Collaboration between two COST actions. Ionosphere and space weather

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Summary. In this paper, we describe the collaboration between two COST action: COST 724 devoted to space weather and COST 296 devoted to the study of the ionosphere and its impact on communication and positionning. Several colleagues work in the two actions. This resulted in an important input on ionospheric models provided by the COST 296 action to COST 724

1 Introduction

The objectives of the COST 724 action are to develop within a European framework the science underpinning space weather applications, as well as exploring methods for providing a comprehensive range of space weather services to a variety of users, based on modelling and monitoring of the Sun-Earth system.
The objectives of the COST 296 action are to develop an increased knowledge of the effects imposed by the ionosphere on practical radio systems, and for the development and implementation of techniques to mitigate the deleterious effects of the ionosphere on such systems. The two actions oughted to work complementary in order to avoid duplication of efforts. Indeed, the ionosphere is a major actor of space weather studies which have applications on positionning and radiocommunications. This is why several colleagues belong to the two actions, COST 724 and COST 296. Thanks to their enthusiasm and will to collaborate, COST 296 prepared a list of ionospheric models to be included in the space weather portal that COST 724 had created. In this paper, we will shortly describe this list. Finally, we will describe a pan-European ionospheric server (DIAS) that, although an idependant European project, beneficiated to the two actions.

2 Report on ionospheric models developed during the last COST actions in ionospheric science

There are different approaches to describe the ionosphere for space weather purposes:

- Based on the goals: long term prediction, forecasting, nowcating or specific phenomena modeling
- Based on the parameter that is being described: electron density profile (*Ne*), total electron content (*TEC*), the maximum value of the electron density in the F region and its associated plasma frequency(*foF2*), or the maximum useable frequency (*MUF*) for short wave communications
- Finally, they can also be classified versus their approach: they may use statitics, physics, fitted laws or a mixture of them.

Fourty ionospheric models have been presented. A brief description of some selected models is given in Table 1. The long term prediction chapter includes the analysis of ~~8~~ different models; ~~7~~ models deal with ionospheric forecasting and 9 with nowcasting; 9 are able to provide electron density profiles and /or total electron content. Finally, ~~7~~ models are more specific, dealing for example with the F1 region, or with scintillations. Those are not less important though for dedicated applications.
The modeling was carried out by collaborative groups, where individuals from different countries worked together to achieve a common goal. From this huge amount of work, it was realized that Europe is satisfactory equiped for ionospheric space weather applications even if further developments are always requested. The skill sits here. Coordination is a major requirement for future applications in space weather.

3 DIAS

DIAS is a pan-European distributed information server providing information on the ionospheric conditions over Europe (`http://www.iono.noa.gr/DIAS/Default.htm`). The action officially finished in May 2006 but is still maintained and very active since then. The system is capable of supporting the acquisition, elaboration, evaluation, dissemination and archiving of the ionospheric observations currently obtained from seven European ionospheric stations operating in Athens, Rome, Juliusruh, Chilton, Ebre, Pruhonice, and Lycksele, serving the development of value added products and services which concern: i) the ionospheric specification in real time, at single-station locations (ionograms, f-plots and electron density profiles) and whole Europe (daily plots of the effective sunspot number and ionospheric nowcasting maps of foF2, M(3000)F2, MUF and electron density), ii) short-term ionospheric forecasting up to 24h ahead for foF2 at single-station locations and for the whole area in terms of European maps and iii) long-term ionospheric prediction maps of foF2, M(3000)F2 and MUF for the European area. More details on the system operation can be found in Belehaki et al., (2005; 2006; 2007).
DIAS products and services are designed to support the continuous and reliable performance of applications that use radio propagation and are affected by space weather. In particular ionospheric disturbances affect mainly the following systems: the VLF-LF Communication

and Navigation, HF Communications, HF Broadcasting, OTH Radar Surveillance, Satellite Communication, Satellite Navigation, Spaced-based Radar and Imaging. Considering the range of applications influenced by ionospheric effects, the community of DIAS potential users is quite extensive. The main users of DIAS are the Defense Industry, the Aviation Industry (both civil and military), the Civil HF Broadcast Operators, the Upper Atmosphere Researchers and Amateur Radio Operators
DIAS has important applications both in space weather and in the ionosphere. This is therefore no surprise that this project has irrigated our two actions: data and code contributors have been suppoorted by the COST actions and in return, the efforts of COST contributors could have a direct application thanks to the DIAS server. The DIAS chair is also vice-chair of the COST 724 action.

