1
Impact of variability of space environment on communications: Working Group 1 overview

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The paper presents an overview of the scientific research carried out in the frames of Working Group 1 activities of the COST Action 271. The basic objective of this Working Group was the study of the impact of ionospheric variability on communications. The main achievements and an overall evaluation are reported.

1.1. INTRODUCTION

The well-recognized impact of the space environment variability on communications affects many modern life activities and various sectors of economy. Therefore, the systematic development of both scientific research and applications in this field is a high priority. The WG 1 of COST Action 271 was established to serve this priority. The first Working Group (WG 1) is focused on the impact of variability of space environment on communications, having two main objectives. The first is scientific oriented and concerns on the one hand the collection of historical and new ionospheric and plasmaspheric data for nowcasting and forecasting purposes and on the other hand the development of methods and algorithms to monitor, predict and minimize the effects of ionospheric perturbations and variations on communications. The second concerns the stimulation of cooperation, at European level, 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 users present and future needs.

The need for cooperation in the field of scientific and technical research on this topic in Europe is well established considering the situation worldwide in providing data and services for ionospheric and plasmaspheric nowcasting and forecasting.

Several non-European organizations especially in the U.S.A. and Australia provide ionospheric data and products significant for scientific and operational applications, mainly based on the global network of ionospheric stations and GPS receivers. The Center for Atmospheric Research (University of Massachusetts, Lowell) provides access to ionospheric observations from the worldwide network of digisondes (http://ulcar.uml.edu/stationmap.html) and access to the DIgisonde DataBase (DIDB) through the SAO Explorer software (Reinisch *et al.*, 2003). IPS Radio Services, Australian Forecast Center (http://www.ips.gov.au/) provides HF information for Europe, North America, Australasia, and Asia, ionospheric maps of *foF*2 and TEC, estimates for

Table 1.I. European Ionospheric Observatories.

Rome (Italy)	http://dps-roma.ingrm.it/
Chilton (U.K.)	http://www.wdc.rl.ac.uk/ionosondes/view_latest.html
Juliusruh (Germany)	http://www.ionosonde.iap-kborn.de/ionogram.htm
Tromsø (Norway)	http://www.eiscat.rl.ac.uk/~ian/ionos_now.html
Norilsk, Irkutsk, Yakutsk, Zhigansk (Russia)	http://ds.iszf.irk.ru/
Dourbes (Belgium)	http://digisonde.oma.be/
Kiruna, Uppsala, Lycksele (Sweden)	http://www.irf.se/~ionogram/
Roquetes/Tortosa (Spain)	http://www.obsebre.es/w3/ionosfer.php
Athens (Greece)	http://www.iono.noa.gr
El Arenosillo (Spain)	http://www.inta.es/iono/
Pruhonice (Czech Republic)	http://147.231.47.3
Tromsø (Norway)	http://www.eiscat.no/updating_dynasonde.html

the *T* index, HAP charts and HF-conditions. NorthWest Research Associates (http://www.nwra-az.com/) provides space weather and ionospheric scintillation services. ISES (http://www.ises-spaceweather.org/) encourages and facilitates near-real-time international monitoring and prediction of the space environment by the rapid exchange of data and its application to the proper services that can reduce the impact of space weather.

On the other hand, the collection and distribution of ionospheric data and products in Europe for scientific and commercial use is currently possible mainly through the following Research Centers with open access to the public: Rutherford Appleton Laboratory in United Kingdom (http://www.wdc.rl.ac.uk/cgi-bin/digisondes/cost_database.pl), and Space Research Centre in Poland (RWC Warsaw http://www.cbk.waw.pl/rwc). Another important database with limited historical ionospheric observations was developed at ICTPAS, in Italy, under the previous COST Action 251 (http://cost251.ictp.trieste.it/). A major advantage of Europe with respect to other regions is the satisfactory coverage by ionospheric observatories that provide data for radio-communication purposes. Some of the European observatories provide access to their observations on the Internet. A list of the European Ionospheric Observatories and their Internet addresses is presented in table 1.I. Nevertheless, the operations of European observatories are mainly independent creating several barriers for transforming the available information into usable usable data, products and services for nowcasting and forecasting the impact of ionospheric variability on communications.

