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A REVIEW OF REMOTE SENSING
TECHNOLOGY
SENSOR TECHNOLOGIES
AND
THEIR APPLICATIONS

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Prepared on behalf of:
PHILIP A. LAPP LIMITED
By
DR. L. W. MORLEY
President
Teledetection International

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1.0 SURVEY AND RECONNAISSANCE CAMERAS

1.1 Survey Cameras

(a) Function and Purpose

Survey Cameras often called 'Mapping Cameras', 'Cartographic Cameras' or 'Metric Cameras' have been used since World War I for topographical mapping. Increasingly sophisticated photogrammetric plotting machines to convert digital photographs into topographical (contour) maps have been developed over the years, resulting in a mature world-wide surveying and mapping industry. In Europe, the Swiss WILD company and the German Carl Zeiss company in the West and Zeiss Jena in the East have been outstanding contributors to technology. In the U.S., Fairchild Camera and Instrument company and later Itek Corporation have developed quality metric cameras.

Since aerial mapping cameras have been used extensively for many years and are well known they will not be discussed here. Only metric cameras used in satellites will be discussed.

(b) Basic Description of Technologies Involved

The desirable characteristics of a metric camera are high geometric fidelity with greatest possible resolution as a trade-off against the widest possible angular coverage of the lens. Since the ground resolution is affected by the resolving power of the film as well as of the lens, the larger the film format, the greater the resolution. Aerial mapping cameras are generally standardized worldwide on a 23x23 cm film format.

Photogrammetrists were slow to take advantage of satellite photography for mapping purposes because they did not believe that sufficiently high resolution could be achieved in stereo. The whole APOLLO program passed by without a metric camera being tried in space. Apollo astronauts used largely hand-held cameras.

(c) Platforms and Applications

1.1.1 SKYLAB Earth Terrain Camera (E.T.C.)

The ETC used on SKYLAB (1972) was the first metric camera to be tested in space. It was referred to as the S190B experiment and was manufactured by ACTRON INDUSTRIES Inc. It incorporated 'rocking camera forward motion compensation' and a chromatically-corrected lens over the wave length range o.40 to 0.90 micrometers. The film format was 11.25 cm. square with a 46-cm focal length lens. The highest resolving power of 180 lines/mm was achieved using Kodak 3414 film type. This corresponded to a ground resolution of 15 metres. This provided sharp photomaps at the 1:50,000 scale. Stereo pairs were not taken. Color photos were also taken but the decreased accuracy limited the photomap scales to 1:100,000.

1.1.2 SHUTTLE, Large Format Camera

This camera has a 305 mm focal length and a 230x460 mm film format. The system is flown with the long dimension of the format in the flight direction in order to obtain the necessary stereo coverage for topographic map compilation. The relative ground positioning accuracy of the system at an altitude of 300 km is 15 metres when measurements of 15 micrometers accuracy are made of the imagery. This is appropriate for map compilation at a scale of 1:50,000 which is the objective of the experiment. This camera was made by the ITEK Corporation. For B&W film 3414 at 220 km altitude the ground resolution is 10 metres.

1.1.3 SPACELAB-1 Metric Camera to be orbited Feb '84

This camera is a standard Zeiss aerial camera type RMK A30/23 with 3 film magazines modified for operation in space. The camera is mounted to an optical quartz window inside the manned module. The format is 23x23 cm with a focal length of 610 mm.

From an altitude of 250 km, the scale of the photography will be 1/820,000. The coverage per frame will be 190 km x 190 km, with a ground resolution of 20 m. The photographs produced should be useful for map compilation at scales up to 1:50,000.

(c) State of the Art and Development Trends

The Spacelab-1 camera is Phase A of an overall ESA camera development program called ATLAS being conducted by the Federal Republic of Germany. Phase B will consider:

1. adding image motion compensation to the RMK A30/23 camera and mounting it externally on the Shuttle pallet in a pressurized container.
2. Adding image motion compensation, increasing the magazine capacity and mounting on an external pallet.
3. Developing a new camera with 60 cm focal length, I.M.C., 11.5 x 23 cm format for operation in the manned module.

Phase C will consider operating these cameras on free-flying spacecraft launched and serviced by the Shuttle. It is the author's opinion that such cameras will not be able to compete in ground resolution, accuracy or operating cuts with pushbroom scanner, once software for data from the latter has been developed for topo mapping. The SPOT satellite should prove this one way or another.

1.2 Multiband Cameras

(a) Function and Purpose of the Sensor

Multiband cameras are used for determining the spectral signature of terrain cover, be it crops, forest, rock, water, or bogs, etc. Emphasis is placed on determining the exact colour of a target rather than on its accurate location, although in the final analysis, both are required.

The use of colour film for this purpose is considered inadequate because the resultant colour depends too much on the particular batch of film used, its age, and the chemistry used to develop it.

(b) Basic Description of Technologies Involved

In multiband photography, a nest of coaxically mounted cameras records a number of images of a scene, each through a different spectral filter. The imagery is ordinarily converted into black-and-white positive transparencies which are illuminated through a second set of spectral filters and brought into register to form an additive colour display.

The geometric requirements for multiband cameras include: high spatial resolution in each band, registration to a fraction of a resolution element between each band across the format and low distortion.

The spectoradiometric requirements for multi-band cameras include: uniform spectral irradriance across format, sharply defined spectral sensitivity in each band and shutter repeatability.

(c) Platforms and Applications

1.2.1 APOLLO-9 S-065, March 1969

The system consisted of an array of four 70 mm Hasselblad cameras which took the first multiband pictures of Earth from space. It was assembled very quickly from off-the-shelf components and led the way for future multi-band experiments. Similar experiments were conducted prior to this from aircraft. The system was used for experimental phtographic purposes on features such as forests and farmland.

1.2.2 SKYLAB S190A, Multiband Camera May '73

Six cameras, mounted on a ring each with a particular filter: 0.5 to 0.6, 0.7 to 0.8, 0.8 to 0.9 nm were used. Colour I.R. film was used in the fifth camera and normal colour was used in the 6th camera. This camera system was used for experimental purposes on surface features of the globe.

1.2.3 Zeiss Jena MKF-6 Multispectral Camera (Flown on Soyuz 22)

This was similar to the S190A camera used on SKYLAB and was used for general global resource mapping experiments. It has an f/4 lens system covering a 40.5° total field. The resolution is 160 lines/mm. For several years it was the main sensor for the Soviet Earth Resources Program. Only recently have they developed a telemetering multi-spectral line scanner.

(d) State of the Art and Development Trends

Multiband photography is a technology which has been made obsolete by digital multispectral scanner technology. The latter has the advantages of automatic transmission from space, inherent band-to-band registration; accurate solid-state radiometry and output in digital form which makes digital image analysis possible.

1.3 Reconnaissance Cameras

(c) Function and Purpose

Reconnaissance cameras are used for military intelligence, arms control verification, crisis monitoring, and weapons targeting. They are used in photo-reconnaissance aircraft and satellites. Cameras carried by photo-reconnaissance satellites can take remarkably detailed pictures of objects on the ground ('close look') or survey larger areas of the earth ('research and find').

(d) Basic Description of Technologies Involved

The reconnaissance camera is designed to operate with high resolving power and low f number. High geometric fidelity is not generally a requirement. Focal lengths range up to one metre in length. Many reconnaissance cameras have narrow fields of view, generally in the range 10° to

40° so that riseaus and vacuum platens are seldom used. Resolving powers of 200 cycles/mm for cameras of 60 cm. focal length are used with regular operational film. Since reconnaissance cameras used in aerial and space applications usually have to operate at high V/H ratios, 'forward motion compensation' and high cycling-rates are available on most reconnaissance cameras.

