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COST 271 Action – Effects of the upper atmosphere on terrestrial and Earth-space communications: introduction

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The COST 271 Action («Effects of the Upper Atmosphere on Terrestrial and Earth-space Communications») within the European ionospheric community has the objectives, embodied in the Memorandum of Understanding (MoU): to study the influence of upper atmospheric conditions on terrestrial and Earth-space communications, to develop methods and techniques to improve ionospheric models over Europe for telecommunication and navigation applications and to transfer the results to the appropriate Radiocommunication Study Groups of the International Telecommunication Union (ITU-R) and other national and international organizations dealing with the modern communication systems. This introductory paper summarises briefly the background and historical context of COST 271 and outlines the main objectives, working methods and structure. It also lists the participating countries and institutions, the Management Committee (MC) Meetings, Workshops and Short-term Scientific Missions. In addition, the paper discusses the dissemination of the results and the collaboration among the participating institutions and researchers, before outlining the content of the Final Report.

1. Background and historical context

Temporal and spatial changes in the upper atmosphere can act to limit and degrade the performance of terrestrial and Earth-space radio systems in many different ways. Command, control and communication systems involving transionospheric propagation may be disrupted; global positioning networks compromised and surveillance (optical and radar) systems affected. In addition, conditions in near-Earth space have other adverse effects on modern technology, ranging from the tracking and the lifetimes of satellites to the induction of damaging currents in power grids and transcontinental pipelines. The vulnerabilities of systems to changes in the upper atmosphere incorporate many different aspects. These include: space-weather effects on communication, navigation and surveillance systems; solar cycle phenomena and their impact on operational systems; modelling, forecasting, and prediction services; ionosonde sounder methods and measurements; applications of ionospheric tomography; transionospheric effects including scintillation; ionospheric propagation for high frequency communication systems; longwave propagation systems and effects; Global Positioning System (GPS) and ionospheric Total Electron Content (TEC) studies. The European ionospheric community has long been aware that co-operative research on an international basis is essential to deal with such complex issues. In particular, international co-operation is required for the collection of data, in both real-time and retrospective modes, the development and verification of new methods to improve the performance of both operational and future terrestrial and Earth-space communications systems and the exchange of expertise on space plasma effects on Global Navigation Satellite Systems (GNSS).

COST (the French acronym for «Co-operation in the field of Scientific and Technical Research») is an intergovernmental mechanism that sponsors scientific and technical co-operation and co-ordination between research teams and institutional partners from the 34 COST countries and with non-European institutions. COST 271 on «Effects of the Upper Atmosphere on Terrestrial and Earth-Space Communications» is an Action within the Telecommunications Information Science and Technology (TIST) Technical Committee. It is a four-year project that started in August 2000 to work collaboratively on the topics outlined above. The core of COST 271 Action has been a dynamic group of more than 100 active participants from 17 COST countries, 3 non-COST institutions and the European Space Agency (ESA), working as a technical community towards a common goal. The primary objective was to examine an area of research that had been given recent impetus by an increased technological interest in terrestrial and satellite radio communications and navigation (Zolesi and Cander, 2002). COST projects are well suited to developing research co-operation in fields where finance is provided at the national level, because the resultant benefits to the sponsors of work are greater than accrue from the efforts of individual organisations. The success of this approach has been demonstrated in the telecommunications domain in previous COST Actions concerned with the prediction of ionospheric propagation characteristics.

The earlier COST Actions relating to ionospheric radio propagation were particularly useful in creating a critical mass of researchers in projects where the initial emphasis was on long-term ionospheric prediction and retrospective ionospheric modelling over Europe. The COST 238 Action PRIME (Prediction and Retrospective Ionospheric Modelling over Europe) was a four-year research project with objectives to develop regional maps and models of the European ionosphere that are more accurate than internationally available global maps and models (Bradley, 1995). It involved the participation of some 72 scientists and engineers from 31 organisations in 17 nations. The work encompassed the production of regional monthly median maps and algorithms for generating 'instantaneous' snapshot maps of the standard vertical-incidence ionospheric characteristics from coordinated sounding measurements within Europe. Additional studies involved height profiles of electron density, the vertical total electron content up to an altitude of 1000 km and research leading to an improved understanding and thus potential for better modelling of ionospheric storm morphologies. Work conducted within COST 238 was continued in the follow-on project COST 251 IITS (Improved Quality of Service in Ionospheric Telecommunication Systems Planning and Operation) on the application of PRIME results in the improved quality of service in ionospheric telecommunication systems planning and operation (Hanbaba, 1999).

