The Radio Science Bulletin

ISSN 1024-4530

INTERNATIONAL
UNION OF
RADIO SCIENCE

UNION
RADIO-SCIENTIFIQUE
INTERNATIONALE

No 314
September 2005

Publié avec l'aide financière de l'ICSU
URSI, c/o Ghent University (INTEC)
St.-Pietersnieuwstraat 41, B-9000 Gent (Belgium)

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Front cover: The new URSI Board of Officers: from left to right: P.H. Wilkinson, C.M. Butler, F. Lefeuvre (President), K. Schlegel, G. Brussaard, P. Lagasse, C.M. Hallikainen. This picture was taken after the new Board Meeting at the end of the XXVIIIth General Assembly in New Delhi, India.

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Editorial

We have three *Reviews of Radio Science* in this issue of the *Radio Science Bulletin*, along with the reports from the business meetings at the New Delhi General Assembly of several of the URSI Commissions.

In a *Review* from Commission G, Norbert Jakowski provides a very interesting review of the use of radio occultation techniques for probing the ionosphere. These make use of the L-band signals broadcast by the various global navigation satellite systems, such as GPS. A receiver on a low-Earth-orbiting satellite is used to measure the phase of the signals from the navigation satellites in geosynchronous orbit. As the Earth moves across the propagation path between the navigation satellite and the observation satellite, the dispersive ionosphere introduces different phase changes into signals at two different frequencies from the navigation satellite. Measurements of these phase differences, plus precise knowledge of the positions of the satellites, allows reconstruction of the total electron content of the ionosphere. By recording the phase differences as a function of the changing geometry and using tomographic techniques, more-detailed information about the spatial distribution of ionospheric electron density can be obtained. The theory of reconstructing the electron density from the data is explained, and illustrated with examples of the types of reconstructions possible.

Paul Cannon's efforts in brining us this *Review* are gratefully acknowledged.

B. Lembège, P. L. Pritchett, M. V. Goldman, and D. L. Newman provide an extensive review from Commission H on kinetic and nonlinear processes in space plasmas. The emphasis of this review is on the synergy among theory, computer simulations, and observations, and the new insights that have recently resulted. Three major topics are considered. The first is collisionless shocks, which are quite common in space plasmas. These occur when plasmas moving at supersonic speeds collide either with each other or with an obstacle, such as a planetary magnetosphere. There are a variety of very interesting, recently-identified mechanisms associated with such shocks, including ways particles can be accelerated to very high speeds by shocks. The second topic is collisionless magnetic reconnection. This is the mechanism whereby energy stored in a magnetic field under stress is converted into high-speed plasma flow. There are a variety of possible mechanisms for this. Much of the recent insight into these has come from studies that moved beyond previous two-dimensional geometries to consider full three-dimensional simulations. The third topic is nonlinear kinetic waves and structures in space plasmas, such as phase-space holes and double layers. Only recently has it been established that such effects occur naturally in space plasmas. Recent spacecraft measurements and advances in simulations have enabled a better understanding of such structures and effects.

Richard Horne's efforts in bringing us this *Review* are much appreciated.

Is a statistically significant increase in the occurrence of brain tumors associated with long-term cell-phone use? The Interphone study is a major international collaboration designed, in part, to answer this question. Anders Ahlbom, Maria Feychting, and Stefan Lönn provide a first look at some of the data from this study. You need to read this Commission K *Review* carefully: there is a lot of data involved, and there are important subtleties to its interpretation. However, the authors conclude that the strongest support for a "Yes" answer to the above question is in their own acoustic neuroma study. It did, indeed, show a statistically significant increase (almost double that for regular use of mobile phones) in the relative risk of such tumors for those who had used mobile phones for at least ten years. Furthermore, when restricted to the side of the head on which the phone is normally held, the risk for those who had more than 10 years of use was increased by almost a factor of four. There are other possible explanations for these results, and the study needs to be supported by other research. This review is very interesting reading not only because of the potential results, but because of the careful look the authors take at what factors need to be considered in interpreting such data.

Frank Prato's efforts in bringing us this Commission K *Review* are gratefully acknowledged.

As always, Phil Wilkinson is the person responsible for overall coordination of the *Reviews*, and his efforts are very much appreciated.

I will keep my comments brief this time. I hope the new year is turning out well for you, and in particular, brining you new and interesting radio science results. Please consider sharing them with the radio science community through the pages of this *Bulletin*.

W. Ross Stone

Radio Occultation Techniques for Probing the Ionosphere

N. Jakowski

Abstract

The availability of L-band radio signals permanently transmitted by a fleet of satellites belonging to Global Navigation Satellite Systems (GNSS) such as the Global Positioning System (GPS) has opened a new dimension for ionosphere sounding. Whereas ground-based measurements of propagation effects, such as travel time delays and phase changes, have been well established since the mid-nineties, space based GNSS measurements onboard Low Earth Orbiting (LEO) satellites are rather new.

Immediately after the proof-of-concept GPS/MET experiment on Microlab-1, flown within the years 1995 - 1997, has demonstrated the huge potential of the limb sounding technique on LEO satellites for atmosphere/ionosphere sounding, the development of improved inversion techniques, assimilation methods and powerful processing systems made a big progress in recent years.

The radio occultation technique provides a rather simple and inexpensive tool for a global profiling of the entire vertical electron density structure from satellite orbit heights down to the bottom of the ionosphere, not achieved so far by any other technique. The reception of multi-satellite navigation signals, affected on their travel through the ionosphere, provides integral key information on the ionospheric state. Modern inversion and data assimilation methods allow a reliable reconstruction of the electron density structure if the amount of data is sufficient. Extensive information provided by current and future satellite missions with GNSS receiver onboard enables permanent monitoring of the Earth's co-rotating plasma environment in near-real time.

The obtained global data sets contribute to a comprehensive understanding of solar-terrestrial relationships, and are valuable for developing and improving global ionospheric models and provide operational space weather information. Consequently, accuracy and reliability of space based Communication/Navigation radio systems will take benefit from this knowledge.

1. Introduction

The radio occultation technique enables the retrieval of the vertical refractivity profile of a planetary atmosphere traveled by an electromagnetic wave in the limb sounding geometry. Measured is the change of ray path bending, phase or signal strength of the radio wave while approaching the planetary surface until it is completely occulted by the planet [1]. Thus, planetary atmospheres from Mars and Venus were explored by radio communication link occultations of sondes Mariner IV [2] and Venera 4, respectively. VIKING and Voyager 1 tracking and telemetry signal occultations were used to explore the ionospheres of Mars [3] and Titan [4].

In the late 1980s, when the occultation science possibilities of GPS were recognized, it was proposed to apply the radio occultation technique also to the Earth's atmosphere sounding using the L-band signals of the global positioning system GPS that was just established [5]. To prove this concept, the GPS/MET experiment onboard the Microlab 1 satellite mission, led by the University Corporation of Atmospheric Research (UCAR) was launched in April 1994 [6]. The GPS/MET results have demonstrated that the GPS radio occultation technique is a powerful tool for remote sensing of the Earth's neutral atmosphere and ionosphere [7-9]. Consequently, several satellite missions have flown with GPS radio occultation receivers, such as OERSTEDT [10], CHAMP [11], and SAC-C. Since future missions will also use the signals from other Global Navigation Satellite Systems (GNSS) such as GLONASS and GALILEO, the following text refers to GNSS only.

The radio occultation measurements rely principally on accurate measurements of the GNSS signal phases onboard a Low Earth Orbiting (LEO) satellite. The so-called phase path excess can then be used to derive the bending angle of the ray path or to determine the Total Electron Content (TEC) along the measured radio link. This measurement is the basis for retrieving the vertical refractivity profile from the LEO orbit height down to the Earth surface. Since the index of refractivity of the ionosphere

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

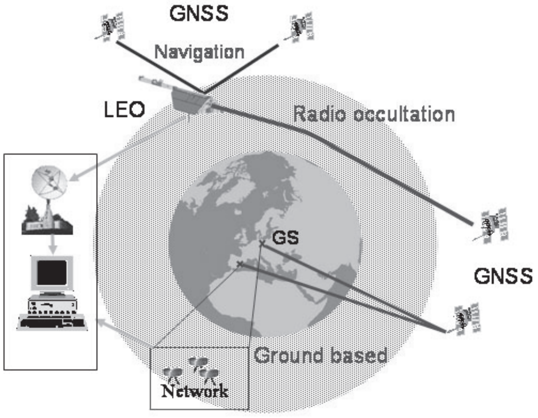

Figure 1a. Schematic view of ground and space based GNSS measurement geometries for ionospheric sounding.

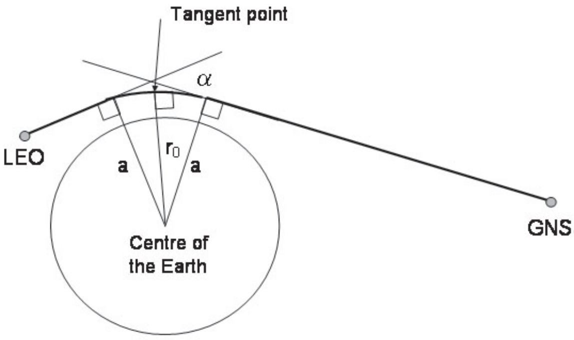

Figure 1b. Schematic view of the occultation geometry between the GNSS and the LEO satellites, α *is the refraction angle, a is the impact parameter and* r_0 *is the distance of the tangent point from the centre of the Earth.*

depends mainly on the number of free electrons, the inversion of the measured signals can provide the vertical Electron Density Profile (EDP) [8,12,13]. In the stratospheric and tropospheric altitude ranges, vertical neutral gas temperature or water vapor profiles may be derived from the refractivity profile [14,15].

The general scheme of radio occultation is shown in Figure 1. The refraction angle α, between the ray path asymptotes can be derived from the GNSS carrier phase measurements onboard the LEO satellite with high accuracy. Since the bending angle is principally less than one degree, the orbit data are required with high precision (centimeter range) and clock drifts have to be removed. High accuracy can be achieved by including a further GNSS satellite, by adding a fiducial GNSS ground station and calculating so-called double phase differences which cancel out the satellite hardware errors. If the clock drift is small, a fiducial GNSS ground network is not needed [16].

The purpose of this paper is to describe the ionosphere sounding capabilities of radio occultation techniques. Opposite to the radio occultation sounding of the neutral atmosphere, the Ionospheric Radio Occultation (IRO) measurements can take advantage of the dispersive nature of the ionosphere. Thus, differential GNSS phases derived from dual frequency GNSS measurements can effectively be used to compute the integral of the electron density along the ray path that is commonly known as the slant total electron content of the ionosphere. As it will be outlined in Section 2 in more detail, the dual frequency technique is much easier to handle than the refraction angle method.

The dual frequency measurement principle is commonly applied also to ground based GNSS measurements for ionospheric monitoring [17] (cf. Figure 1a). Furthermore, dual frequency navigation measurements onboard LEO satellites have also a great potential for sounding the topside ionosphere and plasmasphere in the vicinity of the orbit plane [18].

Combined ground and space based GNSS measurements provide an excellent basis for reconstructing the three dimensional structure of the electron density distribution by data assimilation or tomographic techniques including additional data sources [19-21]. Since the GPS/MET experiment was carried out in 1994-1997, the retrieval methods have been essentially improved to achieve higher accuracy and resolution of vertical refractivity profiles.

From the observational point of view, it was shown that atmospheric and ionospheric key parameters such as temperature, water vapor and electron density profiles may be effectively monitored and processed on a routine basis [22].

Generally speaking, the radio occultation technique is a calibration-free remote sounding method that enables a low cost monitoring of tropospheric, stratospheric and ionospheric key parameters on global scale. Measurement properties such as all-weather-capability, high accuracy and vertical resolution and global coverage (Figure 2) offer a great potential for improving numerical weather forecast, detecting long-term climate trends and monitoring ionospheric space weather.

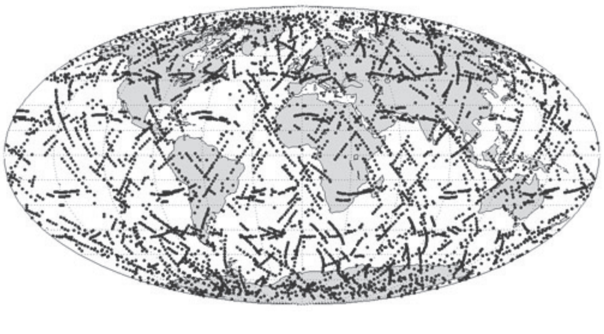

Figure 2. Ionospheric radio occultation data coverage onboard CHAMP during April 2002 indicating the global coverage of IRO measurement sites.

2. IRO Inversion Techniques

As already indicated in the previous chapter, there are different options to retrieve the vertical electron density profile from IRO measurements. The commonly used inversion technique is the Abel inversion based on a spherical symmetry assumption of the refractivity field. It is interesting to note that such a technique was already developed about 100 years ago when the inversion of travel time data of seismic waves was discussed [23].

The refraction index, n, of the ionospheric region depends mainly on the electron density, n_e, and can be written in the first-order approximation as

$$n^2 = 1 - K\frac{n_e}{f^2} \qquad (1)$$

with $K = 80.6$ m3s-2, where n_e is the local electron density and f is the radio wave frequency (for further details see Davies [24]). Higher-order refraction effects can practically be ignored in this field of application.

Introducing the impact or approaching parameter $a = n \cdot r$ that describes the refractive distance of the asymptotic ray path from the centre of the Earth (cf. Figure 1b), the refraction angle α can be expressed by the refraction index n via the integral equation

$$\alpha(a) = -2a\int_{r_0}^{\infty}\frac{1}{\sqrt{r^2n^2 - a^2}}\frac{d\ln(n)}{dr}dr\,. \qquad (2)$$

This integral equation can then be inverted by the Abel integral transform providing the vertical profile of the refractive index in terms of α and a [25] by

$$\ln(n(r)) = \frac{1}{\pi}\int_{nr}^{\infty}\frac{\alpha(a)}{\sqrt{a^2 - r^2n^2}}da \qquad (3)$$

Measuring the bending angle α at the refractive distance $a(r)$ from the satellite orbit height down to the bottom of the ionosphere, one can retrieve the vertical refractivity profile of the entire ionosphere below the satellite orbit height. Since the integration can be performed only up to the orbit height of the LEO satellite, h_{LEO}, some assumptions have to be made for determining the integral between h_{LEO} and infinity. If h_{LEO} is close to the transition height h_{TR} of the ionosphere where the oxygen and hydrogen ion densities are equal [26], the remaining small plasmasphere contribution to the refraction may be simply deduced from an extrapolation of the data [8] or the profile [27]. Because this condition was practically fulfilled for the GPS/MET experiment onboard Microlab 1, flown at about 750 km height, the Abel inversion was successfully applied for deriving electron density profiles [8,12]. If h_{LEO} is essentially lower than h_{TR}, the integration between h_{LEO} and infinity requires special care in Equation (3). This topic will be discussed later in more detail.

The bending angles, which vary only up to a few mrad during an IRO event, can be derived from the satellite geometry (Figure 1b) and the measured GPS carrier phase, ϕ, which includes the ionospheric phase excess, d_I, according to

$$\Phi = \rho + c(dt - dT) - d_I + d_{MP} + dq + dQ + N\lambda + \varepsilon \qquad (4)$$

where ρ is the true geometrical range between GPS satellite and receiver, c is the velocity of light, dt and dT are the satellite and receiver clock errors, d_I is the ionospheric phase delay along the ray path s, d_{MP} is the multipath error, dq and dQ are the instrumental satellite and receiver biases, λ is the radio wave length, N is the phase ambiguity number (an integer) and ε is the residual error. In brief, the bending angle α and the impact parameter $a(r)$, required for the Abel inversion in Equation (3), are a function of the satellite geometry and velocities.

To get more detailed information on the relationship between the refraction angle and the phase excess, the reader is referred to the literature [12].

It becomes evident that very precise orbits/velocities of both the GNSS as well as the LEO satellite are required. Consistency in deriving bending angle profiles requires in addition the correction of clock errors and cycle slips in the phase data in Equation (4).

Problems that arise due to unknown hardware biases and clock drifts can be solved by including an additional GPS satellite as a reference and a fiducial ground station for computing so-called double phase differences which cancel out these errors and biases but enhance on the other side also the residual noise ε .

Due to the dispersive nature of the ionospheric plasma indicated in Equation (1), the ionospheric phase excess term d_I in Equation (4) can be computed directly from the TEC measurements. In the first-order approximation one gets

$$d_I = \frac{K}{2f^2}\int_{LEO}^{GNSS} n_e ds\,. \qquad (5)$$

Thus, it becomes evident that instead of the bending angle α the Total Electron Content TEC as a measure of the spherically layered electron density integrated along the radio occultation ray path between the GNSS and the LEO satellite can be used for retrieving the vertical electron density profile from the IRO measurement. Due to the small bending effect in the ionosphere one can assume that the signals travel along a straight line between the GNSS and the LEO satellite that approaches the Earth surface (r_E) at the tangential height h_T or radial distance $r_T = r_E + h_T$.

$$TEC(r_T) = \int_{LEO}^{GNSS} n_e ds$$

$$\int_{r_T}^{r_{LEO}} \frac{r n_e(r)}{\sqrt{r^2 - r_T^2}} dr + \int_{r_T}^{r_{GPS}} \frac{r n_e(r)}{\sqrt{r^2 - r_T^2}} dr \quad (6)$$

Here the radial distances r_{LEO} and r_{GPS} correspond with the heights h_{LEO} and h_{GPS} in the same way as r_T and h_T (see Figure 3). Since the Abel inversion can refer only to the symmetric part below the LEO orbit, the TEC between LEO and GPS has to be estimated and subsequently subtracted from Equation (6). The so calibrated TEC' can then be transformed according to Schreiner et al. [12] by

$$n(r) = -\frac{1}{\pi} \int_{r_T}^{r_{LEO}} \frac{dTEC'/dr_T}{\sqrt{r_T^2 - r^2}} dr_T \quad (7)$$

To derive TEC from the phase measurements at L1 or L2 frequency the same challenging requirements regarding the elimination of the unknown terms in Equation (4) have to be fulfilled as discussed above.

However, again one can take advantage of the frequency dependency of the refraction index as shown in Equations (1) and (5). Due to the ionospheric frequency dispersion the difference of the L1 and L2 phase $\Delta\Phi = \Phi(L1) - \Phi(L2)$ practically cancels out all variables of non-ionospheric origin contributing to Equation (4).

$$\Delta\Phi = K \frac{f_1^2 - f_2^2}{2 f_1^2 f_2^2} \int_{LEO}^{GNSS} n_e ds + N_1\lambda_1 - N_2\lambda_2 + \Delta\varepsilon \quad (8)$$

From Equation (8) the total electron content can easily be derived and the Abel transformation can be applied according to Equation (7) to retrieve the electron density profile from the IRO measurements. A small rest error remains due to the fact that the signals at L1 and at L2 frequencies don't travel exact along the same ray path. Due to the small ionospheric bending this error is usually negligible [12] but may also be taken into account in a refined analysis [28]. Because this dual frequency differential method doesn't require precise orbits or double differencing to cancel out other hardware biases, it's much more effective than the bending angle based retrieval.

Because the IRO measurements definitively start (or end) at the LEO orbit height h_{LEO}, the contribution of the above lying ionization has to be considered in the same way as already discussed in conjunction with the bending angle based retrieval. If the LEO height is greater than the transition height of the ionosphere, the plasmaspheric content can simply be estimated by extrapolation, ionospheric models or by estimating the topside contribution by measurements [29].

Since ionospheric phenomena may be accompanied by strong spatial plasma density gradients and furthermore, the ray path through the ionosphere is rather long (about 1000-2000 km) the spherical symmetry assumption of the Abel inversion technique does not, in general, hold. Retrieval errors due to the unrealistic spherical symmetry assumption may be reduced by adding horizontal TEC information derived from ground GNSS measurements [27, 29].

To overcome this methodological restriction, tomographic solutions or data assimilation methods are attractive [30-33]. The tomographic approach has the

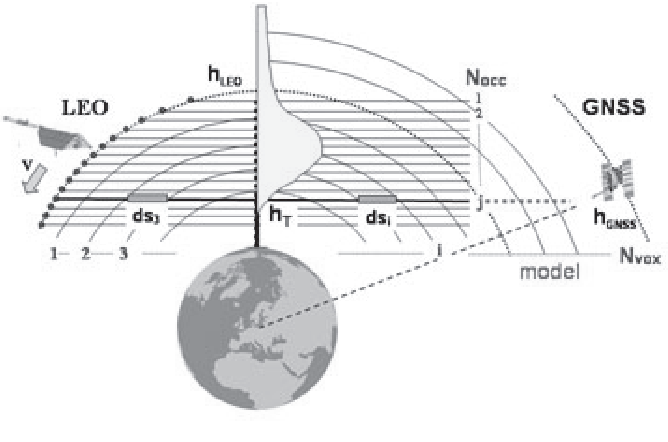

Figure 3. Illustration of the retrieval technique for analyzing IRO data from CHAMP. At altitudes above the LEO satellite height (h_{LEO}) electron density values of an adaptive model are used.

advantage that additional information, e.g. about horizontal gradients from ground based GPS measurements, models and/or other data sources like ionosondes can be included in the reconstruction of the electron density profile in a proper way.

