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Journal of Atmospheric and Solar-Terrestrial Physics 67 (2005) 1092–1099

Journal of ATMOSPHERIC AND SOLAR-TERRESTRIAL PHYSICS

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DIAS Project: The establishment of a European digital upper atmosphere server

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Received 6 November 2004; received in revised form 17 February 2005; accepted 20 February 2005
Available online 29 June 2005

Abstract

The main objective of DIAS (European Digital Upper Atmosphere Server) project is to develop a pan-European digital data collection on the state of the upper atmosphere, based on real-time information and historical data collections provided by most operating ionospheric stations in Europe. A DIAS system will distribute information required by various groups of users for the specification of upper atmospheric conditions over Europe suitable for nowcasting and forecasting purposes. The successful operation of the DIAS system will lead to the development of new European added-value products and services, to the effective use of observational data in operational applications and consequently to the expansion of the relevant European market.

Keywords: Ionosphere; Upper atmosphere; Ionospheric monitoring; Ionospheric nowcasting; Ionospheric forecasting; Digital libraries

1. Introduction

A knowledge of the state of the upper atmosphere, and in particular its ionospheric part, is very important in several applications affected by space weather. The effects of the upper atmosphere on radio frequency communications, satellite positioning and navigation applications are determined by the ionospheric electron density structure and the total electron content. Ionospheric storms can cause large-scale drastic changes to the usable range of HF frequencies. Large solar flares cause short-wave fadeouts resulting in blackouts of HF signals. Also protons emitted from the sun result in polar cap absorption events and consequently to blackouts of HF signals propagating through the earth's polar regions. Ionospheric effects can also generate time-varying ionospheric currents causing problems in ground systems such as systems for power generation and supply, oil and gas pipeline distribution, aerial surveying for minerals oil and gas, drilling for oil and

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1364-6826/$ - see front matter
doi:10.1016/j.jastp.2005.02.021

gas, railways, especially in the northern latitudes. Lately there is increasing interest by the seismic hazards research community in identifying electromagnetic phenomena in the upper atmosphere, as a precursor of seismic events.

Considering the large range of applications influenced by ionospheric effects, it is obvious that the community of potential users is quite extensive. The main groups that could be identified are civil and military aviation, defence organizations mainly interested in HF communications, satellite operators interested mainly in preventing problems due to ionospheric scintillations, space agencies and satellite operators interested in long-term prediction frequency planning services, and finally researchers in various fields of geophysics.

Modern digital ionospheric stations are used worldwide as a tool to remotely sense the ionosphere and identify its structure and properties. Most digital ionospheric stations have the capability of automatically scaling and transmitting in real time all important parameters characterizing the state of the ionosphere and the propagation of radio waves. Currently, ionospheric stations in Europe operate independently, and knowledge on the state of the ionosphere is generated for a limited area around each station only. This independent operation creates several barriers for transforming this information into usable data, products and services.

In order to provide accurate information and reliable prediction to all interested users, the DIAS team will establish a distributed information server capable of supporting the acquisition, elaboration, evaluation, dissemination and archiving of the ionospheric information. The Australian Ionospheric Prediction Service (IPS) (http://www.ips.gov.au) is an excellent example of the effective exploitation of ground-based networks of ionospheric stations for research and operational use. Also the Space Physics Interactive Data Resource—SPIDR (http://www.ngdc.noaa.gov/stp/IONO/ionohome.html) and Space Environment Center (SEC) of NOAA (http://sec.noaa.gov) are two important servers operated in the US and must be considered by the DIAS team as representative and successful efforts to organize ionospheric measurements in a digital form.

2. DIAS implementation

The structure of the DIAS system is presented in Fig. 1. The basic activities can be summarized as follows:

(a) The DIAS digital server integrates in the same environment all the raw ionospheric data gathered by DIAS ionospheric stations whose geographic distribution is presented in Fig. 2.

