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I. Main duties of the research unit in 2016

The object of the current basic research in the Geodetic and Geophysical Institute is the observation, modelling and interpretation of the physical condition and processes of planet Earth, as well as the development of the related theoretical (mathematical, physical) and experimental methods and instrumentation. The public responsibilities covered by our basic activity are: continuous observation of the solid Earth and the space around Earth (geodynamics, geomagnetism and aeronomy), maintenance of the national seismological network and service, provision of data associated with international cooperation, as well as operation of temporary surveillance systems. The activities of the institute that have direct economic importance are the natural resource exploration and the analysis of geological- geophysical hazards.
Research topics of the Institute that have traditionally outstanding success even by international standards are geomagnetism, magnetotellurics, seismology, aeronomy and geodynamics. Through its broadband electromagnetic measurements the Széchenyi István Geophysical Observatory of the Hungarian Academy of Sciences has a significant role in global networks of observatories and in international projects diagnosing the upper atmosphere and the plasma environment of the Earth.

Research grants in 2016 allowed us to launch new research themes and the modernization of the existing research infrastructure. The Zero Magnetic Field Laboratory (ZBL) GINOP project to be established in the Széchenyi István Geophysical Observatory simulate interplanetary magnetic field conditions to conduct space physics and materials science experiments that cannot be carried out in the strong Earth's magnetic field. In the frame of Cosmic impacts and risks GINOP grant a new ionosphere radar equipment will be installed at the observatory to monitor the plasma environment of the Earth. Owing to MTA infrastructure grant a SeismoWave infrasound station has been been purchased for atmospheric tomography and location of sonic boom events. Furher large scale studies starts with the support of *MTA EUHUNKPT* grant such; the investigation of the deep structures and monitoring the recent geodynamic processes by space geodetic techniques of the Carpathians – Pannonian Basin – Dinarides tectonic unit, the mathematical description and instrumental observation of the Earth's plasma space and the ongoing processes in the radiation belts, as well as the elaboration of the Hungarian roadmap of the EPOS (European Plate Observing System) initiative that aims to integrate the research infrastructures in Earth sciences.

II. Outstanding research and other results in 2016

a.) Outstanding research results

Magnetosphere-physics: Within the frame of international ESA-NASA collaboration magnetic, electric and plasma data from MMS (Magnotospheric Multiscale Mission) spacecraft were used

to investigate the occurrence of structures over ion and electron scales in the terrestrial magnetosheath downstream of a quasi-parallel bow shock. It is the first time, that the high-resolution MMS data allowed us to investigate the electron scales, which is required for better understanding of collisionless plasma turbulence and magnetic reconnection. The analysis of the data partially confirmed theoretical expectations and the results of numerical simulations according to which the separatrix region of magnetic reconnection is associated with particle acceleration and plasma heating. To reach these conclusions the terms of the generalized Ohm's law and particle agyrotropic distributions were obtained directly from MMS measurements.
Solar wind entry due to magnetic reconnection occurring in the terrestrial high-latitude magnetospheric lobes, tailward of the cusps under northward interplanetary magnetic field (IMF) has been investigated by using the Cluster data from 2001-2006 period. The role of the IMF B_x and B_y components in the control of solar wind plasma entry was studied at different magnetic dipole tilt angles. The asymmetry distribution of solar wind entry events in the northern and southern lobes could be caused by the variation of magnetic dipole tilt, which could influence the location of the reconnection site on the high-latitude lobe magnetopause. On the other hand, IMF B_x can also affect the solar wind plasma entry rate, therefore, the "north-south asymmetry" of solar wind entry events in the lobes could be the combined result of magnetic dipole tilt and IMF B_x.
A new concept was developed for plasmaspheric electron density measurements. To validate the method a measurement plan was designed for the Van Allen Probes. (It was accepted by NASA and a measurement campaign was performed.) The method relies on the detection and propagation inversion of artificial VLF impulses, instead of the previously used naturally occurring whistler waves. This method can be used for the validation of the electron density profile models along the field line, used in the traditional whistler inversion, and may also extend the measurement range of plasmaspheric electron densities, compared to other satellite based methods.

