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Potential Application of the Open Skies Regime as a Collection Method for Environmental Data

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Preface

The views and positions in this paper are solely those of the author and do not necessarily reflect the views and positions of the Department of Foreign Affairs and International Trade or of the Government of Canada.

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Sommaire

Les activités humaines ont des incidences importantes sur le climat et le réchauffement de la planète entraîne des changements dramatiques qui se font sentir aux quatre coins du globe. En augmentant et s'agglomérant dans les villes, les populations deviennent plus vulnérables aux détériorations de l'environnement et celles-ci combinées à la rareté des ressources contribuent à créer des tensions politiques.

Que les défis soient perçus en terme de perte humaine et économique, de santé publique et de défense civile ou encore de menace environnementale à la sécurité internationale, deux problèmes demeurent constants:

- de nombreuses données environnementales pertinentes ne sont pas disponibles; et
- les États hésitent à partager certaines données qu'ils possèdent.

Cette étude propose une solution intéressante à ces problèmes, soit l'application du concept d'inspections aériennes coopératives - particulièrement sous le régime de "Ciel ouvert" - à la surveillance de l'environnement.

Le Traité sur le régime "Ciel ouvert", en établissant des normes uniformes relatives au droit concernant les survols de territoire et les capteurs d'images, permet aux signataires de ce régime d'obtenir un accès régulier à un éventail de données fiables.

Cet essai explore la façon dont les images obtenues dans le cadre du régime "Ciel ouvert" peuvent être employées de façon productive afin de régler le problème du manque de données environnementales. Trois études de cas sont alors présentées:

- les catastrophes naturelles;
- le réchauffement de la planète; et
- le stress environnemental.

Background

The Treaty on Open Skies was signed in Helsinki on March 24, 1992, by twenty-five countries, including the then-sixteen members of the NATO alliance, the former East European members of the Warsaw Pact, as well as Russia, Belarus, Ukraine and Georgia as successor states to the Soviet Union. After somewhat lengthy ratification period, the treaty entered into force nearly exactly ten years later, on January 1, 2002. Despite that delay, the Open Skies regime should be seen as a landmark achievement. It is of indefinite duration and it opens the national territories of all States-Parties – their landmass, islands, and internal and territorial waters – to unarmed aerial observation overflights, on short notice and without a right of refusal.

The interest in keeping military forces and activities under Very High Resolution (VHR) surveillance, all the way "from Vancouver to Vladivostok", is quite apparent already. Seven additional countries belonging to the Organization for Security and Cooperation in Europe applied for admission into the ranks of the regime upon the entry of the treaty into force, and more than 400 joint trial observation flights had taken place before the year 2000 was over.[1] Now that the treaty is in force, formal overflights were scheduled to have begun in August last year.

As is the purpose of all confidence and security-building measures (CSBMs), the purpose of the Open Skies regime is to enhance mutual understanding and to build confidence regarding the disposition of military forces and activities among members of the regime. By opening national military establishments to sustained, detailed scrutiny, the regime affords its member-states an opportunity to send a clear signal of their peaceful intent. Under conditions of military transparency normal military routines can then be seen for the non-threatening routines that they usually are, and not be mistakenly perceived as threatening. Further, the regime promotes provision of fact-based reassurance of that intent by giving all parties a direct role for gathering the photographic data for themselves. Thus military activities that are out of the ordinary and which might indeed pose a military threat become quickly and independently identified, giving diplomacy time to seek clarification or for the military to react. When actions and behavior are rendered transparent and, thereby, more predictable, mutual relations are placed on a more stable and secure footing. The Open Skies regime too, serves to build political confidence that threatening military developments are not taking place and to reduce the possibility of armed conflict breaking out as a result of misperception, misinformation and fear.

Another important feature of the Open Skies regime has to do with it being designed from the outset to be as flexible an instrument as possible, with the view of being applied to a wider range of questions than just military forces and deployments. This turns out to have been a far-sighted decision indeed, especially in view of the fact that with the passing of the Cold War the concept of security has been cut loose from its traditional moorings. In a strict definitional sense the concept of security might have remained the same: security issues arise to this day in the context of potential or actual, perceived or real threats to the physical integrity or well-being of citizens or to the social life of a political entity. On the other hand, there has been a shift away from the state-centered view of security (traditionally seen in terms of military security) to a more collective security perception (i.e., global security). It has been recognized, for instance, that many of the new threats identified since the ending of the East-West confrontation do not stop at political frontiers of a state but cross them at will and hence have a <u>non-military</u> dimension. The most notable of these are said to be non-military threats to the security of a nation's environment and its natural resources base.

[1] Ernst Britting and Hartwig Spitzer, "The Open Skies Treaty," ch. 13 in: Trevor Findlay and Oliver Meier (eds.), *The Verification Yearbook 2002*. London: VERTIC, 2002, pp. 223. See also: James J. Marquardt, "Not a Moment Too Soon." <u>Bulletin of the Atomic Scientists</u> (January/February 2002), pp. 18-20.

Environmental Insecurity

The placement of environment as one element within national security portfolio is based on recognition of the fact that persistent, widespread environmental degradation and/or scarcity of natural resources can have long-term consequences of strategic nature. Both these factors can raise the temperature of economic competition and, in case of small, economically weak and politically divided states they may even undermine not only the social and economic stability of these states, but their political security as well. Seen from this perspective, forces that lead to environmental degradation or resource scarcity – be it natural catastrophes, global warming or human-induced environmental stress – can each and all be viewed as security risks. What appears to be less clear, however, are the means that ought to be used to address these threats. In particular, while military threats to national security have been traditionally addressed by military means, it is yet to be defined what instruments are available, or appropriate, to deal with environmental security threats.

This study argues that one policy instrument that might be appropriate for dealing with the threats to environmental security are the arms control CSBMs. Such argument might be sustained on the following grounds.

The concept of environmental security, as states routinely use it in their communications, refers fundamentally to the threat that is posed by environmental degradation and/or the sudden scarcity of vital resources to political stability.[2] Such threat is likely to be pronounced in the absence of formal treaties and/or agreements to rule on disputes over resource sharing, abstraction rates and pollution. In case of multiple parties being dependent on a resource held in common (i.e., trans-frontier forests, international river basins) such disputes might turn into political conflicts and even wars, if or when they are compounded by pre-existing political conflicts. Conflicts over access to freshwater resources serve in this context as a particularly salient case in point. The following, for instance, has been reported from the World Water Forum, recently held in Kyoto, Japan:

> "Almost half the world's population lives in 263 international river basins. The Danube, Rhine, Congo, Nile, Niger and Zambezi rivers all pass through nine or more nations. But two-thirds of these basins have no treaties to share the water. With world's water use expected to triple in the next 50 years, "real wars" over water are increasingly likely, said former Soviet president Mikhail Gorbachev, who is in Kyoto representing an international environmental group called Green Cross International."[3]

Given the above, it could be argued that many parties could benefit from entering into agreements designed principally to improve the availability of information with respect to developments and/or activities on one side of the border but which are likely to have a deleterious impact on the natural environment or resource consumption on the other. It could be further argued that such an agreement would have two key benefits:

- Greater openness and transparency would build faith (i.e., political confidence) in the intentions of all sides concerned;
- Factual, objective information would help clarifying misunderstandings and/or misinformation concerning the activities of all sides, and thus would serve to: a) limit or eliminate the role of military factors in conflict resolution; b) reduce and/or possibly eliminate the risk of military conflict arising out of misperception, suspicion and fear, and c) clear away the motives for and chances of the equivalent to a military surprise attack – some engineering *fait accompli*, for instance, designed to divert the flow of a river away from its traditional course, and its traditional downstream water users.

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[2] Katrina S. Rogers, "Pre-Empting Violent Conflict: Learning From Environmental Cooperation," ch. 30 in: Nils Petter Gleditsch *et al.*, (eds.), *Conflict and the Environment*. Dordrecht: Kluwer Academic Publishers in Cooperation with NATO Scientific Affairs Division, (1997), esp. pp. 505-507. For the argument that it is the abundance, and not the scarcity of natural resources that fuels military conflicts, see the *2002 State of the World Report* from the Worldwatch Institute, cited in: "'Resource Wars' Ignite Around the World." A *New Scientist* News Service Story (January 10, 2002), pp. 1-2.

[3] "Scientists to Resolve Future Water Wars." A *New Scientist* News Service Story (March 21, 2003), p. 1.

A third benefit worth mentioning is one that specifically highlights a possible role for the Open Skies regime. Environmental security threats are in their essence cooperative security threats. That is to say, the only "enemy" in a cooperative security design is the threat of strategic instability and the possibility of outbreak of military conflict among the parties rather than one of the parties themselves. As Van Ness points out, "...Rather than trying to build a security alliance against some feared opponent, cooperative security calls for inviting the most likely adversaries to join together to create an arrangement among themselves to attempt to resolves strategic differences and potential conflict within that institutional context."[4] Put differently, cooperative security threats should best be handled by a cooperative security regime and these the Treaty on Open Skies could help to underwrite in two basic ways:

- As an arrangement directly concerned with the threat of military stability, the Open Skies regime already is a kind of cooperative security arrangement in its own right. Through its institutional machinery – the Open Skies Consultative Commission – the regime could provide a venue where environment-related "strategic differences" could be raised and discussed in detail and complete confidence.

