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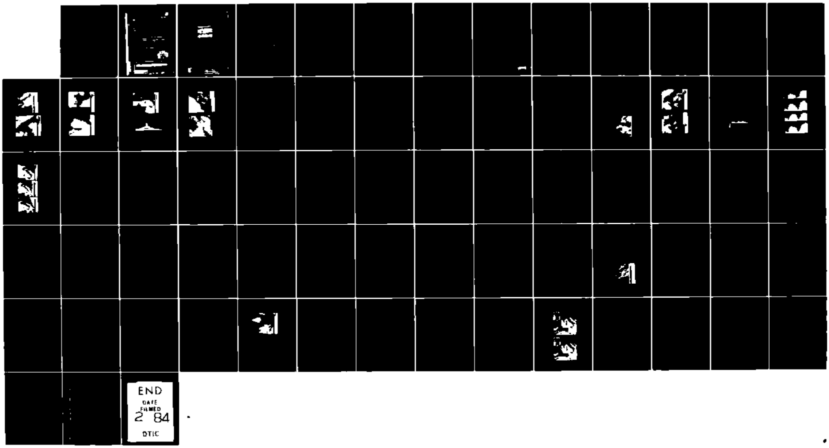

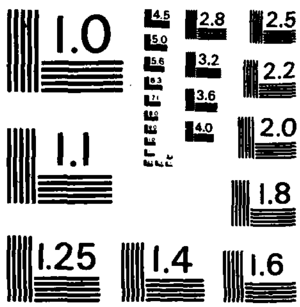

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

SACLANTCEN REPORT SR-74

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A SYSTEM FOR RECEIVING AND ANALYZING METEOROLOGICAL SATELLITE DATA AT SMALL METEOROLOGICAL/OCEANOGRAPHIC CENTRES OR ABOARD SHIP

by

Brian Wannamaker

1 October 1983

This report has been prepared as part of Project 01.

APPROVED FOR DISTRIBUTION

Ralph R. Goodman

RALPH R. GOODMAN
Director

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A SYSTEM FOR RECEIVING AND ANLYZING METEOROLOGICAL SATELLITE DATA AT SMALL METEOROLOGICAL/OCEANOGRAPHIC CENTRES OR ABOARD SHIP

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ABSTRACT

A system to receive and analyze visible and infrared satellite data has been developed for research purposes at SACLANTCEN. Suggestions are made for its development into an operational system to aid meteorological and oceanographic forecasts at small meteorological/oceanographic centres or aboard ship. An appendix gives an annotated list of the software routines in the present analysis system.

INTRODUCTION

Many of the areas for which the NATO Oceanographic Information Centres (NOIC) have forecasting responsibility are coastal waters or enclosed basins in which the hinterlands behind the coasts vary from flat plains to high mountains. Meteorological (and oceanographic) conditions in coastal and enclosed areas often develop very differently from those over the deep oceans or those over the centres of the continents.

There are a number of such geographically localized features in the European area. The Gulf of Genoa is well known as a site of cyclogenisis (the famous Genoa low). Katabatic winds off the mountains of Norway often sweep low stratus cloud away from the coast in spring. Air/sea interaction is especially strong in the Gulf of Lions because of the cold dry mistral wind streaming out from the Rhone Valley. Strong tidal flows in the English Channel induce mixing in the overlying water, so that, combined with wind-induced mixing, the entire water column becomes uniform and is separated from stratified water to the west by a thermal front.

Military operations in such areas are aided by a detailed knowledge of the visibility, winds, sea-state, fog or precipitation, surface levels, oceanic thermal fronts, radar ducting, ice coverage, and so on.

For a number of years the observance and forecasting of such phenomena has been facilitated by a series of meteorological spacecraft operating in near-polar (TIROS, NOAA, DMSP, METEOR) or geostationary (GOES, METEOSAT) orbits. The geostationary satellites offer higher sampling rates, typically one image every half hour, while the near-polar orbiters offer the best spatial resolution, especially in mid and polar latitudes. So far the near-polar orbiters have been better developed to supply quantitative measurements, but to take advantage of this possibility a forecasting centre needs immediate access to a large data-receiving and analysis facility.

A lower cost option has been to receive only the 'cloud pictures' produced by the visible and infrared sensors and transmitted in a lower resolution format called APT (Automatic Picture Transmission). These can be received and displayed on facsimile machines via commercial equipment and used to supplement conventional meteorological data in preparing forecasts. This possibility has been highly developed by the Austrian Weather Bureau, where a number of forecasting algorithms and decision trees have been developed [1].

Unfortunately, facsimile machines are often unreliable and resolve only about eight shades of grey, thereby limiting the amount of information conveyed. To redisplay the data in a way that enhances different levels usually requires storage on analogue tape and rewriting. The writing speed of a facsimile machine is typically 300 lines/minute and the image may be 1600 lines long, thereby requiring five minutes to process. In addition, the information content is constrained by the signal-to-noise ratio of the analogue recording.

To aid its environmental research, SACLANTCEN has therefore developed a reception and analysis system that lies between the two extremes of cost and complexity outlined above. In this system the medium-resolution data are received, converted to a digital format, and passed to an interactive analysis system. Here the operator may quickly and easily manipulate the appearance of the data to improve visual interpretation or may make quantitative measurements of the data.

This report describes such a system and proposes that it could appropriately be used by NATO Oceanographic Information Centres or aboard larger naval ships after it has been adapted for operational use. Chapter 1 outlines some specific uses of satellite data for military environmental forecasting. Chapter 2 describes the present receiving and analysis system. A possible operational system is outlined in Chapter 3. Appendix A gives an annotated list of the software routines in the present analysis system.

1 USE OF APT SATELLITE DATA FOR THE FORECASTER

The use of satellite data for meteorological forecasting is a vast departure from the earlier techniques, which are based on measurements provided by the meteorological reporting grid. It therefore requires new forms of analysis, which are still evolving. However, the two data sources are complementary and the result from the sum will be better than that from either alone.

Qualitatively, satellite 'cloud pictures', such as the examples in Fig. 1, indicate the positions of clouds, the inception of frontal waves and secondary cyclogenisis, and the occurence of features small enough to fall through the reporting net (and which often cause locally different weather). The infrared imagery (Fig. 2) gives a quantitative measure of the location of thermal fronts and eddies on the sea surface. Quantitative analysis of either type of image can increase the information retrieved.

Figure 2a is a portion of an APT near-infrared[1] image of North Africa and Western Europe at 1411Z 29 June 1982. The very bright pattern on the sea surface is due to direct reflection of sunglint from thousands of small facets of waves at the proper geometric orientation. The northward extent of this pattern is evident from the high reflectivity values that also exist over the Bay of Biscay. The primary specular point was at 33.3°N and 1.4°E, i.e., over the Sahara. An analysis of this image provides the following useful information about the meteorological and oceanographic conditions prevailing at the time:

The comma cloud off the Moroccan coast implies easterly flow through the Strait of Gibraltar [2], because clouds form over the southern Alboran Sea as the air converges to pass through the mountain gap. This hypothesis is supported by the fan-shaped pattern of higher albedo (brighter) values west of Gibraltar. The easterly winds have caused higher surface roughness and thereby a greater number of wave facets capable of reflecting sunglint into the satellite sensor. The corresponding thermal-infrared image shown in Fig. 2b indicates that this easterly flow was causing cooler subsurface water to upwell along the Moroccan coast of the Strait.

Figure 3a is a portion of another APT near-infrared image of the western Mediterranean on the following day. The satellite track and the sunglint pattern lay further east. The sunglint pattern was not symmetrical, because of local variability in the wind field; with calm seas the central area of the pattern would have been at 33.6°N, 8.6°E. A high-pressure cell was centred south of Italy. Winds reported at 1200Z [3] were 5 to 10 kn in various directions at the different recording stations. A small high-pressure area (>1015 mbar) lay south of Italy and a frontal band cut across the Gulf of Lion.

[1] **The near-infrared or reflected-infrared channels is at slightly longer wavelength than visible red. The energy received is that of sunlight reflected from the earth, whereas the thermal-infrared channel receives energy emitted by the earth.**

Albedo and temperature profiles taken through the sunglint pattern in the near-infrared and corresponding thermal-infrared images (not reproduced here) are shown in Fig. 3b. Three distinct peaks of reflectivity are visible. The thermal-infrared profile correlates well with the near-infrared profile at albedos above 20%. In this region, which is about 24 km wide, the temperature is about 0.5°C above the background trend and the three distinct peaks of reflectivity are repeated in the temperature profile. This may be related to two effects: at very high intensities of reflection the thermal-infrared sensor senses a measurable amount of the tail of the energy spectrum of the reflected solar input; secondly, and more important, with low wind speed the incoming heat is trapped in a thin surface layer. The latter effect is responsible for the rise in temperature at the eastern end of the temperature profile. A pool of anomalously warm water is shown in this area on the thermal-infrared image, which the near-infrared image of Fig. 3a shows as a region of very low albedo.

Note that high temperatures correlate well with high albedos near the centre of the sunglint pattern and with low albedos away from the centre. Near the centre, increased roughness increases the probability of light being scattered away from the nominal axis of maximum reflection and a portion of this is directed towards the satellite sensor. Away from the centre of the sunglint pattern a smooth sea surface reflects light away from the sensor, whereas increased roughness creates some wave facets at the proper angles for reflection towards the sensor. Increased wind speed and surface roughness over a previously calm sea surface is related to increased mixing of the near-surface water, thereby distributing the incoming heat downwards and lowering the surface temperatures.

The imagery may also show cellular cloudiness, which in turn is an important indicator of the underlying air/sea interaction [4]. This may be two-dimensional in the form of cloud streets (parallel lines of small clouds) or three-dimensional in the form of open or closed cell structures. Figure 1, for instance, shows open-cell convection in the cold air northwest of a front over the eastern North Atlantic.

The presence of cellular cloudiness implies one or more of the following:

- An inversion layer.
- An air/sea temperature difference of > 5°C.
- A surface wind speed of > 5 m/s.
- An approximately dry adiabatic mean lapse rate in the convective layer.
- A vertical heat flux of > 200 W/m^2 for the three-dimensional convection.

The deciding factor between two-dimensional and three-dimensional convection is apparently the vertical profile of the wind speed. Cloud streets are associated with a wind-shear maximum in the convective layer. The cells occur in the absence of shear. The height of the inversion (H) may be estimated as $H = \sqrt{2}\lambda/2$, where λ is the wavelength of the cloud streets. A similar relationship does not exist for the three-dimensional cells, where the aspect ratio depends on the anisotropy of the eddy viscosity in the convective layer. The direction of the change of eddy viscosity with height may determine whether the cells are open or closed [5]. Fett et al [6] use an image as an example in support of their hypothesis that open cells occur typically in regions of straight or cyclonic flow whereas closed cells occur typically in regions of anticyclonic flow. This implies that the area between adjacent regions of open and closed cells has decreased wind speed and sea-state.

Under clear or scattered cloud conditions the surfac ind speed may be estimated along a swath of daytime visible imagery. his technique is based on the Cox and Munk model [7] for changes in the of the sunglint pattern with wind speed (surface roughness). A phot aph of sunglint taken from space shows a roughly circular pattern. ever, the line-scanning instrumentation and the continually changing y between the satellite, the earth, and the sun causes the sungl pattern to be stretched out along the spacecraft's subtrack. The surface wind may be estimated by measuring the width of this pattern [8] or its position relative to the calm-sea situation. Changes in reflectivity away from the centre of the sunglint pattern are also important indicators of variability in the surface wind.

Figure 4 illustrates the use of the thermal-infrared data for locating the positions and surface strengths of oceanic fronts and eddies that could affect sonar operations. The summer image in Fig. 4a shows afternoon conditions under high atmospheric pressure and low wind speeds. Anomalously warm pools of water lay in the triangle between Sardinia, North Africa and Sicily. Oversaturated in this replica, but visible under different contrast enhancements, were the Maltese Front and upwelling along the south coast of Sicily. Cooler water also bordered the east coast of Sicily, probably due to the southward advection of subsurface water brought to the surface by tidal-induced mixing at the Strait of Messina [9].

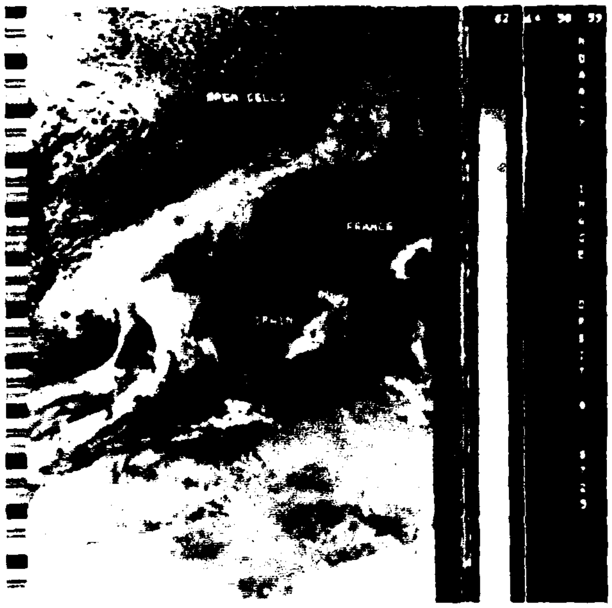
This image illustrates a caveat in the use of the thermal data. Although the temperature values reported in the warm pools would be correct inputs to air/sea interaction modelling, the pools may be masking underlying temperature gradients. Night-time infrared data may be more representative of the bulk temperature because of convective mixing.

In the winter image (Fig. 4b) a thermal front is evident through the heavier cloud cover. This stretches eastward from the southeast tip of Sicily, with cooler water lying to the north. A profile taken perpendicular to the front (from A to B on the image) indicates a temperature change of 0.5°C across it.

The infrared data in themselves are not sufficient to feed acoustic models. Ocean fronts may slope in any direction and below the surface will be encountered at some distance from their surface signature. Experience, historical data, and near-site XBT profiles are all important inputs. Numerical prediction models require a proper mixed-layer sub-section to transfer energy into the deeper layers. Water-mass modelling will give information on the slope of fronts below the surface.

Further discussions and examples of the information content of satellite-image data for meteorological/oceanographic forecasting are given in a three-volume set of reports from the US Naval Environmental Research and Prediction Facility [2,6,10]. These were primarily written for the US Defense Meteorological Satellite Program (DMSP) data but are directly applicable to APT data within the limitation of the lower resolution of the APT data (0.6 or 2 km for DMSP data, compared with 4 km for APT).

The quantitative data available from APT transmissions are discussed in the following chapters.



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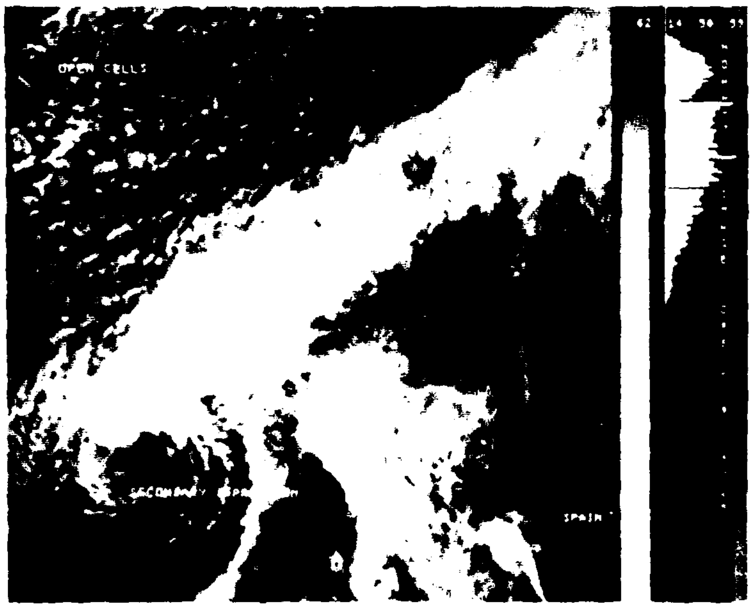
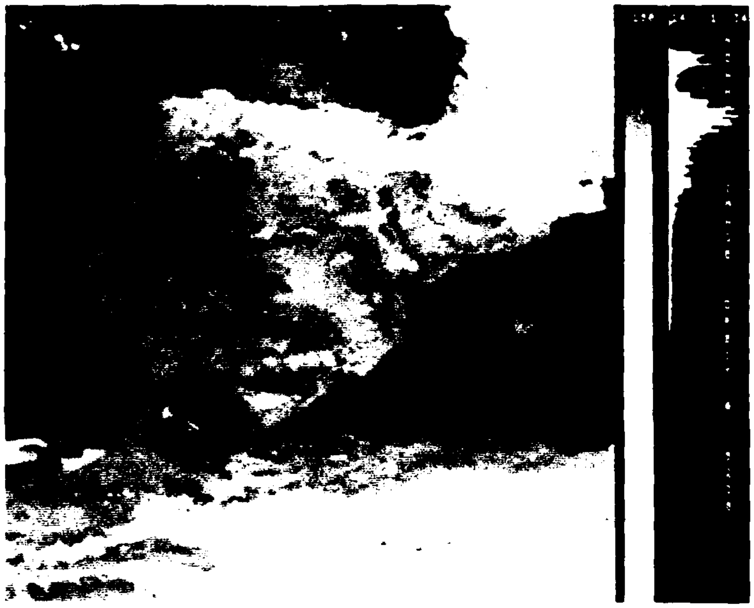


b)

FIG. 1 A NOAA7 APT NEAR-INFRARED IMAGE 3 MARCH 1983.
a) The full image
b) A portion of the image located west of Portugal
A quasistationary front stretches from the Azores to Norway.
A secondary depression (< 1020 mbar) had developed off Portugal.
Open-cell convection was occurring in the cold air west of the front.



