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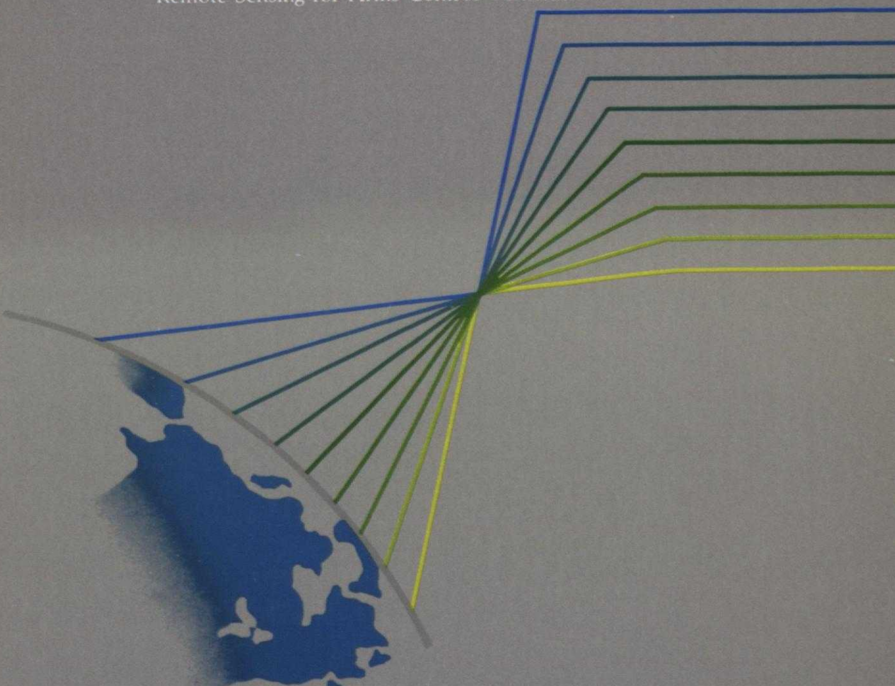
PAXSAT Concept

The Application of Space-Based Remote Sensing for Arms Control Verification



Verification Brochure No. 2

We recommend that Canada intensify its efforts, multilaterally within NATO, the United Nations and in disarmament forums and bilaterally with the United States, the Soviet Union and other countries, to win acceptance for a comprehensive set of arms control measures . . . [including] The prevention of an arms race in outer space.

> Recommendation 16e in the Report of the Special Joint Committee of the Senate and the House of Commons, ("The Hockin Report"), June 1986.

Canada is making substantive contributions to the discussion on this subject at the Conference on Disarmament. Canada's Verification Research Unit has commissioned research on space-based verification as a basis for further Canadian proposals.

> **Canada's International Relations: Response of the Government of Canada to the Report of the Special Joint Committee of the Senate and the House of Commons, December 1986.**

PAXSAT Concept

The Application of Space-Based Remote Sensing for Arms Control Verification

The graphic on the cover page represents the ongoing dialogue on arms control and disarmament issues in Canada and between Canadians and the world community.

On peut se procurer une version française de cette étude en écrivant à l'adresse suivante :

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Introduction

Introduction

Scores of artificial "eyes" are, at this moment, peacefully surveying our planet from outer space. Circling the Earth at different altitudes, these man-made sensors, commercial and military, belong to several countries and watch for various things: some passively gather data for intelligence purposes, some monitor the growth of crops, some watch the weather, some hunt for minerals. Among the multitude of applications for which satellites are employed, one has acquired increasingly critical importance with respect to reaching arms control and disarmament agreements: the use of space-based remote sensing for verification purposes.

Up to now, it has been the United States and the Soviet Union that have adapted their space-based surveillance capabilities to arms control verification, mainly with respect to their bilateral agreements. It is now becoming more and more apparent that other nations, some already with a stake in space, recognize a responsibility to become more closely involved in certain aspects of space surveillance.

One of the major undertakings of the Verification Research Program of the Department of External Affairs over the past several years has been to bring together a team of experts from government, universities and industry to focus Canadian space technology and know-how on its application to the process of arms control verification. A distinctly Canadian concept, termed PAXSAT ('pax' being Latin for peace), has emerged from these investigations. It centres on assessing the feasibility of applying space-based remote sensing technology to the tasks of verification in the context of multilateral arms control and disarmament.

PAXSAT research has concentrated on two potential applications of space-based remote sensing to multilateral arms control verification. The first is space-to-space remote sensing (PAXSAT 'A') which deals with verification of agreements involving space objects. The second, space-to-ground remote sensing (PAXSAT 'B'), focusses on how to assist in the verification of agreements involving conventional forces. This brochure will examine the PAXSAT concept in general terms, outlining the context of multilateral arms control verification and some of the major assumptions underlying the PAXSAT projects.

Figure 1 Definition of Verification

Verify v.t., Establish the truth or correctness of, by examination or demonstration. (Concise Oxford Dictionary)

An arms control agreement is essentially a compromise in which each side bases at least part of its national security on the promises of the other contracting parties rather than on the strength of its own weaponry. Consequently, reciprocal confidence that all parties will live up to their obligations is essential, particularly in conditions of suspicion and uncertainty. Since the benefit to each participating state derives from the compliance of the other participants in the agreement, there is a natural desire for some form of external assurance that all participants are fulfilling their obligations. In simple terms, verification is the means by which such assurance is gained. Consequently, the reliability and adequacy of the verification measures associated with an arms control agreement are usually of vital importance, both to the successful negotiation of an agreement and to its successful implementation once it enters into force.

The actual methods used to verify an arms control agreement can vary widely: from on-site inspection where inspectors physically visit a facility, to the use of remote sensors located some distance from the area being examined. The latter systems have proven of particular importance for verifying bilateral arms control agreements between the USA and the USSR. Such systems, called "national technical means" (NTM), are not identified in the texts of any of these bilateral agreements. However, the United States Arms Control and Disarmament Agency has provided a useful definition of "national technical means":

> *Assets which are under national control for monitoring compliance with the provisions of an agreement. NTM include photographic reconnaissance satellites, aircraft-based systems (such as radars and optical systems), as well as sea- and ground-based systems (such as radars and antennas for collecting telemetry).*

While many technical systems thus come within the scope of NTM, there seems to be general agreement that satellite systems, because of their relative unobtrusiveness, are among the most important.

Remote Sensing

Chapter 1

Remote Sensing

What Is It?

Remote sensing can be defined as the use of electromagnetic radiation to record from a distance, data on the environment (often in the form of images), which can be interpreted to yield useful information. Put more simply, remote sensing means being able to monitor objects or events from far away. The design of remote sensing systems involves consideration of a number of factors such as:

- **The source of the electromagnetic radiation to be recorded:** This source may be natural in origin like the light of the sun and the heat emitted from the Earth, or it may be man-made like radar.

