Graduate academic research program:

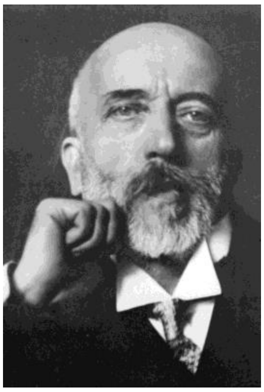
MASTER OF PHYSICS – GEOPHYSICS

UNIVERSITY OF ZAGREB
FACULTY OF SCIENCE
DEPARTMENT OF GEOPHYSICS

Zagreb, January 2015

STUDY OF GEOPHYSICS

Geophysics at the University of Zagreb has a long tradition - it is being taught since 1898, at first at the Faculty of Philosophy of the University. The first lectures were on meteorology and climatology, and in 1910 *Andrija Mohorovičić* introduced lectures on seismology too. When in 1946 Faculty of Science separated from the Faculty of Philosophy, it also incorporated the Geophysical Institute (today within the Department of Geophysics of the Faculty). It is the only institution in Croatia providing academic education in fundamental geophysical disciplines – meteorology, oceanography, seismology, geomagnetism and aeronomy. Besides this, during the last almost 100 years, the affiliates of the Institute held basic geophysical courses at various other faculties in Croatia. Today such courses are offered to other departments of the Faculty, as well as to the Universities of Osijek and Split.



The curriculum is built on the fundamental physical and mathematical education that students acquire during undergraduate study in geophysics. In the course of time, the contents of subjects have constantly been upgraded following advancements and scientific development of particular geophysical disciplines.

The study of geophysics at the Faculty of Science takes three years, with the total of 180 ECTS credits. The requirement for admission is completed the appropriate undergraduate or integrated university study that provides for the acquisition of appropriate competencies required for the MA program in physics-geophysics. Applicants evaluate these competencies by examining the curriculum completion of undergraduate or integrated studies. If necessary, students take supplementary courses. It ends with the exams in all courses included in the program and collecting 180 ECTS credits. The program itself is unique in that it insists on a relatively broad general geophysical education before specialization by individual professions. Thus, the program of the first semester is identical for all students, and in the second semester students have the option to choose one of two available directions: meteorology and physical oceanography and seismology and physics of solid Earth. The study is completed by passing the graduation exam, which consists of two parts: assessment of geophysical courses according to the list of test questions to be determined at the beginning of the academic year and the defense of thesis where the student access after successfully passing the first exam. Graduate study program in physics-geophysics offers a thorough theoretical and practical knowledge of basic geophysical fields (meteorology, physical oceanography, seismology, geomagnetism and aeronomy) and the ability to start scientific research in the area of selected disciplines, as well as the enrolment of doctoral study.

Master of Physics - Geophysics are qualified for the job in the scientific and educational institutions, research institutes, professional services (DHMZ, Seismological Survey), observatories (geomagnetic ...), companies of Applied Geophysics, airports, oceanographic research institutions, etc.

The study of geophysics at the European and world-wide universities is organized in very different ways, and to find two universities where the study is organized in the same manner seems like an impossible task. This is the consequence of the specifics of geophysics, which is strongly linked to physics as well as to other geosciences, and of the fact that geophysics developed in different countries under strong influence of local circumstances and tradition. For instance, some countries with low seismicity do not offer seismological courses at the (pre)graduate level at all, or exists only at the doctoral level (Belgium, for example). Similar situation is also with oceanography which is the most developed in countries with a strong naval tradition. On the other hand, there are geophysical disciplines (like volcanology) that are non-existent in Croatia, but are very much developed elsewhere. Tradition also conditioned the organizational framework providing geophysical education – at some universities it is provided within the structural units dealing with physics (e.g. Helsinki, Bologna), elsewhere it may be under departments of geosciences and/or geology (Trieste, Edinburgh, Athens). Of all the European universities, the most similar program to the one proposed here is that at the Charles University in Prague (A. Mohorovičić studied there!), where meteorology (dynamic and synoptic meteorology and climatology), seismology, gravity and figure of the Earth, geomagnetism and aeronomy are taught at the Faculty of Physics and Mathematics. Our program is also similar to the one offered at the University of Oslo, where bachelors of meteorology and oceanography, as well as the masters of these and related disciplines are educated.

Interest in the undergraduate and graduate studies of geophysics exists in Croatia for a very long time. Graduated students generally easily find employment in professional organizations (Meteorological and Hydrological Service or the Croatian Seismological Survey), scientific institutes, academic institutions, companies dealing with exploration geophysics, banks, etc.

The learning outcomes for graduate university degree in physics-geophysics

After graduation, the student will be able to:

KNOWLEDGE AND UNDERSTANDING

- demonstrate knowledge and understanding of the natural sciences (physics, mathematics) on which the study of geophysics
- demonstrate knowledge and understanding of the main geophysical disciplines (meteorology, seismology, physical oceanography, geomagnetism and aeronomy)
- demonstrate knowledge of major geophysical theory and method which includes logical and mathematical framework, experimental confirmation and description of phenomena
- demonstrate knowledge of the latest scientific knowledge in their specialization field

APPLICATION OF KNOWLEDGE AND UNDERSTANDING

- develop a way of thinking that allows the seting up of basic models or the recognition and use of existing models in the search for solutions to specific geophysical problems
- apply standard methods of mathematical physics, in particular mathematical analysis and linear algebra and corresponding numerical methods in solving geophysical problems
- apply existing models in understanding and explanation of new problems and phenomena
- independently carry out relevant numerical calculations on a personal computer including the development of simple programs
- the ability to use quantitative methods and their application to geophysical problems
- basic ability to combine theory and practice
- the ability of creative thinking in the development of new and original approaches and methods

MAKING JUDGMENTS

- develop the ability to choose and use appropriate analytical methods
- develop the ability to perform appropriate experiments, to analyze and interpret the data, and to draw conclusions
- work in the research team with a high degree of autonomy and to take responsibility for planning and implementing part of the research
- demonstrate knowledge of the ethical principles of scientific research

COMMUNICATION SKILLS

- ability to work individually and within a team
- ability to present own results as well as results obtained by other people

- ability to use English as a professional language in communication, reading literature and writing professional papers

ABILITY OF LEARNING

- independently use the professional literature and other relevant sources of information, which implies a good knowledge of English for specific purposes
- the ability to receive and integrate the information from different sources (e.g. text, numerical, verbal, graphical)
- recognition of the need for lifelong learning
- independently monitor the development of new knowledge in the field of geophysics and give expert opinion on the scope and possible applications
- engage in scientific work and research in the framework of doctoral studies
- engage in highly professional work that requires modelling, implementation of numerical calculations and application of relevant technologies

Description of the graduate study program physics-geophysics

Study group A: SEISMOLOGY AND PHYSICS OF SOLID EARTH

I. YEAR	Winter Semester		Summer Semester	
Compulsory courses	**L+E+S**	**ECTS**	**L+E+S**	**ECTS**
Seismology III	2+1+0	5		
Climatology I	2+1+0	5		
Dynamic Meteorology II	2+2+0	6		
Numerical Methods in Physics	2+2+0	6	2+2+0	6
Seismology IV			2+1+0	6
Engineering Seismology			2+1+0	3
Physics of the Interior of the Earth			2+1+0	6
Geology			3+1+0	5
TOTAL:	**14#**	**22#**	**17#**	**26#**

L = number of teaching hours per week, **E** = number of training hours (practicum) per week, **S** = number of Seminar hours per week.
Without timetable and credits of additional courses.

Optional courses TWO in winter semester and ONE in summer semester	Winter Semester		Summer Semester	
Course title	**L+E+S**	**ECTS**	**L+E+S**	**ECTS**
Selected Chapters in Seismology	2+1+0	4		
Planetology	2+1+0	4		
General and Anorganic Chemistry	2+1+0	4		
Fundamentals of Atmospheric Modelling	2+1+0	4		
Fundamentals of Geophysical Exploration I			2+2+0	4
Statistical Physics			2+1+0	4

II. YEAR	Winter Semester		Summer Semester	
Compulsory courses	**L+E+S**	**ECTS**	**L+E+S**	**ECTS**
Geomagnetism and Aeronomy I	3+1+0	4		
Gravity and Figure of the Earth	2+1+0	3		
Computation of Adjustments	1+1+0	2		
Geophysical Practicum	2+2+0	3		
Seminars in Seismology	0+0+1	2	0+0+1	2
Geophysical Seminars	0+0+1	2	0+0+1	1
Geomagnetism and Aeronomy II			2+1+0	4
Seismotectonics			2+1+0	4
Diploma Thesis		10		15
TOTAL:	**15#**	**26#**	**8#**	**26#**

L = number of teaching hours per week, **E** = number of training hours (practicum) per week, **S** = number of Seminar hours per week.
Without timetable and credits of additional courses.

Optional courses ONE in winter semester and ONE in summer semester	Winter Semester		Summer Semester	
Course title	**L+E+S**	**ECTS**	**L+E+S**	**ECTS**
Fundamentals of Geophysical Exploration II	2+2+0	4		
Optional course from Faculty of Science	2+2+0	4	2+1+0	4

Study group B: METEOROLOGY AND PHYSICAL OCEANOGRAPHY

I. YEAR	Winter Semester		Summer Semester	
Compulsory courses	**L+E+S**	**ECTS**	**L+E+S**	**ECTS**
Seismology III	2+1+0	5		
Climatology I	2+1+0	5		
Dynamic Meteorology II	2+2+0	6		
Numerical Methods in Physics	2+2+0	6	2+2+0	6
Climatology II			2+1+0	5
Dynamic Meteorology III			3+2+0	6
Meteorological Practicum			1+2+0	4
Dynamics of Coastal Sea			2+1+0	5
TOTAL:	**14#**	**22#**	**18#**	**26#**

L = number of teaching hours per week, **E** = number of training hours (practicum) per week, **S** = number of Seminar hours per week.

Without timetable and credits of additional courses.

Optional courses TWO in winter semester and ONE in summer semester	Winter Semester		Summer Semester	
Course title	**L+E+S**	**ECTS**	**L+E+S**	**ECTS**
Selected Chapters in Seismology	2+1+0	4		
Planetology	2+1+0	4		
General and Anorganic Chemistry	2+1+0	4		
Fundamentals of Atmospheric Modelling	2+1+0	4		
Selected Chapters of Meteorology			2+1+0	4
Statistical Physics			2+1+0	4

II. YEAR	Winter Semester		Summer Semester	
Compulsory courses	**L+E+S**	**ECTS**	**L+E+S**	**ECTS**
Geomagnetism and Aeronomy I	3+1+0	4		
Weather Analysis and Forecasting I	2+1+0	3		
Climatology III	2+2+0	4		
Geophysical Seminars	0+0+1	2	0+0+1	1
Geomagnetism and Aeronomy II			2+1+0	4
Weather Analysis and Forecasting II			2+1+0	4
Diploma Thesis		10		15
TOTAL:	**12#**	**23#**	**7#**	**24#**

L = number of teaching hours per week, **E** = number of training hours (practicum) per week, **S** = number of Seminar hours per week.

Without timetable and credits of additional courses.

Optional courses ONE in winter semester and ONE in summer semester	Winter Semester		Summer Semester	
Course title	L+E+S	ECTS	L+E+S	ECTS
Seminar in Dynamic Meteorology	0+0+1	3	0+0+1	2
Seminar in Climatology	0+0+1	3	0+0+1	2
Seminar in Weather Analysis and Forecasting	0+0+1	3	0+0+1	2
Seminar in Physical Oceanography	0+0+1	3	0+0+1	2

Optional courses ONE in winter semester and ONE in summer semester	Winter Semester		Summer Semester	
Course title	L+E+S	ECTS	L+E+S	ECTS
Hydrology I	2+1+0	4		
Physical Meteorology I	2+1+0	4		
Hydrology II			2+1+0	4
Physical Meteorology II			2+1+0	4

Course descriptions

COURSE: **Seismology III**	
YEAR OF STUDY: **I.**	
SEMESTER: **1.**	
TEACHING METHODS	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **5**	
COURSE OBJECTIVES: **Define, derive and analyze generation, propagation and basic characteristics of seismic surface waves in multilayered media. Derive and analyze dispersion of surface waves from seismograms and calculate group velocity in 3-layered model using e.g. Mathematica. Describe the importance of introduction of lateral inhomogeneities in the theory of propagation of seismic waves.**	
COURSE CONTENT: **Seismic surface waves. Rayleigh equation. Propagation and dispersion of seismic surface waves in vertical heterogeneous medium (Thomson-Haskell method and generalisation matrix method). Periodic equation. Determination of eigenvalues and eigenfunctions of surface waves in layered media. Propagation of surface waves in laterally heterogeneous medium.**	
LEARNING OUTCOMES: **After completing the course Seismology III (5 ECTS) the student should be able to:** **- describe the generation and characteristics of surface waves of earthquakes,** **- define the boundary conditions and derive the equation of propagation of waves in vertical heterogeneous layered media (using two methods: the Thomson-Haskell and the matrix method),** **- analyze and compare the dispersion of surface waves of earthquakes for different models,** **- distinguish the propagation of seismic waves in vertical and lateral heterogeneous medium,** **- define equations describing the propagation of seismic waves in laterally heterogeneous medium.**	

LEARNING MODE: **- Attending of lectures, study notes and study literature.** **- Derivation of the equations and analysis of examples.**
TEACHING METHODS **- Lectures, discussion.** **- Derivation of the equations.** **- Solving problems regarding determination of quality factor of coda waves.** **- Teleseismic shear wave splitting analysis**
METHODS OF MONITORING AND VERIFICATION: **Attending of lectures, exercises and solving two problems.**
TERMS FOR RECEIVING THE SIGNATURE: **Solved 2 homeworks, and 2 problems. Oral exam.**
EXAMINATION METHODS: **Oral exam.**
COMPULSORY LITERATURE: **Aki, K., P.G. Richards: Quantitative Seismology, 2nd Ed., University Science Books, Sansalito, California 2002.** **Sato, H., M. C. Fehler: Seismic Wave Propagation and Scattering in the Heterogeneous Earth, Springer Verlag, Berlin 1997.** **Stein, S. & Wysession: An introduction to Seismology, Earthquakes and Earth Structure, Blackwell Publ. 2003.**

COURSE: **Climatology I**	
YEAR OF STUDY: **I.**	
SEMESTER: **1.**	
TEACHING METHODS	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **5**	
COURSE OBJECTIVES: **The students will be introduced into the basics of climatology and its elements. Physical understanding of long-term atmospheric and oceanic state changes. Introduction to basic climatological methods (statistical, analytical, numerical).**	
COURSE CONTENT: **Definitions of climate. Historical development of climatology. Climate system. Climate elements and factors. Solar radiation. Long-wave radiation of the Earth and the atmosphere. Radiation budget. Energy budget. Spatial and temporal changes of the air temperature. Measures of oceanity and continentality of climates. General atmospheric circulation. Air flows of synoptic and local scales. Hydrological cycle. Spatial and temporal changes of precipitation. Basics of bioclimatology. Climate classifications. Natural and anthropogenic climate changes. Climate models and parameterizations of physical processes.**	
LEARNING OUTCOMES: **After completion of the course the students will be able to:** **1. explain the terms of climate, climate elements and factors which affect energy and radiation budget of the Earth and the atmosphere;** **3. analyse real data to estimate oceanity and continentality;** **4. explain spatial distribution of different climate elements;** **5. define climate types and attribute climate type based on real data;** **6. explain natural and anthropogenic climate changes;** **7. explain climate models and used parameterizations**.	
LEARNING MODE: **1. listening lectures, studying notes and available literature,** **2. case study.** **3. solving problems through exercises.**	