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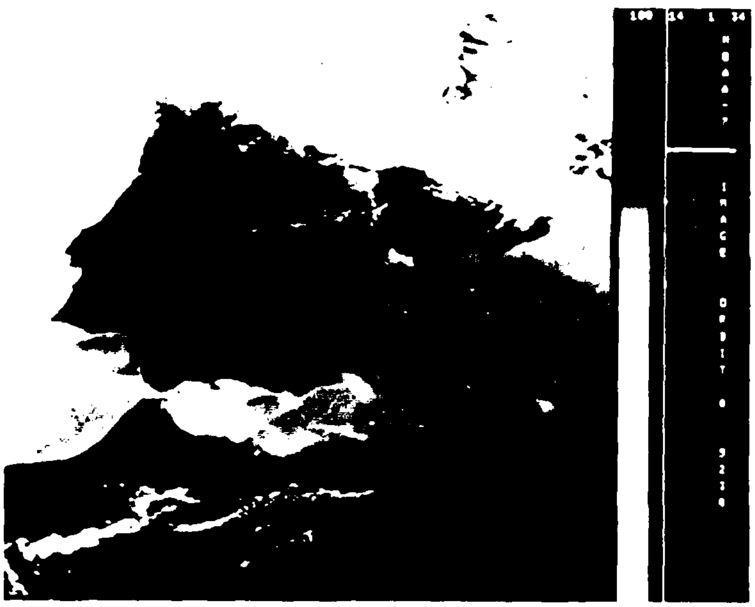
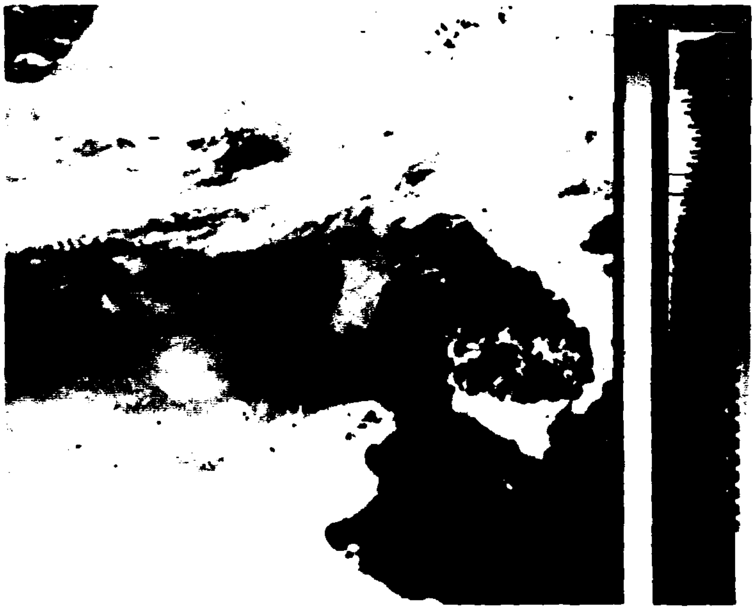


b)

FIG. 2 COMPARISON OF NEAR-INFRARED AND THERMAL-INFRARED IMAGES.
a) Near-infrared APT image 1411Z 29 June 1982. A sunglint pattern is visible in the Alboran Sea and Bay of Biscay.
b) Corresponding thermal-infrared image showing upwelling of cooler (lighter grey) along the Moroccan shore of the Strait of Gibraltar.



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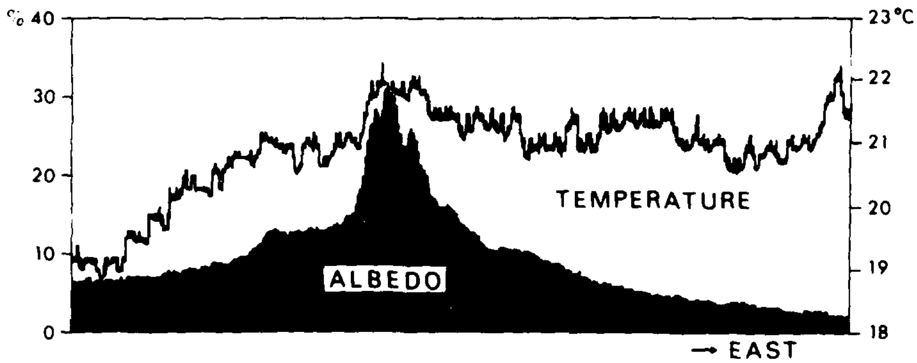
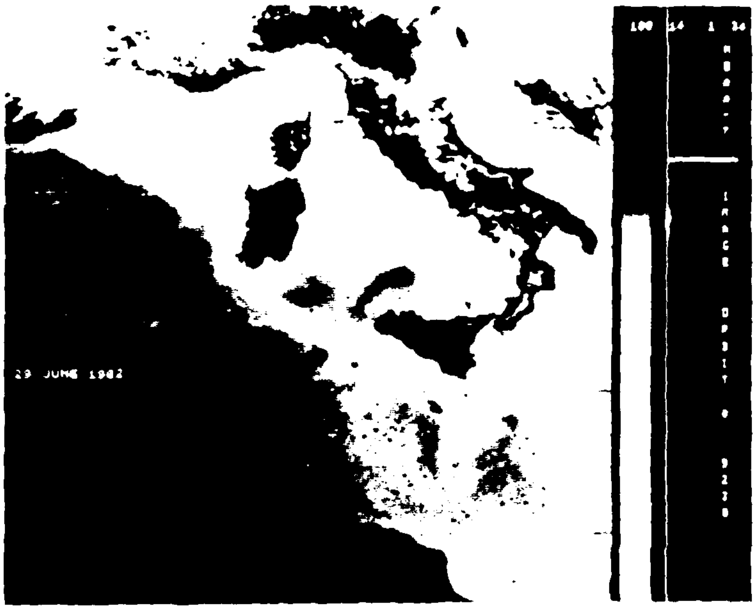


b)

FIG. 3 ALBEDO AND TEMPERATURE IN A SUNGLINT PATTERN.
a) Near-infrared image from NOAA7, 23 June 1983 with exponential grey-scale enhancement.
b) Albedo and temperature profiles taken through the sunglint pattern, showing correlation near high albedos (the temperature profile is taken from a corresponding thermal-infrared image not illustrated here). The profiles are about 300 km long and run eastward along a scan line.



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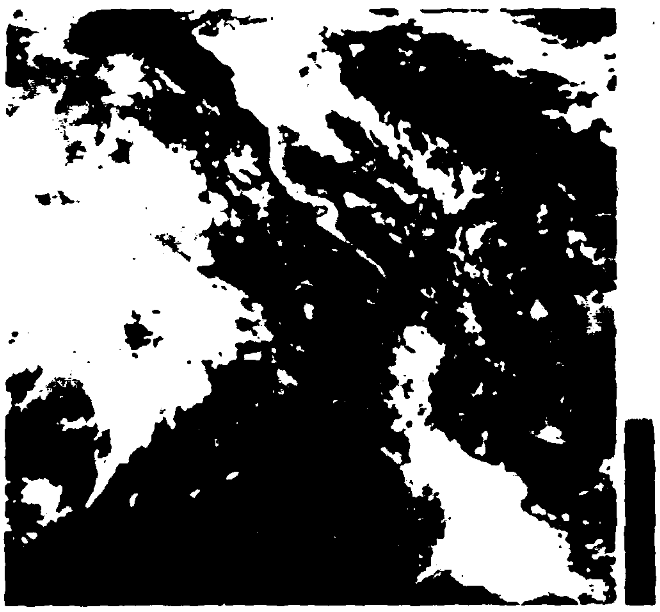


b)

FIG. 4 NOAA7 APT THERMAL-INFRARED IMAGES OF THE CENTRAL MEDITERRANEAN.
a) 29 June 1982 b) 11 March 1983

2 SACLANTCEN APT SYSTEM

2.1 Data

The data at present received at SACLANTCEN are the Automatic Picture Transmission (APT) formatted data from the TIROS-N/NOAA A-J series[2] [11, 12]. The instruments concerned are the AVHRR and AVHRR/2 (Advanced Very High Resolution Radiometers) four- and five-channel scanning radiometers, having the characteristics shown in Table 1.

TABLE 1

SENSOR CHANNEL CHARACTERISTICS
OF THE ADVANCED VERY-HIGH-RESOLUTION RADIOMETERS

Channel	AVHRR Bandspread $m \times 10^{-6}$	AVHRR/2 Bandspread $m \times 10^{-6}$
1	0.58 to 0.68	0.55 to 0.68
2	0.725 to 1.10	0.725 to 1.10
3	3.55 to 3.93	3.55 to 3.93
4	10.5 to 11.5	10.3 to 11.3
5	as channel 4	11.5 to 12.5

Recent budget constraints will limit future spacecraft deployment to one in orbit at a time at a height of about 830 km; the ascending orbit (from south to north) will be moved closer to local noon. The spatial resolution of the AVHRR is about 1.1 km directly under the spacecraft. The curvature of the earth degrades this to 4 km at the edge of the swath (approx. 2800 km). The resulting foreshortening in the imagery is referred to as panoramic distortion. Each of the original four (or five) channels of data are sampled 2048 times across a scan line at 10-bit resolution. The data are transmitted in digital format (High-resolution Picture Transmission = HRPT). There are 360 lines a minute, so that, including the data from other sensors, receiving a full horizon-to-horizon pass requires a storage capacity of some 60 Mbits. This is done at a limited number of stations with 6 to 10 m diameter steerable disk antennas.

[2]The letter designations of the NOAA craft are changed to sequential numbers when successfully launched; for example, NOAA-A became NOAA-6, but NOAA-D will be NOAA-8 because one failed to reach proper orbit. The five-channel instrument is on NOAA-7 and will be on NOAA-E and G-J [18].

To make the information accessible to a wider audience the data are digitally subsampled on board the spacecraft, converted to analogue signals, formatted, and transmitted at VHF frequencies. Every third line of two channels is selectively averaged to maintain a nominal along-track resolution of 4 km (Fig. 5). This reduces the panoramic distortion to create a visually more useful product but increases the difficulty in mapping the data to a standard map projection. Appropriate calibration and telemetry data are added. The two channels are time-multiplexed and amplitude-modulated onto a 2.4 kHz carrier. This in turn frequency-modulates a 137.50 or 137.63 MHz carrier and is continuously transmitted. The two channels transmitted at present are a near-infrared (channel 2) and a thermal infrared (channel 4). For historical reasons these are usually referred to as visible (VIS) and infrared (IR) respectively.

2.2 Data reception

SACLANTCEN's present data-reception system is outlined in Fig. 6. A directional antenna is used for the shore station and an omnidirectional antenna is used on board the Centre's research ship.

The operation is quite simple: the operator enters three parameters of a recent satellite pass: orbit number, equator-crossing time, and longitude. The system determines the subsequent orbits that will traverse the reception cone of the station within a designated time.

Figure 7 shows the reception circles for the SACLANTCEN station, at three antenna elevation angles. The angles apply to a satellite at a height of 830 km directly above the geographical position shown on the diagram. Thus the actual coverage area could be wider than this by one-half the swath width of the sensor. The coverage is effectively limited by the noise-rejection ability of the antenna and by the local topography, which reduces direct line-of-sight paths. The reception circles are true circles only on a stereographic projection centred at the position of the receiving station. Thus, as Fig. 7 is a polar stereographic projection, the 'circles' centred on La Spezia are actually ellipses and will not be correct if transferred to other latitudes.

The geographical coverage of a single satellite pass is substantial. This is demonstrated both in Fig. 1 and in Fig. 8, which latter comes from an orbit crossing the equator at 27.8°E and stretches from the Red Sea to northern Norway and from Israel to Spain. Figure 9, which shows details of Scandinavia from the same orbit, indicates no significant reduction in data quality. The observed noise spikes can quickly and easily be removed by the median-filtering described below.

During the period between passes of the satellite, the computer calculates a "look-up table" of antenna-pointing angles (elevation and azimuth) at 15s intervals by which signals can be received from the subsequent pass. Two or three sequential south-to-north passes lie within the area of reception each day; roughly twelve hours later two or three north-to-south passes are receivable. During a pass, the computer steers the antenna along this predicted path while an off-the-shelf commercial receiver picks up the incoming signal. This is passed to a video decoder, which was built in-house to meet the special needs of quantitative analysis; its functions are as follows: a) to control the sampling frequency of the A/D converter so as to remove the effects of doppler shift in the incoming signal, b) to synchronize the data in time so that the two channels can be separated and the position of calibration data on each line can be determined in subsequent software routines, c) to apply extra filtering to remove residual contamination by the am carrier frequency. The data are then passed to the A/D converter where they are digitized to 10 bits (1024 levels).

2.3 Data analysis

The basic hardware of the present analysis system, which has been designated STARS (Satellite Analysis and Research System) is summarized in Fig. 10. The software is outlined in more detail in Appendix A.

The 120 Mbyte disc stores a number of images for time-series analysis (approx. 20 to 30 full-pass APT images, depending on disc configuration). The data are transferred from tape to disc through a 10-to-8 bit compression look-up table to allow the storage of two picture elements (pixels) per 16-bit computer word. This conversion (see Fig. 11) is piecewise linear to maintain full resolution over the range of interest and still maintain contrast outside that range. One complete satellite pass of typically 1600 lines requires about 4 Mbytes of disc space for the two channels.

An orbit-specific library of ground-control points that lie within the image is created for later use in navigation routines. The selection of points is based on average values of the orbit parameters, the equator-crossing data, and a search of a master library. The precise latitude, longitude and altitude above sea level of 182 points distributed over western Europe and the Mediterranean are stored for APT navigation. For the higher resolution HRPT data, which is also analyzed, some 400 points are kept on file.

2.3.1 Calibration Subsystem (see also Ch. A5 of App. A)

The data then exist in separately named disc files. To be used quantitatively they must be calibrated in albedo (visible or near-infrared channel) and equivalent black-body temperature (infrared channel) with respect to the values received as digital counts. This is done by the calibration subsystem, which also corrects for any non-linearities introduced by the analogue-conversion/modulation/transmission/reception/demodulation/digital-conversion path. Along one side of each image there is a repeating series of 16 steps, each 8 lines deep. Nine of these represent the outputs at pre-set modulation levels. Because the acquisition may have begun at any time during a frame (120 lines or 16 calibration steps) there must be a 'vertical synchronization' before these levels can be retrieved. This is done by re-reading the tape so as to use the 10-bit resolution values and by testing the data until the correct position is located. Then, starting from the beginning of the first frame the mean and standard deviations of the data in each step are recorded in the image file. Under the assumption that the transfer function does not change during an image, the least-noisy values are used to determine a fifth-degree polynomial between the step values and the corresponding full-resolution value. This function can then be used to convert any APT count value to the original averaged full-resolution value on board the spacecraft.

The other seven levels of the 16 steps along the image edge contain sensor calibration values, a channel ID code, and a satellite housekeeping value. Along the opposite side of the image is a strip representing the output of the sensor when viewing deep space, which has a known radiance. Four of the step values represent the temperature of an imbedded black body, as read by a sensor. The sensor's output when viewing this black body is also given by a step level; thus a two-point calibration operation is possible. The conversion of visible and near-infrared channel counts to albedo is accomplished by a fixed formula supplied by NOAA NESS for each satellite [13].

The stored pixel levels remain unchanged, only a look-up table and a flag in the file header are altered, thereby saving a considerable amount of processing time. All output routines for display, profiles, histograms, etc. manipulate and report the data in proper units of counts, reflectivity, or temperature. A comparison of the histograms of a sizable area (>500 APT pixels) with uniform sea-surface temperature from APT and HRPT data showed an insignificant difference (0.01°C) in temperature, with standard deviations of 0.3°C and 0.2°C respectively. A more complete comparison is in process and will be reported later. The calibration routines can be operating while the researcher continues interactive work with the raw data.

