# Research strategy of the Institute of Atmospheric Physics of the Czech Academy of Sciences for the period 2022-2024

The aim of this document is to formulate the medium-term research objectives of the IAP, which are a continuation of basic research activities building on existing activities and based on the evaluation of the Institute; and the recommendation issued by the evaluation committee.

### Inter-connections between cloud microphysics and cloud electrification

In 2022-2024 we plan to elaborate the wide range of options how to utilize the complex data sets from our cloud monitoring platform, which we established at the Milešovka observatory. Specifically, we are going to combine the ground-based measurements of clouds, precipitation and lightning discharges (from a WWLLN sensor installed late in 2020 at the observatory), complemented by the measurements from our second observatory Kopisty, with hydrometeor species, precipitation and vertical air velocity derived from remote sensing equipment, the cloud profiler and the X-band weather radar (installed in autumn 2020) in convective clouds.

We also plan to tune, improve, test and to verify our cloud electrification model, which describes microphysical processes, development of electric field and electric charges in clouds as well as the occurrence of electric discharges (i.e. lightning) explicitly.

Further, we will study the composition of cloud microphysical processes together with the processes of cloud electrification and formation of electric discharges using both the analysis of measured data and the mathematical modelling of cloud and electric field development.

### Further development of the cloud monitoring platform at the Milešovka observatory in the international context

After the installation of a lightning sensor by the World Wide Lightning Location Network (WWLLN) and an X-band weather radar on the top of the Milešovka tower in 2020, we plan to continue with the renovation works and continuous valuable administration of the observatory. We will also continue to support and implement popularization activities at the observatory, including making its virtual 3D tour and its equipment available online to the public.

The IAP will be involved into the Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS) in a close collaboration with current members of the consortium ACTRIS-CZ, particularly with the team of the Department of the Chemistry and Physics of Aerosols of ICPF of the CAS.

### Prediction of dangerous meteorological phenomena

We will perform numerical modelling by using the ICON NWP model including our cloud electrification model with a particular attention paid to short-term forecasting of precipitation and the occurrence of lightning up to 24 hours. We plan to continue developing the methods for nowcasting of severe convective precipitation, lightning and hail.

## Point and areal extremity of various meteorological phenomena, their causal conditions and relations

We will analyse the spatial and temporal variability of meteorological extremes in the context of their circulation conditions. We will detect the relations among meteorological extremes at various spatial scales and among various meteorological phenomena. We plan to assess return periods of sub-daily precipitation intensities and regularities of their spatial and seasonal distribution. We will also evaluate probable antecedent precipitation totals prior to the occurrence of extreme precipitation events as a function of the precipitation intensity distribution in time and the extremity of the event.

## Ongoing activities in road meteorology

We will continue utilizing the satellite data for nowcasting of cloud cover and radiative fluxes. We expect that after launching the Meteosat Third Generation (MTG), the importance of this topic will significantly increase. We plan to apply the ensemble methods in road weather forecast since we consider it an important way of how to quantitatively estimate the inaccuracy of road weather forecasts.

We are about to make our prognostic system of the line forecast for the network of highways and main roads in the Czech Republic operational. The corresponding project was launched in 2020, where we collaborate with the national weather service Czech Hydrometeorological Institute (CHMI) on the development of a forecasting system.

## Historical development and etymological explanation of the Czech meteorological terminology

We plan to reconstruct the history of Czech meteorological glossaries in the international context as well as the ancient interpretation of atmospheric processes from the etymological point of view of respective meteorological terms.

## Extreme events

We will deal with precipitation and temperature extremes including spatial and temporal characteristics of heat waves and cold spells, and compound events. We will examine the role of atmospheric circulation and land-atmosphere coupling in initiating development of extreme events in observed climate and reanalyses. Spatial patterns of differences between individual driving mechanisms (advective, radiative, and land-surface factors) in Europe will be analyzed. We will evaluate ability of current high-resolution climate models to reproduce the driving mechanisms of extremes and their spatial patterns.

