The European COST (Co-operation in the field of Scientific and Technical Research) Actions: an important chance to cooperate and to grow for all the international ionospheric community

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Abstract

The current COST (Co-operation in the field of Scientific and Technical Research) Action 296 on Mitigation of Ionospheric Effects on Radio Systems, along with previous COST238 (Prediction and Retrospective Ionospheric Modelling over Europe), COST251 (Improved Quality of Service in Ionospheric Telecommunication Systems Planning and Operation) and COST271 (Effects of the Upper Atmosphere on Terrestrial and Earth-Space Communications) Actions have addressed investigations of the different effects of the ionosphere on terrestrial telecommunication systems and on Earth-space systems. Throughout their lifetime of 20 years, these COST actions have achieved a great deal in long-term archiving of synoptic soundings of the state of the ionosphere, in enhancing understanding of the morphology of the ionosphere and its dependence on space weather and in producing ionosphere-plasmasphere as well as propagation models for terrestrial radio services available to variety of radio users. Besides the formal contributions to ITU-R and the contributions to international organisations such as URSI, COSPAR, EGU and ESA, these COST Actions have provided a forum for the establishment of collaborative European initiatives, a centre of expertise and excellence in ionosphere knowledge when none other equivalent in Europe or elsewhere exists. In this paper, we review the main achievements of the COST 238, 251 and 271 actions as developed in the past studies.

Key words: Ionosphere, Radio Propagation, Monitoring and Modelling

1. Introduction

European solar-terrestrial research community has long been aware that co-operative research on an international basis is essential to deal with temporal and spatial changes in the ionosphere that influence the performance of terrestrial and Earth-space radio systems. The first two COST Actions 238 and 251 during the period 1991-1999 have been attempts to capture some of ionospheric basic features over Europe in terms of the key ionospheric characteristics of vertical incidence (i.e. critical frequencies of E and F layers, foE, foF1 and foF2 and propagation factor M(3000)F2) used as input parameters to specify the structure of the electron-density height profile model. The next COST 271 Action during the period 2000 – 2004 aimed to perform studies to influence the technical development and the implementation of new communication services, particularly for the GNSS and other advanced Earth-space and satellite to satellite applications.

COST 238 PRIME on “Prediction and Retrospective Ionospheric Modeling over Europe” models were restricted to the geographical area between latitudes 35^o-55^oN and longitudes 10^oW-30^oE to use most effectively European data set of vertical-incidence soundings and to avoid the problems that arise at the higher and/or lower latitudes (Bradley, 1995 and references therein). Objectives of the follow-on COST 251 IITS on “Improved Quality of Ionospheric Telecommunication Systems Planning and Operation” were to further refine PRIME models, to widen their geographical area of applicability to 70^0 N northwards and 60^0 E eastwards and to make them applicable to any geographically restricted area (Hanbaba, 1999 and references therein). PRIME and IITS results have been quite substantial, with newly-developed methods being used to finally deal realistically with the restricted area of Europe. It

was just during the lifetime of these actions that many regional mapping methods were developed world-wide, examined and tested in their application to the European area and finally compared with the performances of the most used global method that is the International Telecommunication Union (ITU-R). COST271 Action on “Effects of the Upper Atmosphere on Terrestrial and Earth-space Communications” has had the following main objectives: (i) to evaluate the influence of upper atmospheric conditions on terrestrial and Earth-space communications, and (ii) to develop methods and techniques to improve ionospheric models over Europe for telecommunication and navigation applications. COST271 Action has successfully managed to transfer some of the results to ITU-R and other national and international organizations dealing with the modern communication systems (Zolesi and Cander, 2004 and references therein).
This paper addresses four main issues of these COST Actions: (1) Ionospheric monitoring and data collection (Section 2), (2) Ionospheric mapping and modelling (Section 3), (3) Ionospheric topside modelling (Section 4), and (4) Propagation models (Section 5). Section 6 then summarizes the conclusions of the paper and makes recommendations regarding the following on COST Actions.

