

From COST 238 To COST 296: Four European COST Actions On Ionospheric Physics And Radio Propagation

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ABSTRACT COST (Co-operation in the field of Scientific and Technical Research) is an important instrument supporting co-operation among scientists and researchers across Europe now joining 35 member countries. Scientific projects in the COST framework are called COST Actions and have the objectives embodied in their respective Memorandum of Understanding (MoU). The main objectives of the COST Actions within the European ionospheric and radio propagation community have been: to study the influence of upper atmospheric conditions on terrestrial and Earth-space communications, to develop methods and techniques to improve existing and generate new ionospheric and propagation models over Europe for telecommunication and navigation applications and to transfer the results to the appropriate national and international organizations, institutions and industry dealing with the modern communication systems. This paper summarises in brief the background and historical context of four ionospheric COST Actions and outlines their main objectives and results. In addition, the paper discusses the dissemination of the results and the collaboration among the participating institutions and researchers.

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1. INTRODUCTION

COST (Co-operation in the field of Scientific and Technical Research) at <http://www.cost.esf.org/> is an important instrument supporting co-operation among scientists and researchers across Europe. COST now joins the efforts of 35 member countries and enables scientists to collaborate in a wide spectrum of activities in research and technology. The objective of the COST actions is to increase the European co-operation and interaction in the field of scientific and technical research for peaceful purposes. The scientific COST activities concerning ionospheric physics and radio propagation are inside the so called dominium of Information technology and Telecommunications.

Since the beginning in 1991, the COST 238 (Prediction and Retrospective Ionospheric Modelling over Europe), COST 251 (Improved Quality of Service in Ionospheric Telecommunication Systems Planning and Operation), COST 271 (Effects of the Upper Atmosphere on Terrestrial and Earth-Space Communications) and the current COST296 (Mitigation of Ionospheric Effects on Radio Systems) Actions have been highly successful in bringing together in collaborative studies many researchers who collectively represent much of the available European

expertise in the field of ionospheric / plasmaspheric research and the application of such knowledge to the improvement of practical radio systems. The COST framework within the Telecommunications, Information Science and Technology domain provides a unique European forum for the progression of such matters.

The results obtained from the measurements and modelling within these, Actions have aided radio-systems planners and designers in two most important aspects. Firstly, better understanding of the upper atmosphere environment over Europe and its effects on terrestrial and Earth-space communications and navigational systems. Secondly, it has been possible to determine and mitigate with higher accuracy the propagation effects imposed by the atmosphere on received signals and consequent interference levels. Additionally, each successive project has raised new questions that have been studied up in the next action. Consequently, while previous COST actions were concerned with identification and investigation of the propagation effects imposed by the upper atmosphere, the current action on Mitigation of Ionospheric Effects on Radio Systems (MIERS) deals directly with the mitigation of such effects on practical radio systems. Significant results and advances in knowledge and

understanding coming from these collaborative projects can be found in reports of the earlier Actions by Bradley and Vernon (1999 and references therein), Hanbaba (1999 and references therein), Cander and Zolesi (2001 and references therein) and Zolesi and Cander (2004 and references therein) respectively, and in the most recent publications (Bourdillon, 2006 and references therein).

This paper is organised in four Sections, each describing the main objectives and results of the following actions: COST 238 (Prediction and Retrospective Ionospheric Modelling over Europe), COST 251 (Improved Quality of Service in Ionospheric Telecommunication Systems Planning and Operation), COST 271 (Effects of the Upper Atmosphere on Terrestrial and Earth-Space Communications) and COST296 (Mitigation of Ionospheric Effects on Radio Systems).

