POTENTIAL OF THE OPEN SKIES REGIME AND SENSOR SUITE FOR ENVIRONMENTAL MONITORING *

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ABSTRACT

The Open Skies Treaty aims at improving openness and transparency in order to strengthen peace, stability and security among the 27 state parties in North America, Europe and Northern and Central Asia. Technical preparations for treaty implementation have been made by military agencies in many of the states. The preamble of the Treaty envisages also “the possible extension of the Open-Skies regime into additional fields, such as the protection of the environment“. One obvious field of application is the rapid monitoring of environmental desasters with border-crossing impact. This contribution addresses three questions:
1) to what extent is the present sensor set of the Treaty suited for monitoring of the environment?
2) Which modifications of the sensor suite would strengthen the capacity for environmental monitoring?
3) Which institutional provisions and operational procedures have to be worked out in order to arrive at agreeable and cost effective solutions?
The most important and straightforward upgrade for environmental monitoring will be the inclusion of false-color infrared film (replacing panchromatic film). However, cost effective applications for military confidence building and environmental monitoring can only be achieved through synergistic solutions, which require institutional flexibility.

1.0 TREATY PROVISIONS RELEVANT TO ENVIRONMENTAL MONITORING

The Treaty on Open Skies, signed in Helsinki on March 24th, 1992, represents the most wide-ranging multinational effort so far to enhance openness, military transparency and confidence building through mutual aerial observation flights. Its purpose is to facilitate the monitoring of compliance with existing or future arms control treaties and to strengthen the capacity for conflict prevention and crisis management. The preamble envisages also “the possible extension of the Open -Skies regime to additional fields, such as the protection of the environment“. Although the current interest of the state

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parties is focussed primarily on the military, confidence and security building aspects of the Treaty, it is worthwile to take a closer look at the potential of the Open-Skies regime for environmental monitoring.
In this respect the following provisions of the Treaty are relevant:

- It includes 27 state parties from ‘Vancouver to Vladivostok’, in particular 16 NATO states, as well as Belarus, Bulgaria, the Czech Republic, Georgia, Hungary, Kyrgyzstan, Poland, Romania, Russia, Slovakia and Ukraine
- It opens virtually the full air space including border areas of all state parties to observation flights. Flights can be arranged on short notice of a few days. They are carried out in a cooperative manner with observers from at least two states on board.
- Presently agreed imaging sensors provide high resolution (30-50 cm) photographic, video and thermal infrared images, as well as moderate resolution (3m) Synthetic-Aperture-Radar (SAR) images. This establishes an all-weather, day-and-night monitoring capability. Sensors have to be commercially available to the state parties.
- Copies of the image data are avilable at nominal cost to all state parties. However, although unclassified, data will be accessible to state agencies only for purposes in accord with the treaty. Hence, there are limits to openness.
- A joint commission, the Open Skies Consultative Commission (OSCC) supports the implementation and further development of the treaty and arrives at decisions by consensus.

Section IV of Annex L to the Treaty addresses additional fields for use of the Open-Skies Regime, as follows:

1. “States Parties may raise for consideration in the Open Skies Consultative Commission proposals for the use of the Open Skies regime in additional specific fields, such as the environment.
2. The Open Skies Consultative Commission may take decisions on such proposals or, if necessary, may refer them to the first and subsequent conferences [of all state parties] called to review the implementation of the Treaty.“

The OSCC has held two informal seminars on the possible use of the Open-Skies regime for environmental monitoring on 3-4 December 1992 and on 11-12 July 1994. However it seems to be common understanding among the state parties that further steps in this direction will not be taken before entry into force of the Treaty. Entry into force can only take place once treaty ratification in the parliaments of Russia, Belarus and the Ukraine has been completed. It also has turned out that responsibility for Treaty implementation and for bearing the costs, so far, has been assigned exclusively to military establishments of the state parties. Hence in order to arrive at a viable scenario for environmental monitoring under Open-Skies basic questions of institutional interest and responsibility have to be clarified. This issue will be addressed below (section 5.0). Before let me take a closer look at the Open-Skies sensor suite and its potential for environmental monitoring.

2.0 CURRENT OPEN SKIES SENSOR SUITE

The state parties have agreed initially on a choice of imaging sensors, in particular:

- optical panoramic and framing cameras with a ground resolution of 30 cm;
- video cameras with real-time display and a ground resolution of 30 cm;
- thermal infrared imaging sensors with a ground resolution of 50 cm at $\Delta T = 3^{\circ}C$ (temperature resolution)[*], and

[*] Thermal infrared line scanners can only be operated for Treaty use three years after entry into force.