Aeronomy, atmospheric physics: Ionospheric Alfrem Resonances (IARs) were observed in the north-south and east-west magnetic field components of Schumann resonance of the Hylaty (Poland) and Nagycenk observatories. IARs appear in the upper part of ULF (0.3- 3 Hz) and the lowest part of ELF (3 Hz-3 kHz) frequency range. Spectral resonance structures related to IARs were clearly identified in both records of the observations in the investigated time period. The excitation source of IARs are mainly thunderstorms at mid- and lower latitudes. All IAR events were related to intense lightning activity in Europe but never in closer distance than ~100 km. The state of the ionosphere was investigated in the time period of the IARs events. It was found that the value of foEs parameter was higher during IARs events than in the reference period.
Q-bursts are globally detectable extremely low frequency (ELF, 3-3000Hz) band wave packets were investigated at the Széchenyi István Geophysical Observatory (NCK, 16.7°E, 47.6°N), The location of parent lightning strokes have been identified in the records of the World Wide Lightning Location Network (WWLLN). The systematic difference between the azimuth determined from the ELF signal and that of the source location was explained by the anisotropy of the Earth crust's conductivity.

Seismic hazard and microzonation of Budapest: Investigations were carried out to assess the local modification effect of earthquakes in Budapest. Resonant frequencies of subsoil and directivities of H/V ratios were determined based on microseismic measurements. Lateral amplification related to topography was detected by analyzing directivities of H/V ratios. Active and passive seismic measurements based on the dispersion properties of surface waves were performed in the near surface layers to determine the S wave velocities. The S wave velocity

profiles have been computed by the joint inversion of complementary (MASW, ReMi, ESAC, H/V) measurements. The local applicability of seismic interferometry was also studied. It was found that applicability mainly depends on the distribution of noise sources.

Seismic investigation of deep structures, noise tomography: Fundamental mode Rayleigh wave group velocity maps for the Pannonian basin were determined by ambient noise tomography using the data of the Hungarian National Seismological Network and altogether 37 stations of the surrounding countries with a spatial resolution of around 70 km for the periods 7–26 s. A four-layer average S wave velocity model for the Pannonian basin was constructed. According to this model the lower boundaries of the layers representing sedimentary basins, the upper and lower crust are located at depths 3, 11 and 27 km, respectively. The average S wave velocity in the crustal layers are 2.34 km/s, 3.10 km/s and 3.53 km/s, while in the uppermost mantle it can be estimated as 4.16 km/s. The three dimensional S wave velocity model for the Pannonian basin down to the depth of around 35 km based on the group velocity maps was also computed. The average direction of the fast axis of the azimuthal anisotropy and the degree of anisotropy were determined on the basis of the dispersion curves. It was demonstrated that for increasing period the fast axis direction turns towards the east. The degree of anisotropy based on the group velocities is in the range of 6.2–9.6% between the periods 10 and 30 s. According to the sensitivity kernel, which was computed from the average S wave profile these results reflect the anisotropy of the crust and uppermost mantle.

Theoretical seismology: Moment tensor determinations of small earthquakes using waveform inversion are limited because the signal-to-noise ratio of the recorded seismograms is satisfactory only at frequencies above ~0.5 Hz, and waveforms up to ~1-2 Hz can be modeled only at relatively near stations. Bayesian procedure was elaborated that jointly inverts waveforms and P- and S-wave polarity data to retrieve the DC mechanism of weak local earthquakes. Inverting first-motion polarity data only produces a broad suite of focal mechanism solutions, but involving a few waveforms reduces the uncertainty of the resulting mechanism. The method not only increases the reliability of the solution but also provides an estimate for the scalar moment.
Attenuation of seismic wave amplitude is an important required parameter to estimate source properties, ground motion characteristics and seismic hazard. Attenuation is described by the quality factor (Q). The frequency-dependent quality factor was determined by the coda normalization method. The amplitudes of both P and S waves are normalized by the coda wave amplitudes. The logarithm of the amplitude ratios and the hypocentral distances are in linear relation at specific frequencies, which enables to determine the quality factor. 1968 seismograms of 274 local earthquakes occurred in Hungary between 2005 and 2014 have been utilized in their computations. Calculations were done using both north-south and east-west components.

