THE ARAMIS REMOTE SENSING SYSTEM

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Abstract. An account is given of the ARAMIS (Antarctic Research in Applied Meteorology, Imaging and Sounding) remote sensing system which has recently been installed in the Ice and Climate Division of the British Antarctic Survey. Details of the hardware are provided along with information on the applications software available to the users. Current meteorological remote sensing research being carried out on the system is outlined and possible applications for other disciplines are described.

Introduction

Over the last 25 years satellite remote sensing has become of great importance in many areas of scientific research including meteorology, climatology, oceanography, geology, land applications and glaciology. Polar research in many of these fields has been hampered by the harsh environment at high latitudes and difficulty in obtaining *in situ* observational data at the resolutions required. Research can therefore benefit significantly by utilizing data from satellite observing systems. The British Antarctic Survey (BAS) has made use of the low resolution satellite imagery from the polar orbiting meteorological satellites for many years and these data, received at the bases in the Antarctic, are used in the meteorological program and in aircraft and ship operations. Over the last few years the greater availability of digital image processing systems has resulted in increased exploitation of the higher resolution, multi-spectral imagery data from the meteorological and earth resources satellites and encouraged more objective use of these data.

During 1986 BAS obtained a mini-computer based remote sensing system to allow greater use to be made of high resolution satellite data in the meteorological research program. The following sections provide a detailed description of the system hardware and software, and describe the current research taking place on the system.

Hardware

The ARAMIS system is based on a DEC MicroVAX II 32-bit mini-computer and Sigmex Electronics Advanced Raster Graphics System (ARGS). Fig. 1 illustrates the major components of the system and the links between the hardware elements. The aim in developing ARAMIS was to produce a self-contained system capable of handling all stages of processing satellite data, from the input of raw satellite telemetry on Computer Compatible Tape (CCT) to the derivation of high level geophysical products. Typical tasks in this processing include conversion of raw instrument counts to geophysical parameters, earth location and image re-mapping, combining several instrument channels according to defined algorithms, interactive manipulation of imagery and merging with other observational data sets. This has been achieved by using the multi-tasking capabilities of the MicroVAX II to allow several users to carry out the pre-processing of satellite data in parallel, while the ARGS is used for the more interactive, single user tasks. These include the display and interpretation of all imagery and the interactive manipulation of data, such as the

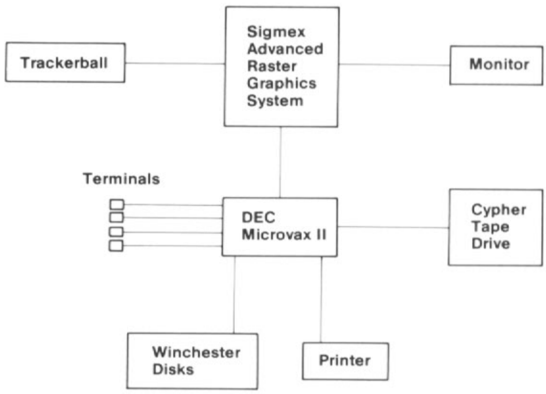

Fig. 1. The hardware components of ARAMIS.

registration of imagery with coastline data sets and comparison of multi-channel data.

Minicomputer system

The ARAMIS mini-computer has 5 Megabytes of memory and a floating point accelerator. The peripherals attached to the computer consist of:

(*a*) Two Fujitsu 2333 Winchester disc drives which provide a total of 540 Megabytes of storage. The discs are linked to the MicroVAX II via an Emulex QD32 disc controller.

(*b*) One Cypher F880 tape deck for reading and writing half inch industry standard magnetic tape at 1600 bits per inch. The tape deck is accessed via an Emulex TC03 interface.

(*c*) Two DEC RX50 floppy disc drives which can each store up to 400 kbytes of data on 5 $\frac{1}{4}$-inch floppy discs.

(*d*) One DEC LA100 draft/near letter quality printer.

The system runs under version 4.5 of the DEC MicroVMS operating system and the licence enables a maximum of eight users to make use of the computer concurrently. The MicroVAX II is accessed via two Kimtron VT220 compatible terminals and various microcomputers running terminal emulation software.

Image processing system

The Sigmex ARGS is a powerful, multi-processor graphics system capable of performing high resolution line-drawn graphics and image processing tasks in colour or monochrome. The ARGS can be operated as a standalone unit; however, most applications are executed from high level software running on the MicroVAX II.