- Perhaps more importantly, the regime already has in place a functional framework the sides could draw on for technical advice and direct data collection support. The smaller states-parties to the treaty stand to benefit the most from bringing their environmental concerns to the OSCC. Participation in the technical working group proceedings offers them an unmatched opportunity for tapping into much richer veins of expertise held by larger states-parties. The ability to purchase data at nominal cost might offer these states their only viable option for gaining full sovereign control over their own natural environment.

The section that follows should be seen as a first step taken toward evaluating the potential utility of the Open Skies regime as a means for collecting environmental data. That section is made up of three mini-case studies. Although connected by a common thread - environment - the cases vary by areas of application in order to explore as broad context of Open Skies missions as possible. The three cases are as follows:

1. Natural Disasters (crisis preparedness and humanitarian aid data);
2. Global Warming (verification of reporting provisions of the Kyoto Protocol);
3. Environmental Stress (scarcity and/or degradation of natural resources data)

In each of the three cases an attempt is made to determine, strictly from the technical point of view, the extent to which it might be practicable to stage an Open Skies overflight in support of these missions. To that end the study examines each of these missions with a set a standardized questions:

1. What are the mission monitoring requirements, i.e., what are its main phases, involving what activities?

2. What are the user requirements (URs) for each phase of the mission in terms of the following criteria: a) spatial resolution (what is the scale and best spatial resolution required on the ground); b) temporal requirement (what is the duration and/or frequency of the observation required; what is the imagery refresh rate); c) data delivery requirement (what is the timeliness with which the data needs to reach the end-user), and; d) wavelength/sensor requirement (in which part of the electromagnetic spectrum is it best to observe a given event and with which technique)?

3. How does the existing Open Skies sensor suite compare to these (optimal) user requirements? What, if any, are the information gaps? How well could the regime do the job right now?

4. What are the points where the Open Skies regime carries a clear-cut advantage over satellite-based observations, and vice-versa?

5. What are the areas of synergy between the Open Skies-type surveillance and other forms of environmental data collection, be it space remote sensing or on-site inspections?

[4] For a useful discussion of the concept of "cooperative security" see Peter van Ness, "Alternative U.S. Strategies with Respect to China." Contemporary South East Asia (August 1998), pp. 154-167, cited in: Ib Damgaard Petersen, *Comprehensive Security in East Asia as Viewed in Light of the European Experience: A Case for Cooperative Security.* Copenhagen: Copenhagen Political Studies Press, 2000, p. 93.

Open Skies Sensor Suite

At the present time the treaty permits two different kinds of sensor packages: 1) the Initial Operational Configuration (IOC) capability, which allows the use of only the visible-light sensors (i.e., standard framing cameras and color videotape) and 2) the Final Operational Configuration (FOC) capability, which consists of the IOC capability plus the addition of a thermal Infra-red Line Scanning device and a Synthetic Aperture Radar (SAR).[5] The IOC is the sensor set allowed for the first three years after the treaty has entered into force; the FOC capability becomes the mandatory Open Skies imaging set after the initial period has passed in January 2006. The full sensor set will then ensure an all-weather, day-and-night observational capability.

The treaty limits the allowable sensor configuration not only to the four types of sensors but also in terms of the maximum allowable ground resolution[6] of these sensors. Adherence to this limitation is assured through a rigorous process of sensor calibration. Only aircraft and sensor set that meet the treaty's technical limitations can be "certified" to be treaty-compliant and only certified aircraft are allowed to fly operational Open Skies Missions. The treaty requirement states the best allowable spatial resolution for the optical, infra-red and radar instrument to be as follows:

1. In case of optical panoramic and framing cameras, a ground resolution no better than 30 centimeters. Fair weather and day-light dependent sensor. Offers ability to identify and map man-made and natural features larger than 30 cm and to identify precisely their characteristics. With respect to the environmental data,[7] this type of sensor would perform best in the following areas of application:
   - Civil cartography: landscape topography data; map generation and updating; creation of highly-accurate digital elevation models/maps (DEMs);
   - Urban management: identification/quantification of urban growth; transportation/industry infrastructure development monitoring; post-conflict/disaster urban damage assessment;
   - Land cover mapping: land-use classification/change detection; delineation of land and water boundaries.
2. In case of video cameras with real-time display, a ground resolution no better than 30 centimeters. As above.
3. In case of infra-red line scanning devices, a ground resolution no better than 50 centimeters. Weather and light independent sensor. Thermal IR detectors respond to the thermal radiation that each body emits. This sensor therefore allows viewing in poor-light conditions and, thanks to its ability to detect changes in ambient heat levels it can be used to profile temperature gradients. In terms of environmental data collection, thermal IR images obtained of the underlying surface could be useful for:
   - Studies of volcanic and geothermal areas;
   - Forest and underground coal seam fire[8] detection and monitoring;
   - Thermal pollution monitoring in urban areas;
   - Assessments of the state of water areas, irrigation and reclamation problems.

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[5] Mark David Gabriele, "Capabilities of the Open Skies Sensor Suite," ch. 2 in: *The Treaty on Open Skies and Its Practical Applications and Implications for the United States*. Santa Monica, CA.: RAND Graduate School, Ph.D. Dissertation, 1998, pp. 7-24.

[6] Ground resolution is defined as the minimum distance on the ground between two closely-located objects distinguishable as separate objects.

[7] It seems also possible for the Open Skies cameras to be able to capture images from select parts of the electromagnetic spectrum by using various combinations of filters and films. The types of imagery that could result, apart from panchromatic (B/W), would include natural color, false-color infrared, and black-and-white infrared photography. This capability may have significant application for vegetation monitoring. See Britting and Spitzer, "The Open Skies," p. 236.

[8] Wild coal seam fires are burning hundreds of millions of tons of coal every year, pumping huge quantities of carbon dioxide and pollutants into the atmosphere, and thus are contributing to climate change and damaging human health. See Jonathan Amos, "Coal Fires Are 'Global Catastrophe'." A *BBC* News service Story (February 14, 2003), pp. 1-3; "Wild Coal Fires Are a 'Global Catastrophe'." A *New Scientist* News Service Story (February 14, 2003), pp. 1-2, and; Harvey Black, "Feature: Coal Fires Threaten Environment." A *UPI* News Service Feature Report (March 6, 2003), pp. 1-2.

4. In case of sideways-looking synthetic aperture radar, a ground resolution no better than 300 centimeters (3 meters). Weather and light independent instrument. In environmental data collection mode, such a SAR would be most useful for:

   - Landscape topography change detection: if used in interferometric mode it can detect minute changes in landscape topography which has important application in monitoring of volcanoes, landslides, earthquake displacements and urban subsidence;
   - Mountain hazard management and disaster mapping (i.e., for glacial flood-burst events, monitoring of glacial advances and retreats, measurement of snow packs and ice sheets, landslide/avalanche inventory mapping);
   - Surface hydrological states and processes: boundaries of flooded rivers and water basins; flood effects mapping and monitoring; coastal-area (hurricane) damage extent-mapping; control of sea-surface pollution caused by damaged oil wells and oil terminals;
   - Deforestation: fire-burn measurement and mapping, illegal logging surveillance; determining boundaries of fields and forests;
   - Mapping of fields and ploughed soils: state of crops; assessment of soil moisture content; desertification of arable soils.

In accordance with the treaty, image data are shared between the observing and the observed state. Copies are also sent to imagery depositories in Ottawa and Budapest, where they are available to any treaty signatory willing to pay the reproduction costs.[9] The use of the thermal IR imaging capability is not permitted during the IOC phase, unless otherwise mutually agreed between the observing and the observed parties. The treaty also establishes a procedure for the introduction of additional categories and improvements to the capabilities of existing sensors on unanimous agreement by states-parties

[9] Michael R. Little, "US Open Skies." Air Forces Monthly Issue 181 (April 2003), p. 53.

Case Study I: Natural Disasters

Background

Natural and man-made crises are taking place today at an ever-increasing rate. Recently completed statistics indicate that the number that the number of reported crises have increased exponentially from just a dozen in the first decade of the 20th century to almost 500 in the 1990-96 timeframe alone. Most crises occur in smaller, developing countries where there is insufficient means to act effectively either before, during or after a crisis. In the main, we are witnessing the persistence of protracted man-made crises, emerging crises in areas considered to be stable in the past and, increasingly, adverse effects resulting from natural disasters.

From 1975 to 1994, for example, natural disasters have killed over 24.000 people and injured some 100.000 in the U.S. and its territories alone.[10] This U.S. experience reflects similar trends worldwide, except for the fact that the human toll elsewhere is in relative terms greater. Similarly, the dollar losses associated with most types of natural hazards are huge and rising. Munich Reinsurance estimates the total direct costs to the global economy due to natural disasters now to exceed some $ 400 billion <u>each</u> year.[11] While these sums may seem high, it is important to realize that when the numbers are disaggregated they represent only a small fraction of the Gross Domestic Product (GDP) for industrialized societies. By contrast, relative losses for smaller and developing nations represent a significantly greater fraction of their national economic output and can, as a result, set back their economic progress by years. Natural disasters are recognized today to be one of major impediments to sustainable development. In addition, what should be noted is the role that natural disasters play in displacing people. There are currently some 20-25 million of Internally Displaced People (IDPs) and around 12 million refugees worldwide.[12]

The Root of the Problem

The rising human toll and growing economic losses due to natural disasters is not an altogether unexpected occurrence but rather a consequence of complex interaction among three known variables.