## Climate variability

Research will focus on long-term changes in short-term (from day-to-day to intraseasonal) variability of temperature and precipitation in the Northern Extratropics, both in the observed data and in outputs of global and regional climate models. Various characteristics of variability will be analyzed, their climatologies and trends will be compared between different dataset types (station, gridded, reanalysis) with the aim to identify biases specific to individual dataset types. We will also focus on mechanisms governing the short-term variability, and the day-to-day temperature changes in particular, in which atmospheric fronts are likely to play a role. We will validate the short-term variability in climate model outputs and evaluate its future projections.

### Climate change

As part of the PERUN project, we will validate regional climate model ALADIN/CLIMATE-CZ. Based on the output from the model, climate change scenarios for the Czech Republic will be created with an emphasis on identification of risks for the environment and society. We will continue in the development of stochastic weather generator and methods for constructing climate change scenarios usable in impact studies. We will also participate in the COST action PROCLIAS, which aims to develop common protocols, harmonized datasets and joint understanding of how to conduct cross-sectoral, multi-model climate impact studies allowing for attribution of impacts of recent climatic changes and robust projections of future climate impacts.

### Biometeorology

We will continue to work with the Multi-Country Multi-City (MCC) Collaborative Research Network, which allows the application of methodological procedures to data from different parts of the world and evaluation of regional and global patterns of the weather-to-health links. We will analyse spatial patterns of links between temperature extremes and mortality/morbidity, and the role of socio-economic factors. The comparison of methodological approaches will allow a better understanding of the impacts of weather on human health and the refinement of biometeorological forecasting. We will deal with historical connections between weather variability, seasonal patterns of mortality, and the occurrence of acute respiratory infections in temperate climate conditions, with special emphasis on how these patterns have been affected by the COVID-19 pandemic.

### Atmospheric waves and the influence of the lower atmosphere on the ionosphere – vertical coupling in the atmosphere-ionosphere system

We will further contribute to the understanding of the atmospheric waves' role in the dynamics of the whole atmosphere-ionosphere system. In detail we will continue studying the vertical coupling from the troposphere up to the ionosphere and thermosphere heights. Using various observational techniques and monitoring systems, we will search for different ways of interactions between neutral and ionized regions. Special attention will be paid to the severe mesoscale troposphere systems and their influence on the ionospheric region. We shall use our measurements as well as data from international databases, including data from the European network of digisonde oblique sounding (we are part of).

Monitoring of the state of the ionosphere and providing gravity wave/TID activity for Czech and international users and transfer of these data to international databases and services including near real time submission of the Doppler sounder/TID information to the ESA space weather web site will continue. We will also continue with monitoring and investigation of infrasound and its application for studies of tropospheric and stratospheric dynamics and coupling processes up to the upper atmosphere and ionosphere. Ionospheric drift investigations will also continue. We anticipate further continuing and deepening of our international cooperation in all research activities.

We will continue and refine analysis of vertical coupling of atmospheric layers via atmospheric waves aiming, for example, to: (i) Identify source regions of the observed GWs. (ii) Investigate the role of tides and planetary waves on the occurrence of GWs and TIDs in the atmosphere and ionosphere. (iii) Investigate the role of polar vortex, jet stream and related wind shears on the generation and propagation of GWs. (iv) Estimate the spatial scales over which the GWs are correlated in the ionosphere using the Czech and European network of Doppler sounders and network of digital ionospheric sounders. (v) Continue investigating the atmospheric and ionospheric waves induced by seismic waves, volcano eruptions, severe weather systems etc. (vi) Further investigate impact of sudden stratospheric warmings on the ionosphere and determine optimum stratospheric parameters for such investigations.