The major components of the ARGS are shown in Fig. 2 and consist of:

(*a*) The Graphics, Pixel Instruction and Pixel Data buses for high speed transfer of data and instructions within the ARGS.

(*b*) The Graphics Processor which implements the 'order codes' or low level commands which are the basic instructions executed within the ARGS. The Graphics Processor also contains firmware holding code for drawing characters and basic geometric figures. It also contains 96 kbytes of storage for user-written graphics routines.

(*c*) A 1.5 Mbyte Pixel Store which holds data to be viewed on the monitor. These

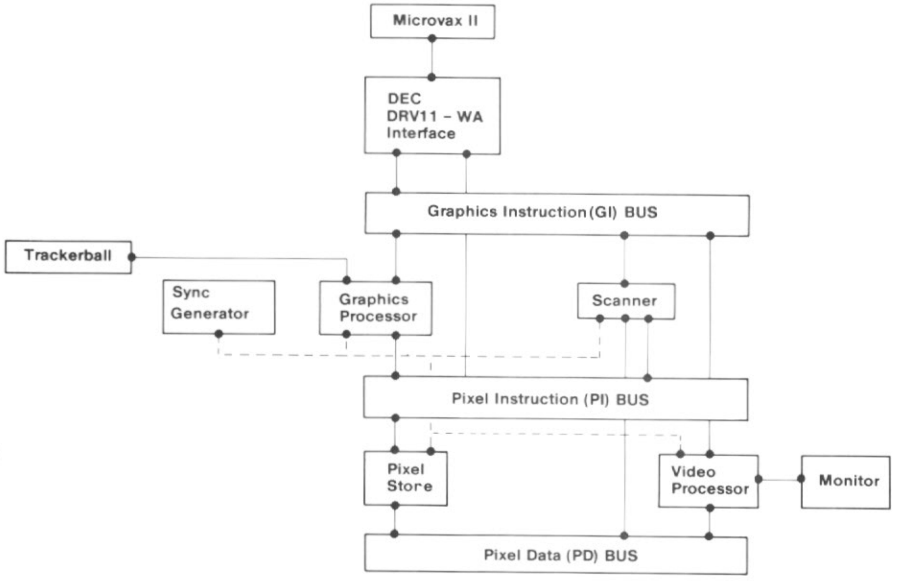

Fig. 2. The Sigmex Advanced Raster Graphics System.

data are generated by the Graphics Processor and consist of line-drawn elements and blocks of imagery data.

(*d*) A Video Processor which performs a digital-to-analogue conversion on the Pixel Store data under control of colour or monochrome transformation tables.

(*e*) The Scanner which controls the hardware zoom facilities and system cursor.

(*f*) A Sync Generator to provide timing signals for the display.

(*g*) A trackerball with four buttons to allow users to control operations such as zooming and panning imagery interactively.

(*h*) A monitor with a resolution of 1024 by 1024 pixels.

Within the ARGS the Graphics Processor acts as the system manager and controls data and instruction transfer to and from the MicroVAX II. Low level instructions for line-drawn graphics are handled by the Graphics Processor as well as transfers of large quantities of imagery data into the Pixel Store.

The 1.5 Mbytes of Pixel Storage can be configured in a number of ways, depending on the size of the imagery to be handled. On ARAMIS, where a 1024 by 1024 pixel monitor is used, the Pixel Store is usually configured as a 1024 by 1024 by 12 block of bit-addressable memory. This effectively gives 12 bit planes at the full resolution of the monitor. These 12 planes are normally assigned into two groups. The first eight planes are used to store imagery data; the top four planes are established as overlay planes for holding titles, coastlines and other data to be viewed in conjunction with imagery. If smaller images are to be handled, such as 512 by 512 pixel scenes, then the system can be re-configured to represent a 512 by 512 by 48 bit store, allowing up to six 8-bit images to be stored at any one time.

The data from the Pixel Store are processed through a colour transformation table before the signals are passed to the monitor. This allows the various pixel values to be transformed into different colours or grey scales according to a pre-defined colour transform table. This table allows up to 256 different colours to be displayed at any one time out of a palette of over 16 million colours.

The scanner provides very fast image zoom and pan facilities by controlling the area of the pixel store which is viewed and the number of times each pixel is scanned. Zooming into an image for detailed examination of a particular area is performed by multiple scanning of selected pixels while simultaneously decreasing the view area. An image can be zoomed up to eight times, with each zoom operation doubling the number of times each pixel is scanned while at the same time halving the number of pixels viewed in the horizontal and vertical directions. Panning across an image is simply carried out by moving the viewing window, with the trackerball often being used interactively to allow the user to control the direction of pan.