(c) Platforms and Applications

Unclassified technical information is generally not available on military reconnaissance cameras. 'Close-look' cameras were carried by U.S. BIG BIRD and KH-11 satellites.

(d) State of the Art and Development Trends

The 'BIG BIRD' cameras are believed to be capable of achieving such high resolution that objects smaller than 30 cm can be distinguished from an altitude of 185 km or more. Better resolution is possible when the target has linear features, such as runways and roads, a characteristic that heightens the contrast between the target and the ground. Photographic cameras are still the best means for obtaining the highest resolutions, but they have the disadvantage that the film must be returned to earth. Telemetering, multi-spectral scanners and return-beam vidicons are expected to eventually replace reconnaissance cameras.

2.0 Non Imaging Electro-Optical Sensors Visible & I.R.

(a) Function and Purpose

Basically, non-imaging sensors are used for research purposes although a few are used operationally. Remote sensing requires sensors which scan large areas from fast-moving platforms. However, the research leading towards the development of these sensors is done initially with non-imaging instruments called 'spectroradiometers' which are used to measure the spectral characteristics of materials.

(b) Basic Description of Technologies Involved

A spectroradiometer or spectrometer is a meter for measuring the radiation from an object as a function of wavelength, be it radiation which is reflected, scattered, emitted or absorbed. A radiometer, on the other hand, operates in a single or a few chosen spectral intervals.

There are three types of spectroradiometers:

(1) Dispersing Spectrometers which use gratings or prisms to split the radiation into its spectral components.

(2) Filter Wheel Spectrometers in which various filters of known spectral transmittance can be sequentially rotated in front of the aperture of the instrument.

(3) Interferometer spectrometers - The radiant intensity as a function of wavelength is obtained by a Fourier transformation of the signal produced by the detector in a two-beam interferometer as the path difference between the two beams is varied.

To determine which of the above types of spectrometer is best suited for a particular measurement program, one must consider a number of design and operational parameters such as spectral resolution desired, field-of-view, complexity, scan rate, environment, data reduction requirements and sensitivity. The fact that there are hundreds of commercially available spectrometers suggests that there is no single "best" spectrometer. Each instrument must be custom-designed and built for the specific research to be done.

(c) Platforms and Applications

The U.S. Civilian Meteorological Satellites use a variety of special-purpose radiometers and spectroradiometers. There is not sufficient room here to describe them. The attached list taken from the American Society of Photogrammetry's Manual on Remote Sensing 1983 is attached for information in Appendix 1.

2.1 Fraunhofer Line Discriminator

Fraunhofer lines are dark lines in the solar spectrum caused by the selective absorption of light by gases in the relatively cool upper part of the solar atmosphere. The lines are sharpest, deepest and most numerous in the near-ultraviolet, visible and near infrared region of the spectrum. The feasibility of using the Fraunhofer line depth method to detect luminescing earth materials was demonstrated at the I.T.&T Labs. The U.S. Geological Survey was sufficiently interested to have Perkin-Elmer produce an airborne Fraunhofer line discriminator.

The instrument measures the ratio of the central intensity of one of the strongest lines to a convenient point on the continuum, a few Angstroms distant. This ratio is compared with a conjugate spectrum reflected from a material that is suspected to luminesce.

The principle application has been to study the distribution of rhodamine dye in water, put there for the purpose of monitoring water movements. Other substances that exhibit fluorescence: lignin sulphanate a by-product of paper manufacturing, of crude oil, chlorophyll and possibly carcinogenic hydrocarbons.

2.2 Optical Correlation Spectrometers

The technique of correlation spectroscopy is based on correlating the spectra of radiation received in real time against a stored reference. The spinning-disk correlator carries two different patterns - one corresponding to the peaks of the spectrum being detected and the other against the minima. There is no signal from the system except when the spectra match.

One version of the instrument manufactured by Barringer Research of Toronto is capable of remotely detecting two gases such as sulphur dioxide and nitrogen dioxide.

Barringer suggests numerous other potential applications for remote sensing correlation spectrometry which include: surveillance for forest fires, detecting gases associated with military targets and measurement of water vapour distribution.

Extension of the correlation spectrometer into the infrared region of the spectrum using the Michelson principle offers a potentially fruitful area of research.

(d) State of the Art & Development Trends

As was stated at the beginning of the discussion on non-imaging sensors, they are used mostly for research and demonstration. In most cases any of these spectroradimeters which are successful in the non-imaging mode can, with admittedly some complex engineering, be made to work in the imaging mode. The method should be particularly effective in measuring the total burden of particular gases such as CO_2, SO_2, NO_x, Ozone etc. in the atmosphere - either from a polar orbiting satellite or in the spin-scan mode from geostationary altitude. In view of the public interest in 'acid rain' and 'the greenhouse effect'; the author commends the development and use of such imaging sensors.

Unfortunately, as far as is known, the distinct type of fine structure exhibited by the absorption spectra of gases is not present in the reflection spectra of natural solids occurring on the earth's surface. Nevertheless a few detectable 'bumps" in the reflection spectra attributed to such things as chlorophyll and clay minerals are measurable. Specialized spectroradiometers should be developed for measuring the targets directly. Present methods tend towards broad spectral measurements in the scanning mode and then trying to extract spectral signatures by complex methods of digital image analysis.

3.0 Electro-Optical Frame Imaging Sensors

(a) Function and Purpose:

Generally speaking, electro-optical imaging sensors can be categorized as either mechanical scanners such as those using a rotating or oscilating mirror or electronic scanners which have no moving mechanical parts, such as the frame imaging sensors which are described here and the pushbroom scanners to be described later.

The frame imaging sensors grew out of the television camera industry. Since mature technology already existed at the time the space programs began, these sensors were used in the first Automatic Picture Transmission satellites to produce cloud pictures of the earth. They were also used in the early Apollo flights to take pictures of the moon and later of Mars. The sensors are best suited for imaging applications in single spectral bands where high radiometric accuracy is not required.

(b) Basic Description of Technologies Involved

The vidicon, frame sensor type of scanner consists of an evacuated tube with a photosensitive surface inside at one end and an electron gun at the other. The photosensitive surface is located at the focus of a wide angle lens; in front of which is a camera-type shutter. When the shutter is opened, the light pattern created by the image is implanted on the photosensitive surface. The shutter is then closed and the electron beam is made to scan, television style, over the surface by beam deflector electrodes located in the tube. As the beam scans the surface, it releases secondary electrons, preferentially from those portions of the surface where no light from the scene had fallen. The secondary electrons are collected sequentially as the beam scans over the image by another electrode, whose resulting change in voltage will electronically represent the image. This time-varying voltage, synchronized with the scanning rate of the electron gun can then either be recorded on a video tape, played onto a television screen or transmitted as a televised signal.

(c) Platforms and Applications

Television cameras are used in small aircraft with video recorders for flight path recovery and for quick evaluation of crops, wildlife and other surface features. The NOAA Meteorological satellites still contain T.V. cameras for Automatic Picture Transmission as well as their more sophisticated multispectral scanners.

Landsats 1 and 2 each contained a multiband package of 3 return-beam, bore-sighted vidicon cameras (RBV's). Each camera was shielded by a spectral filter that would permit optical transmission of only one of the bandwidths of interest. The spectral regions accepted approximated those covered by the colour/infrared photographic films namely blue-green, yellow-red and red.

