Progress report

RSPG OPINION
on
¨a coordinated EU Spectrum approach
for scientific use of radio spectrum¨

1. Introduction

This paper represents the Radio Spectrum Policy Group's (RSPG) progress report to the request from France and The Netherlands for an Opinion on spectrum used by scientific services. (document RSPG05-67 and RSPG 05-82).

Many fields of science depend on the use of radio spectrum. This spectrum could also be used for other purposes, which in certain cases leads to pressure on the spectrum used by the scientific community. These developments have led to concerns about the long-term availability of spectrum for scientific use. Although these alternative applications may represent significant economic value, scientific usage of spectrum also has significant social and economic benefits.

The RSPG agreed to formulate an opinion on the scientific use of spectrum in order to get an overview of all important aspects of the spectrum-based activities of the scientific community and to issue recommendations.

2. Overview of Scientific Use

2.1 Introduction

Spectrum is used by several scientific services. These services use radio emissions to register naturally occurring physical phenomena or to communicate information between different locations. The following services are identified in the Radio Regulations: the Meteorological Aids Service, the Earth Exploration Satellite Service (EESS), the Meteorological-Satellite Service, the Space Research Service (SRS), and the Radio Astronomy Service (RAS). Also the Space Operation Service, the Radiolocation Service (RLS) and the Radionavigation Satellite Service are used for scientific applications[1].

This chapter gives a description of the various scientific activities. It is to be noted that these activities do not always coincide with the definitions of services used by the ITU in the Radio Regulations.

2.2 Meteorology and climatology

Weather forecasting is based on continuous global measurements of the state of the atmosphere. Computer models, using this data, calculate the atmospheric development for the forthcoming days. These measurements include ground-based and satellite-based active and passive observing systems. Furthermore meteorological radars as well as Wind-profiler Radars perform an important part in the meteorological observation processes. Currently there are approximately 100 wind-profiler radars (about 30 in Europe) and several hundreds meteorological radars (more than 160 in Europe) that perform precipitation and wind measurements. These radars play a crucial role in the immediate meteorological and hydrological alert processes, for example in providing valuable information for society on flash floods or severe storms.

Under the auspices of the World Meteorological Organisation (WMO) a worldwide exchange of meteorological data takes place. Beside radio spectrum that is required for

[1] These latter three services also cover applications not related to science.

the measurements and observations, meteorology also uses radio spectrum for the transmission of observed data.

Space-borne passive sensing of the earth's surface and atmosphere is of increasing importance in operational and research meteorology. It contributes also to the scientific understanding, monitoring and prediction of climate change and its impacts. Space-borne observations and their processing in numerical models are to a great extent attributable to the impressive progress made in the recent years in weather and climate analysis and forecasts[2].

Meteorological systems are also used to monitor changes in climate and the environment. Mankind is faced with a variety of environmental phenomena which require careful investigation and analysis. Meteorological systems gather long-term measurement data in support of studies on changes in climate and environment. Computer models derive the most likely scenarios for the development of changes in the climate. Thus, these measurements are essential background information to develop climate scenario's needed for the development of national and global policies concerning global change.
The prime importance of the specific radiocommunication services for meteorological and related environmental activities required for the safety of life and property, the protection of the environment, climate change studies and scientific research has been recognised in Resolution 3 (Cg-XIV) of the WMO[3].

2.3 Earth Exploration Satellite

The main goal of the Earth Exploration Satellite Services (EESS) is to monitor the changes of the earth and of the atmosphere, besides the activities described above (2.2) this also contains monitoring of and understanding the earth's environment[4]. In order to such measurements a wide variety of set frequencies is needed, including passive and active sensing, sending information from satellites to the earth (telemetry) and to control the satellites (telecommand). The long-term collection of data (many decades) provides the basic building blocks to address environmental issues.

Increasing concerns about environmental change have been raised at intergovernmental conferences (such as the Kyoto climate conference) and have led to the establishment of international (both European and global) programme's such as the ad-hoc Group on Earth Observations (GEO) and Global Monitoring of the Environment and Safety (GMES) (See chapter 4 for more information).

2.4 Radio Astronomy

Astronomy provides knowledge of our planet, solar systems, our galaxy and our place in the universe. Radio Astronomy is a part of astronomical science which studies the universe and its components and new discoveries are made.

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[2] Including warnings for dangerous weather phenomena as heavy rain, storms and cyclones.
[3] See Annex 3
[4] For example: Stratospheric ozone depletion, tropospheric pollution, land surface monitoring, sea ice monitoring and glaciology.

For this it is necessary to operate many radio observatories with different instruments and locations, including in space, and to be able to observe at many different frequencies[5].

Radio waves of natural origin are extreme weak; a large reception surface (antenna) and a very sensitive receiver are required. This sensitivity increases the interference potential for a passive service. The combination of fixed frequencies and weak signals asks for a protected environment.

Closer to home, using the technique of very-long-baseline-interferometry (VLBI) provides a tool gather data on the drift of Earth's continents and the mechanisms of global climate and to do high-resolution positioning of spacecraft.