It is therefore obvious that the European research community should exploit the major advantage of the dense network of observations, and the very significant research expertise on this field, aiming to develop products and services which are similar or even more sophisticated from the corresponding tools developed by other non-European organizations to serve the needs of terrestrial and earth-space communication.

1.2. Our scientific results – Overview

The challenges that COST 271 faced were wide and ambitious: monitoring of Earth environment, assimilation of disparate data, development of end-user information, demonstration of its application to the experimental and operational service systems. Moreover, studies to influence the technical development and the implementation of new communication services, particularly for GNSS, as well as regional radio service systems were provided. The progress reached in the frames of WG 1 could be grouped as follows: 1) state-of-the-art study; 2) feasibility study; 3) databases and validation of prompt ionospheric parameters; 4) operational services; 5) modeling techniques leading to new operational services; 6) studies that improve our understanding of the upper at-

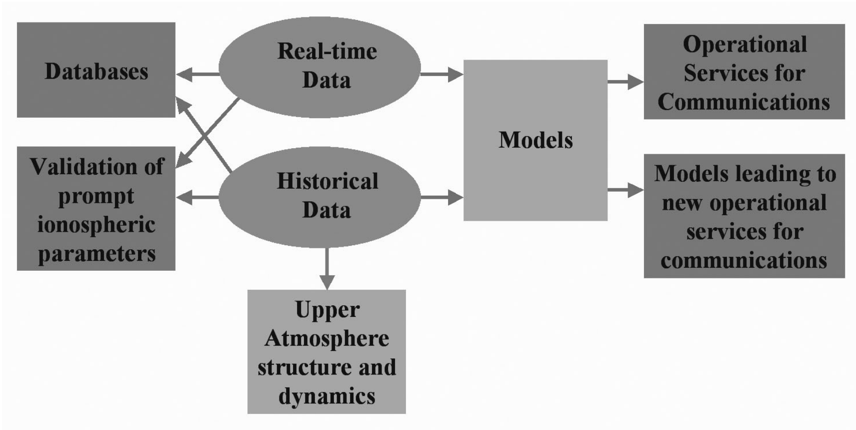

Fig. 1.1. Flow chart of Working Group 1 activities.

mosphere structure and dynamics; and 7) advances in mathematical and physical tools development. The flowchart of WG 1 activities is given in fig. 1.1. In the following sections we will highlight the most important achievements.

1.2.1. State-of-the-art study

The main objective of this COST Action is to study the effects of the upper atmosphere on terrestrial and Earth-space communications. It was therefore, normally, the first step of our activities, to list present and future anticipated terrestrial and Earth-space radio systems that their operation can be affected by ionospheric space weather disturbances (Tulunay and Bradley, 2004). In this respect the radio systems have been taken as including all those associated with communications, navigation and surveillance. This distinction is particularly important because some phenomena, such as for example those concerned with varying signal group delays, influence the performance of navigation and surveillance systems, but are of lesser significance to systems concerned only with the transmission of intelligence. To assess the reliability and compatibility of a radio system, *i.e.* whether it will achieve its intended purpose for the necessary time in the presence of the natural noise background, and whether it is compatible with co-channel and adjacent channel transmissions, appropriate propagation models are needed. These in turn depend on the relevant ionospheric models, which may be formulated in terms of either long-term predictions for system planning, or near-real-time forecasts for operational assessments.

1.2.2. Feasibility study

A feasibility study regarding the development of new models to nowcast and forecast the impact of variability of space environment on communications was performed by Tulunay and Bradley (2004) and Bremer *et al.* (2004). The first target was to identify phenomena that can lead to impairments of radio systems and need to be modeled. A summary of individual impairments that can arise under some circumstances is given. A radio wave is specified in terms of five parameters: its amplitude, phase, direction of propagation, polarization and frequency. The principal effects of the ionosphere in modifying these parameters are considered. As a second task, the space weather key parameters creating impact adversely and significantly on propagation conditions have been identified. Different phenomena that arise under separate conditions with different time scales affect the ionosphere. Such phenomena are the solar flares, *X*-ray enhancements, coronal mass ejections and magnetic effects, and solar radio burst emissions. A detailed examination of the impact of these phenomena on radio propagation is given by Tulunay and Bradley (2004).

