Characteristics of main research directions investigated at the institute and the achievements 2010−2014

Institute	Institute of Atmospheric Physics of the CAS, v. v. i.

Introduction

The IAP is engaged in basic research, applied research and observational activities and deals with scientific investigations of the Earth's atmosphere in its whole vertical extent and up to the interplanetary space. The IAP consists of five departments and one working group, which were for evaluation purposes joined into 4 teams that represent four main directions of research conducted at the IAP. The diversity of research is also reflected in the diversity of team activities, e.g. in the proportions of basic and applied research, in observational activities, etc.

In the following text main directions of our research are described including basic results. Details can be found in the texts concerning individual teams.

Meteorology

Research of the meteorological team consists of the activities that can be characterized as basic research, applied research and observational activities.

In the reported period we operated 3 meteorological observatories. Apart from routine meteorological measurements, the observatories hosted a number of experiments, such as evaluating the atmospheric effects on optical communications, sampling and chemical analyzes of precipitation and fog water and dust sampling.

Our main activities were focused on studies concerning convective storms and specifically precipitation forecast. We dealt with nowcasting and short-range forecasts using numerical weather prediction (NWP) models. In terms of nowcasting we dealt with the assimilation of radar reflectivity and tested the influence of one and two moment microphysics on precipitation forecasts. We also studied methods for identification and forecasting large hail. The obtained results can be summarized as follows. We developed an assimilation method of radar reflectivity based on the water vapour correction and extrapolation of radar reflectivity, which significantly improved the accuracy of convective precipitation forecasts for lead time 2-3 hours. Furthermore, we showed that this assimilation technique allows deterministic forecasting of occurrences of large hail for lead time 60-90 minutes. For this purpose we developed a method identifying occurrence of hail, which uses 3D radar reflectivity fields and aerological data.

Within short-range weather forecast, we studied the performance of precipitation forecasts for two NWP models: the hydrostatic model ALADIN, which is run operationally in the Czech Hydrometeorological Institute (CHMI), and the non-hydrostatic model COSMO, which is used by the German Weather Service. Both models were applied with two horizontal resolutions and the precipitation forecasts were verified for an extended set of days using traditional and spatial verification procedures. As a result of the verifications we found that ALADIN's convection

parametrization does not work appropriately in the higher horizontal resolution. This finding helped to find an error and correct the model.

We also studied and tried to estimate the uncertainty of predictions of convective precipitation by means of ensembles. A regional ensemble COSMO-CZ-EPS was created with a high resolution of 2.8 km, which used the forecasts of the ensemble COSMO-EPS for calculating initial and boundary conditions. We proved that the COSMO-CZ-EPS, which uses the higher horizontal resolution together with the explicit calculation of deep convection, yields more accurate prediction than the parent Ensemble.

Another our activity was focused on causal conditions of heavy precipitation in the Czech Republic (CR) and Central Europe. We developed a method for classification of circulation types, which is based on the quantitative evaluation of the intensity of zonal and meridional moisture fluxes. Apart from the main circulation variant producing heavy rains in the CR (so called “Vb weather”), we distinguished three other variants in Central Europe. We detected four regions with different circulation types responsible for heavy precipitation and we demonstrated that the seasonal distribution of dominant circulation type of heavy precipitation depends on the dominant circulation type producing heavy precipitation in these regions.

We improved the process of the evaluation of the extremity of weather events by a new index (WEI), which takes into account the climatology of the variable and reflects also the duration of the event and the size of the affected area. We demonstrated that the WEI maxima were associated with anomalies of properly selected meteorological variables. Combinations of these anomalies were quantitatively evaluated by a new Circulation Extremity Index.

In the field of land-atmosphere interactions, we pointed out the complex airflow patterns that should be taken into account when estimating the matter and energy budget of forest ecosystems. Our analysis of experimental results supported by an original modelling approach confirmed the theoretical considerations of other authors about the nocturnal airflow regimes over forested ridges.

Our activities in applied research concentrated mainly on road meteorology, wind energy assessment, impact of water reservoir on microclimate and on studies dealing with the impact of cooling tower plumes on the environment. The most important results were: development and putting into operation the model METRo-CZ for forecasting road surface temperature and road conditions, and development of the ALAKE model for estimating the influence of water area on local temperature, humidity and wind speed. Besides that we completed seven studies (contracts) aimed at the evaluation of the impact of cooling towers on environment and several tens of studies focused on the evaluation of wind conditions at given localities.

Climatology

The research team dealt with various topics related to statistical and dynamical climatology, with special focus on atmospheric circulation and its links to surface climate, solar and geomagnetic influences on climate, climate variability/change and its impacts on sectors such as agriculture, water resources and public health, climate model evaluation studies, and extreme value analysis.

We examined how current climate models (global and regional) capture the large-scale atmospheric circulation and links between circulation and characteristics of daily surface air temperatures and precipitation. General biases of climate models in simulating large-scale circulation over Europe include overestimation of the frequency of strong flow days and of strong cyclonic vorticity. Most RCMs improve on the driving global climate model (GCM). RCMs qualitatively reproduce relationships between circulation indices and surface temperatures and precipitation, and the links tend to be more realistic compared to those in the driving GCMs.

We contributed to international project COST 733 (Harmonisation and Applications of Weather Types Classifications for European Regions) by providing a classification method based on principal component analysis, analyzing synoptic-climatological properties of classifications of circulation types, and examining the long-term trends of frequencies of circulation types and how they relate to temperature and precipitation trends.

Our analysis of the effects of the North Atlantic Oscillation (NAO) on European temperature and precipitation indicates that the response of climatic elements to the NAO strongly depends on the exact definition of the NAO, especially in summer

The international collaboration within COST Action ES1005 (Towards a more complete assessment of the impact of solar variability on the Earth's climate) materialized in the quantification of effects of solar variability on the position and intensity of the centres of action in the Atlantic Ocean (Icelandic cyclone and Azores anticyclone).

We studied longitudinal, latitudinal and altitudinal patterns of statistically significant phase coherence between solar/geomagnetic activity and climate variability on the temporal scale related to oscillatory periods about 7-8 years. Consistent patterns of areas of significant response to geomagnetic activity in the troposphere are confined within the areas of coupling with NAO.

We proposed a methodology for estimating high quantiles of distributions of daily temperature in a non-stationary context based on peaks-over-threshold analysis with a time-dependent threshold expressed in terms of regression quantiles. In climate model studies, the method allows splitting the projected warming of extremely high quantiles into two parts that reflect change in the location and scale of the distribution of extremes, respectively. Spatial patterns of the two components were found to differ significantly in the examined climate change projections over Europe.

We examined the capability of ENSEMBLES RCMs to reproduce spatial and temporal characteristics of severe Central European heat waves. The RCMs had a tendency to simulate too many heat waves that were shorter but their temperature peak was more pronounced on average compared to E-OBS. Using as an example the most severe Central-European heat wave of 1994, we demonstrated that its magnitude was underestimated in all RCMs and that this bias was linked to overestimation of precipitation during and before the heat wave.

We improved the methodology for creating future climate scenarios for use in climate change impact studies by changing the weather generator (WG) parameters which are

derived from GCM or RCM simulations. WG as well as the methodology are permanently improved and used in various climate change impact studies in collaboration with partners from the Czech Republic and other countries.

We developed the method for identifying a representative GCM subset. The representative subset was based on objective criteria, which characterize the GCM performance in reproducing the seasonal cycle of temperature and precipitation, and a subset ability to represent future inter-GCM variability. The representativeness of three candidate subsets was validated (with respect to the reference set) and compared for future changes in temperature, precipitation and Palmer drought index Z (direct validation), and occurrence of the European corn borer and snow-cover characteristics.

In human biometeorology, we examined impacts of temperature extremes and sudden air temperature and pressure changes on mortality and morbidity in the population of the Czech Republic, with focus on differences in the effects in urban and rural populations and between chronic and acute cardiovascular diseases. Analysis of long-term changes in the effects of warm temperature extremes on human health showed significant changes towards less pronounced impacts on mortality over the last two decades while there was no trend in the effects on morbidity. Methodological studies that compared different approaches and statistical methods used in air mass classifications were carried out using nation-wide data for the Korean population.

Upper and middle atmosphere

We dealt with studies of behaviour of the ionosphere, thermosphere and middle atmosphere, predominantly in five areas: (1) Atmospheric waves and their impact on the ionosphere and upper atmosphere. (2) Impact of space weather and solar activity on the ionosphere and upper atmosphere. (3) Development of the International Reference Ionosphere (IRI). (4) Long-term trends in the ionosphere-upper atmosphere system. (5) Investigations of ozone and stratospheric dynamics.

To study the propagation of gravity waves (GWs) and infrasound in the ionosphere, we installed multi-point continuous Doppler shift measurement in the Czech Republic, southernmost South Africa (June 2010), northwest Argentina, Tucumán (end of 2012) and Taiwan (end of 2013). At mid-latitudes we found that the most frequently observed velocities of GWs at heights of ~150–250 km are ~100–200 m/s. The GWs propagated roughly poleward during the local summer and equatorward during the local winter, approximately against the background neutral winds from the HWM07 model. Periods of GWs usually ranged from ~8 to 30 minutes. Large scale waves with periods 30-50 min was observed on geomagnetically disturbed days. Measurements at low latitudes have not revealed any systematic dependence of GWs on season. As for equatorial/low-latitude spread-F, we observed oblique spread structures in the Doppler shift spectrograms at the same time as the strong spread-F in ionograms in Tucumán. These structures propagate roughly eastward at velocities ~70 to 200 m/s. All the above results are consistent with results of airglow measurements.

The strong Tohoku earthquake (11 March 2011) generated seismic waves that locally excited infrasound observed by the Czech Doppler sounder 9000 km away from the epicenter. We identified separate wave packets in the ionosphere corresponding to P, S, SS and Rayleigh seismic waves with high cross-correlation (>0.9) with seismic

vertical motion. Narrow infrasound pulses were observed by microbarometer array at Panska Ves during thunderstorms. These pulses are very likely associated with intracloud lightning (electrostatic mechanism).

Time series of foF2 from European ionosonde stations were found to be highly correlated (dominant solar influence). At distances exceeding about 10 degrees of longitude, the correlation coefficients for fluctuations decrease rapidly. As a possible reason we propose mesoscale tropospheric systems (source of atmospheric waves). We found ionospheric response to weak geomagnetic storms around the deep 23/24 solar minimum to be comparable with or even slightly stronger than that of strong storms under higher solar activity conditions, which might be partly due to the dominant role of co-rotating interaction regions (CIR) in the declining phase and solar cycle minimum.

We developed a new global model of the electron temperature TBT-2012 for the upper and topside ionosphere (300-2000 km) with inclusion of the solar activity variation. The model was included in the International Reference Ionosphere (IRI) since IRI-2012. Ion composition in the topside ionosphere was found to be strongly dependent on the solar cycle; during the extreme low solar activity in 2008-2009 the upper transition height was extremely low. The IRI STORM model was found to capture better the negative phases of the summer storms, while during winter storms, recovery phase, strong storms and for lower middle latitudes the behaviour of *foF2* is worse reproduced; it fails for minor storms near the deep solar minimum 23/24.

