Remote sensing in the marine environment

A description of facilities, applications, needs and opportunities in South Africa

L V Shannon and L Y Shackleton

A report prepared under the auspices of the
National Programme for Remote Sensing (NPRS)

SOUTH AFRICAN NATIONAL SCIENTIFIC PROGRAMMES REPORT NO

152

1988

Issued by:

Foundation for Research Development
P O Box 395
PRETORIA
0001

from whom copies of reports in this series are available on request

Printed in 1988 in the Republic of South Africa
by the Graphic Arts Division of the CSIR

ISBN 0 7988 4495 7

Prepared under the auspices of the NPRS by:

L V Shannon
Sea Fisheries Research Institute
Private Bag X2
ROGGEBAAI 8012
Cape Town

L Y Shackleton
Foundation for Research Development
Botany Building
University of Cape Town
Private Bag
RONDEBOSCH 7700

Cover illustration : NOAA AVHRR image of the Benguela region
(Courtesy J J Agenbag, Sea Fisheries Research Institute)

PREFACE

In early 1986 the National Programme for Remote Sensing (NPRS) of the Foundation for Research Development (FRD) announced its new structure. The aim of this restructuring was "to stimulate the development of remote sensing techniques" and "to promote the application of these techniques by taking the programme to the relevant communities and allowing them to express their needs within the existing frameworks for their own activities". The oceanographic community of the existing South African National Committee for Oceanographic Research (SANCOR) was one such community identified by the NPRS, and an *ad hoc* Working Group was established.

A primary task of this new Working Group on Remote Sensing in Oceanography was the determination of the *status quo* with respect to remote sensing in the South African marine environment, and the consequent identification of the present and future needs of the marine community. This report summarizes the findings of the Working Group on Remote Sensing in Oceanography and further hopes to draw the attention of the South African marine community to the vast potential of oceanographic remote sensing.

ACKNOWLEDGEMENTS

This report is based on information assembled by the members of the Working Group on Remote Sensing in Oceanography and its *ad hoc* task groups (see Appendix III). These contributions are gratefully acknowledged, as are the Working Group's comments and corrections to the first draft of the report. Two most useful sources of information on oceanographic remote sensing are also acknowledged - the report of SCOR Working Group 70, "Opportunities and problems in satellite measurement of the sea" and Baker and Wilson's article on "Spaceborne observations in support of Earth Science" in volume 29 of Oceanus, 1986/7.

ABSTRACT

Against a background of the techniques and instrumentation available for remote sensing in the marine environment, this report considers the rationale for their use by the South African marine community. Local applications of remote sensing techniques are described and an assessment is made of the *status quo* in South Africa with respect to satellite reception and image processing facilities, data and data products, as well as non-satellite instrumentation and manpower. Present and future research and applied needs and opportunities are identified and linked to the deployment of ocean-related spacecraft during the next decade. Finally a blueprint for the future development of oceanographic remote sensing in South Africa is presented.

OPSOMMING

Hierdie verslag skets die agtergrond van die tegnieke en instrumentasie beskikbaar vir afstandswaarneming in die mariene omgewing en beskou die beweegredes vir hul gebruik deur die Suid-Afrikaanse mariene gemeenskap. Plaaslike toepassings van afstandswaarnemingstegnieke word ook beskryf en 'n waardebepaling word gemaak van die *status quo* in Suid-Afrika ten opsigte van satellietontvangs en beeldverwerkingsfasiliteite, data en dataprodukte, asook nie-satelliet instrumentasie en mannekrag. Huidige en toekomstige navorsings- en toepassingsbehoeftes en geleenthede word geïdentifiseer en gekoppel aan die lansering van oseaangerigte ruimtevaartuie gedurende die volgende dekade. Ten slotte word 'n bloudruk vir die toekomstige ontwikkeling van oseanografiese afstandswaarneming in Suid-Afrika voorgestel.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

INTRODUCTION

Over the last 200 years there has been a gradual broadening of our perspective on our earth. Beginning with observations from hot-air and hydrogen balloons in the late eighteenth and nineteenth centuries, man realized the value of distancing himself so as to see the broader picture. During the first half of the twentieth century aircraft reconnaissance and photographic techniques were developed and the science of measuring and gaining information from a distance, remote sensing, came into being. In the early sixties, the ability to launch man-made satellites into orbit around the earth greatly stimulated the development of remote sensing techniques and an increasing number of parameters became measurable from afar.

Satellite observations of the sea have progressed a very long way from the first colour photographs obtained from early manned spacecraft. Weather satellites were the first to continuously map the earth, and in April 1960 TIROS-1 was launched as a precursor to today's complex global weather system. But over the years, satellite technology has evolved to give us much more than weather observations, and, following the developments building on TIROS, NASA launched a series of experimental earth observing satellites called Nimbus. This series, the last of which is Nimbus-7, together with the Seasat dedicated oceanic satellite, provided the first successful measurements of a number of oceanographic and atmospheric parameters. Nimbus 7, launched in 1978 is still flying although some sensors are no longer functioning. It uses passive radiation reception to monitor parameters ranging from the changing heat budget of the earth to chemical constituents in the atmosphere, and chlorophyll concentrations near the ocean surface. Seasat, also launched in 1978 demonstrated that global measurements of wind, waves, the shape of the sea-surface and ice topography could be achieved using an active microwave system.

This report is concerned solely with the remote measurement of oceanographic parameters from above the surface of the ocean, primarily using aircraft or satellite-born instrumentation. It is addressed to all those who study, exploit or make use of the oceans around Southern Africa; the scientists, industrialists, coastal zone managers, engineers and meteorologists. Over the past 25 years there has been an increased appreciation of the present and potential roles of satellite remote sensing in ocean science, and in 1987 a Working Group on Remote Sensing in Oceanography was established under the auspices of the National Committee for Remote Sensing (NCRS) in close cooperation with the South African National Committee for Oceanographic Research (SANCOR). One of the prime functions of this Working Group is to make the potential South African user community aware of the oceanographic remote sensing techniques available, an objective in line with the new philosophy of the NCRS to actively take remote sensing to the user communities. By summarizing the techniques available, listing the facilities in South Africa, and by attempting to identify some of the local research and applied needs in this report, we hope to draw the attention of the South African marine community to the vast potential of oceanographic remote sensing both as a sophisticated technique to be used by marine scientists to study global ocean circulation and properties, and as an effective tool for the exploration, exploitation and management of our exclusive economic zone.

The objectives of this document may thus be summarized as follows:

* To increase awareness of remote sensing techniques amongst the South African marine community (research, service and industry)

* To demonstrate to them the potential utility of remote sensing in oceanographic applications

* To document briefly what has, and what can reasonably be, achieved in the local marine environment using remote sensing techniques

* To list the remote sensing facilities available in South Africa

* To identify needs of research and applied users

* To provide a plan for the structured development of remote sensing in support of marine science and industry in South Africa until the year 2000

TECHNIQUES AND INSTRUMENTATION

There are a number of remote sensing techniques and instruments which provide data of relevance to the oceanographic community. Almost all of these are limited by the capabilities of electromagnetic radiation to penetrate the earth's atmosphere and gather useful information from orbital altitudes. In addition, lack of penetration into the sea limits observations to the ocean surface or near surface. Spatial resolution is a function of the instrument being used, the flight or orbit height, and the data recording capabilities of the computers, with aircraft-mounted instrumentation being especially suited to high resolution work.

Satellite sensors can only measure ocean properties that give a detectable signal at a distance. These are:

- colour or spectral reflectance of incident sunlight indicating presence of phytoplankton and other suspended material, bathymetry and coastal vegetation, foam and atmospheric properties.

- thermal emission in the infrared and microwave, giving temperature, ice cover and (in the microwave) wind speed, foam, and water vapour and liquid water in the atmosphere.

- surface roughness, measured with various microwave sensors, giving wind speed and direction, wave height, length and direction, ice cover and various oceanic phenomena such as internal waves.

- surface elevation, which shows the general shape of the geoid and the smaller variations due to ocean circulation patterns and eddies.

Satellites also track and relay environmental and position data from drifting buoys and ships which can add a great variety of other measurements both on the surface and to moderate depths.

Some of the instruments used in remote sensing of the oceans are listed below:

1. <u>Visible and near-infrared imaging sensors</u>

Continued improvement of satellite optical sensors has led to extensive use of visible images in a wide variety of applications ranging from the open ocean to coastal waters, and even inland waters. Photographic and TV cameras, visible-band radiometers, broad band radiometers and spectral scanners have been used to detect, for example, colour variations to study sediment and phytoplankton distribution and sea ice patterns. Quantitative determinations of the concentrations of suspended organic and inorganic particles can even be made using the Coastal Zone Colour Scanner - a sensor specifically designed to study living marine resources. The CZCS is capable of measuring very subtle variations in water colour resulting from variations in phytoplankton concentrations, river inputs and effluent discharges, thus highlighting oceanic fronts, dispersion and circulation patterns.

2. <u>Thermal infrared imaging sensors</u>

Satellite infrared images of the oceans have been used to study ocean features which cause observable variations in surface temperature such as currents, fronts, upwelling and coastal mixing patterns. Cloud cover is a significant limitation to this method in most parts of the world and simultaneous visible images are often needed to identify the clouds. Infrared sea surface temperature measurements have been achieved to an accuracy of 0,6°C using the Advanced Very High Resolution Radiometer (AVHRR). Other infrared sensors include the Very High Resolution Radiometer (VHRR) and the Satellite Radiometer Thematic Mapper (TM) and Coastal Zone Colour Scanner (CZCS)

3. Microwave radiometer (MR)

Passive microwave radiometry measures the radiation naturally emitted by or reflected from the sea surface. Since adsorption of microwave radiation by cloud is small, use of the MR is not significantly hampered by cloud cover. Sea surface temperature (SST) measurements using the Scanning Multichannel Microwave Radiometer (SMMR) have been made with an accuracy of 1,0°C and a spatial resolution of 150 km. Surface winds can also be estimated within certain ranges using SMMR with an accuracy of about 2,5 m/s (i.e. almost as accurately as by using surface observations). SMMR can also be used to determine the integrated water vapour content of the atmosphere. Unfortunately, however, SMMR and other types of satellite microwave data tend to be contaminated in the near-shore region which limits their usefulness in shelf studies. There is no direct reception capability for satellite microwave data in South Africa.

4. Synthetic Aperture Radar (SAR)

Satellite SAR's can now in principle provide images of the sea surface along continuous swaths of the order of about 100 km width at a resolution of about 20 m. Among the ocean features that can be observed using SAR are surface waves and their direction, the surface expression of internal waves, ships wakes, fronts, currents, bottom features visible in shallow water and ice cover.

5. Radar Altimeter

The radar altimeter measures the height of the satellite above the sea surface. It was used in Seasat at an orbit height of about 800 km to a precision of about 10 cm, but it is hoped to improve this in the new generation of satellites to 2 cm. In principle the altimeter is able, when combined with other data and physical models, to provide information on the marine geoid, gravity anomalies, surface currents, tidal elevations, ice cover and any other processes which change the mean sea surface elevation on a large scale (see Figure 1). The Seasat altimeter data set has also been used to produce a map of sea-floor topography and it is hoped that future altimeter missions will produce charts of, not only oceanographic, but also geophysical, interest.

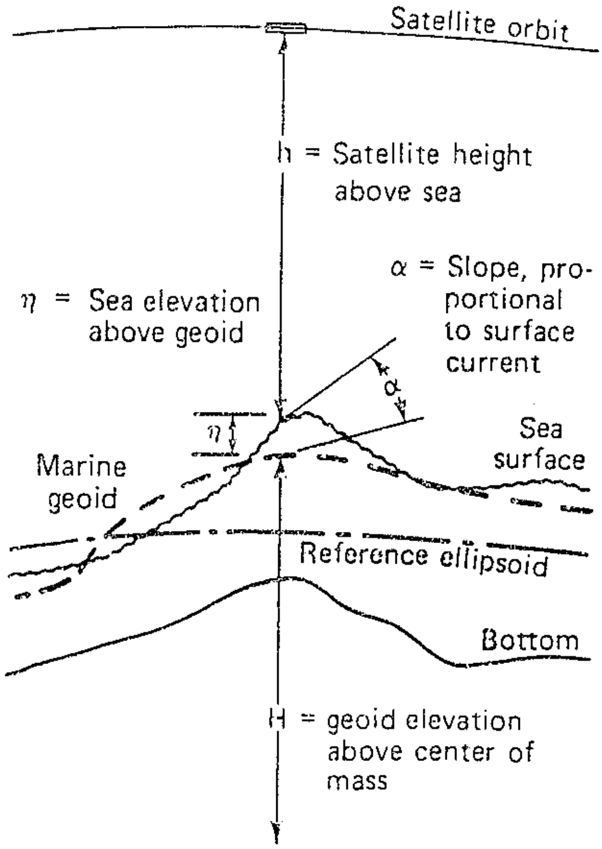


Figure 1. Measurement of sea surface elevation and sea surface slope from satellite altimeters (from: Report of SCOR WG70).

6. <u>Scatterometer</u>

The evolution of satellite scatterometry has led to the development of a sensor capable of producing global estimates of wind velocity on a daily basis to an accuracy superior to ship's observations. Scatterometry is based on the early observation that the character of radar backscatter depended on the surface winds blowing at the time. Further investigation showed that Bragg, or resonant, scattering from ripples on the ocean is dependant on the amplitude of the ripples, which in turn is determined by the wind speed. The fact that the backscatter had been shown to depend on radar azimuth angle, with the maxima in the up- and downwind directions, and minima close to the crosswind direction, also allows an estimate of wind direction to be made (with some ambiguities). Global measurements of surface winds and waves are crucial to the study of large-scale air/sea interaction processes, and, when available in real time, offer obvious economic benefits to a variety of marine activities such as forecasting, offshore exploration, ship routing, etc.