While the normal television camera contains 500 to 1000 resolution elements on a side, the RBV is capable of over 3000 elements on a side. The RBV has been used as a high-resolution multiband earth-mapping device on Landsats 1&2 with optics designed for an angular resolution of 33 microradians. In Landsat 3 only 2 RBV panchromatic cameras are being used side by side, one looking to the right and the other to the left of nadir, thereby doubling the ground resolution to 40 metres instead of the usual 80 m. In Landsat 4, the RBV's have been removed to make way for the Thematic Mapper - a more efficient, higher resolution, multispectral, oscillating mirror scanner which will be described later.

(d) State of the Art and Development Trends

Frame sensors such as return beam vidicons have the advantage that they are compact, light-weight and relatively inexpensive compared to opto-mechanical scanners. When used with powerful lenses they rival reconnaissance cameras for intelligence gathering purpose. Furthermore, the output is in a form which can be readily telemetered to earth either from a high-flying drone, aircraft or from a satellite. However, for civilian and resource-mapping purposes they lack the spectral and geometric fidelity of push-broom scanners and mirror scanners. In order to be used in the multi-band mode, they must be assembled in clusters and fitted with filters - one RBV to a spectral channel.

Charge-coupled devices (c.c.d.'s) which are now used as push-broom scanners in linear arrays are becoming so minute that it soon may be possible to form them into two dimensional matrices like the 'cones' on the retina of the human eye. For example, they have achieved densities of about 10,000 c.c.d.'s per sq. mm. as compared with a density of 1 million cones per sq. mm. in the hawk's eye. When a c.c.d. array changes from one-dimensional to two-dimensional, it no longer remains a 'push-broom' scanner, as described later, but becomes a frame detector more like the human eye and must be used with a shutter to prevent blurring. At that point the problem is then transferred from the detector to the data handling required to create an image.

4.0 MECHANICAL SCANNERS

(a) Function and Purpose

Rotating mirror I.R. scanners or more simply I.R. line scanners were first developed by the military for aerial night-time surveillance. The MSS (multi-spectral scanner) grew out of these. The MSS data initially was used for photo-interpretation instead of colour and colour I.R. film. Later it was found possible to calibrate the data and put it in digital form on a computer compatible tape. Algorithms and programs for image analysis were then developed and finally an MSS was installed in the ERTS satellite, launched in 1972, which firmly established the instrument as a global resource management and environmental monitoring tool.

(b) Basic Description of Technologies Involved

The first mechanical scanners of the rotating mirror type were invented for use in the thermal infrared. This was the only way of creating an image at these wavelengths because there are no lenses through which radiation of this wavelength can pass in order to be focussed on the detector. The first mirror scanners were in the 7-9 micron band. Later it was discussed that if the incoming radiation in the visible and near I.R. from the rotating mirror were passed through a beam-splitter and if solid state detectors were suitably located to intercept and detect the particular wavelengths desired, one could have a multi-spectral line scanner which could produce perfectly registered, black and white images in each of the chosen bands. All frequencies between the ultraviolet and the near infrared would pass through the beam splitter. The thermal I.R. mirror would be attached to the same shaft but was offset so the radiation did not pass through the beam splitter.

The rotating or oscillating mirrors in these scanners provide the across-track scanning while the forward motion of the aircraft or satellite provides the along-track scanning. The resultant image is a raster-scan or line-scan of the underlying terrain.

There are two important advantages of mechanical multi-spectral scanners over colour or colour/I.R film. Firstly the detectors measure the absolute value of the radiation in each band whereas with film, one has to rely on the chemistry of the film emulsion and the developing chemical as well as on the method of processing to achieve consistent results. This is totally unreliable, to say the least. Secondly, the data by nature is already in a digital sequential stream or line which makes it compatible with computer analysis. Aerial film, on the other hand must be scanned with a line scanning recorder to achieve this - a very costly and time-consuming procedure. Mechanical scanners can perhaps better be described as scanning radiometers.

(c) Platforms & Applications

4.1 Advanced Very High Resolution Radiometer (AVHRR)

TIROS-N NOAA-7 Polar Orbiting Meteorological Satellites put into orbit since 1972 contain the Advanced Very High

Resolution Radiometer (AVHRR). This is an imaging mirror-scanning, multi-spectral radiometer with the following characteristics:

5 channels: 0.58-0.68μm, 0.725-1.0μm, 1.53-1.73μm 3.55-3.93μm, 10.3-11.3μm & 11.5-12.5μm. Resolution 1 km, swath width 3000 km; for measuring sea surface temperature, snow cover, albedo, clouds, vegetation cover and ice sheets.

4.2 Visible and Infrared Spin Scan Radiometer (VISSR)

Operational Geostationary Satellites SMS-1, SMS-2, GEOS 1,2,3 (1974-78)

The principal instrument for these satellites is a 16-inch aperture telescope for visible and infrared scanning. Built by the Santa Barbara Research Centre and called VISSR, this sensor permits day and nightime observations of clouds and the determination of temperature cloud heights and wind fields. These data are relayed every 15 minutes for the whole hemisphere in view.

The SMS also relays data received from remotely located data collection platforms such as river gauges, ocean buoys, ships, balloons.

GEOS 4&5 (Sept 80 and May 81)

These are the most recent geosynchronous meteorological satellites which are equipped with an advanced version of the VISSR spin scan radiometer which is called the VAS (Visible Infrared Spin Scan Radiometer Atmospheric Sounder.) Since these are geostationary satellites, the scanner itself must scan in two dimensions as it cannot rely on the forward movement of the satellite to provide scanning in one dimension.

The VAS not only retains the VISSR dual band imaging function but uses a more complex detector configuration with selectable narrow-band optical filters which makes possible the determination of the three-dimensional structure of the atmosphere and water vapour distribution over the hemisphere under observation. The atmosphere is thus scanned in three dimensions!

4.3 LANDSAT MSS (Multispectral Scanner) 1,2,3,4 (1972-82)

Designed for earth resources mapping, this scanner has been perhaps the most successful. The data from it has been widely used by most nations of the world.

Scanning is accomplished in the cross-track direction by an oscillating mirror which sweeps out a 185 km wide swath on the ground in 4 spectral bands, two of which are in the visible and two in the near infrared.

On Landsat 3, a fifth band in the thermal infrared was added. The analog signals produced are digitized and formatted into a 15 megabit data stream for onboard recording and/or transmission to an earth receiving station of which there are now 14 owned by various nations. During subsequent data processing at the ground stations, they are transformed into framed imagery and marketed as either black and white or false colour images or as digital computer compatible tapes (CCT's).

The uses are as varied as those for which aerial photographs - surveys and mapping, forestry, crop inventory, hydrology, oceanography, geology, land use mapping, etc. A world-wide value added industry has been built up in the computer enhancement, analysis and interpretation of the Landsat MSS data.

4.4 LANDSAT THEMATIC MAPPER

Landsat 4, launched in 1983 contains a (TM), Thematic Mapper Scanner as well as the old M.S.S. but contains no R.B.V.'s. Landsat 4 is expected to give out in November '83 and will be replaced about March '84 by Landsat D' which will become Landsat 5 when launched.