A third task of the feasibility study focused on the definition of the potential effect of the long-term trends on prediction models (Bremer *et al.*, 2004). Using observations of about 50 different ionosonde stations with more than 30 years data series of *foF*2 and *hmF*2, trends have been derived with the solar sunspot number R_{12} as index of the solar activity. The final result of this trend analysis is that the differences between the trends derived from the data of the individual stations are relatively large, the calculated global mean values of the *foF*2 and *hmF*2 trends, however, are relatively small. Therefore these global trends can be neglected for practical purposes and could not be taken into consideration in ionospheric models. As shown with the data of the ionospheric station Tromsø, however, at individual stations the ionospheric tends may be markedly stronger and lead to essential effects in ionospheric radio propagation (Rogers *et al.*, 2002).

1.2.3. Databases and validation of prompt ionospheric parameters

1.2.3.1. Databases

Two very important databases of public access have been developed in the frames of Working Group 1 activities.

The ionospheric database developed at Rutherford Appleton Laboratory (http://www.wdc.rl.ac.uk/cgi-bin/digisondes/cost_database.pl) provides real-time and historical data from 11 European observatories: Athens, Chilton, Juliusruh, Rome, Tortosa, El Arenonsillo, Dourbes, Lerwick, Pruhonice, Stanley and Tromsø. The database provides all possible ionospheric parameters derived from the ionograms, and electron density profile data in plot and ASCII format (Stamper *et al.*, 2004). This database is continuously updated with real-time data that are transferred automatically after each sounding.

The EISCAT database developed in the University of Grenoble (http://www-eiscat.ujf-grenoble.fr) stores 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 (N_e, T_e, T_i, V_i), the ionospheric electric field and the following reduced ionospheric parameters: the Integrated Total Electron Content (ITEC), the *F*2-layer maximum altitude and density with the corresponding plasma frequency (*hmF*2, *NmF*2 and *foF*2).

1.2.3.2. Direct validation of prompt ionospheric parameters

An attempt has been made to validate the Ionospheric Total Electron Content (ITEC) based on statistical results from the analysis of long time serried of data. The ITEC is a relatively new parameter (Reinisch and Huang, 2001) computed routinely from the European real-time digisondes and its validation was important to be able to use this parameter for operational applications. Systematic comparison between ITEC and GPS derived TEC values, estimated for the same geographic location (Athens) using 12 consecutive months of measurements, demonstrated that their residual differences have the same qualitative characteristics as the plasmaspheric electron content, as deduced from the diurnal and seasonal behavior and the variation during geomagnetic storms (Belehaki *et al.*, 2003). It therefore resulted that the ITEC parameter is a realistic measure of the electron content up to 1000 km.

As a next step, a statistical investigation of the relationship between the ITEC and the total electron content, both calculated from the same set of electron density profiles that had been obtained from 4000 Malvern Incoherent Scatter Radar (ISR) profiles (Belehaki and Kersley, 2003), showed that especially during nighttime intervals the correlation between the two quantities is very high. This work is in progress to disclose to the derivation of the quantitatively relation of the two parameters.

1.2.3.3. Indirect validation of prompt ionospheric parameters

A significant advantage of ionospheric sounding techniques during the last decade is the possibility to derive in real-time from the ionograms all important ionospheric parameters. The software algorithms built in the real-time ionospheric stations have become more and more intelligent and as a result the automatic derivation of prompt ionospheric parameters is very reliable. The development of nowcasting and forecasting models of the Earth's upper atmosphere able to provide results that can be used for operational applications is based to a great extent on the availability of such real-time data. In the frames of WG 1 activities two efforts have been made aiming to demonstrate the improvement in the models' performance when updated with real-time parameters and therefore demonstrating indirectly the validity of these autoscaled ionospheric parameters. This work is focused on two areas: improving standard ionospheric maps of the *foF*2 parameter (Zolesi *et al.*, 2004) and improving the IRI-2000 electron density profiles (Burešová *et al.*, 2003).

