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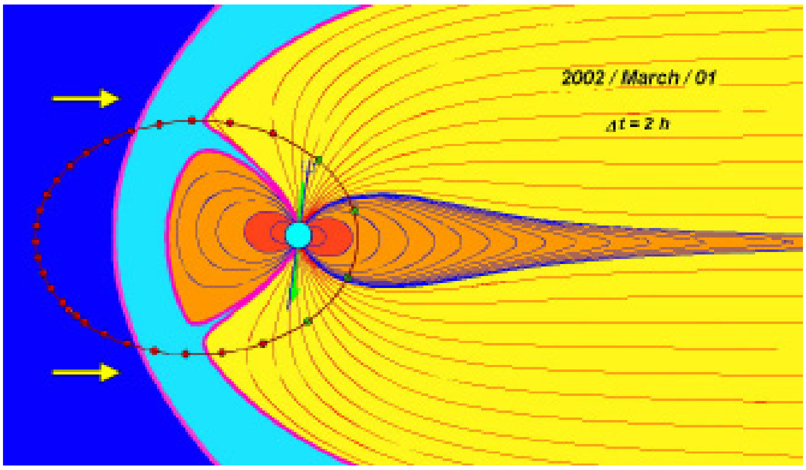

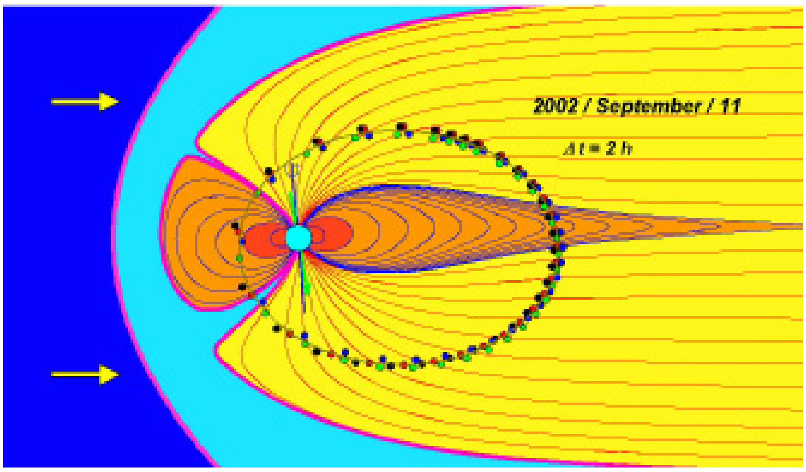

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Editorial

We have three *Reviews of Radio Science* in this issue, plus James Lin's column, and several reports.

The Cluster fleet is a group of four spacecraft designed to provide a three-dimensional picture of the dynamics of the Earth's magnetosphere. In their review, P. M. E. Décréau, Ph. Louarn, R. L. Mutel, M. Parrot, J.-L. Pinçon, P. Robert, and A. Vaivads describe the Cluster fleet in their *Review* from Commission H, and illustrate what it can and has accomplished with examples from the published results of the mission so far. The authors have cleverly captured the five areas of observations they review under an alphabetical set of titles. A covers the observations of auroral kilometric radiation. B is for boundary, covering two sets of boundary-layer observations. The first looks at wavy structures in the plasma sheet that makes up the magnetic tail of the magnetosphere. The second looks at micro-processes in small-scale boundary regions where diffusion occurs in the magnetic tail. C stands for chorus, the intense radio emissions in the plasmapause that consist of discrete rising and falling frequencies with time separations in the range of one-tenth to one second. D stands for dispersion, and this deals with the energy distribution in electromagnetic fluctuations different wave modes present in the magnetosphere.

Richard Horne's efforts in bringing us this *Review* are gratefully acknowledged.

In a *Review* from Commission G, Jürgen Bremer looks at long-term changes in various layers of the Earth's ionosphere. These are examined from two standpoints: are there trends that might have an effect on practical applications, and are there trends that might be related to changes resulting from human activity? The second question is looked at specifically as it relates to correlations with a possible "greenhouse" effect. One conclusion is that the variations in ionospheric parameters induced by solar and geomagnetic effects are stronger than the long-term trends, and thus the data must be analyzed carefully. Furthermore, these variations probably have more impact on practical applications than the long-term trends. However, the review found trends in several ionospheric parameters that could possibly be correlated with an atmospheric greenhouse effect.

Paul Cannon coordinates the Commission G *Reviews*, and his efforts are gratefully acknowledged.

The blood-brain barrier is associated with the very small vessels in the brain. A substantial number of studies have looked at the effects of radio-frequency waves on the blood-brain barrier. In his Commission K *Review*, Jim Lin critically examines the methodologies, experimental conditions, and results of the studies that have reported changes in the permeability of the blood-brain barrier due to RF exposure. It is noted that while one group has reported observed changes at a very low specific absorption rate (SAR) – much lower than the current permissible cell-phone levels – only limited confirmation of these results has been obtained by another group, and then only at SAR levels that were several times higher than permissible cell-phone levels. One of the conclusions of this review is that additional, carefully designed studies need to be done to provide much-needed confirmation of some of the reported results. This review not only provides a very interesting look at the status of this important research. It also provides a substantial amount of information about how to structure such studies, and about the factors that can play a critical role in influencing their outcome.

Frank Prato's efforts with the Commission K *Reviews* are gratefully acknowledged. As always, Phil Wilkinson has overall responsibility for the *Reviews of Radio Science*, and it also because of his efforts that we can bring you these *Reviews*.

Jim Lin has also contributed his column on Radio-Frequency Radiation Safety and Health in this issue. His topic this time is "electromagnetic hypersensitivity." This involves symptoms that vary widely among individuals, can be severe enough to affect lifestyle, and are attributed by the individuals to electromagnetic fields. However, while the symptoms are certainly real, the studies to date – particularly, those looking at an association with cell-phone use – are not conclusive. The analysis of what is known and what studies have been done is fascinating.

If you have interesting radio science results, particularly of a tutorial or review nature, please consider sharing them with the URSI community via the *Radio Science Bulletin*. Submitted papers are most welcome.

W. Ross Stone

The Cluster Fleet Explores Waves in the Magnetosphere: Chosen Illustrations

P.M.E. Décréau
Ph. Louarn, R.L. Mutel
M. Parrot, J.-L. Pinçon
A.Vaivads, P. Robert

1. Introduction

The four-point Cluster constellation is designed to explore in 3D, locally and remotely, phenomena critical to the physics of the Earth's magnetosphere. The purpose of this paper is to illustrate the role of this pioneer mission in the field of plasma and radio waves that are of general importance in space plasma and solar terrestrial physics. We have chosen, somewhat arbitrarily, examples in published literature obtained with the four points fleet, with the objective to present a variety rather than a complete panorama of the major results obtained up to now. Moreover, the emphasis has been to present which novel features are derived from the four spacecraft observations, rather than how they are changing our views about physical processes shaping our environment. The latter would deserve full developments, but a flavor of it is given in the paper. We describe shortly the multiple point analysis tools that were necessary for deriving the results, referring to bibliography for the interested reader. Let's start with a few words of history.

1.1 The Mission

The concept of a four spacecraft fleet, toward a 3D exploration of the magnetosphere, came to life in February 1986, when ESA chose Cluster and SOHO (Solar and Heliospheric Observatory) as the first "cornerstone" in its Horizon 2000 Science Programme [1]. Such a concept had been discussed after the first space era which allowed, through single satellites explorations, to derive a general map of the space environment of the Earth [3], but where many features, in particular essential details of key interface regions, and in general most of the global dynamics, where lacking.

The Earth's magnetosphere forms, as a result of the interaction of the solar wind, a fully ionized, collisionless plasma, with the magnetic field of the Earth. In a stationary picture (see diagram in Figure 1), the magnetosphere presents various cells and their boundaries which result, not only from the solar wind/terrestrial magnetic field interaction, but also from the presence of plasma (also collisionless) formed in the ionosphere, the high altitude layers of our planet's atmosphere. Figure 1 shows the Earth's magnetic field lines and the main regions in space around the Earth. Starting form the Earth, one encounters the plasmasphere (dark orange), a region of high-density plasma that is mainly of ionospheric origin. Chorus waves, the subject of Section 4, are generated just outside the plasmasphere, near the magnetic equatorial plane. At higher latitude, one finds a plasma sheet (orange). It is a very dynamic region filled with plasma originating both in solar wind and the ionosphere. On the night side, the plasma sheet is elongated along the central part of the Earth magnetotail. This part of the plasma sheet is the subject of Section 3.1. A giant plasma accelerator forms here when equatorial currents supporting the magnetic field topology are disrupted. This happens at the onset of dynamic events that are called substorms, leading to auroral activity near the Earth (source of AKR emissions, subject of Section 2). At even higher latitudes, one finds lobes (yellow in Figure 1). Those are regions that usually are almost void of plasma and they are located on open field lines (one end of the magnetic field lines is anchored in the Earth but another goes into the solar wind). The outer boundary of the lobes and plasma sheet is called the magnetopause (pink thick line), and it separates Earth magnetosphere from the solar wind. Solar wind penetrates into the Earth magnetosphere mainly in the cusp regions placed on the dayside between closed and opened field lines, and at reconnection sites (see Section 3.2). The

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This is one of the invited Commission H *Reviews of Radio Science*.

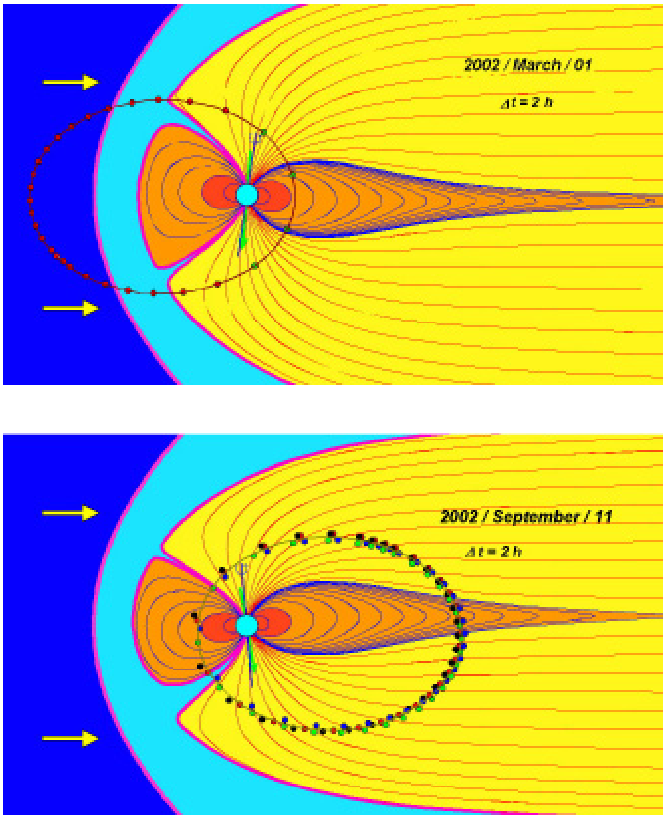

Figure 1. Meridian views of the magnetosphere and Cluster orbit. The magnetic field lines topology corresponds to a static model [2] based on a large data set of instantaneous measurements. It is indicative of the average topology for a given value of the magnetic activity planetary index, Kp, and of the attitude of the Earth magnetic dipole in the GSE frame. Two epochs are chosen, at two different seasons (March 2002, top, and September 2002, bottom). Sketches of the Cluster constellation, at average separations of respectively 100 km (top) and 5000 km (bottom) are drawn along the orbit at time intervals of 2 hours. The topological regions highlighted are: plasmasphere (dark orange), closed field lines outside the plasmasphere (light orange), open field lines (yellow), magnetosheath (turquoise) and solar wind (dark blue). The main boundaries, bow shock (left) and magnetopause, are drawn as thick pink lines.

super sonic solar wind is slowed down at the bow shock (pink thick line on the left), before reaching the magnetopause. In between the bow shock and the magnetopause, the solar wind flows at sub-sonic speed forming the magnetosheath (turquoise), a turbulent region discussed in Section 5.

What could a four spacecraft mission add to this picture?

Since the magnetosphere is constantly in motion, its dynamics is a basic ingredient of its entity. A stationary picture, as detailed as it could be, could not resolve the challenge posed by understanding the physical processes at work [4]. Schematically, in each "cell," or region, the plasma transport is determined by the coupled effects of the large scale magnetic and electric fields, the size and direction of which are determined by the boundary conditions at the interfaces. Any modeling effort, for instance, would have to be tested again and constrained by realistic, observed, dynamical behaviors at interfaces. Thus the understanding of dynamical behavior of the boundaries can be as important as the understanding of large-scale behavior of different regions. Basic, critical questions related to dynamics of boundaries are still not answered. At the bow shock, for instance, the particles of the solar wind change their motion from global translation into thermal agitation. In the absence of collisions, which processes are at work? In the absence of dissipation, instability mechanisms generating intense fluctuations currently observed at boundaries, are thought to play an important role by coupling adjacent regions. They need to be understood before any realistic picture of the magnetosphere can be drawn.

Observations of dynamical phenomena from a single satellite suffer from a basic limitation: the inability of a single observer to unambiguously distinguish spatial from temporal changes. Only a fleet of four spacecraft can form an observatory able to characterize, in 3D, the motion of a wave front, as of any thin boundary in motion. Actually, the normal direction of interplanetary shocks had been determined by using the ISEE-1, 2, and 3 spacecraft together with either IMP-8 or Prognoz-7 as the fourth [5]. A four spacecraft mission would allow enlarging such isolated case event studies allowed by serendipity to systematic studies. That would be possible not only on morphology and dynamics of boundaries, but also, generally speaking, on all aspects of in-situ characterizing and remote sensing physical processes at play in the magnetosphere. Particularly due to possibility to vary in the spatial lengths to be explored, a four points observatory had to carry the capability to be configured over a range of separation distances.

Once the concept of a four spacecraft fleet accepted and put into reality in the Cluster project, new data analysis techniques and tools had to be developed [6]. When the first Cluster fleet was destroyed in 1996 in the explosion of Ariane 501 maiden flight, the four spacecraft concept was thought so important, remaining a major "step to progress" in the field of magnetospheric physics that, thanks to the conjugated efforts of the main partners involved (nothing would have been possible without a strong involvement of the ESA directorate of science and of national agencies), it came out from ashes. A Cluster II fleet was successfully launched in the summer of 2000.

Since the start of the Cluster mission proper (on February 2001) and the date of this writing, continuous operations have allowed to explore the complete range of MLT apogee positions at several values of the Cluster average separation (in the range 100 to 5000 km). Significant amount of time has been necessary to (i) understand the data of the Cluster scientific payload from the unexplored regions of the magnetosphere, (ii) to understand and use the four spacecraft observatory. In particular, the limitation of observing at only one scale at any step in the mission had to be overcome by selecting relevant events and explaining observations at a deeper level than is necessary with a single satellite. Efforts are still ongoing, but it is already clear that a multipoint fleet brings indeed a novel understanding of a range of magnetospheric phenomena.

1.2 Multi-Point Observations

Five different areas where significant progress has been obtained in the field of wave studies are reported in the paper [two under B]:

- *A, as Auroral Kilometric Radiation (AKR)*, presents an example of remote sensing sources of the high frequency AKR sporadic emissions, by precise measurements of delays in arrival times.
- *B, as Boundary*, presents two examples of in situ spatio-temporal observations. The first one explores the wavy structure of the plasma sheet. The second one concentrates on narrow current layers in the diffusion region linked to magnetic reconnection at magnetopause.
- *C, as Chorus*, illustrates how ray tracing and theoretical modeling could elucidate one of the many observations, some still not explained, where the same wave packet displays different properties as observed from the different spacecraft.
- *D, as Dispersion*, looks into the energy distribution of electro-magnetic fluctuations in various wave modes simultaneously present in the medium. Techniques developed a decade before Cluster launch are shown to work brilliantly.

2. A, as AKR

As seen from deep space, the planet Earth is a powerful radio source, emitting ~ 107 to 108 W, in the form of radio waves with a peak frequency at ~ 250 kHz. Those radiations, emitted well above the dense layers of the ionosphere, at frequencies well below the plasma frequency in those layers, are hidden to ground based observatories. They have been discovered by the Electron -2 satellite [7]. Their spectral properties, observed on OGO 1, were first reported in [8].

In a work of reference, Gurnett [9], analyzing IMP 6 and 8 observations, has established the basic characteristics of this radiation, confirmed by later observations [10 and references cited therein], in particular its connection with auroral phenomena which led to the terminology "auroral kilometric radiation" [11]. The AKR coherent radiation, displaying multiple facets [12] was intriguing. Several generation mechanisms have been proposed to interpret its properties. Observations on-board the Viking spacecraft [13], well instrumented and crossing regularly AKR sources (at ~1 Re altitude), have renewed and sharpened discussions about generation mechanisms. The cyclotron maser instability first proposed by Wu and Lee [14], has been acknowledged as being the most likely candidate [15]. A decade later, observations by the FAST satellite have detailed the AKR source region with order of magnitude higher time and frequency resolution than previous missions [16, 17]. They did not contradict the likeliness of the cyclotron maser instability generation mechanism. Recently, important results about the filamentary nature of AKR sources, and about their dynamics have been derived from Interball 2 observations [18].

The Wideband Data (WBD) instrument on board Cluster [19] collects data at a data rate still higher than on FAST or Interball 2. It was designed to detect very high time (37 μs) and frequency (10 Hz) resolution waveform data of plasma and radio waves. In AKR studies, it measures electric field in frequency bands of 10 kHz above one of three frequencies (125, 250 and 500 kHz) chosen by command. It can observe the wave form of AKR emission (translated from high frequency bands) during substantial time intervals, typically a couple of hours, hence complementing information from short wave form captures obtained previously. Those data confirm the bursty character of AKR emissions, already noted in early observations, but at a much higher level of detail.

The remote capture of the AKR signals forbids to rely their individual characteristics to local properties in the source; hence, Cluster cannot directly add to the discussion of generation mechanisms. But, as a remote sentinel, it can instantaneously point to individual AKR burst sources that are sparkling in various parts of an active region. Cluster can recognize that short lived wave packets of few 10 ms total duration, observed by WBD instrument on spacecraft placed at average distances of 5000 km of each other, are coming from the same AKR burst [20, 21].

The recognition method consists in a search of significant peaks in amplitudes of cross-correlation function applied to pairs of signals. Short differential delays in waveform arrival times for each baseline between pairs of spacecraft can be accurately evaluated and used for locating sources as explained below. For baseline connecting spacecraft i and j, the differential delay is given by:

$$\tau_{ij} = \frac{1}{c}\left[\left|\vec{r}-\vec{s}_j\right| - \left|\vec{r}-\vec{s}_i\right|\right], \qquad (1)$$

where $\vec{r}$ is the vector to the AKR source and $\vec{s}_{ij}$ are vectors to spacecraft i and j respectively (Figure 2a indicates

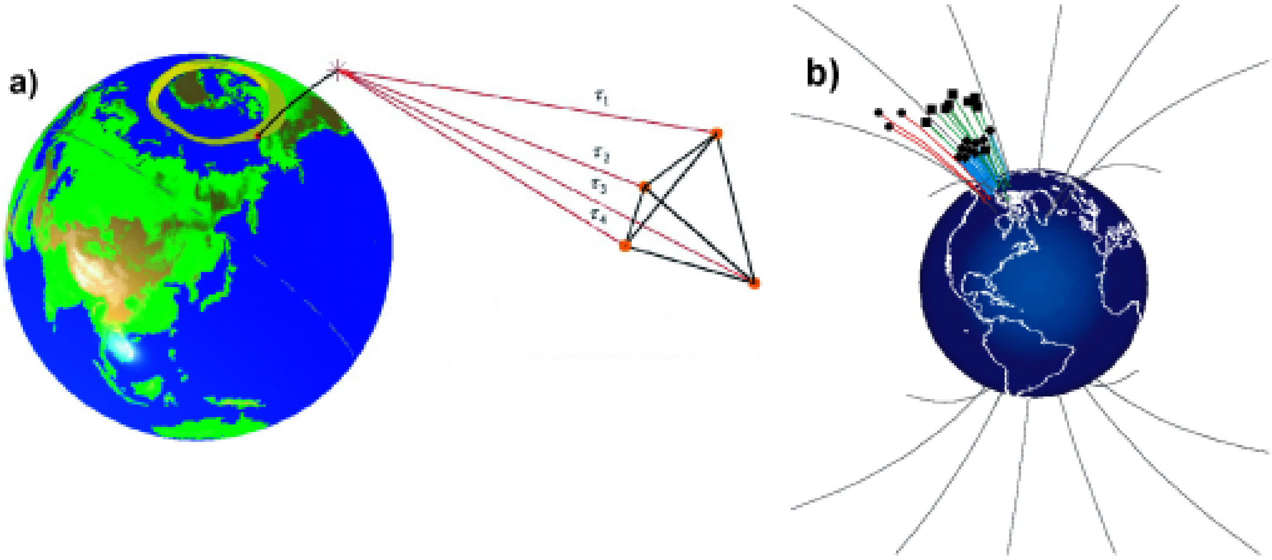

Figure 2. Localization of AKR sources with the VLBI technique (from Mutel et al., [24]): a) delays in AKR bursts arrival times at the four spacecraft allows to locate the source (placed along a magnetic field line, radiating at light speed); b) individual AKR burst location (0.3 s × 1 kHz data windows) within a 15 minute time interval centered on 08:22:30 UT, on 9 November 2002. Magnetic field lines connecting burst locations to the Earth's surface are shown as lines coded by AKR burst frequency (125 kHz red, 250 kHz green, 500 kHz blue).

relative positions of source and spacecraft). Solving Equation (1) yields the value of $\vec{r}$. The delays and spacecraft positions are known at a largely sufficient accuracy: the time stamping applied by NASA's Deep Space Network (DSN) has absolute accuracy of nominally ±0.02 ms, and spacecraft positions provided by the European Space Agency's Operation Centre (ESOC) are measured to ±1 km or less. Furthermore, there are six baselines, hence six observable delays, therefore the solution for the vector position results in a robust solution algorithm.

In practice, the component along the line of sight to the Cluster constellation centre of mass is less well constrained than the orthogonal coordinates, resulting in perpendicular (/ along line) of site position uncertainties of respectively 380 – 1400 km (/ 26000 – 42000 km) at the AKR burst location. The fact that the source position is defined within an uncertainty volume very elongated along the line of site limits the scientific interest of the result. However, it is possible to reduce the uncertainty volume to a much smaller value by incorporating the well established fact that AKR radiation is emitted at frequencies close to the local gyrofrequency, an approach followed in the past by Huff et al. [22]. Mutel et al. show in [21] that the uncertainty volume is considerably reduced when the allowed source positions are constrained to lie within 3% of the expected geocentric distance consistent with the gyrofrequency of the observed emission. Source position results derived that way can be further analyzed.

The search for correlated AKR bursts is performed by systematic exploration of data windows (0.3 s × 1 kHz) in all four datasets. Only a small fraction (~0.2%) of the data windows contain well enough isolated AKR burst to result in an unambiguous recognition. Nevertheless, the total number of AKR burst positions obtained in hours long studies is sufficient to derive systematic statistical properties [21]. The results indicate that the northern AKR sources are located along magnetic field lines threading the statistical auroral oval. This is in good agreement with previous studies on AKR location compared to concurrent auroral images, showing that AKR sources are mapped down to localized auroral features [13, 22]. One should note that in the past, except in a recent case event study with Interball [23], AKR bursts were averaged over significant time intervals (typically a few minutes) hence providing results of intrinsically different nature than WBD measurements (restricted to isolated intense short AKR bursts). Statistics dealing with one or the other type of data could lead to different findings.