2. Ionospheric monitoring and data collection in COST238, 251, and 271 actions

The main objective of all ionospherically related COST actions has been to stimulate further co-operation in the domain of ionospheric and plasmaspheric prediction and forecasting for terrestrial and Earth-space communications, including interactive repercussions on the corresponding standards in this field, taking into account the present and future needs of users. In doing so one of the most important tasks has been to collect historical and new ionospheric and plasmaspheric data as well as real-time satellite and terrestrial measurements for now-casting, forecasting and warning purposes**.** Three very important databases of public access have been developed. The first one is the COST 251 Digital Database of vertical incidence soundings available on a compact disc (RAL CD). It contains scaled 14 ionospheric characteristics for nearly 50 stations in the COST 251 region and the immediate surrounding areas during the years 1957-1997. The second one is the ionospheric database developed at Rutherford Appleton Laboratory, UK (http://www.wdc.rl.ac.uk/cgi-bin/digisondes/cost_database.pl) that provides real-time and historical data from 11 European observatories: Athens, Chilton, Juliusruh, Rome, Tortosa, El Arenonsillo, Dourbes, Lerwick, Pruhonice, Stanley and Tromso. This database offers all available ionospheric parameters derived from the ionograms, and electron density profile data in plot and ASCII format, continuously updated with real-time data that are transferred automatically after each sounding. The third one is the EISCAT database developed in the University of Grenoble (http://www-eiscat.ujf-grenoble.fr) archives ionospheric data. This data stems from measurements performed by the UHF EISCAT radars from 1981 to 1999. The database provides the classical incoherent scatter parameters (Ne,Te,Ti,Vi), the ionospheric electric field and the following reduced ionospheric parameters: the Integrated Total Electron Content (ITEC), the F2 layer maximum altitude and density with the corresponding plasma frequency (hmF2, NmF2 and foF2).

3. Ionospheric mapping and modelling in COST238, 251, and 271 actions

Global methods, as the former CCIR, then replaced by ITUR, have been applied in the sixty and seventy years to long-term mapping and modelling, first step of every performance prediction of the HF radio systems over long distances. While long distance communications were considered exclusively for satellite applications, it was newly considered by radio users the importance of the HF communications via ionosphere for continental or medium distance connections during the second half of the eighty years. This was especially in Europe for the peculiar geopolitical situation connected to the Mediterranean and Middle East regions. Moreover it is extremely important to note that during those years there was an epochal evolution of the computers. The study and the application of regional mapping techniques, both for instantaneous or real time prediction as well for median conditions, emerge from the need to improve their performances. This is possible by use the available or denser network of ionospheric stations and, in a restricted area, by simplifying the difficulties. On the other hand, it is not completely obvious that regional techniques should give always better results than the global methods. The large concentration of operative and historical ionospheric stations in Europe seemed indicate the old continent as the good laboratory for regional methods.

As the principal objective of COST238 Action was to develop improved models of ionospheric mapping for the principal ionospheric characteristics foF2 and M(3000) F2 for the restricted European area, it was necessary to provide: reference monthly median models for different solar epochs to be used in long-term prediction; retrospective models for individual epochs; and forecast models few hours ahead for frequency management. The PRIME computer program produced as output of this Action was based on the various adopted procedures giving: a) monthly median maps for a single epoch; b) diurnal and seasonal trends of the median monthly values; and c) instantaneous mapped values for a given day and hour.

Some of these models as SIRM (Zolesi et al., 1993; 1996), PASHA (De Franceschi et al., 1994), MQMF2 (Mikhailov et al. 1990) and EOF (Dvinskikh and Naiedova, 1991) were initiated before the PRIME project commencement and were improved later on using the updated PRIME data bank. Other models as KGRID, LINLAT, ILCNN, SWILM, ISIRM, SAILT, MQMF2R and UNDIV were generated in the contest of PRIME and IITS (Zolesi and Cander, 1998). It is important to note that firstly during the PRIME Action and then later during IITS Action a testing procedure was developed and applied by an impartial testing team to verify and rank the performances of the different methods inc1uding the global ITU-R. This work was performed by using the improved and valid data bank (Levy et al., 1998). Important consideration was given also to the buffer zone between the global and regional models in an attempt to avoid large gradients especially at high latitudes where a complex behaviour of the ionospheric conditions exists (Leitinger, 1993; Hanbaba, 1999). The UNDIV model was the long-term mapping procedure, first recommended by the COST238 PRIME for use in the European regional area, both for foF2 and M(3000)F2 ionospheric median conditions, and then adopted, after tests in comparison with other developed methods, also by the COST251 only for M(3000)F2. The UNDIV model uses simple SSM (Sing1e Station Model*)* constructed with one and the same algorithm for all ionospheric stations.