Software

A large amount of general graphics software and programs relevant to meteorological remote sensing has already been installed on the system. These programs have been developed over the last few years by groups within the UK who are involved in atmospheric research and who use similar VAX and Sigmex hardware. The laboratories include the Meteorological Office, SERC Rutherford Appleton Laboratory and the Hooke Institute at Oxford University.

Graphics facilities

Several levels of graphics software have been implemented on the system to allow users with different requirements and levels of experience in computer graphics to make full use of the hardware. At the highest level many facilities such as zooming and panning images and interactive manipulation and stretching of grey scales are available directly from commands at the operating system level, provided that the images being viewed are in the system-wide Standard Image File (SIF) format. The SIF standard, which was originally developed at the Meteorological Office, provides a flexible format for imagery files so that common routines can be used to manipulate imagery regardless of the form of the data. This allows meteorological imagery, RADAR data, photographic imagery or other gridded data to be handled by common software. This aids the development of new software facilities and provides easy exchange of imagery between sites.

For the FORTRAN programmer many high level subroutines have been developed so that most of the ARGS graphics facilities can be exploited using simple calls. These cover basic line and figure drawing, selection of colours or grey scales, sending SIF images to the ARGS, zooming and panning images and reading the trackerball.

To use the more advanced features of the ARGS, such as re-configuring the pixel store or independently scrolling different bit planes, the Sigmex supplied FORTRAN Program Library (FPL) can be used directly from FORTRAN programs.

At the lowest level a user can send assembler-like, low level order codes directly to the ARGS. These can be run directly on the ARGS without any communication with the MicroVAX II so that very high speed graphics applications can be executed.

Development tools

Many useful software aids are available on the system for examination and manipulation of data and for executing commonly used graphical or computational tasks required in atmospheric research. These include:

(*a*) Chart drawing routines to generate polar stereographic, Mercator and regular latitude/longitude map backgrounds on the ARGS.

(*b*) ARGS programs to draw the standard temperature–entropy diagrams used for the display of meteorological upper air data.

(*c*) The LOWTRAN and RADCOM radiative transfer models to compute radiances at the top of the atmosphere from user-supplied atmospheric profiles (Kneizys and others 1980; Weinreb and Hill, 1980).

(*d*) A simple orbit model which graphically displays the daily sub-satellite track and instrument coverage for several current satellites. Orbital elements and instrument scan geometry can also be supplied by the user if the coverage of proposed satellites is required.

(*e*) Short sequences of small images can be viewed through the use of movie-loop software. This allows several images to be seen as a time-lapse sequence provided that the data have been re-mapped onto a common projection.

(*f*) Packages for filtering imagery data using various numerical techniques, such as Fast Fourier Transforms (FFTs). Results can also be displayed on the ARGS as graphs or as one or two dimensional histograms.

Satellite data processing facilities

The most important source of satellite data for research and operational meteorological applications is the US TIROS-N series of polar orbiting spacecraft (Schwalb, 1978). This series has been in operation since the mid-1970s and has carried increasingly sophisticated imaging and sounding instruments. The current satellites carry two main observing instruments of meteorological interest, the Advanced Very High Resolution Radiometer (AVHRR) and the TIROS Operational Vertical Sounder (TOVS).

The AVHRR is a scanning radiometer with five channels in the visible and infrared regions of the spectrum. The instrument scans a swath of approximately 3000 km and has a resolution of 1.1 km at the sub-satellite point. With the 100 minute orbital period of the TIROS-N satellites and the wide AVHRR swath, full global imagery at almost 1.1 km resolution is available every 12 h from a single spacecraft. AVHRR data are therefore of great importance for operational meteorology but are equally well fitted for research applications because of the good instrument calibration and range of spectral channels. AVHRR data are available to users via three routes. Firstly, through direct reception of the High Resolution Picture Transmission (HRPT) broadcasts from the spacecraft. These provide the full resolution data, but require a sophisticated reception facility to take the high data rate of 665 kbps. Secondly, through the Global Area Coverage (GAC) data which are a reduced, 4 km resolution form of the imagery stored on board the spacecraft and downloaded each orbit to the satellite operators in Washington, DC. These data have full global coverage and provide a database of satellite imagery beginning in the mid-1970s. Thirdly, the spacecraft are capable of storing about ten minutes of full resolution AVHRR data each orbit on tape as Local Area Coverage (LAC) data. Requests to obtain LAC scenes have to be placed with the satellite operators well in advance and are treated on a priority basis.

