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MANAGEMENT OF EARTH RESOURCES

Background paper 3

The full list of the ackground papers:

1. The Earth and its environment in space
2. Disaster prediction, warning and mitigation
3. Management of Earth resources
4. Satellite navigation and location systems
5. Space communications and applications
6. Basic space science and micro gravity research and their benefits
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PREFACE

The General Assembly, in its resolution 52/56, agreed that the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III) should be convened at the United Nations Office at Vienna from 19 to 30 July 1999 as a special session of the Committee on the Peaceful Uses of Outer Space, open to all Member States of the United Nations.

The primary objectives of the UNISPACE III Conference will be:

(a) To promote effective means of using space technology to assist in the solution of problems of regional or global significance;

(b) To strengthen the capabilities of Member States, in particular developing countries, to use the applications of space research for economic and cultural development.

Other objectives of the UNISPACE III Conference will be as follows:

(a) To provide developing countries with opportunities to define their needs for space applications for development purposes;

(b) To consider ways of expediting the use of space applications by Member States to promote sustainable development;

(c) To address the various issues related to education, training and technical assistance in space science and technology;

(d) To provide a valuable forum for a critical evaluation of space activities and to increase awareness among the general public regarding the benefits of space technology;

(e) To strengthen international cooperation in the development and use of space technology and applications.

As one of the preparatory activities for the Conference, the Office for Outer Space Affairs of the Secretariat has prepared a number of background papers to provide Member States participating in the Conference, as well as in the regional preparatory meetings, with information on the latest status and trends in the use of space-related technologies. The papers have been prepared on the basis of input provided by international organizations, space agencies and experts from all over the world. A set of 12 complementary background papers have been published and they complement each other and as such should be read collectively.

Member States, international organizations and space industries planning to attend UNISPACE III should consider the contents of the present paper, particularly in deciding on the composition of their delegation and in formulating contributions to the work of the Conference.

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SUMMARY

The Earth's human population increases at the rate of more than 250,000 per day. This growth, which occurs mostly in developing countries, creates tremendous pressures to exploit existing resources to meet burgeoning social and economic development needs. The exploitation of resources has led to several significant environmental problems, notably large-scale deforestation, overfishing and destruction of fish habitats, land degradation and desertification, the spread of disease and pests, decreasing biodiversity, inadequate access to fresh water, ozone depletion and global warming. There is now a recognized need to manage the Earth's resources in a sustainable and environmentally sensitive manner. Remote sensing satellites provide a variety of information which is essential in facilitating such management.

Remote sensing technology confers many direct and indirect benefits on society, among which are: (a) cost and time savings, which are produced through achievement of greater efficiency and effectiveness in a wide range of planning, operational and monitoring activities, compared to alternative sources of comparable information, such as aerial photographic surveys; (b) greater savings in human lives through better supply of information useful in disaster management; (c) better quality of life through better food security and enhanced management of the environment and natural resources; and (d) greater reduction of uncertainty in general decision-making.

The number of operational satellites with sensors suitable for detailed mapping of Earth resources is increasing, owing in part to the advent of fully commercial satellite operations. The use of data from these satellites is also on the rise. However, most of the increased use is occurring in industrialized countries. Promotion of global development of the use of satellite remote sensing will require addressing a number of policy issues, including improved access to data and the creation of mechanisms and programmes that allow the greater use of satellite remote sensing in routine development activities.

I. SATELLITE SYSTEMS FOR EARTH RESOURCES

1. There is currently a wide range of satellite remote sensing systems that are useful for providing data to assist in the resolution of issues of national, regional and global significance. These systems range in spatial resolution from kilometres down to metres and record in wavelengths from the ultraviolet through the visible and infrared to the thermal infrared and microwave regions of the electromagnetic spectrum. The particular region over which a sensor acquires data, as well as its spatial resolution and revisit capability (i.e. the time between successive viewing by the satellite of a given site) are important considerations that determine the usefulness of the data for application in a number of key development sectors, such as agriculture, mineral exploration, forestry, hazards monitoring, fisheries and hydrology. Virtually all the satellite systems have comparable airborne equivalents; however, the airborne systems do not regularly acquire the data and can view only limited areas of the Earth's surface.

2. Civilian remote sensing from space began in April 1960 with the launch by the United States of America of the Television and Infrared Observational Satellite (TIROS-1) (a precursor of the Polar-orbiting Operational Environmental Satellite (POES) series of satellites currently operated by the National Oceanic and Atmospheric Administration (NOAA)) as an experimental weather satellite. This polar orbiting satellite produced the first TV-like pictures of the world's surface in a systematic and repetitive manner. The United States military launched its first Earth observation satellite, Discoverer, in August 1960. During the 1960s a series of remote sensing satellites was launched for weather, intelligence and lunar landing programmes by the United States and the Union of Soviet Socialist Republics. In 1972 the first civilian satellite that was designed specifically to collect data of the Earth's

surface and resources was the Earth Resources Technology Satellite (ERTS-1), which was later renamed Land Remote Sensing Satellite 1 (LANDSAT-1). Subsequent satellites in the series LANDSAT-2, -3, -4 and -5 were launched in 1975, 1978, 1982 and 1984, respectively.

3. From 1972 until 1986, satellite remote sensing imagery was available to the general public only from the LANDSAT series of satellites. Since then, however, the options available to data users have steadily increased. Several other Earth resources satellite systems of differing technical characteristics (that is, instrument payload, orbital details, and primary application areas) have been launched and operated by different space agencies with the support of national Governments. The number of possible sources of remote sensing information continues to increase. Systems that can record at very high spatial and spectral resolutions and that will have very short revisit capabilities will be available in the near future. This will assure users of increasing flexibility in obtaining needed information in a timely manner. A synopsis of the current operational systems is presented in the following paragraphs. This is followed by an outline of some of the new systems that will be launched in the near future (i.e. from the beginning of 1998, the date of writing of this report, onwards).

A. Current major operational systems

4. At present, six systems provide most of the current data for Earth resource management on a regular basis. These systems, and the dates of first launch, are: the Advanced Very High Resolution Radiometer (AVHRR) of NOAA of the United States; LANDSAT, 1972; Système pour l'observation de la Terre (SPOT), 1986; Indian Remote Sensing Satellite (IRS), 1988; Earth Resources Satellite (ERS), 1991; Japanese Earth Resource Satellite (JERS), 1992; and RADARSAT, 1995.