TEACHING METHODS **1. presentation with discussion,** **2. independently solving of tasks with real data,** **3. directing student on independent study of literature,** **4. usage of Internet pages.**
METHODS OF MONITORING AND VERIFICATION: **Homeworks, colloquiums, written and oral exam.**
TERMS FOR RECEIVING THE SIGNATURE: **Accurate autonomous drafting of tasks (exercises) on computer.**
EXAMINATION METHODS: **Written (students which successfully pass the colloquiums are released from written exam) and oral exam.**
COMPULSORY LITERATURE: **Hartman, D.L.: Global Physical Climatology. Academic Press, N.Y., 1994.** **Hidore, J.J., J.E. Oliver: Climatology: An Atmospheric Science. Macmillan, 1993.** **Penzar, B., B. Makjanić: Uvod u opću klimatologiju, Sveučilište u Zagrebu, Zagreb, 1978.**

COURSE: **Dynamic Meteorology II**	
YEAR OF STUDY: **I.**	
SEMESTER: **1.**	
TEACHING METHODS	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**2**
Seminars	**0**
ECTS CREDITS: **6**	

COURSE OBJECTIVES:

The main objective of the course is to familiarize students with the basics of the dynamics of the atmosphere of a large scale motions, the mesoscale and microscale dynamics and turbulence. One of the main goals of dynamic meteorology is to interpret the observed structures of atmospheric motions and the analysis and forecasting according to the basic laws of physics. For this purpose, in the course framework is needed to:

- **Describe and analyze the quasi-geostrophic processes, define the basic system of quasigeostrophic equations,**
- **Define the deviation from the quasi-geostrophic balance,**
- **Analyze the hydrodynamic and baroclinic instability of the atmosphere,**
- **Define the general circulation of the atmosphere and describe the law of conservation of the general circulation of the atmosphere,**
- **Define and describe the mesoscale processes,**
- **Analyze and modify the energy and momentum in the stratified fluid,**
- **Describe and analyze the dynamics of two-dimensional buoyancy mountain waves,**
- **Define the basic concepts of nonlinear wave dynamics and hydraulic flow,**
- **Define and describe the concepts related to the atmospheric deep convection,**
- **Define the atmospheric boundary layer, its structure and describe the microscale processes,**
- **To analyze the prognostic equation of the variance for the wind.**

COURSE CONTENT:

Vertical structure of midlatitude large-scale perturbations. Quasi-geostrophic theory. Barotropic and baroclinic models of the atmosphere. Hydrodynamic instability of atmospheric large-scale processes. Baroclinic instability. Conservation of general circulation. Energy conservation of midlatitude atmospheric circulation. Introduction of mesoscale processes. Internal gravity waves. Convection. Atmospheric boundary layer. Laminar and turbulent motions. Spectral analysis of turbulent motion. Turbulent kinetic energy. Hypotheses of Taylor and Kolmogorov. Turbulent fluxes. Similarity theory. Transport and diffusion in the atmosphere. Coastal and mountain circulations. Three-

dimensional modeling of the atmospheric dynamics

LEARNING OUTCOMES:

It is expected that after the completion of this course, the students may:

- **be able to define the basic characteristics of large-scale processes, define the quasigeostrophic system of equations and interpret individual members in these equations,**
- **differ baroclinic from barotropic instability, can compare dispersion relations for the short and long waves in the stratified fluid,**
- **define assumptions and derive equations for the simple mountain waves and discuss the differences between non-hydrostatic and hydrostatic flows,**
- **apply default assumptions and derive basic system of equations for turbulent flow,**
- **recognize introduced assumptions and be able to interpret the meaning of the individual members in the forecasting equation of the variance for the wind,**
- **explain the basic processes at different scales of motion and explain the reasons for the introduction of the assumptions used.**

LEARNING MODE:

Critical discussions during lecturing, studying notes and references, derivation of equations and analysis of examples and problems, individual solving of problem tasks.

TEACHING METHODS:

Lectures, exercises, referring students to independently study the literature, individual solving of problem tasks.

METHODS OF MONITORING AND VERIFICATION:

Students are required to regularly attend classes, solve homework. Additionally, it is necessary to monitor and discus the current synoptic and local weather effects.

The work of the students on the course is monitored and evaluated during the study (completion of homework assignments and additional assignments) and at the final written exam.

TERMS FOR RECEIVING THE SIGNATURE:

The terms of course approval are:

- **Successfully solved all the homework during the semester,**
- **Written course summary, 2-3 pages (basic questions & assumptions, relations and conclusions).**

EXAMINATION METHODS:

The written exam consists of questions that require a short answer and problem solving.

COMPULSORY LITERATURE:

J. R. Holton: An Introduction to Dynamic Meteorology, Academic Press Inc., San Diego, 1992 (or 2004)

R. B. Stull: An Introduction to Boundary Layer Meteorology, Kluwer, Dordrecht, 1988 **N. Šinik and B. Grisogono: Dinamička meteorologija, Školska knjiga, Zagreb, 2008**
ADDITIONAL LITERATURE: **J. Pedlosky: Geophysical Fluid Dynamics, Springer-Verlag, New York, 1987** **F. Mesinger: Dinamička meteorologija, Građevinska knjiga, Beograd, 1976** **Numerous web pages and ECMWF courses**

COURSE: **Numerical Methods in Physics**	
YEAR OF STUDY: **I.**	
SEMESTER: **1 and 2**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**2**
Seminars	**0**
ECTS CREDITS: **6**	

COURSE OBJECTIVES:

To introduce students to modern methods in Numerical Analysis, in the area of ordinary and partial differential equations, with an emphasis on their practical solution on digital computing machines.

COURSE CONTENT:

1. semester

1. **Mathematical models in physics, an introduction: existence, uniqueness, stability.**
2. **Initial value problem for ODE, discretization. Euler-Cauchy method.**
3. **Convergence proof for the Euler-Cauchy method.**
4. **Taylor method.**
5. **Single step and multistep methods.**
6. **Predictor-corrector methods.**
7. **Runge-Kutta method.**
8. **Linear difference equations.**
9. **Consistence, convergence and stability of difference methods,**
10. **Linear boundary value problem for ODE, existence and uniqueness.**
11. **Shooting method.**
12. **Difference methods, matrix formulation. Banded and sparse positive definite matrices, algorithms and convergence proofs. An introduction to numerical linear algebra: techniques and programs for solution of linear systems with banded, block-diagonal and sparse matrices.**
13. **Nonlinear boundary value problems, quasilinearization method.**
14. **Non-smooth coefficients, eigenvalue problem and an introduction to discretization of Sturm-Liouville problem.**
15. **Discussion, comments on computer programs, and an overview of available software (NAG, IMSL, LAPACK).**

2. semester

1. **Variational formulation for one-dimensional problems. A notion of weak solution. Minimum energy principle and Sobolev spaces**

2. **Finite element method (FEM), one-dimensional case.**
3. **FEM for elliptic boundary value problems for PDE, basis functions and form functions, spaces of finite elements, variational formulation and Ritz-Galerkin method.**
4. **Aproximation of domain, local coordinates and the nesting algorithm. The knot enumeration problem.**
5. **An elementary error analysis of the FEM.**
6. **Laplace, Poisson and Helmholtz equation. Elastic plate and PDE's of 4th order. Conforming and non-conforming methods.**
7. **FEM for parabolic problems, Crank-Nicolson method.**
8. **Implicit and explicit schemes, stability.**
9. **Quasilinear parabolic equations, introduction.**
10. **Basic facts about Finite Difference Method (FDM). Methods for parabolic equations, convergence, consistence and stability. Heat equation, diffusion processes and filtration.**
11. **Hyperbolic equations of 1st and 2nd order, numerical integration by finite difference.**
12. **Method of characteristics, propagation of discontinuities, simulation of shock waves.**
13. **Lax-Wendroff formulae and Courant-Friedrichs convergence condition.**
14. **Wave equation and method of characteristics, cones of the past and future.**
15. **Discussion, comments on computer programs and an overview of available software (NAG, IMSL, LAPACK). Special FEM software, FreeFem and GEOFEM packages.**

LEARNING OUTCOMES:

After the successful completion of the subject Numerical methods in physics, the student will be able to:

1. **express the basic definition and theorems associated with the ordinary and partial differential equations, as well as with the approximation methods;**
2. **differentiate the methods for solving initial and boundary value problems for ordinary and partial differential equations;**
3. **choose and apply the correct approximation methods for the given problem;**
4. **derive an analogous approximation method with certain properties;**
5. **analyze a given approximation method;**
6. **write a simple computer program for solving a given problem.**

LEARNING MODE:

Following lectures, study of notes and literature, analysis of examples and practicing, analysis of methods and practicing, analysis of computer programs and the results obtained by solving problems on the computer and practicing.

TEACHING METHODS:

Lectures; solving examples; analysis of the methods; presentation of the computer programs and their results.

METHODS OF MONITORING AND VERIFICATION:

Written exam through midterm exams; writing and presenting programming assignments; oral exam.

TERMS FOR RECEIVING THE SIGNATURE: **One program per semester, successfully tested and documented, thoroughly inspected by the assistant and teacher.**
EXAMINATION METHODS: **Written exam.**
COMPULSORY LITERATURE: **Z. Drmač, M. Marušić, M. Rogina, S. Singer, Sanja Singer: Numerička analiza, skripta na webu, 2003/2004** **M. S. Gochenbach: Partial Differential Equations, Analytical and Numerical Methods, SIAM 2002.** **U. M. Ascher, R. M. Mattheij, R. D. Russel: Numerical Solution of Boundary Value Problems for Ordinary Differential Equation, SIAM 1995.** **E. Isaacson, H. B. Keller: Analysis of Numerical Methods, John Wiley and Sons, London 1966.**
ADDITIONAL LITERATURE: **C. King, J. Billingham, S. R. Otto: Differential Equations, Linear, Nonlinear, Ordinary, Partial, Cambridge Univ. Press 2003.** **G. Strang, G. J. Fix: An Analysis of the FEM, Prentice-Hall, 1973. W. H. Press, B.P. Flannery, S. A. Teukolsky, W. T. Vetterling: Numerical Recipes, Cambridge univ. press, 1987.** **G. D. Smith: Numerical Solution of PDE: Finite Difference Methods,Clarendon press,Oxford, 1978.** **M. Metcalf, J. Reid: FORTRAN 90/95 Explained, Oxford Univ. Press, 1999.** **T. M. R. Ellis, I. R. Philips, T. M. Lahey: Fortran 90 Programming, Addison-Wesley, 1996.**

COURSE: **Seismology IV**	
YEAR OF STUDY: **I.**	
SEMESTER: **2.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **6**	

COURSE OBJECTIVES:

Define, derive and analyse the impact of lateral inhomogeneities and anisotropy on propagation and scattering of seismic waves and generation of coda waves. Analyse and discuss local coda waves. Describe generation and derive the equations of free oscillations of the Earth. Discussion of characteristics of free oscillations of the Earth.

COURSE CONTENT:

Fundamentals of theory of scattering of elastic waves in inhomogeneous media. Coda waves of local earthquakes. Quality factor (Qc) of coda waves, measurements and interpretation. Dependence of Qc on frequency and elapsed time. Seismic anisotropy. Tensor of elasticity and fundamental properties of seismic plane waves in homogeneous anisotropic media. Equations of motion in 1-D and 2-D and in Earth as a uniform elastic sphere. Determination of eigen values and eigen functions of free oscillations. Spherical harmonics.

LEARNING OUTCOMES:

After completing the course Seismology IV (6 ECTS) the student should be able to:
- Outline generation and characteristics of local coda waves.
- Measure, calculate and interpret Qc of coda waves.
- Analyse frequency and time dependence of the Qc factor.
- Discriminate isotropic and anisotropic media.
- Describe seismic anisotropy and its causes.
- Define anisotropic structures in Earth's crust and mantle.
- Define and describe basic systems of symmetry important for seismology.
- Derive and discuss equations of free oscillations of Earth.

LEARNING MODE:

- Attending of lectures, study notes and study literature.
- Derivation of the equations and analysis of examples.

TEACHING METHODS: **- Lectures, discussion. - Derivation of the equations. - Solving problems regarding determination of Qc quality factor of coda waves. - Teleseismic shear wave splitting analysis.**
METHODS OF MONITORING AND VERIFICATION: **Homeworks. Oral exam.**
TERMS FOR RECEIVING THE SIGNATURE: **Solved 2 homeworks, and 2 problems solved. Oral exam.**
EXAMINATION METHODS: **Oral exam.**
COMPULSORY LITERATURE: **Aki, K., P.G. Richards: Quantitative Seismology, 2nd Ed., University Science Books, Sansalito, California 2002.** **Sato, H., M. C. Fehler: Seismic Wave Propagation and Scattering in the Heterogeneous Earth, Springer Verlag, Berlin 1997.** **Stein, S. & Wysession: An introduction to Seismology, Earthquakes and Earth Structure, Blackwell Publ. 2003.**

COURSE: **Engineering Seismology**	
YEAR OF STUDY: **I.**	
SEMESTER: **2.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **3**	

COURSE OBJECTIVES:

Acquiring basic notions of engineering seismology. Students are introduced to basic earthquake statistics and measuring of strong ground motion. They learn about the importance of knowing seismic hazard of an area, as well as the amplification properties of surface soil layers.

COURSE CONTENT:

Earthquake catalogues. Gutenberg-Richter relation, estimation of the catalogue completeness. Functions of attenuation of intensity, PGA, PGV, PGD. Dynamic factor of amplification (DAF), amplification spectra for vertically incident SH-waves. Seismic hazard and risk.

