Current status and perspectives of active microwave imaging for geoscience application

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1 Introduction

There is some question in the Earth science community about the future of imaging radar. Speculations about its prospects are as frequent as are those on remote sensing in general. The period of exaggerated hopes for remote sensing in the 1960's has, after the launch of LANDSAT-1 in 1972, given way to a clearer perspective of satellite multispectral scanning (MSS). This is the result of continued extensive research with LANDSAT data which presently dominates the remote sensing scene. The prospects for Earth science side-looking radar (SLR) are less obvious. Opinions range from optimism to expectations that SLR might disappear as a tool at least for static Earth science applications (Hempenius, 1976). Will it?

In this paper, the author offers an answer to this question. The evidence presented here leads him to conclude that SLR will have continued applications for surveillance and in the Earth sciences, possibly even to a greater extent than at present. This conclusion is found on the basis of a review of the history of imaging radar, a description of the work of major research centres in the field and an analysis of the advantages and limitations of SLR. The contents of the paper reflect a view essentially formed by exposure of the author to the US radar research environment. The reader is assumed to be familiar with the principle of SLR. A recent and excellent account of this principle is found in a Scientific American paper by Jensen *et al* (1977).

2 Historical review of side looking radar

In the late 1930's England, the United States and Germany produced almost simultaneously the apparatus which came to be known as 'Plan Position Indicator (PPI) Radar'. This is the circularly scanning radar which is now used in airports, aboard ships, and in aircraft. However, it was only in 1951 that the concept of SLR was mentioned for the first time by J Wiley, who worked for the Goodyear Corporation's Aerospace Division (Sherwin *et al,* 1962).

This concept was technically feasible from 1953 on, at the University of Illinois, and also within 'Project Michigan', which began in 1953 at the Willow Run Laboratories of the University of Michigan to develop new means for military reconnaissance. Within this project, synthetic aperture radar was theoretically and experimentally explored, leading to the first coherent radar data acquisition and processing system (Cutrona, 1962). Images were produced regularly in the late 1950's. Real aperture SLR was developed from 1954 on, essentially after a beginning had been made with synthetic aperture radar. In retrospect it appears that this development was a by-product of the more complex synthetic aperture.

In the late 1950's, SLR was a privilege of the military. However, under the pressure of civilian researchers, the veil of secrecy around this new sensor was gradually lifted. In 1960, SLR was described for the first time in the open literature (Perry, 1960). Thereafter images soon became generally available. Early images were of the real aperture type; from the late 1960's on, synthetic aperture SLR imagery was also declassified, provided it had a resolution of less than about 10 metres.

Outside the United States, SLR was developed for example, in Britain by the Royal British Radar Establishment (Davies, 1970); the USSR released images in 1972 (Glushkov *et al,* 1972). France has its own SLR-capability (Fontanel 1977).

In the US purely civilian initiatives in imaging radar applications began in 1964 with the creation of an inter-disciplinary, inter-agency radar team under NASA guidance (Matthews, 1975). This team was responsible for providing experimental real aperture radar coverage in excess of 500,000 km^2 in the US.

The first major actual Earth science application of SLR was in 1967, when an area of 17,000 km^2 in Panama's Darien Province was mapped in Project RAMP (Crandall, 1969). Westinghouse's real aperture radar was flown in this project, because synthetic aperture with its higher resolution was still classified. Although this project was an initiative of the US military, it actually represented (together with the NASA effort already mentioned) the beginning of civilian Earth science radar.

Soon after RAMP (1969) the Westinghouse Electric Corp started a commercial venture, offering the services of a real aperture radar system in a DC-6 aircraft. Figure 1a shows an example of the type of imagery produced by this system. Westinghouse was successful until the declassification of synthetic aperture radar. In 1971 Goodyear Aerospace pooled with Aero Service Corporation

Philadelphia (now in Houston), to install one of its synthetic aperture systems in an inertially guided Caravelle twin jet. This system produced the imagery of the type shown in Figure 1b. The investment, particularly in a more expensive aircraft with better navigation, paid off for Aero Service/ Goodyear: most business went to this group, so that Westinghouse decided to stop its commercial radar operation in 1973. A Motorola real aperture radar, commercially operated by the Grumman Aircraft Corp, suffered the same fate as Westinghouse's at that time, leaving the Aero Service/Goodyear system as the only civilian commercial radar venture. However, late in 1974, Motorola successfully started a new commercial radar operation in a Grumman Gulfstream aircraft (Motorola Aerial Remote Sensing, 1975).

The business volume realised by Earth science radar justifies the conclusion that prior to LANDSAT, it was the most successful non-photographic remote sensing system. At the present time, all Latin-American countries sharing the Amazon basin, and countries in Central America, in South-East Asia, in Europe, in North America and most recently in several countries in Africa have acquired side-looking radar data.

The most significant project is the well-published Brasilian 'Radar of the Amazon (RADAM)'. In spite of available LANDSAT-MSS coverage this project was later extended to cover the entire country. Brazil today has complete SAR coverage of its territory and so does Nigeria (however with real aperture) to mention just two large countries.

Most recently radar technology has been stimulated by (a) synthetic aperture radar (SAR) from a satellite (see Figure 2), as originally proposed by Moore (1965), then for the first time realised in the Apollo Lunar Sounder Experiment (ALSE) during the Apollo 17 mission to the Moon (Phillips *et al,* 1973); (b) multi-frequency radar (see Figure 3), resulting in multispectral radar images (Rawson *et al,* 1975); (c) the 'inexpensive real aperture radar' available at Lawrence, Kansas (Moore, 1975); (d) increases in swath width and resolution; (e) digital processing of SAR. These developments in radar technology will be discussed in a later section.

Earth science radar with a real aperture has only a twelve to fourteen year civilian history; with synthetic aperture it is only half as old. During its short history radar has become a successful and commercially viable non-photographic civilian remote sensing system with wide civilian applications. However, small scale satellite MSS-imagery is an important competitor for reconnaissance mapping.

3 Centres of excellence for Earth science radar

The development of side-looking radar technology is led by Great Britain, France, the USSR and the USA (where hardware is being built by companies such as: Goodyear Aerospace Corp, Westinghouse, Motorola, Philco-Ford, Hughes Research Lab, Texas Instruments etc). The main users of radar data are still the armed forces. Therefore radar engineering concerns itself mostly with military needs.