2. COST238: PREDICTION AND RETROSPECTIVE IONOSPHERIC MODELLING OVER EUROPE

COST 238 (Prediction and Retrospective Ionospheric Modelling over Europe) operated from 1991 to 1995 with the principal objective to develop improved models for the European area between latitudes 35-55 N and longitudes 10W-30 E by using mainly ionospheric measurements from existing equipments. The idea of organizing a project on Ionospheric Physics in Europe was firstly discussed in Spring 1988 between Bodo Reinisch and Peter A. Bradley during a friendly conversation in USA. The same year, in October, during a Conference on Geomagnetism and Aeronomy held in Rome, the idea, based on a first USA project to manage a network of ionosondes in Europe but limited only to collect the ionospheric measurements of the European Observatories, was introduced by Peter A. Bradley and discussed among the participants. It was the year after during a meeting held in Paris at the CNET headquarters that the project was finally organized to be submitted for the approval of COST organization. (Bradley and Vernon, 2000)

2.1 Main Objectives

The principal objectives considered were: to develop techniques for using ionospheric sounding information taken from existing measuring equipments to generate improved models of the European Ionosphere, needed to estimate ionospheric propagation effects on telecommunication systems. For this 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; forecast models few hours in ahead for frequency management. The work to be done was shared in five different working groups: 1) Vertical soundings, 2) Oblique sounding, 3) Instantaneous mapping, 4) Forecasting and 5) Monthly Median Mapping and Modelling.

2.2. Major achievements

First a digital data base on optical disk with the routine hourly ionospheric measurements from 27 stations, close to the PRIME area, was produced. 9 coordinate special rapid sequence soundings campaigns were conducted as well 4 oblique soundings were established between ionospheric stations in Belgium, Italy, Spain and Sweden. Secondly a composite model for the electron density profile has been formulated for the PRIME area covering the height 55-1000Km. Finally, after a testing procedure applied to all the mapping methods, the PRIME computer program has been produced based on the various adopted procedures giving (Fig. 1):

- monthly median maps for a single epoch;
- diurnal and seasonal trends of the median monthly values;
- instantaneous mapped values for a given day and hour.

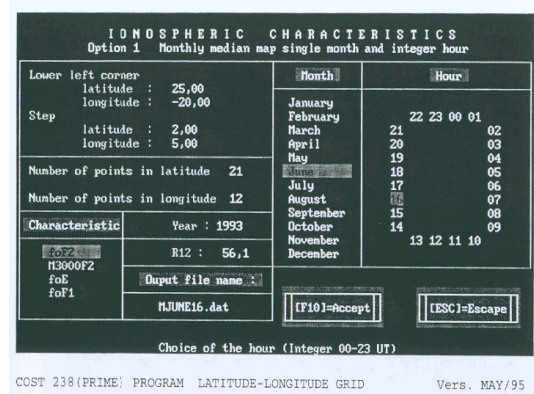


FIGURE 1. Example of input screen of the PRIME computer program

3. COST251: IMPROVED QUALITY OF SERVICE IN IONOSPHERIC TELECOMMUNICATION SYSTEMS PLANNING AND OPERATION

COST251 (Improved Quality of Service in Ionospheric Telecommunication Systems Planning and Operation) was the natural succession to COST238, it was built on existing COST 238 teams and appropriate new groups for the additional activities. The main

objectives were to collect additional quantities and types of ionospheric data, to generate procedures for prediction of ionospheric models over Europe and to promote their use, to extend the validity of the existing models to a more large area, Fig. 2, to give system performance statistics and to develop a methodology for channel simulation for HF systems. As for the COST238 the work to be done was organized in working groups each of them in working package with their sub objective (see Hanbaba, 1999 and Hanbaba and Zolesi, 2000).

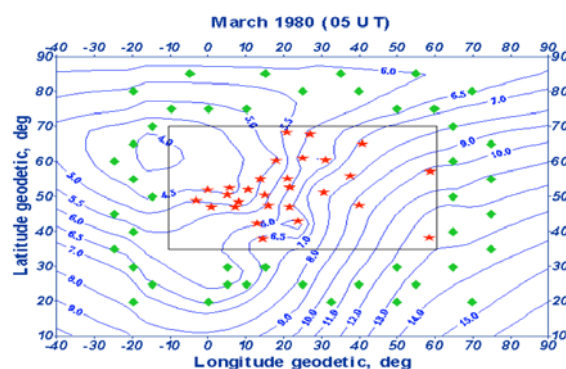
3.1 Main Objectives:

- a) to demonstrate the practical improvement to terrestrial and Earth-space radio systems of COST 238-derived ionospheric models;
- b) to further refine these models and to widen their geographical area of applicability between latitudes 35-70°N and longitudes 10°W-60°E and to promote their use;
- c) to collect additional quantities and types of ionospheric information and to extend the models; to give system performance statistics;
- d) to develop a methodology for channel simulation.