Both projects yielded significant results, but they also identified further areas where future development was needed. The topics for more research included: hour-to-hour and day-to-day variability prediction capabilities in the topside ionosphere, upgrading of the current models to include scintillation effects, the prediction of the ionospheric and plasmaspheric effects on navigational systems and the development of methods for calculating the reliability and compatibility of HF radio systems using digital modulation techniques and over the horizon HF backscatter radars (Zolesi and Cander, 2003).

The COST 271 Action was then established with a remit to examine a range of relevant research areas within four broad groupings.

2. COST 271 Action objectives

COST 271 is an Action for the promotion, stimulation and co-ordination of the European research in ionospheric and plasmaspheric areas. The Memorandum of Understanding laid out the main objectives of the COST 271 Action as follows:

– To perform studies to influence the technical development and implementation of new communication services, particularly for the GNSS and other advanced Earth-space and satellite-to-satellite applications.

– To develop methods and algorithms to predict and 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.

– To collect additional and new ionospheric and plasmaspheric data for nowcasting 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.

3. COST 271 WORKING METHOD AND STRUCTURE

At the outset of the project consideration was given to a wide range of technical questions of practical relevance. In addition, a special issue of the journal *Quaderni di Geofisica* (Cander and Zolesi, 2001) was published at an early stage. The aim was assess the current state of knowledge and to outline the activities in each participating country in the work areas of the COST 271 Action, with an indication of their significance. The research within COST 271 was then organised within four Working Groups arranged into at total of 15 Work Packages that are shown in table I. The activities within each of these areas are documented fully in the papers that follow in this volume that serves to make up the Final Report of the COST 271 Action.

Table I. COST 271 Action structure.

WG 1 – Impact of variability of space environment on communications.	WG 2 – Assessment of space plasma effects for satellites applications.	WG 3 – Ionospheric effects on terrestrial communications.	WG 4 – Space plasma effects on Earth-space and satellite-to-satellite communications.
WP 1.1 – Impact of space weather on communications.	WP 2.1 – Plasma effects on GNSS applications.	WP 3.1 – Effects of large scale ionospheric fluctuations on terrestrial communications, including remote sensing, radio localization and radar.	WP 4.1 – Effects of space plasma variability and irregularities on Earth-space and satellite--to-satellite communication channels.
WP 1.2 – Database and tools for nowcasting, forecasting and warning.	WP 2.2 – Assessment of plasma propagation errors in navigation systems and merits and shortcomings of novel data sources.	WP 3.2 – Effects of small-scale ionospheric irregularities, interference and noise on terrestrial communications.	WP 4.2 – Development of algorithms and software to treat disturbances in Earth-space and satellite-to-to satellite communications.
WP 1.3 – Long term trends in the ionosphere and upper atmosphere parameters.	WP 2.3 – Investigation of extremes of ionization.	WP 3.3 – Mid-latitude ionospheric features in radio propagation models.	WP 4.3 – Application of theoretical considerations to the study of space plasma effects.
WP 1.4 – Upper atmosphere parameters monitoring for nowcasting and forecasting purposes.		WP 3.4 – Development of methods and algorithms to minimize the deleterious effects of the ionosphere on terrestrial communications.	WP 4.4 – Effects of the vertical and horizontal gradients of the electron density on Earth-space and satellite-to-satellite communications.

3.1. Working Group 1: impact of variability of space environment on communications

Space weather and its impact on terrestrial and space communications have drawn increasing attention in recent years. Four working packages were defined under this heading:

Impact of space weather on communication – To identify present and future anticipated terrestrial and Earth space radio systems, to identify propagation phenomena which can lead to impairments of these radio systems that need to be modelled, to identify those space weather parameters that impact adversely and significantly on propagation conditions and to develop mitigation techniques.

Real-time satellite and terrestrial measurements for nowcasting, forecasting and warning purposes – To establish a space weather database consisting of both past and new measurements and to use these measurements for the development of now-casting and forecasting propagation procedures and software tools.

