Near Earth space plasma monitoring under COST 296

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Abstract
This review paper presents the main achievements of the near Earth space plasma monitoring under COST 296 Action. The outputs of the COST 296 community making data, historical and real-time, standardized and available to the ionospheric community for their research, applications and modeling purposes are presented. The contribution of COST 296 with the added value of the validated data made possible a trusted ionospheric monitoring for research and modeling purposes, and it served for testing and improving the algorithms producing real-time data and providing data users measurement uncertainties. These value added data also served for calibration and validation of space-borne sensors. New techniques and parameters have been developed for monitoring the near Earth space plasma, as time dependent 2D maps of vertical total electron content (vTEC), other key ionospheric parameters and activity indices for distinguishing disturbed ionospheric conditions, as well as a technique for improving the discrepancies of different mapping services. The dissemination of the above products has been developed by COST 296 participants throughout the websites making them available on-line for real-time applications.

Key words *Ionosphere – monitoring – data validation – monitoring techniques – campaigns – dissemination*

1. Introduction

The ionosphere is a rather complex and highly variable medium, and to be able to predict and when necessary mitigate the influence of the ionosphere on radio wave propagation including signals from the Global Navigation Satellite Systems (GNSS), ionospheric monitoring measurements are crucial as a necessary basis for studying and understanding the ionosphere.

Real-time data are necessary for operational ionospheric mitigation. Ionospheric monitoring in the European area is done by a network of ionosondes and, in recent years, also by a network of high-accuracy Global Positioning Systems receivers (GPS), which work primarily for

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geodesy and positioning. The COST 296 action joins scientists from all the European institutions operating ionosonde systems (vertical ionospheric sounding instruments, essentially radars but the newest being a combination of radar and Doppler interferometer).

These systems work in a continuous monitoring regime, covering essentially the whole of Europe, including Scandinavia's Sodankyla station. Data from a network of GPS stations have also been used in COST 296 in recent years, as well as radio occultation GNSS measurements.

The aim of this paper is to review the main results achieved by COST 296 working group WG-1«Ionospheric monitoring and modeling» under the working package WP1.1 «Near Earth space plasma monitoring».

The WP1.1 encompassed the ionospheric measurements, data collecting, archiving and dissemination, and development of new methods of ionospheric measurements, monitoring, and conditions characterization.

The WP1.1 created an observational basis for the project COST 296 and its work was defined by four terms of reference: 1) Maintaining and extending the flow of real-time and retrospective ionospheric monitoring data to databases; 2) Supporting and developing INTERNET sites and protocols for disseminating data products; 3) Validating the quality and consistency of monitoring data, particularly those collected in real time; and 4) Developing monitoring techniques and parameters describing the state of the ionospheric plasma, to include ground-based and space based techniques.

The paper is organized according to these terms of reference and related work.

Section 2 summarizes the main efforts for archiving real time and historical databases.

Section 3 describes the main results for validating the monitoring data.

Section 4 reviews the monitoring techniques and parameters describing the state of the ionospheric plasma developed within the project.

Section 5 highlights the main efforts for disseminating data and added value products. Finally, Section 6 presents results from the specific COST 296 campaigns. The paper ends with a summary.

2. Real-time and historical databases

The European ionospheric community has been working for long time on several COST actions; COST 238, 251 and 271 (*e.g.* Zolesi *et al.*, 2007; Zolesi and Cander, 2008). This joint work started on the early nineties and ever since then this community has worked hard to create a large and homogeneous ionospheric data base. The data base has continuously increased and has mainly been fed by data deduced from the ionograms obtained by vertical incidence (VI) soundings.

The ionograms provide the critical frequencies and heights of the ionospheric layers over the measuring station and appropriate ionogram inversion tools provide the vertical electron density profiles. The main reason for this data base is to make data standardized and available to the ionospheric community for their purposes, *e.g.* research, telecommunication applications, etc.

Therefore, having data available is of capital importance for our community and this task has continued in the COST 296 action. This section discusses the task carried out by the COST 296 community to archive ionospheric data. The main data bases dedicated to this task will also be presented. At present, the stations producing ionospheric data linked to the COST 296 community keep information on their measurements and most of them make the measurements available on their own websites. The links to those stations can be found at the COST 296 web site (http://www.cost296.rl.ac.uk/). In addition, these stations also provide data to Data Bases (DB) maintained by COST 296 members. Most of DB keeps the acquired historical data, these being increased by received real-time data.

The real-time data of modern ionosondes is deduced by intelligent algorithms (Galkin *et al.*, 2008a) providing the so called «auto-scaled data». Though known, it is worth noting the importance of real-time data accessibility for monitoring, forecasting and nowcasting the state of the ionosphere.

The COST Prompt Ionospheric Database at the Rutherford Appleton Laboratory (RAL), UK (http://www.wdc.rl.ac.uk/cgi-bin/digisondes/cost_database.pl) continues to receive, catalogue and archive auto-scaled VI data on a real time basis from ionospheric sounders across Europe.