- **Target interaction:** The characteristics of the target will affect the amount and characteristics of the energy emitted or reflected from it.

- **Atmospheric interaction:** The atmosphere may distort or scatter electromagnetic radiation passing through it. In the case of space-to-space remote sensing this factor does not apply.

- **The sensor:** The device which records the energy reaching it from the target is a key element.

- **Data transmission:** Once sensed, the data must be transmitted from the sensor platform to the ground, where it is received and stored.

- **Analysis and interpretation:** Before the data can be used it must be processed and analyzed by computers and skilled human interpreters. This is a significant aspect that is often overlooked.

Remote sensors can be located on the ground, on ships, on aircraft and on spacecraft. This discussion focusses on those devices used on satellites.

A variety of space sensors detect electromagnetic energy. These include photographic cameras, return-beam vidicon cameras, infra-red detectors, and multispectral scanners. Radars and passive microwave sensors can also be used from space. In addition, electronic listening devices mounted on spacecraft can be used to detect communications transmissions and radar emissions.

Civilian and Military Applications

Space-based remote sensors have become an indispensable tool of modern society for both civilian and military purposes. Many of the same types of equipment are used for both. Generally, however, military remote sensors have been designed for much higher resolutions than their civilian counterparts. Resolution is related to the size of the smallest object a sensor can distinguish and it is determined by the focal length of the sensor, its distance from the object being viewed, and the size of the "picture element" or pixel of the sensor's recording medium.

Some reports claim that the most advanced military space surveillance systems have a ground resolution in the order of 10 cm. In contrast, the best ground resolution of current commercial satellites is about 10 m. For some arms control verification tasks, it may be sufficient to merely *detect* an object or activity, while other tasks may require *identification*, which is more demanding in terms of resolution. As an example of the resolution that may be required for verification purposes, studies have indicated that a ground resolution of 4.5 m is necessary to detect an aircraft using optical sensors, while .9 m is needed to identify it.

The Need for Military Sensors in Space

Military surveillance from space has been clearly beneficial in its application to arms control verification. Even when used exclusively for military purposes these systems have contributed directly to international peace and security through the maintenance of effective deterrence. Without them, the fear of surprise attack — especially during periods of political crisis — would have necessitated defence postures and military deployments which would have been much less safe than those of today. As a result, it is reasonable to conclude that military space-based surveillance systems have contributed to the maintenance of peace for the past two decades. To interfere with their effective functioning would have been counter-productive in terms of global security.

Military space-based surveillance systems are, and will probably continue to be, essential to the verification of significant arms control and disarmament agreements. The PAXSAT concept in no way impinges upon the critical role played by these systems.

Commercial Remote Sensing Technologies

The rapid development of civilian remote sensing satellites over the past two decades has been extraordinary. Among those designed to view the Earth's land surface in fair detail, are some that provide data which is sold commercially. Of these, the two most important operating examples are LANDSAT and SPOT. LANDSAT is the name given to a series of remote sensing satellites launched by the United States. The LANDSAT program was "privatized" in 1985 and continues under a consortium called EOSAT. The fifth in this LANDSAT/EOSAT series of satellites was launched in 1984 and there are plans for more. SPOT is a satellite developed by France. The first one, in an anticipated series of four, was launched in January 1986. SPOT also operates on a commercial basis.

Images produced from both these satellite systems, which have recently appeared in the press, on television and in trade publications for a variety of media purposes, have suggested to many the possibility of using such data for arms control verification.

These published photos include the following:

- LANDSAT and SPOT images of the Chernobyl nuclear reactor site in the Soviet Union which suffered a catastrophic fire in April 1986.
- LANDSAT images of the Iran-Iraq war.
- LANDSAT images purportedly showing construction of surface-to-air missile (SA-5) sites in Libya.
- LANDSAT image allegedly showing under-ice launch tests of Soviet submarine launched ballistic missiles (SLBMs) in the Arctic Ocean near Wrangel Island, USSR.
- LANDSAT image of the Kola Peninsula in the northern Soviet Union purportedly showing newly constructed air and naval (submarine) bases.
- LANDSAT image of an alleged mobile intermediate-range ballistic missle (SS-20) base near Kirov, USSR.
- SPOT images of Soviet space shuttle facilities at Tyuratam, USSR.

Figure 2 Electromagnetic Spectrum

This figure illustrates the electromagnetic spectrum and identifies some of the devices used to sense radiation of different wavelenghts. Just as the human eye is sensitive to only a small portion of the spectrum (visible light), some sensors can "see" in one band of wavelengths. However, other sensors can be designed to focus on several of different bands which are optimized for the task at hand.

Not only do remote sensors increase the range of the electromagnetic spectrum with which we can "see" but through the use of magnification as well as image enhancement and analysis techniques, the detail provided can be greatly increased.

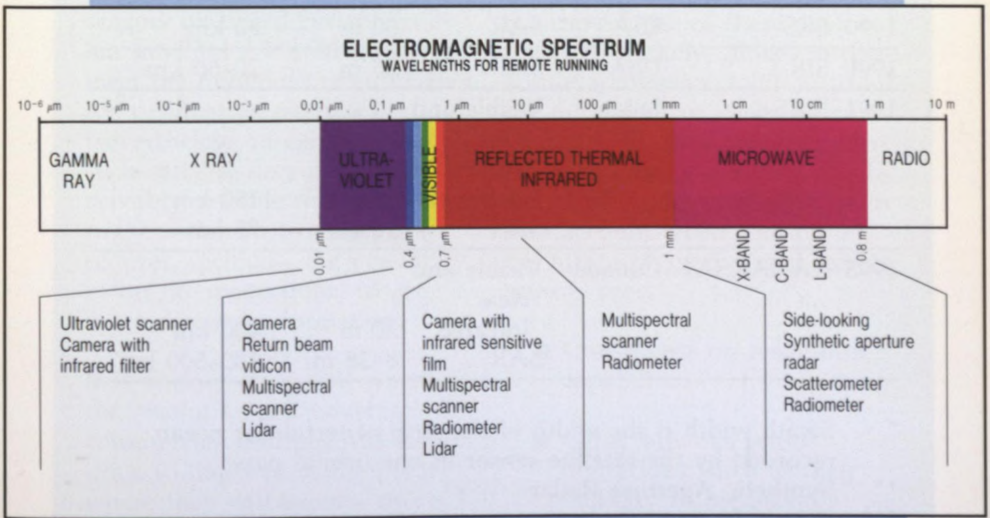


TABLE 1 Some Existing and Proposed Civilian Earth-Sensing Satellites

Year	Program	Country	Sensors	Resolution	Swath Width*
1978	SEASAT-1	USA	SAR**	25 m	100 km
1981	SIR-A***	USA	SAR	40 m	50 km
1982	LANDSAT-4	USA	Thematic Mapper	30–120 m	185 km
			Multi-spectral Scanner	82 m	185 km
1984	SIR-B	USA	SAR	25 m	20–50 km
1986	SPOT	France	Visible and Near Infrared	20 m	2x60 km
			Panchro-matic	10 m	2x60 km
1989	LANDSAT-6	USA	Enhanced Thematic Mapper	15–120 m	185 km
			Emulated Multi-spectral Scanner	60 m	185 km
1990	ERS-1	ESA****	SAR	30 m	80 km
1990	SIR-C	USA	SAR	25 m	20–50 km
1991	JERS-1	Japan	Visible and Near Infrared Radiometer	25 m	150 km
			SAR	18 m	75 km
1993	RADARSAT	Canada	Visible and Near Infrared	30 m	400 km
			SAR	8–28 m	100–500 km

* Swath width is the width of the strip of terrain or ocean recorded by the satellite sensor in one orbital pass.
** Synthetic Aperture Radar.
*** Shuttle Imaging Radar.
**** European Space Agency.

