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HUNGARIAN NATIONAL REPORT ON IAGA 2007–2010

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This report is a collection of institutional and individual reports, edited by the Hungarian national delegates (L Szarka: 2007–2010 and G Sátori: 2010). In the reference lists the readers find papers published mainly between 2007 and 2010 in various geophysical journals (including journals edited in Hungary as *Acta Geodaetica et Geophysica Hungarica*, *Geophysical Transactions*, *Magyar Geofizika*, *Földtani Közlöny*, etc.).

The major IAGA-related conferences in Hungary between 2007–2010 were as follows: the IAGA XI. Scientific Assembly (Sopron, 2009) as the most remarkable event of geo-science in Hungary, in that year; the VERSIM Workshop (Tihany, 2008), as an other international meeting; Ionosphere and Magnetosphere Seminars (Budapest, 2008; Baja, 2010); Inversion Workshop (Miskolc, 2008); annual meetings of the Association of Hungarian Geophysicists; annual meetings of Young Geologists and Geophysicists.

The structure of this report follows more or less the structure of Hungarian activities in frames of IAGA.

The numbering of sections (I–V) indicates the number of IAGA divisions, but the individual sections does not follow exactly the structure of IAGA working groups. Instead, each of the sections is divided into several subsections, corresponding to the related Hungarian results.

Several scientific results are described in Section V, under the observatory descriptions, where activities of two Hungarian geo-electromagnetic observatories: Nagycenk and Tihany are summarized.

The list of participating institutions (with updated names and addresses) is as follows:

Astronomical Institute of the Hungarian Academy of Sciences, POB 67, H-1525 Budapest (www.konkoly.hu)

– Heliophysical Observatory, KLTE Botanikus kert, POB 30, H-4010 Debrecen

– Konkoly Observatory, POB 67, H-1525 Budapest

Eötvös Loránd Geophysical Institute (ELGI), Division of Earth Physics, Division of Mapping, Kolumbusz u. 17–23, H-1145 Budapest; POB 35, H-1440 Budapest (www.elgi.hu)

– Tihany Observatory, Kossuth L. u. 91–93, H-8237 Tihany

Eötvös Loránd University (ELTE), Pázmány Péter sétány 1/C, H-1117 Budapest (www.pangea.elte.hu)

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– Széchenyi István Geophysical Observatory (IAGA code: NCK), Cenki u. 1, H-9493 Fertőboz

Geological Institute of Hungary (MÁFI), Stefánia út 14, H-1143 Budapest (www.mafi.hu)

KFKI Research Institute for Particle and Nuclear Physics of the Hungarian Academy of Sciences, Konkoly-Thege út 29–33, H-1121 Budapest; POB 49, H-1525 Budapest (www.rmki.kfki.hu)

Miskolc University (ME), Geophysical Department, H-3515 Miskolc-Egyetemváros (www.uni-miskolc.hu/~geofiz)

MOL Hungarian Oil and Gas Co., Budafoki út 79, H-1117 Budapest (www.mol.hu)

MTA-ELTE Research Group in Geology, Geophysics and Space Science, Pázmány Péter sétány 1/C, H-1117 Budapest (www.elte.hu, www.mta.hu)

I. Internal magnetic fields

Interpretation of the magnetic anomalies measured by the CHAMP satellite over the Pannonian Basin

(Károly Kis, Geophysics and Space Sciences Department, ELTE, Géza Wittmann, MOL Hungarian Oil and Gas Co., Patric T Taylor, Planetary Geodynamics Laboratory NASA/GFSC)

The German satellite CHAMP was on its orbit between July 15, 2000 and September 19, 2010. It measured the gravity and magnetic fields of the Earth with high accuracy.

The CHAMP measured huge volume of gravity and magnetic data but in this project we investigated only the total magnetic anomaly field over the Pannonian Basin and its vicinity. This anomaly field was derived by the application of the

CHAOS 2 model (Olsen et al. 2009). Some 107 927 data were recorded between January 1 and December 31, 2008 and these were used to derive the total magnetic anomaly field. Gaussian weight function was used for the interpolation of the data that were distributed over a spherical shell at 319–340 km altitude. The selected data were interpolated on a spherical grid of $0.5^\circ \times 0.5^\circ$ at the 324 km elevation. Our derived anomaly field shows a large extension low zone over the Pannonian Basin (Kis et al. 2010).

The vertical gradient of these total magnetic anomalies was computed and mapped to the surface of a sphere at 324 km elevation. Previously Taylor et al. (2005) computed spherical anomaly data at 425 km altitude they downward continued these to 324 km.

To interpret these data we used the Bayesian inversion procedure (Sen and Stoffa 1995). A polygonal prism model was used for the inversion. The minimum problem was solved numerically by the Simplex and as well as the Simulated annealing methods; a L_2 norm was applied for the Gaussian distribution model parameters and L_1 norm was used for the Laplace distribution model parameters.

Both the earlier (Taylor et al. 2005) and the present anomaly field show an excellent correlation with the heat-flow data particularly in the region of central Hungary and northern Romania. These anomalies lie on the axis of the basins thinned crust.

The upper and lower depths of the magnetic polygonal source are 4 km $\pm$ 8 km and 16 km $\pm$ 10.5 km. The magnetic anomaly is probably produced by the exsolution of hemo-ilmentite minerals in the upper crustal metamorphic rocks.

The SWARM constellation will deploy three spacecraft, with one at a high altitude and the other two flying abrest with a separation of between 150 to 200 km to record the horizontal magnetic gradient. They will initially be at the same altitude as CHAMP but eventually they will descent to a lower level. Since the CHAMP satellite was in orbit for nearly nine years and obtained an extensive range of data, both vertically and horizontally, there is a large enough data base to derive the magnetic gradients over the Pannonian Basin region using these orbits. We computed the magnetic anomaly gradients in order to determine how these component data will improve our interpretation and to preview what the SWARM mission will reveal with reference to the horizontal gradient anomalies.

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Electromagnetic study of weak zones in the Earth's crust and mantle

(Antal Ádám, Attila Novák, László Szarka, MTA GGKI)

In order to get more reliable information about the deep geoelectric structure of the lithosphere, data processing methods were developed, incorporating the magnetotelluric rotational invariants of the impedance tensor elements into the data interpretation. By using this imaging technique, the misinterpretation could be reduced, when selecting the family of dimension of the structures (1D, 2D or 3D) for the inversion. This technique was used in the interpretation of the MT dataset along the CEL-7 deep seismic profile in SW Hungary (72 MT deep soundings), and in an areal MT measurement around the village Nagyatád (300 MT soundings). Additionally the phase tensor analysis completed these investigations. The imaging of the structures by tensor invariants was successfully adapted for 3D tensorial geoelectric mapping measurements in an archaeology study around the Pilisszentkereszt Cistercian Monastery (Hungary) (Varga et al. 2008). All these methodical investigations were summarized by Novák (2010).

The CEL-7 seismic profile, along which detailed MT sounding were carried out, crosses very deep 3D sedimentary basins as shown by the "Pre-Tertiary Basement Contour Map of the Carpathian Basin" (Kilényi and Sefara 1989, further referred as K-S depths). In order to estimate the basement depth of the 3D sedimentary basin we carried out 1D inversion of magnetotelluric TE and TM mode sounding curves (Ádám et al. 2007). Comparison of this MT depth estimation with the K-S depth values led to the following conclusions:

a) The MT and K-S depth differences do not significantly depend on the resistivity of the sediment. At the same time, there is a significant difference between the magnetotelluric and the K-S depths over the Balaton line as the most important tectonic (fracture) line crossing the MT profile (so-called conductive weak zone, Ádám et al. 2005).

b) The depth values inverted by TE-mode are smaller, the TM mode-based depth values are larger than the K-S depths. As the adjustment distance in case of the TE mode is larger, than in case of the TM mode, the distortion in TE mode appears in a larger area.

c) Apart from the distortion due to Balaton line as mentioned above, the 1D MT basement depth values in 3D basins, especially the TM mode-based ones, well approximate the K-S depths. In case of the TM mode 76 percents of the differences are less than 600 m in case of an average basement depth of 4000 m of the 3D sedimentary basins. This agreement is only 52 percent in case of the TE-mode soundings certainly in connection with the larger adjustment distance of the great inhomogeneities.

In the continuation of the CEL-7 profile from Hungary to Austria a series of deep magnetotelluric soundings were carried out in 2007. In spite of high man-made EM noise level, the structure of the sedimentary Graz Basin could be well indicated. In the resistive rock matrix of the Eastern Alps and at the boundary of the Graz Basin possibly fluid filled conductive fractures appeared whose conductance is much less than that of the first order tectonic lines in the Pannonian Basin such as the Balaton-, Rába-, Midhungarian-line (Ádám et al. 2008).

The "Central Europe Mantle geoElectrical Structure" project (the so-called "CEMES"), was completed in 2008 (Semenov et al. 2008). In the first phase of the project (2001–2003) long period geomagnetic variations were collected from observatories (including the Nagycenk EM Observatory) situated within few hundreds kilometres along the south-west margin of the East European Craton. The conductance distributions at the depth of the upper mantle (from five independent estimations) were derived beneath each observatory. The final model of the geoelectric structure of the upper mantle beneath CEMES region was obtained by averaging of the individual cross-sections. The results give evidence that the electrical structure of the upper mantle differs in the East European Craton and in the Phanerozoic plate of Western Europe, respectively being separated by the Trans-European Suture Zone (TT line) according to the regional heat flow distribution corresponding to the relationship by Ádám (1978).

A new analysis was carried out with the deep carbon bearing rocks causing the observed high conductivities in NW Transdanubia and crustal weakness associated with seismicity in a co-operation of MTA GGKI with the Laval University Québec, Canada (Glover and Ádám 2008). The field data indicate a correlation between the depths to a zone of high electrical conductivity, earthquake focal depths, and zones of high seismic attenuation. The laboratory triaxial deformation experiments show that progressive shearing of a fracture in carbon-bearing rock can result in a weaker more electrically conductive fracture.

These results provide strong evidence for the role of carbon at depth in both electrical conduction and seismotectonics, explaining the correlation between mid-crustal high reflectivities and high conductivities observed at many locations world wide.

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Electromagnetic induction and electrical conductivity

(Mihály Dobróka, Ákos Gyulai, Ernő Takács, Miskolc University, András Madarasi, ELGI)

CELEBRATION-7 and related areas

A common interpretation of CELEBRATION-7 profile and parallel ALP13 profile confirms the correctness of 2D bimodal approximation (Madarasi and Kiss 2007).

Near-surface and environmental studies

Audio-magnetotelluric measurements for investigation of repository for low- and intermediate level radioactive waste were reinterpreted taking into account IP effect of clay rich gouges is fault core can be found on large areas (Madarasi and Füsi 2009, Madarasi et al. 2010).

On the robustification of the Fourier transform Dobróka and Vass (2007) and on the robust Fourier transform algorithm using inversion tools Vass and Dobróka (2009a) published a paper. Mapping results in the transition zone of the EM fields due to the power lines were presented by Pethő and Takács (2007). 3D EM research was done by Turai et al. (2007a, 2007b, 2008a) for environmental studies, and EM data were also processed in GIS based system (Vass et al. 2007, Dobróka et al. 2008a, 2008b). Additional results were achieved by Turai et al. (2008b, 2008c) and Turai and Herczeg (2010) in the use of TAU-transformation for environmental analysis. To detect tectonic disturbances of coal seams in-mine geoelectric methods were further developed and applied by Ormos et al. (2008a, 2009). Their paper was awarded as “Best papers of NSG”. Model studies demonstrated that the transformation of the measured field components into effective resistivity response in all frequencies offers a useful tool in the interpretation of the controlled electric bipole source measurement (Takács and Pethő 2008). To localize disturbed geology in the vicinity of an underground vertical electric dipole in-mine frequency domain transillumination (Takács 2009) and borehole-surface measurement was developed

(Takács and Pethő 2009). To gain more knowledge of the approximately 2D geology of karst springs' vicinity VLF method was applied (Németh and Pethő 2009). In order to up-grade FEM 2.5D numerical modelling parallelisation was developed by Ficsór et al. (2008a, 2008b) and assuming HED sources current channelling, galvanic, source polarization, source overprint, shadow effect were investigated by Pethő (2007, 2009a, 2009b). Surface fitting methods were applied for magnetic field dataset by Herczeg (2009). Hokkanen and Szabo (2009) dealt with density variation modelling based on resistivity and soil moisture data. Gyulai et al. (2010) developed a new quick 2D interpretation method for geoelectric measurements and its efficiency was proved by field data interpretation as well. Polarization filtering was applied by Turai (2010) for the reduction of random noise effect.