This data set includes 11 contributing instruments in Europe, at Athens, Chilton, Dourbes, El Arenosillo, Juliusruh, Lycksele, Pruhonice, Rome, Ebro, Tromsø and Warsaw (Cander, 2008). The DIAS project (http://www.iono.noa.gr/DIAS/), a pan-European distributed information server providing information on the ionospheric conditions over Europe, is supporting the real-time acquisition and archiving of the ionospheric observations currently obtained from eight European ionospheric stations operating in Athens, Rome, Juliusruh, Chilton, Ebro, Pruhonice, Lycksele and El Arenosillo (Belehaki *et al.*, 2005, 2006). The INGV (Istituto Nazionale di Geofisica e Vulcanologia), Rome, carried out the eSWua project aimed to realize a hardware-software system for DB to standardize historical and real time observations for different instruments installed by the upper atmosphere group of INGV (Romano *et al.*, 2008). The eSWua DB related to the Rome digisonde and the 4 GISTM (GPS Ionospheric Scintillation and TEC Monitor) measurements. A dynamic website (www.eswua.ingv.it) has been opened to the community for real time access to raw and processed data.

The Space Research Centre (SRC) Poland constructed a DB for VI data with standard format for ionospheric data exchange IIWG (http://rwc.cbk.waw.pl/iiwg) which is being distributed via the International Space Environment Service (ISES) network and archiving data distributed worldwide. SRC also makes available daily reviews on solar, magnetic and ionospheric activity also. The Center for Atmospheric Research of the University of Massachusetts at Lowell (UMLCAR) continued to archive in the DIDBase all digisonde data available in real time via Internet (http://umlcar.uml.edu/DIDBase/) including the European COST 296 network. UMLCAR has proposed a new XML-based ionosonde data exchange format allowing addition of measurement uncertainties to the data user, thus making the ionosonde auto-scaled data acceptable to the modern assimilation models based on the Kalman filter method, such as the Global Assimilation Ionospheric Model, GAIM, (Galkin *et al.*, 2008b). All of the above DB handle groundbased ionospheric data, giving information on the bottomside ionosphere. The German Aerospace Center (DLR) automatically retrieves and archives of ionospheric radio occultation measurements onboard CHAMP satellite, giving not only bottomside but also topside ionospheric information. Electron density profiles from CHAMP can be accessed via the new SWACI service (Jakowski *et al.*, 2006) at http://w3swaci.dlr.de/.

In addition to providing the real-time data, it is worth mentioning here the availability of data validated by experts. This type of data has an added value compared to the auto-scaled data, with a double application: they serve for testing the auto-scaling algorithms and a continuous feedback makes possible improvements to the above algorithms and a trusted ionospheric monitoring for research and modeling purposes. Accordingly, the DIDBase archives edited ionogram data together with the autoscaled values for some stations. The edited data files include the name of the expert, and the DIDBase user can select the files with the «most trusted» editor.

The Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation (IZMIRAN) makes available validated data of 14 ionospheric characteristics recorded with the ionosonde system «Parus» at Moscow (http://www.izmiran.ru/services/iweather/daily). The eSWua DB provides the validated data of ionospheric observatories at Rome and Gibilmanna, Italy.

The aforementioned COST Prompt Ionospheric Database provides on-line validated data from the Chilton ionosonde station, UK with one hour resolution. Other individual ionospheric stations make available their edited data through their websites. The Ebro Observatory, Spain makes available a catalogue of their validated data availability and a data request form (http://www.obsebre.es/php/ionosfera.php). Most of these data have a one hour resolution, but 15 minute sampling data is available from May 2004 date. There are also several campaigns at 5 minute sampling available also, these being performed for detailed analyses of ionospheric behavior under specific events (Solar Eclipses, Satellite validation data, etc).

3. Validation of monitoring data

Most of the research and work carried out in the past by the ionospheric community have been done using historical data validated by experts. The current situation has significantly changed mainly due to the facilities of the information society. A large amount of data is now available in real-time providing products to users soon after the data have been produced. However, the real-time data and related products should contain warnings to users noting their quality and consistency. This section discusses the task carried out by the COST 296 community to validate the quality and consistency of monitoring data and products, particularly those collected in real time.

A large amount of ionospheric data produced and used by the COST 296 community has been recorded by VI sounders, in particular the Digisondes built by the UMLCAR (http://ulcar.uml.edu/digisonde.html). This system is supplied with software of automatic scaling of ionograms (ARTIST), providing ionospheric data in quasi-real time. Sometimes, however, the autoscaled data are not good enough and data users should be warned. A significant effort has been made to improve the autoscaled data by the ARTIST software (Galkin *et al.*, 2008a) and uncertainties of the data have been added for user information. This has been done in part thanks to efforts of the experts validating data and subsequent comparisons and statistics. Though validated data are recommended for research purposes and for monitoring fine details of the ionospheric structure, most monitoring ionosonde stations now rely on automatic processing rather than edited processing to provide ionospheric characteristics. A systematic assessment of the quality of all the key ionospheric characteristics scaled automatically was made from hourly ionograms from the midlatitude Chilton ionosonde in the United Kingdom, by comparing them with the definitive values produced by manual scaling (Bamford *et al.*, 2008). The above comparisons clearly showed the improvement the goodness of the autoscaling software from the late 1990s to date (fig.1).

