pacific

APPLICATION: Environment

Role of Phytoplankton

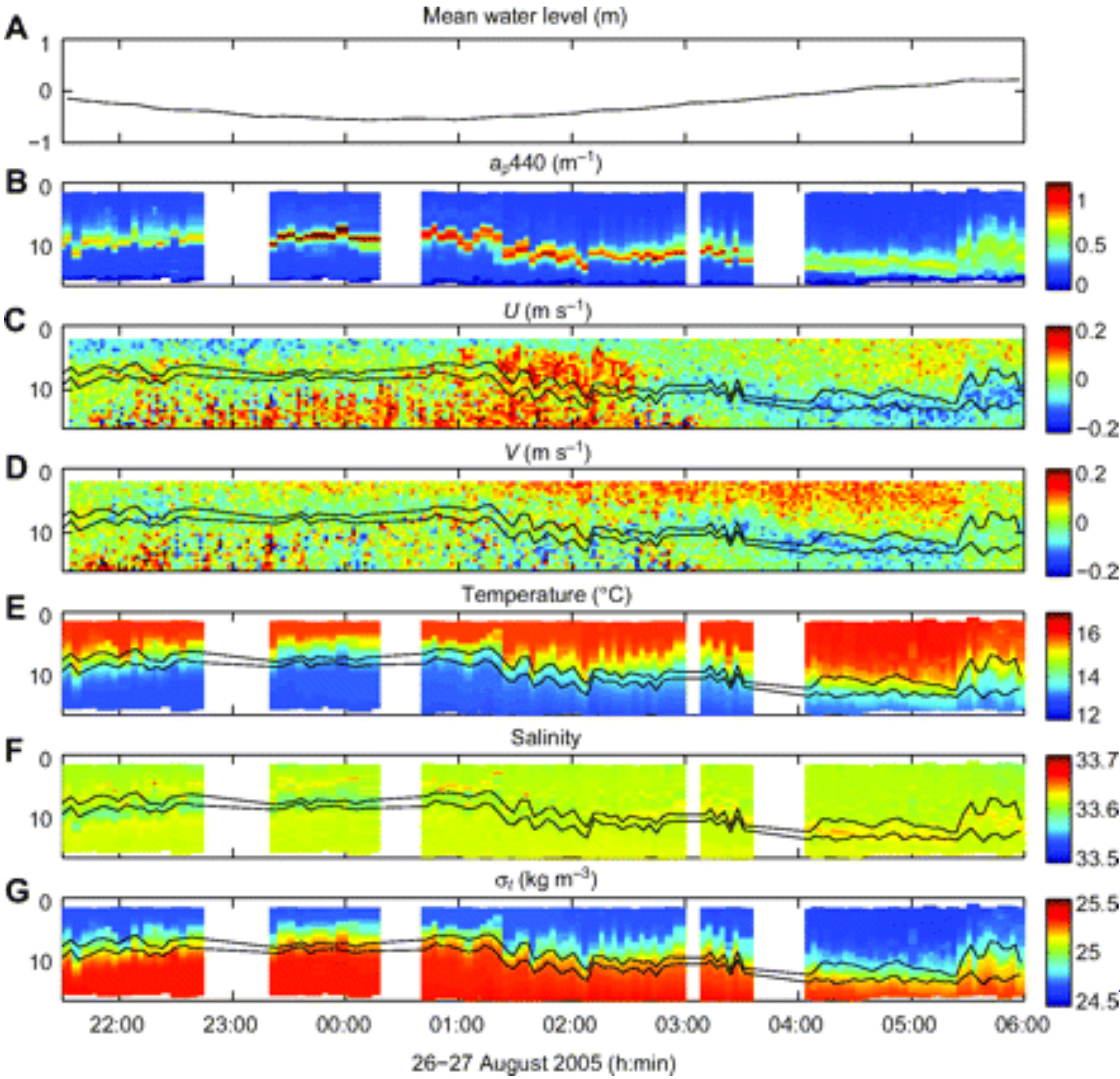
Atmosphere Ocean CO2 transfer





Environmental Applications:

2. Plankton dispersion in oceans & lakes



Mean water level

Plancton biomass concentration

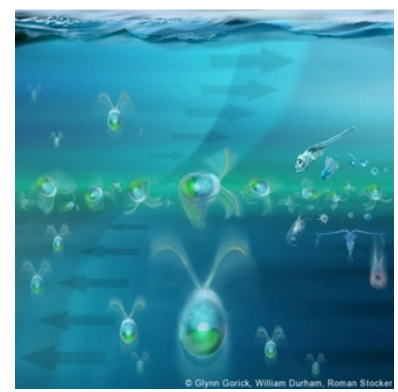
Eastward current velocity

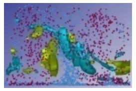
Northward current velocity

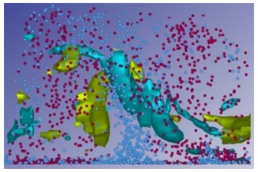
Temperature

Salinity

Density



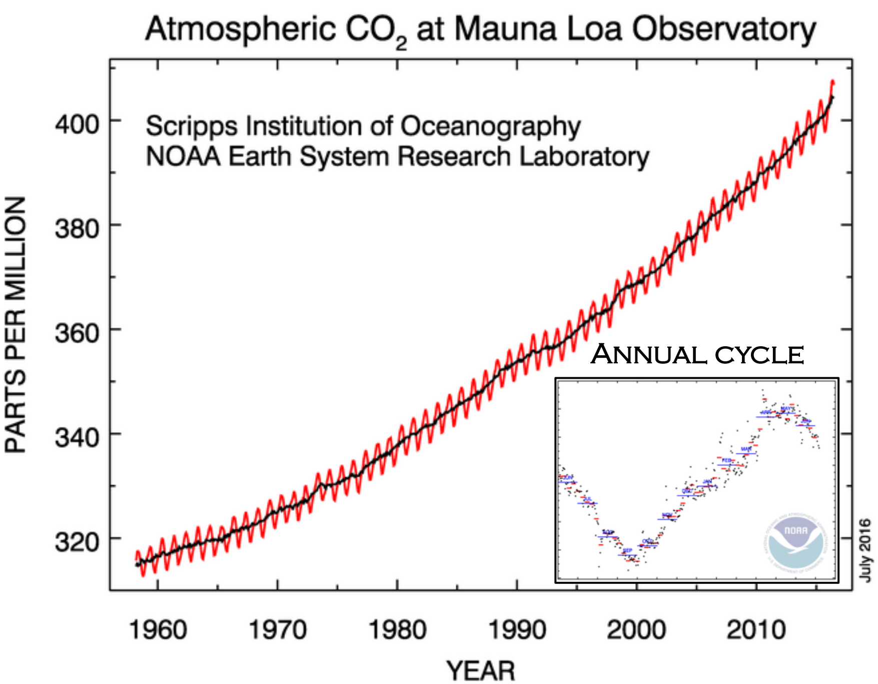


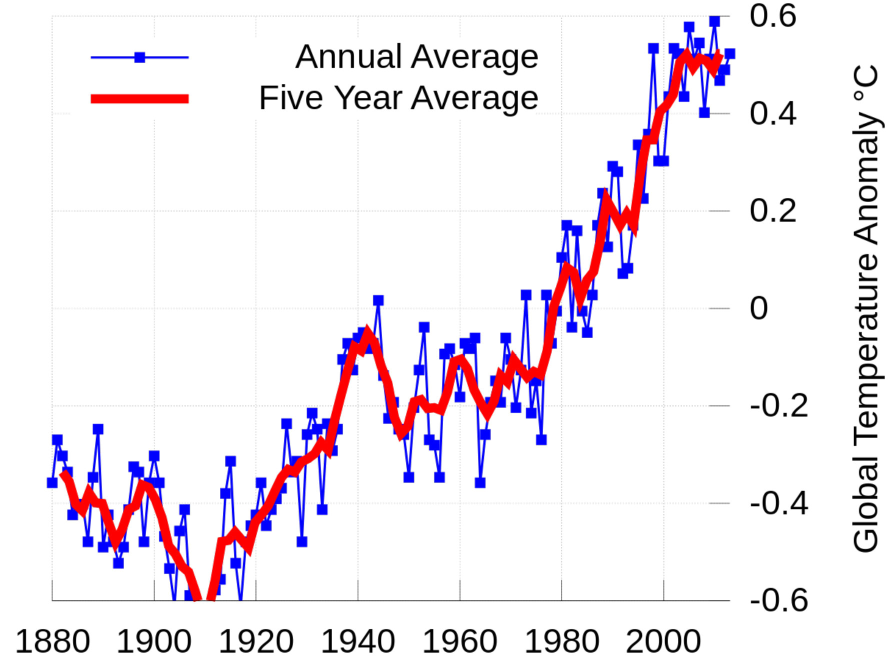


Environmental Applications:

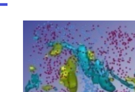
3. Geological CO_2 sequestration

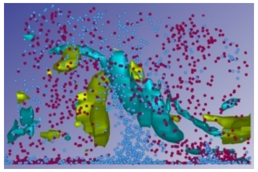
80 % of energy is produced from combustion of fossil fuels, and consequent production of Carbon Dioxide





Global average temperatures rise over the last 130 years (Hansen et al., Proc. Natl. Acad. Sci.,2006)





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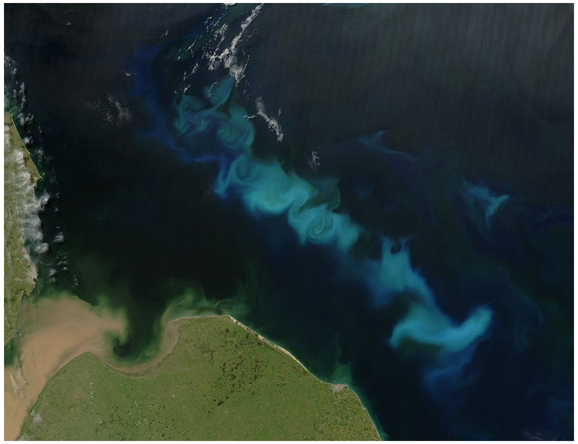
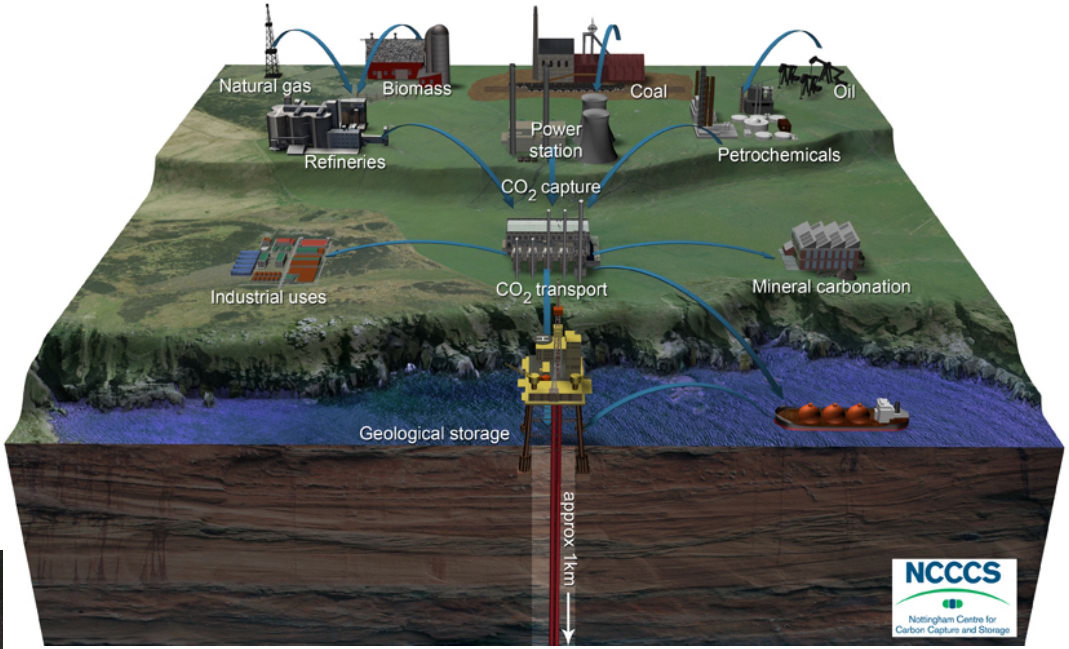
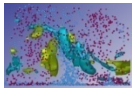