Inversion studies

3D EM robust inversion over a near surface oil contaminated model was presented by Turai et al. (2007b). The strategy of joint inversion using function series is given by Gyulai et al. (2007). The results of 2D geoelectric interpretation method using series expansion are given by Ormos et al. (2008b) and Gyulai et al. (2010). In the latter one a comparison is also made between the resolution of Barker algorithm and the quick method developed by them. A simplified inversion of secondary magnetic field data due to a vertical underground electric dipole was developed by searching the anomalous subsurface horizontal current distribution linked with the discontinuity by Takács and Pethő (2009). Series expansion based inversion is investigated and Fourier transform is considered as an inverse problem by Vass and Dobróka (2009b). For the solution of the TAU transform, considered as an inverse problem, series expansion is recommended by Turai et al. (2010). Inversion reconstruction of the gravity potential based on series expansion developed by Dobróka and Völgyesi (2010).

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Archaeo- and Palaeomagnetism, Environmental Magnetism

(Emő Márton, ELGI and Péter Márton, ELTE)

Archaeomagnetism

Progress in archaeomagnetism studies during the years 2007–2010 was reported in the paper of Márton P (2010) of which a short summary is presented here as follows. Supplemented by 32 new directions the Hungarian archaeomagnetic dataset increased to 217 archaeologically dated directions ranging in age from 300 BC to 1800 AD. From this dataset, reference curves of secular variation of the geomagnetic field direction were computed using hierarchical modelling and curve estimation by moving average technique. Thanks to some of the new data, the gap in the earlier reference curves around 500 AD has now been filled up. For comparison's sake, directional records of comparable length from central Europe were also processed by the same curve building method. For this purpose all dated directional data (declination and inclination with statistics) were drawn from the GEOMAGIA50 database for France, Germany, Ukraine and Moldavia, Bulgaria and Italy and transferred via their virtual geomagnetic poles to a reference point of their respective countries. The resulting reference curves, including those for Hungary, can be used 1. to predict, by interpolation, the geomagnetic field direction at any other location in Central Europe, and 2. to judge the quality of the predictions thereof by existing continuous field models such as the CALS7K.2 and ARCH3k.1, as exemplified in the cited paper (for references to models CALS7K.2 and ARCH3k.1, see Márton P 2010).

Since the beginning of the modern archaeomagnetic investigations in Hungary in the nineteen seventies, some directional data of various prehistorical ages have also accumulated beside a larger body of the historical results. These are presented in the work of Márton P (2009), and compared with 1. coeval directional results which are available from South-eastern Europe, as well as 2. the predictions of geomagnetic field directions for Hungary of the global geomagnetic field model, CALS7K.2.

Palaeomagnetism

Publications by Pálfy et al. (2007) and Grabowski et al. (2010) deal with geological correlation with the aid of palaeomagnetic polarity zones. Karátson et al. (2007), Márton E (2007), Márton E et al. (2007a, 2007b) are concerned in correlation through the combination of palaeomagnetic marker horizons (which are the manifestations of dramatic changes in the orientation of the relevant tectonic unit) and polarity zones. The most important conclusions of the last three papers are that in North Hungary, the type locality of the "Middle Tuff Complex" at Tar (Cserhát Hills) must be a representative of the "Upper Tuff Complex" (i.e. must be younger than 14.5 Ma, instead of about 17 Ma) and the ignimbrites from the famous fossil-footprint site of Ipolytarnóc, considered earlier as members of the "Lower Tuff Complex" in fact belong to the "Middle Tuff Complex".

Papers by Lesić et al. (2007), Márton E et al. (2007c), Rasser et al. (2008), Márton E (2009) and Márton E et al. (2009a) were published about the Tertiary kinematics of the Carpatho-Pannonian region based on palaeomagnetic results. The most important result of these studies is that the Intra-Carpathian area was the site of disintegration during the Miocene of the earlier (probably) existing megatectonic units. At the same time, the Western Outer Carpathians were accreted with the NE part of the North Pannonian megatectonic unit, before the two of them rotated about 60° CCW with respect to stable Europe.

Papers by Márton E et al. (2008a), Márton and Moro (2009), Márton E et al. (2010a) and Márton E (2010b) were concerned with the Late Jurassic-Cretaceous displacements of stable Adria and the Northern part of the Dinarides. The new paleomagnetic results representing stable Adria were obtained from biostratigraphically well-dated carbonates representing basin (foreland of the Southern Alps) and the platform (autochthonous Istria) facies. The direct palaeomagnetic data from autochthonous Adria indicate a relatively fast CCW rotation of Adria during the Late Aptian-Early Albian, which was accompanied by sedimentary hiatus, suggesting an important tectonic event. The data also imply that Adria must have decoupled from Africa at the end of the Cretaceous with a relative CW rotation. Also, the Mesosoic of the northern segment of the External Dinarides on the mainland exhibits a moderate rotation, and Mt. Medvednica, which is part of the Inner Dinarides, a large CW rotation, both with respect to Adria (Tomljenović et al. 2008). The youngest important event, the CCW rotation of Adria with respect to Africa is of post-Eocene age (Istrian data).

Besides palaeomagnetic measurements, the magnetic fabric of Tertiary sediments was also studied from the Outer Western Carpathian and from the Central Carpathian Flysch (Márton E et al. 2009b, 2010c) These papers document that the clay-rich sediments are sensitive indicators of weak deformation and also that the palaeomagnetic vectors are true recorders of the ambient magnetic field, even if the magnetic fabric at some localities exhibits preferred orientation, which is due mainly to paramagnetic minerals.

Environmental magnetism

Environmental magnetic studies were carried out on polluted soils (Klučiarova et al. 2008). Samples were collected on a slope from the topsoil in a beech stand close to an ironworks in N-Slovakia. The results of measurements of low and high frequency magnetic susceptibility allowed to conclude that in the beech stand where the ground is effectively shielded by the canopy from direct precipitation of pollution particles, all susceptibility values unaffected by stemflow are dominated by fine-grained magnetic particulates having formed by biogenic processes during pedogenesis, while those pertaining to the stemflow zone are dominated by larger multidomain particles conveyed to the ground in the stemflow. So, in this particular environment, it is the stemflow and its effect that makes magnetic pollution detectable by using susceptibility parameters. The results of susceptibility measurements on tree barks in Budapest and settled dust samples of industrial origin in Miskolc and elsewhere were published in the work of Márton E et al. (2008b). It was shown that the airborn pollution particles from a major road in Budapest can be detected up to a distance of 90 metres along a perpendicular side street of little or no traffic at all. Also, in the same paper, the concentration of the magnetic particulate matter of the different grain-size fractions and the role of different sources of pollution in the industrial town of Miskolc and another area were analysed.

Finally, the magnetic identification and the widespread occurrence of greigite in the sediments of Lake Pannon were discussed in the papers of Babinszki et al. (2007), Babinszki and Márton E (2009), and the magnetic method was applied to climatic and environmental reconstructions during the Pleistocene by Bradák et al. (2009, 2010).

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II. Aeronomic phenomena

Spatial and temporal variations in the troposphere and ionosphere

(Erzsébet Illés-Almár, Konkoly Observatory of the Hungarian Academy of Sciences)

In an earlier paper (Illés-Almár and Almár 2006) it was demonstrated that there is a North-South asymmetry in the thermospheric density with higher densities over the Northern hemisphere in average. Looking at the origin of this asymmetry an investigation on its seasonal dependence has been carried out (Illés-Almár 2009). It has been found that similarly to the mean annual effect the same North-South asymmetry exists during the different seasons as well. Since the steepness of the asymmetry does not change with seasons: the ocean/continent cover-differences and/or the geomagnetic field asymmetry are favoured as explanations for the asymmetry. A further discrepancy in the upper-atmospheric models has been discovered: the average atmospheric density is globally higher by roughly 4% near perihelion time that near aphelion, following the extrema with a roughly two months time delay.

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Long-term variations of ionospheric parameters

(Bencze Pál, MTA GGKI)

Considering the long-term variation in the height of the F2 layer (h_mF2) of the ionosphere, the problem of the explanation of the geographical distribution in the trend of h_mF2 proved to be unsolved. In the geographical distribution it is remarkable that positive trends indicating an increase of the height occur mostly inside of continents, while negative trends showing a decrease of the height appear in case of ionospheric stations located at the seaside or in the neighbourhood of it. This geographic distribution has been related to the territorial distribution of the declination of the geomagnetic field. However, this relation proved to be valid only for a part of the area of Eurasia. It looked much more obvious the relation between the territorial distribution of the h_mF2 trends, and positive and negative phases of the nonmigrating tides, which originate first of all in the transition zones between continents and oceans. A new view-point emerged by consideration of the effect of ocean currents. The nonmigrating tides are namely thermally driven tides. Thus, their formation may be due to the temperature difference between continents and oceans. The distribution of temperature differences may be strengthened by ocean currents, inasmuch as the direction of the current in the northern basin of the Atlantic and Pacific Oceans is clockwise, while in the southern basin of the Atlantic and Pacific Oceans the direction of the current is counterclockwise. This means that in the northern hemisphere the temperature of the air above the north-south directed cold current will be reduced along the western seashores of the continents, along the eastern seashores the south-north directed warm current will increase the temperature of the air. We meet the same situation in the southern hemisphere. The cooling of the air will induce a downward stream and consequently the decrease of h_mF2, the heating of the air will be associated by an upward stream and as a result will increase h_mF2. The geographical distribution of the h_mF2 trend may be produced by this system, which is proved by the observed geographical distribution of h_mF2 trends.

Coupling between the thermosphere, ionosphere and inner magnetosphere

A research conception has been developed, which is based on the complex measuring activity in the Széchenyi István Geophysical Observatory Nagycenk of the Hungarian Academy of Sciences. In the conception developed investigations related to the space weather are put into the centre. Monitoring of the plasma density in the inner magnetosphere (plasmasphere) is carried out by the determination of the parameters of FLR type geomagnetic pulsations, observation of the state of the ionosphere by vertical incidence sounding and determination of ionospheric parameters, as well as by observation and processing of whistlers. Another element of the conception are analyses referring to the lower and middle atmosphere affected by the space weather (interplanetary field) based on Schumann resonances and atmospheric electricity.

On the basis of this conception a method has been developed for the determination of the electron density along magnetic lines of force. The basis of the method is the relation referring to the period of FLR type geomagnetic pulsations. For the computations data of earth (telluric) current records observed in the Geophysical Observatory Nagycenk are used. In case of Nagycenk namely the magnetic dipole approximation can be applied. It has been found that the behaviour of FLR type pulsations can be approximated by a resonant circuit, where the ohmic load corresponds to the electron density. Thus, if the ohmic load, that is the electron density increases, the resonant period increases, as it is observed in case of pulsations. Hereby the "winter anomaly" of FLR type pulsations could also be explained. Moreover, it has been found that during a solar cycle in years of maximum solar activity the electron density is concentrated at the ends of the field line, in the vicinity of the mirror points, while in years of minimum solar activity the plasma distribution along field lines is uniform.

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Schumann resonances

Background Schumann resonances

(Gabriella Sátori, István Lemperger, Tamás Nagy, Judit Szendrői, MTA GGKI)

High time-resolution Schumann resonance (SR) records were analyzed in a midlatitude (Nagycenk, 47.6°N, 16.7°E, Hungary) and a north polar (Hornsund, 77°N, 15.5°E, Spitsbergen) station from the point of view of the day-night asymmetry of the Earth-ionosphere cavity. The sharp SR amplitude variations at ionospheric sunrise/sunset occur with clock-like accuracy from day to day indicating the ionospheric origins of these changes (Sátori et al. 2007).

