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The use of remote sensing to support the application of multilateral environmental agreements ☆

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Abstract

There is a growing realisation of the increasingly varied and interesting possibilities for the use of Earth observation data to ensure compliance with international obligations generally, and treaty obligations in particular. Most examinations of the application of Earth observation data to monitoring states' compliance with international obligations focus on the environmental sector. This paper proposes the use of remote sensing satellites for the support of multilateral environmental agreements (MEAs), especially land monitoring MEAs such as the Convention on Biological Diversity (1992) and the Kyoto Protocol (1997). It discusses the uses of remote sensing for treaty implementation or enforcement in general, and the admissability of satellite imagery as legal proof, before examining how Earth observation-derived data could be of benefit to specific MEAs. As sensors become increasingly sophisticated the use of remote sensing in this area should grow but it needs to be supported by its more widespread legal recognition as proof.

1. Introduction

In the past 30 years the rapid growth in the number of environmental agreements has been an encouraging sign of international commitment to protecting the environment. The proliferation of environmental treaties has resulted in an increasing need for spatial data on the Earth's biophysical systems. Although the existing Earth observation satellites were not designed to meet the information requirements of international environmental treaties, they can be used to generate key information necessary for developing and implementing such treaties.

The information derived from space has a number of distinct advantages over ground-based measurements, since the information is taken remotely and is comparable between different areas over different periods of time, and provides measurements in different parts of the electromagnetic spectrum.

In recent years remote sensing technology has proven to be a powerful tool to monitor and assess the Earth's surface on a regular basis. Remote sensing satellites, with increasing capabilities in terms of spatial, temporal and spectral resolution, allow more efficient and reliable monitoring of the environment over time at global, regional and local scales.

2. Multilateral environmental agreements

International environmental policy is typically cast in the form of bilateral or multilateral environmental agreements (MEAs), which are agreements contracted between governments to collectively address an environmental problem.

MEAs are formal documents that describe the problem being addressed, the commitments of the governments involved and the institutional infrastructure to be created. As with other treaties and international agreements, they are tools for accomplishing policy objectives commonly held among the parties and they generally include formal, binding commitments [1]. Some of these agreements deal with global phenomena, e.g. ocean pollution and ozone depletion; others cover forms of environmental problems that affect the territories of sovereign states, like deforestation or desertification, but in a more regional or local manner.

MEAs have proliferated as environmental protection has become a major issue worldwide. The 1992 United

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Nations Conference on Environment and Development, and the 1972 United Nations Conference on the Human Environment before it, reflected the rise of concern for the global environment and each was a catalyst for the creation of new accords.

MEAs currently address a wide range of environmental phenomena, both regional and global in nature [1]. The proliferation of MEAs has resulted in an attendant need for spatial data on the health of the Earth. Such information contributes to the design of improved policy instruments [2].

3. Multilateral environmental agreements and remote sensing

Earth observation systems are tools developed in recent decades (Landsat was the first civilian satellite launched in 1972), which have become essential for effectively conducting different types of environmental management and research applications. However, although over 200 MEAs addressing a broad range of environmental issues and concerns have come into existence during the past few decades, few explicitly incorporate or depend on data and information from space-based technology [2].

The International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 (MARPOL 73/78) [3] is one of the only MEAs which explicitly refers to remote sensing in its articles, as a potential support in marine oil pollution monitoring.

The American Institute of Aeronautics and Astronautics (AIAA) has highlighted that remotely sensed data can be used for various aspects of MEAs [4]. The application of Earth observation systems to support MEAs can range from the identification of a new environmental problem (pre-negotiation phase) to the monitoring (negotiation phase) and assessment (implementation phase) of that problem, to the verification of compliance and subsequent enforcement (compliance and dispute resolution). However, it is important to note that there is no binding international regime specifically addressing verification through remote sensing, even though the concept of verification through remotely sensed data is not new (there were provisions in the 1970s' Strategic Arms Reduction Treaties) [5].

