Atmospheric Physics, Meteorology and Climatology

Coordinated by: Department of Atmospheric Physics
Study programme coordinator: doc. RNDr. Petr Pišoft, Ph.D.

Characterization of the study program:

The 'Atmospheric Physics, Meteorology and Climatology' program leads students to acquire knowledge and skills in the field of atmospheric properties and the related processes. Within the framework of Charles University, this program is unique in its comprehensive view of the Earth's atmosphere as a dynamical system of in a broad interdisciplinary context. Even within the Czech Republic this is the only program providing full-scale education in the field of atmospheric physics, meteorology and climatology. The program follows from the bachelor's study of physics, in which students acquire necessary knowledge of basic physical principles (mechanics, thermodynamics, electricity and magnetism, optics and others) as well as of proficiency in related mathematical methods. The elements of the study program are primarily focused on acquiring theoretical knowledge in the field of atmospheric physics (hydrodynamics and atmospheric thermodynamics), thus extending previously acquired expertise in this field. Furthermore, skills necessary for practical as well as scientific activities in the field of atmospheric physics are acquired during the study, especially in the field of numerical mathematics, mathematical statistics, data processing and visualization. Part of the course aims to prepare graduates for basic applications of the atmospheric physics, such as weather forecasting, air pollution analysis and climate research (including modelling and research of higher atmospheric layers). Other subjects of the program serve to deepen the student's focus in particular specialized topics or to expand knowledge in areas close to other physical disciplines (e.g., electrical, optical and acoustic phenomena in the atmosphere or the oceans). As a part of the study, a master-level diploma thesis is prepared and submitted, in which the application of competences acquired during the study is demonstrated, as well as ability to cooperate in solving the assigned scientific problem.

Profile of the graduates and aims of the study:

Graduates have a wide range of knowledge and competencies in the whole field of atmospheric physics, meteorology and climatology. Their skills allow for professional focus on basic and applied research as well as involvement in the commercial sector. Graduates have a broad perspective of career, for example, in the academia, in research institutes and at universities, as well as in industrial development centres focused on flow studies. In the business environment they are able to apply expert knowledge of statistical techniques, in the field of crisis management they can utilize their acquaintance with extreme meteorological phenomena. They can also find employment in a number of economic sectors influenced by atmospheric phenomena such as energetics, transportation or agriculture.

Graduates have extensive and comprehensive knowledge of atmospheric physics, dynamics and thermodynamics of the atmosphere, atmospheric circulation at all spatial scales, problems of electromagnetic and acoustic waves in atmospheric environment, theory of hydrodynamic wave processes, theory of non-linear dynamic systems, structure and development of the climate system, natural and anthropogenic climatic changes. They are familiar with contemporary methods of remote sensing (meteorological radars, lidars, sodars and satellites). They are able to process extensive and complex meteorological and climatological data files and are closely acquainted with mathematical statistics and the relevant IT applications.

Recommended plan of the study

A pre-requisite of the study in this program is knowledge of general physics, hydrodynamics, propagation of acoustic and electromagnetic waves in atmosphere, general climatology, synoptic meteorology and deterministic chaos on the Bachelor level.

First year of the of the Master study

Code	Subject	Credits	Winter	Summer
NMET074	**Atmospheric Dynamics**	6	3/2 C+Ex	—
NMET002	**Boundary Layer Physics**	5	3/1 C+Ex	—
NMET020	**Methods of atmospheric remote sensing**	5	3/1 C+Ex	—
NMAF013	**Methods of Numerical Mathematics I**	3	2/0 Ex	—
NMET036	**Synoptic Meteorology II**	4	3/0 Ex	—
NMET078	**Analysis and interpretation of weather maps and prognostic fields**	6	—	3/2 MC
NMET003	**Physics of Clouds and Precipitation**	4	—	3/0 Ex
NMET010	**Climate change and its causes**	4	—	2/1 C+Ex
NMET067	**Stratosphere**	5	—	2/2 C+Ex
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NMET024	Dynamical forecast methods	7	—	3/2 C+Ex
NMET009	Regional Climatology and Climatography of the Czech Republic	6	4/0 Ex	—
NMET011	Statistical Methods in Meteorology and Climatology	6	2/2 C+Ex	—
NMET075	Climate extremes and their modelling	3	—	2/0 Ex
NMET066	Meteorological Computer Seminar	4	—	0/3 C
NMET079	Methods of atmospheric remote sensing II	3	—	1/1 C+Ex
NMAF014	Methods of Numerical Mathematics II	6	—	2/2 C+Ex
NMET063	Time Series Processing Methods	5	—	2/1 C+Ex
NMET025	Wave Motions and Energetics of the Atmosphere	4	—	3/0 Ex