Software on ARAMIS is available to process all three forms of AVHRR data and convert the raw satellite telemetry on Computer Compatible Tape (CCT) into calibrated imagery. HRPT data are available in different formats depending on the reception site which obtained the broadcast and the processing which has been applied to the data. ARAMIS can handle the formats of the two principal HRPT reception sites in the UK which are at the Department of Electrical Engineering, University of Dundee and the Lasham ground station of the Royal Aircraft Establishment, Farn-

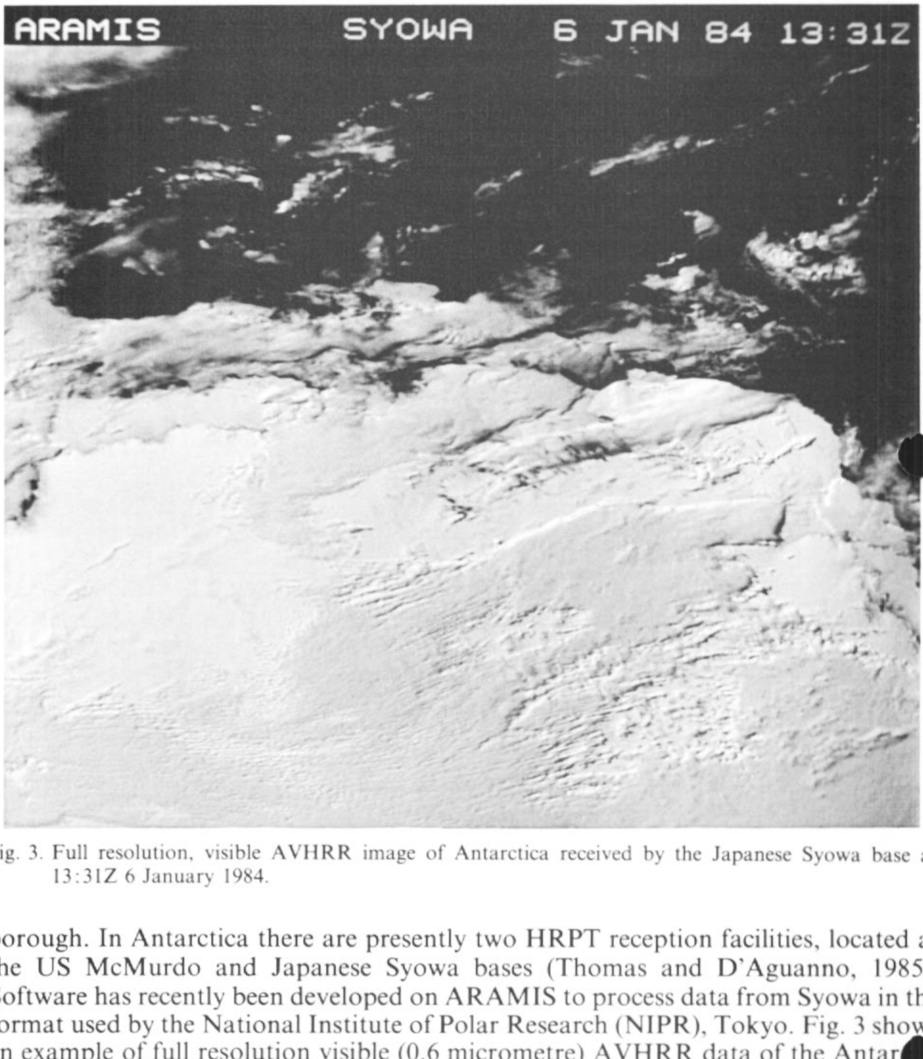

Fig. 3. Full resolution, visible AVHRR image of Antarctica received by the Japanese Syowa base at 13:31Z 6 January 1984.

borough. In Antarctica there are presently two HRPT reception facilities, located at the US McMurdo and Japanese Syowa bases (Thomas and D'Aguanno, 1985). Software has recently been developed on ARAMIS to process data from Syowa in the format used by the National Institute of Polar Research (NIPR), Tokyo. Fig. 3 shows an example of full resolution visible (0.6 micrometre) AVHRR data of the Antar[illegible] provided on CCT by the NIPR and processed on ARAMIS. GAC and LAC data can be obtained from NOAA/NESDIS, Washington on CCT and the telemetry split into instrument counts, calibration data and earth location parameters, using general software packages on ARAMIS.

