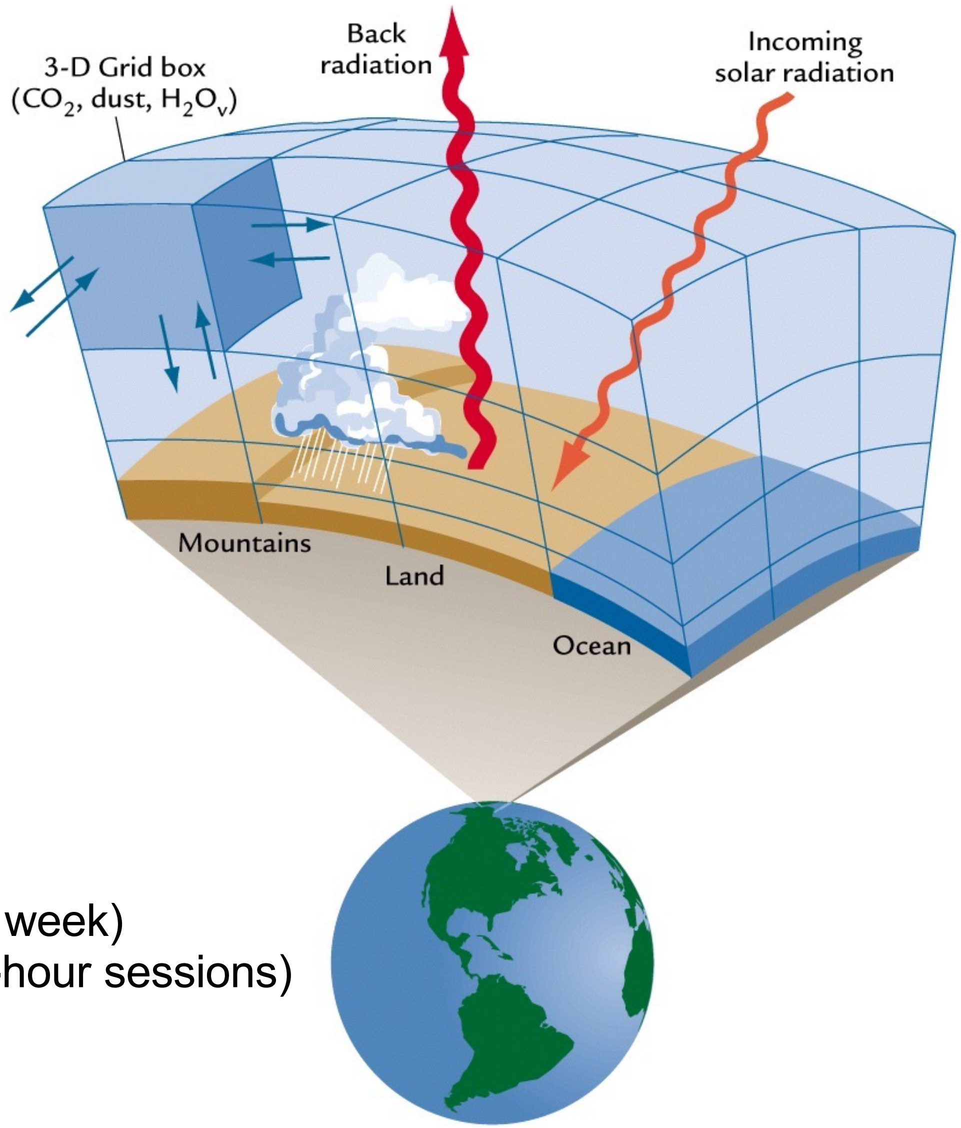
ETH zürich

Weather and Climate Models



Course Information:

Taught by:

- Christoph Schär (schaer@env.ethz.ch)
- David Leutwyler (david.leutwyler@meteoswiss.ch)
- Martin Wild (martin.wild@env.ethz.ch)

Tutorials: lead supervisor:

- Tuule Müürsepp (tuule.mueuersepp@env.ethz.ch)
- Course takes place on Thursday:
- Lectures: 14:15-16:00, Lecture Hall HG D7.1 (every week)
- Tutorials: 16:15-18:00, Lecture Hall HG D7.1 (five 2-hour sessions)

Questions can be asked in class or on Piazza:
https://piazza.com/ethz.ch/spring2024/701121600l

Spring Term 2024
ETH 701-1216-00
https://iac.ethz.ch/edu/courses/master/modules/weather-and-climate-models.html

February 2024

Lectures and tutorials

Lectures:

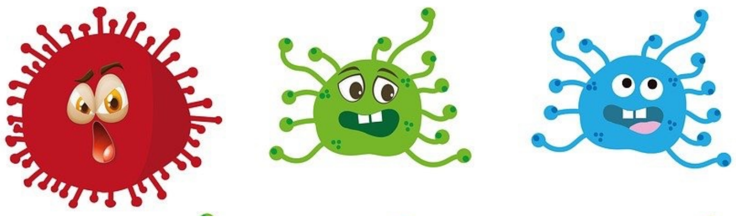
- In class
- Recordings:
  - For most of the lectures, recordings are available from 2022. The link is https://www.video.ethz.ch/lectures/d-usys/2022/spring/701-1216-00L.html
  - Access with special password as provided on the course website

Tutorials:

- In class – strongly recommended
- There are no up-to-date recordings. In case you are unable to attend the tutorial, we might be able to provide some old recordings. Please contact Tuule Müürsepp (tuule.mueuersepp@env.ethz.ch)

Questions:

- For lectures and tutorials: In class or using Piazza: https://piazza.com/ethz.ch/spring2024/701121600l



Aims of course

Understand …

… how weather and climate models are formulated based on governing physical principles, and how they are used for climate and weather prediction purposes.

From ***governing equations*** to ***numerical models*** to ***applications*.**

This involves:

- Numerical aspects (repetition of basic finite differencing, spectral methods)
- Dynamical aspects (atmospheric dynamics, computational fluid dynamics)
- Physical aspects (cloud physics, atmospheric radiation, boundary layer)
- Coupled climate system (atmosphere / oceans / land surfaces)
- Weather forecasting (predictability and chaos theory, data assimilation)
- Climate modeling (anthropogenic versus natural drivers)

Schedule

		Tutorials
22.02.2024	**Outline, Introduction** (CS = Christoph Schär)	
	Dynamics and numerics	
29.02.2024	Repetition Numerical methods (CS)	
07.03.2024	Adiabatic model formulation: Shallow water system (CS)	Python Intro
14.03.2024	Adiabatic model formulation: Vertical coordinates (CS)	
21.03.2024	Adiabatic model formulation: Horizontal discretization (CS)	Tutorial 1
	Parameterizations of physical processes	
28.03.2024	Introduction, parameterization of the planetary boundary layer (MW)	Tutorial 2
04.04.2024	No class: Easter break	
11.04.2024	Parameterization of radiation (MW = Martin Wild)	Tutorial 3
18.04.2024	Data Assimilation (CS)	
25.04.2024	Parameterization of large-scale clouds (DL = David Leutwyler)	Tutorial 4
02.05.2024	Parameterization of convection (DL)	Tutorial 5
09.05.2024	No class: Ascension Day	
	Application of models	
16.05.2024	Predictability, weather and ensemble prediction (CS)	
23.05.2024	Earth Systems Models (MW)	
30.05.2024	Outlook	

We try to upload materials 24 h prior to the lecture to our web-site:
https://iac.ethz.ch/edu/courses/master/modules/weather-and-climate-models.html

Prerequisites

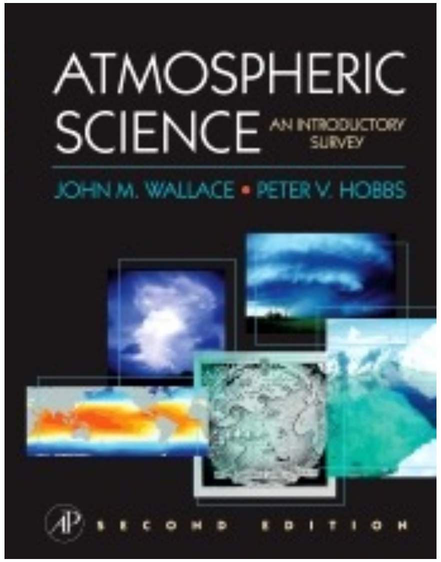
- **Mathematics:**
  essential (including partial differential equations)