Second year of the of the Master study

Code	Subject	Credits	Winter	Summer
NMET019	**Atmospheric Chemistry**	5	3/1 Ex	—
NMET061	**Seminar on Projects I**	3	1/1 C	—

NMET062	**Seminar on Projects II**	3	—	1/1 C
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C
NMET064	Aerosol Engineering	3	2/0 Ex	—
NMET031	Mesosynoptic meteorology	3	2/0 Ex	—
NMET068	Oceans in Climate System	6	2/2 C+Ex	—
NMET005	Emission Propagation in Atmosphere	3	2/0 Ex	—
NMET059	Modelling Techniques for Numerical Weather Forecasting	3	0/2 C	—
NMET032	Atmospheric Turbulence	4	3/0 Ex	—
NMET071	Applied Climatology I	3	2/0 Ex	—
NMET001	Atmospheric electricity	3	—	2/0 Ex
NMET073	Strong convection in the atmosphere	5	—	3/1 C+Ex
NMET072	Applied climatology II	3	—	2/0 Ex

List of courses

319 (P) Atmospheric Physics, Meteorology and Climatology - Obligatory courses

Code	Subject	Credits	Winter	Summer
NMET074	**Atmospheric Dynamics**	6	3/2 C+Ex	—
NMET002	**Boundary Layer Physics**	5	3/1 C+Ex	—
NMET020	**Methods of atmospheric remote sensing**	5	3/1 C+Ex	—
NMAF013	**Methods of Numerical Mathematics I**	3	2/0 Ex	—
NMET036	**Synoptic Meteorology II**	4	3/0 Ex	—
NMET078	**Analysis and interpretation of weather maps and prognostic fields**	6	—	3/2 MC
NMET003	**Physics of Clouds and Precipitation**	4	—	3/0 Ex
NMET010	**Climate change and its causes**	4	—	2/1 C+Ex
NMET067	**Stratosphere**	5	—	2/2 C+Ex
NMET019	**Atmospheric Chemistry**	5	3/1 Ex	—
NMET061	**Seminar on Projects I**	3	1/1 C	—
NMET062	**Seminar on Projects II**	3	—	1/1 C

320 (P) Atmospheric Physics, Meteorology and Climatology - Diploma thesis' courses

Code	Subject	Credits	Winter	Summer
NSZZ023	**Diploma Thesis I**	6	—	0/4 C
NSZZ024	**Diploma Thesis II**	9	0/6 C	—
NSZZ025	**Diploma Thesis III**	15	—	0/10 C

321 (PV) Atmospheric Physics, Meteorology and Climatology - Compulsory-optional courses

Code	Subject	Credits	Winter	Summer
NMET024	Dynamical forecast methods	7	—	3/2 C+Ex
NMET009	Regional Climatology and Climatography of the Czech Republic	6	4/0 Ex	—
NMET011	Statistical Methods in Meteorology and Climatology	6	2/2 C+Ex	—
NMET075	Climate extremes and their modelling	3	—	2/0 Ex
NMET066	Meteorological Computer Seminar	4	—	0/3 C
NMET079	Methods of atmospheric remote sensing II	3	—	1/1 C+Ex
NMAF014	Methods of Numerical Mathematics II	6	—	2/2 C+Ex
NMET063	Time Series Processing Methods	5	—	2/1 C+Ex
NMET025	Wave Motions and Energetics of the Atmosphere	4	—	3/0 Ex
NMET064	Aerosol Engineering	3	2/0 Ex	—
NMET031	Mesosynoptic meteorology	3	2/0 Ex	—
NMET068	Oceans in Climate System	6	2/2 C+Ex	—
NMET005	Emission Propagation in Atmosphere	3	2/0 Ex	—
NMET059	Modelling Techniques for Numerical Weather Forecasting	3	0/2 C	—
NMET032	Atmospheric Turbulence	4	3/0 Ex	—
NMET071	Applied Climatology I	3	2/0 Ex	—
NMET001	Atmospheric electricity	3	—	2/0 Ex
NMET073	Strong convection in the atmosphere	5	—	3/1 C+Ex
NMET072	Applied climatology II	3	—	2/0 Ex