Model and Reference	Description
The Empirical Orthogonal Functions (EOF) method (Dvinskikh, 1988; Dvinskikh and Naiedova, 1989; 1991; Singer and Dvinskikh, 1991)	Global and regional long-term mapping of ionospheric characteristics.
KGRID (Bradley and Dick, 1993)	Long term prediction of ionospheric characteristics over a limited geographic area using krigging technique.
LINLAT (Bradley and Dick, 1993)	Linear latitude and common diurnal variation procedure LINLAT provides estimates of monthly median foF2 and M(3000)F2 within the PRIME area as a function of geographic latitude and longitude, month and UT.
MQMF2R (Mikhailov and Mikhailov, 1993; 1995 ; Mikhailov and Teryokhin, 1992)	The mu1tiquadric (MQ) method was first developed for world-wide monthly median mapping but has subsequently been adapted for regional mapping and for instantaneous mapping. Then the MQMF2R was the COST 251 method for month1y median foF2, based on Sing1e Station Models (SSM) and on the multiquadric method for spatial approximation.
PASHA (Predicted Adjusted Spherical Cap Harmonic Analysis) (De Franceschi and De Santis, 1993a, 1993b; Bradley, 1995)	PASHA was developed during the Cost 238 action . This model is based on the Spherical Cap Harmonic Analysis (SCHA) that is a technique for modelling the geomagnetic field over a limited region of the Earth's globe.
SIRM (Simplified Ionospheric Regional Model) (Zolesi et al., 1993, 1996)	The Improved SIRM is a regional ionospheric model of the standard vertical incidence ionospheric characteristics, evolved from the original SIRM developed under the EU COST 238 project, and applied to a more extended area taking into account the consequences of high latitude regions.

SWILM (Space Weighted Ionospheric Local Model) (Hanbaba, 1999; De Franceschi et al., 2000)	SWILM was introduced during the COST 251 action for the regional long-term prediction of foF2 and M3000(F2) over the European area.
UNDIV (Bradley, 1995)	UNDIV a method for the long term mapping of the monthly median ionospheric chararcteristics foF2 and M(3000)F2 was first presented in the COST238 action and then was developed during the COST251 action.
Autocovariance method (Stanislawska and Zbyszynski, 2001; 2002)	The autocovariance method was developed during the COST271 action. It is a statistical approach for single-station forecasting of the critical frequency of the F2 layer (foF2).
CORLPREV (Muhtarov and Kutiev 1998a; 1998b; 1999)	CORLPREV was developed during the COST 251 action. The model is based on the auto-correlation procedure applied for the short-term prediction of ionospheric characteristics.
DERA (Hanbaba, R. and Zolesi B., 2000)	The DERA Ionospheric Forecasting Service (IFS) neural network model can provide predictions of the hourly variation of the ionospheric parameter foF2 from l to 24 hours ahead. However, the operational package of the model has been designed in such a way that it would be a simple matter to incorporate predictive models for additional geophysical parameters into the same framework.
Empirical modeling of global foF2 ionospheric response to geomagnetic activity Kutiev, I. and P. Muhtarov (2003)	The empirical model was developed during the COST 271 action. This empirical model describes the variations of F2 region ionization induced by geomagnetic activity .
Multiregression method (Mikhailov et al. 1999; Marin et al., 2000)	The Multiregression method was developed during the COST 251 action. This method is based on a multi-regression of deviation of hourly dev(foF2) from foF2 running median with the previous observations and Ap index
METU-NN foF2 Forecast model (Tulunay, 1991; Altinay et al., 1997; Tulunay et al., 2000; Tulunay et al., 2001)	The METU-NN foF2 Forecast Model is employed to forecast the ionospheric foF2 values up to 24-hour in advance. It is a data-driven approach applying the Neural Network (NN) based modelling.
STIF (Short-Term Ionospheric Forecasting) (Cander, 2003; Muhtarov and Kutiev 1998)	STIF an operational tool for the European region based on continuous monitoring of the ionosphere has been developed and is available on the World Wide Web for interactive use (http://www.chilbolton.rl.ac.uk/weather/tec.htm). It provides forecasts for up to 24 hours ahead and archive measurement maps of the critical frequency foF2, the Maximum Usable Frequency for a 3000 km range MUF(3000)F2, total electron content (TEC) and FOT (Frequency of Optimum Traffic) for the area of interest at an each UT hour.