7. Lidar

Light detection and ranging (Lidar) instruments and techniques are at present being developed, but, as yet, none has been demonstrated from a satellite. A narrow-beam light source is used in a similar way to the radio techniques of radar, but with the added advantage that light can penetrate the water surface and give information on optical properties of sea water and scatterers within it to depths of several tens of meters. The full potential of lidar from space remains to be developed in the future.

The greatest single advantage of satellite remote sensing over conventional observations is clearly its wide area and potentially global coverage. Each satellite has a different, specifically-designed orbit around the earth. At any given instant a satellite can view an area whose size depends on the properties of its sensors and its altitude. A low altitude orbit of about 150 km would have the advantage of high resolution, but altitudes of greater than 500 km are needed to give the several years of stable life-time required for most earth-observing missions. Higher altitudes have the advantages of allowing a wider area of view for scanning sensors, the possibility of data communication over larger distances and more precise tracking. Geostationary satellites (which maintain their position relative to the earth) have an altitude of 36 000 km. The high altitude limits the resolution achievable, but such satellites have the great advantage of requiring a relatively simple, fixed transmitting/receiving antenna as well as a continuous look capability and fixed geometry.

The concepts of swath width, scan angle and footprint (pixel size) are illustrated in Figure 2. From a typical height of 800 km, the sensors of a satellite can cover a maximum useful swath of about 2 000 km, that is a 1 000 km out from the nadir point or point immediately below the satellite. However, because of limitations in the data bandwidth, both radar and visible scanners with a 20 m resolution are typically limited to a swath width of 100-200 km. Landsat covers 185 km at 30 and 80 m resolution and AVHRR sensors can scan about 3 000 km with a 1 km resolution.

RATIONALE FOR USING REMOTE SENSING IN LOCAL MARINE SCIENCE

Southern Africa's marine environment is characterized by variety and variability. The warm Agulhas Current, which is one of the world's major western boundary currents, dominates the oceanography of the south-west Indian Ocean. Retroflection south of the continent of this

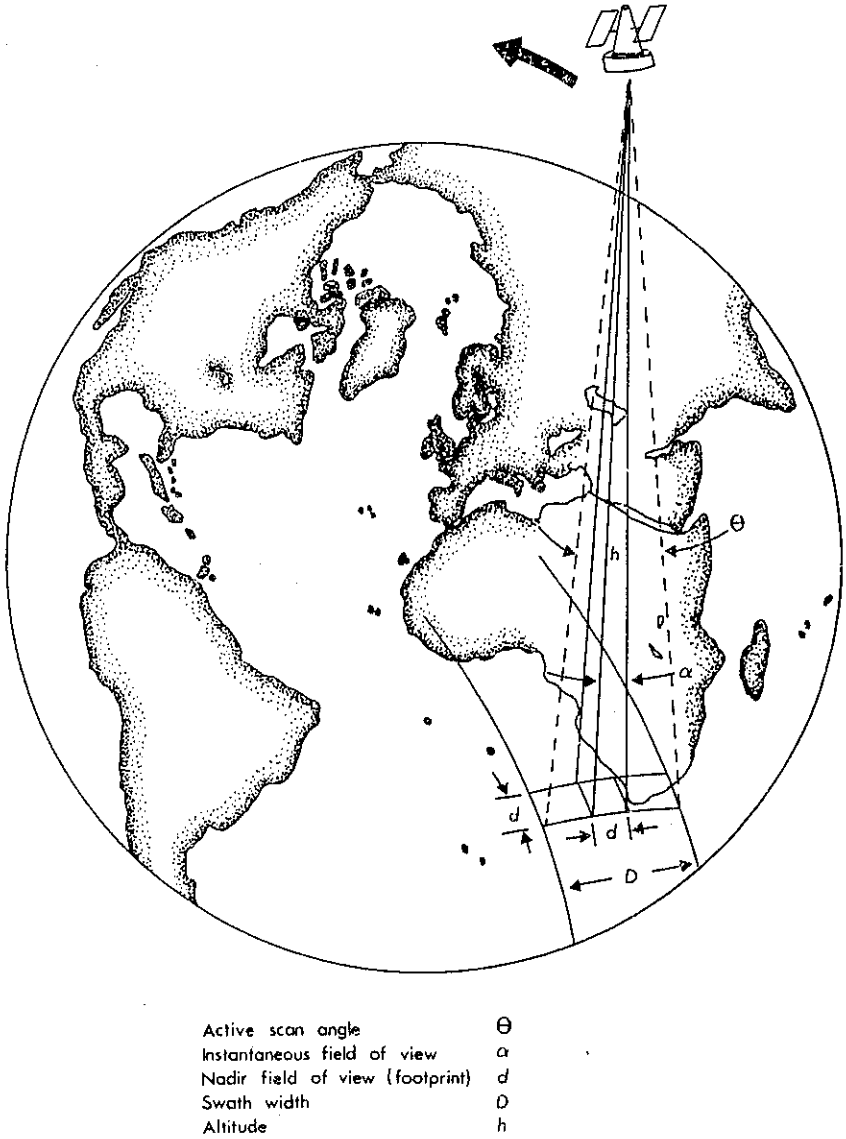


Figure 2. The scanning arrangement for a typical polar orbiting satellite (from Shannon 1985a).

current system contrasts sharply with the Benguela upwelling system on the west coast. The Agulhas retroflection area is a region of enormous complexity and variability - a veritable "hot spot" (Figure 3). Filaments and rings shed from the Agulhas current enter the South-east Atlantic and play a key role not only in terms of the oceanography of the region, but also in respect of the weather and climate of the subcontinent and probably also the climate of western Europe. Further south (at about 40°S) lies the subtropical convergence, a pronounced

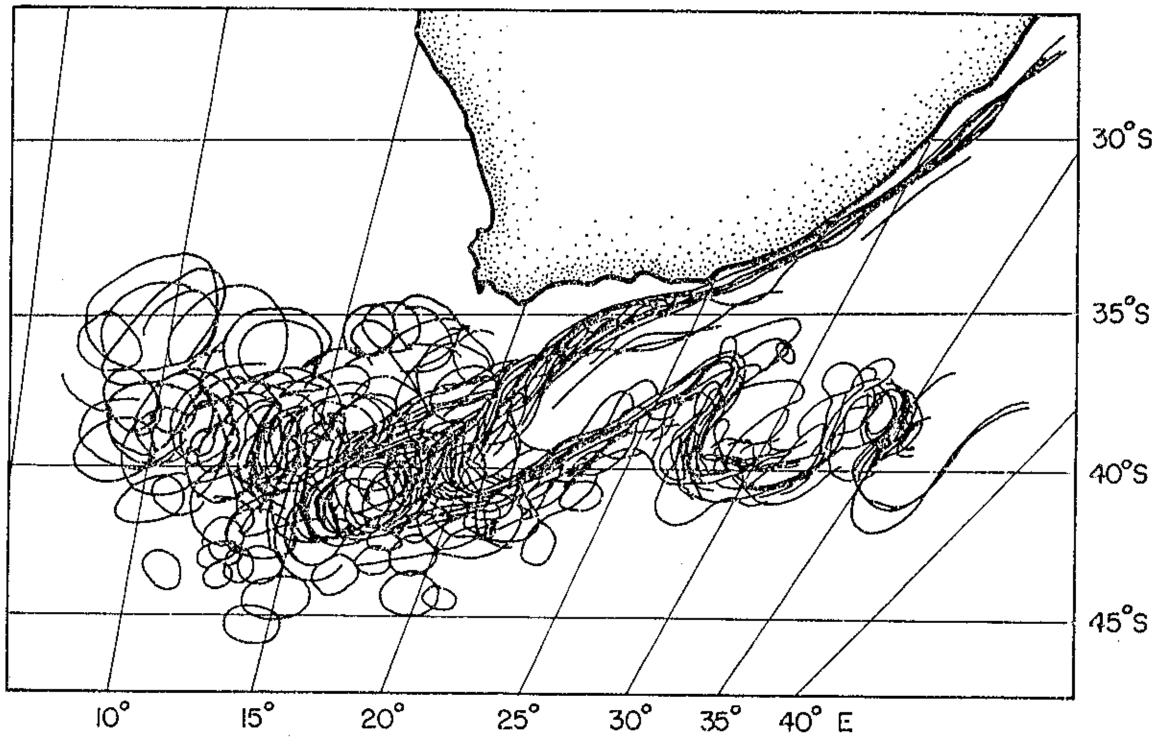


Figure 3. *Concentrations of lines showing the average geographic location of the southern Agulhas Current, the Agulhas retroflection and the Agulhas Return Current over a 13 month period (from Lutjeharms and Anderson 1987).*

meandering front, which separates the subtropical waters of the Indo-Atlantic from the Southern Ocean - the region's "weather factory". The African continent, terminating at a relatively low latitude (35°S), permits the relatively free zonal passage of travelling cyclones, and the wind-pressure systems in the South Atlantic respond accordingly. As a result, upwelling and currents throughout the Benguela system are modulated on a time scale of about three to 12 days. In addition to the variability associated with such pulsing there are shorter period fluctuations (e.g. inertial oscillations and those associated with the land-sea breeze) and longer period changes (weeks to years) associated with changes at the system boundaries (e.g. in the Agulhas retroflection area in the south and the Angola-Benguela front in the north). Like Agulhas intrusions in the south, Benguela Niños in the north cause major perturbations of the Benguela and its associated ecosystem.

The principal oceanographic features of southern Africa's marine environment are reflected in Figure 4. The physical extent as well as the spatial and temporal variability of the systems which was highlighted in the preceding paragraph pose an enormous problem for measurement using classical techniques (ships, platforms, moored devices). Remote sensing can therefore play, and indeed has already played, a vital supportive role in the investigation and monitoring of the local marine environment. The time scale of events and the relatively cloud-free nature of much of the region makes the use of satellites with passive sensors capable of measuring in the visible and infrared wave lengths highly attractive, particularly as data and its processing are fairly cheap. However, it is the development of the new generation of sensors such as the altimeters and scatterometers, that will provide oceanographers and user agencies with a powerful armoury for the intensive study of our ocean area needed to ensure its wise management and utilization.

LOCAL APPLICATIONS – PAST AND PRESENT

AIRCRAFT

Probably the first remote sensing technique to be used successfully in the local marine environment was aerial photography. Apart from obvious early strategic uses, its principal applications have been for shoreline and kelpbed mapping, for effluent disposal studies off Natal, in support of coastal engineering studies (e.g. the study of rip currents and sediment transport in False Bay by the former National Research Institute for Oceanology (NRIO), (Figure 5) and for the ongoing census of island-based seal and seabird colonies by the Sea Fisheries Research Institute (SFRI) (Figure 6). Aircraft surveillance and photography have also been successfully applied to detecting and responding to marine oil spills. Aerial photography has thus provided a relatively cheap means of studying some important coastal features and processes for management purposes as well as for monitoring some "high profile" marine communities, such as whales and dolphins.

Aerial techniques were also used directly to improve efficiency of exploitation of certain living resources. Spotter aircraft have been used in support of whaling operations off Natal in the 1960s, by the pelagic fishing industry in the Cape, and in support of tuna fishing. In the early 1970s an attempt was made by the Sea Fisheries Research Institute to use an aircraft equipped with a low light level television system to estimate the biomass of the Namibian pilchard resource. Although partially successful, this remote sensing system was never fully operational. Nevertheless the novel technique did provide useful management information while pilchard was the dominant species.

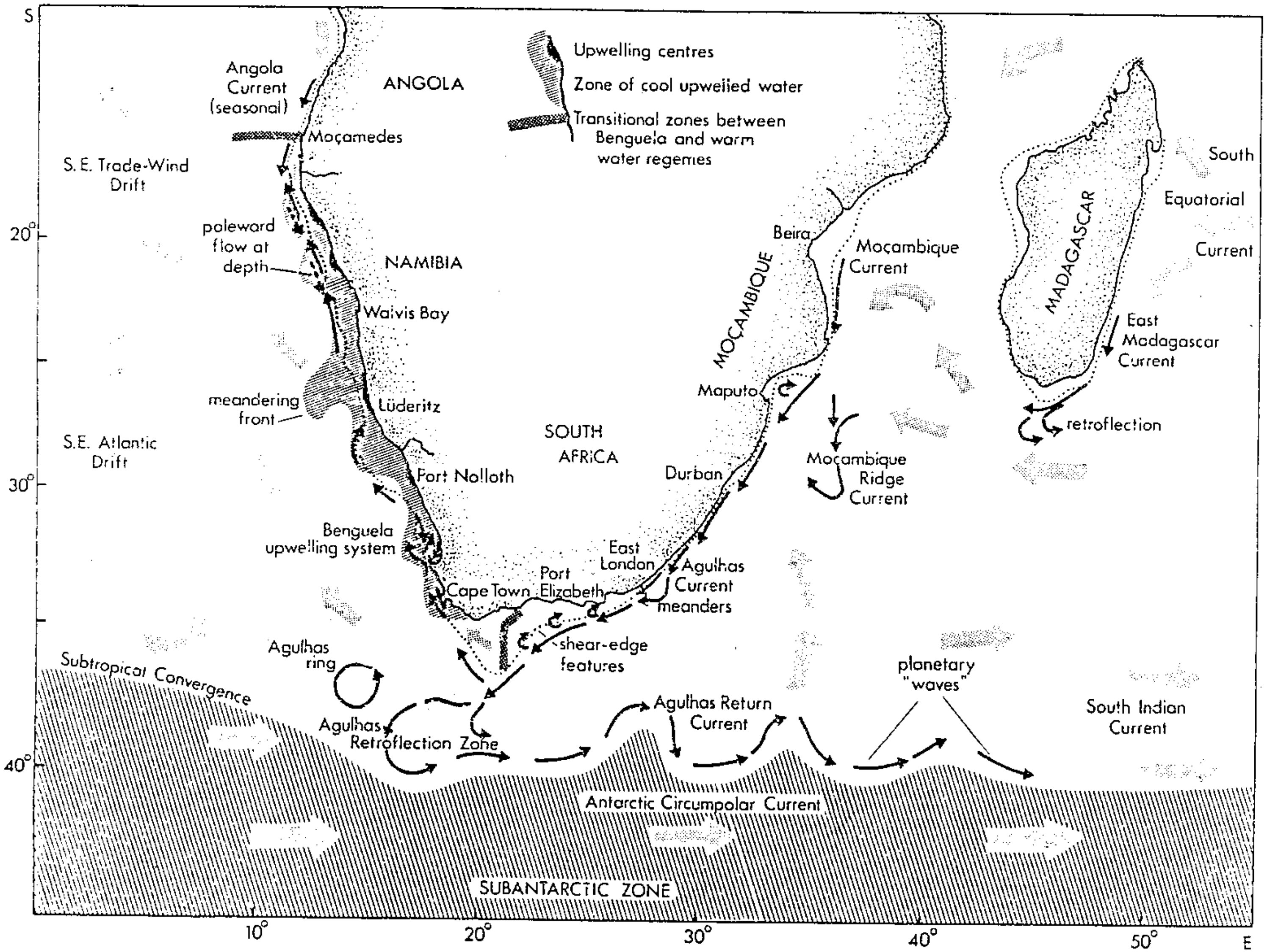


Figure 4. *Principal features of ocean systems around southern Africa. Much of the detail was gleaned from satellite images. (Reproduced with permission from Shannon, in press).*

