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# Monitoring environmental treaties using earth observation

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Earth observation has become a common good since 1972, when the first Landsat satellite was launched. In the 1970s only a handful of satellites were in orbit. Today, more than 60 are continuously monitoring the state of the earth, including the atmosphere and land and ocean surfaces. Over the next 15 years, approximately 150 earth observation satellites with over 300 different instruments will be in orbit. While the first decades of remote sensing were characterised by scientific exploitation, the past decade has shown increased use of space-derived information for global environmental monitoring.

Rapid advances in satellite technology, an increase in the number of available sensors taking more frequent measurements and an increased awareness of the need for global environmental observation have progressively introduced space technology to the environment community. This is not without reason. Information derived from space has a number of distinct advantages over conventional, ground-based measurements:

- Satellite-derived information is *comparable.* The same instrument takes measurements of the whole globe, allowing data to be compared between different geographic areas and times of acquisition.
- Satellite measurements are taken *remotely.* Satellite operators do not need the consent of a country or a party to a treaty to monitor a particular area.
- Satellite measurements are *verifiable.* Raw satellite data can be reprocessed by independent parties from commonly accessible data archives.
- Satellite measurements are *continuous.* Their global nature and long-term operation help close measurement gaps in space and time, providing a more integrated picture of the state of the earth's environment.

These characteristics make satellite measurements an indispensable information source in many cases. However, to exploit their potential they are usually integrated with in situ measurements, climate models, socio-economic data and other relevant information. Geographic information systems and communication, navigation and other information technology are commonly used to add value to earth observation data and convert it into information of relevance to decision makers.

## Taking satellite measurements

A great variety of satellite sensors exist today, designed to take measurements of different 'windows' of the electromagnetic radiation spectrum. Generally, there are two modes of operation for sensors: passive and active.

*Passive sensors* measure the energy of radiation arriving at the satellite sensor. This radiation may be emitted from the sun and reflected back to the satellite off the earth's atmosphere, land or ocean surface. Alternatively, the radiation may have been directly emitted from the earth environment: the latter is commonly referred to as thermal radiation and allows temperature to be measured. While the human eye is sensitive to only a very narrow part of the electromagnetic spectrum (wavelengths from 0.3 to 0.75 microns), satellite sensors measure across a far wider range, from ultraviolet (wavelengths<0.3 microns) to microwave (wavelengths of millimetres to metres), thus spanning several magnitudes of wavelengths.

Sunlight reflected off the earth environment allows the measurement of albedo—the ratio of reflected to incoming radiation, a parameter that can be related to the geophysical characteristics of the object observed. Healthy vegetation, for example, has a high albedo in the near-infrared part of the spectrum (i.e., at wavelengths of *c.* 1 micron) but a much lower value in the visible part of the spectrum. Within the visible part of the spectrum (0.3–0.75 micron), higher values of albedo are around 0.5 micron, which corresponds to green colour, thus giving healthy vegetation a green appearance. Most satellite sensors measure in many narrow windows of the electromagnetic spectrum to increase the number of information channels.

*Active sensors* are instruments that emit electromagnetic radiation and measure the amount scattered back to the satellite sensor. The most commonly used active sensors are radars working in the microwave region of the spectrum (for example, L, C, X bands) as these are able to penetrate clouds and even rain.

In the scientific literature, satellite sensors are also categorised according to the window of the electromagnetic spectrum in which they take measurements. So-called optical sensors measure in the visible (wavelengths=0.3–0.75 microns) and near- and mid-infrared (IR) (wavelengths=0.75–2 microns) part of the spectrum; thermal IR (wavelengths=~10–12 microns) sensors measure the temperature of objects; and microwave sensors (wavelengths=millimetres to metres) measure either emitted energy in a passive mode or backscattered energy if they work actively.