Recently published Cluster WBD observations [24], have been able to locate AKR bursts in the three available high frequency bands (each 10 kHz wide) in consecutive 15-minute time intervals over a total time interval of two hours. Figure 2b displays the AKR bursts positions in one of the 15-minute intervals studied. Interestingly, it shows that the AKR emitting volumes related to each emitting frequency (above, respectively, 125, 250 and 500 kHz) are well separated not only in altitudes (to be expected from the constraint of emission at cyclotron resonant altitude) but also in magnetic foot points, a promising step to study direct relationships with auroral images. In addition, distribution of sources over the Southern Hemisphere, which had not yet been investigated, has been obtained. They can be compared to results in Northern hemisphere, opening new perspectives.

As a conclusion, let's remark that temporal relationship of substorms signatures that occur in different regions of space is an important part of substorm research [18, 25, 26].

We believe that the ability to accurately trace AKR bursts, in time, frequency and source position, is an important support to expectations in that field.

3. B, as Boundary

The two illustrations reported in this section deal with the basic problem of resolving spatio-temporal ambiguities within a boundary region. Waves play a different role in both problems. While they constitute the core of the phenomenon under study in the first case, they might be considered as a “marker” of small scale processes in the second case.

3.1 Large Scale Fluctuations in the Plasma Sheet

The Earth magnetic tail is a region of considerable interest in magnetospheric physics, since it is the region of substorm triggering. The stability of the current sheet (supporting the elongated topology of the tail), as well as its wavy structure, have been observed and theoretically analyzed since decades (see [27, 28] for early works on the subject, and other citations in the introductory section of Louarn et al., [29]). Waves with periods from a fraction of second to a few tens of minutes have been observed, while theoretical analysis of various types of instability indicate that a large variety of perturbations could propagate in current sheets. Multi points observations, which can separate spatial and temporal effects, are crucial toward a correct identification. First case studies with Cluster have displayed unexpected features of the large scale structure and flapping motion of the current sheet [30, 31].

We report here on a series of two papers [29, 33], where multi-spacecraft techniques have been applied to analyze the low frequency fluctuations of the plasma sheet with the objective to determine if they may be interpretable as magneto-hydrodynamic (MHD) eigen modes. To that purpose, a plasma sheet crossing occurring on August 22,

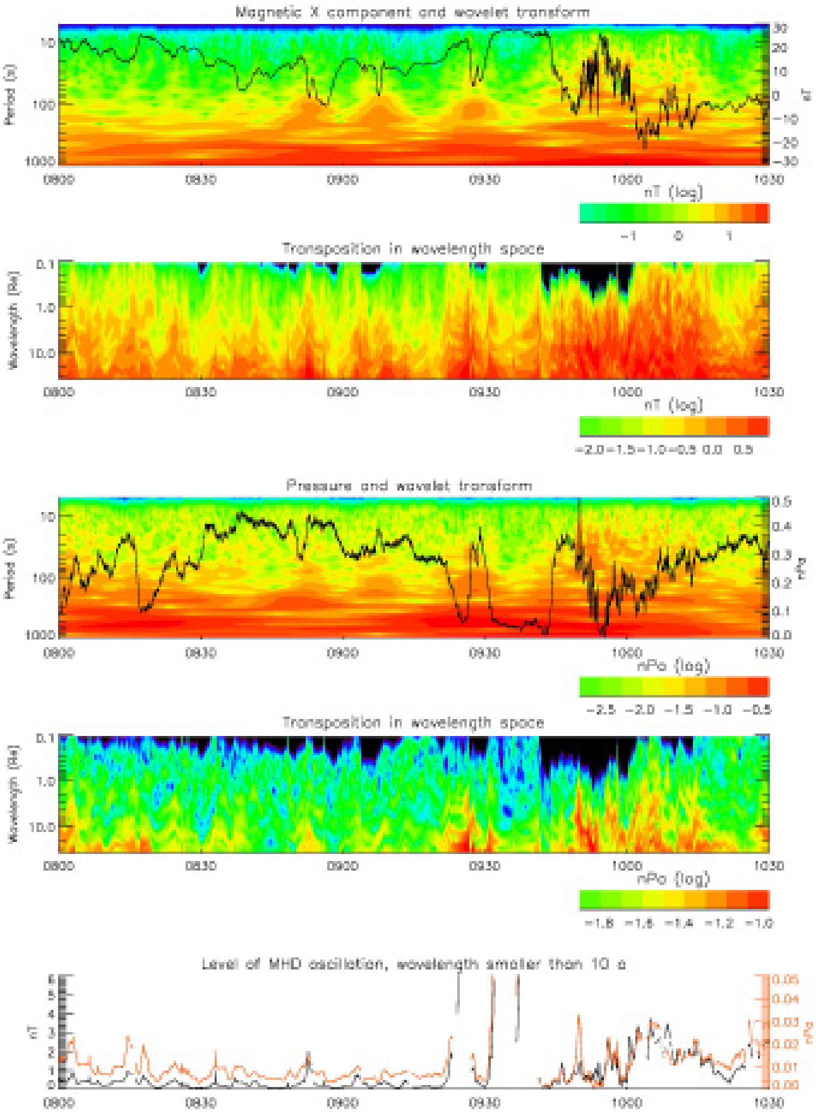

Figure 3. Spatial and temporal scalograms, comparison with the MHD scale of the plasma sheet (from Louarn et al., [29]). Panel (1) and (2): temporal and reconstructed spatial scalograms for the magnetic fluctuations. Panel (3) and (4): same quantities for the pressure fluctuations. Panel (5): integrated amplitude of fluctuations at scales smaller than 10 a (a: characteristic thickness of the modeled Harris sheet).

2001 (Figure 3, discussed later), was investigated and the observations were compared with results of a study of the MHD propagation in a one dimensional Harris sheet, which is an exact 1-D solution of both the MHD and the kinetic Vlasov-Maxwell equations. The theory, developed in a preceding work [32], shows that eigen modes have periods scaled by a characteristic time τ roughly equal to the ratio between (1) the thickness of the sheet and (2) the sound speed. Using the Cluster spacecraft, the thickness of the sheet can be determined with accuracy. The characteristic time can then be estimated and compared with the typical periods of the fluctuations that is deduced from a wavelet analysis of the magnetic field and pressure fluctuations (Figure 3).

The August 22, 2001 observations shown in Figure 3 are obtained successively under quiet and disturbed conditions (before and after 0940 UT). During the quiet period, the fluctuations have periods larger than 100-150 s, which corresponds to at least 15 times τ. If they are interpreted as MHD eigenmodes propagating along the sun-earth direction (X axis), they would have wavelength larger than ~10-20 Earth's radius (Re). Such an interpretation is hardly compatible with the actual position of Cluster which is located at ~18 Re. However, in relation with a substorm onset (at 0940 UT), fluctuations of shorter period (20 s) are observed. Given the characteristics of the sheet, this corresponds to a few times the characteristic time. These shorter period oscillations, with amplitude as large as 10 nT, likely correspond to the fundamental kink-like eigen mode of the sheet. They would propagate in the earthward/tailward direction with a wavelength of ~3 Re. These oscillations have been more quantitatively analyzed (Figure 4). To analyze the spatial-temporal evolution of the sheet, its geometrical parameters are determined from a fit with a Harris sheet [34]. The magnetic field is thus supposed to be written as

$$B_x(z) = B_0 \tanh\left(\frac{z - z_0}{a}\right),$$

where B_0 is the field in the lobe, a the half thickness of the sheet centered at $z - z_0$.

The results are displayed in Figure 4 where the neutral sheet position relatively to Cluster 1 (in blue) and the sheet thickness (in red) are presented in the upper panel. The sheet thickness is ~0.4 Re until 0950:30 UT. It then decreases to 0.2 Re from 0951 to 0955:30 UT before increasing gradually again.

Particularly regular oscillations are observed from 0951:30 to 0954, when the sheet is particularly thin, and concern both the position and the thickness which is indicative of the existence of kink and sausage modes. The kink mode corresponds to undulations of the neutral sheet. It is the fundamental mode of the MHD oscillations, it is associated to antisymmetric displacements. The sausage mode corresponds to variation of the thickness of the sheet, the neutral sheet staying at rest. It is associated to the second harmonic of the MHD oscillations and to symmetric displacements. As seen in panel 2 and 3 where the projection of the normal to the sheet in the plane X/Z and Y/Z is displayed, the observed oscillations also correspond to regular variations of the direction of the normal. They are particularly large (more than 30°) and well-organized in the X/Z plane for the period 0952-0954.

In panel 4, the sheet configuration is reconstructed to get a visual impression of its dynamics. The spacecraft are considered as fix points, their positions along the normal to the sheet being indicated on the plot. Using the sheet position (z_0) and thickness (a), the boundaries of the sheet defined by $z_0 + a$ and $z_0 - a$ are plotted. This plot thus presents the sheet undulations with respect to the spacecraft as a function of time. If these undulations are MHD eigen modes, their phase and group velocities would then be of the order of the sound speed (~800 km/s). This plot would then also represent the spatial structure of the sheet.

This presentation of the sheet suggests that the magnetic fluctuations combines both kink and sausage modes. As seen from the blue curve in panel 5, the neutral sheet undulates between Cluster 1 and Cluster 4 spacecraft (labeled SC1 and SC4 in the quoted paper), with a 20-25 s period corresponding to the spectral peak at 0.04 Hz (left plot below panel 5). The sheet thickness fluctuates in remarkable phase with the position which corresponds to the broad peak centered at 0.04 Hz. However, this spectrum also presents a peak at 0.13-0.14 Hz. If they are interpreted in terms of MHD eigen modes, these results suggest that two sausage-like oscillations, at 0.04 and 0.13 Hz, propagate in the sheet. As shown in Fruit et al, [33], a complete model of the linear MHD response of the plasma sheet can be used to theoretically reconstruct the sheet oscillations starting from arbitrary external perturbations. This includes a quantitative prediction of the expected magnetic and pressure fluctuations, of the relative weight of the kink and sausage-like modes as well as the selection of particular resonant frequencies of the sheet. In the present case, it is shown that the kink mode (0.04 Hz) and the high frequency sausage mode are perfectly compatible with the MHD model of Harris sheet oscillations excited by an external perturbation.

This study can be considered as one of the most precise determination of the specific modes of a non-homogeneous plasma structure. It is interesting to note that the MHD model gives a very good interpretation of some of the observed oscillations. However, it is not the lower frequency perturbations that are compatible with the propagation of MHD eigenmodes and clearly, some of the observed oscillations escape the MHD description.

This work illustrates the unprecedented capabilities of Cluster for quantitatively analyzing plasma physics processes with fundamental interrogations concerning the theoretical models that may be used to explain the observations.

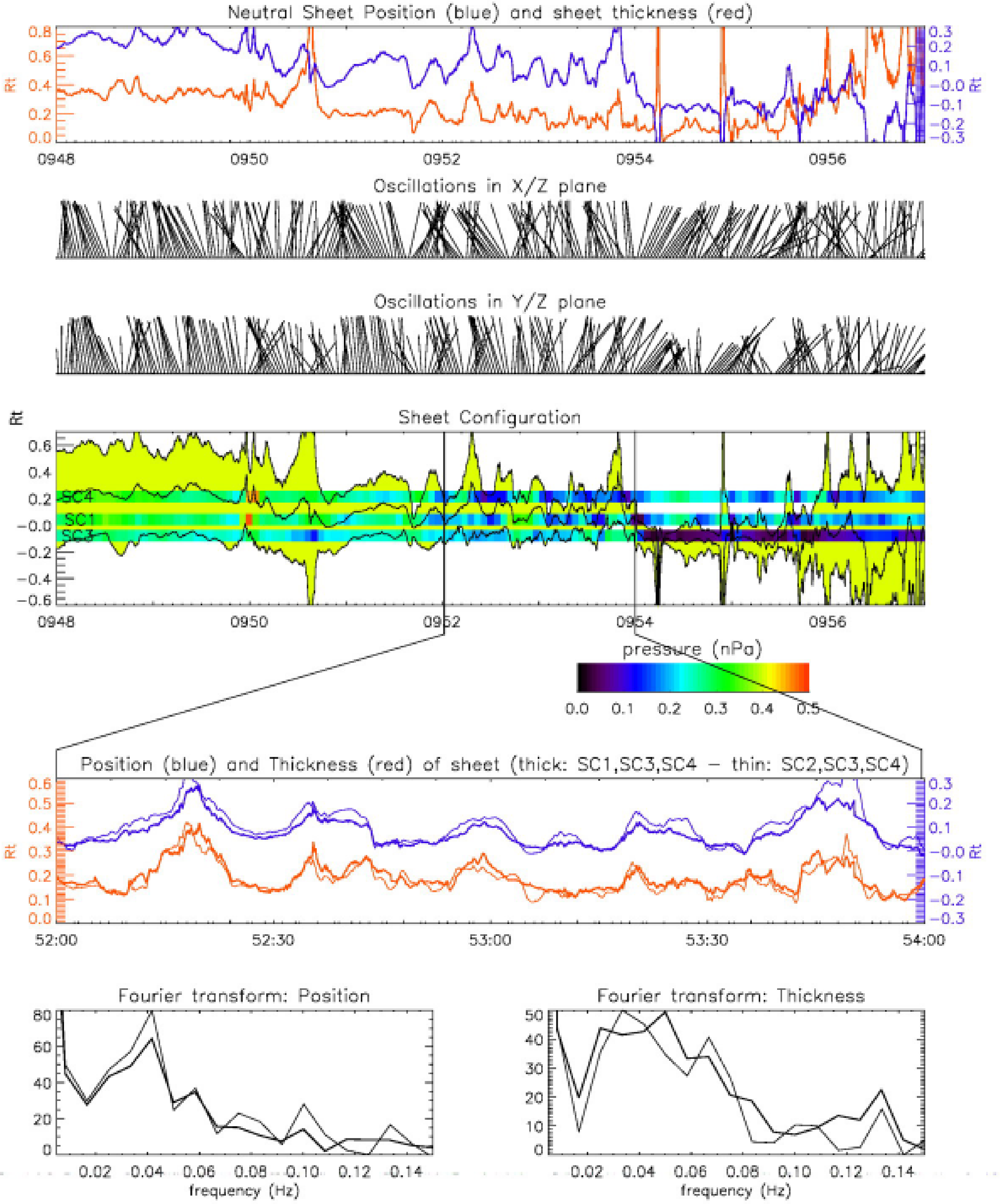

Figure 4. Detailed analysis of the sheet structure (from Fruit et al., [33]). From top panel: (1) neutral sheet position and thickness obtained by a fit with a Harris model; (2) and (3): projections of the normal to the sheet in the X/Z and Y/Z plane; (4) sheet configuration and pressure fluctuations measured by Cluster 1, 3 and 4 spacecraft. (5) and (6): oscillations deduced from STAFF measurements and spectral analysis of thickness and position.

3.2 Waves, as Signatures of Micro-Processes in Small Scale Boundaries

Magnetic reconnection is a major process in astrophysical plasma environments that allows fast conversion of the magnetic field energy of two colliding magnetized plasmas into the kinetic energy of ions and electrons. Better understanding of this phenomenon, key in the dynamics of the magnetosphere, is an important challenge to the Cluster mission. Favorable conditions for the onset of magnetic reconnection are found at locations where narrow current sheets, of the order of the ion inertial length $\lambda_i \approx c/\omega pi$, separate regions in space with nearly opposite directions of the magnetic fields [35, 36]. The reconnection is initiated in small diffusion regions, where the magnetic flux is no longer frozen into the motion of the ions and the electrons.

In a recent study, Vaivads et al. [37] have shown that Cluster could observe for the first time the plasma properties in a diffusion region, without ambiguity in distinguishing spatial and temporal features. On 20 February 2002, around 13–14 UT, the four Cluster spacecraft, separated by an average distance of about 100 km, crossed the magnetopause many times tailward and duskward of the cusp. The study focuses on features on scales in-between the ion and electron scales (particularly traced by waves emissions), at one of the magnetopause crossings. The observations from the Cluster payload are compared with the picture of diffusion region in the neighborhood of the X line as derived from a 2D two fluid simulation. Particularly one is looking for signatures of fast collisionless reconnection [38].

In order to be compared to simulation, Cluster observations have to be placed in the proper reference frame. Top panel of Figure 5 shows results from a 2D two fluid MHD numerical simulation of the diffusion region near the X line [39]. The two directions of reference are respectively the normal N to the discontinuity, and the common direction L of the reconnecting lines. Time delays between the current sheet crossings by different spacecraft give the magnetopause normal direction from observations. This direction is close to the minimum variance direction as obtained by individual spacecraft. The observations of magnetopause are similar on all spacecraft and therefore the diffusion region can indeed be considered as a stable 2D magnetic structure at the scale of Cluster constellation and during the traversal time interval.

Time delays between the current sheet crossings give also the magnetopause velocity, $V_{mp} \approx -120$ km s^{-1}, which allows convert temporal variations to spatial variations. Finally, measurements of local plasma parameters on Cluster can be used to normalize distances with respect to the ion inertial length, hence to compare the observation with the simulation results. Density, as well as magnetic field variations compare very satisfactorily (central panel of Figure 5).

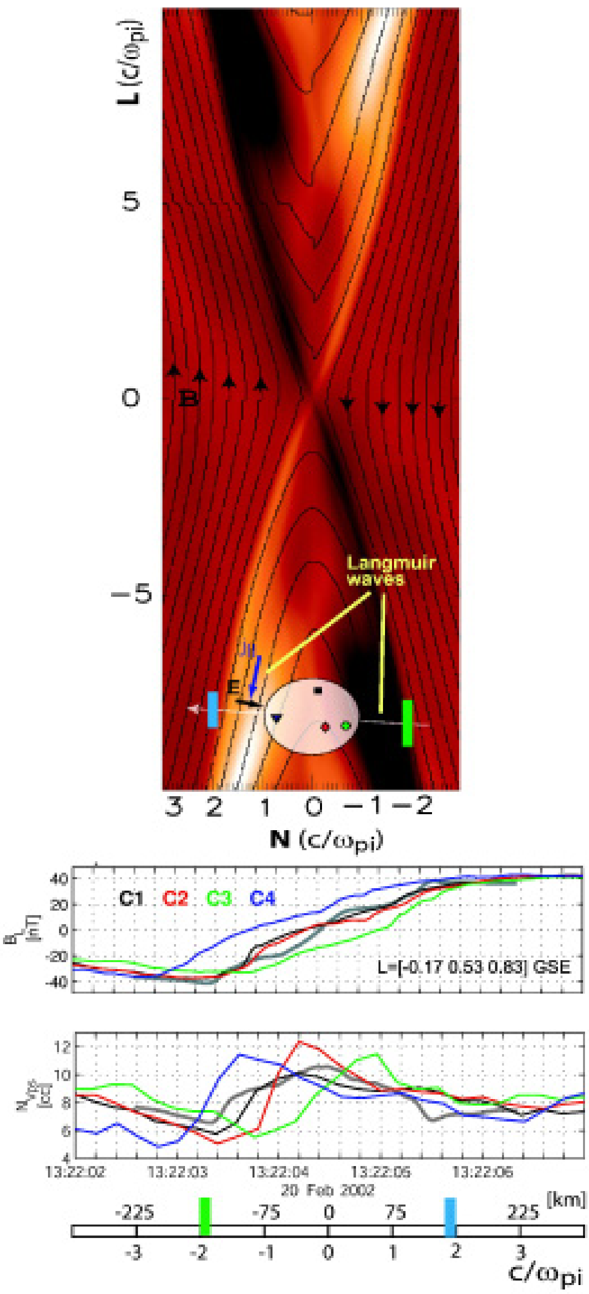

Figure 5. X-line magnetic field configuration observed from a Cluster traversal (reprinted figure with permission from Vaivads et al., *Phys. Rev. Lett.*, **93**, 10, 105001-4, 2004 [37], Copyright (2004) by the American Physical Society). Top 2D structure of the diffusion region from a numerical simulation. The magnetic field lines are shown, and the out-of-plane magnetic field is color coded (white is positive, black negative). The Cluster constellation is projected in the simulation plane. Individual positions are color coded according to a standard code indicated in the panel below, where the four spacecraft are labeled from C1 to C4. Second and third from top observed time variations of the reconnecting (longitudinal) magnetic field component and of plasma density from the satellite potential; simulation results in space are shown with a grey line. Bottom transverse dimension of the structure, expressed in unit of ion inertial length; green and blue rectangles (also drawn at top) mark crossings of the X line branches.

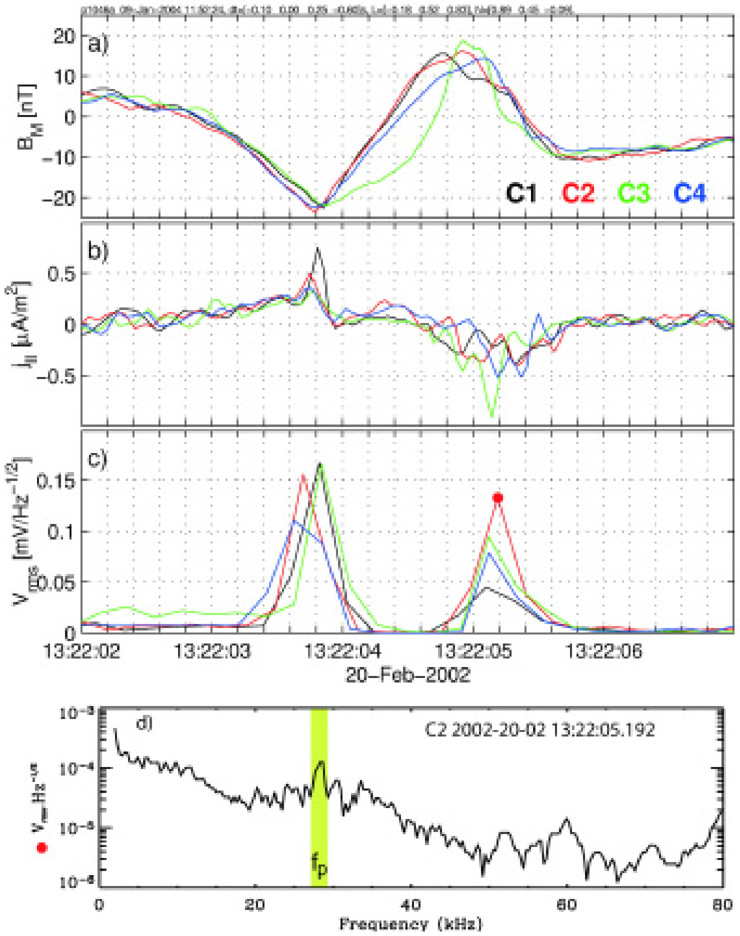

Figure 6. Observations of field-aligned currents and Langmuir/hybrid waves at the separatrices (reprinted figure with permission from Vaivads et al., *Phys. Rev. Lett.,* **93**, 10, 105001-4, 2004 [37], Copyright (2004) by the American Physical Society). The same time interval as in Figure 5; for Cluster 2, 3 and 4 the time series have been shifted –0.09, –0.3 and +0.55 s so that the observations are in the magnetopause frame. (a) out of plane magnetic field component. (b) current parallel to the magnetic field, the direction is away from the X-line. (c) averaged signal amplitude in the frequency range 2 - 80 kHz. (d) wave spectrum from C2 (averaged over 210 ms) at 13:22:05 UT, strong emissions are observed near the plasma frequency, $F_p \sim 28$ kHz.

Cluster observations, shown to mimic the magnetic structure in the N-L plane, can be further examined. Electric field measurements from the EFW instrument [40, 41] (not shown, detailed in [37]), confirm that the model considered is applicable, by indicating a major role of the Hall term in the Generalized Ohm's Law. Figures 6a-6c display three other quantities plotted in the magnetopause frame (time series are shifted adequately). The out-of-plane magnetic field BM, panel a, shows a bipolar variation with the highest amplitude being ~50% of BL outside the current sheet. There is no significant offset in BM, a so called guide field.

