THE CANADIAN RADARSAT PROGRAMME

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ABSTRACT

RADARSAT is a Canadian Programme to orbit a satellite carrying a synthetic aperture radar as it primary payload sensor. The data collected will be used in support of resource management activities. Launch is planned for 1990.

This paper reviews the mission concept and the current status. It also describes some applications and international aspects of the program.

INTRODUCTION

The origins of RADARSAT go back to the early 1970's when a sub-working group of the Data Handling Working Group of the Canadian Advisory Committee on Remote Sensing was formed to investigate mechanisms for actively participating in remote sensing satellite systems. Initially, the sub-working group on Satellite Systems believed that it would be unrealistic for Canada to take the leading role in such a system. However, in the report on its investigation, it found that Canada had both the need and the technical resources to take a leadership role. At about the same time, P.A. Lapp was investigating the use of remote sensing for monitoring off-shore activities. The two reports, when combined formed the preliminary definition of a requirement to develop a Canadian radar satellite for all-weather, year-round monitoring. A preliminary Mission Concept study was performed by Canadian Astronautics Ltd.

In the mid 1970's, there was a growing interest in oil and gas exploration in and around the Arctic Islands. The proposed shipping corridor for the transportation of both oil and liquified natural gas runs through the Parry Channel and then down through Baffin Bay and the Labrador Sea to eastern sea ports. In the vicinity of the Sverdrup Gas Basin at the westerly end of the channel and in the vicinity of Viscount Melville Sound which controls access to the Beaufort Sea oil deposits, multi-year ice may reach a thickness of around ten feet. In addition there are ridges of ice of considerably greater depth. In the Davis Strait and along the Labrador Coast there are great iceberg populations which are maintained by glaciers in Greenland. At any time of year this is one of the most difficult passages for navigation in the world. Drill ships need the best ice information available for planning their operations but, when later on the oil discoveries are put into production, the efficient and safe operation of these facilities as well as the transportation of the oil will both depend on the availability of daily synoptic ice information.

Also in the mid 1970's Canada, like many other countries, had extended the limits of its territorial waters to 200 miles from the coast. Because of the great length of the Canadian shoreline this increased the area of Canadian jurisdictional responsibility by a factor of a hundred or more. Surveillance of such a vast amount of ocean presented severe problems for the existing patrol system.

Faced with these requirements for extensive and frequent surveillance information and building upon the earlier studies, in 1976 the Canadian government established a task force to determine the extent to which satellites could be used to meet the environmental requirements for sea ice and oceans. In its report (Ref. 2) the task force laid special emphasis on the potential value of synthetic aperture radar (SAR) and recommended that Canada take part in the American SEASAT Program which at that time was a year or so away from launch. It is also recommended that an experimental program be set up in order to verify the applications which the task force had identified as feasible and also recommended that the Canadian Government begin a program of technical developments in order to improve Canadian industrial capability in the area of SAR technology.

These recommendations were all accepted and to implement them the SURSAT Program was started in 1977. An experimental campaign was conducted using the airborne SAR leased (and later purchased) from the Environmental Research Institute of Michigan and installed on the Canada Centre for Remote Sensing Convair-580 aircraft. The experiments conducted during the active life of SEASAT were arranged to coincide with SEASAT overpasses so that wherever possible dual airborne and satellite SAR data sets could be obtained. Other notable events of this period include the early Mission Concept Studies and the development of the first digital SAR processor.

The conclusions of this study, reported in March 1980, were still very positive about the applications potential of spaceborne SAR and recommended that the Canadian Government initiate a program which would lead to the launch of a Canadian satellite carrying a SAR. Again the recommendations were accepted and a new program, RADARSAT, began in the fall of 1980. Among its terms of reference was the requirement to seek international partners, primarily in order to share the cost of this venture which for Canada would be very expensive. With this object discussions were held with representatives of NASA during the summer of 1980, as a result of which it was agreed to conduct joint Mission Requirement Studies to determine the extent to which such a mission could serve the needs of both countries.

In 1979 the European Space Agency (ESA) started Phase A Studies for a European remote sensing satellite (ERS-1). Canada had earlier joined the agency and took part in these studies. Shortly after the beginning of the RADARSAT Program the European Program entered Phase B and, since the multi-national partnership offered considerable benefit/cost leverage and the Mission Objectives complemented those of RADARSAT, approval was given for Canada to subscribe to Phase B. In early 1984, approval was given for Phase B of Canada's RADARSAT program and to participate in Phase C/D of ERS-1.

THE RADARSAT MISSION

The Mission Requirements Studies, which were carried out during the first year of the RADARSAT Program, were concerned primarily with the availability of data (orbit and data processing) and the quality of that data (radar design and data processing) needed for ice, ocean and land applications.