The TM is a more advanced scanner with 30 m resolution as compared to 80 m with the M.S.S. Instead of 5 bands, it will have 7. The two additional bands are a new blue band to expand the use of the data in bathymetry and a new infra-red band to assist in rock differentiation. (2.2 microns). The scene size 100 x 100 nautical miles is the same as for the M.S.S. The 7th band is in the thermal infrared (10.4 - 12.5 μm) but only has a resolution of 80 metres.

5.0 PUSH BROOM SCANNER

(a) Function and Purpose:

optical imaging scanner for atmospheric (cloud) land and oceanographic sensing.

(b) Basic description of technologies involved:

Linear array of CCD detectors located at focal plane of optical system tuned to a particular band; 1000 to 6000 individual detectors. The array is mounted at right angles to the satellite path. Each detector is sampled for a few microseconds to build up an image.

This type of scanner was made possible by the invention of charge-coupled devices which are light sensitive solid-state detectors that can be operated at megahertz frequencies.

(c) Source and Application

This generation scanner will be used in the French Satellite SPOT (and possibly by Space America for their proposed satellite.) It will gradually replace rotating and oscillating mirror scanners in the visible and near I.R. bands for airborne and satellite thematic mapping.

(d) State of Art and Development Trends

No moving parts result in a long life for the instrument. Long dwell-time on each ground resolution element results in a high signal-to-noise ratio. The resolution is dependent on the number of elements in the array and the focal length of the optics.
Limitations are the same as for the camera and are largely caused by atmospheric interference.
They are operated now in aircraft in France and Canada, but are not at present used in satellites.

MEIS (Multi-Detector Electro-optical Imaging System

This scanner was developed by M.D.A. of Vancouver for the Canada Centre for Remote Sensing. The MEIS image is freely selectable by changing filters, much as in a camera. Cameras for many applications, such as remote sensing by aerial reconnaissance, TV and process control are being developed with this new technology.

Because of the high signal/noise ratio of the detector, it is useful when light levels are low. Phytoplankton can be more reliably detected than with the rotating-mirror scanner.

The MEIS uses a two-channel prototype sensor which employs linear photodiode detector arrays placed at the focal plane of each lens.

There are two imaging channels, each with its own spectral isolation filter, lens and 512 element linear photodiode array. The spectral isolation filter passband peak may be selected anywhere in the 0.3 to 1.1 micrometer region. The lower limit of the filter spatial bandwidth is determined by the sensitivity requirements and finally by spectral band-shifting due to off-normal axis angular viewing. With the existing lenses, a 10 nm passband is possible.

6.0 PASSIVE MICROWAVE SENSORS (Imaging and Non-Imaging)

(a) Function and Purpose

Microwave radiometry was adapted for remote sensing from the highly-developed technology of radioastronomy. A radiometer is used to measure the effective or radiometric temperatures of land and sea surfaces and of the atmosphere. It can be used in the profiling or scanning mode and has the advantage that it can work in darkness and through cloud (all weather).

The brightness temperatures recorded are correlated with surface electrical, chemical, and textural properties of the target. At the longer wavelengths, there is the possibility of obtaining subsurface properties, particularly in arid regions.

(b) Basic Description of Technologies Involved

The microwave radiometer consists of a scanning or non-scanning antenna, a very sensitive, broad band receiver, an absolute temperature reference and a recorder. The antenna collects thermally generated microwave radiation and focusses it on the receiver, where it is detected, amplified and recorded as a voltage-time record, or if it is a scanning radiometer, as an image on photographic film.

Water vapour in the atmosphere has a strong resonance at 22.235 GHz and Oxygen near 60 GHz. Below 15 GHz, however, the atmosphere is almost transparent.

(c) Platforms and Applications

The following regions of the spectrum are of interest in remote sensing:

0.4 - 1.6 GHz - good soil penetrability yielding information on soil moisture, voids and interfaces

0.4 - 15 GHz - all-weather region suitable for multi-spectral systems to establish surface material properties.

15 - 22 GHz - oceanographic applications, showing useful polarizations and emissivity effects for measuring surface temperature, roughness and salinity.

22 GHz - atmospheric water vapour measurements

60 GHz - For atmospheric vertical temperature profiles.

35, 95, 135 & 225 GHz - atmospheric windows

Cosmos 243 in 1968 contained a 4-band passive microwave radiometer. Since then, more than 13 multi-frequency or imaging microwave radiometers have flown in space for earth observations. Since the size of the antenna had to be kept within reasonable dimensions, the spatial resolutions were of the order of tens of kilometers. Hence satellite microwave radiometers have, so far, been limited to atmospheric and oceanographic applications as well as ice-shelves over the land.

> Cosmos 243 (Sept 68) made measurements at 3.5, 8.8 and 37.5 GHz in a non-scanning mode. Estimates of atmospheric water vapour and liquid water were made. Cosmos 384 (1970) measured sea temperature and sea ice concentration at 22 and 37 GHz.
>
> Nimbus 5 (1972) ESMR scanner measured and classified sea ice 19.3 GHz NEMS at 22.2, 31.4, 53.6 54.9 and 58.8 GHz nadir viewing horns obtained a vertical temperature profile, snow cover, sea-ice classification surface winds and precipitation.
>
> Following these, Skylab ('73), Meteor (1974) Nimbus 6 (75) Block 50 ('78), TIROS 'N' ('78), Seasat ('78) and Nimbus ('78) worked with continually-improved radiometers aimed at measuring the same parameters more accurately. see list of met. sat sensors on page

d) State of the Art and Development Trends

For synoptic meteorology and climatology applications, passive microwave sensors are beginning to be exploited operationally to supplement the traditional passive sensors in the infrared and visible regions of the spectrum because of their ability to penetrate cloud.

Utilization of the 183 GHz water vapour line in addition to the line at 22.2 GHz may improve the ability to derive water vapour information. If enough satellites were orbited to give complete global coverage every six hours, this should meet forecasting requirements.

The use of frequencies above 60 GHz show promise for more quantitative rain measurements over both ocean and land areas.

For oceanography, surface temperatures, surface winds, salinity, oil slick detection and pollution monitoring are further possibilities. The extension of microwave technology to submillimeter wavelengths will allow many new applications. When large antennae become possible with space stations high resolution, low-frequency applications such as salinity and soil moisture and ground water prospecting will become possible.

Few experiments have been applied to hydrologic applications yet this is a field where applications could be very important.

7.0 ACTIVE MICROWAVE SENSORS

7.1 Real Aperture Side-Looking Radar (SLAR)

(a) Function and Purpose of Sensor

SLAR is primarily used as a remote-sensing and surveillance tool. It is a real-aperture, as opposed to a synthetic aperture (SAR) system and is much simpler than the SAR. SLAR signals are recorded on a continuous strip of film similar to that from a strip-camera or an optical I.R. scanner. Invented in the 50's, it was originally a classified military sensor, but became available on a commercial basis in 1965. It has been used for reconnaissance and mapping in regions where prevailing cloud cover restricts the use of visible and I.R. sensors. It has equal applicability in areas of extreme ruggedness as well as flat agricultural and metropolitan areas. Imagery can be interpreted in terms of geomophology, geology, land use, forestry and other natural vegetation.

(b) Basic Description of Technologies Involved

In real aperture or side-looking radar, an antenna with a long horizontal aperture is mounted along the side of the aircraft. The antenna directs microwave energy into a narrow fan-shaped beam, which defines a narrow path or line across the terrain strip that is approximately normal to the flight track. The antenna is fed with a pulse of microwave energy which propagates at the speed of light within the beam and successively illuminates points along the line. The radar echoes, scattered back from targets at different ranges are separated in time at the radar receiver. A spot of synchronized intensity-modulated light scans a line across photographic film to record target echoes at the ground range distance. After each line of video return is recorded, another pulse is transmitted to obtain a new scan. The strip image is produced by advancing the film past the scanning line proportionally with the aircraft ground speed.