According to numerical simulations, the bipolar variation in BM is an indication of the ion diffusion region in collisionless reconnection and has been used as one of the arguments for ongoing reconnection in previous studies [42], [43]. The third component (not shown), B_N , is non-zero (~ 3 nT) inside the current sheet, which also suggests on-going reconnection. Being ~10% of BL, it gives a reconnection rate of ~0.1, typical of fast collisionless reconnection [44].

Observations displayed in panels b and c explore the structure at smaller scales. Simulation predicts that a quadrupolar out-of plane magnetic field structure in the diffusion region is caused by current loops that are mainly perpendicular to the ambient magnetic field in the centre of the current sheet and mainly parallel near the separatrices, directed away from the X-line. The value of parallel currents (panel b) is derived from the variation of magnetic field direction as measured by each of Cluster spacecraft. As predicted by simulations, strong parallel currents occur along the outer edge of the bipolar structure.

Finally, waves at electron scale are taking part in all of this. Examination of a completely independent data set, electric field power integrated over a broad frequency range (including electron plasma frequency) leads to interesting finding: the regions of strong parallel currents are clearly correlated with regions of strong emissions (panel c). Panel d shows the spectra of waves from Cluster 2 in one of the strong emission regions. In addition to broadband spectra there is a spectral peak near the plasma frequency. These waves are probably Langmuir or upper hybrid waves [45].

In summary, Cluster multi-spacecraft measurements allow to unambiguously resolve parallel currents along the separatrices and show that they are correlated with high frequency Langmuir/upper hybrid waves. These waves can be involved in thermalization of electrons, formation of anomalous resistivity, and can be used as a diagnostic tool of reconnection sites.

4. C, as Chorus

Chorus waves are one of the most intense emissions observed in the vicinity of the Earth, just outside the outer boundary of the plasmasphere, called the plasmapause. They are detected near the equatorial plane and they are characterized by a sequence of discrete elements (rising and falling tones) with a time separation between 0.1 and 1 s. They have been extensively studied in the past (see [46] and references cited therein). They are believed to be generated by the injection of substorm electrons [47] through the loss cone instability [48] in the equatorial region. Polar observations, yielding the first Poynting flux measurements of chorus emissions ever performed [49], confirmed that the chorus sources are equatorial. Moreover, they established detailed characteristics of chorus sources [50]. But theoretical efforts are still on-going, aimed at better understanding the exact scenarios and mechanisms of generation. The Cluster fleet has brought new pieces of information which can support those efforts. For the first time, a multi-point mission has been able to find clear correlations between chorus elements observed at several positions in the magnetosphere, thus revealing yet hidden behaviors.

We present below two findings. The first one, published by Parrot at al., [51], is based on observations of the STAFF experiment [52], [53] from Cluster spacecraft placed at an average separation of a few 1000 km: observations for the first time of chorus components reflected at low altitude. The second finding, published by Inan et al. [54], is obtained by WBD instruments placed at separations from about 1000 km to about 100 km: source regions that emit discrete chorus waves are in rapid motion.

4.1 Observation of Reflected Chorus Elements

Detection of a faint chorus emission, after reflection at low altitude, has been possible thanks to an elaborated on-board data processing, part of the STAFF-SA instrument. The processing unit produces 5 × 5 spectral matrices with 27 frequencies distributed logarithmically between 8 Hz and 4 kHz, at a time resolution which varies between 0.125 and 4 s (4 s for the case event presented). Spectral matrices are further processed on ground by a computer program, PRASSADCO, which adds information from FGM, the magnetometer instrument on Cluster [55, 56]. The program estimates polarization and propagation parameters, including the wave vector and Poynting vector directions.

Figure 7a displays the behavior of banded chorus emission around the magnetic equator. It has been shown [57] that the chorus emission frequency is related to the equatorial cyclotron frequency of the magnetic field line passing through the observing point. Cluster travels on a polar orbit, almost tangent to a magnetic field line near the perigee. The L parameter of the crossed field line is decreasing when Cluster is on its inbound leg (heading toward perigee, from South to North), it is increasing on the outbound leg. The related equatorial cyclotron frequency behaves in the opposite way: increasing, then decreasing, as observed. Observations (shown for Cluster 3) are very similar on the three other spacecraft which, grouped at small distances – a few 100 km – cross the same region about 40 minutes sooner. Figure 7b displays frequency–time spectrograms of the Poynting vector component along the *z* axis, which is almost normal to the equator. In this

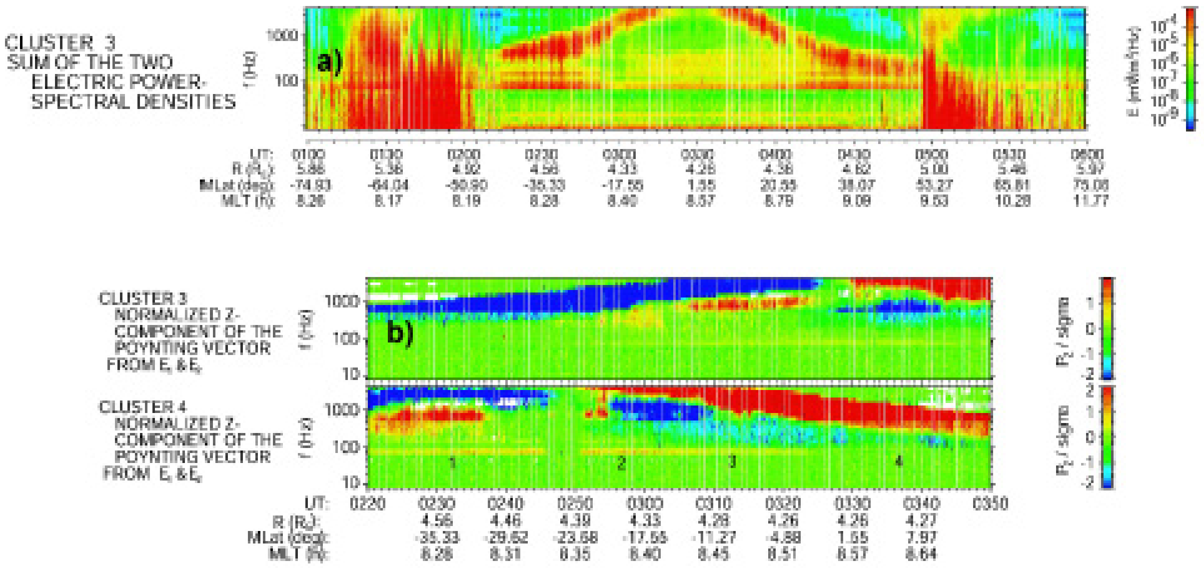

Figure 7. Properties of chorus emissions measured by the STAFF-SA experiment on 29 October 2001 (from Parrot et al., [49]). a) electric power spectral density. Banded emission of chorus type is seen between 100 Hz and 4 kHz, with the maximum frequency being obtained when the Cluster 3 spacecraft (C3) is near the magnetic equator. b) direction of the z-component of the Poynting vector (reliability of the sense of the Poynting vector given by the color-coded scales on the right); compared values from Cluster 3 and Cluster 4 (C4) on a smaller time interval. The geophysical parameters at the bottom are, as on panel a, related to C3.

presentation, Poynting vectors directed along the magnetic field are colored in red, and in blue when they are opposite to the magnetic field. The banded chorus of main intensity shown in Figure 7a is hence propagating away from the equator, as expected for an equatorial source.

In addition to the main banded chorus emission, Figure 7b reveals the presence, close to the equator, of emissions at smaller frequencies with Poynting vectors in the opposite direction (toward the equator). This is the case for instance at ~03:37 UT on Cluster 3 (an event labeled 4 on the panel presenting the Poynting vector for Cluster 4). So that, at the same time and same frequency (~700 Hz), two Cluster spacecraft, both placed in the northern hemisphere, observe potentially the same emission, but propagating in opposite directions. The intensity of the secondary emission is significantly lower than the intensity of the main emission (in a ration ~0.3%), which explains why it is not apparent in Figure 7a. In order to locate the source of both main and secondary emissions and to critically examine the postulate of a common source for those, Parrot et al. [51] have applied an inverse ray tracing algorithm, using as inputs the polar and azimuthal angles of the wave normal direction (calculated from the PRASSADCO software) during a few minutes time interval. The results of the multiple ray tracing for each satellite and for each polar and azimuthal determinations of the wave normal direction, between 03:32 and 03:42 UT and for a frequency equal to 724 Hz, are shown in Figure 8. Stopped when the ray reaches the equator, they locate the source in the same area, hence supporting the postulate that Cluster 3 observes chorus elements having undergone a reflection at low altitudes (when the frequency of the wave approaches the local LHR frequency). The intensity ratio between the direct and the reflected waves corresponds roughly to estimations [58], forming another supporting piece of evidence. Lastly, the wave form of emissions identified by the STAFF instrument as "reflected chorus" has been measured by the WBD instrument [59]. Their frequency/time behavior confirms the postulate that Cluster 3 observed the same emission than Cluster 4, the former coming directly from the equator and the latter after reflection at low altitude.

4.2 Remote Sensing Moving Chorus Sources

Observing chorus elements of higher central frequencies (above STAFF frequency range) with the WBD instrument, Gurnett et al., [20], noted puzzling differences in detailed observations of the same chorus elements: frequency differences Δf of order 1 kHz, and time differences Δt of order 0.1 s. The differences in frequency, as well as the different times of arrival at the different spacecraft, could be explained by Inan et al. [54]. They invoked rapid motion of the compact source regions of chorus, traveling at speeds comparable to the parallel resonance velocity of counter-streaming electrons moving along the Earth's magnetic field lines (the underlying mechanism for generation of ELF/VLF chorus is believed to be the cyclotron resonance interaction). Waves emanating from a compact source can reach two different observers, as Cluster 1 and Cluster 2 spacecraft, only by propagating at two different wave normal angles, and are thus observed at two different "apparent" frequencies. The authors, analyzing three event cases, determined that the sources were moving at speeds of 20,000 $\mathrm{kh\,s^{-1}}$ to 25,000 $\mathrm{kh\,s^{-1}}$ toward the observer.

Only a multiple spacecraft mission, equipped with identical instrumentation of high performances, could derive such an estimation, opening new capabilities for studying the dynamic character of chorus emissions, reported in other studies based on Cluster data [60, 61, and 62].

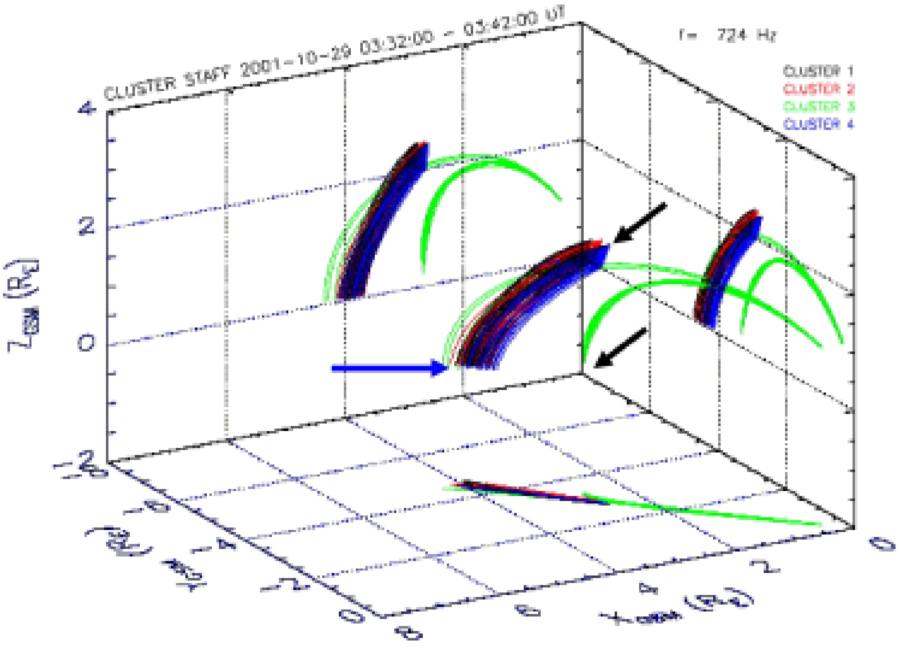

Figure 8. Plots of the ray traces in 3-D and their corresponding projections on the three planes for the time interval 03:32 – 03:42 UT and for a frequency equal to 724 Hz (from Parrot et al., [49]). A blue arrow points to the source area. Black arrows point to Cluster positions when they observe the event.

5. D, as Dispersion

In this section we report what is perhaps the most spectacular outcome of a four spacecraft observatory, in term of wave studies. Locally observed magnetic and electric fluctuations are analyzed via a true 3D tool which identifies $\mathbf{k}$ wave vectors where the energy is propagating. The analysis can be done systematically over a range of frequencies. Wave mode identification is obtained by comparing the identified $\mathbf{k}$ values with theoretical dispersion relations adjusted to the local characteristics of the medium. Applying this approach to turbulent like ULF magnetic fluctuations observed in the magnetosheath, it has been demonstrated that the energy does indeed propagate on several plane waves (i.e., with several wave vectors) with comparable energies, revealing a complex physics. No set of assumptions associated to mono-satellite data, however elaborated, could have yielded such a result.

5.1 *k*-Filtering – Wave Telescope Technique

k-filtering [63], also called the wave telescope technique when restricted to magnetic field fluctuations, identifies 3D-structures in the wave fields. Developed in the context of space plasma physics by Pinçon and Lefeuvre [64], it was applied successfully to Cluster data from FGM instrument [65] and to data from the STAFF-SC and the EFW instruments [66, 67]. Given a measured wave field $\mathbf{B}(t,\mathbf{r}_\alpha)$ at the position $\mathbf{r}_\alpha$ $(\alpha = 1,\ 2,\ldots)$, *k*-filtering estimates the 4D-energy distribution function $P(\omega,\mathbf{k})$ related to the wave field $\mathbf{B}$, assuming that (i) the measured waveform is described as a superposition of plane waves, (ii) fields are translation invariant on distances and stationary on time intervals larger than respectively the studied wavelengths and wave periods, and (iii) the wave field does not contain waves of length shorter than the inter-spacecraft separation. Correlation matrices $\mathbf{M}(\omega,\mathbf{r}_{\alpha\beta})$ are calculated by correlating (over a chosen time interval) measured wave fields (expressed in the frequency domain) at positions $\mathbf{r}_\alpha$ and $\mathbf{r}_\beta$. From all correlation matrices constructed from the Cluster quartet, one forms the (12 × 12) $\mathbf{M}(\omega)$ matrix, which, transformed according to a geometrical matrix $\mathbf{H}(\mathbf{k})$ depending on the positions on the four satellites, yields the distribution function $P(\omega,\mathbf{k})$. For given frequency $\omega(\mathbf{k})$, *k*-filtering allows identifying several waves (i.e. several wave vectors $\mathbf{k}$) carrying different power levels.

5.2 Case Study of High Beta Plasma Parameters

Data used for this case study were obtained around 05:34:00 UT on 18 February 2002. The spacecraft were in the magnetosheath near the magnetopause, separated by about 100 km. The Cluster configuration associated with this data set was checked to correspond to a real 3D configuration (elongation and planarity parameters small enough [68]). The magnetosheath parameters are derived from the Cluster instruments. Averaged magnetic field is measured to be about (5.4, -20.2, 1.2) nT in GSE frame, plasma density from the resonant sounder [69] is about 36 cm^{-3}. Parallel and perpendicular ion temperatures are measured by the CIS instrument [70] to be about 140 eV and 170 eV respectively, and the electron temperature (not available) is known to be typically of the order of 40 eV.

Key parameters are thus obtained: Alfvén velocity $Va \approx 78\ \mathrm{km\,s}^{-1}$; ion gyro-frequency $fci \approx 0.33\,\mathrm{Hz}$; ion Larmor radius, $\rho \approx 79$ km, and ion anisotropy parameter Ai » 0.22. The beta parameters, much larger than unity, are mainly due to ions., with parallel and perpendicular estimations respectively equal to 4.5 and 5.4; the electron pressure is likely to have a negligible role in the wave physics in this case event.

A time interval of 164 s is selected for the analysis. Magnetic data from the STAFF instrument are filtered

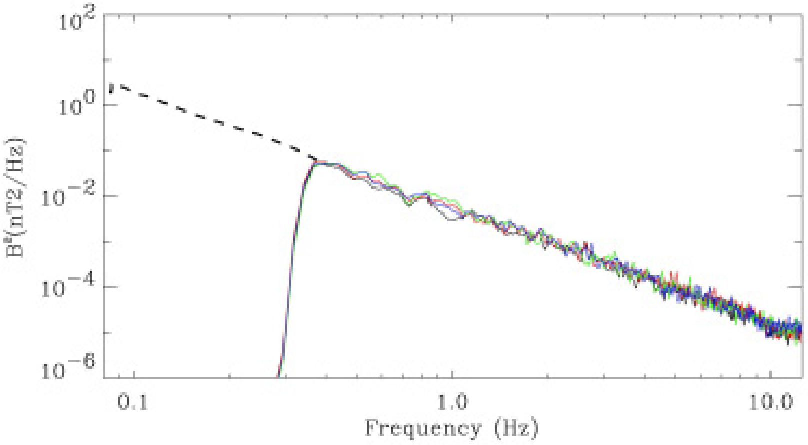

Figure 9. Power spectrum of the ULF magnetic fluctuations (from Sahraoui et al., [64]). The event studied is a 164 s time interval, starting at 05 :34 :01.15 UT on 18 February 2002, wave form filtered at the cut off frequency 0.35 Hz. This spectrum is close to a power-law $f^{-\alpha}$*, with* $\alpha = 2.2$*. The colored lines represent data from Cluster 1 (black), 2 (red), 3 (green), and 4 (blue).*

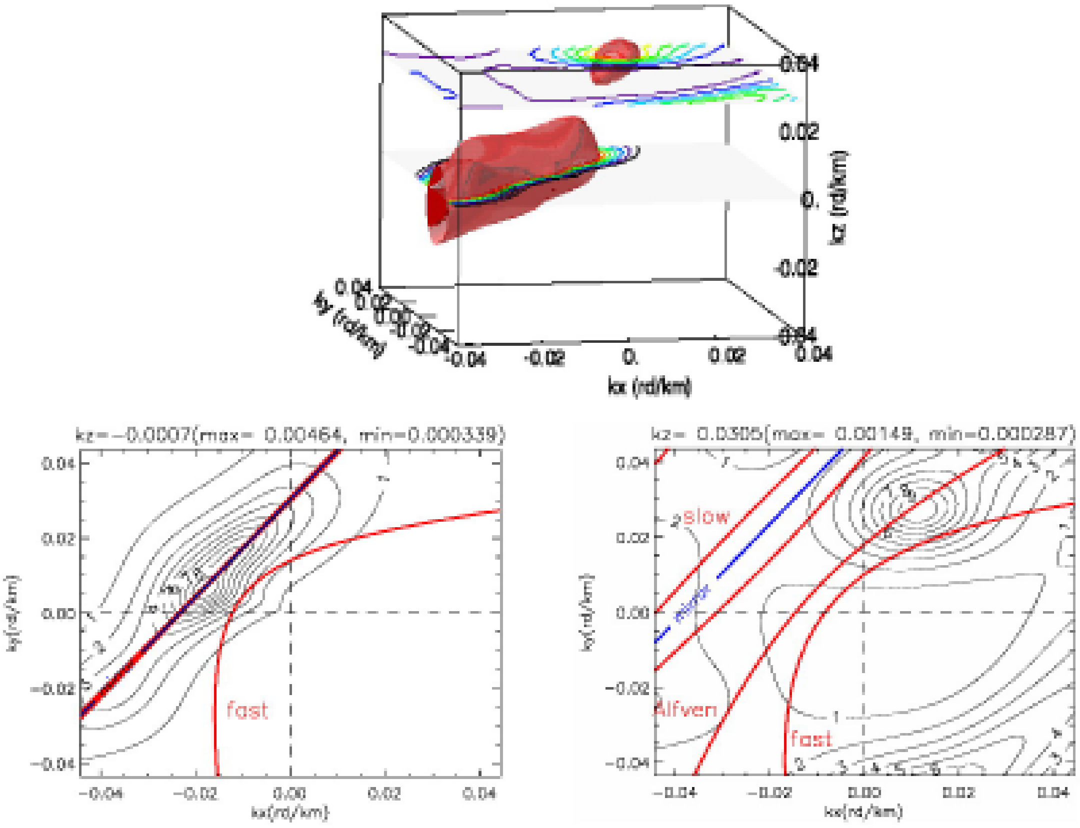

Figure 10. A presentation of the magnetic field distribution, noted MFED, associated with frequency 0.61 Hz in the (k_x, k_y, k_z) domain. Top: 3D view (see text). Bottom (from Walker et al., [65]): superposition of the experimental magnetic energy (thin black lines) with the theoretical dispersion relations of the LF modes (colored thick lines) in the MFA frame for the frequency 0.61 Hz. The blue line is the Doppler shift $\omega = k.v$. *Two main peaks are identified: a mirror mode (left panel) and an Alfvén wave (right panel) having a frequency in the plasma frame close to the second gyroharmonic* $F_{plasma} = 0.71 Hz \sim 2\,F_{ci}$.

using a high-pass filter with a cut-off frequency of 0.35 Hz, in order to filter out any possible spurious signal linked to the spin frequency (0.25 Hz). The power spectrum of the filtered magnetic fluctuations, shown in Figure 9, displays a smooth intensity decay with frequency, identical on all four spacecraft, with a slope parameter consistent with a turbulent cascade of energy from large to small scale [66].

When analyzed by the *k*-filtering tool, the same data indicate a clear organization. The power of the wave at a selected frequency, *f*, is distributed over two main volumes in **k** space. Results are displayed in Figure 10 (at $f = 0.61$ Hz) using the Magnetic Field Aligned (MFA) referential, which is defined as follows: *z* axis is along the mean magnetic field $B_0 = B_0 \mathbf{z}$, the *x* axis is perpendicular to the *z* axis, in the plane containing the Sun-satellite line and the *z* axis, and is directed towards the Sun, and the *y* axis completes the right-handed coordinate system. In the upper panel, the 3D view of the magnetic wave field energy distribution in **k** space, noted MFED, is obtained by displaying the iso-surface in energy per unit of **k** volume, corresponding to 33% of the maximum value.

As can be seen, the two iso- surfaces, linked to the two main volumes in **k** space, are well separated. They are placed near two (k_x , k_y) planes with $kz = -\ 0.0007$ rd km^{-1} and $kz = 0.0305$ rd km^{-1} respectively. Each (k_x , k_y) plane is restricted to the validity domain defined by $k_x,\ k_y \in [-0.04;\ 0.04]$ rd km^{-1} . The validity domain in **k** space is determined from the separations between the Cluster satellites: all the existing wavelengths have to be larger than the satellites separations, which are of the order of 100 km in the present case. In the lower panels of Figure 10 (from [67]), the wave field energy distribution is displayed in the two (k_x , k_y) planes quoted above, linked to the two distinct volumes of significant MFED maxima. Lines of iso-energy are marked by level values associated in each case to the max and min values indicated on the figures.

In order to identify the wave mode associated with each MFED volume, Sahraoui et al. [66] calculated the linear dispersion relations of the low frequency modes: mirror, Alfvén, fast and slow magnetosonic modes. Results are plotted in the two (k_x , k_y) planes determined from observations. Because theoretical values are naturally obtained in the plasma frame, one has to take into account the Doppler effect . The relative velocity between the plasma and the Cluster constellation is provided by the CIS ion analyzer. The Doppler is then easily estimated for each *k* value, and used to obtain the theoretical dispersion results plotted in red. The mirror mode is considered as a non-propagating mode ($\omega = 0$) in the plasma frame.