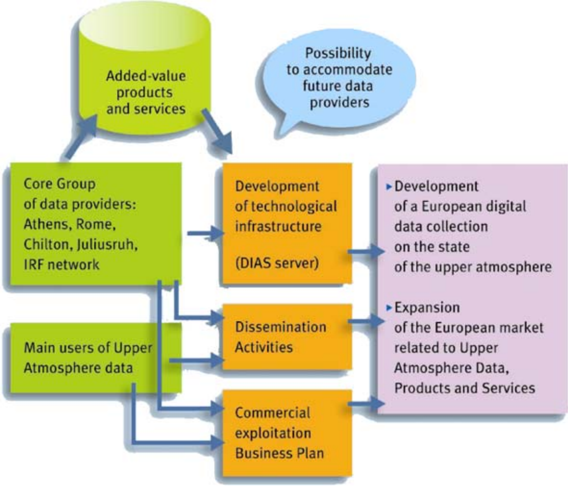

Fig. 1. Structure of the DIAS system.

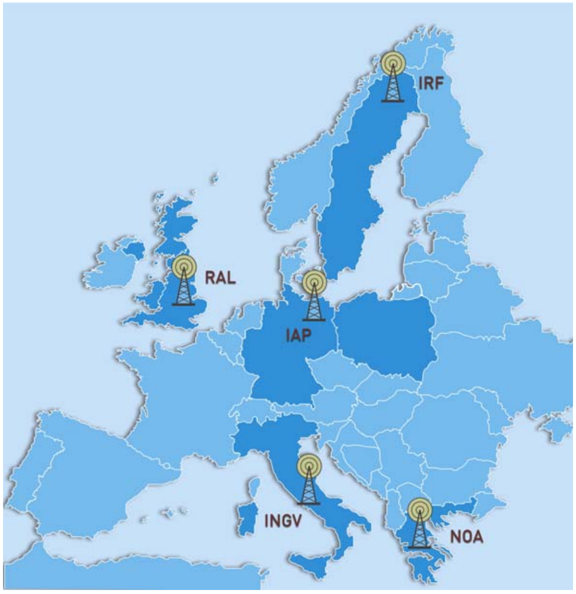

Fig. 2. Geographic distribution of DIAS ionospheric stations.

(b) The DIAS system is capable of integrating in the future any new digital collection that will be created by the operation of any new ionospheric station in Europe.

(c) Through contacts with the potential users, their requirements are being determined and new competitive added-value products and services for Europe are being defined.

(d) A network of users and information providers is being established to constitute the main channel of interaction between DIAS data providers and users from the academic and industrial sectors to work together to bring out the full potential of the information.

(e) Intense dissemination and awareness activities of different forms are developed in order to stimulate the access in this new pan-European data collection. All necessary actions will be taken for the viability of the DIAS system after its first development phase through the commercial exploitation of DIAS products and services.

Through these actions, we believe that DIAS will contribute to the beneficial exploitation of the currently collected information, overcoming the present fragmentation and providing pan-European data and services.

3. DIAS infrastructure and technology

In the context of DIAS, software development includes modules for file transformation from one data format to another, modules for data integration to obtain a European-level coverage from more local information, modules for data-product generation based on post-processing of observations, and modules for answering user requests for specific products and services. For portability, all software development is in Java and associate technologies. With respect to data formats, DIAS deals with all data formats used by the participating ionospheric stations to store data. Data transfer will be over the Web, with information bundled into HTML or XML pages when sent to users, or simply