Orbit

Availability means the frequency of coverage at a given ground location and the delay between the time of acquisition of the data and the delivery of a user product. In both these aspects the requirements varied widely according to application but it was found that the most demanding requirements determined the performance of the mission and that the less demanding requirements could then be accommodated without difficulty. Thus, for example, the requirement for frequent sea ice information in the Northwest Passage had a decisive influence on the selection of the orbit. The greatest coverage of this shipping route is achieved if it also represents the most northerly latitude reached by the SAR swath. Fortunately not only does this produce the most dense coverage of SAR imagery in terms of frequency of coverage but it also does this along an east-west direction which is approximately the direction of the Northwest Passage. This is achieved with a ground track which lies to the north of the Passage and a radar that looks to the left, which is to say always to the south of the ground track. This gives poor coverage of the area to the north of the shipping corridor but this is compensated for to some extent by the data which will be available from ERS-1 whose radar looks to the right and approaches the north pole more closely. By the same token the southerly look direction of the RADARSAT SAR swath makes the coverage of Antarctic very dense, almost up to the South Pole.

A one day coverage map for Canada, plotted with a 150 km swath width, is shown in Figure 1. It can be seen that there are still areas at the high latitutdes which are not covered every day. The problem becomes worse through Baffin Bay to the Labrador Sea. To overcome this difficulty the baseline radar design has the capability of steering the radar beam across a much wider ground range than the swath width. This procedure allows the swath to be placed at one of several positions within a 500 km range to access. Figure 2 illustrates this feature and shows how the position of the radar beam might be stepped across the access swath several times during two of the passes and in so doing cover the entire shipping corridor.

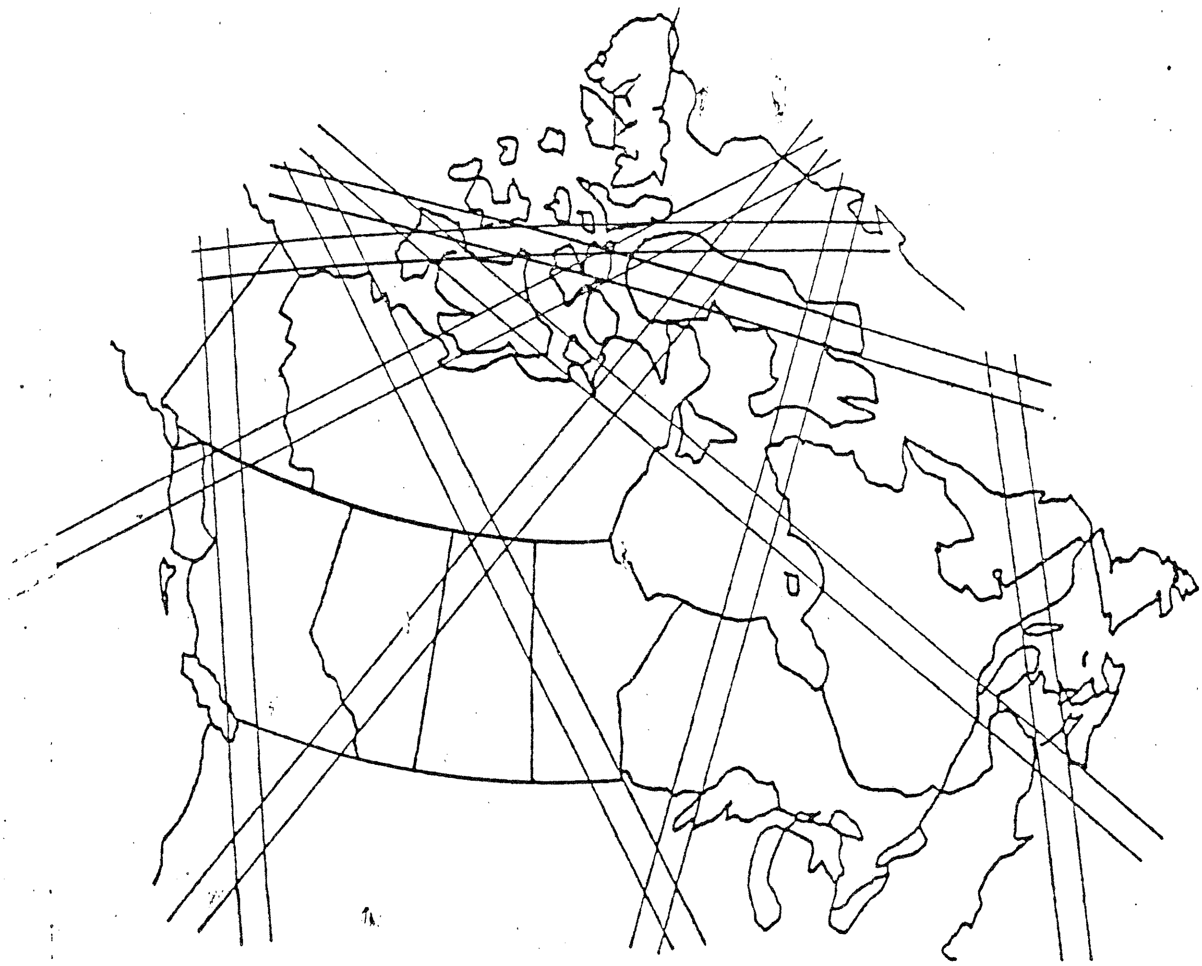


FIGURE 1
Typical one day coverage by the SAR
with nominal swath width of 150 Km.