5. The NOAA-AVHRR system was designed to provide information for hydrological, oceanographic and meteorologic studies, although the data have also been used for land monitoring applications. There are a series of these systems in Earth orbit, and each has a twice daily return period (night and day). The LANDSAT systems were the first to be designed to provide global coverage of the Earth's surface on a regular basis. Two multi-spectral remote sensing instruments of different spatial and spectral resolutions are carried by the current LANDSAT systems. These are the Multi Spectral Scanner (MSS) and the Thematic Mapper (TM) sensors. The SPOT systems 1, 2 and 3 were launched in 1986, 1990 and 1993, respectively. These identical systems can acquire data in panchromatic and multispectral modes. The SPOT systems have a standard repeat cycle of 26 days, but because of a side viewing capacity they can revisit a site at more frequent intervals (up to every 2 days) and also have the capacity to create a stereoscopic pair of images. The IRS satellite systems (1A, 1B, 1C and 1D) were launched in 1988, 1991, 1996 and 1997, respectively. They have a return period of 22 days. The IRS-1C and -1D have both panchromatic and multispectral sensor. Sensor characteristics for these four satellite systems are summarized in table 1.

6. RADARSAT, JERS-1 and ERS-1 and ERS-2 carry radar or microwave remote sensing systems. These are active sensors having their own source of energy, so that data can be acquired at any time, night or day, depending on the satellite's position above the Earth's surface. ERS-1 and ERS-2 were launched in 1991 and 1995, respectively. JERS-1 was launched in 1992 and RADARSAT in 1995. Both ERS and JERS have other sensing instruments in addition to their imaging radar instruments, and RADARSAT has a number of imaging modes at different ground resolution. Additional technical characteristics of these three systems are presented in table 2.

Table 1. Major operational satellite systems routinely used for the management of Earth resources

System	*Characteristics*	*Spatial resolution*
NOAA (AVHRR)	VNIR(2) TIR(3)	1.1 km

LANDSAT	VNIR(4) VNIR/SWIR(6) TIR(1)	56 m × 79 m 30 m 120 m
SPOT	PAN VNIR(3)	10 m 20 m
IRS	PAN VNIR(3) MIR(1)	5.8 m 23.5 m 70 m

Note: VNIR—visible to near-infrared; SWIR—short-wave infrared; PAN—panchromatic; MIR—middle infrared; TIR—thermal infrared. The number enclosed in brackets ( ) refers to the number of spectral bands.

Table 2. Principal specifications for the three major operational radar (microwave) satellite systems

	ERS-1 & 2	*JERS-1*	*RADARSAT-I*
Wavelength	5.7 cm	23.5 cm	5.7 cm
Frequency	5.3 GHz	1.28 GHz	5.3 GHz
Polarization	VV	HH	HH
Incidence angle	23 degrees	35 degrees	20-49 degrees
Swath width	100 km	75 km	100 km/500 km [SM]
Range resolution	30 metres	18 metres	25 metres [SM]
Azimuth resolution	30 metres	18 metres	28 metres [SM]

Note: SM—in standard mode.

B. New and future systems

7. The remote sensing systems that have been developed with the support of national Governments have focused on the collection of broad scale, medium and low resolution data more appropriate for such information as climate research, environmental monitoring and resource management. However, the new systems that are planned or have recently been launched by current and new commercial operators (tables 3 and 4) show a clear trend towards higher spatial and spectral resolution[1] (see also background paper 9 (A/CONF.184/BP/9) on Small satellite missions, some of which are related to remote sensing). In the year 2000, if all current plans for Earth viewing satellites are fulfilled, there would be 31 satellites in orbit at the same time that would be capable of providing data of 30 metres or better resolution. The highest spatial resolution of the systems planned is 0.8 m. As many of these systems will also have a stereoscopic facility, they will be able to provide high-resolution digital terrain models, with equivalent contour intervals of the order of 2 metres. The high spatial resolution offered by these systems will also allow three-dimensional modelling of buildings and the mapping of land use, as opposed to land cover. The main market for the data from many of the high-resolution satellites includes precision crop management, mapping and diverse Geographic Information System (GIS) applications (e.g. those related to public utilities, urban planning, forestry and disaster management). Vendors claim that the products from the commercial systems will generally be available

within a few hours of satellite data acquisition. Such availability will depend, however, on users' access to adequate information-technology facilities that would allow near real-time transfer of data.

8. The next generation of Earth observation satellites will monitor atmospheric structure and chemistry, the oceans, the land surface and vegetation in unprecedented detail and accuracy. These observations will contribute to the comprehensive assessment of the state of the Earth system and identify the nature and cause of natural and human induced changes in the global system.

9. With the increasing availability of a wide spectrum of satellite data to choose from, the concept of data fusion will also become more widely recognized. Rather than using data from one system, at one resolution, from one date, which may not satisfy all the information needs of the user, multiple data sets will be integrated. Software programs for optimizing the extraction of information for specific applications will become available.

Table 3. Satellite systems with capabilities potentially useful for the management of Earth resources, scheduled to be launched during the period 1997-2003 by government-supported agencies[a]

System	*Characteristic*	*Spatial resolution*
CBERS (1999, 2000)	VNIR(4)	20 m, 260 m
	PAN	20 m, 80 m
	SWIR	80 m
	TIR	160 m
RADARSAT-II (2000)	SAR(C)	3 m, 9 m, 25 m, 50 m, 100 m
Envisat-1 (1999)	VNIR(15)	250 m, 1 km
	SAR(C)	30 m, 100 m
SPOT-4 (1998)	VNIR/SWIR(4)	10 m, 20 m
SPOT-5A (2002)	VNIR/SWIR(4)	10 m
	PAN	5 m
IRS-1D (1997)	VNIR(4)	23.6 m
	PAN	5.8 m
	SWIR	70.8 m
	WiFS	188 m
IRS-P5 (1999-2000)	PAN	2.5 m
IRS-P6 (2000-2001)	VNIR(4)	23 m
	VNIR(3)	6 m
	AWiFS(3)	80-100 m
ALOS (2003)	VNIR	10 m
	PAN	2.5 m
	SAR(L)	
KOMPSAT (1999)	VNIR	10 m
Resource-01 N4 (1998)	VNIR(3)	25 m
Resource-F2M (1998)	VNIR(4)	6-9 m, photography