A wide variation in the number and intensity of natural hazards is normal and to be expected. However, there were as many as <u>three times</u> great natural disasters in the 1990s as there were in the 1960s, which led many scientists to suspect that the recent upsurge was a product of something new. Today it is of course recognized that the Earth's physical system itself has been changed, which has led to the current increased warming of the global climate. A warmer climate, in particular higher levels of precipitation and diurnal temperatures, is expected to produce <u>more severe</u> and <u>more frequent</u> weather-related extremes, such as storms, floods, droughts and large-scale forest fires.[13]

Changes in the demographic composition and distribution of population globally increase the direct exposure of greater numbers of people to many natural hazards. Growing population pressure results in increasing residential occupation of hazardous lands, such as coastal zones that are subject to hurricanes, earthquake-prone fault zones, flood plains, unstable slopes of volcanoes and fire-prone areas. The settlement of hazard-prone areas usually also results in the destruction of local ecosystems that otherwise provide protection from natural perils, thus contributing to the next disaster and magnifying its effects.

The built-in urban environment, with its public utilities, vast transportation networks, its plants, homes and office buildings, is growing in <u>density</u>, making the potential losses from natural disasters larger with each passing year. Urban risks are particularly acute in case of the world's <u>megacities</u>, where rapid

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[10] D. Mileti, "Synopsis," in: *Disaster by Design: A Reassessment of the Natural Hazards in the United States.* Washington, D.C.: Joseph Henry Press, 1999, p. 18.

[11] Richard Holdaway, "Is Space Global Disaster warning and Monitoring Now Nearing Reality?" <u>Space Policy</u> 17 (2001), p. 127. See also, Ray A. Wiliamson, <u>*et al.*</u>, "The Socioeconomic Benefits of Earth Science and Applications Research: Reducing the Risks and Costs of Natural Disasters in the USA." <u>Space Policy</u> 18 (2002), pp. 57-65.

[12] Citing the 1999 UNHRC data. See Einar Bjorgo, "Supporting Humanitarian Relief Operations," ch. 19 in: John C. Baker, <u>*et al.*</u> (eds.), *Commercial Observation Satellites: At the Leading Edge of Global Transparency.* New York: McMillan for RAND and ASPRS, 2001, esp. pp. 403-404. See also: European Space Agency, *Crisis Preparedness and Humanitarian Aid.* GMES Working Groups, <u>Draft Requirements Briefing</u> (April 22, 2001), 9 pp.

[13] See, for example, "Climate Change Boosting Flood, Disaster Peril for Billions: Report." An *AFP* News Service <u>Story</u> (February 27, 2003), pp. 1-3.

population influx combines with fragile infrastructure to produce unprecedented vulnerabilities. In general, one expert observes, "... the earthquakes of Tangshan, China, in 1976, with 275.000 fatalities, and Kobe, Japan, in 1995, with losses in excess of $ 120 billion, are harbingers of the extraordinary loss and destruction that natural disasters can cause in a modern urban environment."[14]

A hazard may be defined as a phenomenon that may cause disruption to humans and their infrastructure. Atmospheric and geophysical extremes therefore can be regarded as "natural" hazards in the sense that they are inevitable. By contrast, disasters – i.e., events that can cause such disruptions, often involving entire communities, persisting after the hazardous event has come and gone, and exceeding the ability of the affected communities to recover unaided – reflect the ways societies do business. In this sense, the so-called "natural disasters" are primarily social in origin. They result from decisions and policies with respect to land management and land use, building and engineering practices, as well as the presence of supportive social institutions.[15] In situations where societal care frameworks are weak or altogether absent, the impacts of natural disasters can be politically just as destabilizing as are conflicts that arise out of political, economic, ethnic, religious or territorial disputes.[16] In that sense, natural disasters can be viewed as crises for they can create large numbers of refugees and/or IDPs in need of humanitarian relief and assistance in order to prevent even greater disasters, such as famines, epidemics, large scale political unrest or even complete societal breakdown, from taking place.

Monitoring Requirements

Natural disasters cannot be prevented, but their social and economic impacts can be mitigated though a set of activities and processes designed to lessen their effect – the disaster management program. Typically, a disaster management cycle can be broken down into three components, or phases: 1) Prevention and Preparedness; 2) Emergency Response, and; 3) Recovery. Each phase can be further divided into areas of dominant activity, with each link in the chain subsequently supporting all other and forming together a seamless system for managing disasters.

Prevention and Preparedness

Prevention involves activities implemented in advance of the event and which are aimed at the reduction of risk to human life, property and productive capacity. It leads to the collection and analysis of data to evaluate the likelihood of hazards taking place and the vulnerability of particular locations to these hazards. These result in the production of risk and vulnerability assessments. This activity goes under the term of Danger Assessment. Preparedness, on the other hand, refers to pre-event activities designed to increase the level of operational readiness for responding to and coping with a specific hazard. The dominant activity in that case takes the form of Detection and Early Warning.

Emergency Response

This is the crisis stage. It involves actions taken at the outset, during and immediately after the disaster intended to reduce the impact of the event after it occurs. During the crisis stage the dominant activities are Impact Assessment, to assess the extent, severity and location of the damage and thereby facilitate the provision of appropriate relief measures, and Emergency Relief, which involves activation of pre-planned relief strategies and the delivery of relief measures.

Recovery

These are actions taken to implement remedial measures in the weeks and months after the event. They result both in short-term activities, or Rehabilitation, to quickly revitalize life-supporting system in order to reduce the possibility of secondary damages, as well as long-term activities, or Reconstruction, where the goal is returning life to normal or improved levels.

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[14] Robert M. Hamilton, "Science and Technology for Natural Disaster Reduction." Natural Hazards Review (February 2000), p. 59.
[15] The U.S. Science and Technology Council, Committee on the Environment and Natural Resources, Subcommittee for Natural Disaster Reduction, *Progress and Challenges in Reducing Losses From Natural Disasters – Report*. Available online @: http://www.usgs.gov/themes/sndr/sndr09.html.
[16] G. Ted Constantine, *Intelligence Support to Humanitarian – Disaster Relief Operations*. Washington, D.C.: Central Intelligence Agency, Center for the Study of Intelligence, CSI Monograph 95-005 (December 1995), p. 3.

User Requirements

The system for managing disasters as a whole is highly information-intensive, though the information requirements typically will be different for each phase and activity. The Earth Observation (EO) technology already plays an important role in satisfying these requirements. For each type of disaster and disaster management phase there is a set of specific requirements that can be placed on the overhead sensor in order to make it useful for that particular purpose. The most significant differences in tasking relate to the temporal and spatial resolution and the accuracy of the required information. A search and review of relevant literature reveals however very little international consensus with respect to the actual measurement (resolution) values that are required for each phase and activity within the disaster-management cycle. By averaging out differences a common set of numerical values may nevertheless be obtained. They fall well within the range of what is generally desired and thus may be deemed as being representative of what the user community typically wants.

User requirements should be considered mainly in terms of the type of data needed. Some of that input necessarily comes from non-EO sources. Specific user requirements are described below.

Prevention and Preparedness

The importance of being prepared is currently being recognized as being most salient. This is because a growing number of geographical regions (Balkans, Caucasus, Central Africa, Central-South America) are being identified as having recurrent crisis situations, and in such cases centrals aspects of crisis events can even be anticipated. Thus, the key challenge is to prepare beforehand appropriate information infrastructure to support the aid organizations in the management of crises and in particular to improve the speed and effectiveness of crisis response.

In order to respond timely and efficiently to crises, humanitarian relief officials require landscape information, including transport infrastructure (roads, railways, canals, airports) as well as locational data on human settlements and land use data, specifically on agricultural and forested lands. Where possible, the locational data should be supplemented by information on local health infrastructure, i.e., the number and capacity of clinical centers and shelters. Landscape and locational data are needed the logistics of the aid operations.

Emergency Response

The primary requirement here is for rapid data collection within a short span in areas struck by disaster in order to obtain a first approximate damage assessment. "Damage assessment and rapid mapping capabilities remain key requirements of the humanitarian community." However, what is needed is a quick overview of disaster-struck areas rather than a detailed assessment of its state and extent/severity of the damage sustained. Such data should be delivered within one or two days of the event striking. Timeliness is critical. Data concerning the concentrations of the IDPs or refugees, as well as information on the movements of large numbers of displaced persons is needed on daily basis.

Recovery

A growing number of the reconstruction activities will be in the future increasingly funded by international organizations and, in place of development aid, national governments. These institutions will need data that would allow them to monitor the effects of their grants and transfer payments. High resolution EO data is particularly useful when activity stretching over a larger area needs to be assessed and continuing impact of reconstruction activities needs to be monitored.

The resolution values needed for the purpose of managing natural disasters are presented in the matrix below.

User Requirements	Spatial Resolution	Temporal Resolution	Delivery Timeliness	Sensor/Wavelength
Prevention & Preparedness				
Danger Assessment	10-30 m	2-4 wks	Monthly	- Pan/Optical (basemapping) - SAR (topographic maps, DEMs) - IMSR: vis/IR (NIR-SWIR) - Lidar
Detection & E/W	1-5 m	1-2 days then NR-T daily	Same	- IMSR: vis/IR (NIR+TIR) - SAR
Emergency Response				
Damage Assessment	0.5-1 m	2-3 days then 1-2 wks	Same	- Pan/Optical - SAR interferometry
Emergency Relief	1-5 m	5-14 days	2 wks	- Pan/Optical - SAR
Recovery				
Rehabilitation	1-5 m	1-3 mths	Same	- Pan/Optical - SAR
Reconstruction	1-5 m	4-6 mths	Same	- Pan/Optical - SAR

How does the existing Open Skies Sensor Suite Compare to these URs?