- SPOT images of a secret facility near Samarra, Iraq allegedly producing chemical weapons.

In January 1986 it was also reported that LANDSAT imagery was being used to monitor Soviet military activities in the Far East. Another interesting press report in August 1986 suggested that SPOT images taken on behalf of a Swedish firm indicated apparent preparation in the Soviet Union for a resumption of underground nuclear testing.

All the above seems to suggest that existing civilian Earth observation satellites could be used to provide information of some relevance to arms control verification. Realistically, however, the resolution and the design of sensors on-board current civilian satellites are unlikely to meet the minimum requirements for verification purposes. Nevertheless, in certain cases such satellite data might conceivably provide the impetus to trigger other fact-finding procedures, including the possibility of on-site inspections, to get more detailed information.

It is unclear at present whether the resolution and coverage of commercial satellites will continue to improve to the point where they will become more effective for arms control verification. Their primary mission — civilian Earth sensing — may simply not demand such a capability. There is, however, another possibility suggested by the above examples: perhaps the technology developed for civilian Earth observation, or which is currently planned for such satellites, could be adapted for more direct application to arms control verification. This idea is one of the central themes underlying Canada's PAXSAT research.

A Note of Caution

There has sometimes been a tendency to view space-based remote sensors as almost all-seeing — to believe that they can watch everything going on below. Before ending this general discussion of the use of such sensors, it is important to enter a note of caution about the capabilities of these devices: they are unlikely, alone, to constitute a complete solution to all the difficulties of verifying compliance with arms control undertakings. Among the very significant limiting factors to be taken into account when considering the utility of space-based remote sensors are:

- Constraints on resolution capabilities.

- Other obvious sensor limitations, such as their inability to see inside buildings, underground or deep underwater.

- Environmental and climatic considerations, such as the amount of available light and the extent of cloud over.
- Satellite orbital and coverage constraints.
- Launch vehicle payload constraints.
- Limitations on fuel and lifetime of the spacecraft.
- Data processing constraints caused by collection of massive amounts of satellite data.
- Cost and availability of relevant technical expertise.
- The possibility of interference with the sensors or the use of deception methods such as camouflage.

Through co-operation and the use of other verification methods, many of these limitations can be largely overcome, but serious political problems relating to national sovereignty and the intrusiveness of these other methods must first be successfully addressed.

Figure 3 A Variety of Remote Sensing Images of Ottawa

The images appearing on pages 21-27 show Ottawa, from several altitudes using different remote sensing devices. They illustrate some of the capabilities of a variety of overhead remote sensors sensitive to various parts of the electromagnetic spectrum.

The radiation received by a remote sensing device possesses characteristics dependent in part on the object that has reflected or emitted the radiation. By analysis and interpretation of this data, information concerning the object can be derived. This information content varies depending on the wavelength of electromagnetic radiation being sensed.

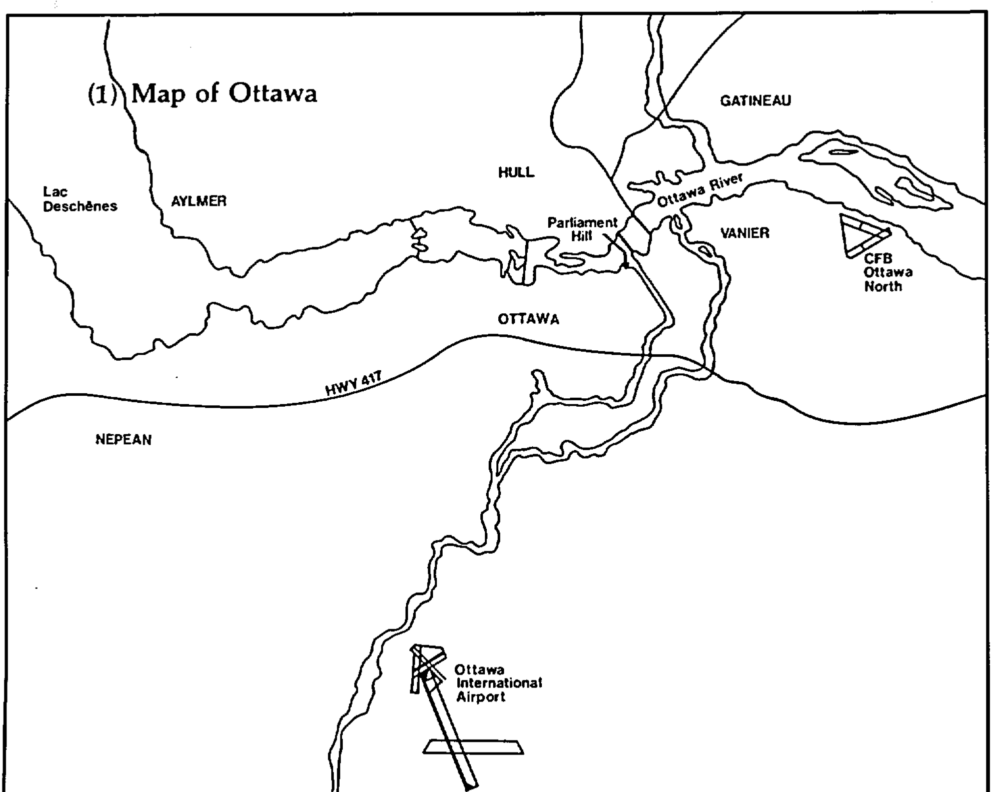
As these images show, the distance of the sensor from the object being imaged is an important factor in remote sensing because it directly affects what can be "seen". Sensors based on aircraft can generally provide images with much greater detail than those on satellites. On the other hand, the "swath width" or amount of terrain viewed by the sensor is usually much narrower for airborne sensors than for satellite-borne ones. In other words, aerial sensors usually see fewer things in greater detail than do satellite sensors which can cover much more territory. This inter-relationship between the detail of imaging and the scope and rate of coverage is indicative of many similar trade-offs involved in choosing the right remote sensor for the task at hand.