The resolution or geometric measurement quality of satellite sensors has improved hugely over the past 30 years. The first sensors had resolutions in the order of 100 x 100 square metres, while today's civilian satellites measure objects smaller than 1 x 1 metre. Military sensors have even better resolutions, although the data they gather are not publicly available. Generally, many of the environmental applications of interest to treaty verification deal with phenomena that are relatively large (such as forest and agricultural areas) and global in scale. For both reasons, resolutions only need to be in the order of several tens of metres up to hundreds of metres.

An important issue is the *accuracy* of the classification of land-cover type, which depends on the number of satellite images available, their quality, and the number and diversity of land-cover types being observed. Typically, the accuracy of a satellite-derived land-use map is in the order of 90 percent or higher, that is, at least 90 percent of the area is correctly mapped. This is considered adequate for most cases and compares well with other methods of observation, such as ground observations, which are normally less accurate.

Higher accuracies may be obtained from aerial photography. However, this method presents significant drawbacks because the image analysis process is more complex. Aerial photography is mostly limited to visual interpretation methods and is therefore subject to the interpreter's skills. Satellite data are mostly analysed using digital processing techniques. Recent developments, such as fuzzy logic, neural network and pattern-recognition techniques, as well as the use of multi-temporal images, have significantly improved the accuracy of satellite-derived land-use maps. This has made such products an everyday information source for many applications, for example, providing information on vegetation type and health, forest cover, vegetation fires, agricultural crops and built-up areas. It is also possible to identify geological parameters for three-dimensional terrain models and to measure temperature, salinity, wave heights of ocean surfaces, the extent of ice and snow cover, or the concentration of atmospheric trace gases, to name just a few types of information. Only some of these parameters are relevant to environmental treaties.

Obviously, earth observation also has its limitations. These fall mainly into two categories: the limitations of technology; and the availability of data. In addition, there are obstacles at the institutional and policy level; these are dealt with briefly at the end of this chapter.

*Limitations in technology* result mostly from the fact that satellite measurements are taken indirectly. For example, a forester may want to determine the biomass of a tree, while the satellite provides a measurement of the albedo of the tree, including its leaves and branches. Biophysical models, multiple measurements in different wavelength spectra and multi-temporal observations are needed in order to extract the parameter the forester wants.

*Limitations in data availability* are set by a satellite's orbit configuration and its sensor characteristics. Commonly used polar-orbiting satellites circle the earth approximately 14 times per day, taking measurements over a strip several tens to hundreds of kilometres wide. Typically, a spot on the earth's surface is revisited every two days or so by the same satellite. This may be sufficient for most environmental or climate studies, but may cause problems where measurements need to be available at a given time, as in the case of natural disasters.

Enormous progress has been made, and continues to be made, in satellite sensor technology. Integration of measurements from different sensors is helping to close the observation gap. Furthermore, the new concept of satellite constellations allows more frequent observations using a fleet of identical, or easily comparable, satellites.

For multilateral environmental treaties, the time-frame for observations is normally in the order of months, years or even decades. The frequency of measurements is therefore, in most cases, not a limiting factor.

## Earth observation for multilateral environmental agreements

The first multilateral environmental agreement (MEA) dates back over a century,[1] although widespread public awareness of 'the environment' only dates back to the 1960s and 1970s. Since the UN Conference on the Human Environment, held in Stockholm, Sweden, in 1972, the number of MEAs has grown considerably—from

140 in 1970[2] to over 240 today.[3] Among these are the three Rio conventions—the 1992 United Nations Framework Convention on Climate Change (UNFCCC), the 1994 Convention to Combat Desertification and the 1992 Convention on Biological Diversity. Many governments established environment ministries and environment protection agencies in the 1970s and 1980s.