2.3.2 Navigation Subsystem (see also Ch. A2 of App. A)

Equally as important as the knowledge of the values of a sea-surface temperature or of a gradient across a frontal region is the knowledge of their positions or of how much their positions have changed quantitatively from one image to the next. The navigation subsystem estimates a time-dependent function of the spacecraft's three-dimensional motion by using spatial ground-truth inputs [14, 15].

This technique is preferable to making a direct surface stretch to an output projection because it increases the flexibility of further processing and is better at extrapolating into open ocean areas when the ground control points (GCP) all lie on one side of the image. It requires only the nominal values of the spacecraft's motion. It is more difficult for APT data than for HRPT data, because APT data have been non-linearly averaged to make a first-order correction of the panoramic distortion and hence must be effectively "uncorrected" to the condition they were in before "navigation". A mapped image should show correct positions within one or two pixels (<8 km). The data may then be gridded (overlain with latitude and longitude lines) or bent to an appropriate map projection; for example, the Standard Mercator projection is common in oceanography, the Polar Stereographic projection is often used in meteorology.

Profiles or histograms of areas may be defined in terms of a number of points defined interactively with the trackball or as keyboard inputs of the latitude and longitude. This allows profiles along ships' tracks to be easily determined. Figure 12 shows a series of temperature profiles taken along the same track, which runs 300 km east of 36°N from the Strait of Gibraltar into the Alboran Sea. The temperature structure in the inflow region and the cool tongue marking the eastern boundary of the gyre show clearly. The absolute values of temperature have not been corrected for the attenuating effect of the atmosphere. The temperature gradients are less affected by the water vapour in the atmosphere.

Figure 13a is an APT image of the central Mediterranean on 7 March 1983. Ground-control points were used to "navigate" this image as outlined above. The rms difference between the positions of these control points as predicted by the program and estimated from the image by the operator was less than 2 pixels (4341 m). The image was then automatically overlain with a latitude/ longitude grid of 2° spacing. The data were later resampled to a Standard Mercator projection with a scale of 4 km/pixel at 42°N (Fig. 13b). The original data were then resampled to a Polar Stereographic projection with the same scale (Fig. 13c).

At the frequency of transmission used, there is sometimes a problem with radio interference, especially in urban areas and at low antenna angles. As seen in Fig. 13, these noise spikes can be efficiently removed by a median filter that replaces the centre value at each position of a sliding window with the median value of the pixels in the window. The median filter removes extremes but maintains the position of gradients, which is important for the spatial measurement of thermal fronts.

Until now only channels 2 and 4 have been used for APT transmission, but there is the choice of switching this (overnight for example) to two of the infrared channels from the command centre in the USA. This will begin with NOAA-8 [16]. This would allow two channels to be combined mathematically in an empirical [17] or theoretical [18] expression to correct for the intervening atmosphere. Similarly, once the data have been mapped to the same projection, images from different times can be combined. This is facilitated by the ability to define the expression via the keyboard at run time in the form of a "macro instruction".[3]

Meteorological centres will generally have access to radiosonde data that can be used for the atmospheric correction with just one infrared channel [19].

In the presence of scattered cloud, the average sea-surface temperature over an area may be estimated by the 'truncated normal distribution technique' [20].

---

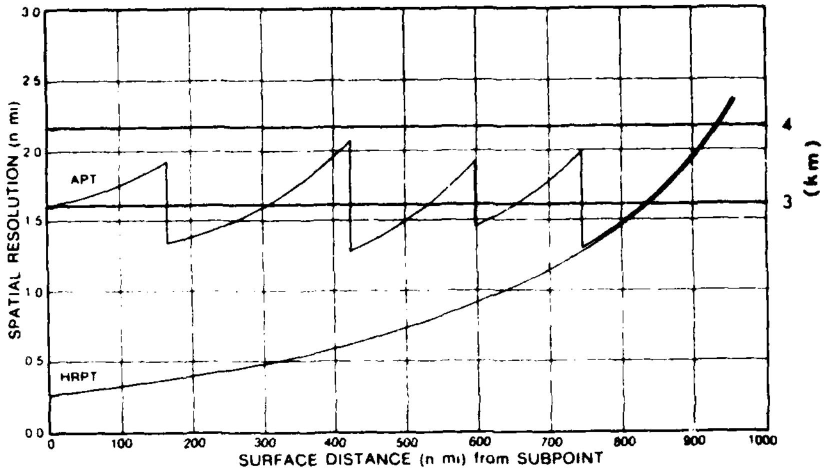
[3] For example to apply McClain's formula for NOAA-6 data,

$$T_{surface} = 1.50\ T_{CHNL3} - 0.44\ T_{CHNL4} + 1.12,$$

the keyword input would be

RES(!RAP, !3APT, !4APT) = 1.5 * !3APT, - 0.44APT + 11.2,

where 11.2 represents 1.2°C, !3APT and !4APT are the input data files, and !RAPT the output file with corrected temperatures.



DISTANCE ON SURFACE ALONG SCANLINE FROM CENTRE

FIG. 5 COMPARISON OF SPATIAL RESOLUTION OF THE DIGITALLY TRANSMITTED (HRPT) AND ANALOGICALLY TRANSMITTED APT DATA OF THE NOAA7. Distance and quoted resolution figures vary because of footprint overlap. (after <6>)

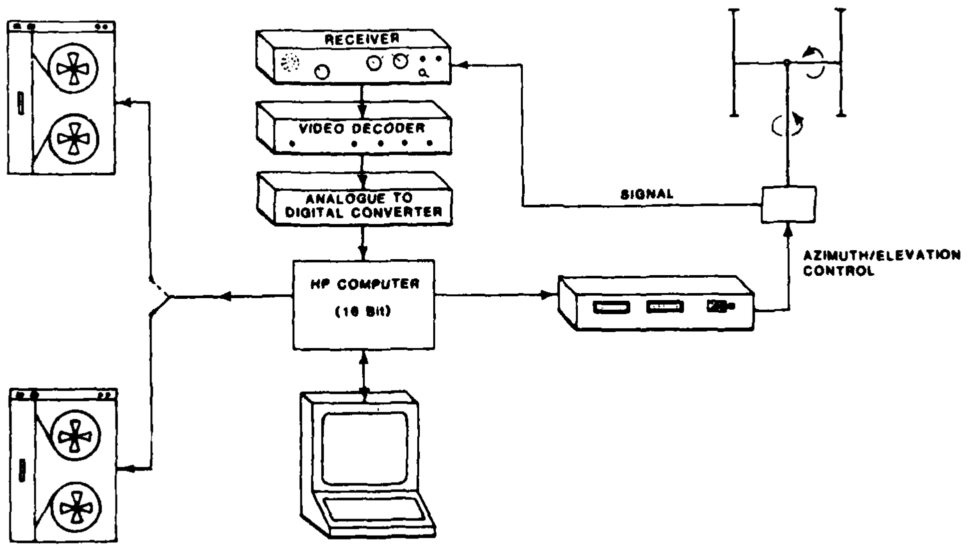


FIG. 6 BLOCK DIAGRAM OF SYSTEM USED AT SACLANTCEN TO RECEIVE TIROSN/NOAA A-J SATELLITE SERIES APT TRANSMISSIONS.

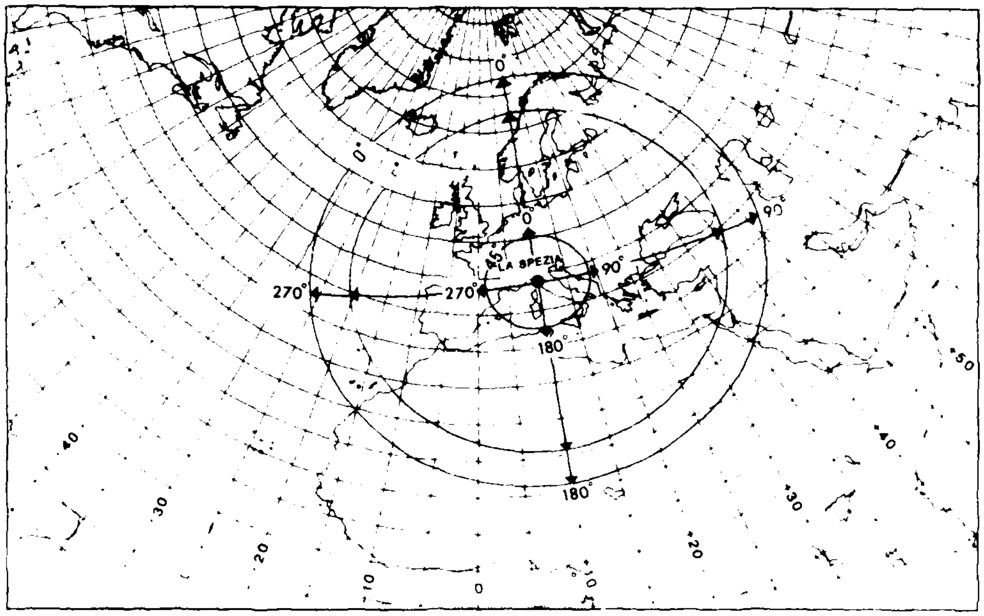
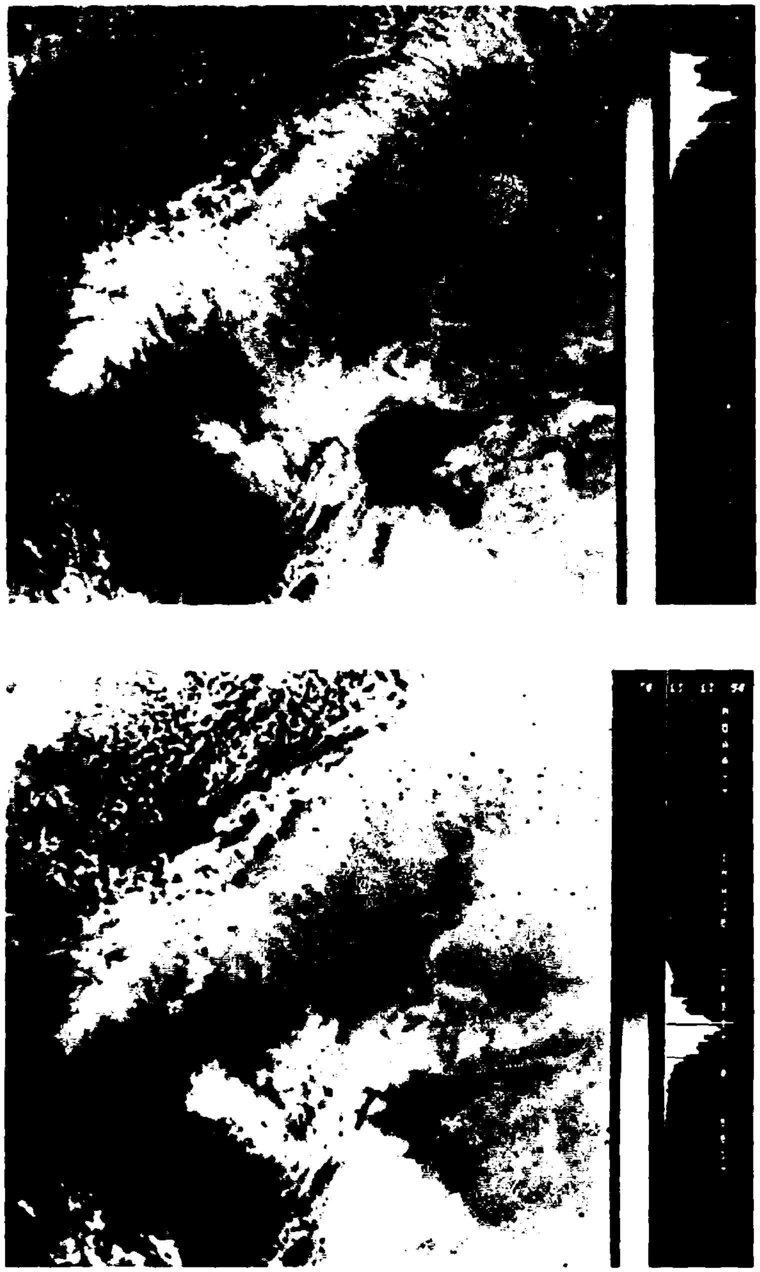


FIG. 7 RECEPTION "CIRCLES" OF THE SACLANTCEN RECEIVING STATION AT 5, 10 AND 45° ANTENNA ELEVATION.

FIG. 8 APT NEAR-INFRARED IMAGE 11 MARCH 1983.



a)

b)

FIG. 9 PORTION OF ORBIT 8837, 11 MARCH 1983 OVER SCANDINAVIA
a) Near-infrared image b) Thermal-infrared images.
Open cell cloudiness exists over the North Sea. The Gulf of Bothnia and Gulf of Finland are partially ice covered.

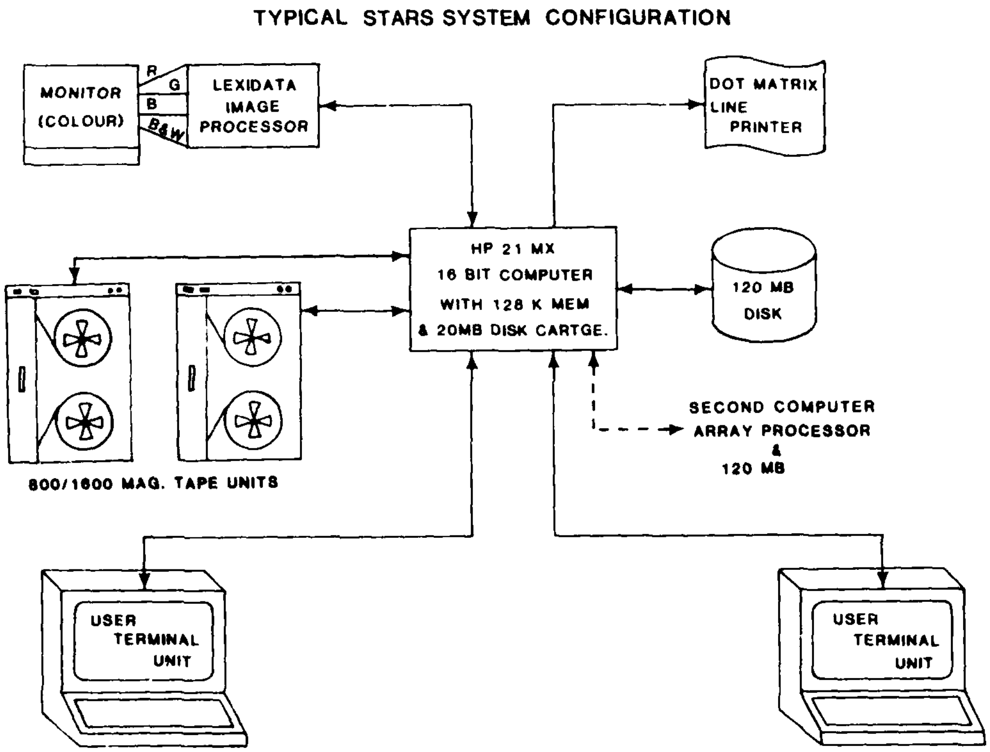


FIG. 10 BLOCK DIAGRAM OF SATELLITE DATA ANALYSIS SYSTEM.

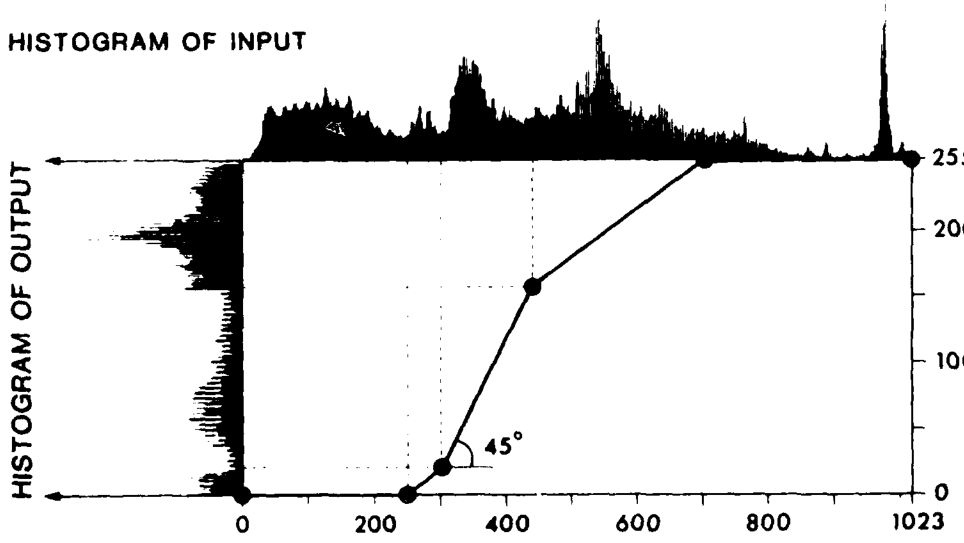


FIG. 11 GRAPHICAL REPRESENTATION OF THE PIECEWISE LINEAR COMPRESSION OF DATA FROM 10 TO 8 BITS.