The best mapping methods in the COST 251 Action appeared to be the MQF2R for the foF2 and the UNDIV for the M(3000)F2) (Bradley, 1999 and references therein). They performed much better than the global of ITU-R and still better than the other models proposed in COST actions. However, all the differences, expressed as standard deviation of the errors in terms of MHz, were rather small especially from the point of view of predictors of the monthly median conditions. MQMF2R (Multiquadric Method of spatial interpolation based on foF2 vs MF2 Regression) was an improved version of MQMF2. As ITU-R, PASHA, KGRID and others, this model is a long-term prediction method first developed for world-wide median mapping (Mikhailov et al., 1990) and then applied to the European region to model foF2 and M(3000)F2 ionospheric characteristics. Other models as the SIRM, ISIRM, the many SSMs and the UNDIV were instead devised to be valid only in a restrict area whatever it may be their simple or complex application. The discussion on the best solar activity index was really a never ending story. Anyway the R12 index was really the most used, making no distinction between solar cyc1es, no distinction between rising and falling parts of the cyc1es and no accounting for hysteresis effects.

An operational Short-Term Ionospheric Forecasting (STIF) tool for the European region based on continuous monitoring of the ionosphere was available on the World Wide Web for interactive use: http://www.rcru.r1.ac.uk/iono/STIF.htm (Dick et al., 1999). A network of about 20 ionosondes in Europe provided the basic inputs, measurements of foF2 and M(3000)F2, for the region of interest (10° W-90° E, 30° - 70° N). Data were updated every 24 hours. An auto-correlation procedure was

developed for the short-term forecasting of ionospheric characteristics (Kutiev et al., 1999) and applied to produce forecast values of foF2, MUF(3000)F2 and TEC at integer hours UT up to 72 hours ahead at each vertical incidence station where sufficient measurements were available. All the maps were drawn using the Kriging interpolation technique (Samardjiev et al., 1993). The Kriging method was also applied in a series of methods called PLES (Poland PL and Spain ES) both for long and instantaneous mapping (Hanbaba, 1999 and reference therein).
Successful attempts to build different artificial neural networks models for ionospheric long-term prediction and short-term forecasting have been made by a number of groups within and outside of the COST 251 project (Altinay et al., 1997; Lamming and Cander, 1999; Wintoft and Cander, 1999). NNARX - Neural network based auto-regressive model with additional inputs (X) is one possible approach that use the hybrid time-delay multi-layer perception neural network with on1y critical frequency of the F2 layer as input parameter to produce one output foF2 value at hour t+1 (Cander et al., 1998). Neural techniques have been also applied to mid latitude trough modeling during COST271 action. (Tulunay et al., 2001).