2.5 Space research

Satellites in the Space Research Service (SRS) are used to explore outer space for scientific purposes. This exploration covers studies on the structure and history of the universe and its dynamics. Depending on the specific scientific objective, these satellites can perform their observations while orbiting around the Earth or travelling across the solar system to explore its elements. Observations from the Space Research satellites range from microwave to optical.
Since these observations are not made in the direction of the Earth and in particular the active sensing is only performed on other planetary bodies than the Earth, no real interference issues are normally associated to the SRS passive or active applications.
Similarly to the EESS case, also for the SRS radio transmissions are used to downlink the satellite data to the Earth station and to control the satellite from the Earth station.

2.6 Radiolocation

Apart from Meteorological radars as described above, other scientific applications make use of the Radiolocation service to determine positions of various types of objects (planets, Teutonic plates, etc.).

2.7 Space Operations

The Space Operations Service allocations can be used for controlling and monitoring any space system. These allocations can therefore be used for scientific space applications, but also for other telecommunication space applications (commercial, military, etc.). It is to be noted that the ITU regulations impose to use telecommunication payload bands for controlling and monitoring the satellite during nominal operations. The use of these bands for space telecommunication services is therefore normally limited to the LEOP (Launch and Early Orbit Phase) and to the emergency situations; however, in deep-space mission, routine ranging and telecommand transmissions are needed during the whole life of a mission

3. Use of the Spectrum: Passive and Active Techniques

3.1 Introduction

[5] Each atom radiates on a certain frequency band (For example hydrogen radiates at 1400 -1427 MHz), these frequencies are determined physically. Radio Astronomy listens to naturally occurring signals from objects, the presence and power of radiation leads to conclusions about the atoms which are present and its location.

The spectrum is used by scientific services for two types of measurements. So called passive techniques are used (measuring radiations which occur naturally, i.e. ‘listening’) and active techniques, where electromagnetic radiation is emitted. In addition to these measuring techniques spectrum is needed for data communication.

3.2 Passive techniques

Passive measurements or passive sensing requires the measurement of naturally-occurring radiations, usually of very low power levels, which contain essential information on the physical process under investigation and involves the use of pure receivers, with no transmitters involved. All matter is continually radiating electromagnetic waves and as each molecule in the atmosphere or each surface property has a unique frequency signature, it can thus be recognised. Consequently, there are no alternative spectral options available for the specific measurements and therefore these frequency bands are an important natural resource.

Of interest are radiation peaks indicating the presence of specific chemicals, or the absence of certain frequencies indicating for example the absorption of the frequency signals by atmospheric gases. The strength or absence of signals at particular frequencies is used to determine whether specific gases (moisture and pollutants being obvious examples) are present and if so, in what quantity and at what location. A variety of environmental information can be sensed in this manner. Signal strength on a given frequency may depend on several variables, making the use of several frequencies at the same time necessary to match the multiple unknowns. The use of multiple frequencies is the primary technique used to measure various characteristics of the Earth surface.

Even low levels of interference received at the input of the passive sensors may degrade passive sensor operations since, in most cases, the sensors are not able to discriminate between these natural radiations and man-made radiations. In this respect Radio Regulations footnote 5.340[6] offers the passive services protection to deploy and operate their systems in the more critical frequency bands. Interference on a ‘passive’ frequency band could have an impact on the overall measurement of an atmospheric component.

3.3 Active techniques

This active use of spectrum consists of active sensors (measuring the reflection of signals generated by the sensor itself) and communication (data and feeder links) between different sections of the system. The active services can be sub-divided on the basis of the type of usage. A distinction can be made between meteorological bands, earth-to-space bands, space-to-Earth bands, space active sensors bands and ground based sensor bands (see Table 1).

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[6] This footnote of the Radio Regulation states that ‘All emissions are prohibited in the following bands’, followed by a list of frequency bands.

Table 1, Different types of scientific use.

			Scientific Usage
Scientific Spectrum	Passive services		Radio Astronomy (2.4)
			Earth exploration satellite (2.3)
			Space research (2.5)
	Active services	Meteorological bands	Meteorology and climatology (2.2)
			Radiolocation (2.6)
		Earth to space data transmission bands	Space operations (2.7)
			Earth exploration satellite (2.3)
			Space research (2.5)
		Space to earth data transmission bands	Space operations (2.7)
			Earth Exploration satellite (2.3)
			Space research (2.5)
		Space science active sensors bands	Earth Exploration satellite (2.3)
			Space research (2.5)
		Ground based sensors	Meteorology and climatology (2.2)

Based on these categories and sub-categories, the RSPG consulted Administrations on the use of the related frequency bands by scientific services and the sharing of these bands with other services. The consultation was organised during the first quarter of 2006 and its result is presented in section X. The questionnaire is contained in annex 4.

4. Economic and Societal Value

4.1 Introduction

In spectrum management it is becoming increasingly important to estimate the social and economic value of different usage of spectrum. In the case of scientific use of spectrum it might not be as straightforward as simply weighing up the quantified costs and benefits when considering alternative usage. This is because the benefits of scientific use can be difficult to quantify as they can relate to the society as a whole, may be difficult to foresee and may be realised over a very long period of time. This chapter gives an indication that the economical and societal returns of scientific usage of spectrum are significant.