One of the chief advantages of space-based remote sensors in the context of arms control verification is the fact that these devices do not intrude into national airspace. However, a key problem resulting from their location hundreds of kilometres above the Earth, is to be able to "see" objects and activities below in sufficient detail to determine whether an arms control obligation is being breached. An additional complication is that such monitoring involves watching and recording events occurring throughout very large tracts of territory, over which a satellite may pass only intermittently.

An important feature of remote sensing to remember in the context of arms control verification, which is also illustrated by these pictures, is the benefit derived from complementary use of different types of sensing devices. For example, thermal infra-red imaging possesses unique sensing capabilities (and limitations) that are not identical to those provided by other types of remote sensors such as visible-light cameras or radar.

Consequently, by employing a variety of types of remote sensors in conjunction, there is greater opportunity to acquire relevant information for verification purposes.

Several of the images on these pages were made using information in digital form, which can be processed using computers. Such processing can considerably increase the useful information derived from the raw data produced by the sensor. For example, while the resolution of an image cannot be improved by such computer enhancement techniques, it is possible to reduce blurring and poor contrast. Photographic film has in the past generally provided better resolution than such electronic sensors, but this is no longer the case.



(2) Airborne synthetic aperture radar (SAR) image of Ottawa, taken on January 28, 1986 from a height of 9.5 km using a STAR-1, K-Band SAR with 6 m resolution. It is interesting to note that the small dots that appear in portions of the Ottawa River are reflections from ice-fishing huts. Civilian applications of SAR imagery include mapping, geology, agriculture, oceanography, and ice studies. **(Courtesy of INTERA Technologies Ltd., Ottawa)**.

(3) SEASAT L-Band synthetic aperture radar (SAR) image of Ottawa. SEASAT was an experimental US satellite intended mainly for oceanography. This image, taken on July 30, 1978 from an altitude of about 800 km, has a ground resolution of about 25 m.

Radar has the advantages of being able to penetrate cloud cover and to operate both during the day and at night. However, because of its longer wavelength, radar generally has a resolution considerably poorer than that of visible light sensors. In the case of SAR, synthesizing a longer aperture for the radar through the use of the motion of the platform, permits greater resolution to be achieved. Some sources suggest that a resolution for space-based SARs of 1 m may be realized within the next decade.

Because radar involves generating electromagnetic pulses which are reflected back to a receiver, they require the use of a greater

power supply than do most other sensors; a disadvantage when weight is critical, as in the case of satellites. SARs also generate a massive amount of data which places a considerable burden on its processing by computer. **(Courtesy of Canada Centre for Remote Sensing)**.

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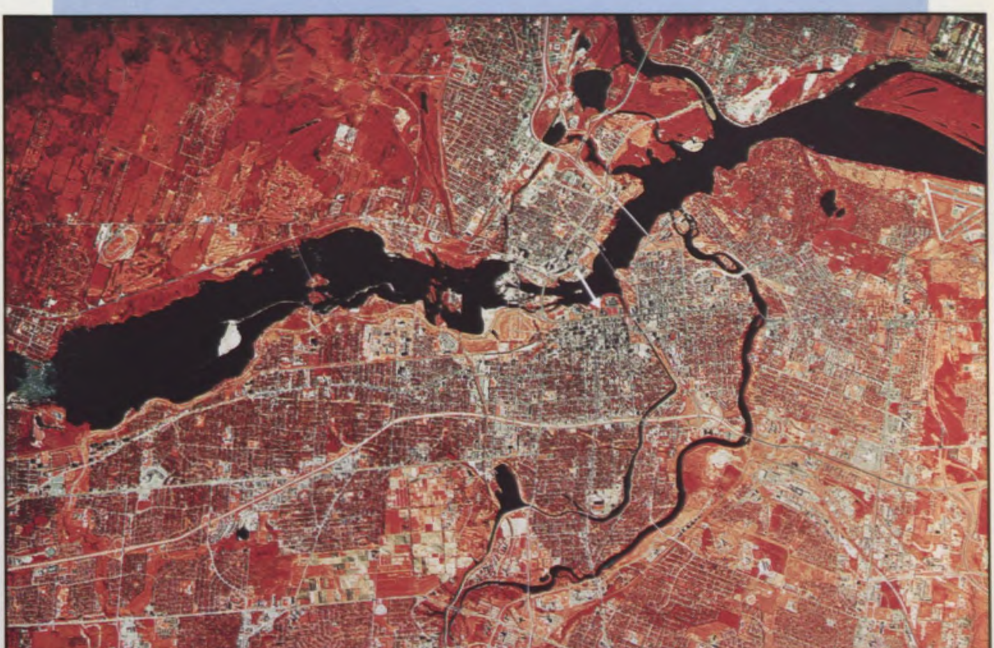
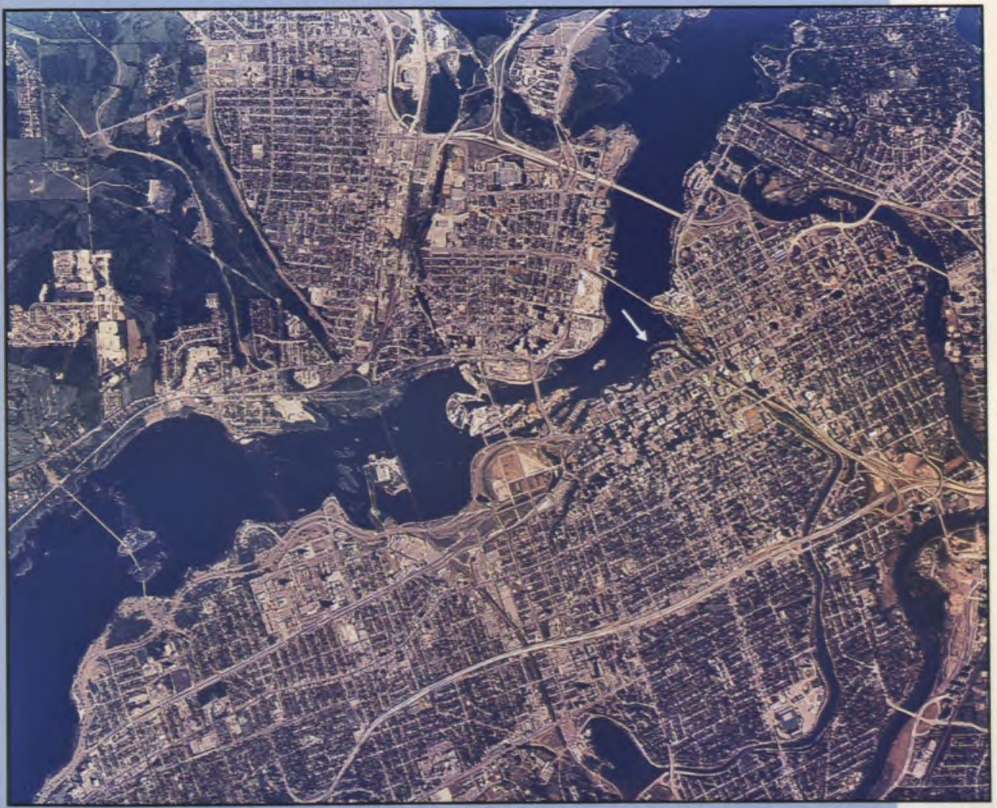
(4) "False-colour" infra-red aerial photograph taken on August 20, 1978 from a height of 12 km using a standard aerial photographic camera with a 15.24 cm lens. Special film and lens filter are used when taking such photographs. Vegetation in the picture appears red, hence the "false colour" designation. Civilian applications of such imagery include agricultural monitoring, mapping, environmental disaster impact analysis, and archeology. **(National Air Photo Library)**.