Following such an approach, the ionosphere is usually represented in a discrete manner by a grid of pixels or three dimensional voxels characterized by a homogeneous electron density n_e inside. The measured TEC of the *j*th observation can then be calculated by the sum of all (N_{vox} in Figure 3) TEC increments along the ray path. TEC_{ij} is simply the electron density in the *i*th pixel (n_{eij}) multiplied by the ray path length within the *i*th pixel (ds_{ij}) as it is illustrated in Figure 3 in a simplified two dimensional graphics:

$$TEC_j\left(h_T\right) = \sum_{i=1}^{N_{VOX}} n_{eij} ds_{ij} \tag{9}$$

or in a general matrix form:

$$\mathbf{Y} = \mathbf{DX} \tag{10}$$

Here **Y** represents the TEC data, **D** the ray path length through the voxels and **X** the electron density structure to be determined [30].

Because the capabilities of the radio occultation technique for sounding the ionosphere are mainly demonstrated on the basis of results we have obtained by GPS measurements on board CHAMP, some peculiarities of the electron density retrieval from these IRO measurements will be briefly discussed subsequently [13].

If the LEO satellite orbit is well above the F2 layer peak height as in the case of the Oersted and SAC-C satellite missions, the comparatively small and low variable plasmaspheric contribution can be estimated with sufficient accuracy as discussed earlier. This simplifying assumption cannot be applied to the CHAMP IRO retrieval algorithms because CHAMP has a rather low orbit height of less than 450 km, which decreases even further below 400 km height during the mission lifetime. At this orbit height, depending on geophysical conditions as local time, latitude, season or solar activity level, more than 50% of the measured TEC may originate from the region above. To overcome this upper boundary problem, a specific model assisted technique has been developed for the CHAMP data analysis [13, 34].

The developed tomographic approach is based on a spherically layered voxel structure from the bottom-side ionosphere up to the GNSS satellite heights. Although additional information as gradients or peak densities from ionosondes could be used, operational requirements of data provision led to the simplifying assumption of a spherically layered ionosphere. This simplification was necessary because supplementary data were not available in an operational mode. After filling the voxels above the LEO orbit height with model electron density values, the retrieval procedure can start. Practically, starting from above, the first measurements at the greatest tangential height h_T provide then the electron density in the uppermost layer via Equation (9). Going downward, this procedure provides successively the electron density of the lower ionospheric layers. Figure 3 illustrates how the electron density of different shells successively contributes to a series of 1 Hz sampled TEC measurements of index *j* when the tangent point of occultation rays comes closer and closer to the Earth down to the bottom of the ionosphere.

Since the initial guess of the model is usually not the best one, the retrieval procedure uses an adaptive Chapman layer model whose topside is extended by a slowly decaying exponential term describing the plasmaspheric electron density with a fixed scale height H_P according to:

$$n_e\left(h\right) = NmF2_M \exp\left\{0.5\left[1 - z - \exp\left(-z\right)\right]\right\}$$
$$+ n_{P0} \exp\left(-h/H_P\right) \tag{11}$$

with

$$z = \left(h - hmF2\right)/H_{TS} \text{ and } z > 0 \cdot \tag{12}$$

Whereas the peak density height, hmF2, and the initial peak density, NMF2$_M$, are already estimated from the input data, the topside scale height, H_{TS} , and the plasmaspheric scale height, H_P , are fixed at physically plausible values (80 and 10000 km, respectively). The plasmaspheric basis density, n_{P0} , is assumed to be proportional to the electron peak density, NmF2$_M$. The crucial model parameters such as peak density, NmF2$_M$, and the topside scale height, H_{TS} , are adjusted during six retrieval iterations at the upper boundary in order to ensure a smooth transition between model and measurements. A smooth transition indicates a reasonable initial guess of the plasmaspheric model.

It has been found that the most crucial element for improving the solution of the upper boundary problem is the topside scale height [35]. Recently, attempts have been made to develop a topside scale height model that is able to improve the initial guess for the retrieval procedure [36].

The developed retrieval technique is robust and sufficiently accurate to be run in an operational mode. Fulfilling operational space weather requirements, the CHAMP data are processed within 3 hours after data dump by an operational processing system [37].

3. Validation Work

Before any retrieved electron density profiles can be used in ionospheric research, the accuracy and reliability of the retrievals have to be estimated. This can be done by comparison with measurements obtained by quite different techniques such as vertical sounding, incoherent scatter radar or in situ measurements. It has to be stated that principally the IRO derived electron density profiles provide a unique measure describing the mean vertical electron density structure in comparably large areas with diameters of up to about 2000 km. These averaged profiles smooth out local structures and are therefore principally different from local measurements, e.g., from vertical sounding. Nevertheless, vertical sounding data should agree in average if the number of data is large enough.

Before starting to validate the entire profile, the key parameters such as the peak density f0F2 and the peak density height hmF2 can be compared separately. The corresponding data were taken from globally distributed vertical sounding stations via the SPIDR database [38]. Since most of these data are auto scaled, their accuracy is restricted. The IRO data from CHAMP were compared with globally distributed ionosonde data within a cross section of about 1600 km diameter [39]. The absolute distribution function shifts by 0.18 MHz for f0F2 and 13.4 km for hmF2. The RMS deviations of 1.28 MHz and 46.8 km for f0F2 and hmF2, respectively, agree in principle with former estimations [12]. The large dispersion of hmF2 values may be due to the restricted reliability of the Dudeney formula [40] by which the SPIDR data heights were estimated. Deriving hmF2 directly from analogue ionograms is unfortunately too difficult for routine analysis. Simulation studies by Hochegger and Leitinger have shown that the peak height error remains less than 20 km in more than 50% of the cases in mid-latitudes [32].

Entire IRO retrieved electron density profiles were systematically compared with European vertical sounding (digisonde) data obtained at stations in Juliusruh (54.6°N; 13.4°E), Athens (38.0°N; 23.5°E), Rome (41.9°N; 12.5°E), Tortosa (40.8°N; 0.5°E) and Dourbes (50.1°N; 4.6°E) within the European COST 271 activity [41, 42]. The comparative results obtained for profiles located within a circle of 6 degrees around the ionosonde station Juliusruh are shown in Figure 4. Optimal occultation results can be obtained if the occultation lies in the orbit plane of the LEO satellite. To avoid bad occultation geometry conditions, the aspect angle between the IRO measurements and the CHAMP orbit plane is generally less than 45°. The comparison of 261 profiles indicates a systematic positive bias of the IRO data in the order of about 0.5 MHz and a standard deviation from the mean of about 1 MHz throughout the entire profile [42].

Vertical electron density profiles throughout the entire ionosphere may be provided also by incoherent scatter facilities. To study the high latitude ionosphere by different techniques, several CHAMP-EISCAT measuring campaigns were initiated in recent years [43]. Figure 5 shows a sample of the comparison of European incoherent scatter and IRO measurements which coincide within a cross section diameter of about 1600 km and within a time window of less than 30 minutes. The majority of profiles agree within the error bounds of the two different methods [43].

Another option to evaluate the accuracy of the IRO derived EDPs is the comparison with the in situ electron density measurements performed by the planar Langmuir probe onboard CHAMP [13] or by comparison with data driven reconstructions of the four dimensional electron density distribution. This has been done with reconstruction results of the MIDAS (Multi-Instrument Data Analysis System) algorithm which has been developed by Mitchell

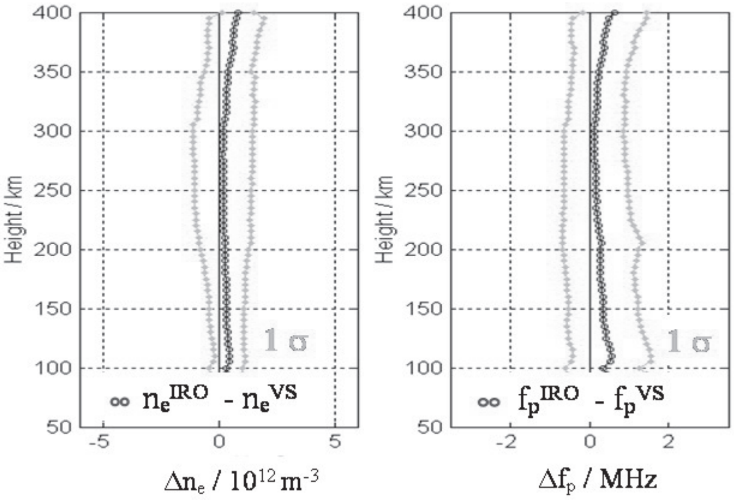

Figure 4. Statistical comparison of IRO and vertical sounding profiles from Juliusruh (January 2002–March 2003, 261 profiles). Left: electron density deviations. Right: plasma frequency deviations, c.f. [42].

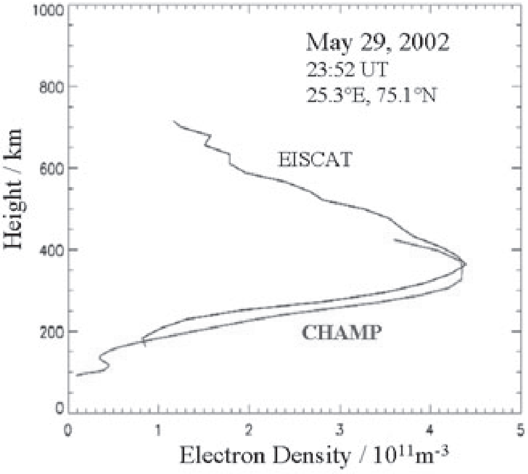

Figure 5. Comparison of a selected CHAMP/IRO derived electron density profile with a corresponding EDP derived from EISCAT measurements on May 29, 2002, 23:52 UT, cf. [43].

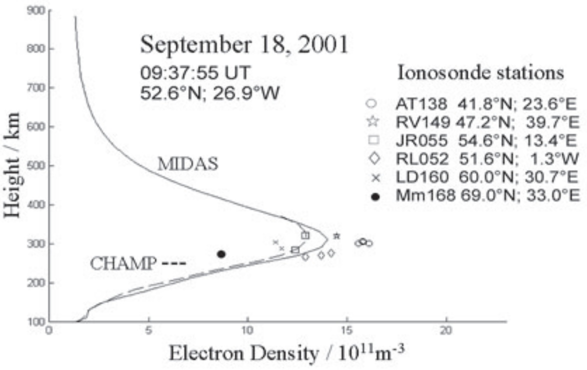

Figure 6. Comparison of a CHAMP/IRO derived EDP (dashed line) with a corresponding profile extracted from the MIDAS reconstruction. Comparison with corresponding NmF2 data from various European vertical sounding stations is indicated by the symbols, cf. [44]

and Spencer [19]. The MIDAS algorithm is designed to assimilate data from a number of different measurement techniques, thus allowing the spatial and temporal factors to be accounted for in the inversion. In the validation study [44] various ionospheric data have been collected over Europe (cf. Figure 6).

The experimental results indicate excellent agreement between the specification of ionospheric electron concentration using MIDAS and those calculated from CHAMP radio occultation.

4. Current Missions and Observations

Current LEO missions such as Oerstedt, CHAMP, SAC-C and IOX that carry dual frequency GPS receivers onboard, offer a unique chance for improving measuring techniques and algorithms for retrieving the electron density improving our knowledge about ionospheric phenomena monitoring the actual state of the global ionosphere on a continuous basis.

The Danish satellite Oersted was launched on February 23, 1999 to measure the geomagnetic field structure [45]. The GPS receiver on board Oersted enables radio occultation measurements and subsequently the retrieval of vertical electron density profiles [10, 46].

SAC-C (Scientific Application Satellite-C) is an international cooperative Earth observation mission launched on November 21, 2000 [47]. The overall objective is to study the structure and dynamics of the Earth's surface, atmosphere, ionosphere and geomagnetic field. IRO measurements are made via the GPS Occultation and Passive Reflection Experiment (GOLPE). Results of radio occultation measurements on board SAC-C are focused so far on sounding the neutral atmosphere [48].

The Ionospheric Occultation Experiment (IOX) is in a 67° inclination, 800 km altitude orbit, enabling it to make ionospheric measurements at all local times over the course of its mission. IOX has been making routine IRO measurements since November 2001 [49].

This paper focuses on selected results obtained from IRO measurements onboard the German satellite CHAMP. More results are discussed in Jakowski et al. [50]. The CHAMP mission was successfully launched into a near polar orbit (I = 87°, h = 450 km) by a Russian COSMOS rocket on July 15, 2000. So far, more than 150000 profiles have been retrieved from IRO measurements onboard CHAMP since 11 April 2001 on a routine basis using an advanced dual frequency GPS receiver developed by the Jet Propulsion Laboratory/USA.

Out of about 200 IRO measurements approximately 150 electron density profiles (EDPs) are successfully retrieved per day automatically after data dump from the CHAMP satellite. Due to the modular structure of the processing system high flexibility is achieved, and retrieval modules can be modified or replaced [37].

Because the processing system works automatically, some EDP outliers cannot be avoided. The number of such "unrealistic" profile outliers is principally less than 1%. Due to the high orbit inclination, the radio occultation measurements onboard CHAMP cover the global ionosphere (Figure 2). To fulfill operational requirements, i.e., to come up with retrieval products within a latency of less than 3 hours, no further data are included in the retrieval procedure, i.e. for reasons of simplicity a spherically layered ionosphere is assumed as it is used by the Abel inversion. The retrieval can surely be improved if additional information, e.g. on horizontal gradients or local densities, is included in the retrieval procedure [51]. Horizontal gradients can easily be deduced from horizontal TEC maps from ground based GPS measurements (e.g. [52, 53].

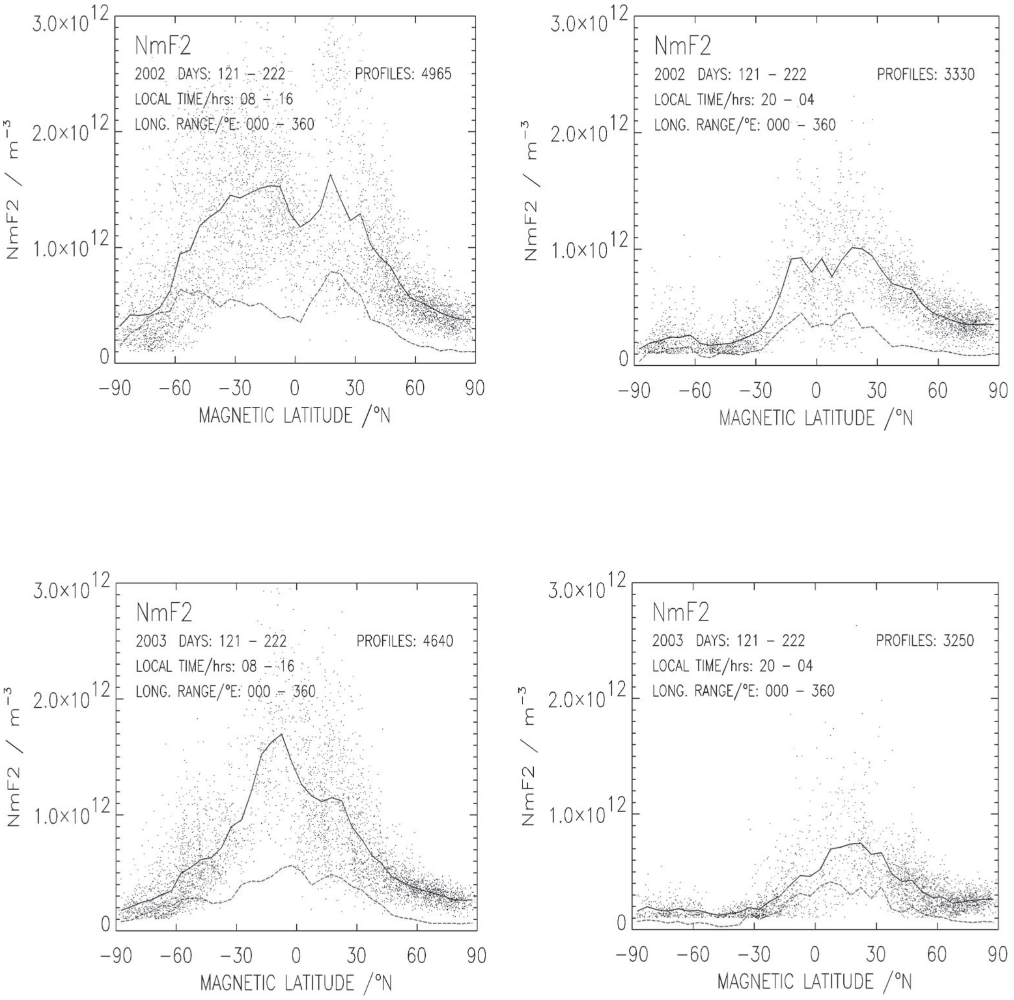

Figure 7. NmF2 as a function of magnetic latitude at day-and night-time during northern summer in the years 2002/03. The dashed curve represents the standard deviation.

The strong latitudinal dependence of the ionospheric ionization is clearly indicated in Figure 7 during day- and night-time hours (08:00-16:00 and 20:00-04:00 LT) at all longitude sectors for northern summer conditions (days 121-222 in 2002/03). At high latitudes the ionization level is clearly enhanced under summer conditions in the northern hemisphere. It is worth noting that the daytime peak electron density is smaller in summer at mid-latitudes although the solar radiation is enhanced. This so-called winter anomaly effect enhances at high solar activity visible in Figure 7 when comparing the years 2002 and 2003 (winter/summer ratios at 45° are 1.4 and 1.2, respectively). The seasonal anomaly disappears at night time when the ionization is stored at greater heights. At daytime the enhanced density of molecular constituents in summer leads to an enhanced plasma loss resulting in a low plasma density although the photo-ionization rate is increased [54]. Furthermore, at least the daytime plots in Figure 7 illustrate quite well a shift of the equatorial crest towards the summer hemisphere by about 5° despite the seasonal anomaly effect in mid-latitudes.

Because the summer hemisphere is characterized by a stronger energy input that leads not only to enhanced photo-ionization but also to an enhanced heating of the thermosphere/ionosphere system, one should observe an expansion of the electron density profile shape that is accompanied by an uplifting of the F2 layer peak height hmF2. Indeed, this behavior is clearly shown in Figure 8 where the peak height in mid-latitudes (45-60°N) is up to 50 km higher in summer than in winter. Due to the upward lifting of plasma in the equatorial anomaly region the corresponding peak density height is additionally enhanced in this region. Principally, due to the rather low CHAMP orbit height £ 450 km the hmF2 values are constrained to values less than about 400 km. This may cause a slight reduction in the average hmF2 value. The standard deviation is less than 50 km except at high latitudes (> 70°).

From Figure 9 it becomes clear that the solar irradiance controlled expansion of the electron density profile is also visible in the topside scale height that is deduced at 425 km from the retrieved EDPs. Hence, the topside scale height at 425 km increases continuously from –60°N towards the summer hemisphere by about 0.16 km/deg. In analogy with the scale height, the bottom-side slab thickness $\tau_b = TEC$ (hmF2)/NmF2 increases from –60°N towards the summer

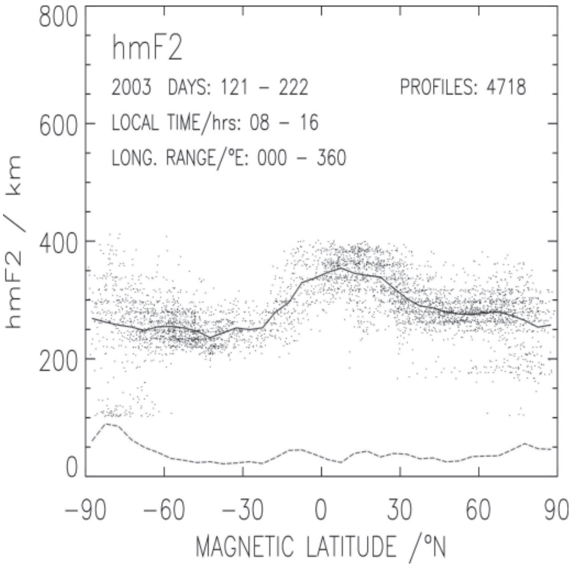

Figure 8. Peak density height as a function of magnetic latitude. The dashed curve represents the standard deviation.