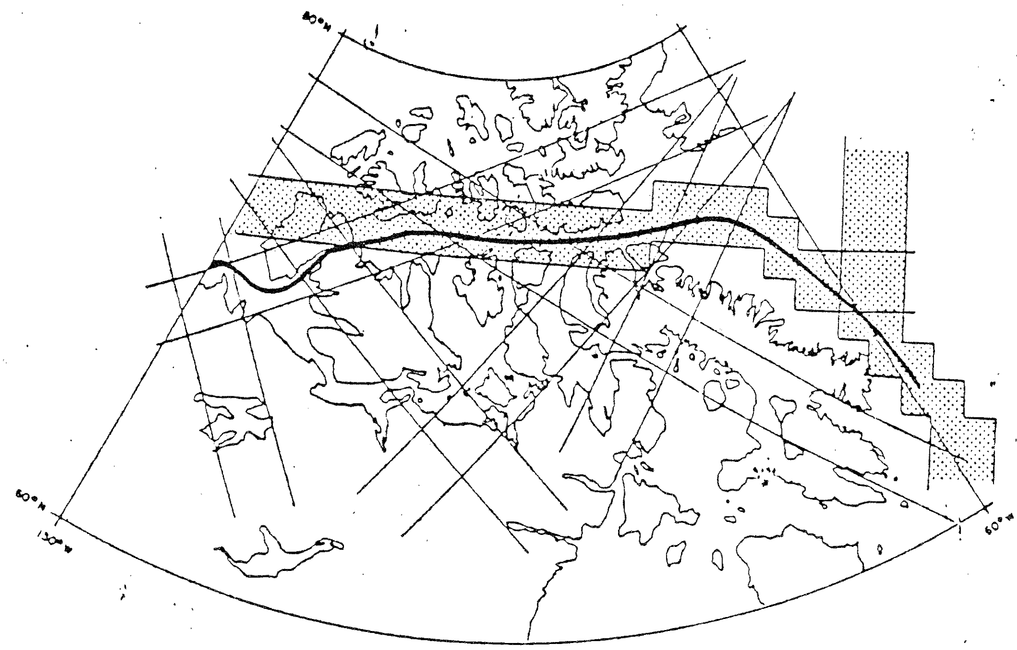
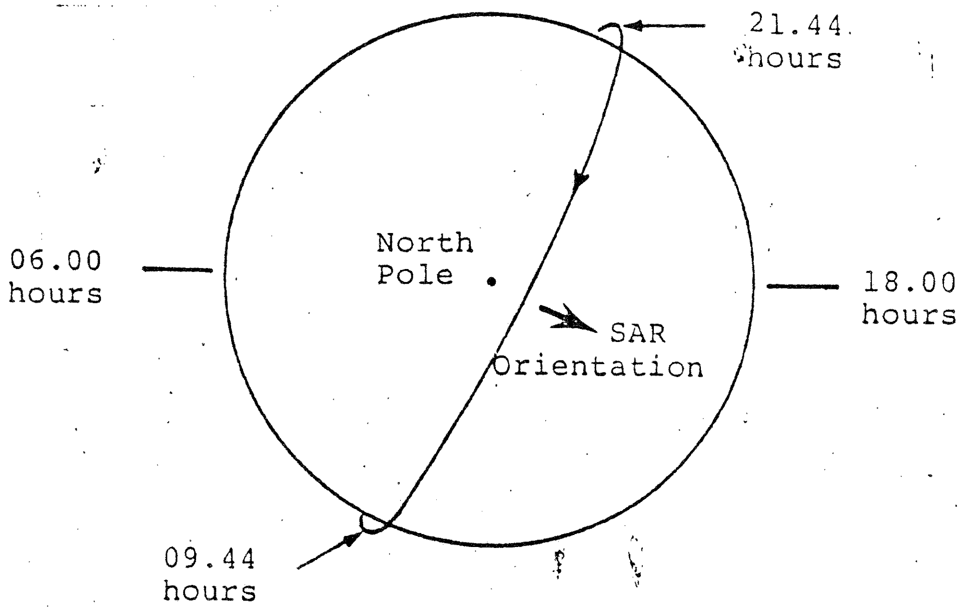


FIGURE 2
The use of SAR swath displacemement
to optimize coverage of shipping routes.