The comparison of theoretical dispersion relation with observations in Figure 10 clearly identifies the two superposed modes of propagation at 0.61 Hz as modes obeying the linear dispersion relation of ULF wave modes. The mirror mode, Doppler shifted to nonzero frequencies in the MFA frame, is confirmed to be the dominant mode in the high b plasma analyzed in this case. An Alfvén wave mode (bottom right panel), about three time lower in intensity, is also present. Similar analysis at other frequencies indicates that the observed magnetic field energy is distributed over several eigen modes close to the theoretical ULF mirror, Alfvén, and slow mode. This result suggests that weak non linear interaction between low frequency modes might counteract the effects of linear kinetic damping. A further analysis of the event [72] (using complementary data, from the magnetometer FGM instrument) confirms the presence of non linear processes. The study indicates that the magnetic energy seems to be injected over the low frequency (FGM band) part of the observed spectrum, at a spatial scale that is in very good agreement with the predicted maximum growth rate of the mirror instability. The validity of a model of weak turbulence is foreseen to be explored in the future [73].

6. Concluding Remarks

This short panorama of findings is a partial and incomplete view. It leads however to a few reflections.

1. What the mission designers "had always wanted to do," i.e. 3D characterization, has been accomplished, as shown by the illustrations presented at both ends of the panorama (the AKR and Dispersion sections). In terms of remote sensing, the WBD instrument, served by the DSN network, had the unique opportunity to try VLBI on terrestrial radiation, hence deriving a new category of results. In term of local wave characterization, the k filtering method has proven to be applicable in the ULF domain, not only in the magnetosheath region, case of the chosen illustration, but for instance in the foreshock [74]. Turbulent plasma regimes which could be studied only from statistics that mixed spatial and temporal variations, are now understood as natural properties of the flowing plasma, opening a brand new field of investigation. It is worth noting that the k filtering method is not the only way to obtain a 3D characterization of the waves. Other methods have been elaborated and successfully applied to Cluster data [67, 75, 76, 77, 78]. They can bring complementary information to the k filtering method, the most powerful in sorting out several co-existing waves, but requiring a reasonably stationary signal. Such a requirement is not necessary, for instance, with the instantaneous local wave analysis [76]. Cluster, hence, provides a good opportunity for further tests on various wave analysis tools.

2. Boundaries, those key regions "where the action is" have been explored in a way as to disentangle time and space variations. Boundary studies rely heavily on independent determinations of the local orientation of the boundary, which provide the adequate frame of study. One should underline the essential role of large-scale magnetic field data and of a 3D (four points) spacecraft fleet to this end. Elaborated tools continue to be developed to support boundary studies, for instance toward a reconstruction of a 2D spatial topology from multi-point temporal variations [79].

The illustrations presented in this review are only a sample of the many findings obtained by Cluster exploring boundaries and their wavy structures. Concerning large and mesoscale structures, one can cite for instance characterization of SLAMS (Short Large Amplitude Magnetic Structures) near the bow shock [80], of bow shock global oscillations [81], of Kelvin-Helmholtz vortices at the magnetopause [82], and of current sheet oscillations [83, 84]. Structures at smaller scales in the vicinity of the bow shock are reported in [85] and [86]. Magnetic turbulence analysis in the current sheet is reported in [87]. Lastly, the multi-point Cluster analysis allow to better characterize ELF and VLF waves present for instance near the electron foreshock boundary [88, 89], in the polar cusp [90], or in the vicinity of the plasmapause boundary [91, 92].

As expected, Cluster brought also "good surprises," as demonstrated by chorus studies (Section 4). Indeed, it was not granted that the instrument's sensitivity would be good enough to detect a reflected chorus radiation, nor that the direct radiation would be in view of another Cluster point, right in time for confirmation of the reflection hypothesis. Likewise, that small frequency and time shifts of the same chorus element as observed from different view points could be measured, and thus lead to a model of chorus drifts and an estimation of their velocity. There are many more findings to come in this category.

1. Other types of Cluster findings in the field of wave studies are not covered by this rapid overview. Important ones are related to very small scale processes (like solitary waves reported in [93, 94]), others to multiple scale studies, in particular in conjunction with ground observations, others to wave particle interactions (see for instance [95]). We can recommend the interested reader to have a look at the Cluster publication list [96].

2. Expectations for the future are that many findings are still to be discovered, some likely by "work in progress," in particular statistics on various phenomena. After four

years of operations as a tetrahedron of regular shape over large parts of the orbit (surveying phenomena with some coherence over a volume of space), Cluster will, in the near future, be configured to larger baselines, which among other capabilities will allow better remote sensing of wave sources like continuum radiations, where first multi- point Cluster results are promising [97, 98].

Finally, Cluster exploration of waves, yielding either confirmations of expected behaviors or discovery of non expected behaviors, will guide global simulations and theoretical studies, toward a better understanding of the mysteries of the magnetosphere equilibrium and dynamics – among others the mechanism of substorm triggering, of turbulence and dissipation in large scale boundaries, of energy and momentum transfers at thin boundaries; all of general interest to the fields of astrophysics and plasma physics.

7. Acknowledgements

This paper is dedicated to the memory of Les Woolliscroft, the principal investigator of DWP [99], one of the WEC (Wave Experiment Consortium) instruments on Cluster, until his ultimate demise. Les, as the head of the WEC group, played a determining role in shaping the scientific payload, which is working beautifully on all four Cluster spacecraft. Most of the material included in the paper is directly borrowed from published papers, whose authors should take the credit for the reported findings. Parts of the introductory section are borrowed from publications of A. Roux and G. Pashmann, who played a leading role in the Cluster mission concept. Finally, we are grateful to all mission teams for their dedication in managing the heavy load of operating the first 3D magnetospheric observatory. Our friendly thanks in particular to J. Pickett, D. A. Gurnett, M. André, G. Gustafsson, A. Erikson, P.-A. Lindqvist, N. Cornilleau-Wehrlin, M. Maksimovic, P. Canu, H. Alleyne, K. Yearby, A. Balogh and E. Lucek, leading members of the WEC and FGM teams.

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Long-Term Trends in Different Ionospheric Layers

J. Bremer

Abstract

The paper deals with investigations of long-term changes in different parts of the Earth's ionosphere to find answers for two questions: (1) Are there trends in the ionospheric plasma which may become important for practical applications? and (2) Can long-term changes in the ionosphere give hints to anthropogenic influences as e. g. an increasing atmospheric greenhouse effect?

In the F2 layer, trends have been derived from worldwide ionosonde observations. The estimated global mean values of the foF2 and hmF2 trends are relatively small and can therefore be neglected for practical purposes. At individual stations, however, the ionospheric trends may be markedly stronger. The reason of the strong differences between the individual observations is quite unknown at the current time.

In the lower ionospheric layers (F1, E, and D), the derived trends of different ionospheric parameters are more consistent and can at least partly be explained by an increasing greenhouse effect.

1. Introduction

Ionospheric trend investigations were mainly initiated by modeling calculations [1-2], which predicted a lowering of peak heights of the F2 layer by 15-20 km and of the E layer by about 2.5 km, assuming a doubling of the atmospheric greenhouse gas CO_2. Modeling results with the TIGCM (thermosphere/ ionosphere general circulation model of the NCAR, Boulder) [3] supported these results and predicted additionally a decrease of the peak electron density of the F2 layer (decrease of the critical frequency of the F2 layer, foF2, by 0.2-0.5 MHz) and increases of the peak electron densities in the foF1 and E layers (increase of the critical frequency of the F1 layer, foF1, by 0.3-0.5 MHz, and of the critical frequency of the E layer, foE, by 0.05-0.08 MHz). To test these predictions, ionosonde observations have been analyzed during the last 10-15 years concerning long-term trends in the ionospheric F2, F1, and E layers. Whereas first ionosonde observations started in the UK during the thirties of the 20th century (station Slough), at many measuring stations of the world continuous ionospheric observations began in the fifties, markedly initiated by the International Geophysical Year (IGY). Therefore, a great amount of long-lasting ionosonde data is now available and is used by several groups for investigations of trends in the ionosphere.

Experimental trends from ionosonde data have often been derived for one or only few stations [4-14]. Most of these investigations are concerned with trends in the F2 layer, only some include also parameters of the E and/or F1 layer [4-5, 8]. During recent years the ionospheric trend analyses have been extended to investigations with many different stations to get more representative results. Most of these papers deal with trends in the ionospheric F2 layer [15-26]. Some other trend investigations include also characteristic parameters of the F1 and E layers [27-31].

For trend analyses in the ionospheric D layer only some data series are available concerning rocket measurements of electron densities [32-33], ionospheric reflection heights in the LF range [34-35], and absorption data at different frequencies [36-40].

In the present paper the main results of the different trend analyses are summarized separately for the different ionospheric layers together with possible explanations of the observed trends, mainly in consideration of a possible connection of these trends with an increasing atmospheric greenhouse effect.

2. Data Analysis

For the trend analyses, mainly monthly median values of different ionospheric standard parameters have been used. As an example, in Figure 1 median values of foF2 and hmF2 from observations at Juliusruh (54.6°N, 13.4°E) are shown for December at two different hours (0 and 12 LMT) together with the corresponding data of solar and

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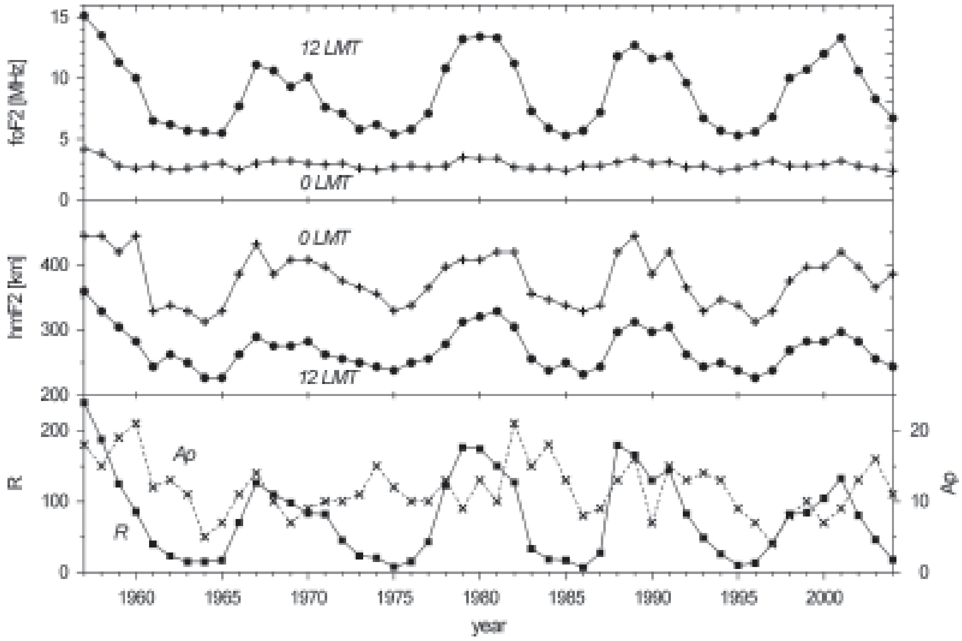

Figure 1. The long-term variations of foF2 and hmF2 in Juliusruh (54.6°N; 13.4°E) in December for 0 and 12 local mean time, together with the corresponding variation of solar sunspot number, R, and geomagnetic activity index, Ap.

geomagnetic activity (solar sunspot number, *R*, and geomagnetic activity index, *Ap*).

As to be seen from Figure 1, the ionospheric parameters markedly depend on the solar (and geomagnetic) activity. Changes up to about 10 MHz in foF2 and more than 100 km in hmF2 may be caused by variations of the solar activity during a solar cycle. If long-term trends with markedly smaller amplitudes will be derived from such ionospheric data, the solar induced part has carefully to be eliminated. This can be done by a simple regression analysis [4] according to the following equations

$$X_{th} = a + b \cdot R + c \cdot Ap \cdot \qquad (1)$$

Here, the solar sunspot number, *R*, is used as the index for solar activity and the global *Ap* index for the geomagnetic activity. Then the differences between the observed ionospheric parameter, X_{obs}, and the calculated value, X_{th}, are estimated by

$$\Delta X = X_{obs} - X_{th}, \qquad (2a)$$

or relative differences are calculated:

$$\Delta X = \left(X_{obs} - X_{th}\right)/X_{th} \cdot \qquad (2b)$$

For analyses of ionosonde data, time series of ΔX can be estimated for each hour and each month (12 × 24 data series). These data series can be analyzed separately, but often yearly mean ΔX values have been used to derive linear trends according to

$$\Delta X = d + e \cdot \text{year}, \qquad (3)$$

with the trend parameter, *e*, for the investigated ionospheric parameter *X* (= critical frequencies of the different ionospheric layers, foF2, foF1, foE, peak height of the F2 layer, hmF2, or the virtual heights of the E and F layer, h'E, h'F).

3. Experimental Trends

In this Section, the trend results are separately presented for the different ionospheric regions, mainly using ionosonde data for the F2, F1, and E layer, whereas in the D layer different data sets have been analyzed.

3.1 Trends in the F2 Layer

Using the method described above, data series of more than 100 different ionosonde stations have been analyzed [27-28, 30-31]. The hmF2 values have been derived from M(3000)F2 values with the simple formula developed by Shimazaki [41]. In these trend investigations, other solar indices instead of R have also been tested (F10.7, E10.7, R12), but the derived trends are not markedly influenced by this choice [28]. In Figure 2, the updated histograms with the individual trends of foF2 and hmF2 are presented together with the corresponding median values. The distributions of the individual trends are relatively broad for both parameters, but the corresponding median values are very small. As shown in Table 1, the mean trends of foF2 and hmF2 are not statistically significantly different from zero as follows from the corresponding mean errors, estimated after a well-known algorithm to be found in [42].

In Figure 3, the individual hmF2 trends are presented in dependence on longitude and latitude. Negative trends

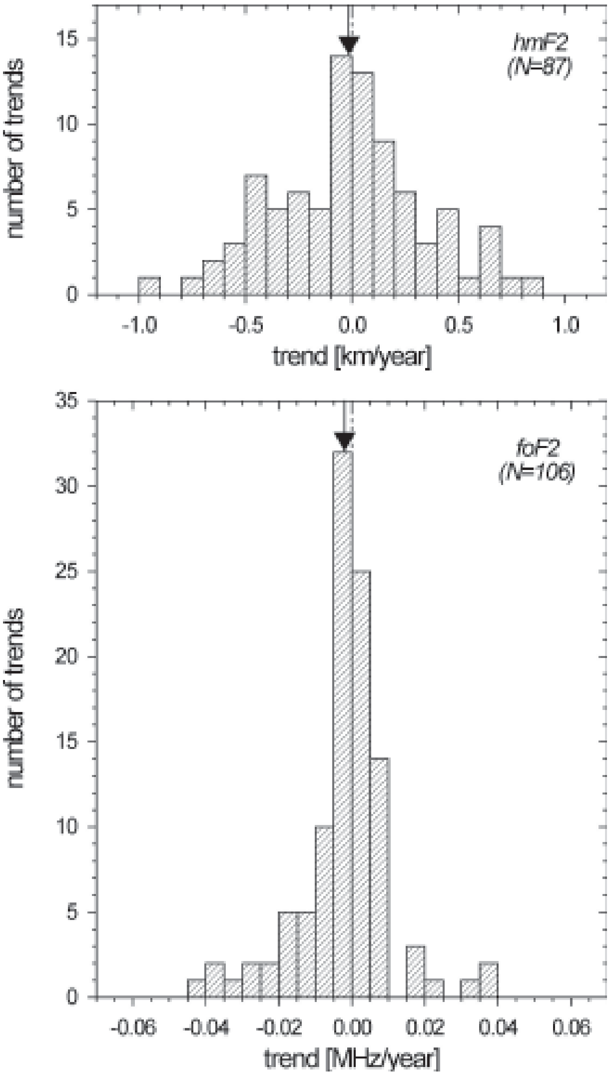

Figure 2. Histograms of individual trends in hmF2 (upper part) and foF2 (lower part). The corresponding median values are marked by arrows.

are marked by crosses, positive trends by full dots. There is no clear dependence of the trends on latitude or longitude, but there seem to exist some regional differences. Whereas in the western part of Europe most trends are negative, in Central Asia the trends are more positive. The causes of these regional differences are not known at the current time.

In similar trend analyses (the data series have been approximated by a multi-parameter model also taking into account the annual and semi-annual variation of hmF2) [18], comparable regional differences in the hmF2 trends have been found as shown in Figure 3. Here also different formulas for the derivation of hmF2 from M(3000)F2 data have been analyzed resulting in quantitative differences of the derived trends depending on the hmF2 formula used. This finding is caused by the fact that the ionization below the F2 layer is differently considered by the different formulas. Therefore, trends in the underlying ionization parameters may also cause differences in the hmF2 trends.

From the analysis of hmF2 data series for some Asian and American stations [16] using the same method as described in Section 2, similar regional differences have also been found with more negative trends at coastal regions and more positive trends inside the continents.

foF2 data from four high-latitude stations [22-23] have been analyzed in a similar way as introduced above. But in these analyses only such experimental data have been included that are not accompanied by qualification letters to reduce the uncertainty of the hourly foF2 values. Furthermore, only geomagnetically quiet days have been used based on a catalogue describing the geomagnetic influence upon the ionosphere [43-44]. All four analyzed data series have negative foF2 trends with a median value of –0.0035 MHz/year, not very far from the corresponding median value in Table 1.

Using 12-monthly running hourly mean values of foF2 or hmF2 and of the solar sunspot number (R12) and geomagnetic activity (*Ap*12) trend analyses [19-21] have been carried out for foF2 and hmF2. Here, however, only

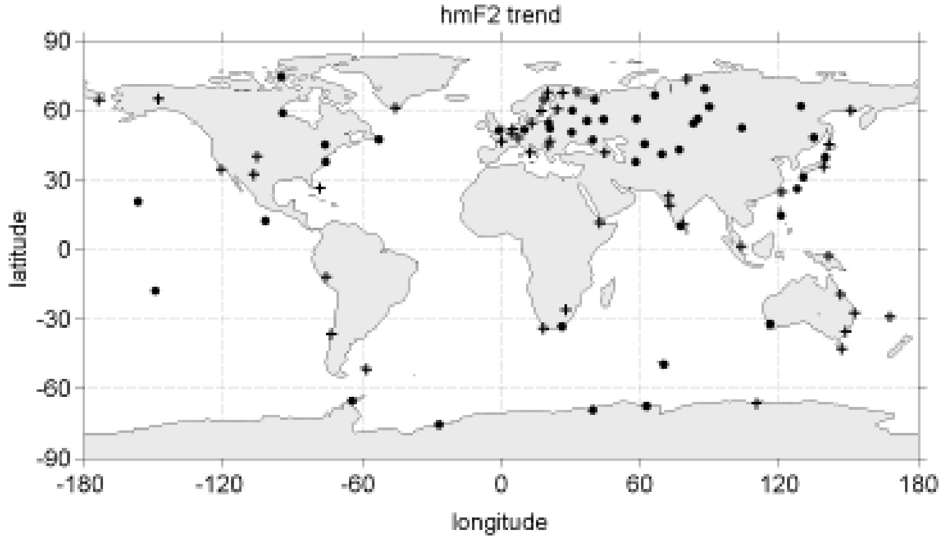

Figure 3. The trends in hmF2 as functions of latitude and longitude derived from ionosonde observations at 87 different stations. Negative trends are marked by crosses, positive trends by full dots.

	Parameter	N	Mean Trend	Error (95 %)
F2 Region	foF2	106	–0.0018 MHz/year	0.0025 MHz/year
	hmF2	87	–0.009 km/year	0.076 km/year
F1 Region	**foF1**	**51**	**0.0027 MHz/year**	**0.0011 MHz/year**
E Region	**foE**	**72**	**0.0014 MHz/year**	**0.0007 MHz/year**
	h'E	31	–0.040 km/year	0.070 km/year

Table 1. The mean experimental trends and error limits (95%) derived from trend analyses of different ionosonde parameters at different stations (N: number of stations used). Significant mean trends are bold-faced.

foF2 data during three years near solar minimum and maximum are taken into consideration to avoid the hysteresis effect whereas for hmF2 data of all years have been analyzed. The regression model used is a modification of Equation (1) according to

$$X_{th} = a + b \cdot R12 + c \cdot R12^2 + d \cdot R12^3 + \left(e \cdot Ap12\right) \cdot \qquad (4)$$

The analyses have been made with and without the geomagnetic term. Relative deviations of the observed data have been used according to Equation (2b). The main results can be summarized as follows:

- The influence of the geomagnetic activity on foF2 and hmF2 can only partly be removed if the term with Ap12 is also included in Equation (4).
- Periods with increasing and decreasing long-term geomagnetic activity are related to different ionospheric trends: foF2 trends are in anti-phase, and hmF2 trends in-phase with *Ap* trends.
- The diurnal and latitudinal variations of the foF2 and hmF2 trends can be explained by the current geomagnetic storm behavior. Therefore, this method is called geomagnetic control concept by their authors.

Another method was developed [25-26] to eliminate the long-term influence of geomagnetic activity on foF2 trends. Starting with relative $\Delta\,\mathrm{foF2}$ values, calculated in a similar way as in [19] but using data of all available years, it is assumed that the derived foF2 trend $k\left(obs\right)$ is the result of a linear combination of a non-geomagnetic trend, $k\left(tr\right)$, and a geomagnetically caused trend. It is further assumed that the geomagnetic activity is described by annual mean values of *Ap* and the geomagnetic trend is proportional to the gradient of $Ap, k\left(Ap\right)$:

$$k\left(tr\right) = k\left(obs\right) + a_l \cdot k\left(Ap\right) \cdot \qquad (5)$$

Here, a_l is a scaling coefficient that includes the efficiency of the geomagnetic activity impact on foF2 and may therefore be different for different stations and local times. Using foF2 data series of 23 stations with observations of more than 35 years a mean non-geomagnetic trend of -0.012 MHz/year was found for the period between 1958 and the mid-nineties, and -0.0075 MHz/year for the earlier interval between 1948-1985 (here only data of eight stations were available).

Another attempt has been tried to eliminate the geomagnetic influence on the foF2 trends [24]. Starting with monthly regressions according to Equation (1) and estimation of relative deviations after Equation (2b), 11-year running mean values of these deviations have been calculated: $\delta\,\mathrm{foF2}_{132}$. The geomagnetic activity effect in $\delta\,\mathrm{foF2}_{132}$ is derived from 11-year running mean values Ap_{132} by

$$\delta\,\mathrm{foF2}_{132th} = b_0 + b1 \cdot Ap_{132}\left(t+n\right) + b_2 \cdot Ap_{132}{}^2\left(t+n\right) \qquad (6)$$

where *n* is the time shift in years of Ap_{132} with respect to $\delta\,\mathrm{foF2}_{132}$ variations. From the residuals,

$$\Delta\,\mathrm{foF2} = \delta\,\mathrm{foF2}_{132obs} - \mathrm{dfoF2}_{132th}\,, \qquad (7)$$

linear trends according to Equation (3) have been calculated with the following main results:

- The derived foF2 trends are nearly independent of latitude and of the phase of long-term changes of geomagnetic activity.
- Most of the residual trends are negative, often however not significant. A significant negative trend was derived for Slough with $-0.000223\ \mathrm{year}^{-1}$, corresponding to -0.0022 MHz/year (assuming a mean foF2 value of 10 MHz).

Summarizing, it can be stated that in all analyses with data of different stations the derived mean trends in the F2 region are relatively small and not important for practical applications. At individual stations [6, 12, 13], however, the trends can be markedly more pronounced, resulting in broad global histograms as shown in Figure 2.