AlpArray project: The AlpArray project started on the January 1 2016 and it is in its data collection phase. During the project period 24 European institutions ensure the background of the researches, namely the maintenance of the AlpArray Backbone Seismic Network, the MTA CSFK takes part in this project with 23 broadband seismic stations. The prerequisite for achieving the scientific objectives is to register and continuously transmit high quality data to the EIDA node (European Integrated Data Archive) data centres. In 2016 we prepared the noise spectra of the stations. On this basis, the institute got into the top-rated category of data providers (Core Group). The planning of the project's scientific program is in progress by developing different working groups (WG). The colleagues of the institute are members of the Surface Wave WG, which had been established for surface wave tomographic studies, and

initiated the formation of the Earthquake Catalogue Working Group, which is aiming to determine the earthquake parameters and the local stress fields as accurate as possible with the help of the high-density network stations. There is also a gravity and space geodetic extension of the project in elaboration, which provides the interdisciplinary examination of the Alpine orogeny.

Space gravimetry, time variability of Earth's gravity field: GRACE-derived gravity models can efficiently be used for investigation of geophysical processes, which generate mass redistribution. Therefore, it also can be used for investigation of polar ice mass variations. Beyond the ice mass variations, many other processes may cause notable mass redistributions. In the case of Antarctica, the mass variation due to the Glacial Isostatic Adjustment (GIA) process is relevant. In order to correct ice mass balance investigations for the GIA effect, GIA models are applied. In an empirical approach the reliability of GIA models has been analyzed by comparing 9 known GIA models. According to the results, the error involved by the GIA correction at most parts of the continent lies in the range of magnitude of the ice mass variations. Thus, ice mass variations derived purely from GRACE are considered to be unreliable. Reliable estimates of ice mass variation can be found at some regions only: in West-Antarctica the accelerating melting process is obvious, a slight mass loss is observed in Wilkes Land, while Enderby Land and Queen Maud Land is definitely increasing the ice mass.
All the 3 – 9 months long gravity tide data series recorded at 5 different places by 6 different gravity meters in the Pannonian basin were analyzed in the diurnal and semidiurnal wavelength bands (O1 – M2). In spite of the outdated Hungarian instrumentation the quality of the records and the reliability of the derived amplitude factors derived from them mostly fulfil the 1 μGal (10-8 m/s2) accuracy required for the analysis of theoretical tidal models and the location dependence of tidal parameters. The time variation of the scale factors of spring gravity meters, as well as the observed systematic differences between the absolute (moving mass) and relativ calibrations (instrument inter-comparison), however, make the direct comparison of the tidal parameters derived by ETERNA analysis impossible. Therefore rather the ratio O1/M2 was analyzed in function of geographical location. The O1/M2 ratios show a small but clear increasing tendency from west to east. This can be an indication of the decreasing of ocean loading effect which mainly decreases the value of M2 tidal constituent.

Environmental geophysics: A comprehensive investigation of geoelectric configurations like traditional Wenner-α and –β, Wenner-Schlumberger, Dipole-Dipole, Pole-Dipol; optimised Schlumberger with four electrodes as well as $\gamma_{11n,\,(n=2\text{-}7)}$, γ_{q0} and a γ_{313} was conducted based on numerical simulations and analogue modelling to determine the parameters such as depth detectability and lateral resolution. Results showed that imaging capability of the Wenner-β configuration proved to be the most accurate amongst the traditional configurations based on the investigated models. The depth detectability of the γ type configurations was higher than in case of all investigated traditional configurations furthermore it was capable to discriminate all sources from each other whereas the traditional method failed. It was demonstrated that less disturbing pseudo anomalies appear in the inverted resistivity map data and the investigated model is better resolved when the $\gamma_{11n,\,(n=2\text{-}7)}$ configurations are applied with their mirrored versions. It was concluded that γ configurations can provide more information in case of small sources and monitoring purposes compared to traditional configurations therefore these can complete those.