CO_2 is the primary trend driver in the mesosphere-thermosphere-ionosphere system. The role of secondary trend drivers was specified. Ozone or geomagnetic activity reversed their own trends during the last 20 years; others like secular change of Earth's magnetic field have regionally very different impact on trends. Consequently we cannot expect spatially homogeneous and temporally stable trends in the upper atmosphere-ionosphere system. Ionospheric trends (foF2 and total electron content TEC) in 1995-2010 were found to be more positive than in the past, probably due to the last extraordinary solar minimum.

At 10 hPa at northern higher middle latitudes in winter (not in summer) we found well-pronounced two-core longitudinal structure in meridional wind, which was explained by a well-developed blocking Aleutian pressure height. It has a pronounced effect also in zonal wind, temperature and ozone fields. Core areas exhibit statistically significant (at 99% level) trends – weakening in 1970-1995 (period of ozone depletion) and strengthening 1996-2012 (period of partial ozone recovery).

Space plasma physics

The team of space plasma physics is active in three main areas of research: experimental study of processes in heliospheric plasmas via analysis of data from spacecraft and ground observatories, large scale numerical simulations of space plasma processes, and design and development of scientific instruments for future spacecraft missions.

In the reported period, the data analysis was largely focused on the study of waves and oscillations in various plasmas in the magnetosphere of the Earth and Saturn and in the solar wind. Numerous studies conducted by team members were dedicated to

electromagnetic waves in the inner magnetosphere and in particular to the properties of whistler mode chorus emissions. Spectral properties of the chorus waves, their global distribution, fine structure and also the correlation with observed features of electron distribution were described in numerous publications using data from Cluster, Double Star and Van Allen Probes spacecraft.

Other magnetospheric phenomena studied by the team included mirror waves in the terrestrial magnetosheath and electromagnetic ion cyclotron emissions in the inner magnetosphere observed by Cluster and quasi-periodic whistler mode emissions observed by DEMETER spacecraft.

We also studied properties and propagation waves observed by the Cassini probe during a flyby of Saturn’s moon Rhea and type II and type III solar radio emissions observed by STEREO spacecraft.

The study of lightning generated radio emissions is a new area of research for the team pursued in preparation for the TARANIS spacecraft mission. We have set up an automated ground observatory equipped with antennas and receivers for a wide range of frequencies in an electromagnetically clean facility in France and already published several articles based on the novel measurements performed there.

Numerical simulations of the interaction of the solar wind and magnetospheric plasmas with magnetized and unmagnetized bodies, i.e., planets and moons, and on the pure expansion of the solar wind itself were carried out. The work was primarily based on numerical simulations using fully particle-in-cell or either hybrid codes which are capable to implement the kinetic aspects of the individual plasma species. Investigation methods further employ data analysis of real space observations and development of plasma diagnostic tools. This research is collaborative effort joint with the Heliospheric and space weather group (Solar Physics Department) of the Astronomical Institute CAS.

In the evaluated period we analyzed the properties of the solar wind interaction with the Mercury's magnetosphere in comparison to the recent observations of the Messenger spacecraft (NASA) and with close relations to the scientific goals of the future space mission Bepi Colombo (ESA/JAXA). In addition we further extended the investigation of the solar wind interaction with the unmagnetized body of the Moon which results into formation of the specific wake region behind the obstacle. In relation to the study of the solar wind expansion we have analyzed namely the possible effects and roles of various kinetic processes with focus on generation and evolution of kinetic plasma instabilities.

The team is involved in the preparation of payload for future spacecraft. Consistently with the scientific focus of the group, the team of space plasma physics specializes in the development of wave analyser instruments. Receivers for the TARANIS spacecraft (CNES – launch in 2017), Solar Orbiter (ESA – launch in 2018) and RESONANCE (Roskosmos – anticipated launch in 2018) have been developed. Another wave instrument for the JUICE mission is in the advanced design phase.

Research Report of the team in the period 2010–2014

Institute	Institute of Atmospheric Physics of the CAS, v. v. i.

Scientific team	Department of Meteorology

Research activities of our team consist of three interrelated parts. These are basic research, applied research and observational activities. Our main activity is the basic meteorological research; however, the applied research is also an important part of our investigations. The observational activities, which take place at our three meteorological observatories, are closely related to both the basic and the applied research. Correspondingly, we have divided this report into three parts.

2.1 Operation of observatories, experimental activities and associated research

Our team operates three meteorological/climatological observatories:

Observatory Milešovka (837 m a.s.l.), located at the top of the mountain of the same name in the České středohoří Mts., is the oldest mountain station in the Czech Republic, with the measurements being performed continuously since 1905. Due to its unique position and a long series of observations, the station was included in the international network of GCOS (Global Climate Observing System) as the only station in the Czech Republic. Apart from routine meteorological measurements, the observatory hosts a number of experiments, such as evaluating the atmospheric effects on optical communications, sampling and chemical analyzes of precipitation and fog water and dust sampling. The station is operated by five observers who ensure continuous operation in pairs, alternating in weekly sessions.

Kopisty observatory is located near the town Most in industrially exposed area. The measurements started in 1969. The observatory is equipped with an 80-meter mast where the temperature, humidity and air flow characteristics (currently by 3D sonic anemometers) are measured at four floors. Experiments at the observatory focused on the air pollution research. The station also transmits the standard meteorological data to the Czech Hydrometeorological Institute. The station is operated by three observers who take turns in weekly sessions.

Dlouhá Louka observatory was built in 1993 for the experimental research on the influence of turbulence, icing and electrical discharges on wind power turbines. The observatory is equipped with a 51-meter mast and an automatic station with remote data transmission and works in the unattended mode.

Experimental investigation of the atmospheric attenuation of electromagnetic signal takes place also at the **IAP location in Prague**.

Analysis of insoluble particles in fog water

Fog samples at the top of Milešovka were collected with an active fog water collector. Water samples were filtered to obtain the insoluble particles. The particles were then categorized according to their shapes, sizes and composition. Groups of typical insoluble particles were classified according to the meteorological conditions, synoptic situations and wind directions that prevailed in the days of the fog events to find out the possible sources of this fog pollution. Our team members analyzed the data, contributed largely to interpretation of the results, and wrote the article.

Reference:

Fišák, J. ; Stoyanova, V. ; Bartůňková, K. ; Tesař, M. ; Shoumkova, A. (2012): Typical Insoluble Particles in Fog Water at Milešovka Observatory (Czech Republic). Pure and Applied Geophysics, 169, 1083-1091. http://hdl.handle.net/11104/0204243

Utility design (Registration No. 22843, 2011): Device to measure deposited precipitation amount

A new device for automatic measurements of the amount of deposited precipitation was developed to evaluate deposited precipitation. It measures the weight of the precipitation deposited on the collecting board. The device can operate off-line recording data to an inner memory or on-line when connected to PC. It is suitable for continuous measurement of the amount of deposited precipitation like dew or white frost, precipitation from fog, or small amount of falling precipitation that is not measurable by a rain gauge. It can be used wherever there is a need to know the weight of deposited precipitation mass for example in meteorological services, hydrological services, transport, agriculture and research. This is a result of our team except for the technical realization of the measurement device.

Reference:

Fišák, J. ; Chum, J. ; Vojta, J. ; Bartůňková, K. (2013): Automatic Monitoring of the Amount of Deposited Precipitation. Journal of Hydrometeorology, 14, 670-676. http://hdl.handle.net/11104/0221385

Atmospheric influence on the signal attenuation in free-space optics (FSO) and millimeter-wave links

Attenuation statistics and rain event analysis on our experimental FSO link were performed. Models to estimate the attenuation due to fog, rain and atmospheric turbulence were formulated. From the Mie scattering theory and the Marshal-Palmer drop size distribution, we derived and experimentally proved a relationship for the signal attenuation by rain. Significantly higher availability performance was achieved for the simulated hybrid FSO / millimeter-wave system than for the FSO link alone. For the FSO link at the Milešovka

observatory, empirical dependence on atmospheric visibility and on turbulent kinetic energy of the air flow as well as on other selected wind parameters was derived. For the conditions without rain and fog, a significant negative correlation was found between the FSO signal attenuation and the sonic temperature. Our team members contributed substantially (measurements, data analysis and interpretation, paper preparation) to most of the results, and with theoretical analysis to the paper by Ijaz et al. (2013).

References:

Grábner, M. ; Kvičera, V. ; Fišer, O. (2012): Rain attenuation measurement and prediction on parallel 860-nm free space optical and 58-GHz millimeter-wave paths. Optical Engineering, 51, 031206/1-031206/6. http://hdl.handle.net/11104/0210134

Pešek, J. ; Fišer, O. ; Svoboda, J. ; Schejbal, V. (2010): Modeling of 830 nm FSO Link Attenuation in Fog or Wind Turbulence. Radioengineering 19, 237-241. http://hdl.handle.net/11104/0187052

Chládová, Z. ; Fišer, O. ; Brázda, V. ; Svoboda, J. (2013): Correlation of free-space optics link attenuation with sonic temperature. Optical Engineering, 52, 030503/1-030503/3. http://hdl.handle.net/11104/0220578

Ijaz, M. ; Ghassemlooy, Z. ; Pešek, J. ; Fišer, O. ; Le Minh, H. ; Bentley, E. (2013): Modeling of Fog and Smoke Attenuation in Free Space Optical Communications Link Under Controlled Laboratory Conditions. Journal of Lightwave Technology, 31, 1720-1726. http://hdl.handle.net/11104/0222962

Data utilization in our applied research

Data from Kopisty and Milešovka were used to create a model ALAKE for estimating the impact of water reservoirs on microclimate (see Applied Research).
Data from Kopisty and Milešovka were also utilized for the contract in order to evaluate dust emissions from the Bílina open coal mine (see Applied Research).
Data from all three observatories were used to develop models for the wind conditions assessment (see Applied Research).

2.2 Basic research

Quantitative precipitation forecasting of heavy convective rainfalls – testing new methods and the verification of forecast performance

Summer convective storms with flash flood response cause significant damage in Central Europe every year. Therefore, quantitative precipitation forecast (QPF) of convective rainfalls, which represents the expected convective precipitation amount accumulated over a specified time period and area, is of high value from a user's point of view. The QPF has

improved over the last few decades; however, it is still one of the most difficult and disputed topics in operational forecasting due to the great uncertainty inherent in this type of NWP model outputs. This is valid, especially when forecasting convective rainfalls due to their rapid time evolution and strong space variability. That is why we paid attention to testing new techniques focused on improving the QPF quality in the regimes of nowcasting (up to 3h) and short range forecasting (up to 24h).

A new nowcasting technique focused primarily on the nowcasting of convective precipitation was developed for the lead times of 1, 2 and 3 hours (Sokol 2011, Sokol and Pešice 2011, Sokol and Zacharov 2011). The technique combines two common forecasting methods: (i) modelling of the atmosphere by a numerical weather prediction model and (ii) the extrapolation of current radar reflectivity measurements.

Our method combines these two techniques in the way that rain rates derived from extrapolated radar reflectivity are assimilated into the numerical model during the first hour of the model integration. The technique was applied to the COSMO NWP model together with the assimilation of radar reflectivity and with adopted two moment Seifer-Beheng microphysics. We substantially modified our previously developed assimilation method based on water vapour correction (Sokol 2011). This nowcasting technique was tested for a set of events with heavy observed precipitation. The extended test at 50 forecasts confirmed that the new method yields apparently more accurate precipitation forecasts than the single methods. It also confirmed that the forecasts of severe convective precipitation yield reasonable results for lead times 2 or 3 h, then the accuracy rapidly decreases (Sokol and Zacharov 2012). The first tests also confirmed positive impact of the new forecasting method on hydrological forecasts.