Products and services based on remote sensing data represent a valuable source of information for the different national and international bodies involved in the implementation of MEAs, in particular on aspects related to land-cover and land-use monitoring. However, despite the fact that Earth observation systems are capable of assisting the MEA process, there is a number of significant problems. These include lack of consistency and standardisation of data sets and fragmented and inadequate data archives.

Remote sensing technology may provide significant new types of data, as well as simply more or better quality data, but linking remote sensing data to policy is not straightforward. At the World Summit on Sustainable Development (WSSD), held in Johannesburg in 2002, state representatives adopted the Johannesburg Declaration which identifies future environmental and development goals. The WSSD produced a Plan of Implementation with 12 specific references to Earth observation as a crucial information source for a number of relevant disciplines to sustainable development. Moreover, Earth observation is specifically mentioned as a key decision-making tool for, inter alia, better management of water resources, natural disasters and climate monitoring.

An important tool for supporting policy activities including MEAs is the joint initiative driven predominately by ESA the European Union, Eumetsat and the national agencies called Global Monitoring for Environment and Security (GMES). GMES is one of the cornerstones of the new European space policy, as set out in the European Commision's White paper. This programme aims to support Europe's goals in sustainable development and global governance by advancing its environmental and security policies. GMES will contribute to key policies of the EU such as the 6th Environmental Action Plan from 2004 to 2010. This addresses climate change, nature and biodiversity, but it will also provide information services for some wider policy needs (such as the Common Foreign and Security Policy).

GMES is intended to deliver policy-relevant services to end users. This could help space technology move from being largely a research-oriented tool to becoming a more user-driven programme, more suitable for supporting MEAs by bridging the communication gap between the science and policy communities.

GMES will combine a range of space-based and in situ Earth observation, modelling and communication technologies and systems within a distributed, coordinated architecture to support exchanges between service providers and users. In 2008 the foundations and the structuring elements of the European capacity for GMES should be in place and operating. Many elements of the modules already exist but they have been conceived, designed and managed in an isolated way, thus limiting interoperability. Current GMES space segments include the Meteosat and SPOT series of satellites, Envisat and TOPEX-Poseidon. In the long term GMES requires the deployment of a comprehensive and complementary set of operational space missions providing permanent and continuous observing capabilities of the Earth's system's components at global, regional and local scales. New Earth observation systems currently being developed and planned will further improve these services. Future systems will consist, among others, of Jason-2, Metop, Pleiades, TerraSAR and Cosmo-Skymed.

Some of the key issues of the GMES programme are its goal to ensure long-term, continuous global monitoring on a time scale of decades and to fill the gaps in the existing infrastructures which are seen as crucial in order to support environmental treaty verification. GMES could also be seen as a contribution to a general international Earth observation effort that could fulfil the various policy needs articulated at the highest political levels during the 2002 WSSD, the 2003 G8 Summit and at the 2003 Earth Observations Summit.

4. Remote sensing data and international jurisdiction

Another issue is whether satellite data are accepted as legally binding proof when it comes to treaty enforcement. In the past satellite images have been considered mainly as an indicator needing to be confirmed by ground verification rather than a complete system of proof by themselves [5]. However, several cases exist where remote sensing has been used as legal evidence.

One case where satellite imagery has been accepted as legal evidence in court is the Singapore *Song San* case. In 1996 oil pollution in the Strait of Malacca was detected using satellite imagery (ERS satellite images) together with laboratory analysis. The Singaporean tanker Song San was identified as the source of the marine pollution. On the basis of the satellite data, legal proceedings were initiated in Singapore [6].

The International Court of Justice (ICJ) has accepted remote sensing imagery as evidence in certain situations, e.g. in the Qatar/Bahrain Case, the Nigeria/Cameroon Case and the Botswana/Namibia Case. Satellite data have also been used by the International Claims Tribunal for the Former Yugoslavia (ICTY).

The European Commission (EC) is using remote sensing and related techniques to assist the implementation of the Common Agricultural Policy through the Monitoring Agriculture with Remote Sensing (MARS) project. This project aims to verify that the policy of leaving land fallow is properly implemented before due compensations is calculated. The EC has established an operational agricultural monitoring system which monitors and predicts yields for the 10 most common crops across the European Union using Earth observation data and field-sampling methods. The method is based on the use of multi-date high-resolution satellite images to verify farmer declarations for area aid. This assists the sorting of declarations and allows field control to be concentrated on non-conforming or suspicious dossiers and parcels.

