Polar Crossroads

Still More Ground Stations Are Being Located in the Arctic

The polar regions of the Arctic and Antarctic are some of the most inhospitable areas on Earth, being largely ice-covered and experiencing frequent and prolonged periods of extreme cold and very high winds. The long periods of winter darkness are another feature of these polar regions. Agriculture is impossible and very few people live there on a permanent basis. So it may come as a surprise to many to learn that these polar areas are becoming ever more important from the point of view of receiving remote sensing image data from satellites on a world-wide basis.

By Prof. Gordon Petrie

Near Polar Orbits

The reason for this is, of course, that all of the satellites that are acquiring image data on the basis of world-wide coverage are polar-orbiting. Furthermore almost all of them have been placed in Sun-synchronous orbits that require orbital inclinations of around 98.7° with respect to the Equator, the exact value depending on the height above the Earth from which the satellite will operate. Thus, on every orbit over the Earth, a polar-orbiting satellite will reach latitudes of around 81.3° North and South. As a consequence, the satellite ground tracks will converge towards the poles. By placing suitably equipped ground stations at high latitudes in the polar areas, it is possible to uplink commands to a specific satellite and to downlink the telemetry and image data that has been collected and stored during the preceding orbit of the satellite. This can be done for a large number of the successive passes of the satellite over the polar area. The result of this is that, in recent years, some organisations - in particular, NASA (with Landsat-7); DigitalGlobe (with QuickBird); and the U.S. and European operators of polar-orbiting weather satellites (NOAA & EUMETSAT) - have concentrated much of their data acquisition activities on ground stations located in polar areas. The economics of being able to receive space image data on a world-wide basis through one or two ground stations are fairly obvious. By utilizing high-bandwidth data links, these organisations can also ensure that the processing of the received image data can be concentrated in a single centre having the required facilities and expertise. In the case of Landsat-7, this is carried out at the EROS Data Center in Sioux Falls in South Dakota; for QuickBird at DigitalGlobe's headquarters in Longmont, Colorado; for NOAA at its processing centre at Suitland, Maryland; and for EUMETSAT at its centre in Darmstadt, Germany.

Map showing the locations of the principal Arctic ground stations. (Drawn by M. Shand)

A. Arctic Ground Stations

In the Arctic, these polar ground receiving stations are concentrated largely in Northern Scandinavia, e.g. at Kiruna, Tromsø and Svalbard, and in the Fairbanks area in Central Alaska.

The ESA ground station at Salmijärvi, near Kiruna, North Sweden. (Source: ESA)

& Antarctic!

Northern Scandinavia

The Kiruna stations, located at 68°N latitude, 21°E longitude, include the ground station established by the Swedish Space Corporation (SSC) in the 1980s. This is located on the site of the Esrange rocket launch facility that is used mainly for the launch of sounding rockets carrying out atmospheric and ionospheric research, including studies of the aurora borealis (Northern Lights). However the SSC ground station with its tracking antennae has provided telemetry, tracking and command (TT&C) facilities for numerous scientific satellites as well as data reception and processing services for quite a number of remote sensing satellites. These include the SPOT series, the earlier Landsat series, JERS, MOS, etc. Besides which, a commercial company such as Space Imaging can simply rent time on the SSC facility to enable it to uplink commands to its IKONOS satellites that have been sent from the flight operations centre at its Thornton, Colorado headquarters. Similarly Metria Satellus (the distributors of EROS imagery in Europe) rents downlink time from the SSC station to enable it to acquire images from ImageSat International's EROS-A1 satellite. At Salmijärvi, only 3km away from the SSC station, is the ESA ground station established in 1990 to support ESA's polar-orbiting remote sensing satellites such as ERS-1 and -2 and Envisat. This is also staffed and operated by SSC personnel, though the station itself is owned by ESA.

The Tromsø station located at 69.5°N, 19°E was also established at an early stage as the national ground station for Norway. Some 80 miles (130km) to the south of

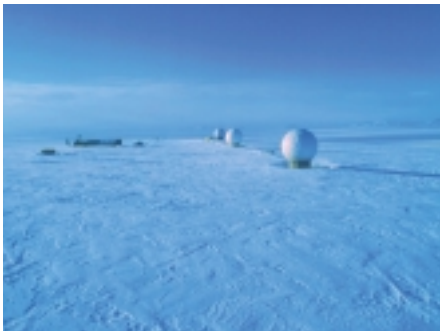
Map of Svalbard. (Drawn by M. Shand)