Although this capability was introduced primarily to meet shipping requirements in fact it proves to be a powerful tool for many other purposes. At lower latitudes, for example, over the land, although during a particular day the amount of surface coverage available is no different from that shown in Figure 1, the fact that the swath can be moved around within the access swath enables any part of Canada to be accessed during a three day period. The limited access is not the drawback that it might at first seem because applications that deal with very large tracts of land such as agriculture can frequently be dealt with very effectively by a sampling technique providing that the areas that are selected can be reached at regular intervals for making measurements. Furthermore, areas which have to be accessed at short notice because of some kind of environmental emergency, for example, can also be reached within this three day period.

As the position of the swath within the accessibility range is moved about the incidence angle also changes. Again this has benefits which can be exploited for various applications. For example, it introduces the possibility of acquiring stereo radar data and it introduces the possibility of exploiting the variation of radar cross-section with incidence angle, which can assist in the identification of certain surface materials or crops.

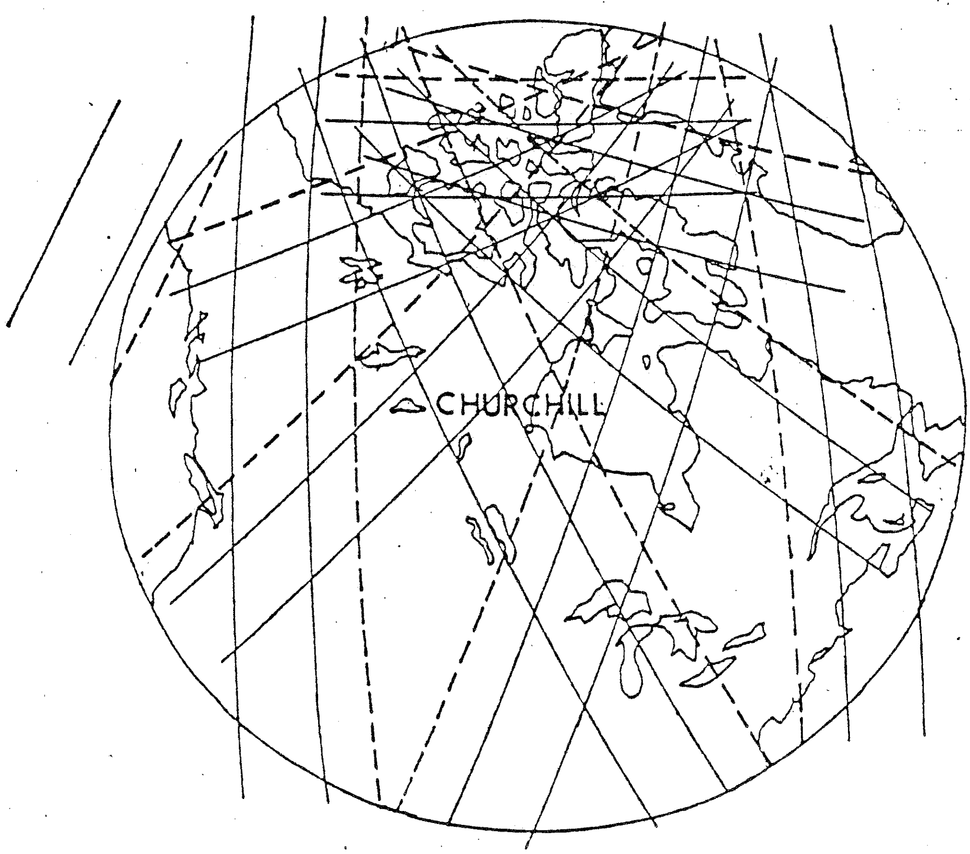
The orbit selected is in fact a 16 day exact repeat with a three day sub-cycle. It is the three day sub-cycle which gives the repeat coverage characteristics described above whereas the 16 day repeat allows the orbit to drift through the sub-cycles and thus move the accessibility swath so as to cover the entire circumference of the equator twice during the repeat cycle. This orbit will have a descending daylight pass which crosses the equator at 09.44. hours. This choice was made for a number of minor reasons which together combined to make this the preferred orbit. For example, the eclipse period is a little less than that of the ascending daylight orbit, which has an impact on the power management and the size of the solar panels. On the applications side this orbit allows the radar to look towards the sun and if, as we hope, there is a visible and infrared sensor on board, then in order to have overalpping optical and radar images the optical sensor will also look towards the sun, which gives more favorable illumination conditions for high latitudes. Because of the possibility of carrying an optical sensor the baseline orbit is sun synchronous. It has an altitude of 1001 km, an inclination of 99.5^{o} and is illustrated in Figure 3.