(5) **Aerial colour photograph of Ottawa** taken in July 1985 from 2 400 m altitude. Civilian applications of air photography are manifold, including mapping and land use planning. (**National Air Photo Library**).

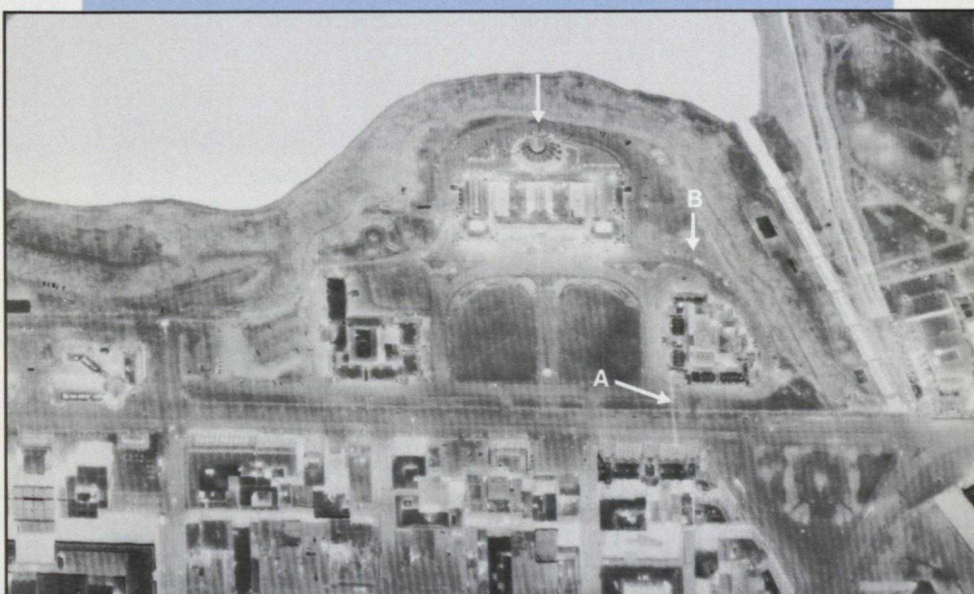
(6) **LANDSAT image of Ottawa.** Taken on October 24, 1982 from a height of 710 km by the Thematic Mapper aboard the US LANDSAT-4 spacecraft that was launched in 1982. The resolution of this image is 30 m. Many roads, airports and large buildings can be discerned in this photographic print. This type of image can be used for a variety of civilian applications including land use, forestry and mapping. (**Courtesy of Canada Centre for Remote Sensing**).

(7) **Colour aerial photograph of Ottawa** taken in July 1985 from 6 300 m. The camera used in this photo and No. 5 both employed a 15.24 cm lens. (**National Air Photo Library**).



(8) **MEIS II image of Parliament Hill** taken from 1 500 m height in October 1983. MEIS II is an airborne multispectral push-broom sensor. Applications of this type of electronic sensor include agriculture, forestry, pollution control, mapping and land management. (**Courtesy of Data Acquisitions Division, Canada Centre for Remote Sensing**).

(9) **"Thermal infra-red" image of Parliament Hill**, taken in December 1983 at 11:00 p.m. from a height of 450 m. Thermal infra-red imagery focusses on a different segment of the electromagnetic spectrum than does the false-colour imagery represented by image No. 7. Brighter areas in this picture are warmer than their surroundings. Note that the image was taken at night which highlights one of the useful characteristics of thermal infra-red imagery: it is not dependent on daylight.



Visible in the photo are several interesting features: heat emitted from buildings, an underground tunnel (A), the thermal "shadows" from automobiles that have recently moved from their parking spaces (B), and street lamps. The visibility of the tunnel points out another advantage of this type of imagery: its ability, in some circumstances, to "see" buried objects and to penetrate camouflage.

Resolution for thermal infra-red sensors is considerably poorer than for visible light cameras. Civilian applications for such imagery include heat waste management and pollution control. **(Courtesy of INTERA Technologies Ltd., Ottawa).**

"Photographs (4), (5), and (7) reproduced from the collection of the National Air Photo Library with permission of Energy, Mines and Resources Canada."

The Expanding Space-faring Club

Chapter 2

The Expanding Space-faring Club

The number of countries possessing space technology and having access to space is growing rapidly. The Space Shuttle program of the United States has probably most popularized the notion of easier access to space while, at the same time, illustrating the immense challenges and unforeseen dangers associated with its exploration. Increasingly, other emerging space powers are providing launch services. The successful development by France and the European Space Agency of the Ariane launch vehicle is a case in point. Japan, China and India, to varying degrees, are all proceeding along this same road. These achievements underline the growing capacity of many countries to build and launch satellites, and they emphasize that the ability to watch the Earth from high above will soon no longer be the preserve of a few nations.

Canada, too, is a space-faring nation. As the third nation after the United States and Soviet Union to operate a satellite in space, we have a long history of expertise in space technology, dating from the launch of Alouette, in 1962. We can rightfully claim to be at the very forefront of knowledge in many areas of space science and technology. As a result, we too have a responsibility to contribute the benefit of our knowledge to the arms control process to which we and our allies are dedicated.

It seems almost a certainly that space-based remote sensing will continue to be an indispensable element for verifying bilateral arms control agreements between the superpowers. What appears to be new today is the growing likelihood that other countries will become able to use similar technologies for multilateral verification. The form that this incipient capability will take is unclear. Certainly, more countries will come to possess their own space-based "national technical means" of verification. It also appears possible, as mentioned previously, that commercial satellites may provide some satellite data relevant to arms control verification to any nation or group willing to pay for it. It is possible, as well, that a group of like-minded nations, with the capacity for advanced space technology and acting on behalf of a wider group of signatories to a treaty, may agree to pool their resources for the purpose of verifying some future arms control agreement. The latter possibility, which might be termed "plurilateral" verification, deserves further exploration.