From another point of view, a comparison was made between the EISCAT ISR and ionosonde data (Lilensten *et al.*, 2003) in an attempt to intercalibrate all instruments able to provide real-time data for space weather applications. A comparison of ionospheric measurements (*foF*2 parameter) between EISCAT and two ionosondes located at the same place showed that the calibration of the EISCAT Incoherent Scatter radar through ionosonde data is not a simple task and can lead to erroneous values when compared to GPS. Therefore a useful approach could be to calibrate IS radars with the plasma line and to inter-calibrate ionosondes with the radars over a large set of cases.

1.2.4. Operational nowcasting and forecasting services

The main category of deliverables provided by WG 1 concerns the development of operational nowcasting and forecasting services. A very important system has been set-up to operate on-line as a result of the collaboration between the Rutherford Appleton Laboratory and the National Observatory of Athens (http://ionosphere.rcru.rl.ac.uk/). Real-time measurements of the critical frequency of *F*2-layer, *foF*2, and the propagation factor for a 3000 km range, *M*(3000)*F*2 from four European Digisondes operating in Athens, Rome, Chilton and Juliusruh and the *Bz*-component of the interplanetary magnetic field, *Bz*-IMF, from NASA Advanced Composition Explorer (ACE) spacecraft mission are combined for the development of a real-time dynamic system, oriented to monitor the ionospheric propagation conditions over Europe (Cander *et al.*, 2004). The system enables extreme conditions to be quantified so that particularly for telecommunications planning likely variability bounds can be defined. The presented facility is available for both operational purposes and scientific studies and it will be upgraded to accept data from real-time digisondes operated in other areas of the planet according to the users' requirements.

Our community can also significantly benefit from the ionospheric nowcasting and forecasting information provided by the Regional Warning Center of Warsaw in Poland (Stanisławska and Zbyszyński, 2001) and the Space Weather Web operated by Rutherford Appleton Laboratory (Cander and Ciraolo, 2002; Cander, 2003; Cander *et al.*, 2003). The services provided by the two research centers are listed in table 1.II.

Table 1.II. Operational services for nowcasting and forecasting the state of the ionosphere over Europe.

Research center	Operational services
Regional Warning Center of Warsaw (http://www.cbk.waw.pl/rwc)	– Up to 24 h *foF*2 forecasts at selected locations. – Up to 24 h regional maps of the ionosphere.
Space Weather Web operated by Rutherford Appleton Laboratory (http://ionosphere.rcru.rl.ac.uk)	– Real-time plots of *foF*2 and MUF(3000)*F*2 at selected locations. – Archive of *foF*2 and MUF(3000)*F*2. – European TEC maps for the previous day. – Daily station TEC profiles for the previous day. – European TEC maps archive. – Archive of daily profiles of TEC for all European stations. – Ionospheric forecast maps of *foF*2, MUF(3000)*F*2 and NeQuick derived TEC provided up to 24 h ahead using STIF. – Archive of *foF*2, MUF and NeQuick derived TEC forecasts.

1.2.5. Modeling techniques leading to new operational services

Various natural and artificial indicators can perturb Earth's environment and affect the radio-communication quality. Therefore, a deeper understanding of the complex, nonlinear physical processes would be very helpful for communication purposes. For instance, the identification of the mutual relations between the quantified ionospheric variability and communication circumstances is expected to enable the construction of relevant models for prediction and forecasting. Gathering recent findings and providing follow on studies on the coupling of different atmospheric layers, aiming to improve our understanding, is an important target of the WG 1 activities.

The changes in the ionosphere and plasmasphere during space weather events, such as geomagnetic and ionospheric storms are very intense. Therefore a sophisticated approach taking into account the global solar wind – magnetosphere – ionosphere interaction is adapted. The investigations undertaken in the frames of COST 271 Action covered a wide spectrum of studies that improve and enlarge our knowledge of the ionospheric behavior, which is a requirement for the reliable operation of telecommunication systems.