At the World Summit on Sustainable Development (WSSD), held in Johannesburg, South Africa, from 26 August to 4 September 2002, heads of state and government adopted the Johannesburg Declaration, which identifies environmental and development goals for the coming century. These will be particularly challenging because of the expected 50 percent increase in global population over the next 50 years. The Johannesburg Declaration's supporting Plan of Implementation[4] has identified satellite earth observation as a crucial information source for a number of disciplines relevant to sustainable development. Earth observation is specifically mentioned as a key decision-making tool for better management of water resources, natural disaster monitoring, conflict management, climate monitoring (including El Niño/La Niña forecasts) and desertification monitoring. The 54-page Plan of Implementation contains 12 specific paragraphs referring to the need for earth observation for sustainable development. Article 36 of the Plan of Implementation states that:

> The United Nations Framework Convention on Climate Change is the key instrument for addressing climate change, a global concern, and we reaffirm our commitment to achieving its ultimate objective of stabilisation of greenhouse gas concentrations in the atmosphere . . . Actions at all levels are required to: . . . (g) Promote the systematic observation of the earth's atmosphere, land and oceans by improving monitoring stations, increasing the use of satellites, and appropriate integration of these observations . . .

Table 1 lists the principal MEAS, as well as the Rio and Johannesburg conference final declaration goals, for which earth observation is playing or could potentially play a key role in monitoring and verification.

Most of these agreements require, directly or indirectly, continuous monitoring of a number of parameters of the land surface, the oceans and the atmosphere. An example is the UNFCCC and its 1997 Kyoto Protocol, whose parties will report on specific parameters to be used for assessing their compliance.

## Table 1 Earth observation in MEA monitoring and verification

### World Summit on Sustainable Development (WSSD), 2002

The Johannesburg Political Declaration and supporting Plan of Implementation commit all governments to ensuring sustainability. Main issues are eradication of poverty, access to clean water, sanitation, energy, health, trade and agriculture.

**Parameters measurable from space for verification purposes:** includes land use and land cover (desertification, drought, water resources, urban sprawl, environmental degradation); climate change (such as El Niño, atmospheric trace gases, global warming, ocean temperature and circulation, ice extent and melting); disaster (floods, forest fires, earthquake damage); food production.

### Agenda 21 and UN Commission for Sustainable Development, 1992

Blueprint for sustainable development in the 21st century.

**Parameters measurable from space for verification purposes:** as for WSSD.

### UN Framework Convention on Climate Change (UNFCCC), 1992

Provides for future action to regulate greenhouse gases (GHGs) in the atmosphere. 1997 Kyoto Protocol commits parties to legally binding targets to limit GHG emissions.

**Parameters measurable from space for verification purposes:** land use, land cover and forestry (LULUCF); afforestation, reforestation and deforestation (ARD); climate change (as for WSSD).

### UN Convention to Combat Desertification (CCD), 1992

Aims to combat desertification and mitigate effects of drought through long-term integrated strategies.

**Parameters measurable from space for verification purposes:** desertification, drought; vegetation cover and stress.

### United Nations Convention on Biological Diversity (CBD), 1992

Aims to conserve biological diversity, promote sustainable use of its components and encourage equitable sharing of benefits from utilising genetic resources.

**Parameters measurable from space for verification purposes:** vegetation; wetlands; land use and land cover.

### Montreal Protocol and Vienna Convention on Protection of the Ozone Layer, 1987

The Protocol sets out legal obligations in the form of timetables for progressive reduction and/or elimination of production and consumption of certain ozone-depleting substances.

**Parameters measurable from space for verification purposes:** atmospheric ozone concentration; concentration of other atmospheric trace gases critical to ozone formation/destruction.

### UN Convention on the Law of the Sea, 1982

Establishes a comprehensive legal regime for the sea and oceans with rules for environmental standards.

**Parameters measurable from space for verification purposes:** oil slicks; marine pollution and algae blooms.

### Convention on Long-Range Transboundary Air Pollution (CLRTAP), 1979

Aims to limit, gradually reduce and prevent air pollution, including long-range transboundary pollution.

**Parameters measurable from space for verification purposes:** concentrations of atmospheric trace gases (such as $CO_2$, $NO_x$, $CH_4$, water vapour); impact of pollution on vegetation.

### International Convention for the Prevention of Pollution from Ships (MARPOL), 1973

Aims to eliminate pollution of the sea by oil, chemical and other harmful discharges from ships.