Range-swath and angular coverage of SLAR can vary greatly for different applications. The angular coverage usually excludes the angles near normal incidence and zero grazing to avoid distortions and shadowing. Range-coverage (swath width) is based on achieving sufficient resolution and high signal/noise required to map terrain features of interest.

(c) Platforms and Applications

SLAR has not been placed in satellites (with the possible exception of Soviet nuclear-powered military satellites) because real aperture radar requires too much power to get results at satellite altitudes. The British and U.S. Military have produced various airborne versions which have since found their way into civilian roles. For example the Motorola APS-94 SLAR in routinely used by both the U.S. Coast Guard and Environment Canada for ice reconnaissance. New small, light-weight versions are being used to provide ice surveillance for drill-rig operators in ice-infested waters. Aircraft are equipped with down-link facilities so that rig operators can get real time information.

(d) State of the Art and Development Trends

As a mapping tool, SLAR will not be able to compete with SAR because of its property of decreasing resolution with range, while SAR resolution is independent of range and is virtually uniform over the swath width. At present it is much simpler, less expensive and lighter in weight than SAR, but as the airborne SAR begins to imitate the satellite SAR and as the SAR data handling becomes more efficient, SAR will undoubtedly replace SLAR in aircraft.

Just as multifrequency passive microwave data can yield much more information on a target than a single frequency, so will multispectral radar (sometimes called colour radar). More research however needs to be done on radar signatures at various frequencies. With the advent of millimeter and sub-millimeter radar, there are more possibilities for multispectral SARs.

7.2 Synthetic Aperture Radar (SAR)

(a) Function and Purpose

SAR can produce extremely fine resolution that is nearly independent of range. For long-range systems such as satellite systems requiring fine resolution, SAR is the only technique that can be used. Vehicle stability problems require elaborate compensation schemes and stabilized antennae to achieve fine resolutions.

SAR is much more complex to build than SLAR but for long range and for quality mapping with fewer distortions, SAR must be used.

As an airborne device it has been used in areas of the world where there is such severe cloud cover that aerial photography has been out of the question. The most famous example of a SAR survey was when the whole of Brazil was surveyed with the Goodyear "GEMS" system. Since limited aerial photography of Brazil is available, because of a high incidence of cloud cover, the data serve as a great boon to the resource community of Brazil.

The only civilian satellite projects with SAR were carried out on Seasat which orbited between June and October, 1978. The same model was flown later on the Shuttle known as SIR-A. A further mission with SAR will be flown in 1984 known as SIR-B (Shuttle Imaging Radar-B). These data are some of the most remarkable imagery of the earth. The problem is that there are many unexplained large features particularly in the oceans which will require considerable research to unravel.

The geological community is now examining these data with great interest because many large structural features were detected which were not visible from air photos or on the ground.

(b) Basic Description of Technology Involved

Unlike SLAR, in which a pencil-sharp beam is projected at right angles to the path of the vehicle, SAR projects a wide beam. This means that all reflectors within the swath of the radar are "seen" by the radar for a much longer period of time than in the SLAR. They will first be seen at a longer range as they come into view ahead and to the side of the vehicle, then pass through a minimum range as they draw abeam and finally increase in range as they fall behind. Thus the return echoes will show a doppler frequency increase as the range becomes smaller, pass through zero doppler and finally show a doppler decrease. Instead of the return echoes being passed from the receiver directly onto a cathode ray display, as is the case with conventional radar, all the signals for all the myriads of echoes for each reflector in the swath area are recorded on a wide-band tape recorder.

The complex software required to convert the raw SAR tape into a SAR image or a digital image (SAR data processing) will not be described here. Suffice it to say that the resultant image looks like a strip photograph of the terrain. SARs can be designed with a large swath width and low resolution or a small swath width and high resolution. It is a trade-off situation. Also there is a choice in the depression angle of the beam. Near-nadir-pointing beams reflect the dielectric properties of the terrain while grazing-angle radars accentuate the roughness and topography by casting long shadows.

Cross-track resolution depends upon the sharpness of the transmitted pulse and along-track resolution on the width of the beam - the wider the beam, the greater the resolution. The reason it is called 'synthetic aperture' is because, by recording the echoes for later processing, the system is "fooled" into thinking it has an antenna which is as long as the distance travelled by the vehicle while a particular reflector is illuminated by the radar beam. This explains the desirability of a wide beam for high along-track resolution. The result is an image in which the resolution is virtually uniform over the whole image. Being in digital form and divided into pixels, the image can be geometrically corrected to conform to geodetic control points or to existing topographical maps.

(c) Platforms and Applications

Outside of the military, there are very few airborne systems available. Aero Service of Philadelphia flies the Goodyear "GEMS" in a Caravelle jet for commercial hire, Intera of Calgary flies the CCRS Convair 580, (known as the SAR 580) for commercial hire, world wide. The latter is a 3 frequency, very high resolution system (1.5 metres). The space SARs have already been mentioned.

Concerning applications, SAR imagery should be thought of as mapping imagery, as opposed to imagery from search radar or SLAR, which is used more for detecting moving objects such as aircraft, ships, ice and icebergs. It should not be thoughtof as being competitive with aerial photography because, being of a vastly different wavelenth, it responds very differently to various targets than does visible light or infrared. The outstanding feature of SAR is its all-weather and day/night capability. This means that it can be used more reliably than the photography or visible and I.R. scanners which cannot see through clouds. The chief complaint about Landsat is that there are not enough cloud-free days over the world's croplands to obtain enough "looks" at the crops during the growing season to make crop predictions. The same is true for mapping floods. Already Europe and Canada are planning to orbit satellites containing SAR for both Land and Sea Applications. Crop prediction is high on their list of missions. The Canadian Radarsat program was aimed, at first, largely on sea ice monitoring in the Northwest Passage for providing navigation information to the large volume of tanker traffic expected there when the Mackenzie Delta and Beaufort Sea oil wells are brought into production. More recently, as research shows that other applications may be just as, or more important than ice, the mission of Radarsat might be altered before it is launched in the 1990s.

One of the most exciting applications of the L-Band SAR used in Seasat and in the Shuttles is its ability to see several tens of feet through dry, surficial material such as sand in arid areas. This could have large implications for the exploration and management of ground water in these regions.

(d) State of the Art and Development Trends

The "secret" of SAR lies in the data processing which is really more than half of the system. As sophisticated users become more familiar with the data, algorithms for processing SAR data to yield estimators for such features as plant vigour, soil moisture and differentiating various kinds of rock, soils and surficial geological material will be developed. This will, in turn, call for more sophisticated multi-frequency, multi-polarized mapping, SAR radars, particularly for use from satellites whose repetitive nature is amenable to monitoring of dynamic phenomena, especially when monitoring will be unimpeded by clouds or darkness.

For military purposes synthetic aperture is being adapted in the "Spotlight mode" which does not mean that the radar beam is moved around in a spotlight fashion, but refers to the processing. "Rough and ready' processing can be used for reconnaissance purposes, but when, for tactical purposes, more detailed information is required on a particular target, the data in that particular region can be processed to very high resolution, providing a radar silhouette of the target for identification.