- ECLIPSES
  - o Occurrence - every orbit
  - o Average duration - 29 minutes
- SOLAR ILLUMINATION
  - o Spacecraft solar aspect - Sun within cone of 55^{o} (approx.) semi-angle
  - o Ground illumination - Orbit favourable for polar latitudes

FIGURE 3
Baseline sun-synchronous orbit

The receiving station in the baseline mission concept will be at Churchill, which is on the west shore of Hudson Bay. The station mask is shown in Figure 4 which also shows the position of the radar accessibility swaths for a one day example of ground tracks through the station mask. It can be seen that the ground coverage mask is shifted to the west for ascending passes and to the east for descending passes. Although this extends the coverage off the eastern seaboard somewhat, it may prove necessary to have a second receiving station further east. This decision to do this has not been made but, if it should be, the choice of the Churchill site may be reviewed.



------- Ground Track

——— } SAR Swath

FIGURE 4
Direct read-out mask for a ground station at Churchill (for satellite 5° above the horizon

Radar

After careful examination of existing data the Mission Requirements Study Teams agreed on the choice of C-band over L-band as the optimal frequency for most applications. Although X-band was also examined it was felt that for the marginal improvement in performance for some applications the technical risk was unacceptable. The radar frequency will be 5.3 GHz and it will operate in vertical transmit/vertical receive polarization mode. The impulse response width is 25 metres in both azimuth and range with 4 look processing, although this may be relaxed somewhat for lower incidence angles, the range being from 20^{o} to 45^{o}.

Figure 5 illustrates one of the possible configurations that might be used for the spacecraft in order to achieve the baseline performance. The single sided solar array position is due to the selection of the orbit which has a large rotational angular range of the sun vector. This configuration includes a thematic mapper and a scatterometer as secondary payload which were the nominal secondary sensor options for the Phase A Study. These instruments may be replaced by others when the secondary payload is better defined. The L-SAT bus which appears in this illustration is the baseline for the mission. It was originally designed for geostationary orbit, but the manufacturer, British Aerospace, plans to modify it for low earth orbit. The configuration also shows a reflecting antenna but a planar array has not yet been ruled out.

The telemetry and ground segment components of the system concept are illustrated in Figure 6. The satellite will downlink data either directly or from on-board recorders to the primary ground receiving station. This data then will be relayed at a lower rate through a communication satellite to the Mission Control Centre which will be in Ottawa. Processing of SAR data and data from other sensors will take place there and the products distributed to user image analysis centres and to archiving facilities.

An important image analysis centre is the Ice Information Centre. There SAR data will be collated with data from other satellites, data from surveillance aircraft, and data from shipping vessels and other surface stations. Synoptic maps of ice conditions and also short term ice forecasts will be prepared and relayed directly to users via a communication satellite. These and related products will be displayed on user systems for decisions on ship routing and drilling operations. It is expected that similar centres will serve the oceanic community with forecasts of sea state and yet others will serve the land users with information on agriculture, forestry, and hydrology.