Table 2 Some Canadian Achievements in Space

September 1962	Alouette 1: Canada became the third country after the Soviet Union and the United States to operate a satellite in space. Alouette 2 was launched in November 1965.
January 1969	ISIS 1 (International Satellite for Ionospheric Studies): ISIS 2 was launched in April 1971.
November 1972	Anik Al: Canada was the first country to operate a domestic telecommunications satellite system using a satellite in geostationary orbit. This was the first of three Anik A satellites. Anik A2 was launched in April 1973 and Anik A3 in May 1975.
January 1976	"Hermes" or CTS Communications Technology Satellite): The first satellite capable of transmitting directly to inexpensive home receivers in the 12–14 GHz band.
December 1978	Anik B: The first communications satellite to operate simultaneously in the 4–6 GHz and 12–14 GHz frequency bands.

August 1982	Anik Dl: The first commercial satellite built by a Canadian private contractor, Spar Aerospace Limited. Anik D2 was launched in November 1984.
November 1982	Anik C3: Launched from the first commercial Space Shuttle mission. Anik C2 was launched in June 1983 and Anik C1 in April 1985, on later Space Shuttle missions.
November 1982	"Canadarm" or the Remote Manipulator System: Declared operational after having been flown and tested successfully on several Space Shuttle missions.
February 1983	SARSAT (Search and Rescue Satellite Aided Tracking): Canada supplied satellite transponders and designed and built several ground stations for this international project.
October 1984	Marc Garneau: The first Canadian astronaut in space flies aboard the Space Shuttle *Challenger*.

?	1991	M-SAT (Mobile Satellite)*: A communications satellite to meet the need for improved voice and data communications to vehicles, aircraft, ships and other portable stations for a wide variety of personal and business communications applications in rural and remote areas of Canada.
?	1993	RADARSAT*: A synthetic aperture radar remote sensing satellite which will provide information on ice conditions, icebergs, ships and ocean conditions in our Arctic and coastal economic zones, as well as data for land mapping. The satellite will also provide global marine wind information and radar stereo-geological mapping.
?	1994	Space Station: One of Canada's contributions will probably be the station's mobile servicing centre.

* As of February 1987, neither the M-SAT nor the RADARSAT projects had been given the final go-ahead.

Figure 4 "Canada, too, is a space-faring nation"

"Stamps Reproduced Courtesy of Canada Post Corporation."

Multilateral Arms Control Verification

Chapter 3

Multilateral Arms Control Verification

The Way of the Future?
To date, partly as a result of a series of significant bilateral arms control agreements, it is the United States and the Soviet Union which possess the bulk of the world's capabilities with respect to verification from outer space. Excluding the Non-Proliferation Treaty of 1986, it can be argued that no multilateral treaty of sufficient significance yet exists that would warrant the high level of technical sophistication and financial expenditure required for space-based remote sensing to verify its provisions. As the arms control process continues to evolve, however, it seems increasingly likely that significant treaties of a multilateral nature will be negotiated. Among such possible agreements might be treaties relating to outer space, chemical weapons and the control of armaments in specific regions, notably Europe. In all three cases, space-based remote sensing is likely to play a significant, if not an essential role in the verification process.

In this context, the recent agreement reached in Stockholm in September 1986 is illustrative. Referred to as the "Stockholm Document", this agreement was signed by 35 member countries of the Conference on Security and Co-operation in Europe (CSCE). It involves a complex arrangement of confidence- and security-building measures (CSBMs) intended to reduce the fear of surprise attack and improve trust regarding military matters in Europe. The verification methods specified in this agreement include the use of ground and air inspections. The development of advanced space-based remote sensors for the sole purpose of verifying only the Stockholm Document may not be justified because the CSBMs specified in the Document may not warrant the same degree of concern about verification as might an agreement that substantially reduces or limits armaments. Nevertheless, the political significance of this agreement should not be underestimated: it was signed by all European countries (except Albania), as well as Canada and the United States, and it is one of the few multilateral security-related agreements adopted in over a decade. As a successful test of the multilateral approach to East-West arms control negotiations, the implementation of the Stockholm Document may well foreshadow future successes in the process of multilateral arms control and disarmament.

As additional multilateral agreements are concluded, it is expected that verification will increasingly involve more countries. Nations have an obvious interest in participating in systems designed to monitor compliance with agreements to which they are party.

This trend toward multilateral agreements is occurring at the same time as more countries become capable of employing space-based sensors to verify arms control agreements. These two mutually reinforcing trends — more multilateral agreements and more countries with space-based sensors — suggest we are reaching a point where the multilateralization of arms control verification is no longer just a possibility: it is on the verge of becoming — in one form or another — a reality. What remains is to devise such a "third system" of verification and to guide its implementation.

"Third Systems"

The term "third system" applies to verification capabilities not owned and operated exclusively by the superpowers. "Third systems" would not act as umpires or arbitrators in matters relating uniquely to the superpowers, but rather would be developed as a result of obligations assumed in specific multilateral agreements.

The PAXSAT concept focusses on the feasibility of developing such a "third system". In contrast to other proposals, it is envisaged as operating in a multilateral context, it recognizes the practical necessity of being treaty-specific, and it reflects Canada's active involvement in the arms control and disarmament negotiating process.

International Satellite Monitoring Agency

At the first United Nations Special Session on Disarmament (UNSSOD I) in 1978, France proposed that the United Nations establish an International Satellite Monitoring Agency (ISMA) to assist in the verification of existing and new arms control treaties as well as other crisis management functions. ISMA was to be developed on a global basis under United Nations auspices in a proposed three-stage plan. It constituted an innovative approach to the multilateralization of verification techniques, a concept with which Canada concurred.

From the outset a number of major problems were evident. Although most of these were identified within the 1982 UN Experts Study concerning ISMA, they were not reflected adequately in the conclusions drawn from that report. First and most notable was a marked lack of enthusiasm on the part of the superpowers. They may have felt, with considerable justification, that participation in such a scheme might have revealed too much about their own "national technical means".

Other countries have shown considerable sensitivity to the use of Earth sensing technology in other contexts. Such sensitivities would predictably be heightened if national security became more directly involved. Verification is not simply a straightforward question of gathering technical data. Interpretation of satellite imaging and judgment on compliance are more than mere technical issues; they are part of a political process.

There was also a financial constraint based upon whether or not it would be acceptable to spend on a single project, such as ISMA, an amount that would exceed the annual budget of the entire United Nations.

Some of these problems were discussed at the twenty-fifth anniversary meeting of Pugwash in 1982. Dr. Mark MacGuigan, then Canada's Secretary of State for External Affairs, observed that before an organization such as ISMA could be established, the world community might first recognize that it had a responsibility to conclude an arms control agreement of sufficient significance to warrant it.