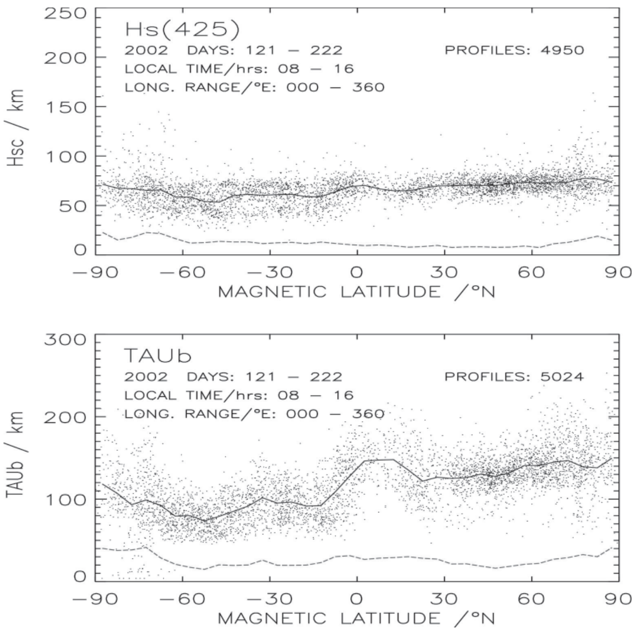

Figure 9. Latitudinal distribution of the topside scale height taken at 425 km height and bottom-side slab thickness τ_b from all longitude sectors at daytime (08-16 LT). The dashed curves represent the standard deviation.

hemisphere by about 0.5 km/deg. It should be mentioned that the scale height is taken from the upper boundary region of the measurements where the topside model has still a certain influence [36]. Hence, these data demonstrate clearly the adjustment of the scale height (start value 80 km) during the initial phase of the retrieval procedure.

Although the IRO data reported here need further validation, a preliminary comparison with ionospheric three dimensional models may be helpful to get more information about the data quality and to get already some indication of the model quality. Following this idea, comparative studies were made with the IRI [55] and with the NeQuick model [56, 57]. The results which are deduced from a comparison of about 78000 profiles, show a systematic overestimation of IRI derived electron density above 250 km in Figure 10. Below this altitude the IRI derived electron density values are significantly lower than corresponding IRO values. The comparison of more than 50000 IRO derived profiles with the NeQuick model showed a good agreement with IRO retrievals at heights above 300 km. NeQuick systematically underestimates the electron density below this height up to 1.5 x10^5 el/cm^3 or about 1 MHz in plasma frequency compared with the IRO derived profiles [57].

Besides a monitoring of the regular behavior of the ionospheric ionization the IRO measurements enable also studies of the occurrence of the sporadic E-layer [58] and F2 layer perturbations, such as Traveling Ionospheric Disturbances (TIDs). As it can be seen in Figure 11, left panel, the 1 Hz sampled TEC measurements may show

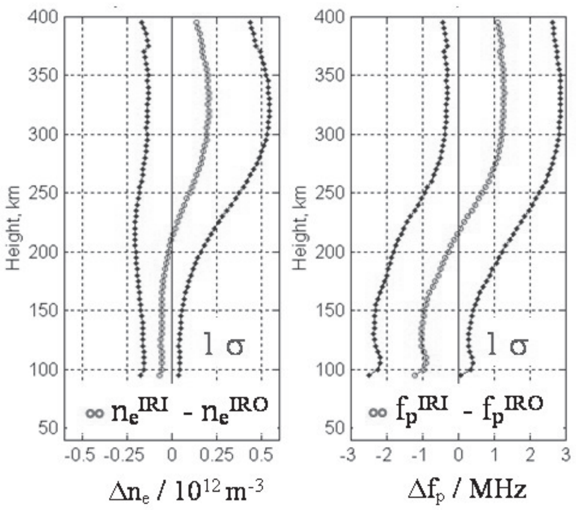

Figure 10. Comparison of vertical electron density profiles derived from IRO data with corresponding profiles computed from IRI according to the differences $\Delta n_e = n_e^{IRI} - n_e^{IRO}$ and $\Delta f_p = f_p^{IRI} - f_p^{IRO}$ for all measurements obtained onboard CHAMP within the period May 2002 - October 2003. Left panel: electron density deviations Δn_e, Right panel: plasma frequency deviations Δf_p, cf. [55].

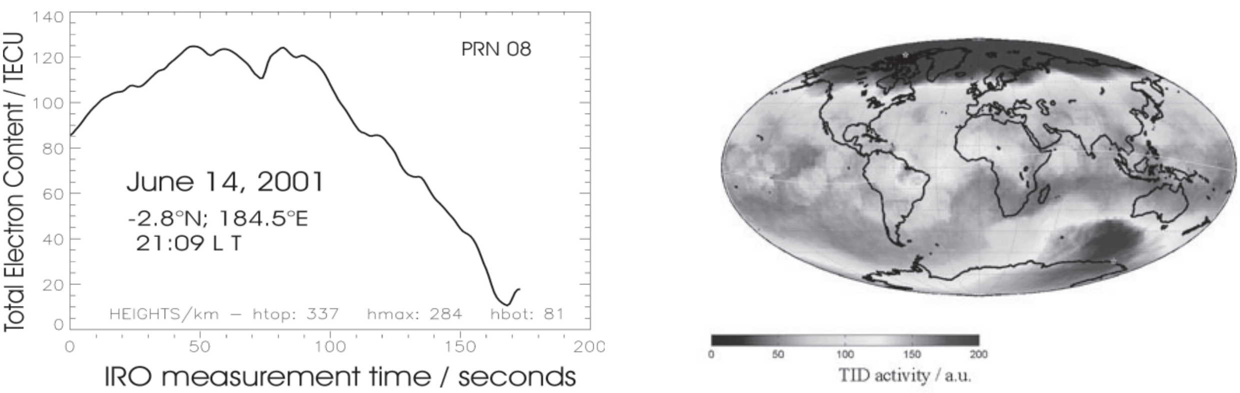

Figure 11. Left side: Wavelike phenomena on IRO TEC measurements observed on June 14, 2001 at low latitudes indicating the existence of spatial electron density structures in the ionosphere. Right side: Global distribution of irregular structures observed in the IRO data during northern winter months in November 2002-January 03. The scale of TID activity (relative measure) is in arbitrary units

some wavelike variations which indicate spatial structures in the vertical ionosphere eventually related to gravity waves. Although vertical and horizontal structures may not be separated without additional information, the capability to detect TID occurrences and to study their relationships to other geophysical phenomena enables new insights into the generation and propagation of ionospheric irregularities. The deviations, absolute or percentage values, from a fitted smooth polynomial give a rough measure of the TID activity during one occultation event. As Figure 11, right panel, shows, ionospheric TID activity (here a relative measure) occurs preferably at high latitudes in the winter night. Absolute values would show a dominance in the low latitude range because of the higher ionization level. Furthermore, ionospheric plasma instabilities in conjunction with high ionization indicate enhanced activity in the equatorial crest region. Because the ionospheric plasma is a trace gas in the thermosphere, observations of this type can contribute to study coupling mechanisms between ionosphere and the atmospheric layers like troposphere, stratosphere and mesosphere.

5. Outlook and Conclusions

The GNSS radio occultation technique for measuring the vertical structure of the atmospheric refractivity from low earth orbiting satellite heights down to the Earth surface has been developed in recent years to a great extend on an international level. This innovative GNSS technique opens a new dimension for operational sounding of the ionosphere and atmosphere.

It is estimated that more than 200000 EDPs have been deduced so far from IRO measurements at various satellite missions such as GPS/MET, Oerstedt, CHAMP and SAC-C thus providing a huge data pool for studying, modeling and monitoring the ionosphere. If compared with localized vertical sounding measurements, the F2 layer peak electron density f0F2 and the corresponding height hmF2 agree within less than 20% deviation.

The standard deviation from vertical sounding derived electron density profiles is in the order of 1 MHz or 1.2 $x10^{11}$ el./m^3 throughout the entire profile from the LEO down to the E-layer height.

This agreement can certainly be improved, if additional information, e.g. on horizontal gradients or local densities, is included in the retrieval procedure to overcome the limitations of the traditional Abel transform. Horizontal gradients can be deduced from horizontal TEC maps from ground based GPS measurements. An essential improvement is expected, if IRO retrievals and tomographic reconstructions of the topside electron density distribution are combined to get a comprehensive view on the entire vertical electron density structure of the ionosphere from the bottom-side up to GPS orbit heights.

Furthermore, the use of IRO slant TEC is complementary to the use of ground-based measurements. This is important because IRO can provide largely horizontal ray paths in contrast to the largely vertical ray paths available from ground based GPS TEC measurements; and secondly IRO can provide data over inaccessible areas of the world, such as the oceans.

Thus, first attempts of tomographic reconstructions of the three dimensional electron density distribution combing both satellite-to-ground and satellite-to-satellite GPS data showed an improved and consistent description of the ionospheric behavior [19, 33]. In other words, IRO measurements data will have great potential for studying and modeling a number of ionospheric phenomena on global scale in future.

Promising tomographic and assimilation techniques for three-dimensional imaging of the ionosphere were developed in recent years such as the 'Multi-Instrument Data Analysis System' (MIDAS) [19], the 'Global Assimilation of Ionospheric Measurements' (GAIM) [20, 59], and the 'Electron Density Assimilative Model' (EDAM)

[21]. When completed, the physics-based data assimilation model GAIM will provide 3-dimensional electron density distributions from 90 to 25,000 km altitude with a horizontal resolution of up to 25 km. The Kalman filter based algorithm enables the assimilation of in situ measured electron densities, bottom-side electron density profiles from ionosondes, TEC measurements between ground-based receivers and the GPS satellites and IRO data from LEO satellites. EDAM uses the Parameterized Ionospheric Model (PIM) as its background model and a background error covariance matrix that is also determined from the background model. EDAM has been tested using measurements simulated by ray tracing through ionospheric models and through tomographic images.

These data assimilation techniques can effectively be applied if ionospheric measurements on multi satellite systems become available. The upcoming Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC) [60], with six satellites will be a big step forward in exploring complex ionospheric phenomena and enhancing forecasts of ionospheric activity and space weather. The planned launch of further satellites carrying occultation GNSS receivers on board such as C/NOFS, TerraSAR-X or SWARM in future years offer permanently growing promise for modeling and near-real-time monitoring the electron concentration in the near-Earth space environment for scientific studies and practical applications.

6. Acknowledgement

The author is very grateful to the international CHAMP team who makes routinely available the GPS measurements onboard CHAMP in high quality. Furthermore, I thank K. Tsybulya and other colleagues for giving valuable support in preparing this paper.

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Kinetic and Nonlinear Processes in Space Plasmas

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1. Introduction

Computer simulations based on full particle in cell (PIC), test particles, hybrid and Vlasov codes combined with theoretical analysis have allowed to analyze the kinetic effects of plasma which are excluded in macroscopic magnetohydynamic (MHD) approach. These effects do have important impacts via wave-particle interactions to account for plasma acceleration and heating, wave damping, particle diffusion, and wave generation. These effects lead to various types of microscopic dissipation processes (responsible for viscosity and resistivity) which can be identified and analyzed in details, in contrast with MHD approach where the corresponding source mechanisms of dissipation are ignored. In addition, kinetic effects allow the accessibility to microscales over which some processes can be initiated, in particular, for nonlinear mechanisms. This accessibility leads to some coupling of processes over micro-meso scales. A quite large variety of mechanisms is concerned by such kinetic effects. In the following sections, we will restrict our review on recent progress to three selected topics performed via theory, simulations and in strong relationship with observations. These topics are respectively (i) collisionless shocks, (ii) magnetic reconnection and (iii) nonlinear kinetic waves and structures.

2. Collisionless Shocks

Collisionless shocks occur when a collisionless plasma streams with a supersonic velocity against an object or discontinuity or when two plasmas stream with supersonic velocity against each other. Such shocks are very common in various types of space plasma. In the heliosphere, collisionless shocks are the so-called bow shocks in front of planetary magnetospheres, shocks bounding co-rotating interactions regions, coronal and traveling interplanetary shocks, and the heliospheric termination shock. In astrophysics, supernova remnant shocks and shocks produced by astrophysical jets are also invoked. More generally, collisionless shocks present a great interest since the bulk energy of the plasma is converted irreversibly into thermal energy through the shock transition region: the shock plays the role of an energy converter. This conversion is established by collective processes which in turn requires upstream and downstream waves. Thus, collisionless shocks are responsible for the generation of waves and turbulence in the upstream and downstream regions. Another interest is due to the fact that such shocks not only lead to thermal heating but also to acceleration of a minority of particles to rather high energies. The energy conversion through the transition region establishes via intricate processes which make the shock front itself non-stationary. In turn, this non-stationarity has a strong impact on both electrons and ions. Due to the combined effort of in situ observations of collisionless shocks in the heliosphere, in particular of the Earth's bow shock via the four spacecrafts of the recent CLUSTER2 mission (which allows to separate temporal and spatial structures), of laboratory experiments [1], of analytical theory and of numerical simulations, the understanding of collisionless shocks has considerably increased. This part will summarize the most recent advances of some relevant features of collisionless shocks. For the purpose of clarity, we will consider the common separation between quasi-perpendicular and quasi-parallel shocks defined respectively by the angular range θ (angle between the shock normal and the upstream magnetostatic field B_o) extending from 90° to 45° and from 45° to 0°. Let us mention that a few reviews on the physics on collisionless shocks have been published within the last four years [2, 3]. At least, a section will be dedicated to slow mode shocks.

2.1 Quasi-Perpendicular Shocks

Herein, we will address three important questions related to the shocks physics. The first one is focused on the

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

advances on particle shock acceleration (in particular the ions). Second, an important effort has been invested not only for evidencing the non-stationary behavior of the shock front but also for identifying the different mechanisms responsible for. Third, electron dynamics have been analyzed with mono- and multi-dimensional full particle PIC (self-consistent) simulations. Because of the complexity of the results to be analyzed, these results have been often completed by test particles (non self-consistent) simulations which offer a relative simplicity. All these results are summarized too.

2.1.1 Particle Shock Acceleration

Particle pre-acceleration from thermal to relativistic energies in high Mach number shocks is an outstanding issue in understanding synchrotron radiation from supernovae remnants. Similar questions are also asked to accelerate particles to strongly relativistic energies by diffusive shock acceleration; this presupposes the existence of mildly relativistic particles whose pre-acceleration mechanism from lower ambient energies (the injection problem) remains an open question. A possible answer is provided by the so-called "surfatron" mechanism [4, 5, 6] where the particle trajectory is similar to a surfer's motion within a breaking wave, also called multiple ion reflection (MRI) acceleration [7]. Another interesting process is the so-called "shock drift acceleration" proposed by Hudson [8]. This process was widely used to account for the solar energetic particles enhancements at the interplanetary traveling shocks [9]. In the shock drift, ion energy gain is due to the ion curvature and gradient drifts in the inhomogeneous magnetic field at the shock front. Although the shock surfing acceleration relies on a strong shock potential and shock drift acceleration does not, the most important distinction between these two mechanisms is the fact the shock drift acceleration energy gain is proportional to the initial ion energy, while the final energy in the shock surfing is greater for ions which have lower incident velocities initially. For this reason, shock surfing is an ideal pre-acceleration mechanism for slow pick-up ions with velocity lower than solar wind velocity. This surfatron process is quite promising in the global scenario including successively the injection and diffusion mechanisms to account for the formation of high energy particles, such as the interstellar pick-up ions at the heliospheric termination shock for instance [10, 11, 12]. A numerical analysis of the shock surfing acceleration up to the relativistic energies has been done by Ucer and Shapiro [13].

2.1.2 Non-Stationarity of the Shock Transition Region

Turbulence of shock front has been well evidenced in previous observations of ISEE mission [14] and more recently by the four satellites space mission CLUSTER-2 [15]. Recent observations of CLUSTER-2 have also evidenced the presence of some substructures in the electric field within the shock front itself [16]. Moreover, numerical simulations of supercritical shocks have shown that the non-stationarity of the shock front establishes over quite different time/spatial scales. For the purpose of clarity, we will consider the turbulence processes according to the spatial scales over which these set up, as these have been analyzed progressively by simulations and theory.

(i) First, over very large scales, the width of the whole shock front (including the precursor and the ramp) has been shown to vary from a narrow ramp to a wide spatial scale much larger than the ion gyroradius. This strong non-stationarity applies to oblique shocks when both dissipation and dispersion effects cannot balance local nonlinear effects at the front any more. This happens for Mach number (or angle) above (or below) a critical value for which nonlinear whistler wave staying within the shock front, reaches an amplitude large enough to be emitted from the ramp [17]. This work is a quantitative extension of previous works made by Krasnosselskikh [18] and Galeev et al. [19, 20].

(ii) Second, over intermediate scales, the whole shock front has a width varying from the ramp width to a foot distance from the ramp (i.e. until its maximum scale covers an ion gyroradius scale). This non-stationarity corresponds to the so-called " shock front self-reformation" characterized by a cyclic time comparable to the ion gyroperiod calculated from the average downstream B field through the overshoot. It is due to the accumulation of ion reflection upstream of the ramp and has been analyzed intensively with full particle simulations [21, 22, 23]. A recent analytical model of Hada et al. [24] allows to estimate versus the Mach number, the critical threshold of reflected ions density over which this non-stationarity is switched on. This self-reformation occurs/disappears for low/high ion β_i (β is the ratio of the kinetic over magnetic pressure) as shown almost simultaneously by hybrid simulations [25], and by full PIC simulations [24, 26]. Moreover, for low β_i, this process persists quite well for oblique quasi-perpendicular shocks within a certain angular range around 90° as shown by PIC simulations of planar shocks [27] and of curved shocks [28, 29]. However, one question remained: why this self-reformation was absent in all previous hybrid simulations, and replaced by local fluctuations of the macroscopic fields at the overshoot [30]. The reason is that most hybrid simulations use a too weak spatial resolution so that the ion inertial length is covered by one to two grid meshes only. Self-reformation is switched on if a higher resolution is used in hybrid simulations [25]. The accessibility to spatial scales smaller than the ion inertia length is intrinsic to full PIC simulations and allows to initiate the self-reformation spontaneously.

(iii) Third, turbulence of the shock front over small scales has been analyzed with full PIC simulations which evidenced that various types of micro-instabilities can be excited within the foot where three plasma components coexist for supercritical perpendicular shocks: reflected ions, decelerated incoming ions and decelerated incoming electrons. For oblique shocks, a fourth component (reflected electrons) is also present. These analysis have been performed starting from conditions where self-reformation is switched on (i.e. for relatively low β_i and modest Mach number). The nature of the excited micro-instability differs according to the Mach number and/or appropriate conditions in the foot. For relatively modest Mach number (but supercritical shock regime necessary to get a noticeable density of reflected ions) and a shock direction around (but different from) 90°, modified two stream instability (MTSI) takes place between incoming decelerated ions and decelerated electrons [26, 31, 32, 33]. This instability occurs for realistic mass ratio which explains its absence in previous PIC simulations using a lower (nonrealistic) mass ratio. However, for much higher Mach number above a critical value and a strictly perpendicular shock (applied to astrophysical shocks for instance), two different micro-instabilities are excited successively within the foot: a Buneman instability (BI) is triggered between the reflected ions and the incident electrons which leads to the formation of large amplitude coherent electrostatic waves (ESW) with electron holes in the phase space [34, 35]. As the incident electrons are decelerated by the instability, other ESW grow in time by another two-stream instability between the incident ions and the decelerated incident electrons. These nonlinear interactions of these waves lead to the electron heating as well as non-thermal high energy electron acceleration within the shock transition.

Then, what is the coupling between these different scales and how does this coupling contributes to the turbulent behavior of the shock front? Shimada and Hoshino [36] have shown that effectively micro-instabilities lead to a strong ion diffusion within the phase space which may smear out the accumulation of reflected ions. As a consequence, the self-reformation of the shock front tends to appear rather smoothly (but still persists). Moreover, Matsukiyo and Scholer [32, 33] evidenced that MTSI leads to ion phase mixing and thermalization which, in their interpretation, contributes to the self-reformation of the shock front. Then, the self reformation persists quite well (for low and realistic mass ratio), and speeds up by the presence of the micro-instability within the foot (with high realistic mass ratio).

All the micro-meso-scale non-stationary processes mentioned above take place along the shock normal direction. However, other non-stationary processes also take place along the shock front direction. These are characterized by a shock front rippling for which different source mechanisms have been proposed: anisotropy-driven instabilities (Mirror/Alfvén Ion cyclotron) as shown by Winske and Quest [37], whistler waves driven by the reflected ions in the foot of the shock and propagating upstream [38], or the presence of a surface wave mode [39]. Shock front rippling (but of smaller spatial scale) has been also evidenced by using 2D PIC simulations [23], and identified as lower hybrid instabilities triggered by cross-field currents (supporting the large field gradients at the front).