System	*Characteristic*	*Spatial resolution*
NIKA-Kuban (2000)	VNIR(1) VNIR(9)	2-4 m, photography 3-5 m, 6-8 m, photography
SICH-1M (1999)	VNIR	45 m
LANDSAT-7 (1998)	VNIR/SWIR(6) TIR PAN	30 m 60 m 15 m, 5 m, 10 m
EOS-AM1 (1998)	VNIR(3) SWIR(6) TIR(5)	1 m 30 m 90 m
EO-1 (1999)-Exp	VNIR/SWIR(9) PAN H	30 m 10 m
LightSAR (2000)	SAR(L)	
TOPSAT (2001)	SAR(L)	

Note: Exp—experimental mission; SWIR—short-wave infrared; VNIR—visible to near-infrared; PAN—panchromatic; SAR(X)—X-band synthetic aperture radar; H—hyperspectral sensor. The number enclosed in brackets ( ) refers to the number of spectral bands.

[a]Launch dates are subject to change. Only missions with at least one major sensor yielding a spatial resolution better than 100 m are mentioned.

Table 4. Recently launched and planned commercial satellite systems

Mission	*Sensor characteristics*[a]	*Special resolution*	*Launch*
Israel Aircraft Industries (IAI)	PAN	1.3 m	-
Orbview-3 (ORBIMAGE)	PAN VNIR(4) H	1 m, 2 m 4 m 8 m	1999
IKONOS-1 (Space Imaging EOSAT)	PAN VNIR(4)	1 m 4 m	1998
IKONOS-2 (Space Imaging EOSAT)	PAN VNIR(4)	1 m 4 m	1998
Quick Bird (Earth Watch)	PAN VNIR(4)	1 m, 2 m 4 m	1998
GDE Systems	PAN	0.8 m	1998
West Indian Space (EROS-A)			1998
Resource 21	VNIR(4) SWIR	10 m 20 m, 100 m	1999

Mission	*Sensor characteristics* [a]	*Special resolution*	*Launch*
ARIES-1	VNIR(32) SWIR(32)	30 m 30 m	2000
EROS-B1 (West Indian Space)			1999
EROS-B2, B3 (West Indian Space)			2000
GEROS I, II (GER Corporation)			2000
GDE Systems			2000
GIBSAT (Kodak)			2000
Resource 21-A, -B (Resource 21)			2000
EROS-B4, -B5 (West Indian Space)			2001
XSTAR A (Matra-Marconi)			2001
OrbView-3B (ORBIMAGE)			2001
GEROS-III, IV (GER Corporation)			2001
Resource 21-C, -D (Resource 21)			2001
EROS-B6 (West Indian Space)			2002
XSTAR-B (Matra-Marconi)			2002
GEROS-V, VI (GER Corporation)			2002
EROS-B6 (West Indian Space)			2003

Note: Exp—experimental mission; SWIR—short-wave infrared; VNIR—visible to near-infrared; PAN—panchromatic; SAR(X)—X-band synthetic aperture radar; H—hyperspectral sensor. The number enclosed in brackets ( ) refers to the number of spectral bands.

[a] Where available, sensor characteristics are shown.

II. REMOTE SENSING APPLICATIONS AND ASSOCIATED BENEFITS

A. Information needs

10. The world's population, currently estimated at approximately 6 billion, is rapidly increasing at a rate of more than 250,000 per day, with much of this growth taking place in developing countries. This growth has placed considerable strain on available resources and has contributed to a number of major environmental problems. Redressing these problems requires better management of the Earth's resources and its environment based on adequate knowledge of the state of the Earth's land and water surface and its atmosphere. Information from satellite remote sensing can contribute significantly to the acquisition of this knowledge and thus to better management of the limited resources.

11. While remote sensing makes a significant contribution to fulfilling information needs, it should be recognized that satellite remote sensing plays a complementary role to other means of spatial data acquisition. Other data

sources, including existing maps, aerial photos, reports, statistical data, historical information and interviews with land holders, should form part of an overall data gathering process. Data collected in the field, from aircraft or from spacecraft, ultimately, are only of benefit if they can assist in the solution of an information need, at a cost appropriate to the user, be it an individual, an institution, a country or an international organization. By understanding its advantages and disadvantages, one is able to develop strategies in which remote sensing contributes notably to the cost-effectiveness of data collection.

12. Among the major information needs for many developing countries are those required to support decision making in several important sectors. These sectors are typically: (a) natural resources (including, agriculture, forestry, mineral, water, and fisheries); (b) the environment; (c) human resources (including education and health services); (d) prevention and mitigation of natural disasters and conflicts; and (e) crime prevention. Successful remote sensing applications have been developed in each of these development sectors, and they confer a number of direct and indirect benefits to society.

B. Distinctive advantages of satellite remote sensing

13. Satellite remote sensing offers several unique advantages over alternate means of data collection, such as airborne and ground surveys, which makes it an ideal tool for fulfilling certain information needs. The advantages generally relate to:

(a) The lower cost of imagery acquisition;

(b) The speed and relative ease with which space-borne imagery could be obtained;

(c) The high frequency of data collection, resulting in current, i.e. up-to-date, information;

(d) The homogeneity of data collection by the use of a single instrument to capture data over large areas;

(e) Improved data coverage, particularly in remote areas and for large regions;

(f) The spatial continuity of observations.

14. The advantages of remote sensing satellites are valid not only for geographically large (e.g. country-wide) areas of interest, as has historically been the case, but also for small areas of several square kilometres, as evidenced by the recent advent of high-resolution commercial remote sensing satellites. These commercial systems are targeted specifically at users requiring information over relatively small areas, for which data acquisition, especially multiple acquisitions, would not be cost-effective using aircraft owing to large fixed costs for undertaking airborne missions. For comparison, it is estimated that, in North America, a satellite ortho-image map derived from 2-m resolution imagery would cost, on average, one half to one third of that derived from aerial photography. In China, a comparative study of aerial survey and satellite remote sensing for mapping an area of 608,000 hectares revealed that the use of satellite remote sensing yielded savings of 55 and 66 per cent in acquisition and labour costs, respectively. In India, the cost for carrying out integrated resources mapping using the satellite remote sensing as opposed to conventional (air photo based) methods results in average savings of 52 per cent. Examples from the agriculture sector in the United Kingdom show cost-benefit ratios of 1:10 by using satellite remote sensing data in operational monitoring programmes.