Solar radiation-induced changes in ionospheric height and the Schumann resonance waveguide were examined on different time scales. The general insensitivity of the Schumann resonance cavity to changes in ionizing radiation lends stability to the medium that is valuable toward quantifying absolute changes in the global lightning activity on various time scale within the cavity (Williams and Sátori 2007).

Global lightning activity were studied on the ENSO (El Niño Southern Oscillation) time scale based on recordings of the Earth's Schumann resonances at Nagycenk (NCK), Hungary as well as observations from the OTD (Optical Transient Detector) and the LIS (Lightning Imaging Sensor) satellites in space. Both the intensity and position of lightning activity vary on the ENSO time scale (Sátori et al. 2008).

Schumann resonance signatures of global lightning activity were reviewed in a book chapter collecting SR observational and modeling results (Sátori et al. 2009).

Seasonal variations of global lightning activity were extracted from Schumann resonances (SR observations at Nagycenk Observatory) using a genetic algorithm method (Yang et al. 2009). Signature of the seasonal migration of global lightning was studied in the variation of Schumann resonance peak frequencies. Theoretical and experiment and experimental results were compared (Sátori et al. 2010).

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Schumann resonance transients and upper atmospheric electro-optical transient luminous events

(József Bór, Gabriella Sátori, Veronika Barta, MTA GGKI)

Peculiar doublets and multiplets of Schumann Resonance (SR) transients have been investigated in cooperation with Slovakian colleagues (Ondrášková et al. 2008). Analysis of time series of the vertical electric and the horizontal magnetic field components in the extremely low frequency (ELF, 3Hz–3kHz) band indicated that consecutive events in these transient trains have been originated from source discharges in the very same thunderstorms. The peculiarity of these events was that the time delay of the source discharges of each transient chain was such that the Earth-ionosphere cavity was excited coherently. The relatively frequent occurrence of such detections (7–8 per hour) suggests that around-the-world electromagnetic signals of a discharge may play a role in the initiation of later similar flashes.

Charge moment change (CMC) and polarity of the source discharge can also be derived from the recorded time series of the corresponding SR transients (Huang et al. 1999). The CMC has been shown to be one of the key parameters which determine the occurrence of sprites, a type of upper atmospheric transient luminous events (TLEs) above intense lightning flashes (Hu et al. 2002). SR transients recorded in the Széchenyi István Geophysical Observatory (NCK) in Hungary have been used in more studies between 2007 and 2010 to characterize the corresponding TLEs observed in the Eastern Mediterranean region (Yair et al. 2009, Yaniv et al. 2010), in West Europe (Soula et al. 2010), and in Africa (Williams et al. 2010).

Sprite halo related SR transients detected at NCK station are involved in an investigation to answer the question of why are the vast majority of sprites associated with positive polarity lightning flashes. Resulting statistics suggest that for sprite halos the occurrence ratio is reversed considering the polarity of the sources (Williams et al. 2007, Williams et al. 2009).

ELF records from NCK together with similar records from other field stations worldwide helped in determining the polarity of a rare species of gigantic jets (an other type of TLE) which has been observed in a winter thunderstorm West from the coasts of Corsica in 2010. This peculiar event has occurred in combination with a sprite and it transported positive charge from the parent thundercloud to the lower ionosphere (van der Velde et al. 2010).

In 2007, optical observations of TLEs have been started in Sopron, Hungary (Bór et al. 2009b). Considering the number of captured TLEs, our site was the most successful in Central Europe in the recent years (107 TLEs in 2007, 79 TLEs in 2008, 278 TLEs in 2009, and 123 TLEs in 2010). The majority of the recorded events were sprites, but few sprite halos were also detected. Analysis of the relationship between the captured events and the peak current, polarity, CMC, and the type (in cloud or cloud to ground) of the source flashes showed that the general characteristics of sprites in Central Europe don't deviate from those sprite properties observed worldwide (Bór et al. 2008). The relatively high number of observed sprites made possible the classification of the events by their optically perceptible properties such are the morphological properties and optical duration (Barta et al. 2009).

Geographical location and size of 23 sprite events have been determined via triangulation based on TLE images from Sopron, Hungary and from Modra Observatory, Slovakia. The results of the investigation pointed out the differences in the height and length variations of columniform and carrot type sprites. The location of triangulated sprites was compared to the locations of sources of very high frequency (VHF, 30–300 MHz) electric signals from lightning flashes occurred before the TLE. From the results of this comparison, connection between the orientation of the discharge channel of the source lightning and the displacement as well as configuration of elements in the appearing sprite cluster can be suspected (Bór et al. 2009a).

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Atmospheric electricity

(Ferenc Märcz, MTA GGKI)

Atmospheric electric potential gradient has continuously been measured in the Observatory of our Institute at Nagycenk. The data are regularly published in periodical reports and they could be used for different analyses. Earlier investigations have shown different time variations in the atmospheric electric potential gradient (PG). Based on data observed at Nagycenk and at two stations in the UK (Eskdalemuir, Lerwick) a long-term decrease has been revealed in the PG (Märcz and Harrison 2003). Previously, Nagycenk PG data have been investigated (Märcz 1997) with the aim at detection of responses in the surface PG to extraterrestrial changes. It was found that surface PG responds with a decrease to important changes in the galactic cosmic rays (GCR) at a time scale of days, to the Forbush decreases. Taking into account this result, it seemed to be reasonable to investigate possible connections between the Nagycenk PG and GCR at further time scales.

Based on a report on the appearance of a period of 1.68 years in the GCR (Rouillard and Lockwood 2004) R G Harrison initiated an investigation for detecting a time variation of this kind in the Nagycenk PG, too. Analysing Nagycenk PG data obtained between 1963 and 2004, Harrison and Märcz (2007) have shown that the variation of 1.68 years might has been present in the PG if an appropriate data selection is applied.

Using the method of power spectrum analysis, two independent investigations have been carried out. The actual period of 1.68 years slightly appeared in the case of an analysis with the total amount of data, however, it has been strengthened by using undisturbed data. As local influences on the PG are particularly weak in the dawn hours, a special data set was selected for this interval. Based on this set, the analysis has revealed a rather significant period of 1.68 years in the surface PG at dawn. When using data measured during really disturbed intervals, this periodicity could not be detected, even if the annual and semi-annual periods appeared in this case, too.

Moreover, Rouillard and Lockwood (2004) have reported that an especially significant period of 1.68 years was present in the GCR (based on neutron monitor data) in the interval 1978–1990, while it was quite weak before 1978 and it was entirely missing before 1975.

Applying the practice of Rouillard and Lockwood (2004), the PG data obtained during undisturbed intervals have also been divided in two groups. Based on the maximum entropy method, it could be stated that the tendency found in the neutron monitor data does appear in the surface PG, too. These results have revealed that the presence of the period of 1.68 years in the PG might not be an accidental event. Actually, certain previous findings are confirmed: surface PG might occasionally be used for indicating effects of extraterrestrial origin. Moreover, Nagycenk data seem to be a suitable tool for this purpose.

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III. Magnetospheric phenomena

Electromagnetic wave analysis

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Theoretical results on monochromatic and UWB propagation in wave guides and in moving inhomogeneous media

In the last three years we have developed the complete computation models of ultra wide band (UWB) signals propagating in wave guides filled by vacuum and anisotropic plasma, using the results of the earlier theoretical developments. The application of these models opened the way for the well based interpretation of satellite measurements. We started the generalization of these theoretical solutions for the case of curved wave guides filled by anisotropic plasma. — These models are important for the planned OBSTANOVKA-ISS experiment and also for the CHIBIS and RELEC satellites, which are under start preparation.

Furthermore, we have developed the real and accurate solution of monochromatic and UWB signal propagation in inhomogeneous and moving media, inside the validity of the special relativity. These results are important in the planetary (e.g. Venus and Mercury) and interplanetary, outer Solar System research, for the preparation of these missions and for the interpretation of the recorded data.

Processing and analysis of satellite waveform data recorded by DEMETER and COMPASS-2 satellites

In the last three years we completed the analysis of some interesting and now identified UWB signal-structures recorded by the French DEMETER satellite in VLF band, and we continued the analysis of the recorded whistlers having crossing traces ("X-type"). We can not exclude that the "X-type" pattern of these signals is an indication of the guided propagation through the magnetosphere; however, further clarification of this phenomenon is needed.

During the active phase of the COMPASS-2 technological satellite, our SAS2 electromagnetic wave analyzer instrument worked perfectly and recorded some interesting UWB ULF-VLF signals. Among these signals, we found similar types of VLF phenomena to those of recorded on the DEMETER satellite. Furthermore, because the noise level of the SAS2 is very low, i.e. the sensitivity is high in the complete ULF-VLF band, it was possible to record and identified a real guided whistler-group first time, which propagated between two layers (in an "onion-skin" like structure of inhomogeneity) in a higher guided mode. This means that the form of a real guided whistler differs from the so called free space mode; and therefore it is necessary to make a critical overview of the general idea that the whistlers (the VLF signals) propagate through the magnetosphere from one hemisphere to the other in ducts in most cases.

Automatic Whistler Detector and Analyzer Network (AWDANet)

We have setup a global network of AWDA systems, spanning over a wide range of magnetic latitude and longitude. This setup allows to use lightning whistler for monitoring the electron density variations in the plasmasphere. The network has 15 existing and 12 planned nodes. We have performed statistical analysis on whistler data recorded at 3 magnetic meridians to find the source lightning of recorded whistler traces. The analysis of data recorded in European-African meridian involved 6 years (2002–2008) and 680 thousand whistler traces showed that the primary source is close to the geomagnetic conjugate point of the receiver (Tihany, Hungary), over the warm Agulhas current. The shape of the most probable source region is an ellipse elongated along the meridian. This may explain the L-discrepancy. The investigated second meridian was the Pacific meridian. The AWDANet receiver at Dunedin (New Zealand) recorded more than 700 thousand whistler traces between 2005–2009. However, practically no lightning over the conjugate area of Dunedin (Aleutean-islands), thus the traditional theory of whistler generation and propagation is not applicable. The statistical analysis showed that the most probable source region is along California and Mexico which opens the question of subionospheric propagation path of the signal before and after the magnetospheric propagation. The data along third meridian (America) exhibit exceptionally high rate, the number of whistler traces recorded at Rothera (Antarctic peninsula) exceeds 5 million/year, while the Palmer data rate is close to 10 million/year. The source region is over the Golf current, southward of the conjugate location, this agreed with the traditional generation theory. The two times higher rate at Palmer than at Rothera, which is just 300 km from Rothera is still unexplained.

We have developed a new whistler inversion method which is based on recent advances on wave propagation theory and experimental field-aligned electron density distributions. An inversion model of multiple-path propagation whistler groups has also been developed. This model is based on the enhanced whistler inversion method and a simplified equatorial electron density model. A new, special transformation based on the multiple-path groups is introduced. This transformation allows not only the inversion of such groups, but forms the basis of an automatic whistlers analyzer algorithm. We worked out the practical implementation of the algorithm. The quasi-realtime mode of operation of automatic whistler analyzer can be made using this implementation on PC clusters with $\sim$100 CPU threads. We are planning to setup such a systems at AWDANet nodes to process the whistler data quasi-realtime providing electron density data for wave-particle interactions in modeling high energy particle acceleration and losses in the Radiation Belt.

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Interaction of the solar wind with Venus

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KFKI Research Institute for Particle and Nuclear Physics is participating in the ASPERA-4 experiment of the Venus Express mission of ESA. Venus Express was launched on 9 November 2005, and after cruising 153 days arrived at Venus on 11 April 2006. Science operation began in the middle of 2006. ASPERA-4 analyses space plasma and neutral atoms, the instrument description was published by Barabash et al. (2007a). According to the current plans, the Venus Express mission is extended till 31 December 2014, with a major review in 2012.

The data analysis of ASPERA-4 was an important task during the current review period. The work was very much facilitated by the excellent cooperation with the magnetometer team, who made available to the ASPERA team the magnetic data almost in real time; which is absolutely necessary for a full interpretation of the plasma data. Since both Venus and Titan are non-magnetic solar system objects, the parallel investigation of these bodies has given us definite advantages, and we also benefited from our previous work with the data of the Pioneer-Venus Orbiter of NASA.