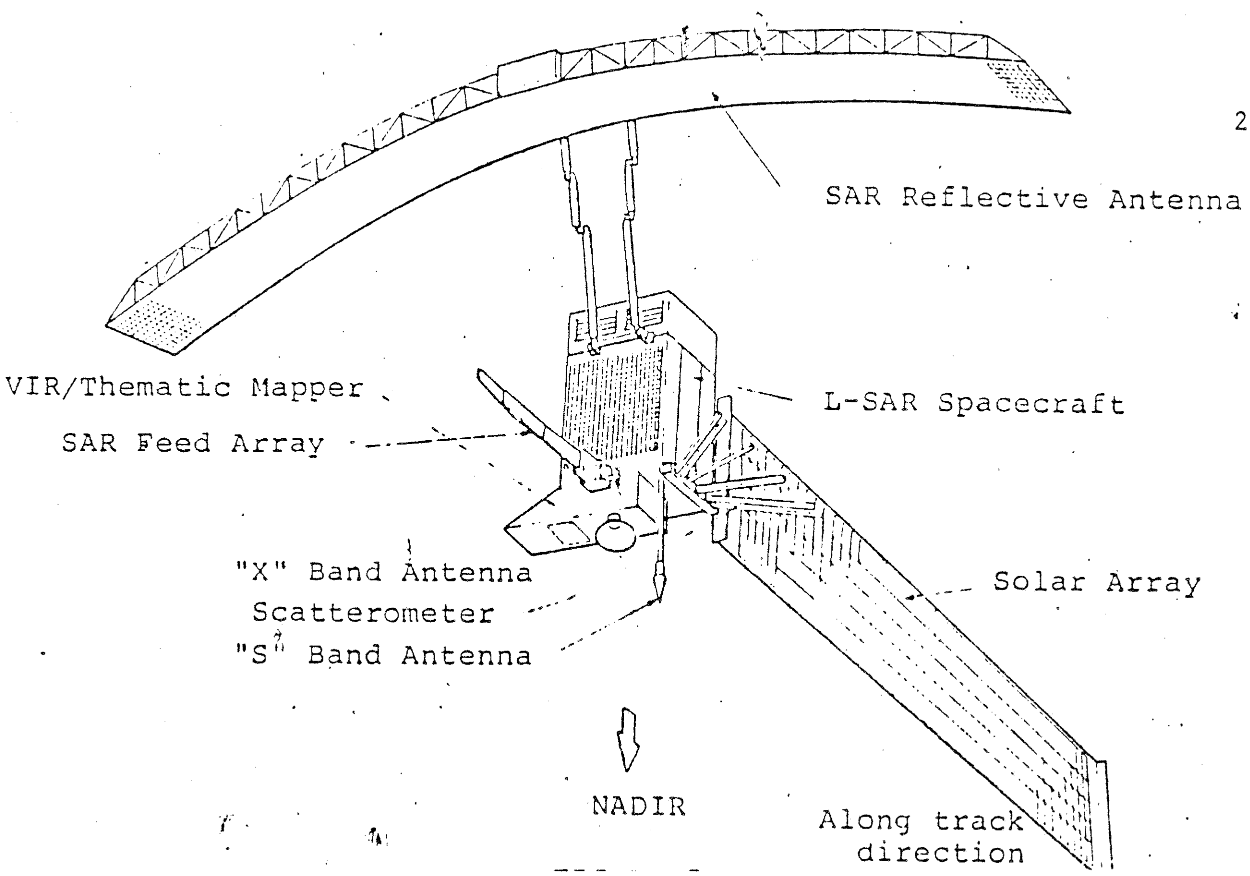


FIGURE 5
Sun-synchronous configuration for baseline payload

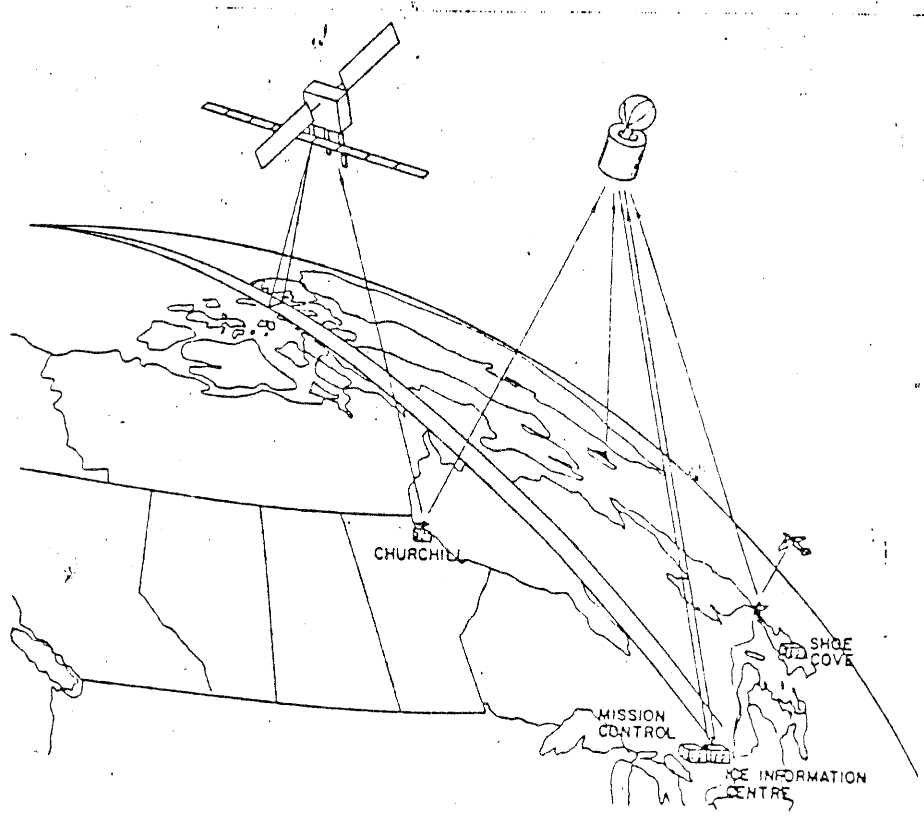


FIGURE 6
Telemetry and ground segment components of RADARSAT

INTERNATIONAL PARTNERSHIPS

Since its inception the RADARSAT Program has pursued its mandate to seek international partners. Besides the agreement with NASA to conduct joint Mission Requirements Studies, a further agreement was signed in September 1982 in which NASA expressed an interest in providing a space shuttle launch and one or two other sensors for the payload. Also in September 1982 an agreement was signed with Great Britain which expressed an interest in providing the spacecraft (the modified L-SAT bus) and possibly also a smaller snesor.