In the context of disaster management, Open Skies data could become relevant if or when: a) the users require primarily VHR optical and/or high resolution (HR) SAR imagery specifically for their basic data input, and b) less stringent requirements obtain (i.e., non-crisis rush) for the frequency (imagery refresh rate) and duration (dwelling time) of the photographic coverage. In practical terms this implies pre-event (i.e., UR #1) and post-event (i.e., UR # 3, 4, 5, 6) overflights, when crisis urgency subsides and the aim of detection shifts from emergency (surge) response to event extent-mapping, detailed damage assessment and reconstruction monitoring.

The most important task during the preparedness phase is the assessment of the exposure and the vulnerability of values (lives, property, natural resources) at risk. Risk assessment and vulnerability studies both depend on the availability of HR topographic and ground elevation data. Cartographic data on human settlements, transport infrastructure and urban-industrial interface in general are also needed. An Open Skies overflight could already satisfy both these requirements. In addition, at 30 cm ground resolution the Open Skies (stereo) optical data can readily be used as an input into the production of high-accuracy topographic maps and digital elevation models. This capability potentially could make a contribution toward satisfying UR #1. In the aftermath of a disaster, the most important activity is the assessment of the affected area. In this case, the Open Skies optical imagery could be used to map out in detail the extent and severity of the damage both to natural and man-made resources and to monitor the pace and progress of the reconstruction efforts, especially if these are funded by foreign aid dollars. This would satisfy UR # 4, 5, and 6.

What is the Information Gap: Which UR Data Needs the Regime Could NOT Support?

The Open Skies regime cannot support users' needs for multispectral data. The users' community regards this type of data as essential input in the production of environmental risk and vulnerability studies and for assessing the extent of the damage, both potential and actual, to the vegetation. An Open Skies overflight cannot be staged either for the purpose of early detection of an event. For catastrophic events, detection accuracy must be very high and time lapse for issuing alarm must be very short. An Open Skies mission simply cannot be expected to be on patrol at the right place at the right time waiting for the disaster to strike. Nor can such an overflight be staged as part of initial crisis response when timeliness of data delivery is critical and even 1 to 2 day delay renders data obsolete. Inability to dwell over an area for sustained periods of time and to relay data electronically in near-real time (NRT) further mitigates against such mission application.

How Well, On Balance, Could the Regime do the Job Right Now?

A tentative answer to this question is that the regime already could do a lot, even on the strength of B/W visible-light photography alone, and it could do it well. One activity in particular, spanning all six user requirements and being of critical importance to the success of each, is cartographic map-making. It might not be considered (by some) as a glamorous reconnaissance tasking but consider the following:

> "... Basic maps simply showing the location of settlements are still considered secret intelligence in many parts of the world. After the Afghanistan earthquake of February 20, 1998, which killed approximately 10,000 people, relief efforts were hampered by the unavailability of simple maps – the aid workers simply did not know the location of the affected villages".[17]

Growing costs of natural disasters together with the growing vulnerability of urban areas to natural disasters, dictate a need for accurate and current information on: 1) transport infrastructure and urban settlement (including refugee camps) location in remote areas since in many instances conventional maps simply are not available, even to "national" governments, or are badly out of date; 2) the exposure of human settlements and their physical proximity to areas of risk. The Open Skies regime can easily support this type of baseline mapping right now[18]. Such map-making could be an invaluable tool under any disaster scenario, i.e., during pre-event phase for planning purposes or during the post-event phase for administering relief and managing supply logistics.

What are the Points where the Open Skies Regime Carries a Clear-Cut Advantage over Satellite Observations, and vice versa?

There are two areas of consequence in the context of disaster management where the Open Skies regime has a clear-cut advantage over satellite observations: cost and spatial resolution.

There is currently no satellite system dedicated to disaster management. All of the systems presently in orbit were not designed with that objective in mind. They are all earth observation instruments with alternative primary missions that over the years have been "creatively" adopted in the service of disaster management.[19] By the same token, the user community is dependent on data feed from several

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[17] See Committee on Earth Observation Satellites (CEOS), *Earthquake Hazard Team Report.* CEOS Disaster Management Support Group (2001), p. 4.

[18] Satellite images with resolution of less than 5 meters are often used by the humanitarian aid community as surrogates for city maps or refugee camp maps in areas for which other type of mapping information is not available. GMES Partnership Working Groups, "Crisis Preparedness," p. 8. See also Bjorgo, "Supporting," pp. 404-407.

[19] This situation is changing. Most notably, seven organizations from Algeria, China, Nigeria, Thailand, Turkey, Vietnam and the UK have formed a consortium and agreed to contribute microsatellites into the Disaster Monitoring Constellation (DMC), the first ever satellite network specifically designed and dedicated to monitoring natural and man-made disasters. See "Microsatellite Constellation to Watch Over Disasters Forges Ahead." A *SpaceDaily* News Service Story (may 15, 2002), pp. 1-3, and, "First DMC Microsat Images Released." A *SpaaceDaily* News Service Story (April 3, 2003), pp. 1-3. The Brazilian and Chinese governments have recently signed an accord to jointly build two environment-sensing satellites, the CBERS-3 and CBERS-4 that are also explicitly intended to help cope with natural disasters. See, "Brazil and China Agree on New Satellite Venture." An *AFP* News Service Story (November 27, 2002), 1 pp. In addition, one of the primary mission objectives for the planned Italian COSMO-SkyMed satellite constellation is the monitoring of environmental disasters, such as floods and landslides. See, "Italy to Fund EO Fleet and Mars Water Search." A *SpaceDaily* News Service Story (March 12, 2003), pp. 1-4.

satellite data providers. When commercial data is used, the cumulative price, uniformity and access to satellite data become, especially for smaller, developing states, a major issue. The Open Skies regime, by contrast, could provide analogous data, with far better resolution, sooner, and at nominal cost.

Complex urban terrain and land use result often in a requirement for VHR data. Airborne sensors provide the best resolution data at present. There are currently no commercial, scientific, or natural resources satellite equipped with a 30 cm resolution sensor.

There are, however, also areas of advantage where capabilities available to EO satellites prevail over those that are available under the Open Skies Regime. These have to do mainly with long-term, sustained data-acquisition and global access.

- While airborne sensors provide data with best spatial resolution, this collection source can be potentially cost and time prohibitive when a need exists to access large areas. If space data were not available, airborne information gathering would be time-consuming and almost certainly could not be as comprehensive in the spatial domain.
- The maintenance of sufficiently dense network of *in situ* sites and stations for the purposes of Detection and Early Warning is very expensive. Space observation thus is often the only viable alternative. The limited resolution (and accuracy) offered by such measurements is however compensated by the wall-to-wall national coverage and high-frequency revisit rates.
- Satellite remote sensing is the only monitoring option for keeping watch over some active area when it is too hazardous to stage an airborne reconnaissance mission (i.e., like flying through volcanic ash plumes).
- Very rapid damage assessment and detailed mapping capability are key requirements of the humanitarian aid community. Only some satellites (medium-resolution, weather) have a daily repeat and rapid delivery (1 to 2 days) capability to provide a first approximate damage assessment. No other tool can provide such information.

What are the Areas of Synergy between Open Skies-Type Surveillance and Other Forms of Environmental Data Collection, be it Space Remote-Sensing or On-Site Inspections?

While VHR data (**Open Skies**, IKONOS, IRS-1C/D, Corona) is needed for infrastructure mapping, urban change detection and the production of DEMs, high resolution satellite radiometric data (SPOT-HRV/VEGETATION, Terra, Aqua, Envisat, Radarsat) is needed for compiling land cover databases, and medium-resolution satellite data (NOAA AVHRR, SPOT-VGT, Landsat-7 ETM), is needed for early warning purposes at national/regional scale. Geostationary satellite data (METEOSAT) is needed for early warning of meteorological events on daily basis.

However, EO data can supply only parts of the information mosaic needed for crisis-struck areas. Collateral data needed in humanitarian missions also includes information on the vulnerability and security of displaced people, the quality and capacity of the health infrastructure and availability of food. Data of that type cannot be obtained by EO means, but can only be obtained from local government institutions or from near real-time human sources present on the ground at the time of the disaster. NGO's, political groups, media/Internet are the most common sources of such information, although the validity of their claims sometimes is in doubt.

Case Study II: Global Warming

Background

The United Nations Framework Convention on Climate Change of 1992 (UNFCCC 1992) has the objective of "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." The Kyoto Protocol to the UNFCCC (UN 1997) is a key policy tool to be used to achieve that Convention objective. The protocol contains legally binding commitments to either reduce or limit the emissions of six key greenhouse gases (GHGs).[20] In addition, the Protocol contains agreed emission reduction targets for the so-called Annex I countries (i.e., the already industrialized states), which collectively amount to a 5.2 % reductions below the 1990 levels to be reached during the first commitment period – that is between 2008 and 2012. The Annex I countries are encouraged to reach these targets mainly by developing and implementing various emission-reducing projects in industrial and economic sectors. Progress must be demonstrated by 2005.