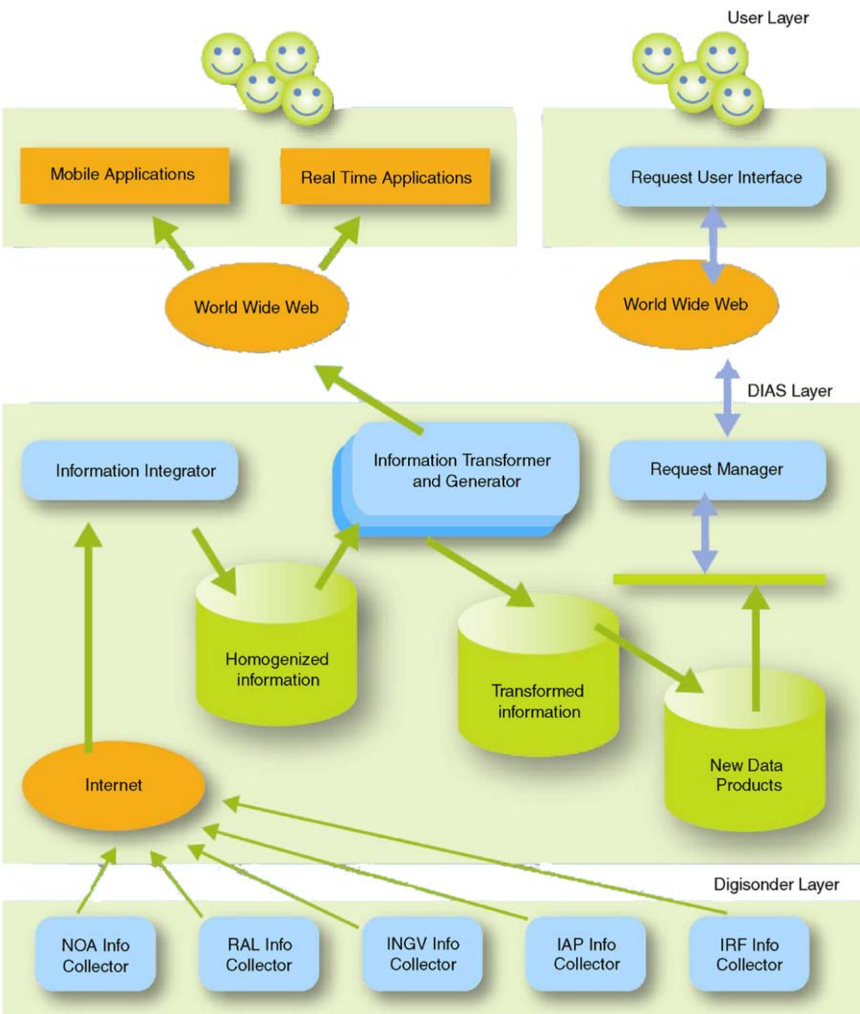

Fig. 3. Architecture of DIAS technological system. In that representation, orange are entities that exist independently of DIAS. Dark blue boxes are software pieces that are developed as part of DIAS. Light blue disks represent information that will be collected or formed as part of DIAS. Finally, dark blue arrows indicate data flow that involves querying (whether initiated by a user or by a software module) and answering, while green arrows indicate data flow that is produced automatically, i.e., it results from data propagation that is triggered without an explicit request at the time.

as byte-streams when sent between systems. HTTP will be the protocol for most transfers, while SMS or WAP will be used for alerts or other messages to mobile users.

The architecture of the DIAS system is shown in Fig. 3. Three main system layers are identified:

1. *Digisondes layer*: At the bottom are the five European ionospheric stations that collect the original information. They will continue to operate in exactly the same way, independently of each other and of the existence of DIAS, collecting their data and supporting their local users autonomously. To support DIAS functionality, an information collector is installed in each station site to acquire all pertinent data collected there and send it up to the next layer of the system, the central DIAS server.
2. *DIAS layer*: This is the heart of DIAS, where the data collected from each Digisonde are brought together, converted in common format, and then further processed appropriately by software modules that are being created within the DIAS effort. For some of these new data products, in addition to storing them, the software modules generating them will also propagate them upwards directly to sites or individuals that expect continuous updates of the required information. These updates could be full-fledged, involving entire files with relevant data, or could be small messages to a user's mobile phone or electronic mailbox as alerts of interesting observations. In addition to the data manipulation software modules and the resulting information products, the DIAS layer will also include a request server, which will process user requests arriving over the web, identifying the data products requested, and sending them back to the requestor at the higher layer. The necessary metadata to support the entire operation will be stored in a relational database management system.
3. *User layer*: At the top layer are the users of DIAS, ranging from individuals to institutions. The user layer will collect the output from the DIAS layer and will be responsible for the presentation of such data. The users will be able to receive the data in various types of peripherals such as: workstations for offices and stable sites; portable PCs for semi-mobile sites; wireless Palm Top (PDA, smartphones) for field applications; cellular telephones just for receiving warning messages.

4. DIAS data, added-value products and services

In this section we present the basic categories of ionospheric products that will be distributed through the DIAS information system.

4.1. Ionograms and ionospheric sounding parameters

Real-time and archive ionograms in 15 min *resolution from the DIAS network of five vertical-incidence ionospheric soundings*: The ionograms will be accessible through the web and will be presented in a common format for comparison. The results of the automatic scaling using the ARTIST software (Reinisch and Huang, 1983) will be given with each ionogram. Through this page, DIAS users will be able to get information about the current values of the most important ionospheric parameters and characteristics at the geographic position of the five DIAS ionospheric stations. Moreover, the simultaneous representation of all ionograms will give to the user information about the development of spread F and sporadic E layer in Europe, which is important for HF communications.

Real-time updated daily plots of the international standard ionospheric characteristics from DIAS stations: minimum ionospheric reflected frequency fmin, the F2 layer critical frequency foF2, and propagation factor M(3000)F2 with a 15 min resolution. The corresponding values for quiet ionospheric conditions are overplotted to indicate the reference ionospheric conditions.

4.2. Ionospheric maps of foF2 and M(3000)F2

Ionospheric maps over European area of monthly median foF2 and M(3000)F2 for different solar epochs with hourly time resolution for the long-term frequency planning services: They will be based on the Simplified Ionospheric Regional Model (SIRM), a model developed specifically for European ionospheric area. The SIRM calculates the values of the key vertical incidence ionospheric characteristics such as foF2, M(3000)F2, virtual height of the ionospheric F2 layer h'F2, critical frequencies of the ionospheric F1 and E layers foF1 and foE that are used for prediction of operational parameters of HF telecommunication systems in a restricted area (Zolesi et al., 1993, 1996, 1999). The SIRM was developed under the Co-operation in the field of Scientific and Technical Research (COST) Action 238 PRIME (Prediction and Retrospective Ionospheric Modelling over Europe, Bradley, 1995) and improved and tested under the COST Action 251 IITS (Improved Quality of Service in Ionospheric Telecommunication Systems Planning and Operation, Hanbaba, 1999). The reliability of this mapping technique has been tested and the results show that the overall root mean square (RMS) error from SIRM was slightly smaller than the RMS error for the ITU recommended model (ITU-R, 1994; Levy et al., 1998). This validation test prove that SIRM performance is satisfactory for median ionospheric condition description in a restricted area of mid-latitudes. Some indicative examples are given in Fig. 4.