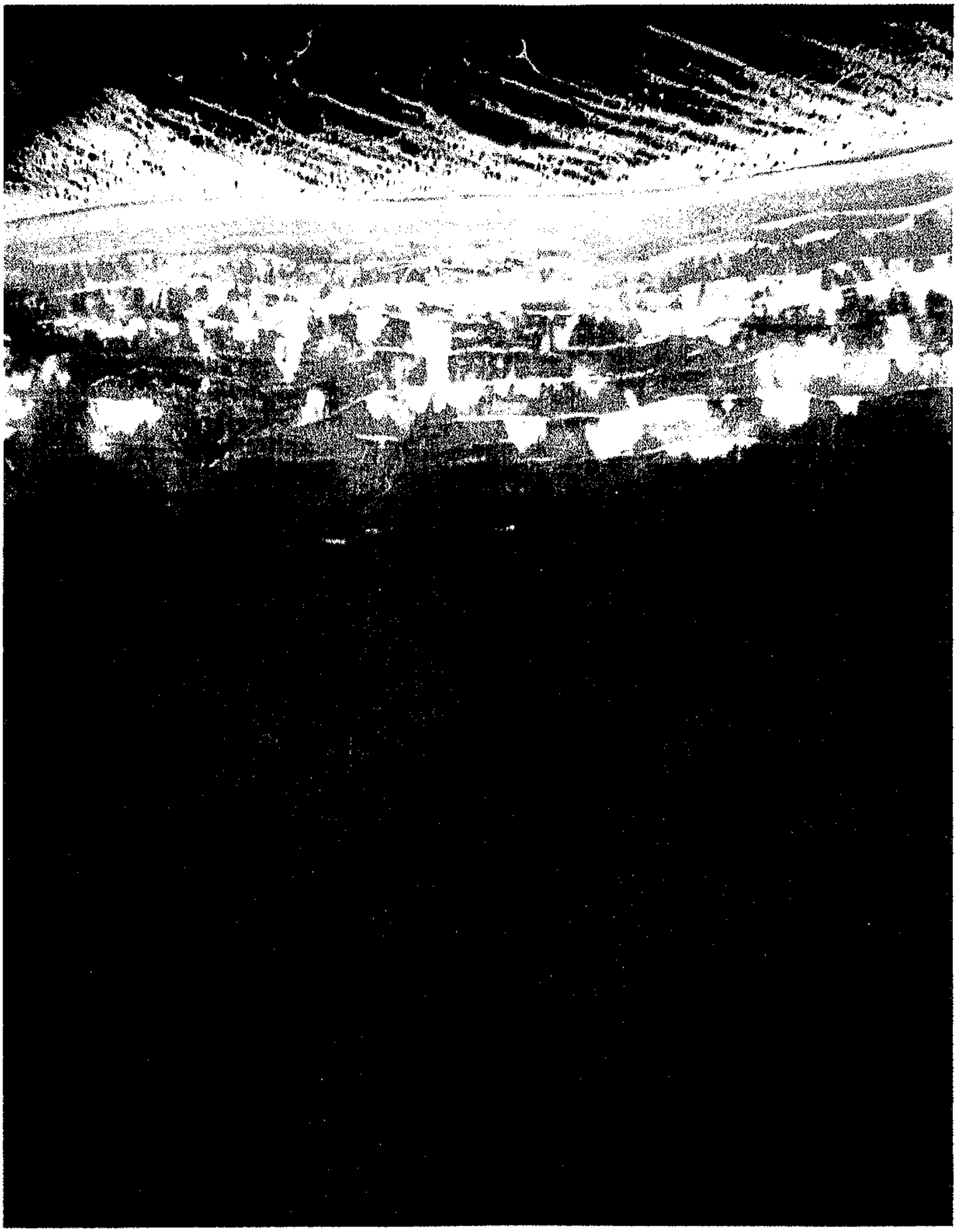


Figure 5. *Aerial photograph showing rip currents in False Bay (photograph courtesy of DEMAST).*

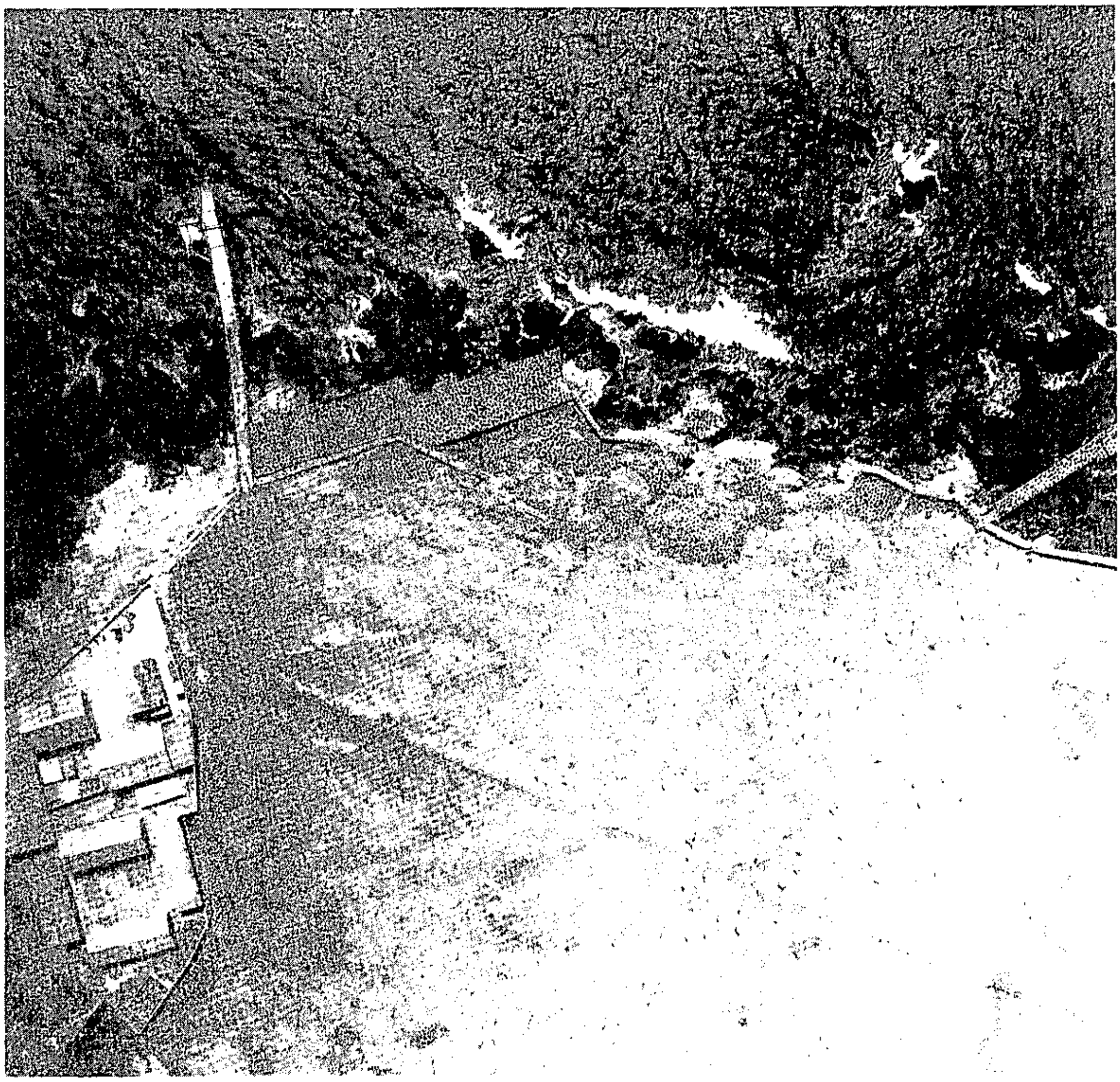


Figure 6. *Aerial photograph of birds on Ichaboe Island (SWA). The light dots are Cape gannets and the dark dots are cormorants and jackass penguins.*

With the obvious exception of radar with its strategic and navigational applications, limited use has been made locally of microwave techniques from ships and aircraft. However, extensive use has been made of airborne infra-red sensors for sea surface temperature mapping and in studies of mesoscale oceanographic processes. In the 1960s the Oceanography Division of the National Physical Research Laboratory introduced the airborne radiation thermometer (ART) to local oceanographers. Use of this instrument demonstrated for the first time the substantial short period variability of the Agulhas current off Durban. Subsequently ART was used to provide a synoptic picture of upwelling between Cape Hangklip and Cape Columbine - in particular the structure of the Cape Peninsula upwelling tongue. During the early 1970s, as part of the Cape Cross Programme, SFRI conducted extensive (and thus costly) ART surveys along the west coast as far north as southern Angola. While useful, in that some of the structural features of the Benguela system were highlighted, experience showed that ART is more suited as a tool in support of studies of mesoscale processes, rather than as a survey instrument.

The most successful application of airborne remote sensing was during the Cape Upwelling Experiment (CUEX - 1978 to 1983). CUEX was the first detailed study of mesoscale processes in the southern Benguela, and the investigation of the growth and decay of upwelling tongues (Figure 7) proved particularly successful as it contributed to an improved understanding of not only local upwelling, but also of upwelling processes in general.

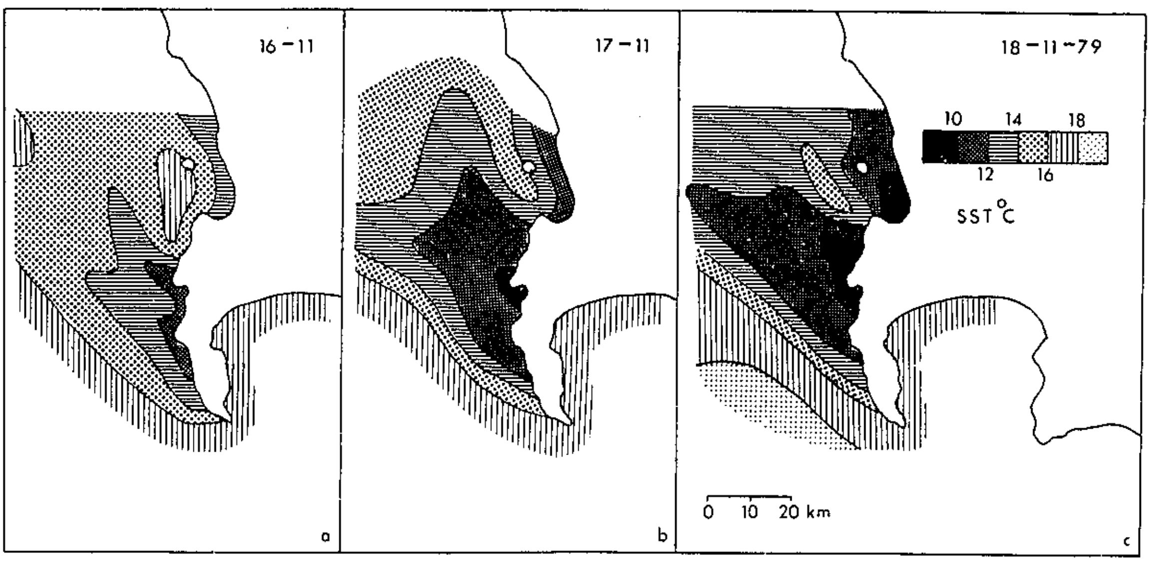


Figure 7. The SST distribution in a three-day sequence representing the growth phase of the upwelling cycle (from Jury, 1985).

Many of the concepts which emerged from CUEX were subsequently embodied in the Benguela Ecology Programme (BEP) and have contributed to improved management of the living resources of the region. While ART proved so successful, some of the visible band remote sensing instrumentation such as the multi-spectral camera and spectrally scanning radiometer proved less so, both in their application in the Benguela and in krill research in the Southern Ocean. However, because of the increased availability of satellite data and products, ART is used less now than in the past although its value in support of research cruises is still recognized.