At the present time the United States (NASA) has confirmed its interest in supplying the launch a scatterometer. Candidate instruments for a third sensor are also being considered; one of these is an altimeter proposed by the United Kingdom; another is an ocean colour instrument proposed by the United States..

Besides these agreements which refer to specific contributions to the mission, there is the possibility of other partners also joining the program to provide, for example, parts of the synthetic aperture radar sub-system. Although some discussions on such possibilities have taken place, no agreements have yet been signed.

SAR RESEARCH AND DEVELOPMENT

The RADARSAT Terms of Reference also provided for a Research and Development Program to improve the Canadian industrial and technical capabilities in the area of synthetic aperture radar. This work has supported the selection of C-band for the mission by the design, construction and installation of a C-band scatterometer on the Convair-580. This will be followed later this year by the installation of a new C-band airborne SAR to replace the old ERIM system. These facilities will be used in support of the applications development program and to assist in studies relating to image quality and radar cross section. Design studies on a ground based high speed digital SAR processor have been conducted, and on the space segment studies on the high power amplifer, the antenna, and space radar sub-systems are in progress.

APPLICATIONS DEVELOPMENT

After the RADARSAT Mission Requirements Document had been written the experimental program which had begun in order to assist this work continued partly to resolve outstanding problems and partly to continue research on applications. The latter is an activity of growing importance in the overall program because, for the full benefit of the availability of radar data to be achieved, before the satellite is launched there must be a complete suite of algorithms and procedures to generate the products which users will need. Already considerable progress has been made in this direction. There is not space here to review this work in detail and so instead, some of the more interesting and challenging topics are selected for comment.

Ice

The fact that the satellite will give twice daily coverage over the entire Arctic shipping corridor gives a temporal continuity to the available data. This is important for two reasons; the first that it provides information on ice dynamics which can be used in ice forecasting models; the second that such frequent coverage will enable changes in the mechanical and structural characteristics of the ice masses to be monitored from day to day. Thus, for example, the appearance of new ridges in the area being tracked shows both the increasing difficulty of passage and the presence of pressure in the ice field. In support of this use of the data experimental work in the Arctic is conducted to collect data under different ice conditions and image analysis algorithms are being developed which will emphasize structural features and other patterns to enable ice types to be differentiated.

Work on recognition of icebergs is particularly important because of their variable size and the variation of radar return with the geometry of the iceberg and the radar illumination. Of particular concern is the lower limit at which icebergs can be detected and, for a given noise level in the scene, this means the lower limit of signal to noise level that can be tolerated. This has been investigated by taking an airborne SAR image, which has a much smaller resolution element, and smoothing the radar speckle by averging the data to a resolution element representative of the satellite data set. Assuming this to be an ideal image, noise representing the radar speckle is then added in increasing amounts and at each stage new images generated. The first work of this kind was done with an iceberg in a field of sea ice but it can be readily appreciated that, besides the effect of differing sea ice conditions which might alter the conclusions of this work, the variations of iceberg detectability in different sea states in open water could be even greater. For these reasons the work on icebergs also will continue both in data acquisition and the development of image analysis techniques during the coming years.

Oceans

Most of the oceanographic applications of interest to Canada are concerned with sea conditions off the east coast because of the extreme sea conditions in the area where offshore drilling is taking place. For this reason work on surface wave spectra is receiving particular attention at this time. The current experimental program includes flying patterns over areas of ocean where there are directional wave buoys in order to determine the limits of interpretability of the wave spectrum as a function of the direction of travel of the waves. This again has to be done in various sea states because the problem is a function of wave height. Besides determining the limit of data which can be extracted from the SAR as such, the aircraft used for these experiments will also collect a C-band scatterometer data for studying the relationship between the two. In particular, the data on wave length and direction as a function of wind velocity will assist in the development of models for sea generation that can be used in forecasting.

small change of incidence angle. From a set of such images a hologram can be created in which a three dimensional radar image can be viewed using white light. The first of these scenes generated from airborne data will be available soon.

BENEFIT STUDIES

During the early stages of the RADARSAT Program a number of economic studies were conducted covering the areas of applications that offered the most significant benefits. Besides providing some justification for the RADARSAT Program these studies also assisted the Mission Requirements activities. One of the problems which was experienced during this work, for example, was to know exactly how much importance to attach to applications with dissimilar requirements. These benefit studies allowed a degree of weighting to be used in the selection of preferred requirements.

More recently, however, it became apparent that these specialized investigations were insufficient and that an economic overview was required. For this reason a contract was given to a major economic consulting company with the object of integrating the previous work and including also some other benefits which had not previously been examined. Although the evaluation of potential benefits was very conservative in comparison with previous work the conclusion was that a "worse scenario" would still give a positive benefit/cost ratio of 3:1. One of the major tasks of the remainder of the program is to prepare the way for these potential benefits to be realized.