Further to the emission-mitigation projects in industry, a number of Articles within the Protocol make provision for the use of biological sources and sinks[21] to help parties to meet their commitments. The Protocol actions pertaining to biological sources and sinks center on Land Use, Land Use Change and Forestry (LULUCF) activities. The Protocol in addition makes provisions for countries to obtain (and trade) carbon credits (and debits) via the so-called "flexible mechanisms". These are governed by the Joint Implementation scheme in the developed world, and by Clean Development Mechanism (CDM) for the rest of the world. In the former case, developed countries may obtain emission reduction credits by implementing forestation projects within the territory of other Annex I countries and, in the latter case, by implementing them in developing countries (known as the "Kyoto Forests").

Kyoto Verification System

The verification system has been aptly described as "the backbone for the effective implementation of the Kyoto Protocol".[22] The prime objective of this system is to measure whether and to what extent States-Parties meet their emission reduction commitments. It is furthermore intended to provide reassurance that the reductions countries claim are genuine and not exaggerated or fictitious.

The Protocol's verification system builds on the provisions for monitoring, reporting and review established under the UNFCCC. Article 5.1 of the Protocol obliges Annex I countries to establish by 2007 "a national system for estimation of anthropogenic emissions by sources and removal by sinks of all greenhouse gases not controlled by the Montreal Protocol". Article 7 requires them to submit an annual report, including a national inventory, of all GHG emissions by sources and removals by sinks. Other articles specify the types of data for estimating national levels of GHG emissions and removals when compiling the annual inventories. Thus, Article 3.4 calls on countries for "data to establish its levels of carbon stocks in 1990 and to enable an estimate to be made of its changes in carbon stocks in subsequent years." Article 3.3 requires measurement data pertaining to the "net changes in greenhouse gas emissions by sources and removal by sinks resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation (ARD) since 1990". National inventories will be subject to in-depth reviews, as stipulated by Article 8, and in cases where the inventory data is missing or is deemed to be inaccurate national figures will be adjusted according to standard methodology defined in Article 5.2.

The Protocol's insistence on national systems for verification, reporting and accountability results in specific information requirements for its signatories. Earth Observation (EO) technology represents in that context a valuable source of environmental data, most notably in two areas of specific application:

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[20] These are: Carbon Dioxide (CO2), Methane (CH4), Nitrous Oxide (N2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), and Sulphur Hexafluoride (SF6).

[21] A carbon sink is a place where carbon is removed from the atmosphere. A forest ecosystem may be a sink if its assimilation of carbon through photosynthesis exceeds the levels of carbon emissions through harvest, fire or respiration.

[22] Molly Anderson, "Verification Under the Kyoto Protocol," ch. 9 in: Trevor Findlay and Oliver Meier (eds.), *The Verification Yearbook 2002*. London: VERTIC, 2002, p. 149.

1. The development of annual GHG inventories. As part of that commitment the signatories are required to: a) monitor measures promoting the protection and enhancement of carbon sinks and reservoirs on national territory (Art. 2); and b) measure changes in carbon stocks resulting from anthropogenic land-use changes and forestry activities (Art. 3.3). While these reporting instruments are essentially a national requirement, both the JIS and the CDM require information beyond any one's nation's boundaries. This automatically raises the need for trans-boundary information.

2. The verification of the accuracy of national declarations. Estimating net carbon emissions and withdrawals, and identifying land-use change within forested, cropped and agricultural areas on an annual basis, is by means an easy task, even for many Annex I countries. Reporting errors and inconsistencies are bound to appear as are attempts to deceive.

User Requirements

Within the verification process the user requirements for information are centered on four main areas. EO products can be used to satisfy each of these needs.[23]

1. National 1990 carbon stock estimate. This requirement calls for detailed mapping of forest sinks for the base year 1990, or shortly thereafter, including structured and comprehensive data on forest cover characteristics (Art. 3.4);

2. Annual variation in the carbon stock from the 1990 baseline. This requires regular, accurate mapping and measurement of changes in national forest inventory as related to forestry activity (ARD) and forest fires. To the extent that forestry projects under the terms of JIS and CDM become worldwide activities, then assessments of changes in land-use on global scale will become a reporting requirement. Of particular concern in that case will be issues related to forest fires and illegal logging. These too will become an automatic monitoring requirement.

3. Estimates of above-ground vegetation biomass. This requirement calls for mapping and monitoring of land resources and land-use change detection, including the provision of data suitable for conducting ecosystem productivity measurements.

4. National soils status and trends. Soils remove carbon from the air but they are very sensitive (and hence vulnerable) to over-exploitation and inappropriate land-use. Deforestation (drought, fire, illegal logging), overgrazing and bad irrigation practices can all undermine the land's fertility and thus the ability of the soils to circulate carbon to and from the atmosphere. The carbon stored in soils is nearly three times that in the above-ground biomass and approximately double that in the atmosphere. This requirement calls for baseline inventory and mapping of soils and for monitoring land-use changes.

[23] European Space Agency, *Global Forest Monitoring*. GMES Working Groups DRAFT Requirements Briefing (February 12, 2001), pp. 1-6, and also, European Space Agency, *The Terrestrial Carbon Sink*. GMES Working Groups DRAFT Requirements Briefing (April 23, 2001), pp. 1-9.

User Requirements	Spatial Resolution	Temporal Resolution	Delivery Timeliness	Sensor/Wavelength
1990 Baseline Estimate -Forest Status -Forest Type	 1-5 ha 1-5 ha	 1 x Year 1 x Year	 Same Same	 -IMSR: vis (Red)/IR (NIR) -IMSR: vis (Red)/IR (NIR)
1990 Baseline Variation (incl. ARD + Fire)	1-5 ha	1 x Year	Same	-IMSR: vis (Red, Blue)/IR (NIR-SWIR) -IMSR: vis/IR (TIR for fire detection) -SAR -Lidar
Land Cover Status/Trends	1-5 ha	1 x Year	Same	-IMSR: vis (Green, Red)/IR (NIR-SWIR) -IMSR: Passive Microwave -Lidar -SAR
Land Use	1-5 ha	1 x Year	Same	-Pan/Optical -IMSR: vis (Blue for soils)/IR (SWIR-TIR) -SAR

How does the Existing Open Skies Sensor Suite Compare to these URs?

Which UR Data Needs Could the Regime Support?

Of the four main categories of the users' need for data, at present time the Open Skies regime could provide suitable imagery to support only one of them – the variation to the 1990 carbon stock baseline – and even then only partially. Two monitoring parameters are of relevance here, namely the forest cover conversion (ARD) activities and the burned (or logged) areas of the forest. In either case, the Open Skies visual and SAR data could usefully complement radiometric measurements taken by orbiting satellites. Once it becomes available operationally in 2006, the Open Skies thermal infra-red data could be used for low-temperature hotspot detection, tracking of active fires at night and long-term monitoring of coal seam fires, both on the surface and below the ground.

What is the Information Gap?

Insofar as environmental monitoring goes in general, the most serious deficiency of the Open Skies regime at the present moment lies in its inability to collect multi-spectral radiometric imagery in visual and infra-red bands. In the narrower context of the Kyoto Protocol this deficiency effectively forecloses for the regime any possibility for contributing data in three areas of some import:

1. detection and tracking of fire-emission products (smoke, aerosols and particulate matter) in the atmosphere[24];
2. classification of vegetation by species, density, health and vigor, and;
3. detection, measurement and mapping of biomass change.[25]

[24] Although fighting forest fires may seem to be a local concern, the effects of forest fires are not only local. By emitting both GHGs and particulate matter into the atmosphere fires play an important part in climate change and they contribute to problems such as deforestation, desertification and air pollution. One of the main problems is that information on the effects of forest fires does not exist at regional and international scales. In addition, current global (and regional) estimates of fire emissions are extremely approximate and vary considerably. With the Kyoto Protocol in place the accuracy of biomass burning emission estimates must be improved for national commitments to be met and for national reporting to be verified as being accurate. See European Space Agency, *Forest Fires*. NADIS, Draft Requirements Briefing (February 21, 2001), p. 1.

[25] National biomass inventories and information on land cover changes (in terms of rate of changes, land use changes, processes driving changes and directions of change) are an essential element for producing national carbon release estimates. Yet even with Kyoto Protocol in place, this baseline information is often lacking, especially in the developing world. This results in a lack of consistency, if nothing else, in national reporting.

The regime is similarly unable to contribute related data sets on forest canopy structure characteristics and soil moisture, as these require input from a lidar instrument and a passive microwave radiometer respectively.

How Well, on Balance, Could the Regime do the Job Right Now?

The Open Skies cameras package deployed operationally at the present time compares unfavorably with the users' data needs required by the Kyoto Protocol. A guestimate arrived at for this study suggests that the regime could satisfy less than 20 percent of the users' data needs. This somber assessment should however be balanced by two qualifications which should be noted on the positive side of the ledger.

Should the Open Skies SAR instrument be capable operating in polarimetric mode, the door would open to high-resolution data that then could be used for estimating vertical structure and properties of forested areas and vegetated surfaces, including biomass volume and characteristics, its growth dynamics and floral biodiversity. A polarimetric SAR holds the potential[26] of providing high-quality data that is not simply complementary to radiometric imagery but which is in many respects directly substitutable for it.

While it is an established fact that wildland fire is the main mechanism of carbon release in northern latitudes, the question of whether fires render the boreal ecosystems a net "source" or "sink" of carbon remains an area of high scientific uncertainty. The fact that historically the boreal fires issue has been poorly documented and reported by the Russian authorities[27] compounds the extent of this uncertainty even further. As recent research shows, however, a C-band SAR can be used to recover the patterns and extent of burn scars in boreal forest areas long after the actual fires have burned.[28] A C-band SAR is sensitive to long-term moisture and roughness patterns that persist in the post-fire environment for long time and that, potentially, could make such SAR surveys particularly valuable for taking a "retrospective look" in order to detect and delineate the burned areas now long overgrown with fresh vegetation.[29] One can thus envisage an Open Skies SAR mission staged to help firming up the carbon emission numbers for areas where they are "soft" or simply are not available.