The developed nowcasting method was also applied to hail forecast. Here we used for verification a new hail detection technique developed by Skripnikova and Rezacova (2014), which combines 3D radar reflectivity data with meteorological data from free atmosphere. The ability of the COSMO model using the extrapolation, assimilation of radar reflectivity and two moment microphysics to forecast hail occurrence up to 90 min. ahead was demonstrated in (Sokol et al. 2014). It was found that for hail forecast it is necessary to use a horizontal resolution about 1 km and increase the number of model vertical levels.

Quantitative precipitation forecasts (QPF) were evaluated by using several verification techniques including the spatial techniques SAL and FSS (Zacharov et al. 2013). The forecasts were produced by two limited-area numerical weather prediction models: the ALADIN-CZ model operated by the Czech Hydro-Meteorological Institute (CHMI) and the COSMO model. Each model was run using two horizontal resolutions over the domain covering the Czech Republic.

The forecast quality was studied for the flash flood period that occurred in June and July of 2009, when convective rainfalls with durations of 1 to 3 h and a return period of more than 100 years caused devastating floods in many Czech localities. The verification radar-based rainfalls were produced by the CHMI operational product MERGE, which merges radar-derived rainfalls with the rainfalls that are measured by ground rain gauges.

The quality of QPF depended strongly on the scale of convective precipitation, and all models provided good forecast quality for extended rainfall systems. The opposite was true for the local and more or less chaotic convection during the final part of the time period. The

COSMO 2.8 model was able to determine the largest local rainfall values, but models with lower resolution, such as the ALADIN 9 km and COSMO 7 km, provided better results for lower thresholds and larger scales.

The verification results also indicated that the forecasts of the two ALADIN-CZ runs with different horizontal and vertical resolution were similar and the run with higher resolution did not provide any new skill. That is why the ALADIN-CZ was modified by the CHMI ALADIN Group and new results for the 2009 episode were provided for verification (Zacharov et al. 2014). That new verification indicated a pronounced improvement in the QPF in particular in cases with convective precipitation without a strong synoptic forcing. The new ALADIN-CZ version was able to produce isolated structures in the precipitation field which showed high rainfall values. This result was achieved by the team from the Department of Meteorology except for the computation of ALADIN rainfall data, which was done in the CHMI (Dr. Brožková).

References:

Sokol, Z. (2011): Assimilation of extrapolated radar reflectivity into a NWP model and its impact on a precipitation forecast at high resolution. Atmospheric Research, 100, 201-212. http://hdl.handle.net/11104/0198914

Sokol, Z. ; Pešice, P. (2012): Nowcasting of precipitation – Advective statistical forecast model (SAM) for the Czech Republic. Atmospheric Research, 103, 70-79. http://hdl.handle.net/11104/0206597

Sokol, Z. ; Zacharov, P. (2012): Nowcasting of precipitation by an NWP model using assimilation of extrapolated radar reflectivity. Quarterly Journal of the Royal Meteorological Society, 138, 1072-1082. http://hdl.handle.net/11104/0210022

Zacharov, P. ; Řezáčová, D. ; Brožková, R. (2013): Evaluation of the QPF of convective flash flood rainfalls over the Czech territory in 2009. Atmospheric Research, 131, 95-107. http://hdl.handle.net/11104/0223381

Sokol, Z. ; Zacharov, P. ; Skripniková, K. (2014): Simulation of the storm on 15 August, 2010, using a high resolution COSMO NWP model. Atmospheric Research, 137, 100-111. http://hdl.handle.net/11104/0226290

Satellite estimates of heavy convective precipitation

Satellite precipitation estimates can effectively complement the data from rain gauges and weather radars measured at the same time. The method of satellite estimates of convective precipitation using data derived from meteorological geostationary satellite “Meteosat Second Generation” (MSG) with a time step of 15 minutes was developed for the area of the CR. The algorithm development (so called “Convective Rainfall Rate” algorithm) was based on the calculation of the own calibration matrices, which assign the corresponding value of rain rates to a given combination of spectral channel values in infrared and visible (during the daytime) parts of the electromagnetic spectrum. Measured data derived from the Czech

weather radar network CZRAD (Brdy, Skalky) with a horizontal resolution of 1 km were used for calibration. The algorithm was complemented with the correction of the distribution of estimated rainfalls, which improved the resulting accuracy of the satellite precipitation estimates. A new method of the 5 min MSG data application (so called Rapid Scan mode) brought significant improvement of the accuracy of the calibration matrices from the qualitative and quantitative point of view, where the original assumption of the higher probability of agreement between satellite and radar measurements was proven.

References:

Bližňák, V. ; Sokol, Z. (2012): The exploitation of Meteosat Second Generation data for convective storms over the Czech Republic. Atmospheric Research, 103, 60-69. http://hdl.handle.net/11104/0204283

Bližňák, V. ; Sokol, Z. ; Pešice, P. (2014): The application of Rapid Scan data to the Convective Rainfall Rate algorithm from SAF NWC for the area of the Czech Republic. Atmospheric Research, 144, 82-94. http://hdl.handle.net/11104/0232087

Variants of causal conditions of heavy precipitation in the Czech Republic and Central Europe; Extremity evaluation of weather events

a) We developed a method of classification of circulation types which is based on the quantitative evaluation of the intensity of zonal and meridional moisture fluxes on a spatial scale of the order of 100 km. The method enables to compare the circulation causes of hydro-meteorologically extreme events in various regions. We applied the method to heavy precipitation events which occurred in the Czech Republic (CR) and selected catchments in Central Europe in warmer half-years 1958-2002. We showed that the events were accompanied by very intensive moisture fluxes in the vicinity of the rainfall area. Apart from the main circulation variant producing heavy rains in the CR (so called “Vb weather”), we distinguished three other variants using a technique of divisive fuzzy clustering of the events. These variants are characterized by recurring passages of frontal waves from the southwest and alternatively by passages of individual cyclones south of the CR. In Central Europe, we proved a close relation between three-day areal precipitation amounts in a catchment and the increase of average daily flow. We detected four regions with different circulation types responsible for heavy precipitation and demonstrated the dependence of the seasonal distribution of heavy precipitation on the dominant circulation type producing them in these regions.

References:

Kašpar, M. ; Müller, M. (2010): Variants of synoptic-scale patterns inducing heavy rains in the Czech Republic. Physics and Chemistry of the Earth, 35, 477-483. http://hdl.handle.net/11104/0189032

Müller, M. ; Kašpar, M. (2010): Quantitative aspect in circulation type classifications – An example based on evaluation of moisture flux anomalies. Physics and Chemistry of the Earth, 35, 484-490. http://hdl.handle.net/11104/0189028

b) We have improved the process of evaluation of extremity of weather events. Whereas the classical approach is based on the comparison of maximum/minimum values at individual gauges, the presented Weather Extremity Index takes into account the climatology of the variable and reflects also the duration of the event and the size of the affected area. Moreover, both the time window and the considered area are optimized for individual weather events in order to compare heterogeneous events. We have demonstrated the fact that circulation conditions conducive to an atmospheric hazard can be characterized not only qualitatively by circulation types but also quantitatively by combinations of anomalies of properly selected meteorological variables. The Circulation Extremity Index, designed with respect to historical weather extremes, correlates with the extremity of consequent events, for example heavy rains. Best results were reached by using weighted combinations of the anomalies.

References:

Müller, M. ; Kašpar, M. (2014): Event-adjusted evaluation of weather and climate extremes. Natural Hazards and Earth System Sciences, 14, 473-483. http://hdl.handle.net/11104/0231922

Kašpar, M. ; Müller, M. (2014): Combinations of large-scale circulation anomalies conducive to precipitation extremes in the Czech Republic. Atmospheric Research, 138, 205–212. http://hdl.handle.net/11104/0228763

Influence of a mountain ridge on the nocturnal airflow and CO_2 fluxes in a forest canopy

Night-time airflow within a deep and dense forest canopy near the top of a mountain ridge was investigated based on measurements at the Experimental Ecological Study Site Bily Kriz, Czech Republic. A well-defined flow pattern typically develops at night, with frequent occurrence of opposing flow directions of the lower-canopy and above-canopy flow. These experimental results confirm the theoretical considerations published by Belcher et al. (Ecological Applications, 2008) about the nocturnal airflow regimes over forested ridges. We introduced a simple diagnostic model, which gives realistic values of the downslope or upslope direction and speed of the lower-canopy flow that agree well with the measurements. A similar pattern, being consistent with previous theoretical considerations and numerical simulations of the flow and scalar transport across a forested hill, was experimentally found over the Wetzstein hill in Germany. We explained that in some cases, the terrain-induced complex airflow pattern was the cause of the unrealistic values of the CO_2 balance that was calculated based on direct measurements of the wind, CO_2 concentration and CO_2 eddy fluxes (international experiment ADVEX). The result for Bily Kriz was achieved with substantial contribution of the team members P. Sedlák and K. Potužníková (data

analysis, model formulation, interpretation and discussion of the results, writing the paper). Based on his experience with the Bily Kriz and ADVEX data, P. Sedlák contributed to interpretation and discussion of results in the paper on Wetzstein (Zeri et al. 2010) and in the ADVEX evaluation paper (Aubinet et al. 2010).

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2.3 Applied research

Our applied research includes the grant projects (e.g. Technological Agency of the Czech Republic) and the studies or assessment activities that are carried out on the basis of contracts.

Forecast of road surface temperature and condition in winter season

We have developed a model METRo-CZ for road surface temperature and condition forecasts in winter season. The model is based on computation of the road surface heat and water balance. It utilizes current knowledge, available data, and is adapted to conditions in the Czech Republic. The major novelty is a nowcasting approach, which every hour provides new forecasts using latest road data. This approach has not been applied yet, and we proved that it significantly improves forecasts mainly for the first 4 hours. We also proved that in the condition of Central Europe, the basic problem is the forecast of short wave radiation by the numerical weather prediction models. This result is an example of application of theoretical findings in meteorological practice. It was achieved by the team from the Department of Meteorology except for obtaining and preparing the data from road weather stations, which was the task of M. Škuthan from the Czech Hydrometeorological Institute (CHMI). In collaboration with CHMI, we have created a forecast line and started a pilot application, which enables the winter road maintenance controllers to make optimal decisions.

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The influence of a lake area on microclimate

We started this application topic because the influence of water reservoirs on microclimate is important for planning the hydric reclamation of open coal mines and a solution of this problem was not available.

We used the COSMO numerical weather prediction model with a horizontal resolution of 333 m to simulate the influence of a lake on local temperature, humidity and wind speed. The research was focused on the Most lake (area approx. 4 km^2) in North Bohemia, which is a recent result of hydric reclamation. As COSMO is not being used with such a high resolution, we first had to tune some model boundary layer parameters and to show that COSMO is suitable for this task. Using the outputs of several hundreds of COSMO integrations for various meteorological and hydrological conditions, we developed a new model, ALAKE, a simple mathematical model suitable for estimating the influence of a new lake on temperature characteristics in its vicinity. The model consists of simple physical equations containing free parameters whose values were determined so that ALAKE outputs approached the COSMO values. The comparison of the COSMO and ALAKE outputs showed that the outputs have similar statistical features, suggesting that the ALAKE model can estimate the influence of a lake on the temperature characteristics in its vicinity. Knowing basic climatology of a given place and information on the size and shape of a new water area, using ALAKE we can estimate the influence of the water area on local temperature, humidity and wind speed.