In May 1986 the periodical *Space Policy* published a succinct and thoughtful article entitled "The ISMA Proposal — Time for a Reappraisal". In it, the authors who are both officials of the French government, summarized some of the institutional, financial, political and methodological issues which militated against the ISMA proposal and suggested a reassessment of the context in which space-based remote sensing technology might be applied for arms control verification purposes.

Indeed the genesis of the PAXSAT concept in 1981 had its origin in the problems identified by Dr. MacGuigan at Pugwash and recently summarized in *Space Policy*. Unlike ISMA, PAXSAT was conceived from the beginning as *only* being developed within a specific treaty. Unlike ISMA, PAXSAT is based on a regional context. Unlike ISMA, PAXSAT would in no way have application outside the treaty. In PAXSAT, participants would be parties to the treaty itself.

PAXSAT: A Canadian Approach to Multilateral Verification

Chapter 4

PAXSAT: A Canadian Approach to Multilateral Verification

Canada is committed to promoting progress in arms control and disarmament negotiations. The Canadian emphasis is on the practical, which is one reason why we have identified research into the verification of arms control agreements — like the PAXSAT studies — as an area where we can make a useful contribution. Speaking in the House of Commons on January 23, 1986, the Right Honourable Joe Clark, Secretary of State for External Affairs, expressed it this way:

> *Effective verification provisions can help ensure compliance with arms control treaties as well as facilitate their negotiation. Verification is an area where Canadian expertise and diplomacy come together . . . We are second to none in our activity to develop verification procedures and technology that meet the practical requirements of arms control agreements actually under negotiation or envisaged.*

From the outset, the PAXSAT research has recognized the important realities and trends described in previous chapters. As a result, certain themes form core elements of the PAXSAT concept and add to the chances of actually realizing such a multilateral verification system. These include the following:

- There must be the prospect of a significant multilateral agreement to warrant the level of sophistication of technology and the expenditure of funds required for the actual development of such an advanced technical verification system.

- Parties to such an agreement should have the option, at least, to participate in its verification procedures.

- The PAXSAT system would be treaty-specific: it would be used only with respect to the agreements to which it expressly applied, as part of an overall verification process for those agreements alone.

- The treaty being verified would establish the requisite political authority for the verification mechanism and its operation.

- Technology requirements would be met by the collectivity of participants and would not depend upon or call for superpower participation, although the treaty would, of course, be open to all states.

- PAXSAT should be based, to the extent possible, on existing openly available technology, without requiring major costly improvements. The technology possessed by the Canadian commercial sector provided a base for the PAXSAT studies.

Although the PAXSAT research is not yet complete, a number of initial observations have emerged which are summarized briefly in the next two sections.

PAXSAT 'A': Space-to-Space Remote Sensing

The aim of the PAXSAT 'A' feasibility study was to determine whether a space-based observation system could help verify an outer space arms control regime. To this end, the study sought to answer two principal questions:

1) Can space observation of an object in space determine the role or function of the object, particularly regarding a weapons system?

2) Would the operational requirements permit a viable spacecraft design for the PAXSAT 'A' mission?

The answer to both these question was a tentative "yes". Among the initial observations from the PAXSAT 'A' study were the following:

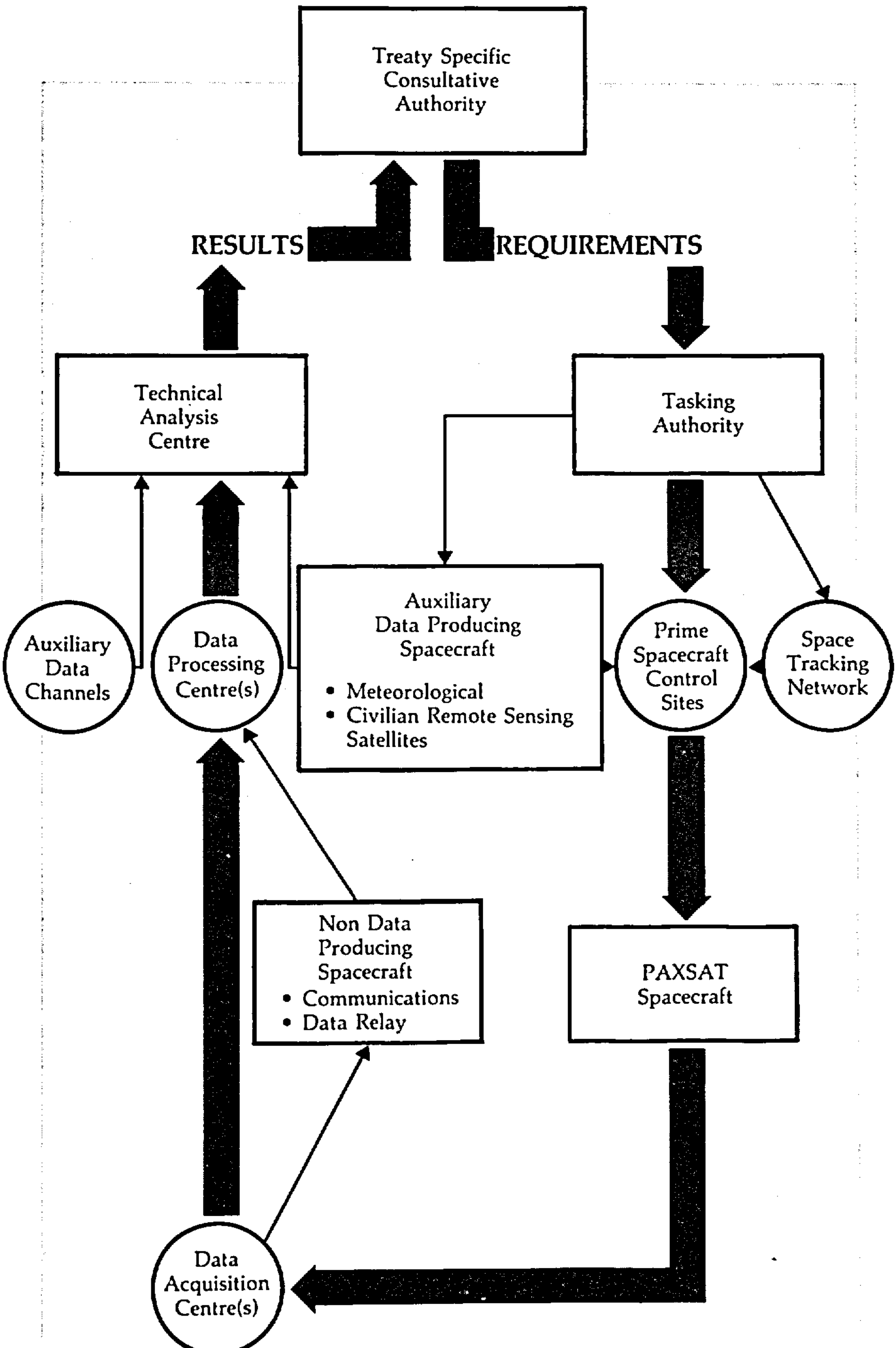
- The high degree of optimization inherent in the design of all spacecraft and in their orbital parameters, together with the nature of signals to and from the spacecraft, can provide highly significant data as to that spacecraft's function.