LEARNING OUTCOMES:

The course on Engineering seismology enable students to:
- **Describe the typical contents of earthquake catalogues.**
- **Define and discuss the Gutenberg-Richter relation, and to estimate its parameters, given an earthquake catalogue.**
- **To estimate the catalogue completeness with respect to the smallest magnitude and/or the time interval.**
- **Define properties of the Poissonian process.**
- **Describe main factors influencing recorded strong motion at some location.**
- **Compute amplification spectra for given geotechnical models of soil layers.**
- **Differentiate between properties of soil based on the corresponding amplification spectra.**
- **Differentiate between the deterministic and probabilistic approach to hazard determination.**
- **Argue for the properties of seismic hazard as described by a given hazard map.**

LEARNING MODE:

Attending lectures, study notes and study literature, derivation of the equations and

analyses of examples.
TEACHING METHODS: **Lectures, discussions, derivation of the equations, solving problems.**
METHODS OF MONITORING AND VERIFICATION: **Regular attendance to the lectures. Oral exam.**
TERMS FOR RECEIVING THE SIGNATURE: **Successful completion of the exercises and homeworks, attending lectures.**
EXAMINATION METHODS: **Oral exam.**
KOLEGIJI PRETHODNICI: **Seismology III (completed)**
COMPULSORY LITERATURE: **Agarwal, P.N.: Engineering Seismology, Oxford & IBH Publishing, New Delhi 1991.** **McGuire, R. K: Seismic Hazard and Risk Analysis, EERI, Oakland CA, 2004.** **Reiter L.: Earthquake Hazard Analysis. Columbia University Press. New York 1991.**

COURSE: **Physics of the Interior of the Earth**	
YEAR OF STUDY: **I.**	
SEMESTER: **2.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **6**	
COURSE OBJECTIVES: **The course prepares students to describe and define the structure of the Earth's interior and to analyze the displacement field on the surface of the Earth based on the analysis of the seismic sources.**	
COURSE CONTENT: **Inverse problems (Lanczos's decomposition, Moore-Penrose matrix inverse, determination of seismic waves velocities using inverse method). Density, pressure and constants of elasticity in the Earth's interior (basics of density determination in the Earth's interior, Adams-Williamson equation for the variation of density in mantle). Physics of seismic sources (causes of earthquakes, elastic rebound theory, strain energy before an earthquake, Clapeyron's form of strain energy density, faulting sources, equivalent body forces, radiation pattern). Elastostatics (static displacement field due to a single force, a force couple and a double couple). Elastodynamics (near and far field displacements, far field radiation patterns, seismic moment tensor). Earthquake magnitude (energy of earthquake waves, energy per unit area of wave front in an emerging wave, energy of body and surface waves, earthquake magnitude).**	
LEARNING OUTCOMES: **Students will be able to:** 1. **define and solve inverse problems in seismology using Lanczos decomposition** 2. **compute density distribution, pressure and constants of elasticity in the Earth's interior using the Adams- Williamson's law** 3. **explain the basic concepts of physics of seismic sources** 4. **explain the difference between elastostatics and elastodynamics** 5. **explain the concept of magnitude, as well as compare different magnitudes**	
LEARNING MODE: **Listening sessions, study notes and literature, case study, derivation of equations and problem solving.**	

TEACHING METHODS:

Presentation, discussion, task of equation derivation and solving numerical problems.

METHODS OF MONITORING AND VERIFICATION:

Homeworks, written and oral exam.

TERMS FOR RECEIVING THE SIGNATURE:

Regular attendance to the lectures (at least 70%), homeworks.

EXAMINATION METHODS:

Written and oral exam.

COMPULSORY LITERATURE:

Aki, K., P.G. Richards: Quantitative Seismology, 2nd edition, University Science Books, Sausalito 2002.

Ben Menahem, A., B.A. Singh: Seismic Waves and Sources, Springer-Verlag, New York 1981.

Stein, S., M. Wysession: An Introduction to Seismology, Earthquakes and Earth Structure, Blackwell Publishing, Hoboken 2003.

Tarantola, A.: Inverse Problem Theory, Methods for Data Fitting and Model Parameter Estimation, Elsevier Science Publishers, Amsterdam 1987.

Lay, T., T.C. Wallace: Modern Global Seismology, Academic Press, San Diego 1995.

COURSE: **Geology**	
YEAR OF STUDY: **I.**	
SEMESTER: **2.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**3**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **5**	
COURSE OBJECTIVES: **Introduction to geology, acquainting with geological composition of the Earth, and processes in its interior and at the surface. Learning about tectonic processes and structures, Earth's inner dynamics, earthquakes and volcanism, karst and seas, their geological importance, evolution of life on the Earth and basic fossil types. Mastering basic methods of geological research.**	
COURSE CONTENT: **Evolution and composition of the Earth. Earth physics: isostasy, heat, magnetism. Plate tectonics (boundaries, causes, consequences). Earth dynamics: volcanism (causes, volcano types, types of eruptions and products), seismics (causes, detection methods, impact of substratum on earthquake damage). Tectonics: bed strike and dip, conformity and disconformity, folds, faults, overthrusts. Hydrological cycle, underground water. Weathering, transport and erosion, slope processes. Karst: genesis, hydrology, geomorphology, evolution. Sea: sea dynamics (tides, waves, currents), sea regions, sea-level changes. Geological time: dating methods (relative, radiometric). Environments, facies, fossilization and fossils. Presentation of geological data: geological maps, sections and columns. Geological compass.**	
LEARNING OUTCOMES: **Student will be able to:** **Identify common rock-forming minerals and major rock types and describe the conditions under which each of them formed; Recognize various types of geologic structures on geologic map, and use them to reconstruct and interpret the structural history of the area, and write a short report on the geology of the area; Identify the common types of fossils and interpret their approximate age, the environments in which they lived and their evolution through geological time; Describe the plate-tectonic history of the earth.**	
LEARNING MODE: **Presentations, literature and notes, sample analysis and training, systematic observation /**	

inference.
TEACHING METHODS: **Lectures, exercises, independent assignments.**
METHODS OF MONITORING AND VERIFICATION: **Tests, written exam, oral exam.**
TERMS FOR RECEIVING THE SIGNATURE: **All exercises successfully completed and colloquiums passed.**
EXAMINATION METHODS: **Written and oral exam.**
COMPULSORY LITERATURE: **Nusset A.E. & Khan M.A. (2000): Looking into the Earth. An introduction to geological geophysics. Cambridge University press. Cambridge.** **Plummer, Ch.C., McGeary, D. & Carlson, D. (2001): Physical Geology, 8th Ed., Mc Graw Hill, Boston.** **Tarbuk, E.J. & Lutgens, F.K. (1988): Earth Science. 5th. Ed., Merrill Publ. Company, Columbus.**

COURSE: **Climatology II**	
YEAR OF STUDY: **I.**	
SEMESTER: **2.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **5**	

COURSE OBJECTIVES:

The students will be introduced into the basics of climatology and its elements. Physical understanding of long-term atmospheric and oceanic state changes. Introduction to basic climatological methods (statistical, analytical, numerical).

COURSE CONTENT:

Solar radiation components. Long-wave radiation of the Earth and the atmosphere. Radiation budget. Energy budget. Specifics of the general atmospheric circulation and air flows of different scales. Microclimatology. Hydrological cycle. Bioclimatology. Natural and anthropogenic climate changes. Parameterizations of physical processes in climate models. Integration of climate with other models.

LEARNING OUTCOMES:

After completion of the course the students will be able to:

1. **Define solar and Earth radiation components and hydrological cycle,**
2. **Argue the relation between radiation budget and the energy balance of the Earth and the atmosphere,**
3. **Explain the specifics of the general atmospheric circulation of the atmosphere and air flows on different spatiotemporal scales,**
4. **To define natural and anthropogenic causes of climate changes**
5. **Explain physical parameterizations used in climate models and**
6. **Compare climate and meteorological models.**

LEARNING MODE:

Listening lectures, studying notes and available literature, case study and solving problems through exercises.

TEACHING METHODS:

Presentation with discussion, independently solving of tasks with real data, directing student on independent study of literature and usage of Internet pages.

METHODS OF MONITORING AND VERIFICATION: **Homeworks, colloquiums, written and oral exam.**
TERMS FOR RECEIVING THE SIGNATURE: **Accurate autonomous drafting of tasks (exercises) on computer.**
EXAMINATION METHODS: **Written (students which successfully pass the colloquiums are released from written exam) and oral exam.**
KOLEGIJI PRETHODNICI: **Climatology I (completed)**
COMPULSORY LITERATURE: **Hartman, D.L.: Global Physical Climatology. Academic Press, N.Y., 1994.** **Hidore, J.J., J.E. Oliver: Climatology: An Atmospheric Science. Macmillan, 1993.** **Penzar, B., B. Makjanić: Uvod u opću klimatologiju, Sveučilište u Zagrebu, Zagreb, 1978.**

COURSE: **Dynamic Meteorology III**	
YEAR OF STUDY: **I.**	
SEMESTER: **2.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**3**
Exercises	**2**
Seminars	**0**
ECTS CREDITS: **6**	

COURSE OBJECTIVES:

The main objective of the course is to deepen the knowledge about midlatitude large-scale dynamics. Weather analysis and forecasting. Extending knowledge about mesoscale and microscale dynamics and turbulence. One of the main goals of dynamic meteorology is to interpret the observed structures of atmospheric motions and the analysis and forecasting according to the basic laws of physics. For this purpose, in the course framework is needed to:

- **Describe, analyze and interpret the processes of quasi-geostrophic adjustment, define the basic system of quasi-geostrophic equation**
- **Define the omega equation, Q-vector and explain the mechanisms of vertical motion in baroclinic waves**
- **Explain the energy of the baroclinic waves and basic concepts related to it**
- **Refine the general circulation of the atmosphere, the circulating cells and describe the law of conservation of angular momentum**
- **Define and describe the Lorenz energy cycle**
- **Provide a basis of the semi-geostrophic theory and derive Eliassen-Sawyer equation**
- **Describe and analyze the dynamics of buoyancy waves over bell-shaped mountain ·**
- **Define and describe the concepts related to convective storms and the rotation of the super-cell**
- **Define the spectral theory of turbulence**
- **To analyze the prognostic equation of turbulent Reynolds stresses**

COURSE CONTENT:

Structures of midlatitude large-scale perturbations. Quasi-geostrophic prognosis, semi-geostrophic theory. Barotropic and baroclinic dynamical models of atmospheres. Atmospheric instabilities of large-, meso- and micro-scale processes: baroclinic, isentropic-inertial and buoyant instability. Fronts. Conservation of atmospheric circulations. Mountain waves. Deep convection. Atmospheric boundary layers and turbulence. Turbulent kinetic energy prediction. Monin-Obukhov length. Reynolds stress tensor prediction. Modeling transport and diffusion in the atmosphere. Local circulations. Modeling of the atmospheric

dynamics, parameterizations for micro-scale processes. Prandtl model for inclined boundary layers.

LEARNING OUTCOMES:

It is expected that after the completion of this course, the students may:

- **Define the basics of geostrophic adjustment and interpret the physical meaning of individual members in the equation of Q-vector**
- **Distinguish the two models (for short and long wavelengths) for description of baroclinic instability in continuously stratified rotating fluid**
- **Define requirements and derive expression for dispersion relation of buoyancy waves over bell-shaped mountain and explain the concept of wave drag**
- **Be able to list and compare the different types of linear waves**
- **Apply default assumptions and derive the basic system of equations for turbulent flows of momentum, heat, humidity and scalars**
- **Recognize introduced assumptions and be able to interpret the meaning of individual terms in the forecasting equation of the turbulent Reynolds stresses**
- **Explain the basic processes at different scales of motion and explain the reasons for the introduction of the assumptions used.**

LEARNING MODE:

Critical discussions during lecturing, studying notes and references, derivation of equations and analysis of examples and problems, individual solving of problem tasks.

TEACHING METHODS:

Lectures, exercises, referring students to independently study the literature, individual presentation (seminar), individual solving of problem tasks.

METHODS OF MONITORING AND VERIFICATION:

Students are required to regularly attend classes, solve homework. Additionally, it is necessary to monitor and discus the current synoptic and local weather effects.

The work of the students on the course is monitored and evaluated during the study (completion of homework assignments, presentation and additional assignments) and at the final written exam.

TERMS FOR RECEIVING THE SIGNATURE:

Successfully solved all the homework during the semester; written course summary, 2-3 pages (basic questions & assumptions, relations and conclusions).

EXAMINATION METHODS:

The written exam consists of questions that require a short answer and problem solving.

KOLEGIJI PRETHODNICI:

Dynamic Meteorology II (completed)

COMPULSORY LITERATURE: **J. R. Holton: An Introduction to Dynamic Meteorology, Academic Press Inc., San Diego, 1992 (or 2004)** **R. B. Stull: An Introduction to Boundary Layer Meteorology, Kluwer, Dordrecht, 1988** **N. Šinik and B. Grisogono: Dinamička meteorologija, Školska knjiga, Zagreb, 2008**
ADDITIONAL LITERATURE: **J. Pedlosky: Geophysical Fluid Dynamics, Springer-Verlag, New York, 1987** **F. Mesinger: Dinamička meteorologija, Građevinska knjiga, Beograd, 1976** **Numerous web pages and ECMWF courses**

COURSE: **Meteorological Practicum**	
YEAR OF STUDY: **I.**	
SEMESTER: **2.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**1**
Exercises	**2**
Seminars	**0**
ECTS CREDITS: **4**	

COURSE OBJECTIVES:

Primary goal is to gain competencies in applying theoretical dynamic meteorology concepts in the analysis of the current state of the atmosphere and the forecast of the future processes. During lectures and practical exercises the students will be taught about different procedures of meteorological measurements and observations, visualization of the observations using meteorological symbols and practical use of different measurement and observation data in the analysis of the current state of the atmosphere. The students will be familiarized with numerical weather prediction models and taught how to use the model results in practical short and medium range forecasting.

COURSE CONTENT:

Meteorological symbols, measurements and observations. The use of remote sensing. Initial and boundary conditions for numerical prediction models; initialization. Some numerical model schemes and errors. Atmospheric predictability and prognostic models. Practical aspects of mountain, coastal and urban meteorology. Elements of short- and medium-range forecasting.