4.2 Benefits of meteorology

Direct economic and social benefits can be associated with general benefits deriving from improved weather forecasting capabilities as well as specific benefits such as support to civil aviation, shipping, land transportation and savings resulting from the timely preparation for adverse weather conditions.

An illustration of the value of meteorology has been given by the WMO[7]:

> "Studies in the United States have shown that the value of improved seasonal weather forecasts to farming in the south-eastern quarter of the country alone amounts to some US$ 145 million a year".

[7] The Sixth World Meteorological Organisation Long Term Plan (2004-2011)

Furthermore,

> "WMO has estimated that overall economic benefits of modern meteorological services typically outweigh the national cost of maintaining such services by a ratio of as much as 10 to 1."

For Europe this would lead to the following figures: The total annual budget of European National Meteorological services and related organizations (EUMETSAT and ECMWF) is roughly between 1.8 and 2 Billions Euros. On the basis of the WMO calculation the economic benefits can be estimated between 18 and 20 Billions Euros per year.

Concerning natural disasters the WMO states, amongst others, that:

> "The economic impacts of natural disasters have worsened over the past few decades. Data from the International Federation of Red Cross and Red Crescent Societies as well as the Centre for Research on Epidemiology of Disasters reveal clearly that, during the period 1992–2001, about 90 per cent of natural disasters are weather and climate related and that the impacts of such disasters have been most pervasive during the past 10 years. During the same period, natural disasters worldwide have killed 622 000 people and affected over 2 billion people."

4.3 Benefits of climatology

Global Change is an important item on the international political agenda. The Kyoto protocol now being ratified, the yearly Conference of the Parties (CoP) of the UN Framework Convention on Climate Change (UNFCCC) continues to give worldwide political guidance. Based on inventories and recommendations developed by WMO's Global Climate Observing System, Parties are urged to implement climate monitoring systems that are essential to improve our understanding of climate change. This process has led to the establishment of the ad-hoc Group on Earth Observations (GEO), which developed a strategy to realise a Global Earth Observation System of Systems (GEOSS). In parallel to this the EU, in cooperation with ESA, started the Global Monitoring for Environment and Security initiative (GMES). Aiming at an operational system in a few years time, GMES is now being developed using EU Framework Programme funding. GMES should establish a network infrastructure all across Europe to facilitate information gathering for a wide variety of purposes. GMES is seen as the European contribution to GEOSS.

4.4 Benefits of natural hazard assessment

The UK Natural Hazard Working Group issued in June 2005 a Report to UK Prime Minister on "The role of science in physical natural hazard assessment". This report, which executive summary and Recommendations is given in Annex 4, recognises the high value of scientific services in mitigating natural hazard and is now one of the reference documents of the "Group on Earth Observation" program.

In particular, it highlights an information from the World Bank that, during the 90's, an efficient warning systems could have decrease the economic impact of natural disasters by 240 Billions dollars and that it is reasonable to assume that the cost-effectiveness of anticipatory measures will apply at least as much to catastrophes of global extent as to local natural disasters.

Finally, this Report also states that "*The cost effectiveness of spending to mitigate economic losses is an important part of the argument for taking action on preparedness and mitigation, including early warning. However other potential consequences of a global catastrophe are manifold and incommensurable in economic terms, from large* *losses of life to threats to socio-political stability and security. We are faced with a stark choice when it comes to dealing with global geophysical events. Either take no action and incur the risks –potentially trillions of dollars of economic losses and millions of lives lost – or exercise precaution in the face of scientifically established global threats and take practicable measures to mitigate their impact."*

4.5 Benefits from Radio Astronomy

Radio astronomy is a science whose progress is driven by the pace of technological improvements to its research instrumentation. The instruments that are employed must be at the forefront of the associated technologies.

Since radio astronomy has no control over the natural radio signal transmitters that are attempted to detect radio astronomers has been forced to develop antennas with the largest collecting area, receivers of the highest sensitivity, and -in general- instrumentation that defines the state-of-the-art in signal reception and data analysis. The technical requirements of radio astronomy have directly or indirectly fostered technological innovations of very wide applicability. Examples are:

- Sensitive microwave receiving systems, including high-gain antennas, low-noise receivers, solid-state oscillators and frequency multipliers, cryogenics;
- Data correlation and recording technology;
- Image restoration techniques;
- Time and frequency standards;
- Remote sensing, navigation, position determination, and geodesy;
- Computer languages and software development

4.6 Public investments in scientific services

The facilities used by the science services represent billions of Euros of public investments on national or European basis. This includes the building of radiotelescopes, scientific or meteorological spacecraft, and the deployment of scientific or meteorological and climatological stations all over Europe of which European companies are stakeholders.

On a general basis, costs for a single passive sensor instrument for radio astronomy, meteorology or Earth observation (both active and passive) can easily be in excess of 100 millions Euros. These costs are very often driven by the need to achieve front-line state-of-the-art system performance by means of completely innovative technical developments (including research). Because these instruments define the state-of-the-art, most are by their nature their own prototypes. The construction of these sensor instruments is very labour-intensive and requires specialized hardware.

The 6th and 7th Framework Programme of the European Union actively stimulates the development of forefront scientific instrumentation and also provides partial funding for the hardware infrastructure.