In addition, all these non-stationary processes do have important impacts on both electron and ions dynamics and can contribute to the particle acceleration efficiency. As an illustration, inclusion of lower-hybrid wave turbulence into the model of shock surfing, can explain the preferential acceleration of heavier particles expected around the termination shock [40, 41]. All effects combined together may lead to the formation of both energetic electrons [42, 43, 44] and energetic ions [45]. The next section summarizes main results obtained on the electrons behavior.

2.1.3 Electron Dynamics

The study of electrons dynamics has received renewed attention within the last four years. Indeed, high energy electrons are considered as important sources of waves emissions and are often invoked in planetary physics, solar physics and/or astrophysics. However, instead of considering high Mach number shocks, several works have been dedicated to answer to selected questions on electrons dynamics in moderate Mach regime . These questions concern respectively reflected and transmitted electrons. First, for transmitted electrons, breakdown of adiabaticity [46, 47] has been mentioned in observations and analyzed in previous analytical [48] and simulation works [49, 50]. However, the mechanisms responsible have not been elucidated. As proposed theoretically by Balikhin et al. [51, 52, 53], a possible answer is associated to the macroscopic structure of the shock front namely to the characteristic width of the electric and magnetic field at the ramp and to the local electron Larmor radius. A quantitative answer has been given with measurements of these scales issued from PIC simulations [54]. With the use of PIC and test particle simulations, Lembège et al. [55] have confirmed that (i) electrons demagnetization takes place within the first half of the ramp (where the gradient of the electrostatic field seen by the electron is positive), (ii) within this range, the parallel momentum exhibits a net increase and convection effects are much stronger than gyromotion effects. This analysis has been completed by statistics which show that the relative percentage of demagnetized/magnetized electrons is strongly dependant on the non-stationarity of the shock front (self reformation) which affects in time the width scales of the different parts of front (ramp, foot and whistler precursor for oblique shock). Moreover, the dynamics of transmitted electrons having crossed a rippled shock front has been analyzed by Lowe and Burgess [56] with test particles simulations where macroscopic fields profiles are issued from 2D hybrid simulations; these electrons suffer a large Fermi acceleration (associated with trapping within 2D rippling structures) during the shock transition before being convected downstream with the magnetic field.

Second, formation of energetic reflected electrons has recently received larger interest. Previous works have stressed the magnetic mirror process (also so-called Fermi-type) as the dominant mechanism responsible for electron reflection [57, 58]. However, these previous works have been based on simplifying assumptions where the shock front is assumed to be homogeneous and stationary. By analyzing trajectories of pre-selected electrons interacting self- consistently with waves in 2D PIC simulations of a planar shock, Lembège and Savoini [59] have shown that magnetic mirror is not a unique mechanism for reflection. Trapping can also take place both within the shock rippling and the gap between the ramp and the growing foot. As a consequence, energetic reflected electrons form field aligned beams which are not homogeneous in space (effects of the shock front rippling) and not continuous in time (formation of electron bursts under the effects of the shock front self-reformation along the shock normal).

Extensively, 2D PIC simulations of a curved shock and of the associated electron foreshock [29] has allowed to retrieve typical signatures of local distribution functions observed experimentally by ISEE [60, 61, 62] and WIND [63, 64, 65], and to evidence that different mechanisms responsible for local electron ring (signature of Fermi-type reflection) and electron bump-in-tail distributions (field aligned beam) coexist in the foreshock region.

Moreover, shock acceleration is also presumed to be the important process producing high-energy particles up to the knee in the cosmic ray spectrum. In contrast with the formation of energetic ions predicted by the diffusive acceleration (prediction of a power-law energy spectrum) which can be often observed in spacecrafts measurements at planetary shocks and the interplanetary shocks, electron non-thermal acceleration still remained an unresolved question. For a perpendicular shock, Shimada and Hoshino [34] extended the previous work of Cargill and Papadopoulos [66] and have shown that spiky structures are formed in the electron phase space associated with vortex representing the nonlinear evolution of the (BI) two-stream instability excited within the foot (Sec. 2.1.2). As for the mechanism invoked for producing the non-thermal electrons, Hoshino [67] addressed the so-called shock surfing acceleration. Shock surfing is usually considered for pick up ions to be a pre-acceleration mechanism to initiate the diffusive shock acceleration [68, 69]. Hoshino [67] and Hoshino and Shimada [70] stressed that series of large amplitude ES waves excited by the BI in the shock transition layer can effectively trap electrons and the electron shock surfing can be switched on. This may be an efficient process for the origin of high energy particles which can apply for many astrophysical applications such supernovae shocks [71].

2.2 Quasi-Parallel Shocks

Studies of quasi-parallel shocks are in relative limited number as compared with those dedicated to quasi-perpendicular shocks. Reinforced interest has been activated by the high resolution measurements of SLAMS (Short Large Amplitude Magnetic Structures) made by CLUSTER-2 mission [72, 73] and the first campaigns of 1-D PIC simulations of quasi-parallel shocks (most previous simulations on this topics have been performed with hybrid codes). Tsubouchi and Lembège [74] have analyzed the progressive transformation of ULF waves (initially excited by the interaction of the field-aligned reflected beam with incoming ions) into SLAMS, and have retrieved typical SLAMS signatures already identified by ISEE mission [75, 76]. In particular, transitory spiky structures of the electrostatic field (not accessible in previous hybrid simulations) are evidenced in association with a local strong ion trapping within the large amplitude whistler precursor emitted from the leading edge of the SLAMS. At late times, a self-reformation of the leading edge (SLAMS front) takes place similar to that of a local quasi-perpendicular shock front. On the other hand, Scholer et al. [77] have analyzed the respective contribution of SLAMS and of the phase standing whistler precursor emitted from the steepened edge of the SLAMS in the overall self-reformation process of the quasi-parallel shock. All these results stressed the importance of using high spatial resolution in simulations, or equivalently the accessibility to scales lower than the ion scale, even for a transition region where ion dynamics plays a key role.

It is well established observationally that interplanetary shocks associated with co-rotating interaction regions (CIR) and coronal mass ejections (CME) accelerate ions from several 100 kev/nuc. to a few Mev/nuc. for shocks about 5 AU of the sun. Within this region of the solar wind, shocks are often quasi-parallel. An important question for particle acceleration at shock wave is how particles are accelerated from the thermal core of the solar wind up to energies sufficiently large that they can be accelerated diffusively at a shock wave. This is the well known ‘injection’ problem. For a particle to be accelerated diffusively at a shock by the first-order acceleration Fermi mechanism, the particle must be sufficiently energetic that it can scatter diffusively across all the micro- and macrostructure of the shock, experiencing compression between converging upstream and downstream states. Based on a quasi-analytical numerical model, Zank et al. [78] have shown that pickup ions incident on a quasi-parallel shock can experience specular reflection at the shock as a result of either the electrostatic cross-shock potential or the mirroring associated with the shock compression of the magnetic field. A large part of pick up ion distribution is reflected. This mechanism is termed stochastic reflected ion acceleration or SRI in short. Later, hybrid simulations where solar wind alpha particles and pick-up ions are included self-consistently have been performed by Scholer and al. [79]. They confirmed quantitatively the results of Zank et al. [78], and showed that the reflection efficiency is almost independent of magnetic field-shock normal angle, which indicates that magnetic mirroring is unimportant and does not lead to larger reflection efficiencies. In addition, Scholer et al. [79]

found that the reflection efficiency of pick up ions rapidly decreases when the pick up ions density exceeds a few percent of the solar wind density, and that upstream diffuse solar wind ion densities and spectra are rather independent of the solar wind temperature or details of the core distribution function. The acceleration of protons to energies higher than have been obtained previously with self consistent plasma simulation has been performed by Giacalone [80], who used very large scales hybrid simulations. Moreover, these results showed that the energetic particles fluxes upstream decay with distance from the shock and approach a constant. This implies that the accelerated particles have mean free paths that increase with distance upstream away from the shock.

2.3 Slow Shocks

The above results are only related to fast mode shocks. Works dedicated to slow mode shocks are in relative limited number as compared to fast shocks. In contrast with fast shocks which convert flow energy into thermal energy, slow shocks convert magnetic energy to plasma kinetic energy. Then, the slow mode shock is hypothesized to play an important role in the process of magnetic reconnection. Most of previous simulations on slow shocks are based on the use of hybrid simulations. Only recently, an effort has been invested to analyze slow shocks with full particle simulations by Daughton et al. [81]. These simulations retrieved all the main features of slow shocks and ion heating obtained by hybrid simulations. Moreover, Daughton et al. [81] have evidenced clear non-Maxwellian features for electrons. In the upstream region, back-streaming electrons give rise to double-peaked distributions, while in the downstream region, back-streaming electron distributions are observed with a temperature anisotropy. Such patterns are found in quite good agreement with experimental results of Geotail mission. By using 1-D full particle simulations and a hybrid model in which off-diagonal electron pressure tensor terms are retained in the Ohm’s law, it Yin and al. [82] have demonstrated that downstream electron temperature is anisotropic at very oblique angle and that very oblique slow shocks can be modeled by including the electron quasi-viscous effects resulting from the presence and relaxation of the electron pressure anisotropy. The anisotropy results from both the large mirror effects and the electron heating due to the parallel electric field of very obliquely propagating kinetic Alfvén waves [82].

3. Collisionless Magnetic Reconnection

Magnetic reconnection enables the conversion of energy stored in stressed magnetic fields into high-speed plasma flows and thermal energy and serves as a fundamental plasma transport mechanism in collisionless plasmas [83]. The understanding of magnetic reconnection in a collisionless plasma has been a topic of long-standing interest. Traditionally, most studies have been limited to the idealized two-dimensional (2-D) problem. During the period under review, however, the study of 3-D effects in reconnection has received increasing attention. The ultimate goal of understanding reconnection in a topologically open system remains a daunting challenge.

3.1 Fast Reconnection in 2D: Hall Physics

The classical problem in magnetic reconnection involves the evolution of the tearing instability in a reversed-field configuration [84] in two spatial dimensions. A long history of investigation of this problem led up to the Geospace Environmental Modeling (GEM) magnetic reconnection challenge [85, 86, 87, 88, 89, 90, 91, 92]. This effort involved investigation of a standard reconnection configuration and boundary conditions by a variety of numerical codes ranging from fully electromagnetic particle-in-cell (PIC) simulations to conventional resistive magnetohydrodynamic (MHD) models. The goal was to identify the essential physics that is required to model collisionless magnetic reconnection.

An essential feature of the standard GEM challenge configuration was the inclusion of a finite amplitude magnetic island perturbation to trigger the dynamics. The rationale for using a large initial perturbation was to put the system in the nonlinear regime of reconnection from the outset and thus avoid the well-known dependence of the linear stage of the tearing instability on the precise form of the dissipation mechanism. Although not discussed explicitly at the time, the perturbation B_z results in a $J_y B_z / c$ stress along the current sheet directed away from the X-line which is not compensated by any pressure difference [93]. The resulting order-unity MHD stress imbalance removes the plasma that provides the initial current which supports the field reversal, and so the current sheet starts to collapse. This creates an inductive electric field E_y that acts to replace the lost current carriers with newly accelerated electrons and ions. Since all of the models obeyed the MHD momentum equation, it is not surprising that the initial response was similar in all cases. The initial hydromagnetic stage was over by $\Omega_{i0} t \sim 12$, where $\Omega_{i0} = eB_0 / m_i c$ is the ion cyclotron frequency in the asymptotic field B_0 . Beyond that time, it was found that all of the models which included the Hall term in the generalized Ohm’s law experienced a similar enhancement in the reconnection rate, corresponding to an inflow speed of a few tenths of the Alfvén speed v_A based on B_0 and the downstream density. The key conclusion was that this enhanced rate of reconnection, which far exceeded that which was produced in resistive MHD, was insensitive to the specific mechanism which breaks the frozen-in condition, be it resistivity, electron inertia, or electron thermal motion.

The Hall term brings the dynamics of whistler waves into the system [94]. A general analysis of the role of dispersive waves (either whistler or kinetic Alfvén) in collisionless magnetic reconnection was carried out by Rogers et al. [95] based on the results of a two-fluid model with finite electron inertia. They identified two key parameters that determine whether dispersive waves will be present and thus lead to an enhanced rate of magnetic reconnection: (1) the plasma beta β_x outside of the plasma sheet defined using B_0 and (2) $\mu_x = (m_e/m_i)\left(1 + B_{0y}^2 / B_0^2 + \beta_x/2\right)$ (where B_{0y} is the value of the out-of-plane or "guide" field). The GEM challenge configuration corresponds to $\beta_x/2 \ll 1$ and $\mu_x \ll 1$, where whistler waves only are responsible for the fast reconnection.

The GEM challenge studies were originally performed for rather modest values of the ion to electron mass ratio, $m_i/m_e = 25$ and 100. A significant increase in the value of m_i/m_e that can be treated in PIC simulations has been made possible by further advances in the area of implicit particle simulation [96]. This approach, although still considered experimental, allows more rapid simulations on ion length and time scales than do conventional explicit schemes while retaining the kinetic effects of both the electrons and ions. The 2-D GEM problem was successfully modeled using the physical value $m_i/m_e = 1836$ [96]. The agreement with the physical picture based on the low mass ratio simulations was very good, and in particular the scaling laws based on reconnection via non-gyrotropic electron pressure were verified up to the physical proton/electron mass ratio.

A number of other studies pursued aspects of Hall physics applied to reconnection. Wang et al. [97] discussed the linear dispersion properties of waves in the reconnection layer including Hall current and electron pressure gradient effects and estimated nonlinear reconnection rates. Yin and Winske [98, 99] compared the Hall-MHD and hybrid (kinetic ions, fluid electrons) treatments of current sheet thinning and reconnection with particular emphasis on the role of electron pressure tensor effects. Dorelli and Birn [100] used resistive Hall MHD to identify three distinct regimes of magnetic coalescence: the resistive MHD limit, the whistler-mediated limit, and the whistler-driven limit. The origin of hot and suprathermal electrons associated with magnetic reconnection was studied by Hoshino et al. [101] using a 2-DPIC simulation. They found that in addition to acceleration due to meandering/Speiser motion near the X-line, the grad B and curvature drift near the magnetic field pileup region were important processes in producing non-thermal electrons.

3.2 3-D Effects in Reconnection

A full 3-D geometry allows for the excitation of finite-k_y instabilities that have the potential to alter the basic 2-D structure of reconnection. In particular, the localized current layers observed in the 2-D solution could break up. An investigation based on two-fluid equations with finite electron inertia [102] found that two of these modes, an electron shear flow instability and the lower hybrid drift instability (LHDI), combined to produce a strongly turbulent configuration in which the sharp gradients near the X-line broke up.

PIC simulations of 3-D reconnection have produced quite different results. These studies are generally of two different types: in the first ("biased"), a substantial X-line perturbation is introduced as in the 2-D GEM challenge problem; in the second ("unbiased"), a pure initial-value approach is used, typically starting from the Harris neutral sheet with a half-thickness wc/ω_{pi}, where c/ω_{pi} is the ion inertia length based on the peak density. The conclusions from these two approaches were rather different. The X-line perturbation simulations [103, 104, 105] found that the 3-D effects were minor; the thin electron current layer near the X-line formed on a scale $> c/\omega_{pe}$ and remained a 2-D structure with essentially no variation as a function of y. The absence of electron shear-flow-driven modes has been explained by the heating of the electrons in the low magnetic field region which then causes the electron gyroexcursion, and hence the self-consistent current sheet half width, to exceed c/ω_{pe} [105]. Weak LHDI did occur along the boundaries of the outflow region, but they played a very limited role in the reconnection process. In the initial-value simulations [87, 106, 107, 108], however, the LHDI played a prominent role. It had been found in 2-D y, z simulations [109, 110, 111] that the nonlinear evolution of the LHDI led to the formation of a thin electron current layer with scale size $< c/\omega_{pi}$ within the original current sheet. The 3-D simulations then showed that this electron layer triggered reconnection on a much faster time scale than expected from the usual 2-D x, z tearing instability.

The 3-D PIC simulations typically have relatively short extensions $L_y < 10 < c/\omega_{pi}$ in the direction of the equilibrium current. While the unbiased simulations initially showed the development of several reconnection patches within this distance, these patches tended to extend to form a single X-line. In a biased simulation with an open geometry [103], there was evidence for the formation of a pressure-driven kink-like mode in the outflow region when the length $L_y 10\, c/\omega_{pi}$. A two-fluid simulation with a stretched grid in the y direction and a very large value of $L_y = 128\, c/\omega_{pi}$ [112] found that reconnection proceeded via the formation of isolated patches with characteristic size of $10\, c/\omega_{pi}$. These regions propagated in the direction of the electron flow. 3-D Hall MHD simulations with half width $w < c/\omega_{pi}$ and in which reconnection was initiated with a magnetic field perturbation localized along the current channel [113] showed that a magnetic wave structure propagated opposite to the current (in the direction of the electron drift) and led to the asymmetric thinning of the plasma layer and strong plasma flows in the direction of the current.

3.3 Guide Field Reconnection

3-D PIC simulations have been performed of both the biased [93, 114] and unbiased [107] types. Drake et al. [114] used a current sheet with half thickness $w = 0.25\, c/\omega_{pi}$, very cold electrons and ions with $T_e = T_i = 0.04 m_i v_A^2$, a uniform plasma density, and a very strong non-uniform guide field varying between 5.0 B_0 and 5.1 B_0. They observed the formation of intense electron beams near the magnetic X-line and separatrices. These beams were unstable to the Buneman instability; this resulted in strong turbulence which collapsed into localized 3-D nonlinear structures in which the electron density was depleted. These holes formed initially in the vicinity of the X-line and later spread along the full length of the magnetic separatrices. Pritchett and Coroniti [93] used a sheet with half thickness $w = 0.5\, c/\omega_{pi}$, $T_i = 0.42 m_i v_A^2$, $T_e = T_i/5$, a Harris density profile with a 20% background component, and a uniform guide field equal to B_0. They observed only a ~ 20% reduction in the growth rate compared to no guide field; the ion outflow polarized the separatrices, forming a pair of positively charged and a pair of negatively charged separatrices. On the positive separatrices, the inductive E_y electric field was not shorted out, and the resulting $E_{||}$ produced an electron beam component with $v_{||}$ of the order of the electron Alfvén speed $(m_i/m_e)^{1/2} v_A$. The beam-dominated electron distribution produced turbulence with ω/ω_{pi} ~ 1-2 in the vicinity of the positive separatrices, but no intense waves developed near the X-line. The acceleration of electrons within the diffusion region appeared to be limited by their ballistic transit time across the region. Scholer et al. [107] used a half thickness $w = 0.5 c/\omega_{pi}$, a temperature ratio $T_i/T_e = 2.7$, a double Harris sheet with no background component, and a uniform guide field equal to B_0. They found that the guide field reduced the effect of the LHDI so that the onset of reconnection was considerably delayed; the eventual rate of reconnection was comparable to that seen without a guide field. The reconnection was 2-D right from the onset. Studies in both 2-D and 3-D [91, 93, 115, 116, 117, 118, 119] indicated that the guide field strongly altered the structure of the magnetic field and particle dynamics. In particular, the formation of a spatially antisymmetric (quadrupolar) out-of-plane magnetic field, which characterizes the guide-field-free case [120, 121] and is frequently cited as a signature of collisionless reconnection, was not maintained.

3.4 More General Configurations

Reconnection normally occurs in configurations more complicated than a simple current sheet. Among the additional features which have been considered in recent years are density gradients across the current sheet at the magnetopause, magnetotail configurations with a normal field component, and a truly open geometry in which magnetic flux and particle flows can escape.

A 2-D PIC simulation of collisionless magnetic reconnection in the presence of a large density asymmetry across the current layer was performed by Swisdak et al. [122]. In the presence of a finite guide field, such a density asymmetry will yield a component of the diamagnetic drift parallel to the current layer. This will cause an advection of the X-line. It was found that when this drift becomes of the order of the Alfvén speed, the large scale outflows from the X-line necessary for fast reconnection could not develop and the reconnection was suppressed. This effect leads to a stabilization condition on β_x,

$$\beta_x > \left(B_y/B_x\right)\left(2L_p/\left(c/\omega_{pi}\right)\right),$$

where B_x is the amplitude of the reconnecting field, $\beta_x = 8\pi nT/B_x^2$, and B_y and the scale length L_p are evaluated at the current layer. Thus, at high β_x one expects suppression of magnetic reconnection in the presence of a significant guide field. Semi-global hybrid simulations in 2-D of the dayside reconnection layer were conducted by Lin [123] with emphasis on the structure of the magnetopause boundary layer and the formation of field-aligned currents.