Dóbé and Szego (2007) reviewed earlier investigations based on data of the Pioneer Venus Orbiter and previous missions. They concluded that a physical picture is still valid for the description of the interaction of the solar wind with a non-magnetized, conductive obstacle like Venus, namely behind the bow shock an extended layer (the so-called mantle) is separating the shocked plasma flow and the ionosphere. Elements of this picture were forgotten, and reinvented then under new names. It was shown that current results validate the early picture, while its details are much enhanced. Dóbé and Szego (2007) presented a model that describes wave excitations, attempting to explain how events on microphysical scale can be connected to the more general macrophysical experimental results. The results of the Cassini mission near Titan are used as examples.

In the streaming solar wind, Venus forms an obstacle dominated by ions of planetary origin. Szego et al. (2009) investigated the properties of the O^+ ions in the different plasma regions inside the obstacle boundary of Venus in the wake. The study was based on the data collected by the ASPERA-4 plasma analyzer flying onboard of the Venus Express spacecraft in a region never explored before experimentally. The obstacle boundary was approximately identified from the dropout of magnetospheric electrons and from the sharp decrease of the proton speed; the entry point correlated well with the location of the magnetic barrier derived by eyes from magnetometer data. The most characteristic structures seen during the various flybys were 1. the tailward continuation of the mantle was evident; 2. in the mantle near Venus, the O^+ ion flow was significantly intense in low-energy counts; 3. the inbound and outbound crossings of the tailward boundary were sharp, characterized by less intense but higher-energy O^+ beams; 4. the crossing of the central tail region (current sheet) was marked by the change of the sign of B_x magnetic field component and by an intense low-energy O^+ ion flux; 5. the O^+ ion outflow was not confined to the central tail region; the intensity elsewhere was highly variable, resulting in a ray-like outflow pattern in most of the cases.

The Venus Express mission set a number of key questions to fill the gap in our current knowledge about Venus, one of those is to clarify the past and present water balance in the atmosphere. The ASPERA-4 data contributed to that by measuring major loss processes. Barabash et al. (2007b) reported Venus Express measurements showing that the dominant escaping ions are O^+, He^+ and H^+. The escaping ions leave Venus through the plasma sheet (a central portion of the plasma wake) and in a boundary layer of the induced magnetosphere.

A summary of the analysis of the first measurements were published by the whole team in a special section of Planetary and Space Sciences in 2008 in a number of papers (Coates et al. 2008, Fedorov et al. 2008, Futaana et al. 2008, Galli et al. 2008, Kallio et al. 2008, Martinecz et al. 2008). These publications gave a more complete picture of the interaction of Venus with the inflowing solar wind. Measurements were reported which were made by the ion and electron sensors of ASPERA-4 during their first five months of operation and, determined the locations of both the Venus bow shock (BS) and the ion composition boundary (ICB) under solar minimum conditions. Statistical and case studies were performed to reveal the properties of the magnetosheath ion flows and the flows of planetary ions behind Venus, results were compared with Mars. The detection of electrons due to photo-ionization of atomic oxygen and carbon dioxide in the Venus atmosphere by solar helium 30.4 nm photons was also reported. Plasma and magnetic field measurements in the induced magnetosphere of Venus were made onboard the Venus Express, and were analyzed and compared with predictions of a global model. A typical signature of solar energetic particle events, i.e. intensive MeV particle fluxes were also captured and compared with observations at Mars and at the Earth. The source of the events was a single active region on the Sun which in December 2006 produced a series of proton solar flares. The ASPERA-4 instrument on board the Venus Express spacecraft offered for the first time the possibility to directly measure the emission of energetic neutral atoms (ENAs) in the vicinity of Venus. When the spacecraft was inside the Venus shadow, a distinct signal of hydrogen ENAs was usually detected.

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Environment of the Earth

(Gábor Facskó, Mariella Tátrallyay, KFKI Research Institute for Particle and Nuclear Physics)

The Cluster mission of the European Space Agency is studying the small-scale spatial and temporal characteristics of the terrestrial plasma environment in three dimensions. Simultaneous data collection by the four identically equipped Cluster spacecraft began on 1 February 2001. Ten of the eleven experiments are still collecting data, several of them aboard all four satellites. Processes of different scales can be studied by changing the separation distances between the spacecraft. A multi-scale configuration is maintained since 2006, the distance between Cluster-3 and Cluster-4 is now a few hundred km, while the other separation distances are around 10 thousand km. The polar orbit is slowly evolving, as the major axis is gradually turning to the south from the ecliptic plane. This way, different regions of the terrestrial plasma environment can be studied which were not sampled earlier in the mission. The Cluster mission is extended up to the end of 1014 subject to a review in 2012 to confirm the last two years.

Since the beginning of the Cluster mission, KFKI Research Institute for Particle and Nuclear Physics has been providing the infrastructure and management of the Hungarian Data Centre (HDC). The HDC is preparing the Auxiliary parameters for the Cluster Science Data System and exchanging data with the other national Data Centres which are producing plasmaphysical parameters (1 min and 4 sec resolution) from data measured by the different instruments (http://hdc.rmki.kfki.hu/cdms/). Raw data and data processing softwares are available for the whole space community at the Cluster Active Archive (http://caa.estec.esa.int/caa/).

Hot Flow Anomalies (HFA – magnetic cavity filled with hot plasma) were studied using observations of the magnetometer and the plasma instrument aboard the four Cluster spacecraft. HFAs are produced by the interaction of the bow shock with a tangential discontinuity propagating in the interplanetary space. The size of the region affected by the HFA was estimated by using two different methods. Facskó et al. (2009) confirmed the results of the previous hybrid simulations that the size is mainly influenced by the magnetic shear, the angle between the discontinuity normal and the Sun-Earth direction, furthermore by the Alfvén Mach number of the solar wind. The size grows with the Alfvén Mach number, the shear, and (up to a certain point) with the angle as well. After that point it starts decreasing. The favoured orientation and the shear were also determined based on large number of events. The HFAs were mostly observed at the quasi-parallel bow shock (Facskó et al. 2009). These results were compared with the outcome of recent hybrid simulations. Facskó et al. (2008, 2009, 2010) found the same condition for forming HFAs during solar minimum (in 2003) and solar maximum (in 2006 and 2007), i.e. that the solar-wind speed and the fast magnetosonic Mach number values are higher than average. ACE magnetic field and solar-wind plasma observations at the L1 point were used for determining long time averages of plasma parameters in order to compare them with values observed at the time of HFA formation.

The evolution of mirror mode waves was investigated in the magnetosheath from Cluster magnetic field and plasma measurements (Tátrallyay et al. 2008, 2010). The growth rate γ of the field strength perturbations δB was estimated by comparing the amplitudes of fluctuations observed simultaneously at distant locations ($\sim$10 000 km) based on the assumption that $\delta B \sim \exp(\gamma t)$. A model was developed for the calculation of plasma flowtime t from the bow shock to the observation point. The obtained growth rate values were about an order of magnitude smaller than those provided by linear models and they decreased in the inner regions of the magnetosheath, indicating some saturation in the growth of the waves when proceeding towards the magnetopause. The results suggest that mirror type fluctuations originate from the compression region downstream of the quasi-perpendicular bow shock, and they cannot grow beyond a certain degree.

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Environment of Jupiter and Saturn

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Bebesi et al. (2010a, 2010b) discussed some interesting plasma observations in the Jovian magnetosheath taken by the Cassini spacecraft during the 2000–2001 Jupiter flyby. For the analysis, data of the Cassini Plasma Spectrometer (CAPS), the Magnetospheric Imaging Instrument (MIMI), and the Magnetometer (MAG) were used. It was proposed that the observations are consistent with a slow-mode shock transition. In the terrestrial magnetosheath, a number of observations have been made that are consistent with slow-mode waves or shocks. In the Jovian plasma environment, only one observation was previously reported as a slow-mode shock-like transition which was made in the dayside magnetosheath. The observation reported by Bebesi et al. (2010a) was made well downstream of the magnetosphere in Jupiter's magnetosheath, at local time ∼19:10.

The ionosphere of Titan, moon of Saturn is directly exposed to the streaming plasma either of magnetospheric or solar wind origin. A turbulent interaction region between the two different plasma types is formed, called here flowside plasma mantle, where both ionospheric and hot streaming plasma are present at comparable densities. In order to study the microphysics of the collective plasma phenomena taking place within the flowside plasma mantle of Titan, Dóbé et al. (2007) constructed a one dimensional electromagnetic hybrid simulation, retaining the inertia of the electrons. It was shown that the excited waves are very effective in generating "anomalous viscosity" type interaction between the hot plasma flow and cold ionospheric ions, leading to significant bulk velocity loss of the proton component of the external plasma flow and turbulent heating of the ionospheric ions. The stochastic energy transfer from the streaming plasma to the ionospheric ions may also increase the tailward planetary ion escape by collective pick-up mechanism enhancing the rate of erosion of the atmosphere of Titan (sputtering). Dóbé et al. (2007) made predictions for the characteristic frequency range and saturation energy level of the excited wave electric field, and for the energy range where superthermal charged particles of ionospheric origin can be detected by the charged particle analyzers onboard of Cassini spacecraft near Titan.

Cassini's T9 flyby (5–6 R_T Titan radii downstream from the moon) was analysed in details when the plasma flow and magnetic field directions in the distant plasma environment of the moon were distinctly different from other observations. Magnetometer (MAG) measurements revealed a well-defined, induced magnetic tail consisting of two lobes and a distinct central current sheet (Bertucci et al. 2007). The analysis of MAG data in a coordinate system based on the orientation of the background magnetic field and an estimation of the incoming flow direction suggested that Titan's magnetic tail was extremely asymmetric. An important source of these asymmetries was the connection of the inbound tail lobe and the outbound tail lobe to the dayside and nightside hemispheres of Titan, respectively. Another source could be the perturbations generated by changes in the upstream conditions.

Electron and ion data measured by the CAPS spectrometer showed an unusual split signature with two principal intervals of interest during the T9 flyby. The first region was dominated by dense, slow, and cold ions in the 16–19 and 28–40 amu mass range and penetrating magnetospheric electrons were also observed. The second region contained only ions with mass 1 and 2, much less dense and less slow. Szego et al. (2007) concluded that Event 1 was due to the crossing of the mantle of Titan, whereas Event 2 very likely was a wake crossing. Coates et al. (2007) suggested a mechanism for explaining the observed plasma escape based on ambipolar electric fields set up by suprathermal ionospheric photoelectrons.

Sittler et al. (2010) presented new results of Cassini's T9 flyby with complementary observations from T18. The upstream flow for both T9 and T18 was composed of light ions (H^+ and H_2^+), with external pressures ~30 times lower than that for the earlier TA flyby where heavy ions dominated the magnetospheric plasma. The T9 flyby unexpectedly resulted in observation of two "wake" crossings referred to as Events 1 and 2. Event 2 was evidently caused by draped magnetosphere field lines, which are scavenging pickup ions from Titan's induced magnetopause boundary with outward flux $\sim 2 \times 10^6$ ions/cm^2/s. The composition of this outflow is dominated by H_2^+ and H^+ ions. Ionospheric flow away from Titan with ion flux $\sim 7 \times 10^6$ ion/cm^2/s is observed for Event 1. T18 observations are much closer to Titan than T9, allowing one to probe this type of interaction down to altitudes ~950 km. Comparisons with previously reported hybrid simulations were made.

During the T31 Cassini flyby, Titan was observed in the shocked solar wind, outside of Saturn's magnetosphere. Bertucci et al. (2008) reported that Titan's flow-induced magnetosphere was populated by "fossil" magnetic fields originating from Saturn, to which the satellite was exposed before its excursion through the magnetopause. In addition, strong magnetic shear observed at the edge of Titan's induced magnetosphere suggests that reconnection may have been involved in the replacement of the fossil fields by the interplanetary magnetic field.