3.2 Trends in the F1 Layer

Trends in foF1 data series have been derived from observations at 51 different ionosonde stations [31]. For the elimination of the solar and geomagnetically induced parts the twofold regression Equation (1) has been used. In Figure 4, the histogram of the updated individual foF1 trends is shown together with the global median value (marked by an arrow). The distribution is asymmetric to zero (dashed line) as seen by slightly more positive than negative trend values. The estimated mean trend with 0.0027 MHz/year is significantly different from zero as to be seen in Table 1 where also the corresponding mean error can be found. Therefore, this trend has been marked there by bold letters.

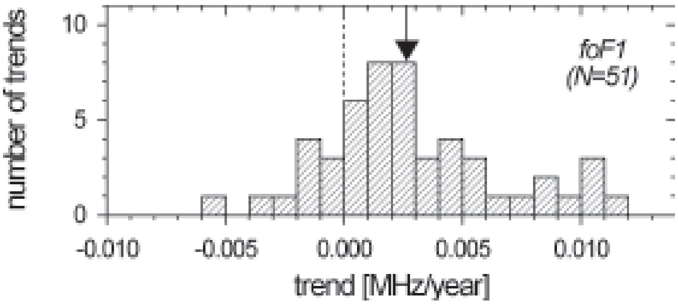

Figure 4. A histogram of individual trends in foF1. The corresponding median value is marked by an arrow.

3.3 Trends in the E Layer

Trends in the ionospheric E layer have been estimated from h'E and foE observations at different ionosonde stations using the method described in Section 2 above [31]. The results of the trend analyses are shown by histograms together with their global median values (marked by arrows) in Figure 5. The estimated mean foE trend is with 0.0014 MHz/year significant with a reliability level of more than 95%, whereas the mean h'E trend is with -0.040 km/year not significantly different from zero (vertical dashed lines in Figure 5). These mean data can be seen in Table 1 where the mean trend values are presented together with their errors.

A similar method as derived for foF2 trend investigations [24] described above together with Equations (6) and (7) has been developed also for foE trend analyses [29]. Instead of Equation (7), however, a slightly modified equation has been used:

$$\delta\,\mathrm{foE}_{132th} = b_0 + b_1 \cdot Ap_{132}{}^{\beta}\left(t+n\right), \qquad (8)$$

where β is a fitting parameter and *n* is again the time shift in years of Ap_{132} with respect to $\delta\,\mathrm{foE}_{132}$. The main results are:

- Before about 1970 $\delta\,\mathrm{foE}_{132}$ and Ap_{132} are negatively correlated. The authors call it "natural foE variation."
- After about 1970 marked foE increases were detected which could be caused anthropogenically.

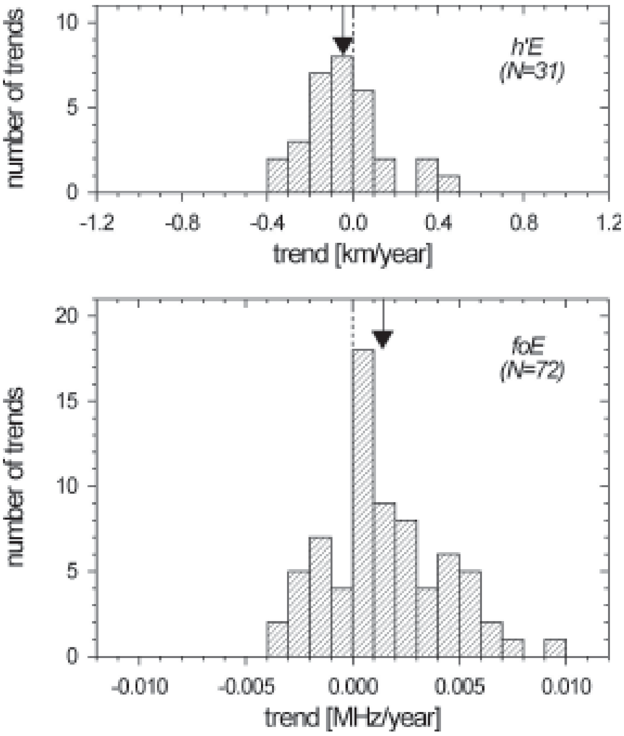

Figure 5. Histograms of individual trends in h'E (upper part) and foE (lower part). The corresponding median values are marked by arrows.

3.4 Trends in the D Layer

In the ionospheric D layer, the available data series for trend analyses are limited, therefore these investigations are restricted to some long-term observations of ionospheric reflection heights and ionospheric absorption as well as electron densities measured by rocket soundings.

From the interference field between the ionospherically reflected sky wave and the ground wave of a far distant radio transmitter it is possible to derive ionospheric reflection heights (often called phase heights, for details of the method see [34] and references therein). From long-term field strength observations of a measuring path at 162 kHz in mid-latitudes trends of the reflection height have been derived for a constant solar zenith angle $\chi = 78.4°$. In the upper part of Figure 6, the long-term variation of the LF reflection height can be seen. In the lower part of this figure, the solar and geomagnetically induced variations have been removed according to Equation (1) by using the solar Lyman a radiation instead of the solar sunspot number, *R*. A significant negative trend could be derived with about -0.030 km/year using the data for the whole time interval. Subdividing the full interval into two intervals before and after 1979, the derived trend becomes steeper in the last interval.

Such a shrinking of the lower ionosphere could also be detected from observations of reflection heights at ionospheric drift measurements during night-time [35]. These measurements are carried out in the LF range

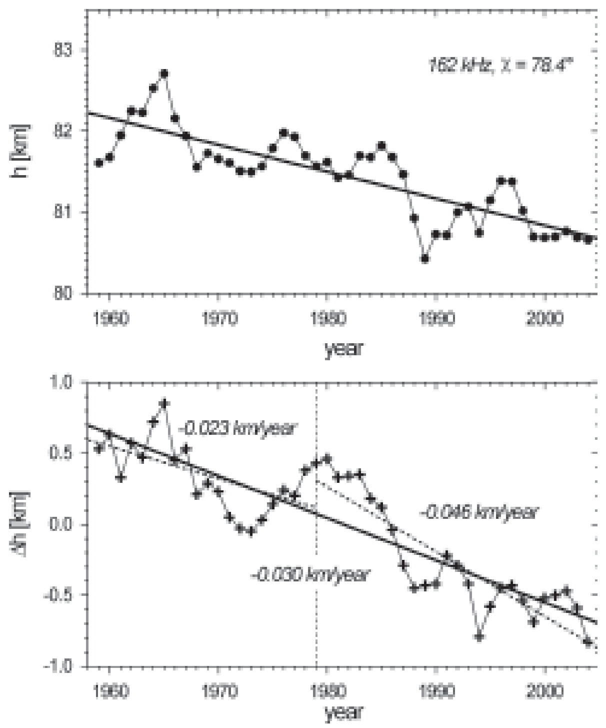

Figure 6. Upper part: The long-term variation of observed yearly mean phase heights at mid-latitudes. Lower part: The long-term variation of phase heights after elimination of the solar and geomagnetically induced parts. The full line marks the linear trend for the whole observation interval the dashed lines the corresponding trends for the intervals before and after 1979.

(177 kHz) at a short distance between transmitter and receiver (170 km).

Both mean trends of reflection heights near 82 km (LF phase heights) and near 95 km (drift measurements) as well as the trends in the E-layer peak height near 110 km (h'E trends in Section 3.3) have negative values which may slightly increase with increasing height. The significance level of the phase height trend is rather high (greater than 99%), for the two other methods this level is however lower due to the shorter data series (drift method) or due to marked differences between individual ionosonde stations (see the broad histogram in Figure 5 (upper part) and the derived mean trend and error values in Table 1).

Ionospheric absorption data have been analyzed for three different reflection height ranges, below about 80 km, between about 80-90 km, and above about 90 km.

From long-term observations of the absorption at a very long measuring path at 164 kHz (distance between transmitter and receiver: 1720 km) during summer and noon conditions [36-37] a clear positive trend could be detected. The reflection height of this measuring path is clearly below 80 km.

Using, however, data from LF absorption measurements at short distances (about 180-220 km) the derived trends change their general behavior. In Figure 7, some absorption trends are shown for a measuring path at 243 kHz at different solar zenith angles χ. With increasing reflection height (corresponding with increasing χ) the trends become more positive. We observe the same behavior if trends have been estimated for measuring path with different frequencies but the same solar zenith angles (an example can be found in [39]). With increasing frequency the trends becomes again more positive.

Investigating ionospheric absorption measurements in the MF and HF ranges at oblique incidence (distances between transmitter and receiver are from about 170 km to 550 km) only positive trends have been estimated [38, 40]. The reflection heights of these measuring paths are above 90 km. The tendency detected at the LF absorption data

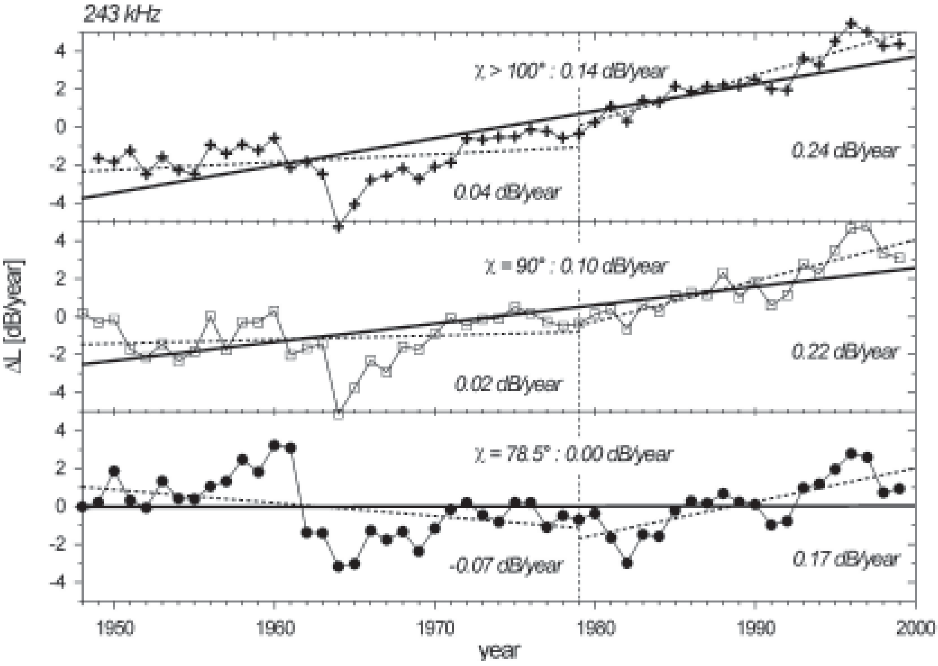

Figure 7. The long-term variation of ionospheric absorption for a LF measuring path at 243 kHz at different solar zenith angles ÷ after elimination of the solar and geomagnetically induced parts. The full straight lines represent the mean trends for the whole measuring interval, the dashed lines the corresponding trends before and after 1979.

series that with increasing reflection height the trends become positive, is therefore confirmed by the absorption measurements in the MF and HF ranges.

Investigations of long-term trends have also been carried out using rocket observations of electron densities in the lower ionosphere [32-33]. In both different analyses positive trends have been observed below about 87 km. Above this height both results differ with negative trends [33] and insignificant trends [32]. The significance level of these trends is however restricted due to the limited number of rocket experiments, the different observation sites available and the fact that the rocket observations are instantaneous measurements markedly influenced by the atmospheric short-term variability.

4. Discussion

Based on the experimental results presented in Section 3, two questions have to be discussed here concerning (a) the practical importance of ionospheric trends and (b) the scientific reasons of possible trends in the different parts of the ionosphere.

4.1 Practical Importance of Ionospheric Trends

Ionospheric HF propagation is mainly influenced by the behavior of the F2 layer characterized by their parameters foF2 and hmF2. As shown in Section 3.1 by investigation of different authors using different methods, the derived global trends of both parameters are very small. This finding fully agrees with other investigations [31] analyzing data series of more than 50 ionosonde stations with a duration of at least 30 years by different methods using $R12$ values as proxy of the solar activity. Therefore, in global ionospheric prediction models it is not necessary to include the effect of ionospheric long-term changes. The solar and geomagnetically induced variations are markedly more important.

At individual stations however the trends can be essentially more pronounced. This can be seen in the relative broad histograms of the foF2 and hmF2 trends in Figure 2. The trend values of the stations Sodankylä [6] and Tromsø [12,13] are essentially stronger than the mean global trends but are well inside the corresponding histograms in Figure 2. Unfortunately the reasons of the strong differences between the trends derived at individual stations are unknown at the current time. One reason for such differences between the trends at (partly neighboring) stations could be artificial steps in the data series caused by technical changes at the ionosonde equipment (installation of new ionosondes or antenna systems) and/or changes of the evaluation algorithms (differences between manually and automatically scaled data, manually controlled data should preferably be used in trend analyses). Some examples of such disturbances can be found in [27-28, 30]. Therefore, the quality of ionosonde data sets has carefully to be checked before trend analyses are carried out. As long as we do not have definite information as to the quality of the ionosonde data series we can only use mean or median values of all reasonable data sets, hoping that some errors of the derived individual trends may compensate each other.

Another point to be considered in trend analyses of ionosonde parameters is the use of ionospheric data with qualifying letters. Normally these values are included in trend analyses, assuming that the monthly median values are not systematically influenced by them. First attempts to use only hourly values without such qualifying letters have been made [22, 23], but until now no final conclusion can be given if the inclusion of data with qualifying letters will markedly bias the derived trend results.

4.2 Scientific Aspects of Ionospheric Trends

What are the reasons of trends in the different layers of the ionosphere? At least two mechanisms are often discussed: anthropogenic pollution (e.g. CO_2, CH_4, O_3, ...) and geomagnetic trends.

To investigate the influence of an increasing atmospheric greenhouse effect the trends in the ionospheric F2, F1, and E layers can be compared with model calculations [2-3]. These theoretical results have been derived for a doubling of the atmospheric greenhouse gases CO2 and CH4. The effective change of the greenhouse gases during the last 40 years where trends of the ionosonde data have mainly been investigated is about 20% [45-46]. Assuming a linear dependence between the content of the atmospheric greenhouse gases and the ionospheric effect, the experimental trends of Table 1 can be used to estimate the changes of the different ionospheric parameters due to a doubling of the greenhouse gases. These values called $CO_2 * 2(\exp)$ can now directly be compared with the corresponding model values $CO_2 * 2(\mathrm{mod})$ in Table 2.

4.2.1 F2 Layer

The agreement between the experimental and model trends in foF2 and hmF2 seems to be quite reasonable looking at the data in Table 2. However, the differences between the individual trends in foF2 as well as hmF2 at different stations are very strong, and the derived mean trends are not statistically significant different from zero as can be seen in Table 1. Therefore, the agreement between model and experimental data is accidental. The reason of the strong variability in the F2 layer is not quite clear. Following Figure 3 there seem to be regional differences which could be caused by dynamical effects in the plasma of the F2 layer. Such regional differences of the hmF2 trends have also earlier been detected by other authors using

	Parameter	Mean exp. Trend	$CO_2*2(exp)$	$CO_2*2(mod)$
F2 Region	foF2	–0.0018 MHz/year	–0.36 MHz	–0.2 ... –0.5 MHz
	hmF2	–0.009 km/year	–1.8 km	–10 ... –20 km
F1 Region	foF1	0.0027 MHz/year	0.54 MHz	0.3 ... 0.5 MHz
E Region	foE	0.0014 MHz/year	0.28 MHz	0.05 ... 0.08 MHz
	h'E	–0.040 km/year	–8.0 km	–2.5 km

Table 2. The mean experimental (exp) trends of different ionospheric parameters (from Table 1) and expected changes of these data assuming a doubling of the atmospheric greenhouse gases (CO_2*2). The model data (mod) are from [2, 3].

a more limited data volume [16, 18, 27]. The significance level of such differences has only partly been estimated until now. It could be shown [27] that the mean hmF2 trends derived from individual observations in the European part east of 30°E (mainly negative trends) and west of 30°E (mainly positive trends) are clearly significant different (>99%), a similar tendency has also been detected for foF2 trends but with a clearly smaller significance level (84%).

From satellite observations [47-48] it is known that the observed long-term neutral density reduction near 350 km altitude is in good agreement with model calculations of an increasing greenhouse effect [49]. That means that the possible greenhouse effect in ionospheric data series is superposed by unknown dynamical processes which are more important for the variability of the ionized component than for the neutral gas at F2-layer heights.

Long-term trends have been derived using differences of hmF2-h'F, which contain information about the plasma temperature of the lower part of the F2 layer [50]. For most of the investigated 20 European stations negative trends have been detected in qualitative agreement with an expected cooling of the atmosphere due to an increasing atmospheric greenhouse effect.

According to the geomagnetic control concept developed by Mikhailov et al. [19-21] the estimated trends in foF2 and hmF2 are explained by the remaining influence of small geomagnetic activity variations which cannot be eliminated by simple a regression analysis (see Equation (4)) using geomagnetic *Ap* values. Due to these investigations the derived trends depending on local time and latitude should be caused by long-term variations of geomagnetic activity.

With a revised method [24] this geomagnetic influence should be removed. The remaining relative trend in foF2 noon values for the station Slough with -2.2×10^{-4} year-1 can be converted to a mean trend of -0.0022 MHz/year if a mean foF2-value of 10 MHz is assumed. This trend value agrees well with the mean global trend for foF2 in Table 1 and is thus in reasonable agreement with the model value in Table 2. Therefore, this foF2 trend can be explained by an increasing greenhouse effect. However, an influence of the very long-lasting increase of the geomagnetic activity, as found in long-term variations of the geomagnetic *aa* index during the last century [51], on trends in foF2 should also lead to a negative foF2 trend due to the negative correlation between trends in geomagnetic activity and foF2 according to the geomagnetic control concept [19-21].

Another method to remove the geomagnetic influence on foF2 trends was developed by using only geomagnetically quiet hourly data in these analyses [22-23] The mean foF2 trend derived from four different stations at high latitudes is with -0.0035 MHz/year slightly stronger but not very different from the expectations according to the greenhouse effect (see Table 2).

Non-geomagnetic trends in foF2 have also been derived also by quite another method [25-26]. The estimated mean trends, derived from 23 different stations, are with -0.012 MHz/year (23 stations, measuring interval 1958-1995) or -0.0075 MHz/year (eight stations, 1948-1985) also negative but markedly stronger than the trends in Table 1. But such differences are not very surprising if we remember the strong variability between the trends detected at different stations and the fact that different authors used different stations in their analyses.

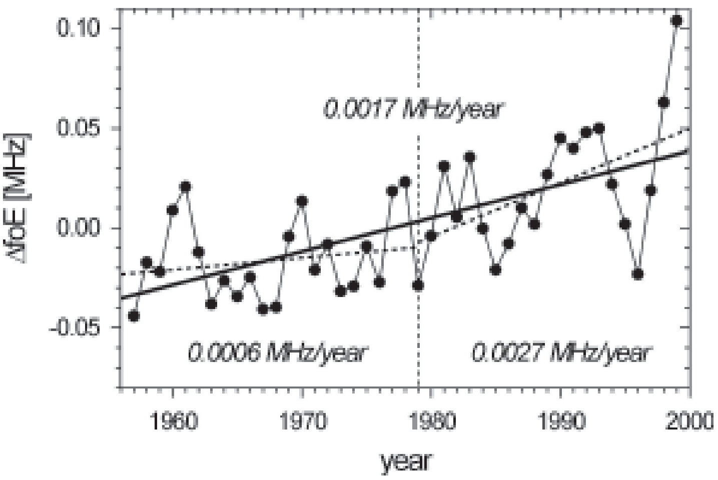

Figure 8. The mean long-term variation of foE derived from 72 individual ionosonde trends after elimination of the solar and geomagnetically induced parts. The full straight line represents the mean trend for the whole measuring interval, the dashed lines the corresponding trends before and after 1979.

4.2.2 F1 Layer

The agreement of the mean experimental trend in the F1 layer (described in Section 3.2, Table 1) with model trends in Table 2 is surprisingly very good. Therefore, the global foF1 trend can be explained by an increasing atmospheric greenhouse effect.

4.2.3 E Layer

As to be seen from Table 2, in the E layer the experimental and theoretical trend values agree qualitatively with a lowering of the height h'E and an increase of foE. However the experimental trends are markedly stronger than the model values. In Figure 8 the mean foE trend is shown. This trend was derived from all individual foE trends included in the histogram shown in the lower part of Figure 5. The mean trends in Table 1 and in Figure 8 differ slightly caused by the different methods of their estimation. More interesting, however, is the fact that the mean foE trend increases after about 1979. Whereas the trend before 1979 with 0.0006 MHz/year is relatively near the model prediction of an increasing greenhouse effect, after 1979 the observed foE increase is markedly stronger. The derived positive foE trend is in qualitative agreement with rocket mass spectrometer measurements of the ion density ratio $\left[NO^+\right]/\left[O_2^+\right]$ in the E-region [52]. The observed negative trends of $\left[NO^+\right]/\left[O_2^+\right]$ cause increasing electron densities and therefore increasing foE values as the dissociative recombination coefficient of NO^+ is markedly larger than that of O_2^+.

With a revised trend method [29] increasing foE values have also been found for years after about 1970. A quantitative comparison with the model trends in Table 2 is however impossible. Nevertheless it was proposed to explain this foE increase by an enhanced chemical pollution due to an increasing number of rocket launchings and/or an increasing atmospheric greenhouse effect.

4.2.4 D Layer

The shrinking of the lower ionosphere as derived from LF reflection height observations (Figure 6) can be explained by a cooling of the strato- and mesosphere as expected from an increasing atmospheric greenhouse effect [39]. The estimated amount of the atmospheric cooling depends however also on possible changes of the density of nitric oxide n_{NO} and of the effective recombination coefficient α_{eff} near the reflection height of about 82 km. Unfortunately there are no experimental data of long-term changes of these two quantities, however there exist model results which predict a decrease of n_{NO} [1, 53-54] and an increase of α_{eff} in the mesosphere [53-54]. A common interpretation of the trends of the LF reflection heights and of the absorption data at different frequencies (one example is shown in Figure 7) is only possible if the trends in n_{NO} and α_{eff} as predicted from model calculations are taken into consideration. The mesospheric temperature trends derived from the trends in LF reflection heights and ionospheric absorption data are in reasonable agreement with other experimental trends derived from long-term lidar and rocket measurements [39]. As shown by model results [34, 39] the experimental temperature trends can qualitatively be explained by an increasing atmospheric greenhouse effect. The experimental trends are however stronger than the model results.

We observe an increasing trend in different ionospheric parameters after about 1979 (phase heights: lower part of Figure 6, ionospheric absorption: Figure 7, foE: Figure 8). This increasing trend is not caused by changes of solar activity, probably it is connected with an increasing content of ozone or of other greenhouse gases in the atmosphere [55].

The positive trends of the electron densities from rocket observations [32-33] below about 87 km altitude agree qualitatively with trends of phase heights and ionospheric absorption. Some discrepancies exist, however, between negative trends [33] in electron densities above about 87 km compared with positive trends in MF and HF absorption data series [38, 40] and in foE (Figure 8). As remarked in Section 3.4 the reason of this discrepancy may be caused by the low significance level of the rocket measured electron density trends due to the limited data volume available.

5. Conclusions

Based on long-term observations of different characteristic ionospheric parameters trends have been estimated for the ionospheric F2, F1, E, and D layers, summarized by the following conclusions:

General aspects:

- The homogeneity of long-term ionospheric data series have to be carefully checked. Discontinuities caused by different technical changes can markedly disturb the results of trend analyses.
- The solar and geomagnetically induced variations of most ionospheric parameters are essentially stronger than the long-term trends and have carefully to be eliminated in trend analyses.

F2 layer:

- The mean global ionospheric trends are unimportant for practical applications of ionospheric prediction models. In such models the solar and geomagnetic variability are the most important external factors.
- Due to a large variability of the individual trends in the F2 layer no significant global trends could be derived for foF2 and hmF2. Therefore, the relatively reasonable

agreement between the mean global experimental and model results could be accidental. The regional differences of the trends hint at unknown dynamical processes which may superpose a possible greenhouse effect in the F2 layer.