- **Atmospheric dynamics and processes: basic introduction**
  e.g. lecture courses „Wettersysteme“ or „Atmosphärenphysik“.
  Recommended book:
  - John M. Wallace and Peter V. Hobbs: Atmospheric Science: An Introductory Survey Academic Press, 2nd Ed. (2006), digital Version available from ETH Library

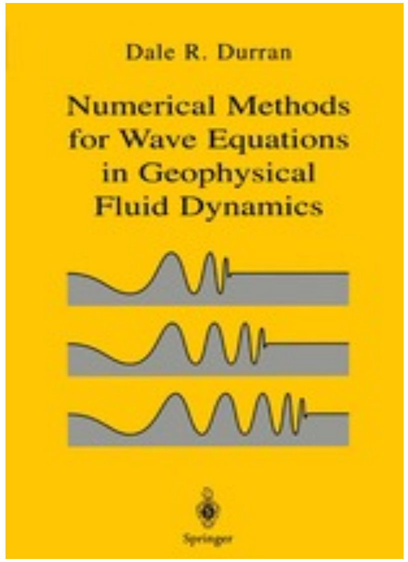
- **Numerical methods: basic finite difference methods**
  essential. Brief repetation provided in 2nd lecture. Available materials:
  - ETH course “Numerische Methoden in der Umweltphysik”, lecture notes in German: https://www.iac.ethz.ch/edu/courses/bachelor/vertiefung/numerical_methods_in_environmental_physics
  - Riddaway (2001), most relevant are chapters 1-3 and 6, download at above link.
  - Durran (1998), extract from Dale Durran’s book, download at above link.

- **Programming:**
  some programming experience is essential,
  PYTHON experience is helpful but not required.

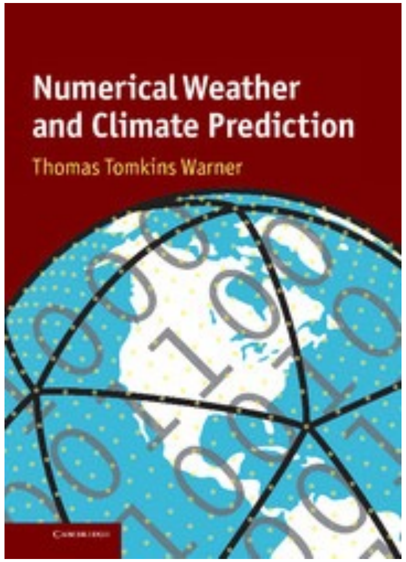
Literature



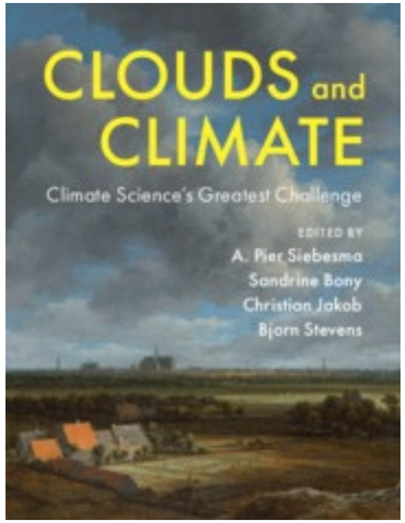
J. M. Wallace and P. V. Hobbs
Atmospheric Science*



D. R. Durran
Numerical Methods for Wave Equations
in Geophysical Fluid Dynamics



T. T. Warner
Numerical Weather and Climate Prediction*



A.P. Siebesma et al (Eds.)
Clouds and Climate*

* Available As pdf-files from ETH library

Prerequisites in atmospheric science

- **If you did not have any courses, you will need to catch up with some of the material.**
- **Here an (incomplete) list of terms that you will need some familiarity with:**