Juhász et al. (2007) studied why the peak of the optical depth in Saturn's E ring is observed outside the orbit of Enceladus, which had been long suggested as the main dust source. The displacement of approximately 104 km was suspected to be a result of electromagnetic forces. Juhász et al. (2007) showed that it is intimately related to the initial inclinations of the grains produced in the recently discovered plumes. For grains with radii smaller than 0.5 mm, the small initial inclination greatly reduces their re-collision probability, allowing for sufficiently long lifetimes for plasma drag to transport them outwards. The numerical results can also be used in the simultaneous interpretation of the measurements by the Cassini CDA, RPWS instruments and imaging.

Horányi et al. (2008) reported on modeling results of the long-term evolution of dust particles comprising the E ring to show that grains from Enceladus could indeed reach the outskirts of Saturn's magnetosphere. The ring was traditionally thought to span the region between 3 to 8 Saturn radii (RS). However, new *in situ* dust measurements indicated that the density of small grains might continuously extend far beyond these boundaries, and the E ring could reach even beyond the orbit of Titan (20.3 R_S).

Horányi and Juhász (2010) explored the dynamics of small charged dust particles in Jupiter's innermost magnetosphere and showed that the systematic charge variation of the grains results in surprisingly short lifetimes. Assuming a constant production of small dust particles via continual micrometeoroid bombardment of the larger parent bodies of the main ring, this model reproduces remote sensing observations of the ring/halo region at Jupiter made by Voyager, Galileo, Cassini, and New Horizons spacecraft and observations from the ground by the Keck telescope during ring plane crossings. We used this model to make predictions for the dust impact rates for the JUNO mission, which is expected to traverse this region multiple times starting in 2016.

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MHD simulations of Saturn's magnetosphere

(Bertalan Zieger, MTA GGKI)

A series of 3-dimensional single-fluid MHD simulations of Saturns magnetosphere has been carried out with the BATS-R-US MHD code developed at the University of Michigan. The most important magnetospheric plasma sources, the icy satellites, Enceladus, the rings, and Titan are taken into account as source-terms in the MHD equations (Hansen et al. 2005). We studied the solar wind control of large-scale mass loading and plasma release phenomena in the Kronian magnetosphere (Zieger et al. 2010). We showed that, at high solar wind dynamic pressure, the loss of plasma in the magnetotail is continuous. At medium dynamic pressure, plasmoids are pinched off periodically along an X-line in the post-midnight sector through a cascade of helical reconnection due to the Vasyliunas cycle characteristic of mass-loaded magnetospheres with fast rotation. Plasmoids have a magnetic topology of a helical flux rope with its ends anchoring in the polar regions of Saturn. With decreasing dynamic pressure, the repetition period of plasmoids gradually increases. A higher mass-loading rate or a higher axial tilt of Saturn makes the repetition period longer. At low dynamic pressure, the release of plasmoids becomes quasi-periodic or chaotic. The pressure control of the repetition period is very similar to the behaviour of a dripping faucet. The mass and volume of the closed magnetosphere are smaller at lower dynamic pressures because of a relatively longer X-line. In our simulations, large-scale plasmoids are responsible for less than 8% of the total mass loss, and the rest of the plasma is lost via cross-field diffusion or other small-scale mechanisms.

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IV. Solar wind and interplanetary field

Heliosphere, energetic particles

(Géza Erdős, Károly Kecskeméty, Péter Király, Zoltán Németh, KFKI Research Institute for Particle and Nuclear Physics)

Erdős and Balogh (2008) studied the spatial distribution of MHD discontinuities in the solar wind, based on the long time data series of the magnetometer onboard Ulysses. The analysis supported earlier observations that the density of discontinuities decreases with increasing distance from the Sun. Erdős and Balogh (2008) suggested that the distribution of the discontinuity normals should be revised, retaining only those discontinuities for further study that have reliable normals. Contradicting to earlier investigations, this study showed that the vast majority of well defined discontinuities had a small magnetic field component parallel to the discontinuity normal.

Erdős and Balogh (2010) revisited the possible latitudinal offset of the location of the heliospheric current sheet (HCS). Earlier investigations proposed a southward displacement of the HCS by 10° to explain the north-south asymmetry of energetic charged-particle fluxes measured by Ulysses in the declining phase of the previous, 22nd solar cycle. According to Erdős and Balogh (2010), the Ulysses magnetic field measurements did not give direct evidence for such a large displacement of the HCS. Careful analysis of the HCS crossings observed by Ulysses during the fast latitude scans showed that a southward displacement of the HCS by 2°–3° is possible and consistent with the data for cycles 22 and 23. The impact of the HCS location on the latitudinal gradients of energetic particle fluxes was also discussed.

Németh (2008) presented a theoretical model of particle acceleration by the interaction of a magnetic field directional discontinuity and a collisionless shock. The geometry of the interaction region, the relative angles of the shock, discontinuity, and magnetic field highly influences the acceleration process. In certain geometries the particles can re-enter the acceleration region again and again, which leads to more effective acceleration and higher final energies. This mechanism can contribute to the generation of energetic particles in hot flow anomalies (HFA observations were discussed in Section III), and can play an important role in the pre-acceleration of anomalous cosmic rays.

Three-dimensional correlation functions of the interplanetary magnetic field (IMF) were determined and studied using Cluster multi-point magnetic measurements. Németh et al. (2010) found that the correlation length varies over almost six orders of magnitude. The IMF turbulence showed significant anisotropy with two distinct populations. Most of the time, the ratio of the three axes of the correlation ellipsoid was 1:2.2:6 while extremely high correlation was found along one axis in the remaining time. The major axes of the ellipsoids favored the Sun-Earth direction, the minor axes favored the direction perpendicular to the ecliptic plane.

The decay phase of solar energetic particle (SEP) events was investigated by Kecskeméty et al. (2009) on a broad statistical sample of more than 600 events using IMP-8 data over more than two solar cycles between 1973 and 2001. They found that the majority of proton fluxes (>90%) in the energy range of ∼1–50 MeV exhibit exponential law decrease, suggesting the dominant role of convection transport and adiabatic deceleration. They determined the characteristic decay time and examined its variation on various parameters as the energy spectral index, the solar wind speed, and the distance from the Sun. The observed decay times were in good agreement with theoretical expectations assuming convection transport and adiabatic deceleration in nearly 50% of all decays for constant values of plasma speed. The comparison of proton profiles at various radial distances (Helios, IMP-8, Ulysses) showed that MeV protons in the same events decay more slowly with increasing distance, in agreement with theory. The observational results were compared with a numerical simulation in a propagation model involving scattering, adiabatic cooling, and a propagating shock which gave similar results but showed that nearly exponential profiles can be obtained at low energies. Using SOHO data

Daibog et al. (2009a) extended this study to electrons and suggested that they are subject predominantly to the same propagation mechanism. Daibog et al. (2009b, 2010) showed that combining electron and proton decays results in a diversity of events as a function of rigidity.

Zeldovich et al. (2009) examined low-flux protons throughout the solar cycles 21–23 in comparison with the MgII index. They found a positive correlation between them at quiet solar activity periods, the lowest MgII index values were observed simultaneously with low values of the proton/alfa ratio. At lower proton energies the correlation of the particle intensity and MgII index value becomes stronger. The radial and latitude gradients of 1–30 MeV energy proton fluxes were estimated using Voyager and Ulysses data during the solar activity minima of 1985–1987 and 1996–1998 (Kecskeméty et al. 2008b). From the radial gradient the radial mean free path was calculated and compared with a two dimensional, full drift model. Its radial variation exhibits a slight minimum near 300 MV rigidity. The slope of the energy spectrum was found to decrease with increasing radial distance.

Király (2008b) introduced a new measure for the variability of time-integrated energetic ion fluences (called K parameter because of its relationship to Kolmogorov statistics), and discussed its dependence on particle energy and on heliospheric radial distance. It was found that in the inner Heliosphere K depends linearly on the logarithm of kinetic energy in a fairly large energy interval, extending from tens of keV to a few MeV. Extrapolating to lower energies one obtains plausible K parameter values for the variability (intermittency) in the several keV range. As was pointed out on Voyager data, however, the same linear relationship is not valid in the outer regions of the Heliosphere.

Suprathermal and energetic ion intensities and streaming directions from about 30 keV to several MeV at both Voyagers were discussed by Király (2008a). Substantial differences were found in the upstream region between the streaming directions of ions at Voyager 1 and 2 (V1, V2). While streaming is mostly outward along the spiral field for V1 at most energies, fluxes at V2 show radial outward streaming (and practically no termination shock-related enhancements) at low energies. At higher energies, where flux enhancements are present, streaming is mostly inward along the spiral field at V2, as expected for shock-accelerated ions. Possible scenarios for the discrepancy were discussed.

Király (2009a, 2009b) discussed solar-wind and ion data as measured before and after the termination shock transit(s) of V2 at the end of August 2007. Solar-wind plasma data were of particular importance because V1 had no working plasma instrument at its termination shock transit in 2004. It was pointed out that the transformation of most of the solar-wind kinetic energy into energetic ions of several keV may have important implications for the injection of energy into cosmic ray accelerators in various stellar environments. An interesting correlation between post-shock plasma density and thermal speed was also pointed out, indicating effects of compressive turbulence in the post-shock region.

The propagation of the solar wind in the heliosphere was also investigated to clarify whether measurements made near Earth could help to identify upstream conditions at other planets. The *in situ* plasma measurements by STEREO A and

B, SOHO, Venus Express, and Mars Express were used for this study during the last, long solar activity minimum. Opitz et al. (2010) found an appropriate extrapolation that might serve as a good solar-wind input information for planetary studies of magnetospheric and ionospheric processes.

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ULF phenomena: upstream waves and field line resonances

(B Heilig, G Vadász, ELGI)

Dayside Pc3-4 pulsations are most commonly associated with field line resonances (FLRs), i.e. standing oscillations of field lines in the magnetosphere. The resonant frequency is determined by the field line length, plasma mass density and magnetic tension. If the topology of the magnetic field is well described by a model, FLRs can be used to monitor the plasma mass density of the magnetosphere.

FLRs can be most safely detected by the phase gradient method which requires closely separated north-south stations pairs (e.g. Green et al. 1994). In Hungary, FLRs have been routinely observed this way since 2000. Moreover, ELGI coordinates a quasi meridional European magnetometer network (MM100) the aim of which is to monitor the plasmaspheric mass density in the latitude range $L = 1.8 - 3.4$. MM100 is now suitable to monitor plasma dynamics (depletion, re-filling) during and after geomagnetic storms.

We found that the equatorial plasma mass density observed by the Nagycenk-Tihany station pair ($L = 1.85$) has both a seasonal and a solar cycle variation (Heilig et al. 2009a). The latter results in a modulation of the seasonal changes, the seasonal variation fades with time approaching sunspot minimum. The seasonal variation follows the seasonal variation of the electron density recorded at Juliusruh (Germany). This correlation is maintained by the ambipolar diffusion of plasma along the geomagnetic field lines.

Conjugate comparisons of FLR observations demonstrated the reliability and limitations of the method. Plasma mass density at $L \sim 1.85$ was inferred from FLR observations made on both hemispheres, at Nagycenk-Tihany in Hungary and at Hermanus-Southerland in South Africa (Heilig et al. 2009a, 2009b). The resulting density values, as well as, the variation of the density fitted well. The mass density estimations were found to be accurate within 15–20% in 90% of the cases. A slow drift in the difference of the two time series was attributed to the change of the magnetic field topology not reflected by the model applied.

Plasma mass density estimations were also compared with electron density estimations inferred from VLF whistler observations carried out at Tihany Geophysical Observatory by Space Research Group, ELTE (Heilig et al. 2009a). The comparison made during a severe geomagnetic storm demonstrated that the results yielded by both independent methods are in reasonable agreement. Further work is needed, however, to intercalibrate the two methods in order to make the calculation of average ion mass possible.