SATELLITES

Despite satellite infrared images being available in the 1960s, it was only around 1973 following the launch of ERTS, the first of the Landsat series, that satellite remote sensing was really introduced to South African scientists - largely through the efforts of the team at the former National Physics Research Laboratory at the CSIR. Most of the early applications of Landsat data were, however, in the terrestrial environment and the first effective oceanographic utilization of satellite imagery (viz NOAA thermal infrared) was in the study of the structure and kinematics of local marine systems.

During the last decade the applications of thermal infrared and visible band imagery in local marine science have been numerous, and knowledge of the structure and functioning of the Agulhas and Benguela Current systems has mushroomed as a result - yet relatively few South African oceanographers exploit the enormous potential which satellite data products offer. Admittedly many remote sensing techniques only provide information about the sea surface *per se*. However, so much of the subsurface structure can often be successfully inferred from the study of sequential images. The launch of Nimbus-7 with its Coastal Zone Colour Scanner (CZCS) in 1978 and the participation by South Africa in the international surface truth experiment was an important catalyst for the development of local image processing technology and skills, as was the quasi-real time availability of visible and thermal infrared data from Meteosat at around the same time.

Locally generated Meteosat imagery, supported by high resolution products from NOAA satellites, has led to an improved understanding of the dynamics of the Agulhas Current system, in particular that of the retroflection area, and the formation of shear-edge features, rings and filaments (see Figure 4). As a result, a conceptual understanding of the retroflection process has emerged which has revolutionized our thinking on the dynamics of the region.

The direct reception of NOAA data and the development of a viable processing capability by the Satellite Remote Sensing Centre (SRSC) (now Satellite Application Centre - SAC) at Hartebeeshoek in 1984 resulted in further advances. (Thanks to the contributions made by members of the Working Group on Remote Sensing in Oceanography, geometrically corrected and atmospherically corrected and temperature calibrated NOAA images were routinely available from SAC by late 1987). The satellite data products have had applications not only in marine science *per se*, but also as a tool for resource management. For example, it was possible to monitor the 1984 Benguela Niño and the subsequent major perturbation in the retroflection area which is thought to have caused substantial changes in the fish populations (pilchard, anchovy, hake) in the Benguela system. In this respect the development of an in-house image processing capability at the Sea Fisheries Research Institute has proved invaluable - not only for retrospective investigation and monitoring, but also for real-time survey strategy planning. A brief visual inspection of a good image by an experienced individual can provide a wealth of information about the state or phase of local marine systems and processes, and the potential for the application of automated feature tracking and pattern recognition techniques is enormous.

Apart from the obvious application of thermal infrared imagery in the Benguela system for both process orientated studies (e.g. growth and decay of upwelling bands, tongues, filaments and frontal kinematics) and monitoring (particularly useful when used in conjunction with climate and ship data for examination of large scale perturbations), the applications of visible band imagery in the study of habitats of the principal shoaling fish species have been considerable. The broad spectal bands and the high resolution of Landsat have been useful in studies of internal waves (which have a characteristic surface manifestation) on both the south and west coasts (e.g. Figure 8) and in the investigation of rip currents in False Bay. Following the highly successful Nimbus-7 CZCS surface truth experiment which was conducted in South Africa between 1978 and 1981 and the ensuing adaptation of algorithms for chlorophyll and suspended solid estimation, the utility of ocean colour imagery in the study and management of the marine environment was clearly demonstrated. The synoptic chlorophyll maps along the west coast provided a new insight into the southern and central Benguela system, while relatively high concentrations evident in images of Algoa Bay suggested the existence of a potential food source which could be expected to support substantial shoals of pelagic fish (as was subsequently verified). The chlorophyll and sea surface temperature distributions often display similar patterns (Figure 9), while features not always obvious from thermal infrared images are sometimes visible in the ocean colour imagery. Using CZCS chlorophyll data in conjunction with ship measurements, estimates of the phytoplankton standing stock and primary production of the southern Benguela were made and its approximate potential carrying capacity was established. There has also been some success in relating CZCS chlorophyll to fish shoal distribution.

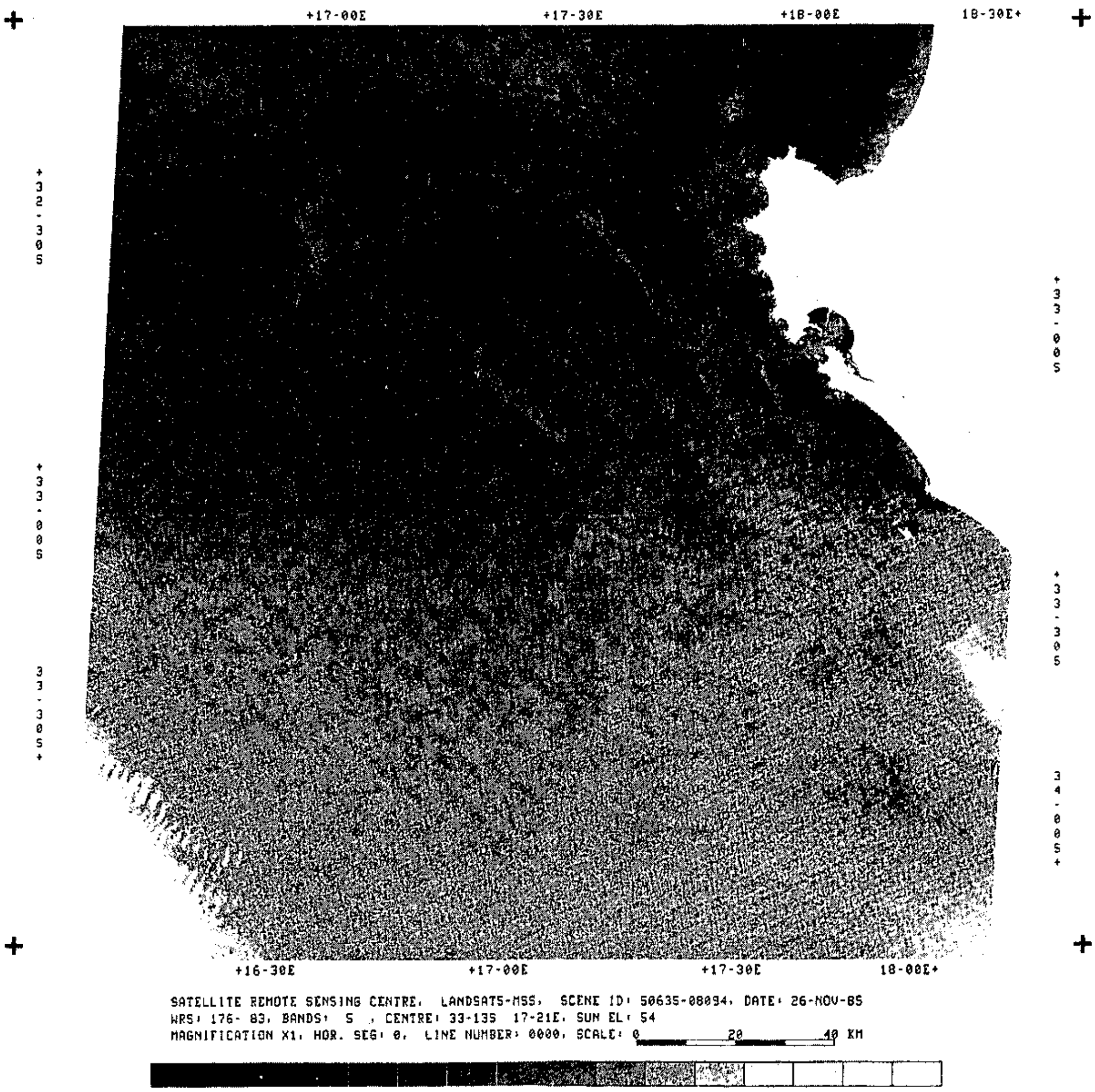
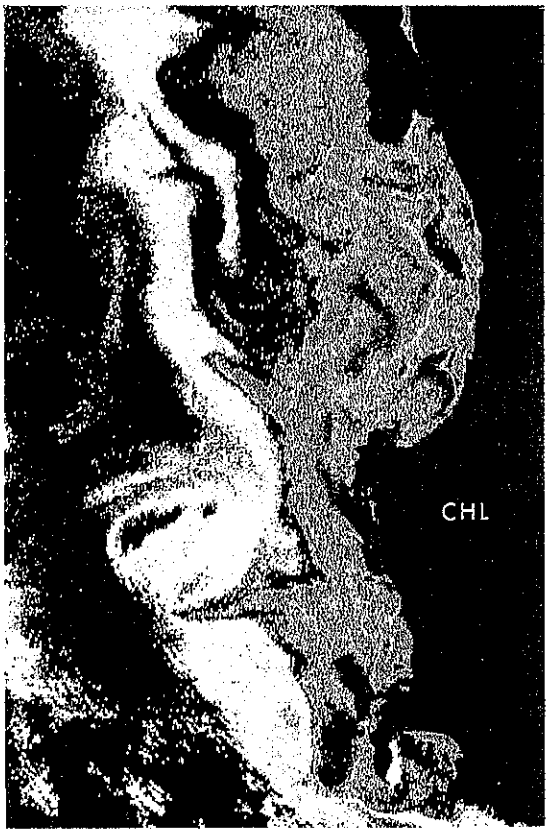


Figure 8. *Surface features indicative of internal waves evident west of Saldanha Bay on a Landsat MSS band 5 image, 26 November 1985.*

Some spectacular pictures of dust plumes over the Benguela during Berg wind events have been constructed from CZCS data, and the one shown in Figure 10 is a classic example. The extent and directional coherence of the plumes in this figure are evident, and it has been suggested that such events may result in a substantial input of terrestrial material into the sea. Figure 11 shows an equally spectacular input of silt into the sea by rivers on the east coast.

Although until recently local scientists have had very little experience with altimeter and microwave data, some of their potential applications in local waters have been demonstrated by workers overseas, e.g. the variability in the Agulhas retroflection area (Figure 3). Preparatory work for the Topex-Poseidon experiment is paving the way for the future application of the new generation of remote sensing techniques in South African marine science.



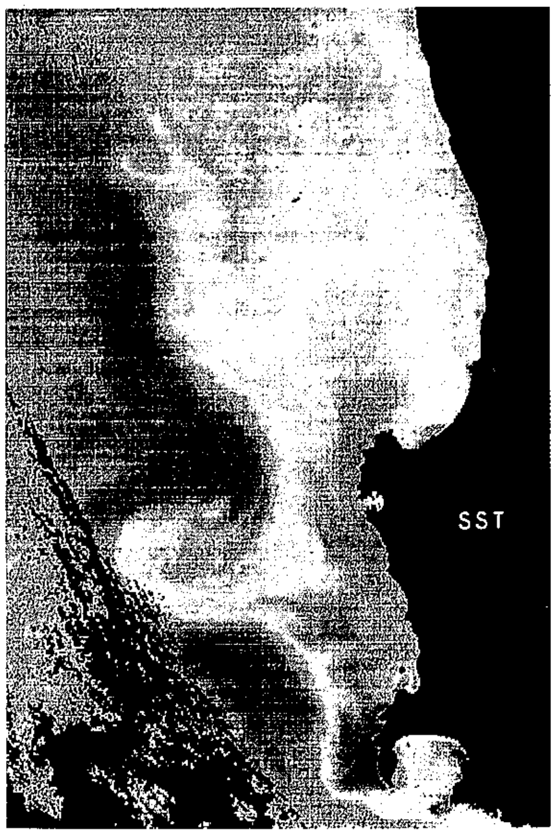


Figure 9. *Chlorophyll and sea surface temperature distribution off the south western Cape on 6 December 1978 (Nimbus 7 CZCS) (from Shannon, Walters and Mostert 1985).*

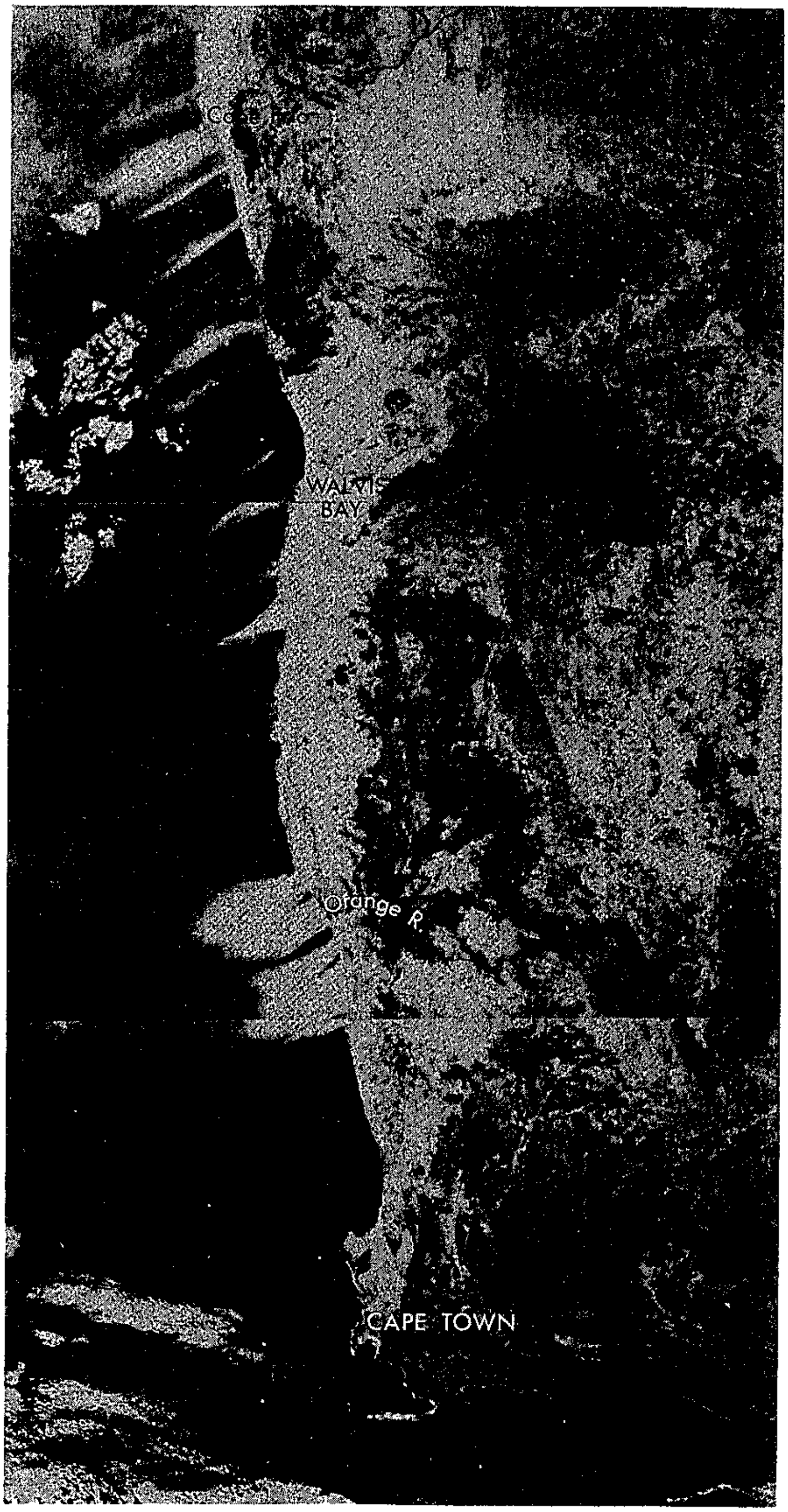


Figure 10. *Aeolian dust plumes along the west coast during a major berg wind event, 9 May 1979 (Nimbus 7 CZCS) (from Shannon and Anderson 1982).*