Long-term trends in the ionosphere and upper atmosphere parameters – To investigate and understand the nature of the long-term behaviour of all ionospheric regions and potential effects of the long-term trends on prediction models.

Upper atmosphere parameters monitoring for nowcasting and forecasting purposes – To develop methods to extract thermospheric parameters using routine ionospheric observations and to develop a version of the Self-Consistent method which would use routine electron density ionosonde profiles to monitor the upper neutral atmosphere above Europe.

Some initial activities on improved robustness of prediction, which were separated as additional work packages at the beginning of the investigation, were later incorporated into the studies of real-time satellite and terrestrial measurements for nowcasting, forecasting and warning purposes.

3.2. Working Group 2: assessment of space plasma effects for satellites applications

The distribution and dynamics of the ionospheric plasma have a significant impact on GNSS applications for navigation, positioning and remote sensing of the Earth's atmosphere. Three working packages were included in this area:

Plasma effects on GNSS applications – To explore the amplitude and dynamics of horizontal structures in TEC by combining data derived by different measuring techniques (ground- and space-based GPS, NNSS, satellite altimetry), in particular under perturbed ionospheric conditions, to detect and analyse TID's and the resultant phase fluctuations that degrade accuracy in GNSS applications under various geophysical conditions.

Assessment of plasma propagation errors in navigation systems and merits and shortcomings of novel data sources – To assess ionospheric effects in non-ionospheric applications of GNSS signals, a) ionospheric influences in the use of GNSS occultation for stratosphere/troposphere applications, b) the effects of higher order ionospheric propagation errors in advanced ground based applications, like water vapour retrieval.

Investigation of extremes of ionization – To deal with observations aimed to come up with reasonable occurrence statistics when possible, to guide the data collection, to collect well-documented extremes and to provide a list of criteria to define type and nature of the extreme cases.

3.3. Working Group 3: ionospheric effects on terrestrial communications

Additional knowledge of the effects of large-scale ionospheric fluctuations, small-scale ionospheric irregularities, noise and interference with terrestrial communications including remote sensing, radio location techniques and radar is required. Four working packages were established within this general area:

Effects of large-scale fluctuations on terrestrial communications – To determine at regional/global scale the percentage contribution to the variability of main ionospheric parameters.

Effects of small-scale ionospheric irregularities, interference and noise on terrestrial communication, including remote sensing, radio localization and radar – To give a definition of the classes of irregularities to be taken into account, an analysis of their effects on the performances of the systems, the establishment of a catalogue of the known characteristics and of the available equipment for the studies.

Mid-latitude ionospheric features in radio propagation models – To assess the role of ionospheric and plasmaspheric irregularities of various dimensions in radio propagation at middle latitudes.

Development of methods and algorithms to minimize the above-referred effects on terrestrial communications, including remote sensing, radio localization and radar – To identify the most important problems due to the ionospheric characteristics and variability, to develop possible methods, if any, to minimize the deleterious effects and when possible, propose specific algorithms.

3.4. Working Group 4: space plasma effects on Earth-space and satellite-to-satellite communications

Space plasma variability and irregularities effects are of increasing interest to the practical operation of satellite systems. Four working packages were included in this topic:

Effects of space plasma variability and irregularities on Earth-space and satellite-to-satellite communication channels – To develop a database of space plasma variability and irregularities characteristics, using both measurements and results from theoretical models and to review the effects of variability and irregularities on communications, considering different locations of transmitter and receiver.

Development of algorithms and software to treat with disturbances in Earth-space and satellite-to-satellite communications – To forecast TEC in time and space from 1 to 24 h in advance by using neural networks, signal processing and other relevant techniques and to obtain quantitative description of the TEC variability and develop algorithms for nowcasting and forecasting.

Application of theoretical considerations to the study of space plasma effects – To study the ionospheric disturbances generated by natural electromagnetic and electrostatic instabilities.

Effects of the electron density vertical and horizontal gradients on satellite communications – To assess the effect of electron density gradients in the slant to vertical time delay conversion in Earth-space communications, to assess the effect of electron concentration gradients in satellite-to-satellite communication, to validate and improve existing topside electron concentration models by using the large Russian topside profiles database and to validate models of electron concentration profiles based on instantaneous (nowcasting) maps of basic parameters from vertical soundings data by using IGS slant TEC data and tomographic reconstruction.