Once the AVHRR data have been converted into the SIF format the processing can take place regardless of the resolution or origin of the data. Data from the infra-red channels can be converted into radiances or equivalent black body temperatures (brightness temperatures) through the use of calibration data from the spacecraft. As no on-board calibration of the visible channels takes place the counts from the visible channels must be converted to radiances through the use of pre-launch calibration data. These radiances can be converted to albedos by using estimates of the incoming solar radiation derived from a knowledge of the spacecraft location and the solar zenith angle. Further processing of AVHRR data usually takes place with the general image processing facilities which allow channels to be combined according to particular algorithms or compared using the interactive facilities of the ARGS. For final

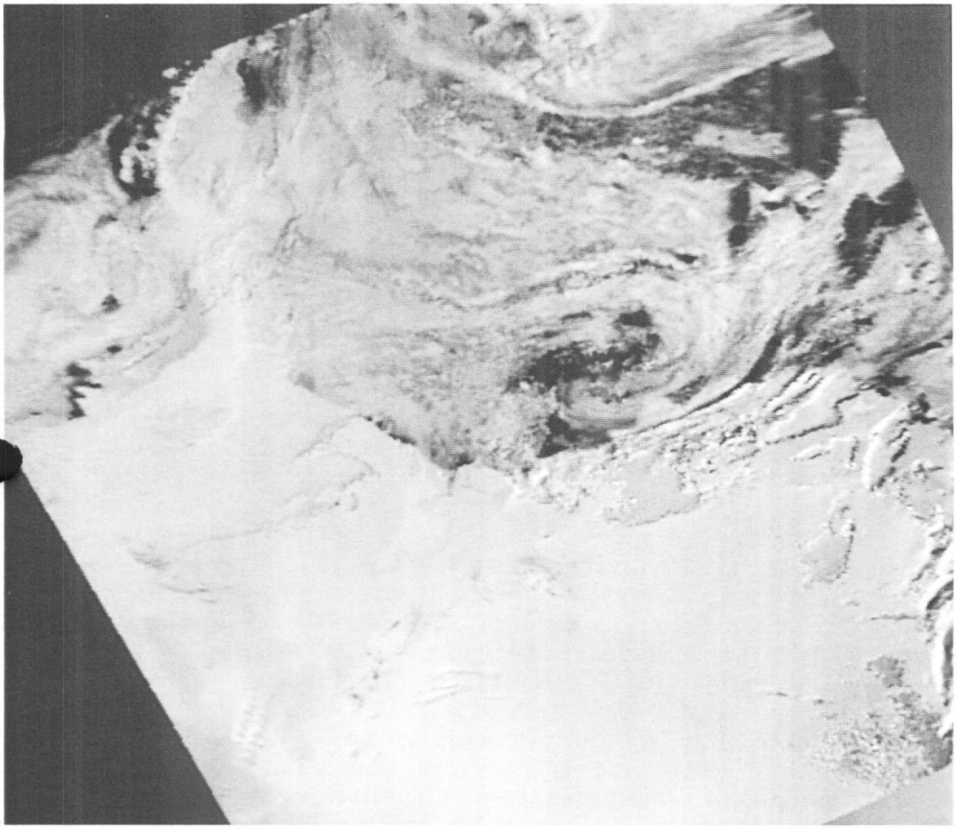

Fig. 4. 4 km resolution AVHRR image of an intense low pressure system over Halley Bay at 18:14Z 5 January 1986.

presentation of imagery or new derived products, the data can be re-mapped onto a Mercator or polar stereographic projection using orbital ephemeris data and a simple orbit model. Fig. 4 shows an example of 4 km GAC data for the Weddell Sea and Halley Bay (75.5° S, 26.8° W) area. The data have been converted to albedos and re-mapped onto a polar stereographic projection.