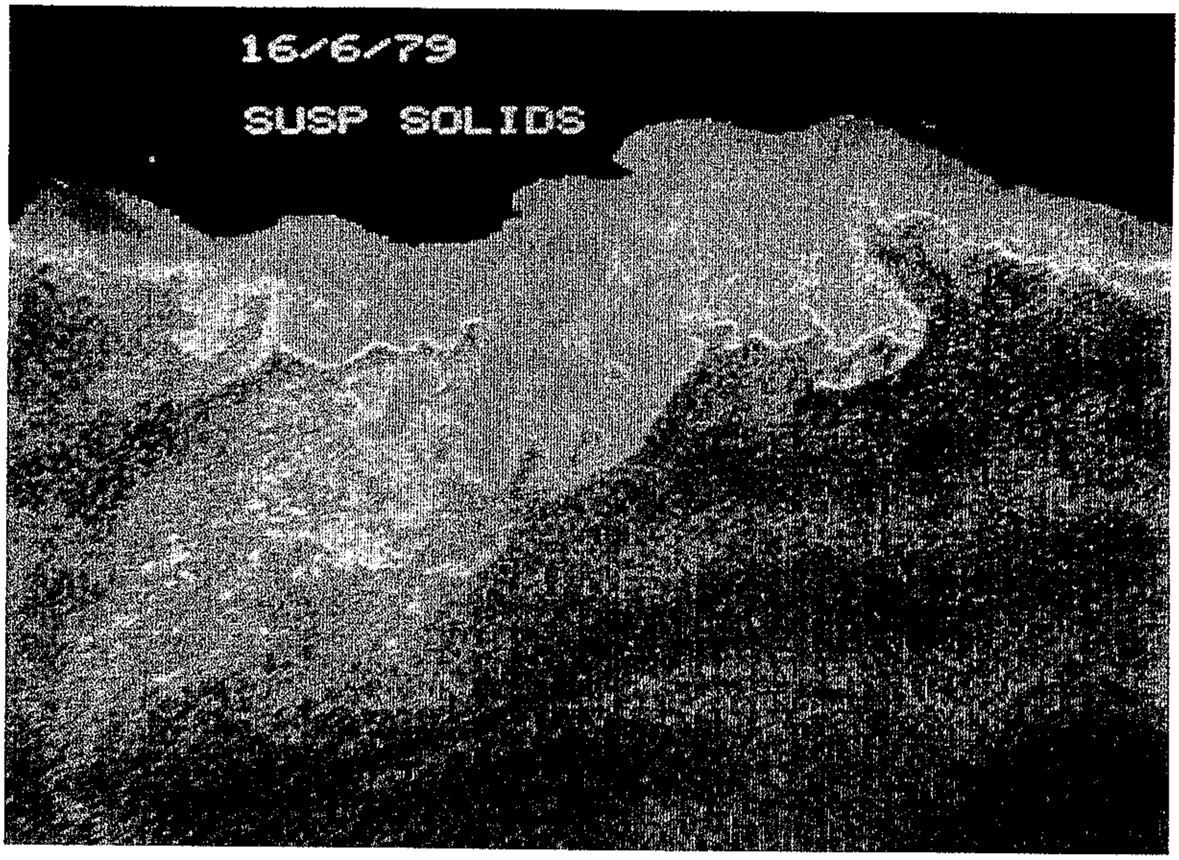


Figure 11. Satellite photograph processed to show the total suspended sediment distribution emanating mainly from the flooding Gouritz River. (Photograph courtesy of DEMAST).

THE STATUS QUO IN SOUTH AFRICA

SATELLITE RECEPTION FACILITIES

The Satellite Applications Centre (SAC) of the CSIR at Hartebeeshoek in the Transvaal is the only sophisticated receiving centre in southern Africa. At present it receives the NOAA satellites, Meteosat and Landsat, in the visible and infra-red wave bands. It is in the process of being upgraded to receive higher resolution data. This upgrading is primarily aimed at receiving the French SPOT data and Landsat Thematic Mapper images, but data from the Japanese MOS satellite may also become available. After the upgrading it is hoped that the SAC will also be able to receive and process microwave and SAR data.

"Quick-look", low resolution reception facilities are, however, available at a number of institutions around South Africa (e.g. CSIR Stellenbosch, Port Elizabeth Museum, Oceanographic Research Institute, SABC, Department of Environmental and Geographic Sciences UCT, Water Research Commission at Nelspruit Airport). These mainly receive Automatic Picture Transmission (APT) data with the exception of the CSIR in Stellenbosch which receives data from the NOAA satellites.

IMAGE PROCESSING FACILITIES, DATA AND DATA PRODUCTS

Image processing facilities exist at a number of organizations. These range from essentially "low key" processing at places such as UCT, SABC, CSIR Stellenbosch and the Water Research Commission at Nelspruit Airport, to the sophisticated facilities of, for example, the CSIR Pretoria, the Sea Fisheries Research Institute, and the SAC. Complex scientific image processing is also undertaken by, among others, University of Natal, Geodass, Anglo American, the Hydrological Research Institute at Roodeplaat, the Soil and Irrigation Research Institute, while it will soon become a reality at the CSIR, Stellenbosch.

As mentioned above, the SAC at Hartebeeshoek is at present able to receive Landsat, Meteosat and NOAA data, all of which can be purchased from them. (Enquiries should be directed to: The Director, Division of Microelectronics and Communications Technology, CSIR, P O Box 395, PRETORIA, 0001, For attention: The Programme Manager, Satellite Applications Centre). Their processing of Landsat data include: sensor balancing (destriping), haze removal, line length corrections, earth rotation correction, earth curvature corrections, mirror scan non-linearities and sensor offset, geometric correction to a UTM projection, edge enhancing, and contrast stretching. UTM or latitude/ longitude grids can also be provided. Precision geometric corrections using ground control points can be performed on Landsat imagery where 1:500 000 survey maps are available. Raw Meteosat data is available from the SAC, as are declouded composite sea surface temperature images geometric correction). The products from NOAA data have recently been upgraded and temperature corrected and calibrated and geometrically corrected images on a number of projections are available.

Data is also available from the CSIR in Stellenbosch (Division of Earth, Marine and Atmospheric Science and Technology (DEMAST)). This includes a comprehensive set of images and tapes acquired by the Nimbus Coastal Zone Colour Scanner and thermal infrared images from Meteosat I & II and NOAA4-9. They also have a complete set of 1:10 000 colour air photos of the Cape coast from the Olifants River to the Great Kei River (excluding the Ciskei) which was flown in February 1987 and a survey of the Natal estuaries flown after the floods of late 1987.

NON-SATELLITE INSTRUMENTATION

Besides aerial photography, which is a fairly widely available technique, there is very little non-satellite instrumentation available in South Africa. The SFRI has a number of ART's and the CSIR in Stellenbosch possess a 4-channel radiometer. In addition a Daedalus 10 Channel Airborne Scanner is available locally through Aircraft Operating Company. This is felt to be an area which could profitably be stimulated, possibly by the development of an oceanographic aircraft package as a national facility. Such a package might comprise a digital data logger with input channels for navigational position and time, an infrared sea surface temperature radiometer, a multi-spectral scanner for ocean colour and a microwave radiometer for sea state/wind stress. It would be logical to include a logging capability for key meteorological parameters as well.

MANPOWER

Expertise in the processing and use of remote sensing techniques is available in South Africa and has been developed by the CSIR and institutes such as the University of Natal. However, the number of people working in satellite oceanographic remote sensing is small and essentially limited to the Division of Earth, Marine and Atmospheric Science and Technology of the CSIR and the Sea Fisheries Research Institute.

IDENTIFIED NEEDS

An extensive survey of perceived needs of users and potential users of remote sensing and data products was undertaken by the various *ad hoc* Task Groups (see Appendix III) during 1987. The following text and Tables I and II provide a summary of the findings of the survey.

INDUSTRIAL AND/OR APPLIED USERS

Shipping

There appears to be a need for thermal, colour, sea state, wind and ice information with a resolution of $1 \times 1\ km^2$ in the principal shipping routes and research areas. In most instances information older than 48 hours is useless, but both direct reception of satellite imagery on board and reception via a shore centre would be welcomed. Most of the users surveyed are prepared to pay for data products and special hardware.

Fisheries

There is an interest in quasi real-time thermal and colour imagery of moderate resolution over the principal fishing areas as an operational support system. Similarly information on currents and large scale perturbations would be helpful, while sea state and weather data would only be useful if of a predictive nature. Preparedness to pay for data products etc. would depend on cost-benefits.

Table I. Perceived needs of industrial and/or applied users

User	Sea surface tempera-	Ocean/ land colour (visible and near IR)	Sea state (waves)	Wind stress	Ice cover	Water vapour	Currents	Area/ coverage	Spatial resolution	Frequency	Response time	Prepared to pay?
Shipping (Commer- cial)	X	X	X	X				100x100 km	1 km	Daily	<48 hrs	Yes
Shipping (Research)	X	X	X	X	X		X	Various	1 km	Daily	<48 hrs	Yes
Fisheries	X	X	Pre- dictive	Pre- dictive			X	EEZ	1 km pre- ferred 5 km accep- table	Daily	<48 hrs	Yes
Oil explora- tion			Pre- dictive	Pre- dictive			Pre- dictive	EEZ	1 km (?)		<4 hrs to days	Yes
Sea* diamonds		X (Low al- titude colour photo- graphy)	Pre- dictive	Pre- dictive				Coastal strip			<4 hrs	Yes, if utility proven
Coastal zone manage- ment	X	X	X				X	Coastal strip	10-80 m (satellite) 1 m (photo- graphy)	Daily- seasonal	>30 days	Yes
Coastal engi- neering	X	X	X	X			X	Coastal strip	10 m (satel- lite) 1 m (photo- graphy)	Daily- seasonal	>30 days	Yes
Oil spill response	X	X	X	X			X	EEZ	Various	Daily in emergency	Imme- diate	Yes
South African Weather Bureau	X		X	X	X	X	X	Large scale	5 km (SSt,water vapour) 50 km (winds)	Twice daily	<12 hrs	

*No real interest in remote sensing evident

Table II. Needs of researchers

Data Type	Research group/ Institute	Spatial resolution	Frequency	Preferred product response time
<u>Sea surface temperature</u>				
(a) Satellite TIR	SFRI DEMAST UCT JLBS ORI	1 km	Daily	<48 hrs
(b) Satellite microwave	SFRI DEMAST UCT JLBS	25 km	Daily/Weekly	<48 hrs (cruises) >30 days (other)
(c) Airborne TIR and micro-wave	SFRI UCT	5 m	*ad hoc*	Immediate
<u>Ocean/land colour</u> (Visible and near IR wave lengths)				
(a) Satellite CS	SFRI DEMAST JLBS ORI	10 m - 1 km depending on application	Daily/Weekly	<48 hours (cruises) >30 days (other)
(b) Airborne multichannel radiometer	SFRI DEMAST UCT	5 m	*ad hoc*	Immediate
(c) Aerial photo-graphy	SFRI DEMAST UP UCT	5 cm - 1 m depending on application	*ad hoc*	>30 days

Table II. Needs of researchers (continued)

Data Type	Research group/ Institute	Spatial resolution	Frequency	Product response time
<u>Currents and/or sea level</u>				
(a) Satellite altimeter	DEMAST SFRI US UCT	1 km	Daily/Weekly	>30 days
(b) CODAR	US UCT			
(c) Feature/ drifter tracking	SFRI DEMAST UCT US	1 km	Daily	<48 hrs (cruises) >30 days (other)
<u>Windstress and windfield</u>				
(a) Satellite scatterometer	SFRI DEMAST SAWB UCT	50 km	Daily	<48 hrs (cruises) >30 days other
(b) Airborne microwave radiometer	UCT	?	*ad hoc*	?
<u>Waves</u> (synthetic aperture radar)	DEMAST SAWB UCT US	25 km ?	6 hourly	<24 hrs
<u>Water vapour</u>	SAWB DEMAST	1 km	Daily	<12 hrs

Oil exploration

For rig and pipeline design criteria it is unlikely that remotely sensed data will be helpful except where they contribute to a better understanding of worst conditions, e.g. the 50 year storm. Operational forecasts of wind, sea state and currents with a quick response (four hours to days depending on application) are required. Direct measurement and reception will be necessary.