15. Many of the non-commercial satellite systems routinely acquire imagery of large regions of the Earth. The archived data represent a valuable source of consistent information that permit retrospective (time-series) studies, such as determining the origin of marine pollution or the rate of depletion of a specific resource. Satellite image archives can now be readily consulted from remote locations, thanks to the growth of information systems and the Internet, thereby improving access to users throughout the world. Examples of relevant World Wide Web sites

include the following: Centre for Earth Observation (www.ceo.org); Committee on Earth Observation Satellites (ceos.esrin.esa.it/dossier/); Satellite Active Archive (www.saa.noaa.gov); and European Space Research Institute (http://shark1.esrin.esa.it/informations.html).

16. The digital format of imagery and the synoptic coverage of remote sensing satellites facilitates processing of the imagery into products meeting a variety of needs. Imagery relating to a range of sizes (e.g. a site, a standard map sheet, a state or a whole country) could easily be extracted or created using mosaics. This characteristic allows, for example, the elaboration of value-added GIS-ready products meeting the specific needs of various groups of users from the same set of source images. This encourages economies of scale and competitive pricing and further enhances the cost-effectiveness of satellite data acquisition.

17. It is now widely recognized that many environmental problems are global in scope and cross international boundaries. Decisions for redressing these problems cannot therefore be made in isolation. Satellite remote sensing systems represent the only source of data that can provide an all-encompassing, integrated view that is consistent with the scale of the problems.

18. Operational remote sensing has today evolved to the stage where an end-user could, with comparative ease and at short notice, obtain new or archived imagery of any desired geographic area, within a relatively short period ranging from a few hours to a few weeks. On the other hand, aerial surveys of comparable areas may require several months for implementation.

C. Applications

19. With the wide range of sources of remotely sensed image data, at varying wavelengths and spatial resolutions, the applications of Earth observation systems for natural resources management are varied, as indicated by the following list:

(a) Agriculture, e.g. disease detection, water needs assessment;

(b) Fire and hazards detection and tracking;

(c) Disaster monitoring and relief;

(d) Environmental monitoring, particularly oil spills and pollution;

(e) Coastal resource management and engineering;

(f) Land information, and other urban and regional planning products;

(g) Navigation safety;

(h) Topographic mapping at large scales;

(i) Hydrologic monitoring of urban and other catchment areas;

(j) Placement of facilities, e.g. roads, pipes, power lines and other infrastructure;

(k) Census, tax and property evaluation;

(l) Tourism and recreation;

(m) Business and marketing, including market research and demographics;

(n) Law enforcement, peacekeeping and treaty monitoring.

20. The usefulness of data from Earth observation systems is directly related to the spectral bands used for acquisition. Table 5 lists the wavelengths that are routinely used for the remote sensing of a range of Earth resources, including those that are of particular interest to developing countries such as coastal and freshwater, forestry and agricultural resources. A comparison of these wavelengths with the spectral bands of the sensors on the various existing and planned satellite systems listed in tables 1 to 4 can be used to gauge the usefulness of the satellite systems for a given application. Other considerations include the spatial resolution of the image as well as the frequency with which images can be acquired.

Table 5. Wavelengths in the electromagnetic spectrum routinely used for various remote sensing applications

Wavelength range	*Application related areas*
0.40-0.50 μ m (blue)	Water penetration and water depth
0.50-0.60 μm (green)	Vegetation greenness, ocean colour
0.60-0.70 μm (red)	Chlorophyll absorption in healthy plants, iron oxide content in soils, water sediment load
0.70-0.90 μm (near IR)	Healthy vegetation response, crop monitoring and classification, land/water separation; vegetation and soil separation; separation of built and vegetated surface cover
1.55-1.75 μm (near IR)	Soil moisture content
2.00-2.40 μm (SWIR)	Presence of clay-based minerals
3.00-4.00 μm (mid IR + thermal IR)	Volcanic activity, bush fires, underground fires
9.00-12.50 μm (far IR + thermal IR)	Earth ocean and land temperatures
2.4-3.75 cm (X-band microwave)	Forest canopy shape, crop classification. Ocean roughness, wind speed
3.75-7.5 cm (C-band microwave)	Crown thickness, leaf/branch size and orientation. Plant morphology. Ocean surface roughness, wind speed; oil seeps; surface elevation; land cover; bathymetry; geology; gravity fields; sea-ice and iceberg monitoring
15-30 cm (L-band microwave)	Trunk size and tree density; ocean roughness; soil surface roughness; soil moisture content; forest clearcut areas
30-100 cm (P-band microwave)	Trunk size and tree density; soil moisture content; soil surface penetration and under surface phenomena; snow penetration

21. From a technical operational standpoint, the successful application of remote sensing will depend on several factors including: (a) an understanding of the relative spectral responses of the materials being sensed; (b) an appropriate choice of spectral, spatial and temporal resolutions of the remotely sensed data to be used, taking into consideration the characteristics of the features or phenomenon of interest and the scale of presentation; (c) the acquisition of images at the most opportune time or times when the features of interest are most easily differentiated and therefore amenable to detection; and (d) the use of appropriate interpretation methodologies, including the use of visual and digital approaches and the use of data integration/modelling techniques using GIS.

D. Benefits to society

22. Society benefits considerably from the use of satellite remote sensing. Several examples of beneficial applications are presented in this section. Emphasis is placed on applications whose technical and economic feasibility depend largely on the inherent advantages of satellite remote sensing over alternative means of data collection. Indeed, for certain applications, owing to constraints of time, geographical coverage, costs or the essential

characteristics of the parameters measured, satellites provide the only feasible means of data collection. Applications can generally be categorized into one of the following classes: mapping, monitoring, modelling and measuring. Societal benefits are presented following this categorization.