The development and evolution of new techniques and models into operational tools was one of the most important challenges of WG 1 activities. We could distinguish the modeling techniques into two main groups:

a) Regional ionospheric mapping (Burešová *et al.*, 2003; Pietrella *et al.,* 2003; Stanisławska *et al.*, 2004; Zolesi *et al.*, 2004).

b) Modeling and forecasting of ionospheric characteristics (Y.K. Tulunay *et al.*, 2001; De Franceschi *et al.*, 2002; E. Tulunay *et al.*, 2002; Kutiev and Muhtarov, 2003; Stankov *et al.*, 2003; Antonov *et al.*, 2004).

The main characteristics of these models are summarized in table 1.III.

1.2.6. Studies that improve our understanding of the upper atmosphere structure and dynamics

Two very important studies have been carried out in the frames of the Working Group 1 activities aiming to study in depth the physics of the upper atmosphere structure and dynamics under the influence of solar and geomagnetic disturbances as well as under anthropogenic activities.

Table 1.III. Summary of the model's characteristics.

Model	Input	Technique	Output	Reference
Real-time updating of the Simplified Ionospheric Regional Model (SIRM) for operational applications.	SIRM, automatic scaled *foF*2 values from European digisondes.	Estimation of the effective sunspot number.	Regional ionospheric mapping.	Zolesi *et al.* (2004).
The ISWILM model for instantaneous mapping of the critical frequency of the *F*2-layer in the European region.	The Space Weighted Ionospheric Local Model (SWILM), prompt *foF*2 measurements.	Space weighted correction of the basic grid values.	Regional maps of *foF*2.	Pietrella *et al.* (2003).
Real-time updating of IRI electron density profiles.	IRI-2000, real-time measurements of ionosondes.	Combination of IRI-2000 $N(h)$ profiles with real-time $N(h)$ profiles from COST 271 space weather database.	Deficiencies of IRI-2000 with and without storm option.	Burešová *et al.* (2003).
Updating the NeQuITUR model to produce electron concentration maps.	NeQuITUR model, electron density profile measurements.	Construction of maps from spatially distributed measured data using kriging and fitting interpolation techniques.	Three dimensional electron concentration profile instantaneous maps.	Stanisławska *et al.* (2004).
Kp index.	Interplanetary magnetic field Bz, solar wind speed and pressure.	Estimation of a modified Bz function which exhibits a delayed reaction to Bz changes.	Forecasted *Kp* index.	Antonov *et al.* (2004).
Global empirical model of *foF*2 parameter.	Data from 55 ionosondes, 11 years of observations.	Determination of model parameters by fitting the model expression to the data in each bin.	Relative deviation of the *foF*2 parameter as a function of local time and *Kp* index.	Kutiev and Muhtarov (2003).
Forecasting geomagnetic activity.	*Kp* index for preceding hours.	Time weighted accumulation of the 3 h *Kp* index.	Forecasted *Kp* index.	De Franceschi *et al.* (2002).
Magnetopause crossing.	Solar wind parameters (velocity, density, pressure) and interplanetary magnetic field Bz.	Neural network system properly constructed and trained to learn the shape of the magnetopause.	Radial distance of the Earth's magnetopause.	Tulunay *et al.* (2002).
Real-time construction of electron density profiles.	Ground-based measurements of the total electron content, ionospheric vertical soundings, and empirical values of the upper transition level.	Construction of the bottomside and topside electron profile, assuming Exponential, Epstein or Chapman type of vertical density distribution.	Electron density profiles at middle latitudes.	Stankov *et al.* (2003).
Forecasting *foF*2 in the midlatitude trough.	*Kp* index, local time, geographic and invariant latitudes and *foF*2 values.	Data driven neural network METU-NN model applied in *foF*2 predictions.	Forecasts of *foF*2 in midlatitude trough.	Tulunay *et al.* (2001).