Thermodynamics:
- relative versus specific humidity, saturation vapor pressure
- potential temperature
- lapse-rate
- stable versus unstable versus conditionally stable atmospheric stratification
- adiabatic and moist-adiabatic ascent

Dynamics:
- advection operator (or transport operator)
- hydrostatic law
- vorticity
- geostrophic wind relation

Atmospheric processes:
- radiation balance, radiative transfer, short-wave versus long-wave radiation
- absorption, emission, transmission (scattering/reflection)
- planetary boundary layer, turbulence

Tutorials

- Term project:

  Implementation of a two-dimensional isentropic model to study the nonlinear flow of a stratified atmosphere past a ridge. Consideration of dry and moist flows (with simple cloud microphysics).

- Programming language: PYTHON (introduction will be provided),
  Codes and visualization tools will be provided (website).

- Please install PYTHON on your own laptop. If you don’t know PYTHON, we offer a 2-hour introduction on March 7, 16:15-18:00

- Lead supervisor: Tuule Müürsepp (tuule.mueuersepp@env.ethz.ch)
  Assistants: Nicolai Krieger, Vishnu Selvakumar, Jan Zibell

- Dates: five 2-hour sessions, 16:15-18:00, HG D7.1, starts March 21

- Hand in a model verification plot after exercises 2 and 5.

- Hand in at end of term: Short summary (a few pages) including examples of simulations and their interpretation (upload pdf-file). Team work is encouraged, but individual reports are needed.

Tutorial project

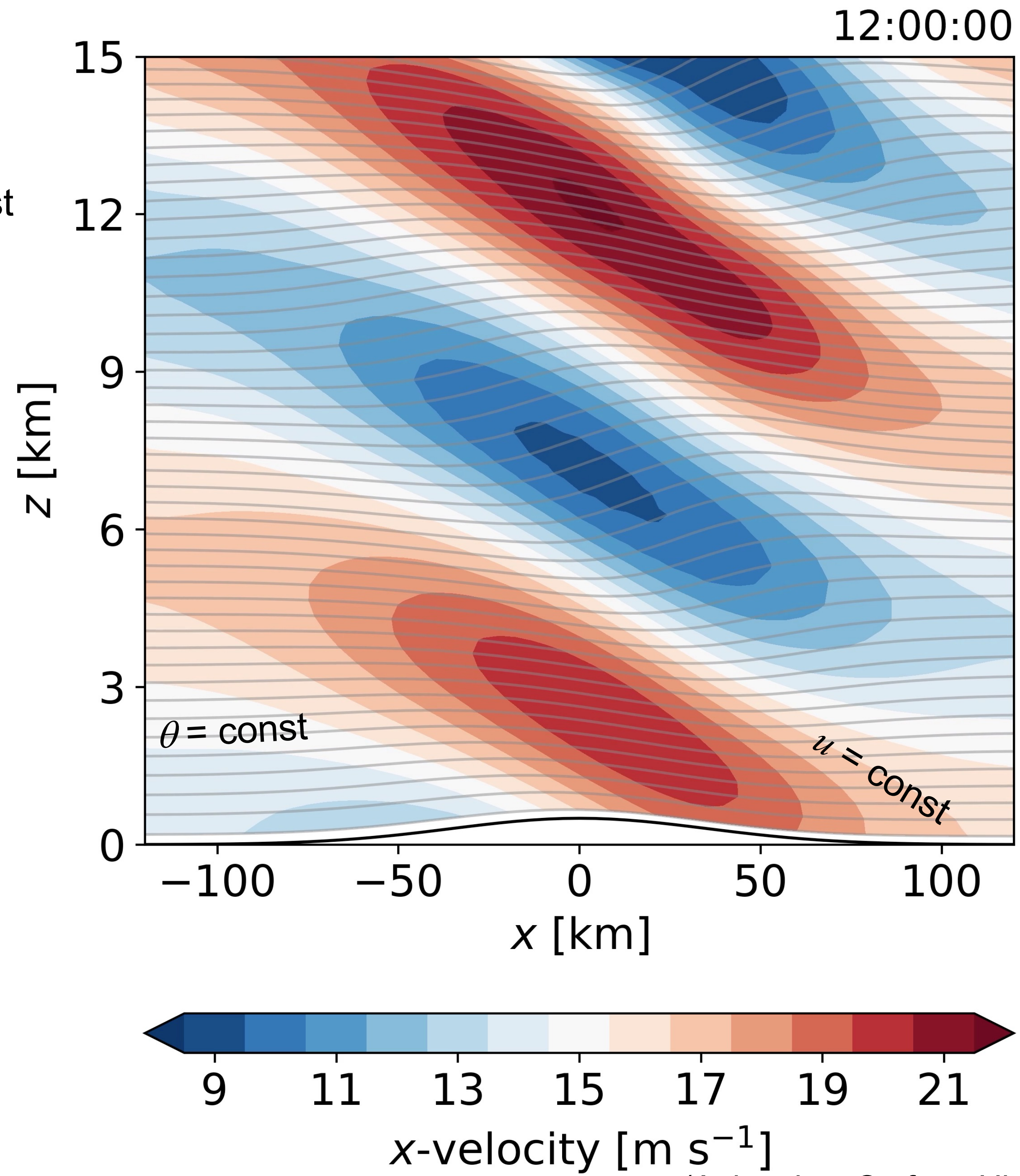
Goal: Develop a two-dimensional model for the flow of a stratified atmosphere past a mountain ridge.