**Parameters measurable from space for verification purposes:** oil slicks.

## Access to earth observation data

The use of space-based earth observation systems is firmly anchored in international space law, as well as national law, customary law and the application of equity principles. The first, and most important, of these is the 1967 Outer Space Treaty,[5] which determines that there is freedom of scientific investigation in space for governmental, intergovernmental and non-governmental entities. All nations have the non-exclusive right to use space. Earth observation systems have been accepted as legal users of space since the early 1970s.

The Principles Relating to Remote Sensing of the Earth from Outer Space, adopted in UN General Assembly Resolution 41/65 in 1986,[6] define the general purpose of space-based earth observation and regulate the rights and duties of states conducting or being sensed by earth observation. According to the principles, the sensed state has access to primary and processed data acquired by any other state on a non-discriminatory basis and at reasonable cost. Although the UN resolution is not a treaty, the principles have achieved the status of customary international law and have been incorporated in the domestic law of some nations, as well as in many earth observation missions and agreements.

Earth observation data are generally available to everyone. The only exception is when the national security of a country may be at risk. Some governments choose to exercise the right to withhold access to such data with 'shutter control' agreements, which allow them to stop the acquisition or distribution of satellite data over certain areas. However, these instances are generally limited to war zones during time of war.

Each data provider has its own data policy, and there is no standard pricing policy for earth observation data. Generally, data for research or other non-commercial use are available at very low cost (perhaps just the cost of reproduction, or the cost of data storage, which may be in the order of only tens or hundreds of euros for a 10,000-square kilometre ($km^2$) image). In some cases data will be provided free, as in the case of many of the meteorological satellites, or for data exploitation research projects. However, for commercial or operational applications a fee is normally charged, which varies between providers. A commercially available, high-resolution optical image can cost in the order of €1 per $km^2$. However, even where data are purchased at commercial rates, their cost may still only be 10–15 percent of an average earth observation project. Other costs are related to data analysis and its integration into other data sets and models to extract parameters of relevance to end-users. During the past 10 years the cost of satellite data has fallen substantially.

## Monitoring the Kyoto Protocol

The Kyoto Protocol strengthens parties' obligations under the UNFCCC by imposing quantified, legally binding commitments to reduce atmospheric concentrations of a 'basket' of six greenhouse gases (GHGs).[7] These commitments can be met either by reducing emissions or by balancing them using biological carbon sinks. Although the protocol left many details unresolved, it set the course for subsequent negotiations in the conferences of the parties (COPs). COP7, held in Marrakech, Morocco, in October 2001, concluded enough detail to allow parties to ratify the protocol.[8]

A matter of great controversy during this process was the question of accounting for sinks, or land use, land-use change and forest (LULUCF) activities. COP7 also agreed that an afforestation, reforestation and deforestation (ARD) scheme was covered by Article 3.3 of the UNFCCC and that forestry projects are permitted under the Clean Development Mechanism (CDM).

### *Reporting and earth observation*

Countries' information requirements related to their commitments under the UNFCCC, Kyoto Protocol and the various guidelines of the convention can be grouped into two major categories: national inventories and global climate observations.

The first category covers information needs related to the LULUCF sector—yearly national inventories of anthropogenic emissions by sources and removals by sinks of all GHGs;[9] the second covers the need for global climate change observation systems in order to improve climate forecasts and the impact of climate change.[10] The information needs in these two categories are different in scale, scope and content.

As regards global change observations, earth observation can provide a number of measurements, including concentrations of atmospheric trace gases, rises in sea level, the extent and evolution of sea ice cover and ice shelf melting, or the dynamics of the atmosphere and oceans. These are mostly issues of climate change research, which may feed into the evolution of the Kyoto Protocol but do not have a direct impact on parties' national reporting requirements. Hence, the present chapter only deals with the national reporting requirements and the potential for earth observation data to be used for this purpose.

## *National inventories*

The UNFCCC commits all parties to prepare 'national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies to be agreed upon by the Conference of the Parties'. Reporting guidelines were subsequently developed and revised to help Annex I countries meet their obligations.[11] These guidelines are to be complemented by the International Panel on Climate Change's (IPCC) *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories,* which is to be applied from 2003 onwards (parties with economies in transition must do so two years later).