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Wind energy assessment

Wind energy is a traditional topic of the applied research in our department. In the period 2010-2014 the activities concentrated on performing selected studies and expert services, which provided the highest added value. Wind measurement services, which made a large

part of our contractual activity in the past, were discontinued in 2011. Special wind measurements and experiments, however, continue at our observatories Milešovka, Kopisty and Dlouhá Louka. Roughly 80 contractual studies and expert services were completed during 2010-2014.

Research activities are focused on wind climatology topics. The main results are:

- Actualization of the map of the wind energy potential in the CR. This is the only map for the CR.
- Developing the methods and calculation of the map of extreme wind speeds in the CR, including the analysis of return periods (L. Pop, Ph.D. thesis).
- A novel measure-correlate-predict technique for simulation of long-term wind data series from short-term wind measurements (D. Hanslian, Ph.D. thesis).

References:

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Cooling tower plumes

We developed a model CT-PLUME that simulates the rise and diffusion of plumes from cooling towers. It is a 1D Lagrangian model based on the simplified primitive equations and the Kessler´s microphysics. After reaching its maximum height, the plume is treated as a passive tracer. By using the Lagrangian diffusion model, the plume is advected and mixed with surrounding air. For a given locality, CT-PLUME is able to calculate the impact of cooling tower plumes, specifically the change of temperature and humidity, shading effects, increased occurrence of icing or fog.

In the last 5 years, we had several contracts to perform studies focused on the evaluation of the impact of new cooling towers on the environment. Among others, we performed several studies for the nuclear power stations Temelín and Dukovany, and a similar study for the nuclear power station Jaslovské Bohunice in Slovakia.

Quantitative estimation of leakage of airborne dust PM10 from the Bílina open mine into environment

For Severočeské doly, a. s., a study was performed based on the numerical simulations of air flow in the Bílina open coal mine and its surroundings for 32 scenarios representing typical synoptic situations as well as extreme situations from the point of view of dust dispersion. The air flow model was able to provide wind field results suitable for the application of air pollution dispersion models. A dust dispersion model including the deposition effects was developed and applied. According to the results, 50% of the PM10 dust particles originating in the open mine remain in the mine.

Research Report of the team in the period 2010–2014

Institute	Institute of Atmospheric Physics of the CAS, v. v. i.

Scientific team	Department of Climatology

The research team dealt with various topics related to statistical and dynamical climatology, with special focus on atmospheric circulation and its links to surface climate, solar and geomagnetic influences on climate, climate variability/change and its impacts on sectors such as agriculture, water resources and public health, climate model evaluation studies, and extreme value analysis.

Although the department is relatively small (also in comparison to other teams of the Institute), its members published 50 papers in international peer-reviewed journals in 2010–14; in 34 of them the first author was from the department, which illustrates significant contribution of the team to these results, and in 12 of them the first author was a PhD student, in most cases supervised by a senior researcher from the team. The latter provides evidence on large involvement of students in research activities of the department, and hence good opportunities and prospects for positive development in the near future. The journals in which the team members published in 2010–14 included top journals in the field of climatic research (Climate Dynamics, Climatic Change, Global and Planetary Change, Journal of Geophysical Research, etc.). Three senior researchers have their h-index between 19 and 20 (M. Dubrovský, R. Huth, J. Kyselý), which underlines international relevance and impact of the research conducted by the department.

Main results of the scientific work of the department in 2010–14 included the following topics:

Links between atmospheric circulation and surface temperature and precipitation in climate models

We examined how current climate models capture the large-scale atmospheric circulation and links between circulation and characteristics of daily surface air temperature and precipitation, with focus on Central Europe. Regional climate models (RCMs) were found to suffer from deficiencies in simulating large-scale circulation over Europe: general biases include overestimation of the frequency of strong flow days and of strong cyclonic vorticity. However, most RCMs improve on the driving global climate model (GCM). The influence on circulation characteristics in the nested RCM differs among GCMs. Relatively strong relationships between circulation indices and surface temperature and precipitation were found in the observed data. RCMs qualitatively reproduce these relationships and the links tend to be more realistic compared to those in the driving GCMs.

The analysis of the links between circulation and surface air temperatures allows for better understanding biases in simulated diurnal temperature range (DTR): underestimation of DTR, which is a common feature of current climate models in Central Europe, is larger under anticyclonic circulation, and in warm half-year, it tends to be largest for the southeast to south flow associated with warm advection. Our results also suggest that the large negative

bias in DTR for anticyclonic circulation cannot be explained by a bias in cloudiness. Errors in simulating heat and moisture fluxes between land surface and atmosphere probably contribute to the biases in DTR as well.

References (team members are in bold):

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Temperature extremes in observed data and climate model simulations

We proposed a methodology for estimating high quantiles of distributions of daily temperature in a non-stationary context based on peaks-over-threshold analysis with a time-dependent threshold expressed in terms of regression quantiles. The extreme value models were applied to estimate 20-yr return values of maximum daily temperature over Europe in transient GCM simulations for the 21st century. We demonstrated that application of the stationary extreme value models in temperature data from GCM scenarios yields results that may be to a large extent biased, while the non-stationary models lead to spatial patterns that are robust and enable one to detect areas where the projected warming in the tail of the distribution of daily temperatures is largest. The method also allows splitting the projected warming of extremely high quantiles into two parts that reflect change in the location and

scale of the distribution of extremes, respectively. Spatial patterns of the two components were found to differ significantly in the examined climate change projections over Europe.

We examined the capability of ENSEMBLES RCMs to reproduce spatial and temporal characteristics of severe central-European heat waves. The multi-model mean reflected the observed characteristics of heat waves quite well, but considerable differences were found among the individual RCMs. The RCMs had a tendency to simulate too many heat waves that were shorter but their temperature peak was more pronounced on average compared to E-OBS. Using as an example the most severe Central European heat wave of 1994, we demonstrate that its magnitude was underestimated in all RCMs and that this bias was linked to overestimation of precipitation during and before the heat wave. This illustrates that land–atmosphere coupling is crucial for developing severe heat waves and its proper reproduction in climate models is essential for obtaining credible scenarios of future heat waves.

We dealt also with long-term variability of heat waves (in Central Europe and Argentina, within a joint project with the University of Buenos Aires), evaluated the hot central-European summer of 2013 in a long-term context, and estimated recurrence probabilities of recent severe heat waves using simulations with a stochastic time series model in the recent climate and under climate change scenarios.

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Statistical modelling of precipitation extremes and their climate change scenarios

We compared several approaches to estimating distributions of precipitation extremes by means of simulation experiments, and evaluated their applications into observed data as well as climate model outputs. The region-of-influence method with a built-in regional homogeneity test was recognized as a particularly useful approach, with the model based on

proximity of sites outperforming the Hosking-Wallis regional frequency analysis. Comparison of estimates of the return period of a heavy precipitation event on June 24, 2009, which triggered a disastrous local flash flood in the NE part of the Czech Republic, illustrated that the at-site analysis leads to unrealistic estimates that strongly depend on whether or not a single outlying observation is involved in the sample, while all regional methods yielded return periods in the same order of several hundreds of years, notwithstanding whether the 2009 data was included in the sample. The region-of-influence method was also found to represent an efficient tool for smoothing random variations in the estimates of model parameters and high quantiles of precipitation in high-resolution RCMs.

In another simulation study, we compared coverage probabilities of confidence intervals (CIs) of high quantiles obtained by the nonparametric and parametric bootstrap for heavy-tailed distributions, typical for maxima of precipitation amounts. We showed that both bootstrap methods underestimate the width of the CIs; the parametric bootstrap is superior to the nonparametric one, especially for small and moderate sample sizes and for very heavy-tailed data; and even a misspecification of the parametric model, often unavoidable in practice, does not prevent the parametric bootstrap from performing better in most cases. A tendency to narrower CIs from the nonparametric than parametric bootstrap was demonstrated in the application to high quantiles of distributions of observed maxima of 1-day and multi-day precipitation amounts.

For the Mediterranean region, which represents one of the climate change hot spots, we examined scenarios of precipitation extremes in an ensemble of RCMs from the ENSEMBLES project. Precipitation extremes were considered at a wide range of time scales from hourly to multi-day amounts and in individual seasons. Climate change scenarios for the late 21st century (2070–99) were found to differ substantially for short-term (hourly) and multi-day (5-day and 15-day) extremes, mainly in the western Mediterranean. Projected increases in short-term extremes exceed those of daily and multi-day extremes, and occur even in regions and seasons in which mean precipitation is projected to decline. This change in the patterns of extreme precipitation may have important hydrological consequences, with increases in the severity of flash floods in a warmer climate in spite of the overall drying projected for the region. However, uncertainty of the scenarios of precipitation extremes related to within-ensemble variability is large. Consistency of the projected changes amongst the RCMs is highest in winter and lowest in summer, and generally it is larger for short-term than multi-day extremes.

We also proposed algorithm for disaggregating precipitation data into predominantly convective and stratiform, and evaluated biases in characteristics of convective (subgrid) and stratiform (large-scale) precipitation in an ensemble of RCM simulations for recent climate in Central Europe, with focus on extremes. We found that characteristics of total precipitation are often better simulated than are those of convective and stratiform precipitation evaluated separately. Extremes are underestimated for convective precipitation while they tend to be slightly overestimated for stratiform precipitation, which results in a relatively good simulation of extremes in total precipitation amounts. For convective precipitation extremes, the effect of areal averaging (as estimated by area reduction factors) is small in comparison to the identified biases. The results support previous findings that errors in precipitation characteristics in climate models are mainly related to drawbacks in the representation of convection.

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Phase coherence between solar/geomagnetic activity and climate variability

In previous studies we observed statistically significant phase coherence among the common oscillatory modes with the period of approximately 7–8 years beginning from the 1950s, detected in long-term monthly time series of sunspot numbers, geomagnetic activity aa index, North Atlantic Oscillation (NAO) index and near-surface air temperature from several mid-latitude European stations. Focusing on geographical distribution of the phenomenon we studied Northern Hemisphere patterns of phase coherence between solar/geomagnetic activity and ERA40 and NCEP/NCAR near-surface air temperature. Both the reanalysis datasets provide consistent patterns of areas of response which are confined within the areas of coupling with the NAO. Applying the conditional phase coherence, we identified the role of the NAO in transfer of geomagnetic/solar influences from stratosphere to troposphere.

Non-linear dependence quantification methods were tested for use in the climate teleconnection studies using the same reanalysis datasets.

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period 7–8 years oscillatory modes. Nonlinear Processes in Geophysics 18, 251–260 [doi:10.5194/npg-18-1-2011].

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Analyses of atmospheric circulation (synoptic) classifications and modes of low-frequency variability

We contributed to international project COST 733 (Harmonisation and Applications of Weather Types Classifications for European Regions) by providing a classification method based on principal component analysis (PCA), analyzing synoptic-climatological properties of classifications of circulation types, and examining the long-term trends of frequencies of circulation types and how they relate to temperature and precipitation trends. International collaboration within COST Action ES1005 (Towards a more complete assessment of the impact of solar variability on the Earth's climate) materialized in the quantification of effects of solar variability on the position and intensity of the centres of action in the Atlantic Ocean (Icelandic cyclone and Azores anticyclone).