322 (V) Atmospheric Physics, Meteorology and Climatology - Recommended optional courses

Code	Subject	Credits	Winter	Summer
NMET034	*Hydrodynamics*	6	3/1 C+Ex	—
NMET021	*Meteorological Instruments and Observational Methods*	4	3/0 Ex	—
NMET004	*Propagation of Acoustic and Electromagnetic Waves in Atmosphere*	4	3/0 Ex	—
NOFY077	*Introduction to Linux*	3	1/1 MC	—
NMAF026	*Deterministic Chaos*	3	—	2/0 Ex

NOFY078	*Programming and data processing in Python*	4	—	1/2 MC
NMET050	*Statistical methods of physical data processing*	6	—	2/2 Ex
NMET035	*Synoptic Meteorology I*	3	—	2/0 Ex
NMET012	*General Climatology*	6	—	3/1 C+Ex

Conditions that must be satisfied to register for the final oral exam

– gain of at least 120 credits
– passing all compulsory courses
– passing the compulsory-optional courses in the extent of at least 25 credits
– submission of the completed diploma thesis within the given deadline

Requirements for the state final exam

A Common basis

1. Statics and dynamics of atmosphere

Atmosphere in hydrostatic balance - homogeneous, adiabatic, isothermal atmosphere. Atmospheric vertical stability - parcel method, Brunt-Vaisala frequency, layer method, entrainment, thermal inversion and its causes. Kinematics and dynamics of air flow, effect of surface drag, basic types of air flows (geostrophic, ageostrophic wind and its components, gradient, divergent and non-divergent). Variation of air flow with height, wind shear, thermal wind. Vorticity and circulation - circulation theorem, vorticity equation, potential vorticity, divergence theorem, balance equation and its using. Vertical atmospheric movements and methods of their calculations, Richardson equation, omega equation and its discussion. Convection forecast. Atmospheric energetics, transformations of energy in the atmosphere, available potential energy, wave movements and oscillations in atmosphere.

2. Thermodynamic processes in atmosphere

Ideal (perfect) gas and real gases, values of thermodynamic state, basic thermodynamic processes (polytropic, isothermic, isobaric, isosteric, adiabatic process), thermodynamic solenoids, thermodynamic work, I. and II. law of thermodynamics, entropy, enthalpy, specific and latent heats, state equations, phase transitions, Clausius-Clapeyron equation, thermodynamic potentials. Thermodynamic of dry, moist and saturated air, dependence of saturated water vapour pressure on temperature, analysis of water phase diagram, characteristics of moisture, reversible adiabatic processes in atmosphere, pseudoadiabatic process, phase changes of water, Gibbs thermodynamic potential and its conservativeness - applications on systems with several components (solutions, Raoult law), dependence of saturated water vapour pressure on curvature of water or ice surface, supercooled droplets, explanation of supercooling.

3. Cloud and precipitation physics

Microstructure and macrostructure of clouds, cloud classification, thermodynamical and dynamical conditions for cloud formation and evolution, warm clouds, mixed phase clouds, cold clouds, nucleation of water vapor, water vapor condensation in the atmosphere, role and mechanisms of acting of the cloud condensation nuclei, diffusional growth and freezing of cloud drops, coalescence of cloud drops, ice nuclei, ice nucleation, supercooled liquid in clouds, primary and secondary ice production in clouds, cloud ice diffusional growth, aggregation, riming, size spectra of cloud and precipitation drops and ice crystals, ice crystal habits, cloud liquid content, precipitation formation, precipitation in stratiform and convective clouds.