4. COST 271 Participating countries and institutions

4.1 COST 271 Management Committee

The 17 COST member countries signatories of the COST 271 MoU are indicated in table II by names and addresses of their representatives. Some 34 institutions, listed in table III, formed the core of the activity. In addition, the institutions from 3 non-COST member countries listed in table IV participated, together with one observer organization (ESTEC-ESA).

Table II. Members of the COST 271 Management Committee.

Prof. R Leitinger Insitute for Geophysics, Astrophysics and Meteorology University of Graz Universitaetsplatz A-8010 Graz - Austria	Dr. R. Warnant Royal Observatory of Belgium Ave Circulaire 3 B-1180 Brussels -Belgium	Prof. I. Kutiev Geophysical Institute Bulgarian Academy of Sciences «Acad. G. Bonchev» Str. Block 3 1113 Sofia - Bulgaria
Dr. J. Laštovička Institute of Atmospheric Physics Academy of Sciences of Czech Republic Bocni II cp 1401 14131 Praha 4 - Czech Republic	Dr. E. Turunen Geophysical Observatory Sodankyla - Finland	Prof. C. Goutelard Universite Paris-SUD 11 Laboratoire d'Etude des Transmissions Ionospheriques Bat. 214 91405 Orsay Cedex - France
Dr. N. Jakowski DLR/DFD Fernerkundungsstation Neustrelitz Postfach 5123 D-17235 Neustrelitz - Germany	Prof. S.S. Kouris Department of Telecommunications Aristotelian University of Thessaloniki Thessaloniki - Greece	Dr. P. Bencze Geodetic and Geophysical Research Institute Hungarian Academy of Sciences H-9401 Sopron POB 5 - Hungary
Dr. B. Zolesi (Chairman) Istituto Nazionale di Geofisica e Vulcanologia Via di Vigna Murata 605 00143 Roma - Italy	Dr. I. Stanisławska Space Research Centre Polish Academy of Sciences Bartycka 18A 00-716 Warsaw - Poland	Prof. A.M. Casimiro FCT Universidade do Algarve Campus de Gambelas 8000 117 Faro - Portugal
Mr. M. Mihaljcic Geomagnetic Institute Narodnog Fronta 45/VI 11 000 Belgrade Serbia and Montenegro Fed. Rep.	Dr. B.A. De La Morena INTA, Atmospheric Sounding Station 'El Arenosillo' Space Science Division Mazagon (Moguer) 21130 Huelva - Spain	Prof. Y.K. Tulunay Istanbul Technical University Faculty of Aeronautics and Astronautics Ayazağa Campus 80626 Maslak Istanbul - Turkey

Dr. Lj.R. Cander (Vice Chairperson) Rutherford Appleton Laboratory Chilton, Didcot Oxon OX11 0QX - U.K.	Mrs. A. Vernon (Secretary) Rutherford Appleton Laboratory Chilton, Didcot Oxon OX11 0QX - U.K.	Dr. Balodis Latvia

4.2. Participating Institutions

Table III. Participating Institutions from COST countries.

Insitute for Geophysics, Astrophysics and Meteorology, University of Graz, Austria
Geophysical Institute, Bulgarian Academy of Sciences, Bulgaria
Royal Observatory of Belgium, Belgium
Institute of Atmospheric Physics, Academy of Sciences of Czech Republic, Czech Republic
Geophysical Observatory, Finland
University of Ouly, Finland
DLR/DFD Fernerkundungsstation, Germany
Leibniz-Institute of Atmospheric Physics, Germany
Universite Paris-SUD 11, Laboratoire d'Etude des Transmissions Ionospheriques, France
Universite de Rennes, France
CNRS, Grenoble, France
IEEA, France
University Paris 11, France
Istanbul Technical University (İTÜ), Faculty of Aeronautics and Astronautics, Turkey
Middle East Technical University, Turkey
INTA, Atmospheric Sounding Station, 'El Arenosillo, Spain
Observatorio del Ebro, Spain
Universidade do Algarve, Portugal
Space Research Centre, Polish Academy of Sciences, Poland
Istituto Nazionale di Geofisica e Vulcanologia, Italy
Istituto di Fisica Applicata, CNR, Italy
The Abdus Salam International Centre for Theoretical Physics, Aeronomy and Radiopropagation Laboratory, Trieste, Italy
Department of Telecommunications, Aristotelian University of Thessaloniki, Greece
National Observatory of Athens, Greece
Geodetic and Geophysical Research Institute, Hungarian Academy of Sciences, Hungary
Rutherford Appleton Laboratory, U.K.
QinetiQ, U.K.
University of Bath, U.K.
University of Wales, Aberystwyth, U.K.
University of Leeds, U.K.
University of Leicester, U.K.
University of Nottingham, U.K.
University of Sheffield, U.K.
Geomagnetic Institute, Serbia and Montenegro Fed. Rep.