The predominant source of magnetospheric FLRs are upstream waves (UWs) generated in the Earth's foreshock (Heilig et al. 2007a). The characteristics of UW related Pc3 pulsations are controlled by solar wind (SW) and interplanetary magnetic field (IMF) parameters. Because of their ion-cyclotron origin, the frequency of UWs is proportional with IMF strength. Their amplitude is controlled by the SW speed and IMF direction. Although the first results demonstrating the strong correlation of the properties of ground Pc3 and SW/IMF parameters (e.g. Verő 1980), in the last decades several author inspired by findings of MHD modellers turned to another possible source, the fast mode cavity resonances (FMRs) and got skeptic about UW origin (e.g. Kivelson 1985). The main reason was that according to models UWs get evanescent at the turning point (in the inner magnetosphere) and do not reach the ionosphere at low and mid latitudes. However, since then the reliable detection of dayside FMRs remains unsuccessful.

We compared UW activity observed by the Cluster satellites in the foreshock with ground observations of ULF waves in trying to answer the question (Heilig et al. 2008a). It was found that foreshock UW activity, as well as ground Pc3 activity is controlled by the direction of the IMF in the same way. Pc3s were observed on the ground when the bow shock nose was within the ULF foreshock.

A statistical study involving seven years of geomagnetic observations at MM100 stations and SW and IMF observations yielded new arguments for the UW origin of mid latitude dayside Pc3s (Heilig et al. 2010). Ground Pc3 activity was found to be strongly dependent on SW density and on other density dependent quantities, such as SW dynamic pressure, Alfvén Mach number, stand-off distance of the nose of the magnetopause (L_{mp}). It was also clearly demonstrated that Pc3 activity ceases during periods with extremely low SW density (< 3 cm^{-3}). The lack of Pc3s when the SW is sub-Alfvénic, or when SW protons are missing are in accordance with the UW theory. The strong decrease of Pc3 amplitude with increasing L_{mp} suggests a kind of damping mechanism. Our analysis supports UW activity as the dominant source of mid-latitude Pc3s.

We introduced a procedure for an automated detection of UW signatures based on cross spectral analysis, both in ground and space data (Heilig et al. 2007a). Using the magnetic field measurements from the satellite CHAMP, a detailed picture could be obtained of the UW distribution in the topside ionosphere. The low, near-polar orbit of CHAMP, covering all local times, allowed the global distribution of this type of pulsation to be revealed. The observations from space were compared to recordings of the ground-based MM100 meridional array. UWs showed up very clearly in the compressional component of the satellite magnetic field data, whereas on the ground, their signature was found in the H component but mixed with oscillations from field line resonant pulsations. The statistical analysis of CHAMP (Heilig et al. 2007a) and MM100 (Heilig et al. 2007b) observations clearly proved their UW origin.

Together with Russian researchers we also made an attempt to reconcile observational evidence with MHD models (Pilipenko et al. 2008). The following possibilities of ULF compressional disturbance excitation were considered: 1. an incident Alfvén wave generates an evanescent fast mode as a result of its interaction with the anisotropically conducting ionosphere; 2. transport of ULF wave energy from a distant source toward the ionosphere predominantly occurs by a fast mode. We estimated quantitatively the expected relationships between the Pc3 wave magnetic components above the ionosphere and on the ground produced by these different mechanisms and derived simple analytical relationships between the compressional and ground signals for both mechanisms. This model was applied to the interpretation of Pc 3 waves observed by CHAMP in the upper ionosphere and by ground stations at mid latitudes. In general, the observed ratio between the compressional component in space and the ground signal corresponds better to the scenario of direct fast mode transmission to the ground.

Since the ULF waves can accelerate the plasmasphere particles through wave-particle interaction, we investigated the relation between high-energy particles recorded by the Demeter spacecraft and Pc activities observed at MM100 observatories. Affirming the expectations, in a period of a series of strong solar flares between 16th and 20th of January 2005, we found similar trends in the variation of the number of relativistic particles detected by Demeter and the Pc2-Pc3-Pc4 activities recorded in the Tihany and Nurmijärvi observatories (Vadász 2010).

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Nonlinear study of solar wind – magnetosphere dynamics

(Péter Kovács, ELGI)

Several studies evidence the nonlinear behaviour of fluctuations of physical parameters in the space regions (e.g. in the cusps, magnetosheath or foreshock) under certain solar conditions. In our current investigations we argued that the level of turbulent dynamics could be adequately monitored in space and time by the investigation of the change of the intermittent properties of *in situ* magnetic time-series. The level of intermittency was measured by computing the probability density functions (PDF) and the fourth statistical moments of the temporal differences of the time-series, i.e. their flatness. In many of our analyses, the magnetic records of the Cluster space mission were used. The multi-spacecraft observations had key role, since with them the intermittency in the plasma fluctuations could be revealed not only in temporal but also in spatial scales. However, in the analyses, it had to be taken into account that the dynamics of several space regions was governed not only by turbulent fluctuations but also by wave phenomena occurring in certain frequencies. It was shown through synthetic data that the wave activities could strongly complicate the interpretation of the results of the turbulent analyses. For this reason, we introduced a dynamic wavelet filter technique for discriminating between wave and turbulent components of the analysed time records.

Quasi-parallel foreshock – One of our nonlinear studies concerned with the variation of turbulent behaviours of the plasma fluctuation in the quasi-parallel foreshock region. We intended to show correlation between the turbulent and upstream wave activities of the region. In the study, the 5 Hz magnetic field (MF) variation recorded in the foreshock region during February and March of 2004 has been used. We mapped the level of turbulent intermittency of the recorded magnetic variation in the foreshock in terms of 1. the angle of incidence of the MF vector to the bow shock (BS) normal and 2. the IMF-aligned distance from the BS. The varying position of the BS was monitored according to the Farris and Russell (1994) model. As it was expected, the turbulent activity increased both with decreasing BS distance and with angle of incidence to the BS normal (Kovács et al. 2010). Considering the results in different solar wind conditions, we showed that the level of turbulent activity was enhanced with increasing Alfvén Mach number, increasing particle density and decreasing solar wind speed. Stronger turbulence in slow than in fast solar wind was already known from the dynamics of the distant solar wind (Bruno et al. 2003). On the other hand, the strong direct correlation between particle density and turbulent activity is suggested to be resulted in by the interaction between downstreaming and upstreaming particle beams in the quasi-parallel foreshock region.

Hot Flow Anomaly – The turbulent dynamics of Hot-Flow anomalies (HFA) has also been investigated. HFAs are transient high-energy plasma populations that evolve along the interaction line of the shock and a tangential discontinuity (TD) plane embedded in the solar wind (Schwartz et al. 1985, Thomsen et al. 1986). Using the k-filtering analysis of the magnetic records of the multi-spacecraft Cluster mission it was shown by Tjulin et al. (2008) that the magnetic variations inside the HFA cavity are strongly determined by wave phenomena. In our studies, we investigated the noisy background of the HFA magnetic fluctuations using the 22.5 Hz magnetic records of the Cluster mission. It was evidenced through probability density function, structure function and multifractal spectrum analyses of the magnetic data that the high-frequency, small-amplitude background magnetic fluctuations of the HFAs exhibit multifractal turbulent features (Kovács and Facskó 2009). This finding was affirmed by phase space reconstruction (Packard et al. 1980), which, in correspondence with the multidimensional feature of turbulence, showed the increasing of the number of degrees of freedom inside the HFA cavity. We have also computed statistical distribution of waiting-times between intermittent bursts of the HFA magnetic field. This test evidenced power-law decrease of the probabilities of increasing waiting-times that, similarly to the property of turbulent models (e.g. shell model), referred to correlation between the intermittent events, i.e. statistical memory in the system.

Magnetosphere – We have studied the nonlinear dynamics of the magnetosphere system and its relation to the behaviour of the solar wind dynamics, in active and quiescent geomagnetic periods. For that, contemporary ground observation of the geomagnetic field and Cluster observation of the space (solar wind, magnetosphere) magnetic field have been used. On the basis of the results of chaos analyses (embedding dimension analysis, singular value decomposition, and surrogate data test) of

1 Hz geomagnetic data recorded in the Tihany observatory we have previously argued that the number of degrees of freedom in the phase space of the geomagnetic system was considerably higher under quiet than disturbed magnetic conditions. Later, this finding was affirmed with the analysis of *in situ* magnetic data recorded in the magnetosphere by the Cluster space mission (Kovács 2008). On the other hand, it was also presented that during the disturbed periods the solar wind exhibited multidimensional signatures referring to turbulent or stochastic dynamical processes. This dynamical state was evidently different from that of the magnetosphere. It means that despite the close dynamical impact of the solar wind to the magnetosphere, the latter exhibits intrinsic dynamical behaviour during storm periods.

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MHD simulations of the solar wind

(Bertalan Zieger, MTA GGKI)

In collaboration with the University of Michigan, we developed a one-dimensional (1D) numerical magnetohydrodynamic (MHD) code to propagate the solar wind from 1 AU through 10 AU, i.e., beyond the heliocentric distance of Saturn's orbit, in a non-rotating frame of reference. The time-varying boundary conditions at 1 AU are obtained from hourly solar wind plasma and interplanetary magnetic field data observed near the Earth. The numerical solution can be mapped to any spacecraft or planet in space and time, assuming that the solar corona is in steady state on the time scale of half a solar rotation. This solar wind propagation model (MSWiM = Michigan Solar Wind Model) can be applied to predict solar wind conditions in the outer heliosphere. We validated the statistical accuracy of such solar wind predictions using 12 selected years of solar wind data from the major heliospheric missions Pioneer, Voyager, and Ulysses (Zieger and Hansen 2008). Our superposed epoch analysis suggests that the prediction efficiency is significantly higher during periods with high recurrence index of solar wind speed, typically in the late declining phase of the solar cycle. Solar wind predictions are most accurate near the time of opposition when the Earth and the spacecraft are located approximately at the same helioecliptic longitude. The prediction efficiency gradually decreases with increasing distance from opposition but remains acceptable within a deviation of ±75 degrees. Among the solar wind variables, the solar wind speed can be predicted to the highest accuracy, with a linear correlation of 0.75 on average close to the time of opposition. We estimate the accuracy of shock arrival times at Jupiter or Saturn to be as high as 10–15 hours during years with high recurrence index. Propagated solar wind data upstream of Jupiter and Saturn for the last 13 years are published at the MSWiM web site http://mswim.engin.umich.edu/, which are freely available for registered users. Our solar wind propagation data were used in, among many other studies, the interpretation of auroral observations at Jupiter and Saturn by the Hubble Space Telescope (Clarke et al. 2009).

In 2008, the solar wind propagation model (MSWiM) was further developed to model solar wind propagation from 1 AU not only forward to the outer heliosphere but also backwards in time to the inner heliosphere. In the reverse propagation model, the time-varying boundary conditions at 1 AU are fed into the simulation in a time-reversed manner and the solar wind is propagated toward the Sun. This MHD model is adiabatic and isentropic, thus reversible, which is a reasonable approximation in the inner heliosphere as log as we neglect entropy changes due to interplanetary shocks. The reverse propagation model has been properly validated with another solar wind model as well as with magnetic field observations at Mercury during the January 2008 MESSENGER flyby (Zieger et al. 2009). We compared the reverse propagated solar wind data with the results of a steady-state three-dimensional MHD model of the solar corona and inner heliosphere, which simulates solar wind propagation in a co-rotating frame from the source surface outward to Mercury using synoptic charts of the photospheric magnetic field as input (Cohen et al. 2007). The two models starting from completely independent boundary condition yielded surprisingly good agreement at Mercury, which justifies the validity of both simulation methods. The most accurate estimates of the solar wind plasma parameters and the magnetic sector structure near Mercury could be obtained with the combined application of the two solar wind models (Zieger et al. 2009).

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Solar activity

(András Ludmány, Heliophysical Observatory)

The Heliophysical Observatory extended the sunspot catalogue work supported by an ESA-PECS grant and an FP7 project named SOTERIA (SOlar-TERrestrial Investigations and Archives). These projects enabled us to produce the most detailed sunspot catalogue for the SOHO-era: the SDD (SOHO/MDI-Debrecen sunspot Data). This work demanded most of our energies for a few years and their publication constitute the major part of our publications. The new datasets provide quite new perspectives for the analysis of sunspot activity.