What are the Points where the Open Skies Regime Carries a Clear-Cut Advantage over Satellite Observations, and *vice versa*?

In case of carbon budget audits or investigations, the relative advantage for each of the two systems is largely defined in the trade-off between how much surface detail data should be collected (spatial resolution) and how much area should be observed at a given time (spatial coverage) and how often. The advantage rests with the Open Skies regime in the former case and with the satellite observations in the latter. The regime holds the advantage for conducting observations at local scales, while the satellites are the preferred mode of observation at national, regional and international scales.

There are, however, circumstances in the Kyoto monitoring process when access to details will make a difference. And it is in the details that possibility lies for improving carbon emission estimates. For example, mapping and inventorizing an area by forest type (down to species level and stand age), detecting, mapping and measuring vegetated areas damaged by fire or illegal logging activity, or compiling land cover change maps and statistics, are activities that all require high-resolution EO data – from both

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[26] See especially, European Space Agency, *Roundtable: New Radar Imaging Technologies For Earth Observation.* Observing the Earth Report (July 19, 2002), pp. 2-3.

[27] Eric S. Kasischke, et al., "Satellite Imagery Gives Clear Picture of Russia's Boreal Forest Fires." EOS Transactions 80 (1999), pp. 141 and 147. See also: David Herring and Robert Simmon (Design), *Evolving in the Presence of Fire.* A NASA Earth Observatory Features Report (October 1999), pp. 6-7.

[28] L. L. Bourgeau-Chavez, et al., "The Detection and Mapping of Alaskan Wildfires Using Spaceborne Imaging Radar System." International Journal of Remote Sensing 18:2 (1997), pp. 355-373; L. L. Bourgeau-Chavez, et al., "Mapping Fire Scars in Global Boreal Forests Using Imaging Radar Data." International Journal of Remote Sensing 23:20 (October 2002), pp. 4211-4234, and Brigitte LeBlon, et al., "Fire Danger Monitoring Using ERS-1 SAR Images in the Case of Northern Boreal Forests." Natural Hazards 27 (2002), pp. 231-255.

[29] This is in contrast to multi-spectral radiometers, the utility of which is largely restricted to spotting the initial changes in temperature and vegetative cover.

optical and radar sensors – which an Open Skies mission could provide and which satellites as readily cannot provide[30].

At the same time, it needs to be re-emphasized that climate change is a global phenomenon.[31] Scientific and technical research designed to reduce uncertainties related to climate change needs global-scale data and information. Global in scale, uniformly consistent and repetitive, and continuous measurements of the carbon stored in terrestrial vegetation and soil can at present be obtained only through the use of EO satellites. These systems also offer the most cost-effective means for obtaining long-term data sets on biomass productivity and vegetation structure generally.

What are the Areas of Synergy between Open Skies-Type Surveillance and Other Forms of Environmental Data Collection, be it Space Remote-Sensing or On-Site Inspections?

The capacity for determining land-use changes of vegetated surfaces and tracking developments in forested areas will be of paramount importance for the monitoring of compliance with the Kyoto Protocol. In case of forests, of particular importance will be the issue of forced forest conversion through unaccountable activities, like illegal logging, grazing and/or cropping, as well as timely and accurate mapping of burned areas. In that context there exists a number of opportunities for synergistic combination of data derived from Open Skies missions with measurements taken both by satellites and *in situ*.

For instance, as a preparatory step in support of ground inspections, the Open Skies optical photography could be used for mapping the layout of the terrain, including access routes, as well as local settlements and structures related to the activity being investigated. Where ground inspections could not take place (i.e., physical access, insurgency) Open Skies slant photography might be the closest thing to a pair of eyes on the ground.

In case of burned area mapping (and damage characterization) unique opportunities exist in the use of an Open Skies instrument to complement functionally the same instruments carried by the satellites. Most notably, the Open Skies high-resolution SAR imagery could be used to complement the medium-resolution SAR imagery produced by the numerous SAR-carrying satellites. Such combination offers opportunity for improving the frequency of observations and for intercalibration and comparison of measurements taken by independent sensors. The combining of the Open Skies optical and SAR data with satellite medium-resolution multi-spectral radiometric data offers even more unique synergistic opportunities, although mainly for purposes of event bio-geophysical characterization rather than event detection and areal delineation.[32]

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[30] The images produced by the satellite sensor most commonly used now in carbon budget investigations – the Moderate-resolution Imaging Spectroradiometer (MODIS) instrument flown on-board of NASA's *Terra* and *Aqua* spacecraft – vary between 250 to 500-meter and 1-kilometer resolution. A single MODIS-type pixel (i.e., the smallest visible unit in the picture) thus represents quite a large area. An area 500 square meters in size can easily contain highly variegated mixture of vegetation, yet the MODIS-pixel will record only one type of ground cover. The satellite, as one user of MODIS imagery has commented wryly, is always "going to average something out of the picture." And so he supplements his MODIS-type data with the CORONA-program B/W framing cameras photography! See Michon Scott, *Fiery Temperament*. NASA Earth Observatory Features Report (May 14, 2002), p. 5.

[31] Both the Convention and the Protocol are international treaties with global character. Article 10(d) of the Protocol puts an obligation on the committed parties to contribute to global observing systems and to support scientific and technical research concerning the climate system and climate change.

[32] A very useful discussion of space instrument synergies can be found in R. A. Vaughan and S. T. Wilson, "*Envisat* – the Mission," ch. 13 in: Arthur P. Cracknell (ed.), *Remote Sensing and Climate Change: The Role of Earth Observation*. Chichester, UK: Praxis Publishing, 2001, esp. pp. 248-251.

Case Study III: Environmental Stress

Background

The last area where one might envisage extending the application of the Open Skies regime has to do with *environmental stress*, or the depletion and/or degradation of the natural resources of the land. The depletion and degradation of and the subsequent the competition over renewable resources is the result of contamination, mismanagement and over-utilization. Environmental change impact on four basic media of the environment: air, water, soils and various components of biological diversity. These range from ecosystems and habitats to species and genetic resources. Many species and resources are found in more than one country (i.e., trans-boundary river basins and/or boundary watercourses) and require international cooperation for their conservation. This reality highlights the critical importance of developing productive links between and among countries.

Presented below are some natural and man-made pressures behind environmental stress.

Climate Change

Climate change is expected to have a range of consequences, notably effects on agriculture and water resources. There is also growing scientific evidence that natural ecosystems are among most sensitive to global warming. Changes in the volume and distribution of precipitation as well as changes in the incidence of climatic extremes, especially high temperature extremes, put crops at risk from late frost, summer drought and emergent plant diseases. More frequent and intense heatwaves and/or drought will stress water resources, increasing the risk of fires. Shifts in climate zones will move faster than the ability of many plant species to migrate – a way of escape which in any event may already be foreclosed because of the intensity of land-use by man. Recently it has been reported that "habitat loss to climate change in the next 50 years will be greater than all the land lost to agricultural clearing to date."[33]

Disasters due to Natural Hazards

Much attention traditionally has been focused on the threat that natural hazards pose to people and structures. The threat of natural hazards to habitat and various ecosystems demands a similar priority, especially when ecosystems are the basis for economic livelihood. The maintenance of productive fishing, agriculture together with livestock raising and forest product utilization depends on minimizing all forms of ecosystem degradation.[34] Damage from floods and drought, landslides, wildfires (with associated smoke and haze) and other disasters with climatological background (i.e., severe and adverse temperature variation) is increasing as a result of changes in the landscape as well as from more frequent appearance of extreme weather events attributable to climate change.

Chemical Pollution and Contamination

The enormous increase in waste and the widespread use of chemicals during the past 40 years have resulted in large swathes of potentially productive land being lost due to soil and groundwater contamination. Major sources of chemical contamination include inappropriate and unauthorized waste dumpings, improper handling of hazardous and toxic substances, abandoned industrial/mining sites and military installations, and agricultural intensification. At present time, soil (and groundwater) contamination with heavy metals, oil products and PCBs around abandoned military bases in Eastern Europe and on the territory of the FSU poses the most serious ecological risk. Chemical pollution is also caused by ozone concentrations in the troposphere and by emissions of ozone-depleting substances into the stratosphere. Decreased ozone in the stratosphere is unwanted because a thinner ozone layer results in more ultraviolet-B (UV-B) entering the lower atmosphere and reaching the Earth's surface. UV-B radiation can initiate a number of chemical and biological processes that are harmful to the humans and, especially, aquatic ecosystems. UV-B radiation can also adversely affect the growth of terrestrial plants.

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[33] Reported at the annual meeting of the American Association for the Advancement of Science by Thomas Lovejoy, president of the H. John Heinz III Center for Science, Economics and the Environment in Washington. See Dan Whipple, "Climate Change Threatens Biodiversity." A *UPI* News Service Story (February 18, 2003), p. 1.
[34] See Hamilton, "Science and Technology," p. 59.