However, military research has led to improved hardware, software and understanding of the energy-matter interaction. This of course is also of great benefit to civilian radar applications. To give an example, scientists at the US Army Engineer Topographic Laboratory (USAETL) in Fort Belvoir, Virginia, have worked for many years on an Earth science applications programme for SLR. An entire topographic mapping system, including contouring and orthophoto capability was built (Yoritomo, 1972). Although this effort was abandoned after 1972 (mapping accuracies apparently did not meet the needs of the sponsors) the work was essential for later civilian applications.

A leading centre for imaging radar is the Environmental Research Institute of Michigan (ERIM, formerly Willow Run Laboratory), where SLR was originally developed. At present ERIM has an (unclassified) operational multi-frequency, multi-polarisation SAR system capable of producing images with a resolution better than 3 m x 3 m on the ground. Processing of these data is optical, with an option of on-line digitisation by image dissection of correlated synthetic aperture radar data. Digital image processing may then be applied to the data (Jackson *et al,* 1975).

Imaging radar expertise in the North American academic world is wide-spread (e g Universities of Illinois, Georgia, New Mexico, Ohio State, Texas A & M etc). Particularly intensive studies are carried out at the University of Kansas, Lawrence, Kansas. This is one of the few centres where radar back-scattering functions of different materials have been and are being systematically studied, where the value of multi-frequency radar is under evaluation (Bush *et al,* 1975) and where radar 's capability for measuring soil moisture is being studied. An inexpensive brute force radar that could be duplicated for less than $100,000 was built there. However, this system has hardly been put to use in applications studies (Moore, 1975).

After extensive radar work in the period of 1964–1966 the US National Aeronautics and Space Administration (NASA) reduced its efforts to concentrate on multi-spectral scanning. Intensive involvement began again with the lunar Apollo 17 mission where an orbital SAR system was used for imaging and subsurface sounding of the Moon. This development was carried out primarily at the Jet Propulsion Laboratory (JPL) in California. Radar developments at this laboratory demonstrated that airborne SAR images clearly show ocean wave patterns (Brown et al, 1973). This in turn created interest in an Earth-orbiting imaging radar on board an oceanographic satellite (SEASAT-A). In 1974 the decision was taken at NASA to launch SEASAT-A in May 1978 with the first civilian* Earth orbiting imaging radar system (McCandless, 1975). This decision greatly increased interest in radar science and caused a change from the perfunctory role that it originally had.

The development for SEASAT-A will be followed by a project for the second orbital flight of the Space Shuttle later on board the Space-Lab (Cohen *et al,* 1975; Rouse, 1977). Work is also progressing for the orbital exploration of the planet Venus by a Venus Orbital Imaging Radar (VOIR) (Rose *et al,* 1974; Beal, 1977).

Another important effort of NASA concerns the radar study of ice. NASA had a brute force system flying over the Great Lakes to conduct lake ice surveys (Schertler *et al,* 1975) and engaged in the Arctic Ice Dynamics Joint Experiment (AIDJEX, see Campell *et al,* 1978).

Outside the US the Netherlands have executed an Earth science radar programme with an emphasis similar to that at the University of Kansas (de Loor, 1971). Extensive radar studies are being reported at the British Royal Radar Establishment (Davies, 1970), in the USSR (Glushkov *et al,* 1972) and in France (Fontanel, 1977).

There is little publicity on an important group of users of radar imagery: oil, mining and engineering companies. In many instances radar seems to be a fairly standard tool in prospecting for oil and minerals, probably partly for logistics. In the US it is also used in site reconnaissance for nuclear reactors and dams. Also belonging to this group of radar users are the many governmental agencies in the countries which have acquired SLR coverage, such as Brazil etc.

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* From various recent indications (January 1978) one must conclude that classified satellite imaging radars are available to both the Soviet as well as US-military.

4 Earth science imaging radar – pros and cons

There are four often quoted capabilities of imaging radar that have been, and still are, the main reason for its use:

- It can penetrate clouds
- It can produce synoptic views of large areas, typically for mapping at a scale of 1:100,000 to 1:400,000
- Coverage is possible within predetermined and short periods of time
- It permits imaging at very shallow look angles and thus results in perspectives different to those of common vertical photographs.

Other imaging radar capabilities have not been a major reason for its use in the Earth sciences, but they could become important in the future, because radar offers the following advantages:

- A general penetration capability beyond that concerning clouds (penetration of vegetation, surface layers of soil, snow, rock etc)
- Provision of its own illumination and thus enabling control over the illumination angle
- Employment of wavelengths different from photographic sensors thus enabling the provision of different information (soil moisture, surface roughness)
- Ability to perform resolution, independent of the distance of the object with pixel sizes of up to 3 m x 3 m (military radars down to 1 m x 1 m?)
- Ability to make use of polarisation effects
- Ability to operate in several wavelength bands simultaneously (radar MSS)
- Ability to image ocean waves from orbital distances;
- Ability to produce overlapping images suitable for stereoscopic viewing.

Some of the above properties are unique to radar. However there are some characteristics which compare unfavourably with other sensors:

- The radar imaging process is optical-mechanical, leading to problems of defining a precise internal geometry
- The object is scanned along the flight line so that flight perturbations enter fully into the image geometry
- Radar swath width is not a function of flight or orbit altitude; from an aircraft radar usually provides coverage that is wide compared to photography; from a satellite the swath will be basically as wide as from the aircraft
- SAR images are normally not produced during flight; an off-line process is required to generate useful, interpretable imagery

- Effects in the radar echo due to surface roughness, slope, shape and di-electric properties of the object are hardly separable
- Stereo models have poor geometry and there is the possibility of artifacts.

A more detailed discussion of advantages and drawbacks of radar is beyond the scope of this review. When comparing radar with other sensors a basic question is always: can the radar image provide information that cannot be provided otherwise, at less expense, faster, or with better capabilities to protect the data? One will be tempted to compare radar with photography, or with orbital MSS imagery. The above short review of radar characteristics demonstrates that radar has unique features that are valuable even in instances where photography or MSS could be made available as well. However, SLR imagery is generally flown only when aerial photography (at small scales) cannot be taken economically and within a reasonable time (clouds etc).

5 A future for geoscience radar?

5.1 Expected advances in radar technology

Before considering future geoscience applications for radar imagery it is appropriate to explore the possible developments of imaging radar technology. A major step consists of the before-mentioned advent of *satellite radar:* SEASAT (Table 1), Space-Shuttle, Space-Lab and VOIR may well present the essential thrust and motivation to carry SLR to new horizons. But apart from this there are several other areas of possible technological development.