IMASHA (Instantaneous Mapping Adjusted Spherical Cap Harmonic Analysis) (Bradley, 1995)	IMASHA was developed during the COST 238 action. IMASHA is the same method of adjusted spherical cap harmonic analysis (ASHA) developed for long-term ionospheric mapping and app1ied to the instantaneous mapping of the hourly values of ionospheric characteristics over a restricted area .
ISWIRM (Instantaneous Space Weighted Ionospheric Regional Model) (De Franceschi et al., 2000; Perrone et al., 2002; Stamper et al., 2004; Pietrella and Perrone, 2005)	ISWIRM a regional model for the now-casting of the critical frequency of the F2 layer (foF2) over Europe has been developed during the COST271 action. Inside this region the hourly values of foF2 are obtained, correcting the monthly medians values of foF2 predicted by the space-weighted ionospheric local model (SWILM) on the basis of hourly observations of foF2 coming from four reference stations (Rome, Chilton, Lycksele, and Loparskaya or Sodankyla).
K2 (Kriging 2) (Stanislawska et al. 1995, 1996)	K2 was developed during the COST 238 action as an alternative Kriging procedure. In particular, it was introduced a separate latitude scaling factor which allows for differences in NS and EW correlation distances.
KGRID (Bradley and Dick, 1993b; Samardjiev et al, 1993a).	KGRID, a computer-based procedure for instantaneous ionospheric mapping developed by M I Dick of RAL for implementation with the NEW ionospheric measurement data set (Bradley and Dick, 1993b), is an implementation of the method of Kriging (Samardjiev et al, 1993a).
KIM/KIMS (Bradley et al, 1994a; 1994c, 1995a).	Two specific instantaneous mapping procedures have been developed known as KIM, which is based on Kriging alone, and KIMS in which synthetic ‘screen-point’ values are added in remote areas to constrain mappings to physically realistic figures, rather than to let these be determined by the mathematical expressions which are optimised to the measurement data from elsewhere.
MQMF2-IM (MultiQuadratic method with ionospheric index MF2 for Istantaneous Mapping) (Mikhailov et al 1994, 1995; Hanbaba 1999; Hanbaba and Zolesi, 2000).	MQMF2-IM was developed during the COST 238(PRIME) and COST251 Action. The method MQMF2-IM was recommended for instantaneous mapping within the PRIME area. MQMF2-IM for foF2 and M(3000)F2 uses the following: (1) Single Station Model(SSM) for foF2 and M(3000)F2, (2) screen points inside the area, (3) effective hourly MF2eff and R12eff indexes, (4) buffer zone, (5) main ionospheric through model and (6) multiquadratic method for spatial approximation