In addition, the IPCC, following a request by the Subsidiary Body for Scientific and Technological Advice to the UNFCCC (SBSTA), prepared a Special Report on Land-Use, Land-Use Change and Forestry.[12] According to the report, the information-gathering process (under articles 3.3, 3.4 and 3.7) includes two main tasks:

- identification of land use and land cover in 1990 to serve as the baseline; and
- monitoring of ARD activities between 1990 and 2012.

The base year for GHG inventories is 1990 in most cases. Only Annex I countries with economies in transition may use an alternative base year.[13] For the base year, land and forest cover must be recorded and the forest biomass (above and below ground and including, litter, dead wood and soil organic carbon) must be expressed in carbon stocks. The IPCC notes that approximately three-quarters of the anthropogenic emissions of carbon dioxide ($CO_2$) into the atmosphere during the past 20 years was due to the burning of fossil fuels. The rest was predominantly due to land-use change, especially deforestation.

The IPCC special report states that: 'Scenarios that create ARD land on the basis of a wide range of activities, including harvest/regeneration cycles and natural disturbances followed by regeneration (as in land cover or FAO [Food and Agriculture Organization] scenarios), will result in a much larger area of ARD land. The data requirements for area determination under such scenarios may be met through approaches that are based on monitoring land-cover change, such as remote sensing'.[14]

### *Satellite sensors since 1990*

The mapping of land-cover change during the 1990s and at the beginning of the new millennium has benefited from the proliferation of very high-resolution sensors (with resolutions in the order of 1 m or less), as well as more frequently available radar imagery (around 10 m resolution). Sensors with intermediate resolutions (a few hundred metres) but more frequent coverage complete the arsenal of useful satellite sensors. Table 2 lists the major earth observation missions, launched during the past 12 years, which can be used for the purposes of national reporting under the Kyoto Protocol.

The Kyoto Protocol sets specific resolution standards. Forest area must be determined using a spatial resolution no larger than 1 hectare, corresponding to a satellite sensor resolution of less than 100 metres. This limits data collection from earth observation sensors to two main types, available in 1990. These are the sensors on board the Landsat (US) and Spot (France) satellite series. Both operate in the visible and IR region of the electromagnetic spectrum and measure reflected sunlight.

Since 1990, a number of new sensors have become available for monitoring ARD activities in the period up to 2012. These are also listed in table 2. They include radar imaging sensors on the ERS (European Remote Sensing Satellite) series (ESA, European Space Agency, 1991 onwards), the JERS-1 (Japan, 1992–1998) and the Radarsat (Canada, 1995 onwards) satellites, and the recently launched dual-polarisation radar imager on board Envisat (ESA, 2002 onwards). Envisat is the most advanced and complex space-based earth observation mission ever.

In addition to these radar missions, the Indian IRS series offers an optical/IR imaging sensor similar to the ones on the Landsat and Spot satellites. Some recently-launched very-high-resolution sensors, with resolutions of 1 metre or less, show some interesting characteristics, which may give a better distinction between forest and tree types. However, the relatively small imaging size, of the order of 10 x 10 km, presents a major technical limitation in constructing countrywide land-use maps.

### *Earth observation measurements of interest to the Kyoto Protocol*

Forestry is one of the key activities allowed under the Kyoto Protocol's LULUCF and ARD provisions. Earth observation can provide information about forest area, forest type, density, species and the health of a forested area. Deciduous, coniferous, broadleaf and mixed forests can be distinguished from each other. Very-high-