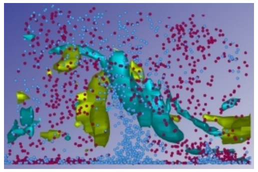
Iron fertilization of phytoplankton

Chemical scrubbers

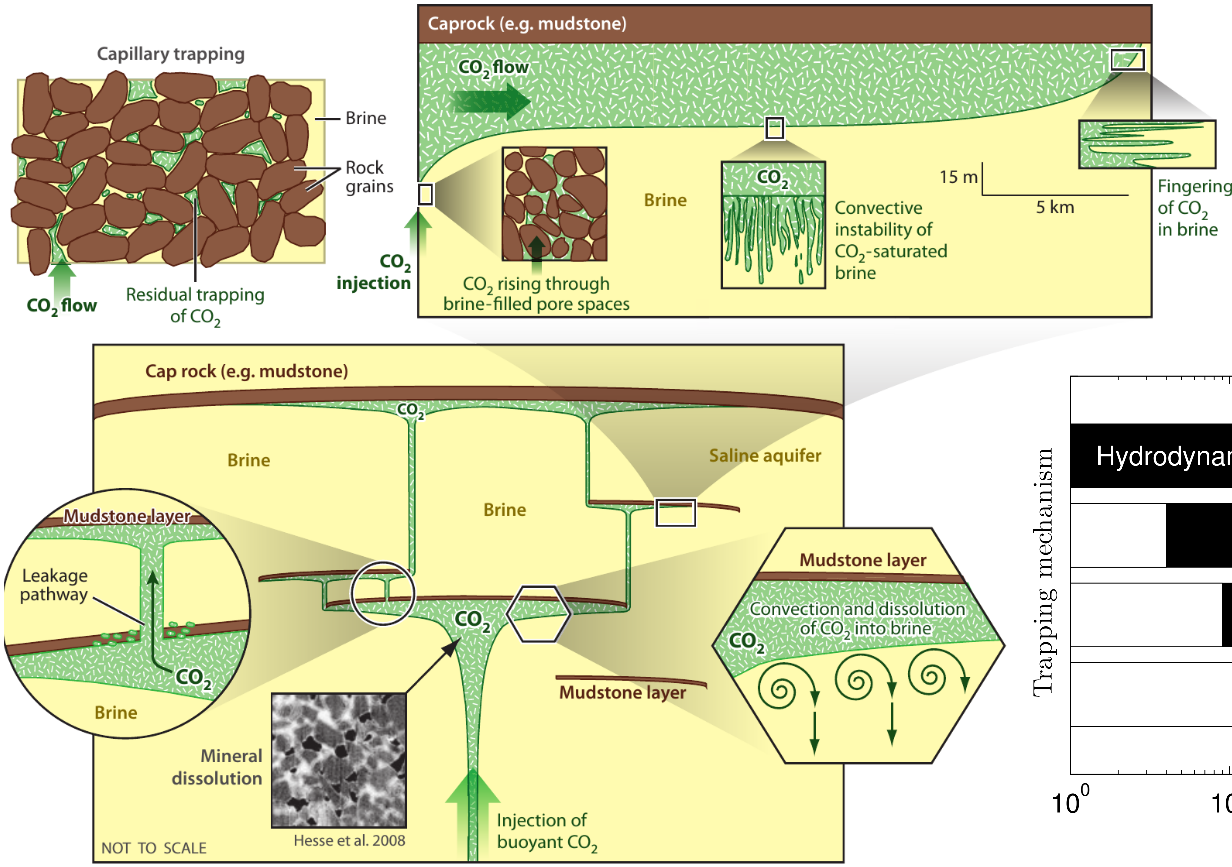


Carbon Capture and Storage (CCS) has been identified as a possible solution to the green-house effect (Intergovernmental panel on Climate Change, 2005)

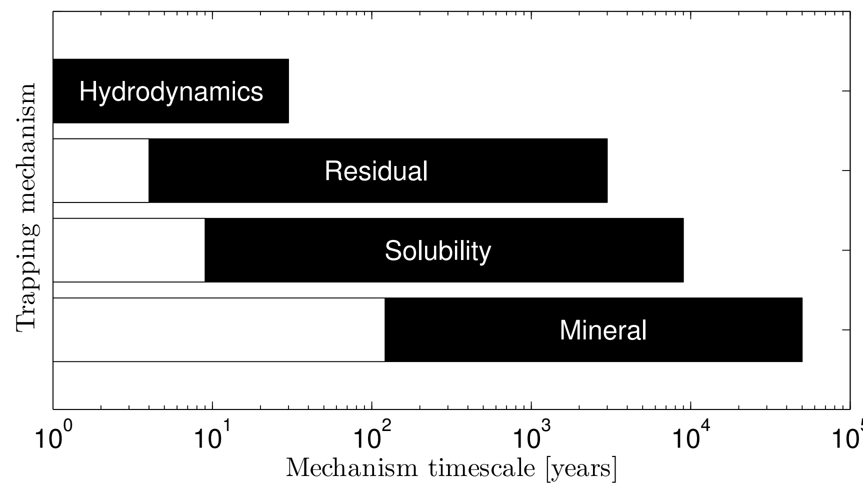




Environmental Applications:
3. Geological CO_2 sequestration



Leakage is undesirable for efficient long-term storage



CO_2 dissolution mechanisms (*Huppert & Nuefeld, Ann. Rev. Fluid Mech., 2014)*

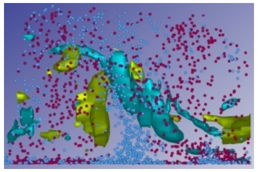
Wide range of space and time scales to consider