To date, satellite imagery has not been used directly and solely as evidence in the enforcement of environmental law. Satellite law enforcement is still in its infancy but its potential is increasingly being recognised, especially considering the fact that aerial photography and the use of data generated by computers and other equipment (digital imagery from security and speed cameras) are currently used as evidence in many countries [7].

5. Application of multilateral environmental agreements for land monitoring

This section provides examples of applications of remote sensing in three domains: The convention on wetlands of international importance especially as waterfowl habitat, The convention on biological diversity (CBD) and The convention to combat desertification in those countries experiencing serious drought and/or desertification, particularly in Africa (CCD).

5.1. Convention on Wetlands of International Importance Especially as Waterfowl Habitat

This Convention, signed in Ramsar, Iran, in 1971, is an intergovernmental treaty which provides the framework for national action and international cooperation for the conservation and wise use of one of the most productive types of environment in the world: wetlands. The Convention's mission is "the conservation and wise use of national action and international cooperation as a means to achieving sustainable development throughout the world".

Remotely sensed data could be useful to inform the Secretariat of the Convention, "... at the earliest possible time if the ecological character of any wetland in its territory and included in the list has changed, is changing or likely to change as the result of technological developments, pollution or other human interference" (Article 3.2). Remote sensing can also help to survey the actual distribution and extent of wetlands (Article 8).

The use of remote sensing data can increase scientific and technical knowledge about wetlands, support the efficient management of wetlands areas and contribute to improving the performance of the Convention (enhance reporting mechanisms).

5.2. Convention on Biological Diversity

The overarching aim of the CBD is the conservation and sustainable use of biological resources. The CBD makes commitments to integrate the sustainable use and conservation of biodiversity into national and international decision making, including:

- scientific and technical cooperation, including access to and transfer of biotechnology;

- natural resource management: establishment of protected areas and rehabilitation; restoration of degraded ecosystems and threatened species; prevention/control and eradication of alien species which threaten biodiversity.

According to the CBD, remote sensing can help in habitat suitability mapping to "rehabilitate and restore degraded ecosystems and promote the recovery of threatened species, inter alia, through the development and implementation of plans or other management strategies" (Article 8, Paragraph f). This information would also help to "develop, where necessary, guidelines for the selection, establishment and management of protected areas" (Article 8, Paragraph b).

The Meso-American Biological Corridor is an excellent example of habitat suitability mapping. This biological corridor is a planned combination of protected areas and managed landscapes that forms a continuous wildlife migration route from Panama to the Mexican border. This project is a collaboration between the University of Maine, the Jet Propulsion Laboratory and JAXA (formerly NASDA) and it is using remote sensing imagery in support of the corridor agreement.

5.3. Convention to Combat Desertification in those Countries Experiencing Serious Drought and/or Desertification, particularly in Africa

The Convention to combat desertification seeks not only to tackle the impacts of desertification but also to mitigate the effects of drought, particularly in Africa, through effective action at all levels, supported by international cooperation and partnership arrangements. Under the Convention, desertification refers to dryland areas vulnerable to over-exploitation and inappropriate land-use as a result of poverty, political instability, deforestation, overgrazing and bad irrigation. Implementation is defined at a regional level since the Convention breaks down into five regions, as defined in the "Implementation Annex" (Central and Eastern Europe, Africa, Asia, Latin America and Caribbean and the Northern Mediterranean).

The areas which could directly benefit from use of remote sensing technology in the implementation framework of the CCD fall under three main headings:

1. The collection and analysis of short- and long-term data and information to identify causal factors, both natural and human, contributing to land degradation, desertification and/or drought and to increase knowledge of the processes leading to land degradation, desertification and drought.
2. The systematic observation of the state of the environment to assess qualitative and quantitative trends in natural resources; evaluate the causes and consequences of desertification, notably ecological degradation; and monitor the effects of land degradation and desertification to improve the value of strategies to combat desertification.
3. The establishment and/or strengthening of early warning systems to evaluate the impacts of natural climate variability on regional drought and desertification and generate seasonal to inter-annual climate predictions to improve the efficiency of programs mitigating the effects of droughts on affected populations.