3.2. Major achievements

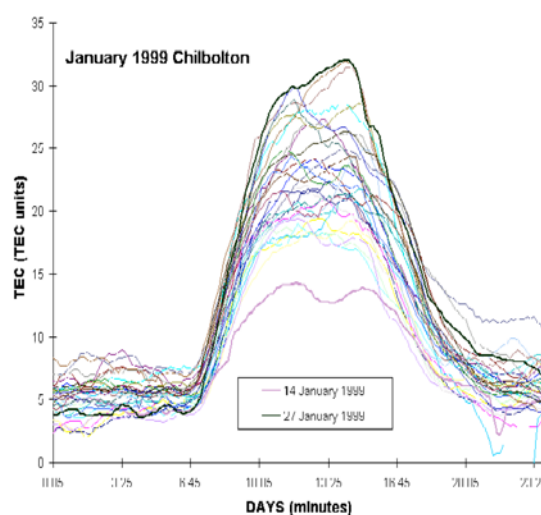
The results obtained in the frame of COST Action 251 during the period 1995-1999 may be below e summarised with particular reference to their application for terrestrial and Earthspace ionospheric telecommunication systems planning and operation:

- a) Production of mapping functions and associated coefficients for the monthly median ionospheric characteristics foF2, M(3000)F2 and TEC (Fig. 2);
- b) Production of spatial-interpolation algorithms for instantaneous values of foF2, M(3000)F2 and TEC from measured data for the same epoch;
- c) Elaboration of forecasting algorithms for estimating values of foF2, M(3000)F2 and TEC up to 24 hours ahead of the present (Fig. 3);
- d) Generation of expressions for the electron density height profile.



Example of COST 251 to ITU-R foF2 maps interfacing ground-based ionosondes: red asterisks
buffer zone points: green squares

FIGURE 2. The COST 251 model for the monthly median ionospheric characteristic foF2



TEC(10¹⁶ m⁻²) 20 JAN 1999 1200 UT

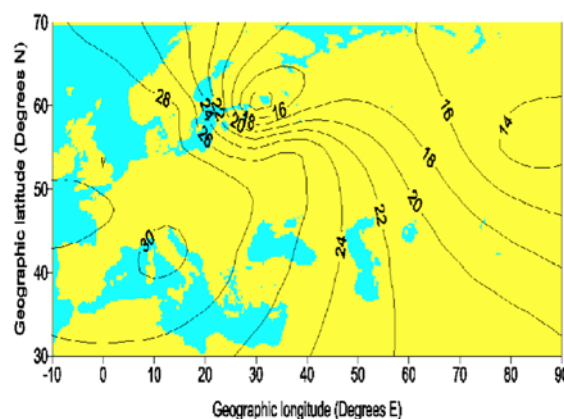


FIGURE 3. Forecasting model for TEC over Europe

4. COST271: EFFECTS OF THE UPPER ATMOSPHERE ON TERRESTRIAL AND EARTH-SPACE COMMUNICATIONS

4.1 Main Objectives

COST 271 (2000-2004) was an Action for the investigation, promotion, stimulation and co-ordination of the European research in ionospheric and plasmaspheric areas. Its main objectives were laid out as follows:

- to perform studies to influence the technical development and the implementation of new communication services, particularly for the GNSS (Global Navigation Satellite System) and other advanced Earth-space and satellite-to-satellite applications,

- to develop methods and algorithms to predict and to minimise the effects of ionospheric perturbations and variations on communications and to ensure that the best models over Europe are made available to the ITU-R (International Telecommunication Union-Radio Communication),

- to collect additional and new ionospheric and plasmaspheric data for now-casting and forecasting purposes,

- 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.