The complicating feature of reconnection in the magnetotail is the presence of a normal magnetic field across the current sheet; this makes the initial equilibrium 2-D. Arzner and Scholer [124] performed a large scale 2-D x, z ($100R_E \times 25R_E$) hybrid simulation in which a localized resistivity was used to initiate reconnection. They studied the ion kinetic structure in the post plasmoid plasma sheet where the ions are demagnetized and are picked up by the electron fluid ejected from the X-line. Slow mode shocks were not observed; rather the structure in the fields had the form of a standing large-amplitude whistler. The long-standing problem of tearing stabilization due to electron compressibility in the presence of the normal field component was addressed by Sitnov et al. [125] in a Vlasov linear stability analysis. They included the different response of the trapped and transient electrons in the drift-kinetic description. They found that the tearing mode is unstable for ion to electron temperature ratios typical for the magnetotail if the sheet is sufficiently long so that the electrons leaving it may be treated as transient particles.

Neither the initial-value nor X-line perturbation approaches to reconnection are entirely adequate to model the magnetotail where reconnection often occurs in response to driving by a convection electric field imposed by the solar wind. Such a driven system can be modeled by imposing a localized, time-dependent electric field E_y at the lobe boundaries [103, 109]. An important consideration is then to have a downstream boundary where flux, perturbed magnetic field, and particle flows can escape. In 2-D PIC simulations such a driven system can reach a steady state where the reconnection is balanced by the external driving field [126].

4. Simulation and Theory of Nonlinear Kinetic Waves and Structures

4.1 Introduction

As a result of new measurements obtained from satellites in the auroral ionosphere and elsewhere [127, 128, 129, 130, 131], the period between 1999 and 2003 has seen a renewal of simulations and theory of nonlinear kinetic waves and structures such as phase space holes and double layers. Although such structures have been intensively studied for over 40 years, it has only recently been established that they occur naturally in space plasmas. The combination of the recent spacecraft measurements and advances in simulations have furthered our understanding of the evolution of phase space holes, double layers, their origins, the interactions between them and the role of other waves, such as electrostatic whistlers and ion-cyclotron waves in the multidimensional time-evolution of the field structures and their self-consistent distribution functions.

Figure 1 illustrates the topological shape of 1-D electrostatic double layers and of 1-D electron holes in $z - v_z$ phase space, when visualized in terms of their associated scalar potential, electrostatic field, total charge density or electron phase space trajectories. The electric potential of a double layer is a ramp in space, while that of a phase space hole is a hill. In terms of the electrostatic field a 1-D double layer appears in space as a unipolar localized field structure, whereas a phase space hole shows up as a bipolar localized field structure. It is the electric field signature (primarily the component parallel to $\mathbf{B}$) that is typically used to identify phase-space holes or double layers from in situ satellite measurements.

In terms of the total charge density in real space, the double layer appears bipolar (and thus derives its name), whereas the phase space hole is a ridged *caldera* (i.e., a tripolar hole). Finally, in (electron) phase space, the electrons associated with a 1-D double layer are accelerated in one direction (down the potential energy ramp) and reflected in the other (up the potential energy ramp). The electron phase space hole takes its name from its phase space appearance. There are generally both left and right moving "passing" electrons in addition to the trapped ones forming the "hole."

In addition to the above-mentioned variety of names for the structures, localized bipolar fields have sometimes been loosely called "solitons" or "solitary waves," although these are not really suitable mathematically rigorous names for these structures. For example, the spatial width of the bipolar electric field associated with an electron phase-space hole increases as its amplitude increases, which is opposite to the behavior exhibited by a classical soliton [132].

In the late 1960's, electron phase space holes were identified as the saturated state of electron two-stream instabilities using computer simulations. Morse and Nielson [133] found them in one, two, and three dimensional kinetic simulations, although in an unmagnetized plasma they were found to be stable only in 1-D. Other simulations and kinetic theory were carried out by Roberts and Berk [134] and Berk et al. [135].

The concept of a double layer was first developed by Langmuir [136], but not within the context of kinetic theory. A good review of early theoretical work on the kinetic theory of double layers, including both laboratory space plasma physics can be found in the review article by

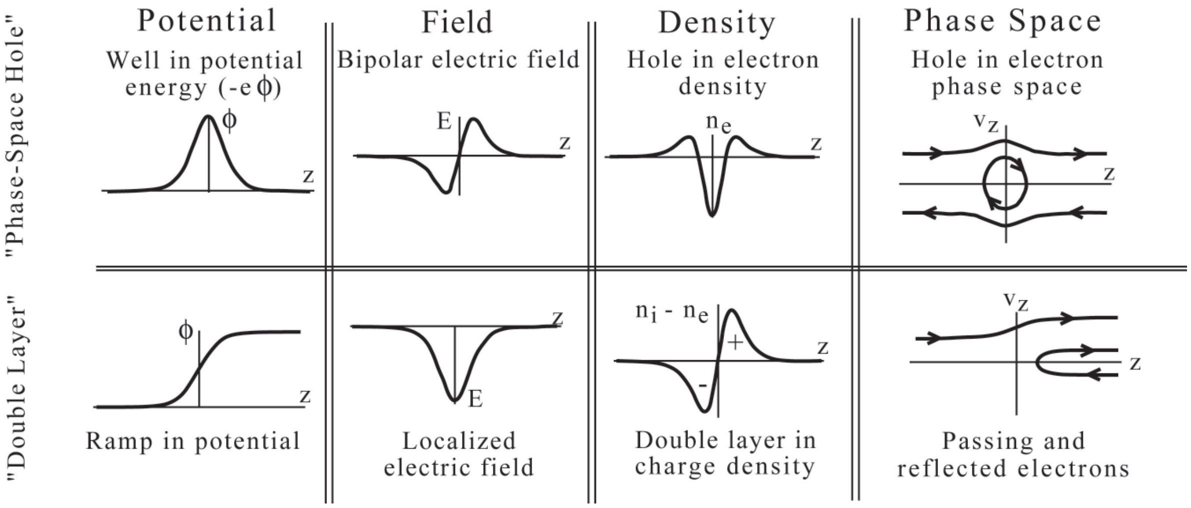

Figure 1. A schematic representation of a phase-space hole and of double layer properties.

Block [137]. Much of the early kinetic theory was concerned with the construction of stationary nonlinear solutions of the 1-D Vlasov equations – the so-called Bernstein-Green-Kruskal (BGK) solutions [138] – with electron phase space features similar to those in Figure 1, above. Such solutions were limited in at least three different ways: they were not dynamical solutions, they were constructed only in one spatial dimension and they were commonly untested for stability or for accessibility.

4.2 Recent Work on Phase-Space Holes and Double Layers

4.2.1 Theory of Stationary Structures

A theoretical analysis of the structure of stationary 1-D electron holes has been the subject of several recent papers [139, 140, 141, 142, 143]. These references are not specifically directed at space-plasma applications. A general application to the magnetospheric environment is contained in Krasovsky et al. [144] and a study of the interaction dynamics of electrostatic solitary waves is contained in Krasovsky et al. [145]. Shukla et al. [146] have developed a theory for 3-D phase-space vortices associated with electron-acoustic waves. These structures have been invoked by Matsukiyo et al. [147] as contributing to high-frequency electric wave spectra in their 1-D particle simulations that address FAST observations in the auroral upward-current region.

Theoretical stationary 1-D models based on specific space observations are presented in Muschietti et al. [132, 148]. Here, a relationship between the size and maximum potential of electron holes is established and compared with FAST measurements. Other general theoretical discussion is contained in Lakhina et al. [149].

Stationary models of electron holes in 3-D (with azimuthal symmetry about the magnetic field direction) have also been developed [150, 151, 152, 153, 154, 155]. Specific issues raised in these references are interaction of holes [152] and "stretched" solitary waves [151].

Theoretical modeling of double layers has been more limited during this time period. Stationary BGK models of strong double layers constrained by "boundary" distributions measured in the auroral ionosphere are presented in Ergun et al. [156, 157].

4.2.2 Simulation of Dynamically Evolving Structures

Recent satellite observations of bipolar structures in various space environments have prompted a number of new simulation studies. Periodic 2-D PIC simulations [158, 159, 160, 161, 162] were carried out for two-electron-stream distributions in "strongly" magnetized plasmas with the electron cyclotron frequency Ω_e well in excess of the electron plasma frequency ω_e. These simulations revealed new phenomena characterized by the formation of phase-space "tubes" (in $z - v_z - x$ phase space). Here z is parallel to the magnetic field $\mathbf{B}$ and x is perpendicular to $\mathbf{B}$. The tube axis is in the x direction. The tubes undergo instability and break up while electrostatic whistlers and lower-hybrid waves grow. Longer runs [163, 164] showed slower instabilities associated with a residual bump on the evolved electron distribution driving waves at ion cyclotron harmonics.

Simulations were also carried out in 3-D [165, 166, 167]. Differences were observed between the way lower-hybrid waves (with wave vector approximately perpendicular to $\mathbf{B}$) develop in 3-D versus 2-D.

Particle simulations (in 2-D) were carried out for weaker beams relevant to GEOTAIL observations [168, 169], and were extended to an open boundary-injection configuration [170] and driving by an applied parallel electric field [171]. Several theoretical models were proposed to address the interaction of phase-space tubes and electrostatic whistlers leading to tube breakup. If the magnetic field is sufficiently weak ($\Omega_e < \omega_b$, where ω_b is the bounce period electrons on trapped orbits in the unperturbed electron hole), phase-space tubes are unstable to a transverse instability [172]. Similar dependence was found in Singh et al. [173]. For stronger magnetic fields, bounce-resonance interactions [174, 175] occur for whistler frequencies at multiples of ω_b. Resonant interactions of electrostatic whistlers with vibrational normal modes of phase-space tubes [176, 177, 178] occur for whistler frequencies below ω_b. Cerenkov radiation of lower-hybrid and electrostatic whistler waves by moving electron holes [179] has also been proposed.

Simulation of double layers can be either potential driven, with a fixed potential drop across the simulation domain, or current-driven, where the potential drop develops self-consistently with the plasma evolution. In all cases, electron holes routinely form on the high-potential side of the double layer. Potential-driven 1-D Vlasov simulation studies include those of Singh [180, 181], with the application to plasmas with background density gradients [182] and expanding plasmas [183].

Particle simulations in 2-D of plasmas of different density expanding into a vacuum [184] show the formation of structure near the ion gyroradius scale and perpendicular ion heating. An alternative approach to studying plasma expansion into a vacuum (specifically, the lunar wake) is considered in Birch and Chapman [185, 186].

Current-driven double layers in 1-D simulations with open boundary conditions have been initialized with either a deep density depression [187] or with a weak density depression that subsequently evolves self-consistently into a strong double layer with a deeper depression [178, 188]. These double layers can be either laminar (smooth) or turbulent (noisy), with the latter described by the more general term, "transition layers." In addition to electron holes on the high potential side of the transition layer, trains of alternating electron and ion holes can be driven on the low-potential side [189].

5. Conclusions

Within the four-year period covered by this review, much effort has been devoted to the analysis of the nonlinear and kinetic aspects of processes in space plasmas. Numerical simulations which include the kinetic effects of ion dynamics, or both electron and ion dynamics, have played a key role in the analysis of processes whose space and time evolution cannot be described by quasi-linear theory or simple configurations involving a uniform and/or stationary system. This work has been concentrated in two complementary areas: (i) multidimensional simulations are now much more prevalent than in previous periods, and (ii) more realistic conditions and physical values of plasma parameters have been treated. Further progress in combining these two efforts is still essential since different types of instabilities and processes can compete or couple with each other, and the properties of instabilities can change for realistic parameters. The list of topics reviewed here is not exhaustive, and similar remarks may apply to other fields where the kinetic approach is also (or soon will be) necessary. The present results provide a good illustration of the status of investigation of kinetic and nonlinear processes in space plasmas.

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Mobile Phones and Tumor Risk: Interpretation of Recent Results

A. Ahlbom
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S. Lönn

The focus of this review is on the latest Interphone Study results. Quite a number of further reports from the Interphone Study are anticipated, and these results may obviously change the assessment of the science. However, we believe that the discussion of existing reports to date that we present in the current review might be helpful in the evaluation of reports to come. We conclude that the strongest support for the hypothesis that RF exposure from mobile phones increases the risk of tumor comes from our own acoustic neuroma study, although bias, in particular recall bias, cannot be ruled out as an explanation for the findings. To date, however, this study has only weak support from other research. Thus, it is essential to wait and see whether our results are replicated or not. As for other brain tumors, available data so far provide little evidence for an association with mobile phone use. However, this conclusion must be qualified with the comment that studies to date have looked at relatively short induction and latency periods.

There is extensive public and scientific interest in the possibility that exposure to radiofrequency (RF) electromagnetic fields from mobile telephony might increase the risk of disease, and particularly the risk of brain cancer and other intracranial tumors. The background to this interest does not appear to be a biologically based hypothesis, but rather a concern that the current understanding of how fields interact with the human body might be incomplete or misconceived. This concern is clearly amplified by the rapid worldwide penetration of mobile phone use. Yet, despite quite extensive experimental in vivo and in vivo research, there is no known biological or biophysical mechanism that could explain how low-level RF exposure might lead to an increased risk of disease. The only established effect of RF exposure remains heating. Thus, if epidemiologic studies were to suggest that RF exposure from mobile telephony indeed increases the risk of cancer, they would have to stand on their own.

Quite a number of reviews have been published on this topic, some of them taking a broad perspective and some being narrower. Two of the latest looked at all RF epidemiology, regardless of source of exposure and outcome and provide rather comprehensive reviews [1, 2].

The Interphone study is an international collaboration consisting of more than a dozen brain-tumor case control studies, focusing on RF exposure from mobile telephones. There are considerable expectations that the Interphone study will provide a rather clear answer regarding whether or not mobile phone use is linked to an increased brain-tumor risk. It remains to be seen to what extent such expectations are justified. While it will take several years before all results are made available, and even before the first results from all individual centers will be made available, two of the centers have already published their first results [3, 5]. However, these publications are recent, and so far no review has had the opportunity to discuss them in any detail. The focus of this review will be a discussion of these latest Interphone Study results in the context of previously reported findings from other studies. Quite a number of further reports from the Interphone Study are anticipated to be published during 2005 and shortly after, and these results may obviously change the assessment of the science. However, we believe that the discussion of existing reports to date that we present in the current review might be helpful in the evaluation of reports to come.

Probably the strongest support for the hypothesis that RF exposure from mobile telephones increases the risk of tumor comes from our own Interphone Study publication on acoustic neuroma that was published in the fall of 2004 [4]. The study was based on 148 cases and 604 controls. Overall, the relative risk for regular use of mobile phones was 1.0 (95% *CI* = 0.6-1.5). However, the relative risk ten years after first use was 1.9 (0.9-4.6), and when restricted to

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

tumors on the same side of the head as the phone was normally held, the relative risk was 3.9 (1.6-9.5). There are several possible explanations for the observed excess risk, besides causality. While chance seems an unlikely candidate given the numbers, we cannot rule out bias.

Classical recall bias is indeed a possible explanation, but it is not clear why this would only produce an excess risk ten years after first use of mobile phones. In addition, we would have expected recall bias to operate also in the study on brain tumors such as glioma and meningioma – not only in the study on acoustic neuroma – but we found no excess risk for mobile phone use in the brain-tumor results [5]. A detection bias would be introduced if undiagnosed cases of acoustic neuroma were detected earlier in mobile phone users, perhaps because they would be more sensitive to hearing impairment. However, this scenario would have resulted in a marked increase in diagnosed acoustic neuroma that would have been evident already. Note that this increase would be simultaneous with the increase in mobile phone use and would not, for example, require a long latency period. Thus, detection bias would have produced increased risks also among short-term mobile phone users. A further possible source of bias is the non-responders. Response rates were 93% among cases and 72% among controls. A small sub-sample from the non-responders indicated that phone users were more likely than nonusers to participate in the study. Since participation rate is higher in cases than in controls, this would rather suggest that any bias would pull the relative risk downwards rather than inflate it. This notion is supported by the fact that our glioma and meningioma results point towards a slight under-risk [5]. Even though we find little support for bias, it remains a candidate for explanation of the excess risk, and it is essential that the results are viewed in the context of other existing and future data.

The most obvious comparison of the above paper is with the corresponding Danish report that was published early in 2004 [3]. This paper was based on 106 cases and 212 controls, with a response rate among cases of $106/(106+23)=82\%$ and among controls of $212/(212+120)=64\%$. There is no indication of a positive association between mobile telephone use and acoustic neuroma risk reported in the paper; indeed, many of the reported odds ratios were in the reverse direction. For less than 10 years since first regular use, the results were very similar to the Swedish results discussed above. For more than 10 years, the Swedish results pointed towards an excess risk while the Danish results didn't: the odds ratio was 0.22 (0.04-1.11). It is, however, worth noting that this estimate was based on only two exposed cases; the corresponding control number was 15. It is not clear what explains this low odds ratio, although small numbers obviously may play a role. The authors speculate that hearing loss due to the disease may have decreased mobile phone use. The authors, however, argue against the influence of selection bias created by the non-responders, based on their analysis of the dropouts. Yet, just as in the Swedish data, it remains a possibility that this type of selection bias plays some role. In conclusion, it is not possible to assess with any certainty the degree of consistency or inconsistency between Swedish and Danish long-term user results, except that there was a considerable agreement for less than 10 years of regular mobile telephone use.

The first report on acoustic neuroma and mobile phones was the hospital-based case control study from the National Cancer Institute, USA (NCI) [6]. The study included 96 cases of acoustic neuroma and 798 controls. Participation rates were not reported separately for acoustic neuroma cases, but were 92% for all types of brain tumors combined, and 86% for patients with the control diseases. For regular use compared to no use, the relative risk was 1.0 (0.5-1.9), while for a duration of regular use of ≥ 5 years it was 1.9 (0.6-5.9), based on five cases. The laterality analysis did not indicate any association between exposure and disease risk. On face value, these results might be taken as support of our own findings, in that prolonged exposure was linked to some excess risk. However, this excess risk was uncertain, as indicated by the wide confidence interval, and the relative risk was certainly also compatible with no risk increase. It is also worth noting that the laterality analysis did not result in an increased relative risk.

Another hospital-based case control study was published almost simultaneously with the one discussed above [7]. This study included 90 cases and 86 controls. No participation rates were reported. For more than three years of use, the odds ratio was 1.7 (0.5-5.1), based on 11 cases and six controls. There was no trend with increasing amount of use, and the laterality analysis indicated a reversed association. Just as for the previously discussed study, taken at face value these results might be taken as support for an association between extended use and acoustic neuroma. Again, however, the relative risk estimate was unstable due to small numbers, and the results were not internally consistent. Furthermore, the longest duration of mobile phone use found in the study was six years.

In a cohort study based on telephone bills, a Danish group reported standardized incidence ratios for 420,095 phone users followed during 1982-1996 [8]. While this study focused on other cancers at the time, considered to be of primary interest, it also reported results for nerve sheath tumors. The SIR was 0.64 (0.49-1.40), based on seven observed cases. However, no further analysis was presented, for example, for longer duration of use. The vast majority of the cohort had recent mobile phone subscriptions; only 8% had used a mobile phone at least six years at end of follow-up.

A second Swedish group has conducted two studies on brain tumors in relation to mobile phone use, and has published at least ten articles on these studies [9, 10]. The validity of these articles has been called into question by previous reviewers, most recently by an independent expert group commissioned by the UK NRPB [2]. We want to emphasize two aspects of particular relevance for the acoustic neuroma results. It is only in the second of the two studies that they reported an excess risk for acoustic neuroma, and in a 2003 paper they reported the odds ratio to be 4.4 (2.1-9.2) [10]. So, the question is whether the results of this study should be taken as support of the hypothesis that RF exposure from mobile phone use causes acoustic neuroma, or if there are reasons to question the findings? A feature of the study, advertised by the authors, is that it only included cases with a histopathologically verified diagnosis [9]. While this clearly produced a high specificity, it had two less appealing aspects. First, since most acoustic neuroma cases are first diagnosed by means of MRI or CT, a certain, but unknown, percentage of the cases will be lost if histopathology is also required for inclusion. The consequences of this are not known, but since MRI and CT are perfectly valid and accepted diagnostic tools for this tumor, there is basically only a downside to requiring a histopathological diagnosis for inclusion as a case. Second, the histopathological diagnosis is only available significantly later in the disease process than an MRI- or CT-based diagnosis. The delay may be several years, perhaps as long as ten years. There are data to suggest that the average period between first symptoms and diagnosis is more than five years [11]. The effect of this in a case-control study is quite clear: The delay between origin of disease and diagnosis must be compensated for when considering duration of phone use and timing of phone use in relation to the disease. This is quite important, because the results reported by Hardell and colleagues seemed to indicate a substantial risk increase also for phone use closely preceding diagnosis [9]. Even though results were reported in overlapping latency intervals, one can use the provided absolute numbers in Table 6 to calculate the odds ratio for ≤ 5 year latency, and this turns out to be 3.0 (1.0-9.3). This result was not commented upon in the paper. Whatever the explanation, any correction would also affect the other results for acoustic neuroma, and it is not possible to anticipate what the end result would be. Thus, the findings cannot be taken at their face value as support of the hypothesis of an association between acoustic neuroma and mobile phone use.