5. Status of Radio Spectrum used by Scientific Services

5.1 Introduction

The allocation and protection of spectrum used by the scientific services is mainly regulated by the ITU Radio Regulations which is an international treaty.

Among the numerous ITU Radio Regulations footnotes related to the scientific services, two of these recognise the case of frequency bands used passive services. Footnote 5.149 urges administrations to take all practicable steps to protect the Radio Astronomy Service from harmful interference in a number of specific frequency bands, Footnote 5.340 lists a number of essential frequency bands in which all emissions are prohibited,

It should be noted that the EC and ECC decisions on SRR 24 GHz created a precedent authorising exceptionally and on a temporary basis, in-band emissions in the 23.6-24 GHz band[8].

5.2 Relationship between ITU Radio Regulations and the EU Treaty

From the beginning, harmonisation in the radiocommunications domain was achieved at the global level through WRC and incorporated in the Radio Regulations (RRs) of the ITU. These Regulations have the status of an international treaty.

This harmonisation meant that certain frequency bands were reserved for a certain use worldwide or regionally. The nature of the frequency usage determines whether and how much harmonisation is necessary. National allocation tables generally comply with ITU-RR and WRC decisions.

More recently measures to harmonise the usage of spectrum in the EU (EC Decisions) are taken on the basis of the Radio Spectrum Decision[9]. In order to avoid legal incompatibilities between provision of the RRs and the legal obligations under the EU Treaty and it's instruments the EU Members declare in the Final Acts of a ITU conference that: "The delegations of the Member States and future Member States of the European Union declare that the Member States and future Member States of the European Union will apply the revision of the Radio Regulations adopted at this conference in accordance with their obligations under the EC Treaty".[10]

With regards to scientific and meteorological services, there is currently a very high level of global harmonisation for active applications whereas, for passive bands, this harmonisation is obvious. It should also be noted that the scientific and meteorological communities coordinate among themselves to make the most efficient use of the corresponding frequency band.

5.3 Sharing Conditions

Exclusive use by scientific services is only necessary in a few cases. In general the scientific services achieve a significant degree of sharing with other services, and among themselves.

i) *Sharing in space science passive sensors bands*

A limited set of bands is purely passive, for these bands sharing is not possible (footnote 5.340: "all emissions are prohibited") and the remaining issue in these bands is the compatibility with unwanted emissions received from active services allocated in adjacent or nearby bands. Possible inclusion in the Radio Regulations of regulatory unwanted emissions limits is being studied under WRC-07 Agenda Item 1.20.

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[8] This band is mentioned in Footnote 5.340 as one of the bands in which all emissions are prohibited.
[9] Radio Spectrum Decision 676/2002/EC, 7 March 2002.
[10] Declaration # 6, Final Acts WRC-03, Page XXXIV (English version)

The other passive bands are typically shared with FS/MS, in some cases also with FSS. For some of these bands the ITU has defined sharing criteria that resulted in recommendations or regulatory limitations. One of the main sharing risks relates to possible future decisions to use these bands for high-density commercial applications that would change the assumptions under which the sharing feasibility and conditions were determined. As an example, the case of the bands 10.6-10.68 GHz and 36-37 GHz are currently studied under WRC-07 Agenda item 1.2.

Due to specific physical characteristics, no frequency band used by passive services can be substituted by other bands. Interference that could impact a given "passive" frequency band could have an impact on the overall measurement of atmospheric components; this is in particular important for meteorology and climatology.

ii) *Sharing in space science active sensors bands*
Nearly all the space science active sensors bands are shared with radiolocation; in some cases the bands are shared also by radionavigation. Many years of coexistence without interference problems have confirmed the compatibility of these services in the bands allocated. A potentially critical sharing situation might develop in the range 5250-5350 MHz, where the decisions by WRC-03 only discourage but do not prohibit outdoor usage of wireless LAN. This part of the band is used for Synthetic Aperture Radar (SAR) imaging and supports the main GMES space element.

iii) *Sharing in space science data transmission bands (Earth-to-space, space-to-Earth)*
In general, there are no difficult sharing situations in most of the bands used for space science data transmission. For the Earth-to-space emissions, the fact of having ground stations in relatively remote and naturally shielded sites limits any possible interference to terrestrial services. Also the possibility of interference by terrestrial systems to the receiving ground station (space-to Earth transmission) is strongly limited by the remote location of these stations. As for the satellite part, by respecting the Article 21 limits, the space-to-Earth transmissions do not interfere with terrestrial systems.
On the other hand, the high power required to reach the satellite receivers ensures that typically no interference is suffered by the space science satellites from terrestrial systems.

iv) *Sharing in radio astronomy bands*.
Sharing scenarios have been investigated for radio astronomy operations but have only been implemented on an ad-hoc basis. By necessity the most sensitive observations are done during early morning hours when many of the terrestrial transmitters are off the air. This type of time sharing of active service bands on a non-interference non-protection basis is common practise.