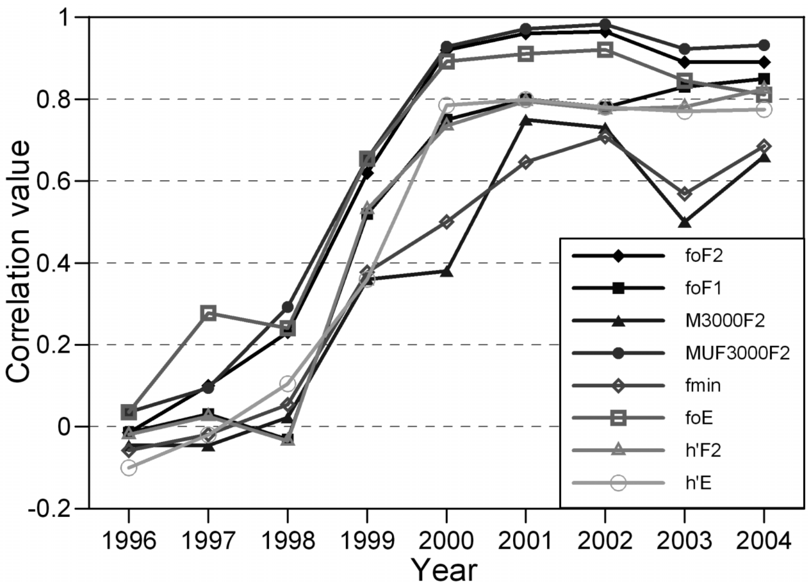

Fig. 1. Time evolution of the correlation coefficients calculated for years 1996-2004 between manually scaled and autoscaled values of the indicated ionospheric characteristics. Results are obtained for Chilton station. Adapted from Bamford *et al.* (2008).

The investigation has been the first comprehensive examination of the performance of automatic scaling without any data pre-selection over an extended period covering the majority of solar cycle 23. The accuracy of autoscaled values during storm periods was examined against the global storm index Dst for the whole 9-year data set. Geomagnetic conditions were found to have only a small effect on autoscaling performance, with the most important identifiable cause of error being the truncation of automatic layer traces due to broadcast interference. Overall, the performance of the autoscaling algorithms was found to be acceptable, with the characteristics *foF*2, *h'E*, *M*(3000)*F*2, and *MUF(3000)F*2 within defined error bounds for more than 90% of the time and all characteristics within these bounds more than 80% of the time. Also, the performance of the ARTIST algorithm used in digisondes for N(h) profiles and Doppler system measurements (common volume measurements) were tested for Pruhonice station (Buresova *et al*., 2007). It was found there that the results of ARTIST, as for height determination in N(h)-profiles, are essentially of good quality and reliable under quiet geomagnetic conditions and in the absence of the sporadic-*E* layer, but rather unreliable during moderate and strong geomagnetic storms or in the presence of a well-developed sporadic-E layer. The discrepancies could be related to the uncertainties of the observational inputs and to the interpretation of the digisonde data.

The groundbased data generated by digisondes served for calibration and validation of space-borne sensors, as the GUVI instrument onboard the TIMED spacecraft (DeMajistre *et al*., 2007) and CALVAL campaign for UV sensor onboard DMSP F-16 spacecraft and COSMIC constellation Radio Occultation profiles. The CVALVAL was supported by the real-time work of 34 digisondes (10 of them located in Europe). The COSMIC (Constellation Observing System for Meteorology, Ionosphere, and Climate) campaign in December 2006 was supported by 41 digisondes around the globe collecting electron density profiles at a 5-min cadence, including nine of the European COST stations.

In addition to the above, the COST 296 community contributed to testing and validating other data and techniques. The changing state of the ionosphere is generally monitored by networks of vertical ionosondes that provide us with regular ionospheric sounding. Many ionospheric applications require determination of the true-height electron density profiles N(h). Therefore, ionograms must be further inverted into N(h). The consistency of two different methods of obtaining electron density profiles from inversion of ionograms POLAN (Titheridge, 1985) and NHPC (Huang and Reinish, 1996; Reinish *et al*., 2005), widely used by the ionospheric research community was analyzed. The analyses were carried out for two midlatitude ionospheric stations (Sauli *et al*., 2007) and the results show significant systematic differences between N(h) calculated by these two inversion methods. NHPC provides smoother time variation than POLAN does. POLAN systematically obtains heights lower than NHPC for nighttime profiles, the opposite being true for daytime profiles. The best agreement of these two methods is seen for two-layer profiles. Location of the largest difference between profiles corresponds to the *F*1 region and transition region between *F*1 and *F*2 regions. The results are consistent at two distant observatories and they remain the same through changing solar and geomagnetic activity.

As the validation of vTEC maps refers, the accuracy of the European RAL vTEC maps under stormy conditions of 17-21 January 2005 were assessed by applying the tests used to validate the International GNSS Service (IGS) vTEC (Orus *et al*., 2007). The results show discrepancies between the RAL vTEC and IGS maps which lead to significant RMS and bias values regarding to the self-consistency and altimeter test of several TEC units during storm conditions. A Kriging technique applied in this work gave a relative improvement up to 26% in the highest storm conditions.

4. Development of ionospheric monitoring techniques and parameters

The main monitoring techniques and parameters describing the state of the ionospheric plasma developed by the COST 296 community, including ground-based and space based techniques, are discussed in this section.

The variability of the critical frequency of the *F*2 layer, *foF*2, over ionospheric station Grocka (44.48°N, 20.31°E) was studied during the declining phase of the solar cycle 23 from 2004 to 2006 (Mitic and Cander, 2008). The variability index was introduced to identify the daily and seasonal patterns characterizing the local mid-latitude ionosphere during quiet and disturbed geomagnetic conditions. In addition, the behavior of the vTEC values, obtained from GPS measurements in the surrounding area under these conditions is reported. The analysis shows a number of interesting features representative of the ionospheric variability relevant for ionospheric modeling as well as ionospheric propagation applications based on a single station approach.