### Impact of space weather on the ionosphere

In this area, we will focus mainly on large-scale traveling ionospheric disturbances (LSTIDs) driven by SIR/CH HSSs, transition of these disturbances from the polar regions through the midlatitudes. We will analyze the frequency of occurrence, the main parameters of the LSTIDs, their seasonal dependence, peculiarities compared to disturbances generated by CMEs and their influence on HF technologies. Here, it will be very important to continue our involvement in the European TID monitoring network (ionospheric oblique sounding between individual European digisondes). For analysis of medium-scale TIDs (MSTIDs) we will utilize data from our Doppler sounder. Furthermore, we will continue to study the variability of the ionosphere under severe space weather conditions and differences of the variability over both hemispheres. Impact of space weather on propagation of GNSS signals and their applications will also be studied.

### Long-term trends (climate change) in the stratosphere-mesosphere-thermosphere-ionosphere system

The efforts will be focused on broadening and completing the scenario of long-term trends in the mesosphere-thermosphere-ionosphere system, in filling gaps and removing controversies in the scenario of trends. Our activities associated with organizing international scientific meetings dealing with this topic will continue (J. Laštovička co-chairs the respective working group of IAGA). The trend scenario will be broadened by joining trends in the stratosphere into one unified trend scenario.

### Development of the International Reference Ionosphere (IRI)

We will continue contributing in validation of the outputs of the IRI model especially for midlatitudes over both hemispheres under calm and disturbed ionospheric conditions. We will also continue to improve and develop global models of ionospheric parameters (particularly for the topside ionosphere) that include dependencies on solar and geophysical parameters using data from our extensive database, which is continuously being updated with newly available measurements from new satellite missions and also from existing ground-based projects (ionosondes, incoherent scatter radars, etc.). V. Truhlik will play an important role in coordinating international efforts as chairman of the COSPAR/URSI working group on IRI.

## The stratosphere – dynamics and ozone

We will continue investigations of stratospheric dynamics and of the behavior of stratospheric ozone. The problem is with the coverage of data, because the ground-based measurement is sparse and the satellite measurements are not from everywhere. The data from reanalysis is regular in space and time, but there are artificial discontinuities in these data due to changes in data types used in assimilation process. These discontinuities make the trend studies inaccurate. Our goal is estimation of discontinuities in reanalysis data, namely for ERA-5, MERRA-2 and JRA-55. We are also part of the international group S-RIP, which is focused on the reanalysis comparison and implementation into the middle atmospheric research. We will develop new methods for discontinuity detection. Investigations of long-term trends in both stratospheric dynamics and ozone will continue, as well.

## Atmospheric electricity

We will continue investigating relations between atmospheric electricity and secondary cosmic rays (CR), for example thunderstorm ground enhancements (TGE) and potential influence of space weather and CR on atmospheric electricity and lightning. Both phenomena are not fully understood and require further experimental and theoretical investigations.

## Observational activities

Ionospheric Observatory Panská Ves hosts equipment for primary and supportive ground based ionospheric investigation - one transmitters of Doppler sounding network, riometer, array of micro-barometers, measurement of electrostatic field, airglow measurements of OH layer in mesopause region, and the seismic station. These measurements will continue. Telemetry part of the station continues in receiving data from CLUSTER-2 project satellites. The set of receiving antennas will be expanded. We will also continue the reception of data from the cubesat InspireSat-1. We are preparing and testing reception in the X-Band frequency range, both for the Low Earth Orbit satellites, and for the Moon orbit distance.

The ionospheric measurements at the Observatory Průhonice will continue to be carried out by the Digisonde DPS-4D. Three basic types of measurements are realized: (1) Classical ionospheric vertical sounding with routine repetition (15 min) or dense in campaigns. (2) Ionospheric plasma drift measurements (15 min repetition). (3) Synchronized D2D measurements – oblique sounding between ionospheric observatories in Europe with 5 min repetition. The data from the Digisonde are automatically distributed to data-centers and also are available on webpage in real time.

We are operating a multi-point and multi-frequency continuous Doppler sounding system (CDSS) in the Czech Republic. Signals on three different frequencies are transmitted from at least three spatially separated sites. Similar single-frequency multi-point CDSSs were also installed in South Africa, Tucumán (Argentina), and Taiwan. Our CDSS international network will be extended by new installation in Belgium and eastern Slovakia (longitudinal chain. We will maintain, together with our international partners, this network.