4.2. Major achievements

In COST271 a survey has been carried out of modern radio systems in different frequency bands, within the context of international regulations and the propagation phenomena that can lead to system impairments, together with the space-weather effects that can cause significant adverse impacts on propagation conditions that need to be modelled. Accordingly, studies have been carried out to advance knowledge of the structure and dynamics of the upper atmosphere and provide tools needed for the investigation of thermospheric-ionospheric interactions under various geophysical conditions. Investigation has been made of gravity and planetary waves at mid-latitudes, responsible for some of the

residual uncertainty in ionospheric radio-wave propagation predictions, with a view to identifying patterns to improve the accuracy of forecasts for telecommunication purposes. Studies have been carried out leading to better understanding of the behavior of the ionospheric F1-region, sporadic-E (Es) and spread F phenomena at European middle latitudes under geomagnetic storm conditions. Improvements have been made to existing understanding of the physical mechanisms responsible for possible long-term trends in the Earth's ionospheric and atmospheric parameters that may possibly link such trends with anthropogenic activities. Modelling techniques has been formulated, leading to experimental and real-time operational services involving new mathematical methods and computational tools for the forecasting and regional mapping of ionospheric characteristics (Zolesi and Cander, 2004 and references therein).

Ionospheric stations over Europe have made a vital contribution in maintaining the high standard of vertical-incidence measurements and providing data on a regular basis. Collection and distribution of the historical, new and prompt ionospheric data has been carried out at both the Rutherford Appleton Laboratory (http://www.wdc.rl.ac.uk/cgi-bin/digisondes/cost_database.pl), Fig. 4, and the Space Research Centre (<http://www.cbk.waw.pl/rwc>). In addition, there has been continuing support of the limited database of past ionospheric observations that was developed under the previous COST Action 251 (<http://cost251.ictp.trieste.it/>).

A database of EISCAT observations from 1981 to 1999 has been developed at the University of Grenoble (<http://www-eiscat.ujf-grenoble.fr>). Operational services for nowcasting and forecasting the state of the ionosphere over Europe are now available at the Regional Warning Center in Warsaw (<http://www.cbk.waw.pl/rwc>) and the Rutherford Appleton Laboratory (<http://ionosphere.rcru.rl.ac.uk>).

Models, and other tools to assess ionospheric effects in non-ionospheric applications of GNSS signals, have been investigated at the University of Graz (<http://www.uni-graz.at/igamwww/cost271/>) including (a) ionospheric influences in the use of GNSS occultation for stratosphere / troposphere applications and b) the effect of higher-order ionospheric propagation errors in advanced ground-based applications, like water vapour retrieval. GPS-based regional maps and the TECEDA data bank are now available at the Deutsches Zentrum für Luft und Raumfahrt (<http://www.kn.nz.dlr.de>) (Fig.5).