The KSAT ground station with its multiple antennae located at Tromsø in North Norway. (Source: Kongsberg Satellite Services)

Tromsø in the Lofoten Islands is the Andøya Rocket Range (ARR) which is the base for studies of atmospheric and ionospheric phenomena using sounding rockets and balloons along much the same lines as the Esrange facility. The Tromsø ground station has been receiving HRPT data from the NOAA polar-orbiting satellites for many years. Since then, it has expanded its facilities and activities greatly. During the 1990s, the station began to specialize in downloading and processing SAR image data from the ERS-1 and -2 satellites and from Radarsat. Arising from the steady expansion of its activities, in 1995, the Tromsø Satellite Station (TSS) became a public company, with the Norwegian Space Centre (NSC) and the Swedish Space Corporation (SSC) each holding 50% of the share capital. Both are state-owned organisations. As a result of this particular development, another large tracking antenna with a 10m diameter dish was installed at Tromsø in 1996. Like the SSC Kiruna station, the Tromsø facilities are being used by a wide range of agencies and companies. Thus, for example, DigitalGlobe uses it both for TT&C purposes relaying commands from its headquarters in Longmont, Colorado and for the downloading of the image data recorded and stored on its QuickBird satellite.

The most recently established of the Scandinavian stations are located on the Svalbard archipelago owned by Norway. They are sited at Platåberget, near the small town of Longyearbyen on the main island of the group. With lat/long positional coordinates of 78°N, 15.4°E, they lie some 1,050km (650 miles) north of the Tromsø station. This means that all 14 successive passes of a polar orbiting satellite will lie within sight of the Svalbard ground stations - whereas five of these passes cannot be seen from the Kiruna or Tromsø stations. This highly advantageous geographical position was first exploited by NASA, which, in 1997, in cooperation with NSC and TSS, established the Svalbard Satellite Station (SvalSat) on the site. NASA refers to this as its Svalbard Ground Station (SGS). This station was equipped with an 11.3m diameter tracking antenna. The actual manning and operation of the station was carried out on NASA's behalf by TSS. Primarily this station has been used to carry out TT&C operations and data acquisition for NASA's Earth Observation System (EOS) satellites (including Terra, Aqua and the forthcoming Aura), QuikScat and Landsat-7.

Showing the orbital tracks of a polar orbiting satellite relative to the coverages of the Tromsø & Svalbard ground stations. (Source: Norwegian Space Centre)


The development of the ground station facilities at Platåberget, near Longyearbyen, Svalbard showing (a) the radomes of the original SGS (Svalbard Ground Station) and SvalSat antennae; (b) the radomes of the first three antennae; and (c) the radomes of the five antennae now currently installed at Platåberget (Source: Norwegian Space Centre; Photographer for (a) is Stéphane Compoint)

The advantages of using this remote geographic location soon became clear and, in 1999, this led to the establishment of a second station on the same site. This was equipped with an 11m diameter antenna supplied by Datron that was purchased by a joint venture company, Space Data Services (SDS), owned by Kongsberg (the Norwegian armaments company) and Lockheed Martin. It was also operated by the Tromsø Satellite Station (TSS), the joint venture between the NSC and the SSC mentioned above. In 2001, a third major (13m diameter) antenna costing $4.3 million, which was also supplied by Datron, was added to the site by TSS. In June 2002, a consolidation of all these different facilities located at Tromsø and Svalbard took place. The SSC interest in TSS was bought out, as were the Lockheed Martin shares in SDS. With all the foreign interests removed, a single Norwegian company, Kongsberg Satellite Services (KSAT), was then formed to take over and run the various ground station facilities at Tromsø and Svalbard. The new company is owned jointly on a 50:50 basis by Kongsberg Defense & Aerospace and the Norwegian Space Centre (NSC). The original station at Svalbard is still used mainly by NASA; the two newer stations are used by a variety of space agencies and satellites and are controlled remotely from the main control centre at Tromsø.

The latest development at the Platåberget site in Svalbard has been its selection for the location of the Command & Data Acquisition (CDA) ground stations for the new polar-orbiting METOP weather satellites that are to be introduced by EUMETSAT, the European Meteorological Satellite organisation. Up till now, EUMETSAT has only operated geostationary weather satellites - the well-known Meteosat series. The new METOP satellites will complement the existing series of NOAA polar-orbiting weather satellites. Under a cooperative agreement, EUMETSAT will supply and operate a METOP satellite for the morning pass with NOAA continuing to supply the satellite for the afternoon pass. Global image data from the two satellites will be shared and exchanged freely between the two agencies. For TT&C and data reception purposes, EUMETSAT has had two further ground stations installed and commissioned at Platåberget. These are equipped with 10m diameter antennae. This work has been carried out by the Spanish Indra Espacio company in collaboration with the German arm of Astrium (formerly Dornier), which is supplying the antennae, and the Norwegian NRSE organisation (a wholly owned subsidiary of NSC), which has been carrying out the civil engineering work. This consortium won the contract after an open European-wide competition.