PLES (Poland PL, Spain ES) (Stanslawska et al. 1999, 2000; Hanbaba 1999; Hanbaba and Zolesi, 2000)	PLES was developed during COST251 action . PLES for instantaneous values of foF2 and M(3000)F2, combines monthly median maps of ionospheric characteristics and a set of screen points-measurements for a single moment of time of different origin using two interpolation methods modified for ionospheric purposes: Kriging and fitting.
SAIM (Eliseyev and Besprozvannaya, 1998; Hanbaba, 1999)	SAIM was developed during the COST 251 action. The objective was to provide maps of foF2 even in extreme situations when foF2 observations are not available or available only from 1-3 ionosondes, using the effective Kp-index.
SIRMUP SIRM UPdating method (Zolesi et al., 2004)	SIRMUP is based on the idea that real time values of foF2 at one location can be determined from the SIRM model by using an effective sunspot number, Reff, instead of the 12-month smoothed sunspot number, R12. The final output from the SIRMUP now-casting method are maps of foF2 and M(3000)F2 covering the European area from 5oW to 40oE in longitude and 34oN to 60oN in latitude.
NeQuick (Di Giovanni and Radicella, 1990; Radicella and Zhang, 1995; Leitinger et al., 2001)	NeQuick is a quick-run ionospheric electron density model designed for transionospheric propagation applications. It has been developed at the Aeronomy and Radiopropagation Laboratory of The Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy, and at the Institute for Geophysics, Astrophysics and Meteorology (IGAM) of the University of Graz, Austria. To describe the electron density of the ionosphere above 100 km and up to the peak of the F2 layer, the NeQuick uses a modified DGR profile formulation, which includes five semi-Epstein layers with modeled thickness parameters.
NTCM (Neustrelitz TEC Content Model) (Jakowski, 1998, 1999)	The regional TEC model NTCM was developed during the COST 251 action. Two versions of the model were developed and applied to map construction: NTCM 1 algorithm includes fundamental ionospheric variations and solar activity dependence. NTCM 2 version compared with NTCM l includes additionally a geomagnetic latitude dependence term.
COSTTEC Leitinger and Hochegger (1999)	The COST 251 model for TEC, known as COSTTEC, is based on 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 interval. The medians were gained for the latitudes 45, 50, 55 and 600N from latitudinal profiles of electron content.

COST 251 recommended model COSTPROF for the electron-density height profile (Hanbaba, 1999; Hanbaba, R. and Zolesi B., 2000)	The COST 251 recommended model COSTPROF for the electron-density height profile consists of two parts: 1) A bottom side model for the height region below the F2-layer peak based on the ionospheric characteristics foE, foF1, foF2 and M(3000)F2 and on rocket soundings. 2) A topside model for the height region above the F2-layer peak based on O+-H+ diffusive equilibrium with built-in maps for three parameters: the oxygen scale height at the F2-layer peak, its height gradient and the 0+- H+ transition height. The model is continuous in all spatial first derivatives, a necessity in applications e.g. ray tracing and location finding.
METU-NN GPS TEC Forecast Model METU-NN GPS TEC Forecast Map Model (Tulunay, 1991; Tulunay et al., 2002; Tulunay et al., 2004a; 2004b)	Highly nonlinear and complex processes in the Near-Earth Space can be modeled by the METU-NN models, which have been developed by the Group since 1990. The METU-NN, Neural Network, has one input one hidden and one output layer. Levenberg-Marquardt Backpropagation algorithms with validation stop are used for training the METU-NN. The METU-NN GPS TEC Forecast Model is employed to forecast the Total Electron Content (TEC) values up to 24-hour in advance.
RAL-MQP Dyson and Bennett (1988) Baker and Lambert (1988) Dick and Bradley (1993)	This model composes a height profile as a combination of quasi-parabolic (QP) and inverted QP segments. In this way, continuity of gradient is preserved throughout all segment interfaces. The model is completely specified by means of empirical formulations in terms of the standard ionospheric characteristics foF2, foF1, foE, and M(3000)F2, together with a knowledge of the solar-zenith angle.
TEC Monthly Median Mapping (Leitinger and Feichter, 1992, 1993; Leitinger and Spalla , 1994)	A monthly median mapping was developed during the COST 238 action giving TEC up to a nominal height of 1000 km for the whole PRIME area. The adopted mapping is based on the differential Doppler data sets for Lindau/Germany calibrated with the Graz/Austria measurements and grouped into latitude bands centred on 45, 50, 55 and 60deg. N for a nominal geographic longitude of 15deg. E.
The Brussels Meteorogical Institute Physical Models (DYMEK)	This is a photochemical equilibrium mid-Latitude daytime model using Chapman function production terms and the continuity equations for positive and negative ion production and losses (Dymek, 1989). In its initial form vertical transport by neutral winds and diffusion was excluded. Likewise, there was no allowance for day-to-day changes in solar EUV flux with production taken to be governed solely by solar-zenith angle. However, further model development (Dymek and Jodogne, 1993) has led to incorporation of the latest MSISE-90 model of neutral composition and temperature.