- Using, however, differences hmF2-h'F a general cooling of the lower part of the F2 could be derived from the trend results in qualitative agreement with an increasing atmospheric greenhouse effect.
- The derived trends according to the geomagnetic control concept contain geomagnetically induced components causing typical local time and latitudinal trend variations.
- Different approaches to eliminate geomagnetic activity changes lead to negative foF2-trends as proposed by model results of an atmospheric greenhouse effect. The experimental trends are however partly stronger than the model predictions.

F1 layer:

- The mean global trend in the F1 layer (increase of foF1) agrees quite well with model results of an increasing greenhouse effect.

E region:

- The mean global trends in the E layer (lowering of h'E, increase of foE) are in qualitative agreement with rocket mass spectrometer observations and with model results of an increasing greenhouse effect. However, the experimental trends are stronger than the model values.
- The mean global foE trend increases after about 1979, probably caused by an increasing greenhouse effect. Investigations with a revised trend method lead to a foE increase even after about 1970.

D layer:

- The trends in the ionospheric D layer (lowering of reflection heights and different trends of ionospheric absorption in dependence on frequency) can qualitatively be explained by an increasing atmospheric greenhouse effect. The experimental trends are however stronger than expected from model results.
- The trends become stronger after about 1979, probably due to an increasing greenhouse effect.

Summarizing it can be stated that the investigation of ionospheric trends is an important task for the understanding of the structure and dynamics of the ionosphere in general and for the derivation of anthropogenic influences in particular. Different long-lasting ground based radio propagation experiments play an essential role in such investigations. Combined experimental trend analyses (including quality control of existing data series as well as introduction of additional data sets) and model activities are necessary for future trend analyses.

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Interaction of Wireless Communication Fields with Blood-Brain Barrier of Laboratory Animals

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Abstract

The blood-brain barrier is an anatomic and physiologic complex associated with the cerebral microvasculature. Anatomically, it consists of tight junctions between the endothelial cells of the blood capillaries, which is enveloped by a network of astrocytic foot processes. Many investigators have published studies on the effect of radio waves on the blood-brain barrier of animals, with varied results. Several reports during the past decade have observed leakages of endogenous serum albumin in blood, suggested that repeated exposure to microwave radiation from cellular mobile telephones could alter the permeability of the blood-brain barrier at SARs that are well below the maximal permissible level for mobile telephones. While an effort to confirm had failed at SARs of 0.3-1.5 W/kg, it had confirmed extravasation of serum albumin at 7.5 W/kg: a level about four times greater than the maximal permissible level for cellular mobile telephones. Currently, there are considerable interests from several laboratories around the world to replicate the reported occurrence of abnormal neurons in the rat brain – resulting from leakages of endogenous serum albumin – following low-level RF exposure. This review examines the methodologies and conditions under which BBB permeability changes have been reported to occur.

1. Introduction

The effect of radio-frequency (RF) electromagnetic fields on the central nervous system continue to occupy the focal spot of interest – in assessing the health impact of human exposure to RF radiation – from cellular mobile telephone operations. A series of reports from Sweden [1-3] on RF-induced blood-brain barrier (BBB) permeability changes at very low levels of exposure – well below 1.6 to 2.0 W/kg, the maximal permissible levels for cellular mobile telephones – have captured increasing attention. In addition, recent studies, using endothelial cell models of the BBB *in vitro* that suggest exposure to mobile phone microwave radiation at the permissible level could increase BBB permeability significantly compared to unexposed samples [4, 5], have raised further interests. However, it is noted that the results at low levels are still inconclusive and others have asserted that there is no association.

The first reports on the interaction of microwave radiation with the BBB system of experimental animals appeared in the early 1970s [7, 8]. Specifically, in 1973, Polyashchuk [7] observed that rabbits injected with ^{32}P and with their heads exposed to 50 W, 2.3 GHz microwave radiation for 10 or 20 min had two to three-fold increases in the ^{32}P uptake in some parts of the brain, compared to control. Two years later, Frey et al. [8] showed that a single exposure to 1.2 GHz microwaves for 30 min at average power densities of 24 W/m^2 for continuous wave (CW) or 2 W/m^2 for pulses resulted in significant fluorescence in the rat brain. Moreover, pulse microwaves produced significantly greater staining by sodium fluorescein than CW microwaves. Since then, many investigators have published studies on the effect of microwaves on the blood-brain barrier of animals, with varied results [9]. Studies showing – and not showing – a microwave-induced increase in BBB permeability changes have used both high and low levels of microwave exposure. Until recently, the general understanding had been that the observed effect of microwaves on the blood-brain barrier of animals was the result of microwave-induced brain temperature elevation. However, in recent years, the topic has become more controversial at low levels of energy absorption. In particular, a series of publications in the past ten years [1-3, 6] has reported leakages of endogenous serum albumin from blood into the brain. These results appear to indicate that repeated exposure to microwave radiation from cellular

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mobile telephones could alter the permeability of the blood-brain barrier at specific absorption rates (SARs) that are below the maximal permissible level for mobile phones.

This review examines the methodologies and conditions under which microwave induced BBB permeability changes have reported to occur. A particular emphasis is placed on RF fields associated cellular mobile telephony. It is noted that disruption of the BBB permeability in rats has also been reported by exposure to RF magnetic fields associated with magnetic resonance imaging at 1.5 Tesla (T), a field strength corresponding to a Larmor frequency of 64 MHz [10, 11]. The sections which follow will begin with a discussion on the basic anatomy and physiology of the blood-brain barrier.

2. The Blood-Brain Barrier

The term blood-brain barrier was first introduced about 100 years ago by Paul Ehrlich to account for the observation that Prussian blue dye injected into the blood circulation failed to stain brain tissues [12]. The earlier concept of a true barrier between blood and brain – and not an issue of dye affinity – was augmented when it was shown that trypan blue injected into the blood circulation stained virtually every body tissue but the brain. Furthermore, it was found that the same dye injected directly into the cerebrospinal fluid stained the brain [12].

The blood-brain barrier is an anatomic and physiologic complex associated with the cerebral microvasculature [13]. Anatomically, it consists of a tight junction between the endothelial cells of the blood capillaries, which is also enveloped by a network of astrocytic foot processes. However, the blood-brain barrier system is not found in some areas of the brain – including tissues close to the ventricles of the brain – where there is a lack of tight junctions. The blood-brain barrier separates the circulating blood in the capillary vessels from the brain cells. It is a natural defense system, which maintains the physiochemical environment of the brain within certain narrow limits that are essential for life. It functions as a differential filter that permits the selective passage of biological substances from blood to brain. Specifically, it regulates the passage of amino acids, glucose and other essential nutrients into brain cells, while carbohydrates and proteins are excluded from brain tissues by the BBB. It also allows the passage of carbon dioxide and metabolic waste products out of brain cells. The selective passage prohibits harmful toxins and most microorganisms from infiltrating the brain, and also excludes many drugs and therapeutic agents from reaching brain cells.

Unintentional opening of or change in the blood-brain barrier may subject the central nervous system to assault from extraneous microorganisms. Thus, questions have been raised concerning repeated exposures of the human brain to microwaves from cellular mobile telephones. If exposure to mobile-phone-like microwave radiation can alter BBB permeability, could potentially toxic molecules gain entry into, and accumulate around and in the brain cells?

3. Methods for Studying BBB Permeability Changes

Several laboratory-based investigational procedures have been employed to study the integrity of BBB in animals. They include (a) visual dye markers, such as Evans blue, sodium fluorescein, and rhodamine_ferritin; (b) radioactive tracer uptake; (c) electron microscopy and horse radish peroxidase (HRP); (d) endogenous albumin, and (e) delivery of therapeutic agents. Indeed, all five methods have been used to examine the influence of RF fields on the integrity of the blood-brain barrier.

One of the most commonly used visual markers, Evans blue dye, is normally excluded from the brain [1, 18, 20, 32, 34]. It tightly and completely binds with serum albumin, and it is very easy to use. Staining of brain tissue provides a clear indication of any dye-albumin penetration into the brain. However, like other visual dye markers, it is a qualitative method. While sodium fluorescein is also widely used, a considerable fraction of injected sodium fluorescein remains in the free form. Since it is invisible to the naked eye, it must be viewed with the aid of a fluorescent microscope [8, 24, 25, 29]. The observations can be affected more easily by sample contamination.

The uptake of radioactive tracers offers a quantitative analysis to assess breaching of the blood-brain barrier. One method uses an internal reference standard such as ^{3}H-H$_2$O, mixed with a radioactive substance [14, 26-28, 31, 33]. The BBB permeability is measured using a brain uptake index, i.e., the ratio of the fraction of tracer and standard radioactivities of brain to the fraction of tracer and standard radioactivities of blood. Another procedure relies on the determination of a blood-brain partition coefficient, i.e., the ratio of radioactivity of brain to radioactivity of blood [19].

The integrity of the blood-brain barrier to electron-dense horse radish peroxidase (HRP) can be observed by electron microscopy following HRP injection [15,16,30]. Anatomically, electron microscopy is more precise, and was responsible for demonstrating that the blood-brain barrier is located in the tight junctions of endothelial cells of brain capillaries. The canvassing of HRP distribution was used in several investigations of microwave-induced BBB permeability differences (see Tables 1 and 2).

Alterations in the partitioning of albumin between circulating blood and the brain can be measured to demonstrate BBB permeability change to serum albumin [1, 6, 22, 34]. Minute amounts of extravasated albumin – from the capillaries through the BBB into the brain tissue – can be detected immunohistochemically. This sensitive technique also allows for the determination of the exact constituents (neurons, glial cells, or the extracellular spaces) of the rat brain that accumulate the leaked albumin

As mentioned previously, many pharmacological agents are known to be blocked by the blood-brain barrier from entry into the brain [13]. Thus, biochemical techniques developed to assay drug delivery to the brain and the drug's ability to cross the blood-brain barrier can also be employed to evaluate BBB function. However, the exact assay methodology may be different for different pharmacological agents.

4. RF-Induced Disruption of BBB Permeability

Since the first study on the effect of microwave radiation on BBB of experimental animals, many investigators have reported on related studies with varied results. To date, there are more than 40 reported investigations on the effect of microwave radiation on BBB permeability. Studies showing microwave-induced increase in rat BBB permeability have used both high and low levels of microwave exposure to induce a permeability increase [1-8; 14-23]. It can be seen from Table 1 that the microwave frequencies investigated spanned the range used for cellular mobile telephones, 0.9 and 2.45 GHz, and the incident power density varied from 3 to 100 W/m^2. Most of these studies did not report local SARs inside the head, with the exception of the average brain SAR at 0.0016 and 7.5 W/kg, and local-peak-brain SAR of 240 W/kg, reported by Salford et al. [1, 2] and Persson et al. [3], Fritze et al. [22], and by Lin and Lin [18], Goldman et al. [19], and Lin et al. [23], respectively.

Other studies had difficulty in confirming the reported microwave-induced disruption of BBB [24-35]. A summary of these studies is given in Table 2. These studies have involved both continuous waves and pulsed mode of operation. The incident power density ranged from 300 to 750 W/m^2. The reported local SAR value inside the head varied from 0.1 to 80 W/kg. Also, the results were obtained using a variety of assays and exposure procedures to assess changes in BBB permeability. It is significant to note that the paper by Lin and Lin (25) was the first attempt to correlate SAR and BBB permeability changes.

Some of the apparent discrepancies might have stemmed from differences in microwave exposure protocol including SAR distributions, or from the lack of an assay of BBB permeability that combines sensitivity and specificity. Clearly, the highly complex physical and biological phenomena involved requires the development of new experimental, measuring, and assay procedures that were not always completely controlled in the early research projects. Accordingly, there were some noteworthy inconsistencies in the data summarized in Tables 1 and 2. For instance, those studies showing no BBB disruption have reported incident power densities as high as 300-750 W/m^2. However, those showing positive results involved peak incident power densities that were not as high (10 to 100 W/m^2). The relationship between incident power density and SAR was not defined in many cases. Also, the distribution and location of absorbed energy inside the brain were not given. Therefore, it is difficult to draw any conclusion on the basis of incident power density from these studies.

However, studies with reported SARs in the brain show a different picture. The studies indicating no disruption generally have used lower SARs, i.e., 1.5 W/kg average [22] or 80 W/kg local peaks [25]. Reports from the same laboratories, using the same experimental methodology, tended to show positive results if higher SARs were used, i.e., 7.5 W/kg in the rat head [22] or 240 W/kg local peaks [18, 19, 23]. The latter experiments had induced local brain temperatures to rise to 42-43°C. It has been shown that brain hyperthermia played a critical role [18, 35]. In particular, intravenous injection of ethanol prior to the microwave irradiation resulted in cooling of the brain - mitigating against an excessive temperature increase, which attenuated the observed changes in BBB permeability [20].

Authors	Frequency (GHz)	Exp. Time (min)	Peak IPD or SAR	CW/P Study Methods
Frey et al. 1975	1.2	30	24 W/m^2	CW/P Sodium fluorescein (SF)
Oscar and Hawkins 1977	1.3	20	3 W/m^2	CW/P Inulin or Mannitol
Sutton and Carroll 1979	2.45			CW HRP
Albert and Kerns 1981	2.45	2-hour	100 W/m^2	CW HRP
Lin and Lin 1982	2.45	20	240 W/kg*	PSF or Evans blue
Goldman et al. 1984	2.45	20	240 W/kg*	P ^{86}Rb
Neubauer et al 1990	2.45	20	100 W/m^2	P Rhodamine-ferritin
Salford et al. 1993, 94	0.9	2-hour	0.016 W/kg**	P/GSM Albumin or Evans blue
Persson et al. 1997	0.9	2-hour	0.016 W/kg**	GSM/P Albumin or Evans blue
Fritze et al. 1997	0.9	4-hour	7.5 W/kg***	GSM/P Albumin
Lin et al. 1998	2.45	20	240 W/kg*	CW Methotrexate

CW/P - Continuous wave or pulse; IPD – Incident power density; SAR – Specific absorption rate.
* Peak SAR in brain; ** Whole-body-average SAR including head; ***Average SAR in rat head.

Table 1. Results showing an RF-induced increase in BBB permeability

Authors	Frequency (GHz)	Exp. Time (min)	Peak IPD or SAR	CW/P Study Methods
Merritt et al. 1978	1.2	30	750 W/m^2	CW/P Sodium fluorescein
Preston et al. 1979	2.45	30	300 W/m^2	CW Mannitol
Lin and Lin 1980	2.45	20	80 W/kg*	P Sodium fluorescein/Evans blue
Gruenau et al. 1982	2.8	30	400 W/m^2	CW/P Sucrose
Ward et al. 1982	2.45	30	300 W/m^2	CW/P Inulin or sucrose
Williams et al. 1984 (a-d)	2.45	90	650 W/m^2	CW Sodium fluorescein, HRP, or sucrose
Ward and Ali 1985	1.7	30	0.1 W/kg**	CW/P Inulin or sucrose
Fritze et al 1997	0.9	4-hour	1.5 W/kg***	GSM Albumin
Tsurita et al. 2000	1.44	2-4 wk	2.0 W/kg***	TDMA Albumin/Evans blue

CW/P - Continuous wave or pulse; IPD – Incident power density; SAR – Specific absorption rate.
* Peak SAR in brain; ** Whole-body-average SAR including head; ***Average SAR in rat head.

Table 2. Studies that didn't show RF-induced BBB changes.

There had been a general consensus that BBB permeability changes are induced by microwave exposure if the SAR is sufficiently high so that the temperature of the brain was raised substantially. That was the situation until the series of reports from Sweden [1-3], which showed microwaves induced BBB permeability changes at nonthermal SAR levels that are at or below 1.6 W/kg: the maximal permissible level for cellular mobile telephones. Rats were exposed singly to microwave fields in a transverse-electromagnetic (TEM) exposure chamber at 900 MHz. It is noteworthy that these studies had employed a very sensitive, if not the most, sensitive immunohistochemical method. The technique is capable of detecting the extravasation of minute amounts of endogenous serum albumin from the capillaries through the BBB into the surrounding brain tissues.

A more recent publication from this group explored the question of whether leakage of albumin across the BBB might parallel damage to the neurons? They showed occurrences of "dark neurons" in the cortex, hippocampus, and basal ganglia in the rat brains [6]. The so-called "dark neurons" are abnormal neurons that appear as black and shrunken nerve cells, which were interpreted by the investigators as evidence for neuronal damage in microwave-exposed rats. In their experiment, rats were exposed for 2 hr to GSM cell-phone fields of various strengths. The reported SARs were 0.02 W/kg and 0.2 W/kg, for the occurrence of dark neurons in the animal's brain, up to 50 days following microwave exposure. Their results have generated questions about repeated exposures of the human brain to microwaves from cellular mobile telephones. Could the normally excluded albumin and other toxic molecules leak into and accumulate around and in the brain cells?

5. Discussion

A particularly vexing problem with the recent studies is that they have employed very sensitive assays and that increased barrier permeation appears to have been observed at or below the permissible SAR levels. In the case of the Swedish studies [1-3], they have reported observing the changes at an extremely low level (0.0016 W/kg). Since the SAR is 1000 times lower than that allowed for cell phones, if independently confirmed, these results could raise serious questions about prolonged and repeated exposures of the human brain to microwaves from cellular mobile telephones. Indeed, a limited confirmation of the Swedish studies, by a different group [22], has reported that while they had difficulty in confirming the Swedish findings at SARs below 1.5 W/kg, they were able to observe extravasation of albumin in rat brains when their head was exposed to an average SAR of 7.5 W/kg. This SAR is about four times the general range of SAR rules adopted by the International Commission on Nonionizing Radiation Protection (ICNIRP – 2 W/kg) and U.S. Federal Communications Commission (FCC –1.6 W/kg). Clearly, it is extremely important to resolve the discrepancy in SAR thresholds between the reported studies.

The health-related questions raised by the most recent report from Sweden, and the lack of independent efforts to confirm the Swedish studies, had prompted the European project COST 281 to convene a workshop between the blood-brain barrier experts and bioelectromagnetics experts, who had published on blood-brain barrier interactions, at Schloss Reisensburg in Germany. This scientific meeting, entitled "The Blood-Brain Barrier (BBB): Can It be Influenced by RF-Field Interactions?" was held in November 2003, and was organized through the cooperation of the German Research Association for Radio Applications (Forschungsgemeinschaft Funk, FGF e.V.).

At the Schloss Reisensburg workshop, nearly every group that was engaged in microwave-related blood-brain barrier research in the past 10 years was invited to give presentations on their research and findings, in addition to overviews on state-of-the-art techniques by invited experts in the field. The critical reviews and discussions included all relevant reports. Indeed, an important feature of the workshop was the gathering of the principal investigators under one roof to discuss their results and ask questions of each other, at length.

Perhaps to no ones surprise, there were considerable disagreements and speculations on the recent experimental results and interpretation. Concerns expressed included the specific strain of rats used in the experiments, size and age of the rats, exposure system and dosimetry, and potential confounding factors, such as restraint- and handling-induced stresses on the animals, as well as experimental protocols associated with exposure and termination of the animals and processing of tissue samples. Of course, there were issues of interpretation and relevance of the findings versus human health and safety of cell-phone use. If the results are true, is the degree of extravasation of blood albumin sufficient to be toxic to the brain, or under what conditions does the leakage reach the threshold concentration for brain damage?

A conspicuous and significant factor in the uncertainty is the paucity of attempts to replicate or confirm the reported albumin-leakage experiments. A decade following the first reports from the Swedish researchers, there were only two published attempts to confirm the well-known findings [22, 34]. Unless impeccable, unreplicated evidence or poorly replicated experimental evidence tends to be taken as defective. It is important to note that the two attempts were not replication studies. Instead, they were experiments designed to either confirm or refute the findings: the investigations had employed different experimental protocols and exposure systems. As mentioned previously [36, 37], a fundamental requirement for acceptance of scientific findings is repeatability and confirmation. Without a question, empirical observations can be flawed. Thus, only replicable observations of experimentally determined effects can serve as legitimate evidence for or against scientific claims.

Living organisms are famously complex. The responses of biological systems to wireless communication radiation can be variable. The behavior of biological systems can often be uncertain, even under similar circumstances of exposure. It is important that the same investigator replicate a given observation – which the Swedish researchers apparently have done. Indeed, most working scientists are reluctant to accept or reject scientific claims on the basis of unreplicable or poorly replicated experimental findings. Because a single, self-repeated study – however well conducted – seldom provides the definitive evidence for or against a biological response, several independently repeated or confirmed studies are needed to arrive at a statistically significant association, or at a convincing answer to the health effect question.

Significant amounts of albumin leakage can be visualized in brain slices as Evan blue dye staining, and very low level signals of extravasated albumin can be enhanced by immunohistochemical staining. Immunohistochemical staining of serum albumin was employed in the two subsequent attempts to assess cell-phone-radiation-induced blood-brain-barrier permeability changes. In an acute study, groups of individually-restrained rats were sham- or microwave-exposed, in a carousal exposure system, for four hours at average SARs ranging from 0.3 to 7.5 W/kg, using 900 MHz GSM fields [22]. The extravasation of serum albumin was assessed either at the end of exposure, or seven days later. A significant increase in serum albumin extravasation was observed only in the group exposed to the highest SAR, 7.5 W/kg, immediately after microwave exposure.

In the other study, immunostaining of serum albumin was used to investigate the effect of exposure to a 1439 MHz, time-division-multiple-access (TDMA) cell-phone field on the permeability of the blood-brain barrier in rats exposed for two or four weeks [34]. Rats were positioned in an exposure system similar to the one used by Fritze et al. [22], and had their heads arrayed, in a circle, near the antenna at the center of the exposure system. A peak SAR of 2 W/kg was measured in the rat brain, and the average SAR over the whole body was 0.25 W/kg. There were no significant changes in any of the groups of rats investigated. Results from Evans blue-dye injection were also negative.

Note that albumin extravasation was studied immunohistochemically in a paper by Finnie et al. [38]. In this study, instead of rats, mice were exposed to 900 MHz fields, modulated by GSM-type pulses in the far field, for 60 min/day and 5 day/wk for two years with whole body SARs of 0.25, 1, 2, or 4 W/kg. It was reported that albumin extravasation was minimal both in control and exposed groups. The authors had deemed the result insignificant as the numbers of venues with albumin extravasation were small.

A potentially beneficial outcome from the workshop at Schloss Reisensburg is a concerted effort to replicate the reported occurrences of abnormal neurons in rat brains. Specifically, at a joint meeting of the Bioelectromagnetics Society and the European BioElectromagnetics Association, held in Dublin, Ireland, three laboratories from France, Japan, and the United States, respectively, have announced initiation of laboratory experiments. It is noteworthy that the one from the US appears to be a continuation of an extensive replication effort which has been underway by the US Air Force Laboratory in San Antonio, Texas, since shortly after the Swedish studies were published. Some results from this effort, using the same exposure systems as the Swedish group, have been presented at the recent conference [39]. It is hoped that the results from the new studies from France and Japan, and the continuing US Air Force-sponsored in-house replication effort will speed the scientific process further along.

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XXVIIIth General Assembly

BUSINESS TRANSACTED BY COMMISSION B

Chair: Dr. Makoto Ando
Vice Chair: Dr. Lot Shafai

Commission B Business meetings were held by Dr. Makoto Ando (Chair) on the following three days:
Meeting 1: Monday, October 24th, 18:00-19:30h
Meeting 2: Wednesday, October 26th, 18:00-19:00h
Meeting 3: Friday, October 28th, 18:00-19:00h

The following issues were discussed and decided upon.