Since Svalbard is a remote island chain, high bandwidth telecommunications links could not be provided directly using land lines. So a separate ground station and satellite communications links have been provided by Telenor (the Norwegian state-owned telecomms company). These utilize both its own Thor II and III geostationary satellites and the Intelsat geostationary satellites to transmit data from Svalbard to ground stations located in Norway and elsewhere. However the latest development in this matter of communication links is the announcement (on April 23rd, 2003) that an undersea fibre-optic cable system is to be laid between Svalbard and Harstad in the Lofoten Islands, located near the Andøya Rocket Range (ARR). It will comprise two separately routed fibre-optic segments with a total route length of 2,800km. This development is being initiated by the Norwegian Space Centre (NSC) specifically to provide high-speed, real-time transmission of the data received by the ground stations on Svalbard to mainland Norway. The work is to be carried out by the Tyco Telecommunications company from the U.S.A.

Besides the ground stations used for tracking and receiving data from polar-orbiting satellites, Tromsø and Svalbard are the locations for two powerful incoherent scatter radar systems that are operated by EISCAT, an international research association formed by the research councils of Norway, Sweden, Finland, Japan, Germany, France and the U.K. These radars are used to study the disturbances in the magnetosphere and the ionised parts of the atmosphere in the Arctic region of Scandinavia, which give rise to the spectacular visible aurora (Northern Lights). Besides the transmitting/receiving stations located at the two Norwegian sites, two other stations that can receive the back-scattered radar signals from these transmitters have been built at Kiruna, Sweden and Sodankylä, Finland by EISCAT. Another recent development is the establishment of a rocket range to launch and track sounding rockets from Svalbard. This is called SvalRak and is located at Ny-Ålesund, another small village located at 79°N, 12°E on the main island of Svalbard. This is also the site of the Space Geodetic Laboratory of the Norwegian Mapping Authority and the research station of the Norwegian Polar Institute. EISCAT will provide technical and scientific support for the SvalRak project which will be operated as part of the Andøya Rocket Range (ARR).

Alaska

It is most interesting to observe that a whole series of parallel developments of ground tracking and receiving stations similar to those described above for Northern Scandinavia have taken place in Alaska. These are mostly sited in and around Fairbanks located at 65°N, 147.5°W in the central part of the state. One of the main sites is the Poker Flat Research Range (PFRR) located about 30 miles (48km) north-east of Fairbanks. This also started as a high-latitude site, complete with sev-

eral launch pads, that has been used extensively for the launch and tracking of sub-orbital sounding rockets for auroral and atmospheric research by the Geophysical Institute of the University of Alaska and numerous other agencies. In fact, the range is owned by the University and operated by this Institute. Besides smaller antennae used for the tracking of sounding rockets, the range also houses NASA's Alaska Ground Station (AGS) equipped with a large (11.3m) diameter antenna providing both S- and X-band tracking and data acquisition facilities. These are used with a number of NASA remote sensing satellites. As with the Svalbard Ground Station (SGS), the scheduling of the AGS antenna to track and to send commands and receive data from specific satellites such as EO-1 is carried out by NASA's Wallops Flight Facility (WFF) in Virginia. A second antenna at Poker Flat was commissioned in 2001 and is operated by the DataLynx subsidiary of Honeywell on behalf of NASA. This provides S-band uplinks and telemetry downlinks and X-band data reception for Landsat-7.

Not far from the PFRR is another group of tracking antennae forming a powerful ground station called the Fairbanks Command & Data Acquisition Station (FCDAS). This is located on a Federal reservation at Gilmore Creek, some 14 miles (22km) north-east of Fairbanks. It includes a major NOAA ground station equipped with three large (13m) diameter tracking antennae installed by Allied Signal in 1998. These provide both TT&C and data reception facilities for the weather satellites operated under the agency's own Polar-orbiting Operational Environmental Satellite (POES) programme and the Defense Meteorological Satellite Program (DMSP). In addition, data from numerous space geodetic missions and programmes (including GPS/CORS, DORIS, PRARE, etc.) is being acquired by this station. It also has a large radio telescope that is used for VLBI observations for NASA's Space Geodesy programme that is being carried out in cooperation with the U.S. Naval Observatory (USNO). Finally the Plasma Physics Lab of UCLA (University of California, Los Angeles) operates its HIPAS (High Power Auroral Stimulation) observatory at the same site. This includes yet another incoherent scatter radar for ionospheric research operating along somewhat the same lines as EISCAT.