Remote Sensing Pressure Meter

(Ont J.R.S. 1983 Vol. 4 No. 2 465-478

Atmospheric surface pressure can be remotely sensed from a satellite by an active instrument which measures return echoes from the ocean at frequencies near the 60Ghz O_2 absorption band. The instrument is optimized by selecting the frequency transmitter power and antenna size by numerical simulation which maximizes the retrieval accuracy. The predicted standard deviation error in the retrieved surface pressure is 1 mb. In addition, the measurements can be used to retrieve water vapour, cloud liquid, water and sea state which is related to wind speed.

A development program for the microwave pressure sensor is in progress at Heriot-Watt Univ., The SERC Rutherford and Appleton Lab., U.K. Met office, and The Jet Propulsion Lab, Pasadena, California.

7.3 Microwave Scatterometer

(a) Function and Purpose

A radar scatterometer is a device that measures the microwave scattering properties of the region observed. Any radar that makes an accurate measurement of the strength of the relfected signal is therefore a scatterometer. However, most existing radars that produce images are uncalibrated. Consequently most radar scatterometers are not imaging systems. A calibrated imagery, however, would also be considered a scatterometer.

The radar scatterometer has oceanographic applications where its poor resolution is not of significance. Over land, its primary purpose is in collecting information which can be used to design imaging radars.

(b) Basic Description of Technologies Involved

Scatterometers can be used from spacecraft or from aircraft. The most common variety transmits four continuous wave beams from the vehicle pointed slightly downwards. If the vehicle, for discussion purposes, is proceeding north, the beams are transmitted in a NE, SE, SW and NW direction. The reflected signals beat against the outgoing signal. What is measured is proportional to the calibrated intensity of the return signal after the motions of both the sensing vehicle and the target have been compensated for. This technology was borrowed from that of the "Doppler Navigator" which is used for determining true ground speed and direction of an aircraft. In the Doppler Navigator, it is the motion of the aircraft relative to the ground that is sought. In the scatterometer, the latter effects are removed and it is the intensity of the reflected signal which is recorded.

(c) Platforms and Applications

The original scatterometer experiments were done from aircraft. It was discovered that certain frequencies were preferentially reflected by capillary waves in the ocean. These are the small wavelets on the top of the larger waves which are caused by the gusts of surface winds. These capillary waves,which reflect the present strength and direction of the surface wind reflect the scatterometer signals which are then processed to determine the wind direction within 5 degrees and the speed with 3 km/sec.

The only satellite trial was with SEASAT in 1978. As the researchers analysed the data they found they could use it to determine the low/intermediate surface wind velocity and direction over a swath wide of 1200 km., providing global coverage every 36 hours on a 100 km grid basis.

The only other application was to determine the best frequency look-angle and polarization to be used for classifying sea ice.

(d) State of the Art and Development Trends

Other than for measuring ice and winds at sea which admittedly are very important, there seem to be few other promising applications which merit further development.

Radar Altimetry

(a) Function and Purpose

Radar altimeters developed during and since World War II have been used first by survey and military aircraft and later by all commercial airlines to measure the height of the a/c above the ground. They fall into two categories: the frequency-modulated continuous wave variety and the pulsed variety. Such altimeters will not be discussed further here because they are so common.

Satellite altimetry has been confined to the study of the ocean surface because the size of the footprint cannot be sufficiently reduced to make land measurements meaningful. Accurate measurements of the ocean surface level contribute to the detection and measurement of ocean currents, tides and storm surges and to accurate mapping of gross underwater features such as ocean ridges and trenches.

(b) Basic Description and Technologies Involved

The Seasat altimeter which is the latest and most advanced sensor, achieved an altitude measurement precision of less than 10 cm, and a significant wave height accuracy of ± 0.5 meters. It operated at a frequency of 13.5 GHz using a 1 metre diameter horn-fed parabolic dish antenna. The local oscillator generates 12.5 nanosecond impulses at a 250-MHz centre frequency which are applied to the chirp generator. The chirp generator is a surface acoustic wave (SAW) device fabricated on a lithium tantalate substrate. The resulting chirped pulse has a linearly decreasing frequency with a 80 MHz bandwidth and a pulse length of 3.2 μ sec. Subsequent multiplication by 4 increases the pulse bandwidth to 320 MHz. The pulse repetition frequency is 10.20 Hz.

During the transmit mode, the chirp pulse at 20 MHz is converted to 3375 MHz, amplified to a 1-watt level and multiplied by 4 to 13.5 GHz, thus achieving the desired 320 MHz bandwidth. In the receive mode, the chirp pulse is converted to 3250 MHz, amplified to 0.1 watt and multiplied by 4 to 13.0GHz. The travelling wavetube amplifies the transmit pulse to 2 kw before it is sent to the five port circulator that provides for transmit/receive mode switching as well as calibration mode switching. In the receiving mode the I.F. frequency is 500 MHz which is mixed with a 500MHz CW signal to form in-phase and guadrature signals which are stored in a digital filtering scheme. The bank of digital filters and an adaptive tracking unit are then used for height tracking and wave height estimation.

(c) Platform and Application

Since the exact shape of the satellite orbit can be monitored, it is possible, using the altimetric data to calculate the exact figure of the earth. Due to the added mass of ocean ridges and lack of mass in the trenches, the surface of the sea tends to rise over the ridges and sink over the troughs by as much as 10 metres. The depression in the centre of an ocean gyro compared to its edge can also be measured.

The most practical long-term use of this altimeter would be to produce global sea-state charts on a 36 hour schedule so that ships could be routed around heavy seas, and so drill rigs would have longer-term warning as to when to pull their rods and close down.

State of the Art and Development

Other than reducing weight and cost, little needs to be done to this altimeter to improve its usefulness. More altimeters need to be orbited and sea states observed, calculated and promulgated to ship captains as an aid to navigation and ship routing and to rig operators for warning of high seas.

8.0 LASER/LIDAR

(a) Function and Purpose

To date, laser sensors have not been used from satellites. From aircraft laser altimeters, bathymetres and fluorosensors have been used for measuring tree heights, ice ridge heights, depth of shallow waters, the identification and tracking of oilspills and chlorophyll in the lakes and oceans. Ground based lasers pointing skyward have been used for measuring Raman backscatter as a measure of pollution.

(b) Basic Description of Technologies Involved

Pulsed lasers, when used in the radar mode are called LIDAR. A new laser working in the blue-green will penetrate clean water up to 30 m. Hence the name 'Lidar Bathymeter'. When used from an aircraft a partial reflection is obtained from the water surface and another one from the bottom. The two-way difference in travel time is a function of the water depth.

Pulsed lasers, when used in the fluorosensor mode can discreetly identify oil and chlorophyll which respond to certain wavelengths by fluorescing at a different wavelength. A collector telescope and detection in the aircraft is used to measure the fluoresence.

A similar ground-based pulsed LIDAR, pointing skyward with an associated collector telescope can be used to detect and measure Raman backscatter. In some cases the nature and height of the polluting aerosol can be determined.

(c) State of the Art and Development Trends

Canada and Australia have both produced airborne bathymetric operational systems for inshore hydrography. The Canadian Hydrographic service is now in the process of developing a scanning lidar to perform bathymetry in two dimensions or image form. One of the main difficulties is obtaining accurate flight path recovery so that when a depth is determined, its location can be plotted. This should present no problem when the Global Positioning System begins to come on stream.