An ionospheric activity index was developed in the DIAS project co-funded by the eContent program of the European Union (Belehaki *et al*., 2005). It proposed a new ionospheric activity index derived from automatically scaled online data from several European ionosonde stations (Bremer *et al*., 2006). The index describes the ionospheric disturbance level at different European ionosonde stations and it is derived on-line from automatically scaled ionosonde observations. These indices are used to distinguish between normal ionospheric conditions expected from prevailing solar activity and ionospheric disturbances caused by specific solar and atmospheric events (flares, coronal mass ejections, atmospheric waves, etc.). The most reliable indices are derived from the maximum electron density of the ionospheric *F*2-layer expressed by the maximum critical frequency *foF*2. Similar indices derived from ionospheric *M*(3000)*F*2 values show a markedly lower variability indicating that the changes in altitude of the *F*2-layer maximum are proportionally smaller than those estimated from the maximum electron density in the *F*2-layer. By using the ionospheric activity indices for several stations the ionospheric disturbance level over a substantial part of Europe (34°N-60°N; 5°W-40°E) can now be displayed online.

A planetary index of the ionospheric changes does not exist so far because it can be difficult to immediately deduce it from a mixture of increases and decreases of plasma density and electron content on the globe. This task is resolved using the numerical GPS-IONEX maps of the vTEC, available daily since 1998 (Gulyaeva and Stanislawska, 2008). The vTEC values are extracted at 600 grid points of the map at latitudes 60ºN to 60ºS with a step of 5º and longitudes 0º to 345ºE with a step of 15º providing hourly values for 0 to 23 h of local time for a representative set of conditions during a period 1999-2008. The local effects of solar radiative energy are filtered out. The derivation of the planetary perturbation index is a two-step process.

The first step consists of generating a W-index map, a degree of perturbation computed as the logarithm of vTEC relative to quiet reference taken as daily-hourly median for 27 days prior the day of observation. The planetary Wp index is obtained in the second step from the above W-index map as the latitudinal average of the ranges between maximum positive index and minimum negative index which are weighted by the latitude-longitude extent of the extreme index values on the map. The single-sign Wp index varies from 2 to 16 units providing the solar cycle variation of the planetary ionospheric storms. The Wp index shows equinoctial maxima, these being correlated with the Dst index. The planetary Wp index discloses the disturbances which may belong either to magnetosphere or the ionosphere-plasmasphere system or both providing broader proxy index driving the space weather than the geomagnetic indices alone.

Instantaneous mapping techniques have been applied to monitor European, Asian and Japanese region as well as a 24 hours ahead forecast for the above regions and at some ionospheric stations (Stanislawska *et al*., 2000).

The INGV has developed a computer program (Autoscala) for the automatic scaling of the critical frequency *foF*2 and *MUF*(3000)*F*2 from ionograms (Pezzopane and Scotto, 2007) that has been extended for obtaining the sporadic-*E* layer (Scotto and Pezzopane, 2007) and the *F*1 layer (Pezzopane and Scotto, 2008). Autoscala was designed to scale automatically the ionospheric parameters from the ionograms recorded by the AIS (Advanced Ionospheric Sounder) developed at the INGV but it can be easily applied to scale the ionograms obtained by any kind of ionosonde. The INGV has recently developed the above software related to the AIS with a routine for the real time computation of the electron density profile, which is essential for space weather applications. The electron density profile is computed with a model (called Adaptive Ionospheric Profiler, AIP) with 12 free parameters (6 related to the *E*-region and 6 to *F*2-*F*1 layers). The parameters defining the profile are initially estimated considering the helio-geophysical conditions and the ionospheric characteristics obtained automatically from the ionograms by Autoscala. Then the candidate profile is inverted into trace and is adapted to a final computed profile by minimizing the root mean square error between the trace restored from the candidate profile and the recorded one. The model is capable of describing a wide set of ionospheric profiles and the related research has been accepted for publication in *Advances in Space Research*.

The Standard DDA method of drift velocity evaluation (Reinisch *et al*., 2005) has been improved by skymap-points selection in three steps as a quality control and improvement (Kouba *et al*., 2008): (i) robust height range selection, (ii) setting limits on Doppler frequency shift, and (iii) setting limits on the echo arrival angle. Such approach requires a sufficiently large amount of data points in skymap. Raw drift data from Pruhonice observatory for period Jan-May 2006 were recalculated using this method. Preliminary results show the behavior of the *F*-region drift: velocity components diurnal variability during quiet geomagnetic conditions and seasonal trends of daily characteristics. As significant decrease in the daily-maximal horizontal component from winter to summer 2006 was found within the analyzed data. This method excludes multiple and/or too oblique reflections. The above method enables *E*-region and *F*-region drifts to be separated (this is not routinely done by any other ionospheric sounding station), characteristics of which are substantially different. Since May 2005, the Pruhonice Digisonde measures *E*-region drifts every 15 minutes, using four fixed frequencies between 2.0 and 2.6 MHz. Unlike the autodrift setting, *E*-region sounding frequencies do not depend on critical frequency, they are set and fixed for all measurements. During summer 2006 the first special campaign for monitoring drifts in *Es*-layer was performed. Drift-measurement on a higher sounding-frequency window 3.2-4.7 MHz was run every 15 minutes in addition to the standard *E*-region drift measurement. *E*-region drift measurement with a two frequency-window setting represents an important source of information on the dynamics of the *E*-region ionosphere and brings new pieces of information on sporadic *E* layer formation and its behavior. Differences of the plasma motion confirm the different dynamics of *E* and *Es* layers.