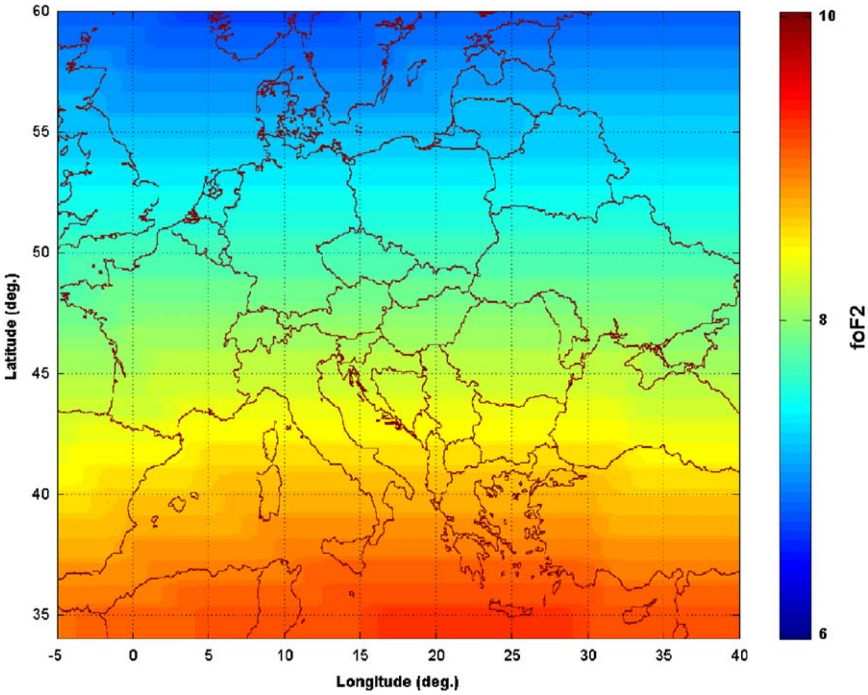

Fig. 4. Map of the foF2 parameter describing the median conditions over Europe for August 2001, at 1200UT. The grid points were estimated using the Simplified Regional Ionospheric Model (SIRM).

Ionospheric maps over European area of the real-time foF2 and M(3000)F2 for individual epochs in 15 min time resolution for the nowcasting frequency management and for forecasting up to 24 h ahead for use in spectrum management: For the development of these maps we will follow the method of real-time updating of the Simplified Ionospheric Regional Model (SIRMUP) with autoscaled ionospheric parameters observed by DIAS ionosondes, proposed by Zolesi et al. (2004). This method is based on the rapid conversion of real-time data from five DIAS ionosondes to the driving parameters of the simplified ionospheric regional model. The reliability of the real-time SIRM update method has been tested for various ionospheric conditions and the simulation results show a clear improvement when comparing with monthly median maps (Zolesi et al., 2004), demonstrating that the SIRMUP procedure has the potential to be used in real time for nowcasting the standard ionospheric characteristics over Europe for operational applications. Some indicative maps using the SIRMUP method are presented in Fig. 5 for the same months as in Fig. 4 but for disturbed epochs.

4.3. Maps of electron density

Ionospheric maps over European area of the real-time electron density profile, N(h), at an altitude resolution of 10 km and a 15 min resolution to be applicable to the design of ionospheric propagation services, using real-time calculated electron density profiles from DIAS ionosondes:

Instantaneous three-dimensional maps of electron concentration can be constructed at any chosen height. In recent years many techniques have been used to construct instantaneous maps from spatially distributed measured data. The mapping scheme applied here uses two interpolation techniques: (1) a modification of the geostatic kriging technique that interpolates the deviations of measurements from the background model, and (2) a specific technique that fits the background model to the set of measurements (Stanislawska et al., 2001). To avoid numerical instabilities and ensure a higher accuracy, additional data taken from a background model are added during the interpolation procedure. This may be seen as a retrogression to information from the past. For the background values, standard ionospheric models such as IRI 2000 (Bilitza, 2001) can be applied. A representative map is shown in Fig. 6.