Sea diamonds

Apart from some applications of aerial photography with respect to distribution of rock and sediment there does not appear to be any interest in remote sensing on the part of this industry. However, it is the view of the Working Group that CODAR could be useful operationally, although it may not prove cost effective.

Coastal zone management

Aerial photography and high resolution (80 x 80 m or better) satellite imagery in the visible and infrared bands have a number of applications within the broad topics of geomorphology, vegetation patterns and pollution, while information on waves and nearshore currents could be useful. The market for suitable data products is potentially large. A comprehensive survey of users and user agencies would have to be preceded by an application demonstration programme.

Coastal engineering

High resolution true colour aerial photography of the coastal strip and radar measurements of ocean wave spectra including wave direction, height and period are high priorities, while multi-spectral imagery also has a number of engineering applications. Real time data is not a requirement. Clients are willing to pay for suitable information.

RESEARCH

The needs for the various research groups and individuals cover the full spectrum of techniques and applications. As it is impractical to review the requirements group by group, an attempted synthesis appears as Table II. Researchers are prepared to pay within reason for useful data products and services. Although real time imagery is an operational requirement, there is nevertheless a firm need for non real-time data products.

EDUCATION AND TRAINING

In South African marine science there is need for a greater appreciation and awareness of the potential of remote sensing as a tool. Although the possible establishment of a remote sensing centre at a South African university (with subvention from FRD) is at present under consideration, such a centre on its own is unlikely to meet the needs of marine science where the emphasis must necessarily be placed on education and training in specific disciplines e.g. physical oceanography, marine biology. What we believe is required is for oceanographic-related graduate courses to include a comprehensive treatment of remote sensing and the applications. Actual manipulative skills such as image processing are probably best acquired subsequently through "hands-on" experience or through a suite of intensive specialist training courses (logically, hopefully to be offered by the centre referred to above).

HARDWARE, SOFTWARE AND DISPLAY

Reception of high density digital data

The only facility in South Africa capable of receiving high density digital data directly from satellites is the Satellite Applications Centre at Hartebeeshoek. It is obviously impractical to duplicate this facility at the coast for marine users but there are two options for obtaining the high density digital data in processed or unprocessed forms. The first is transmission using the GPO diginet system, when this becomes available. Here the cost of access to the CSIR computer network plus the necessary hardware and software for data storage, processing and display may be considerable (>R100 000). The second option (which applies only to users having their own image processing systems who require quasi-real time high density data that can be properly calibrated and corrected) is to use a courier service for data tapes. There nevertheless remains no practical means of receiving high density data at sea at present.

Automatic picture transmission (APT)

It is evident that less accurate, degraded (lower resolution) images which show structure would be acceptable to several users provided they were available in real time - in particular for use on ships. A definite market exists for a cheap, turn-key system for operational use by researchers in the laboratory and at sea.

Television

In principle it could be relatively simple to broadcast processed SST images (even calibrated and geometrically and atmospherically corrected) via commercial television in the same manner as Meteosat images are displayed, e.g. during weather forecasts. The availability of such maps during television off-time periods would be extremely useful to a broad spectrum of viewers, including coastal shipping.

Aircraft remote sensing package

Airborne radiation thermometry has been used in South Africa since the 1960s, mainly in *ad hoc* surveys or for case studies. In the absence of a satellite colour imager suitable for quantitative pigment and turbidity measurement, a multichannel radiometer suitable for use in aircraft may be viable as a cruise support to some users (notably Sea Fisheries Research Institute), particularly if fitted with a thermal infrared channel and linked with a microwave radiometer to a general purpose data logger.

FUTURE PROSPECTS

OCEAN-RELATED SPACECRAFT SCHEDULED FOR THE NEXT DECADE

During the next decade there are plans to improve and expand earth observation from satellites. Detailed meteorological monitoring will continue using the array of five geostationary weather satellites sponsored by the USA, the European Space Agency (ESA), India, and the Japanese National Space Development Agency (NASDA), and the three polar-orbiting meteorological satellites sponsored by the USA and USSR. Upper atmosphere observations are planned from NASA's new Upper Atmosphere Research Satellite (UARS) the land surface measurements will continue to be made by NOAA's Landsat series satellites and the French SPOT system. It is proposed that geodesy and geophysics will be addressed by the USA's Geopotential Research Mission (GRM) and the earth's radiation budget by the Earth Radiation Budget Experiment (ERBE).

For the oceans, the currently proposed missions build on those of Seasat and Nimbus. The United States Navy's Remote Ocean Sensing System (NROSS) is an approved mission scheduled to fly in 1990 to provide operational sea state, surface wind, sea surface temperature and sea-ice distribution. The instruments will include an active radar, altimeter, scatterometer and radiometers. ESA's ERS-1, also scheduled to fly in 1990, will have a similar complement of instruments. NROSS and ERS-1 will provide the first continuing global measurements of these parameters which will be as important to research in understanding global ocean processes as they are in operational ocean forecasting. Global ocean currents will be able to be measured using the precise data on ocean topography that will be available when the US/French TOPEX/Poseidon mission is underway in 1991. The Marine Observation Satellite, MOS-1, the Japanese satellite dedicated to oceanic measurements, was launched in 1987 and, as it comes onto line, it should give increasingly valuable oceanographic data. One of the new instruments that is being developed is the Ocean Colour Imager and it is hoped to fly this on Landsat-7 and follow-on SPOT missions. This, combined with the wide spectral range of the Moderate Resolution Imaging Spectrometer (MODIS) currently being designed to fly as part of the Earth Observing System of the mid-1990s, will bring the high resolution of the land-observing satellites to the oceanographers. Data from these instruments will be especially useful in the coastal zone.

LOCAL APPLICATIONS AND OPPORTUNITIES

Expansion of applications and refinement of existing techniques

(a) Thermal infrared radiometry

Although useful Meteosat and NOAA AVHRR images have been routinely available in South Africa at low cost for some years, the full potential of these products has still to be realized by oceanographers in general and the biological community in particular. There are probably two reasons for this. First, before late 1987 geocorrected and calibrated data products were not routinely available, which means that correct image interpretation was difficult - sometimes impossible. Second, many applications required the availability of images in near real time. The recent development of a routine geocorrection and calibration capability, however, is likely to improve the utility of AVHRR data substantially, even given the present cost (R120 per monochrome print or negative). Images can now be ordered on various projections, including Mercator, which means that marine scientists without access to image processing systems can do some useful work with sequential images in terms of feature tracking. Positions of features can be measured with reasonable accuracy. There is thus considerable scope for examining the kinematics (in a statistically acceptable manner) of, for example, the Agulhas Current, its retroflection and leakage into the Atlantic, Benguela upwelling, the Benguela oceanic front, the Angola- Benguela front, etc. on time scales from days to years. The potential utility for process related research and modelling is considerable as is its usefulness for resource and environmental management.

The likely availability of lower resolution thermal imagery in quasi-real time to users at coastal centres, and possibly ships, by 1990 will, we believe, be a milestone in the local application of remote sensing. There is a very real need for research scientists, industry and management authorities, to have such a capability. A proliferation of hardware (provided it is cheap) and applications can be anticipated once the facility becomes operational. The principal applications will be in fisheries and as cruise support - fields where the cost-benefits have already been demonstrated overseas. The fisheries most likely to benefit in South Africa are those for "frontal" species. Annotated frontal maps routinely made available to fishermen are likely to be the most beneficial output product. Essentially it is our opinion that the more readily available satellite data products are, the more they will be used by the community.

(b) Ocean colour

Apart from the obvious potential utility of the proposed Sea-WiFS (Sea-viewing, Wide Field of View Sensor) sensor in biological oceanography and in sediment transport studies, there exists a substantial source of historical data from the Nimbus-7 CZCS mission. The CZCS material published to date has merely scratched the surface. The in-house image processing capability at Sea Fisheries Research Institute and DEMAST provide the capability for a detailed statistical analysis of some two thousand scenes in terms of phytoplankton patch sizes, distributions and patterns as well as for estimating variability of primary production. For biological oceanographers it would be logical to fully exploit the existing data prior to the Landsat-6 mission. In addition to satellite measurement of ocean colour, the need for an airborne multichannel radiometer has already been identified. As a real time cruise support this could be the most cost effective option for providing information on horizontal structure, and a suitable instrument might also prove more beneficial for studies of coastal processes than satellite sensors in view of the high resolution and frequency of sampling possible.

(c) Environmental change

Both for research and for resource management there is an ongoing need for reasonably up-to-date information on the state of the environment. The data products which come closest to providing this information are the ten day SST averages generated by the South African Weather Bureau and the NOAA/NWS Climate Diagnostics Bulletin Series. These products, however, have limitations in terms of data density or resolution. Monthly maps on a usable scale for the area 10-45°S, 0-50°E based on composites of satellite and ship data, suitably blended with a resolution of one degree of latitude and longitude, would be a most worthwhile product - particularly if anomalies (deviations from the monthly mean) were displayed.

These data would be extremely useful for studies of weather and climate and for fisheries, provided they were available with a lag time of less than two months. The potential utility of available satellite data to supplement field measurements (which are by their nature spatially limited over the sea) as inputs into local weather, climate and fisheries models should be recognized.

(d) Surface currents

The utility of satellites for position fixing and buoy interrogation in local waters is well established. The utility of spacecraft for passive feature tracking is less so. The suitability of the new generation AVHRR products from SAC has already been indicated, and what follows are just two potential applications of feature tracking. First, information on currents in the EEZ if available routinely in near-real time could be useful for navigation and in fishing operations. Second, in emergency situations such as maritime disasters and oil spills, the data could provide the necessary inputs into predictive trajectory models to aid rescue and salvage operations and to help with the protection of sensitive areas and clean-up in the case of oil pollution.

Development and implementation of new techniques

(a) Currents and sea level

Three components of a South African proposal to participate in the Topex/Poseidon mission which is scheduled to start in 1991 have been tentatively accepted by CNES. These are: Agulhas Current system topography; Indian-Atlantic interaction; and Meridional heat transport. All three rely on the application of altimeter data in conjunction with AVHRR and shipboard measurements to document the variability in time and space of the Agulhas current, its retroflection and leakage into the Atlantic Ocean. An attempt will also be made to quantify the meridional heat transport into the Southern Ocean in this area which has high mesoscale turbulence. All three components form part of the South African contribution to WOCE, and, in addition to obvious benefits to studies of regional and global climate, the information should provide an improved understanding of the key physical processes operative at the crossroads of three ocean systems, and, among other applications, provide useful inputs for fisheries. At present there is only a limited local capability for handling and processing altimeter data. In preparation for the local processing of Topex/Poseidon data (none of which will be in real time) a suite of computer programmes is at present being developed and adapted using Seasat and Geosat data for test purposes.

Although not part of the official Topex/Poseidon project, the Sea Fisheries Research Institute proposes to use altimeter data to study the influence of changes in the large scale flow field in the Cape Basin on shelf circulation between Cape Frio and Cape Agulhas and its resultant impact on the fisheries of the region. Like the other altimeter-sourced activities this project does not rely on the availability of an accurate geoid, although it would obviously be highly beneficial.

It is likely that the main new thrust in remote sensing in South African marine science during the next decade will be related to the use of satellite altimetery.

(b) Current-wave interactions

South Africa is in a unique position to undertake research on wave-current interactions. The combined use of SAR and scatterometer data in conjunction with platform/ship based CODAR to investigate the role a shearing current plays in giant wave generation is an attractive research possibility. Such research could have a wide range of applications in coastal and ocean engineering during the next decade.

(c) Other applications of microwave techniques

Although it seems probable that local scientists will make increasing use of microwave-based data products during the next decade it seems probable that these will be generated overseas. Apart from the obvious application of satellite-derived surface wind stress data in large scale studies of air-sea interactions (e.g. modelling Agulhas Current retroflection), microwave sourced estimates of SST could be extremely useful in the study of frontal kinematics in areas with a high percentage of cloud cover such as the Angola-Benguela front and the Subtropical Convergence, particularly if linked to satellite altimetry. Another likely application of both altimeter and microwave data is in monitoring the ice edge. It is the authors' view that such investigations could have spin offs for the study and forecasting of South Africa's weather and climate and possibly also for fisheries.

THE BROAD PICTURE

The opportunity for us in South Africa to apply oceanographic remote sensing techniques is not limited by our immediate local scientific and management needs. There is an ever increasing awareness of the Earth as a unified system. Earth system science sees our world as a related set of interacting processes operating on a wide range of spatial and temporal scales, rather than as a collection of individual components. Satellite remote sensing is the key technique of these global studies and forms the basis for a number of collaborative international programmes aimed at furthering our understanding of our Earth. The World Climate Research Programme, sponsored by the International Council of Scientific Unions (ICSU) and the World Meteorological Organization, has two ocean-related programmes, the Tropical Ocean Global Atmosphere (TOGA) programme aimed at determining the causes and establishing the predictability of El Niño and Southern Oscillation events, and the World Ocean Circulation Experiment (WOCE). WOCE aims to develop improved models of ocean circulation on time scales of decades or longer and is probably the most complex experiment ever attempted by the world oceanographic community. South Africa has established a National South African WOCE programme under the auspices of SANCOR and hopes to contribute significantly to global understanding of the ocean circulation by virtue of our expertise and unique geographic position. South African participation in other global programmes such as the Joint Global Ocean Flux Study (JGOFS) which proposes to extend our understanding of processes responsible for the production and fate of biogenic materials in the sea from regional to ocean-basin and global scales is also encouraged. Input from these international collaborative programmes will contribute towards the International Geosphere/Biosphere Programme (IGBP), the ambitious integrative programme designed to understand global environmental change on a broad scientific front.