Table IV. Participating institutions from non-COST countries.

Institute of Terrestrial Magnetism, Ionosphere and Radiowave Propagation, Russia
University of St. Petersburg, Russia
University of Massachusetts Lowell, U.S.A.

5. MC Meetings, Workshops, Short-term Scientific Missions

Management Committee Meetings

9 October 2000, Brussels, Belgium (Inaugural Meeting).
24-27 January 2001, Trieste, Italy.
25-29 September 2001, Sopron, Hungary.
6-9 March 2002, Graz, Austria.
1-5 October 2002, Faro, Portugal.
27 February-1 March 2003, Roma, Italy.
23-27 September 2003, Spetses, Greece.
18-20 March 2004, Roquetes, Spain.
26-28August 2004, Abingdon, U.K.

COST 271 Workshops

1st COST271 Workshop on «Ionospheric Modelling and Variability studies for Telecommunication Applications», 25-27 September 2001, Sopron, Hungary.

2nd COST 271 Workshop on «COST 271 Products for ITU-R and other radiocommunication applications», 2-4 October 2002, Faro, Portugal.

3rd COST 271 Workshop on «Significant results in COST 271 Action», 23-27 September 2003, Spetses, Greece.

COST 271 Meetings of the Working Groups

26 March 2001, EGS Meeting, Nice, France.
23 April 2002, EGS Meeting, Nice, France.
20 August 2002, URSI Meeting, Maastricht, The Netherland.
10 April 2003, EGS/AGU Meeting, Nice.
21 April 2004, EGU Meeting, Nice.

COST 271 Short-term Scientific Missions

A. Belehaki from NOA to RAL, U.K.
E.T. Senalp from METU to RAL, U.K.
G. Miro from INTA to Aristotelian University of Thessaloniki, Greece.
V. Depuev from IZMIRAN to Abdus Salam ICTP, Italy.
I. Tsagouri from NOA to RAL, U.K.
N. Malan from The University of Wales, Aberystwyth to DLR, Germany.
D. Burešová from Institute of Atmospheric Physics to RAL, U.K.
M. Cuerto from Universidad Complutense de Madrid to DLR, Germany.
M. Materassi from CNR to SRC, Poland.

In addition, the following young scientists: P. Sauli (Czech Republic), I. Tsagouri (Greece), M. Cueto (Spain), E.T. Senalp (Turkey) and M. Rieger (Austria) were invited to attend the 2nd COST 271 Workshop held in Faro, Portugal, 2-4 October 2002.

The Chairman and Vice Chairperson attended the E-STAR Meeting on 1-2 December 2003 in Strasbourg and the joint ESA/COST271/COST274/SWWT/E-STAR/FP6: SW-RISK Meeting on 27 February 2004 in Paris, respectively.

6. Dissemination of results

6.1. Major Publication

Most of the papers reporting activities of the COST 271 Action have been published in the following special issues:

– 1st COST 271 Workshop CD Proceedings on «Ionospheric Modelling and Variability Studies for Telecommunication Applications», 25-27 September 2001, Sopron, Hungary.

– Special volume of *Acta Geophysica Hungarica* devoted to the selected papers from the COST 271 Workshop on «Ionospheric Modelling and Variability Studies for Telecommunication Applications», vol. 37, no. 2/3, 2002.