LEARNING OUTCOMES:

It is expected that after the completion of this course the students will be able to:

- **Describe the principles of meteorological measurements and observations**
- **Measure and observe basic meteorological parameters**
- **Read and draw meteorological symbols**
- **Analyze surface and upper-level measurement data**
- **Explain remote sensing methods and principles**
- **Interpret and practically apply different satellite data and products**
- **Explain and apply radar data**
- **Analyze the current state of the atmosphere using all available data types**
- **Describe the principles, limitations and possible errors of NWP models**
- **Demonstrate practical short and medium range weather forecast on real-time data and NWP model results.**

LEARNING MODE: **Lectures, studying notes and references, studying e-learning materials, individual solving of problem tasks.**
TEACHING METHODS: **Lectures, exercises, referring students to independently study the literature, individual presentations, individual solving of problem tasks.**
METHODS OF MONITORING AND VERIFICATION: **Students are required to regularly attend classes and do their homework. Additionally, it is necessary to monitor and discus the current synoptic situation.** **The work of the students is monitored and evaluated during the course (completion of homework assignments and additional assignments) and at the final written exam.**
TERMS FOR RECEIVING THE SIGNATURE: **Successfully solved all the homework during the semester, measurements and observations at meteorological station Horvatovac, presentation and interpretation of the data.**
EXAMINATION METHODS: **The written exam consists of questions that require a short answer and problem solving.**
COMPULSORY LITERATURE: **Mesinger, F.: Dinamička meteorologija. Građevinska knjiga, Beograd. 1976.**
ADDITIONAL LITERATURE: **Numerous web pages (EUMeTrain, COMET, ECMWF)**

COURSE: **Dynamics of Coastal Sea**	
YEAR OF STUDY: **I.**	
SEMESTER: **2.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **5**	
COURSE OBJECTIVES: **The course prepares students to analyze barotropic processes that are generated by wind in inland seas.**	
COURSE CONTENT: **Wind-driven currents in the seas: models developed by Weenink, Felzenbaum and Welander. Comparison with the wind-driven currents in the oceans: models proposed by Sverdrup, Stommel and Munk. Seiches: analytical modeling of generation and decay, development of a simple one-dimensional numerical model, comparison with the observations. Topographic Rossby waves: analytic models for the straight coast and circular basin. Exercises include analyses of analytic solutions for various sets of parameters and one-dimensional numerical modeling of seiches.**	
LEARNING OUTCOMES: **Students will be able to** **1. identify wind-driven currents in the seas and oceans,** **2. analyze seiches, on the basis of measurements, not only in time domain but also in frequency domain,** **3. formulate a simple numerical model of the seiches,** 4. **identify topographic Rossby waves in inland seas.**	
LEARNING MODE: **Following the lectures as well as studying the lecture notes and literature, analyzing the data (time series of sea level), and performing one-dimensional numerical modeling.**	
TEACHING METHODS: **Presentation and discussion, posing the problems relying on data collected in the Adriatic, and formulation of one-dimensional numerical model.**	
METHODS OF MONITORING AND VERIFICATION:	

Attending the lectures, homeworks, written and oral examination.
TERMS FOR RECEIVING THE SIGNATURE: **Regular attendance to the lectures, successful completion of the exercises.**
EXAMINATION METHODS: **Written and oral exam.**
COMPULSORY LITERATURE: **LeBlond P.H.and L. A. Mysak: Waves in the Ocean, Third Impression, Elsevier, Amsterdam, 1989.** **Pugh D. and P. Woodworth: Sea-Level Science, Cambridge University Press, Cambridge, 2014.** **Schwind J. J.: Geophysical Fluid Dynamics for Oceanographers, Prentice Hall, Englewood Cliffs, 1980.** **Simons T. J.: Circulation Models of Lakes and Inland Seas, Department of Fisheries and Oceans, Ottawa, 1980.** **Stocker T. and K. Hutter: Topographic Waves in Channels and Lakes on the f-Plane, Springer Verlag, New York, 1987.**

COURSE: **Selected Chapters in Seismology** ***(optional)***	
YEAR OF STUDY: **I.**	
SEMESTER: **1.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **4**	

COURSE OBJECTIVES:

Preparing students to extend their knowledge and skills in selected sub-disciplines of seismology. For instance: Training students, using theory and practical skills, for determination and interpretation of fault-plane solutions.

COURSE CONTENT:

E.g.: Theoretical fundamentals – displacement caused by the force in an infinite medium, dipoles, pairs of forces. Models of the seismic source. Types of faults. Stereographic projections. Practical determination of fault-plane solution.

LEARNING OUTCOMES:

After the course Selected chapters of seismology students are able to, e.g.:

- **Define and differentiate between force models used to describe ground motion in an infinite medium.**
- **Defend the choice of the double-couple to describe earthquake faulting.**
- **Derive and explain expressions describing radiation of the double-couple source in various coordinate systems.**
- **Define and describe fault types.**
- **Define and describe Wulff's and Schmidt's stereographic projections.**
- **Describe faults as presented by their stereographic projection, as well as the tectonic stress field causing the faulting.**

LEARNING MODE:

Studying textbook and other literature (including lecture notes), attending lectures.

TEACHING METHODS:

Lectures, discussion.

METHODS OF MONITORING AND VERIFICATION:

Regular attendance at lectures, solved problems. Oral exam.
TERMS FOR RECEIVING THE SIGNATURE: **Regular attendance to the lectures, successful completion of the exercises.**
EXAMINATION METHODS: **Oral exam.**
COMPULSORY LITERATURE: **Kasahara, K: Earthquake mechanics, Cambridge University Press, 1981.** **Aki, K., P. G. Richards: Quantitative Seismology, 2nd edition, University Science Books, Sausalito, California, 2002.** **Stein, S. and M. Wysession: An introduction to Seismology, Earthquakes and Earth structure, Blackwell Publ., 2003.** **Lay, T., T. C. Wallace: Modern Global Seismology, Academic Press, San Diego, 1995.** **Udias, A.: Principles of Seismology, Cambridge University Press, United Kingdom, 1999.**

COURSE: **Planetology** ***(optional)***	
YEAR OF STUDY: **I.**	
SEMESTER: **1.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **4**	
COURSE OBJECTIVES: **Introduce students to the bodies of the Solar system, especially to the planets.** **To achieve the goals it is necessary to:** **- define the body in the Solar system, their mutual positions and distances between them** **- describe internal structure of planets, discuss similarities and differences** **- describe planetary surfaces and explain relevant physical processes** **- describe planetary atmospheres, their interaction with solar radiation** **- discuss the evolution of extra-solar planets.**	
COURSE CONTENT: **Earth in the Universe, astronomical data about planets, satellites and small bodies in the Solar system. Methods for determination of distances. Description of the Earth's interior, mechanical properties of the Earth- Moon system, tides, change of the Earth's axis and length of the day. Milanković's cycles and glaciations. Moon structure and evolution. Internal structure of planets and representative elements. Surface features and geological processes. Termal regime in Solar system and proper source of energy. General features of planetary atmospheres and interaction with solar radiation. Planetary ionosheres and magnetosheres. Cosmology and extrasolar planets.**	
LEARNING OUTCOMES: **After completing the course and passing the exam students are able to:** **- describe basic characteristic of the Solar system** **- define characteristic of planetary interiors, planetary surfaces and atmospheres** **- distinguish planets of the Earth's group from those of the Jovian group** **- recognize the importance of studying the evolution of Solar system planets for detecting extrasolar planets** **- independently analyze professional literature** **- prepare and present seminars, discuss the presented topics.**	
LEARNING MODE:	

Attending lectures, study literature, preparation and discussion of seminars.
TEACHING METHODS: **Lectures, individual and group discussions, consultations.**
METHODS OF MONITORING AND VERIFICATION: **Mid-term exams, written and oral exam.**
TERMS FOR RECEIVING THE SIGNATURE: **Attending lectures 70%.**
EXAMINATION METHODS: **Writing (the students may not have to attend writing part of the exam if they successfully complete all mid-term exams) and oral examinations.**
COMPULSORY LITERATURE: **de Pater, I., Lissauer, J.J.: Planetary Sciences, Cambridge University Press, Cambridge 2001.** **Chamberlain, J.W.: Theory of Planetary Atmospheres, Academic Press, London 1978.**

COURSE: **General and Anorganic Chemistry** ***(optional)***	
YEAR OF STUDY: **I.**	
SEMESTER: **1.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **4**	

COURSE OBJECTIVES:

The main objective of the course is to familiarize students with the basic chemical principles. For this purpose, within the required courses:

- **Define pure substances and mixtures and to compare their properties;**
- **Define and compare the physical and chemical changes;**
- **Describe the structure of atoms;**
- **Compare and analyze the reactivity of different elements;**
- **Describe and analyze the nature of chemical bonding and molecular structure of the substance;**
- **Describe the characteristics of a particular aggregation states and to describe and analyze the changes that occur in phase transitions;**
- **Describe the types of crystalline solids and compare their properties;**
- **Define and compare the types of intermolecular interactions;**
- **Define the composition of pure substances and mixtures;**
- **Classify chemical reactions and analyze the changes that occur during them.**

COURSE CONTENT:

Substances - mixtures (homogeneous mixtures, heterogeneous mixtures), pure substances (natural substances, compounds). Physical changes, separation of a mixture of ingredients. Chemical changes. The knowledge of the atomic structure of matter (Law of conservation of mass, law of constant weight ratio, Law multiple weight ratio, Dalton's atomistic theory). The discovery of the electron, the discovery of the atomic nucleus.

The atomic theory today - an introduction to the structure of the atom. Symbols atoms, atomic number, mass number (nuclides, a chemical element, isotopes, isobars). Expression of the mass of atoms (relative atomic mass, relative atomic mass of the element). Plural, abundance. Periodic Table of Elements - historical overview. Build the periodic table - periods, groups (metals, semimetals, nonmetals).

Electronic configuration - Bohr model of the atom, quantum mechanical model of the atom. Energy states of atoms and atomic orbitals (quantum numbers and their relationship with the periodic table). The principle of construction of electron cloud.

Atom radius, ionization energy, electron affinity.

Chemical bond - ionic bond (Hess's law, the enthalpy of the crystal lattice), covalent bond (the term electronegativity), the properties of ionic and covalent compounds. Lewis structural formula (oxidation number, formal charge), molecular shape (VSEPR theory). Metallic bond.

Formulas and nomenclature of covalent and ionic compounds, polyatomic ions. Molar quantities (molar mass, relative molecular mass, molar volume). The composition of the substance (ratios, shares). Determining the formula of unknown compound.

Aggregation state (solid, liquid, gas) and phase changes. Changes at phase transitions (enthalpy of phase transitions), the balance at the phase transition. The phase diagram (pressure and temperature influence on the aggregation state).

Intermolecular interactions (ion-dipole, dipole-dipole, hydrogen bonding, and polarizability term induced dipole, dispersion forces). The properties of the liquid phase (surface tension, viscosity, capillarity).

Solid - amorphous and crystalline solid. Types and properties of crystalline solids (atomic, molecular, ionic, metallic, covalent solids). Crystal Systems. Cubic structures, hexagonal structure, the structure of the diamond. The structure of selected ionic solid (NaCl, CsCl).

Solutions - kind of solution. Liquid solutions - processes which take place in the melting solid into the liquid (dissolution enthalpy, melting as equilibrium process), the effect of temperature on the solubility of a solid in water. Dissolution of gases in water (influence of temperature and pressure). The composition of solutions (concentration molality).

Colligative properties of solutions (solvent vapor pressure, boiling point, melting point and osmotic pressure of the solution)

Types of chemical reactions. Reversible reactions. The stoichiometry of chemical reactions, the notion of excess and limiting reagenses.

Acids and bases. Neutralization reaction.

Oxidation and reduction reactions. Equating the redox reaction (ion-electron method, oxidation number). Electrochemical reactions (standard electrode potential). Galvanic cell, electrolytic cell (Faraday's laws of electrolysis).

LEARNING OUTCOMES:

After this course the student is expected to be able to:

- **Distinguish pure substances or mixtures of substances and their properties;**
- **Distinguish the physical change of the chemical changes;**
- **Compare the properties and reactivity of individual elements and connect them to their position in the periodic table;**
- **Clarify the concept of ionic, covalent and metallic bonds;**
- **Compare the properties of gaseous, liquid and solid phase and qualitatively and quantitatively analyze the changes that are happening at the phase transition;**
- **Distinguish between types of intermolecular interactions and connect their influence with the aggregation state in which a substance exists (at given conditions) and the solubility of certain substances in a given solvent;**

- **Distinguish between types of crystalline solids and connect the inner structure of matter with its properties;**
- **Calculate the composition of pure substances and mixtures of substances;**
- **Distinguish between types of chemical reactions and qualitatively and quantitatively analyze the processes that occur during them.**

TEACHING METHODS:

Lectures, seminars, independent assignments.

METHODS OF MONITORING AND VERIFICATION:

Attending of lectures, colloquiums and homeworks.

TERMS FOR RECEIVING THE SIGNATURE:

Homeworks, colloquiums, seminars.

EXAMINATION METHODS:

Two colloquiums - at each colloquium student must achieve a threshold of at least 50% in order to be released from written exam.

Seminar that student must submit before the oral exam. The success of the written and oral examination.

COMPULSORY LITERATURE:

S. Silberberg, Chemistry, 2. izd., McGraw-Hill, NewYork, 2000.

M. Sikirica, Stehiometrija, Školska knjiga, Zagreb, 1987.

P. W. Atkins and M. J. Clugston, Načela fizikalne kemije, Školska knjiga, Zagreb, 1989.

T. Cvitaš, I. Planinić and N. Kallay, Rješavanje računskih zadataka u kemiji, I.dio, HKD, Zagreb, 2008.

T. Cvitaš, I. Planinić and N. Kallay, Rješavanje računskih zadataka u kemiji, II.dio, HKD, Zagreb, 2008.

COURSE: **Fundamentals of Atmospheric Modelling** ***(optional)***	
YEAR OF STUDY: **I.**	
SEMESTER: **1.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **4**	

COURSE OBJECTIVES:

The course prepares students for (i) work with selected models, and (ii) for the development and understanding of the analysis and forecasts of atmospheric processes from the model output at different scales of varying complexity.

COURSE CONTENT:

Classification of atmospheric models. Types of atmospheric numerical models: global and climate models, meso-scale models, micro-scale models. Numerical schemes, initial and boundary conditions. Model initialization. Nesting. Parameterisations in atmospheric models: turbulence, surface layer, microphysics, convection, radiation, etc. Shallow-water model. Mesoscale model of high complexity. Air quality models: Gaussian, Euler, Lagrange. Coupling of atmospheric and oceanographic models.

LEARNING OUTCOMES:

Students will be able to:
1. explain the basic concepts about used numerical methods in the model;
2. set hypothesis about the origin and/or interaction of meteorological phenomena that is going to be modeled;
3. properly apply the model to the selected problem with the correct choice of model parameterization and other simplifications/options during numerical computation;
4. identify and discuss the limitations on the use of numerical models in meteorology due to various types of numerical instabilities during calculation;
5. formulate and generalize observed physical relationships among meteorological phenomena provided by the model results.

LEARNING MODE:

Listening to the lectures, making the homeworks, run the models, analysis of model results and writing reports.

TEACHING METHODS:

Presentations, discussions, resolving equations and practical work with models.

METHODS OF MONITORING AND VERIFICATION:

Written reports and theirs oral discussions. The final grade also includes the credits earned during the course.

TERMS FOR RECEIVING THE SIGNATURE:

Attending lectures and exercises, homework, working on simulation models and writing reports.

EXAMINATION METHODS:

A written report and its oral discussion linking with the acquired knowledge. The final score includes points acquired during class.

COMPULSORY LITERATURE:

Beniston, M. (1998): From Turbulence to Climate. Springer, Berlin.

Pielke, R. A.(2002): Mesoscale Meteorological Modeling. Academic Press, San Diego.

Mesinger, F.(1976): Dinamička meteorologija. Građevinska knjiga, Beograd.

Šinik, N. and B. Grisogono (2008): Dinamička meteorologija – uvod u opću cirkulaciju atmosfere. Školska knjiga, Zagreb.

ADDITIONAL LITERATURE:

Durran, D. R. (1999): Numerical Methods for Wave Equations in Geophysical Fluid Dynamics. Springer, New York.

Jacobson, M. Z. (1999): Fundamentals of Atmospheric Modeling. Cambridge University Press, New York.