An important element is *resolution.* The maximum available resolution of 3 m x 3 m as shown in Figure 4 can be obtained only if a reduced swath width is accepted: the total number of resolution cells is limited to about 6000 per swath. In addition the expense of getting increased resolution is high (stability of the antenna, navigation accuracy, processing precision, etc). However, resolution is still expected to increase.

In order to relate radar to photographic resolution, one can define a simple relationship between the diameter 'n' of a ground resolution element of SLR, expressed in metres (m), the resolution 'k' in line pairs per millimetre (lp/mm) and the scale number 'M' of aerial photography:

$$M = n \times 2.8 \times k \times 1000 \quad [n \text{ in m/pixel; } k \text{ in lp/mm}]$$

For a ground resolution of n = 3 m, and photography of 20 lp/mm, the equivalent photo scale is 1:168,000. The factor 2.8 enters to relate 'pixels' to 'line pairs'. With a blow-up to 8 pixels/mm, the enlargement is at a scale of 1:24,000, good for the unaided eye at 25 cm viewing distance.

With the advent of civilian satellite radar and the resulting increase in interest in radar one may hope that *digital processing* of raw synthetic aperture data will soon reach a level that is practicable and will lead to high resolution being obtained without sacrifice of swath width. Digital processing of the raw signals also promises to lead to more economical SAR in *real time,* thus doing away with the awesome off-line optical conversion of signal data to interpretable images.

The development of *multi-frequency* satellite radar is planned for the era of the Space Shuttle and will not be available before 1980. Aircraft multi-frequency radar is at present being studied: Figure 3 shows an example of ERIM's X- and L-band (3 cm, 25 cm). JPL has an X-, L- and VHF-band SLR (3 cm, 25 cm, 2 m). The experience with this type of imagery is still very limited. First results indicate, however, that there is considerable potential, for example, in agricultural tasks (Bush *et al,* 1975).

5.2 Geoscience applications of radar

NASA's interest in developing satellite radar has been accompanied by the compilation of extensive annotated bilbiographies on imaging radar applications (Bryan, 1973; Dellwig *et al,* 1974) and of applications reviews and studies to support proposed NASA satellite projects (Matthews, 1975; Texas A & M University, 1975). In this section it is attempted to list operational and potential radar image applications on the basis of these (generally optimistic) NASA-funded studies. Any such listing may have shortcomings but can at least serve as a basis for further studies.

(a) Operational applications

There have been a number of operational applications established for SLR (Table 2). Of these the requirements for *reconnaissance type mapping* of cloud-covered areas will disappear when no unmapped areas are left on Earth. So far this was the major application of geoscience radar. But other operational Earth science applications will remain. Of these, *monitoring the sea* and coastal environment (e g traffic) is considered, for example, in the USA (Kraus *et al,* 1977) and in the Netherlands. In view of the extended 200 mile fishing zones in many countries this monitoring task may become increasingly significant (see Report of the Interdepartmental Task Force on Surveillance Satellites (1977) concerning satellites and national sovereignity).

Application to exploration tasks and to the site selection for dams and power plants has reportedly accounted for a commercial business volume in excess of $1 million during 1975 in the US alone.

(b) Potential applications

Table 3 lists potential radar applications of some promise. A major application will concern the *oceans.* Figure 5 presents an example of a SAR image that can serve as an input to meteorological forecasting by providing information on the length, amplitude and direction of ocean waves. Radar is also capable of imaging *sea and lake ice* (Thompson *et al,* 1972), as shown in Figure 6. These capabilities will provide a means to direct ship traffic, trace icebergs (Super *et al,* 1975) and monitor the polar ice (Leberl *et al,* 1976; Bryan *et al,* 1977).

The application of radar to the mapping of vegetation and soils for *agricultural purposes* is still largely unexplored. This type of mapping is at present based on photographic and MSS-images. Particularly in the MSS-case many of the maps produced are experimental. However, if the addition of radar to MSS data can improve agricultural (or geological etc) mapping then a significant radar application would be presented. Current research efforts address the radar measurement of *soil moisture* as an added parameter in plant growth analysis and other applications. The improved understanding of the radar back-scatter functions is accompanied by development of data processing methods to merge data from different sensors for the purpose of augmented interpretability. Figure 7 presents an example of a portion of LANDSAT and radar images that have been superimposed. Other examples may be found in Science (Anon, 1977). Harris and Graham (1976) have also presented numerous examples for this technique. However, interpretation experiences with these composites do not yet exist.

Subsurface sounding with fairly long wavelengths (2 m, 20 m, 60 m) was successful on the (dehydrated) Moon (Phillips *et al,* 1973). Considerable research is however still required to understand the capabilities and limitations of radar to penetrate vegetation and surface layers on Earth. Most statements on this potential application must at present still be based on speculation. It is this category of evidence that led to the cartoon in Figure 8: the suggested technological capability exists but is certainly still far from operational.

5.3 Satellite SLR

In the near future satellite SLR will be experimental only to be tested and evaluated in high technology, industrialised environments. A satellite SLR system like that of SEASAT-A could, however, also meet the needs of less developed nations for basic mapping of their territories. Resolution of imagery is higher than that of present LANDSAT-MSS (compare Diagram 1). The capability of penetrating clouds would seem to permit coverage to be practically repetitive at will.

Unfortunately the fact that at this time satellite radars are designed as 'proof-of-concept'-missions results in some technological (and possibly also financial as well as legal) restrictions on the acquisition of the data: SEASAT-A SAR data will be received through modified LANDSAT receiving stations; a country has to be within the radius of activity of such a station to receive the raw SAR data of its territory. In addition it must have access to the technology of converting the raw data into useful images. Provided that the technological problems were solved then SEASAT-costs would seem to be competitive with airborne radar (Diagram 2, based on informal quotes from NASA).

SEASAT-A receiving stations will be located to receive data from the North-American continent (USA, Canada) and of the surrounding oceans. Imaging of other areas would be possible with appropriate arrangements made with NASA to equip ground stations in other parts of the world. The experimental character of SEASAT-A is further evident from the fact that imaging will only take place during short intervals of time of at most 10 minutes per day: during a single orbit image strips of about 4000 km length and 100 km width could be produced.

From the above it seems that SEASAT differs from LANDSAT in that it cannot fulfil the role of a semi-operational imaging system. A similar situation applies to the other planned satellite radar missions: Space-Shuttle will be in orbit only for a few days at near equatorial orbits. The same applies to Space-Lab. This severely limits the coverage that is possible.