The Alaska Ground Station (AGS) located at the Poker Flat Research Range (PFRR) near Fairbanks. (Source: Univ. of Alaska)

The Fairbanks Command & Data Acquisition Station (FCDAS) operated by NOAA at Gilmore Creek, near Fairbanks, Alaska. (Source: NOAA)

Besides its involvement in the PFRR, the University of Alaska also has several ground stations located on its campus within Fairbanks. A major station is the Alaska SAR Facility (ASF) which includes a large (10m) diameter X-band tracking antenna that is located on the roof of the University's Geophysical Institute. This is supplemented by a second 11m diameter S- and X-band antenna located in a forest clearing close by. These antennae are dedicated mostly to receiving SAR image data from Canada's Radarsat and ESA's ERS-2 and Envisat satellites. Previously the ASF had also received the SAR image data collected by the Japanese JERS-1 and ESA ERS-1 satellites during the early 1990s while these satellites were still operational. Besides TT&C and data reception operations, the ASF also carries out the processing, archiving and distribution of SAR image data on a world-wide basis. In this role, it is acting as a Distributed Active Archive Center (DAAC) that is funded by NASA as part of its Earth Observing System (EOS) programme.

Also on the University campus, located on the roofs of the Geophysical Institute and the adjacent International Arctic Research Center (IARC), are the smaller antennae belonging to the International Observatory of the North (ION). This comprises two ground receiving stations. The larger of these ION stations has a 3.6m diameter X-band tracking antenna that was installed in 2001. This station acquires image data from the MODIS image scanners that are operated on-board NASA's Terra and Aqua satellites. In addition, the Global Imager (GLI) scanner data from the recently launched Japanese ADEOS-II satellite will also be taken down by this station. In this particular context, the International Arctic Research Center (IARC) is an institute that was established through a joint U.S.-Japan cooperative agreement signed in the mid-1990s, the U.S. partner being the National Science Foundation (NSF). The Center was opened in 1999. The second ION facility is an HRPT ground station that has been in operation since 1993. It is equipped with a 1.2m diameter antenna that receives low-resolution image data from NOAA's AVHRR and NASA's SeaWiFS scanner instruments. Both of the ION tracking antennae have been supplied by the SeaSpace Corporation from San Diego. On average, the two ION stations receive data from around 20 AVHRR and 15 MODIS passes per day

Given the number of tracking antennae and ground stations and the large supporting infrastructure that has been built up in the Fairbanks area, it has also become attractive to commercial satellite operators. So much so that a local enterprise authority has initiated a Fairbanks Satellite Ground Station Spacepark! Prior to this development, in 1997, Space Imaging established its own ground station located a short distance to the south-east of Fairbanks. This was used first to download IRS image data and then, later, IKONOS image data. DigitalGlobe has also established one of its two major ground stations in the Fairbanks area, complementing its Tromsø station. Between them, these two stations at Fairbanks and Tromsø carry out the downloading of all the image data stored on the QuickBird satellite's on-board data recorder, so allowing the acquisition of its high-resolution space image data taken over other areas of the Earth. Until relatively recently, the onward transport of image data to the main processing centres in the U.S.A. had

The various antennae located on the roofs of buildings on the campus of the University of Alaska and operated by its Geophysical Institute and the International Observatory of the North (ION). (Source: Univ. of Alaska)

to be carried out either using expensive satellite communication links or using cheaper (but slower) tapes sent by air. However nowadays there are good terrestrial connections between Alaska and the main (conterminous) part of the U.S.A. using fibre-optic links.