Lin, Y.-L. (2007): Mesoscale Dynamics. Cambridge University Press.

COURSE: **Fundamentals of Geophysical Exploration I *(optional)***	
YEAR OF STUDY: **I.**	
SEMESTER: **2.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**2**
Seminars	**0**
ECTS CREDITS: **4**	

COURSE OBJECTIVES:

Introduction to the methods of geophysical research and their application in defining the geological structure and composition of terrain: in exploration of hydrocarbons and solid mineral resources, in geotechnical researches, groundwater and environmental studies.

COURSE CONTENT:

Lectures :
Gravimetric researches - Theoretical basis. Gravimeter. Gravimetric effect of 3D structures. Instruments and equipment. Field measurements and data processing. Gravimetric correction. Transformation of gravimetric maps. Rock densities. Interpretation. Gravimetric ambiguity. Isostasy. Application of gravimetric surveys.
Magnetic researches - Earth's magnetic field. Instruments and equipment. Measuring the total field. Theoretical foundations. Magnetic minerals and rocks. Elementary dipoles and monopoles. Induced and remanent magnetization. Field measurements. Use of the protone magnetometer. Data processing. Interpretation. Magnetometric ambiguity. Application of magnetic researches. Geoelectric researches - Electrical properties of rocks. Self - potential method. Electrical resistivity method. Electrical sounding and profiling: instruments and equipment. Measuring, data processing, interpretation. Electrical ambiguity. Application of geoelectrical researches. Induced polarization method.

Exercises:
Defining 3 exercises. Explanations related to preliminary exams and field work. Gravimetry – Introduction. Interpolation of values on Bouguer anomaly maps. Transformation of Bouguer anomaly maps using Griffin method. Calculation of residuals for different radiuses. Interpolation of calculated values on the map of gravimetric residuals for different radiuses. Magnetometry - Introduction. Defining the profile on the geomagnetic maps. Defining the cause of anomaly. Tangents methods - horizontal gradient Method of tangents – Peter´s method, tangent-intersection method. Calculating the depth of the anomaly cause. Geoelectric sounding – Introduction. Calculating the apparent resistivity for two layers Interpretation of depth distribution of resistivity for two layers using theoretical curves. Calculating the apparent resistivity for several layers.

Interpretation of depth distribution of resistivity for multiple layers, using theoretical curves. Interpretation of depth distribution of resistivity for multiple layers, using theoretical curves. Field work - Geoelectrical sounding, geoelectrical profiling, Magnetometry.
LEARNING OUTCOMES: **To understand gravimetric regional and residual; define the depth of the causes of magnetic anomalies with tangents methods; to calculate and interpret the curve of geoelectric sounding; to understand the operation of instruments for gravimetric, magnetic and electrical surveys.**
TEACHING METHODS: **Lectures, exercises, practical and field work.**
METHODS OF MONITORING AND VERIFICATION: **Regular attendance of lectures, practical work, preliminary exams, oral exams.**
TERMS FOR RECEIVING THE SIGNATURE: **Class attendance (lectures, exercises and field work), handed solved exercises, passed at least one preliminary exam.**
EXAMINATION METHODS: **Passed preliminary exams or oral exam (80%), solved exercises (20%).**
COMPULSORY LITERATURE: **Šumanovac, F. (2012): Osnove geofizičkih istraživanja, Sveučilište u Zagrebu.**
ADDITIONAL LITERATURE: **Griffits, D.H. & King, R.F. (1981): Applied Geophysics for Engineers and Geologists, Pergamon Press, Oxford.** **Parasnis, D.S. (1986): Principles of Applied Geophysics, Chapman and Hall, New York.**

COURSE: **Statistical Physics** ***(optional)***	
YEAR OF STUDY: **I.**	
SEMESTER: **2.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **4**	

COURSE OBJECTIVES:

Understanding the relationship between thermodynamics and statistical physics and the adoption of the fundamental concepts of statistical description of the thermodynamic limit: entropy, thermodynamic potentials, an ensemble, single distribution, fluctuation.

COURSE CONTENT:

Thermodynamics as an autonomous discipline: Introduction. Basic concepts. The first law of thermodynamics. Machines. The second law of thermodynamics. The reversibility and entropy. Thermodynamic potentials. Practical accounts.

Introduction to statistical physics: Basic considerations. Ensemble: universal random model. The connection with thermodynamics.

Canonical and grand-canonical ensemble: The canonical ensemble. Grand-canonical ensemble. Sums by conditions such as generating functions. Classical ideal gas. Maxwell distribution and equiparticion energy.

Quantum statistical physics: Basic considerations. The ideal fermion gas. The ideal boson gas.

Examples and models: the barometric formula. Diatomic molecules. Heat capacity of the crystal. Van der Waals model of gas liquefaction.

LEARNING OUTCOMES:

Upon successful completion of the course Statistical Physics student will be able to:

1. **Demonstrate a thorough knowledge of abstract thermodynamics at an elementary level of the theory of functions of several variables;**
2. **Explain the difference of thermodynamics and theoretical mechanics, or thermalization as real physical process;**
3. **Describe the role of thermalization and Liouville theorem in the foundation of statistical physics;**
4. **Explain the physical construction of the thermodynamic potential, through the interaction energy between the system and the outside world;**

5. Demonstrate a thorough knowledge of statistical interpretation of thermodynamic potentials, especially entropy and Massieuovih function; **6. Explain the role of the chemical potential and the qualitative behavior of the classical and quantum border;** **7. Qualitatively and quantitatively described four ideal gas (fermions, bosons, light, sound) in classical and quantum border;** **8. Discuss basic properties of the phase transition of Van der Waals's gas liquefaction.**
TEACHING METHODS: **Lectures, exercises.**
METHODS OF MONITORING AND VERIFICATION: **Colloquiums, written and oral exam.**
TERMS FOR RECEIVING THE SIGNATURE: **Students are required to pass two of three colloquiums that are held during the semester.**
EXAMINATION METHODS: **Students can take the oral exam if they have passed the written exam. The written examination can be taken if they pass two of the three colloquia during the year with a passing grade. If all three are passed with grade 4 or 5, student receive a higher grade on the written exam.**
COMPULSORY LITERATURE: **C. Kittel, Elementary Statistical Physics, Dover 2004, ISBN 0486435148.** **R. Kubo et al., Statistical mechanics: an advanced course with problems and solutions, North-Holland, Amsterdam 1988, ISBN 0444871039.** **Skripta: http://www.phy.hr/dodip/notes/statisticka.html**

COURSE: **Selected Chapters of Meteorology** ***(optional)***	
YEAR OF STUDY: **I.**	
SEMESTER: **2.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **4**	

COURSE OBJECTIVES:

The course prepares student to describe, define and analyze climate forcing and atmospheric processes of different scales of motion; to analyze and interpret causes and consequences of climate change; to interpret atmosphere-ocean interaction.

COURSE CONTENT:

The course consists of several offered thematic modules. Each module contains the newest accomplishments in meteorology and links them to the existing knowledge of students. The modules topics deal with the following areas: dynamic and synoptic climatology (e.g. atmospheric oscillations at large scales such as North Atlantic Oscillation or Madden - Julian Oscillation), regional climatology (e.g. influence of the climate changes on local winds), climate change (e.g. scientific justifiability of the long - term climatic projections), interaction of the atmospheric processes at different scales (e.g. spectral energy cascade of the atmospheric processes), planetary and synoptic complex phenomena (e.g. potential vorticity (PV) thinking, structure and dynamics of warm and cold conveyor belts), atmospheric mesoscale phenomena (e.g. wind meandering, thermal local circulations such as sea/land breeze, slope winds, mesoscale convective systems), Adriatic meteorology (e.g. characteristic of the atmospheric phenomena along the Adriatic and their interaction with the sea, etesian, bora, sirocco), air quality (e.g. dispersion of pollutants under low wind speed conditions). The contents of modules are changeable following the newest achievements in the field.

LEARNING OUTCOMES:

Students will have the knowledge and skills to
1. list, analyze and discuss a range of atmospheric processes
2. provide and analyze feedback processes in the atmosphere and ocean
3. analyze and interpret climate forcing
4. analyse, distinguish and compare natural and anthropogenic causes of climate change
5. define and interpret teleconnections; analyze them using appropriate statistical methods
6. formulate and solve issues related to the chosen thematic module

7. analyze and compare observed and modelled data associated with a given phenomena.
LEARNING MODE: **Listening, sessions, study the notes and literature, case study, derivation of equations and problem solving.**
TEACHING METHODS: **Presentation, discussion, interactive tutorials, solving numerical problems and group discussion.**
METHODS OF MONITORING AND VERIFICATION: **Homework, project and oral exam.**
TERMS FOR RECEIVING THE SIGNATURE: **Regular attendance to the lectures (at least 70%), homework, project report.**
EXAMINATION METHODS: **Oral exam.**
COMPULSORY LITERATURE: **Marshall, J. and R. A. Plumb: Atmosphere, Ocean, and Climate Dynamics: An Introductory Text. Elsevier, Amsterdam, 2008.** **Vallis, G. K.: Atmospheric and Oceanic Fluid Dynamics. Cambridge University Press, Cambridge, 2006.** **Beniston, M.: From Turbulence to Climate. Springer, Berlin, 1998.**

COURSE: **Geomagnetism and Aeronomy I**	
YEAR OF STUDY: **II.**	
SEMESTER: **3.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**3**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **4**	

COURSE OBJECTIVES:

To introduce students to the properties of the geomagnetic field, and complex connections of the magnetic field with the highest layers of the Earth's atmosphere. For this purpose it is necessary to:

- **Handle the physical processes that generate a magnetic field,**
- **Explain the equations that connect the electric and magnetic field,**
- **Process and discuss the evolution of all components of the geomagnetic field,**
- **Describe the method of measuring the geomagnetic field,**
- **Define the distribution of the particles in all layers of high atmosphere (magnetosphere) and interaction with the magnetic field.**

COURSE CONTENT:

Elements and basic characteristic of the geomagnetic fields. Basic of spherical astronomy. Instruments and methods of measuring the geomagnetic field elements. Electromagnetic induction and electrical conductivity. Results of paleomagnetic investigations, secular variations and reversals. Relations of kinetic theory of gases, atomic structures, atomic and molecular processes related to the atmospheric physical properties. Atmospheric distribution, chemical atmospheric composition. Physics and chemistry of the ozone layer. Global atmospheric electric field. Global changes in high atmosphere. Transfer of the electromagnetic radiation through the atmosphere, absorption and formation of layers in the distant atmosphere. Chapman layers and measuring the ultraviolet radiation.

LEARNING OUTCOMES:

After completing the course and passing the exam students are able to:

- **specify the characteristics of the geomagnetic field**
- **define and explain Maxwell equations**
- **interpret physical mechanisms responsible for the existence of the magnetic field and changes of the field**
- **describe changes of the geomagnetic field on both short and long time scales**
- **classify different contributions to the measured magnetic field**
- **collect data from the geomagnetic observatories**

- analyze the measured data **- interpret the characteristics of ions in different magnetosferic layers** **- prepare and hold seminars, discuss the presented topics.**
LEARNING MODE: **Attending lectures, study literature, analyses of examples and practicing, discussion of homeworks.**
TEACHING METHODS: **Lectures, individual and group discussions, set individual tasks, using internet, discussion of examples.**
METHODS OF MONITORING AND VERIFICATION: **Attending lectures. Written and oral exam.**
TERMS FOR RECEIVING THE SIGNATURE: **Attending lectures 70%.**
EXAMINATION METHODS: **Writing (the students may not have to attend writing part of the exam if they successfully complete all mid-term exams) and oral examinations.**
KOLEGIJI PRETHODNICI: **Numerical Methods in Physics (completed)**
COMPULSORY LITERATURE: **Kasumović, M.: Opća and primijenjena geofizika s osnovama sferne astronomije III. dio, PMF, Sveuč. u Zagrebu, 1971.** **Campbell, W.H.: Introduction to Geomagnetic Fields, Cambridge Univ. Press, Cambridge 2003.** **Banks, PM, Kocharts, G.: Aeronomy, Academic Press, London 1980.**

COURSE: **Gravity and Figure of the Earth**	
YEAR OF STUDY: **II.**	
SEMESTER: **3.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **3**	
COURSE OBJECTIVES: **The course prepares students to describe, define and determine the shape of the Earth and the forces on the Earth's surface.**	
COURSE CONTENT: **Forces acting on the Earth's surface. Gravity. General features of the gravitational field. Potential of the gravitational field. Poincare theorem. Potential and the gravitational field due to an ellipsoid of rotation. Clairaut theorem. Geoid. Stokes's formula. Boundary conditions on the geoid surface. Development of the theory of the figure of the Earth. Reduction of the gravity and anomalies. Fundamentals of the theory of isostasy and isostatic reduction of measurements.**	
LEARNING OUTCOMES: **Students will be able to:** **1. state and discuss the elements of the theory of potential** **2. describe the forces on the Earth's surface and explain gravity** **3. explain, numerically demonstrate and discuss normal gravitational field** **4. explain the concept of the geoid** **5. specify the basic theory of isostasy and know how to apply isostatic reduction of measured values.**	
LEARNING MODE: **Listening sessions, study notes and literature, case study, derivation of equations.**	
TEACHING METHODS: **Presentation, discussion, task of equation derivation.**	
METHODS OF MONITORING AND VERIFICATION: **Homeworks, oral exam.**	

TERMS FOR RECEIVING THE SIGNATURE: **Regular attendance to the lectures (at least 70%), homeworks.**
EXAMINATION METHODS: **Oral exam.**
COMPULSORY LITERATURE: **Kaufmann, A.A., R.O. Hansen: Principles of the gravitational method, Elsevier, Amsterdam 2008.** **Lambeck, K.: Geophysical Geodesy, Clarendon Press, Oxford 1988.** **Vaniček, P., E. Krakiwsky: Geodesy, The Concepts, Elsevier, Amsterdam 1986.**

COURSE: **Computation of Adjustments**	
YEAR OF STUDY: **II.**	
SEMESTER: **3.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**1**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **2**	
COURSE OBJECTIVES: **The course prepares students for the application of adjustment calculus of measurements in geophysics.**	
COURSE CONTENT: **Types of errors. Basic theory of random errors. Gauss's law on probability of errors. Estimation of precision of direct observations (measurements). Error equations and normal equations. Errors of adjusted measurements.**	
LEARNING OUTCOMES: **Students will be able to:** **1. expose the theory of random errors** **2. analyze and apply Gauss's law of probability of errors** **3. explain and discuss direct and indirect observations** **4. perform and solve normal equations and errors equations for a set of measurements (the direct and indirect).**	
LEARNING MODE: **Listening sessions, study notes and literature, case study, derivation of equations and problem solving.**	
TEACHING METHODS: **Presentation, discussion, task of equation derivation and solving numerical problems.**	
METHODS OF MONITORING AND VERIFICATION: **Homeworks, written exam.**	
TERMS FOR RECEIVING THE SIGNATURE: **Regular attendance to the lectures (at least 70%), homeworks.**	

EXAMINATION METHODS: **Written exam.**
COMPULSORY LITERATURE: **Vanicek, P.: Introduction to Adjustment Calculus, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Fredericton 1995.** **Feil, L.: Teorija pogrešaka i račun izjednačenja, Geodetski fakultet, Zagreb 1989.**

COURSE: **Geophysical Practicum**	
YEAR OF STUDY: **II.**	
SEMESTER: **3.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**2**
Seminars	**0**
ECTS CREDITS: **3**	

COURSE OBJECTIVES:

Introduce students to the measurements of geomagnetic elements. Implement knowledge about inverse problems to solve the problem of location of earthquake epicentre. Practice determination of fault-plane solution by the graphical method on the basis of first motion polarities.