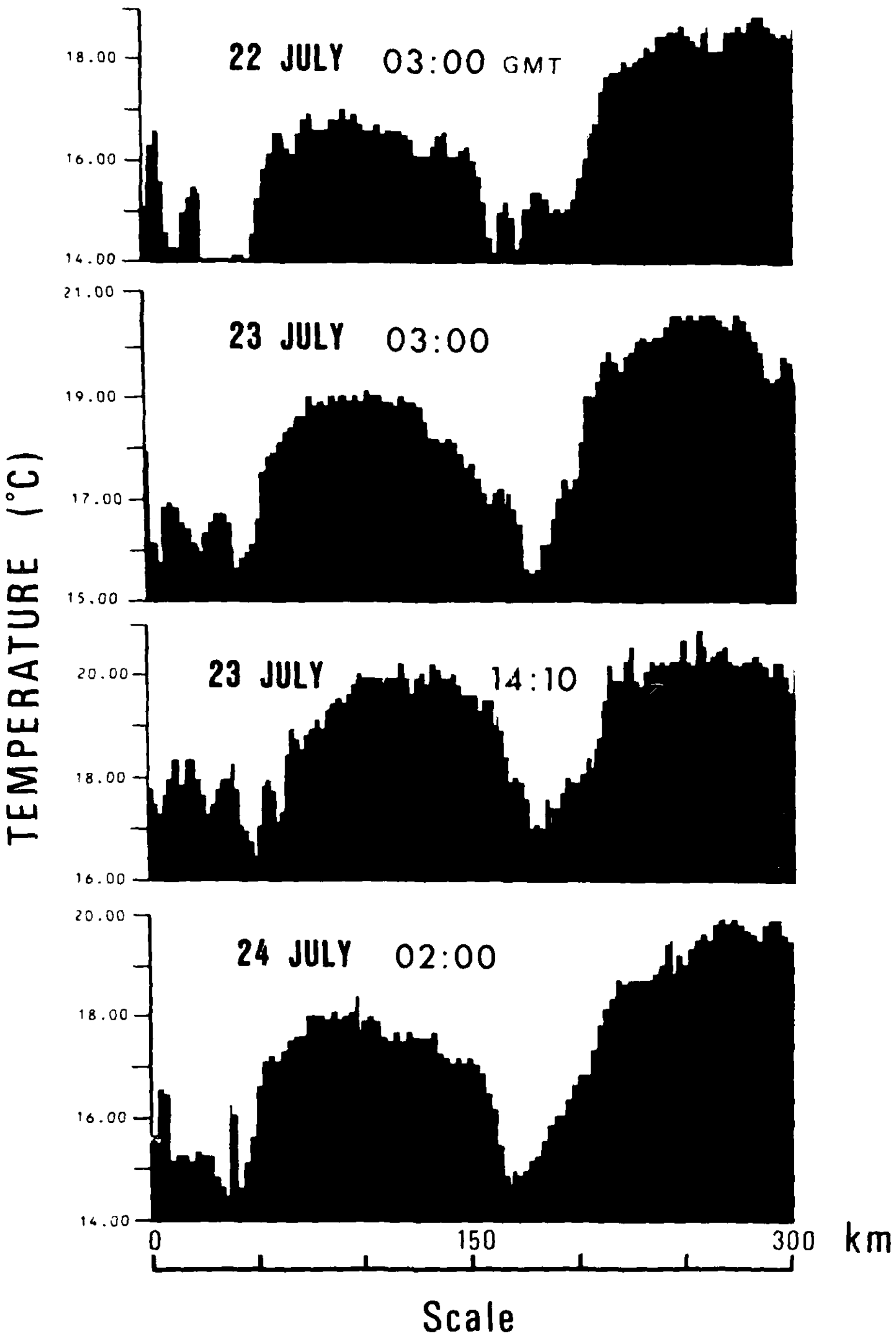
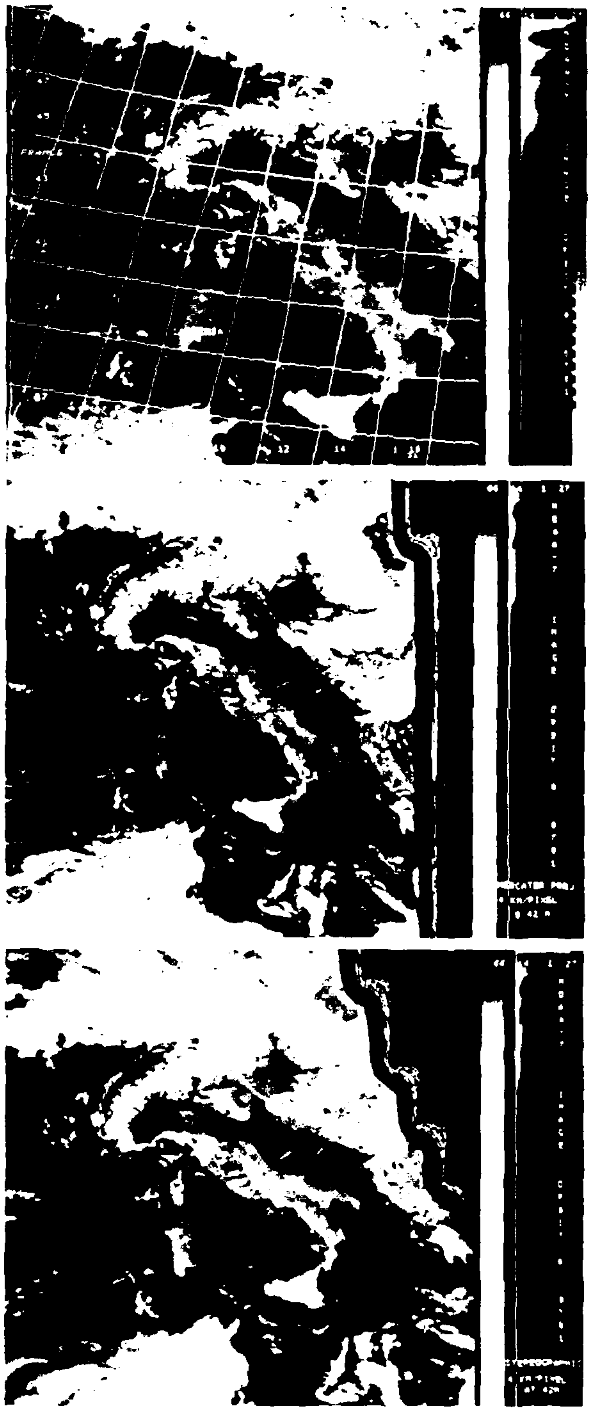


FIG. 12 PROFILES OF EQUIVALENT BLACK BODY TEMPERATURE ACROSS THE ALBORAN SEA AT DIFFERENT TIMES OVER THREE DAYS.
Not corrected for atmospheric attenuation.



a)

b)

c)

FIG. 13 NEAR-INFRARED IMAGE OF THE CENTRAL MEDITERRANEAN 7 MARCH 1983.
a) Original data gridded at 2° intervals in latitude and longitude.
b) Data bent to a Standard Mercator Projection with north at the top of the image.
c) Data bent to a Polar Stereographic Projection.

3 POSSIBLE OPERATIONAL SYSTEM

3.1 APT Data

For the immediate needs of short-term weather forecasting quick access to good data is of greater value than delayed access to data of the highest resolution and quality.

This has been achieved by the SACLANTCEN APT system described in Ch. 2, which was designed for reasearch purposes. However, the system is considered to be amenable to modifications for use as a strictly operational system by meteorological/oceanographic centres or aboard operational ships. An example of an optimized operational system using only one mini-computer is illustrated in Fig. 14. If a directional antenna were to be used it could be steered by a microprocessor. On board ships a smaller geographical coverage may be enough and an antenna with a fixed 45° beamwidth may be sufficient (see Fig. 7). The minicomputer may also be shared with other tasks (e.g., ICAPS) and may be a new small 32-bit machine, such as a Hewlett-Packard HP-9000. The operating routines are available on a disc that would also hold one or two images.

The present suite of software (STARS, see App. A) would need to be supplemented with routines for the retrieval of meteorological parameters. An image processor would be required to hold the image and to perform certain functions at video rates (i.e. <1/50 s). A high-quality colour television monitor would also be necessary, as would a hard-copy unit. This may be an electrostatic or hammer matrix printer that would also serve for general printed output, or it could be a laser facsimile machine that could have a second connection to the receiving system so as to display data direct from the incoming analogue signal. This would allow both a quick look at the data before digital analysis and the reception of sections of weather facsimile (WEFAX) data not requiring digital analysis.

3.2 Conventional data

It may be useful to display the following parameters after they have been computed from grid-point values of numerical analysis and prognosis charts [1]:

Relative geostrophic vorticity at 850 and 500 mbar
Shear vorticity at 850 and 500 mbar
Curvature vorticity at 850 and 500 mbar
Vorticity advection at 500 mbar
Thermal vorticity at 500 and 1000 mbar
Vertical motion (mean value between 500 and 1000 mbar)
Vertical lapse rate
Showalter index
Thermal-front parameter
Hyperbaroclinic zones ($\Delta t/\Delta x > 0.5°C/1000$ km)

3.3 WEFAX Data

An antenna and downconvertor for geostationary satellite WEFAX (weather facsimile)-formatted data is suggested for the operational system. This allows reception of data that have been received by the satellite, analyzed at a primary ground station, and retransmitted via the same satellite. Shipboard receiving stations cannot receive such data, because these satellites are about 36 000 km above the earth and the low-level signal requires accurate aiming of the reception antenna.

For the NATO area one or two such satellites may be within range. Figure 15a illustrates the contours of elevation angles required for the antennas to be in line of sight of the two spacecraft. Generally a 1 m disk antenna is used, but at lower elevation angles a larger receiving area would be required.

The satellite "GOES EAST", which covers the Americas, is situated above 75°W. The geographical area imaged in one complete scene is shown in Fig. 15b. The WEFAX data stream from this supplies [21]:

- Gridded and contrast-stretched geostationary imagery in the visible and infrared, in four quadrants approximately one per hour.
- Geostationary imagery sectors of the region between 20°N and 20°S.
- Contrast-stretched stereographically mapped imagery from the polar-orbiting satellites.
- Computer-generated analysis and upper-air charts from the US National Meteorological Center.
- Orbit-prediction information for the polar-orbiting spacecraft.
- Messages concerning operational anomalies, new spacecraft, etc.

The Meteosat II spacecraft, whose area of coverage is shown in Fig. 15c, is situated over the Greenwich meridian. It transmits the following in WEFAX [22]:

- Visible images in 24 sectors at intervals varying from 0.5 h to 1.5 h intervals depending on geographical area.
- Infrared and water-vapour images in lower resolution. The full earth disc is partitioned into nine sectors.
- Sections of the U.S. geostationary satellites.

The Meteosat images are transmitted at full geometrical resolution after having been broken down into pieces. The visible imagery contains the equivalent of 64 levels, the infrared and water-vapour images contain 256 levels.

3.4 Data-Collection Platform Satellites

Another possibility is to receive data from "Data-Collection Platforms" through a satellite link [11]. Such satellites receive up to 200 s of data from 4 to 32 eight-bit sensors on remote platforms whenever they are within sight of them, and then retransmit the data. The sensors on the remote platforms might measure wind, sea-state, ocean temperature, ambient noise, etc. SACLANTCEN is at present considering the feasibility of using such a satellite service to relay data from its long-term oceanic instrument moorings to a low-cost receiver (similar to the APT receiver).

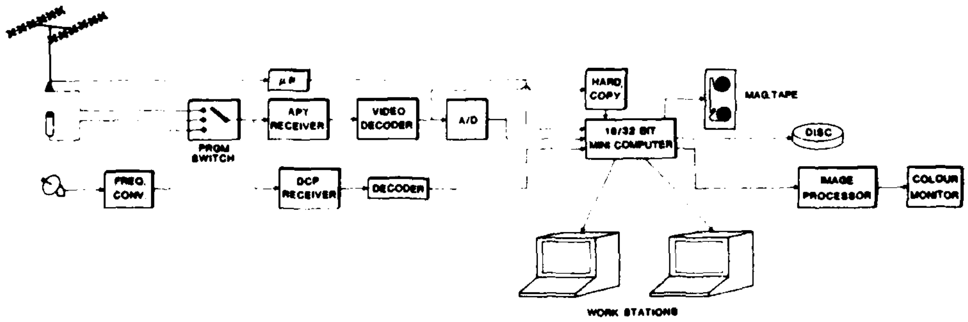


FIG. 14 POSSIBLE OPERATIONAL SYSTEM FOR SATELLITE DATA RECEPTION.

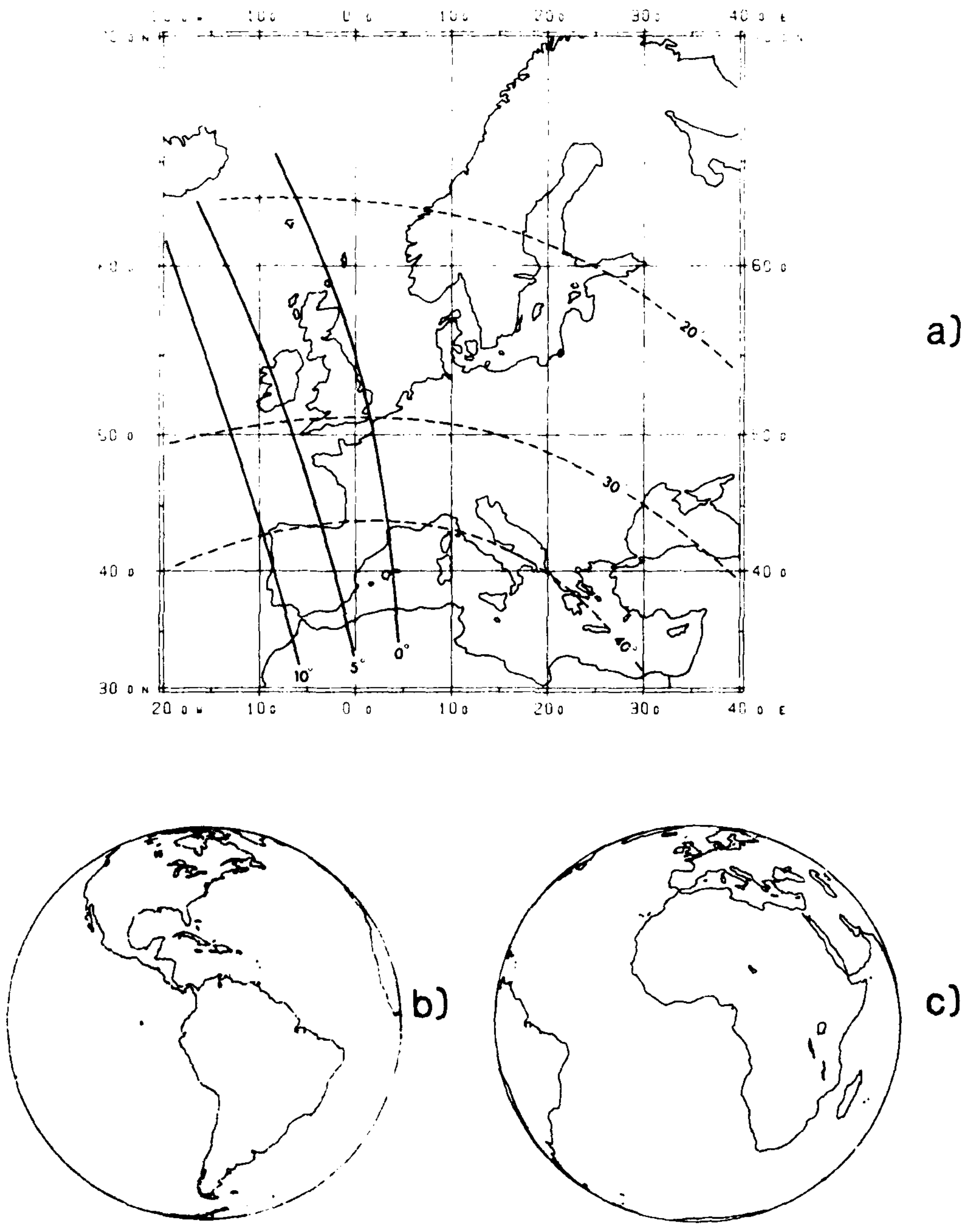


FIG. 15 WEFAX DATA SATELLITES.
a) Approximate antenna elevation angles to receive data from GOES EAST (—) and METEOSAT (---) from ground stations in Europe.
b) Area of the globe viewed by the GOES East Satellite.
c) Area of the globe viewed by the METEOSAT II satellite.