The new phase-difference technique for Digisondes was evaluated for monitoring precise heights records of ionospheric layers. The program settings for this technique were provided by the UMLCAR. The technique, which analyzes the phase differences between signals at slightly different frequencies, allows measurement of the reflection range, *i.e.*, the virtual height h'(f) for vertical sounding, with accuracies better than one kilometer (Reinisch *et al.*, 2008). First results of measurements carried out at Millstone Hill demonstrate the robustness and reliability of the developed technique, and show the potential of the method for routine application. The technique has been applied in a specific campaign of precise measurements of virtual height of the *E*-layer carried out under the International Heliophysical Year (IHY) initiatives of the COST 296 whose preliminary results will be discussed later.

The mapping techniques developed by Krankowski *et al.* (2007) provide regular vTEC monitoring over Europe. The vTEC maps are created from GPS observations collected at IGS and EUREF Permanent Network (EPN). The large number of stations in Europe provides good data coverage yelds high-accuracy vTEC maps with an error at a level of 1-3 TEC units. The vTEC maps are available with a spatial resolution of 100-300 km and a time resolution of 5 minutes. Figure 2 shows examples of the above TEC mapping technique above European area for particular time intervals.

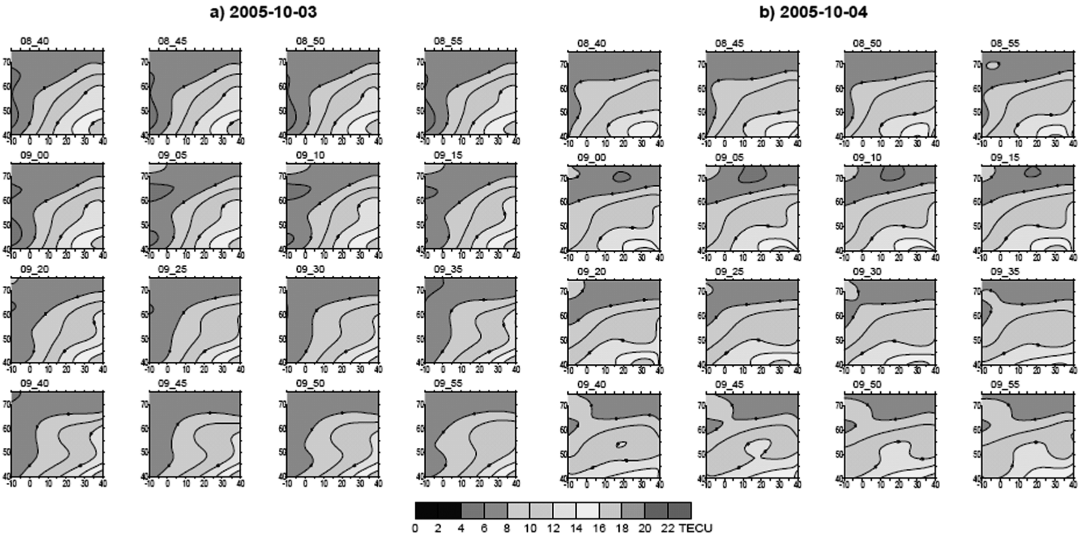

Fig. 2. The detailed TEC maps over Europe with 5-minute resolution during the eclipse day on 3 October 2005 (a) and one day after the solar eclipse on 4 October 2005.

5. Dissemination of data and products

Most of the above ionospheric data and products have been set on-line and disseminated to the e research community and users. As already mentioned above, most institutions participating in the COST 296 action have their own websites making available their data and products. This section highlights, the main tasks carried out by the COST 296 community to support and develop internet sites and protocols for disseminating data products.

The Space Weather Web Facilities for Radio Communications Users of the RAL has continued to maintain, support and improve (http://ionosphere.rcru.rl.ac.uk/). This facility is based on the contributions of a number of COST 296 participating institutions and it is 24/7 on-line service that includes the following products: (1) Interactive forecast maps of *foF*2, *MUF*(3000)*F*2 and ITU-R NeQuick modelled TEC values over Europe based on ionosonde measurements. (2) Near real-time dynamic system for monitoring ionospheric propagation conditions over Europe. (3) Near real-time TEC maps over Europe and 24 hours single station plots based on TEC evaluation from IGS GPS measurements. (4) Near real-time solar-terrestrial and ionospheric indices and warning messages so that ionospheric and trans-ionospheric propagation conditions are known to worldwide users. (5) Archive of all data and images. The service has also been extended to enable users to extract ionospheric profiles from Standard Archive Output files (SAO) as calculated by the NHPC algorithm applied by UMLCAR digisondes, in addition to those calculated by POLAN.

The server at Regional Warning Centre (RWC) of the SRC, Poland, fed with URSIGRAMS of COST 296 stations and others provides some ionospheric characteristics in quasi-real time and from the previous 2 months (http://cbk.waw.pl/rwc and ftp://www.cbk.waw.pl/idce/).

In addition, it provides 24 hours ahead forecast maps of ionospheric characteristics for European, East Asia and Australia regions and the forecast of some ionospheric characteristics for individual stations. In particular, the Web services of the Ionospheric Dispatch Centre in Europe (SRC) provide on line access to data base of the critical frequency of *F*2 ionospheric layer and *M*(3000)*F*2 forecast for all available sites. The ionosonde data are available from 1983 up to the latest measurements from all over the world in IIWG format. The GPS measurements from Warsaw station are also available. Daily plots for 30 stations from all over the world are presented along with their digital version. It also makes available daily reviews on solar, magnetic and ionospheric activity. Catalogues of the quiet and disturbed days and of ionospheric disturbed periods lasting three hours or longer are compiled and presented for European stations (these catalogues are available at the IZMIRAN Web site also). Finally, the links to the websites of COST 296 related topics are available on the web navigator (http://rwc.cbk.waw. pl/cost296/).