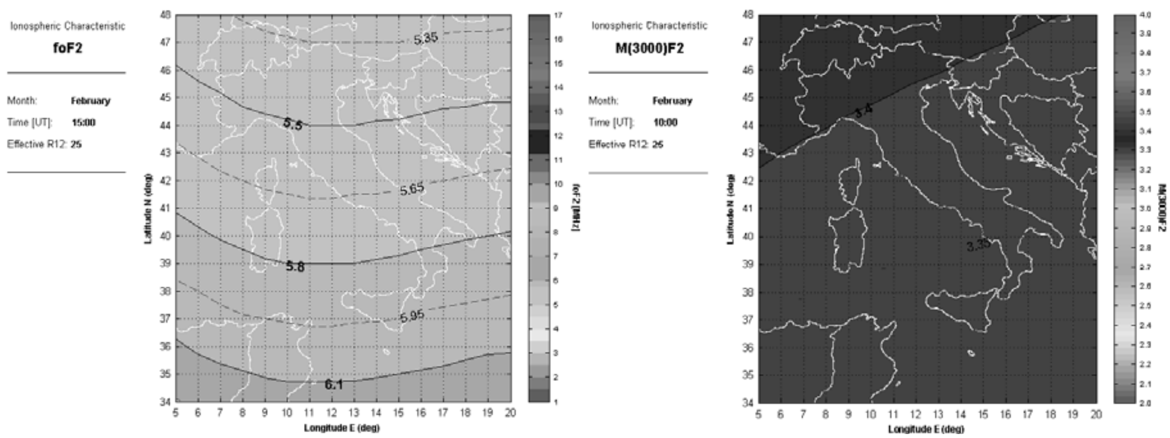

Fig.1. GIFINT ionospheric maps over the Central Mediterranean area for the real time foF2, left, and M(3000)F2, right, based on SIRMUP (Zolesi et al., 2004).

Finally, SIRMUP an instantaneous mapping method was developed during COST271 Action and applied within two European projects, the DIAS (Digital Upper Atmosphere Server) promoted by eContent framework activity (www.iono.noa.gr/DIAS), and GIFINT (http://gifint.ifsi.rm.cnr.it) promoted by the European Space Agency to perform long-term and instantaneous maps of foF2, M(3000)F2 and MUF over Europe and Central Mediterranean Areas, respectively. An example of GIFINT generated maps is shown in Fig.1.

4. Ionospheric topside modelling in COST238, 251, and 271 actions

Models for the electron density profile and the ionospheric total electron content to be applied in the European region were first presented during the COST238 action (Bradley, 1995 and reference therein) but was in the COST 251 that they were developed and refined. The COST 251 model for TEC, known as COSTTEC, was based on the monthly and hourly medians of electron content derived from the Differential Doppler effect on the signals of the polar orbiting NNSS satellites for three solar activity intervals. Technically the longitude dependence was derived from the UNDN 251 foF2 map and formulated with two more sets of Fourier coefficient (Leitinger and Hochegger, 1999). The COST 251 recommended model COSTPROF family of models for the electron-density height profile consists of two parts: a bottom side model for the height region below the F2-layer peak and a topside model for the height region above the F2-layer peak the bottom side model is a modified Di Giovanni-Radicella (DGR) model (Radicella and Zhang, 1995). Regional or global map or measured values are adopted as input for the ionospheric characteristics foE, foF1, foF2 and M(3000)F2. The model uses five semi-Epstein layers. Two semi-Epstein are used for the E-layer (top and bottom), two for the F1-layer (also top and bottom) and one for the bottom of the F2-layer. The D region model covering the 55-85 km height range was produced by the University of Rostock (Singer et al., 1995) and has been interfaced with the DGR model. The topside ionosphere formulation, for the height region above the F2-layer peak up to 2000 km, uses three physical parameters modelled according to solar activity, season, local time and modified dip latitude (Leitinger et al., 1995). An example of NeQuick electron density profil**es i**s shown in Fig.2.

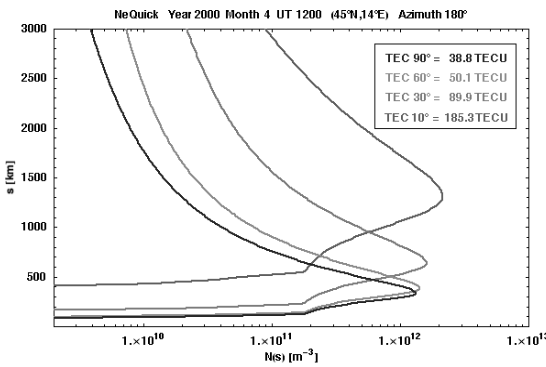

Fig. 2. NeQuick electron density profiles at different elevation angles towards South, as function of the distance from the ground location. TEC are calculated up to 20000 km height (Radicella and Zhang, 1995).