6. The Analysis of the Responses Received From Administrations to the Questionnaire's

6.1 Introduction

On meteorological services, three bands are exclusively allocated to this service according to the RR (401-403 MHz, 403-406 MHz & 1690-1700 MHz) representing 15 MHz out of the 158 MHz allocated to this service with a primary status below 3 GHz and the 440 MHz between 3 and 20 GHz. Below 3 GHz, around 300 MHz is allocated to this service with a secondary status. However, few countries allocated part of this spectrum band to other services, sometime even with a primary status. Other countries did not allocate some of the bands allocated to meteorological services in the ITU-RR to any service and therefore the bands appear as being not used.

Eight bands are exclusively allocated to passive services (25.55-25.67 MHz, 1.6605-1.6684 GHz, 1.4-1.427 GHz, 2.69-2.7 GHz, 10.68-10.7 GHz, 15.35-15.4 GHz, 31.3-31.5 GHz, 50.2-50.4 GHz). The band 23.6-24 GHz is temporarily allocated to SRR in national allocation tables according to the EC Decision and despite footnote 5.340. This represents 45 MHz in bands below 3 GHz and 668 MHz out of approximately 4 GHz allocated to this service with a primary status in bands below 50.4 GHz. As indicated above some exceptions can be seen in the list of bands and some countries did not allocate some of the bands allocated to passive services in the ITU-RR to any services and therefore the bands appear as being not used.

On earth to space data transmission bands, only one band is exclusively allocated to this service according to the RR but not in reality (34.2-34.7 GHz). This represents 500 MHz out of around 1.7 GHz. The bands allocated to this service are generally shared with fixed and mobile services which have the same primary status.

On space to earth data transmission bands, no band is exclusively allocated to this service according to the RR. The bands allocated to this service are generally shared with fixed and mobile services which have the same primary status.

On space science active sensors bands, the bands allocated to this service according to the RR are shared with radionavigation and radiolocation. And in some cases these bands are also shared with SRR, SRDs and ISM.

On ground based sensor bands no band is exclusively allocated to this service according to the RR. The bands are shared with EESS-RAS-SR only, with the exception of SRR in the band 23.6-24 GHz which is temporarily allocated to SRR.

From the above it appears that 60 MHz is exclusively allocated to scientific services below 3 GHz and 1668 MHz in total even though some part of this spectrum is in reality shared with other services in some countries.

6.2 Conclusions from the Questionnaire

The amount of spectrum used by scientific services is only a small portion of the total amount of available spectrum. Exclusive use is exceptional, in most cases the spectrum is shared by different users.

[Text to be added here at a later stage]

7. The Public Consultation

[Text to be added here at a later stage]

8. Conclusions

Many of the scientific activities are organised at a global level and, therefore, spectrum related issues must be considered globally since unilateral European Decisions may have worldwide impact on related frequencies use and measurements. This is, for example, the case for GEOSS.

Due to the specificity and uniqueness of passive bands there are no alternatives to gather the same information. Therefore these passive bands are unsuitable for migration and any potential interference would lead to the loss of the given molecular channel.

With regards to active services, the current extensive use of some of the bands should be considered prior any migration. As for other services, certain bands have specific characteristics (propagation, related antenna size) that do not allow a migration to a different frequency.

It should also be noted that certain measurements, for example EESS sensing, current data are compared with historical data. For these long term measurements and trends long-term consistency of measurements is essential.

Much of the radio astronomy operations have been concentrated and have been placed outside major metropolitan areas. Because of increased sensitivity of the instrumentation, these stations have become increasingly vulnerable to increased spectrum use and expansion of commercial operations into new frequency ranges. Because the frequencies used in astronomical research are determined by fundamental physics, there is no choice in frequency and sharing of the bands is not possible.

With regards to new generation radio telescopes, the locations are carefully chosen in order to reduce the impact of man-made noise. The selection process for the SKA telescope is largely based on remoteness. Similarly, the location of the ALMA telescope in the high Andes in Chile was based on the height and remoteness. Geographical sharing of frequencies for ground based operations would only be possible when appropriate coordination distances are used that have been determined with terrain dependent propagation models. Because of the frequency dependence of the propagation, only geographical sharing would be possible for terrestrial frequencies above 60 GHz.

Scientific usage of spectrum has considerable societal weight and economic value. It might be difficult to quantify the benefits of scientific use as they can relate to society as a whole, may be difficult to foresee and maybe be realised over very long periods of time. In this opinion examples have been presented of some attempts at quantifying the benefits. Further attempts to describe in qualitative and quantitative terms, the benefits of these services should be made.

Therefore it is recommended that the cost and benefits should at least be described and the types of cost and benefits be spelled out so that an informed comparison can be made, between the qualitative description of the benefits and the quantified costs.

9. Draft Elements for an Opinion of the RSPG

1. Scientific use of radio spectrum covers a variety of services which are identified in the Radio Regulations as the Meteorological Aids Service, the Earth Exploration Satellite Service (EESS), the Meteorological-Satellite Service, the Space Research Service (SRS), the Radio Astronomy Service (RAS), the Standard Frequency and Time Signal Service and the Standard Frequency and Time Signal-Satellite service, the Space Operation Service, the Radiolocation Service (RLS) and the Radionavigation Satellite Service. In some cases, these may also cover other applications not related only to science, but the purpose of which is for both scientific and operational usage.

