A.A. 2025/2026 991DF Dinamica del Clima [SM23-FISICA]

Fisica dei Sistemi Complessi, Clima e Finanza
SSD: ICAR/01, FIS/06
48 hours, 6 CFU

Lecturers: Riccardo Farneti (rfarneti@ictp.it), Fred Kucharski (kucharsk@ictp.it), Erika Coppola (coppoale@ictp.it)

Aims: To introduce students to the physics and dynamics of climate, to the main theories of ocean and atmospheric circulations, and the basics of climate variability and change

Syllabus

Part I Ocean Dynamics

Lecture 1 **Fundamentals:** Geostrophy, Thermal Wind and Hydrostasy
Lecture 2 **Air-sea interactions**: the oceanic heat and freshwater budgets, the mixed layer
Lecture 3 **Ekman Dynamics**: the introduction to Friction
Lecture 4 **Ocean Waves**: Kelvin, Poincarè and Rossby Waves
Lecture 5 **Large scale ocean circulation theory**: Wind-driven gyres: Sverdrup flow, Stommel model
Lecture 6 **Large scale ocean circulation theory**: Wind-driven gyres: Munk model, topographic effects
Lecture 7 **Large scale ocean circulation theory**: buoyancy-driven and wind-driven global Meridional Overturning Circulation
Lecture 8 **Large scale ocean circulation theory**: Ocean heat transport and climate change

Part II Atmospheric Dynamics

Lecture 1 **Recap of some thermodynamics principles:** First and second laws of thermodynamics applied to the atmosphere, Thermodynamics equilibrium state for a closed atmosphere, atmosphere as a mixture of gases, its composition, including GHG and water vapor. Distribution of moisture sources and sinks in the atmosphere.
Lecture 2 **Some basics of Atmospheric Dynamics:** Laws of conservation of potential vorticity and applications.
Lecture 3 **Rossby wave recap:** Free Rossby waves, orographically forced Rossby waves, turning latitude.
Lecture 4 **Equatorial waves:** Dispersion relationships for equatorial waves, including Rossby-Gravity and Kelvin waves.
Lecture 5 **ENSO:** Enso phenomenon and teleconnections, positive atmospheric and oceanic feedback mechanisms. Reduced gravity model for ocean thermocline, Gill model.
Lecture 6 **Large-Scale Adjustment to tropical heating:** Mechanism of remote rainfall responses to a tropical heating anomaly, including Ekman pumping, upper-level divergence, and thermal stabilization of the atmosphere.
Lecture 7 **Features of atmospheric General Circulation and Tropical zonal and meridional circulations:** Zonal mean circulations, role of eddy momentum and heat fluxes, Drivers of Hadley and Ferrell cells. Application of Sverdrup balance to atmosphere to explain walker circulation. Monsoons.
Lecture 8 **Modes of variability in the climate system:** ENSO, NAO, AO, PDO, AMO, SAM, and others, their impact on climate variables.

Part III Natural and Anthropogenic Climate Change

Lecture 1 **The global Energy balance** -Greenhouse effect- The energy balance at the top of the atmosphere
Lecture 2 **Atmospheric radiative Transfer and Climate -** Clouds and Radiation- The role of clouds in the Earth Energy Balance
Lecture 3 **Energy Balance of the Surface** - The surface Energy Balance - The Atmospheric Boundary Layer
Lecture 4 **The Hydrological Cycle -** The water balance - surface water storage and runoff -Modelling the land surface water balance
Lecture 5 **History and evolution of Climate -** Paleoclimate records - Historical records
Lecture 6 **Climate Sensitivity and Feedback** - Ice albedo feedback - Cloud feedback
Lecture 7 **Global and regional climate models** - What is a climate model - Atmosphere, Ocean and Land component
Lecture 8 **Natural and Anthropogenic Climate Change -** Detection and attribution - Emission scenarios - Projection of future climate - Long term climate change

Books: any textbook on Fluid Mechanics / GFD, but particularly:

- `Introduction to Geophysical Fluid Dynamics - Physical and Numerical Aspects' by B. Cushman-Roisin J.-M. Beckers (https://www.elsevier.com/books/introduction-to-geophysical-fluid-dynamics/cushman-roisin/978-0-12-088759-0) (http://www.ccpo.odu.edu/~klinck/Reprints/PDF/roisinGFD2010.pdf)
- `Physical Fluid Dynamics' by D. J. Tritton
- `Fluid Mechanics' by P. K. Kundu
- `Atmospheric and Oceanic Fluid Dynamics' by G.K. Vallis
- `Essentials of Atmospheric and Oceanic Dynamics', by G.K. Vallis