- imaging radar (Synthetic Aperture Radar, SAR) with ground resolution of 300 cm.

With regard to photographic cameras the Treaty allows for one panoramic camera, one vertically mounted framing camera and two obliquely mounted framing cameras. The ground coverage of these cameras is limited to 50 km on each side of the flight path[**] . Radar coverage will be limited to a ground swath of 25 km on one side of the aircraft. The transverse ground distance of this swath from the flight track can be chosen freely. The *recording media* will be (a) black-and-white film for photographic cameras, (b) magnetic tape for video cameras, (c) black-and-white photographic film or magnetic tape for thermal infrared sensors, and (d) magnetic tape for radar.

The resolution definition for the photographic systems is not the standard photogrammetric definition. The Treaty resolution is approximately equivalent to a pixel resolution of 30 cm of a electro-optic sensor. For further information on sensors and sensor resolution see e.g. (Spitzer 1996) and references given therein. Table 1 gives an overview of current and planned sensor types on Open-Skies aircraft. A group of ten states, the so called pod-group (Belgium, Canada, France, Greece, Italy, Luxemburg, the Netherlands, Norway, Portugal, Spain) have jointly pursued the development of a sensor pod to be installed under a C-130 Hercules aircraft. This concept allows for any like model C-130 to be used for Open-Skies observation missions. The other states listed in Table 1 operate one or several aircraft exclusively for Open-Skies use. Table 2 gives more detailed information on the performance of the sensors of the German Open-Skies aircraft.

Table 1 Current and planned sensors on Open-Skies aircraft

State	vertical framing camera	oblique framing camera	panoramic camera	video camera	infrared line scanner	radar
Bulgaria	1	-	1	1	1	-
Czech Republic	1	-	-	-	-	-
Germany	1	2	1	3*	1	1
Hungary	1	-	-	1	-	-
Romania	1	-	-	1	-	-
Russia and Belarus	1	2	1	1	1	1
Turkey	1					
Ukraine	2	-	-	-	-	-
United Kingdom	1	-	1	1	1**	-
United States	1	2	1	1	1	1
Pod group	1	2	1	2	-	-

* The german video system provides color images (red, green, blue)
** optional

[**] In practice, the ground swath covered by photographic cameras will be smaller. E.g. a Russian-made panoramic camera A-84 on board of the German Open-Skies aircraft (opening angle 143˚) will cover a ground swath of 20-40 km at flight altitudes of 4000 to 8000 m.

3.0 POTENTIAL OF CURRENT SENSORS FOR ENVIRONMENTAL MONITORING

The current Open-Skies sensor suite can be applied for a number of monitoring tasks, which require spatial resolution between 30 cm and 3 m. Applications might exploit either one sensor type only (e.g. photographic cameras for mapping under fair weather conditions), or take the benefit of jointly exploiting different sensor types through sensor fusion (e.g. photographic and thermal images for urban heat loss studies). Study of vegetation is currently hampered by the lack of color and multispectral information (except for the german color video system). Table 3 gives the authors estimate of the usefulness of current sensors for different monitoring tasks. SAR systems will be particular useful for situations where three meter resolution is sufficient but all- weather capability is mandatory. The usefulness of different SAR systems for environmental monitoring is further discussed in (Schmullius 1997).

Table 3 Estimated potential of current Open Skies sensors at Treaty resolution for different monitoring tasks. The number of stars gives estimated usefulness.

	photographic camera *	thermal imager	SAR
mapping and urban planning	* * *	* *	*
urban heat losses	*	* * *	-
Vegetation, crops	*	* *	*
water supplies	*	* *	* *
soils	*	* *	* *
air quality	-	-	-
fires	*	* * *	* *
floods	*	*	* * *
earthquake and hurrican damage assessment	**	* *	*
reactor accidents	*	* * *	*

* With sufficient image overlap for stereo viewing and panchromatic film

The bottom part of Table 3 addresses monitoring of emergencies. Here thermal imagers will provide very good 24 hour coverage of fires and other heat releases (e.g. from reactor accidents). SAR sensors can spot the extent of flooding at day and night. Although rated lower, photographic images will provide accurate spatial information as a baseline information on the spatial impact of environmental emergencies.