Both stations PVCI and WBCI of the Czech microbarograph network are integrated in the Central and Eastern European Infrasound Network (CEEIN). The CEEIN group will continue its activities which particularly include localization, identification, and monitoring of infrasound sources in Central and Eastern Europe. The results are published in the Central and Eastern European Infrasound Bulletin. Data from stations PVCI and WBCI are sent to the CEEIN database (www.ceein.eu).

Atmospheric electrostatic field is measured at the observatory of Panska Ves and at the seismic station of Studenec. Their data are included in the international network created in the GLOCAEM project. Measurements of electrostatic fields in High Tatras at Lomnicky peak and Skalnaté Pleso are performed in collaboration with Slovak partners. All these activities will continue.

### Experimental and theoretical research

Experimental and theoretical research of processes in the ionosphere and magnetosphere of the Earth and planets of the Solar system, Solar wind, space weather, and atmospheric electricity using analysis of data from spacecraft and ground-based observatories, with a particular focus on:

a) Space weather effects on the radiation belts in connection with our participation in two H2020 projects started in 2020 and running until 2022 (SafeSpace and Pager).

b) Waves and instabilities in the Solar wind in connection with our instrumentation onboard the ESA's Solar Orbiter spacecraft. After the successful launch of Solar Orbiter in February 2020, the team has been involved in the commissioning of the instrument and its scientific operations as well as processing and calibration of the measured data. Scientific exploitation of the data has already started and will become particularly intense after the start of nominal Solar Orbiter mission in 2022.

c) Lightning initiation and electromagnetic phenomena linked to lightning processes, ransient luminous events, and terrestrial gamma-ray flashes, in connection with our instrumentation onboard the CNES's TARANIS spacecraft and with our ground based instruments in Czechia, France, Slovakia and The Netherlands.

d) Electromagnetic waves on the surface of Mars and in the vicinity of Jupiter, in connection with our instrumentation on the ESA/Rosscosmos ExoMars and ESA's JUICE missions, both scheduled to be launched in 2022.

### Design and development of scientific instruments

Design and development of scientific instruments for future spacecraft missions. We will finalize the development of the hardware and in particular the flight software for the JUICE mission. The mission is scheduled for launch in 2022 and initial commissioning is planned after the launch, as well as ground processing and calibration of the data. There are new instrumentation projects approved in the department, in particular a hardware contribution to the scientific payload of the new Comet Interceptor mission (to be launched in 2028), Lagrange space weather mission (launch after 2025) and the Luna-26 mission.

### Kinetic heliosphysics and the solar wind

Current understanding of the solar wind has made significant progress in the last several decades based on a number remote sensing, direct in situ measurements, and numerical simulations. Still its complete nature in terms of acceleration mechanisms and an overall energetics along the expansion into the heliosphere is not yet fully resolved. We will aim to bring further insights on these phenomena with focus on the role of local kinetic processes, such as wave-particle interactions and Coulomb collisions, on the background of the ubiquitous magnetohydrodynamic turbulence by means of advanced numerical simulations and detailed analysis of unprecedented observation made by recent solar plasma missions Parker Solar Probe (NASA) and Solar Orbiter (ESA).

### Plasma interaction effects with solar system bodies

Solar system bodies, like planets, satellites, asteroids, or even small dust particles, are impacted by a supersonic flow of solar wind plasma particles which further carry a frozen-in ambient magnetic field. Such interactions cause significant disturbances to the plasma flow as well to the impacted bodies themselves. The study of these interactions is therefore an interdisciplinary subject dealing with the plasma physics of the process and the impact of the interactions on the central body's magnetospheres, atmosphere or surfaces. We will aim to study in particular the interaction of the solar wind with Mercury and it's magnetosphere with focus on (i) the plasma particle precipitation on the planetary surface and (ii) formation of trapped particle population within specific magnetospheric regions. The study will be conducted by use of global numerical simulations and in the frame of the recent BepiColombo mission.