Space geodesy: The Copernicus program of the European Space Agency has opened a new era of Earth observation with Sentinel mission. The interferometric processing of synthetic aperture radar scenes (SAR) of Sentinel-1 twin satellites enables to determine the surface deformations

with high precision furthermore with high temporal resolution (6 days) and for a relative big region with high space resolution (100 m^2).
In the framework of *Integrated Sentinel-1 PSI and GNSS technical facilities and procedures for determination of 3D surface deformations caused by environmental processes* ESA project the applicability of space geodetic methods and developments has started for the observation of tectonic processes. The electromagnetic and geodetic design of artificial backscatters which enable to determine deformations with mm accuracy were accomplished. The optimisation of the electromagnetic properties of backscatters was determined based on analogue, analytic and numerical investigations. The radar cross section (RCS) of various trihedral reflectors (TT-triangular, ST- square, CT- circular) was computed. The background signal level (clutter) was determined based on the parameters of Sentinel-1 mission (size of resolution cell, incidence angle, wavelength) as well as clutter for different land cover types. It was demonstrated that 20 dB and 40 dB SCR (signal-toClutter Ratio) are required to determine line-of-sight (LOS) deformations with 0.1 mm and 1 mm accuracy in case of C band microwave remote sensing respectively. The side lengths of trihedral backscatters for the required 40 dB RCS are 1.66m, 1.19 m and 0.96 m for the TT, ST and CT backscatters respectively. The 3dB beamwidth which provides almost constant RCS were determined by numerical calculations for the investigated backscatters. Results demonstrated that triangular trihedral backscatter has the widest beamwidth therefore it is the least sensitive to the precise orientation in the direction of the satellite. However, the TT backscatter can produce the required RCS with the longest sidelength, the central part of the backscatter ensures its RCS. Numerical simulations were carried out to examine the possible truncation of TT backscatter to improve the mechanical stability and robustness of benchmarks included backscatters provided that the required RCS is restored. It was demonstrated that truncation of the sidelength with 0.3 m does not change notably the reflecting energy and the beamwidth is approximately the same as for non-truncated TT backscatter. The aim of analogue modelling using the 1:5 ratio scaled models of various backscatters was to investigate the reflectivity properties by real environmental conditions. Results have confirmed that the proposed truncated trihedral backscatters will fulfil the requirements of long-term observation of tectonic processes based on Sentinel-1 mission.

Atmospheric radiation research: A mathematical model for the spread of radiative flux was set up in order to study the greenhouse effect of radiation, and lower as well as upper limits were introduced for the radiative flux captured by the atmosphere. Based on measured and calculated flux, the radiative gain of greenhouse gases was calculated for the warming of the Earth that had been observed between 1880 and 2010.

Geomagnetism: Direct and inverse model calculations have been started on the explanation of geomagnetic secural variations and on indirect observation of the magneto-hydrodinamic (MHD) processes of the outer core of the planet. Initially single vortices of different sizes and directions (or equivalent dipoles) were used as a simplified MHD source. Later on the initial model was developed to a more adequate one. The latest model is a complex system of vortices which provides stable inversion parameter estimation, and seems to be applicable for imaging of the sources in the outer core.

Feasibility study of the Einstein Telescope (ET) in Hungary: Recent break-through in gravitational wave (GW) detection by LIGO inspired further developments and new concepts in the field of GW detectors. The ET is a broadband third generation gravitational wave detector wich may open new perspectives in GW astronomy. The low frequency band of ET is overlapping with the global microseimic noise and the energetic ELF-ULF natural geo-electromagnetic activity. The feasibility of GW observatory requires thorough study of the

geophysical noises and the physical properties of the embedding rocks. In 2016 simultaneous surface and underground observations started at the Mátra Gravitational and Geophysical Laboratory (MGGL) established by the Wigner Researh Centre for Physics. GGI runs two search coil system for electromagnetic and two broadband seismological stations for seismological investigations.

a.) Science and society

The seismotectonics, the vulnerability of geologic structures and formations and the analysis of emergency situations of Solar-terrestrial physics origin, their prevention and forecast are core responsibilities of the Institution. Maintenance of the National Seismology Service and diagnosis of space around the Earth are also essential public tasks. Extreme changes in the conditions occurring in the Earth's plasma environment due to extreme solar flares status changes, geomagnetic storms pose a real and steadily increasing risk to contemporary telecommunication technologies, navigation and energy-transmission systems.

The staff of the institute was interviewed by radio Kossuth in their documentary programme called "Tér-Idő" (Space-Time) in connection with this year's earthquake series in Italy. Within the two-part programme they presented the Kövesligethy Radó Seismological Observatory of MTA CSFK GGI and also the research methods, the instruments of earthquake research methods were described, as well as the history of the national seismologic researches from the 19th century to the present. The report touched the issue of the predictability of earthquakes and how the earthquakes can be detected from space.