4.0 CHOICES OF ADDITIONAL SENSORS IN SUPPORT OF ENVIRONMENTAL MONITORING

The current sensor suite was optimized for recognition of heavy military equipment and military infrastructure, rather than for environmental monitoring. However, the Treaty contains an option for including additional sensors at a later stage. According to Article IV "the introduction of additional [sensor] categories and improvements to the capabilities of existing categories of sensors provided for in this Article shall be addressed by the Open Skies Consultative Commission...." Such addition can be decided upon three years after entry into force of the Treaty.
From the point of view of environmental monitoring the most cost-effective upgrade will be the inclusion of *Color Infrared Film* as a recording medium of photographic cameras. Color Infrared Film is the 'workhorse' of civilian monitoring of urban areas, vegetation, soils, water supplies etc. in the pre-digital age. It is sensitive to radiation in the near infrared at wavelengths from 0.7 to 0.9 µm, where different kinds of vegetation are strong and distinctly different reflectors of sunlight. Such film provides also much improved contrast and recognition potential for objects in built areas. Although more expensive than panchromatic (black and white) film by a factor of three use of such film will raise the overall cost of an observation flight by a small fraction only.

As a next step *multispectral digital imaging sensors* have to be considered for environmental monitoring. Again civilian multispectral sensors, like the Thematic Mapper on the LANDSAT Satellites (featuring seven spectral channels) and their airborne counterparts have been the work horses of wide area monitoring of built land, agricultural areas, nature reserves and geological sites for two decades.

The United States Defense Nuclear Agency has led a comparative study, which evaluated the potential benefits of multispectral and hyperspectral sensor additions for Open-Skies missions (Ryan 1996). The study considered multispectral imaging sensors to be the most beneficial addition both for environmental monitoring and for military Open-Skies objectives (e.g. camouflage detection). The authors recommend as a low risk approach the Daedalus Thematic Mapper ATM. This sensor has 11 spectral channels at wavelengths from 0.4 to 12.5 µm and an instantaneous field of view of 1.25 mrad in one of two possible operation modes, providing a ground sample distance of 2.5 meters at a flight altitude of 2000 m. Multispectral sensors will enhance considerably the potential for monitoring of urban areas, agricultural land, forests, rivers and special problem areas like waste deposits. Hence they open the door to detailed studies of land use and the state of the environment. Digital multispectral imagery is also a very useful basis for computer based semiautomatic change detection (see e.g. Wiemker 1997). Needless to say, analysis of multispectral digital imagery requires some investments and expertise in computing, atmospheric corrections and geocoding. In addition the quality of analysis will benefit a lot when airborne data are complemented with ground truth data.

A large number of *non-imaging-sensors* has been discussed at the informal seminars on the possible use of the Open Skies regime in the field of environmental monitoring, which were mentioned above. I want to emphasize here only two types of devices;
a) Lidar (Laser reflection measurements) for detection of atmospheric composition and pollution.
b) Air samplers as a basis for detection of radioactivity in the atmosphere.

5.0 APPLICATION SCENARIOS AND INSTITUTIONAL QUESTIONS

In spite of initial enthousiasm the interest in an extension of the Open Skies regime into environmental monitoring has cooled down, at least on the level of the governments of major state parties like Germany and the United States. The reason is quite obvious. Many state parties of the Treaty have adequate facilities in the state and commercial sector for monitoring of the environment.

These aircraft are usually much smaller than current Open-Skies aircraft and hence can be operated at lower cost. There is also an element of inter-agency competition.

In consequence, several basic questions have to be answered first, before environmental application scenarios can be developped:

1. What kind of environmental situation in state A could motivate state B to perform a dedicated environmental monitoring flight in state A under the Open-Skies regime in spite of the cost?
2. Which kind of environmental monitoring tasks would exploit and require the special ‘virtues’ of the Open Skies regime (unlimited territorial access, short response time, priority over any other air traffic)?
3. Are dual-use flights negotiable, which would cover both military and other target areas in one go? Such flights would be most cost-effective.
4. Who would be responsible for requesting and analyzing data from environmental Open-Skies flights? Who would bear the costs?
5. To what extent can data from environmental monitoring flights under Open-Skies be made fully open and accessible e.g. to researchers and local users?