COURSE CONTENT:

Basis of spherical astronomy. Determination of the horizontal component of the magnetic field and the declination. Lamont and Gauss's positions. Basics of inverse problems. Geiger's method for earthquake location. Graphical method for the fault-plane solution on Schmidt net.

LEARNING OUTCOMES:

Students will be able to:

- **define the geomagnetic elements,**
- **describe methods of measuring the horizontal component of the magnetic field and the magnetic declination,**
- **discuss geomagnetic field measurements data,**
- **describe the method of least squares and conditions for its application to locate the hypocenter of the earthquake,**
- **display the location of the focal point of the earthquake on the basis of seismic waves phase arrival time data at seismic stations,**
- **graphically locate the parameters of seismogenic faults for each earthquake, and describe its properties,**
- **debate which datasets will lead to reliable and unambiguous solutions, which to ambiguous results.**

LEARNING MODE:

Studying literature, listening to presentations, solving homework, discussion of the results of homework, practical work.

TEACHING METHODS: **Presentations, homeworks, use of websites, discussions of homework.**
METHODS OF MONITORING AND VERIFICATION: **Oral exam.**
TERMS FOR RECEIVING THE SIGNATURE: **Attending all practices, preparation of practices and homeworks.**
EXAMINATION METHODS: **Oral discussion of practices.**
KOLEGIJI PRETHODNICI: **Seismology III** **Seismology IV (completed)**
COMPULSORY LITERATURE: **Stein, S. and M. Wysession: An introduction to Seismology, Earthquakes and Earth structure, Blackwell Publ., 2003.** **Lay, T., T. C. Wallace: Modern Global Seismology, Academic Press, San Diego, 1995.** **Udias, A.: Principles of Seismology, Cambridge University Press, United Kingdom, 1999.** **Kasumović, M., Opća i primjenjena geofizika s osnovama sferne astronomije I dio – opća geofizika, PMF Sveučilište u Zagrebu, 1971.** **Kasumović, M., Opća i primijenjena geofizika s osnovama sferne astronomije III dio-opća geofizika, PMF Sveučilište u Zagrebu, 1971.** **Fanselau, G., Geomagnetismus und Aeronomie – Band II, VEB Deutscher Verlag der Wissenschaften, Berlin 1960.**

COURSE: **Weather Analysis and Forecasting I**	
YEAR OF STUDY: **II.**	
SEMESTER: **3.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **3**	

COURSE OBJECTIVES:

The main goal is to teach students about traditional and modern methods for the weather analysis. Knowledge of such kind is necessary for all areas of theoretical and practical meteorology: deployment of measurements, data analysis as well as weather nowcasting and forecasting. In this purpose, it is necessary within this course to:

- **Define and remove errors in the meteorological data**
- **Analyse analytical meteorological materials**
- **Objectively analyse spatially distributed data**
- **Analyse atmospheric pressure systems and associated physical processes**
- **Define and describe the horizontal wind field and vertical motions in the atmosphere**
- **Describe the link between the atmospheric systems and the general atmospheric circulation**
- **Describe and analyse the lee cyclogenesis**
- **Describe the influence of the orography to the weather.**

COURSE CONTENT:

Global Observing System – World Weather Watch. Weather data control. Analytic materials, stressing weather map projections (conic, cylindrical and polar-stereographic). Objective analysis of the weather fields: fitting methods (polynomial and spectral), optimal (statistical) interpolation, successive correction method and variational approach. Isoplet construction technique. Atmospheric systems: air masses, atmospheric fronts (frontogenesis and frontolysis), jet stream including its genetic mechanism, baric circulation systems (cyclone, anticyclone, trough and ridge) including cyclogenesis (cyclolysis), anticyclogenesis (anticyclolysis) and tendencies of constant pressure surface heights. Differential characteristics of wind field, streamlines and trajectories. Vertical atmospheric motion diagnosis. Baric systems within global atmospheric circulation. Lee cyclogenesis, especially on the southern side of the Alps. Humidity field analysis and precipitation amount estimation. Atmospheric systems and the weather. Orographic influences on the weather. Coastal air circulation and the weather.

LEARNING OUTCOMES:

It is expected that after completion of this course, the students should know how to:

- **Recognize random and systematic errors in meteorological data and deploy suitable methods to remove them.**
- **Explain what particular analytical meteorological material represents and what does it mean for the weather**
- **Deploy a suitable objective analysis method to spatially inhomogeneous data**
- **Recognize/distinguish atmospheric pressure systems and associated physical processes and explain how particular pressure system modulates the weather**
- **Explain differential properties of the horizontal wind and its relationship with the vertical motions in the atmosphere**
- **Explain the influence of orography to lee cyclogenesis.**

LEARNING MODE:

Attending teaching of the theory and exercises, studying of the literature and notes, deriving equations and analysis of the examples, independently solving problems.

TEACHING METHODS:

Theory, exercises, encouraging students to explore the literature by themselves, solving the problems independently.

METHODS OF MONITORING AND VERIFICATION:

The progress of students is monitored and evaluated during the course (homework, oral presentations and other assignments) and on the final oral exam.

TERMS FOR RECEIVING THE SIGNATURE:

Homework reports; attending the classes at least for 50 %.

EXAMINATION METHODS:

The oral exam consists of written preparation and its oral presentation/discussion. Here the level of formal adoption of course topics (especially their understanding) is evaluated, observing the professional terminology.

KOLEGIJI PRETHODNICI:

Dynamic Meteorology II, Climatology I

COMPULSORY LITERATURE:

Bluestein, H.B., 1992: Sinoptic-dynamic meteorology in midlatitudes, (Vol. I). Oxford University Press, New York. 431 pp.

Bluestein, H.B., 1993: Sinoptic-dynamic meteorology in midlatitudes, (Vol. II). Oxford University Press, New York. 431 pp.

Daley, R., 1991: Atmospheric data analysis.Cambridge University Press, Cambridge. 457 pp.

Pandžić, K., 2002: Analiza meteoroloških polja i sustava. HINUS, Zagreb. 314 pp.

ADDITIONAL LITERATURE:

Atlas, D., 1990: Radar in meteorology. American Meteorological Society, Boston, 806 pp.

Blumen, 1990: Atmospheric processes over complex terrain. American Meteorological Society, Boston. 323 pp.

Carlson, T.N., 1994: Mid-latitude weather systems. American Meteorological Society, Boston. 507 pp.

Kurz, M., 1998: Synoptic meteorology. Deutscher Wetterdienst, Offenbach. 200 pp.

Palmen, E. and C.W. Newton, 1969: Atmospheric circulation systems – Their structure and physical interpretation. Academic Press, New York. 603 pp.

Petterssen, S., 1956: Weather analysis and forecasting (Vol. I and II). McGraw- Hill, New York, 428 (266) pp.

Radinović, Đ., 1969: Analiza vremena. Univerzitet u Beogradu, Beograd. 367 str.

Saucier, W.J., 1955: Principles of meteorological analysis. The University of Chicago Press, Chicago. 438 pp.

Schott, J.R. 1997: Remote sensing – the image chain approach. Oxford University Press, Oxford. 394 pp.

Zverev, A.S., 1977: Sinoptičeskaja meteorologia. Gidrometeoizdat, Leningrad. 710 pp.

COURSE: **Climatology III**	
YEAR OF STUDY: **II.**	
SEMESTER: **3.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**2**
Seminars	**0**
ECTS CREDITS: **4**	

COURSE OBJECTIVES:

To familiarize student with climatological data, to make him able to analyze climatological time series and interpret the results.

COURSE CONTENT:

Sources of climatological data. Climatological bulletins and atlases. Climatological data on Internet. Nature of climatological series: random and non-random part. Annual cycle, ways of computation and properties. Trend and long-term oscillations. Calculation of climatological normals for real data. Stationary stochastic processes, ergodicity, estimation of the autocorrelation function. Pseudo-random numbers. White noise, general linear process, AR(1), AR(2) processes, higher-order models. Fitting the model to measured data. Simulations of climatological time series.

Exercises comprise the processing and analysis of real time series. This includes writing programs (in Matlab) for analysis and simulation of time series, as well as interpreting the results.

LEARNING OUTCOMES:

To be able to:

- **list and describe the sources of climate data**
- **to explain the nature of climatological time series and identify various time scales**
- **calculate annual cycle and trend**
- **define and explain the notion of stochastic process and stationarity**
- **define white noise and general linear process**
- **define models of autoregression and moving average and interpret their properties in climatological context**
- **fit theoretical stochastic model to real time series and interpret the obtained results.**

LEARNING MODE:

Attending lectures, study of literature and lecture notes, programing, analysis of examples,

solving of assigned problems by using computer, doing homework.
TEACHING METHODS: **Presentation, discussion, problem solving by using computer.**
METHODS OF MONITORING AND VERIFICATION: **Project assignment (writing a computer program and analyzing real data), oral exam.**
TERMS FOR RECEIVING THE SIGNATURE: **Regular attendance to lectures and exercises. Submitted homework.**
EXAMINATION METHODS: **Oral exam.**
KOLEGIJI PRETHODNICI: **Climatology I** **Climatology II (completed)**
COMPULSORY LITERATURE: **Wilks, D.S.: Statistical Methods in the Atmospheric Sciences, Academic Press, New York, 1995.**
ADDITIONAL LITERATURE: **Box G.E.P., G.M. Jenkins: Time Series Analysis: Forecasting and Control, Holden Day, San Francisco, 1970.** **Thompson, R.D., A. Perry: Applied Climatology, Routledge, London, 1997.**

COURSE: **Seminar in Seismology**	
YEAR OF STUDY: **II.**	
SEMESTER: **3. and 4.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**0**
Exercises	**0**
Seminars	**1**
ECTS CREDITS: **2 + 2**	
COURSE OBJECTIVES: **An overview of recent papers dealing with selected chapters of seismology is presented by students to their peers (one presentation per student per semester).**	
COURSE CONTENT: **An overview of recent papers dealing with selected chapters of seismology is presented by students to their peers (one presentation per student per semester).**	
LEARNING OUTCOMES: **After completing the course of the Seminar in Seismology students will:** **– Better read and understand research papers** **– Improve their skills in presenting the research** **– Improve their discussion skills** **– Be able to defend and argue for the research conclusions.**	
LEARNING MODE: **Studying papers and other literature, presenting research, listening to presentations, participation in discussions.**	
TEACHING METHODS: **Students' presentations, discussion, moderation of discussions.**	
METHODS OF MONITORING AND VERIFICATION: **Regular attendance to the lectures.**	
TERMS FOR RECEIVING THE SIGNATURE: **Held presentation.**	
EXAMINATION METHODS:	

Oral presentation.
KOLEGIJI PRETHODNICI: **Seismology III, IV**
COMPULSORY LITERATURE: **Recent seismological research papers, internet pages, etc.** **Numerous web pages.**

COURSE: **Geophysical Seminar**	
YEAR OF STUDY: **II.**	
SEMESTER: **3. and 4.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**0**
Exercises	**0**
Seminars	**1**
ECTS CREDITS: **2 + 1**	
COURSE OBJECTIVES: **The course prepares students for the preparation and presentation of research or scientific topics in the field of geophysics.**	
COURSE CONTENT: **Course provides an opportunity for students to learn about recent research in geophysics both in Croatia and in the world.**	
LEARNING OUTCOMES: **Students will be able to:** **1. learn how to prepare a presentation** **2. show the results of measurements or models** **3. organize public presentation.**	
LEARNING MODE: **Listening to presentations.**	
TEACHING METHODS: **Presentation, discussion.**	
METHODS OF MONITORING AND VERIFICATION: **Regular attending of lectures.**	
TERMS FOR RECEIVING THE SIGNATURE: **Regular attendance (at least 80%) to the lectures.**	
EXAMINATION METHODS: **There is no exam.**	

COURSE: **Geomagnetism and Aeronomy II**	
YEAR OF STUDY: **II.**	
SEMESTER: **4.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **4**	
COURSE OBJECTIVES: **To acquaint students with physical properties of plasma, plasma behavior in the ionosphere and magnetosphere, and processes on the Sun and in interplanetary space that lead to changes in these properties. For this purpose it is necessary to:** **• describe the motion of charged particles in the gravitational, magnetic and electric field,** **• explain the collision processes in ionospheric layers, and other areas of the magnetosphere,** **• define the magnetospheric currents,** **• explain the physics of interactions between Earth and the Sun,** **• explain space weather,** **• analyze the physical processes that generate planetary magnetic fields.**	
COURSE CONTENT: **Physical characteristic of plasma. Movements of charged particles in gravitational, magnetic and electric field. Atmospheric electrodynamic and thermodynamics. Process of collisions in thermosphere and propagation of radio waves. Atomic and molecular processes in ionospheric layers, ionization and photo-dissociation. Atmospheric lightening and sounding of ionosphere. Magnetosphere and processes within it. The solar activity and physics of the Sun-Earth environment. Interplanetary magnetic field. Space weather. Theory of magnetic field origin and modeling the geomagnetic elements. Aeronomy and magnetic fields of Solar system planets.**	
LEARNING OUTCOMES: **After completing the course and pass the exam students are able to:** **• explain physical laws related to the motion of charge particles in gravitational, magnetic and electric field** **• classify collision processes in the ionosphere and magnetosphere** **• define and distinguish different currents within the magnetosphere** **• specify characteristics of the solar activity** **• explain interplanetary magnetic field** **• identify characteristics of the interplanetary magnetic field which drive significant**	

geomagnetic activity

- interpret changes in the ionosphere and magnetosphere governed by physical characteristic in the interplanetary space
- apply the acquired knowledge in understanding the basic features of mother planets magnetic fields
- prepare and hold seminars, discuss the presented topics.

LEARNING MODE:

Attending lectures, study literature, team analyses of the real, measured values, discussion of results obtained by solving individual and team tasks, preparation of seminars.

TEACHING METHODS:

Lectures, individual and group discussions, set individual and team tasks, using internet, discussion of examples.

METHODS OF MONITORING AND VERIFICATION:

Monitoring class attendance. Written and oral examination.

TERMS FOR RECEIVING THE SIGNATURE:

Attending lectures 70%.

EXAMINATION METHODS:

Writing (the students may not have to attend writing part of the exam if they successfully complete all mid-term exams) and oral examinations.