Originally, most of the concern related to cancer and mobile phones was directed towards malignant brain tumors. All of the studies discussed above in the context of acoustic neuroma have also looked at these other brain tumors [5, 6, 8, 9, 12, 13]. In addition, a registry-based Finnish case-control study has reported on brain tumors and salivary gland tumor [14].

Most of these studies were entirely negative in relation to brain tumors [5, 6, 8, 13]. There was, indeed, a rather consistent tendency for a decreased risk in mobile phone users. The reason for this is not clear, but it is possible that the explanation is a slight recall bias, due to a higher participation rate in exposed subjects, as discussed above. The Finnish study did find an association between analog telephone use and glioma risk [14]. The results, however, were unlikely to reflect a causal association, because the excess risk appeared already after a short duration of phone use. Indeed, an excess risk was seen already with less than two years of phone use duration. This was a registry-based study that made selection bias unlikely, and exposure misclassification should pull relative risks towards the null rather than inflate them. However, random variability remains a candidate for explanation.

Also, the two studies by the Hardell group displayed elevated brain-tumor risks [9, 12]. However, these studies have been discussed in detail by previous reviews and their validity questioned. With respect to the Hardell group's first study, the UK NRPB report wrote: "...there would be considerable potential for selection bias, but also for disquiet about the way in which the study has been reported and whether other aspects of the study has similarly been reported in an unsatisfactory manner" [2]. Without repeating earlier arguments, we conclude that these results carry little weight in an overall assessment. In their second study, there was an overall excess for brain tumors, but a substantial part of this excess was due to an increased risk of acoustic neuroma that has been discussed already above [9]. For malignant brain tumors, the odds ratio was 1.1 for each of analogue, digital, and cordless type of phone. When restricted to >10 year latency and tumors occurring in the temporal area the analogue phone, this yielded an odds ratio of 2.0 (0.4-10.9), but based on small numbers; for the other phone types, estimation was precluded because of small numbers. In a later publication, the group presented other estimates and reported ipsilateral results for astrocytoma with an odds ratios of 1.8 with confidence intervals starting at 1.1 for each of analogue, digital, and cordless phones [10]. However, these results did not take duration of phone use into account.

In addition, there are some scattered reports on mobile phone use in relation to other tumors, such as melanoma of the eye and intratemporal facial nerve tumor [15-17]. However, no consistent findings were reported.

In conclusion, the strongest support for the hypothesis that RF exposure from mobile phones increases the risk of tumor seems to come from our own acoustic neuroma study, although bias, in particular recall bias, cannot be ruled out as an explanation for the findings. To date, however, this study has only weak support from other research. The strongest support may be from the two US case-control studies, but the excess risks that were reported in those two studies may very well have been due to chance. The excess risk reported by the other Swedish group is questioned, particularly on the grounds that the risk elevation was associated with phone use too close in time to diagnosis to be credible. Thus, it is essential to wait and see whether our results are replicated or not in later Interphone Study reports. As for other brain tumors, and particularly the malignant brain tumors, the available data so far provide little evidence for an association with mobile phone use. However, this conclusion must be qualified with the comment that studies to date have looked at relatively short induction and latency periods. Again, further Interphone Study reports are anticipated to provide essential information.

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BUSINESS TRANSACTED BY COMMISSION A

Chair: Dr Q Balzano
Vice Chair: Dr S Pollitt

I. Commission A Business Meeting 1, Monday 24 October 2005

Dr. Balzano called the meeting to order at 18:00. Those present introduced themselves giving their name and affiliation, and added their details to the list of participants. 6 voting members were present.

I.1 Approval of agenda

Dr. Balzano proposed an agenda for the meeting that was accepted unanimously.

I.2 Election of new Vice Chair

The Chairman had received 9 ballot papers by mail prior to the meeting. Misters Van Lil and Davis were asked to confirm their ballots, which they did. The other voting members voted by paper ballot at the meeting. The ballots were counted and recounted by the Chairman and Vice Chairman. The result was:

Dr. P Banerjee:	20
Prof. C Davis:	19

I.3 Report on Commission A activities and 1st Council Meeting of the XXVIII GA

The Chairman reported on the activity of the previous three years, specifically on the support given to meetings and conventions, to the Solar Power Satellite (SPS) project, to the Scientific Committee on Telecommunications (STC) and to Commission K. (More detail can be found at www.ursi.org/India05/ComTriReports/ComAtrirep.)

The Chairman also reported on the 1st Council Meeting held on 23 October 2005, including the following items: paper handling for future General Assemblies, the financial report, a position paper on SPS, the report of the STC and the venues for the 2008 General Assembly.

I.4 Activity Report of members

The members present reported no activities of relevance or requiring discussion.

I.5 First discussion of future activities of Commission A

There was substantial discussion about the future of Commission A. The sense of those present was that activities of other Commissions are intruding upon the domain of Commission A.

Those present agreed that the Terms of Reference of Commission A needed to have a sharper focus. It was noted that measurement papers were being presented in other Commissions' programmes. It was proposed that Commission A should propose to Council that the Terms of Reference should be amended from 'Measurement' to 'Measurement Methodology and Calibration'. In future any paper dealing with methods of measurement and calibrations should be presented in Commission A only.

I.6 Commission A Terms of Reference

Dr. Pollitt undertook to draft a 'straw man' revised Terms of Reference which took the previous discussion into account, and to table it for discussion at the 2nd Business Meeting.

I.7 AOB

No other business was tabled. The Chairman adjourned the meeting at 19:20.

II. Commission A Business Meeting 2, Wednesday 26 October 2005

Dr. Pollitt deputised for Dr. Balzano and chaired the Business Meeting. Dr. Pollitt called the meeting to order at 18:00. Those present introduced themselves giving their name and affiliation, and added their details to the list of participants. 9 voting members were present.

II.1 Approval of agenda

Dr. Pollitt proposed an agenda for the meeting that was accepted unanimously.

II.2 Topics of discussion

Those present identified the need for a Web-site to share and communicate the activities of Commission A.

Dr . Davis kindly offered to host a Web-site for Commission A. All members of the Commission are expected to contribute to the site.

Dr. Mishra kindly offered to host a list-server for Commission A.

Commission H had asked Commission A to discuss:
1) The continuation of the SPS ICWG
2) Intercommission session on SPS

Those present unanimously agreed to support Commission H's proposal. Dr. Marvin was asked and agreed to continue as Commission A's representative.

Dr. Tobar drew the members' attention to the AP-RAC'07 to be held in 2007 in Australia.

II.3 Terms of Reference

Dr. Pollitt presented a 'straw man' Terms of Reference:
1) Primary standards, including those based on quantum phenomena, for electromagnetic measurements
2) Time and frequency realisation and measurements
3) Calibration and measurement methodology to support the development and exploitation of electromagnetic technologies, including telecommunications.
4) Characterisation of electromagnetic properties of materials.
5) Electromagnetic dosimetry.

There was discussion on the frequency band covered by Commission A; there was consensus in retaining the present range from DC to optical frequencies. There was agreement that the Commission should emphasize the development and refinement of new measurement techniques. It was also proposed and accepted that there should be reference to measurement intercomparisons and standardisation.

Dr. Pollitt agreed to capture the discussion and modify the 'straw-man' Terms of Reference accordingly and to present a summary at the 3rd Commission A Business Meeting

II.4 AOB

No other business was tabled. The Vice Chairman adjourned the meeting at 19:00.

III. Commission A Business Meeting 3, Friday 28 October 2005

Dr. Balzano called the meeting to order at 18:00. Those present introduced themselves giving their name and affiliation, and added their details to the list of participants. 6 voting members were present.

III.1 Approval of Agenda

Dr. Balzano proposed an agenda for the meeting that was accepted unanimously.

III.2 Review of notes of the 1st Business Meeting

Dr. Balzano presented the notes of the 1st Business Meeting which were accepted without amendment by those present.

III.3 Report of the 2nd Business Meeting

Dr. Pollitt summarised the discussions that took place at the 2nd Business Meeting.

III.4 Report of Council Meetings II and III

Dr. Balzano reported that Council had approved the appointment of Vice Chairs at Council Meeting II, and confirmed that Dr. Banerjee is the new Vice Chair of Commission A.

Dr. Balzano also reported the results of election for URSI President, Secretary General and Vice Presidents and the venue for the 2008 General Assembly (Chicago, USA) which had been determined at Council Meeting III. He also reported on the publication of RSR and RSB and noted that there had not been a contribution from Commission A.

III.5 Discussion of proposed new Terms of Reference

Dr. Pollitt presented the revised 'straw man' Terms of Reference' and the discussion which followed led to the final draft detailed in the next section.

III.6 Final draft of the new Terms of Reference for Commission A

Those members present agreed that the following final draft should be presented to Council and Council's approval sought for the changes.

Commission A: Electromagnetic Metrology (Electromagnetic Measurements and Standards)

The Commission promotes research and development in the field of measurement standards, in calibration and measurement methodologies, and the intercomparison of such.

Areas of emphasis are:
1) The development and refinement of new measurement techniques.
2) Primary standards, including those based on quantum phenomena.
3) Realization and dissemination of time and frequency standards.

4) Characterization of the electromagnetic properties of materials.
5) Electromagnetic dosimetry.

The commission fosters accurate and consistent measurements needed to support research, development and exploitation of electromagnetic technologies across the spectrum.

III.7 AOB

Dr. Pollitt on behalf of members of Commission A thanked Dr. Balzano for his excellent chairmanship of Commission A over the three-year period up to and including the XXVIII General Assembly.

No other business was tabled. The Chairman adjourned the meeting at 19:00.

BUSINESS TRANSACTED BY COMMISSION C

Chair: Professor M. Akaike (Japan)
Vice-Chair: Dr. A.F. Molisch (USA)

I. Business Meetings

I.1 Welcome to URSI General Assembly in New Delhi

The Commission held open business meetings on 24th, 26th, and 28th, October, 2005. The following persons were present at least at one meeting, but mostly at several: Masami Akaike (Chair); Takashi Ohira, Makoto Taromaru, Japan; Said E-El-Khamy, Egypt; Claude Vloeberghs, Belgium; Naurice Bellangen, France; Alain Sibille, France; Jacquis Palicot, France; Marian S. Piekarski, Poland; Paul Wittke, Canada; Sana Salous, UK; Blagovest Shishkov, Bulgaria; Jose Leitao, Portugal; Paul Walter Baier, Germany; V. E. Lyulchenko, Russia; Hendrik Schoneich, Germany; Viacheslav Potapov, Russia.

At the opening of the first business meeting, the Chair welcomed everyone to the meeting and attendees introduced themselves. The Chair then reported briefly the activity of Commission C in this triennium and set the scene.

I.2 Election of the next Vice-Chair

Two candidates, S.E. El-Khamy(Egypt) and T. Ohira (Japan), for the next Vice-Chair were nominated. T. Ohira was elected as a result of 30 points to S.E. El-Khamy of 24 points.

I.3 Commission Editor for the new Radio Science Bulletin

T. Ohira agreed to serve as Commission Editor for RSB (incorporating RRS).

I.4 Review of the Terms of Reference

The Terms of Reference was discussed on the business meeting on 28th October. Since the Terms of Reference were changed to the existing ones three years ago, we agreed to continue as they are : "*Radio-Communication Systems and Signal Processing*".

The Commission promotes Research and Development in:

a) Radio-Communication and Telecommunication Systems;
b) Spectrum and Medium Utilization;
c) Information Theory, Coding, Modulation and Detection;
d) Signal and Image Processing in the area of radio science.

The design of effective radio-communication systems must include scientific, engineering and economic considerations. This Commission emphasizes research into the scientific aspects, and provides enabling technologies to other areas of radio science.

I.5 Role of National Representatives of "C"

Further enhancement of the national and international activity of Commission C should strongly be prompted for the next triennium. While National Representatives are desired to have close contact with Commission C, Commission C also is encouraged to try to cooperate with radio scientists in each country in parallel to National Representatives

I.6 The program for the next General Assembly

The program of the next General Assembly will focus the sessions on mobile radio communications, including wireless access and ultra-wide-band access, and image processing. Since the field of Commission C is very broad, cooperative organization of sessions with other Commissions is necessary.

For organizing the next General Assembly held in Chicago, a wide contact with american scientists in the field of Commission C will be solicited. A list of leading scientists in USA based upon the international conferences held in USA so far will be helpful.

I.7 Other business

Further discussions will be made on the following points:

(1) Necessity for the steering committee to assist chair,
(2) Representative of Commission C for SCT,
(3) Future Terms of Reference, as it is or the commission split and renamed,
(4) Competition, cooperation, and/or interaction with other international conferences and organizations.

II. Review of General Assembly

Commission C organized two tutorials, nine C sessions, and two joint sessions. Among two joint sessions, two sessions were led by Commission C. Since the technical field that Commission C deals with is wide and has relating parts with other Commissions, such joint sessions show characteristic feature of Commission C. Close contact/ collaboration henceforth with other Commissions will be further encouraged. The discussions among the presenters and audience were quite active, which reflects a wide interest to technical subjects of Commission C.

The following are the sessions organized by Commission C:

Tutorials:

- Ultrawideband (UWB) Communications and Ranging, presented by Huan-Bang Li (Proxy of R. Kohno).
- Signal Processing for Analog Smart Antennas, Takashi Ohira.

Other Sessions:

C1: Affordable Wireless Communications for Rural Areas, organized by Ashok Jhunjhunwala.
C2: Analog Smart Antennas, organized by Takashi Ohira.
C3: Beyond 3G and 4G Wireless Communications, organized by Hitoshi Yoshino,
C4: Ultrawideband Systems, organized by Alain Sibille.
C5: Advances in Signal Processing towards Fully Reconfigurable Radio Systems, organized by Jacques Palicot.
C6: Trend in Millimeter-Wave Wireless Access Systems and Their Technologies," organized by Hiroyo Ogawa.
C7: Radio Science for the Ubiquitous Network Society, organized by Shozo Komaki.
C8: Multiantenna Systems," organized by Surenda Prasad.
C9: Radio Resource Management and Spectrum Efficiency, organized by Cengiz Evci and Bernard Fino.
CB: Antennas for Wireless Systems and Mobile, organized by Gerhard Kristensson, and Buon Kiong Lau.
CBA: Measurement of Wireless Channels, organized by Reiner Thomae (C and A), and Girish Kumar (B).
CP1: Propagation for Terrestrial Mobile Systems, organized by Pretti Vainikainen.
CP2: Advanced Technologies for RF/Optical Circuits and Systems," organized by Woo-Young Choi.
CP3: Coding, Modulation, Equalization, and Detection, organized by Convener: Makoto Taromaru
CP4: Recent Advances in Radio Communication Technology and Signal Processing Technology, organized by Convener: Yukihiro Kamiya
CP5: General Poster Session Commission," organized by Masami Akaike

BUSINESS TRANSACTED BY COMMISSION F

Chair: Prof. Martti Hallikainen (Finland)
Vice-chair: Prof. Piotr Sobieski (Belgium)

The Commission held three Open Business Meetings respectively on 24, 26 and 28 October 2005 all chaired by Prof. M Hallikainen.

I. Meeting A

I.1 Agenda

The proposed agenda is approved by the attendees as is.

I.2 Credentials

14 members representing Commission F National Committees are present or represented at the meeting.

I.3 Election of Vice-chair for 2005-2008

Four candidates have proposed to act as incoming Commission F Vice Chair: alphabetically:

- Prof M. Chandra (Germany),
- Prof Inggs (South Africa),
- J-J. Isnard (France)
- Prof Mazanek (Czechia).

After verification of the validity of the credentials, the ballots already received by mail before the deadline are checked and reconfirmed by the voting representatives. Ballot forms are distributed to members who have not yet expressed their vote by mail. Each voting member has to attribute points to the candidates following their preference: 2 points for the first one, 1 point for the second one, 0 points for the next ones.

The results of the ballot are: 19 voters have expressed their vote as follows:

- Prof Chandra : 24 points
- Prof Inggs: 12 points
- J.J Isnard: 5 points
- Milos Mazanek: 16 points.

The Commission confirmed its wish that Prof. Piotr Sobieski would become Chairman at the conclusion of the General Assembly. {The URSI Council subsequently confirmed the appointment of Prof. M. Chandra as vice-chair}.

I.4 Commission F 2005 General Assembly Program

a. Commission F organised ten oral sessions of invited and contributed papers as follows:
- F01: Satellite and terrestrial propagation
  (10 announced papers - 0 no-show = 10)
- F02: Propagation and scattering in vegetation
  (10 announced papers – 1 no-show = 9)
- F03: Mobile and personal access radio propagation
  (7 announced papers – 1 no-show= 6)
- F04: Mobile and indoor propagation
  (7 announced papers- 1 no-show 6)
- F05: Scattering and diffraction effects in remote sensing
  (7 announced papers- 4 no-show = 3)
- F06: Global Remote Sensing (7 announced papers)
- F07: Urban Remote Sensing
  (7 announced papers- 2 no show ; 2 moved to F08= 5)
- F08: Novel sensors and data fusion
  (10 announced papers - 2 no-show = 8)
- F09: Microwave remote sensing of the cryosphere
  (7 announced papers- 1 no-show = 6)
- F10: Remote sensing of atmosphere and ocean
  (10 announced papers- 2 no-show +1added= 9)

as well as the three Inter-commission sessions :
- FG: Signal degradation by ionosphere and troposphere
  (7 announced papers- 1 no-show = 6)
- BCF: Propagation models ands Maxwellian approach to smart antennas
- GF1: Atmosphere-ionosphere sounding by using global navigation satellite systems.

The tutorial FT had to be changed in last minute due to the unavailability of C. Schmullius. This tutorial has been given by P. Pampaloni and S. Paloscia. The Commission F community is very thankful to them for this rush replacement.

Also a large poster session totalling 48 Commission F announced papers and 9 intercommission announced papers has been spread by the LOC over two days with discussion periods of two hours. In this poster session 17 of the accepted poster papers did no-show.

b. The chairman summarises the guidelines, that were given to the convenors before the GA, and those he distributed to all sessions chairman at the GA. He reminded to stick with the announced schedule: no anticipation if earlier or no-show, shorten coffee-breaks if later.

The chairman also prepared forms with a short questionnaire handed to all session chairman who have been requested to fill in their reports immediately at the end of the session. The attendance statistics showed that commission F sessions were followed in average by around 30 to 50 persons with higher numbers for inter-commission sessions (around 50) and the tutorial (around 60).

I.5 Requests from Coordinating Committee and Council and response to co-ordination committee and the publication committee

Prof. Hallikainen first expresses his thanks to those having contributed to Commissions F contributions to RRS. Incoming Vice-Chair Dr. M Chandra is appointed as RRS/RSB editor for Commission F. For the future, the following suggestions for topics are mentioned: polarimetric interferometric radar and/or radiometric techniques; propagation problems related to the use of higher frequencies; articles in relationship with the International Polar Year to be held in 2007; similarly as in July 2006 ISPRS (Photogrammetry) is organised, scientists concerned by this field could be requested to write an article in RSB; dynamic properties of the troposphere with implications on telecommunications systems.

Also, following a request to have representatives of commission F to the URSI publication committee: Steve Reising and Ian Glover accept to volunteer join this committee head by Ross Stone.

II. Meeting B

II.1 Discussion of terms of reference

After a short discussion it is approved to clarify sub item (a,ii) by changing it as follows:
(a)(ii) wave interaction with the planetary atmospheres, surfaces (including land, ocean and ice), and subsurfaces,

II.2 Inter-assembly meetings

Sponsorship modes: A (no financial support), B (financial support), C (loan, very rarely)

a. Meetings since last GA
   i. List of “A” meetings: about 20 meetings (moral sponsorship) see triennium report
   ii. List of “B” meetings: 6 meetings (see triennium report)

III. Meeting C

III.1 Proposed meetings for next triennium 2006-2008

III.1.a Commission F Open symposia:

Volunteers for organising: during the discussion up to four proposals to organize one of the two open symposia are made, well distributed geographically. The chair reminds the tradition to turn from country to country, and displays the list of all previous open symposia organised in the last three decades. He thanks very much the four candidates asking them their preferences:

i. Garmisch Germany: preference for open symposium
ii. Brazil may 2007: preference for open symposium
iii. India: preference for open symposium, either remote sensing
iv. South Africa in Cape Town: preference for remote sensing

Decision:

- Commission F Open Symposium: after presentation by the candidates of the possibilities and advantages of their respective proposals, a vote is made as follows: 13 for Brazil; 4 for Germany.
- Commission F specialist Meeting on remote sensing: after presentation by the candidates of the possibilities and advantages of their respective proposals, a vote is made as follows: 14 for Cape Town; 1 for India.