We analyzed the sensitivity of the effects the NAO exerts on surface temperature and precipitation in Europe to the definition of the NAO index. Seven different NAO indices were examined: two based on station sea level pressure (SLP) data, two based on action centres, and three based on correlation/covariance structures described by PCA. We found out that the influence of the NAO differs considerably between NAO definitions, the difference being larger in summer than in winter. Correlations differ among the NAO indices not only in their magnitude but in some regions in summer also in their sign. These effects can be explained by a northward shift of the whole NAO pattern and its action centres in summer, away from the sites on which the station indices are based, and by a decoupling of the Azores high and Icelandic low from the centres of high covariability, identified by PCA.

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Development of climate change scenarios and their applications in impact assessments

Stochastic weather generator as well as the methodology for creating future climate scenarios have been permanently improved and used in various climate change impact studies in collaboration with partners from the Czech Republic and other countries. As an example, future climate conditions for the Mediterranean region based on an ensemble of 16 GCMs were expressed and mapped using several approaches. Changes in drought conditions represented by the Palmer Drought Severity Index indicate a significant decrease in soil moisture in all seasons, mainly in summer; the changes exhibit high inter-model agreement. Temperature maxima are projected to increase not only because of an overall rise in temperature, but in some areas also because of increases in temperature variability and the diurnal temperature range.

We developed a methodology for identifying a representative subset of GCMs for use in large-scale climate impact research. Based on objective criteria (GCM performance in reproducing the seasonal cycle of temperature and precipitation, and a subset ability to represent future inter-GCM variability), two candidate subsets were selected from a reference set of 16 GCMs. An additional subset based on subjective expert judgement was also included in the analysis. The representativeness of the three subsets was validated and compared for future changes in temperature, precipitation and Palmer drought index Z (direct validation), and occurrence of the European corn borer and snow-cover characteristics. The direct validation indicates that one of the objective-based subsets (ECHAM5/MPI-OM, CSIRO-Mk3.0, HadGEM1, GFDL-CM2.1 and IPSL-CM4 models) provides the best choice for the Europe-wide climate change impact study. Its performance is balanced between regions, seasons and validation statistics. However, the expert-judgement-based subset achieved slightly better results in the indirect validation. The differences between the subsets and the reference set are generally much lower for the impact indices compared to their mean (across all GCMs in the subset) changes due to projected climate change. The ranking of the candidate subsets differs between regions, climatic characteristics and seasons, demonstrating that the subset suitability for a specific impact study depends on the target region and the roles of individual seasons and/or climatic variables on the processes being studied.

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Human biometeorology

We examined impacts of temperature extremes and sudden air temperature and pressure changes on mortality and morbidity in the population of the Czech Republic, with focus on differences in the effects in urban and rural populations and between chronic and acute cardiovascular diseases (CVDs). Analysis of relationships between hospital admissions and sudden air temperature and pressure changes showed that sudden pressure drops in winter were associated with significant rise in hospital admissions while a similar effect was not observed in summer, nor for pressure increases. Comparison of datasets on CVD mortality and hospital admissions suggests that observed declines in in-hospital case-fatality rates (which contrast with little pronounced trends in CVD hospital admissions) explain significant part of the decline in national deaths from ischaemic heart disease, acute myocardial infarction and stroke. Oppressive air masses associated with negative effects on human health were identified using Spatial Synoptic Classification and Temporal Synoptic Index. Analysis of long-term changes in the effects of warm temperature extremes showed significant changes towards less pronounced impacts on mortality over the last two decades while there was no trend in the effects on morbidity. Methodological studies that compared different approaches and statistical methods used in air mass classifications were carried out using nation-wide data for the Korean population, resuming cooperation with the Korea Meteorological Administration.

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The department has been involved in international collaboration through joint research projects, including participation in COST projects (ES1005 – TOSCA – Towards a more complete assessment of the impact of solar variability on Earth's climate; ES1102 – VALUE – Validating and Integrating Downscaling Methods for Climate Change Research; 733 – Harmonisation and Applications of Weather Types Classifications for European Regions) as well as bilateral research projects with institutions in Italy, Spain, and Argentina. Numerous other collaborative partnerships in which the team members have been involved are informal, being realized without support of projects within international networks, or resuming previous collaboration established in the framework of finished projects.

Research Report of the team in the period 2010–2014

Institute	Institute of Atmospheric Physics of the CAS, v. v. i.

Scientific team	Research team of upper and middle atmosphere

The team dealt with studies of various aspects of behaviour of the ionosphere, thermosphere and middle atmosphere, predominantly in the five following areas:

1. Atmospheric waves and their impact on the ionosphere and upper atmosphere (Chum, Sindelarova, Koucka Knizova, Lastovicka, Buresova, Base Hruska, Fiser, Boska, Kouba, Mosna)

To study the propagation of gravity waves (GWs) and infrasound in the ionosphere, we installed multi-point continuous Doppler shift measurement in the Czech Republic, southernmost South Africa (June 2010), northwest Argentina, Tucumán (late 2012) and Taiwan (late 2013). The installation of the Doppler system in Argentina and Taiwan are very useful since they are below the crest of the Equatorial Ionization Anomaly (EIA) and hence make it possible to monitor equatorial spread F. This unique worldwide network of Doppler arrays could significantly contribute to global studies of the impact of tropospheric gravity and infrasonic waves on the ionosphere, better understanding of troposphere-ionosphere coupling, seismo-ionospheric coupling and improvement of ionospheric models.

Our recent results from the mid-latitude stations (Czech Republic and South Africa) can be summarized as follows: Most frequently observed velocities of GWs are ~100–200 m/s. The GWs propagated roughly poleward at both locations during the local summer and equatorward during the local winter (northeast propagation in South Africa). Westward propagation was rarely observed in the Czech Republic, whereas eastward to southeast propagation was rare in South Africa. The observed GWs propagated approximately against the background neutral winds obtained by the HWM07 model. Typical reflection heights of the observed waves measured by nearby ionosondes were ~150–250 km. The observed periods of GWs usually ranged from ~8 to 30 minutes. It should be emphasized that we have mainly focused on relatively short period and short to medium scale GWs for which the multipoint Doppler sounding system is appropriate. Our results from the mid-latitude ionosphere are quite similar with the GW directions found in the neutral atmosphere in the middle-latitude mesopause region by optical measurements. The poleward propagation in the local summer is usually associated with the intense convective activity in the equatorial troposphere. The similarity between seasonal variation of GW propagation directions reported from optical observations in the mesopause region and our results indicates that it is likely that we observed GWs that propagated upward from the lower atmosphere. It should be noted that secondary waves could be generated from wave-wave interactions and wave breaking in the mesosphere-lower thermosphere (MLT) region. We cannot exclude that some of the analyzed waves were generated in the thermosphere by solar terminator. [Chum et al., 2010, JGR, 115, doi:

10.1029/2010JA015821; Chum et al., 2012, JGR Space Phys., 117, doi: 10.1029/2011JA017161]

Our measurements in the low-latitude ionosphere, both in Tucumán and Taiwan, have not revealed any systematic dependence on season. In Tucumán, meridional direction of GW propagation dominated. In Taiwan, the south-west propagation was rare. The continuous Doppler sounding can also be used to investigate horizontal propagation of equatorial/low-latitude spread F. We showed that oblique spread structures are observed in the Doppler shift spectrogram at the same time as the strong range spread F in the ionograms in Tucumán. These structures propagate roughly eastward at velocities ~70 to 200 m/s. This is consistent with optical measurements based on the airglow from F2 layer. The Doppler measurements are however independent on weather conditions. [Chum et al., 2014, JGR Space Phys., 119, doi: 10.1002/2014JA020184]

The strong Tohoku earthquake on 11 March generated seismic waves that propagated world-wide. These seismic waves then excited acoustic waves locally. Infrasound waves generated locally were also observed by Doppler sounding system in the ionosphere above the Czech Republic, about 9000 km away from the epicenter. We identified in the ionosphere separate wave packets corresponding to P, S, SS and Rayleigh seismic waves that exhibited high cross-correlation (>0.9) with the vertical motion of the ground surface below. The wave packets in the ionosphere were observed about 9 minutes after the arrival of the corresponding seismic waves, which was in good agreement with the calculated time for vertically propagating infrasound waves to the height of observation (~210 km). The usually used “radar” formula, which is based on mirror-like reflection, cannot be used to obtain the air particle oscillation velocities from Doppler shift values. We derived simple approximation that takes into account the air (plasma) compression owing to the infrasound waves at the altitude of observation and avoids the integration along the whole sounding path. [Chum et al., 2012, JGR Space Phys., 117, doi: 10.1029/2012JA017767]

Waves of periods 1-60 min in the ionosphere above South Africa were studied using the measurements from the Doppler sounding systems. Wave activity in geomagnetically quiet and geomagnetically disturbed periods was compared. The 4-30 min waves occurred independent of the level of geomagnetic activity, whereas large scale waves with periods 30-50 min were observed on geomagnetically disturbed days. [Sindelarova et al., 2012, Adv. Space Res., 50, doi: 10.1016/j.asr.2012.04.016]

Pruhonice observatory routinely provides ionospheric drift measurements in both E and F region in addition to classical ionospheric sounding since 2004. Such data are used among others for GW/TID investigations. Method for correct data processing was developed for drift measurement technique. This method guarantees high data quality and it was included to the standard software for digisonde data processing. [Kouba and Koucka Knizova, 2012, JASTP, 90-91, 10.1016/j.jastp.2012.05.006].

A study has been started that deals with infrasound environment at Czech infrasound stations. A good knowledge of the station environment is essential for correct evaluation of infrasound detections and for the search of potential signal sources. Background noise levels in the Czech microbarograph network were estimated and seasonal and diurnal variability was studied. The wind generated micropressure fluctuations seem to be the main source of background noise in the microbarograph records. The seasonal variability is strong particularly in the frequency range 0.1-0.35 Hz. A spectral peak related to microbarom signals is observed in winter with amplitudes about one order higher than in summer. The

microbaroms observable in Central Europe are mainly generated in the Northern Atlantic. The seasonal variability of microbarom amplitudes depends (except for the intensity of the source) on direction of stratospheric winds and responds to the seasonal reversal of the winds. The study will continue in the next period 2015-2019 with focus on directions of signals arrivals. [Sindelarova et al., 2015, JASTP, 122, doi: 10.1016/j.jastp.2014.10.014]

Case studies were performed that dealt with infrasound generated from local sources, particularly from convective storms and weak earthquakes. The analysis of infrasound measurements close to the earthquake epicentral zone showed that signals are generated by vertical motions of the Earth surface. Narrow infrasound pulses comprising compression phase and consequently decompression were observed by microbarometer array at Panska Ves observatory during thunderstorms. Relating the observed infrasound pulses to the lightning locations and times from EUCLID (European Cooperation for Lightning Detection) shows that these pulses are very likely associated with intracloud lightning. The preceding rapid changes of the electrostatic field, potential association of the pulses with intracloud discharges, spectral characteristics and high elevation angles of infrasound signals arrivals indicate that electrostatic mechanism can be responsible for generation of the signals. We found that those electrostatic models, which are based on only one charge layer, are inconsistent with the measurements. [Lastovicka et al., 2010, JASTP, 72, doi: 10.1016/j.jastp.2010.08.005; Chum et al., 2013, JGR Atmospheres, 118, doi: 10.1002/jgrd.50805]

The team was involved in EU 7th FP project ARISE (2012-2014). The main objective was to establish international collaboration of European teams involved in investigations of different atmospheric layers, to review existing knowledge of atmospheric dynamics and to assess network and types of available observatories. The measurements of the Doppler sounding system were assessed as a sounding technology that suitably complements the three main technologies of atmospheric sounding involved in the project (microbarograph, lidar, airglow). Data have been provided in the ARISE database. We prepared our microbarograph measurements for inclusion into the ARISE database. The team contributed to ARISE reports.