DANILOV D-Region modeling Danilov and Smirnova (1994) Danilov et al, 1995	This is a model for the D-region electron density developed based in comparisons with rocket measurements. A new four-classes model has been formulated for day-time winter conditions with electron densities separately given in tabular form at 5 km intervals over the 60-90 km height range for quiet, major stratospheric warming, weak and strong winter-anomaly conditions. The model is based on comparisons with extensive sets of rocket measurements and takes account of two chemically distinct cluster ions including hydrated protons. It incorporates a dependence on solar-zenith angle X and is defined for the range X = 40-90. No changes with solar activity have been detected or are included.
Prediction of the F1 layer occurrence and L-condition (Scotto, 1999, 1998,1997)	The critical frequency foF1 predicted by the Du Charme formula assumes limits for the presence of the layer as a function of the solar zenith angle and of the solar activity given by the R12 index. In the study undertaken in the frame of COST 251, a new probability function to evaluate the occurrence of the F1 layer and L condition (cases where electron density profiles on the ionograms traces show a ledge rather than a remarkable cusp, so no critical frequency can be assigned to the layer) was proposed.
Long-term trends of ionospheric changes (Bencze et al., 1998; Bremer, 1998, 1999a,b; Danilov and Mikhailov, 1998; Lastovicka, 1997).	Studies in the area dealt with long-term trends observations of different ionospheric parameters. It has been shown that the detected ionospheric trends are relatively small compared with the solar and geomagnetic influences. Therefore, during the next years it is not necessary to take into account their influences on the ionospheric HP radio propagation. Neverthe1essthis effect has to be carefully monitored in the future. Especially it should be noticed that the scientific problem of a possible increasing atmospheric greenhouse effect requires further investigations. Mainly in the F2 region the results of the trend analyses are partly controversial and cannot be explained by the greenhouse effect.
Trough modeling (Mitchell et al., 1997) (Mitchell et al., 1999a,b)	A new approach to modelling the trough has been demonstrated. This method is based on a tomographic image of the ionosphere over United Kingdom that is extrapolated to other longitudes across the European sector. Initial results from the mapping were shown to compare well with observations from ionosondes east of the tomography receiver chain. In a separate study a seasonal variation has been revealed in the latitudinal position of the trough, showing the trough to be further south during the winter than the summer.

GISM and Hybrid Scincillation models Beniguel, 2002 Forte and Radicella; 2002 Gherm et al., 2000; 2002	GISM model developed at IEEA uses the Multiple Phase Screen technique (MPS). It consists in a resolution of the Parabolic Equation (PE) for a medium divided into successive layers, each of them acting as a phase screen. Within the scope of the activities of COST271 relevant to the problem of transionospheric propagation a second model for scintillation on transionospheric links (such as employed for satellite navigation) has been developed in co-operation between the University of St.Petersburg, Russia and the School of Electronic and Electrical Engineering, the University of Leeds, United Kingdom. The Abdus Salam ICTP, Italy also collaborated with both the teams providing the experimental data on scintillation, ideas for proper processing of the scintillation data and necessary expertise and data on the ionosphere modeling. The developed technique is based on a hybrid method and it is extended to combine the complex phase method and the technique of a random screen.

4 Conclusion

Meteorology is not a unified discipline. It includes several very different domains. Such is space weather. During the last years, we had this great opportunity to have two actions that were complementary in the *ESSEM* domain. This has given very important deliverables in our two actions and right support for their future developments for a mutual benefit.

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