REFERENCES

1. Remote Sensing Energy-Related Studies
J. Nejat Vexiroglu
John Wiley & Sons 1975

2. Remote Sensing Application in Agriculture and Hydrology
Georges Fraysse
Ispra Est., Ispra Italy
A. A. Balkema/Rotterdam 1980

3. Oceanus Vol. 24, No. 3, Fall 81
Oceanography from Space
Woods Hole Mass. 02543 U.S.A.

4. 3rd Earth Resources Technology Satellite - 1 Symposium
Vol. 1 Technical Presentations
A symposium held by Goddard Space
Flight Center, Washington, D.C.
Res. 10-14, 1973
National Aeronautics & Space Administration
Scientific and Technical Information Office
Washington, D.C. U.S.A.

5. Earth Observation Systems for Resource Management and
Environmental Control
edited by D. J. Clough and L. W. Morley
Nato Conference Series
Series 11: Systems Science
Published in coordination with NATO
Scientific Affairs Division
Plenum Press 1976

6. Sixth Canadian Symposium on Remote Sensing
May 21-23, 1980
Halifax, Nova Scotia, Canada
Published by Canadian Aeronautics & Space
Institute
Saxe Bldg. 6075 Sparks Street, Ottawa, Ontario
Canada
K1P 5A5

7. Seventh Canadian Symposium on Remote Sensing
September 8 - 11, 1981
Winnipeg, Manitoba
Published by Canadian Aeronautics & Space Inst.
Saxe Bldg. 60-75 Sparks Street, Ottawa, Ontario
Canada
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8. Manual of Remote Sensing
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FALLS CHURCH, Virginia 22046 U.S.A.

TABLE 14-1

U.S. ENVIRONMENTAL SATELLITE PROGRAMS

Name	Launched	Period (Min)	Perigee (km)	Apogee (km)	Inclination (Deg)	Sensors Remarks
TIROS I	01APR60	99.2	796	867	48.3	1 TV-WA and 1 TV-NA
TIROS II	23NOV60	98.3	717	837	48.5	1 TV-WA, 1 TV-NA, passive & active IR scan
TIROS III	12JUL61	100.4	854	937	47.8	2 TV-WA, HB, IR, IRP
TIROS IV	08FEB62	100.4	817	972	48.3	1 TV-WA, IR, IRP, HB
TIROS V	19JUN62	100.5	680	1119	58.1	1 TV-WA, 1 TV-MA
TIROS VI	18SEP62	98.7	783	822	58.2	1 TV-WA, 1 TV-MA
TIROS VII	19JUN63	97.4	713	743	58.2	2 TV-WA, IR, ion probe, HB
TIROS VIII	21DEC63	99.3	796	878	58.5	1st APT TV direct readout & 1 TV-WA
Nimbus I	28AUG64	98.3	487	1106	98.6	3 AVCS, 1 APT, HRIR "3-axis" stabilization
TIROS IX	22JAN65	119.2	806	2967	96.4	First "wheel"; 2 TV-WA global coverage
TIROS X	02JUL65	100.6	848	957	98.6	Sun synchronous, 2 TV-WA
ESSA 1	03FEB66	100.2	800	965	97.9	1st operational system, 2 TV-WA, FPR
ESSA 2	28FEB66	113.3	1561	1639	101.0	2 APT, global operational APT
Nimbus II	15MAY66	108.1	1248	1354	100.3	3 AVCS, HRIR, MRIR
ESSA 3	02OCT66	114.5	1593	1709	101.0	2 AVCS, FPR
ATS I	06DEC66	24 hr	41,257	42,447	0.2	Spin scan camera
ESSA 4	26JAN67	113.4	1522	1656	102.0	2 APT
ESSA 5	20APR67	113.5	1556	1635	101.9	2 AVCS, FPR
ATS III	05NOV67	24 hr	41,166	41,222	0.4	Color spin scan camera
ESSA 6	10NOV67	114.8	1622	1713	102.1	2 APT TV
ESSA 7	16AUG68	114.9	1646	1691	101.7	2 AVCS, FPR, S-Band
ESSA 8	15DEC68	114.7	1622	1682	101.8	2 APT TV
ESSA 9	26FEB69	115.3	1637	1730	101.9	2 AVCS, FPR, S-Band
Nimbus III	14APR69	107.3	1232	1302	101.1	SIRS A, IRIS, MRIR, IDCS, MUSE, IRLS
ITOS 1	23JAN70	115.1	1648	1700	102.0	2 APT, 2 AVCS, 2 SR, FPR, 3-axis stabilization
Nimbus IV	15APR70	107.1	1200	1280	99.9	SIRS B, IRIS, SCR, THIR, BUV, FWS, IDCS, IRLS, MUSE
NOAA 1	11DEC70	114.8	1422	1472	102.0	2 APT, 2 AVCS, 2 SR, FPR
NOAA 2	15OCT72	114.9	1451	1458	98.6	2 VHRR, 2 VTPR, 2 SR, SPM
Nimbus 5	11DEC72	107.1	1093	1105	99.9	SCMR, ITPR, NEMS, ESMR, THIR
NOAA 3	06NOV73	116.1	1502	1512	101.9	2 VHRR, 2 VTPR, 2 SR, SPM
SMS 1	17MAY74	1436.4	35,605	35,975	0.6	VISSR, DCS, WEFAX, SEM
NOAA 4	15NOV74	101.6	1447	1461	114.9	2 VHRR, 2 VTPR, 2 SR, SPM
SMS 2	06FEB75	1436.5	35,487	36,103	0.4	VISSR, DCS, WEFAX, SEM
Nimbus 6	12JUN75	107.4	1101	1115	99.9	ERB, ESMR, HIRS, LRIR, T&DR, SCAMS, TWERLE, PMR

Sensor
Payload

APT	Automatic Picture Transmission TV
AVCS	Advanced Vidicon Camera System (1" Vidicon)
AVHRR	Advanced Very High Resolution Radiometer
• BUV	Backscatter Ultraviolet Spectrometer
CZCS	Coastal Zone Color Scanner
DCS	Data Collection System
ERB	Earth Radiation Budget
ESMR	Electronic Scanning Microwave Radiometer
FPR	Flat Plate Radiometer
• FWS	Filter Wedge Spectrometer
• HB	Heat Budget Instrument
HEPAD	High Energy Proton and Alpha Particle Detector
• HIRS	High Resolution Infrared Sounder
• HRIR	High Resolution Infrared Radiometer
IDCS	Image Dissector Camera System
IR	Infrared - 5 Channel Scanner
• IRIS	Infrared Interferometer Spectrometer
IRLS	Interrogation, Recording and Location Subsystem
IRP	Infrared Passive
ITPR	Infrared Temperature Profile Radiometer
LIMS	Limb Infrared Monitoring of the Stratosphere
• LRIR	Limb Radiance Infrared Radiometer
MEPED	Medium Energy Proton and Electron Detector
MRIR	Medium Resolution Infrared Radiometer
MSU	Microwave Scanner Unit
MUSE	Monitor of Ultraviolet Solar Energy
NEMS	Nimbus E Microwave Spectrometer
PMR	Pressure Modulated Radiometer
SAM-II	Stratospheric Aerosol Measurement-II
SAMS	Stratospheric and Mesospheric Sounder
SBUV	Solar Backscatter Ultraviolet Spectrometer
SCAMS	Scanning Microwave Spectrometer
SCMR	Surface Composition Mapping Radiometer
SCR	Selective Chopper Radiometer
SEM	Solar Environmental Monitor
SIRS	Satellite Infrared Spectrometer
SMMR	Scanning Multichannel Microwave Radiometer
SPM	Solar Proton Monitor
SR	Scanning Radiometer
SSU	Stratospheric Sounding Unit
T&DR	Tracking and Data Relay
THIR	Temperature Humidity Infrared Radiometer
TDMS	Total Ozone Mapping Spectrometer
TV	Television Cameras (½" Vidicon) NA Narrow Angle - 12° MA Medium Angle - 78° WA Wide Angle - 104°
TWERLE	Tropical Wind Energy Reference Equipment
VAS	VISSR and Atmosphere Sounder
VHRR	Very High Resolution Radiometer
VISSR	Visible Infrared Spin-Scan Radiometer
VTPR	Vertical Temperature Profile Radiometer
WEFAX	Weather Facsimile