In much the same way that the advantages of establishing ground stations ever further north have been realised in Scandinavia, currently there is a similar discussion about the suitability of Point Barrow as the location for new U.S. ground stations. Point Barrow is the most northerly point in Alaska, located at 71.3°N, 156.5°W, 450 miles (720km) north of Fairbanks. In fact, the area - which includes the small town of Barrow with a population of 4,500 - is being promoted heavily by the local native people via their Ukpeagvik Inupiat Corporation (UIC) as a centre for Arctic research. As such, UIC has taken over the former U.S. Naval Arctic Research Lab (NARL) in Barrow to act as a science support centre and provide an infrastructure for scientific research activities. Partly as a result of these promotional and supportive activities, NOAA has placed its Climate Monitoring & Diagnostics Lab (CMDL); the U.S. Dept. of Energy (DOE) has established its Atmospheric Radiation Measurement (ARM) facility; and the USGS has built its Barrow Magnetic Observatory, all located in close proximity to one another in the area between Barrow and Point Barrow. Now the hope is to establish satellite ground stations in the area. In fact, in 1999, ORBIMAGE did establish a major ground station at Point Barrow that was supplied by Macdonald Dettwiler Associates (MDA). Unfortunately, with the failure of the OrbView-4 satellite at launch and the several postponements of OrbView-3, so far, it has not been able to carry out the operations for which it was built. However, at the time of writing (in April), OrbView-3 is scheduled to be launched on 1st June 2003.

B. Antarctic Ground Stations

There are, of course, some major differences in the overall disposition of the polar land and oceanic areas in the Antarctic as compared with those of the Arctic. The Arctic is a large ocean basin enclosed by the land masses of North America and Eurasia, with a few island chains such as Svalbard, Novaya Zemlya, etc. lying offshore. Whereas Antarctica is a continent that is almost wholly covered by ice and is surrounded by the Southern Ocean. Apart from the Antarctic Peninsula stretching out along the 60°W Meridian towards the southern tip of South America, the main Antarctic land mass lies very far from the other two nearest continents - Africa and Australia. Nevertheless Antarctica has a ring of ground receiving stations located at several of the many scientific research bases from different countries that have been established along the fringes of the continent - though some of these bases are only occupied and become operational during the short summer season.

Three major satellite ground receiving stations, each equipped with a large diameter antenna have been established in Antarctica. Each of these is capable of taking down the high data rates associated with the downlinking of SAR image data. This SAR data is especially important for coverage of Antarctica given its day/night and all-weather capability in an area of frequent bad weather and long periods of darkness. These three major ground stations are supplemented by a larger number of smaller antennae located at land-based stations and on research vessels. These mostly take down the data from the lower-resolution imagers mounted on weather satellites and other similar satellites - e.g. NOAA/AVHRR, DMSP, SeaWinds, SeaStar, etc.

The first of the three major stations with SAR capabilities was the ground station set up at the Japanese base at Syowa, located at 69°S, 40°E facing the Indian Ocean. This station with its 11m diameter dish antenna was first installed in 1989 and received SAR image data from the Japanese JERS-1 satellite from 1992 onwards until it ceased operation in 1998. It also received SAR data from the ERS-1 satellite until it stopped operations in 2000 and it still takes down ERS-2 SAR data. Besides this major facility, a smaller ground station was also installed at Syowa in 1997 to receive data from the NOAA and DMSP weather satellites.

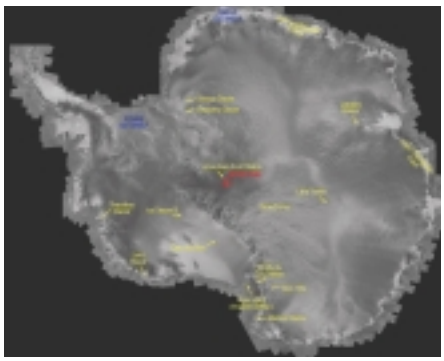
The second major Antarctic ground receiving station is the German Antarctic Receiving Station (GARS) operated by DLR at the Chilean O'Higgins military base located at 63°S, 58°W at the northern tip of the Antarctic Peninsula. It is equipped with a 9m diameter dish antenna. This station was also optimised for the reception of SAR image data from JERS-1, ERS-1 and -2 and Radarsat. In this respect, it should be remembered that the ERS-1 and -2 satellites had no on-board recording and storage capabilities, while Radarsat had only a comparatively limited storage capacity when high-volume SAR image data is being considered. Like the Syowa station, the GARS facility was also designed for and has taken part in VLBI space geodetic operations to help determine continental drift. The main GARS station has been in operation since 1992, supplemented by a smaller antenna that takes down NOAA weather satellite data.