III.1.b Other anticipated supported (type A) meetings

- MicroRAD2006 28 feb-03 Mar, San Juan, Puerto Rico
- 36th COSPAR
- IGARSS2006
- IGARSS2007
- AP-RASC2007
- ISMOT-2007
- ISAP'2007 20-24-Aug Niigata Japan
- IGARSS'2008 Boston 7-11 July 2008
- MicroRAD 2008 dates (??)
- COMITE 2007 Prague ?Sept 2007
- EUSAR 2006 Jan 22-27 ; Lihue, Hawai, USA

III.1.c Other anticipated supported (type B) meetings

- Commission F Open Symposium (see above)
- Commission F specialist Meeting on remote sensing (see above)
- AP-RASC07 (in addition for sponsorship "A")
- ClimDiff 2007

III.2 Commission F proposals for sessions and organisation at 2008 URSI GA Chicago

The commission was content with the organisation of the sessions in 2005, as well as by the chosen topics. For the next GA several new topics are proposed: sub-millimetric and terahertz propagation (Mazanek+Chandra as possible co-convenors), Cryosphere (Marco Tedesco + Richard Kelly as possible co-convenors; polarimetric methods in radar and remote sensing (Chandra), data fusion from different satellites; special scaling issues in remote sensing; dynamic effects in the troposphere and mitigation techniques (B. Arbesser as possible convenor); interference problems and mitigation techniques.

The members wish to keep a full 4 page paper on CD (with some flexibility on the number of pages) plus a short abstract to be included in the program.

A proposal for a tutorial in the field of wave propagation should be proposed in 2008 as the tutorial in 2005 related to remote sensing of the vegetation. Alos a public lecture for members of other commissions should be proposed at the mid-term co-ordinating committee to be held in spring 2007.

III.3 Inter-commission working groups

III.3.a The WG automatically end at the GA and must be renewed by resolution

i. FG Ionosphere/Atmosphere RS using satellite systems: continues
ii. GF Middle atmosphere
iii. as several members express their concern about the problems related to the solar power satellite (SPS) project, commission F will continue to participate to the WG, if such a WG will continue to exist, and Steven Reising is appointed as commission F representative. Note there is a chance this will be a WG from all commissions and a White Paper would be produced.
iv. Commission F agrees also to participate to inter-commission sessions related to the previous topic (on SPS) at GA2008 : by getting at least 1 commission F paper voicing the opinion of the commission.

III.3.b SCT

suspended

III.4 Representatives to other organisations

III.4.1 SCOR

Commission F interests will be looked after by the vice-chair M. Chandra

III.4.2 IUCAF

For the triennium 2005-2008, Steven Reising is appointed to represent Commission F interests.

III.4.3 COSPAR

For the triennium 2005-2008, Bertram Arbesser-Rastburg is appointed to represent Commission F interests.

III.5 Publications and publicity

a. Radio Science Bulletin (see above)

b. Information dissemination

i. The chairman mentions that the Commission F Home page was established in 2002 in connection of URSI Home Page
ii. Some problems of email mailing lists are reported and the vice chair will take care of having a reliable data base.
iii. The important to get email list from other colleagues addresses (outside URSI Comm F) is also mentioned
iv. Some specific list for Young Scientists should be welcomed either

III.6 Any other business

The commission expresses by means of applause its warm thanks to Prof. M Hallikainen for the work done for the past 3 years as the Chair of the commission.

BUSINESS TRANSACTED BY COMMISSION G

Chair: Professor C. Hanuise (France)
Vice-Chair: Professor P.S. Cannon

I. Business Meeting 1: Monday, 24 October 2005

I.1 In Memoriam

The business meeting commenced with a brief moment remembering past friends of Commission G. They were: L.H. Brace, A. Breed, E. Essex, M. Maundrell, P.J. Melchior, U. Sultangazin, C. Sutton, M. Yamada, K.C. Yeh

I.2 Election of Commission G Vice-Chair for 2005-2008

Four candidates were nominated: Jorge Chau, Anthea Coster, Michael Rietveld, Bruno Zolesi. Voting slips were distributed to the Commission G national delegates and, including votes cast during the assembly, Michael Rietveld was the successful candidate and Bruno Zolesi was second.

Subsequently, the URSI Council endorsed Michael Rietveld as the Vice-Chairman of Commission G for 2005-2008.

I.3 Terms of reference

The terms of reference of Commission G were reviewed and it was decided that no amendment was necessary.

I.4 Commission G triennial report

The report on commission G activities during the past triennium was prepared by the Chairman Christian Hanuise and published well in advance of the General Assembly.

I.5 Commission G Working Groups and Joint Working Groups

All Working Groups triennium reports were included in the Commission triennium report. These reports are the responsibility of the lead commission representative. A very brief verbal report was provided at the Business Meeting.

- *G.1: Ionosonde Network Advisory Group (INAG)*
  Chair: Terence. Bullet (USA)
  Vice-Chair: Christopher. Davies (United Kingdom), INAG Editor: P. Wilkinson (Australia)
  Recommend continuing with Lee-Anne McKinnell (SA) replacing C Davies as Vice- Chair
- *G.2 : Studies of the Ionosphere Using Beacon Satellites*
  Chair: R. Leitinger (Austria)
  Vice-Chairs: J.A. Klobuchar (USA; until October, 2004); P. Doherty (USA, since October, 2004) and P.V.S. Rama Rao (India).
  Recommend continuing.
- *G.3 : Incoherent Scatter*
  Chair: Chair: W. Swartz (USA)
  Vice-Chair: J.P. Thayer (USA).
  Recommend continuing with Ingemar Häggström (Sweden) as Vice-Chair.
- *G.4 : Ionospheric Research to Support Radio systems*
  Chair: P. Wilkinson (Australia)
  Co-Chair: M. Angling (UK).
  Recommend continuing – see record of third business meeting.
- *GF : Middle atmosphere*
  Co-Chair for Commission G: J. Röttger (Germany), Co-Chair for Com. F: C. H. Liu (China, SRS).
  Recommend continuing with the same officers.
- *FG: Atmospheric Remote Sensing using Satellite Navigation System*
  Co-chair for Commission G: C. Mitchell (UK)
  Co-Chair for Commission F. Bertram Arbesser-Rastburg.
  Recommend continuing with the same officers.
- *HGEJ : Supercomputing in Space Radio Science Working Group.*
  Commission G required a representative but one could not be found at this meeting.
- *Inter-commission Working Group on Solar Power Satellite*
  Co-Chair for Commission G: M. Rietveld (Norway).
  Decision for continuing rests with URSI board.

I.6 Publications

The Chair, C Hanuise, on behalf of the Commission, thanked Paul Cannon as the Commission G editor and Vice-Chair for Reviews of Radio Science, for his hard work. Paul Cannon in turn thanked the authors for their hard work and excellent reviews. Commission G had five reviews accepted during the triennium and more than met its quota.

- The Lower Ionosphere: Abandoned by Communication, to be Re-discovered by Aeronomy, M Friedrich, June 2004.
- Progress in Radio Ray Tracing in the Ionosphere JA Bennett, PL Dyson, RJ Norman, September 2004.
- New Techniques and Results From Incoherent Scatter Radars, R Robinson, December 2004.
- Radio occultation techniques for probing the ionosphere N Jakowski, Awaiting publication.
- Long-term trends in different ionospheric layers, J. Bremer, Awaiting publication.

Michael Rietveld, the incoming vice-chair of Commission G, accepted to act as the Commission G editor for the new Radio Science Bulletin and Reviews of Radio Science.

I.7 Commission G resolutions

There were no Commission G resolutions.

I.8 Discussion on GA 2005 organisation and programme

Submission of abstracts: The subject of the length of Commission G abstracts and papers (1 versus 4 papers) was discussed, as it was at the last GA. There was once again a general agreement on having a one-step only submission. A one page extended abstract with a short (~100 word abstract) for incorporation in the conference booklet was deemed preferable.

I.9 Proposals for sessions in 2008

A call for proposals was made.

I.10 SCT

At the last GA M. Hall was tasked to re-activate the Scientific Committee on Telecommunications (SCT). SCT: Patrick Lassudrie Duchesne (France) was confirmed as the Commission G representative to SCT and he explained that there had again been limited activity during the last triennium and promised to report back later in the week.

II. Business Meeting 2: Wednesday, 18 August 2002

This business meeting was a joint meeting between commissions G and H.

II.1 Joint Working Groups 2002-2005

Activities during the past triennium and recommendations for future activities were reviewed and presented for the joint Commissions G and H working groups and activities.

- *GH1: Active experiments in Space Plasmas*:
  Co-Chair for Commission G: Sa. Basu (USA)
  Co-Chair for Commission H: T.Leyser / B. Thidé (Sweden).
  Recommend continuing with Commission G representative as Dr Keith Groves (USA) as Commission G Co-Chair. The meeting expressed its thanks to Santimay Basu for the long and dedicated service that he has given leading this WG.
- *GHC : Wave and Turbulence Analysis:*
  Co-Chair for Commission G: D. Hysell (USA)
  Co-Chair for Commission H: T. Dudok de Wit (France),
  Co-Chair for Commission C: G Kubin (Austria)
  Recommend discontinuing as the work of the working group is completed.
- *EGH: Seismo-Electromagnetics.*
  Co-chair for Commission G: S. Pulinets (Russia).
  Recommend continuing with the same officers.
- *HGEJ: Supercomputing in Space Radio Science.*
  Co-chair for Commission G: A. Barakat, USA.
  See record of 3rd business meeting.

Commission G and H also coordinate the reports from certain other Groups which fall under the aegis of both URSI and another union. Further, Commissions G and H make recommendations to the URSI Board in respect to the URSI representation to these Union.

- *URSI-COSPAR on International reference Ionosphere (IRI).*
  Chair: B.W. Reinisch (USA)
  Vice Chair for COSPAR: Martin Friedrich (Austria),
  Vice Chair for URSI: Lida Triskova (Czech Republic);
  Secretary: D. Bilitza (USA).
  Recommend continuing with same officers.
- *URSI/IAGA VLF/ELF : remote Sensing of the Ionosphere and Magnetosphere (VERSIM)*
  URSI Rep: M. Parrot (France).
  Recommend continuing with Janos Lichtenberger (Hungary) as representative.

II.2 Commissions G and H resolutions

There were none.

II.3 Proposed URSI Representatives

Commissions G and H recommended the following external representatives from within their own ranks:

- CAWES (Climate and Weather of the Sun-Earth system): Sunanda Basu.
- COSPAR (Committee on Space Research): Dr Z. Klos for a second term.

- FAGS (Federation of Astronomical and Geophysical Data Analysis Services): Phil Wilkinson
- ICSU Panel on World Data Centres (Geophysical and Solar) : Dr. D. Bilitza (USA)
- ISES (International Space Environment Service): Dr. S. Pulinets (Russia)
- SCAR (Scientific Committee on Antarctic Research) : Dr. M Clilverd (UK)
- SCOSTEP (Scientific Committee on Solar-Terrestrial Physics) : Christian Hanuise (Fr)

  Commissions G and H assumed that the following members from Commissions G and H would continue in the following roles:
- ICSU (International Council for Science) : Prof. K. Schlegel (Germany)
- IUGG / IAGA (International Union of Geodesy and Geophysics/International Association of Geomagnetism and Aeronomy): Prof. H. Matsumoto (Japan).

II.4 Joint Programme for 2005-2008

There was no discussion

II.5 Other business

There was no other business.

III. Business Meeting 3: Friday, 28 October 2005

III.1 Opening Comments

The outgoing Chair, Christian Hanuise, thanked the Commission for the support they have given to him during his tenure and especially for the assistance given by the incoming Chair, Paul Cannon. The incoming Chair, Paul Cannon, then acknowledged the work put by Christian Hanuise and thanked him for his efforts and expressed the pleasure he had working with him, as well as expressing his pleasure at being the new Chair. Paul Cannon then took over chairing the meeting and the Commission.

III.2 Commission G sessions for GA 2008

The incoming Chair, Paul Cannon presented a list of proposed sessions (and in some cases convenors), a subset of which will form basis for the 2008 General Assembly. It will cover, as much as possible, all interests within Commission G and will involve convenors from younger scientists and various countries. A detailed discussion followed. Paul Cannon pointed out that based on the 2005 GA only eleven oral and 1.5 poster sessions would be possible and this list would consequently need to be rationalised. For reference the sessions appropriate to the 2005 GA are given at Appendix A.

III.2.a Proposed Sessions for 2008 GA

- Imaging of the ionosphere – measurements, modelling and validation (Wilson - agreed). - multiple data type assimilation
- Beacon satellite studies of the ionosphere (TBD) - including tomography but not scintillation studies
- Tomography – new opportunities (Leitinger - agreed)
- Small scale structures and radio scintillation (TBD) – to include CNOFS results (hopefully)
- Ionospheric density profiles – measurements and models (Reinisch and Bilitza, agreed)
- Radar remote sensing of the ionosphere (Lestera greed) including coherent backscatter meteor radars and associated science
- Meteors (TBD).
- Ionosonde data analysis and techniques (McKinnell, agreed)
- The latest and greatest from incoherent scatter radars – methods and results (Swartz and Häggström- agreed)
- Ionospheric and radio wave propagation implementations of geostorms and super storms (Shirochkov, agreed & TBD)
- Improving radio systems through radio science (Angling, agreed and TBD)
- Open session and latest results (Hanuise, agreed)
- GH - Ionospheric modification by high-power radio waves (Groves, agreed and TBD from Commission H)
- GF - Degradation of navigation systems by the ionosphere and troposphere (Coster, agreed, Arbesser-Rastburg for F agreed)

The following sessions with other commissions have been variously proposed:

- FG - Atmosphere-Ionosphere sounding by using global navigation satellite systems (TBD)
- JGH - Low frequency astronomy and the ionosphere – problems and opportunities (post meeting note – Commission J has agreed a session that could include this topic)
- HG - Radio frequency observations in space (TBD)
- HGE - Lightning effects on the ionosphere and magnetosphere (TBD)
- Inter-union - Solar Power Satellites (TBD)

The following suggestion was made for the Commission G tutorial at GA 2008:

- Ionospheric Mapping and Forecasting Using Assimilative Techniques. Dr Brian Wilson of the USA has agreed to give the talk.

III.2.b Suggestions for commission G General Lecture at GA 2005:

There were no suggestions

III.3 URSI Sponsored Meetings

The following meetings were noted as being or likely to be sponsored by URSI, Commission G.

- Advanced School on Space Weather, ICTP, Trieste, Italy, S. M. Radicella , 2 May 2006
- Characterising the Ionosphere, 12-16 June 2006, Fairbanks, Alaska, USA – sponsorship already agreed
- IRI, COSPAR 16-23 July, Beijing, China, 2006 (3 half-day sessions)

- IRI, Workshop, Buenos Aires, Argentina 16-20 Oct 2006
- IRI Workshop, Prague, Czech Republic, Summer 2007
- Ionospheric Radio Systems and Techniques, 18-21 July 2006, London, UK
- Workshop on the future of ionospheric research for satellite navigation and positioning: its relevance for developing countries, ICTP, Trieste, Italy, 27 November until 8 December, 2006, S.M. Radicella and R. Leitinger
- Vertical coupling in the atmosphere – ionosphere system, Bulgaria, 2006.
- AP–RASC'07, Perth, Western Australia, Aug/Sep 2007, sponsorship already agreed
- Beacon Satellite Symposium, 2007

III.4 Working Groups

- *HGEJ: Supercomputing in Space Radio Science Working Group*
  After consultation and after discussion at this meeting Commission G has decided to withdraw from this WG.
- *G.4 Ionospheric Research to Support Radio Systems*
  With the election of Phil Wilkinson to URSI Vice President he expressed a desire to withdraw from the chair of this WG. Dr Matthew Angling was elected in his place but no replacement vice-chair could then be identified. Chair Commission G was given authority to appoint as appropriate before the next GA. (Chairs note; Dr Chris Coleman from Australia has kindly agreed to fulfil this role).

III.5 Publications

The incoming Vice-Chair, M. Rietveld was confirmed as the Commission G editor for the new Radio Science Bulletin, incorporating the Review of Radio science. Contributions are requested.

III.6 Review of GA 2005

The General Assembly was considered quite successful for Commission G. The discussions after papers were particularly animated and beneficial. Several sessions attracted well over 100 scientists, many from other commissions.

III.7 Resolutions

There were no resolutions from Commission G.

IV. Appendix A: Sessions held at the 2005 General Assembly

IV.1 Sessions organized by Commission G or with Commission G leading:

- G01a and b Imaging of the Ionosphere (Wilson/Codrescu/Mitchell)
- G02a and b Ionospheric Effects on Radio Systems (Chandra/Lassudrie)
- G03 Density profiling and validation (Foster/Bilitza)
- G04 Open Session (Wilkinson/Wu)
- G05 and b Small Scale structures (Decameter and less in the ionosphere (St Maurice/Chau)
- GF1a and b Atmosphere-Ionosphere sounding by using global navigation satellite systems (Jakowski and Spalla)
- GHJ Novel Ground-Based Radio Techniques for studying the sun-earth plasma environment (Hanuise/Thidé/Butcher)
- Posters - Two sessions - General Poster session (Cannon/Zolesi) plus those associated with the oral sessions

IV.2 Sessions organized by other Commissions

- HG1 Radio Frequency Observations in Space (Reinisch/James)
- HG2 Ionospheric Modification By High-Power Radio Waves (Leyser and Basu)
- HG3 Dusty Plasmas and Laboratory Plasmas (Ganguly/Havnes/Mareev)
- HGE Ionospheric Effects on Lightening (Blanc/Price and Su)
- HGCJ Diagnostic of Media Fluctuations with Radio Methods (DeWilt/Wernik)
- EGH Seismo-Electromagnetics (Hayakawa/Pulinets/Molchanov)
- FG Degradation by Ionosphere and Troposphere (Arbesser-Rastburg /Coster/Leitinger)

Conferences

CONFERENCE ANNOUNCEMENT

Asia-Pacific Microwave Conference
APMC 2006

Yokohama, Japan, 12 - 15 December 2006

The 2006 Asia-Pacific Microwave Conference (APMC 2006) will be held at the Pacifico Yokohama, Yokohama, Japan, on December 12-15, 2006. This conference is organized and sponsored by the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan. This conference is cooperatively sponsored by IEEE MTT-S, URSI and IEEE MTT-S Japan Chapter, and is technically co-sponsored by EuMA. Microwave Exhibition, which is the largest trade show dedicated to RF and microwaves in Asia, will also be held as a part of APMC 2006 on December 13-15 at Exhibition Hall in Pacifico Yokohama.

The Conference Chair is Dr. Makoto Nagao (NICT), the Organizing Committee Chair is Prof. Yoshio Kobayashi (Saitama University), the International Steering Committee Chair is Dr. Takashi Ohira (ATR) and the Steering Committee Chair is Prof. Masayoshi Aikawa (Saga University).

Topics

A. Active Devices and Circuits

Low-Noise Devices and Circuits, High-Power Devices and Circuits, Control Circuits (MIX, Osc., SW, etc.), MMICs and HMICs (Receivers, Transmitters, etc.), SiGe/RF-CMOS Devices, Microwave Tubes, Active and Adaptive Antennas, Others

B. Passive Components

Filters and Resonators, Ferrite and Surface Wave Components, Packaging, Passive Devices and Circuits, Waveguides and Striplines, WDM Components, RF MEMS, LTCC Devices, Directional Couplers and Hybrids, Others

C. Systems

Wireless Systems, Broadband Wireless Access, Optical Fiber Systems, Microwave Applications (ITS, SPS, etc.), Microwave Medical & Biological Applications/EMC, Phased Array Antenna Systems, Millimeter-Wave Radar and Sensor, Remote Sensing, Wireless LAN and Bluetooth, Quasi-Zenith Satellite Systems, Digital Broadcasting, Others

D. Basic Theory and Techniques

Scattering and Propagation, Electromagnetic Field Theory and CAD, Antenna Theory, Microwave Antennas, Microwave Photonics, Microwave Superconductivity, Measurement Techniques, Artificial Materials, Others

E. Emerging Technologies

Photonic Bandgap, Software Defined Radio, Wireless Ad hoc Network, Mobile Access, 4G Communication Systems, Tera Hertz and Submillimeter Wave Components, System on Package, HAPS, MIMO Systems, UWB Systems, Others

Deadlines

Paper Submission Deadline: May 31, 2006
Notification of Acceptance: August 1, 2006
Final PDF file with Camera-Ready Manuscript Deadline: September 15, 2006

All submissions must be in PDF format. Complete information on how to submit a paper and register for the conference, as well as other important information, can be found at the APMC2006 website (http://www.apmc2006.org/).