- The most useful procedure for determining a spacecraft's function, using space-based observation systems, would be to co-orbit and keep station with the target over a reasonably lengthy period of time.

- An alternative procedure for observing a spacecraft, involving less fuel consumption, would be a "fly-by". This might be used for preliminary screening of a target.

Figure 5 PAXSAT Conceptional Systems Data Flow

This diagram illustrates the general flow of information as well as key decision-making points for a proposed PAXSAT space-based verification system. One of the important elements requiring careful consideration by participants in any PAXSAT system will be development of the Treaty Specific Consultative Authority that will be required to make critical political decisions relating to verification activities. Another important requirement will be to develop measures to ensure confidentiality of data collected and analyzed by the technical portions of the system.


Treaty Specific
Consultative
Authority
RESULTS
REQUIREMENTS
Technical
Analysis
Centre
Tasking
Authority
Auxiliary
Data Producing
Spacecraft
• Meteorological
• Civilian Remote Sensing
Satellites
Auxiliary
Data
Channels
Data
Processing
Centre(s)
Prime
Spacecraft
Control
Sites
Space
Tracking
Network
Non Data
Producing
Spacecraft
• Communications
• Data Relay
PAXSAT
Spacecraft
Data
Acquisition
Centre(s)

- The fact that military and related space missions have orbits clustered in limited portions of space simplifies the problems of space-based observation.

- The PAXSAT 'A' spacecraft might carry several sensors including a visible-light imaging system, a thermal imaging system, a receiver to measure communication signals, and radiation and chemical sensors.

- All the proposed PAXSAT 'A' spacecraft components are available within the scope of the technology of civilian space organizations in non-superpower countries, with some modules readily available without further development.

PAXSAT 'B': Space-to-Ground Remote Sensing

The aim of the PAXSAT 'B' feasibility study was to examine the application of space-based remote sensing for verifying controls on conventional weapons in a regional context. To help focus the research effort, a specific well-defined geographic area was chosen: Europe. Among its preliminary observations were the following:

- The arms control agreements likely to be concluded in Europe will require various forms of verification measures and space-based verification may fulfil some of these requirements.

- Current or planned civilian remote sensing satellites have insufficient resolution performance and coverage frequencies to meet full PAXSAT 'B' requirements.

- Civilian satellites such as Canada's proposed RADARSAT do, however, have the potential to provide useful "detection" level information for use in a confidence-building context.

- Dedicated PAXSAT 'B' sensors and platforms are required to meet the full verification requirements of the expected agreements.

- The technology base exists in non-superpower nations from which the full PAXSAT 'B' system could be developed for the mid-to-late 1990s.

Conclusion

Conclusion

Conclusion

Canada cannot alone induce other countries to agree to arms control and disarmament treaties, nor is it Canada's desire to develop alone, verification systems such as those envisaged in the PAXSAT studies. Those endeavours, by their very nature, require the co-operation of many nations. We do not pretend to have all the answers to the political and technical difficulties surrounding negotiation of arms control agreements and their verification provisions. We can, however, through our research efforts into space-based verification technology hope to shed some light on the application of such technology to the development of a multilateral verification capability and thereby contribute significantly to practical progress in the arms control process.

Figure 6 For Further Reading

The following documents are available through public and university libraries across Canada.

1 John N. Barry. "Application of Space and Remote Sensing Technology to Verification of Weapons Systems for Use in Outer Space". In Compliance and Confirmation: Political and Technical Problems in the Verification of Arms Control of Chemical Weapons and Outer Space pp. 97–111. Edited by Harald von Riekhoff. Ottawa: Norman Paterson School of International Affairs, Carleton University, 1986.

2 R. Buckingham. Satellite Surveillance and Canadian Capabilities. Background Paper, No. 7. Ottawa: Canadian Institute for International Peace and Security, September 1986.

3 Canada. Verification in All Its Aspects: A Comprehensive Study on Arms Control and Disarmament Verification Pursuant to UNGA Resolution 40/152(o). Report submitted to the United Nations, April 1986.

4 F.R. Cleminson. "Feasibility of Space-based Remote Sensing in the Verification of a Treaty to Prevent An Arms Race In Outer Space". In Modelling and Analysis in Arms Control, pp. 399–408. Edited by Rudolf Avenhaus, Reiner K. Huber and John D. Kettle. NATO ASI Series, Series F. Computer and Systems Sciences, Vol. 26. Berlin: Springer-Verlag Heidelberg, 1986.

5 F.R. Cleminson and E. Gilman. **A Conceptual Working Paper on Arms Control Verification.** Arms Control Verification Studies, No. 1. Ottawa: Department of External Affairs, 1986.

6 F.R. Cleminson and E. Gilman. "Proposals and Technology in Arms Control Verification: A Survey." In **Quantitative Assessment in Arms Control: Mathematical Modelling and Simulation in the Analysis of Arms Control Problems**, pp. 359–381. Edited by Rudolf Avenhaus and Reiner K. Huber, Federal Armed Forces University, Munich, Federal Republic of Germany. New York: Plenum, 1984.

7 A. Crawford, et al. **Compendium of Arms Control Verification Proposals.** Second edition. ORAE Report No. R81. Ottawa: Operational Research and Analysis Establishment, Department of National Defence, March 1982.

8 William C. Heine. "Canada from Space". **Canadian Geographic** (December 1986/January 1987): 42–55.

9 N.M. Matte. "International Verification Procedures: Past and Future Prospects". **Annals of Air and Space Law** XI (1986): 237–257.

10 F.J.F. Osborne. "The PAXSAT Concept: A Study of Space-to-Space Remote Sensing". In **A Proxy for Trust: Views on the Verification Issue In Arms Control and Disarmament Negotiations.** Edited by John O'Manique. Ottawa: Norman Paterson School of International Affairs, Carleton University, 1985.

We urge all nations to co-operate and indeed participate in the development of the verification techniques needed to provide the confidence necessary to ratify these agreements, and which will enable us to plan the subsequent steps which we must take in all areas of arms control. For verification is not just a question of technical capacity but of the political will to reach agreement on the application of technologies and techniques.

In this spirit and in co-operation with others, Canada will continue to work vigorously towards real progress on verification.

The Right Honourable Joe Clark, Secretary of State for External Affairs, Address to the United Nations General Assembly, September 24, 1986.

Verification Brochures
No. 1 *Seismic Verification*, 1986

Canada