Prompt Ionospheric Database

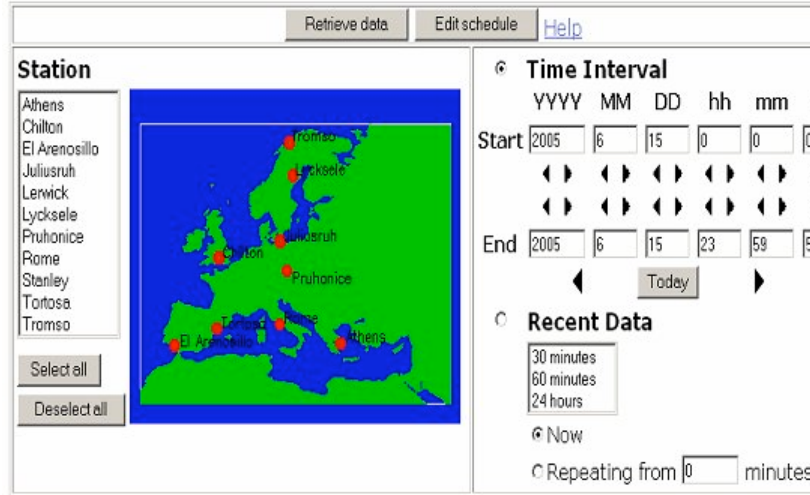


FIGURE 4. Example of the input screen of the Prompt Ionospheric Data base

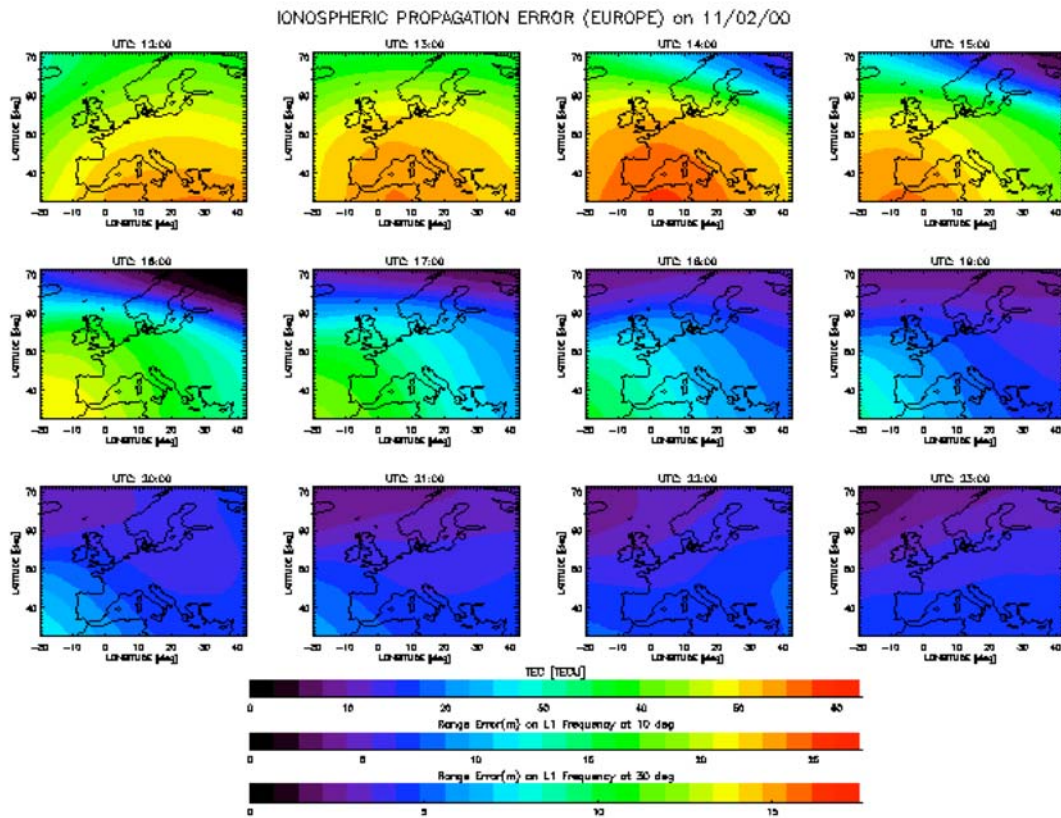


FIGURE 5. Hourly maps of vertical TEC over Europe during different UTC hours, from 12.00 to 23.00 , in TEC units derived from GPS ground station measurements of IGS : first color scale. Corresponding range errors (m) on L1 frequency at 10(deg), second color scale and on L1 frequency at 30 (deg), third color scale.

Important to note “ The model Family” developed at ICTP (International Center for Theoretical Physics) in cooperation with the University of Graz : (NeQuick, COSTprof, NeUoG-plas), generated on the auspices of COST Action 271 and delivered to ITU-R, namely the monthly median electron density model NeQuick(ITU-R) . Fig.6.