Very similar facilities to those at the Syowa and O'Higgins bases exist at the large American McMurdo base which is located at 78°S, 166°E on Ross Island at the junction between the Ross Ice Shelf and Ross Sea facing the Pacific Ocean. The high latitude of the station is almost

Space Imaging's ground station located south-east of Fairbanks with the tracking antenna used to communicate with the polar-orbiting remote sensing satellites in the background and the antenna that is directed towards a communications satellite in geo-synchronous orbit in the foreground. (Source: Space Imaging)

Map showing the locations of the principal Antarctic ground stations. (Drawn by M. Shand)

identical to that of Svalbard and gives similar advantages in terms of viewing polar-orbiting satellites. The main antenna with its 10m diameter dish is called the McMurdo Ground Station (MGS) and replaced an earlier 7.2m tracking antenna. MGS has been in operation since 1995. Like its sister SGS (Svalbard) and AGS (Alaska) stations, it is mainly controlled from NASA's WFF facility at Wallops Island, Virginia. MGS offers the great advantage of being the first major tracking station overflown by the polar-orbiting satellites being launched from Vandenberg



Radar mosaic of Antarctica compiled from Radarsat SAR imagery collected during the Antarctic Mapping Mission. (Source: Alaska SAR Facility [ASF]; Copyright: Canadian Space Agency)

The ARIES (Antarctic Reception Imagery for Environmental Studies) antenna located at the Rothera Base of the British Antarctic Survey (BAS) for the acquisition of HRPT weather imagery from NOAA satellites, prior to the erection of its radome. (Source: BAS; Photographer: P. Bucktrout)

(a) The site of the German Antarctic Receiving Station (GARS) at the Chilean O'Higgins military base located at the northern tip of the Antarctic Peninsula. (b) A close-up of the 9m diameter antenna of GARS. (Source: DLR)

Air Force Base in California. Thus it has often been used for launch support operations, including tracking, uplifting commands and receiving telemetry, as well as image data acquisition. However the station is best known for taking down SAR imagery from the European ERS-1 and -2 satellites and the Canadian Radarsat. In this context, it has taken down a substantial part of the Radarsat imagery that has been used to compile the spectacular radar mosaics of Antarctica that have been produced for 1997 and 2000 under the Antarctic Mapping Mission (AMM), a joint project of NASA and the Canadian Space Agency (CSA). As with the two previous stations, McMurdo also has a smaller antenna, in this case supplied by GTI Electronics, that receives both NOAA/AVHRR and SeaWIFS data.

Since there is no land line from Antarctica to the rest of the world, image data has either to be sent using satellite communication links or shipped out on tape or disk using aircraft or ships. In the case of the McMurdo MGS station, the direct view towards NASA's TDRS West communications satellite situated in geo-synchronous orbit above the Equator is blocked by the Mount Erebus volcano. So the data is sent first via a microwave link to a ground communications station located 20 miles (34km) to the south on Black Island. This station then relays the data up to the TDRS satellite. From there, the data is sent onwards to the ground station at White Sands, New Mexico in the U.S.A. In fact, much of the McMurdo SAR data is then forwarded to the Alaska SAR Facility (ASF) since this has the major NASA facility for SAR data processing mentioned above. So ERS and Radarsat SAR data of the Antarctic is often processed in the Arctic! The Syowa base has a similar satellite-based communications link to Japan, where the SAR data processing is carried out at the Japanese National Institute of Polar Research.

Finally, as mentioned above, there are a number of other smaller satellite ground receiving stations in Antarctica that take down lower-resolution NOAA/AVHRR, DMSP, SeaWIFS and SeaWinds data mainly for use by research scientists and logistic personnel working in the Antarctic. These stations include the TeraScan antenna systems and software supplied by the SeaSpace Corporation in the U.S.A. that are used at the American McMurdo and Palmer Stations and at the Japanese (Syowa), German (Neumeyer) and Italian (Terra Nova) stations. Other HRPT stations are located at the British (Rothera) and Australian (Casey) bases, as well as several that have been installed on a number of research vessels, ice-breakers and supply ships.

Conclusion

As this account has attempted to show, the barren polar areas of the Earth occupy a position of special importance in the acquisition of remote sensing image data from space. Those ground receiving stations located in the Arctic are of particular importance since the major operators of remote sensing satellites are all based in the Northern Hemisphere and nowadays they can have excellent communications with these Arctic stations. This has allowed them to concentrate their TT&C and data reception facilities in one or two stations located in the Arctic and still carry out Earth observation and imaging operations on a world-wide basis. By contrast, the not inconsiderable number of stations that have been established in the Antarctic have mainly been concerned with the supply of imagery for mapping and scientific research purposes within Antarctica and for monitoring and forecasting the weather and the extent of sea ice around the continent.

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