6 Conclusion

This paper has attempted to offer a view on the future of side-looking imaging radar for geoscience applications. Background information for such a view was presented on the basis of the history of imaging radar and centres of excellence in geoscience orientated radar analysis. An enumeration of the pros and cons of SLR lead then to a review of expected advances in radar technology. These relate to satellite SLR, to increase in resolution, to multi-frequency and real time synthetic aperture radar.

These considerations serve as a basis for the discussion of present and future geoscience applications of imaging radar. The conclusion is that SLR will continue to be an important tool for surveillance and geoscience analysis in spite of reducing application to reconnaissance type mapping. In fact radar has considerable potential: there are proven capabilities of monitoring ocean surfaces, sea ice and coastal environments. Also SLR has been found to be a tool suitable for a number of geological, geomorphological, hydrological etc tasks. Finally there are many additional potential applications that still need increased understanding of the interaction of radiation and matter.

A general conclusion of the paper then may well be that geoscience radar does not disappear. On the contrary, it may just be at the beginning and requirements may emerge for more information and training opportunities relating to radar imaging and interpretation.

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Recent Goodyear data was made available by Messrs Lee Graham and Walter Nyman of Goodyear Aerospace Corp, Figure 3 by the Environmental Research Institute of Michigan. The relevance of the cartoon in Figure 8 to radar science was discovered by M L Bryan of JPL. S A Hempenius did the proof-reading and offered many valuable suggestions to improve the paper. For all these various forms of support I wish to express my sincere gratitude.

TABLE 1
Geoscientifically relevant parameters of the SEASAT Synthetic Aperture Radar

Launch	May 1978 (planned)
Orbit altitude	790 – 820 km
Orbit inclination	108° retrograde
Orbit period	100 min
Radar wavelength	L-band (25 cm)
Elevation angles of line of sight	16.9° – 23.1°
Swath width	100 km
Resolution along track	7 m (25 m)*
Resolution across track	
in slant range	8 m
in ground range	25 m
Dynamic range	50 db
Radar signal transmission	To modified LANDSAT receiving stations
Recording of radar signal	Probably digitally on magnetic tape
Generation of map film	Optical or digital correlation

* The 7 m resolution in most radar presentations will be artificially degraded to 25 m to achieve equal resolution along and across track, and to improve the appearance of the images by smoothing ('filtering') of some of the graininess of the original data (multi-look mode)

TABLE 2
Operational or near-operational geoscience application of imaging radar

1. Reconnaissance-type original mapping of cloud-infested remote areas for the purpose of
   - Geology
   - Geomorphology
   - Forestry
   - Land use
   - Cartography (planimetry at scales 1:100,000 and smaller)
2. Regional geological fracture patterns
   - Dam site selection
   - Nuclear power plant site selection
   - Petroleum exploration
   - Mineral exploration
3. Meso and macro scale stream network analysis
4. Monitoring of catastrophic damages due to
   - Floods
   - Hurricanes
   - Earthquakes
5. Maritime traffic
6. Ice distribution on lakes
7. Monitoring icebergs

TABLE 3
Potential future geoscience applications of imaging radar

1. Lakes and oceans
   - Lake levels
   - Surface plant growth
   - Oil spills
   - Ocean waves and sea state
   - Internal waves
   - Polar ice motion
   - Polar ice thickness, age
   - Monitoring of hurricanes
2. Coasts
   - Shoreline erosion
   - Wetlands mapping
   - Coastal wave diffraction
3. Water Management
   - Drainage basin geometry
   - Planting patterns
   - Soil moisture
   - Snow cover
   - Frozen and unfrozen ground
   - Ground water through vegetation and fracture analysis
   - Glacier subsurface sounding
4. Vegetation
   - Crop species
   - Soil moisture
   - Range species, spread of woody weeds
   - General species type of timber stand
5. Soils
   - Soil type in arid, arctic, and cloud-infested areas
   - Microrelief (surface roughness)
   - Subsurface sounding
6. Geology and geomorphology
   - Regional geomorphology
   - Subsurface sounding
7. Mapping
   - Land use assessment at meso and macro scale
   - Urban meso scale change detection
   - Revision of small-scale maps
   - Monitoring of large construction (Alaska-pipeline)
   - Geodetic multi-lateration (using synthetic aperture radar signals)

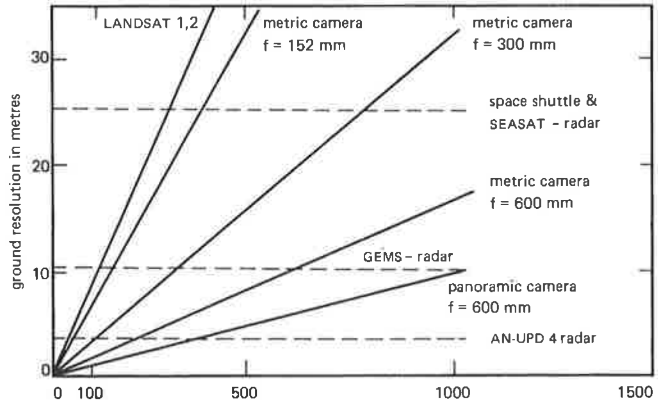


DIAGRAM 1
Comparison of resolution of radar, camera and LANDSAT type imaging at orbital altitudes. Resolution is defined as the diameter of a 'resolution cell' or 'instantaneous field of view'. For cameras, a 35 l/mm resolution was converted to the equivalent resolution cell diameter

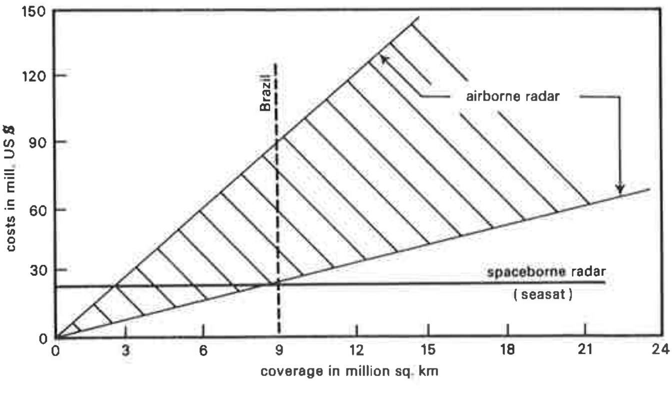


DIAGRAM 2
Costs of air and spaceborne radar. SEASAT radar costs (according to informal comments): $14 million; launch and mission support: $6 million. (There are 6 instruments aboard SEASAT. Total costs for mission support are split among them).