These new programmes offer South Africans a marvellous opportunity to participate in Earth system science, the integrative global science of the future. Crucial to our involvement, however, is our access to, and ability to handle, the vast quantities of remotely sensed data that the new generation of satellites will be producing.

BLUEPRINT FOR THE FUTURE

A number of different research activities can be identified which, if implemented, will contribute towards remote sensing in South African marine science being placed on a sound footing during the next decade. These activities vary in scale and complexity from participation in major international programmes to the development of specific products for specific needs. Software development is needed across the spectrum of local oceanographic remote sensing techniques, both for data handling and for developing personal computer image-processing facilities. An

Table III. Proposed activity schedule

Activity	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Development of APT system/real time SST capability			XXXX	XXXX										
Development of airborne multichannel radiometer package			XXXX	XXXX										
Development of multipurpose air-sea sensus package		XX	XXXX	XXXX	XXXX									
Development of corrected and calibrated AVHRR hard copy	XXXX													
Explore possible distribution of visible and TIR images through TV network	XX	XXX												
Statistical analysis of existing Nimbus7 CZCS scenes		XX	XXXX	XXXX	XXXX									
Development of feature tracking software for sequential data		XX	XXXX											
Development of software package for altimeter data in preparation of Topex/Poseidon		XXXX	XXXX											
Documentation of the Agulhas perturbation of 1986	XXXX	XXXX												
Application of corrected and calibrated AVHRR data in oceanographic studies		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
Preparation for Sea-WiFS				XXXX										
Participation in Topex/Poseidon mission and WOCE		X X	X X	X X	X X	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
Development of monthly environment/anomaly map				XXXX										
Development of surface current predictive model using feature tracking inputs				XXXX	XXXX	XXXX								
Explore application of satellite microwave techniques locally			XXXX	XXXX	XXXX									
Demonstrate utility of satellite products as aid to fisheries (research, directing operations and management)		XXXX	XXXX	XXXX	XXXX									
Application of remote sensing in support of local weather and climate studies/prediction (model inputs)					XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
Development of PC based IPS					XXXX	XXXX								
Develop Cape Town based satellite data product centre		X X	X X	XXXX	XXXX									
Cost benefit analysis of remote sensing in local marine industry operations			XXXX	XXXX	XXXX									
Technology transfer		XXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX
Development of capability to analyze data useful in studies of heat flux and wind forcing				XXXX	XXXX	XXXX								

APT system which would facilitate a real-time sea surface temperature capability is highly desirable, as would be the development of monthly environment/anomaly maps. Of on-going importance will be the application of corrected and calibrated AVHRR data in oceanographic studies and the development of remote sensing support for fisheries and other offshore industries. The application of satellite microwave techniques also needs to be explored locally. Table III summarizes these future activities.

THE ROLE OF THE FRD

The mission of the Foundation for Research Development within the new orientation of the CSIR clearly states that the FRD aims to develop experts and expertise of a high quality in natural sciences and engineering to improve the quality of life for all South Africans. Both experts and expertise in oceanographic remote sensing are sorely needed in South Africa. At present a handful of people are successfully using their ingenuity to improve our remote sensing capabilities over coastal and ocean areas, mainly as an adjunct to their main jobs. There is a need for a more coordinated, directed approach to develop the techniques and skills required in oceanographic remote sensing. It is our opinion that this could best be provided by the establishment of one or more tightly- defined, limited-term research development programmes within the FRD.

APPENDICES

SELECTED READING

Opportunities and problems in satellite measurement of the sea. Report of SCOR Working Group 70, JFR Gower, (Ed.). UNESCO technical papers in marine science, 46, 1986. 70 pp.

South African ocean colour and upwelling experiment. Shannon L V (Ed) Cape Town; Sea Fisheries Research Institute. 1985.

Applications of remote sensing to fisheries and coastal resources. Report of a California Sea Grant Workshop. Amidi E (Ed). Scrips Institution of Oceanography, Report No T-GSGCP-012, 1983.

Baker D J and W S Wilson 1986/7. Spaceborne observations in support of Earth Science, *Oceanus* 29(4) 76-85.

Lutjeharms J R E 1984. Afstandwaarneming vandag. *S. Afr. J. Sci.* 80(8): 386-387.

Lutjeharms J R E and F P Anderson 1987. The World Ocean Circulation Experiment (WOCE); A South African perspective. *S. Afr. J. Sci.* 83(1):10-14.

APPENDIX II

BIBLIOGRAPHY ON SOUTH AFRICAN REMOTE SENSING TECHNIQUES AND THEIR APPLICATIONS

The following publications deal with remote sensing and its applications in South African marine science. In general, theses, reports and conference papers (unless subsequently published following peer review) have not been included. Although reasonably comprehensive, the list is by no means exhaustive.

AGENBAG J J 1980. General distribution of pelagic fish off South West Africa as deduced from aerial fish spotting (1971-1974 and 1977) and as influenced by hydrology. *Fish. Bull. S. Afr.* 13:55-67.

AGENBAG J J and F P ANDERSON 1985. The role of satellite remote sensing in South African marine research: the present and the future. In *South African Ocean Colour and Upwelling Experiment*. Shannon L V (Ed). Cape Town; Sea Fisheries Research Institute: 251-255.

AGENBAG J J and L V SHANNON 1987. The preliminary note on a recent perturbation in the Agulhas Current retroflection area. *Trop. Ocean - Atmos. Newsl.* 37:10-11.

AGENBAG J J and L V SHANNON 1988. A suggested physical explanation for the existence of a biological boundary at 24°30'S in the Benguela system. *S. Afr. J. mar. Sci.* 6:119-132.

ANDERSON F P 1979. Remote sensing in South African oceanography. *S. Afr. J. Sci.* 75(12):552-553.

ANDERSON F P, SHANNON L V, MOSTERT S A, WALTERS N M and O G MALAN 1981. A South African ocean colour experiment. In: *Oceanography from Space*. Gower J F R (Ed) New York; Plenum Press: 381-386.

ANDREWS W R H and D L CRAM 1969. Combined aerial and shipboard upwelling study in the Benguela Current. *Nature* 224(5222):902-904.

BERGH M O, FIELD J G and L V SHANNON 1985. A preliminary carbon budget of the southern Benguela ecosystem. In: *International Symposium on the Most Important Upwelling Areas off Western Africa (Cape Blanco and Benguela). Barcelona, November 1983.* 1. Bas C, Margalef R and P Rubiés (Eds). Barcelona; Instituto de Investigaciones Pesqueras: 281-304.

CRAM D L 1970. A suggested origin for the cold surface water in central False Bay. *Trans. Roy. Soc. S. Afr.* 39(2):129-137.

CRAM D L 1979. A role for the Nimbus-C Coastal-Zone Colour Scanner in the management of a pelagic fishery. *Fish. Bull. S. Afr.* 11:1-9.

CRAM D L and J J AGENBAC 1974. Low light level television - an aid to pilchard research. *S. Afr. Ship. News and Fishing Ind. Rev.* 29(7):52-53.

CRAM D L, AGENBAG J J, HAMPTON I and A A ROBERTSON 1979. SAS Protea cruise, 1978; The general results of the acoustics and remote sensing study, with recommendations for estimating the abundance of krill (*Euphausia superba* Dana). *S. Afr. J. Antarc. Res.* 9:3-14.

CRAM D L and I HAMPTON 1976. A proposed aerial acoustic strategy for pelagic fish stock assessment. *J. Cons. int. Explor. Mer.* 37(1):91-97.

CRAM D L and O C MALAN 1977. On the possibility of surveying krill (*Euphausia* dana) in the Southern Ocean by remote sensing. *S. Afr. J. Antarc. Res.* 7:14-19.

CRAM D L and F H SCHULEIN 1974. Observations on surface-shoaling Cape hake off South West Africa. *J. Cons. Int. Explor. Mer.* 35(3):272-275.

GILLOOLY J F and J R E LUTJEHARMS 1984. The ocean and climate: Large-scale ocean-atmosphere interactions in the southern hemisphere. *S. Afr. J. Sci.* 80(1):36-40.

GILLOOLY J F and M D WALKER 1984. Spatial and temporal behaviour of sea-surface temperatures in the South Atlantic. *S. Afr. J. Sci.* 80(2): 97-100.

GRÜNDLINGH M L 1974. A description of inshore current reversals off Richards Bay based on airborne radiation thermometry. *Deep-Sea Res.* 21:47-50.

GRÜNDLINGH M L 1979. Observation of a large meander in the Agulhas Current. *J. Geophys. Res.* 84:3776-3778.

GRÜNDLINGH M L 1986. Features of the northern Agulhas Current in spring, 1983. *S. Afr. J. Sci.* 82:18-20.

GRÜNDLINGH M L and J R E LUTJEHARMS 1979. Large-scale flow patterns of the Agulhas Current system. *S. Afr. J. Sci.* 75(6):269-270.

GRÜNDLINGH M L and A F PEARCE 1984. Large vortices in the northern Agulhas Current. *Deep-Sea Res.* 31:1149-1156.

HAMPTON I, AGENBAG J J and D L CRAM 1979. Feasibility of assessing the size of the South West African pilchard stock by combined aerial and acoustic measurements. *Fish. Bull. S. Afr.* 11:10-22.

HARRIS T F W 1978. Review of coastal currents in southern African waters. *S. Afr. Natnl. Sci. Programmes Rep.* 30, CSIR, Pretoria, 103 pp.

HARRIS T F W, LEGERCKIS R and D VAN FOREEST 1978. Satellite infrared images in the Agulhas current System. *Deep Sea Res.* 25:543-548.

HARRIS T F W and L V SHANNON 1979. Satellite-tracked drifter in the Benguela Current system. *S. Afr. J. Sci.* 75:316-317.

HARRIS T F W and C C STAVROPOULOS 1965. Some experiences with a radiation thermometer over the Agulhas Current. *S. Afr. J. Sci.* 63(4): 132-136.

JURY M R 1981. Coastal winds and upwelling. *Trans. Roy. Soc. S. Afr.* 44(3):299-302.

JURY M R 1985. Mesoscale variations in summer winds over the Cape Columbine - St Helena Bay region of South Africa. *S. Afr. J. mar. Sci.* 3:77-88.

JURY M R 1985. Air temperature gradients along the Western Cape coast during southerly winds. *S. Afr. J. Sci.* 81(1):17-20.

JURY M R 1985. Case studies of alongshore variations in wind-driven upwelling in the southern Benguela region. In: *South African Ocean Colour and Upwelling Experiment.* Shannon L V (Ed) Cape Town; Sea Fisheries Research Institute: 29-46.

JURY M R 1985. Wind shear and upwelling along the S W tip of Africa. In: *International Symposium on the Most Important Upwelling Areas off Western Africa (Cape Blanco and Benguela). Barcelona, November 1983.* 1. Bas C, Margalef R and P Rubiés (Eds). Barcelona; Instituto de Investigaciones Pesqueras: 149-159.

JURY M R 1986. The sudden decay of upwelling off the Cape Peninsula, *S. Afr. J. mar. Sci.* 4:111-118.

JURY M R 1986. Wind-driven upwelling off the Namaqualand coast of South Africa in spring 1980. *S. Afr. J. mar. Sci.* 4:103-110.

JURY M R 1987. Aircraft observations of meteorological conditions along Africa's west coast 30-35°S. *J. Climate Applied Met.* 26(11):1540-1552.

JURY M R 1988. A climatological mechanism for wind driven upwelling near Danger Point, South Africa. *S. Afr. J. mar. Sci.* 6 (in press).

JURY M R, KAMSTRA F and TAUNTON-CLARK J 1985. Diurnal wind cycles and upwelling off the northern portion of the Cape Peninsula in summer. *S. Afr. J. mar Sci.* 3:1-10.

JURY M R, KAMSTRA F and TAUNTON-CLARK J 1985. Synoptic wind cycles and upwelling off the southern portion of the Cape Peninsula. *S. Afr. J. mar. Sci.* 3:33-42.

JURY M R and G SPENCER-SMITH 1988. Doppler sounder observations of trade winds and sea breezes along the African west coast near 34°S, 18°E, *Boundary Layer Met.* (in press).

JURY M R and N D WALKER 1988. Marine boundary layer modification across the edge of the Agulhas Current. *J. Geophys. Res.* (in press).

LUTJEHARMS J R E 1978. Studying the ocean by satellite. *S. Afr. Shipping News Fish. Ind. Rev.* 33(10):28-31.

LUTJEHARMS J R E 1978. Shipping disasters: a role for satellite oceanology. *S. Afr. J. Sci.* 74(10):385-387.

LUTJEHARMS J R E 1979. What the Agulhas current did to the *Venoil* tow. *S. Afr. Shipping News Fish. Ind. Rev.* 34(8):11-13, 15.

LUTJEHARMS J R E 1980. Drift of the ULCC *Venoil* in the Agulhas Current. *Mar. Weath. Log.* 24(1):1-6.

LUTJEHARMS J R E 1981. Satellite studies of the South Atlantic upwelling system. In: *Oceanography from Space*, Gower J F R (Ed). Marine Science Vol. 13. Plenum Press, New York. 195-199.

LUTJEHARMS J R E 1981. Features of the southern Agulhas Current circulation from satellite remote sensing. *S. Afr. J. Sci.* 77(5): 231-236.

LUTJEHARMS J R E 1982. Die geskiedkundige ontwikkeling van fisiese navorsing oor die oseane grensend aan Suider-Afrika. *S. Afr. Tydskrif Natuurwet. Tegnol.* 1(1):42-52.

LUTJEHARMS J R E 1984. Afstandwaarneming vandag. *S. Afr. J Sci.* 80(8):386-387.