**Table 2 Sensors on satellites launched since 1990 for baseline mapping and national reporting**

| Satellite | Agency (country) | Sensor | Resolution (metres) | Operational life |
|---|---|---|---|---|
| **Landsat-4** | NASA/NOAA (US) | Multispectral scanner (MSS) | 60 | July 1982–Aug. 1993 |
| **Landsat-5** | | Thematic mapper (TM) | 30/120 | Mar. 1984– |
| **Spot-1** | CNES (France) | High resolution visible (HRV) | 10 (pan) | Feb. 1986–Feb. 2002 |
| **Spot-2** | | | 20 (VIR) | Jan. 1990– |
| **ERS-1** | ESA (Europe) | Synthetic aperture radar (SAR) | 30 | July 1991–1999 |
| **JERS-1** | NASDA (Japan) | SAR | 18 | Feb. 1992–Oct. 1998 |
| **SPOT-3** | CNES (France) | HRV | 10 (pan) 20 (VIR) | Sep. 1993–Nov. 1996 |
| **ERS-2** | ESA (Europe) | SAR | 30 | Apr. 1994– |
| **RADARSAT-1** | CSA (Canada) | SAR | 28 | Sep. 1995– |
| **IRS-1C** | ISRO (India) | Linear imaging self-scanning | 23.5 (VIR) | Dec. 1995– |
| **IRS-1D** | | system (LISS-III) | 70 (IR) 5.8 (pan) | Sep. 1997– |
| **SPOT-4** | CNES (France) | High-resolution visible and infrared radiometer (HRVIR) | 20 (VIR) 10 (pan) | Mar. 1998– |
| **IKONOS-2** | Space Imaging (US) | Optical sensor assembly (OSA) | 4 (VIR) 1 (pan) | Sep. 1999– |
| **LANDSAT-7** | NASA/NOAA (US) | Enhanced thematic mapper plus (ETM+) | 30 (VIR) 15 (pan) 60 (TIR) | Apr. 1999– |
| **QUICKBIRD-2** | Earth Watch Inc. (US) | Ball global imaging system (BGIS) | 2.8 (VIR) 0.7 (pan) | Oct. 2001– |
| **ENVISAT** | ESA (Europe) | Advanced synthetic aperture radar (ASAR) | < 30 | Mar. 2002– |
| **SPOT-5** | CNES (France) | High resolution geometry (HRG) | 10/20 (VIR) | May 2002– |
| | | High-resolution stereoscopic (HRS) | 2.5/5 (pan) | |

NOTES NASA=National Aeronautics and Space Administration; NOAA=National Oceanic and Atmospheric Administration; CNES=Centre National d'Études Spatiales; ESA=European Space Agency; NASDA=National Space Development Agency of Japan; CSA=Canadian Space Agency; ISRO=Indian Space Research Organization; pan=panchromatic (one channel only); VIR=visible/IR channels (more than one channel); TIR=thermal IR.

SOURCE Committee on Earth Observation Satellites, *CEOS Handbook 2002,* European Space Agency, Paris, 2002, available at www.eohandbook.com; Herbert J. Kramer, *Observation of the Earth and its Environment: Survey of Missions and Sensors*, 4th edn, Springer Verlag, Heidelberg, 2002; http://earth.esa.int/ers/instruments/index.html; www.csc.noaa.gov/products/maine/html/rs_mang.pdf; http://ceos.cnes.fr:8100/cdrom-98/ceos1; www.esa.int/atsrconf/; http://envisat.esa.int/instruments/asar/data-app/app/land.html; http://apex.neonet.nl/browse/www.neonet.nl/Document/FZUVFOVVFWTGRWHMPHWYEXWGS.html; and www.spotimage.fr/home/system/introsat/payload/welcome.htm.

resolution sensors (1 metre or less) can be used to identify individual trees for forest type classification. Sensors in the visible, IR and radar range of the electromagnetic spectrum are suitable for monitoring changes in ARD. The state of a forested area—whether healthy or stressed—can be determined and monitored. This affects the carbon storage of the forested area.