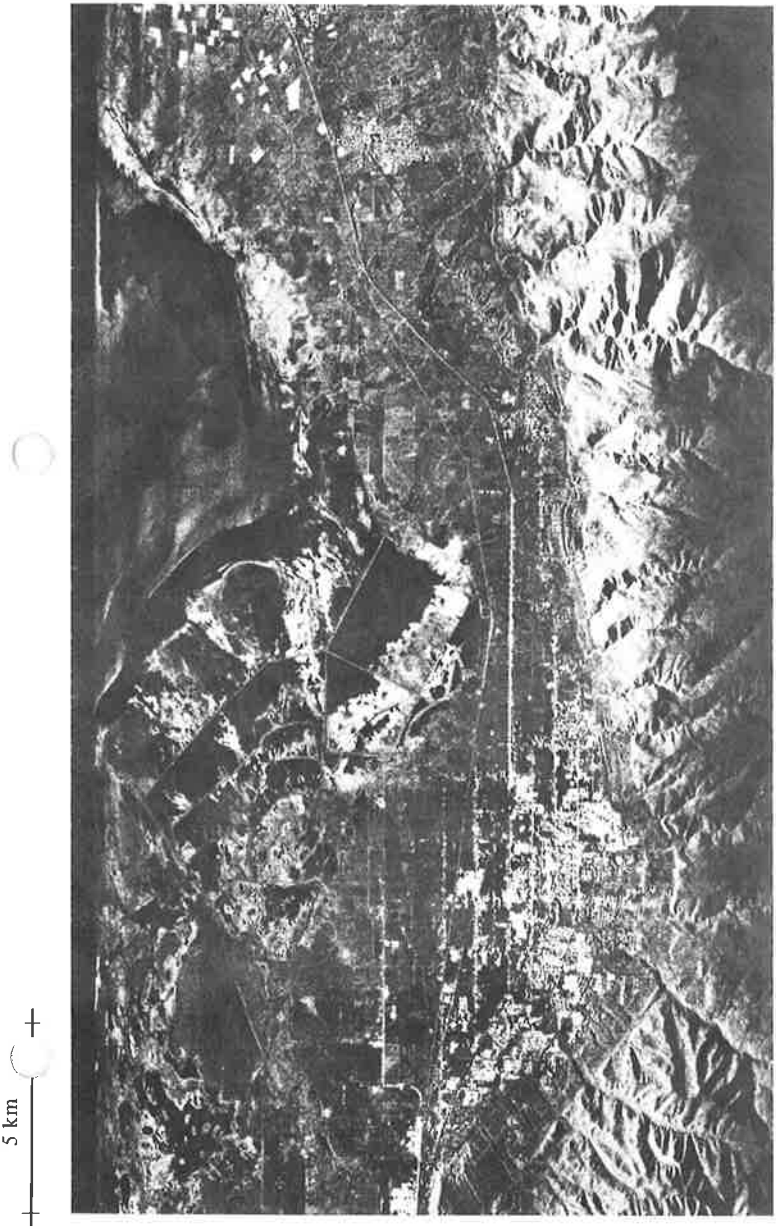


FIGURE 1a
Example of a radar image produced by the Westinghouse real aperture system AN/APQ97 over Bountiful, Utah

FIGURE 1b
Example of a radar image produced by the Goodyear GEMS 1000 synthetic aperture radar near Needles, California

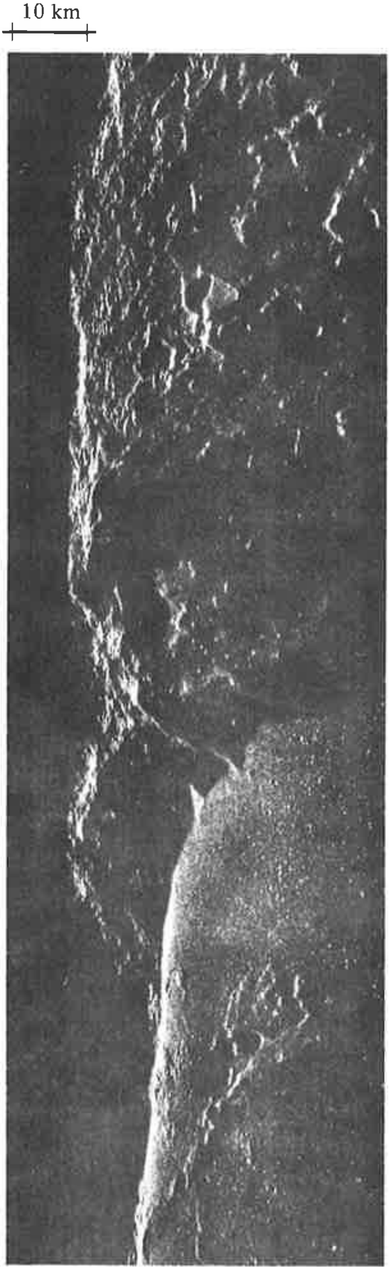
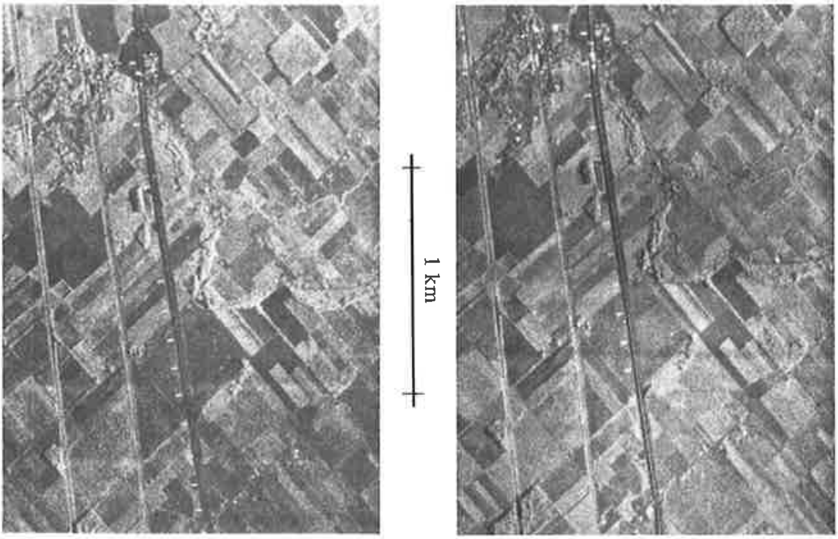
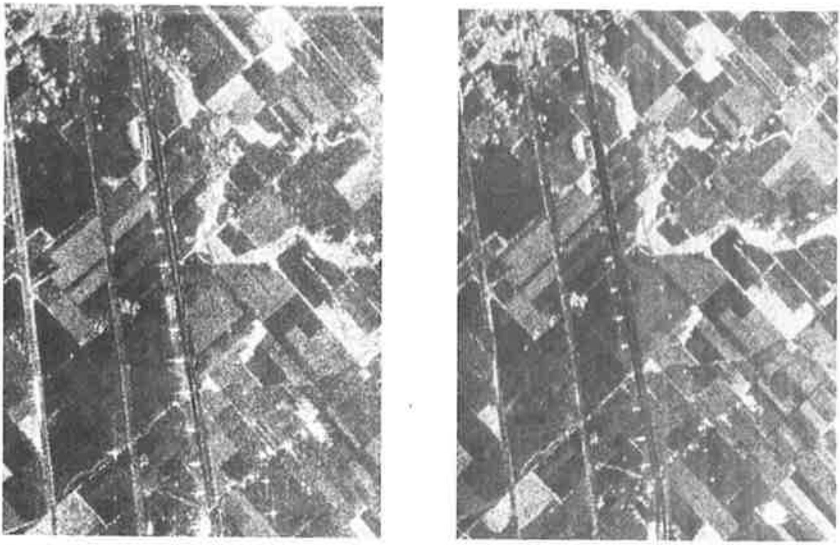