Mapping

23. Appropriate maps are a necessity for a wide range of planning and development activities. However, in developing regions and even in some industrialized countries, such maps are scarce or outdated, owing partly to the high cost of preparing them using traditional approaches. The increasing availability of satellite remote sensing imagery is modifying the way in which maps are currently prepared and subsequently used. Rather than manually extracting thematic data from air photos and presenting these as maps, the imagery itself is ortho-rectified, annotated and used as maps. Such maps provide more information content and are more readily understood by a wider variety of end-users, of differing levels of formal education. They are being used increasingly as an effective, unfiltered tool for communication between various parties in natural resource and environmental projects, particularly those where rural communities in developing countries are involved. The high positional accuracy of ortho-rectified maps derived from high-resolution remote sensing satellites makes these maps a cost-effective alternative to field surveys, especially in remote and inaccessible areas in which ground surveying or aerial surveying could prove very difficult.

24. Land reform is being undertaken in a number of countries throughout the world, including those where economies are in transition to a free-market system. Private ownership of land is a major driving factor in national economies and a significant factor in sustainable development. The need to respond rapidly to the huge demand for land titles at affordable costs is being fulfilled through the use of novel, inexpensive approaches to cadastral mapping involving the use of high-resolution satellite imagery and land-based surveys.

25. The wide perspective of satellite images has allowed geologists to map quite readily subtle regional geological features (such as faults, lineaments, geomorphological or lithological contacts), which would not otherwise be easily observed from the ground, owing to lack of surface expression, but which can be recognized on small-scale imagery. The mapping of such features facilitates the exploration for minerals as well as for groundwater, both of which are often key target resources for development.

26. Topographic data, a frequent input in many planning and engineering studies, can be derived from either stereo optical or radar images. Digital elevation models are generated from satellite radar imagery using interferometry or radargrammetry techniques. The high precision of these models allows their use in monitoring hazards that are preceded by ground movements, such as volcanoes, earthquakes and landslides.

27. In regions of the world where almost permanent cloud cover prevents the acquisition of conventional optical satellite images, radar imagery is being used to create updated maps at a 1:200,000 scale with acceptable levels of positional accuracy. This has been achieved using block triangulation and precision orbital data, without the need for local ground surveys.

28. In agriculture, remote sensing (from optical as well as radar satellites) is used to supplement conventional sources of information in determining agricultural statistics at the national as well as regional levels. Low to high spatial resolution optical imagery from a number of dates during the growing season as well as radar imagery are used in the identification of crops. Radar imagery is particularly useful in areas such as the humid tropics and northern Europe, where frequent cloud cover may obscure the land surface. Satellite imagery in conjunction with limited ground sampling is routinely used to identify and measure crop area as well as areas of arable land in countries comprising the European Union under its common agricultural policy programme. This activity is undertaken to support the administration of area-based subsidies to farmers. Some 3 million crop declarations are made each year, and their accuracy needs to be checked before the crops are harvested. Approximately 5 per cent of the individual declarations are systematically checked using information from either satellite remote sensing or

aerial photography, or both in combination. Similar programmes for measuring areas under cultivation and predicting crop yields exist in several other countries, such as China, India, Morocco and Senegal.

29. Maps developed from satellite remote sensing are used to support sustainable development. In India, for example, satellite-derived maps of natural resources, in conjunction with collateral data on socio-economic, cultural, demographic and meteorological aspects, are used to map unique land units for which specific sustainable development plans (e.g. allowable land use practices and conservation measures) are elaborated.

30. Some agricultural activities have a significant impact on the concentration of greenhouse gases and contribute to global warming. Satellite remote sensing is playing an invaluable role in mapping wet-land rice fields and consequently determining the extent to which they are contributing methane gases to the atmosphere.

Monitoring

31. The frequency of overhead passes of a satellite over a given location combined with the capability of many sensors to view off-nadir positions facilitate a variety of monitoring activities over land as well as sea. Targets of interest are usually phenomena or features that change over time.

32. A key factor in sustainable development is knowledge of the rate at which an existing resource is being depleted so that appropriate management strategies can be formulated. The frequent coverage of remote sensing satellites facilitates this goal by providing time-series information on a variety of important resources including vegetation (forests, rangelands), soils and surface water sources. In forestry, for example, remote sensing information facilitates the monitoring of areas of deforestation, afforestation, biomass volume, disease, insect infestations and forest fires. Such monitoring allows Governments to assess quickly the impact of various policies and institute changes, as necessary. Satellite images of many regions of the world dating back to 1972 (or earlier, in the case of images gathered for military intelligence purposes) exist in the archives of the various satellite operators or related agencies. These data represent a consistent and valuable resource for studies requiring the analysis of widespread regional changes over time, e.g., deforestation, coastal erosion and lake level variations.

33. Sea surface temperature and colour have been correlated with zones where fish productivity is highest. Ocean colour information is regularly used to track marine areas where phytoplankton-rich waters or relatively cold “upwellings” occur. This information is transmitted in near real-time to fishing fleets for exploitation, thereby increasing their profitability. Unfortunately, many local fishing boats in developing countries are not large enough or suitably equipped to take advantage of this capability. Historical ocean-colour information also allows identification of regions that are at high risk of degradation owing to pollution and that therefore require protection. Remote sensing data are also useful for identifying algal blooms and coastal fishing grounds that are threatened by pollution from land-based sources or by destruction of spawning grounds, e.g. wetlands. Routine acquisition of satellite imagery of areas of the world that are at risk owing to high levels of marine traffic are helpful in detecting pollution plumes and in analysing their trajectories. The data are also useful for evaluating the impact of pollution on the marine as well as near-shore environments. In some countries, such as Indonesia, satellite remote sensing data are being routinely used for monitoring the growth of coral reefs as well as for assessing marine fish stocks.

34. During emergencies, such as earthquakes, hurricanes and extensive floods, the ready availability of up-to-date imagery allows emergency response agencies to know the areas of greatest damage and need, thereby permitting the planning and subsequent implementation of effective relief measures. This information is also used by insurance companies to settle claims for damages caused to homes or to crops rapidly. In the case of weather-related disasters, satellite meteorology is used to develop a better understanding of weather systems leading to improved disaster warnings. Satellite remote sensing facilitates the regular monitoring of the extents of annual floods, and the mapping of zones at risk to floods, as well as the formulation of appropriate measures for reducing vulnerability to flood hazards. Usually, ground-based synoptic observation networks for monitoring the weather

are inadequate, generally owing to a low density of observation points. Space-based platforms, on the other hand, provide wide spatial coverage over land as well as marine areas and are not limited by factors that normally hinder access by ground-based surveys.