Satellite sensors can also be used to monitor agricultural activities. Important parameters include type of crop (such as wheat, maize, rice, barley, soya beans, potatoes or sunflowers) and the state and productivity of crops. Taking several images during the growth cycle makes it possible to draw conclusions about field management practices, such as crop rotations, irrigation cycles and harvesting times. If remote sensing data are combined with agro-meteorological models and plant physiology information, yield estimates can be retrieved to obtain countrywide agricultural statistics. The European Commission, for example, has established an operational agricultural monitoring system which monitors and predicts yields for the 10 most common crops across the European Union using field-sampling methods. Information on rice fields, for example, is important, since they contribute up to one-quarter of global methane emissions.

Vegetation fires are a significant element in global carbon stock changes because the burning process releases $CO_2$ and the vegetation cover which absorbs carbon from the atmosphere is reduced. Changes in vegetation cover need to be accounted for in the national inventories submitted under the Kyoto Protocol. Vegetation fires are monitored daily and globally by a number of satellite sensors at medium resolution. If more detailed area analyses are required, high-resolution satellites are commonly used.

### *The application of earth observation in practice*

Earth observation is undoubtedly a very appropriate, and in many cases the only, viable tool to provide the land-use, land-cover and forest information required by the Kyoto Protocol. However, there remains a challenge in converting this information into the equivalent carbon stock figures required under the reporting guidelines. Although progress has been made since the Kyoto Protocol was negotiated, further standardisation of methods is needed. It should be possible to have globally applicable methods for deriving carbon stock figures from satellite-retrieved land-use maps. Default methodologies would greatly facilitate the reporting process.

Remote sensing from space is most likely to be used by:

- countries which lack regular inventories;
- countries which do not have information on the baseline year;
- large countries where remote sensing from space is inexpensive compared to ground-based or airborne methods (if available for 1990); and
- countries with well-developed inventories which want to introduce comprehensive national full-carbon-accounting projects.

The National Carbon Accounting System of Australia is a good example of the latter.[15] Another is the research programme of the International Institute for Applied Systems Analysis (IIASA) for setting up a full-carbon-accounting approach in Russia and other countries, which is supposed to contribute to the work of the IPCC. According to IIASA, 'current findings stipulate a heavy use of remote sensing in order to implement the Kyoto Protocol'.[16]

## Looking ahead

Earth observation is a viable tool for monitoring the implementation of the Kyoto Protocol. In particular, LULUCF and ARD activities can be monitored using space technologies and data can be used to meet the reporting provisions under the treaty. Satellite data offer several key advantages over other methods—independence, repeatability and comparability of the information retrieved.

There is a need to further develop internationally accepted and standardised methodologies for using satellite information. This is a major challenge which remains to be tackled.

At the institutional level, there are several possible ways in which earth observation may be used to meet national reporting requirements under the Kyoto Protocol (in addition to advancing research on climate change in order to improve UNFCCC guidelines more generally). First, national governments can use earth observation as a way of collecting national activity information, in accordance with the rules of the Kyoto Protocol. Second, an independent body can use earth observation to verify estimates of carbon stocks submitted in national inventories. Third, some parties may decide to establish a joint, independent (space-based) reporting mechanism in order to reduce their individual reporting burdens.

The second option might meet resistance from some signatories, which may feel that their national interests would be compromised by an external verification mechanism. That leaves earth observation as a largely voluntary choice for governments. It is therefore the task of space agencies to convince the international community that earth observation is a valuable and practical information source. Some signatories have already started major projects to incorporate satellite data into their inventory preparation. The results are expected in time for 2007, when national reporting for the first commitment period will begin.

The use of earth observation to verify MEAs other than the Kyoto Protocol follows the same principal. For most of the agreements dealing with issues relating to land surface (biodiversity, wetlands and desertification), earth observation has proved in hundreds of individual cases how it can be used to map and continuously monitor the type and state of health of vegetation, changes in land use and other environment-related parameters. Similarly, space techniques allow the measurement of concentrations of trace gases in the troposphere and stratosphere. Several efforts are under way, using remote sensing, to support the 1973 International Convention for the Prevention of Pollution from Ships (the MARPOL Convention) or the UN conventions to combat desertification and on biodiversity. While the advantages of using space techniques for these agreements are clear, the challenges remain the same as those for the Kyoto Protocol, namely, to convert space-derived data into the required parameters and to introduce the tool as an internationally accepted method of verifying treaties. Here, the challenges of science end and the challenges of politics begin.