6. The particular case of climate change

Over the millennium before the industrial era the atmospheric concentrations of greenhouse gases (GHGs) remained relatively constant. Since then, however, the concentrations of many of these gases have increased directly or indirectly because of human activities, in particular combustion of fossil fuels for international or domestic usage and biomass burning, etc.

Global climate change, in part caused by the rapid and uncontrolled increase of GHGs in the Earth's atmosphere during the past 150 years, is a major public, political and scientific concern worldwide.

6.1. United Nations Framework Convention on Climate Change

Public concern resulted in the 1992 United Nations framework convention on climate change (UNFCCC) which is an official acknowledgement of the climate change phenomenon, as well as a recognition by international policy makers that immediate cross-border actions are required to halt and reverse the current destructive trend of global warming and its environmental effects.

The convention sets an "ultimate objective" of stabilising atmospheric concentrations of GHGs at safe levels that would prevent dangerous gas concentrations in the atmosphere at a level that would avoid anthropogenic interference with the climate change. Such levels, which the convention does not quantify, should be achieved within a timeframe sufficient to allow ecosystems to adapt naturally to climate change. To achieve this objective, all countries have a general commitment to address climate change. 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". The convention then divides countries into two groups: those listed in its Annex I (known as "Annex I Parties") and those that are not so listed (so-called "non-Annex I Parties"). The Annex I Parties are the industrialised countries who have historically contributed the most to climate change. They include both the countries that were members of the Organization for Economic Co-operation and Development (OECD) in 1992, and countries with "economies in transition". The principles of equity and "common but differentiated responsibilities" enshrined in the Convention therefore require these Parties to take the lead in modifying longer-term trends in emissions. All remaining countries have a timeframe for the submission of their initial national communications, including their emission inventories, which is less constraining than for Annex I Parties since they do not have to use 1990 as the base year for GHGs inventories (they may use an alternative base year).

6.2. Kyoto Protocol

The UNFCCC was strengthened in 1997 by the Kyoto Protocol, which contains quantified, legally binding commitments to limit or reduce atmospheric concentrations of GHGs in the atmosphere that are related to human induced interference with the climate system to 1990 levels. This may be achieved either by reducing emissions of GHGs or by balancing them using biological carbon sinks. The Kyoto Protocol to the UNFCCC was adopted at the third Conference of the Parties. It commits Annex I Parties to limit or reduce their GHGs emissions, adding up to a total cut of at least 5% from 1990 levels in the "commitment period" 2008–2012. The targets cover emissions of the six main GHGs : carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6).

6.3. Relevance of earth observation to the Kyoto Protocol

The Kyoto Protocol allows emissions to be balanced by vegetation, which may sequester or release GHGs depending on the land use, and this is where remote sensing may potentially be relevant.

Two of the main GHGs within the Kyoto Protocol's remit are methane and carbon dioxide [8]. Carbon dioxide is mainly stored in forests, methane in wetlands and rice paddies. Earth observation can provide information about forests (area, type, density, health, etc.) and also be used to monitor agricultural activities (type, productivity of crops, etc.) so remote sensing data could support the implementation of the Kyoto Protocol reporting obligations.

The Kyoto Protocol sets specific resolution standards. Forest areas must be determined using a spatial resolution no larger than 1 ha, corresponding to a satellite sensor resolution of less than 100 m. This limits data collection from Earth observation sensors to only two systems available in 1990 which is the base year reference. These are the sensors on board the Landsat (US) and SPOT (France) satellite series. Since 1990 a number of new sensors have become available for monitoring land inventory activities, complementing the aforementioned systems in the optical domain or in new modes of operation as is the case with active systems (Radarsat, JERS), which in general have better technical capabilities in terms of temporal, spectral and geometric resolutions. These systems will be further complemented in the near future by hyper-spectral systems allowing better spectral discrimination among ground features.