FIGURE 2
VHF band (2 m wavelength) radar image of the lunar Apennine Mountains, taken by the first satellite side looking radar in 1972, during the Apollo 17 mission to th oon



X-band HH-Polarisation ▼

X-Band HV-Polarisation ▼



L-Band HH-Polarisation ▼

L-Band HV-Polarisation ▼

FIGURE 3

Example of multi-frequency, multi-polarisation radar imagery of an agricultural scene in Michigan (courtesy of Env Research Inst of Michigan)

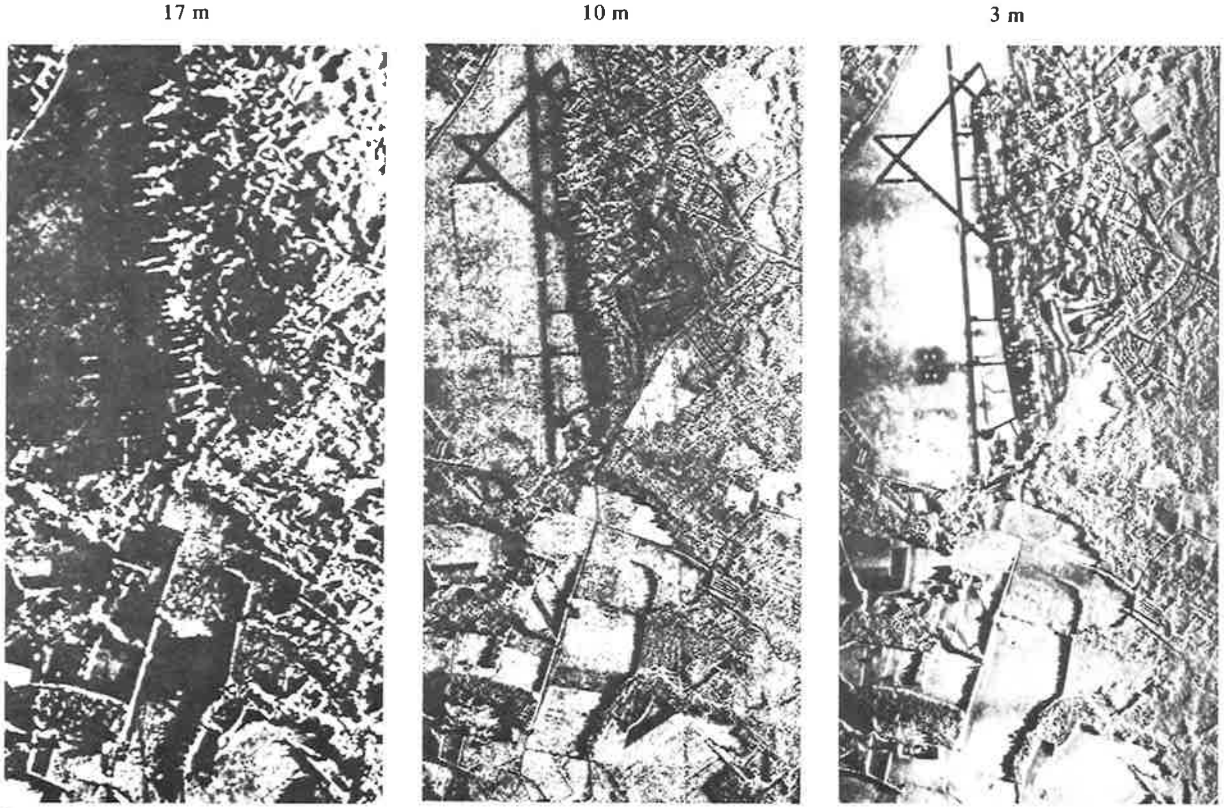


FIGURE 4
Side looking radar images with resolutions of 17 m x 17 m, 10 m x 10 m, 3 m x 3 m (courtesy of Goodyear Aerospace Corp)

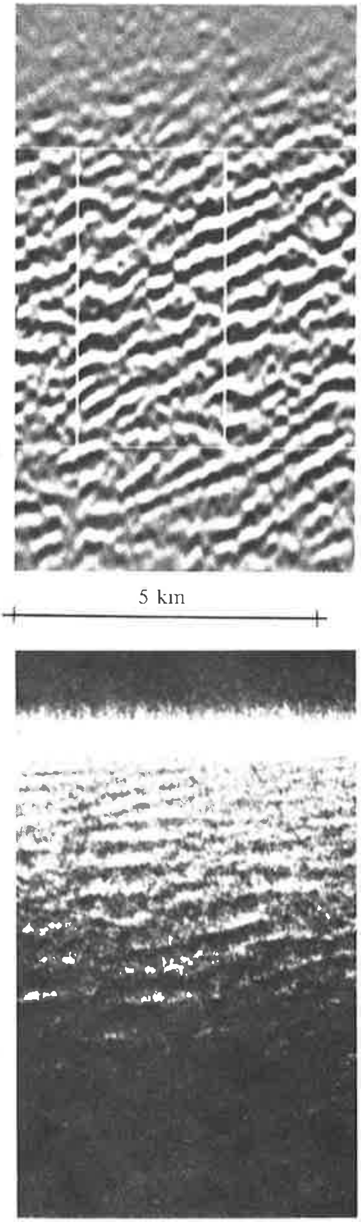


FIGURE 5
Ocean waves show on JPL's L-band side looking radar imager, with (left) raw image, (right) image after digital filtering (from Brown et al, 1973)