The IZMIRAN team has set up a website on ionospheric weather (http://www.izmiran.ru/services/iweather/). Data of 30 ionospheric stations (*foF*2, *hmF*2 and their deliverables) are presented therein for the current month. The past data are available in the archive for two years proceding the current month. Missed data are reconstructed by cloning data of other stations so the data sets are complete for the daily-hourly grids (Gulyaeva *et al*., 2008). The ionospheric disturbances are being indexed in comparison with the running median of the preceding 27 days calibrated with ITU-R prediction of the seasonal trend. A proxy for *foF*2 critical frequency has been created by applying a technique for reducing the *foF*2 critical frequency as a function of the solar zenith angle (Gulyaeva, 2009). The technique improves the correlation between the data of different stations and the inter-seasonal correlations at a given location, and it is applied for reconstruction of missed observations of *foF*2 at 30 stations worldwide, thereby increasing the number of stations data at the Ionospheric Weather web site, including some stations at low and high latitudes in both North and South Hemispheres.

A dynamic website has been opened to the community for real time access to raw and processed data within the eSWua project of the INGV (www.eswua.ingv.it), also reported in Section 2. The site is based on measurements performed by all the instruments installed by the upper atmosphere group of INGV (Romano *et al*., 2008). This interactive website supports a well organized data base aiming to be a powerful tool for the scientific and technological community in the field of telecommunications and Space Weather. The eSWua is contributing to the projects in the frame of international collaborations where the interoperability of the system and effective data access are necessary requirements (Virtual Observatories, www.egy.org, and Interhemispheric Conjugacy Effects in Solar-Terrestrial and Aeronomy Research, ICESTAR, http://www.scar-icestar.org). The eSWua allows the user to explore and download validated vertical sounding data since 1976, view the ionograms and access the automatic scaled data. Specific tools to survey the ionospheric behaviour both for real and historic time have been developed and are already accessible by web.

6. COST 296 campaigns

Using the potential of the different observing and monitoring systems belonging to the participating institutions in COST 296, two campaigns have been carried out, a campaign to follow ionospheric effects of the annular eclipse occurred over Europe on 3 October 2005 and a campaign contributing to the objectives of the third CAWSES Global Tidal campaign from 1 June to 14 August 2007.

On the occasion of the annular eclipse, which occurred over Europe in the morning hours of 3 October 2005, the COST 296 community prepared a specific campaign for monitoring its effects on the ionosphere to obtain a comprehensive view of the eclipse by utilizing different observation techniques. The well-defined obscuration function of solar radiation during the eclipse provided a good opportunity to study the ionospheric/thermospheric response to solar radiation changes during the eclipse (Jakowski *et al*., 2008). Since the peak electron density behavior of the ionospheric *F*2 layer follows the local balance of plasma production, loss and transport, the ionospheric plasma redistribution processes significantly affect the shape of the electron density profile. These processes have been discussed based on a comparison of vertical incidence sounding (VS) and vertical total electron content (TEC) data above-selected ionosonde stations in Europe. The equivalent slab thickness, derived with a time resolution of 10 min, provides relatively good information on the variation of the electron density profile during the eclipse. The computations reveal an increased width of the ionosphere around the maximum phase (fig. 3).

As indicated by the available measurements over Spain, the photo production is significantly reduced during the event leading to a slower increase in the total ionization in comparison with the neighboring days. The supersonic motion of the Moon's cool shadow through the atmosphere possibly generated atmospheric waves that were detected at ionospheric heights above the Spanish station (fig. 4). High-frequency (HF) Doppler shift spectrograms were recorded during the eclipse showing a distinct disturbance along the eclipse path. Although ionosonde and HF Doppler measurements show enhanced wave activity, the TEC data analysis does not, which is an indication that the wave amplitudes are too small for detecting them via this interpolation method. More about wave activity is in Bremer *et al.* (this issue). The total ionization decreases up to about 30% during the event. A comparison with similar observations from the total solar eclipse of 11 August 1999 revealed a remarkably different ionospheric behavior at different latitudes.

A detailed analysis based on GPS observations from EUREF were used to observe the response of TEC (Total Electron Content) to the total solar eclipse on October 3, 2005 (Krankowski *et al.*, 2008). The effect of the eclipse was detected in diurnal variations and more distinctly in the variations of TEC along individual satellite passes. The trough-like variations with a gradual decrease and followed by an increase in TEC at the time of the eclipse were observed over a large region. The depression of TEC amounted to 3-4 TECU. The maximum depression was observed over all stations located at the maximum path of the