The research work covered the following topics: Connection of photospheric features with irradiance variations, spatial and temporal distribution of sunspot Coriolis motions, a new long-term variation in the north-south phase lags of the solar cycles, connections between sunspot distributions and torsional belts, forecasts for the maximum of cycle 24, solar rotation, methodological problems of sunspot position measurements. Recently started new topics based on the new datasets: dynamics of flux emergence and decay, fragmentation of active region magnetic fields, active region tilts, build-up of unstable magnetic configurations.

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V. Observatory, instruments, surveys and analyses

Tihany Geophysical Observatory

(A Csontos, L Hegymegi, B Heilig, L Merényi, P Kovács, A Koppán, ELGI)

Introduction

Tihany Geophysical Observatory (IAGA code: THY) is maintained by Eötvös Loránd Geophysical Institute of Hungary (ELGI). The observatory is situated in a national park on the Tihany peninsula of Lake Balaton. The observatory has been continuously recording geomagnetic data since 1955. Tihany is one of the founding members of the INTERMAGNET. The geomagnetic data gathered here are published yearly on the INTERMAGNET CD-ROMs.

Instrumentation and data acquisition

During the last IAGA period two fluxgate variometers and two Overhauser effect based magnetometers were operating for continuous recording at the observatory: a suspended DMI FGE triaxial fluxgate magnetometer with XYZ orientation, a Narod triaxial ring-core fluxgate magnetometer installed in HDZ orientation, a GSM-19 Overhauser magnetometer (GEM-Systems) for recording the total field and a dIdD (delta inclination delta declination vector overhauser magnetometer) system.

The fluxgate magnetometers are installed in the variation pavilion of the observatory. The temperature in this hut is being controlled within ± 0.2°C. Nevertheless the temperature of the sensor and the electronics is monitored by the built-in temperature sensors of the FGE magnetometer.

The GSM-19 Overhauser magnetometer is installed in the absolute house of the observatory. The distance between the absolute pillar and the sensor of the magnetometer is about five meters.

The dIdD system is installed in the old variation house. This building is a cellar that is why the yearly temperature variation is very low.

The FGE magnetometer is equipped with an ADAM 4017 type, 16-bit A/D converter. Its output signal is transmitted to the recorder through a 120 m long optical cable. Optical cable is applied for protection against lightning hazard. Accuracy of time synchronizing to GPS time is ± 2 msec. The 1-second resolution data are also recorded in addition to the 1-minute mean values required by INTERMAGNET. This instrument is the main recording system of the observatory since 1999.

The high resolution NAROD fluxgate magnetometer, which belongs to the MM100 geomagnetic pulsation recording array, works at a 16 Hz sampling rate to register the variation in the DC-5 Hz frequency range. The resolution of the A/D converter of LAWSON Labs is 23 bits and it is synchronized to a GPS unit with ± 0.001 sec accuracy. This system also provides 1-minute mean values.

The dIdD system registers inclination and declination, as well as total field data in every five seconds. When these data are used as input to a task-oriented digital acquisition (DAQ), they produce real-time XYZF 1-minute means. Of course, all the original readings are stored, as well. Thus, the dIdD instrument can serve as back-up systems for our base FGE magnetic recording system.

The development of a modular data collecting system, i.e. the DIMARK system, based on standard PC technology, was started in the ELGI in 1998. The basic hardware elements of this flexible system are a low consumption data logging PC and the following members of the DAQ ADAM module family: 16-bit A/D converters, RS-232/RS-485 converters, and optical modules. The old version of DIMARK's data acquisition software (MAGADAM1) runs under DOS and has low hardware requirements, it can be run on low power, fan-less single-board PCs.

In order to apply some convenient networking technologies (i.e. remote control, file transfer, secured connections, etc.) a Linux based data logger was developed. A special Debian-based Linux distribution is used that have been re-configured and optimized for embedded computers having lower amount of RAM, low CPU speed and lower capacity flash drives. Some features have been added for continuous and safe data acquisition (read-only file system for Linux, easy backup and upgrade, decrease of serial port latency in kernel, software and hardware watchdog management, system-monitoring, data file synchronization, etc.). A Linux data acquisition program is installed and configured on this system. The program is able to acquire magnetic data and housekeeping data from one or more different instruments, including fluxgate, Overhauser, dIdD magnetometers or temperature sensors (through A/D converters or RS-232 protocol). The program has many convenient features for geomagnetic observatories. Different methods can be selected for average calculation, including INTERMAGNET minute filter. The program helps the observer with log file creation and alarm function in case of out-of-scale data. GPS PPS is used for sample triggering and time labeling of magnetic data.

All the DAQ tasks are realized by the DIMARK family at THY.

All of our data acquisition units are linked into a local network, while communication between the observation site and the office is realized by a microwave (2.4 GHz) transmitter. The whole network is synchronized in time by a GPS receiver. For data security reasons, the recorded data are stored parallel on three different computers located in different buildings.

The observatory has two absolute instruments: a Zeiss 20A theodolite and a Zeiss 10A theodolite equipped with a DMI D&I sensor. The absolute measurements are taken weekly according to the null reading method. A set of absolute observations consists of two or four independent measurements of D and I. Total field is continuously recorded by a GSM-19 and even by the dIdD. All the baselines are derived from standard absolute observations.

Observatory data and database

The data from the main observatory system are transmitted to INTERMAGNET via e-mail, and are also available to partner researchers through a real time ftp server. The observatory developed a website where the recordings of all instruments are plotted near real time. Since 2005 the second sampled XYZ variation data have been real time transmitted to National Institute of Information and Communication Technology (Japan) Space Enviroment Information Service. The preliminary minute mean data of the observatory is available on the INTERMAGNET website. Since 2009, the metadata base of the definitive data sets of the observatory is available on the GEOMIND (www.geomind.eu) and KINGA (kinga.elgi.hu) Internet information services.

Additional measurements and activities in Tihany Geophysical Observatory

— Since 1968 onwards whistlers have been detected in the Observatory as a joint project with the Space Research Group of Eötvös Loránd University (ELTE), Budapest.

— Seismological recording is performed using Guralp CMG3T seismometer. The instrument belongs to University of Leeds.

— Temperature gradient observation for geothermal studies has been started in 2010.

— Nonmagnetic temperature test hut was built in the observatory in order to study the most important source of temperature effect on magnetometers by using high amplitude thermal change.

— Checks of UXO detectors are performed from time to time in the observatory.

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Development of a suspended fast dIdD

Since the beginning of the 1990's fast dIdD magnetometers have been also applied to record the geomagnetic variation as an "INTERMAGNET standard" instrument following that GEM Systems developed an Overhauser sensor with 15 cm in diameter. For this sensor ELGI designed and produced a spherical coil system which has a diameter of 20 cm. By using this coil system we developed a small size and user-friendly suspended magnetometer. During the temperature test it was found that temperature coefficients of this instrument is very low i.e. < 0.1 nT/°C for each component.

We also started to test the prototype of dIdD based on potassium magnetometer (GSMP-35 model with a built-in current generator). This technology proved to be ideal for the construction of a high-resolution (0.1 pT) system. The length of a complete dIdD cycle was 1 s. The first results are promising.

The principle of the instrument makes it clear, that the values recorded by dIdD are void from offset and scalar factor errors. For the description of the reference frame only four parameters are needed: The angle between the two magnetic axes of the coil system ($\varepsilon_{\mathrm{ID}}$) and the three orientation angles of the instrument (I_0, D_0 and ε_0).

New method was developed in Tihany Geophysical Observatory to find and monitor the relative orientation of a dIdD and a triaxial fluxgate magnetometer. Methodologically this inter-calibration process is based on the different principles of the two instruments.

The dIdD can have only one orthogonality error, i.e. the non-orthogonality of the two deflection coils. The other two orthogonality conditions are satisfied automatically, since the 3rd dIdD axis is virtual, defined mathematically to be perpendicular to the two physical axes of the instrument. The orientation of the instrument can be found with the help of a well-oriented reference (e.g. absolute) instrument.

We introduced a simple method to estimate the measure of non-orthogonality of the dIdD directly from dIdD measurements without any additional instruments. The same method can be applied to estimate the orthogonality of any (e.g. calibration) coil system. The main advantage of the method is that it can be easily automated, while for the DIM absolute measurements an observer is always needed. The first results of the experiments carried out in the US, Canada and in Hungary are very promising.

We also improved the calibration process of dIdD. Supposing that the dIdD coils are orthogonal, now we can calibrate the dIdD (determine its absolute orientation) by means of absolute measurements.

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Repeat station surveys

The repeat station network of Hungary was established in 1966 (Aczél and Stomfai 1966) to monitor the secular change of the geomagnetic field in the country. The network is maintained and surveyed by ELGI. In 2003, ELGI became the founding member of the MagNetE European co-operation, which was initiated to unify the geomagnetic repeat station surveys of the European countries at comparable and high standards.

During the last four years, the 13 stations of the network were reoccupied in 2008 and 2010, according to the recommendation of MagNetE. The magnetic components of the campaigns were reduced to the epochs of 2008.5 and 2010.5, using the permanent records of the Tihany Geophysical Observatory. In the last campaigns, on-site dIdD variometer has been also installed near the Aggtelek station in the Baradla cave in order to increase the accuracy of the temporal reduction of the easternmost sites. To fulfil the recommendation of MagNetE, the results of the campaigns, i.e. the 2008.5 and 2010.5 magnetic elements of the sites were submitted to the WDC node in Edinburgh. On the basis of the measured spatial and temporal variation of the geomagnetic field, the normal model and the model of the yearly variation of the field elements have been expressed for Hungary by first-order polynomials of the geographic coordinates.

In 2009, the metadata of all of our repeat station campaigns have been integrated in the GEOMIND (www.geomind.eu) and KINGA (elgi.kinga.hu) Internet driven information services built for the introduction and exchange of metadata of any geophysical surveys carried out by ELGI and other six European geophysical institutions.

In 2010, the Hungarian Repeat Station Network became the member of the Strategic National Research Infrastructures compiled by the National Office for

Research and Technology according to the initiative of the European Strategy Forum on Research Infrastructure.

Magnetic survey for archeology

ELGI carried out high resolution magnetic surveys on a 5 ha area of the Great Hungarian Plain near Tiszabő and Tiszagyenda, prior to an archaeological investigation to delimit the excavation area populated by Sarmatian, Gepid and Magyar tribes in the 6–11th centuries. The observed anomalies ranging from a few to a few tens of nanotesla reflected closely the contours of ancient foundations, houses, pits and ditches, roads, clay mines or fireplaces. The excavation verified the findings of the magnetic survey, especially at Tiszabő, where the coincidence was close to perfect. A similar survey carried out near Paks by the Danube on the territory of a Roman fortress, Lussonium, also proved that magnetic surveys could efficiently help the planning of archaeological excavations.

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Observation and interpretation of the natural electromagnetic field variations (at the Geophysical Observatory – IAGA code: NCK)

(Árpád Kis, István Lemperger, Judit Szendrői, Viktor Wesztergom, MTA GGKI)

Monitoring of ULF-ELF-VLF signals

The main objectives of the ground based electric and magnetic observations are monitoring the solar-terrestrial environment and development of models to specify and predict the state of the Sun-Earth system (space weather and climate) from the data. Measurements include the monitoring of geomagnetic field variation, ionospheric parameters, solar emissions and determination of solar wind and radiation environment parameters. As a result of permanent development observations extend from main field variations to VLF band.

In the frame the latest developments the geomagnetic measurements has been supplemented by quasi absolute baseline reference measurement (DIDD), the baseline determination was improved by new DI fluxgate theodolite.

Continuous observation of geomagnetic elements with control of the absolute observations are recorded by 5 sets of magnetometers.

The observatory equipped with 3 sets of triaxial fluxgate magnetometers. The temperature variations of the triaxial fluxgates are maintained within 0.5°C between the weekly absolute observations. The fluxgate variometer sensors are aligned in X, Y, Z directions. For better time resolution one of them is run with 16 Hz second sampling rate. This (CHIMAG) system is the northern more station of the high resolution meridional SEGMA observations (1.56 < L < 1.88). Simultaneous low altitude satellite and SEGMA measurements were used to interpret the controversial relation between space and ground ULF signals, evaluate the effect of the ionosphere on the transmission and study the field line resonance phenomenon and study the expected ULF precursors of seismic activity.