2. Scientific use of spectrum has a considerable societal value. Most of the data retrieved from the use of the so-called "scientific bands" are directly dedicated to the benefit of every citizen as they relate in particular to meteorology, climatology, environment, civil security and fundamental research. Most of the associated investments are coming from public funds.

3. Most of this societal value is incommensurable in financial terms, as they relate to preventing large losses of lives or threats to socio-political stability and security. However, scientific use of spectrum also has a direct impact in many economic areas, which can be estimated, and in producing economic spin-offs in technology and economic developments in energy, transportation, agriculture, communications, medicine, etc. An assessment of the overall benefits of scientific uses of spectrum needs to be taken into account and complemented, as appropriate, using the guidelines set out below, in order to facilitate future decisions by administrations which may impact on such uses.

4. The importance of inter-governmental commitments, among which the GMES initiative (Global Monitoring for Environment and Security), is a European priority, as is the World Weather Watch program of the World Meteorological Organisation, which rely on the availability of observations on every point of the Earth. This requires spectrum harmonisation at a global level, which is already achieved and should be maintained. Members States should take appropriate measures to ensure the availability and adequate protection of this globally harmonised spectrum in all countries, since unilateral European or national decisions may have worldwide impact on the quality and availability of data.

5. Exclusive allocations to scientific services are needed only to a limited portion of the spectrum, corresponding to unique frequencies. The RSPG considers that these represent essential natural resources and urges Member States to comply with their obligations under No. **5.340** of the Radio Regulations, which prohibits all emissions in the corresponding frequency bands.

6. In all cases not covered by No. **5.340**, scientific use of spectrum achieves a significant degree of sharing with other services, as well as with other scientific uses, with varying degrees of limitations:

   - in most of the bands allocated to satellite active sensors, no limitations are imposed on other services;

- in the bands allocated to radio astronomy and to SRS/EESS/METSAT for data communication purposes, limitations to other services only apply in the vicinity of a few geographical sites;
- Passive sensing from satellites requires worldwide protection, and limitations on other services are more significant.

7. The current and expected pressure on spectrum may lead to consider increased levels of sharing between scientific uses and other services. In such cases, there would be a need to assess the impact of a potential decision on both scientific uses and other services. This assessment should, in a proportionate manner:

   - identify the **objectives** of a proposed decision and identify a **range of options**;
   - draw up a list of different groups of **stakeholders** likely to be affected;
   - identify the **impact of the various options** on the interests of the particular groups of stakeholders;
   - take into account **commitments/obligations** in international initiatives/agreements;
   - identify and, where possible, quantify the **costs and benefits** flowing from the impacts which each option would have;
   - Assess the **risks** associated with each option.

Annex 1

Earth observation

The past decade has seen increasing public concern about the Earth, its environment and mankind’s impact upon it. Global threats such as climate warning, stratospheric ozone depletion, tropospheric pollution and increasing number of extreme weather events, have left us more concerned than ever about the need to monitor and understand what is going on in the Earth’s environment. There are many aspects of the complex evolving Earth System that we still do not understand.

These concerns have led to the establishment of international (both European and global) programme concepts, including both space- and surface-based systems, to measure on a routine basis all major elements of the global climate system.

Some of the earliest initiatives, including METEOSAT and SPOT, have already developed into long-term applications programmes integrated into regular operational use. For example, the fleet of geostationary Meteosat satellites that is observing the weather in real-time is providing a reliable stream of data ever since the launch of the first Meteosat in 1977, helping to significantly improve weather forecasting.

Earth observation from space using microwave remote sensing is a critical tool in this task because of the all-weather/ day-night capabilities, unique view and high revisit rate that it provides. ESA’s European Remote Sensing satellites (ERS-1,-2) and ENVISAT carrying a multitude of instruments have made major contributions in areas as diverse as global and regional:

- ocean observations;
- atmospheric composition and chemistry;
- sea ice monitoring;
- glaciology and snow cover investigations;
- land cover monitoring;
- Investigations into the dynamics of the Earth’s crust (seismology and volcanology).

Active remote sensing in the microwave region offers several advantages over visible region sensors and passive microwave sensors. Besides being uniquely sensitive to several land/ocean/atmosphere variables (e.g. plant moisture and cloud height), active sensing can, for instance, penetrate the surface and vegetation, operate on an all-weather and day/night basis. Active sensors differ from passive sensors in that they illuminate the object under observation and respond to the reflected energy.

For most of the EESS (active) sensors, the operating frequency range is linked to the geophysical parameters to be observed. For instance, to enable measurement of clouds and precipitation, the wavelength needs to be small enough to reach the required sensitivity.

To illustrate one of the applications, Figure 1 shows an artificially coloured ERS-1 SAR image, covering an area of 75 km x 75 km. It shows the Teles Pires river in Brazil and a regular pattern of deforestation is clearly visible in the rectangular patches of destroyed forest extending over areas as large as 20 kilometres. More recently, spaceborne SAR imagery was used to detect illegal logging activities in Indonesia after which action was taken to arrest and detain the responsible persons.