Correlation of long time series of foF2 from European ionosonde stations was analysed with respect to latitudinal and longitudinal difference and surface distance of stations. Time series of foF2 are highly correlated reflecting the dominant solar influence. Correlation coefficients are high for fluctuations around mean as well. At the surface distance exceeding 1000km and/or about 10 degrees in longitude, the correlation coefficient of fluctuations decreases rapidly. The correlation coefficients for latitudinal differences decrease with increasing distance with less pronounced threshold. The 'break point' distance of 10 degrees in longitude is comparable with the size of mesoscale tropospheric systems that are known to be an important source of atmospheric waves in a broad period range.

Significant oscillations at periods corresponding to tidal (diurnal and semidiurnal) and planetary wave domains were detected in the sporadic-E data (foEs, hEs) and stratospheric and mesospheric temperature and wind data. However, only limited coherent wave bursts occur. They are located predominantly on periods close to main modes of planetary waves (Rossby modes, periods 2, 5, 9-10, and 15 days). Phase lags between analysed data are highly variable. This supports non-linear relationship between analysed vertically distant regions. It was also shown that classical ionosondes provide in average higher values of

foEs than modern DPS digisondes due to their inability to distinguish between vertical ordinary mode reflections, extraordinary vertical mode reflections and oblique reflections from sporadic-E. [Mosna and Koucka Knizova, 2012, JASTP, 90-91, 10.1016/j.jastp.2012.04.007; Lastovicka et al., 2012, JASTP, 74, doi: 10.1016/j.jastp.2011.10.008]

2. Impact of space weather and solar activity on the ionosphere and upper atmosphere (Buresova, Lastovicka, Koucka Knizova, Mosna, Kouba, Boska, Urbar)

Our investigations addressed disturbed ionosphere F region variability, its seasonal, longitudinal, hemispheric, storm intensity, solar activity and solar wind dependence, and scenario of the ionospheric behaviour during the storm main and recovery phases at middle latitudes. Investigations were based on ionosonde and GPS TEC data from European, African and American sectors. [Habarulema *el al.,* 2013, JASTP,102, doi: 10.1016/j.jastp.2013.05.008; Kutiev *et al*., 2013, J. Space Wea. Space Clim., 3, A06, doi:10.1051]

Particular attention we paid to ionospheric response to weak geomagnetic storms during the late declining phase of the 23rd solar cycle and the deep 23/24 solar minimum; the response is found to be comparable with or even slightly stronger than that to strong storms under higher solar activity conditions, which might be partly related to specific impact of different drivers of geomagnetic activity (ICME- and CIR-related storms). CIRs (Corotating Interaction Regions) dominate geomagnetic activity during the declining phase and solar cycle minimum. The CIR-related magnetic storms are weak-to-moderate. Typically Bz fluctuates, AE and Kp is increasing but effect in Dst is relatively small with the positive phase of Dst often larger than the negative one, as it often happened in 2007-2009. Under higher (normal) geomagnetic/solar activity conditions the negative phase dominates in the Dst storm behavior as a rule. Although Dst remains smaller, the fast solar wind streams with southward IMF last much longer and consequently CIR-related storms are of longer duration. Thus the cumulative effects of the fast wind-driven storms could be more severe than the effects of ICME events with large peak Dst. When evaluating observed ionospheric behaviour under magnetic storm conditions of different magnitude, our results show that in general, both positive and negative long- and short-lasting departures of *foF2* and *hmF2* from their 27-days running means took place in all seasons and studied locations for all strong-to-intense and minor events involved in the analysis. [Buresova et al., 2014, Adv. Space Res., 54, doi: 10.1016/j.asr.2014.04.007]

Hemispheric asymmetry of ionospheric response at middle latitudes, in average is not a dominant and/or strong feature. The asymmetry in individual events may be well pronounced both in *foF2* and *hmF2*, but mostly it seems to be an impact of other factors like seasonal variation, magnetic coordinates or local time.

Our analysis of the *foF2* values observed at European middle latitude stations for 45 strong-to-severe magnetic storms indicates some seasonal dependence of the electron density variation within the recovery phase, mostly: (i) night time decrease with occasional daytime increase during the winter storms; (ii) daytime and night time increase in summer; (iii) daytime (occasionally also night time) increase at equinoxes. An alternation of positive and negative effects has been observed for most of the analysed events. The comparison showed that *foF2* values are generally within ±30-40% of the quiet time reference.

To obtain patterns of variation of mean *foF2* and *hmF2* values over European region as a function of solar activity, location and daytime we analysed all available ionosonde data from 8 stations and for four solar cycles. We studied daily, semi-annual and annual variation of *foF2* and *hmF2* and latitudinal, longitudinal and solar activity dependence of the variation. The results of the analysis indicate that the annual and semi-annual variation could be different events within the European sector. Significant differences exist particularly in daily and annual course of *hmF2* at higher-middle and lower-middle latitudes for quiet conditions. In general the following observations for *hmF2* are noted: (i) European stations show well-pronounced annual variation during the daytime with winter minima and summer maxima. (ii) The data analysis show some features of the semi-annual variation in *hmF2* with some indications of local time and latitudinal dependence. The vernal peak is usually of higher amplitude than the autumnal peak. (iii) The analysed annual variation of *hmF2* indicates, in general, smallest differences between higher and lower solar activity during local winter time. [Mosert et al., 2012, Earth Planet. Space, 64, 10.5047/eps.2011.04.013]

Analysis of interplanetary magnetic field (IMF) during extreme solar events from periods of both high and low solar activity and corresponding ionospheric response in the F-region from different European ionospheric stations revealed an increase of wave-like activity in *foF2* during several days after a strong southward Bz occurrence.

3. Development of the International Reference Ionosphere (IRI) (Truhlik, Buresova, Triskova, Podolska, Sindelarova)

The main goal of these investigations was to improve and develop models of thermal plasma parameters (concentration, temperature) that could contribute to the improvement of the reference model of the ionosphere IRI. The members of our team have been involved in this task due to the long tradition of measuring and processing data from satellites and ionosondes. The modelling was based on the extensive database of the thermal plasma measurements including all available satellite measurements (from early Explorers to most recent DMSP and CHAMP). The database is continuously updated by new available data sets.

We developed a new global model of the electron temperature for the upper and topside ionosphere (altitude range 300-2000 km) with inclusion of the solar activity variation. This model (TBT-2012) was included in IRI as the recommended option for the electron temperature since IRI-2012. Although many attempts in the past were made to understand influence of the solar activity on the electron temperature, it remained unsolved due to inconsistency among various datasets, measurement errors (e.g., contaminations of satellite probes), inconsistency between results of different techniques (ISR vs. satellite) and also because this variation is mostly of the second order. The model consists of the core model describing global distribution of the electron temperature on main geophysical parameters. The variation with solar activity was modelled as a correction term of the core model. [Truhlik et al., 2012, Earth Planet. Sci., 64, 10.5047/eps.2011.10.016]

In addition to the own modelling we studied some phenomena whose understanding is important for the modelling and we found as follows:

- Electron temperature in the morning overshoot and in the upper ionosphere (particularly at the altitude of 450 km) decreases with increasing solar flux by about 10K per 1 s.f.u. of F10.7. [Stolle et al., 2011, JGR Space Phys., 116, doi: 10.1029/2010JA016235]

- Electron temperature in the Southern Hemisphere at mid-latitudes shows a strong longitudinal dependence.

- Electron density and ion and electron temperature in the high latitude topside ionosphere are strongly dependent on the solar zenith angle.

- Time delays between 27-day solar rotation period and F2-region plasma frequency is dependent on longitude and varies from 1 to 4 days. Similar dependence shows TEC, as well. [Triskova et al., 2011, JASTP, 73, doi: 10.1016/j.jastp.2010.12.017]

- Ion composition in the topside ionosphere is strongly dependent on the solar cycle; during the extreme low solar activity in 2008-2009 the upper transition height was extremely low. However, extrapolated data from Atmosphere Explorer C and E to these low solar activities (F10.7 about 65) can be used to adequately describe the ion composition for these conditions.

- Electron density in the high latitude ionosphere is strongly dependent on geomagnetic conditions. During large storms electron density can increase or decrease depending on local time, latitude and hemisphere.

- We also studied influence of geomagnetic disturbances on the ion composition and plasmapause position (using re-evaluated OGO-5 data set). It was found that the ion concentrations of both H^+ and He^+ describe the plasmapause position sufficiently accurately but with an exception of the cases of the recovery phase of geomagnetic disturbances. [Truhlik et al., 2014, JASTP, 119, doi: 10.1016/j.jastp.2014.06.007]

For the modelling adequate data sources are needed. Due to the tradition of our team in development of instruments we used an opportunity to take part in the RESONANCE project. We have developed and built in collaboration with a team in IKI RAS (Moscow, Russia) an instrument for measurement of plasma temperature, density and composition for the project RESONANCE (identical four satellites in the topside ionosphere and plasmasphere region). The launch of the RESONANCE satellites is planned on 2018.

We validated the IRI Storm-Time Ionospheric Correction Model (STORM) for selected locations at Northern and Southern Hemisphere middle latitudes using 65 strong-to-severe geomagnetic storms from the period 1995-2007. In the validation data from some ionospheric stations not included in the development or the previous validations of the model, were used. Hourly values of *foF2*, measured for 5-7 days during the main and recovery phases, were compared with the predicted IRI 2007 *foF2* with the STORM model option. The results of the comparative analysis show that the STORM model captures more effectively the negative phases of the summer ionospheric storms, while the electron density enhancement during winter storms and the alternation of the different storm phases, as well as behaviour of *foF2* during storm recovery phase is reproduced with less accuracy. The STORM model corrections are less efficient for lower than higher middle latitudes and severe geomagnetic storms. The IRI STORM model gave no reliable corrections of *foF2* for analyzed minor CIR-related storms, which occurred during the prolonged declining phase of

the 23rd solar cycle and deep solar minimum 23/24. [Buresova et al., 2010, Adv. Space Res., 46, doi: 10.1016/j.asr.2010.06.007; Araujo-Pradere et al., 2013, Adv. Space Res., 51, 10.1016/j.asr.2012.02.010; Buresova et al., 2014, Adv. Space Res., 54, doi: 10.1016/j.asr.2014.04.007]

V. Truhlík has been vice-chairman and D. Buresova member of the COSPAR/URSI IRI working group. V. Truhlik was member of Program Committees of several IRI workshops and IRI sessions during COSPAR scientific assemblies.