Monitoring Requirements

A review of literature suggests there are no clear-cut phases or stages associated with monitoring of environmental stress. Nevertheless, information requirements for that process may be extensive and demanding. Monitoring environmental stress means in practice monitoring each medium of the environment for the presence of principal threats inherent to that medium and for effects of these threats on that medium in terms of extent, severity and dynamics of progression. Additional data may be needed to support analyses and assessments of particularly severe instances of environmental degradation, the "hotspots" of environmental stress, and also to establish legal liability in case of man-made pollution. Specific user requirements may be as follows.

Air

Concern here is with gaseous emissions, as a source of environmental stress, and the levels of air (and environmental) pollution, as the effect. Emissions of particular concern are: 1) dioxins and heavy metals output from industrial smelters and waste incinerators; 2) smoke and aerosol output from forest fires and volcanic eruptions; 3) GHG output from industrial plants and transportation; 4) ozone output from transportation and industry and its deposition in the troposphere, and 5) acidifying substances (mainly sulphur dioxide and nitrogen oxide) output from the burning of fossil fuels. The EO technology has a role to play at least in three areas: 1) detection and identification of emitters and toxic air pollutants[35], especially in urban areas; 2) supply of maps of atmospheric load of particulate matter, especially over urban areas, and; 3) assessment of environmental degradation and of its impact on trans-boundary and regional security. The relevant parameters where EO data is required are: regional and trans-continental transport paths and loads; particle characterization, and; spatial distribution and local concentration by volume.

Water

The total freshwater resource of a country is the water held in dynamic storage in rivers, lakes, reservoirs and aquifers. It includes water flowing into these states from neighboring countries. Trans-boundary flows make a significant contribution to the total freshwater resources of many states. Increasing population, industrialization, the intensification of agriculture (irrigation, land reclamation), impoundment (building reservoirs, dams), not to mention over-exploitation and pollution, have all significantly increased pressure on inland waters worldwide and more conflicts are developing between various users and uses. Tensions arise especially where resources are limited.[36] Droughts add to the problem. The role for EO technology is basically two-fold: monitoring of water use patterns by multiple parties and providing assessments of impacts of shortages/scarcity on security. The EO data needed includes the following parameters: 1) total availability volume and recharge rates; 2) levels of abstraction surface and ground water; 3) surrounding land use, especially percentage of irrigated lands; 4) surface water quality and levels of pollution (water color, films), and; 5) flow regulation works and impoundment works affecting trans-boundary flows.

Soils

Soil is necessary for the growth of crops of food, fiber and timber, and it is an essential component of all terrestrial ecosystems. Degraded soils are no longer capable of supporting cultivation, resulting in land abandonment and migration. Soil loss is thus not only a direct threat to sustainable development but it has wider strategic implications for food security and trans-border refugee movements. Today soils are subject to increasing pressures worldwide. Among the most severe soil degradation threats are: 1) erosion, both by water and wind;[37] 2) pollution by heavy metals, pesticides and other organic contaminants, nitrates and phosphates, and artificial radionuclides; 3) desertification and deforestation. Other important threats

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[35] Not only trace gases but also aerosols and volatile organic compounds.

[36] See, for example, "Pakistan-India Water Talks Fail to Resolve Kashmir Dam Row." An *AFP* News Service Story (February 7, 2003), pp. 1-3, and, "Conflict Looms Over India's Colossal River Plan." A *New Scientist* News Service Story (February 27, 2003), pp. 1-3.

[37] This is a major and accelerating cause of soil loss today. Reduction in vegetative cover through inappropriate farming practices, unsustainable forestry, fires and overgrazing have all significantly contributed to this end as has inappropriate water management practices.

include: 4) agricultural intensification;[38] and 5) urbanization and transportation infrastructure development.[39] EO technology can assist sustainable soil management efforts by providing assessments of the quality of arable soils. To that end, EO data would be required on the following parameters: 1) moisture content; 2) mineral content and composition; 3) surface temperature; 4) salinity; 5) extent of erosion; 6) lands added to or abandoned from agricultural production, and changes in cropping systems, and; 7) fertilizer and irrigation use.

Biological Diversity

Biological diversity is a measure of variation in genes, species and ecosystems. Diversity is the base of stability and sustainable functioning of natural systems and thus is the basis for the survival of the human species. Further, biological resources are renewable and with proper management can support human needs indefinitely. These resources, and the diversity[40] of the systems which support them, are therefore the essential foundation for sustainable development. There is a large (and growing) body of evidence indicating that human activities are eroding biological resources and greatly reducing the planet's biological diversity. The main environmental changes responsible for biodiversity decline and loss are: 1) highly intensive, partially industrial forms of agricultural land use; 2) deforestation; 3) expanding urbanization and infrastructure development; 4) industrial pollution of water, air and soils, and 5) climate change. Estimating the current rates of loss or even current status of ecosystems is however challenging, because "no systematic monitoring system is in place and much baseline information is lacking."

To measure (and prevent) the decline in biodiversity EO technology might be of considerable help. It could provide data which could then be used to establish baselines for further monitoring of biodiversity status and trends, and which could also be used for detecting change. With respect to biological diversity, what needs to be observed for evidence of stress are the known ecosystems and habitats in general, with emphasis to be placed on the internationally and nationally-protected conservation areas and/or areas particularly sensitive to environmental change (i.e., polar regions). Baseline data is needed on habitat definition and on areas located in unaffected nature. Change detection data is required to identify landscape changes and to establish paths and patterns of habitat migration. Baseline data is also needed especially on land cover (for classification, characterization, inventory mapping and change detection of vegetation) and land use (for classification, inventory mapping and change detection) for both protected areas and areas located in unaffected nature. Continuous monitoring in both cases may also be required to keep track of urban encroachment and infrastructure expansion, and to detect and assess the impact of environmental damage resulting from mining operations (ground subsidence, tailings, chemical effluents and waste) and other industrial activities.

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[38] Agricultural clearing of land in addition results in habitat and species loss. Abandonment of fragile croplands, often followed by fire and/or overgrazing, strips the soil bare promoting severe soil erosion.

[39] This results in irreversible soil loss through sealing under constructions, such as urban/industrial premises and transport infrastructure, reducing soil use options for future generations. Road building leads to habitat fragmentation. Mining, quarrying, and excavation for landfills – industrial landscape modification – further leads to soil loss as well as soil and groundwater chemical contamination.

[40] Genetic diversity provides the variability within which a species can adapt to changing conditions. While this is important to all species, genetic variability in cultivated and domesticated species has become a significant socio-economic resource. Without the genetic variability which enables plant breeders to develop new varieties, food production would be far lower than it is at present, and far less able to adapt to inevitable changes brought on by global warming.

User Requirements	Spatial Resolution	Temporal Resolution	Delivery Timeliness	Sensor/Wavelength
Atmospheric Pollution	10-50 km	Daily at National Scale	< 1 week	-IMSR: vis/IR (NIR) -Spectrometer: UV-SWIR -Lidar: vis-NIR -Interferometer: MIR-TIR
Inland Water Bodies	30-60 m	1wk – 1m	1 m	-Pan/Optical -IMSR: vis/IR -SAR -Thermal IR Scanner (TIR)
Arable Soils	30m–1km	1m-4xannually	1-4 m	-Pan-Optical -SAR -IMSR: vis (Blue)/IR (SWIR-TIR) -IMSR: Passive Microwave -Thermal IR Scanner (TIR)
Biodiversity Loss -Land Cover	60-250 m	Annually	Same	-IMSR: vis/IR (NIR) -SAR
-Land Use	10-30 m	Annually	Same	-Pan/Optical -SAR

How does the existing Open Skies Sensor Suite Compare to these URs?

Which UR Data Needs Could the Regime Support?

The Open Skies regime can at the present moment support a partial monitoring of the natural environment in three of its media: water, soils and biodiversity. The best data that the regime could provide would be with respect to urbanization and infrastructure mapping for soils and biodiversity and flow regulation works for water. Further, the regime could usefully monitor patterns of land use, especially the cropped and irrigated lands, and it could equally usefully watch for signs of environmental degradation in form of soil erosion and salination (using SAR imagery) as well as for signs of desertification and deforestation.

What is the Information Gap: Which UR data needs the regime could not support at the present?

At the present time, the Open Skies regime lacks the sensing equipment to monitor one whole medium of the environment – the atmosphere and its chemistry. As a consequence, the regime cannot support the detection, identification and measurement of toxic pollutants in the air.[41] Lacking the ability to collect multispectral radiometric data in particular, the regime can neither be used to monitor the levels of chemical pollution in surface waters and soils, to assess the mineral content and/or composition of the soil, or the health and characteristics of vegetative biomass.

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[41] This has significant implications especially in case of the numerous civilian nuclear reactors, used both for commercial purposes and to advance scientific research. During their operation, every reactor generates gaseous, liquid and solid radioactive waste that can cause radioactive contamination of air, soil, water and vegetation. Radioactive gases and aerosols ejected in air are the source of radioactive contamination of airspace far beyond the reactor building itself. In many countries, not all necessary *in situ* monitoring systems are functional or even present, making it difficult to determine the level of contamination of ambient air by radioactive aerosols or the direction of their airborne travel. For more detail on remote sensing of dust, smoke, aerosols and rare gases see: Yoram J. Kaufman, et al., "A Satellite View of Aerosols in the Climate System." Nature 419 (September 12, 2002), pp. 215-223, and Mike Sharpe, "Analyst in the Sky: Satellite-Based Remote Sensing." Journal of Environmental Monitoring 2 (2000), pp. 41-44, and, European Space Agency, *Satellite Sniffs Out Chemical Traces of Atmospheric Pollution.* Observing the Earth News Story (November 16, 2002), pp. 1-2.