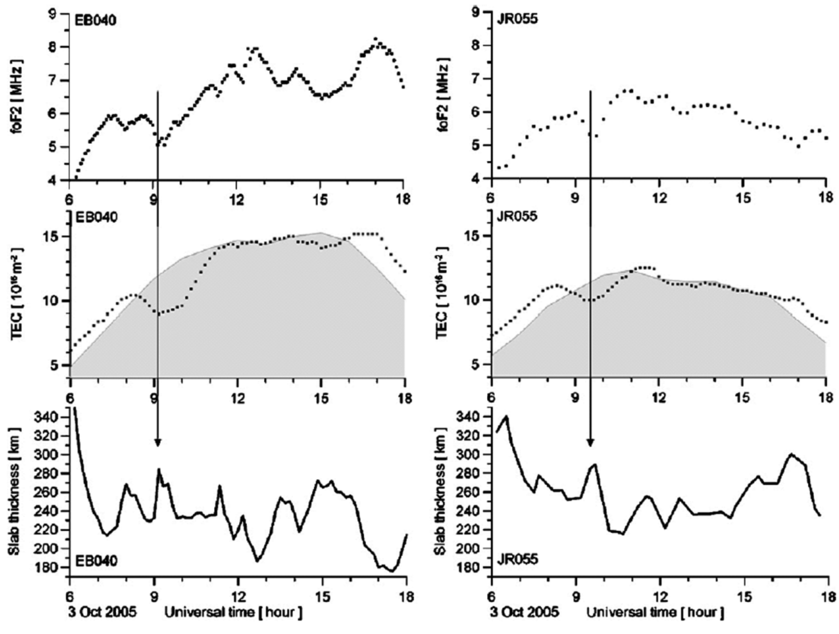

Fig. 3. Variations of the ionospheric slab-thickness over the Ebro, Spain (left) and Juliusruh, Germany (right) stations during the solar eclipse on 3 October 2005. After Jakowski *et al.* (2008).

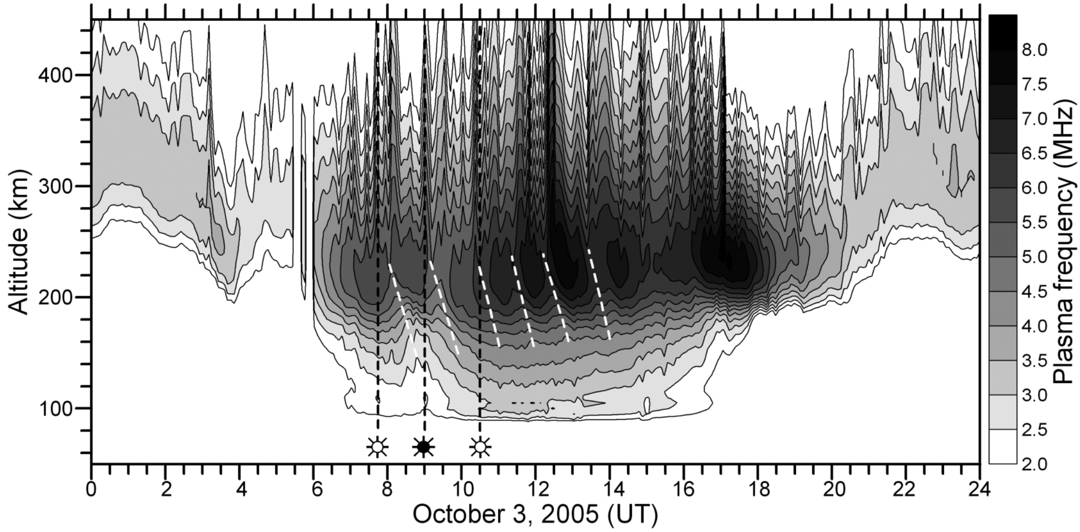

Fig. 4. Contour of the electron density above Ebro station, Spain as function of time and height for October 3, 2005. Note the train of height oscillations starting at about 08:00 UT and further developed from 10:00 to 14:00 UT. After Jakowski *et al*. (2008).

solar eclipse. The delay of a minimum level of TEC with respect to the maximum phase of the eclipse was about 20-30 min. The two-dimensional TEC maps constructed with high temporal resolution (5-min interval) show that the eclipse produced remarkable changes in the structure of the ionosphere. These TEC maps demonstrate also that the depression of TEC reached 20-30% compared to a quiet day (October 4, 2005).

The COST 296 community had performed a coordinated *E*-Layer Precision Group Height Measurement (PGHM) campaign to contribute to the objectives of the Third CAWSES Global Tidal campaign run from 1 June to 14 August 2007. The campaign was based on the advantage of High Doppler resolution mode technique embedded in the Digisondes which makes able to measure the virtual heights h'(f) of the *E*-layer with an accuracy better than 1 km (Reinisch *et al*., 2008). Eight European ionospheric stations participated to this initiative; Tromso (69.6°N, 19.2°E), Juliusruh (54.6°N, 13.4°E), Chilton (51.6°N, 358.7°E), Pruhonice (50.0°N, 14.6°E), Rome (41.8°N, 12.5°E), Ebro (40.8°N, 0.5°E), Athens (38.0°N, 23.6°E), and Arenosillo (37.1°N, 353.3°E). Ebro and Arenosillo had stopped the campaign on July 14 due to noisy and unreliable measurements. Athens and Rome recorded good nighttime data, making possible analyses for nighttime sporadic *E*-layer height changes. The other stations recorded high quality measurements clearly showing the two different regimes for nighttime and daytime *E*-layer height variations. An example of the campaign measurements recorded at Chilton station is depicted in fig. 5.