This year the Hungarian "Science Festival" bore the motto "Investigative Science", indicating, that the meticulous scientific research activities are based on methods which had been developed by successive generations. Within the framework of the event organized by the Institute, interested parties could take part in the interactive presentation *“"The weirdness of earthquakes, or what are the prognostication and accompanied signs caused by earthquakes?*" Beside very interesting natural phenomena before and after earthquakes, visitors acquainted to the construction of seismographs, furthermore they could cause earthquakes themselves.

As a part *of the programme “Seismology at school*" in a primary school in Székesfehérvár, a so called "school-seismograph" was installed. The success of the program, students' and teachers' interest shows, that implementing a physical device and interpreting measurements can bring the students closer to the world of natural science.

III. A presentation of national and international R&D relations in 2016

School of Earth and Environment, University of Leeds, Department of Broadband Infocommunications and Electromagnetic Theory, Faculty of Electrical Engineering and Informatics, Budapest University of Technology and Economics: radar interferometry, Sentinel-1 mission, design of backscatters for microwave remote sensing;
Conrad Observatory, Austria: highly sensitive tiltmeters for the observation of tectonic processes;
Massachusetts Institute of *Technology*: research of aeronomy and the Schumann Resonance;
Finnish Meteorological Institute (Ilmatieteen Laitos): geomagnetic induction, magnetotelluric deep soundings;

The Catholic University of America, NASA Goddard Space Flight Center: solar wind-magnetosphere energy coupling;
Thunderstorm effects on the Earth-Ionosphere System (IS-TEA) European Science Foundation Research Networking Programme: aeronomy, observation and analysis of upper atmospheric electro-optical emissions;
Laboratoire de Physique et Chimie de l'Environnement et de l'Espace (LPC2E) / CNRS; Institut de Recherche en Astrophysique et Planétologie, Université de Toulouse: magnetosphere studies, magneto-hydrodynamic research;
INTERMAGNET: international geomagnetic observatory network;
AlpArray Steering Committee: ETH Zurich, University of Vienna, University of Berlin, National Institute of Oceanography and Experimental Geophysics (OGS), ISTerre Grenoble, Istituto Nazionale di Geofisica e Vulcanologia, Prague IG ASCR, GeoForschungsZentrum Potsdam, HAS RCAES GGI
Eötvös Loránd University TTK; Lithosphere Fluid Research Laboratory: research of the magneto-telluric deep structure and xenoliths of mantle origin for the research of the listosphere-asthenosphere boundary.

Organization of domestic events:

X. Seminar on Geomatics, MTA CSFK Geodetic and Geophysical Institute, Sopron, November 10-11. 2016

The aim of the conference is to introduce modern Earth's science data collection and processing methods and describing related reference systems from theoretical and practical aspects, as well as introduce geodesy, geophysics, instrumentation technology, photogrammetry, remote sensing, GIS (geographic information system), geomathematics, modelling the gravity field, cosmic geodesy, GNSS systems and the presentation of the latest research results of geodynamics.

Organization of international events:

Preparatory Meeting of the Geodynamics of the Carpathians Bend Interior, MTA CSFK Geodetic and Geophysical Institute, Sopron, March 23-25. 2016

TOPO-TRANSSYLVANIA meeting, Poiana Brasov, 2016. október 13-15.

The goal of the project is modelling the tectonically most interesting part of the European lithospheric plates, the Carpathian subduction, volcanism associated with the subduction and the effects of volcanic activity on salt tectonics in the complex space geodesy, furthermore magnetotelluric- and seismic tomography-based observation and modelling. Beside the GGI - the project leader, the initiative has been joined also by the ELTE (Eötvös Loránd University), by the Romanian National Institute for Earth Physics, by the Institute of Geodynamics of the Romanian Academy of Sciences, by the Sapientia University, and the Babes-Bolyai University, as well as by the Utrecht University - the world-leading centre for lithosphere dynamics.
In March 2016, a preparatory meeting was held in Sopron, in October in Poiana Brasov all institutions involved in the project signed a cooperation agreement and outlined the scientific program of the project. The planned studies of the project will allow the initiative in the sub-program of the TOPO-EUROPE European Science Foundation.