4. Long-term trends in the ionosphere-upper atmosphere system (Lastovicka, Kozubek, Krizan)

Long-term strategic goals of these investigations have been to improve and broaden the scenario of global climate change in the upper atmosphere-ionosphere, to specify roles of different non-greenhouse trend drivers, and activities towards joining stratospheric and upper atmospheric trends into one scenario. Some similarities have been observed between change of trends in stratospheric and mesospheric temperatures including their simultaneous response to reversal in ozone trend. We found a similar longitudinal structure and reversal of trends (in coincidence with ozone trend reversal) in winds from the middle stratosphere up to (preliminary) lower mesosphere based on the MERRA reanalysis global northern midlatitude data. However, break-up points of upper mesospheric wind trends are in most cases not related to the break-up points of ozone trends. The trend pattern of the MLT region (mesosphere and lower thermosphere) winds is complex, regionally substantially different and changing in time (piecewise linear trends). Moreover these trends strongly depend on season (might be even opposite for winter and summer) and altitude. Model results confirm regionally substantially different trends but they do not allow find origin of these differences. For such a pattern of trends we do not have enough observational data. We also took part in studies of mesospheric wind trends at equatorial latitudes, where model-simulated results qualitatively agree with observations. [Venkat Ratnam et al., 2013, Geophys. Res. Lett., 40, doi: 10.1002/jgra.50158; Lastovicka et al., 2012, Space Sci. Rev., 168, doi: 10.1007/s11-214-011-9799-3; Lastovicka, 2013, JGR Space Phys., 118, doi: 10.1002/jgra50341]

Main open problem consists in trends in atmospheric waves, which are the main factor responsible for vertical coupling in the system troposphere-stratosphere-mesosphere-thermosphere. We now know for sure that trends of all types of waves, planetary, tidal and gravity waves are regionally different and unstable with time. Some gravity wave trend sources, like shifts of tropospheric storm tracks, can cause opposite trends on opposite sides of storm tracks. Planetary wave trends for different period sub-ranges are significantly different. [Lastovicka et al., 2012, Space Sci. Rev., 168, doi: 10.1007/s11-214-011-9799-3; Lastovicka, 2013, JGR Space Phys., 118, doi: 10.1002/jgra50341]

Changing trends in response to changing ozone trends have been detected in the stratospheric, mesospheric (role CO_2:O_3 = 2:1) and mesopause region temperature, as well as in stratospheric winds. We succeeded to show that the hypothesis on possible impact of ozone trends on the total electron content is wrong. The role of various secondary (= non-CO_2) trend drivers, namely ozone, geomagnetic activity and secular change of geomagnetic field has been specified; there are several other drivers like atmospheric wave activity and (mesospheric) water vapour, the long-term

behaviour of which is not yet clear enough to make estimation of their role possible. CO_2 is the primary driver of long-term trends in the mesosphere-thermosphere-ionosphere system. Several other trend drivers like ozone or geomagnetic activity reversed their own trends during the last 20 years; others like secular change of Earth's magnetic field or atmospheric wave activity have regionally very different impact on trends, whereas the effect of CO_2 trend is global and stable in time. Consequently we cannot expect spatially homogeneous and temporally stable trends in the upper atmosphere-ionosphere system. [Lastovicka, 2012, Ann. Geophys., 30, www.ann-geophys.net/30/811/2012/; Lastovicka et al., 2012, Space Sci. Rev., 168, doi: 10.1007/s11-214-011-9799-3; Lastovicka, 2013, JGR Space Phys., 118, doi: 10.1002/jgra50341]

Our analysis has shown that part of the discrepancies and problems between different published results in trends in F2-region parameters is caused by data problems and another part by the use of sunspot number instead of F10.7 for solar activity correction when trends are calculated. The other reason is behavior of other non-greenhouse trend drivers, mainly of geomagnetic activity. Whereas the geomagnetic activity was increasing almost throughout the whole 20th century, now it is low; the geomagnetic activity control of foF2 trends was lost around 2000, that of hmF2 around 1990 and now the increasing concentration of CO_2 is the main driver. Another important effect in some regions (not in Europe) is caused by the secular change of the Earth's magnetic field. Model calculations of greenhouse gas effect on the ionosphere show that foF2 (maximum of ionospheric electron density) is in average located very close to the boundary between the increasing electron density below and decreasing electron density above, which makes foF2 not very suitable parameter for studies of trends of greenhouse gas origin. [Lastovicka et al., 2012, Space Sci. Rev., 168, doi: 10.1007/s11-214-011-9799-3; Qian et al., 2011, JGR, 116, doi: 10.1029/2010JA016317]

Recently reported trends in total electron content (TEC) over 1995-2010 with satellite-observed solar EUV radiation for correcting TEC to solar activity are large and positive trend (almost 3 TECU/decade) and even assuming the same level of EUV in minimum 23/24 as in the previous solar minimum the trend is positive. We looked at European historical TEC data and foF2 in order to confirm or disprove the above positive trends in TEC. Ionospheric trends (foF2 and TEC) in 1995-2010 were found to be more positive than in the past, probably due to the last extraordinary solar minimum. Historical European TEC data do not provide any trend in TEC. Explanation of positive trends in TEC is not clear; they rather disagree with model simulations. [Lastovicka, 2013, JGR Space Phys., 118, doi: 10.1002/jgra50261, 2013]

J. Laštovička vice-chaired (until July 2011 chaired) the IAGA/ICMA working group „Long Term Trends in the Mesosphere, Thermosphere and Ionosphere", and co-chaired the CAWSES-II Task Group „How will Geospace Respond to Global Climate Change". Currently he is co-chairman of WG-3 "Trends in mesosphere and lower thermosphere" of ROSMIC/VarSITI/SCOSTEP. He was chairman of Program Committees of several workshops and sessions on trends in the upper atmosphere-ionosphere. He authored/co-authored (mostly as first author) 3 review papers and 19 review presentations at international scientific meetings.

5. Investigations of ozone and stratospheric dynamics (Krizan, Kozubek, Lastovicka)

Unexpected problems with reliability of stratospheric wind data appeared. We compared wind data from broadly used reanalyzes ERA-40, ERA-Interim and NCEP/NCAR, and also compared them for February with Prague-Libus radiosonde observations. The ERA-40 10 hPa winds in the last four winters 1998/99-2001/02 are shown to be wrong. A systematic difference between ERA-40 and NCEP/NCAR in the early years (1950s-1960s) was found in wind strength. [Kozubek et al., 2014, Ann. Geophys., 32, www.ann-geophys.net/32/353/2014/]

At 10 hPa (middle stratosphere) at northern higher middle latitudes in winter (not in summer) we found a well-pronounced two-core longitudinal structure in meridional wind with strong poleward wind in the eastern hemisphere core and strong equatorward wind in the western hemisphere. This structure is explained by the existence of a well-developed blocking Aleutian pressure height, which pushes the very predominantly zonal stratospheric wind poleward on its eastern side and equatorward on its western side. This structure has a pronounced effect also in zonal wind, temperature and a slightly less in ozone fields. In the center of cores the magnitudes of zonal and meridional winds are quite comparable. Core areas exhibit statistically significant (at 99% level) trends – weakening of core in 1970-1995 (period of ozone depletion) and strengthening of core in 1996-2012 (period of partial ozone recovery), i.e. the trend appears to depend on evolution of ozone layer. The two regions between core areas display much weaker trends, either statistically insignificant, or significant at 95% level only. This all should have impact on the Brewer-Dobson (B-D) circulation. [Kozubek et al., Atmos. Chem. Phys., 2015, 15, www.atmos/chem/phys.net/15/2203/2015/]

Trends in laminae in ozone profiles depend both on the total ozone (i.e. on chemistry) and even more on changes in dynamics. Therefore we updated our studies on trends in laminae, which confirmed with prolonged data series that the change of trend in laminae from negative to positive in the mid-1990s continues. [Lastovicka et al., 2014, JASTP, 120, http://dx.doi.org/10.1016/j.jastp.2014.09. 006]

We found some solar cycle effect impact on the B-D circulation. We found also a height dependence of the annual cycle of ozone, which potentially can contribute to interpretation of results on stratospheric winds.

Part of the above investigations was done in frames of the project COST ES1005.

In a bilateral project with China, focused on the annual variation of total ozone at 20°- 60° N, we found that there is a strong longitudinal and latitudinal dependence of this variation. With increasing latitude its amplitude increases with winter/spring maximum and summer/autumn minimum. Longitudinally the maximum amplitude of annual variation is observed near the eastern coast of Asia and the smallest one in Europe and adjacent Atlantic Ocean. We found an increasing trend of the total ozone annual amplitude in recent years. The lowermost tropospheric concentration was found to be much higher in Beijing than in Europe due to Beijing air pollution. [Krizan et al., 2011, Adv. Space Res., 48, 2016-2022]

We ran observatory Pruhonice (digisonde, GPS receiver since late 2013), Czech ionospheric Doppler sounder (up to 5 measuring paths, up to 3 frequencies), and the Czech microbarograph network (5 microbarographs at 3 stations – array of 3 receivers at Panska Ves observatory). We installed our Doppler sounders in the southernmost South Africa (Hermanus), in northwest Argentina (Tucuman), and in Taiwan (the last two close to the crest

of the equatorial ionization anomaly). Our data (particularly digisonde data) have regularly been sent to international databases or data services ISES (we ran the Regional Warning Center (RWC) Prague), DIDBase (Digital ionogram Data Base, USA – we have mirror site for Europe and Asia), DRIFTBase, European ionospheric server DIAS, WDC for Solar-Terrestrial Physics, Chilton, UK, German ionospheric server SWACI, GIRO network, ARISE database.

D. Kouba, M. Kozubek and Z. Mosna defended PhD theses, all in 2014. These theses contributed to the above reported results.

Strength of the team:

- Important role of team and some of its individual members in international scientific collaboration both in international projects and in international scientific bodies.
- Contribution to international monitoring of the ionosphere and atmosphere. We lead international network of ionospheric Doppler sounders. Important role in the development and evaluation of the International Reference Ionosphere.
- Age structure is sufficient to guarantee long-term continuation and sustainability of research. Numerous international contacts of young team members. Close collaboration inside the team.

Weakness of the team:

Lack of stable and sufficient institutional funding of research infrastructure. Although it still enables us to run the current infrastructure (in case of no major accidents/technical troubles), it makes future innovation and maintenance of instrumentation uncertain.

Research Report of the team in the period 2010–2014

Institute	Institute of Photonics and Electronics of the CAS, v. v. i.

Scientific team	Synthesis and Characterization of Nanomaterials

a) Research team

In the evaluated period the Synthesis and Characterization of Nanomaterials Research Team went through a major transformation both in terms of scientific topics and in terms of personal composition and instrumental equipment. This transformation was based on the recommendations of the final evaluation report from 2011, in which the previous period 2005-2009 was evaluated. The major identified issues included an uneven age structure, where only a limited number of scientific workers had a long-term perspective, and a highly fragmented research focus.

In 2010-2011 the section of Materials comprised two teams focusing on the technology and diagnostics of materials for electronics and optoelectronics. These two teams were unified in 2012 and formed grounds for the establishment of the team Synthesis and Characterization of Nanomaterials in 2013. The transformation of the research structure has led to a substantial reduction in the size of the team mostly by retirement and most importantly, streamlining the research by focusing on three major topics.

b) Description of research and main achievements

The following topics were studied by the team in the evaluation period:

(1) Schottky barriers on compound semiconductors and their application to hydrogen sensors.
(2) Optical properties of semiconductors and special glasses.
(3) Nanodiagnostics of semiconductor and photonic materials using scanning ion and electron beams.
   - Interaction of ions with solid surfaces, including focused ion beams and secondary ion mass spectroscopy (SIMS).
   - Ballistic electron emission spectroscopy and microscopy (BEEM/BEES).
(4) Preparation of porous III-V semiconductors and their application in epitaxial growth (phased out in 2013).
(5) Thermoelectrics (phased out in 2012).
(6) Rare-earth elements in III-V semiconductors prepared by liquid phase epitaxy and their application in radiation detectors (phased out in 2011).