35. Inexpensive ground stations for receiving weather information from polar-orbiting and geostationary satellites are now affordable by most developing countries. In some developing countries, the imagery has allowed the identification of areas that will be affected by cyclones and facilitated the issuing of warning messages. In this manner, remote sensing has helped to save many lives by providing warnings and allowing the timely evacuation of people and livestock. Warnings issued sufficiently in advance allow other specific remedial measures such as the recall of fishing boats to harbour, the advanced harvesting of crops and the protection of reservoirs. Other benefits from satellite meteorological observations include improved aviation safety and efficiency and better detection of dust storms and sandstorms, as well as of volcanic ash plumes.

36. Monitoring of crops on individual farms using high-resolution imagery helps to identify areas that are under stress owing to lack of water, are in need of fertilizers or are affected by diseases, long before the plants begin to show visible evidence. This facilitates the optimal distribution of water, thereby enabling savings as well as improving crop yields. It also avoids the excessive application of fertilizer with its potentially deleterious effects on the environment.

37. Ready access to Earth observations is already creating new opportunities for greater social and political openness among countries. Government officials can legally purchase information that can contribute to timely decisions leading to greater security. Examples are information relating to major environmental trends in neighbouring countries or disputed territories. The remote sensing information serves as an impartial medium for discussing potentially contentious issues.

Modelling (forecasting)

38. Most satellite remote sensing data are readily available in digital format. Numerous classification algorithms have been developed to transform the digital data automatically into useful thematic information. This transformation simplifies the incorporation of remotely sensed information into GIS. GIS are now in widespread use, not only as a database for the storage and retrieval of spatial information but also as an interactive management tool for analysing alternative strategies for resource allocation. GIS software now supports a variety of modelling approaches for forecasting outcomes based on the information provided in a spatial database. For certain applications, the spatial database may consist of time-series information derived mainly from remote sensing satellites.

39. Multi-date satellite imagery (both optical and radar) of crops at different phenological stages is used in conjunction with other information, such as meteorological and soil data, to develop models for forecasting production several weeks before harvesting. This application can be of considerable value in developing countries that lack reliable agricultural surveys. Forecasts are useful in setting prices, providing vital inputs for crop insurance and making timely arrangements for the storage, importation, exportation and efficient local distribution of agricultural produce. Low production forecasts (e.g. as a result of drought conditions) would allow time for appropriate remedial measures to be implemented. Such is the basis for programs such as the famine early warning system (FEWS) being applied to a number of developing countries in Africa.

40. Data furnished by regular monitoring of sea surface temperature and elevation by Earth observation satellites are used to forecast the onset of the El Niño phenomenon in the Pacific Ocean. This phenomenon is associated with abnormal weather conditions in America, Asia and Africa. El Niño forecasts are beneficial in that potentially adverse impacts on human activities, such as reduced agricultural production, can be anticipated.

41. Remote sensing data in combination with other information in GIS are used to analyse the associations, in time as well as in space, between the patterns of landscape elements that are critical to disease transmission and the spatial distribution of infectious diseases, both emerging and re-emerging. These analyses allow the development of remotely sensed predictors of disease risk that can be applied to larger regions where field data are unavailable. Examples of some recent applications include the identification of high anopheline mosquito-producing rice fields in California; the prediction of the abundance of mosquitoes in several villages in Chiapas, Mexico; the measurement of the exposure to risk to Lyme disease in the United States; and studies of cholera in Bangladesh, Leishmaniasis in Brazil, vector-borne diseases in south-eastern Turkey, and equine encephalitis in Venezuela.

42. Satellite imagery showing the areal extents of snow are used as input to hydrological models to predict run-off from snow melt. This allows better irrigation management of cultivated areas located downstream of catchment areas.

43. Historical wave and wind information collected by ERS satellites are being used in sea state forecasting and "hindcasting" applications. Hindcasting is used to confirm ocean and weather conditions at particular locations and at specific times. The information obtained is used by insurance companies in conducting risk analysis and in settling claims. Radar satellites also permit improved sea-ice and iceberg monitoring for offshore activities and ship routing in polar regions. Databases containing historical observations of sea-ice conditions permit the establishment of design parameters for ships and offshore platforms and the selection of optimum shipping routes.

44. A rising demand worldwide for potable (drinking) water owing to increasing population and generally higher levels of water use has heightened the need for water resources assessment and management. Remote sensing satellites provide data on several key hydrological variables (e.g. rainfall, soil moisture, evaporation and snowfall) at a scale that is appropriate for this assessment. Satellite systems that are useful for water resources assessment include polar-orbiting (e.g. NOAA series, the Tropical Rainfall Measuring Mission (TRMM)) and geostationary (e.g. METEOSAT, GMS, GOES) primarily meteorological satellites. In addition, radar satellite systems (see table 2), from which information on soil moisture can be obtained, and optical systems (see table 3), which yield information useful for run-off and hydrological modelling, are indispensable for proper assessment. This satellite-based approach to water resources assessment is especially important in regions of the world where adequate hydro-climatological networks do not exist.

45. The forecasting of droughts is greatly assisted by information on past and current drought conditions. Droughts tend to affect large areas at a time, and monitoring should be carried out at an appropriate scale. Generally it is not necessary to monitor droughts at high spatial resolution, but it is important to observe their impact on a regular basis. An appropriate system to monitor droughts is NOAA-AVHRR, which has the appropriate spectral bands and the capacity to monitor vast areas on a daily basis. The onset of drought conditions in a given year can be predicted by comparative analysis of the trend in satellite-derived vegetation indices for that year relative to the trend in a normal year. This warning capability has allowed authorities in some developing countries, where annual rainfall is highly variable, to mitigate the effects of droughts through an appropriate redistribution of food supplies for humans and fodder for livestock. The Food and Agriculture Organization of the United Nations (FAO) "Artemis" early-warning system for Africa, is based on this capability and involves the use of vegetation indices and cloud-cover duration parameters, both of which are derived from remote sensing satellites. The cost of reception and use of NOAA data is low. Thus, for some developing countries, this application may well represent a low-cost means of developing local expertise in the use of Earth observation systems for resource management.