Figure 1: Brazil Deforestation (copyright ESA 1992)

Passive microwave radiometry is a tool of fundamental importance for the EESS. The EESS operates passive sensors that are designed to receive and measure natural emissions produced by the Earth surface and its atmosphere. The frequency and the strength of these natural emissions characterize the type and the status of a number of important geophysical, atmospheric and surface parameters (land, sea, and ice caps), which describe the status of the Earth/atmosphere/oceans system, and its mechanisms:

- Earth surface parameters such as soil moisture, sea surface temperature, ocean wind stress, ice extension and age, snow cover, rainfall over land, etc;
- Three-dimensional atmospheric parameters such as temperature profiles, humidity profiles, total water vapour content and concentration profiles of radioactively and chemically important trace gases (for instance ozone and chlorine monoxide).

Microwave techniques render possible observation of the earth's surface and its atmosphere from space orbit even in the presence of clouds, which are almost transparent at frequencies below 100 GHz. This "all-weather" capability has considerable interest for the EESS because more than 60% of the earth's surface is overcast with clouds. Passive microwave sensing is an important tool widely used for meteorological, climatological, and environmental monitoring and survey (operational and scientific applications), for which reliable repetitive global coverage is essential.

Annex 2

Radio Astronomy

The purpose of the Radio Astronomy is to do fundamental research on the nature of the universe in which we live. This research seeks to answer some of the biggest questions we can ask, such as how did the universe begin (or did it begin), how big is it, how old is it, and how will it end (or will it end)? As the science that provides the framework knowledge of where we, and the planet on which we live, fit into the environment of the universe, astronomy is a vital part of the culture of all mankind. From the dawn of civilization, astronomy has provided important stepping stones for human progress. Our calendar and system of timekeeping came from astronomy. Much of today's mathematics is the result of astronomical research. Trigonometry was invented by Hipparchus, a Greek astronomer. The adoption of logarithms was driven by the needs of astronomical calculations. The calculus, the basis of all modern science and engineering, was invented by Sir Isaac Newton for astronomical calculations. Astronomy provided the navigational techniques that allowed sailors and aviators to explore our planet (and today allow spacecraft to explore our solar system). Astronomy's appetite for computational power drove the development of many of the earliest electronic computers. The space age, which brought us the communication and weather satellites upon which we depend each day, would have been impossible without the fundamental knowledge of gravity and orbits discovered by astronomers. Radio astronomers led the development of low-noise radio receivers that made possible the satellite communications industry. Image-processing techniques developed by astronomers now are part of the medical imaging systems that allow non-invasive examination of patients' internal organs. At today's observatories, the needs of astronomers for better instruments continue to drive developments in such diverse fields as electronics, mechanical engineering, and computer science.

Astronomy has much yet to contribute to human knowledge and progress. From the airplane to the transistor, from radio to lasers, the developments of the Twentieth Century were based on fundamental knowledge of the physics of matter and energy. Astronomy offers scientists from a wide range of backgrounds with a nearly infinite variety of cosmic "laboratories" for observing physical phenomena. It is unlikely that any laboratory on Earth will ever produce matter as dense as that of a neutron star, temperatures as hot as those inside a supernova, or gravity as strong as that of a black hole. Yet, astronomers can study the physics of such extreme conditions routinely with modern radio telescopes. Closer to home, using the technique of very-long-baseline-interferometry provides a primary tool gather valuable data on the drift of Earth's continents and the mechanisms of global climate and to do high-resolution positioning of spacecraft.

Adapted from Dave Finley, National Radio Astronomy Observatory, Charlottesville VA, USA http://www.nrao.edu/whatisra/valueofastro.shtml

Technological Contributions from Radio Astronomy

Radio Astronomy has long-term cultural and scientific returns, but it also provides benefits in the shorter term:

(a) The development of *very-low-noise receivers* with system temperatures as low as 10 K and frequencies extending from a few MHz to 1500 GHz. These have wide applications in radio technology.

(b) *Thermography of the body* by use of millimeter radio techniques (~45 GHz).

(c) The detection of *cancer* at centimetre wavelengths (~10 GHz) with modern radiometers and using a method of mini-aperture synthesis (interferometric triangulation).

(d) Computerized *x-ray tomography*, which employs methods originally developed for mapping radio sources.

(e) The detection of *forest fires* by their microwave radiation.

(f) Development of *radio sextants* for marine navigation, allowing accurate determinations of positions at sea even on overcast and rainy days.

(g) *Forecasting of earthquakes* by VLBI measurements of fault motion by a determination of the apparent positions of small radio sources.

(h) Determination of many geophysical parameters such as *continental drift, polar wandering, latitude measurements*, and *variation in the earth's rotation*, with the use of connected elements and VLBI techniques.

(i) Experimental verifications of Einstein's *General Theory of Relativity* and the phenomenon of gravitational lensing using radio interferometry, and verification of the existence of gravitational waves, and precise confirmation of Einstein's *General Theory of Relativity*, from timing measurements of binary pulsars.

(j) Testing *theories of the origin of the Universe* by observing the 3 K background radiation, the relic of the primeval fireball or Big Bang.

(k) Major contributions to navigation -including that of spacecraft- and timekeeping resulting from pulsar observations and very-long baseline interferometry (VLBI)..

(l) Adoption of radio astronomy interferometric methods to develop *passive remote-sensing* techniques for measuring the temperature of the earth's atmosphere, surface properties, and the distribution of water vapour, cloud water, precipitation, and impurities such as carbon monoxide.