FIGURE 6
Arctic ice images by the L-band (25 cm wavelength) radar system of the Jet Propulsion Laboratory, August 1975

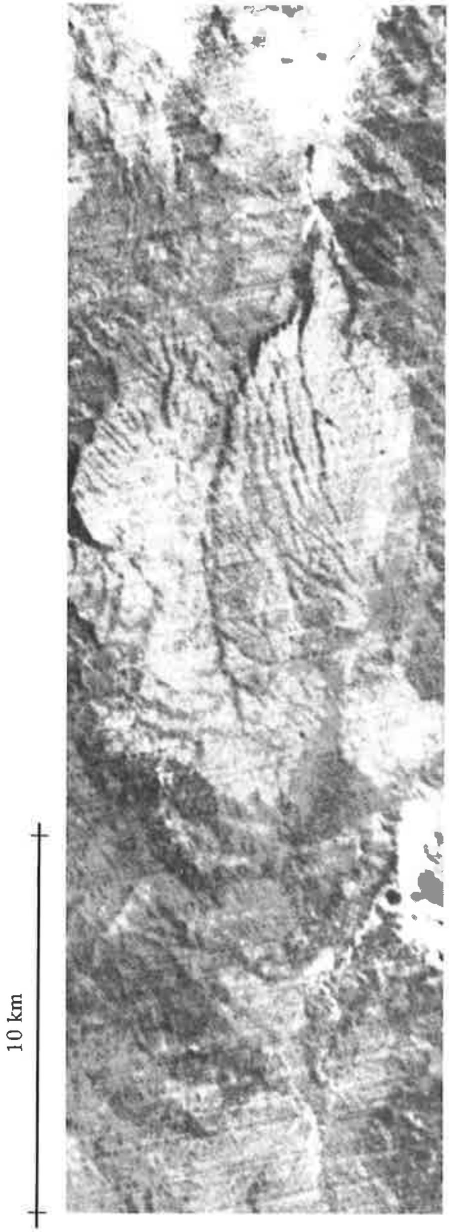


FIGURE 7a (above) *LANDSAT image (Bands 4, 5 and 7) of an area near Tuscon, Arizona, and*
FIGURE 7b (below) *showing a radar image of the same area.(Courtesy of Goodyear Aerospace Corp.)*

FIGURE 7c *Result of a first attempt at combining the LANDSAT data and radar image of Figures 7a and b.*
(Courtesy of Goodyear Aerospace Corp.)

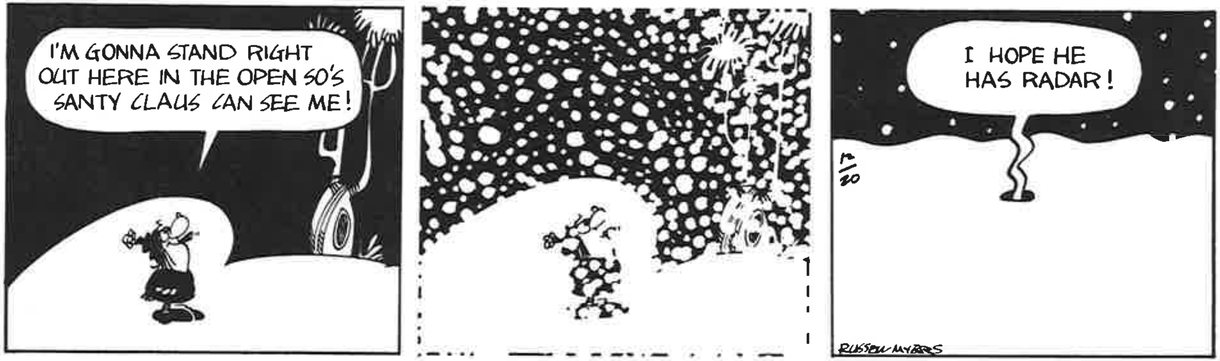


FIGURE 8
This suggested application of radar images is not yet entirely proven (courtesy of Chicago Tribune, New York News Syndicate)

References

Anon 1977 — Three articles *'Remote Sensing'*. Science (1977), Vol 196, No 4289, pp 511–516.

Beal, R 1977 — *Venus Orbiter Imaging Radar Study Report,* Jet Propulsion Laboratory, Technical Report 660-60, Pasadena, California.

Brown, W E *et al* 1973 — *Oceanographic Observation with Imaging Radar,* Union de Radio Scientifique Internationale, Fall Meeting, Boulder, Colorado.

Bryan, M L 1973 — *Radar Remote Sensing for Resources, an Annotated Bibliography,* Environmental Research Institute of Michigan, Ann Arbor, Michigan.

Bryan, M L , W D Stromberg, T Farr, 1977 — *Computer Processing of SAR L-Band Imagery,* Photogrammetric Engineering and Remote Sensing, Vol XLIII, No 10.

Bush, T F, F T Ulaby 1975 — *On the Feasibility of Monitoring Croplands with Radar,* 10th Conference on Remote Sensing of the Environment, Ann Arbor, Michigan.

Campell, W *et al* 1978 — *Microwave Remote Sensing of Sea Ice in the AIDJEX Main Experiment,* Journal of Boundary Layer Meteorology (in press)

Cohen, E *et al* 1975 — *An Earth and Ocean SAR for Space Shuttle – User Requirements and Data Handling Implications,* Proceedings National Telecommunication Conference, New Orleans, Louisiana.

Crandall, C J 1969 — *Radar Mapping in Panama,* Photogrammetric Engineering , Vol XXXV.

Cutrona, J L 1962 — *Synthetic Aperture Radar,* in 'Radar Handbook', ed Skolnik, McGraw-Hill, New York.

Davies, D H 1970 — *Radar – A New Mapping Device,* De Ingenieur, Nr 33, Technisch Wetenschappelijk Onderzoek 6, The Netherlands

Dellwig, L *et al* 1976 — *Applications of Imaging Radar – A Bibliography,* The University of Kansas Space Technology Center, RSL Technology Report 265–2, Lawrence, Kansas.