4.4. Ionospheric warnings

Ionospheric alert index for ionospheric propagation conditions over Europe and customer's warning purposes: Warnings for forthcoming ionospheric disturbances will be based on the deviation of the real-time ionospheric parameters from the corresponding forecasted values at

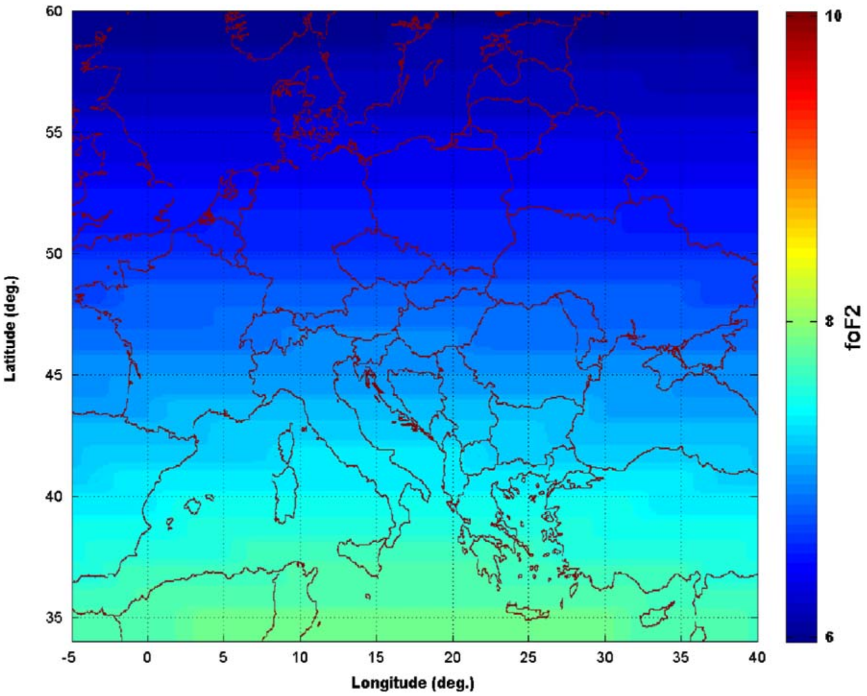

Fig. 5. Map of the foF2 parameter describing the instantaneous conditions over Europe on 23 August 2001, at 1200UT. The grid points were estimated using the Real-time Updated Simplified Regional Ionospheric Model (SIRMUP). Here, an ionospheric storm caused depletion of the ionization over Europe, which is evident in the map.

the location of the five DIAS Digisondes. Moreover, the variations of the interplanetary magnetic field will be considered for warning purposes. According to recent studies (Belehaki and Tsagouri, 2002), a point of great importance that determines ionospheric disturbances at middle latitudes is the rate of the solar wind energy entering the magnetosphere–ionosphere system, which is reflected in the rate of change of Bz-IMF. A very effective mean of making this idea operational is the use of the Advanced Composition Explorer (ACE) observations since the information obtained on the ground by telemetry from the satellite at the L1 vantage point is 1 h ahead of the consequent effects on the Earth's ionosphere. Based on that, an advanced real-time dynamic system was very recently developed (Cander et al., 2004) to monitor and specify ionospheric propagation conditions over Europe. Currently an automated data analysis at 30 min interval is operational at RAL http://ionosphere.rcru.rl.ac.uk/. In the example given in Fig. 7, it can be seen that after a strong disturbance in the Bz-component (red line) at 1200UT, the foF2 parameter (blue line) presents a drastic decrease starting at 1600UT until 0000UT. The decrease in foF2 in Athens was 30% while in Juliusruh, which is in higher latitude, it reached 40%. The variations of M(3000)F2 (red line) and of the total interplanetary magnetic field (black line) are also presented in this graph and they are currently used for scientific investigation. The analysis presented by Cander et al. (2004) shows that such a system enables extreme conditions to be quantified so that for telecommunications planning likely variability bounds can be defined.

The implementation of additional methods and tools to be included in the DIAS products as European maps for the Maximum Usable Frequency for a propagation path of d km, MUF(d), the Optimum Usable Frequency FOT, ionospheric storm forecasting and other potentially useful products will be considered by the DIAS team, taking into account the needs of users to support specific operational applications.