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TABLE 14-1 (Continued)

U.S. ENVIRONMENTAL SATELLITE PROGRAMS

Name	Launched	Period (Min)	Perigee (km)	Apogee (km)	Incli-nation (Deg)	Sensors Remarks
GOES 1	16OCT75	1436.2	35,728	35,847	0.8	VISSR, DCS, WEFAX, SEM
NOAA 5	29JUL76	116.2	1504	1518	102.1	2 VHRR, 2 VTPR, 2 SR, SPM
GOES 2	16JUN77	1436.1	35,600	36,200	0.5	VISSR, DCS, WEFAX, SEM
GOES 3	15JUN78	1436.1	35,600	36,200	0.5	VISSR, DCS, WEFAX, SEM
TIROS-N	13OCT 78	98.92	849	864	102.3	AVHRR, HIRS-2, SSU, MSU, HEPAD, MEPED
Nimbus 7	24OCT78	99.28	943	955	104.09	LIMS, SAMS, SAM-II, SBUV/TOMS, ERB, SMMR, THIR, CZCS
NOAA-6	27JUN79	101.26	807.5	823	98.74	AVHRR, HIRS-2, SSU, MSU, HEPAD, MEPED
GOES-4	9SEPT80	1436.1	35,600	35,600	0.5	VAS, DCS, SEM, WEFAX
GOES-5	15MAY81	1436.1	35,600	35,600	0.5	VAS, DCS, SEM, WEFAX
NOAA-7	23JUN81	101.92	852	869	98.9	AVHRR, HIRS-2, SSU, MSU, HEPAD, MEPED

January 23, 1970, of ITOS-1,[1] the second-generation operational weather satellite. This satellite dramatically surpassed the capabilities of the predecessor ESSA satellites, moving rapidly closer to the objectives of the U.S. National Operational Meteorological Satellite System. ITOS-1 provided a single spacecraft the combined capability of two ESSA spacecraft—the direct readout APT system, and the global stored images of the AVCS system. Additionally, ITOS-1 provided, for the first time, day-and-night radiometric data in real time, as well as stored data, for later payback. Global observation of the earth's cloud cover was provided every 12 hours with the single ITOS spacecraft as compared to every 24 hours with two of the ESSA satellites. ITOS-1 was equipped with a flat plate radiometer for earth radiation measurements. A second ITOS spacecraft, NOAA-1 (ITOS-A), was launched on December 11, 1970.

As the ITOS system evolved to become the ITOS-D system, the flexibility inherent in the spacecraft design permitted a broader and more sophisticated array of environmental sensors to be carried, with only minor changes to the spacecraft. This new sensor complement provided day-and-night imaging by means of Very High Resolution Radiometers (VHRR's) and medium resolution Scanning Radiometers (SR's) (Conlan, 1973). It included Vertical Temperature Profile Radiometers (VTPR's) for temperature soundings of the atmosphere and a Solar Proton Monitor (SPM) for measurements of proton and electron flux. Six spacecraft (ITOS-D, E-2, F, G, H, and I) were planned for the ITOS-D series. NOAA-2 (ITOS-D), the first satellite in this series, was successfully launched on October 15, 1972. Three additional satellites of this type (NOAA-3, NOAA-4, and NOAA-5) were placed into orbit in 1973, 1974, and 1976, respectively (Fortuna and Hambrick, 1974). Due to the longevity experienced in orbit by the ITOS/NOAA satellites, ITOS-E-2 and -I launches were cancelled. The ITOS system, as it matured, brought closer the realization of the goals of the U.S. National Operational System.

The ITOS satellite system evolved from the proven technology of the TIROS and ESSA spacecraft. Many devices and techniques employed on the earlier series were enhanced, and the enhanced versions were used on the ITOS spacecraft. This orderly evolution permitted growth from a spin-stabilized spacecraft to a three-axis, stabilized, earth-oriented, despun platform.

The principal objectives of this growth pattern during the evolution from an R&D satellite to a global operational system were improved performance, the provision for increased quality and more frequent acquisition of meteorological data, and more timely dissemination of the processed data to the users. The evolving system had to be compatible with the global ground network of local receiving stations as well as the two principal command- and data-acquisition sites. Finally, the operational system had to be cost-effective and have the capacity for future growth.

TIROS-N

The third-generation operational polar-orbiting environmental satellite system, designated TIROS-N, completed development and was placed into operational service in 1978. Eight spacecraft in this series will provide global observational service from 1978 through 1986 (Schnapf, 1980). This new series has a new complement of data-gathering instruments. One of these instruments, the Advanced Very High Resolution Radiometer (AVHRR), increases the amount of radiometric information for more accurate sea-surface temperature mapping and identification of snow and sea ice, in addition to day and night imaging in the visible and infrared bands. Other in-

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[1] This spacecraft was originally designated TIROS-M. After being placed into orbit, it was redesignated ITOS-1. Subsequent spacecraft in this series were named NOAA-1 NOAA-2, etc. by the National Ocean and Atmospheric Administration, the successor to ESSA as operator of the system.

APPENDIX 2

MIZEX (Marginal Ice Zone Experiment)

This experiment is sponsored by the U.S. Office of Naval Research. It is a sea-ice investigation to monitor the dynamics of the southern edge of the permanent ice pack at the boundary of the extreme N.E. Atlantic Ocean and the Arctic Sea. Of particular interest is how the ocean eddies, swinging north, affect the edge of the ice pack and also to determine what effect the bottom topography of the ocean has on the eddies.

Several naval ships were deployed in the area of interest to do "ground truth". The Earth Resources Institute of Michigan was under contract to O.N.R. to carry out the airborne remote sensing. They leased the SAR-580 from CCRS and used it to repetitively carry out macro-scale ice surveys of the area of interest using the X, L & C bands. They also used imaging passive microwave radiometers operating at 90, 140 and 220 GHz providing 20 metres resolution at about 3,000 feet altitude.

The CCRS Scatterometer which operates at 13.3 GHz was also used to differentiate old ice from new ice.

Some recent results of their analysis are to be discussed at a meeting in Bremerhaven in late October 1983. The results will later be published.

The O.N.R. contact is Charles Luther ph. (202) 696-4118 or 4119.

APPENDIX 3

POLAR AEROSOL MEASUREMENT TRAILS (PAM)

This is a D.O.D. program (EP78-1)
The project leader is Dr. Theodore Pepin, University of Wyoming
The trial is planned for January, February 1984.
It is aimed at long-term weather forecasting-specifically
for understanding the Iceland "Low".

Both aircraft and satellites will be used. Several groups from within NOAA are involved:
Leonard Fedor phone 393-497-6440 at Boulder, Colorado
(NOAA) is the NOAA coordinator.
Len Johnson of the Office of Naval Research is involved.

This program is a spin-off from MISEX.