A real tool for investigation of the thermospheric-ionospheric interaction under various geophysical conditions has been proposed by Michailov and Lilensten (2004). Ionospheric observations were widely used in the past to obtain thermospheric parameters such as winds, vertical plasma drifts in the equatorial *F*2-layer, and neutral composition winds. Incoherent Scatter Radar observations turned out to be the most appropriate for such analysis as they provide the most reliable and consistent set of ionospheric plasma parameters in *E*-, *F*1- and *F*2-regions. Much valuable and interesting information on thermospheric winds, temperature and neutral composition has been obtained from ISR data analysis. The main approaches are based on the use of energy equation for O^+ ions to find atomic oxygen concentration and neutral temperature at the *F*2-region heights and on the momentum equation for O^+ ions to retrieve meridional winds. In the frames of the work carried out as part of WG 1 activities, at a preliminary stage, worldwide ionospheric reference data on *NmF*2 and *hmF*2 were used to establish a system of aeronomic input parameters. At the next stage, this system of parameters was substituted to the ionospheric model to find *NmF*2 and *hmF*2, and the results were compared with another set of experimental data, thus confirming the validity of the model, which has been developed. Using routine ISR observations ($N_e(h)$, $T_e(h)$, $T_i(h)$, $V_i(h)$ profiles) the method allows to obtain a self consistent set of the main aeronomic parameters responsible for the *F*2-region formation. The list of derived parameters includes: neutral temperature profile $T_n(h)$ depending on the exospheric temperature T_{ex}, the temperature at 120 km and the shape parameter which determines the temperature profile, concentration of neutral species, vertical plasma drift, which may be converted to the meridional thermospheric winds, total solar EUV flux and ion composition as a result of $N_e(h)$ fitting. Therefore the method gives a complete description of the upper atmosphere condition in the vicinity of ISR facility for the periods of observation. The approach turns out to be very useful for physical analysis of the *F*2-layer disturbance mechanisms giving a complete picture of the phenomenon in question.

A second topic investigated to improve our understanding on the physics of upper atmosphere is the reasons for possible trends in the Earth's atmosphere and ionosphere. Trend investigations of different ionospheric and atmospheric parameters have become more and more important during recent years as such trends could be caused by anthropogenic activities (Bremer *et al.*, 2004). Mainly in the *F*2-region different analyses have been carried out. The derived trends are mainly discussed in connection with an increased greenhouse effect or by long-term changes of the geomagnetic activity. In the *F*1-layer the derived mean global trend in *foF*1 is in good agreement with model prediction of an increasing greenhouse effect. In the *E*-region the derived trends in *foE* and *h′E* are compared with model results of an atmospheric greenhouse effect, or explained by geomagnetic effects or other anthropogenic disturbances. The trend results derived from different ionospheric reflection height and absorption measurements in the LF, MF and HF ranges can at least partly be explained by an increased atmospheric greenhouse effect.

1.2.7. Advances in mathematical and physical tools development

Development of the new tools, techniques, and algorithms can decrease the unreliability of the proposed approach, or, at least, compensate some not fully satisfied effects. Lifetime of the Action prevents exploiting new techniques and finalizing them to the end-user's figure, but the demonstration of their necessity creates well-defined further development for diagnostic and application purposes. Such direction was represented by the development of the updating of the global or limited-area models, as updating the IRI model to produce maps of *N*(*h*) over Europe, where the findings on deficiencies of IRI-2000 model with and without the *foF*2 storm option were shown (Burešová *et al.*, 2003), or updating the SWILM model to produce local nowcast maps (Pietrella *et al.*, 2003).

Another very interesting technique for short-term prediction of ionospheric parameters was presented by Muhratov *et al.* (2002). The model consists of one part representing the weighted past time variation of the ionospheric parameter that is to be predicted ($\Phi = foF2 - foF2med/foF2med$)

and a second part representing geomagnetic activity as described by the index *Ap*. Each part is constructed according to the autocorrelation function of the relative quantity while the interdependence between the two parts is represented by the cross correlation function. The model is termed Geomagnetically Correlated Autoregression Model (GCAM). Testing the model with data from 2 years of high solar activity and 2 years of low solar activity showed a large decrease in the mean squared error by GCAM in the first 8-10 h of prediction relative to median based prediction. Finally in order to present a better comparison between the GCAM and median based prediction errors during disturbed ionospheric conditions, a new error estimate called «prediction efficiency» is used.