PROGRAM STATUS

At this time the Phase A studies have been completed and the SAR Research and Development Program is at the mid-point. Cabinet approval for Phase B to begin in 1984 has been received. These and the follow-up activities to launch are shown in the RADARSAT schedule, Figure 7. It can be seem that the ground segment leads the space segment by two years approximately. This is so that Canada may receive and process data from ERS-1 at the time of its launch. This is partly to permit continued participation in the ESA ERS-1 Program, but also to benefit from the opportunity it gives us both to make data from ERS-1 available to the Canadian user community and to carry out practical tests on data distribution and analysis facilities prior to the launch of RADARSAT.

Because the areas where drilling takes place are frequently relatively shallow and have a bottom topography which is conducive to the formation of internal waves, this phenomenon is also of great interest. Large amplitude solitons can cause considerable difficulty to drill ships, and forecasting their time of arrival and magnitude will become increasing important as offshore resource development increases. The ability of SAR to map the dimensions of these features under different conditions of wind and tide is being used to obtain a better understanding of their behavior.

Renewable Land Resources

In applications relating to renewable resources on land there are two major areas of interest at this time. The first concerns the use of multi-temporal data sets for following the progress of crops. The first experiment to be conducted in Canada took place this summer in the prairies where the test site was visited by the Convair-580 five times during the growing season. At this time the data is being processed and results will be published in the scientific literature in the near future.

The use of the C-band scatterometer is also of considerable importance because the C-band radar cross-section as a function of crop type, crop condition, soil moisture, and other parameters is not very well documented at this time. These are essential data for the analysis of crop information which may be gathered at varying incidence angles by the satellite. They are also necessary for radar image simulations which will be used both for interpreting real radar images and for teaching purposes.

Geology

One of the more interesting applications activities in geology concerns the use of multiple data sets. Current work is being conducted using overlays of SEASAT SAR data, LANDSAT data, geomagnetic data, and gamma radiation data. After analyzing these jointly for geological information content the results are compared with geological maps of the test area in order to evaluate the improvement which can be achieved using this approach. The early results using a site in Nova Scotia led to many corrections to the existing map. A follow-up multiple site experiment will be conducted as part of the SIR-B program.

Another area of endeavour, relating to geology in particular, in which we have been very active is concerned with stereo presentation of radar data. There are various approaches to this technique depending on the end use which is to be made of the information. The efforts to data have been concerned with making geometric corrections for the distortions in the radar images. In the case of airborne data this relates variable incidence angles across the scene. The same kind of approach that allows the incidence angle to be corrected to one standard figure also allows this figure to be changed by the

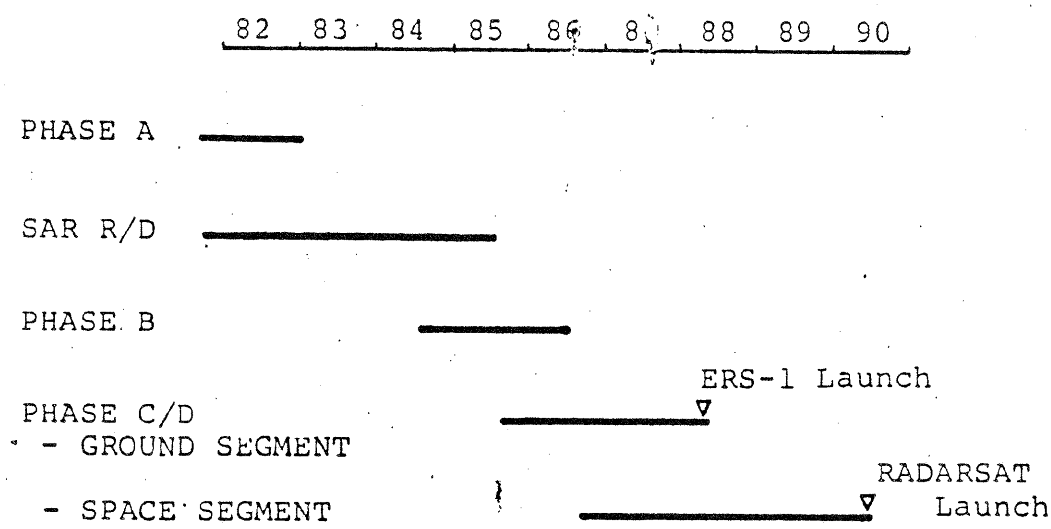


FIGURE 7
RADARSAT Schedule

Now that approval for Phase B has been given, the level of effort in all aspects of the programme will increase, and negotiations with partners will reopen. The Phase B decision marks an important transition from a period of review of options and preparatory work to a period of more intensive and directed work on system and programme development.

REFERENCES

Ref. 1 A Conceptual Design Study for Future Operational Remote Sensing Satellite Systems, Effective Summary, Canadian Astronautics Limited, Ottawa, Canada, March 28, 1980.