I. Triennial Activity 2002-2005

Dr. Ando reported on the:

- the Triennial Activity for 2002 – 2005. The report will be posted on the URSI website.
- the 2004 International Symposium on Electromagnetic Theory (EMTS 2004): a special section in Radio Science was published in Fall 2005.
- Preparations made for GA 2005
- the sponsorship of conferences related to Commission B.

II. Election of Vice-Chair

The voting was held for the incoming Commission B Vice-Chair 2005 – 2008. The successful candidate was K. Langenberg.

III. Terms of Reference

The Terms of Reference were reviewed and discussed. Two minor changes were accepted and approved by the Board (attached). It was agreed other recommendations for changes, suggested at the GA Business meeting, be refined and drafted by the Adhoc Group, (Staffan, Ando and Shafai) into a proposal for discussion at the next EMT symposium, and be proposed to the Board at the next GA.

New Terms of Reference

The interest of Commission B is fields and waves, encompassing theory, analysis, computation, experiments, validation and applications. Areas of emphasis are:
(a) Time-domain and frequency-domain phenomena;
(b) Scattering and diffraction;
(c) General propagation including waves in specialized media;
(d) Guided waves;
(e) Antennas and radiation;
(f) Inverse scattering and imaging.

The Commission fosters the creation, development, and refinement of analytical, numerical, and measurement techniques to understand these phenomena. It encourages innovation and seeks to apply interdisciplinary concepts and methods.

IV. Next General Assembly 2008

Paper submission was discussed and agreed upon, that a centralized electronic submission and review system be used. It was also agreed on that a one time submission of a paper (up to four pages), plus an abstract in the specified format, be used in the program.

Three proposals were placed by Commission B colleagues for holding GA 2008:

1. Gothenberg, Sweden
2. Chicago, USA
3. Istanbul, Turkey

It was agreed to support all three. The submission from Chicago, was selected by the Board, to hold XXIX GA on August 7–16, 2008.

V. *Preparation for the 2007 EMTS in Alexandria*

A brief presentation was made by Dr. El-Khamy chair of the Alexandria local organizing committee. The suggested dates were May 7–12, 2007. It was pointed out that, the timing may not be convenient for some countries, because of the university term. It was suggested to consider moving it one week later to May 14–17.

The conference will be chaired by Dr. L. Shafai, and assisted by the Commission B-Technical Advisory Board (B-TAB) and the International Advisory Group (IAG) consisting of Dr. El-Khamy LOC Chair, Dr. Y. Antar, Dr. M. Iskander, Dr. A. Kishk, Dr. A. Zaghloul, Dr. Abdel Razik Sebak, Dr. Atafll Sherbeni, Dr. Ozlem Kilic, Prof. E. Heyman, Prof. R. Ziolkowski, Prof. Y. Rahmat-Samii, Dr. R. Stone, and Dr. P. Uslenghi.

Two suggestions were made by the IAG to Dr. El-Khamy:

1. Security, that the local organizers consider some limited, special security arrangements to make visitors feel more comfortable.
2. Number of attendees be carefully re-estimated, by checking the statistics of previous conferences in Alexandria.

Dr. Ando reported on the schedule for EMTS, using the following time table from EMTS 2004 in Pisa.

- 1st Circular of EMTS 2004, July 2001
- 1st Call For Papers, July 2002
- URSI-GA, Maastricht, August 2002
- TPC formation, October 15, 2002
- Call For Papers draft, November 17, 2002
- Special Sessions & Convener, May 12, 2003
- Deadline for YSA application, November 1, 2003
- Deadline for 3-page summaries, November 15, 2003
- TPC meeting 2-days, January 9-10, 2004
- Notification to authors, January 15, 2004
- Pre-registration, March 15, 2004
- Plenary Session Speaker, February 20, 2004
- Final Program on website, April 20, 2004

VI. Discussion on future EMTS

Procedure for selecting the venue for 2010 EMT-S was decided, allowing for the voting after GA.

1) Preliminary Proposal for 2010 EMT-S Venue: 2005.06.05, GA-3 months.
2) Review by Adhoc Committee to select 2 or 3 proposals: 2005.06.30, GA-2 months.
3) Final Proposals (2 or 3) and ballot forms sent out: 2005.07.10, GA-1 month
4) Vote by Letter Ballot (Final Prop. Only): 2005.07.20 – 2005.09.10
5) Short Presentation at 2005 URSI GA: 2005.10.23-29
6) Minor revisions as per feed back from discussion at GA, GA + 2weeks.
7) Final Vote at GA Commission B Business meeting: 2005.10.23-29, GA + 1 month.
   1st (5 Nov. - 25 Nov.)
   2nd (27 Nov. - 17 Dec.)
8) Announcement to official members etc.: GA + 2 months

Advantages of the new procedure, is that the official members receive the following, useful information before voting.

1) The 2008 GA Venue.
2) The name of the Commission B Vice-Chair, who will serve as the Chair for 2010 EMTS.
3) Proposals would be improved by reflecting the comments made at the GA meeting.

Three presentations of the proposals to host the 2010 were made.

- Toulouse, France
- Hiroshima, Japan
- Berlin, Germany

VII. Technical Advisory Board

Commission B will continue with Technical Advisory Board (B-TAB). Paper statistics are as follows:

- 2005 GA Com B papers 244 (Oral 90 + Poster 129 + 25)
- 2002 GA Com B papers 252 (Oral 77 + Poster 175) / Total 1523(O782, P741)
- 1999 GA Com B papers 355 (Oral 111 + Poster 244) / Total 1704(O934, P770)
- 2004 EMTS papers 421/464
- 2001 EMTS papers 215/275
- 1998 EMTS papers 290/470

VIII. Inter-Commission Working Group (IWG) for Solar Power Satellites (SPS)

Guidelines for the production of the URSI Position Statement and White Papers were discussed.

Prof. Y. Rahmat-Samii will represent COM B in Solar Power Satellite Systems. Next White Paper possibly on “biological effects of electromagnetic fields ??”. SCT had an open meeting during the GA, and will continue as the ITU Liaison.

IX. URSI Publication

Commission B Editor for RRB and RSB 2005-2008 will be, Prof. K. Langenberg (incoming Vice-Chair)

X. Publication Committee Membership

Should include one young scientist, someone who will enhance the URSI visibility.

XI. Commemoration of scientific achievements

Prof. Uslenghi said a few words about Prof. Tiberio and his achievements.

Prof. Heyman said a few words about Prof. Felsen and his achievements.

XII. Other business

XII.1 EM-Prize Committees

2002-2005
C.E. Baum, C.M. Butler (Chair), K.J. Langenberg, T.B.A. Senior, and S. Ström
2005-2008
M. Ando, C.M. Butler, K.J. Langenberg, T.B.A. Senior, L. Shafai and S. Ström (Chair)

XII.2 2003 EM Prize

The 2003 Prize was announced on 15 September 2001 and entries were due on 15 January 2003. Only 2 applications were received, neither in accordance with the objective. Therfore, no prize was awarded (see June 2003 RSB)

XII.3 2004 Prize

The2004 Prize was announced on 15 September 2002 and entries were due on 15 January 2004. Six received. The paper by L. Klinkenbusch (Germany) was selected. The Prize was presented at a meeting in Germany.

XII.4 2005 Prize

The Prize was announced on 15 February 2004 (see March 2004 RSB)and entries were due on 15 January 2005; only one application was received.

XII.5 URSI Board of Officers

Election results for the URSI Board of Officers, Triennium 2005-2008

- President: Prof. F. Lefeuvre (France)
- Vice-Presidents:
  Prof. G. Brussaard (Netherlands)
  Prof. C. Butler (USA)
  Prof. M.T. Hallikainen (Finland)
  Prof. P.J. Wilkinson (Australia)
- Past President: Prof. K. Schlegel (Germany)
- Secretary General: Prof. P. Lagasse (Belgium)

BUSINESS TRANSACTED BY COMMISSION J

Chair: Professor Makoto Inoue (Japan)
Vice-chair: Professor Richard Schilizzi (Netherlands)

I. FIRST BUSINESS MEETING: 24 OCTOBER 2005

I.1 Election of Vice-Chair

Two candidates were nominated for the position of Vice-Chair, Professor Subramaniam Anathakrishnan of the National Centre for Radio Astrophysics in Pune, India, and Professor Thibaut Le Bertre of the CNRS in France. A vote was held amongst the Official Members which resulted in the election of Professor Ananthakrishnan. Professor Ananthakrishnan accepted the position of Vice-Chair of Commission J.

I.2 Discussion of Issues Arising from the Meeting of the Coordinating Committee for the General Assembly

The proposed guidelines for abstract and paper submission for future General Assemblies were discussed. Commission J members agreed that only one abstract should be requested that would serve for the selection of papers and for printing in the Program Book. Submitting a full paper should be optional.

I.3 URSI White Paper Policy and Solar Power Satellites

Following considerable discussion, Commission J members felt strongly that any URSI White Paper must be a balanced scientific exposition of the topic under consideration. The current draft White Paper on SPS was not felt to fulfill these criteria.

I.4 Budget

Professor Inoue reviewed the activities and budget expenditures of the previous triennium. It was noted that very few proposals had been received for URSI support for meetings, or for travel support for young scientists to the General Assembly. It was agreed that a more active policy should be followed for the next triennium.

I.5 Resolutions

Professor Inoue informed Commission members about the follow up to URSI Resolutions from GA2002 of interest to Commission J. He invited proposals for new Resolutions to be presented at this GA.

I.6 IUCAF

The Commission approved the nomination of Dr. Uday Shankar (Radio Research Institute, Bangalore, India) to succeed Dr Yashwant Gupta as one of the three URSI members on IUCAF. The Commission also approved extension of the terms of the other IUCAF members, Dr Tasso Tzioumis (ATNF, Australia) and Dr Wim van Driel (Paris Observatory), for the coming triennium.

It was noted that Commission G planned to nominate an IUCAF representative before the IUCAF meeting on 27 October.

II. SECOND BUSINESS MEETING: 26 October 2005

II.1 URSI White Paper on Solar Power Satellites

Professor Inoue distributed copies of the draft White Paper to members of the Commission. Further discussion of the draft White Paper was postponed until the Third Business Session.

II.2 SCT

Professor Inoue reported on URSI Council discussions on the future role of the SCT. It has been decided that the SCT will continue at a low level to promote cross-commission interaction. It will be disbanded at GA2008 if no activity has taken place.

II.3 IAU Working Group of the History of Radio Astronomy

Professor Govind Swarup described the activities of the IAU WG, and suggested that Commission J funds be used to partially support travel by Commission J representatives to WG meetings. The Commission strongly supports the work of the IAU WG, and authorized the Commission Chair to investigate whether travel support of this nature is within the remit of URSI. Professor Swarup is prepared to act as Commission J contact person for the IAU WG.

II.4 Commission J Resolutions

No Resolutions were proposed to be submitted by Commission J at this GA.

II.5 Editor for Radio Science Reviews

Nominations were called for the position of Editor for Radio Science Reviews. Professor Ray Norris (ATNF, Australia) was nominated and accepted the position. The following reviews were noted:

- "Fibre optics in radio astronomy" – McCool et al, in press
- "Advances in Radio Astrometry" – Fomalont and Kobeyashi, under revision
- "Calibration of High Frequency Telescopes" – to be commissioned

It was agreed that the Editor would obtain the approval of the Commission Chair and Vice-Chair before commissioning any further articles.

II.6 US Senior Review of Astronomy

Professor Don Backer informed Commission members of the background and mandate of the Senior Review panel established by the National Science Foundation to provide advice on US national facilities for astronomy.

II.7 Working Groups

Leap Second
Following a splinter meeting of the Leap Second WG, it was decided to discontinue the WG, since it is not of direct interest to URSI.
Global VLBI
The Commission decided to continue the WG for the next triennium.

II.8 Budget 2002-2005

Professor Inoue invited proposals for travel support for a small number of individual participants in this URSI GA, to be finalized at the Third Business Meeting.

III. THIRD BUSINESS MEETING: 28 October 2005

III.1 Report on the 27 October URSI Council Meeting

Professor Schilizzi reported the decisions of the Council meeting on the venue of the next GA, Chicago, and the election of the URSI President for the next triennium, Professor F. Lefeuvre. He also reported on the continuing Council discussions on the Solar Power Satellite System White Paper.

Following this report, Commission members discussed SPS at length. It was concluded that all statements in the White Paper and Appendices advocating SPS should be removed, and that considerable revision of the remainder of the material was required for this paper to reach the standard expected from URSI. The Commission Chair and Vice-Chair were mandated to make this position clear at the next Council Meeting.

III.2 General Assembly 2008

Possible topics for Commission J at the next General Assembly are:

1) Observatory Reports
2) Phased arrays in radio astronomy
3) Signal processing
4) Calibration and imaging techniques
5) Future large telescopes
6) RFI mitigation (together with Commission E
7) High Frequency radio astronomy
8) Cosmic Microwave Background
9) Virtual Observatories and Large Surveys
10) Radio astronomy in Space

A selection will be made at the appropriate time during the triennium after consultation with Commission members via email. In addition, splinter meetings for IUCAF, GVWG, and VSOP-2 need to be planned, as well as proposals for the Commission J Tutorial and a General Lecturer.

III.3 Budget 2002-2005

Travel support for three participants (Aaron Chippendale, Wei Wang, and Aaron Parsons) was approved.

Radio-Frequency Radiation Safety and Health

James C. Lin

Hypersensitivity to Mobile Phones and Subjective Symptoms

Several months ago, the summary of a Workshop on "Electromagnetic Hypersensitivity" was made available on the World Health Organization's EMF project Web site [1]. In addition to the World Health Organization, the meeting was cosponsored by the European Commission Coordinated Action EMF-NET, the European Cooperation in the Field of Scientific and Technical Research (COST 281), and the Ministry of Health of the Czech Republic. The report concluded that electromagnetic hypersensitivity is "characterized by a variety of nonspecific symptoms that differ from individual to individual. The symptoms are certainly real and can vary widely in their severity. For some individuals the symptoms can change their lifestyle." Moreover, it had suggested that there are also "some indications that these symptoms may be due to pre-existing psychiatric conditions as well as stress reactions as a result of worrying about believed electromagnetic health effects, rather than the electromagnetic exposure itself."

For more than a decade, the phenomenon of electromagnetic hypersensitivity has evoked debates among individuals in the general population, medical professionals, and research scientists [2-4]. Electromagnetic hypersensitivity, or EHS, consists of several nervous-system symptoms, such as headache and fatigue; skin symptoms, like facial irritations and rashes; as well as some other health-related problems. Electromagnetic hypersensitivity has been reported to be caused by exposure to electromagnetic fields emitted from power lines, household appliances, visual display units, cellular telephones, and cell-phone base stations. Exposure of the affected persons was generally below the recommended guidelines promulgated in internationally accepted standards. Coupled with the prominence of cell phones in everyday lives, the subjective symptoms have created a situation where electromagnetic hypersensitivity has attracted growing attention, as cell-phone operators encounter regulatory and public-interest constraints.

The prevalence of electromagnetic hypersensitivity associated with cell-phone use varies considerably with geographic location. The highest reported prevalence is found in northern Europe, although it has been reported elsewhere, as well [5-9]. The severity of reported symptoms varies greatly. In some cases, they are sufficiently severe to prevent the affected individual from carrying out normal life activities.

In the Roosli et al. survey [9], health questionnaires were distributed in Switzerland to people who reported symptoms of ill health that they ascribed to exposure to electromagnetic fields. Of the 429 questionnaires returned within one year, 394 persons reported some type of symptom. The average age of the responders was 51.0 years and 57% were female. They had a higher educational level and they were more likely to be married, compared to the general Swiss population. The survey found a mean of 2.7 different reported symptoms. The most common symptoms, in descending order, were sleep disorders (58%), headaches (41%), nervousness or distress (19%), fatigue (18%), and concentration difficulties (16%). These subjective symptoms most often were ascribed to exposure to cell-phone base stations (74%), followed by cell phones (36%), cordless phones (29%), and power lines (27%). However, the survey did not show a one-to-one correspondence between the reported symptoms and a specific source of exposure. It is worthy of note that two-thirds of the responders had taken some action to reduce their symptoms.

An epidemiological investigation, which included 6379 digital-system (GSM) users and 5613 analog-system (NMT 900) users in Sweden, and 2500 from each category in Norway, did not show any increased risk for symptoms for digital-system users compared to analog-system users [3]. However, the study observed a statistically significant lower risk for sensations of warmth on the ear for GSM users compared with NMT 900 users. The same trend was

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seen in Norway for sensations of warmth behind or around the ear, and in Sweden for headaches and fatigue. An interesting side finding indicated that the prevalence of many of the subjective symptoms increased with increasing calling time and number of calls per day.

In a follow-up study, 2402 subjects, who had used the GSM cell phones, were extrapolated from the above epidemiological study. The information on the prevalence of symptoms, calling time per day, and number of calls per day was correlated with measurements of the Specific Absorption Rate (SAR). The results suggested that SAR values greater than 0.5 W/kg may be an important factor for the prevalence of some of the symptoms, especially in combination with long calling times per day [10]. An understandable explanation for the prevalence of warmth behind/around or on the ear is the circuit-current-induced elevation in handset temperatures and any conductive heating that may result from it. However, other factors that distinguish the two systems – the scheme used for radio frequency (RF) emission, and various ergonomic factors – also may be responsible for these results.

A particularly vexing challenge in studying this phenomenon is that the symptoms reported by electromagnetically hypersensitive individuals, such as headache and fatigue, are common and nonspecific: they may have many causes. Electromagnetic hypersensitivity appears to be a real, and sometimes disabling, condition for the affected individual – whatever its cause may be.

Sensitivity of human beings to electromagnetic field exposure has been known ever since the discovery of electricity. Indeed, thresholds for perception have been incorporated into electrical safety codes worldwide. However, it is important to differentiate electromagnetic sensitivity from hypersensitivity. For example, electromagnetic sensitivity pertains to the ability to perceive electric or electromagnetic exposure, without health implications. In contrast, electromagnetic hypersensitivity describes exposure conditions that may lead to the development of health symptoms in some individuals.

There is evidence for the existence of subgroups of the general population with significantly higher sensitivity (hypersensitivity) to electromagnetic fields [11]. This study showed that the variation in perception threshold for electricity among the general population is significantly larger than the factor of two to three that had been estimated in the past. The perception thresholds for the most sensitive males and females were reported to be 18 and 15 times lower than their respective mean values. However, whether the increased sensitivity to low-frequency electromagnetic fields is transferable to RF electromagnetic fields from cell-phone operations remains to be investigated.

An approach typically used in laboratory investigations of hypersensitivity is the provocation study. To date, there have been two provocation-type studies: one involving normal subjects [12], and the other involving self-declared electromagnetically hypersensitive individuals [13].

In the first study, the influence of RF fields from digital cell phones (GSM 900) on subjective symptoms or sensations in healthy subjects were studied in single-blind experiments [12]. There were 24 males and 24 females in each of two experiments. The duration of the RF exposure was about 60 min in one and 30 min in the other. Each subject rated symptoms or sensations at the beginning of the experimental session, and at the end of both the RF exposure and the sham exposure conditions, which were sequenced but not randomized. The symptoms rated were headache, dizziness, fatigue, and sensations of warmth on the skin, among others. The results did not reveal any consistent differences between RF exposure and sham exposure conditions.

Investigators of the second study exposed electromagnetically hypersensitive individuals to RF electromagnetic fields similar to those that the hypersensitive individuals believed to be the cause of their symptoms, in an attempt to elicit the symptoms under controlled laboratory conditions [13]. The study consisted of 20 volunteers (seven males and 13 females) who considered themselves to be sensitive to cellular phones. It was conducted using a double-blind design. The RF exposure sources were analog (NMT 900) and digital phones (GSM 900 and 1800). The duration of the test sessions was 30 min, and three or four sessions were performed in random order for each subject during one day. The subjects were asked to report symptoms or sensations as soon as they were perceived. The investigators also tested whether these sensitive subjects were able to detect whether the phone was on or off by sensing the cell-phone RF fields. Throughout the provocation experiments, the subjects' blood pressure, heart beat, and breathing rates were monitored in 5 min intervals. The systolic blood pressure and heart rates were found to be significantly higher during sham conditions than during RF exposures. The higher values were deemed to be the result of nervousness of the subjects, since sham exposures took place at the beginning of each test session.

The most commonly reported symptoms were headache, pain and warmth in the head, and sensation on the face, among others. However, the number of reported symptoms was higher during sham exposure than during cell-phone RF exposure conditions. In addition, none of the test subjects could distinguish cell-phone RF exposure from sham exposure, although most of the subjects perceived a variety of adverse symptoms. The authors concluded that adverse subjective symptoms or sensations perceived by the test subjects were not produced by cellular phones.

Note that the term "idiopathic environmental intolerance (IEI) with attribution to electromagnetic fields (EMF)" was proposed at the Prague Workshop to replace electromagnetic hypersensitivity, since the latter may be construed to imply that a causal relationship has been established between the reported symptoms and EMF. The term idiopathic environmental intolerance is a descriptor without any implication of etiology, immunological sensitivity, or EMF susceptibility. It has the qualifications that: (1) It is an acquired disorder with multiple recurrent symptoms; (2) it is associated with diverse environmental factors tolerated by most people, and (3) it is not explained by any known medical, psychiatric, or psychological disorder. Idiopathic environmental intolerance incorporates a number of disorders sharing similar non-specific medically unexplained symptoms that adversely affect people and cause disruptions in their occupational, social, and personal functioning.

In summary, the published laboratory research, to date, on electromagnetic hypersensitivity and subjective symptoms from exposure to cell-phone RF fields is very limited. One study suffered from a single-blind design, and the exposure conditions were not randomized. The other was a carefully executed, double-blind study, with randomized exposures. The statistical strength was weakened by a small number of subjects in the study. Nevertheless, the evidence now available suggests that while the reported hypersensitivity and subjective symptoms may be real, the question of whether they are associated with cell-phone use must await more comprehensive studies.

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CONFERENCE REPORTS

2005 INTERNATIONAL SYMPOSIUM ON ANTENNAS AND PROPAGATION (ISAP 2005)

Seoul, Korea, 3 - 5 August 2005

The 2005 International Symposium on Antennas and Propagation (ISAP2005) was held at the Seoul KyoYuk MunHwa HoeKwan, Seoul, Korea during August 3-5, 2005. The ISAP2005 was the tenth symposium in the ISAP series and all the past ISAP symposia have been held in Japan. The ISAP2005 was an international forum for sharing the most up-to-date research and development information about antennas, wave propagation, electromagnetic wave theory, systems, and related topics.

This symposium was sponsored and organized by the Korea electromagnetic Engineering Society (KEES). This symposium was cosponsored by the Communications Society of the Institute of Electronics, Information and Communication Engineers (IEICE). This symposium was held under the technical co-sponsorship of the Antennas and Propagation Society of the Institute of Electrical and Electronics Engineers (IEEE/AP-S) and was held in cooperation with the Antennas and Propagation Professional Network of the Institution of Electrical Engineers (IEE), the Chinese Institute of Electronics (CIE), and the International Union of Radio Science (URSI). This symposium was financially supported by many Korean organizations.

This symposium covered a wide range of topics on antennas, propagation, electromagnetic wave theory, and wireless application systems. The technical sessions covered the following areas:

1) Antennas:
   Active and Integrated Antennas, Microstrip Antennas, Reflector and Lens Antennas, Antenna Measurements, Adaptive Array, Handset Antennas, Multi-Band and Wideband Antennas, Array Antennas, UWB Antennas, Small Antennas, Slot Antennas, RFID Antennas
2) Propagation:
   Mobile and Indoor Propagation, MIMO, Recent Advances of DOA Technologies, Propagation and Remote Sensing, Earth-Space and Terrestrial Propagation
3) Electromagnetic Wave Theory and Others:
   Time Domain Techniques, Computational Electromagnetics, Metamaterials and Applications, Inverse Problems, Scattering and Diffraction, Waveguide Structures, Periodic and Band-Gap Structures, Theoretical and Analytical Methods, EMC/EMI, Biological and Medical Applications, Millimeter Wave Technology, Terahertz Wave Technology

The technical program comprises two plenary sessions, nine special sessions, thirty-seven regular sessions, and one poster session. In total, 318 papers from 27 nations were presented in oral and poster sessions.