An important aspect for the success of the DIAS project is the reliability of the provided information. Most of DIAS added-value products and services are based on raw data obtained from automatically scaled ionograms using the ARTIST application. Recently, many papers demonstrated that ionospheric models updated in real time with automatic scaled data improve significantly the performance of the output products (Stamper et al., 2004; Belehaki and Stanislawska, 2004). Moreover the new version of ARTIST software released recently improves considerably the reliability of automatic scaled ionospheric parameters, since it can overcome the gaps in the ionograms due to electromagnetic interference. During the implementation of the DIAS project, statistical studies will be performed to give the expected accuracy of each of the DIAS products in order

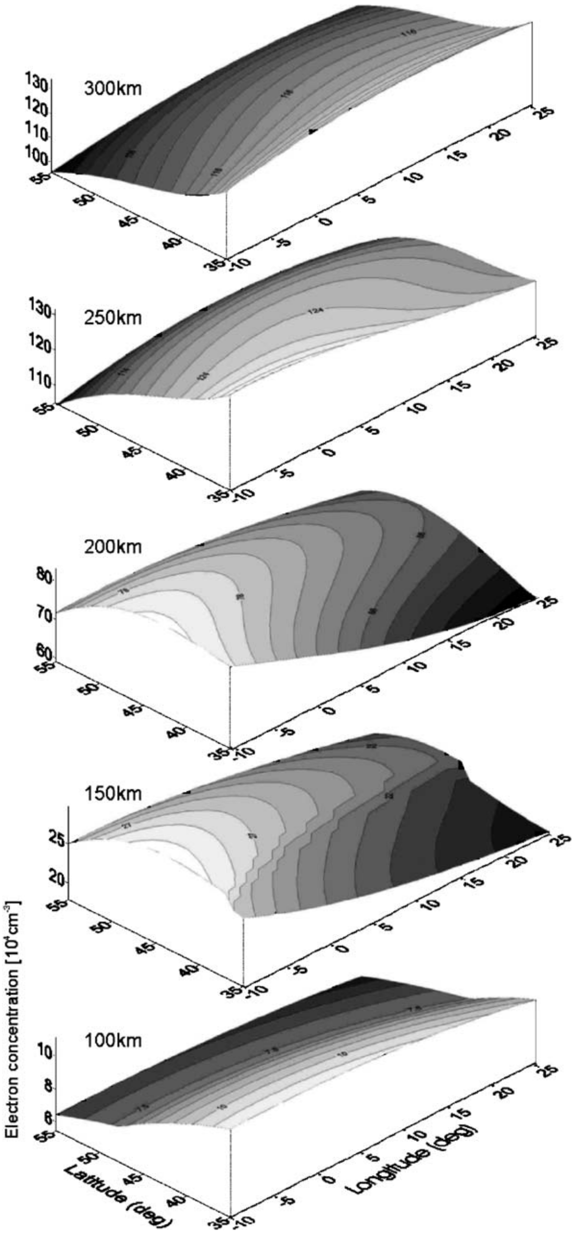

Fig. 6. Maps of electron density for 12 November 1998 12UT obtained for five height levels by fitting technique with background IRI2000 model.

to inform the customers about the accuracy of the actual and predicted information on the state of the upper atmosphere.

5. Summary and conclusions

As a Europe-wide effort, DIAS aims at developing a facility for the extensive use of upper atmosphere observations. Although there are some efforts at the national level to provide services to users interested in upper atmosphere data, this unprecedented close collaboration of five content generators guarantees that the necessary critical mass will be present to organize the relevant information at the European level, and offer a counterpart to similar US, Australian and Japanese ventures. DIAS can be realized only through such collaboration since the five European institutes operating the real-time ionosondes are needed to have the appropriate geographical distribution to fully cover the entire European region.

DIAS will act at two levels. The first level concerns the added-value products and the improved exploitation of the digital information provided by European research institutes. The second level targets the organization of a common network between the public research institutes and the industrial and commercial sector, aiming at the effective exploitation and dissemination of the added-value products, contributing to the competitiveness of the European presence in these high-end technological areas and the widening of European market for these products.