Institutional and political obstacles are certainly among the more difficult ones to overcome. While the merit of using space technology is in many cases acknowledged, the main difficulty is the introduction of a new observation technology into an existing, often decades- or centuries-old, political and institutional structure. Changes may require the abolition or modification of current techniques, such as ground-based observation, the reorientation of budget and staff resources in government organisations, or the creation of a new legislative framework.

To help overcome these obstacles, several governments have initiated programmes to move space technology from a predominantly research-oriented tool to a more user-driven one. Among the most prominent is the European Global Monitoring of Environment and Security (GMES) initiative, which aims to develop a global monitoring capability in support of European environment and security policies, including implementation of the Kyoto Protocol.[17] Another example is the recent initiative of the Committee on Earth Observation Satellites (CEOS)[18] in actively participating in the negotiations at the 2002 Johannesburg summit. The CEOS achieved the inclusion of a large number of specific references to space in the final Johannesburg Political Declaration and its supporting Plan of Implementation. Established in 1984 under the auspices of the Group of Seven (G7—today's G8), the CEOS co-ordinates earth observation programmes at the international level. Its membership comprises all government agencies which are developing or operating earth observation satellites or which are major users of earth observation data.

In moving towards an internationally agreed mechanism to use earth observation for MEA verification, committees such as the CEOS might act as catalysts by being politically unbiased and having a technologically optimised approach. However, it would be helpful if the preparedness of the space community were matched by a proactive approach by the negotiators and implementers of MEAs in foreseeing, and even encouraging, the use of earth observation for treaty monitoring and implementation.

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# Endnotes

[1] For a historical listing of environmental agreements, see SEDAC website at http://sedac.ciesin.org/rs-treaties/rs-treaties_bckgnd.pdf. SEDAC is the Socioeconomic Data and Applications Center at Columbia University, New York.

[2] See http://sedac.ciesin.org/rs-treaties/adesherbinin_riopaper.pdf.

[3] See http://sedac.ciesin.org/rs-treaties/rs_treaties.pdf; and www.un.org/esa/sustdev/agreed.htm.

[4] See www.johannesburgsummit.org.

[5] The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies entered into force 10 October 1967, available on the website of the UN Office for Outer Space Affairs at www.oosa.unvienna.org/SpaceLaw/outerspt.html.

[6] Available at www.oosa.unvienna.org/SpaceLaw/rs.html.

[7] Annex A to the Kyoto Protocol. The text of the protocol is available at http://unfccc.int/resource/docs/convkp/conveng.pdf. See also chapter 9 in this volume.

[8] An instructive summary of the Marrakech accords (COP7) is provided on the website of the Pew Center on Global Climate Change, Arlington, VA, US, at www.pewclimate.org/cop7/update_110901.cfm.

[9] United Nations Framework Convention on Climate Change, Articles 4.1(a) and 12.1(a). The text of the convention is available at http://unfccc.int/resource/docs/convkp/conveng.pdf.

[10] United Nations Framework Convention on Climate Change, Articles 4.1(g) and (h), 5 and 12.1 (c); and Kyoto Protocol, Article 10(d).

[11] Annex I countries are the 35 industrialised countries that are signatories to the convention, plus the European Community. See website of the International Panel on Climate Change at www.ipcc-nggip.iges.or.jp/public/gl/invs4.htm.

[12] See United Nations Environment Programme (UNEP) GRID-Arendal website at http://www.grida.no/climate/ipcc/land_use/index.htm.

[13] Kyoto Protocol, Article 3.5.

[14] See www.grida.no/climate/ipcc/land_use/139.htm.

[15] See www.greenhouse.gov.au/ncas/files/abstracts/tech09.html.

[16] See www.iiasa.ac.at/Research/FOR/carbon.html?sb=3.

[17] See http://europa.eu.int/comm/space/gmes_en.html.

[18] See www.ceos.org.