KOLEGIJI PRETHODNICI:

Geomagnetism and Aeronomy I (completed)

COMPULSORY LITERATURE:

Vršnak, B.: Temelji fizike plazme, Školska knjiga, Zagreb 1996.

Backus, G., Parker, R., Constable, C.: Foundations of Geomagnetism, Cambridge Univ. Press, Cambridge 2003.

Jacobs, J.A.: The Earth's Core, Academic Press, London 1987.

Chamberlain, J.W.: Theory of Planetary Atmospheres, Academic Press, London 1978.

COURSE: **Seismotectonics**	
YEAR OF STUDY: **II.**	
SEMESTER: **4.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **4**	
COURSE OBJECTIVES: **To learn about recent tectonic activity, classification of structures and faults within seismo-tectonic activity. Use of knowledge in engineering (construction of large scale buildings, bridges, tunnels, hydro and power plants) and spatial planning.**	
COURSE CONTENT: **Research methods. Regional tectonic movements. Classification of structures and faults. Types of structures (examples). Relation between stress and deformation of structures. Seismogene structures. Underthrusting, reverse, normal, transform and transcurrent displacement. Seismotectonic active faults. Structural relations in space, marker horizons. Earthquakes and zones of occurrence. Tectonical causes of earthquakes. Energetic, spatial and temporal characteristics of earthquakes. Epicentral areas. Seismic sources. Effects of seismic forces at the surface. Non-seismic evolvement.**	
LEARNING OUTCOMES: **After successful completion of the course, student would be able:** **1) To describe the basics of seismotectonics along the major plate boundaries, in active orogenic belts and in plate interior** **2) To describe the basics of seismotectonics along the Adriatic plate boundary and in the Pannonian basin of Croatia** **3) To conduct a seismotectonic analysis of selected area by synthesis of geophysical, geological and seismological data** **4) To recognize potential seismogenic structures based on seismotectonic analysis of surface and subsurface, with definition of their arrangement, orientation and kinematic characteristics** **5) To write a report on seismotectonic analysis of selected area.**	
LEARNING MODE: **Regular class attendance.**	

TEACHING METHODS:

Lectures, exercises, practical work, oral exam.

TERMS FOR RECEIVING THE SIGNATURE:

Attending lectures 70%, correctly designed and submitted programs.

EXAMINATION METHODS:

Oral exam.

COMPULSORY LITERATURE:

Uyeda, S. (1979): The New View of the Earth. Freeman and Co. New York.

Moores, M. E. & Twiss, J. T. (1999): Tectonics. Freeman and Co., New York.

Balt, B. A. (1999): Earthquakes. Freeman and Co., New York.

Keller, E. & R Pinter, N. (2002): Active Tectonics, Earthquakes, Uplifts and Landscape. Prentiuc Will New York.

RGN university and Department of Geiphysics PMF (1990): Seismotectonic map of Croatia.

COURSE: **Weather Analysis and Forecasting II**	
YEAR OF STUDY: **II.**	
SEMESTER: **4.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **4**	

COURSE OBJECTIVES:

The main goal is to teach students about traditional and modern methods for the weather analysis. Knowledge of such kind is necessary for all areas of theoretical and practical meteorology: deployment of measurements, data analysis as well as weather nowcasting and forecasting. In this purpose, it is necessary within this course to:

- **Define and describe subjective and objective methods of weather forecasting**
- **Describe the hydrodynamic equations in different coordinate systems**
- **Define and describe numerical methods for numerical solving of hydrodynamic equations**
- **Define and describe the operation principle of particular atmospheric numerical models**
- **Describe and define special weather forecasts**
- **Define and describe methods for verification of weather forecasts.**

COURSE CONTENT:

Subjective way of weather forecasting. Objective methods of weather forecasting: deterministic, stochastic and deterministic-stochastic approach. The governing equations of the atmosphere in different co-ordinate systems (generalised, spherical, tangential and map projections). Review of numerical methods for solving the governing equations: method of final differences and function expansion into series (spectral and final elements). Non-linear numerical nonstability and filtering (low-pass and bandpass filters). Initialisation of numerical models: equilibrium equations, normal modes, 4-dimensional variational analysis. Boundary conditions. Barotropic limited area model in conic map projection. Six-layer hemispheric forecasting model with primitive equations. Global spectral model of the European Centre for Medium Range Weather Forecasts (ECMWF). Introducing with the regional models ALADIN (Aire Limitee Adaptation et Development International) and HIRLAM (High Resolution Limited Area Modelling). Stochastic (regression) approach to the weather forecasting. Analogy method. Deterministic-stochastic approach: atmospheric predictability, ensemble forecasts. Subjective interpretation of the prognostic model outputs. Regression way of interpretation (Method output Statistic, perfect Prognosis). Adaptive deterministic models (e.g. adaptation of air

flow to the orography). Forecasts for special applications. Verification of the forecasts.

LEARNING OUTCOMES:

It is expected that after completion of this course, the students should know how to:

- **Explain the meaning of individual terms in hydrodynamic equations with respect to coordinate systems**
- **Numerically solve the system of differential equations**
- **Compare and contrast the meaning of the output of numerical models and the meaning of the analytical material**
- **Make the subjective and the objective weather forecast**
- **Distinguish between special and standard weather forecasts.**

LEARNING MODE:

Attending teaching of the theory and exercises, studying of the literature and notes, deriving equations and analysis of the examples, independently solving problems.

TEACHING METHODS:

Theory, exercises, encouraging students to explore the literature by themselves, solving the problems independently.

METHODS OF MONITORING AND VERIFICATION:

The progress of students is monitored and evaluated during the course (homework, oral presentations and other assignments) and on the final oral exam.

TERMS FOR RECEIVING THE SIGNATURE:

Homework reports; attending the classes at least for 50 %.

EXAMINATION METHODS:

The oral exam consists of written preparation and its oral presentation/discussion. Here the level of formal adoption of course topics (especially their understanding) is evaluated, observing the professional terminology.

KOLEGIJI PRETHODNICI:

Weather Analysis and Forecasting I (completed)

COMPULSORY LITERATURE:

Haltiner, G.J. and R.T. Williams, 1980: Numerical weather prediction. John Wiley & Sons, New York. 477 pp.

Kalney, E., 2003: Atmospheric modeling, data assimilation and predictability. Cambridge University Press, Cambridge. 341 pp.

Mesinger, F. and A. Arakawa, 1976: Numerical models in atmospheric models. Volume I. GARP Publication Series No. 17, WMO, Geneve. 135 pp.

Pielke R.A. and R.P. Pearce, 1994: Mesoscale modeling of the atmosphere. American

Meteorological Society, Boston. 167 pp.

Radinović, Đ., 1979: Prognoza vremena. Univerzitet u Beogradu. Beograd. 266 str.

Zdunkowski, W. and A. Bott, 2003: Dynamics of the atmosphere – A course in theoretical meteorology. Cambridge University Press, Cambridge. 719 pp.

ADDITIONAL LITERATURE:

Haltiner, G.J., 1971: Numerical weather prediction. John Wiley & Sons, New York, 317 pp.

Houghton, D.D, 1985: Handbook of applied meteorology. John Wiley & Sons, New York, 1461 pp.

Petterssen, S., 1956: Weather analysis and forecasting (Vol. I and II). McGraw- Hill, New York, 428 (266) pp.

Richardson, L.F., 1922: Weather prediction by numerical process. Cambridge University Press, London, 236 pp.

Riley, M.P., Hobson, M.P. and S.J. Bence, 1998: Mathematical methods for physics and enginering. Cambridge University Press, Cambridge, 1008 pp.

Zverev, A.S., 1977: Sinoptičeskaja meteorologia. Gidrometeoizdat, Leningrad, 710 pp.

COURSE: **Fundamentals of Geophysical Exploration II** ***(optional)***	
YEAR OF STUDY: **II.**	
SEMESTER: **3.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**2**
Seminars	**0**
ECTS CREDITS: **4**	

COURSE OBJECTIVES:

Introduction to the methods of geophysical research and their application in defining the geological structure and composition of terrain: in exploration of hydrocarbons and solid mineral resources, in geotechnical researches, groundwater and environmental studies.

COURSE CONTENT:

Lectures :
Seismic research – Introduction. Seismic wave spreading. Time-distance graph for a layered medium. Instruments and equipment: seismic sources, seismometers seismographs. Seismic Refraction: measuring and data processing, interpretation methods, difficulties in interpretation, application of refraction methods.
Seismic reflection: seismic velocity measuring, data processing, static, NMO, and residual corrections, velocity analysis. Interpretation of seismic profiles, migration Application of seismic reflection methods.
Geophysical research in boreholes – introduction to logging methods, electrical properties of rocks and formation factor. Distribution of liquids and resistivity in permeable layer. Self-potential (SP) logging. Resistivity logging: normal and lateral logs, focused current logs, microlog, induction log. Sonic logging, other logging methods: temperature logging, caliper logging, dipmeter logging.

Exercises:
Introduction. Defining 4 exercises. Explanations related to preliminary exams and field work.
Geoelectrical profiling - Introduction. Calculation of resistivity on profiles. Interpretation of lateral resistivity changes.
Seismic Refraction – Introduction. First arrivals on seismograms. Calculation of average 3 velocity for each layer, calculation of layers depths and inclination.v
Seismic reflection – Introduction. Estimating velocoties from first arrivals and selected reflexes. Diagram of seismic velocites. Calculation of NMO correction. Interpretation of seismic reflection profile.
Resistivity logging - measuring normal and lateral logs in the borehole model. Working in

teams. Measuring normal and lateral logs in the borehole model. Working in teams. Measuring normal and lateral logs in the borehole model. Working in teams. Measuring normal and lateral logs in the borehole model. Working in teams. Measuring normal and lateral logs in the borehole model. Working in teams. Calculating resistivity for borehole model. Interpretation of resistivity curve. Determination of layer boundaries and depths in model.
Field work – Measuring using seismic refraction and reflection methods. Geological and geophysical interpretation.

LEARNING OUTCOMES:

To understand creation and spreading of seismic waves, to interpret seismic profile using seismic refraction method, to understand the application of static and NMO corrections, to interpret seismic profile using seismic reflection method, to understand the operation of a seismometer and seismograph. To understand the logging methods in borehole geophysical explorations, to interpret resistivity distribution diagram on the borehole model.

TEACHING METHODS:

Lectures, exercises, practical and field work.

METHODS OF MONITORING AND VERIFICATION:

Regular attendance of lectures, practical work, preliminary exams, oral exams.

TERMS FOR RECEIVING THE SIGNATURE:

Class attendance (lectures, exercises and field work), handed solved exercises, passed at least one preliminary exam.

EXAMINATION METHODS:

Passed preliminary exams or oral exam (80%), solved exercises (20%).

KOLEGIJI PRETHODNICI:

Fundamentals of Geophysical Exploration I

COMPULSORY LITERATURE:

Šumanovac, F. (2012): Osnove geofizičkih istraživanja, Sveučilište u Zagrebu.

ADDITIONAL LITERATURE:

Griffits, D.H. & King, R.F. (1981): Applied Geophysics for Engineers and Geologists, Pergamon Press, Oxford.

Parasnis, D.S. (1986): Principles of Applied Geophysics, Chapman and Hall, New York.

<table>
<tr><td colspan="2">COURSE: Hydrology I (optional)</td></tr>
<tr><td colspan="2">YEAR OF STUDY: II.</td></tr>
<tr><td colspan="2">SEMESTER: 3.</td></tr>
<tr><td>TEACHING METHODS:</td><td>CONTACT HRS PER WEEK</td></tr>
<tr><td>Lectures</td><td>2</td></tr>
<tr><td>Exercises</td><td>1</td></tr>
<tr><td>Seminars</td><td>0</td></tr>
<tr><td colspan="2">ECTS CREDITS: 4</td></tr>
<tr><td colspan="2">COURSE OBJECTIVES:
Students will become acquainted with basic hydrological and hydraulic characteristics of runoff from the basin. It is the aim of the course to train students to do hydrological calculations.</td></tr>
<tr><td colspan="2">COURSE CONTENT:
Definition of hydrology and its connection with other sciences. Hydrological cycle. History, development, tasks and applicatin of hydrology. Estimated amounts of water on the Earth. Mean annual precipitation on a basin. PDF and IDF curves and their application in hydrology. Evaporation from water surface and evapotranspiration. Infiltration and humidity in the ground.
Hydraulics of open channels: application of Bernouly equation for ideal and real liquid, uniform flow, Chezy formula, Manning-Strickler formula, measuring equipment, spillways, ununiform flow. Filtration: Darcy's law, Dupuit's theory.</td></tr>
<tr><td colspan="2">LEARNING OUTCOMES:
It is expected that after completion of the course students should know:
• explain the historical development, application and significance of hydrology and its links with geophysics,
• make a subjective and an objective analysis of the amount of water on Earth,
• explain the terms evapotranspiration and infiltration,
• know the basics of hydraulics of open streams, Darcy's law and Dupuit's assumption.</td></tr>
<tr><td colspan="2">LEARNING MODE:
Attendance of lectures.</td></tr>
<tr><td colspan="2">TEACHING METHODS:
Lectures, exercises.</td></tr>
</table>

METHODS OF MONITORING AND VERIFICATION: **Colloquium, oral exam.**
TERMS FOR RECEIVING THE SIGNATURE: **Regular attendance of lectures.**
EXAMINATION METHODS: **Oral exam.**
COMPULSORY LITERATURE: **Žugaj, R.: HIDROLOGIJA textbook, Sveučilište u Zagrebu, Rudarsko-geološko-naftni fakultet, Zagreb, 2000.**

COURSE: **Physical Meteorology I** ***(optional)***	
YEAR OF STUDY: **II.**	
SEMESTER: **3.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **4**	
COURSE OBJECTIVES: **An introduction to processes of radiation, absorption, reflection and diffusion in the system Earth-atmosphere will be given.**	
COURSE CONTENT: **Sun and Earth radiation processes. Solar radiation extinction in the atmosphere. Measurement and estimation of direct, diffuse and global solar radiation. Radiation modelling.**	
LEARNING OUTCOMES: **After completion of the course the students will be able to:** **1. Explain and derive the laws of radiation** **2. Explain the processes of solar radiation attenuation in the atmosphere** **3. Apply and compare methods for calculation and estimation of solar radiation components** **4. Describe and apply deterministic and stochastic models of radiation.**	
LEARNING MODE: **Listening lectures, studying notes and available literature, case study and solving problems through exercises.**	
TEACHING METHODS: **Presentation with discussion, independently solving of tasks with real data, directing student on independent study of literature and seminar work presentation.**	
METHODS OF MONITORING AND VERIFICATION: **Colloquiums, written and oral exam.**	
TERMS FOR RECEIVING THE SIGNATURE:	

Presented seminar.
EXAMINATION METHODS: **Written (students which successfully pass the colloquiums are released from written exam) and oral exam.**
KOLEGIJI PRETHODNICI: **Climatology 1**
COMPULSORY LITERATURE: **Coulson, K.L.: Solar and Terrestrial Radiation, Academic Press, New York 1975.** **Selby M.L.: Fundamentals in Atmospheric Physics. Academic Press 1996.**