Example: flow from left to right over a bell-shaped mountain of 500m:

- color shading: velocity u
- contours: isentropes (θ=const), represent streamlines

Formulation: The model is formulated in isentropic coordinates: All variables are expressed as $u = u(x, \theta)$, where θ denotes potential temperature.

Tutorial: In the tutorial you will code the model in several steps. Initially we will consider dry flows, but later we will also address wet flows with stratified clouds and precipitation.



(Animation: Stefano Ubbiali)

How to earn credits

- The tutorial is an integral part of the course and will help you to understand the lecture and pass the exam.
- Tutorial-Reports
  - Reports will be graded
  - Contributes 15% to final grade (it is possible to pass course without report)
- Attend written exam:
  Grade 4 is assigned for completion of >60% of tasks
- Credits are awarded if grade (exam plus report) ≥ 4
  Course yields 4 ECTS credit points
- Same rules apply to BSc, MSc and PhD students (few exceptions for some ETH departments)

Tutorial Reports

- **What should be in the report:**
  - demonstrate that you have understood and mastered the tutorial
  - report does not need to cover all aspects of tutorial, you may focus on one specific aspect
  - include key figures and your own interpretations
  - no code (except if essential modifications, in appendix)
- **Length**: 3-6 pages (excluding title page, appendix), font 11 pt
- **Tutorial will be graded:**
  - weight ½ for nicely written reports (layout, figures)
  - weight ½ for creativity (interpretations, own experiments, modified code)
- **Contribution to total grade**: 15%
- **Hand-in filename:** <fist name>_<last name>.pdf
- **Due**: Date will follow, likely in early July 2024
- **Feedback:** will be provided before written exam

Written exams

- Exam: Session exam, in early August 2024 (date to follow)
- Contents of exams:
  - Consistent with the guiding principle of this course: "understand how weather and climate models are formulated from the governing physical principles and how they are used for climate and weather prediction purposes."
  - Focus is on understanding, mixture of text and math questions.
  - Non-trivial equations will be provided on exam sheets. Examples:
    - trivial equation: CFL-criterion
    - non-trivial equations: shallow-water equations
  - Materials that can be omitted for the exam:
    - Info will follow towards end of course
- Bring along:
  - 6-10 (one-sided) pages of hand-written notes on paper (printout of iPad notes is fine).
  - pocket calculator is not needed
- Question: on Piazza (use lecture tabs)