The TOVS is the primary atmospheric sounder system used by operational and research meteorologists. It consists of three separate sounding instruments, the Stratospheric Sounder Unit (SSU) for determination of stratospheric temperatures, the High Resolution Infra-red Sounder (HIRS) for the derivation of tropospheric temperature and humidity profiles in cloud free or partly cloudy conditions, and the Microwave Sounder Unit (MSU) for temperature sounding in completely cloudy regions. In the USA NOAA/NESDIS have operationally derived global temperature and humidity profiles from TOVS data for a number of years and these soundings are crucial for the operational numerical weather prediction systems run by the major weather services. The data disseminated by NOAA/NESDIS have, however, only relatively coarse horizontal resolution because of the limitations of the meteorological Global Telecommunications System (GTS). Since 1983 the UK Meteorological Office has been modifying the original NOAA/NESDIS TOVS processing scheme to produce soundings at the full resolution of the TOVS instruments. These data are extremely useful for the regional numerical weather prediction model but are also an invaluable source of data for meteorological research in remote, data sparse regions. The Meteorological Office local area sounding system is now installed on ARAMIS and is being developed to operate over the Antarctic.

Meteorological applications

Satellite remote sensing offers one of the most powerful means for investigating the meteorology and climatology of Antarctica and research on ARAMIS will be directed towards exploiting these data within the BAS meteorological program. Although observations from satellite instruments are generally less accurate in absolute terms than observations from *in situ* observing systems, they are obtained with higher spatial resolution and better temporal coverage; further there is good consistency of the observations. Data from surface observing sites are ideal for the compilation of long-term records required for climate studies and for detailed micro-meteorological investigations such as the BAS STABLE project which is investigating the very stable boundary conditions found over Antarctica. However, the wide separation of bases within the Antarctic prohibits the full investigation of weather systems on the meso and synoptic scales. These are extremely important to operations on a day-to-day basis, yet are poorly represented in the current generation of atmospheric models. Low resolution satellite imagery, such as that received at the BAS bases, has highlighted the range of weather systems that occur over the continent and along the ice edge, although the lack of objective observations has limited the full investigation of such systems. Current meteorological research on ARAMIS is therefore directed towards investigating the various types of weather system over Antarctica and the surrounding sea areas, their formation and development and their interaction with the sea-ice and large-scale atmospheric flow. This work will be carried out using high resolution imagery to provide surface and cloud top temperatures and to give upper-air wind velocities through the derivation of cloud motion vectors. High resolution temperature and humidity profiles will be generated from the TOVS data for analysis of the thermal structure and air-masses affecting the areas under investigation. Although these data will provide a greatly increased resolution over the *in situ* measurements, there is still a need for the radio-sonde data for verification of the satellite soundings and for use in the statistical inversion process of converting the satellite radiances into atmospheric temperature profiles.

The use of satellite data at high latitudes is still considerably more difficult than in the tropics or mid-latitude regions. This is because of the lack of contrast between features in the visible and infra-red imagery and the problems of using the radiometers at the limits of their calibration range. One of the most fundamental problems is effectively discriminating clouds from the snow and ice covered surfaces, since both have similar visible albedos and surface temperatures. The development of an effective automatic algorithm for separating clouds and ice has assumed a new importance with the start of the International Satellite Cloud Climatology Programme (ISCCP) under the World Climate Research Programme (WCRP). ISCCP aims to produce the first accurate global climatologies of cloud cover for use within the WCRP (Schiffer and Rossow, 1983) and clearly algorithms for use in polar regions will be vital to this work. ISCCP has recently established a sub-group to consider cloud detection in the polar regions and recommend an algorithm to be used operationally. The BAS remote sensing section has recently joined this group and will be working closely with other groups on the development of these techniques.

Other applications

Satellite remote sensing techniques are becoming of great importance in a number of scientific disciplines and their role in many areas of polar research is increasing. The ability to derive accurate sea surface temperature (SST) data and monitor fronts and anomalies in remote ocean regions is of great importance to both physical and biological oceanographic research. For some time BAS has received the NOAA/NESDIS global maps of weekly mean SST derived from satellite data. These are currently used by members of the Marine Life Sciences Division within their research on the distribution of krill. Software on ARAMIS now allows specific cases of interest to be examined in detail through the use of digital GAC imagery which can provide SST analyses at a resolution of 4 km.

Glaciological research has made use of the high resolution imagery from the earth resources satellites, such as LANDSAT, for a number of years, although, until recently, these data were mostly used in hard-copy, photographic format. The current generation of satellites such as LANDSAT 4 and SPOT provide very high quality, multi-spectral imagery with horizontal resolution as high as 10 m. These data are now used for a variety of tasks including mapping, determining the movement of ice streams, monitoring iceberg calving and locating surface features such as flow lines and ice rises. The use of such data is greatly improved if the imagery can be interpreted on an interactive graphics system with full control over grey scale enhancement and image manipulation. Work has therefore begun on ARAMIS to allow greater use to be made of these data through the development of software for processing CCTs of LANDSAT and SPOT data and converting the imagery into the SIF format.