COURSE: **Seminar in Dynamic Meteorology**	
YEAR OF STUDY: **II.**	
SEMESTER: **3. and 4.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**0**
Exercises	**0**
Seminars	**1**
ECTS CREDITS: **3 + 2**	
COURSE OBJECTIVES: **Deepening knowledge of the midlatitude large scale dynamics. Expanding knowledge of mesoscale and microscale dynamics and turbulence. The focus is on the student's choice of the problem. The aim is to focus students on the selection of the high quality research topic in the field of dynamic meteorology. Students are prepared for the public presentation of scientific hypotheses, methods and results analysis.**	
COURSE CONTENT: **Structures of midlatitude large-scale perturbations. Mesoscale cyclones. Buoyancy waves. Atmospheric boundary layer. Turbulent kinetic energy prediction. Spectral description of turbulence. Transport and diffusion in the atmosphere.**	
LEARNING OUTCOMES: **It is expected that after the completion of this course, the students may:** • **Critically analyze and compare methods and results of the scientific work done by scientists.**	
LEARNING MODE: **Attendance of seminars given by others, critical studying of the literature, participating in discussions.**	
TEACHING METHODS: **Referring students to independently study the literature, individual presentation (seminar), consultative sessions.**	
METHODS OF MONITORING AND VERIFICATION: **Regularly and actively participate in the seminar. Presentation of their own essay on a selected topic.**	

TERMS FOR RECEIVING THE SIGNATURE: **Individual presentation (seminar).**
EXAMINATION METHODS: **No exam.**
KOLEGIJI PRETHODNICI: **Dynamic Meteorology II, Climatology I**
COMPULSORY LITERATURE: **Holton, J. R., 2004: An introduction to dynamic meteorology. Elsevier Academic Press, Amsterdam, 535 str.** **Stull, R.B.: An Introduction to Boundary Layer Meteorology, Kluwer, Dordrecht, 1988**
ADDITIONAL LITERATURE: **Numerous web sites and ECMWF courses.**

COURSE: **Seminar in Climatology**	
YEAR OF STUDY: **II.**	
SEMESTER: **3. and 4.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**0**
Exercises	**0**
Seminars	**1**
ECTS CREDITS: **3 + 2**	
COURSE OBJECTIVES: **The course prepares students for research in the field of climatology, for preparation and presentation of research results.**	
COURSE CONTENT: **Student is required to study on his/her own a given topic from climatology. Topics are taken from scientific papers as well as from monographs. One problem per semester should be analyzed and presented, giving the motivation, results and conclusions. During discussions with teacher and other participants the knowledge acquired previously is deepened.**	
LEARNING OUTCOMES: **Students will be able to:** **1. autonomously design, conduct and evaluate a small original research project using appropriate scientific methods and analytical methodologies** **2. organize and give a public presentation.**	
LEARNING MODE: **Listening sessions.**	
TEACHING METHODS: **Presentation, discussion.**	
METHODS OF MONITORING AND VERIFICATION: **Attending of lectures, writing reports and oral presentation of two seminars.**	
TERMS FOR RECEIVING THE SIGNATURE: **Regular attendance to the lectures (at least 80%), writing and oral presentation of two seminars.**	

EXAMINATION METHODS: **No exam.**
KOLEGIJI PRETHODNICI: **Climatology I** **Climatology II (completed)**
COMPULSORY LITERATURE: **Relevant scientific journals, monographs and sources from Internet.**

COURSE: **Seminar in Weather Analysis and Forecasting**	
YEAR OF STUDY: **II.**	
SEMESTER: **3. and 4.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**0**
Exercises	**0**
Seminars	**1**
ECTS CREDITS: **3 + 2**	
COURSE OBJECTIVES: **Expanding the knowledge about the dynamics of the atmosphere on large scales in mid-latitude. The aim is to motivate the students to select an advanced research topic in the field of weather analysis and forecasting. Students prepare for the public presentation of scientific hypotheses, methods and results of the analysis.**	
COURSE CONTENT: **The teacher recommends to the students a topic for the seminar paper related to the weather analysis and provides appropriate literature. The topic should be related with operational meteorology as it is possible. The topics related with Croatian territory have some priorities (e.g. Mediterranean cyclones) or the topics devoted to special applications e.g. in aeronautical and marine meteorology.**	
LEARNING OUTCOMES: **It is expected that after completion of this course, the students should know how to:** • **Critically analyze and compare methods and results of scientific work obtained by different authors.**	
LEARNING MODE: **Attending weekly seminars, critical studying of the literature, participate in the discussions**	
TEACHING METHODS: **Independent exploration of the literature, consultations with the teacher.**	
METHODS OF MONITORING AND VERIFICATION: **Students are obligatory to attend weekly seminars.** **Active engagement during the course. Oral presentation of the seminar work on selected topic.**	

TERMS FOR RECEIVING THE SIGNATURE:

Preparation and oral presentation of the seminar work on selected topic.

EXAMINATION METHODS:

No exam.

KOLEGIJI PRETHODNICI:

Dynamic Meteorology II, Climatology I

COMPULSORY LITERATURE:

Bluestein, H.B., 1992: Sinoptic-dynamic meteorology in midlatitudes, (Vol. I). Oxford University Press, New York, 431 pp.

Bluestein, H.B., 1993: Sinoptic-dynamic meteorology in midlatitudes, (Vol. II). Oxford University Press, New York, 431 pp.

Daley, R., 1991: Atmospheric data analysis.Cambridge University Press, Cambridge, 457 pp.

Haltiner, G.J. and R.T. Williams, 1980: Numerical weather prediction. John Wiley & Sons, New York, 477 pp.

Kalney, E., 2003: Atmospheric modeling, data assimilation and predictability. Cambridge University Press, Cambridge, 341 pp.

Mesinger, F. and A. Arakawa, 1976: Numerical models in atmospheric models. Volume I. GARP Publication Series No. 17, WMO, Geneve, 135 pp.

Pandžić, K., 2002: Analiza meteoroloških polja i sustava. HINUS, Zagreb, 314 pp.

Pielke R.A. and R.P. Pearce, 1994: Mesoscale modeling of the atmosphere. American Meteorological Society, Boston, 167 pp.

Radinović, Đ., 1979: Prognoza vremena. Univerzitet u Beogradu. Beograd, 266 str.

Zdunkowski, W. and A. Bott, 2003: Dynamics of the atmosphere – A course in theoretical meteorology. Cambridge University Press, Cambridge, 719 pp.

ADDITIONAL LITERATURE:

Atlas, D., 1990: Radar in meteorology. American Meteorological Society, Boston, 806 pp.

Blumen, 1990: Atmospheric processes over complex terrain. American Meteorological Society, Boston, 323 pp.

Carlson, T.N., 1994: Mid-latitude weather systems. American Meteorological Society, Boston, 507 pp.

Kurz, M., 1998: Synoptic meteorology. Deutscher Wetterdienst, Offenbach, 200 pp.

Palmen, E. and C.W. Newton, 1969: Atmospheric circulation systems – Their structure and physical interpretation. Academic Press, New York, 603 pp.

Petterssen, S., 1956: Weather analysis and forecasting (Vol. I and II). McGraw-Hill, New

York, 428 (266) pp.

Radinović, Đ., 1969: Analiza vremena. Univerzitet u Beogradu, Beograd, 367 str.

Richardson, L.F., 1922: Weather prediction by numerical process. Cambridge Unuversity Press, London, 236 pp.

Saucier, W.J., 1955: Principles of meteorological analysis. The University of Chicago Press, Chicago, 438 pp.

Schott, J.R. 1997: Remote sensing – the image chain approach. Oxford University Press, Oxford. 394 pp.

Zverev, A.S., 1977: Sinoptičeskaja meteorologia. Gidrometeoizdat, Leningrad, 710 pp.

COURSE: **Seminar in Physical Oceanography**	
YEAR OF STUDY: **II.**	
SEMESTER: **3. and 4.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**0**
Exercises	**0**
Seminars	**1**
ECTS CREDITS: **3 + 2**	
COURSE OBJECTIVES: **The course prepares students to follow the scientific literature, to present results of investigation in written form, and to present results of investigation in oral form.**	
COURSE CONTENT: **After an introductory lecture each student considers two physical oceanographic topics. The topics are selected from the papers recently published in scientific journals or from the monographs. Results of his/her study the student describes in writing and orally, paying attention to development of the problem, results of data analysis and/or mathematical modeling and main conclusions. Discussion with the teacher and other students enables the student to deepen the knowledge gained while attending the lectures and exercises during the previous years of study.**	
LEARNING OUTCOMES: **Students will be able to** **1. identify scientific texts that are needed to perform the investigation,** **2. analyze the selected scientific texts,** **3. present results of scientific work in written form, and** 4. **present results of scientific work in oral form.**	
LEARNING MODE: **Study of the selected scientific texts, writing of seminar essays, and oral presentation of the essays.**	
TEACHING METHODS: **Presentation and discussion, commenting on the seminar essays, and discussion of the oral presentations.**	
METHODS OF MONITORING AND VERIFICATION:	

Attending the seminars, writing and presenting two seminar essays.
TERMS FOR RECEIVING THE SIGNATURE: **Preparation of two seminar papers and presentation of two seminar lectures.**
EXAMINATION METHODS: **No exam.**
KOLEGIJI PRETHODNICI: **Dynamics of Coastal Sea**
ADDITIONAL LITERATURE: **Papers recently published in scientific journals.** **Monographs.**

COURSE: **Hydrology II** ***(optional)***	
YEAR OF STUDY: **II.**	
SEMESTER: **4.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **4**	

COURSE OBJECTIVES:

Students will become acquainted with basic hydrological properties of runoff from the basin. It is the aim of the course to train students to do hydrological calculations.

COURSE CONTENT:

Properties of hydrological occurrences, hydrological data, basin, runoff factors. Hydrometry: measurements of water level, velocity, water and sediment discharge. Stage hydrograph, discharge curve, hydrograph and its component parts, frequency curves and water level and discharge curves, runoff coefficient and specific discharge from a basin.
Probability and statistics in hydrology. Linear and nonlinear correlation, double mass amounts.
High waters: distribution curves, unit hydrograph, triangle-shaped hydrograph, isochrone method. Rational formula and other empirical formulas. Low waters of various return periods, periods of low water and of hydrological drought. Sedimentation in watercourses. General equation of hydrological balance. Regional hydrological analysis.

LEARNING OUTCOMES:

It is expected that after completion of the course students should know:
- **explain the features of hydrological phenomena,**
- **be familiar with the most important aspects of hydrometry,**
- **learn the application of probability and statistics in hydrology,**
- **distinguish between large and small water and know their characteristics,**
- **apply the regional hydrological analysis.**

LEARNING MODE:

Attendance of lectures.

TEACHING METHODS:

Lectures, exercises, colloquium, oral exam.

METHODS OF MONITORING AND VERIFICATION: **Regular attendance of lectures, colloquium, oral exam.**
TERMS FOR RECEIVING THE SIGNATURE: **Regular attendance of lectures.**
EXAMINATION METHODS: **Oral exam.**
COMPULSORY LITERATURE: **Žugaj, R.: HIDROLOGIJA textbook, Sveučilište u Zagrebu, Rudarsko-geološko-naftni fakultet, Zagreb, 2000.**

COURSE: **Physical Meteorology II** ***(optional)***	
YEAR OF STUDY: **II.**	
SEMESTER: **4.**	
TEACHING METHODS:	CONTACT HRS PER WEEK
Lectures	**2**
Exercises	**1**
Seminars	**0**
ECTS CREDITS: **4**	

COURSE OBJECTIVES:

An introduction in optical and acoustical atmospheric phenomena, the physics and modelling of cloud and precipitation formation and feasibilities of artificial influence on weather will be given.

COURSE CONTENT:

Optical and acoustic phenomena in the atmosphere. Physics of clouds and precipitation. Artificial weather modification. Radars and the radar equation. Cloud and precipitation formation modelling by numerical weather models.

LEARNING OUTCOMES:

After completion of the course the students will be able to:

1. **Explain conditions and modes of genesis of optical and acoustic phenomena in the atmosphere;**
2. **Define processes of cloud and precipitation formation;**
3. **Explain the ways of artificial weather modification;**
4. **Describe radar and the radar equation and**
5. **Explain the principles of cloud and precipitation genesis in the numerical weather models.**

LEARNING MODE:

Listening lectures and exercises, studying notes and available literature, deriving equations and solving problems through exercises.

TEACHING METHODS:

Presentation with discussion, independently solving of tasks with real data, directing student on independent study of literature and seminar work presentation.

METHODS OF MONITORING AND VERIFICATION:

Colloquiums, written and oral exam.
TERMS FOR RECEIVING THE SIGNATURE: **Presented seminar.**
EXAMINATION METHODS: **Written (students which successfully pass the colloquiums are released from written exam) and oral exam.**
KOLEGIJI PRETHODNICI: **Dynamic Meteorology II**
COMPULSORY LITERATURE: **Rogers R.R. and Yau, M.K.: A Short Course in Cloud Physics, Pergamon Press, 1989 (3rd ed.)** **Mason, B.J.: The Physics of Clouds. Clarendon Press, Oxford, 1971.**

List of all the changes that have been made since 2005 in the graduate academic study of physics-geophysics

Changes made to the above study program can be divided into the following groups:

1. Change of teachers on courses (45508) Climatology I, (45521) Climatology II, (45517) Planetology, (45522) Meteorological Practicum, (45524) Geomagnetism and Aeronomy I, (45536) Geomagnetism and Aeronomy II, (45531) Geophysical Practicum, (45540) Seismotectonics, (45571) Physical Meteorology I, (45573) Physical Meteorology II, (45543) Climatology III, (45566) Seminar in Dynamic Meteorology, (45522) Meteorological Practicum, (45563, 45567) Seminar in Climatology, (45516) General and Anorganic Chemistry, (45544) Weather Analysis and Forecasting I, (45545) Weather Analysis and Forecasting II, (45564, 45568) Seminar in Weather Analysis and Forecasting, (45525) Gravity and Figure of the Earth, (53596) Computation of Adjustments, (45510, 45511) Numerical Methods in Physics (due to a teachers retirement, due to the reduction of teachers teaching hours or due to teachers election to a new scientific-educational/teaching professional position).

2. Introduction of a new optional courses (63391) Selected Chapters of Meteorology and (66352) Fundamentals of Atmospheric Modelling (due to the appreciation of new insights from a broad field of meteorology and the small number of elective courses in the first year of graduate study of physics-geophysics, and to provide the best quality education to our students).

3. Changing the name of courses (45544, 45545) Synoptic Meteorology I and II to Weather Analysis and Forecasting I and II and (45564, 45568) Seminar in Synoptic Meteorology to Seminar in Weather Analysis and Forecasting, without changing the content of courses.

4. Minor change in the course (45522) Meteorological Practicum program with the aim of introducing modern knowledge about the collection, processing and exchange of meteorological information according to the World Meteorological Organization.