1.3. Overall evaluation of the progress achieved

Working Group 1 has two main objectives, first the development of tools and models for nowcasting and forecasting ionospheric variability and secondly the stimulation of cooperation at European level. From the review presented it is clear that all objectives have been fulfilled. Work of excellent quality published in scientific journals with high impact factors is considered a great scientific achievement of WG 1. Operational and experimental services based on the newly developed and/or improved models and algorithms provide substantial improvement in the telecommunication performance.

As a result of international collaboration between different institutes in the frames of WG 1 activities (Appendix), our colleagues raised funds for specific projects from international organizations. An important output in this direction was our contribution to demonstrate the necessity for Action on Space Weather, since this field is not covered by COST 271, but our community needs this kind of input. The final result was the approval for a new COST Action on «Developing of Scientific Basis for Monitoring, Modeling and Prediction Space Weather» (Lilensten *et al.*, 2004). Also several proposals and projects were submitted and funded within EU calls based on consortia formed by COST 271 participating institutes. Finally, the number of bilateral agreements between COST 271 participating partners has sufficiently increased for the implementation of the COST 271 research programs as well as new subjects.

Overall the activities in the frames of Working Group 1 contributed significantly to EC policies. With respect to research and innovation, WG 1 activities contributed a) to the cooperation of several entities at different levels; b) to an increase in the mobility of individuals and ideas between different research organizations; and c) to the reinforcement of European competitiveness mainly with the US and Australia.

Our activities have successfully contributed to maximize European synergy and added value in research cooperation and they have been proved to be a step for further European integration, in particular concerning central and eastern European countries.

More advanced work towards the practical implementation of the obtained knowledge is further needed. For future development the major orientations would be in three directions:

– The development of models able to operate on line to satisfy the requirements of the scientific community and of the industry oriented users community.

– The linkage with other non-European organization in our effort to develop a global system for monitoring and predicting ionospheric and plasmaspheric conditions.

– Further increase in scientific and technological capacity of the European community by integrating COST 271 results.

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Appendix. Collaborations in the frames of WG 1 activities

- IZMIRAN (Russia)-Laboratoire de Planetologie de Grenoble (France).
- Faculty of Aeronautics and Astronautics, Instabul Technical University (Turkey)-IZMIRAN (Russia)-Department of Electrical and Electronics Engineering, Middle East Technical University (Turkey)-Information Technologies Research Institute (Turkey).
- INGV (Italy)-Aristotle University of Thessaloniki (Greece).
- Institute of Atmospheric Physics (Czech Republic)-RAL (U.K.)-INGV (Italy).
- Laboratoire de Planetologie de Grenoble (France)-RAL (U.K.)-EISCAT Association (Norway)-Qinetiq (Norway).
- Laboratoire de Planetologie de Grenoble (France)-RAL (U.K.).
- SRC (Poland)-Observatorio de l'Ebre (Spain).
- NOA (Greece)-University of Wales (U.K.).
- NOA (Greece)-RAL (U.K.).
- RAL (U.K.)-CNR (Italy).
- NOA (Greece)-DLR (Germany).
- Bulgarian Academy of Sciences (Bulgaria)-DLR (Germany).
- INGV (Italy)-NOA (Greece)-RAL (U.K.).
- DLR (Germany)-Royal Observatory of Belgium (Belgium).
- ITU, METU (Turkey)-SRC (Poland).
- SRC (Poland)-Institute of Atmospheric Physics (Czech Republic).
- Institute of Atmospheric Physics (Czech Republic)-SRC (Poland)-Observatory de l' Ebre (Spain)-INTA (Spain)-Geophysical Observatory (Finland).
- Leibniz- Institute of Atmospheric Physics (Germany)-Institute of Atmospheric Physics (Czech Republic)-QinetiQ (U.K.)-University of Tromsø (Norway).
- INGV (Italy)-IZMIRAN (Russia)-SRC (Poland).
- Department of Electrical and Electronics Engineering, Middle East Technical University (Turkey)-Goddard Space Flight Center, NASA (U.S.A.)-Faculty of Aeronautics and Astronautics, Instabul Technical University (Turkey)-Marmara Research Center (Turkey).

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