Let me discuss several application scenarios in the light of these questions:

5.1 ENVIRONMENTAL EMERGENCIES

Certain emergency situations and desasters in state A could justify a monitoring flight by state B under Open-Skies, if

- the impact is of border crossing nature (like the radioactive plume of the reactor catastrophe at Chernobyl).
- humanitarian reasons require rapid response from the outside (like a major earthquake or flood damage which cannot to dealt with by local/national resources).

Here, one can assume sufficient interest on the side of state B. Flights costs would have to covered by state B from funds for international emergency situations.

5.2 BORDER CROSSING ENVIRONMENTAL PROBLEMS

Certain environmental problems and management tasks are of border crossing nature (like pollution and flood control of border crossing rivers, salination and wind erosion in arid areas , effects of acid rain etc.). Here we can assume a mutual interest of two or several states in a joint monitoring flight. Such flights under Open-Skies will be only attractive if

- civilian monitoring capacities are lacking;
- civilian monitoring agencies of state A do not have full territorial access to state B;
- Open Skies flights can be arranged in a cost-effective, dual-use way serving both military and civilian customers.

Here, a mutual interest of two or several state parties affected by the particular environmental problem can be assumed. Hence it would be natural to share the flight costs or to arrange flights on a reciprocal basis. Within each state cost sharing between military and civilian users has to be clarified also, as well as mechanisms for mission request, mission planning, shutter control and data distribution. From the authors perspective dual-use flights are financially most attractive. Another way of tackling the cost problem would be an arrangement of declaring such flights as mutually agreed training flights.

5.3 VERIFICATION OF INTERNATIONAL ENVIRONMENTAL CONVENTIONS

Several international environmental conventions have been concluded or are in preparation (like the Montreal Ozone Protocol, the Climate Convention, the Convention on Biodiversity etc.). At present these conventions lack agreed verification procedures based on satellite or airborne monitoring. However airborne multispectral monitoring under Open-Skies could make useful contributions in future in situations where good spatial and spectral resolution matters (see e.g. di Primio 1994).

6.0 CONCLUSIONS

The Open Skies regime opens interesting avenues for environmental monitoring, in particular through

- data fusion from different sensors (photographic cameras, thermal imager, SAR);
- inclusion of color infrared film and eventually also multispectral imaging sensors
- inclusion of non-imaging sensors.

In competition with other data sources (civilian airborne and satellite monitoring) application scenarios should concentrate on areas which encompass major intentions and virtues of the Open-Skies Treaty, in particular confidence building and management of (environmental) crises in a cooperative way. Thus, applications for monitoring of

- environmental emergencies and desasters
- border crossing environmental problems
- verification of international environmental conventions

should be considered first and studied in more detail. Challenging institutional questions have to be solved in order to make best use of Open Skies in this area.

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	Sensor	Focal Length	Film Format	Operation Altitude	Ground Resolution at Operation Altitude	Ground Swath covered at Operation Altitude
1.	3 Framing cameras LMK2015 (Zeiss, Jena)	152mm	228 x 228mm^2	1600-5900m	30cm$^{(1)}$ (with degrading filters)	8.3-32.5km (3 cameras)
2.	3 Video cameras, 3 colours VOS-60 (Zeiss, Oberkochen)	60mm	3 x 6000 pixels pixel size 0.012mm	1500-5000m	30-100cm$^{(1)}$	5.9-19.5km (3 cameras)
3.	Panoramic camera A-84 (Zenit, Moscow)	300mm f/4.5	130 x 127mm	4000-8000m	30-60cm$^{(1)}$	20-40km
4.	Thermal infrared line scanner AN/AAD-5 (Honeywell, USA)	angular resolution : 0.25mrad thermal resolution : 0.2K digitization : 8 bits		1500m	50cm$^{(1)}$	5.2km
5.	Synthetic Aperture Radar ROSSAR (Kulon, Moskau; Dornier)			$\geq$ 1000m	300cm$^{(2)}$	25km$^{(3)}$ (sideways)

Notes (1): Optimum ground resolution will only be achieved in the vertical direction.
(2): This is the ground resolution transverse to the flight direction.
(3): The ground swath can be moved sideways from the flightline.

Table 2

Technical parameters of the sensors of the German Open-Skies aircraft. Sensors 3-5 will be operational in 1999. Two framing cameras and two video cameras are mounted obliquely at 33^o relative to the vertical direction (source: [WEITZEL 1996] and information from "Zentrum für Verifikationsaufgaben der Bundeswehr, Geilenkirchen")