Measuring (detection)

46. The multi-spectral nature of most satellite images allows the identification and discrimination of a wide variety of surface features as a consequence of their distinctive responses over different regions of the electromagnetic spectrum (ranging usually from the visible to near-infrared, short-wave infrared, middle infrared, thermal infrared and microwave regions). This capability is responsible for the detection of various targets of interest in natural resource management, such as water bodies, wetlands, oil spills, algal blooms, discharges of heated water from power plants, geological alteration products that are indicative of mineralization, iron oxides that are responsible for acid run-off from mines, tree diseases and zones of salinization in agricultural fields. Airborne surveys could also be used in these applications; however, the costs of collecting data of comparable quality would be considerably higher.

47. Airborne sensors with a far larger number of spectral bands than the maximum currently available seven bands on a space-borne platform (LANDSAT 5) have been developed for some time now. However, the radiometric resolution of sensors on board satellites is improving. The EO-1 spacecraft, scheduled for launch in 1999 (see table 3), will carry two experimental sensors having 233 and 309 narrow spectral bands covering the 0.4-2.5 micrometer spectral range and a spatial resolution of 30 m. The ill-fated Lewis spacecraft, launched in August 1997, carried a hyperspectral sensor with a capability to acquire images over 384 bands. Hyperspectral imagery would allow, for example, not only the detection but also the estimation of the magnitude and cause of vegetation stress in an agricultural crop. Stress can be due to a variety of factors, including insufficient or excess fertilizer or inadequate water.

48. In addition to increased radiometric resolution, sensors of increasingly greater dynamic range are being developed. This permits greater contrast enhancement and hence better capability to derive information from imaged areas, especially if these are acquired under low-light conditions. At least one proposed commercial system will have a dynamic range of 11-bits (2048 levels) as opposed to the 8-bits (256 levels) of most of today's Earth resource satellites.

III. INTERNATIONAL COOPERATION

A. Global environmental programmes

49. There is now a general heightened awareness of the global influence of human actions on the habitability of the Earth and the need to enact appropriate measures to address complex, interlinked global problems related to human activity. The problems of greatest concern highlight the need to manage the Earth's resources and environment in a sustainable manner. These problems relate, among others, to: (a) stratospheric ozone depletion; (b) deforestation; (c) destruction of fisheries; (d) land degradation and desertification; (e) spread of disease and pests; (f) decreasing biodiversity; (g) inadequate access to fresh water; and (h) global warming of the Earth arising from the use of fossil fuels with its attendant problems (e.g. rises in pollution and sea level, increased evaporation and changing patterns of precipitation leading to increased risks of flooding and droughts).

50. Several international agreements, monitoring and research programmes, as well as global observing systems relating to the global environment, now exist. The agreements include, for example, the Montreal Protocol on Substances that Deplete the Ozone Layer, concluded at Montreal on 16 September 1987, the Rio Declaration on Environment and Development, 1992,[2] the Convention on Biological Diversity, 1992,[3] the Non-Legally Binding Authoritative Statement of Principles for a Global Consensus on the Management, Conservation and Sustainable Development of All Types of Forests, 1992,[4] the United Nations Framework Convention on Climate Change, 1994 (A/AC.237/18 (Part II)/Add.1 and Corr.1, annex I) and the United Nations Convention to Combat Desertification in those Countries Experiencing Serious Drought and/or Desertification, particularly in Africa, 1994 (A/49/84/Add.2, annex, appendix II). International monitoring and research programmes include the Earth Science Enterprise (ESE), the International Geosphere-Biosphere Programme (IGBP), the World Climate Research Programme (WCRP), DIVERSITAS and the International Human Dimensions Programme on Global Environmental Change (IHDP) and focus on diverse aspects of the global environment. The acquisition of

remotely sensed information is critical to the successful execution of these programmes. Three global observation systems, comprising both ground-based and remote measurements, that facilitate the collection and sharing of global data sets have recently been developed: the Global Climate Observing System (GCOS) initiated the United Nations Environment Programme (UNEP), the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (IOC/UNESCO), the World Meteorological Organization (WMO) and the International Council of Scientific Unions (ICSU); the Global Ocean Observing System (GOOS) being developed by UNEP, IOC/UNESCO, WMO and ICSU; and the Global Terrestrial Observing System (GTOS) developed by UNEP, FAO, UNESCO, WMO and ICSU.[5]

B. Education, training and technology transfer

51. Several countries have bilateral arrangements that provide limited training, education and technology transfer opportunities for developing countries in satellite remote sensing technology. Education and training opportunities in the form of fellowships, workshops, conferences, expert meetings and short training courses are also regularly provided to participants from developing countries by various space agencies, professional scientific societies, universities (including the International Space University), regional commissions of the United Nations, as well as by the Office for Outer Space Affairs through its Programme on Space Applications. This Programme is financially supported by Member States, which host the events, and by various co-sponsors including government-aided and private-sector organizations involved in space-related activities.

52. Several regional centres for space science and technology education are being established throughout the developing world with the aid of the Office for Outer Space Affairs. The first of these centres, established in India in 1996, serves countries in Asia and the Pacific. Efforts are under way to establish similar regional centres in Africa, Latin America, eastern Europe and western Asia. Apart from the fostering of South-South cooperation, these centres contribute to the building of local expertise and ultimately to the success of technology-transfer programmes.

C. International coordination of Earth observations

53. In light of the increasing number of satellites and the need to fulfil the information needs of end-users, improved coordination of Earth observation satellites has become necessary. The Integrated Global Observing Strategy (IGOS) initiative being developed by the Committee on Earth Observation Satellites (CEOS) specifically aims at providing an integrating framework for space-based and ground-based observations needed to support the requirements of international global observing systems (e.g. GCOS, GOOS, GTOS), as well as global and regional research programmes.

D. International data access

54. Adequate access to the data needed to tackle global environmental problems is a necessity for the global scientific community. Several international programmes have established Internet-based information systems that allow users throughout the world to gain access to data. These systems now include the Earth Observing System—Data and Information System (EOS—DIS), the Global Land Information System (GLIS), the European Earth Observation System (EEOS), the Earth Observation Data and Information System (EOIS), the Global Environmental Information Locator Service (GELOS) and the International Directory Network of CEOS (CEOS—IDN). National space and remote sensing agencies are developing their own interoperable networks (e.g. CEONet in Canada) to provide access to domestic and international data from several sources. Effective access to these information systems is dependent on having adequate telecommunications links to the Internet.