4. Boundary layer meteorology

Atmospheric boundary layer. Viscous flow theory, Navier-Stokes-equations, dynamic similarity, Reynolds number. Atmospheric turbulence, Reynolds equations of turbulent flow, Reynolds stresses, mixing length, eddy diffusion coefficient, surface layer, spiral layer, vertical profiles of flow in the surface layer, Ekman spiral. Convective boundary layer, stable boundary layer, diurnal cycle of the boundary layer, characteristic profiles of temperature, wind speed and turbulent fluxes, clouds in the boundary layer. Interaction of the boundary layer with the Earth's surface, fluxes of momentum, heat and moisture, radiation and heat budgets of the Earth's surface. Transformations of kinetic energy in the boundary layer, turbulent kinetic energy and its mechanical and buoyant production, isotropic and anisotropic turbulence, spectrum of turbulent kinetic energy. Similarity theory and scaling, Richardson number, Obukhov length, Monin-Obukhov similarity theory, dimensionless vertical profiles of momentum, temperature and moisture. Atmospheric boundary layer in urban areas, flow over mountains. Closure problem, models of the atmospheric boundary layer, large eddy simulation. Methods of observation of the boundary layer, experimental methods for turbulent flow research.

5. Synoptic meteorology and weather phenomena

Horizontal and vertical distribution of meteorological phenomena, daily and annual courses. Air masses - genesis, sorts, transformation, characteristics and weather conditions. Atmospheric fronts - definition, dynamical and kinematic condition, pressure field, types of front, weather condition. Frontogenesis a frontolysis. Pressure systems - barotropic a baroclinic instability. Structure and development of pressure systems, regeneration, pressure and temperature changes, weather conditions in cyclonic and anticyclonic pressure fields, upper level frontal zones, explosive cyclogenesis. Jet streams. Clouds on fronts and inside of air masses, cellular circulation in clouds, structure of storm clouds (Cb), severe convective storms and connected extreme weather phenomena, multicells, supercells, tornadoes. Tropical cyclones. Föhn.

6. Climate and climate system

Climate system, observed state of atmosphere and ocean (temperature, precipitation, salinity), climate definition. Radiative and thermal balance of surface, atmosphere, Earth-atmosphere system (physical laws, solar radiation, long-wave radiation, radiative transfer equation). Greenhouse effect, greenhouse gases in the atmosphere, carbon cycle. Heat transport to lithosphere and hydrosphere. Diurnal and annual cycles of radiative and thermal balance. Influence of active surfaces on radiative and thermal balance. Water balance of atmosphere, continents, oceans. Atmospheric circulation. General circulation of troposphere and stratosphere, trade winds and monsoon circulation, intertropical zone of convergence, local circulation systems. Climate types and their classifications. Basic features of climate in Czechia. Oceanic circulation. Atmosphere-ocean interactions, variability modes, teleconnections. Natural and anthropogenic climate changes, their causes, Milankovitch theory. Sensitivity of the climate system to external and internal influence, feedbacks, global and regional climate models. Methods of statistical analysis of climate variables and fields. Specifics of urban climate.

7. Higher atmospheric layers

The stratosphere and mesosphere, pauses, vertical profiles and horizontal distribution of basic meteorological variables, circulation in the middle atmosphere. Annual cycles of temperature and circulation, polar circulation characteristics, comparison of the Northern and Southern Hemispheres. Sudden stratospheric warmings, classification, evolution of the warmings, influence of various forcing factors, impact of the other parts of the atmosphere. Middle atmospheric transport, Brewer-Dobson circulation, formation and basic characteristics, annual cycle, exchange between the troposphere and stratosphere. Radiation processes. Gravity waves, planetary waves, role of the wave processes in the middle atmospheric dynamics. Stratospheric ozone, creation and destruction, related chemical processes, role of the halogen hydrocarbons and other chemical families, the ozone hole formation and evolution, ozone long-term trends. Impact of the volcanic eruptions and volcanic activity.