There are five specific areas where remote sensing may support the Kyoto Protocol [8]:

- provision of systematic observations of relevant land cover (Articles 5, 10);
- support for the establishment of a 1990 carbon stock baseline (Article 3);
- detection and spatial quantification of change in land cover (Articles 3, 12);
- quantification of above-ground vegetation biomass stocks and associated changes therein (Articles 3, 12);
- mapping and monitoring of sources of anthropogenic CH_4 (Articles 3, 5, 10).

Within the context of the Kyoto Protocol, Article 10 can be recognised as a key driver, in which contributions can be made to provide systematic observations and data archives in order to reduce uncertainties in the global terrestrial carbon budget [8].

For biomass retrieval, as in the context of the Kyoto Protocol, it is an absolute requirement that Earth observation data acquisitions are performed in a consistent manner providing systematic, repetitive observations over large areas. There is a general inadequacy of current Earth observation data archives because high resolution satellites do not generally collect data in a homogeneous way over large areas, instead data are collected in a fragmented manner over several local sites that have been specifically requested by commercial or scientific users [9]. Some scenes might be acquired over subsequent paths but adjacent scenes might never been acquired since they have not been requested. In the case of "global scale" environmental problems such as climate change issues, it is therefore important to have a global data acquisition strategy ensuring spatial and temporal consistency over extensive ecological regions [9]. Gaps that inevitably do occur occasionally in the data acquisition strategy (e.g. because of cloud cover for optical sensors) should be covered during the next orbit in order to have a spatially consistent data set [9]. Timing is an important component of repetitive observations, as seasonality may introduce bias in data time series (backscatter variations). Annual acquisitions should therefore preferably be planned during the same season every year [9]. Most of the terrestrial parameters that need to be characterised and quantified within the Kyoto Protocol are in a state of constant change and, in many cases, it is these changes that the scientific community is interested in. The temporal dynamics of the terrestrial parameters therefore need to be taken into account. The temporal repetition frequency of the acquisitions need to be adapted with respect to the land use, and a land-use-based stratification of the Earth may thus be required in a global data acquisition plan [9]. Long-term continuity of acquisitions with intercomparable sensors is also required in order to have a coherent long term database needed to monitor the evolution of the environment.

Earth observation is a very appropriate tool for providing the land-cover information required by the Kyoto Protocol [10]. It may be the only reasonable way of deriving an estimate of the global terrestrial carbon storage of the reference year 1990 as well as of monitoring development of the changes in biomass and land cover from local to global scales. However, a challenge remains in converting this information (land-cover information) into equivalent carbon stock figures. Some progress has been made since the establishment of the Kyoto Protocol but more efforts are needed in order to standardise methods since satellite measurements are taken indirectly and biomass evaluations are done using different biophysical models [11].

6.4. *World Summit on Sustainable Development (WSSD)*

The WSSD reinforced the critical issues related to climate change and the potential support that remote sensing can play. Article 36 of The Johannesburg Declaration's supporting Plan of Implementation states that: "The United 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" [12].

7. Conclusions

In the past 30 years, international environmental agreements have proliferated as environmental protection has become a major issue worldwide. The environmental protection of the Earth has given birth to a corpus juris specialised in environmental law. These international regulations have a general weakness because of the lack of mechanisms of control or constraint that would make them more effective.

Earth observation systems have become essential for effectively conducting different types of environmental management and research applications. They can prompt new agreements, influence behaviour under existing agreements, and evaluate past performance and effectiveness. Remote sensing imagery has already been accepted as legal evidence in court (Song San case) and is also used by the European Commission in support of its agricultural policy through the MARS project.

Novel capabilities of recently available and scheduled sensors are opening new possibilities for developing more advanced and efficient tools for environmental monitoring. The use of remote sensing could be an important and effective support to MEAs. However, in order to fully achieve this goal the international community needs to move towards the legal recognition of the use of remote sensing imagery as proof and as a decisive tool in the framework of the defense of the environment.

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