Two plenary talks were given by:

- Prof. Jean-Charles Bolomey, Paris XI University, France, *'Near Field Antenna Measurement Techniques: Current Status and Future Trends'.*
- Prof. Raj Mittra, Pennsylvania State University, USA, *'Computer-Aided Design of Antennas and Radomes Mounted on Complex Platforms and Performance Enhancement of Communication Antennas using Metamaterials.'*

The 2005 International Symposium on Antennas and Propagation (ISAP2005) was an important international forum for engineers and scientists in the Pacific Rim to exchange new technical information about antennas and radio wave propagation. Due to enthusiastic participation in the symposium, the ISAP2005 turned out to be a forum that was mutually beneficial. It is worth mentioning that many papers of antennas and propagation in wireless and mobile communications were presented and discussed during ISAP2005.

The exhibition was held on the Seoul KyoYuk MunHwa HoeKwan hall lobby and 11 participants were involved. The welcome reception was informally given on August 2 at the venue. The opening ceremony was held on August 3. The banquet was given on August 4 and best paper awards were given during the banquet. The closing ceremony was given on August 5.

Three best paper awards were given to honor the authors' distinguished scientific and technical achievements. The ISAP2005 best paper awardees were:

- Soon-Ho Hwang, Young-Jun Cho, and Seong-Ook Park, Korea, A Printed Multi-Band Antenna for 2.4/5GHZ WLAN and Satellite DMB Applications'.
- Tran Thi Huong, Takafumi Kai, Jiro Hirokawa,

Yoshinori Kogami, and Makoto Ando, Japan, *'Evaluation of Conductivity and Complex Permittivity of a Copper-Clad Dielectric Substrate by using a Whispering Gallery Mode Resonator'*.
- Kazuyuki Saito, Satoru Kikuchi, Masaharu Takahashi, and Koichi Ito, Japan, *'Numerical Calculation of Temperature Distribution around a Coaxial-Slot Antenna Aiming at Treatment of Brain Tumor'*.

On behalf of the Organizing Committee of ISAP2005, it is my great pleasure to report that the 2005 International Symposium on Antennas and Propagation (ISAP2005) was more than successful. I would like to thank all of paper presenters, participants, and participating organizations for their contributions.

The ISAP2006 (http://www.isap06.org) will be held in Singapore on November 1-4, 2006. The ISAP 2007 (http://www.isap07.org) is also planned for August 20-24, 2007 in Niigata, Japan.

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INTERNATIONAL SYMPOSIUM ON MICROWAVE AND OPTICAL TECHNOLOGY (ISMOT 2005)

Fukuoka, Japan, 22 - 25 August 2005

The 2005 International Symposium on Microwave and Optical Technology (ISMOT2005) was held at Fukuoka Institute of Technology in Fukuoka, Japan on August 22-25, 2005.

The symposium has started in 1986 as the International Symposium on Recent Advances in Microwave Technology (ISRAMT) and is being biennially held in USA, India, China, Ukraine, Spain, Canada, and Czech Republic. In accordance with the global technological trend, the scope of the ISRAMT was expanded and the name was renewed to the ISMOT in the 2001 symposium held in Montreal, Canada. The ISMOT is a unique conference in which professionals and young scholars working in both microwave and optical engineering can join together and exchange new ideas, thoughts, and most recent achievements on physics, applications, and technological development common in microwaves and optoelectronics. Since 1986, the ISMOT has contributed to creating the mutual interactions between microwave and optical technologies.

The ISMOT2005 was jointly hosted by Kyushu University, Fukuoka Institute of Technology, and University of Nevada, Reno, and was held in cooperation with the International Union of Radio Science (URSI), the Electronic Society of the Institute of Electronics, Information and Communication Engineers (IEICE), the IEEE MTT/LEOS Japan Chapters and Fukuoka Section, the IEEE Northern Nevada Section and MTT/LEOS Chapters, the Chinese Institute of Electronics (CIE), and the Institute of Electronics Engineers of Korea (IEEK).

Organizers

The Symposium Chair was Prof. Kiyotoshi Yasumoto, supported by the Organizing Committee (Chairpersons: Prof. Kazunori Uchida, Prof. Banmali Rawat, and Prof. Yasumitsu Miyazaki) and the International Advisory Committee (Chairperson: Prof. Banmali Rawat). The ISMOT2005 was financially assisted in part by the Inoue Foundation for Science, the International Communications Foundation, the Telecommunications Advancement Foundation, the Support Center for Advanced Telecommunications Technology Research Foundation, and the Fukuoka Convention and Visitors Bureau.

Conference Program and Highlights

Among the highlights of the symposium were the presentations in the plenary sessions. The speakers and their subjects were:

- Prof. Yahya Rahmat-Samii (University of California, Los Angeles, USA), "Metamaterials in Antenna Applications: Novel Electromagnetic Design Paradigms"
- Dr. Hiroyo Ogawa (National Institute of Information and Communication Technology, Japan), "Technology and Standardization of Millimeter-Wave Wireless Personal Area Network"
- Dr. Masashi Usami (KDDI R&D Laboratory Inc., Japan), "All Optical Devices and Signal Processing for All Photonic Network"
- Dr. Alaudin M. Bhanji (California Institute of Technology, USA), "Changes in Deep Space Network to Support the Mars Reconnaissance Orbiter"

The ISMOT2005 had 38 technical sessions in which the latest research and development in microwave and optical technology were discussed. There were 49 invited papers and 157 contributed papers presented, 169 of these being oral presentations and 37 posters. The subjects of the papers cover: Metamatials in Microwave and Photonics, Propagation and Scattering, Numerical Techniques, Integrated Optics, Fiber Optics, Nonlinear Optical Fibers, Photonic Bandgap Structures, Optical Devices, Optical Communications, Laser Technologies, Antennas, Microstrip Antennas, Wideband Antennas, Microwave Filters, MMICs, Microwave Resonators, Solid-State Devices, Microwave Power Dividers and Mixers, Microwave Materials, Microwave and Millimeter-Wave Components/ Systems, Measurements and Remote Sensing, and Communication Systems. The presentations were attractive, with a very interesting technical content on relevant topics of current interest.

A Symposium Digest including one-page abstracts of all papers and a CD-ROM Proceedings of four- page full papers were issued and distributed to participants at the symposium. The Online Proceedings was provided to the pre-registered participants through the ISMOT2005 webpage one month prior to the symposium.

Attendance

260 participants attended from 21 countries. Figure 1 shows details of ISMOT 2005 participation. Thanks to the financial contributions obtained from the assisting foundations, it was possible to support 20 participants including young scientists.

Workshop

The ISMOT 2005 workshop took place on August 22. Four lectures presented under the topic "Physics, Modeling, and Applications of Metamaterials" were:

- Application of Metamaterials for Microwave Resonators and Antennas, Prof. Ikuo Awai (Ryukoku University, Japan)
- One and Two Dimensional Metamaterials for Microwave and Their Applications, Prof. Yewen Zhang (Tongji University, China)
- Characterization, Design, and Synthesis of Metamaterials of Low Loss and Broad Bandwidth, Prof. Le-Wei Li (National University of Singapore)
- Genetic Algorithms (GA) and Particle Swarm Optimization (PSO) in Engineering Electromagnetics, Prof. Yahya Rahmat-Samii (University of California, Los Angeles, USA).

Next Symposium

The symposium, which was 10th ISMOT, was very successful. The Meeting of International Advisory Committee was held on August 23 and discussed the issue on next meeting. It was decided that the next ISMOT would be held in Brest, France in 2007. This decision was announced by the ISMOT 2007 Chairperson, Prof. Jean Le Bihan, at the Banquet on the evening of August 24.

Prof. K. Yasumoto
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Country	Papers	Participants
Canada	4	3
China	17	21
Czech Republic	5	5
France	2	4
Georgia	1	1
Greece	1	2
India	11	9
Iran	1	1
Israel	1	1
Japan	84	116
Korea	23	41
Russia	1	3
Saudi Arabia	0	1
Singapore	4	4
Spain	2	2
Sweden	1	1
Switzerland	1	1
Taiwan	23	28
UK	3	2
Ukraine	3	4
USA	10	10
Total	**198**	**260**

Table 1: ISMOT 2005 participation

WORKSHOP ON MICROWAVES, RADAR & REMOTE SENSING (MRRS 2005)

Kiev, Ukraine, 19 - 21 September 2005

The Workshop "Microwaves, Radar & Remote Sensing" (MRRS 2005) was held on 19 – 21 September 2005 as a part of the World Congress "Aviation in 21th Century", which was organized under the General Chairmanship of Professor Vitaliy Babak, the Rector of the National Aviation University, Kiev, Ukraine.

The purpose of MRRS 2005 Workshop was to discuss the research results in the field between the Ukrainian and the Western scientists, and more broadly between scientists from the former USSR and from the rest of the World. Ukraine really has extremely strong electromagnetic, microwave and radar community. Unfortunately, at present, majority of Ukrainian scientists still cannot attend International conferences in Western Europe, USA and other places outside Ukraine. That is why this Workshop held in Kiev city gave a good chance to gather together representatives of Ukrainian scientific community including young scientists and a strong team of both internationally known and young scientists from different countries.

Dr. Felix Yanovsky, Professor of the Aero-navigation Systems Department, Institute of Information and Diagnostic Systems, National Aviation University was the Chairman of the Workshop “MRRS 2005”. Except the National Aviation University, the organizers of workshop were IEEE East and Central Ukraine Joint Chapters. The Workshop was technically sponsored by the European Microwave Association (EuMA) and IEEE Geoscience and Remote Sensing Society (IEEE GRS-S). The International Union of Radio Science (URSI) actively supported the workshop, particularly, URSI Commission C: Radio-Communication Systems and Signal Processing gave financial support, and URSI Commissions E (Electromagnetic Noise and Interference), F (Wave Propagation and Remote Sensing), and J (Radio Astronomy) gave moral support.

After the Opening Ceremony and Plenary Session of the World Congress “Safety of Aviation” that was held in the beautiful Assembly Hall, the lunch was arranged. The Opening of the International Workshop on Microwaves, Radar and Remote Sensing (MRRS 2005) was on September 19 at 14:00. The working language at MRRS-2005 was English. Some details about the Workshop can be found at the website <www.congress.org.ua/mrrs>.

The scientific Program of MRRS 2005 comprised 12 sessions held in 2 parallel streams and included 63 accepted papers from 18 countries. Nearly 100 attendees were registered. Number of presented papers was 56, number of no-shows (on different reasons) was 7. During three days the following sessions were conducted (Fig. 1):

- SESSION A1 – Radar Theory and Systems, Chairman – Prof. Felix Yanovsky, Ukraine
- SESSION B1 – Antenna Theory and Engineering, Chairman – Prof. Roberto Sorrentino, Italy
- SESSION A2 – Radar Systems and Technology, Chairman – Prof. Hermann Rohling, Germany
- SESSION B2 – Space and Air Radio-Electronic Systems, Chairman – Prof. Vladimir Schejbal, Czech Republic
- SESSION A3 – Remote sensing of atmosphere I, Chairman – Prof. Herman Russchenberg, The Netherlands
- SESSION B3 – UWB signals and through obstacles detection, Chairman – Prof. N.T.Cherpak, Ukraine
- SESSION A4 – Remote Sensing of the Earth, Chairman – Prof. Dusan Zrnic, USA
- SESSION B4 – Passive and Semi-Active Systems, Chairman – Dr. Guy Vandenbosch, Belgium
- SESSION A5 – Remote sensing of atmosphere II, Chairman – Dr. Yahya Khraisat, Jordan
- SESSION B5 – Microwave elements and devices, Chairman – Dr. R. Sauleau, France
- SESSION A6 – Radar Signal Processing, Chairman – Dr. A. Andrenko, Japan
- SESSION B6 – Measurements, Analysis and Optimization in Microwaves, Chairman – Prof. Yu. Poplavko, Ukraine

During the conference 10 invited speakers, some of the world’s leading experts presented their distinguished lectures. They were Prof. D.S. Zrnic (NSSL, NOAA, USA), Prof. H. Rohling (TUHH, Hamburg, Germany), Prof. H.W.J. Russchenberg (TU-Delft, The Netherlands), Dr. A. Andrenko (Fujitsu Laboratories LTD, Japan), Prof. R. Sorrentino (University of Perugia, Italy), Prof. G. Vandenbosch (Leuven Catholic University, Belgium), Dr. R. Sauleau (Université de Rennes, France), Prof. D.I. Vavriv (Institute of Radio Astronomy, Kharkiv, Ukraine), Prof. Y.M. Poplavko (KPI, Kiev, Ukraine), Prof. N.T. Cherpak (Institute of Radiophysics and Electronics, Kharkiv, Ukraine).

Fig. 1. A session of MRRS 2005.

The geography of presented papers is illustrated in the diagram (Fig. 2). The joint papers reflected the works done by scientists from Ukraine together with Netherlands, UK, France, Germany, USA, and Jordan.

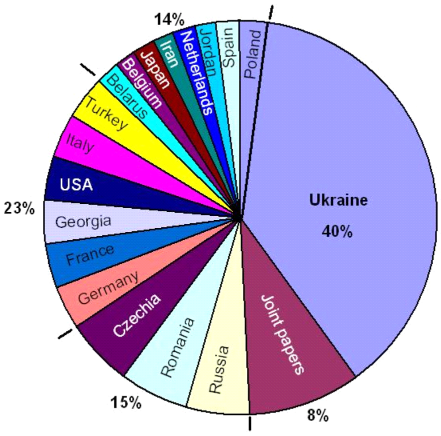

Fig. 2. The Geography of the paper presented at MRRS 2005.

Participants and attendees consider that scientific program was really interesting. In particular:

1) Papers on remote sensing of the atmosphere provided a state-of-the-art analysis of new Doppler-Polarimetric approach to extract reliable weather information. Another direction concerned the challenging approach to future

multifunctional phased array radar for air traffic control and providing comprehensive weather data.

2) Papers on remote sensing of the Earth considered current researches on polarimetry and high resolution radar imaging. Radar observations of snow cover from space-borne carriers over Russia, Ukraine and Iran were discussed.
3) Last achievements in radar theory and technology were considered, low cost airborne SAR was demonstrated, and important results on automotive radar network were presented, as well as new ideas in signal processing were discussed.
4) Interesting results also concerned: new antenna developments, optimization and applications in EU, Japan and Ukraine; UWB signals and through obstacle detection; new source of femto-second wave packages; passive and semi-passive systems applications.

The MRRS 2005 Proceedings is a book of 350 pages with rather good polygraphic quality, ISBN 966-8550-28-5. It was published in time and participants got it at the conference.

Participation of ten scientists from Ukraine and other countries were supported by the organizing committee from the funds given by URSI Commission C.

Kiev is the important scientific an academic center of Ukraine. It has at least 35 Universities and large scientific community. Presidium of the National Academy of Sciences of Ukraine (NASU) and majority of NASU research institutes are situated in Kiev. The National Taras Shevchenko University of Kiev (founded in 1834) has now more than 30 000 students. The National Technical University "KPI" (1898) today counts 41700 students. It is the biggest University in Ukraine. The National Aviation University (NAU), host of the Conference was founded on the basis of aviation faculty of "KPI" in 1933. About 35 000 students study in NAU today. Today the University has all necessary conditions and experience to conduct successful conference events.

Fig. 3. Welcome party

Fig. 4. Professors H. Russchenberg (TU-Delft, The Netherlands) and D. Zrnic (NOAA, USA) with Ph.D. Students from NAU (Ukraine), MRRS presenting authors

The place of the conference met the participants with quite comfortable and pleasant environment and nice weather during the whole event. The city is located at the both banks of the Dnieper-river. Kiev counts its history from the 6th century. Now its steady population is about 3 million. Kiev has innumerable architectural, historical and culture treasures. Some of them survive intact from the 11th century, for instance, interiors of St. Sophia Cathedral. It is the oldest survived church in Eastern Europe that was built in 1037 by Prince Yaroslav the Wise. It is a national shrine and is under the patronage of UNESCO.

Another sight of universal importance is Kiev-Pechersk Laura, the orthodox monastery, which was founded in 1051 in caves close to Kiev. In the 11th century the monastery became a centre of expansion and consolidation of Christianity and chronicle writing in Kiev Rus. Defensive walls were built around Laura at the end of the 12th century. Laura is burial-place of several outstanding historical persons as Kiev Prince Yuriy Dolgorukiy, founder of Moscow, and legendary hero Ilya Muromets. The Laura architectural complex consists of more than 80 buildings. During the last several years the face of Kiev was significantly renewed, many old buildings and streets were repaired and restored, and a lot of new objects for tourists were created.

The excursion for Interested MRRS-2005 participants was arranged to visit some important sights of Kiev.

Finally, the Conference Dinner was arranged in the University restaurant for all participants of the Congress "Aviation in 21th Century", and for interested participants of MRRS 2005 the banquet was arranged in historical part of Kiev with a night walk after that.

Generally, I consider the Workshop MRRS 2005 as very successful. Next MRRS is planned to be held in September 2007 at the National Aviation University in Kiev, Ukraine.

Professor Dr. Nickolay Cherpak
cherpak@ire.kharkov.ua

CONFERENCE ANNOUNCEMENT

11TH WORKSHOP ON THE PHYSICS OF DUTY PLASMAS

Williamsburg, Virginia ,USA, 28 June - 1 July 2006

We are pleased to invite you to the 11th Workshop on the Physics of Dusty Plasmas. This meeting, sponsored by the Naval Research Laboratory and Virginia Tech University, will be held in Williamsburg, Virginia from Wednesday, June 28 - Saturday, July 1, 2006. Local assistance for this meeting is provided by the Virginia Tech University.

Lodging and all meeting activities will take place at the Woodlands Hotel and Suites near historic Colonial Williamsburg.

Topics

Meeting activities will begin with an opening reception on the evening of Wednesday, June 28, 2006. This will be followed by two and one-half days of workshop sessions which includes a mixture of oral and poster presentations with many opportunities for discussions.

As in past meetings of this workshop series, the scope of this meeting covers the entire range of dusty plasma physics phenomena, including, but not limited to:
* basic and applied science topics
* laboratory experiments
* space observations
* theory and simulations
* microgravity experiments

It is planned that the proceedings will be published in a Special Issue of the IEEE Transactions on Plasma Science. For further conference details, please see the workshop web page at http://www.conted.vt.edu/dustyplasma/.

Contact

For general correspondence regarding the workshop, please contact Bill Amatucci (bill.amatucci@nrl.navy.mil) or Wayne Scales (wscales@vt.edu).

URSI CONFERENCE CALENDAR

May 2006

ISSTT 2006 - International Symposium on Space Technologies
Paris, France, 10-12 May 2006
Contact : Chantal Levivier, ISSTT 2006, Observatoire de Paris, 61, avenue de ‘lObservatoire, F-75 014 Paris, France, E-mail : isstt2006@mesiog.obspm.fr, Web : http://wwwusr.obspm.fr/gemo/ISSTT06/Accueil/PageAccueil.html

EUSAR 2006 - 6th European Conference on Synthetic Aperture Radar
Dresden, Germany, 16-18 May 2006
Contact : VDE CONFERENCE SERVICES, Stresemannallee 15, D-60596 Frankfurt am Main, Germany, Tel. : +49 69-63 08-275 / 229, Fax: +49 69-96 31 52 13, E-mail : vde-conferences@vde.com , Web : http://www.eusar.de

June 2006

11th Workshop on the Physics of Dusty Pasmas
Williamsburg, Virginia, USA, 28 June - 1 July 2006
Contact: Dr. William E. Amatucci, Plasma Physics Division, Code 6755, Naval Research Laboratory, Washington, DC 20375, USA, Fax: +1 (202) 767-3553, E-mail: bill.amatucci@nrl.navy.mil, Web: http://www.conted.vt.edu/dustyplasma/

July 2006

36th COSPAR Scientific Assembly
Beijing, China, 16-23 July 2006
cf. announcement in the Radio Science Bulletin of June 2005 p. 85
Contact : COSPAR Secretariat, 51, bd. de Montmorency, F-75016 Paris, France, Tel : +33-1-45250679, Fax : +33-1-40509827, E-mail : cospar@cosparhq.org
Web : http://meetings.copernicus.org/cospar2006/

IRST2006 - Ionospheric Radio Systems and Techniques Conference
London, United Kingdom, 18-21 July 2006
cf. announcement in the Radio Science Bulletin of June 2005 p. 85
Contact : IRST 2006 ORGANISER, The IEE, Event Services, Michael Faraday House, Six Hills Way, Stevenage, Hertfordshire SG1 2AY, United Kingdom, Tel : +44 1438 765647, Fax : +44 1483 765659, E-mail: eventsa2@iee.org.uk, Web : http://conferences.iee.org/IRST2006/

September 2006

Vertical Coupling in the Atmospheric/Ionospheric System
Varna, Bulgaria, 18-22 September 2006
Contact : Dr. Dora Pancheva, Centre for Space, Atmospheric & Oceanic Science, Dept. of Electronic and Electrical Engineering, University of Bath, Bath BA2 7AY, United Kingdom, Fax : +44 1225-386305, E-mail : eesdvp@bath.ac.uk, Web : http://www.iaga.geophys.bas.bg/

ISROSES - International Symposium on Recent Obsrvations and Simulations of the Sun-Earth System
Varna, Bulgaria, 17-22 September 2006
Contact : E-mail : isroses2006@abv.bg, Web : http://www.isroses.org/

October 2006

IRI Workshop 2006
Buenos Aires, Argentina, 16-20 October 2006
Contact : Marta Mosert, Av. Espana 1512 (sur), Capital, CP 5400, Ciudad de San Juan, Argentina, Fax +54 2644213653, mmosert@casleo.gov.ar

November 2006

EuCAP 2006 - European Conference on Antennas and Propagation
Nice, France, 6-10 November 2006
Contact : EuCAP 2006 Secretariat, ESA Conference Bureau, Postbus 299, NL-2200 AG Noordwijk, The Netherlands, Tel. : +31 71 565 5005, Fax : +31 71 565 5658, E-mail : eucap2006@esa.int, Web : www.eucap2006.org and http://www.congrex.nl/06a08/

December 2006

APMC 2006 - 2006 Asia-Pacific Microwave Conference
Yokohama, Japan, 12-15 December 2006
cf. announcement in the Radio Science Bulletin of September 2005 p. 44
Contact : Dr. Takashi Ohira, 2-2-2 Hikaridai, Keihanna Science City, Kyoto 619-0288, Japan, Fax : +81 774-95 1508, E-mail:ohira@atr.jp, Web : http://www.apmc2006.org

August 2007

ISAP 2007 - International Symposium on Antennas and Propagation
Niigata, Japan, 20-24 August 2007
Contact : Yoshihiko Konishi (Publicity Chair), Mitsubishi Electric Corporation, 5-1-1 Ofuna, Kamakura, 247-8501 Japan, E-mail : isap-2007@mail.ieice.org, Web : http://www.isap07.org

AP-RASC 2007 - Asia-Pacific Radio Science Conference
Perth, Western Australia, August or September 2007 (exact date not fixed yet)
Contact : Dr. Phil Wilkinson, Deputy Director IPS Radio and Space Services, Department of Industry, Tourism and Resources, P O Box 1386, Haymarket, NSW 1240, AUSTRALIA, Tel : +61 2 9213 8003, Fax : +61 2 9213 8060, E-mail: phil@ips.gov.au, Web : http://www.ap-rasc07.org/

August 2008

URSI GA08 - XXIXth URSI General Assembly
Chicago, IL, USA, 9-16 August 2008
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