CONCLUSIONS

The operational meteorological/oceanographic forecaster needs quick access to reliable synoptic data. The combination of satellite remote-sensing and the decreasing cost of computing power makes this possible.

This report has outlined a system for obtaining better data for environmental research by the reception and quantitative analysis of medium-resolution near-infrared and infrared data from the TIROS-N/NOAA A-J series of meteorological satellites. The proposed system would include data reception from geostationary satellites and satellite-relayed data from collection platforms.

Systems similar to this could be developed to operate at locations such as the NATO Oceanographic Information Centres or on board major ships, thereby giving the forecaster interactive access to quantitative data on cloud-top heights, surface fronts, cloud types, etc. to feed meteorological, oceanographic and acoustic models.

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Electronic/Acoustic Engineering Dept.	- Design and construction of the video decoder.
Digital Computing Dept. including P. Kitchen (Consultant) and A. Forber (Summer Research Asst.)	- Software.

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APPENDIX

APPENDIX A

AN INTRODUCTION TO THE "STARS" SOFTWARE FOR ANALYZING SATELLITE DATA FOR MARINE ENVIRONMENTAL RESEARCH

INTRODUCTION

This appendix outlines briefly the main features in the present STARS (Satellite Analysis and Research System) software, which has been written as a utilitarian tool for marine environmental research. It lacks many enhancements of some other image-analysis packages but stresses the retrieval of quantitative data. The data can be calibrated both in temperature/albedo and in spatial location, and different channels of data can be combined to reduce the effect of certain unknown parameters. It is designed to be flexible and easy to use and expand.

STARS manipulates and analyzes large arrays of image data. At present these data are limited to those from the third-generation polar-orbiting meteorological satellites of the (TIROS-N/NOAA6 A-J) series.[1] These satellites are used for daily inputs to most of the major world-weather forecasting services. Thus they have a large market that will maintain the presence of at least one such satellite in orbit at all times. Data from more specifically oceanographic satellites, such as NIMBUS-7 (with the coastal-zone colour scanner) or SEASAT (with many oceanographic sensors), were experimental craft with short lives and/or the necessity of special permission for use. The geostationary Meteosat II satellite has the special property of supplying hourly data rather than 12-hourly data but has poorer spatial resolution/temperature precision at the latitudes of interest. With the proper arrangement of the data in the correct format many of the STARS routines could handle these other data sources.

The TIROS-N/NOAA A-J series of spacecraft supply data in two forms. There is a digital transmission (HRPT) of five channels of data at 10 bits with a sub-satellite resolution of 1.1 km. At the same time, every third line of two channels is subsampled and transmitted in an analogue form (APT) <A.1>. The two channels chosen at present are a near-infrared (0.725 to 1.10 m) and a thermal-infrared (10.3 to 11.3 μm for NOAA-7). These are often referred to as visible and infrared (IR) respectively for mainly historical reasons.

[1] The near-infrared or reflected-infrared channels is at slightly longer wavelength than visible red. The energy received is that of sunlight reflected from the earth, whereas the thermal-infrared channel receives energy emitted by the earth.

The STARS software was developed primarily for the study of oceanic variability by the SACLANTCEN's Applied Oceanographic Group. It is however quite "user-friendly", i.e. it should be easily useable by other types of researchers after a short familiarization and has, for example, been used by researchers into long-range acoustic propagation to estimate horizontal variability. Used wih SACLANTCEN's growing archive of satellite data and its SONDA data base of environmental data <A.2> it assists in pre-cruise planning. It is expected that some of the processing techniques reported here will be of use to others doing two-dimensional analysis and will generate suggestions for improving STARS itself.

The following text outlines the system structure and then describes the details of each of the subsystems, considering their puposes and some of their features and limitations.

A.1 SYSTEM STRUCTURE AND STATUS

A.1.1 Structure of STARS

The present version of STARS runs at SACLANTCEN in a multi-user mode on a distributed system of two computers, two dual-ported 120 Mbyte discs, and a single 20 Mbyte disc (Fig. A.1). This is a more extensive system than would be necessary to complete the basic tasks but is efficient in a research environment with shared facilities. The configuration releases the image processor for other research groups while non-interactive routines are proceeding on the first computer. The computers used are both of the Hewlett-Packard 21MX F series with 192 kbytes of core storage. An attached firmware/hardware Floating-Point Processor greatly increases the processing speed for calculation-bound routines. Disc storage of 260 Mbytes is allocated as shown in Fig. A.2.

Other cartridges of the discs are reserved for general subroutine libraries, for other users, and for data. The large number of signal-processing routines in these libraries gives scope for continued development of the program. The array processor attached to the first computer opens the possibility of increased frequency-domain analysis. Most programs are written in FORTRAN-4, all are being compiled under, and newer ones written in, FORTRAN 7X — the HP expanded version of FORTRAN 77. Certain subroutines are coded in Assembler language to speed computations.

Interactive data display is via a Lexidata-3400 image processor feeding a Conrac colour monitor. The image processor consists of 10 640 × 512 picture element (pixel) planes with two overlay planes. Cursor control is via trackball with six control switches.

All programs in general use are automatically loaded on entry of the user's password. To allow greatest flexibility, routines are called from menu lists divided into four subsections. The master menu program is STARS (Fig. A.3). Programs that are seldom used are loaded and run direc· from the File Manager (: prompt). Program priorities are set to allow interactive routines quick access when two or more programs time-share one computer.

Hardcopy output is to a matrix lineprinter configured for ten grey scales or via tape to an Applicon jet plotter. This allows accurate geometric and colourmetric copies to be made in any number on ordinary or transparent paper. Colour or black-and-white photographs are produced through a Matrix Instruments Colour Graphics Camera in 8 in. × 10 in. or 35 mm format. Colour-separated masters can also be produced automatically for offset colour printing. A separate STARS system has been configured to use one 20 Mbyte disc for shipborne application.

A.1.2 Status of STARS

STARS is the master program manager; the abortion of any program running under STARS returns control to it (Fig. A.3). Table A.1 reproduces a computer output of the current (May 1983) status of the program. The various subsystems, routines and subroutines listed in that table are described in the following chapters.

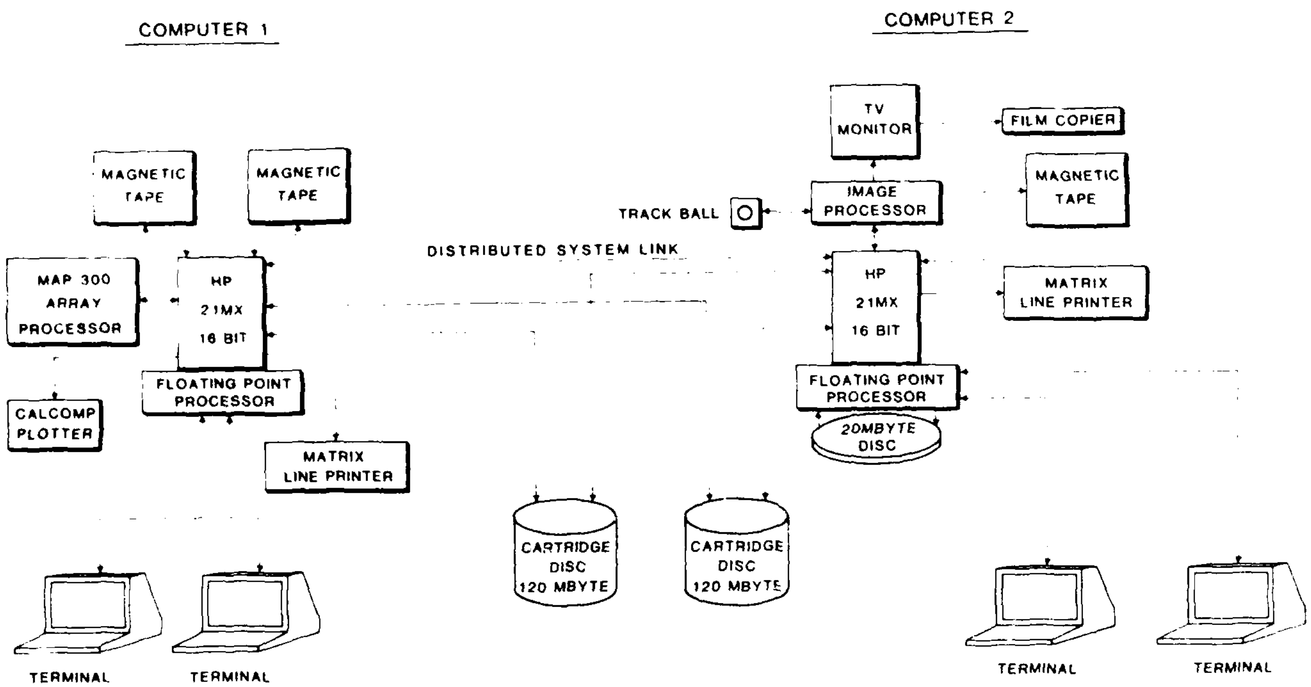

FIG. A1 PRESENT STARS CONFIG RATION FOR SATELLITE DATA ANALYSIS. The shipboard version is similar to the computer-2 configuration without the large discs.

LU	LAST TRACK	CR	LOCK	P/G/S	USER/GROUP	STARS ACCESSIBLE	SIZE (MByte)
02	00449	SY		S	MANAGER.SYS	Y	7.4
11	00099	UT		S	MANAGER.SYS	Y	1.5
44	00615	N1		S	MANAGER.SYS	N	10.0
50	00615	UN		G	SYS	N	10.0
45	00615	00015		G	URD	N	10.0
46	00615	00025		G	URD	N	10.0
48	00615	MI		G	ANG	N	10.0
49	00615	N2		S	MANAGER.SYS	N	10.0
51	00615	R1		G	SRD	N	10.0
59	00615	S8		G	STARS	Y	10.0
60	00615	S9		G	STARS	Y	10.0
61	00615	S0		G	STARS	Y	10.0
54	00615	S3		G	STARS	Y	10.0
55	00615	S4		G	STARS	Y	10.0
56	00615	S5		G	STARS	Y	10.0
57	00615	S6		G	STARS	Y	10.0
47	00615	U1		G	COM	N	10.0
41	00615	RT		S	MANAGER.SYS	Y	10.0
42	00615	LB		S	MANAGER.SYS	Y	10.0
63	00560	RW		G	ORD	Y	9.1
58	00615	ST		G	STARS	Y	10.0
43	00615	PO		G	SDB	N	10.0
52	00615	S1		S	MANAGER.SYS	Y	10.0
53	00615	S2		G	STARS	Y	10.0

FIG. A2 DISC STORAGE DISTRIBUTION.

```
         S a T e l l i t e   A n a l i s y s   &   R e s e a r c h

                                S y s t e m

                        AC = ACQUISITION
                        NA = NAVIGATION AND MAPPING
                        DI = DISPLAY
                        AN = ANALYSIS
                        SP = SPOOL OUTPUT
STARS>
```

FIG. A3 STARS MASTER MENU.

TABLE 1

Current STARS System - Program Status. Last Update 16-May-83

Note This file gives the names of files required to load a program using the following LOADR command.

:SYRU,LOADR,$XXXXX,,,RP <carriage return>

where $XXXXX is one of the names listed below.
By listing any of these files, it is possible to establish which files contain the sources which make up the program
NB.On RTE-VI Distributed Sys. loading is slightly more complex
NBB. Now use LINK,#XXXXX on RTE-VI

The program sources comprising the STARS system can be listed by the following FMGR command (takes quite a while)

::/LIST <carriage return>

Navigation Sub-system.

Loadr file	Description
$PRENV	Refine time values in header of an APT image
$NAVIG	Navigation of an acquired image (APT or HRPT)
$GRUTM	Forms a GRID template from a NAVIGed image.
$BEND	Bends an image to a given GRID formed by GRUTM

Acquisition Sub-system.

Loadr file	Description
$APT1	Mag tape -> Disc file APT acquisition.
$TNLAN	Mag tape -> Disc file HRPT acquisition. (load with command ,$tnlan(segmented prog))
$DUNDE	Mag tape(Dundee format)->Mag tape(Lannion)

Display Sub-system.

Loadr file	Description
$APPLI	LEXIDATA screen -> Mag tape for APPLICON (UNIVAC)
$BORDE	To draw/rotate/shift boundary border on LEXIDATA (trackball driven)
$DFARE	Determine histogram over a rectangular area

TABLE 1 (Cont'd)

	(trackball driven)
$GRD	To draw a projection GRID over a NAVIGed LEXIDATA image or create shiptrack file for use by TCURV
$HC	Hard copy from LEXIDATA screen to LINE PRINTER
$LUTCH	LEXIDATA look up table change
$ZOOMM	Zoom LEXIDATA image by factor of N
$POINT	To draw/shift pointer arrow on LEXIDATA (trackball driven)
$SATDI	General image display program (menu driven).
$TAREA	Temperature/Albedo/Pixel level histogram over an an defined irregular area (trackball driven)
$TCURV	Temperature/Albedo/Pixel level along a defined curve on the LEXIDATA (trackball driven)
$TOUR2	Temperature/Albedo/Pixel level thresholding (trackball driven)
$TTAKE	To measure Temp/Albedo/Pixel level at a point on the LEXIDATA (trackball driven)
$TXY	Draw pixel level curve along X/Y axis on the LEXIDATA (trackball driven)
$ANOTB	Annotate an image with a message on the terminal at a location defined by the trackball

Calibration Sub-system.

Loadr file	Description
$XCAL	Calibration <PHASE I> (extract wedges etc..).
$RADIC	Calibration <PHASE II> (radiances -> temperature).

Analysis Sub-system.

Loadr file	Description
$CRAO	Histogram technique for SST.
$VALB2	Valbonne filter.
$MEDF	Fast Median filter.
$IMATH	N-Channel image mathematics.
$WIND	Image windowing program.

Maintanence Sub-system.

Loadr file	Description
$LGEN	Update navigation constants for new satellites (!ORBIT)
$MSAT	Update calibration constants for new satellites ($$CAL)

TABLE 1 (Cont'd)

$PDET	Determine poly.coeffs. for radiance->temp. for a sensor

Miscellaneous

Loadr file	Description
$STARS	System menu program -- calls most sub-systems
$HSTRY	History program -- determines image history
$QUEST	Detailed command explanation.
$TNPRT	HRPT tape direct to line printer
$NOAA	Calculates orbit ascending node parameters
$IMSTR	Stores lexidata image in a named disc file
$IMGET	Retieves image stored by IMSTR
$PHOTO	Separates image into primary colours for photographing / colour printing
SPOOL	A transfer file used for spooling output to a remote lineprinter

Libraries available

VIS	Vector instruction set-firmware
SIGNAL/1000	Signal processing,"IEEE progs. for digital analysis-firmware/software
SPLIB	SACLANTCEN signal processing library
MPIFP	Multi-plotter interface package
UNIRAS	Generalized raster graphics system
SNPLB	Array processor routines
LXLBA	Lexidata subroutines
LEXLB	Higher level lexidata calls
LOCLB	Navigation,co-ordinate transforms etc
CBLIB	General-see a listing
CVLAT	General-see a listing

** E n d O f F i l e ** <PK&BW>

A.2 THE NAVIGATION SUBSYSTEM ('NA')

This suite of programs was developed in co-operation with the Canadian Atmospheric Environment Service and is a sizeable extension of a system written for them by MacDonald Dettwiler and Associates to assist in ice-coverage studies in the Gulf of St. Lawrence.

A satellite is a slightly wobbling moving platform that builds up an image by scanning — one line at a time — a rotating, spheroidal earth from different aspects on different orbits. The routines in this navigation subsystem use geographic ground-truth input to transform these distorted data from the satellite into a more acceptable distortion — a known map projection. This is essential for quantitative analysis of spatial information, because it means that sizes, positions, and changes of posicion can be measured (Fig. A.4).