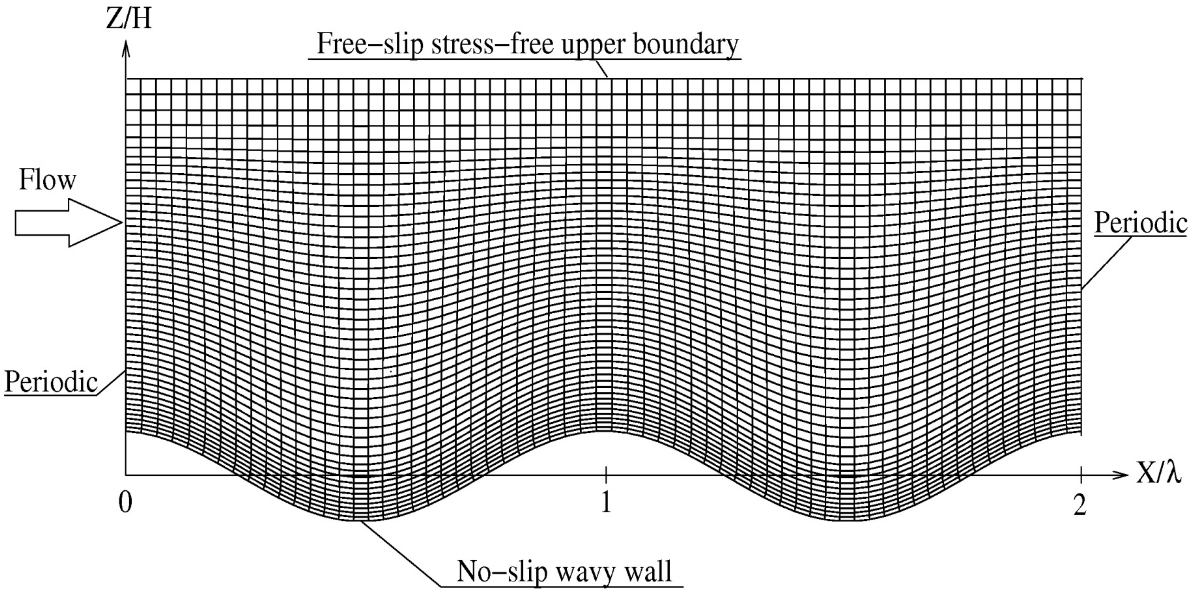
Environmental Applications:

3. Geological CO_2 sequestration

Environmental Applications:

4. Sediment transport over dunes/ripples





Wave shape: $Z(X) = a \cos(kX)$

AIR

- Fluid Density ρ_f = 1.3 kg/m^3
- Droplet Density ρ_p = 1000 kg/m^3

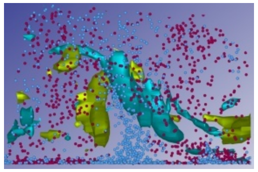
WATER

- Fluid Density ρ_f = 1000.00 kg/m^3
- Droplet Density ρ_p = 2500.00 kg/m^3

Bulk Reynolds Number: 3100

Particles:

τ_p (ms)	St $=\tau_p/\tau_f$	d_p (micron)	
0.35	0.1	10.9	12.7
1.76	0.5	24.4	28.4
3.52	1.0	35.0	40.2
7.04	2.0	48.9	56.8
		AIR	WATER



Environmental Applications:

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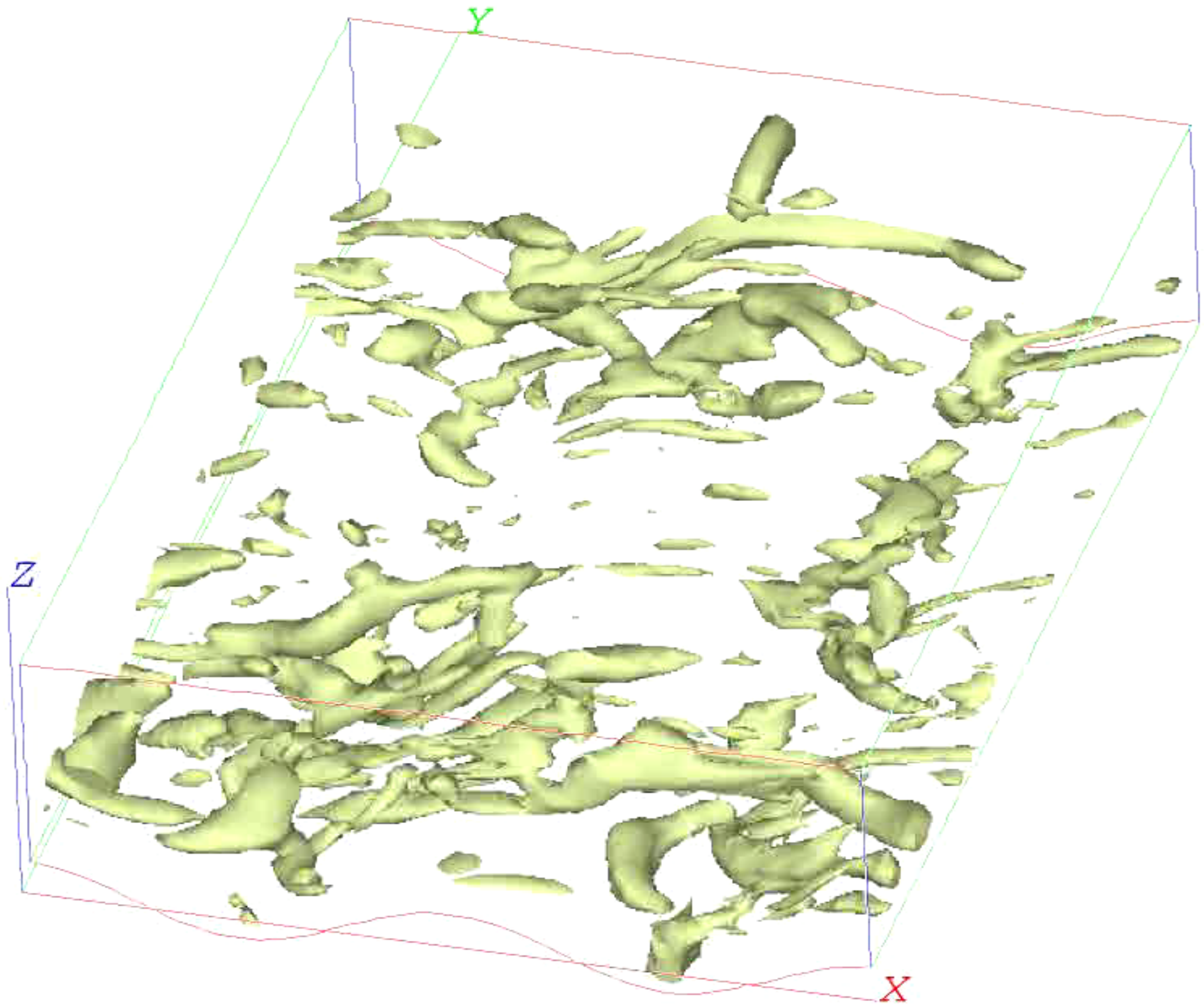
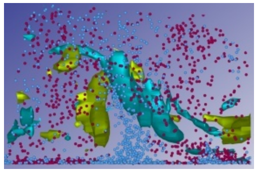


Mixing mechanisms induced by Interactions between wave structures And BL structures



Environmental Applications:

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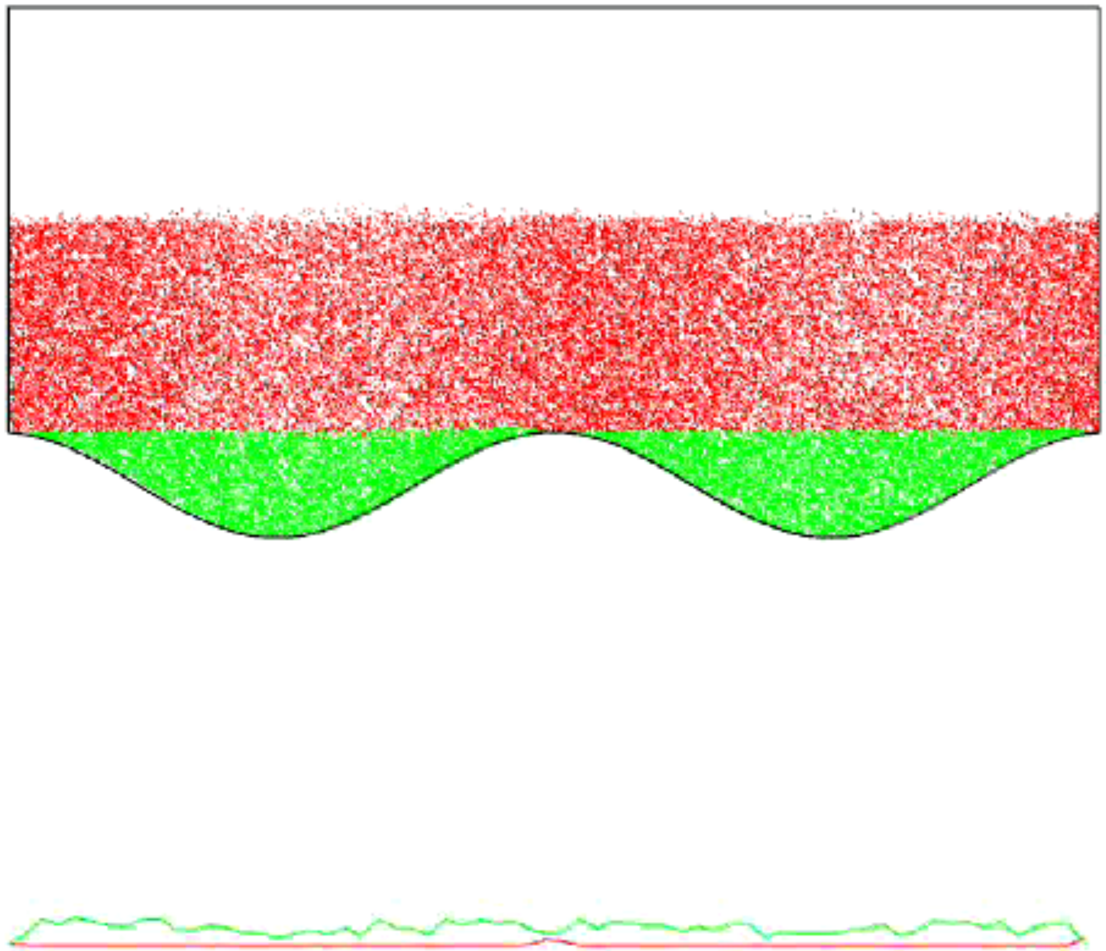