Fontanel, A 1977 — *Détection d'une nappe d'huile et étude de l'état de la mer par radar latéral aéroporte.* IFP Res 25 269. Institut français du pétrole, Rueil, France

Glushkov, V M *et al* 1972 — *Toros Side-looking Radar System and its Applications for Sea-Ice Conditions Study and for Geologic Explorations,* Archives of the International Soc Photogrammetry, 12th Congress, Ottawa, Canada

Harris, G, L Graham 1976 — *Radar-Landsat Synergism,* Goodyear Aerospace Report, Litchfield Park, Arizona, USA, and Presented Paper, 13th Congress of the Intl Soc of Photogrammetry, Comm III, Helsinki, Finland

Hempenius, S A 1976 — *Critical Review of the Status of Remote Sensing,* Bildmessung und Luftbildwesen, 44(1), p 29–42.

Jackson, P *et al* 1975 — *Utilization of Digitized Multichannel Microwave Data,* 10th Conference on Remote Sensing of the Environment, Ann Arbor, Michigan.

Jensen, H L Graham, L Porcello, E Leith 1977 — *Side-Looking Airborne Radar,* Scientific American, October, pp 84–95.

Kraus, S P *et al* 1977 — *Radar Detection of Surface Oil Slicks,* Photogrammetric Engineering and Remote Sensing, Vol XLIII, No 12.

Leberl, F *et al* 1976	*Study of Arctic Sea Ice Drift from L-band Synthetic Aperture Radar,* Proceedings of Am Soc Photogrammetry, Annual Meeting, Washington, D C.
Loor, G P de, A A Jurriens 1971	*The Radar Backscatter of Vegetation,* AGARD – Propagation Limitations in Remote Sensing.
Manual of Remote Sensing, 1975	Chapters 2, 9, 14, American Society of Photogrammetry, Falls Church, Virginia.
Matthews, R E ed 1975	*Active Microwave Workshop Report,* National Aeronautics and Space Administration, Special Report 376, Washington, D C.
McCandless, S W 1975	*The U S SEASAT Program;* 10th Conference on Remote Sensing of the Environment, Ann Arbor, Michigan.
Motorola 1975	*Motorola Aerial Remote Sensing,* Company Folder, Phoenix, Arizona, USA.
Moore, R K 1965	*Satellite Radar and Oceanography, An Introduction,* in 'Feasibility of Conducting Oceanographic Exploration from Aircraft', Proceedings Woods-Hole Oceanographic Inst, Mass.
Moore, R K 1975	Personal Communication, University of Kansas, Lawrence, Kansas.
Perry, W 1960	*Scouting Battlefield of Tomorrow,* Electronics, Vol 33, No 47.
Phillips, R *et al* 1973	*Apollo Lunar Sounder Experiment,* Apollo 17 Preliminary Science Report, NASA SP–330, Washington, D C.
Rawson, R, F Smith 1974	*Four Channel X–L Band Imaging SAR Radar,* Proceedings 9th Symp on Remote Sensing of Environment, Ann Arbor, Michigan.
Report, Government of Canada, 1977	*Satellites and Sovereignity,* Report of the Interdepartmental Task Force on Surveillance Satellites, Government of Canada, Ottawa, Canada.
Rose, J R, L D Friedman 1976	*A Design for a Venus Orbital Imaging Radar Mission,* American Institute of Aeronautics and Astronautics, AIAA-Paper No 74–222.
Rouse, J 1977	*Microwaves remote sensing from Spacelab.* GDTA Journées de Télédétection, Saint-Mandé, France 21-23.9, 1977
Schertler, R J *et al* 1975	*Great Lakes All-Weather Ice Information System,* 10th Conference on Remote Sensing of the Environment, Ann Arbor, Michigan.
Sherwin, C W *et al* 1962	*Some Early Developments in Synthetic Aperture Radar Systems,* IRE Transactions on Military Electronics, MIL–6, No 2, p 111–115.
Super, A D, S R Ogwes 1975	*Remote Sensing Applied to the International Ice Patrol,* 10th Conference on Remote Sensing of the Environment, Ann Arbor, Michigan.
Texas A & M University 1975	*Shuttle Imaging Radar Experiment Workshop,* Texas A & M University, Remote Sensing Center, Contract Nr 953929, College Station, Texas.
Thompson, T W *et al* 1972	*Progress Report on 25 cm Radar Observations of the 1971 AIDJEX Studies,* Arctic Ice Dynamics Joint Experiment (AIDJEX) Bulletin No 12, University of Washington, Seattle, Washington.
Yoritomo, K 1972	*Methods and Instruments for the Restitution of Radar Pictures,* Archives of the Intl Soc of Photogrammetry, Comm II, 12th Congress, Ottawa, Canada.

Abstracts

Current status and perspectives of active microwave imaging for geoscience application
This paper presents an optimistic view of the usefulness of Side-Looking Radar (SLR) for Earth sciences applications, based on a historical review, analysis of the work of the major research centres, and study of the advantages and limitations of radar. Current and future applications of airborne as well as of satellite radar are sketched in anticipation of the May 1978 launch of SEASAT-A. Radar images taken from this satellite will trigger interest in orbital radar remote sensing for civilian purposes.

Applications courantes et futures des moyens actifs micro-ondulaires d'obtention d'images pour utilisation de ces derniers aux sciences de la terre
Cet article, basé sur un historique, sur une analyse du travail réalisé dans les grands centres de recherches et sur les avantages et les limitations du radar, présente un point de vue optimiste quant à l'utilité du radar latéral dans ses applications aux sciences de la terre. L'auteur esquisse les applications courantes et futures du radar aéroporté aussi bien que celles du radar embarqué à bord d'un satellite, en prévision du lancement, en mai 1978, du SEASAT–A. Les images qui seront alors obtenues, déclencheront un intérêt certain pour la télédétection, dans des buts civils, à l'aide des radars placés sur orbites.

Estado actual y posibilidades futuras de aplicación de las imágenes de micro-ondas activas en las geociencias
Este artículo presenta una consideración optimista de la utilidad y aplicación del Radar de Visión Lateral (SLR) en las ciencias de la tierra. El examén está basado en una revisión histórica y en en análisis del trabajo de los principales centros de investigación y en el estudio de las ventajas y limitaciones del radar. El autor describe las aplicaciones actuales y futuras del radar aeroportado así como del radar a bordo de un satélite, con anticipación al lanzamiento del SEASAT–A en mayo de 1978. Las imágenes de radar tomadas desde éste satélite, despertarán interés en los sensores remotos teledetectados desde satélites y en su aplicación para propósito civiles.