In the frame of the INTERMAGNET data service 10 second samples are used to provide minute values centred on the minute, by means of a 7-point cosine filter. Geomagnetic indices and transient events are also scaled from these data.

Protonmagnetometer (Overhauser effect magnetometer) in $\Delta I/\Delta D$ configuration consists of two orthogonal sets coils (proton head is mounted at the centre). Coils orientated so that one provides bias fields approximately perpendicular to **F** vector in the magnetic meridian and the other provides bias fields approximately perpendicular to **F** in the horizontal plane. ΔD and ΔI relative to the initial values (D_0, I_0) are calculated. $\Delta D/\Delta I$ proton magnetometer (DIDD) takes samples in every second from which F (total force) and quasi absolute values of D an I are obtained. To ensure continuous recording a high stability torsion photoelectric magnetometer (type PSM-8711) is run as backup system. Data along with telluric data are logged by a DR-02 type digital recording system. The PSM magnetometer records the H, D and Z component with an exceptionally high parameter stability. The baseline variation never exceeds 1.5 nT/year. Maximum resolution is 3 pT, sampling rate applied is 10 s, frequency response: 0.3 Hz to DC, sensitivity to tilting: less than 10 nT/′.

Baselines of the variometer systems are derived from absolute observations of F, D I. The standard instrument for absolute measurements are the proton magnetometer (type: GSM 19 of GEM Systems) and the new fluxgate theodolite. To determine the momentary angle of declination four observations (four null positions in the horizontal plane) are taken and it is repeated at least two times. Inclination angle is determined in the plain of the momentary magnetic meridian in the same way as D. Total intensity is measured simultaneously with I-measurements on the next (F) pillar with the Overhauser magnetometer. Absolute values of all geomagnetic elements are referred to the same pillar of the absolute hut. Observations are made weekly, occasionally more often.

Analysis of the observatory data

The value of the telluric data of the observatory lies in the exceptional length of data series. The long-term noise-free stability of the observations had been ensured by the reconstruction of the electrode system. This more than fifty years long unique geoelectric (telluric) data set was used for statistical analysis of the long-term variation of the geomagnetic activity and its induction effect. Occurrence of high geomagnetically induced electric fields and their coincidence with the phases of solar activity is less clear than that of maximum magnetic activity but it was shown that K_p and T indices reflect essentially the same geoelectromagnetic activity which is turn correlated with sunspot parameters. As the weights of variations with different periods are rather different in geomagnetic and earth-current indices, there are also differences between the two kinds of activities. It is tried to identify such differences between the two time series and also in the connection with solar activity time series. Several kinds of differences result from the influence of the pulsation activity on the T index. Several features of the geomagnetic activity have been confirmed and some further information have been obtained from this study. Impedance tensor spectra have been calculated for a four years interval. In spite of general expectation based on plane wave assumption time variation of the transfer function has been found. Dominant spectral peaks are to be investigated on a longer interval.

Whistlers and other VLF phenomena are selected and scaled by semi automated whistler analyzer, direction of arrival is identified. Main goals are the better understanding of whistler duct structure and formation, its connection with field line resonance, the effect of magnetic activity on the plasmasphere and study of energy sources (lightning, anthropogen sources), coupling and propagation mechanism. Outstanding feature of the observatory is the conjugate point measurement in South Africa. The Hungarian whistler observation network maintained by the Space Research Group, ELTE forms a near equilateral triangle (station distance: 150–200 km). Whistler statistics were used to verify the supposed connection between the whistler mode electromagnetic waves and geomagnetic activity. This statistical study suggests that strong magnetic storm change the plasma environment in such way that leads sequentially to unusually high whistler occurrence and enhanced Pc3 activity.

Efforts on determination of electric and magnetic fields possibly associated with seismic and volcanic activity have a long history but the understanding of physical processes behind are still limited. From geomagnetic point of view long term and short term effects are to be distinguished.

Statistics on recent observations reveal that the diurnal variations of the Earth's magnetic field, commonly known as Sq-variations, are involved in the geodynamic process of earthquake activity variation with the time of day. The process is supposed as an interaction between the induced Sq-variation currents in the lithosphere and the regional geomagnetic field. The mechanism influences the tectonic stress field and the seismic activity. Nevertheless, the effect can also be appeared in the correlation of seismic activity and variations of the Earth's magnetic field in the long term, where magnetic changes — in terms of the cause and effect relation — are on the cause side. Statistical investigations of INTERMAGNET dataset and earthquake catalogue seems to be promising for selected seismically active regions.

Explanation of short term electromagnetic perturbation is found in microfractures i.e. the EM field is a consequences of fracturing. One source of ULF emission is the piezoelectric effect, better to say the observed ULF signal is a part of the wideband signal due to intense microfracture electrification. The other possible source of the ULF signal is the magnetohydrodynamic effect of the propagating seismic wave. Most crucial question in ULF signature studies is the extraction of seismogenic emissions. It requires well equipped magnetometer array, possibly meridional, in the vicinity of seismically active region and detailed knowledge of pulsation activity.

The magnetometer array, SEGMA consists of meridional distributed observatories: Nagycenk (NCK), Castello Tesino (CST), Ranchio (RNO), L'Aquila (AQU) (between $1.88 < L < 1.56$) and Panagyurishte (PAG) and Ottana (OTN). All stations are equipped by high resolution CHIMAG triaxial fluxgate magnetometers (accuracy: 8 pT, sampling rate: 1 Hz, timing: provided by GPS).

A statistical study of ground based magnetic field observations by the SEGMA array in the ULF and ELF frequency range during seismic events in the Adriatic region was initiated by Schwingenschuh et al. (2005). The seismic events under investigation have been chosen from a table provided by the DEMETER project. The criteria for the event selection are the magnitude of the seismic event, the distance between the ground magnetometer and the epicenter as well as the location of the DEMETER satellite and the availability of DEMETER data. In order to determine a possible correlation between ground based magnetic field fluctuations and seismic events the statistical properties of intensity and polarization of magnetic disturbances — found one month before and after seismic events — were computed. Additionally the observed ground based events were correlated with the DEMETER magnetic field observations.

Segma ULF data (CST, RNO, NCK) were investigated during seismically active periods (June to August 2004, Bovec earthquake, $M = 5.5$, depth = 6km) by Prattes et al. (2008). Intensity and polarization ratio (Z/H) of the observed data were analyzed. Significant increase of polarization ratios appeared at the nearest station (CST) to the epicenter. From the surface magnetic intensities the amplitude of the seismogenic signal in the epicenter region was also estimated by a plane wave assumption.

A sophisticated signal analysis method was proposed and tested by Nenovski et al. (2007). In this study detrended fluctuation analysis (DFA) was applied on SEGMA data in order to separate ULF signals of magnetosphere and seismic origin. In DFA index dynamics the magnetospheric activity effect appeared as frequent and short DFA index increase while anomalous local fluctuations cause Z component DFA index decrease in Pc3–Pc5 range

The behaviour of the long-term periodical variations related to the broad spectral region of the electromagnetic surface impedance tensor has been studied on the geomagnetic and telluric records of the Széchenyi István Geophysical Observatory of the Hungarian Academy of Sciences comprising 4 years. Frequencies with amplitudes of extreme 27-day modulation have been found in spectral distribution of temporal variation of the EM impedance tensor in the period range of 12–120 min.

An ionospheric source model of the magnetospheric Pc5 pulsation sources has also been developed, for which the formula of the theoretical electromagnetic surface tensor was derived. The fitting and comparison of the observed data and theoretically derived model was carried out, too.

Study of the foreshock region in the front of the Earth's quasi-parallel bow shock

One of the most interesting fields from the scientific aspect of the near-Earth plasma environment is the region in front of the Earth's bow shock. The bow shock is formed when the supersonic solar wind plasma meets the Earth's magnetosphere and it is slowed down to subsonic velocity; the bow shock is formed in the process. Since the Earth's magnetosphere is an obstacle in the way of the solar wind plasma the subsonic plasma is forced to slow down and flow around the magnetosphere of the planet. The incoming solar wind plasma is a magnetized plasma which means that practically the magnetic field lines (known as the interplanetary magnetic field) are frozen-in in the plasma. Because of the curvature of the Earth's bow shock the region in front of it can present basically two fundamentally different aspects. The region in front of the Earth's bow shock where the angle between the interplanetary magnetic field lines and the normal of the bow shock surface is larger than 45 degrees is known as the quasi-perpendicular bow shock. When the angle between the interplanetary magnetic field lines and the bow shock surface normal angle is less then 45 degrees the region is called the quasi-parallel bow shock. The quasi-perpendicular bow shock is a well known and studied region because of its clean transition between the supersonic and subsonic plasma conditions. On the other hand the quasi-parallel region presents a turbulent and complicated picture between the supersonic and subsonic plasma states. The exact location of the transition is hard to be established. This is due to the direction of the interplanetary magnetic field which allows that the particles escaping from the bow shock can freely propagate in the upstream direction. The escaping particles interact with the incoming solar wind plasma and through different physical processes they generate waves. These waves further interact with the particles which are present in the region and together they form a very complex and turbulent region known as the foreshock. In the foreshock the waves are generated mostly by the escaping energized particles from the bow shock. On the other hand the particles are scattered by the waves. The result is a complicated and feed backed system between the particles and waves. The physical mechanism is further complicated by the fact that the plasma which can be found in the foreshock region is collisionless. This means that the direct collisions between the particles are practically negligible because the number density of the plasma is very low; the common number plasma density in the region is generally between 1 and 10 particles per cubic centimetres. All these facts together ensure the foreshock region to be scientifically a very important and interesting region.

The Cluster spacecraft mission consists of four identical spacecraft orbiting around the Earth scanning the key regions of the near Earth plasma environment including the foreshock in tetrahedral formation. The Cluster is capable of measuring the important space plasma parameters simultaneously on multiple locations. This enables the time variations of the plasma parameters to be separated from the spatial variations. This kind of separation is essential to understand the important space plasma physical processes in the foreshock region. The data from the Cluster mission is available for the scientific community through the Cluster Active Archive (CAA).

One of the key physical processes at the quasi-parallel bow shock is the acceleration of ions to high energies through a mechanism known as diffusive acceleration. Although this mechanism has been proposed and studied for a long a time it is not fully understood. A key factor of diffusive acceleration is the efficient scattering of energized particles by local waves which are known to be self-generated by the energized ions. With the Cluster mission we have the first time the opportunity to study the diffusive acceleration process using simultaneous multi-point measurements. The multi-spacecraft data is essential in order to separate the time processes of the plasma from the truly special ones. This was not possible before when only one spacecraft was available for the measurement and therefore the studies had to be done mostly on statistical bases. Using the Cluster data it becomes possible for the first time to study individual upstream ion events and to determine the spatial variation of the key plasma parameters directly from the data on multiple spacecraft. In a previous study (Kis et al. 2004) it has been demonstrated that the energetic ions in the 10–32 keV energy range which are to be found in the foreshock region are indeed subject to diffusive acceleration process. However, the obvious question remained still open: how the ions on higher energy levels behave in the foreshock? Do they also take part in the diffusive acceleration process being further accelerated towards even higher energies? These question were successfully answered by showing that practically the ions in the 30–160 keV energy range behave the same way as the lower energy ions which shows that the higher energy ions also can gain further energy by the same Fermi acceleration mechanism (Kronberg et al. 2009). This makes the quasi-parallel bow shock to be an effective ion acceleration site.

Other studies were focusing on the behaviour of the so-called field-aligned beam (FAB) ions which are known to consist of solar wind ions reflected on the quasi-perpendicular side of the bow shock and which propagate in the upstream direction along the magnetic field lines. It has been demonstrated that the initial coherent ion beam becomes gradually more and more scattered by the local waves. This directional scattering leads to spatial separation of the initial FAB ions and combined with the convection by the solar wind plasma leads to the appearance of FAB ions population in the foreshock region on the quasi-parallel side of the bow shock. This partially scattered and convected FAB ion population appears to overlap the local diffuse ion population, an effect which has never been seen before (Kis et al. 2007d)

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