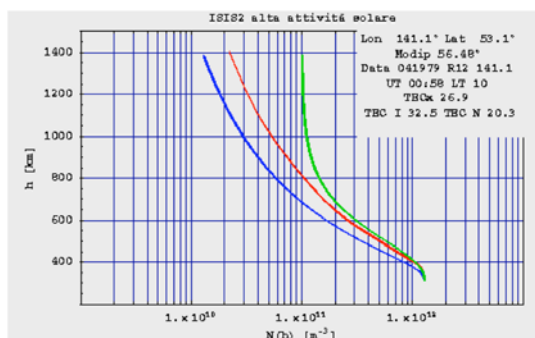


FIGURE 6. Comparison between experimental profiles,red line, NeQuick ,blu line, and IRI, green line

Collection has been started of examples of ionospheric extremes and anomalous cases with unusually high or low electron content values, anomalous gradients and variations that could be attributed to the influence of magnetic storms, travelling ionospheric disturbances (TIDs) and other as yet partially unexplained effects.

A physically-based software simulator has been developed for the HF ionospheric reflection channel and UHF simulators for transionospheric channels, which overcome the limitations of existing empirically-based models. Measurements and simulations have been made and results of importance to applied radio systems obtained, relating to the propagation of HF radio waves over northern European paths, where ionospheric effects impose large Doppler and delay spreads on the propagating signal. A heterogeneous array has been investigated to improve HF transmission, offering the possibility to transmit images via the ionospheric channel by providing an increase of the data rate of 15 kHz within a 3 kHz bandwidth (QAM-64) without coding or interleaving.

Improvements to the GISM (Global Ionospheric Scintillation Model) include use of the multiple phase screen technique to give statistical characteristics of transmitted signals; fade duration and other parameters like the probability of signal loss of lock. Maps of scintillation index S4 and standard deviations of the phase fluctuations can be produced.

Model simulation studies have been made of extreme propagation effects on GPS-to-geostationary satellite ray paths. Information has been gathered about effects of the vertical and horizontal gradients of the electron density on Earth-space and satellite-to-satellite communication. Algorithms and software tools have been developed to treat disturbances in Earth-space and satellite-to-satellite communications. Studies have been made of plasma effects in the magnetosphere-ionosphere-thermosphere system generated by different natural processes and by human activity.

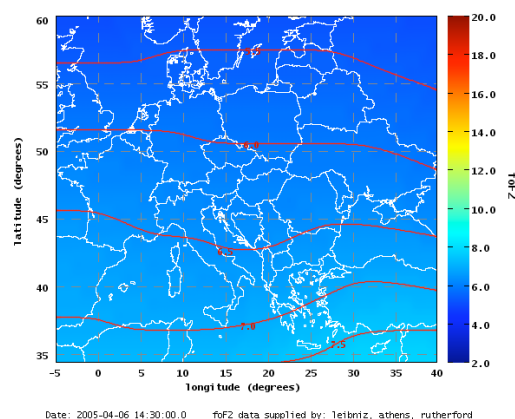


FIGURE 7. DIAS Ionospheric map over the European area for the real-time foF2 [based on SIRMUP, Zolesi et al., 2004]

5. COST296: MITIGATION OF IONOSPHERIC EFFECTS ON RADIO SYSTEMS

5.1 Main Objectives

COST 296 Action (2005-2009) aims 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 main objectives are as follows:

- to support and enhance the existing European facilities for historical and real-time digital ionospheric data collection and to exchange information needed on methods and algorithms to mitigate the effects of ionospheric perturbations and variations on advanced terrestrial and space-based communication services by creating an effective computing infrastructure;

- to develop an integrated approach to the ionospheric modelling, create the mechanism needed to ingest processed data into models, extend and develop suitable mitigation models and define the protocols needed to link models together;

- to make applicable results available to the ITU-R and to promote the research aspects to funding agencies;

- to strengthen the areas of expertise that already exist by stimulating closer cooperation between scientists and users, focusing the scope of all the previous COST ionospheric related studies to the mitigation of ionospheric effects on specific radio systems, which are in operational use or in the development stage into new systems.