How Well, on Balance, Could the Regime do the Job Right Now?

Under the terms of the IOC the regime lacks the sensing capability to monitor central aspects of environmental stress. Most notably, the regime cannot provide data on the chemical contamination in all four media of the environment or on the levels of water stress within the vegetative land cover. On the other hand, the panchromatic, high-resolution photography holds enormous promise for a certain category of environmental "hotspot" monitoring, specifically with respect to instances of stress that came into being as a consequence of large scale land use practices and/or man-made works. Two examples can illustrate this point.

- Although urban sprawl normally covers only a small fraction of the total land area, that land is usually the most arable.[42] In countries where there is relatively little arable land to begin with, urbanization and infrastructure development that takes place at the expense of prime farmland have obvious and direct implications for food security and, in longer run, political stability. The Open Skies regime could play an early-warning role here, and not only in keeping watch over the direction of urban and infrastructure development, but also to identify "hotspot" areas subject to high levels of soil degradation or desertification risk;

- A significant factor in regional security is competition for scarce resources. Of particular relevance in that context is competition over water, concerning specifically both the quantity and quality of freshwater derived from rivers shared in common among a number of parties. Many of these rivers are heavily polluted as a result of mining, industrial and other activities and pose a threat to the environment and the health and safety of users living downstream. The total volume of available water for many downstream users is also shrinking. The main reason is that the water demand for agricultural use has increased dramatically worldwide and water is drawn off from the feeding rivers for irrigation purposes. Regional competition can be exacerbated by uncertainty over the upstream country's river regulation works and whether such sensitive activities constitute a threat. Shared river basins present a unique opportunity for cooperative environmental monitoring to enhance local and regional security[43]. The Open Skies regime could play a potentially useful role under this scenario too. By providing a measure of transparency, in form of high-resolution panchromatic monitoring of water works (i.e., various flow regulation and impoundment schemes), it could help alleviating reasons for conflict and help building confidence as a precursor for a more elaborate trans-border resource management regime. And, if a multilateral or a bilateral water sharing agreement is struck, why not have the Open Skies regime monitor it?

What are the Points where the Open Skies Regime Carries a Clear-Cut Advantage over Satellite Observations, and *vice versa*?

There are two viable points that could be made in favour of the Open Skies regime:

- The surveillance of the urban and industrial infrastructure requires very high to high resolution photography. Panchromatic B/W photography in fact is optimal. In that regard, the Open Skies regime can provide data that is of higher quality, and much cheaper, than that offered either by the U.S. IKONOS or India's IRS-C satellites – the two systems most commonly used at the present time for that purpose;

- The Open Skies regime is not bound in place by orbital dynamics. It can follow a winding river, a pipeline or a rail line – much as the early U-2s flying over the Siberian wilderness

[42] See John Weier and Robert Simmon (Design), *Reaping What We Sow: Mapping the Urbanization of Farmland Using Satellites and City Lights.* NASA Earth Observatory Features Report (November 1, 2000), pp. 1-8. See also, "Cities Eat Away at Earth's Best Land." A *New Scientist* News Service Story (December 20, 2002), pp. 1-3, and, Michon Scott, *The Human Footprint.* NASA Earth Observatory Features Report (February 25, 2003), pp. 1-7.

[43] Perhaps the best known examples of cooperative monitoring of transborder river flows, both in terms of their quantity and quality, are the experimental research projects instituted by the Sandia National Laboratory's Cooperative Monitoring Center for: 1) Tumen River that forms part of the border between China and North Korea and between Russia and North Korea; 2) the Kura and Araks rivers both originate in Turkey, but then flow through Georgia and Armenia, respectively, and then into Azarbaijan, and; 3) rivers Syr Darya and Amu Darya as well as their major tributaries, all of which are shared among the Central Asian republics of Kazahstan, Kyrgyzstan, Tajikistan, and Uzbekistan. For more information see www.cmc.sandia.gov/index.htm.

followed the "first-class roads with wide radius turns" all the way to the Soviet ICBM silo complexes.[44]

Because changes in land use (and especially in agricultural land use) are likely to dominate near to medium term changes in the quality and quantity of goods provided by ecosystems to humans, it is of critical importance to have an adequate characterization of the spatial distribution of vegetative cover. For exploitation purposes the spatial resolution in this case does not need to be very high. A resolution of 1-5 kilometer is finer than many researchers are currently using, and not finer than the scale over which significant variation in vegetative processes occurs. What matters more instead is assured spatial coverage and availability of multispectral data, which only satellites at the present moment and for that purpose can provide.

What are the Areas of Synergy between Open Skies-Type Surveillance and Other Forms of Environmental Data Collection, be it Space Remote-Sensing or On-Site Inspections?

Environmental stress monitoring is an activity that may range from very large areas to parts of individual cities. The kind of data to be used depends, in part, on the size of the area and the scale of the application. For large areas and for a regional scale satellite data is most appropriate, for example NOAA (AVHRR) and Resurs, and Landsat 7 and SPOT (HRV and/or VEGETATION instrument), respectively. For a city scale, on the other hand, the Open Skies photography could most usefully supplement the IKONOS or IRS-C imagery.

[44] See interview with Dino Brugioni, "Master of the Surveillance Image." A *PBS* NOVA Special in Spies That Fly Series (February 2003), p. 4.

CONCLUSION

Natural Disasters

The current (IOC) Open Skies EO capability has some limited use in the Prevention and Preparedness (i.e., Mitigation) phase of natural disasters risk management and a somewhat greater use in the Response and Recovery phases, but none for the purposes of early warning. In the latter context, the Open Skies regime simply cannot come anywhere near to the required levels of timeliness and reliability. In terms of mitigation, the Open Skies EO capability could be useful, particularly in case of smaller, developing nations, for base-mapping of emergency relief logistics and estimation of settlement/structure vulnerability (i.e., soundness of building design) and exposure (i.e., direct physical proximity to risk areas). In the response phase, the potential of the regime for making a useful contribution comes from its capability for conducting detailed urban and industrial damage assessment and mapping; and in the recovery phase, from the monitoring of reconstruction progress.

In the context of disaster risk management, the relevance of the Open Skies regime is real and substantial. That relevance stems from two characteristics of the situation as it obtains right now. First, an increasing percentage of the world population is concentrating in urban areas that in turn depend on complex infrastructure for their effective functioning. Roads, pipelines, power grids and telecom networks are all particularly vulnerable to natural hazards because a single break in the network can render the entire system useless. The Open Skies panchromatic photography is ideally suited to conducting detailed assessments of urban/industrial infrastructure, including estimates of the number of people affected by a disaster and/or being displaced into refugee camps. The second reason as to why the Open Skies regime enjoys a niche advantage has to do with the fact that remote sensing satellites have significant limitations for supporting humanitarian relief operations. Persistent cloud cover can delay the delivery of the satellite EO data by weeks. Another limiting factor is the cost of satellite imagery.

The Kyoto Protocol

The importance of and the need for terrestrial carbon sink monitoring cannot be overstated. Climate change is a major factor behind an increasing incidence of natural disasters and an increase in their severity. Rising global temperatures constitute also an important category of environmental stress. The Kyoto Protocol makes provisions for the use of biological sources and sinks to meet national commitments especially related to afforestation, reforestation and deforestation, the so-called ARD activities. Further, if forestry projects are allowed to proceed on a wider scale under the terms of the CDM, then not only national but worldwide assessments of changes in ARD become a mandatory monitoring requirement.

Both the current and FOC technical capabilities of the Open Skies regime are simply too limited to provide sound basis on which to build a reliable terrestrial carbon sink measurement and monitoring system that could satisfy user requirements at international, regional and possibly even national scales. The regime cannot provide radiometric data at 500 m-1 km spatial resolution that is required in order to produce central baseline inventories: the forest cover statistics for reference years 1990 and 2000 and forest fire statistics for reference years 1990 and 2000. By the same token, the regime cannot provide data that are needed to produce land cover maps and land cover change maps. Lacking global coverage and daily revisit capability, the regime can neither be used for near real-time monitoring of the major perturbation that can radically alter forest carbon stocks – vegetation fires. However, by using its SAR sensor in particular, the regime potentially could contribute data at local scale. The Open Skies SAR data could be used to provide maps and statistics of ARD at a local scale to be used as input for national inventory. In could be also used to assess fire impact on ARD activities and to provide detailed quantitative estimates of forest conversion in general.

Environmental Stress

Land cover changes resulting from human activities constitute a major cause of environmental degradation and of biodiversity loss. For instance, biomass burning plays a major role in the human-induced land cover changes. Repeated burnings can force changes in various ecosystems and promote the process of desertification and/or shifts in biodiversity. Land clearing by fire also contributes significantly to the release of carbon dioxide into the atmosphere. In turn, natural hazards forced by global warming pose a growing threat of long-term and even permanent damage to the environment and the biodiversity on which all societies depend.

Both the IOC and FOC capability of the Open Skies regime are insufficient to characterize the state of the vegetated surfaces or to document the seasonal and inter-annual land cover change. However, the SAR and the thermal IRLS instruments potentially give the regime a theoretical capability to identify and monitor areas, specifically areas having to do with water and soils, where the most drastic changes take place. The Open Skies panchromatic photography could provide data for land use mapping and land use change detection. That data could also be used for the monitoring of infrastructure development.

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