The idea to develop DIAS was born during the COST271 Action ''Effects of the upper atmosphere on terrestrial and Earth–space communications'' (Zolesi and Cander, 2002). During the implementation of the action, most of the European ionospheric data providers worked closely to fulfil the main objective of this action, which was the development of models to predict and to minimize the effects of ionospheric perturbations and variations on communications. This close four-year collaboration revealed the necessity to develop a pan-European digital collection of ionospheric and upper atmospheric data and to provide specialized services to the extended users' community.

The DIAS project was submitted to the *eContent* programme of the European Commission on March 2003 under the co-ordination of the National Observatory of Athens and the project was approved and started in March 2004. The participating institutes working on the acquisition, elaboration, archiving, dissemination of data and services and on the development of the technological system are the Rutherford Appleton Laboratory, the Instituto Nationale di Geofisica e Volcanology, the Swedish Institute of Space Physics, the Leibniz Institute of Atmospheric Physics, the Space Research Centre of the Polish Academy of Science, and the Department of Informatics and Telecommunications of the University of Athens. The official web site can be accessed at http://www.iono.noa.gr/DIAS. The project has a duration of two years and the DIAS server will operate in its final configuration from February 2006.

The long tradition of ionospheric observations in the European observatories participating in DIAS, the continuous maintenance and upgrade of DIAS

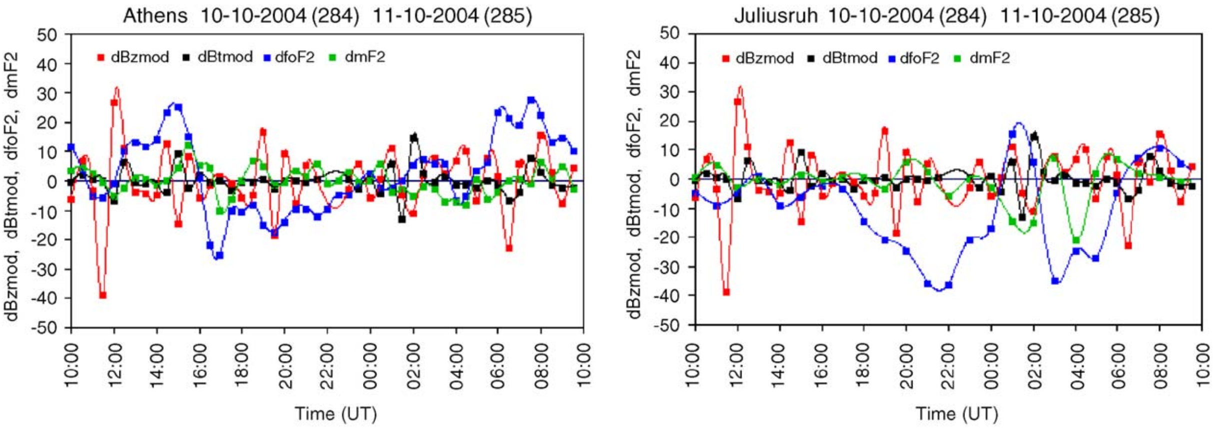

Fig. 7. Bz-IMF rate of change over the preceding 30 min interval, with the corresponding percentage deviation from the median of foF2, dfoF2(%), and percentage deviation from the median of M(3000)F2, dmF2(%), for two DIAS ionosondes.

ionosondes, the frequent upgrade of the DIAS on-line models with more and more sophisticated versions, and the commercial exploitation of some of the DIAS products and services guarantee the success of DIAS and its viability after the end of the phase sponsored by EC.

Acknowledgements

The DIAS project is co-funded by the *eContent* Programme of the European Commission. The authors would like to thank the two referees for their constructive comments.

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