A.2.1 The NAVIG routine ('NA')

This is the interactive part of the navigation subsystem. A library of known positions (ground control points, or GCP's) is held in a file created during the original transfer of data from tape to disc (see the Acquisition Subsystem, Ch. A.3). The latitudes and longitudes of these positions have been converted to line/pixel co-ordinates in the image. The user asks for a display of the area around a GCP. Via the cursor and trackball he then indicates his idea of where the true position lies. The difference between this and the estimated position is used to drive a kalman-filtering technique to estimate the spacecraft's motion. From this the line/pixel co-ordinates of the other CGP's are updated. This is repeated until the user is satisfied with the accuracy between his and the algorithm's position estimates. The image has then been "NAVIG'ed". Although the image remains unchanged, the library file now contains third-degree polynomial coefficients in roll, pitch, and yaw and an average altitude vs time during the image. Thus any point can be accessed by lat/long input, or the lat/long of any pixel can be determined. This allows flexibility in further processing by other routines (GRUTM, GRD, TCURV, TAREA).

A.2.2 The GRUTM routine ('GR')

In principle any output map projection could now be built up point by point from the original image. Recall that the location algorithm must consider the type of projection desired in order to go interactively from x,y on paper to lat/long on a spheroidal (not spherical) earth, to spacecraft co-ordinates, to platform co-ordinates, and finally to sensor co-ordinates, in order to relate x,y to the scanner view angle. The SDEC (systems decision) on output image size was 1024 × 1024 pixels and it was estimated that it would take twelve days of CPU time to do the mapping. Without compromising a better than 1-pixel location accuracy, an interpolation scheme is used. The position of each point on the input image is found for every 32nd point horizontally and vertically in the output image. These create the 'benchmark grid'.

With the floating-point processor (FPP) attached to the computer this takes about 5 minutes for a 1024 × 1024 pixel image. At present, Universal Transverse Mercator, Standard Mercator, and Polar Stereographic projections are supported. This is easily expandable. In general, high-resolution HRPT images are mapped on the basis of 1 km/pixel at some reference latitude, and the medium-resolution APT images are mapped at 4 km/pixel (see the Acquisition Subsystem, Ch. A.3). Also available for the stereographic projection is a scale of 25.7 km/ pixel, which, when output on the Applicon jet plotter, matches the scale of the daily European weather charts [A.3].

A.2.3 The BEND routine ('BE')

This routine makes a bilinear interpolation to determine the positions of the desired pixels inside each area bounded by the benchmarks and thereby to create a new 'mapped image' of up to 1024 pixels square. With the floating-point processor this takes about 15 minutes for an HRPT image. It takes over an hour for an APT image, because of the smaller scale (greater north-south extent) and thus greater rotation of the data from the inclined satellite image to a north-at-the-top representation. The user need not wait for these to finish, they can continue to run in a time-sharing mode with most other programs. With two input terminals, up to three BEND routines may be run at the same time as an interactive routine.

A.2.4 The PRENAV routine ('PR')

The greatest uncertainty in positioning the data in lat/long is to know the exact time that each pixel was acquired. The uncertainty can be resolved with the NAVIG routine (Sect. A.2.1), but the library and image file headers must be updated if the error is of more than a few seconds (satellite speed over the ground is about 7 km/s). Otherwise the spacecraft-motion-fitting routines will become unstable. For APT data this is accomplished with the PRENAV routine, which reports the current values and accepts keyboard inputs of new values for the equator crossing and acquisition parameters. The positions of the ground control points (GCP's) are updated in the library and the file headers corrected. For HRPT data, the TNLAN routine is used (see Sect. A.3.2).

```
              [ N a v i g a t i o n ]

PR = Prenavigation (APT)
NA = Navigation.
GR = Grid for stnd/trnsvrs mercator or stereographic.
BE = Bend raw data with grid data.
NA>
```

FIG. A4 THE MENU FOR THE NAVIGATION SUB-SYSTEM.

A.3 ACQUISITION SUBSYSTEM ('AC')

The APT format direct from the satellite is received daily at SACLANTCEN or on board its research vessel. The HRPT data over Europe are received at the University of Dundee, Scotland and at the Centre Meteorologie Spatiale, Lannion, France, which provide data on computer-compatible tapes (CCT's), but in different formats.

SACLANTCEN's first data came from Lannion and a tape-read program TNLAN (Sect. A.3.2) was written around that format. A separate program DUNDE (Sect. A.3.3) was later written to read Dundee-format tapes and write Lannion-format tapes. The decision (SDEC) was to store two eight-bit pixels (individual picture elements or data points) per 16-bit computer word. Both APT and HRPT data are stored at 10 bits/pixel, hence one of the tasks of the acquisition routines is to compress the data. Acquisition here refers to acquisition by the analysis system (i.e., from mag-tape to disc). The compression is done by a piecewise linear curve that maintains full resolution over the range of temperature/albedo of interest for a particular purpose but maintains some variation in constrast over the rest of the range. This is more aesthetically pleasing and aids interpretation. Nominal values of the orbit characteristics are determined from a permanent file accessed via the satellite name stored on the tape header. These and the equator-crossing time and image-acquisition times are used to estimate which of the ground control points (GCP's) filed in the permanent libraries should lie within the image. A library is created with these GCP's recorded in lat/long, height above sea level, and line/pixel co-ordinates. Image files of appropriate length are created with eight header blocks for general information, navigation and calibration data, compression table, and image-processing history (Fig. A.5).

A.3.1 The APT1 routine ('AP')

APT data consist of two channels of time-multiplexed data. The format of the tape from the acquisition computer is shown in Fig. A.6. The hardware of the acquisition system should have synchronized the data, so that the first data point will be the first pixel of channel A — the near-infrared (often called visible) channel 2. If not, the user has the option to interactively synchronize the data by shifting the display on the monitor of the Lexidata image processor. Before reading the tape the user has no values for the calibration or spatial locations. Hence the breakpoints for the data compression are entered in units of digital counts. These are functions of season and of acquisition electronics, and are determined by experience. An example of the user-interaction with this program is shown in Fig. A.7. A tape of a full satellite pass contains data from the central Sahara to north of Norway (Fig. A.8). Scan lines may be skipped initially and the acquisition stopped cleanly at any point. There is no east-west control of data stored (i.e., portions of scan lines cannot be thrown away) but this is not a problem in practice. The user may initiate the first stage of calibration and request tables and plots of the 10-bit and 8-bit histograms of each channel. The WIND routine (Sect. A.6.6) can later be used to create a smaller image.

A.3.2 The TNLAN routine ('HR')

This routine reads computer-compatible tapes (CCT's) in Lannion format (Fig. A.9). The data to be stored can be designated as a certain size (SDEC limit of 2048 × 2048 pixels) centred around an input latitude and longitude. The first ten lines of an image are unavailable to the user; they are read for the calibration data they contain in order that the compression breakpoints can be input in temperature values for the infrared channels. Any or all of the five channels may be acquired. The user may optionally change certain header information to improve navigation (see PRENV, Sect. A.2.4). Since the image to be stored is designated in lat/long, a portion of a scanline can be read and the library is created before data transfer. The routine also collects calibration data during the transfer and initializes the history file. The portion of the tape to be read is calculated from stored orbit parameters and from the times of equator crossing and of acquisition of the first line. If these times are in error the wrong portion of the data will be stored, and the tape may need to be read again after the time errors have been determined through the NAVIG routine (Sect. A.2.1). The user interaction is illustrated in Fig. A.10.

A.3.3 The DUNDE routine ('DU')

This routine reads Dundee-format tapes and writes Lannion-format tapes that can be read by the TNLAN routine (Sect. A.3.2). Dundee archives their data, whereas Lannion rotates their tapes every two months, thus this extra processing step is necessary if the data are not requested soon after acquisition by the satellite. Dundee tapes do not contain a header block with information on the equator crossing or acquisition time, so that this must be separately determined.

A.3.4 The TNPRT routine (see under Miscellaneous on Table A1)

This routine is available from the File Manager. It reads Lannion-format tapes and writes an image on the matrix line printer in ten grey levels. Input parameters are in line/pixel co-ordinates and no data are stored on disc. It is very useful for determining the geographical extent of data/cloud cover on the tapes and for the quick-look archive of data. A first-order correction for earth-curvature is made and the data are sub-sampled according to an input-scale value.

SACLANTCEN STARS FORMAT

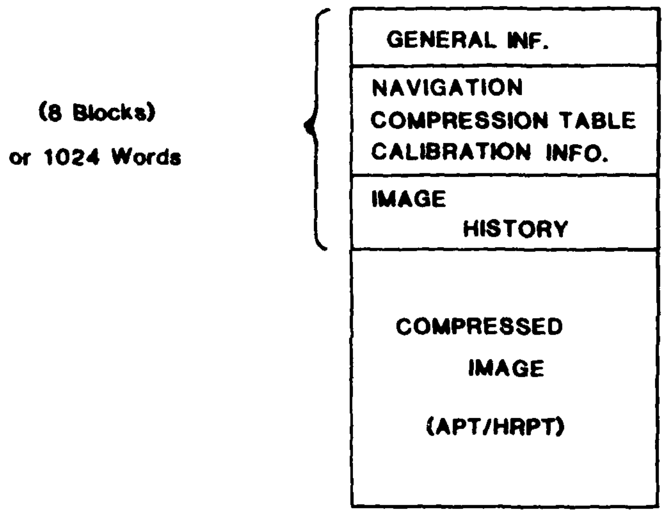

IMAGE FILENAME FORMAT IS IYXXXX

WHERE: I DENOTES THAT THE THIS FILE IS AN IMAGE

Y CHANNEL NUMBER

XXXX USER CHOSEN NAME.

FIG. A5 STARS IMAGE FILE CONFIGURATION ON DISC.

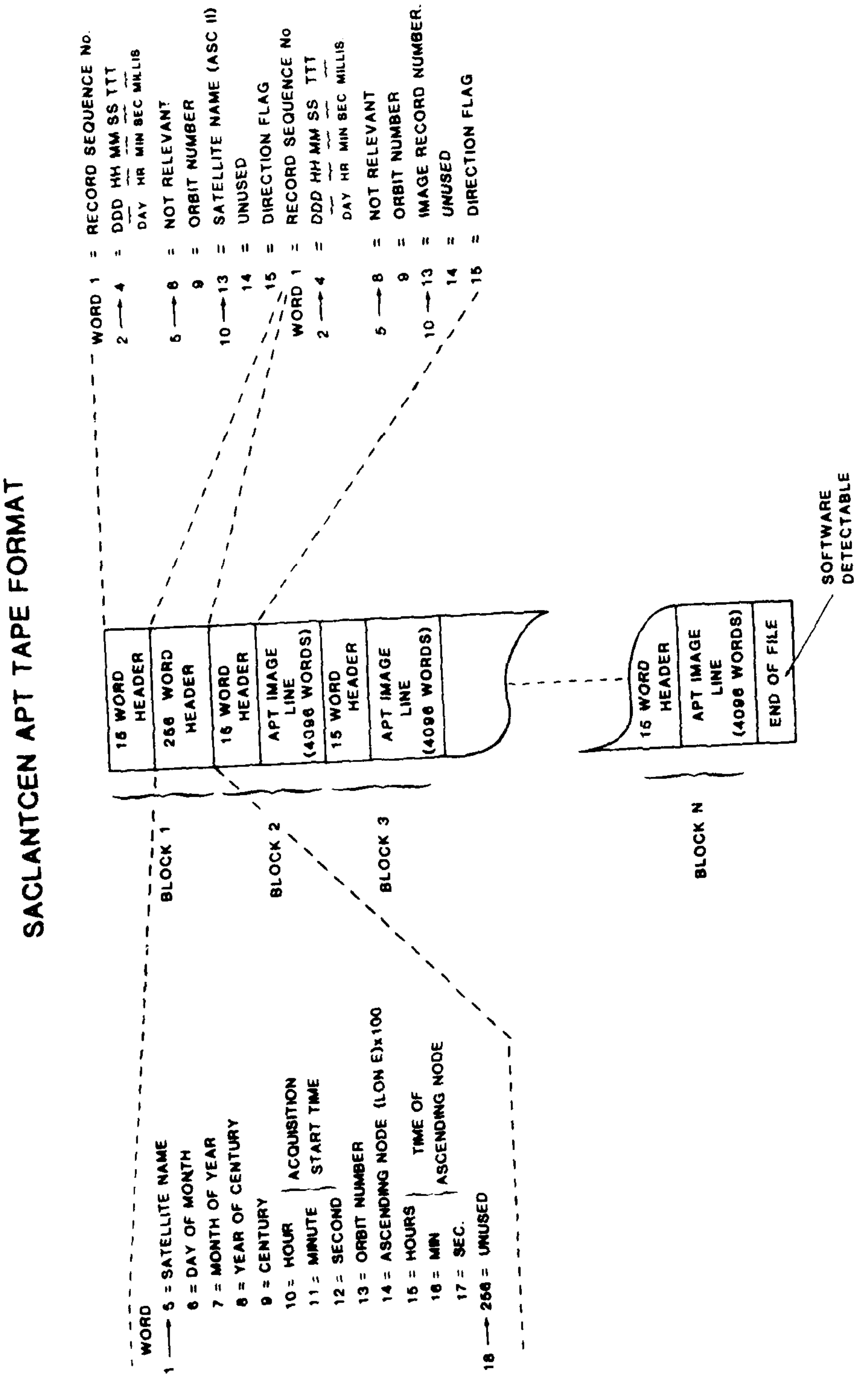

FIG. A6 TAPE FORMAT CREATED BY APT ACQUISITION COMPUTER.

```
                    [ Acquisition ]

              HR = HRPT type tapes
              AP = APT  type tapes
AC> AP

Enter filename > AP1
Bypass LEXIDATA? > NO
Rewind? (YES or NO) > YE
Enter image number > 1
Enter number of rows to be skipped > 100
Enter compression breakpoint vals for CH-1 > 50,500,80,200
Enter compression breakpoint vals for CH-2 > 250,700,400,500
-999
Enter number of rows to be skipped > 0
Enter compression breakpoint vals for CH-1 > 50,500,80,200
Enter compression breakpoint vals for CH-2 > 250,700,400,500

Starting point [    708]
```

FIG. A7 TYPICAL USER INTERACTION WITH PROGRAM APT1 TO PASS APT DATA FROM TAPE TO DISC FILES !APP1 AND !BAP1 WITH A LIBRARY !LAP1.

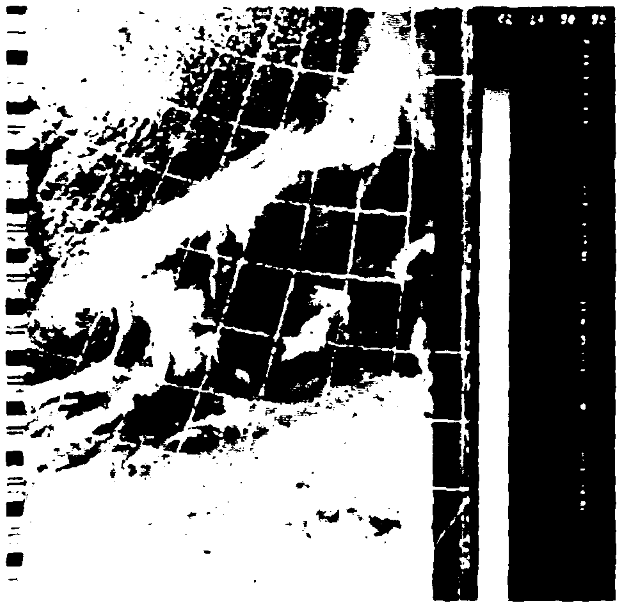

FIG. A8 TYPICAL SINGLE SATELLITE PASS COVERAGE.