It was in the COST 271 Action that the activities concerning the top side ionosphere have been the major efforts by two important areas: (1) Assessment of space plasma effects for satellite applications, and (2) Space plasma effects on Earth space and satellite to satellite communications. Important results were achieved in the first area concerning the behaviour of large scale structures of the electron content as a key parameter for range errors in GNSS applications (Jakowski et al., 2004a), the radio occultation techniques for probing the ionosphere (Jakowski et al., 2004b), as well the study of the total electron content as key parameter for the tomographic image of the ionosphere (Kersley et al., 2004). In the second area the scintillations effects on satellite to earth links for telecommunications purposes have been considered by Beniguel et al. (2002; 2004) and by Wernik et al. (2004). An example of these results is shown in Fig. 3.

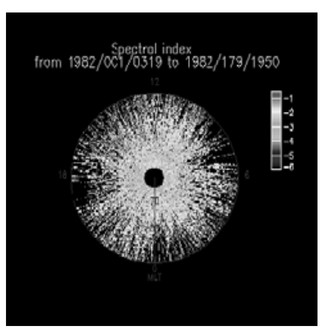

Fig. 3. Polar plot of the spectral index p of the electron density fluctuations for the collection of DE2 spacecraft passes of the first six months of 1982 over the Northern Polar Cap (Wernik et al., 2004).

5. Propagation models in COST238, 251, and 271 actions

Propagation models in COST Actions have been developed to assist operators, system designers and spectrum managers in their often difficult and challenging roles within modern communication and navigation systems. These products are regionally based and use quality-assured data, some of the above described models of the ionosphere and improved ionospheric mapping, now-cast and forecasting procedures (Bradley, 1995; Hanbaba, 1999; Zolesi and Cander, 2004 and references therein). One of the latest European digital upper atmospheric servers for radio systems applications is DIAS (Belehaki et al., 2007). DIAS has developed and currently maintains a distributed server at http://dias.space.noa.gr to support the acquisition, evaluation, dissemination and archiving of ionospheric information, products and services. An example of real-time MUF map over European area provided by DIAS server is shown in Fig. 4.

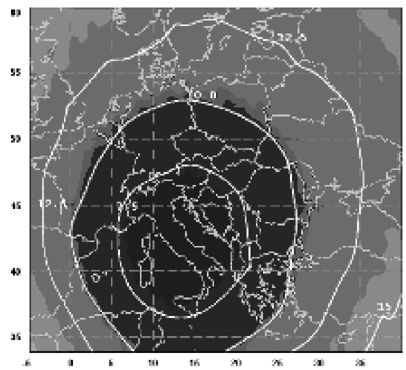

Fig.4. DIAS ionospheric map over the European area for the real-time MUF based on SIRMUP (Zolesi et al., 2004).

6. Conclusions

Significant results and advances in knowledge and understanding of ionospheric medium that have been achieved within COST 238, 251, and 271 Actions are briefly summarized in this paper and should be considered in detail using the large number of references and the final reports that follows. As it is very difficult to include in few sections of this paper a large spread of scientific arguments considered within COST 238, 251, and 271 Actions, it is important to mention those related to the ionospheric effects on radio propagation (Lastowicka and Bourdillon, 2004) and to the long-term variations and their consequences on environment and global change (Bremer et al., 2004). The studies described here are a progressive set of investigations leading to an improved understanding and better modelling of ionospheric structure and dynamic. Work conducted within COST 238, 251 and 271 Actions is currently continuing within follow-on project COST 296 on “Mitigation of Ionospheric Effects on Radio Systems” (MIERS). MIERS builds on the experience of COST’s several successful Actions on ionospheric research and application in it is going to last until the beginning of 2009. The main functions of MIERS are: (a) to provide continues ionospheric monitoring and modelling; (b) to significantly enhance our understanding of ionospheric influence on both advanced terrestrial and space based systems; and (c) to mitigate ionospheric effects on these systems. Its results will be given in accompaning paper by Bourdillon and Zolesi (2008).
Anyway all the participants in these actions, that joined their efforts along twenty years of their life, think that the best result has been the wonderful chance given to the ionospheric community in

Europe within the COST framework to work and to cooperate in peace, to give to the new and young generations of ionospheric scientists the opportunity to grow their experience in a really friendly atmosphere.

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