A number of interesting effects on the daily variations of the *E*-region virtual heights were observed: day-to-day variability of the *E*-region heights, repetitive «hooks» in the height records (inter-diurnal variations) and a distinct diurnal variation. Preliminary ideas on the observed effects suggest that day-to-day variability of the *E*-region height variations could be related to planetary wave modulation of metallic ion transport while inter-diurnal variations may be caused by tidal/gravity wave activity in that region. Although not shown here, spectral analysis revealed other interesting phenomena: station-to-station variations in the diurnal harmon-

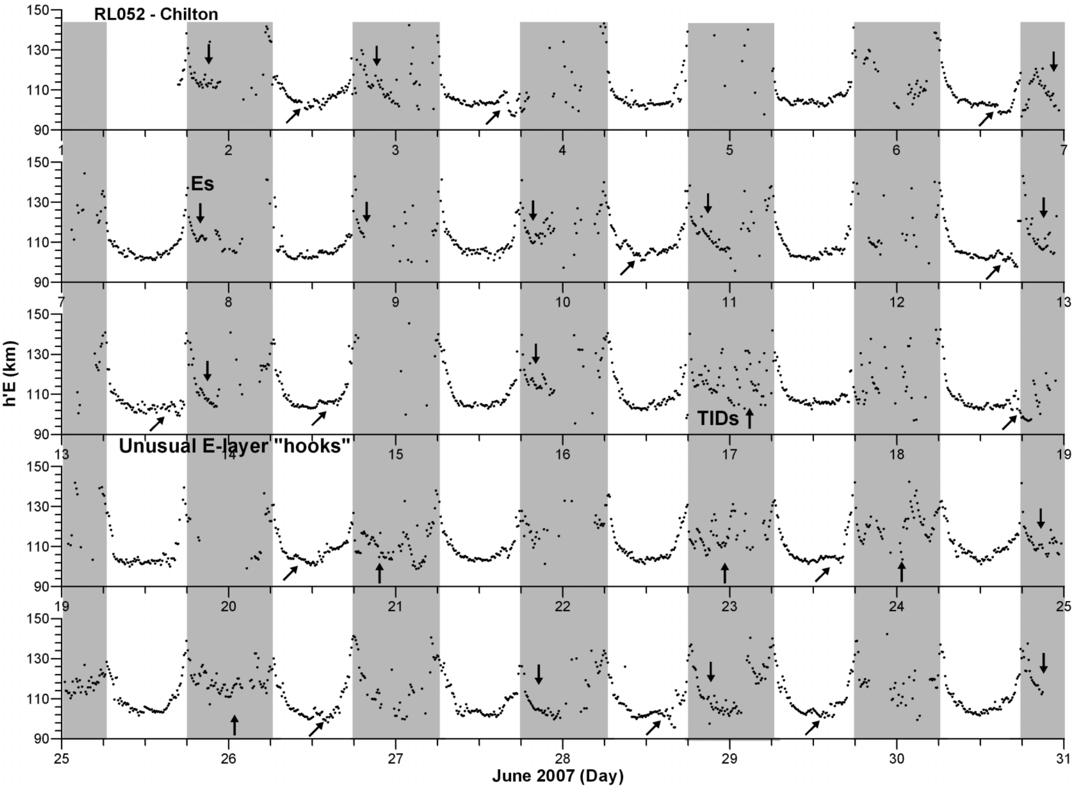

Fig. 5. *E*-region precision group height measurements at Chilton, UK as function of time for June 2007. The horizontal axes represent time (Universal Time) and the vertical axes represent virtual height (km). The grey shaded areas indicate night-time measurements and the arrows point out significant inter-diurnal height variations as hook shaped or trains of height oscillations.

ics (24, 12, 8 hours), and possible evidence for the coupling of tidal (24 h) and long period oscillations (120 h). Results of the data analysis demonstrated great potential offered by the ionospheric sounding with enhanced range resolution. Though results presented are focused on the *E*-region, the technique may be applied to other ionospheric regions.

7. Summary and concluding remarks

The main achievements of the near Earth space plasma monitoring under COST 296 may be summarized as follows. The historical and real-time data bases of the soundings of the ionosphere have been maintained and increased with continuous flowing of monitoring data. The COST 296 community succeeded in making data standardized and available to the ionospheric community for their purposes as research, modeling and telecommunication applications, this being possible throughout the websites of the stations managed by COST 296 participants. Many validated data have also been made available. The added value of the validated data served for testing the auto-scaling algorithms and a continuous feedback makes possible improvements to the above algorithms, and a trusted ionospheric monitoring for research and modeling purposes. The quality of the real-time data quality was systematically assessed for key ionospheric parameters, serving to provide data users measurement uncertainties and to improve automatic scaling algorithms, and so making the real-time data acceptable to modern assimilation models. The availability of the edited data also served for calibration and validation of space-borne sensors. Moreover, a technique for improving the discrepancies of different mapping services under stormy conditions has been developed. Further techniques and parameters have been developed for monitoring the near Earth space plasma.

Time dependent 2D maps of TEC and key ionospheric parameters are available on-line throughout the websites of the COST 296 participants and activity indices for distinguishing disturbed ionospheric conditions have been obtained for real-time applications. Most of the above achievements have been obtained for ground VI data or for vTEC derived from GNSS signals. The potential of the different observing systems for ionospheric monitoring has been combined to obtain a comprehensive view of the effects of a solar eclipse on the ionosphere.

Thanks to the cooperation for the last 4 years in the frame of the COST 296 action, significant progress has been achieved for data availability and validation, 2D monitoring products, and dissemination of products. However, a step forward is needed in the future, especially to combine different ionospheric observing systems for monitoring. The development of 4D techniques of ionospheric monitoring (time dependent 3D products) would be the goal of further cooperation actions.

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