Participation in national higher education (occasional):

Habilitation Committee, PhD Thesis Defence 2 persons.

Participation in national higher education (regular):
ELTE TTK: 6 theoretical courses, 2 practical courses;
NyME (EMK, KTK, FMK): 6 theoretical and 4 practical courses.

Educational activities in foreign universities
BBTE, Cluj-Napoca: 2 theoretical courses, 1 practical course.

Doctoral School core members:
NyME EMK Kitaibel Pál Doctoral School of Environmental Sciences: 1 person;
NyME FMK Cziráki József Wood Science and Technology Doctoral School: 1 person;
NyME KTK István Széchenyi Management and Business Administration Doctoral School: 1 person.

Education in the Doctoral School:
BME Vásárhelyi Pál Doctoral School: Inertial Structure of the Earth, Geophysical data processing.
NyME Cziráki József Wood Science and Technology Doctoral School: Measurement theory, Digital image processing.

NyME Kitaibel Pál Environmental Sciences Doctoral School: Modelling of geodynamic processes, Environmental science applications of GNSS systems, measurement of environmental movements, methodology of scientific research, Solar activity and weather, Geomagnetics, space weather and climate, Atmospheric electrodynamics, Structure of the Earth and its processes.

NyME Széchenyi István Doctoral School of Economic and Management Sciences: Theory of statistical analysis.

Thesis supervision (undergraduate paper):
ELTE Faculty of Science: 1 person,
ÓE Alba Regia Faculty of Technical Science: 3 persons.

Thesis supervision (BA, BSc degree):
ELTE Faculty of Science: 2 persons,
NYME Simonyi Károly Faculty of Engineering, Wood Sciences and Applied Arts: 1 person,
ÓE Alba Regia Faculty of Technical Science: 9 persons.

Thesis supervision (MA, MSc degree):
BME Faculty of Civil Engineering : 1 person;
ELTE Faculty of Science: 4 persons.

Thesis supervision (PhD dissertation):
ELTE Doctoral School of Earth Sciences: 3 persons;
NyME (EMK, KTK, FMK): 6 persons.

IV. Brief summary of national and international research proposals, winning in 2016

Creating a magnetic zero field laboratory (GINOP-2.3.3-15), 2017-2019, consortium leader,

project cost: 435 million HUF, GGI: 175.4 million HUF
The project aims to create an electromagnetically "clean" laboratory chamber, in which the static and variable geomagnetic field can be reduced about five orders of magnitude by means of active compensation and additional efficient shielding of the residual field. So a magnetic environment characterizing the interplanetary field can be created.

Cosmic impacts and risks (GINOP-2.3.2-15), 2016-2020, GGI sub-project (159.8 million HUF) within László Kiss's (Konkoly Observatory) project
By mapping the real threats from space against our planet, the first step is to study and understand the celestial bodies which are getting close to the Earth. Besides monitoring small passing by asteroids and meteorites impacting the Moon, our goal is also to develop a monitoring system, which is capable of registering any transient phenomena of cosmic origin occurring in the Earth's atmosphere, like plasma irregularities caused by meteorites or geomagnetic storms.

Creating an infrasound station at the "Piszkéstető Observatory" (MTA grant supporting establishment of infrastructure for outstanding scientific research activities) 88 million HUF
The goal of the ARISE H2020 is to create such an infrastructure that integrates data from different monitoring systems in order to image the Earth's atmosphere in 3D, from its surface to the mesosphere. The infrasound station - installed with the help of the grant - allows the tomographic determination of the structure of the atmosphere and involving Hungary to the European initiative.

Preparation to apply for grants
- *in connection with the lithosphere dynamics of the Inner Carpathian Bend (the organization of meetings, production of integrated geodynamic benchmarks, installation)*
- *AlpArray - to participate in the Steering Commitee work, borehole seismometers for a more accurate seismic imaging of the sediment covered lowland areas*
- *Preparatory costs of the FETOPEN tender - monitoring the plasmasphere with VLF transmitters*
- *Additional costs for ESA 4000118850/16/NL/SC (Integrated Sentinel-PSI and GNSS technical facilities and procedures for the determination of 3D structure deformations caused by environmental processes)*

Winning grant - total: 21.5 million HUF

V. List of important publications in 2016

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