IV. SELECTED ISSUES OF INTEREST TO MEMBER STATES

A. Effective transfer of operational technologies

55. There are a number of obstacles to the use of data from Earth observation systems, particularly in developing countries. These are the cost of data purchase, the cost of data acquisition facilities, the cost of data-processing facilities, the limited number of appropriately trained staff at the technician, professional, project management and research level, the lack of knowledge of potential users and the inflexibility of existing resource managers. As a consequence, only a few developing countries are currently making optimum use of data from Earth observation systems. It is considered that the lack of appropriate mechanisms for technology transfer is a major factor limiting the use of these data. While there are many instances of equipment, sensors and image analysis systems being directly transferred, the transfer concept must also include the concept of absorption of the technology on the part of the receiving country.

56. For technology transfer to be effective, education and training are required at a number of levels to produce the full spectrum of activities ranging from research to technical support. While the number of staff required for research is relatively small compared to technician-level support, the need for developing countries to develop a local, autonomous basic research capability rapidly cannot be over-emphasized. Such a capability promotes creative thinking and enhances the indigenous ability to adapt, modify and create new techniques that contribute to national development. For optimum research development it may be appropriate to consider the establishment of focal research centres, attached to universities where a "threshold concentration" of scientists and technologists can operate in a catalytic manner to maximize the return of research and development expenditure.

57. To date, little effort has been directed by countries at determining their human resources needs and the required educational programmes they need to develop. Education and training have been piecemeal, undertaken as part of a variety of projects sponsored by various aid, bank, bilateral or multilateral agencies. In the main this training has been directed to the professional class, usually with emphasis on specific applications. Without research or technical support, the transferred technology eventually wilts, and these well-trained professional staff seek alternative career paths or leave the country.

58. Equipment for the transfer of expertise in the various applications of remote sensing technology are no longer expensive. However, successful transfer cannot take place without adequate funds. Because of this, many developing countries have had to rely on a range of bilateral and multilateral sources for funding and other support. However, the activities generated by these groups are in the main uncoordinated, leading to many cases of inefficient overlap of similar projects and programmes. In addition, and importantly, areas targeted by these agencies do not necessarily cover the full remote sensing needs of the country or may have low priority. Thus, while international funding is desirable and indeed necessary, much greater effort by each country should be directed to determining their own specific needs and to better coordinating activities through national committees. Each country must assess its funding requirements and determine the merits of each funding opportunity on the basis of national needs. Great care should be taken with funding proposals that impose specific equipment and methodologies on the user country. In the long term, these may lead to costly maintenance, restriction of opportunities and inappropriate technology transfer.

B. Data access

59. It is critical to the development of indigenous capabilities in remote sensing that countries have access to data from Earth observation systems. While this can be achieved through the establishment of a national receiving facility and an appropriate data distribution mechanism, such a facility may not be affordable or even appropriate for all countries. Of far greater importance to many countries are the ways in which they can cost-effectively access the data that they need.

60. The advent of fully commercial remote sensing data providers augurs well for the increased availability of data that would meet a wide range of needs. However, users in some developing countries are unlikely to afford commercial rates.

61. The data policies of government-supported remote sensing systems vary considerably. Key opposing factors that influence pricing policies are the affordability of the data on the one hand and the sustainability of Earth observation programmes on the other. Making the data available freely or at a low cost is only sustainable with continuous government funding. Leaving the availability entirely to market-driven forces or providing data at the true cost would exclude users with low budgets. Other pricing schemes, such as a two-tiered system or pricing based on the value of the information derived from the Earth observation data, have been proposed. The ideal solution appears to be one in which there are high-volume sales at low unit prices. This would provide cheap data for users as well as high revenues for data suppliers, thereby allowing them to continue their Earth observation programmes. The policies and mechanisms for progressively attaining this objective need to be developed.

C. Development of operational remote sensing services

62. While there has been significant growth in the volume of Earth observation data, there has not been a comparable growth in the applications of the data, particularly in the operational and commercial domains. Even industrialized countries have found it necessary to set up national programmes to stimulate the development of applications. The exploitation of space is therefore not only a function of technical capability to process data and to produce a product. At present, most of the activities in Earth observations are limited to the development of technical capabilities to acquire and process Earth observation data and the carrying out of demonstration studies. However, to be effective, the promotion of space technology must involve greater investments in the subsequent stages of application development, namely, the implementation of pilot services, followed by pre-operational services that are adjusted to meet user requirements and, finally, continuous operational services that are fully integrated into the user environment.

63. A primary challenge in ensuring greater use of remote sensing information is the development of new ways to use available data more effectively and for a wider set of applications. This will require the development of new software for analysis, visualization and display. It will also require a renewed effort to provide training for communities of potential data users.

D. Local development of appropriate space programmes

64. Many barriers to the greater use of remote sensing information exist in some developing countries, and appropriate mechanisms must be found for overcoming them. Some of the activities that would contribute to the local development of space programmes and that present opportunities for international cooperation are: (a) the building of local awareness of space technology and its benefits; (b) the strengthening of training and technology transfer programmes, including the sharing of experiences among developing countries; (c) the development of appropriate national regulatory frameworks and policies in space-related matters; (d) the development of the local private remote sensing sector; (e) the establishment of national points of contact for promoting remote sensing in a manner consistent with real needs; (f) the promotion of remote sensing in academic institutions and the provision of more opportunities for both short- and long-term training and education;* and (g) the recognition by Governments of space technologies as a priority measure for meeting national development needs.

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*The benefits that a country can reap from satellite remote sensing can roughly be gauged from the number of professionals engaged in mapping and surveying activities. A comparison shows that mapping professionals in developing countries are under represented, often by a factor greater than 7, relative to their numbers in industrialized countries of equal size and population density.

Notes

[1]Spatial resolutions are classified as follows: very low ≥300 m; low ≥30 <300 m; medium ≥3 <30 m; high ≥0.5 <3 m; very high <0.5 m.

[2]*Report of the United Nations Conference on Environment and Development, Rio de Janeiro, 3-14 June 1992* (United Nations publication, Sales No. E.93.I.8 and corrigenda), vol. I: *Resolutions Adopted by the Conference*, resolution I, annex I.

[3] See United Nations Environment programme, *Convention on Biological Diversity* (Environmental Law and Institutions Programme Activity Centre), June 1992.

[4]*Report of the United Nations Conference on Environment and Development* ..., annex III.

[5]See also background paper 1 on the Earth and its environment in space (A/CONF.184/BP/1).