The main difficulty in using visible imagery from earth resources satellites in the polar regions is the need for cloud-free conditions. Over the next few years several satellites will be launched with all weather microwave imaging systems based on the Synthetic Aperture RADAR (SAR) principle. Most experience in space-based SAR instruments has emerged from the ill-fated SEASAT satellite which operated for only three months during 1978. Research on SEASAT SAR imagery has shown its value in oceanographic research and the small amounts of SAR data from Greenland have highlighted its potential in glaciology. An example of SEASAT SAR data of the North French coast around Dunkirk is shown in Fig. 5. The image of RADAR backscatter shows considerable detail of the town and surrounding area, but also provides a wealth of detail over the ocean with many features of the seabed topography apparent; possibility because of turbulence generated over these features. Although the conversion of raw microwave data from a SAR instrument into an image of backscatter is a major task requiring the use of powerful computers, it is planned that the final, processed data from future missions will be available to users in a format that is as easily used as the digital SPOT and LANDSAT imagery. Within the UK a data centre is being established at the Royal Aircraft Establishment, Farnborough, to process SAR and other microwave data from the European Space Agency's ERS-1 satellite following its launch in 1990. The Data Centre will supply fully-processed products which will be used by BAS in its glaciological research programme. BAS is also planning to investigate ocean currents in the Weddell Sea through the monitoring of sea-ice motion via sequences of ERS-1 SAR data. This work will be carried out within the Programme for International Polar Oceans Research (PIPOR).

Data from other instruments on ERS-1 are also of great potential value to BAS research. The RADAR Altimeter (RA) on the satellite will be used to obtain precision measurements of surface elevation over both land and sea areas. The sea surface

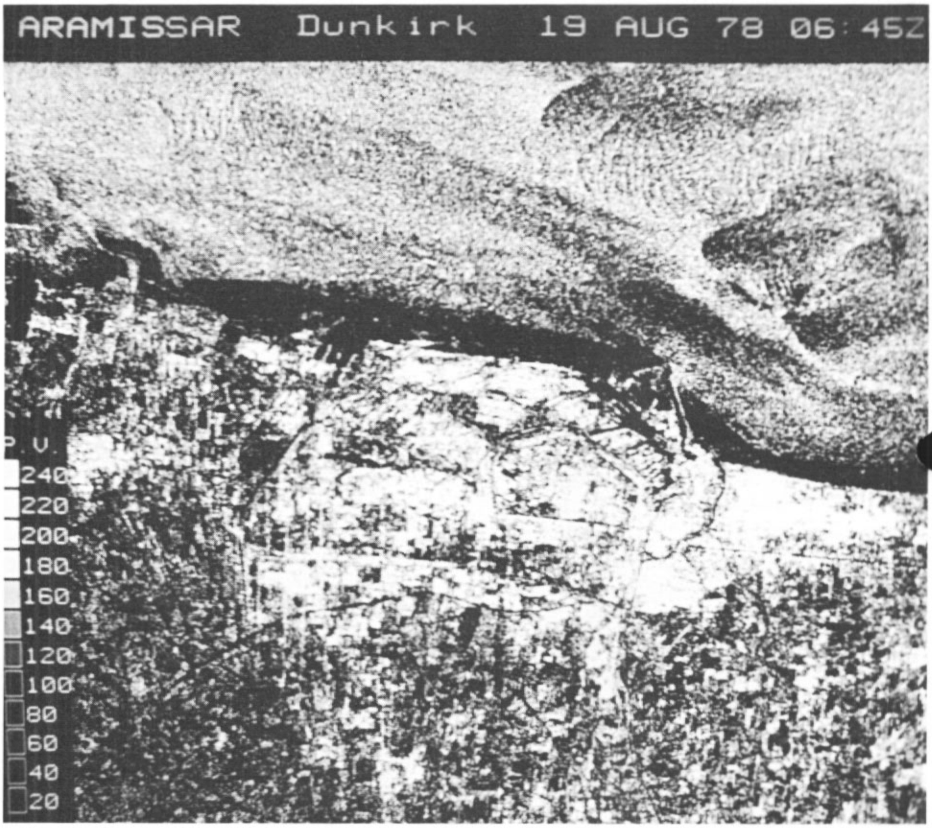

Fig. 5. Synthetic Aperture RADAR image of Dunkirk taken by SEASAT.

elevations will be used for investigation of ocean currents and will be of great value for the World Ocean Circulation Experiment (WOCE) planned for the 1990s. BAS will make use of the RA observations over Antarctica for research into the mass balance of ice sheets, although the orbit of ERS-1 will prohibit complete coverage of the continent.