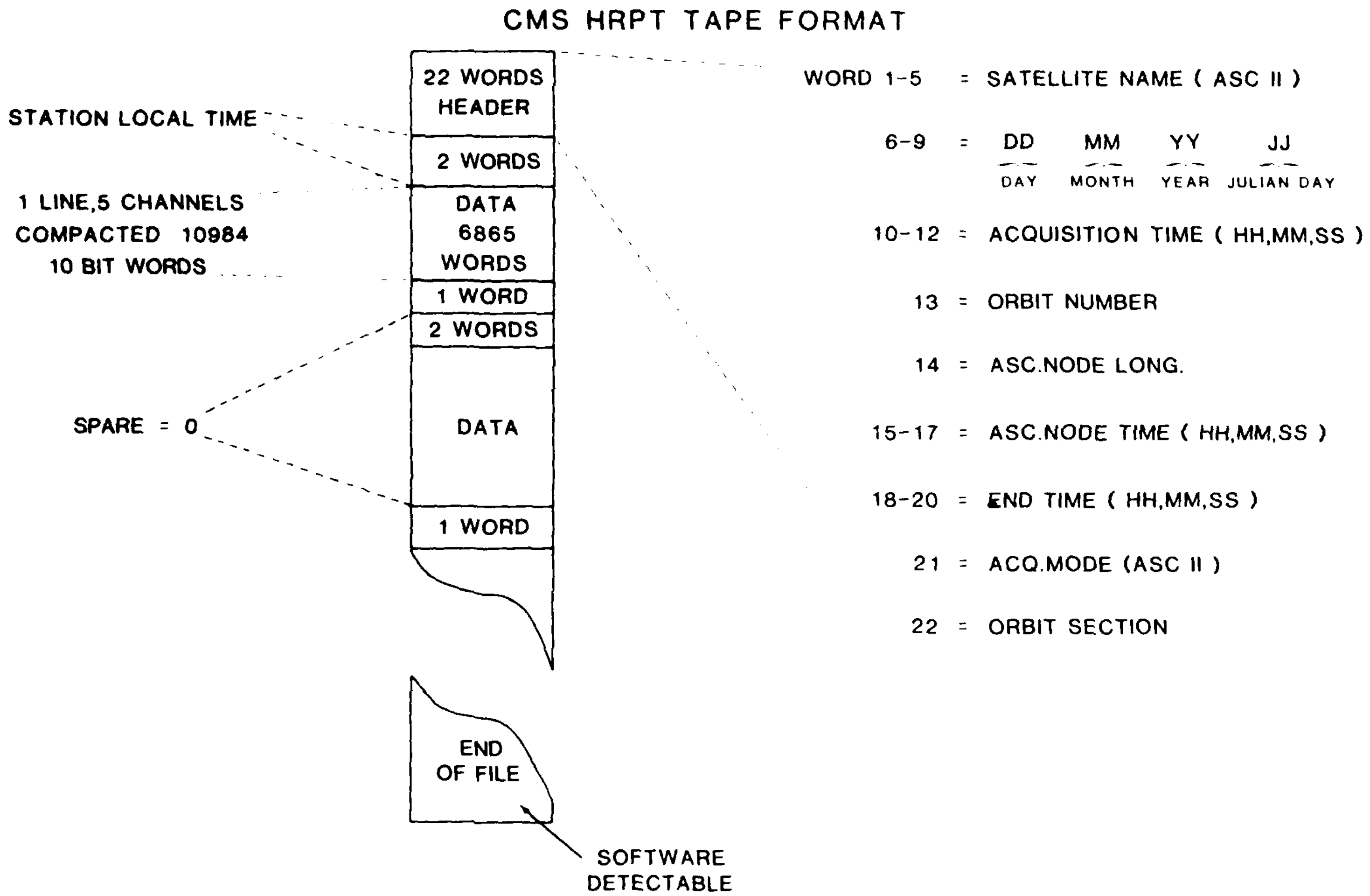

FIG. A9 COMPUTER COMPATIBLE TAPE FORMAT FROM CMS LANNION.

```
 NOAA7          ORBIT# 5253 DATE 30/ 6/1982
ASC. NODE AT 13:44:26 LONGITUDE  15.08 DEG. E.
ACQUIRED AT  13:52: 6
 ENTER 0 TO SAVE ,-1 TO QUIT
      -2 TO CORRCT,+1 TO SKIP >0
 ENTER FILENAME CHARS:4 CHARS >30/6
ENTER PIC CENTRE LAT,LONG,HEIGHT(LINES),WIDTH(PIXELS)
 (POSITION IN DEGREES NORTH AND EAST)
 >36,-5,512,512
 CANNOT IDENTIFY SPACECRAFT NOAA7
 ENTER REAL SPACECRAFT NAME (-1 TO STOP)
NOAA-7
 AREA MOVED TO FIT INSIDE SOURCE DATA.
 THE FIRST POINT REQUIRED IN THE DATA IS AT
 LINE =    928   PIXEL=  1537

      512      256        2        8      512


 DEFINE THE IMAGE PARAMETERS FOR FILE #1
 ENTER CHANNEL NUMBER (1-5) >4
 FILE = !430/6  LENGTH =   1032
 DATA WILL BE STORED IN FILE !430/6::**
 ENTER TMIN,TMAX,TMINF,TMAXF TEMPERATURES IN DEGREES C,
 TEMP RANGE OF DATA, TEMP RANGE AT MAXIMUM RESOLUTION
-30,30,12,20
      225      735      333      413


 DEFINE THE IMAGE PARAMETERS FOR FILE #2
-1
 FILE = !L30/6  LENGTH =    200
    -1
```

FIG. A10 USER INTERACTION WITH PROGRAM "TNLAN" TO TRANSFER DATA FROM TO DISC FILES FOR THIS CASE, TWO CHANNELS ARE TRANSFERRED. In this case, two channels are transferred.

A.4 DISPLAY SUBSYSTEM ('DI')

A.4.1 *The SATDI routine ('DI')*

Most of the routines for the Display subsystem can be called from SATDI through its menu (Fig. A.11). A number of these are simple but necessary image processor commands to shift the image, invert it, etc.

The display is 640 × 512 × 10 bits with a blink plane and overlay plane. The data are at present displayed in 10 bits, passing through the inverse of the compression table first. Except when 'zoomed' the image is constrained to the 512 × 512 bits section on the left of the monitor. The remaining portion of the monitor is used to display the look-up table, image histogram, and annotation (Fig. A.12). A trackball with five switches controls the cursor. A file, *SAT**, holds the initialization parameters for the image (Fig. A.13). This file may be 'EDIT'ed from the File Manager to manipulate scale factors etc. to values not allowed by standard default values.

The command 'IM' is used to recall an image from disc to image processor from a designated top left position. The default to a position input is a display of the entire image properly subsampled to fit the screen.

Some of the possibilities of the image processor have not been used. These include splitting the screen vertically and displaying two images side by side (it can now be done only horizontally), storing two 5-bit images in the 10-bit levels, and a movie feature.

A.4.2 *The ANOT8 routine ('AN')*

This routine is used to replicate labels from the terminal to the Lexidata screen. The position of the top left of the first character is entered with the trackball, The message is composed on the terminal (< 20 characters) and sent complete. It may be written on the overlay plane or into the image.

A.4.3 *The APPLI routine ('AP, n')*

The Applicon jet plotter produces a full-colour precise copy of the satellite image displayed on the Lexidata. To make the copy the user mounts a magtape on the primary tape unit and responds 'AP, n' to the display prompt. Three files corresponding to the red, green, blue values at each pixel are written to the tape. 'n' is an optional designation of bit planes to be copied, 2047 includes the overlay, the default is just the image. A number of images can be written to one tape; two is the easiest choice for the following processing. This tape, with another for output, and a deck of appropriate cards are given to the UNIVAC computer operators. There, in batch mode, the files are converted and re-oriented with the proper delays for the three (cyan, magenta, yellow) ink jets and written on the second tape to be read by the jet-plotter system. The colour plot is about 41 × 52 cm (512 × 640 pixels) in size and can be printed on normal papers or transparent foil. 4 × 4 matrices of Applicon pixels are used, so that 16 × 16 × 16 colours are possible. Note that for map-scaling purposes an Applicon pixel is not 0.2 mm square, as often reported, but 0.008 in. square (= 0.2032 mm square); hence one pixel on the image processor via this routine becomes 0.8128 mm square on the jet-pl tter output. The tape read by the Applicon can be retained for printing further individual copies.

A separate Univac routine is available to output the three colour files separately so as to produce primary images for offset colour printing (see also the BORDE routine in Sect. A.4.4. However, for large-scale reproduction of coulour plots by offset printing it is now better to use the PHOTO routine (Sect. A.8.7), which is faster and produces better results.

A.4.4 The BORDE routine

When the APPLI routine (Sect. A.4.3) is used to produce three separate images for offset colour printing, registration marks are required to accurately overlay the images. This is provided by the BORDE routine, which runs from the File Manager. It places on the screen a white frame that is equivalent to A3, A4, A5, or AM (8.5 in. × 11 in.) paper sizes on the Applicon printer output, or is of a user-defined size. This border may be rotated or shifted with the trackball into the desired position. Then on command, a corresponding black-and-white frame is written into the image plane.

A.4.5 The POINT routine

This routine puts a black arrow enclosed in a white rectangle into the image to indicate some feature of interest. As in the BORDE routine, it is controllable on the overlay by the trackball until the proper position is found and it is then written into the image. Any number of arrows may be entered. The normal arrow template points from left to right; to make the arrow point from right to left the image is inverted. Vertical arrows are not now supported.

A.4.6 The TXY routine ('TX','TY')

This routine, which is available from the SATDI routine (Sect. A.4.1) as TX or TY, draws on the overlay plane a profile of the data along a line parallel to the x or y axis of the overlay plane. It has been more or less superceded by the TCURV routine (Sect. A.4.11).

A.4.7 The DFARE routine ('A R')

This routine calculates the histogram of the data within a rectangular area of the image defined via the trackball. The histogram is displayed down the edge of the look-up table vector. It is run by the SATDI routine (Sect. A.4.1) for each new image displayed and can be used to update the display of the histogram if the overlay plane is cleared. The displayed histogram is used when interactively determining the look-up table (see LUTCH, Sect. A.4.10 and TAREA, Sect. A.4.12).

A.4.8 The GRD routine ('GD')

This routine draws and annotates an overlay plane of an image with latitude and longitude lines at selectable spacings. This is much quicker than BENDing an image (see Sect. A.2.3) and is sufficient for many purposes. It can also be used to create a file for the 'TCURV' or 'TAREA' routines (Sects. A.4.11 and A.4.12). Points entered in lat/long at the terminal are converted to line/pixel co-ordinates and stored in a named, titled file. This is then used, via the TCURV, to retrieve temperature/albedo profiles along a ship's track. This can be done only for NAVIGed but original images. The simple cases of gridding mapped images have not been installed.

A.4.9 The HC routine ('HC')

This routine copies the Lexidata 3400 Image Processor screen to the Matrix Instruments lineprinter, either pixel by pixel (four output sheets of computer paper) or subsampled by four. The look-up table limits in *SAT** (see Sect. A.4.1) are used to create an output image through linear 10-level grey scale. An option allows this to be changed to output a 'histogram'-equalized image. The lineprinter is the quickest way to produce useable hard copies. Photographic hard copies can also be made in various formats with the Matrix Instruments Colour Graphics Camera, using any normal or polaroid film. This is under separate control and can be done whenever the Lexidata memory is stable (i.e. not being written to), and the look-up table is not being changed.

A.4.10 The LUTCH routines ['LU',(n1),(n2); 'BW'(n1,n2)n2]

These routines control the look-up table, converting pixel levels to colour (LU), or black and white (BW) in a linear fashion. The 'EL' subroutine creates a black-and-white look-up table according to a logarithm/exponential curve. The limits n1 and n2 are the limits beyond which the image is saturated black or white (except in the LU routine, where a linear black-and-white scale runs from the minimum of the compression scale to n1). If neither n1 nor n2 is explicitly given they are determined via the cursor and trackball switches; if n1 is given it may be used as a max (min) value and the other limit varied via the trackball until a suitable value is found. For the 'EL' subroutine the coefficient of the exponential curve is also determined interactively.

A.4.11 The TCURV routine ('TC')

This is one of the more useful routines for retrieving quantitative data. A curve is defined by a number of points designated by the trackball (or by the GRD routine, Sect. A.4.8). A spline curve with optional tension factor (affecting curvature) is fitted to the points and pixel values are read along it. The profile is then plotted on the Matrix lineprinter in proper units of temperature/albedo/count with a table of the basic statistical parameters. A named file containing the defining points and tension can be created and recalled during the next run of the routine. Thus profiles of any shape (such as a ship's track) can be retrieved from different channels or different images mapped to the same projection. The routine writes the line of the profile on the overlay plane and this can be used to delineate thermal fronts to compare with other images.

A.4.12 The TAREA routine ('TH')

This routine operates like the TCURV routine (Sect. A.4.11) except that the last and first points are joined to form an enclosed area. Thus an area such as the Alboran Basin can be defined from one day to the next by outlining the coastlines, even though it is distorted in different ways. The area need not be simple; for example, the area inside an 'E' shape of any orientation can be properly sampled. Because of this, the routine runs more slowly than the DFARE routine (Sect. A.4.7), which is limited to rectangular areas.

A.4.13 The TOUR2 routine ('CT')

Some systems call this type of routine "contouring", but it is more correctly "thresholding". Eight colour values can be assigned to different ranges of the imaged parameter. For example, red may be assigned to all values between 15°C and 16°C (or 2% and 3% albedo, or 300 and 310 counts, etc..). This emphasises the larger scale features of an image — showing the form at the expense of detail. A hard copy can be made only photographically or by jet-plotter.

A.4.14 The TTAKE routine ('TT')

This routine returns the temperature/albedo/count value of a point designated by the trackball. The value is written on the terminal and temporarily or permanently on the image overlay, as desired. It also returns line/pixel values that can be used to determine distances between points, though this is not yet done automatically since the distance in metres depends on the type of projection. Reporting the line/pixel co-ordinates allows the retrieval of a temperature value from the same location on another channel or another image mapped to the same projection.

A.4.15 The ZOOM routine (ZO,n)

This routine uses pixel replication to enlarge the image on the screen by an integer factor n $(0 < n < 16)$. The enlarged image may be scrolled (i.e. shifted back and forth or up and down), thus changing the portion of the enlarged image in view on the screen. The TCURV and TAREA routines (Sects. A.4.11 and A.4.12) may be used on zoomed images. If the same profile is then requested on another image, this second image will be automatically zoomed and offset by the correct amount, since the zoom factor is stored in *SAT**.

```
Commands Table - use '??command' for HELP

CQ = Command tables listing              AP = Dump image for applicon plotter
LU = Change look up tables               BW = Black-white look up tables
EL = Contrast stretching on BW image     IM = New image display

SD = Image shift down                    SU = Image shift up
SR = Image shift right                   SL = Image shift left
DR = Image shift down-right              DL = Image shift down-left
UL = Image shift up-left                 UR = Image shift up-right

SC = Scale X,Y integer                   ZO = Zoom ,N times
IN = Invert                              CL = Clear LEXIDATA Screen
OC = Clear overlay plane                 HC = Hard copy on lineprinter
AR = Define histogram area               HI = 512*512 Histogram area
TX = Temperature along X-axis            TY = Temperature along Y-axis
TC = Temperature along curve             TH = Area histogram
CT = Contour building                    GD = Navigated image gridding
'' = Image history                       TT = Take temp/albdo from screen
AN = Annotate                            EX = Stop
AB = Stop                                ST = Stop
```

FIG. A11 MENU FOR IMAGE DISPLAY PROGRAM SATDI.

FIG. A12 MONITOR ARRANGEMENT.
The image is kept within 512 × 512. The Standard legend and look up table run down the right of the screen. The image histrogram displayed vertically is useful for interactive contrast enhancement.

```
*SAT** T=00004 IS ON CR ST

0001  FI   '41M2
0002  DE     1024  1024    8
0003  LU      696   750    1
0004  ZO        0     0    0
0005  SF        0     0   -1
0006  SC        2     2    C
0007  TX      312    89    0
0008  TY      137    67    0
0009  OR     3142    82   33
0010  DA        3    22    0
```

FIG. A13 TYPICAL OUTPUT OF THE DISC HISTORY FILE *SAT** FOR PROGRAM SATDI.
This file is updated by image inversion, scaling shifting etc. so that these interactions can be progressive.

A.5 CALIBRATION SUBSYSTEM

The purpose of the STARS system is to obtain quantitative data. The spatial part of this requirement is covered by the Navigation subsystem (see Ch. A.2). The purpose of the Calibration Subsystem is to calibrate the instruments, i.e., from voltage counts to albedo or equivalent black-body radiation at the top of the atmosphere, as appropriate.

A.5.1 The XCAL routine ('P1')

This routine is available as 'P1' in the Analysis Subsystem (Ch. A.6) or as part of the APT1 routine (Sect. A.3.1) by requesting calibration. It is required only for APT1 data; the equivalent for HRPT data is automatically done as part of the TNLAN routine (Sect. A.3.2). For APT data there must first be a vertical synchronization of the data to the beginning of a frame. This routine locates and determines the calibration values from the data stream and uses some of them to correct for non-linearities during the processing from original digital data (o HRPT) to analogue, or during the data transmission, reception and digitization. It requires the original data tape and the APT image on disc. It reads the 10-bit values from tape and prints the results in the image file and on the lineprinter.

A.5.2 The RADIC routine ('P2')

This routine uses the data determined in the XCAL or TNLAN routines (Sects. A.5.1 and A.3.2) to make a two-point instrument calibration for each image requested. Visible and near-infrared calibration equations are constant for each satellite and supplied by NOAA NESDIS. For infrared data the output of the sensor viewing cold space of known temperature and of an internal black body of separately reported temperature are used to determine an equation that transforms counts to equivalent black-body temperatures. The image values remain the same, only the look-up tables and header flag are changed. An example of the tabulated output is shown in Fig. A.14.