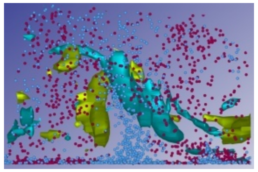

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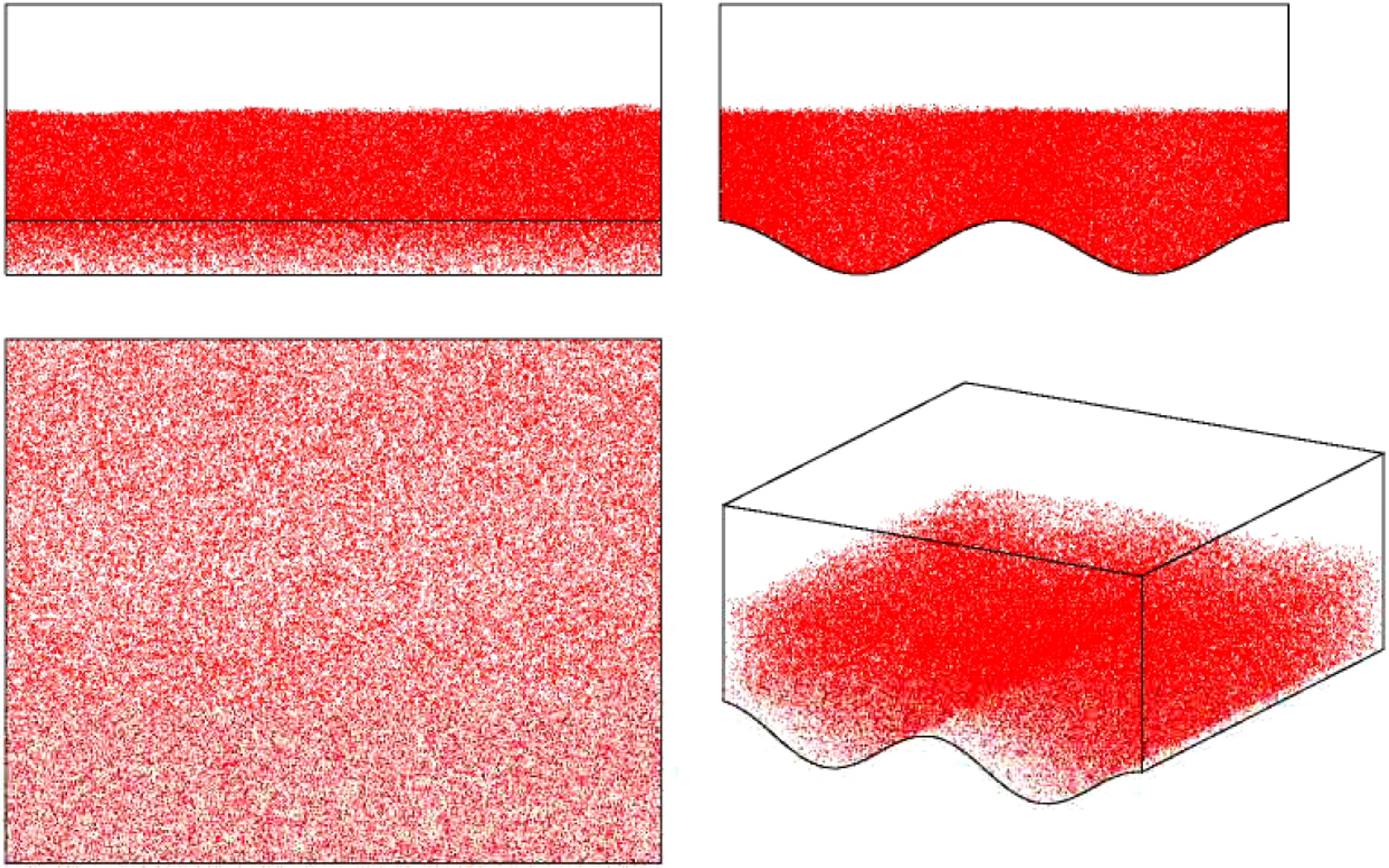

Environmental Applications:

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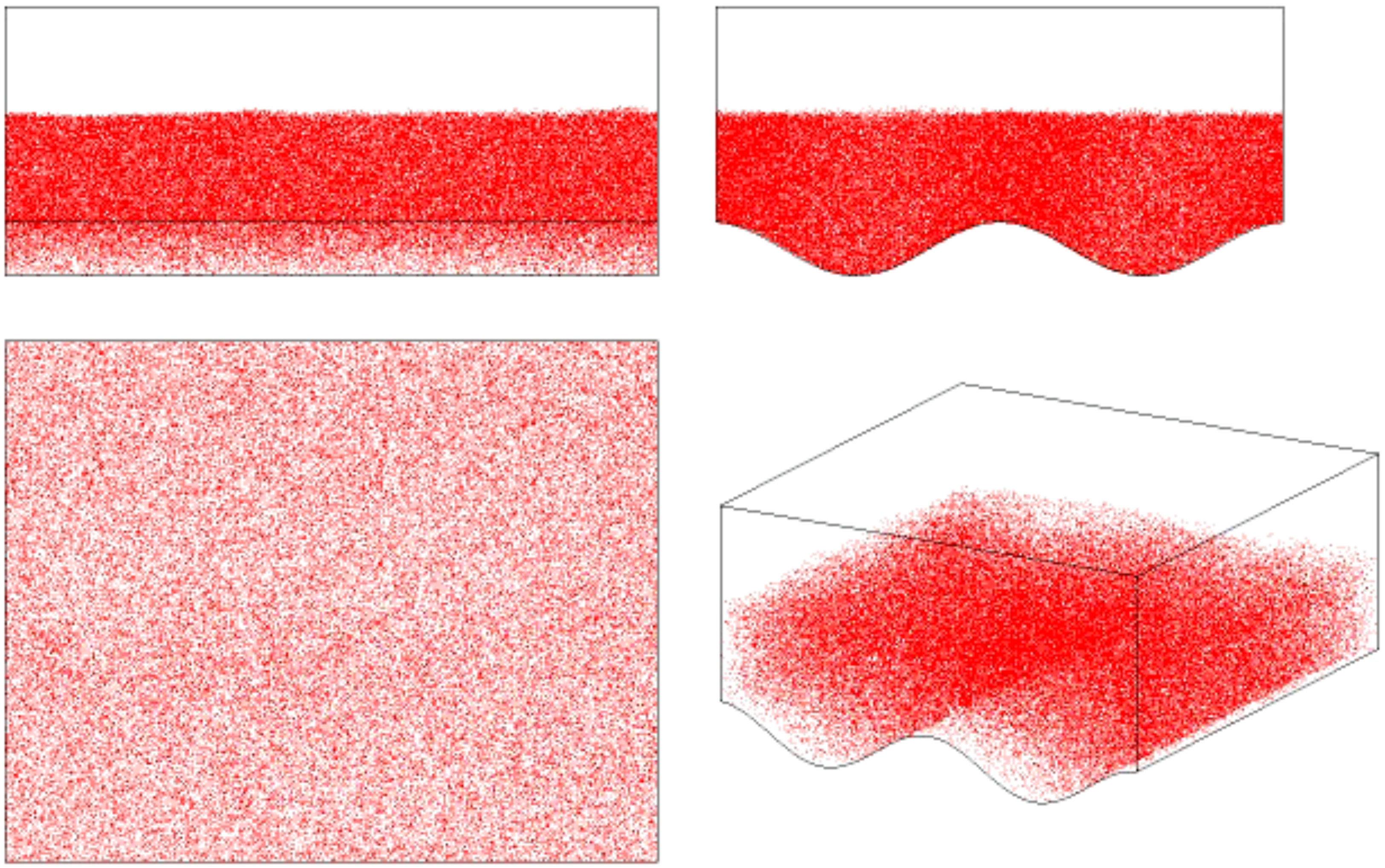
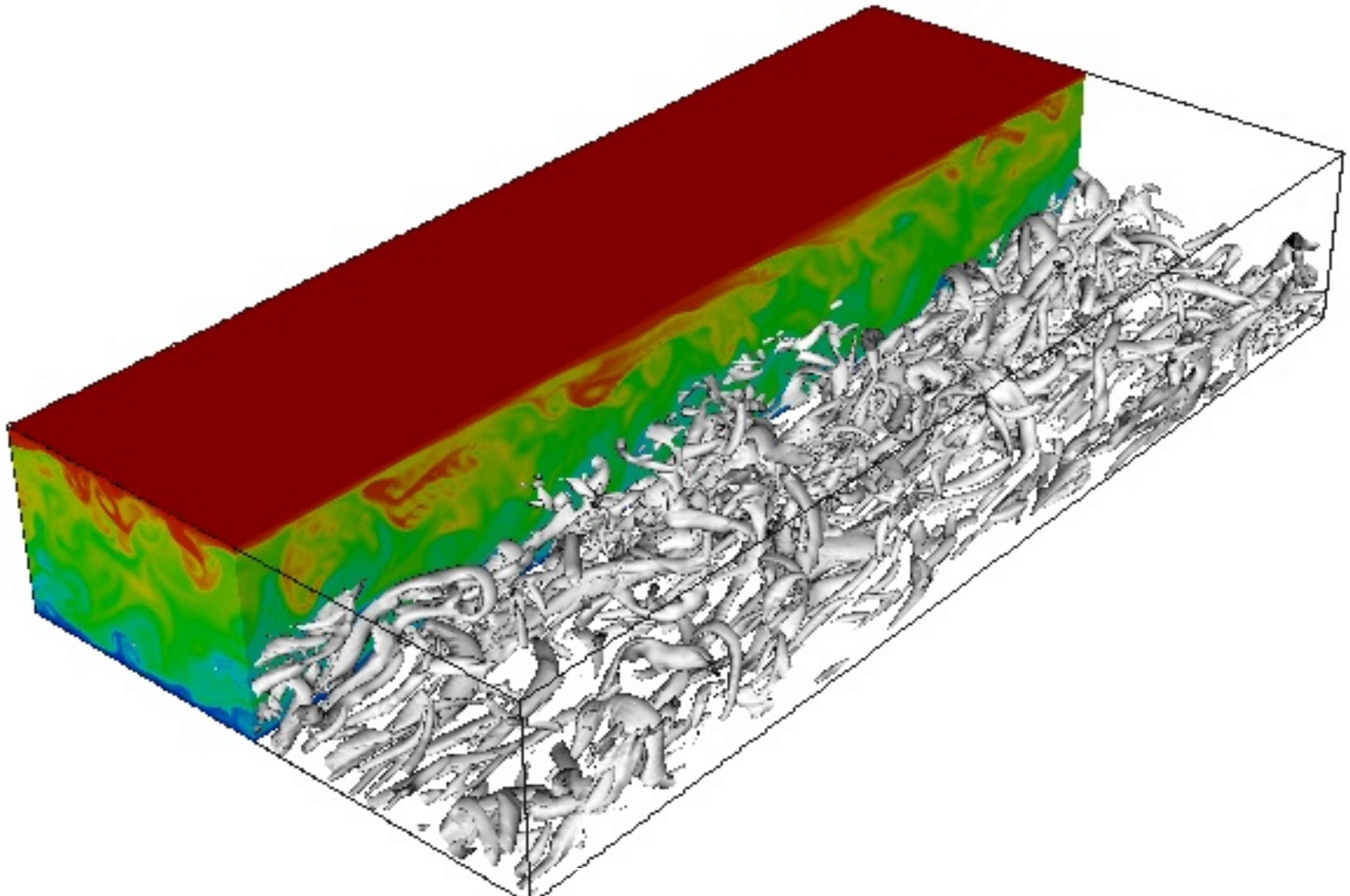