8. Methods of atmospheric remote sensing

Satellite observation, measurement of meteorological parameters and of atmospheric composition. Meteorological geostationary satellites, polar-orbiting satellites. Spectral bands and channels, their basic characteristics. Reflectivity, transmissivity, emissivity and brightness temperature. Basic spectral characteristics of cloudiness and earth surface.Nowadays operative satellites, basic principles of satellite images processing, satellite remote sensing of atmospheric columns of gases (ozone, NO2, SO2, formaldehyde, CO etc.) and aerosols, aerosol optical properties. Radar measurement. Principle of radar function and using of radar in meteorology, radio locator reflectivity, Doppler radar data, polarimetric measurement. Radar equation, microwave refraction, attenuation, surface reflection. Radar precipitation estimates, combination with rain gauge data. Methods of scanning and data processing. Interpretation of radar measurements, radar characteristics of convective and stratiform cloudiness. Radar network in Czechia. Lightning detection, time of arrival method, direct finding method. Lidar measurement, surface lidars, airborne lidars. Sodar measurement, acoustic waves dispersion in atmosphere. GPS data and its usage, radio occultation (RO) method.

B. Optional focus

Students will choose two of the following four topics.

1. Atmospheric chemistry and air quality

Composition of the atmosphere, fundamentals of chemical kinetics, introduction to tropospheric and stratospheric chemistry, chemistry of the background atmosphere, chemistry of oxides of nitrogen, chemistry of hydrocarbons - alkanes, alkenes, carbonyl chemistry, alkohols, (polycyclic) aromatic hydrocarbons, organic substances containing nitrogen, halogens, ozone depleting substances, radicals and their role in atmospheric chemistry, anthropogenic and biogenic volatile organic compounds and their reactions, atmospheric oxidation of sulfur and nitrogen, aerosol forming processes, primary and secondary aerosol, aerosol size spectra. Typical anthropogenic pollutants and their sources, emissions vs. concentrations, emission databases, atmospheric diffusion of pollutants, dry- and wet deposition. Typification of meteorological conditions for air quality protection, air pollution monitoring, types of models for atmospheric chemistry and transport of pollutants, lagrangian and eulerian models, gaussian models, puff models, dispersion and receptor modelling, physical modelling, marker modelling.

2. Climate models, their types, structure, and applications

Climate model types and their applications. Structure of energy models and radiative-convective models, parametrization of inter-latitudinal flows and radiative processes, feedbacks. Global climate models, Earth system models (ESM). Statistical downscaling methods and regional climate models, their applications. Model structure, parametrization of basic physical processes, interpretation of outputs. Model output validation. Emission scenarios. Climate change scenarios construction. Uncertainty sources in climate model outputs. Multimodel and ensemble simulations and projections.

3. Methods of numerical modelling of the atmosphere

Formulations of equations of atmospheric models, simplifying approximations, inclusion of wave motions, hydrostatic approximation, shallow water equations, formulation of initial value and boundary value problems (global model, limited area model), model horizontal and vertical coordinates, input data preparation, objective analysis and data assimilation, initializations, normal modes, spatial discretization methods and temporal integration methods of meteorological models, stability and convergence of numerical schemes, parametrizations of physical processes. Synoptic interpretation of model outputs, main factors limiting successful forecast of meteorological fields, predictability of atmospheric processes, theoretical and practical limits of predictability.

4.Electromagnetic and acoustic waves in the atmosphere, atmospheric electricity

Maxwell equations and their application for atmosphere, wave equations, refraction, reflection and attenuation of electromagnetic waves in atmosphere, radar equation, Rayleigh scattering, Mie scattering, astronomical refraction, lower, upper and lateral mirror, fata morgana, depression and elevation of horizon, deformation and lamination of solar disc, green flash, colours of sky, twilight, twilight phenomena, rainbows, corona, glory, halo phenomena, visibility, polarization of skylight. Propagation of sound in atmosphere, sound speed, acoustic refraction index, acoustic shadows, anomalous audibility, shock waves, sound attenuation in atmosphere. Electrical field in atmosphere, Earth spherical condensator, ionization of air, electrical conductivity of air, vertical electrical currents, cloud and thunderstorm electricity, electrical properties of clouds, electrical charge in precipitation, electrical structure of Cumulonimbus, theories of cloud electricity production, point discharges, lightnights, atmospherics, TLE, transport of electrical charge in atmosphere.