5.2. Major results during the first two year

Some of the initial COST296 results were presented during the 2nd Workshop on Radio systems and Ionospheric effects, at University of Rennes 1, 3-7 October 2006 (Bourdillon, A., 2006) as the follows:

New ionospheric activity indices have been derived from automatically scaled online data from several European ionosonde stations. These indices are used to distinguish between normal ionospheric conditions and ionospheric disturbances caused by specific solar and atmospheric events (flares, coronal mass ejections, atmospheric waves, etc.). 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 novel space weather monitoring service (SWACI) focused on high precision GNSS positioning applications has been established (<http://w3swaci.dlr.de/>). The forecast based on this method is realised for 1-hour ahead, considering the availability of Kp prediction from solar wind estimations and user requirements. The NTCM coefficients are regularly updated by the use of former TEC measurements.

A technique has been developed allowing assessing higher order ionospheric effects on dual frequency high accuracy GNSS applications using IGS global TEC maps. Research work is being performed in order to estimate higher order refraction effects in GNSS systems that can easily be applied in operational measurements. Solutions were found to correct second order ionospheric effects for GNSS users in Germany without knowing the geomagnetic field structure and the exact shape of the electron density profile. The correction formulas need only TEC, which may be derived by the GNSS user or may be provided by a

service as mentioned above. Two new quasi-analytical methods for higher order corrections have also been

developed. The computations reach mm-accuracy and show excellent agreement with corresponding numerical ray-tracing results.

Analyses have been addressed to the investigation of differences and similarities of high and low latitude scintillations during some selected space weather events. In particular, the attention is focused on the detection of patches and bubbles, typical signatures of the ionospheric irregularities at some selected receiver-satellite path. For more details, see Bourdillon, 2007.

6. CONCLUSIONS

The research links, initially established under the COST 238 and 251 Actions, led to a number of bilateral and multi-lateral collaborations that have continued in COST 271 and 296 Actions. In addition, COST participants have been very active in many different international projects. There is a significant participation in the ESA Space Weather Program, in particular in the Space Weather Working Team (SWWT) and the Pilot Projects scheme. The Geomagnetic Indices Forecasting and Ionospheric Nowcasting Tools (GIFINT) pilot project and the Space Weather European Network (SWENET) pilot projects been supported by this ESA framework. The URSI Beacon Satellite Group is linked closely to the work of the COST Actions, providing important contacts between ionosphere, plasmasphere and upper atmosphere scientists, engineers and users of satellite beacon applications. Several COST members are advisers and observers in the International Geodynamics Service (IGS) and offspring organisations like the GPS-IONO group.

While designed to meet the needs of Europe, COST Actions has also made an impact to the international work of ITU-R, through some contributions to the Recommendations of that organisation, the provision of data for the validation of prediction models for Europe and by assuming a leading role in Working Party on Ionospheric Propagation. Close links have also been established with several organizations that deal with GNSS applications for navigation and surveying. There is a strong involvement of COST Action members in ESA/ESTEC projects: (a) concerning EGNOS and GALILEOSAT and (b) in connection with assessment studies for the use of GNSS occultation for atmospheric and ionospheric research. Another ongoing collaboration involves the International Reference Ionosphere (IRI) on improvements to the IRI model. Participants in COST 271 have made a considerable contribution to the international HIGH

RAte Campaign (HIRAC) of the International GPS and in the validation of CHAMP results. They are also involved in the DIAS (Digital Upper Atmosphere Server) eContent framework activity (www.iono.noa.gr/DIAS), see Fig. 7, (Belehaki et al 2007) and the ROSE project on establishing an international geophysical observatory at Gaudos in Greece.

Finally, authors of this paper are sure that all the participants of the four COST actions are proud to have built and get stronger the European Ionospheric community, friendly open to the cooperation with the scientists of the other continents.

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