– Special volume of *Annals of Geophysics* devoted to the selected papers from the XXVI EGS General Assembly Session on «Ionospheric Variability and Modelling», vol. 45, no. 1, 2002.

– 2nd COST 271 Workshop CD Proceedings on «COST 271 Products for ITU-R and other Radiocommunication Applications», 2-4 October 2002, Faro, Portugal.

– 3rd COST 271 Workshop Proceedings on «Significant results in COST 271 Action», 23-27 September 2003, Spetses, Greece, published on line at the COST 271 web site.

– Special volume of *Annals of Geophysics* devoted to the selected papers from the EGS/AGU General Assembly Session on «Effects of the Ionosphere on Terrestrial and Earth-Space Communications» (in press).

– Supplement to *Annals of Geophysics* devoted to COST 271 Final Report, this volume.

6.2. COST 271 Action web site

The Web site of the COST 271 Action has been active since the beginning of the action on the following address: http://www.cost271.rl.ac.uk/.

It is maintained by Mrs. A. Vernon at Rutherford Appleton Laboratory and contains the COST 271 Action main information documents with Management Structure, the Minutes of the Management Committee Meetings, the Calls for Papers for Workshops and other relevant documents for the Action, in addition to the related web sites.

7. Scientific and technical cooperation

The research links, originally established under the previous COST 238 and 251 Actions, led to bilateral and multi-lateral collaborations that have continued in COST 271. In addition, participants have been very active in many different international projects. There is a significant participation of members from Working Group 1 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, involving Italian, Greek and U.K. partners, and the DLR pilot project have been supported financially by the ESA framework of the SWENET (Space Weather European Network) program. The URSI Beacon Satellite Group is linked closely to the work of the second and fourth Working Groups of this Action, providing important contacts between ionosphere, plasmasphere and upper atmosphere scientists, engineers and users of satellite beacon applications. Several COST 271 Group 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 271 has also made an impact on the international work of ITU-R Study Group 3L, through major 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 SG3L (Ionospheric Propagation). Further steps are planned to make the most applicable results of the Action available to ITU-R. Close links have also been established with several organizations that deal with GNSS (at present mainly GPS) applications for navigation and surveying. There is a strong involvement of 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. There is an active collaboration of group members in INTAS projects with Russian and Ukrainian participation. Another ongoing collaboration involves the International Reference Ionosphere (IRI) Working Group, with international Task Force Activities being carried out at the Abdus Salam ICTP 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 and the ROSE project on establishing an international geophysical observatory at Gaudos.

8. Outline of the report

This COST 271 Final Report, published as a supplement to the international journal *Annals of Geophysics*, is organised in five Sections.

The *First Section* comprises this Introduction that contains the COST 271 Action background and historical context, the general objectives and priorities agreed in the Memorandum of Understanding, the working methods and structure, the participating countries and institutions, information about the MC meetings, workshops and short-term scientific missions, dissemination of results and finally the scientific and technical cooperation

The *Second Section* contains 18 scientific papers concerning the main activities and results achieved in the four Working Groups of COST 271. Each paper is in the form of an independent review of one of the activities of the Action with an introduction, discussion of the results and references.

Four scientific papers, in which each WG Leader reviews the main achievements obtained in their respective areas of responsibility, make up the *Third Section* of the report, together with an additional paper containing some latest results.

The *Fourth Section* summarises the main achievements of COST 271 as a whole in the context of the MoU requirements and looks to the way ahead. Significant achievements have been made, developing out understanding of the issues and relevance of field and offering new knowledge that will serve to increase economic and social development. In addition, new challenges have been identified and a concrete proposal is outlined for a follow-on from COST 271.

The *Fifth Section* comprises a joint paper by two internationally recognized experts, not directly involved in the Action, who provide a final comment on COST 271. In particular, they assess the results within the context of the research activities in the other parts of the world, their importance to ITU-R and the IRI and consider the future for this area of radio science and its applications.

The Final Report is addressed primarily to those in the MoU signatory countries involved in frequency planning, spectrum management and system design; to those who sponsored the work undertaken; to industrial partners concerned with the technology who will learn from the results and to those in national radio regulatory administrations and international planning. In addition, the report is of interest to students of radiowave communication and navigation and others in the propagation research community.

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