The main achievements in the listed research directions follow.

Schottky contacts are one of the key structures in semiconductor devices. We developed a novel method for the preparation of high-quality Schottky contacts on different semiconductor materials by the deposition of colloidal graphite at room

temperature and described the charge transport mechanisms [1-3]. The Schottky diodes showed a high rectification ratio, a large Schottky barrier height, and were stable at elevated temperatures [2]. The graphite contacts have great potential to replace conventional contacts prepared by metal evaporation. We further demonstrated that when the graphite/semiconductor interface is decorated with catalytic metal nanoparticles, extremely sensitive hydrogen sensors can be fabricated [4-6]. The preparation and characterization of Schottky contacts in semiconductor nanostructures has received much less attention than their bulk counterparts. We demonstrated for the first time that graphite creates a Schottky contact to upright standing arrays of ZnO nanorods and described the charge transport mechanism through the graphite/ZnO nanorod junction [7]. An excerpt from the article [3] was selected for the section Highlights in the European Journal/Condensed Matter in Europhysics News 45/2, page 9, (2014).

In collaboration with domestic and foreign laboratories we investigated optical and in particular luminescence properties of special glass materials doped with rare-earth (RE) ions. Chalcogenide and heavy metal oxide glasses are promising materials that are widely studied since they are transparent in the near- and mid-infrared spectral regions and enable drawing of optical fibers. These glasses are also characterized by the high quantum efficiency of the radiative transitions from the doped-in RE^{3+} ions. Low-temperature photoluminescence (PL) spectroscopy was used to systematically investigate radiative efficiencies of RE^{3+} ions in various glass matrices. Low-temperature measurements enabled the simultaneous observation of the luminescence of the host glass with superimposed narrow features due to *4f-4f* transitions in the doped-in RE^{3+} ions. Our laboratory has been the only one to observe these narrow absorption dips superimposed on the broad-band luminescence of the host glass, and to come up with a proper interpretation of these absorption dips as being due to *4f-4f* up-transitions within the doped-in RE^{3+} ions [8]. Low-temperature PL also enabled the determination of the Stark levels splitting of corresponding 4*f* manifolds by identifying the fine structure of relevant emission bands of RE^{3+} ions [9].

We have been studying the interaction of ions with solid surfaces since the late 70's and continued this research in the evaluation period. A fundamental result, which we value the most from that period, is the development of a phenomenological theoretical model [10, 11] describing ion-induced electron emission from solid surfaces at very low impact velocities of the projectiles on the order of ~0.01 or less Bohr velocity. The emission at those velocities was named the subthreshold kinetic electron emission – a phenomenon that has not yet been fully explained. The model provides an analytical formula for the total electron yield as a function of the surface work function, the impact velocity and the atomic number of the projectile and therefore can be directly verified by experiments [12]. The importance of this work consists in the observation that for slow ions, the electron yield depends asymmetrically on the atomic number of the projectile and on that of the target; strongly on the former, weakly on the latter.

One of the team's achievements preceding the current evaluation period was the design and manufacture of an in-house BEEM/BEES instrument. In the evaluation period we significantly improved the long term stability of our BEEM/BEES system, which enabled us to map the density of states of self-assembled InAs quantum dots in the GaAs/AlGaAs matrix grown by metal-organic vapour phase epitaxy (MOVPE) in correlation to the shape of the quantum dot for the two lowest observed energy levels.

Moreover, a relation between the inhomogeneous stress distribution in non-symmetrical quantum dots and the lowest energy level splitting was found [13].

The preparation of high quality lattice mismatched epitaxial layers is among the most challenging tasks related to semiconductor technology. We culminated our long term effort in the preparation of porous semiconductors by showing that highly uniform porous GaAs substrates with low surface roughness are capable of reducing the density of misfit dislocations, thereby increasing the critical epilayer thickness in the InGaAs/GaAs system [14]. The lack of appropriate semi-insulating (SI) substrates for epitaxial growth of InAs layers has stimulated certain interest in the heteroepitaxy of InAs on SI GaAs substrates. One of the methods to overcome the large lattice mismatch between InAs and GaAs consists in the deposition of a low temperature InAs buffer layer. Based on a detailed experimental analysis, we established for the first time the optimum thickness of the low temperature buffer layer to grow high quality InAs [15].

c) Collaborations

The team has developed an intensive collaboration in the preparation and characterization of semiconductor structures with the MOVPE group of the Institute of Physics ASCR. In the evaluation period our collaboration was focused on:

- the characterization of HVPE grown GaN:Fe supplied by Kyma Technologies, USA within the project *Characterization of Low Defect Density Native Gallium Nitride Materials* funded by the Missile Defence Agency, USA. P. Gladkov discovered the method of non-destructive quantification of Fe doping levels in GaN using optical measurements and had a major contribution to the data interpretation [16, 17].
- the direct measurement of the quantum levels in self-assembled InAs quantum dots (QD) present in a GaAs/AlGaAs matrix grown by metal-organic vapour phase epitaxy. A significantly improved home-built BEEM/BEES system enabled us to map the density of states of QDs (in correlation with their shape) for the two lowest observed energy levels [13].
- the technology of lattice mismatch compensation in epitaxial growth by introducing porosity into the substrate [14] and by the deposition of a low temperature buffer layer [15] within the project *Lattice mismatch compensation in heteroepitaxy on micro and nanoporous A3B5 semiconductors and deposition of metals and semiconductors into micropores* of the Czech Science Foundation.

Another long-term collaboration in the field of preparation and characterization of special glasses was with Petr Kostka, head of the group of Special Glass Materials within the Laboratory of Inorganic Materials, University of Chemistry and Technology Prague and Institute of Rock Structure and Mechanics AS CR. This collaboration was supported by two joint projects in the evaluation period [8, 9].

The team had a broad range of international collaborations (only those with common journal articles are listed) in all principal research directions with:

- James H. Dickerson: assistant director of the Centre of Functional Nanomaterials, Brookhaven National Laboratory, USA. This collaboration was established under the international collaboration project *Electrophoretic deposition through a time-varying electric field for research into new physical properties of nanostructured materials* [6].

- Philomela Komninou: head of the Nanostructured Materials Microscopy Group, Dpt. Physics, University of Thessaloniki. This collaboration was established under the EC mobility project *III-V semiconductor heterostructures/nanostructures towards innovative electronic and photonic applications* and focuses on advanced characterization and modelling of semiconductor interfaces and nanoparticles by transmission electron microscopy [14, 15, 18].
- Viktor Brus: University of California, Santa Barbara, USA. This collaboration is on the modelling of transport properties in semiconductor materials [7, 18].
- Leonid A. Kosyachenko: Dpt. of Optics and Electronics, Chernivtsi National University, Ukraine. This collaboration aims at the description of charge transport in semiconductor structures [3].
- Andrey Lomov: Institute of Physics and Technology, Russian Academy of Sciences, Moscow. This collaboration focuses on the characterization of porous semiconductors by X-ray diffraction.
- Peter Williams: Dpt. of Chemistry and Biochemistry of the Arizona State University. This collaboration was established under the bilateral Czech – US project *Micro-Faraday array detector with high dynamic range for multicollector isotopic SIMS* and focuses on SIMS fundamentals [19] and instrumental development [20, 21].
- a number of laboratories in the optical characterization of special glasses: Marcel Poulain, Verres et Ceramiques of Université de Rennes, Zoya.G. Ivanova, Institute of Solid State Physics Bulgarian Academy of Sciences, Marian Kubliha, Slovak Technical University in Bratislava, Vladimir Labas, Catholic University of Ruzomberok, Mihail Iovu, head of laboratory of photoelectrical properties of semiconductors, Institute of Applied Physics, Academy of Sciences of Moldova.

d) Impact

The team has significantly contributed to the scientific and technological development of the Czech Republic by advancing fundamental knowledge in the field of electronic and photonic materials. Unique laboratories of low-temperature photoluminescence spectroscopy and ballistic electron emission spectroscopy have been highly competitive at an international level.

Schottky-based hydrogen sensors which employ the graphite/metal nanoparticle/semiconductor interface are highly sensitive and selective with short response times. Fast monitoring of minute hydrogen concentrations is essential for early-warning against the leaks of combustive hydrogen gas.

The research of the optical properties of infrared transmitting glasses represents one of the most important branches of today's chemistry and physics of non-crystalline solids. The findings obtained have deepened our knowledge and broadened the basis of materials for applications in photonics. In the short term view, the infrared transmitting glasses will find applications in signal transmission and amplification, fibre lasers, or in medicine.

Besides the dominant application of GaN in high brightness light-emitting diodes and lasers for which Japanese scientists were awarded the Nobel Prize in Physics in 2014, GaN also has significant applications in the microwave power electronics. The apparatus developed for the express contactless determination and mapping of the Fe-

concentration in GaN crystals pushes forward the technology of high electron mobility field effect transistors, which demand an electrical isolation between the transistor conductive channel deposited as a thin film and the lattice matched high thermal conductivity substrate. The semiinsulating state is achieved by Fe doping.

e) Resources

The team was active in competing for research funding; 19 research projects were pursued during the evaluation period, twelve of them had a principal investigator from the team, seven had a co-principal investigator from the team. The funding structure was as follows: The Czech Science Foundation (8), bilateral international projects (5), multilateral international projects COST with additional funding from the Ministry of Education CR (3), and The Academy of Sciences CR (3). The projects cover all the topics listed in the research description section. The total budget was 758 thousand euros. A full list of projects is available in part 3.1.

Three unique commercial as well as home-built instruments are installed in the laboratories of the team.

Low-temperature photoluminescence (PL) spectrometer designed and assembled by the team members enables sensitive and high resolution measurements in broad spectral (300-9000 nm) and temperature (3.5-300 K) ranges. It consists of the Sumitomo optical closed cycle helium optical cryostat coupled to the THR 1000 monochromator (Jobin-Yvon) with a spectral range of 300-1700 nm and to uniquely designed setup consisting of modified FTIR spectrometer Nicolet 5700 with spectral range 700-9000 nm. The spectrometer with its exceptionally broad spectral range allows us to investigate a wide range of phenomena and materials.

The team members designed and built ambient condition Ballistic Electron Emission Microscopy/Spectroscopy (BEEM/BEES) instrument based on the Lyding type Scanning Tunneling Microscope (STM). Additional temperature compensation to the microscope shielding and concentric emplacement of the measuring piezoelectric tubes improve the system time stability of lateral drift to 0.4 angstroms per hour. Moreover, the team members developed the on-fly software registration utility maintaining identical scanning area for more than one week measurement duration.

Since 2013 the team has had a new major facility available – multifunctional nanotechnological instrument, which combines the techniques of scanning electron and ion beam microscopy with electron and ion beam induced deposition and etching and time-of-flight mass spectrometry. This instrument allows us to observe, machine, and manipulate nanostructures; to prepare contacts to them; and to perform their in-situ electrical and chemical analysis.

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