Contact

APMC 2006 Secretariat:
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http://www.apmc2006.org/

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

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/

An up-to-date version of this Conference Calendar, with links to various conference web sites can be found at www.ursi.org/ Calendar of supported meetings

August 2008

URSI GA08 - XXIXth URSI General Assembly
Chicago, IL, USA, 9-16 August 2008
Contact : URSI Secretariat, c/o INTEC, Ghent University, Sint-Pietersnieuwstraat 41, B-9000 Ghent, Belgium, Tel. : +32 9 264 3320, Fax : +32 9 264 4288, E-mail : info@ursi.org

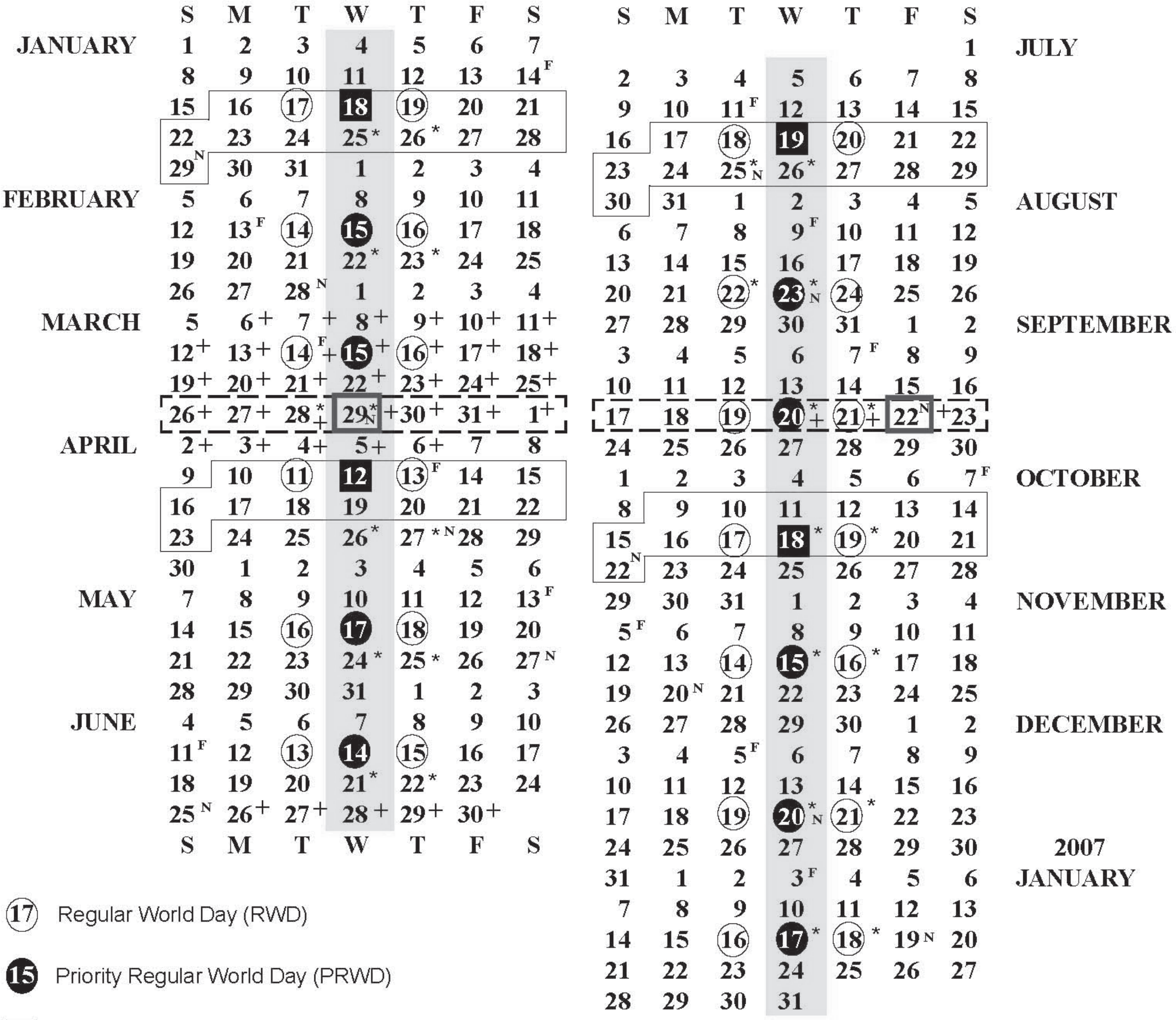
If you wish to announce your meeting in this meeting in this calendar, you will gind more information at www.ursi.org URSI cannot held responsible for any errors contained in this list of meetings

Photos taken during the URSI General Assembly in New Delhi, October 2005

The Local Organisers kindly sent us a number of lovely photos taken during the New Delhi General Assembly. In order to allow you to download photos, we scanned them and put them on the URSI Web Site at

http://www.ursi.org/India05/PhotosGA05/PhotosGAindex.htm

International Geophysical Calendar 2006



	S	M	T	W	T	F	S
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N NEW MOON F FULL MOON

⑰ Regular World Day (RWD)

●15 Priority Regular World Day (PRWD)

■18 Quarterly World Day (QWD)
also a PRWD and RWD

4 Regular Geophysical Day (RGD)

16 17 World Geophysical Interval (WGI)

26 + Incoherent Scatter Coordinated Observation Day

29 Day of Solar Eclipse: Mar 29 and Sep 22

26 27 Airglow and Aurora Period

25* Dark Moon Geophysical Day (DMGD)

This Calendar continues the series begun for the IGY years 1957-58, and is issued annually to recommend dates for solar and geophysical observations which cannot be carried out continuously. Thus, the amount of observational data in existence tends to be larger on Calendar days. The recommendations on data reduction and especially the flow of data to **World Data Centers (WDCs)** in many instances emphasize Calendar days. The Calendar is prepared by the **International Space Environment Service (ISES)** with the advice of spokesmen for the various scientific disciplines.

The **Solar Eclipses** are:

a.) **29 March 2006 (total) eclipse** will be visible in Brazil, Ghana, Togo, Benin, Nigeria, Niger, N.W. Chad, Libya, the N.W. tip of Egypt, Turkey, N.W. Georgia, S.W. Russia, Kazakstan, Russia south of Novosibirsk, ends in the N.W. tip of Mongolia. Maximum duration 4 min 7s in Libya; 3min 45s in Turkey. Partial phase in Africa (except southeast), all Europe, Asia as far south as Pakistan and mid-India.

b.) **22 September 2006 (annular) eclipse** visible in Guyana, Suriname, French Guiana, the South Atlantic Ocean and ends south west of the Kerguelen Islands. Maximum duration 7 min 9 s. >5 min in S. America. Partial phases visible in eastern half of S. America and S.W. half of Africa.

Description by Dr. Jay Pasachoff, Williams College, Chair of IAU WG on Solar Eclipses, jmp@williams.edu based on maps from Fred Espenak, NASA GSFC. See http://sunearth.gsfc.nasa.gov/eclipse/SEcat/SEdecade2001.html and http://www.williams.edu/Astronomy/IAU_eclipses. See also IAU Program Group on Public Education at the Times of Eclipses: http://www.eclipses.info.)

Meteor Showers (selected by R. Hawkes, Mount Allison Univ, Canada (rhawkes@mta.ca)) include important visual showers and also unusual showers observable mainly by radio and radar techniques. The dates are given in Note 1 under the Calendar.

Definitions:

Time = Universal Time **(UT)**;

Regular Geophysical Days **(RGD)** = each Wednesday;

Regular World Days **(RWD)** = Tuesday, Wednesday and Thursday near the middle of the month (see calendar);

Priority Regular World Days **(PRWD)** = the Wednesday **RWD**;

Quarterly World Days **(QWD)** = **PRWD** in the **WGI;**

World Geophysical Intervals **(WGI)** = 14 consecutive days each season (see calendar);

ALERTS = occurrence of unusual solar or geophysical conditions, broadcast once daily soon after 0400 UT;

STRATWARM = stratospheric warmings;

Retrospective World Intervals **(RWI)** = MONSEE study intervals

For more detailed explanations of the definitions, please see one of the following or contact H. Coffey (address below): URSI Information Bulletin; COSPAR Information Bulletin; IAGA News; IUGG Chronicle; WMO Bulletin; IAU Information Bulletin; Geomagnetism and Aeronomy (Russia); Journal of Atmospheric and Terrestrial Physics (UK); ISES homepage: http://www.ises-spaceweather.org/.

Priority recommended programs for measurements not made continuously (in addition to unusual **ALERT** periods):

Aurora and Airglow — Observation periods are New Moon periods, especially the 7 day intervals on the calendar;

Atmospheric Electricity — Observation periods are the **RGD** each Wednesday, beginning on 5 January 2006 at 0000 UT, 11 January at 0600 UT, 18 January at 1200 UT, 25 January at 1800 UT, etc. Minimum program is **PRWDs**.

Geomagnetic Phenomena — At the minimum, need observation periods and data reduction on **RWDs** and during **MAGSTORM Alerts.**

Ionospheric Phenomena — Quarter-hourly ionograms; more fre-quently on **RWDs,** particularly at high latitude sites; f-plots on **RWDs;** hourly ionogram scaled parameters to **WDCs** on **QWDs**; continuous observations for solar eclipse in the eclipse zone. See **Airglow and Aurora.**

Incoherent Scatter — Observations on Incoherent Scatter Coor-dinated Days; also intensive series on **WGIs** or **Airglow and Aurora** periods. **Special programs:** Dr. Wes Swartz, School of Electr. & Computer Eng., Cornell University, Ithaca, NY 14853 USA; tel. +1 607-255-7120; Fax 607-255-6236; e-mail wes@ece.cornell.edu. URSI Working Group G.5. See http://people.ece.cornell.edu/wes/URSI_ISWG/2006WDschedule.htm.

Ionospheric Drifts — During weeks with **RWDs.**

Traveling Ionosphere Disturbances — special periods, proba-bly **PRWD** or **RWDs**.

Ionospheric Absorption — Half-hourly on **RWDs**; continuous on solar eclipse days for stations in eclipse zone and conjugate area. Daily measurements during Absorption Winter Anomaly at temperate latitude stations (Oct-Mar Northern Hemisphere; Apr-Sep Southern Hemisphere).

Backscatter and Forward Scatter — **RWDs** at least.

Mesospheric D region electron densities — **RGD** around noon.

ELF Noise Measurements of earth-ionosphere cavity resonances — WGIs.

All Programs — Appropriate intensive observations during unusual meteor activity.

Meteorology — Especially on **RGDs**. On **WGIs** and **STRAT-WARM** Alert Intervals, please monitor on Mondays and Fridays as well as Wednesdays.

GAW (Global Atmosphere Watch) — WMO program to integrate monitoring of atmospheric composition. Early warning system of changes in atmospheric concentrations of greenhouse gases, ozone, and pollutants (acid rain and dust particles). WMO, 41 avenue Giuseppe-Motta, P.O. Box 2300, 1211 Geneva 2, Switzerland.

Solar Phenomena — Solar eclipse days, **RWDs,** and during PROTON/FLARE ALERTS.

CAWSES (Climate and Weather of the Sun-Earth System) — SCOSTEP Program 2004-2008. Focus on fully utilizing past, present, and future data; and improving space weather forecasting, the design of space- and Earth-based technological systems, and understanding the solar-terrestrial influences on Global Change. Contact is Su. Basu (sbasu@bu.edu), Chair of CAWSES Science Steering Group. Program "theme" areas: Solar Influence on Climate; Space Weather: Science and Applications; Atmospheric Coupling Processes; Space Climatology; and Capacity Building and Education. See http://www.bu.edu/cawses/.

Space Research, Interplanetary Phenomena, Cosmic Rays, Aeronomy — QWDs, RWD, Airglow and Aurora periods.

The **International Space Environment Service (ISES)** is a permanent scientific service of the International Union of Radio Science (URSI), with the participation of the International Astronomical Union (IAU) and the International Union of Geodesy and Geophysics (IUGG). ISES adheres to the Federation of Astronomical and Geophysical Data Analysis Services (FAGS) of the International Council for Science (ICSU). The ISES coordinates the international aspects of the world days program and rapid data interchange.

This Calendar for 2006 has been drawn up by H.E. Coffey, of the ISES Steering Committee, in association with spokesmen for the various scientific disciplines in SCOSTEP, IAGA, URSI and other ICSU organizations. Similar Calendars are issued annually beginning with the IGY, 1957-58, and are published in various widely available scientific publications. PDF versions are available online at ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/IGC_CALENDAR.

Published for the International Council for Science and with financial assistance of UNESCO.

Additional copies are available upon request to either ISES Director, Dr. David Boteler, Geomagnetic Laboratory, Natural Resources Canada, 7 Observatory Crescent, Ottawa, Ontario, Canada, K1A 0Y3, FAX (613)824-9803, e-mail dboteler@NRCan.gc.ca, or ISES Secretary for World Days, Ms. Helen Coffey, WDC-A for Solar-Terrestrial Physics, NOAA E/GC2, 325 Broadway, Boulder, Colorado 80305, USA, Fax number (303)497-6513, e-mail Helen.E.Coffey@noaa.gov.

The calendar is available on-line at http://www.ises-spaceweather.org/.

NOTES on other dates and programs of interest:

1. Days with **significant meteor shower** activity are: Northern Hemisphere 4 Jan; 21-23 Apr; 4-5 May; 6-11, 27-29 Jun; 11-13 Aug; 21-22 Oct; 13-15, 21-23 Dec 2006. Southern Hemisphere 4-5 May; 6-11, 27-29 Jun; 27 Jul-2 Aug; 21-22 Oct; 13-15 Dec 2006. These can be studied for their own geophysical effects or may be "geophysical noise" to other experiments.
2. **GAW (Global Atmosphere Watch)** — early warning system for changes in greenhouse gases, ozone layer, and long range transport of pollutants. (See Explanations.)
3. **CAWSES (Climate and Weather of the Sun-Earth System) —** SCOSTEP Program 2004-2008. Theme areas: Solar Influence on Climate; Space Weather: Science and Applications; Atmospheric Coupling Processes; Space Climatology; and Capacity Building and Education. (See Explanations.)
4. + **Incoherent Scatter Coordinated Observations Days** (see Explanations) starting at 1300 UT on the first day of the intervals indicated, and ending at 1600 UT on the last day of the intervals: **World Month** 6 Mar-6 Apr 2006 — Assimilative Models, support **CAWSES, LTCS, CVS, CPEA, M-I Coupling, GEM, & MST**; 26-30 Jun **CVS, MST, CAWSES (CEDAR** is Jun 19-23); 20-22 Sep **GPS-Radar: wide F-region coverage** with topside at **AO** and **JRO**. See **http://people.ece.cornell.edu/wes/URSI_ISWG/2006WDschedule.htm**.

   where

   CAWSES= Climate and Weather of the Sun-Earth System S. Basu —(sbasu@cawses.bu.edu);

   CEDAR = Coupling, Energetics & Dynamics of Atmospheric Regions (**http://cedarweb.hao.ucar.edu/**);

   CPEA = Coupling Processes in the Equatorial Atmosphere (S. Fukao — fukao@kurasc.kyoto-u.ac.jp); See **http://people.ece.cornell.edu/URSI_ISWG/CPEA-panf.pdf**

   CVS = Convection Variability— Ionospheric Convection & Variability Studies (Shun-Rong Zhang — shunrong@haystack.mit.edu);

   GEM = Geospace Environment Modeling (**http://www-ssc.igpp.ucla.edu/gem/**);

   GPS-Radar = Global Plasma Structuring-Radar Experiment (J. Foster — jcf@haystack.mit.edu);

   M-I Coupling = Magnetosphere-Ionosphere Coupling-Storm/Substorm Effects Mid & Low Latitude Iono. (C. Huang — cshuang@haystack.mit.edu);

   MST = Studies of the Mesosphere, Stratosphere, and Troposphere—Coordinated D- and E-region campaigns in high resolution MST mode (G. Lehmacher — glehmac@clemson.edu);

   AO = Arecibo Obs (**http://www.naic.edu/aisr/olmon2/omframedoc.html**);

   JRO = Jicamarca Radio Obs (**http://jro.igp.gob.pe/english/radar/operation/real-time_en.php**);

   World Month = month-long observations for model validation and studies of long period waves (W. Swartz — wes@ece.cornell.edu)

Wireless Networks

The journal of mobile communication, computation and information

Editor-in-Chief:
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The University of Texas at Dallas
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Richardson, TX 75083-0688
email: chlamtac@acm.org

Aims & Scope:
The wireless communication revolution is bringing fundamental changes to data networking, telecommunication, and is making integrated networks a reality. By freeing the user from the cord, personal communications networks, wireless LAN's, mobile radio networks and cellular systems, harbor the promise of fully distributed mobile computing and communications, any time, anywhere. Numerous wireless services are also maturing and are poised to change the way and scope of communication. WINET focuses on the networking and user aspects of this field. It provides a single common and global forum for archival value contributions documenting these fast growing areas of interest. The journal publishes refereed articles dealing with research, experience and management issues of wireless networks. Its aim is to allow the reader to benefit from experience, problems and solutions described. Regularly addressed issues include: Network architectures for Personal Communications Systems, wireless LAN's, radio , tactical and other wireless networks, design and analysis of protocols, network management and network performance, network services and service integration, nomadic computing, internetworking with cable and other wireless networks, standardization and regulatory issues, specific system descriptions, applications and user interface, and enabling technologies for wireless networks.

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The Journal of Atmospheric and Solar-Terrestrial Physics

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The *Journal of Atmospheric and Terrestrial Physics* (JASTP) first appeared in print in 1951, at the very start of what is termed the "Space Age". The first papers grappled with such novel subjects as the Earth's ionosphere and photographic studies of the aurora. Since that early, seminal work, the Journal has continuously evolved and expanded its scope in concert with - and in support of - the exciting evolution of a dynamic, rapidly growing field of scientific endeavour: the Earth and Space Sciences. At its Golden Anniversary, the now re-named *Journal of Atmospheric and Solar-Terrestrial Physics* (JASTP) continues its development as the premier international journal dedicated to the physics of the Earth's atmospheric and space environment, especially the highly varied and highly variable physical phenomena that occur in this natural laboratory and the processes that couple them. The *Journal of Atmospheric and Solar-Terrestrial Physics* is an international journal concerned with the inter-disciplinary science of the Sun-Earth connection, defined very broadly. The journal referees and publishes original research papers, using rigorous standards of review, and focusing on the following: The results of experiments and their interpretations, and results of theoretical or modelling studies; Papers dealing with remote sensing carried out from the ground or space and with in situ studies made from rockets or from satellites orbiting the Earth; and, Plans for future research, often carried out within programs of international scope. The Journal also encourages papers involving: large scale collaborations, especially those with an international perspective; rapid communications; papers dealing with novel techniques or methodologies; commissioned review papers on topical subjects; and, special issues arising from chosen scientific symposia or workshops. The journal covers the physical processes operating in the troposphere, stratosphere, mesosphere, thermosphere, ionosphere, magnetosphere, the Sun, interplanetary medium, and heliosphere. Phenomena occurring in other "spheres", solar influences on climate, and supporting laboratory measurements are also considered. The journal deals especially with the coupling between the different regions. Solar flares, coronal mass ejections, and other energetic events on the Sun create interesting and important perturbations in the near-Earth space environment. The physics of this subject, now termed "space weather", is central to the Journal of Atmospheric and Solar-Terrestrial Physics and the journal welcomes papers that lead in the direction of a predictive understanding of the coupled system. Regarding the upper atmosphere, the subjects of aeronomy, geomagnetism and geoelectricity, auroral phenomena, radio wave propagation, and plasma instabilities, are examples within the broad field of solar-terrestrial physics which emphasise the energy exchange between the solar wind, the magnetospheric and ionosphericplasmas, and the neutral gas. In the lower atmosphere, topics covered range from mesoscale to global scale dynamics, to atmospheric electricity, lightning and its effects, and to anthropogenic changes. Helpful, novel schematic diagrams are encouraged. Short animations and ancillary data sets can also be accommodated. Prospective authors should review the *Instructions to Authors* at the back of each issue.

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Editorial Office:
P.O. Box 1930, 1000 BX Amsterdam, The Netherlands

Special Rate for URSI Radioscientists 2003:
Euro 149.00 (US$ 149.00)
Subscription Information
2002: Volume 65 (18 issues)
Subscription price: Euro 2659 (US$ 2975)
ISSN: 1364-6826

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☐ B Fields and Waves	☐ G Ionospheric Radio and Propagation
☐ C Signals and Systems	☐ H Waves in Plasmas
☐ D Electronics and Photonics	☐ J Radio Astronomy
☐ E Electromagnetic Noise & Interference	☐ K Electromagnetics in Biology & Medicine

The fee is 50 Euro.
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