NOAA-7 Calibration PHASE II> Channel 4 -- Orbit 11917 On Day 288 At 14 17 5 -- From 'BAP1

Best Calibration Values

	MEAN	SD	CALCULATED	RESIDUALS
10 6% MDLN	172 53	27	126 22	62
21 5% MDLN	293 53	0 00	253 30	50
32 6% MDLN	413 27	27	381 21	79
43 3% MDLN	534 39	27	511 39	1 29
54 2% MDLN	652 88	0 00	638 66	36
65 2% MDLN	771 56	0 00	765 99	1 71
76 0% MDLN	891 85	0 00	895 88	1 18
87 0% MDLN	1007 55	38	1023 73	27
0 0% MDLN	49 43	23	84	16
THERM TMP 1	289 91	13	249 45	0 00
THERM TMP 2	301 70	0 00	261 97	0 00
THERM TMP 3	263 46	19	221 45	0 00
THERM TMP 4	270 90	35	229 31	0 00
PATCH TMP	492 38	0 00	466 22	0 00
BACK SCAN	406 29	27	373 72	0 00
CHANNEL ID	534 33	0 00	511 32	0 00
SPACE DATA	978 96	0 00	991 69	0 00

Polynomial Coefficients

COEFF 1	COEFF 2	COEFF 3	COEFF 4	COEFF 5	COEFF 6	COEFF 7	COEFF 8	COEFF 9
- 48015E+02	97849E+00	20500E-03	- 12225E-06	- 91277E-10	93285E-13	00000E+00	00000E+00	00000E+00

Conversion Values

Gain = - 15562E+00 Intercept = 15315E+03

NOAA-7 Calibration <PHASE II> Channel 2 -- Orbit 11917 On Day 288 At 14 17 5 -- From 'AAP1

Best Calibration Values

	MEAN	SD	CALCULATED	RESIDUALS
10 6% MDLN	172 50	23	126 39	79
21 5% MDLN	293 70	13	252 92	88
32 6% MDLN	414 16	27	381 61	39
43 3% MDLN	534 06	27	511 11	1 01
54 2% MDLN	652 37	46	638 89	59
65 2% MDLN	770 47	38	765 79	1 91
76 0% MDLN	891 43	38	895 97	1 27
87 0% MDLN	1007 22	38	1023 70	30
0 0% MDLN	48 51	28	81	19
THERM TMP 1	289 74	23	248 73	0 00
THERM TMP 2	301 24	13	260 92	0 00
THERM TMP 3	263 72	13	221 30	0 00
THERM TMP 4	270 88	13	228 83	0 00
PATCH TMP	491 85	19	465 46	0 00
BACK SCAN	48 74	29	1 04	0 00
CHANNEL ID	292 91	38	252 08	0 00
SPACE DATA	85 96	04	38 33	0 00

Polynomial Coefficients

COEFF 1	COEFF 2	COEFF 3	COEFF 4	COEFF 5	COEFF 6	COEFF 7	COEFF 8	COEFF 9
- 47397E+02	98865E+00	77503E-04	25510E-06	- 50832E-09	24998E-12	00000E+00	00000E+00	00000E+00

Conversion Values

Gain = 10690E+00 Intercept = - 34880E+01

FIG. A14 OUTPUT FOR THE SECOND STAGE OF INSTRUMENT CALIBRATION FOR APT DATA RECEIVED 10 OCTOBER 1982.
The values in the MEAN column are the average of the eight lines of the corresponding calibration wedge exhibiting the least noise during the satellite pass (see text). SD gives the standard deviation about this mean. The "CALCULATED" values are estimates of the digital values input into the APT data stream on board the spacecraft. These are calculated via the polynominal with coefficients listed below which is a best fit between the measured values from the eight modulation levels and their theoretical values. The calculated values of thermistor levels (THERM TMP), back scan and space data are used to calibrate instrument in that channel. Note that for image BAP1 the level of the "CHANNEL ID", is the same as the level of the fourth wedge in the frame thus this data is from channel 4 of the instrument.

A.6 ANALYSIS SUBSYSTEM ('AN')

This sub-system includes routines to analyze the data in various ways to make the information content more readily accessible to the user. The calibration routines of Ch. A.5 are callable from this sub-system. The menu is shown in Fig. A.15.

A.6.1 The CRAO routine ('HT')

One of the major problems in determining the sea-surface temperature (SST) from space is the presence of clouds, including those smaller than the Instantaneous Field of View (IFOV). One can assume that over an area of constant sea-surface temperature the spacecraft sensor will return a gaussian distribution of standard deviation, τ, equal to the noise value of the instrument. Clouds (which are colder than SST) in this area will change the histogram but not its warm tail. The underlying SST can be estimated by fitting a gaussian curve to this warm tail. This routine does this and at the same time compares the results of this estimation with the results obtained by ignoring those pixels in the infrared image that correspond to bright pixels (clouds) in the visible image. This is an expansion of a routine coded at the Rutherford Appleton Laboratory, UK <A.4>

A.6.2 The VALB2 routine ('VB')

This is a subjective filtering algorithm from L'Ecole des Mines, France, that was more appropriate for the noisier instruments of earlier satellites than it is now. It averages all the pixels in a given window when the difference between successive pairs is not above a threshold. It can be used iteratively to reduce random noise while preserving gradients (fronts). Although it is slow it can also be used to simulate low-pass filters, gradient operators, etc.

A.6.3 The MEDF routine ('MF')

The median filter routine replaces the centre value of a sliding window with the median value of the pixels in that window. This removes spikes caused by radio-frequency interference in APT images very effectively and quickly (2 to 3 min for a 512^2 image and 3×3 window). Again it leaves strong gradients unchanged in space or level. The value replaced can easily be changed to any rank, such as the maximum or minimum. An example of median filtering is given in Fig. A.16.

A.6.4 The IMATH routine ('IM')

This routine allows the operator to write equations directly on the terminal so as to combine files or functions of files in any multiplicative or additive combination. For this purpose, files can be defined simply by their names. Thus, for example, an image of mean sea-surface temperatures could be obtained by typing the following equation:

RES(!R1211, !41211, !31211) = (!41211 + !31211)/2,

in which !41211 and !31211 define two files containing sea-surface temperature images. The result would be to put the pixel-by-pixel interpolated image into file !R1211.

An important, but not the only, reason for this routine is that single-channel calibration of the sensors cannot correct the temperature to account for the attenuating effects of the spatially varying atmosphere between the sensor and the sea surface. This routine allows the use of empirical and theoretical equations that combine two or three infrared channels to do this.

The IMATH routine accepts the following functions:

+,-,X,÷
SQRT
EXP
ALOG
ALOG10
SIN
COS
TAN
COTAN
ATAN
ARSIN
ARCOS
SINH
COSH
TANH

A.6.5 The WIND routine ('WI')

Acquisition from tape to disc is slow. A reduced portion of an image or a copy of an image already on disc is often desired for a processing step. This routine quickly creates a new disc file with appropriate header from a user-defined portion of an image that is resident on a disc. It is useful for defining a particular area that is to be stored on tape for transfer to the Univac or Vax computers for contouring or special filtering, or for reducing the size of an image before the IMATH (Sect. A.6.4), VALB2 (Sect. A.6.2), etc. routines.

```
                    !! = Image History
                    WI = Image Windowing
                    MF = Median Filter
                    VF = Valbonne Filter
                    HT = Histogrm Technique
                    P1 = Calibration <PHASE  I>

                    P2 = Calibration <PHASE II>
                    IM = Image Mathematics
AN>
```

FIG. A15 MENU FOR THE ANALYSIS SUB-SYSTEM.

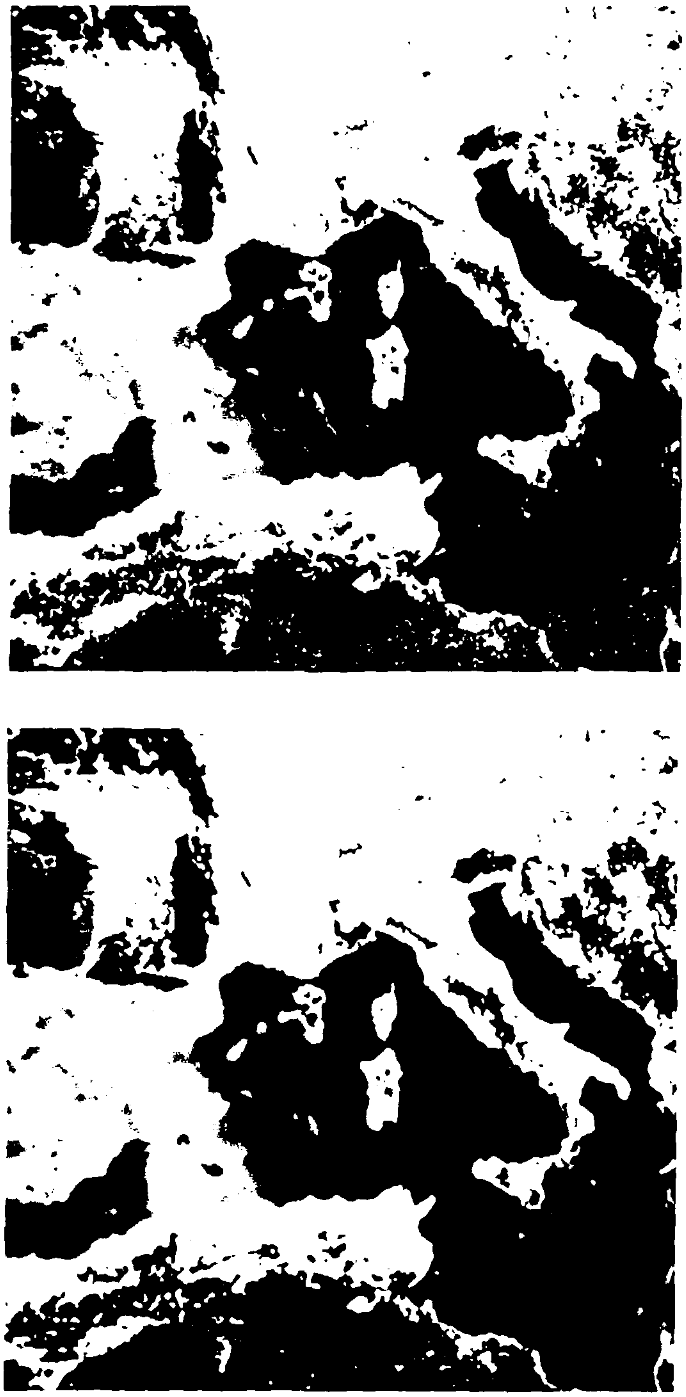

FIG. A16 AN APT IMAGE BEFORE AND AFTER MEDIAN FILTERING IN A 3 × 3 WINDOW.

A.7 MAINTENANCE SUBSYSTEM

A.7.1 The LGEN routine

This routine is available from the File Managerand needs to be run only after a new satellite is launched. It maintains the !ORBIT file, which contains such information as orbital period, nominal altitude, etc, retrievable by satellite name, needed for the TNLAN (Sect. A.3.2), NAVIG, (Sect. A.2.1), etc. routines.

A.7.2 The MSAT routine

This routine was created when the !ORBIT file (see Sect. A.7.1) became too small. It maintains the $ CAL file, which allows the editing or input of data for new satellites by holding the response functions for each channel of the satellite (60 values each) and other calibration data supplied by NASA through NOAA NESDIS. Also included are the calculated coefficients of a 3rd-order polynomial relating radiance to temperature values between 0°C and 20°C.

A.7.3 The PDET routine

This routine determines the 3rd-order polynomial coefficients relating radiance to temperature, considering the Stefan-Boltzman spectrum and the sensor-response curves.

A.8 MISCELLANEOUS

A.8.1 The HSTRY (!!) routine

When the user has forgotten what he has done to an image he may remind himself by entering !!; it may be used in either the Display or Analysis Subsystems (see Sects. A4 and A6). The routine reports on the processing history of a named image (Fig. A.17).

A.8.2 The QUEST (??) routine

This routine prints a description of any of the commands on the terminal.

A.8.3 Libraries of ground-control points (GCPLST and GCPAPT)

Two master libraries of ground-control points exist permanently on the STARS disc: GCPLST for use with HRPT data and GCPAPT for APT data. The latter is a subset of the former. Because of the larger effective field-of-view of APT data, and especially since HRPT data is skipped in the along-satellite track direction to create APT data, many GCP's become unresolvable or only occasionally resolvable. Since the APT images generally cover a greater geographical area than the HRPT images, including these GCP's might crowd more useful ones out of the image libraries, which are limited to a maximum of 200 GGP'S.

Generally only four to ten of these GCPs are used, but the oversupply gives great flexibility in case of high cloud cover. The GCPLST library contains the names, latitude, longitude and height above sea level for some 400 positions around the shore of the Mediterranean and the coasts of Europe and the British Isles. The GCPAPT library contains 180 of these. The GCP's are usually lighthouses for which the location values are accurately tabulated by hydrographic services, or the positions of significant coastal/island features, such as the Italian island of Vulcano. Coastal features are preferred because of the strong contrast between land and water in the near-infrared, and under certain conditions also in the thermal infrared. This makes visual determination of the positions in the image easier.

A.8.4 The SPOOL ('SP') transfer file

This is a transfer file required by a distributed computer system with one lineprinter when that lineprinter is on another node of the system. It allows lineprinter data previously accumulated on disc files during processing to be passed through the second computer to the printer while control is passed back to STARS.

A.8.5 The IMSTR routine

This routine stores the exact image seen on the TV monitor into a user-designated disc file.

A.8.6 The IMGET routine

This routine retrieves the named image stored by the IMSTR routine (Sect. A.8.5). This is a much faster routine than the IMSTR routine in the display menu, which unpacks data from (usually) a larger image in a disc file. The resulting image cannot however be used for further processing, because the image has no header blocks and neither the IMSTR nor the IMGET routine updates the *SAT** file.

A.8.7 The PHOTO routine

This routine allows another approach to colour printing and is preferable for multiple copies. The image is scanned into its cyan, magenta, yellow and black components, from which four 35 mm photographic negatives are made via the Matrix Instruments Colour Graphics Camera. This are then used to produce four offset masters. This has the advantage over the APPLI routine (Sect. A.4.3) in that it is a simpler and faster method of producing offset masters and allows four-colour, instead of three-colour, separation.

```
******************************

    History of image '410M1

******************************

** WARNING --  The LIBRARY file 'C1OM1 does NOT EXIST''

General information  -

Satellite   NOAA-7              Type    APT

Channel    4

Pixels/line = 1024          Lines in image = 1024

Orbit number   11847           Date   10/10/  83          Acquired at   15 17 97

Time of ascending node   15 10  4           Longitude of ascent     1 46 Degrees EAST

Compression breakpoint values      80  800  300  450

---------------------------------------------------------------------------------------------------

C a l i b r a t i o n

<PHASE I> and <PHASE II> CALIBRATION Completed'

Gain = - 1533E+00          Intercept =  15216E+03

---------------------------------------------------------------------------------------------------

M e d i a n   F i l t e r

Filtered from   '4AP2          Window Size    3 x 3          Starting Line =  100      320 Lines Filtered

---------------------------------------------------------------------------------------------------

G r u t m

From NAVIGed image   '4AP2          Projection Used   ST

Centre Position LAT =  36 00 Degrees          Centre Position LON =  -5 00 Degrees          Reference =  36 00 Degrees

Number of VERTICAL Blocks to Output = 4          Number of HORIZONTAL Blocks to Output = 4

---------------------------------------------------------------------------------------------------

B e n d

This image has been BENDed from '4AP2

---------------------------------------------------------------------------------------------------
```

FIG. A17   AN EXAMPLE OUTPUT OF "HSTRY".

A.9 SUBROUTINE LIBRARIES

Most STARS routines use subroutines as much as practical and these are often kept in separate libraries, as, for example, the LOCLB of navigation, coordinate transforms, etc. Thus many valuable processing techniques could be implemented with little more than "cutting and pasting". This is especially true with the recently acquired access to the SIGNAL/1000 and SPLIB signal-processing libraries and the SNPLB array-processing library. The Firmware Vector Instruction Set (VIS) could greatly increase the speed of image-processing steps and the UNIRAS and MPIFP plotting packages should ease the interpretation.

CONCLUSION

The present status of the STARS Satellite Analysis and Research software has been outlined. This package is being developed to extract quantitative information from environmental satellite transmissions. Flexibility and ease of use have also been guiding factors during the development. Recently acquired access to signal-processing and raster-graphics libraries will widen the field of information retrievable for oceanographic and underwater acoustic research.

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