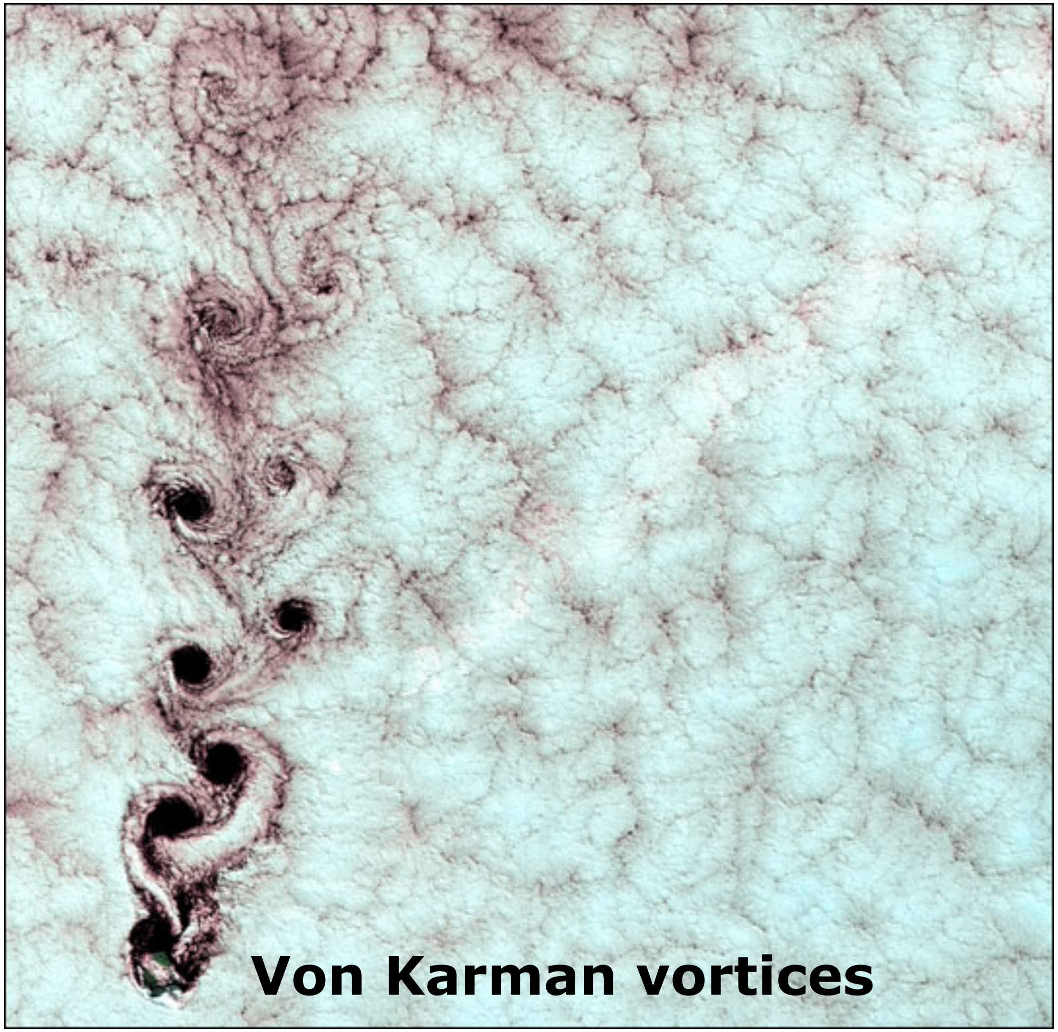
… What is Turbulence?

TURBULENCE IS A COMPLEX PHENOMENON …

... un esempio di flusso turbolento.
Un fluido scorre tra due pareti piane e forma vortici (parte dx)
Le due pareti sono a temperatura diversa e il calore è trasportato
Dalla turbolenza (parte sx)



… But just vortices are NOT turbulence

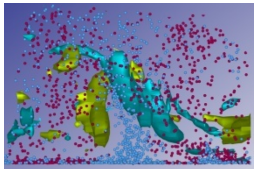


… So the big question is:
What is turbulence?

- Turbulence is…
  - Disorderly
  - Unpredictable
  - Wide range of length scales ("eddies")

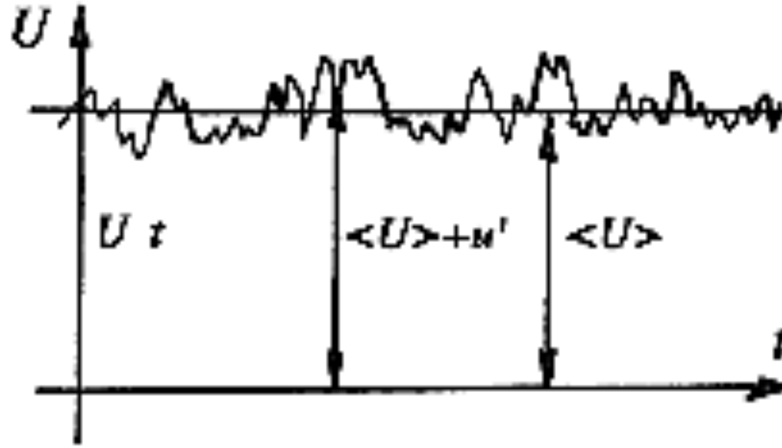
"Observe the motion of the water surface, which resembles that of hair, that has two motions: one due to the weight of the shaft, the other to the shape of the curls; thus, water has eddying motions, <u>one part of which is due to the principal current, the other to the random and reverse motion.</u>"

- Leonardo da Vinci, ca.1510



Modeling and Prediction of Turbulence

- "*Principal current*": mean (density, velocity, pressure, temperature...)
- *"Random and reverse motion":* fluctuation about the mean



Good news and bad news

- Fluid motion, including turbulence, is governed by the Navier-Stokes equations
- The Navier-Stokes equations are non-linear and do not permit analytic solution for arbitrary geometries and boundary conditions

Require physical models and numerical simulation for engineering applications, various hierarchies of simulation are possible depending on level of modeling