Trends in Radio Astronomy

Trends in radio astronomy are towards higher sensitivity and higher frequencies. Since receivers are reaching the quantum limit and cannot be further improved there is a drive towards larger collecting areas and the use of broader bandwidths. International efforts are underway to construct new generation radio telescopes that have significantly larger collecting surfaces. Examples are: The Square Kilometre Array project, which seeks to build a single telescope with a square kilometre surface at 1400 MHz in a radio quiet environment, the Low Frequency Array (LOFAR) in The Netherlands that has 100 planned stations on a maximum baseline of some 400 km and is aimed at further opening up the range 30 – 250 MHz for radio astronomy, and the Atacama Large Millimetre Array on a 5 km high plateau in the Andes.

In the development process towards larger sensitivities, the actual use of frequencies will not change significantly. The existing bands allocated to the RAS that enjoy protecting status will continue to be used for long term integrations to detect weak signals of interest. Because these bands have been chosen for physical reasons and for the presence of important spectral lines, the continual protection for these bands is essential for the continuation of radio astronomical research in a large number of key areas.

Annex 3

World meteorological organisation

RESOLUTION 3 (Cg-XIV)

RADIO FREQUENCIES FOR METEOROLOGICAL and related environmental ACTIVITIES

The congress,

Noting

(1) The Sixth Long-term Plan.

(2) Resolution 3 (Cg-XIII) – Radio-frequencies for meteorological activities.

(3) The current radio frequency allocations and regulatory provisions related to the Meteorological Aids, Meteorological Satellite, Earth Exploration-Satellite and Radiolocation (weather and wind profiler radars) Services in the Radio Regulations of the International Telecommunication Union (ITU).

(4) The outcome of ITU World Radiocommunication Conferences (esp. WRC-2000).

(5) The agenda of the forthcoming ITU World Radiocommunication Conference (WRC-2003).

Considering

(1) The prime importance of the specific radiocommunication services for meteorological and related environmental activities required for the safety of life and property, the protection of the environment, climate change studies and scientific research.

(2) The crucial importance of the allocation of suitable radio-frequency bands for the operation of surface-based meteorological observing systems, including in particular radiosondes, weather radars, wind profiler radars.

(3) The crucial importance of the allocation of suitable radio-frequency bands for the operation of Meteorological and Research & Development satellites, including remote sensing, data collection and data distribution links.

Stressing that some radio-frequency bands are a unique natural resource due to their special characteristics and natural radiation enabling spaceborne passive sensing of the atmosphere and the Earth surface, that deserve adequate allocation to the Earth Exploration Satellite Service (passive) and absolute protection from interference.

Expresses its serious concern at the continuing threat to several frequency bands allocated to the Meteorological Aids, Meteorological Satellite, Earth Exploration-Satellite and Radiolocation (weather and wind profiler radars) Services posed by the development of other radiocommunication services.

Requests the Commission for Basic Systems to pursue the continuous review of regulatory and technical matters related to radio-frequencies for operational and research meteorological and related environmental activities, in coordination with other technical commissions and in liaison with other relevant international bodies, in particular the Coordination Group for Meteorological Satellites (CGMS).

Urges all Members to do their utmost to ensure the availability and protection of suitable radio frequency bands required for meteorological and related environmental operations and research, and in particular:

(1) To ensure that their national radiocommunication administrations are fully aware of the importance of and requirements for radio frequencies for meteorological and related activities, and to seek their support in the ITU World Radiocommunication Conferences and Radiocommunication Sector (ITU-R) activities.

(2) To actively participate in the national, regional and international activities on relevant radiocommunication regulatory issues and, in particular, to involve experts from their Services in the work of relevant regional radiocommunication organizations and of the ITU Radiocommunication Sector (ITU-R), especially ITU-R Study Group 7 on Science Services.

(3) To adequately register with their national radiocommunication administrations all radiocommunication stations and radio frequencies used for meteorological and related environmental operations and research.

Appeals to the International Telecommunication Union and its Member Administrations:

(1) To ensure the availability and absolute protection of the radio-frequency bands which, due to their special physical characteristics, are a unique natural resource for spaceborne passive sensing of the atmosphere and the Earth surface; In this regard, the exclusive 23.6-24 GHz passive band that is associated with a water vapour absorption line is of crucial importance for weather, water and climate research and operations.

(2) To give due consideration to the WMO requirements for radio frequency allocations and regulatory provisions for meteorological and related environmental operations and research.

Requests the Secretary-General:

(1) To bring this resolution to the attention of all concerned.

(2) To pursue as a matter of high priority the coordination role of the Secretariat in radio frequency matters, especially with the Radiocommunication Sector (ITU-R) of the International Telecommunication Union, including participation of WMO in ITU-R Radiocommunication Study Groups, conference preparatory meetings and World Radiocommunication Conferences;

(3) To facilitate the coordination between National Meteorological and Hydrological Services and their national radiocommunication administrations, particularly in preparing the ITU World Radiocommunication conferences, by providing appropriate information and documentation.

(4) To assist the Commission for Basic Systems in the implementation of this Resolution.