The ERS-1 microwave wind scatterometer will provide 50 km resolution surface wind vectors over the oceans and provide the first long term series of surface winds over remote ocean areas. Fig. 6 shows the coverage of scatterometer winds which will be available around Antarctica from a single swath of ERS-1 data. The ERS-1 sub-satellite track is represented as a solid line with the scatterometer swath shown as a hashed area. This image has been created with the ARAMIS orbit model and data on the scanning geometry of the ERS-1 wind scatterometer.

Conclusion

ARAMIS is a very powerful and flexible graphics and image processing system which can handle most of the processing and interpretative procedures required in remote sensing research. Initially the system will be used in research on Antarctic meteorological problems through the use of high resolution imagery and sounder

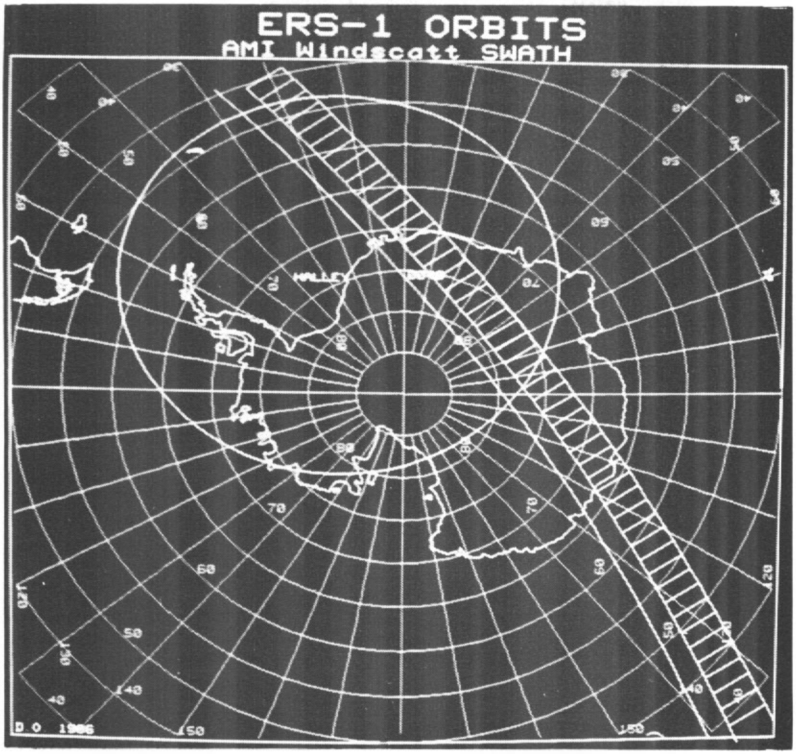

Fig. 6. A simulation of the wind scatterometer coverage from a single pass of the ERS-1 satellite.

data. However, work has already begun on the development of software to handle LANDSAT and SPOT imagery to aid glaciological research and extend the use of the system to other scientists within BAS.

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REFERENCES

[illegible]IZYS, F. X., SHETTLE, E. P., GALLERY, W. O., CHETWYND, J. H., ABREN, L. W., SELBY, J. E. A., FENN, R. W. *and* MCCLATCHEY, R. A. 1980. Atmospheric transmittance/radiance computer code LOWTRAN 5 AFGL-TR-80-0067 *Environmental Research Paper* No. 697.

SCHIFFER, R. A. *and* ROSSOW, W. B. 1983. The International Satellite Cloud Climatology Programme (ISCCP). The first project of the World Climate Research Programme. *Bulletin of American Meteorological Society* **64**, 779.

SCHWALB, A. 1978. *The TIROS-N/NOAA satellite series.* NOAA Technical Memo NESS 95.

THOMAS, I. L. *and* D'AGUANNO, J. A. 1985. AVHRR monitoring applications in Antarctica. *Proceedings of the International Conference on Advanced Technology for Monitoring and Processing Global Environmental Data.* Remote Sensing Society and Centre for Earth Resources Management. London 1985.

WEINREB, M. W. *and* HILL, M. L. 1980. *Calculation of atmospheric radiances and brightness temperatures in IR window channels of satellite radiometers.* NOAA Technical Report NESS 80