LUTJEHARMS J R E 1987. Die Substropiese Konvergensie en Agulhasretrofleksievaart (SCARC). *S. Afr. J. Sci.* 83(8):454-456.

LUTJEHARMS J R E 1988. Meridional heat transport across the Sub-Tropical Convergence by a warm eddy. *Nature*, 331:251-253.

LUTJEHARMS J R E and F P ANDERSON 1987. The World Ocean Circulation Experiment (WOCE); a South African perspective. *S. Afr. J. Sci.* 83(1): 10-14.

LUTJEHARMS J R E and D J BAKER 1979. Intensities and scales of motion in the Southern Ocean. *S. Afr. J. Sci.* 75(4): 179-182.

LUTJEHARMS J R E and A JORGE DA SILVA 1988. The Delagoa Bight eddy. *Deep-sea Res.* (in press).

LUTJEHARMS J R E and W J EMERY 1983. The detailed thermal structure of the upper ocean layers between Cape Town and Antarctica during the period Jan-Feb 1978. *S. Afr. J. Antarc. Res.* 13:3-14.

LUTJEHARMS J R E and A FOLDVIK 1986. The thermal structure of the upper ocean layers between Africa and Antarctica during the period December 1978 to March 1979. *S. Afr. J. Antarc. Res.* 16(1): 13-20.

LUTJEHARMS J R E and M L GRUNDLINGH 1987. Die Wereld Oseaansirkulasie-eksperiment (WOCE). *S. Afr. Tydskrif Natuurwet. Tegnologie*, 6(2):64-71.

LUTJEHARMS J R E and A L GORDON 1987. Shedding of an Agulhas Ring observed at sea. *Nature* 325(7000):138-140.

LUTJEHARMS J R E and L J MARAIS 1986. Real-time use of satellite remote sensing and telemetry on oceanologic research cruises. *S. Afr. J. Photogram., Rem. Sens. and Cartog.* 14(6):313-319.

LUTJEHARMS J R E and L H McQUAID 1986. Changes in the structure of thermal ocean fronts south of Africa over a three month period. *S. Afr. J. Sci.* 82(9):470-476.

LUTJEHARMS J R E and J M MEEUWIS 1987. The extent and variability of South East Atlantic upwelling. In: *The Benguela and Comparable Ecosystems* Payne A I L, Gulland J A and Brink K H (Eds). *S. Afr. J. mar. Sci.* 5: 51-62.

LUTJEHARMS J R E, MEY R D and I T HUNTER 1986. Cloud lines over the Agulhas Current. *S. Afr. J. Sci.* 82(11):635-640.

LUTJEHARMS J R E and H R ROBERTS 1988. The Natal pulse; an extreme transient on the Agulhas Current. *J. Geophys. Res.* (in press).

LUTJEHARMS J R E and P L STOCKTON 1987. Kinematics of the upwelling front off Southern Africa. In: *The Benguela and Comparable Ecosystems*. Payne A I L, Gulland J A and Brink K H (Eds). *S. Afr. J. mar. Sci.* 5:35-49.

LUTJEHARMS J R E and H R VALENTINE 1981. Ocean circulation studies in the vicinity of southern Africa: preliminary results using FGGE drifters and remote sensing. *Advances in Space Research* 1(4):211-223.

LUTJEHARMS J R E and H R VALENTINE 1988. The formation of eddies at the Sub-Tropical Convergence south of Africa. *J. Phys. Oceanog.* (in press).

LUTJEHARMS J R E and H R VALENTINE 1988. Evidence for persistent Agulhas rings south west of Cape Town. *S. Afr. J. Sci.* (in press).

LUTJEHARMS J R E and R C VAN BALLEGOOYEN 1984. Topographic control in the Agulhas Current system. *Deep-Sea Res.* 31(11A):1321-1337.

LUTJEHARMS J R E and N M WALTERS 1985. Ocean colour and thermal fronts south of Africa. In: *South African Ocean Colour and Upwelling Experiment*. Shannon L V (Ed). Cape Town: Sea Fisheries Research Institute. 227-237.

LUTJEHARMS J R E, WALTERS N M and B R ALLANSON 1984. Oceanic frontal systems and biological enhancement. In: *Antarctic Nutrient Cycles and Food Webs*. Siegfried W R, Condy P R and R M Laws (Eds). Heidelberg: Springer-Verlag: 11-21.

MALAN O G 1974. The ERTS Programme and its achievements. *S. Afr. J. Photogram.* 6(1):4-16.

MALAN O G 1979. Ein verfahren der digitalen bildverarbeitung zur hervorhebung ozeanographischer phanomene aus LANDSAT-Daten. (A method of digital image processing for the enhancement of oceanographic features in LANDSAT data). *Bildmessung und Luftbildwesen.* 47:161-165.

MALAN O G, CRAM D L and J J AGENBAG 1978. Methods for optimising airborne LLLTV detection of fish induced plankton bioluminescence. In: *COSPAR: The Contribution of Space Observations to Global Food Information Systems*, Godby E A and S Otterman (Eds). Pergamon Press, Oxford: 157-160.

MALAN O G and E H SCHUMANN 1979. Natal shelf circulation revealed by LANDSAT imagery. *S. Afr. J. Sci.* 75(3):136-137.

MARACCI G 1985. Results of atmosphere optical measurements at two sites on the Cape west coast. In: *South African Ocean Colour and Upwelling Experiment*. Shannon L V (Ed). Cape Town: Sea Fisheries Research Institute. 171-174.

NELSON G and L HUTCHINGS 1983. The Benguela upwelling area. *Prog. Oceanogr.* 12(3):333-356.

SCHUMANN E H 1985. South African South Coast: In: *Nimbus-7 CZCS Coastal Zone Color Scanner Imagery for Selected Regions*. Hovis W A, Szajna E F and W A Bohan (Eds), NASA, Goddard Space Flight Centre: 91-93.

SCHUMANN E H 1987. The coastal ocean off the east coast of South Africa. *Trans. Roy. Soc. S. Afr.* 46(3):215-229.

SCHUMANN E H and L J BEEKMAN 1984. Ocean temperature structures on the Agulhas Bank. *Trans. Roy. Soc. S. Afr.* 45(2):191-203.

SCHUMANN E H, PERRINS L-A. and I T HUNTER 1982. Upwelling along the south coast of the Cape Province, South Africa. *S. Afr. J. Sci.* 78(6): 238-242.

SCHUMANN E H, ROSS G J B and W S GOSCHEN 1988. Cold water events in Algoa Bay and Cape south coast of South Africa. *S. Afr. J. Sci.* (in press).

SHANNON L V 1983. Preliminary report of the southern Benguela warm event, 1982-1983. *Trop. Ocean-Atmos. Newsl.* 22:8-9.

SHANNON L V (Ed) 1985. South African Ocean Colour and Upwelling Experiment. *Sea Fish. Res. Inst. S. Afr.* 270 pp. ISBN 0 621 07386 5.

SHANNON L V 1985(a). Description of the ocean colour and upwelling experiment. In: *South African Ocean Colour and Upwelling Experiment*. Shannon L V (Ed). Cape Town: Sea Fisheries Research Institute. 1-12.

SHANNON L V 1985(b). The Benguela Ecosystem. I. Evolution of the Benguela, physical structure and processes. In: *Oceanog. Mar. Biol. Ann. Rev.* Barnes M (Ed). Aberdeen; University Press: 23:105-182.

SHANNON L V The abiotic environment. In: *South Africa's open sea. Its living resources and their distributional ecology*. Payne A I L and Crawford R J M (Eds) (in press).

SHANNON L V and J J AGENBAG 1987. Notes on the recent warming in the South-east Atlantic, and possible implications for the fisheries of the region. *Colln. scient. Pap. int. Commn S.E. Atl. Fish.* 14(II):243-248.

SHANNON L V, AGENBAG J J and M E L BUYS 1987. Large and mesoscale features of the Benguela front. In: *The Benguela and Comparable Ecosystems* Payne A I L, Gulland J and K Brink (Eds). *S. Afr. J. Mar. Sci.* 5:11-34.

SHANNON L V and F P ANDERSON 1982. Applications of satellite ocean colour imagery in the study of the Benguela Current system. *S. Afr. J. Photogram, Rem. Sens. and Cartog.* 13(3):153-169.

SHANNON L V and F P ANDERSON 1985. South Africa West Coast: The Benguela Current - Coastal Upwelling. In: *Nimbus-7 CZCS Coastal Zone Color Scanner Imagery for Selected Regions.* Hovis W A, Szajna E F and W A Bohan (Eds), NASA, Goddard Space Flight Centre: 87-89.

SHANNON L V, BOYD A J, BRUNDRIT G B and J TAUNTON-CLARK 1986. On the existence of an El Niño-type phenomenon in the Benguela system. *J. Mar. Res.* 44:495-520.

SHANNON L V and P CHAPMAN 1983. The incidence of *Physalia* on beaches in the South Western Cape during January 1983. *S. Afr. J. Sci.* 79: 454-458.

SHANNON L V and J G FIELD 1985. Are fish stocks food-limited in the southern Benguela pelagic ecosystem? *Mar. Ecol. Prog. Ser.* 22(1):7-19.

SHANNON L V, HUTCHINGS L, BAILEY G W and P A SHELTON 1984. The spatial and temporal distribution of chlorophyll in southern African waters as deduced from ship and satellite measurements. *S. Afr. J. mar. Sci.* 2:109-130.

SHANNON L V, MOSTERT S A, WALTERS N M and F P ANDERSON 1983. Chlorophyll concentrations in the southern Benguela Current region as determined by satellite (Nimbus-7 Coastal Zone Colour Scanner). *J. Plankt. Res.* 5(4):565-583.

SHANNON L V, NELSON G and M R JURY 1981. Hydrological and meterological aspects of upwelling in the southern Benguela Current. In: *Coastal and Estuarine Sciences. 1. Coastal Upwelling.* Richards F.A. (Ed). Washington D.C.: American Geophysical Union: 146-159.

SHANNON L V and S C PILLAR 1986. The Benguela Ecosystem. Part III Plankton. In: *Oceanogr. Mar. Biol. Ann. Rev.* Barnes M. (Ed) Aberdeen; University Press. 24:65-170.

SHANNON L V, SCHLITTENHARDT P and S A MOSTERT 1984. The Nimbus-7 CZCS experiment in the Benguela Current region off southern Africa, February 1980. Interpretation of imagery and oceanographic implications. *J. geophys. Res.* 89:4968-4976.

SHANNON L V, WALTERS N M and A G S MOLDAN 1983. Some features in two bays as deduced from satellite ocean colour imagery. *S. Afr. J. mar. Sci. 1:111-122.*

SHANNON L V, WALTERS N M and A G S MOLDAN 1985. Satellite observations of marine pollution and rip currents. In: *South African Ocean Colour and Upwelling Experiment.* Shannon L V (Ed). Cape Town; Sea Fisheries Research Institute. 239-250.

SHANNON L V, WALTERS N M and S A MOSTERT 1985. Satellite observations of surface temperature and near-surface chlorophyll in the southern Benguela region. In: *South African Ocean Colour and Upwelling Experiment.* Shannon L V (Ed). Cape Town; Sea Fisheries Research Institute: 183-210.

TAUNTON-CLARK J 1985. The formation, growth and decay of upwelling tongues in response to the mesoscale wind field during summer. In: *South African Ocean Colour and Upwelling Experiment.* Shannon L V (Ed) Cape Town; Sea Fisheries Research Institute: 47-61.

VAN FOREEST D and G B BRUNDRIT 1985. Numerical modelling of the southern Benguela system. In: *South African Ocean Colour and Upwelling Experiment.* Shannon L V (Ed) Cape Town; Sea Fisheries Research Institute: 111-123.

VAN FOREEST D and M R JURY 1985. A numerical model of the wind-driven circulation in False Bay. *S. Afr. J. Sci.* 81(6):312-317.

VAN FOREEST D., SHILLINGTON F.A. and R. LEGECKIS 1984. Large scale, stationary, frontal features in the Benguela current system. *Cont. Shelf Res.* 3(4)465-474.

WALKER N D 1986. Satellite observations of the Agulhas Current and episodic upwelling south of Africa, *Deep-Sea Res.* 33:1083-1106.

WALTERS N M 1982. Satelliet-waarneming van oseaankleur aan die Suid-Afrikaanse weskus. *S. Afr. Tydskr. Natuurwet. Tegnol.* 1(3):156-161.

WALTERS N M 1983. Verification of the utility of the CZCS in portraying pigment concentrations along the Cape West Coast. *S. Afr. J. Phys.* 6(2):63-66.

WALTERS N M 1985. Algorithms for the determination of near-surface chlorophyll and semi-quantitative total suspended solids in South African coastal waters from Nimbus-7 CZCS data. In: *South African Ocean Colour and Upwelling Experiment.* Shannon L V (Ed). Cape Town; Sea Fisheries Research Institute: 175-182.

WALTERS N M, KOK C J and C CLAASE 1980. Optical measurements at sea: South African Nimbus-7 programme. *S. Afr. J. Phys.* 3:55-59.

WALTERS N M, KOK C J and C CLAASE 1985. Optical properties of the South African marine environment. In: *South African Ocean Colour and Upwelling Experiment*. Shannon L V (Ed). Cape Town; Sea Fisheries Research Institute: 157-170.

WALTERS N M, MALAN O G and D C NEETHLING 1983. Aerosol observations from Nimbus-7 CZCS along the South African West Coast. *Adv. Space Res.* 5:105-107.

WALTERS N M and E H SCHUMANN 1985. Detection of silt in coastal waters by Nimbus-7 CZCS. In: *South African Ocean Colour and Upwelling Experiment*. Shannon L.V. (Ed). Cape Town; Sea Fisheries Research Institute: 219-225.

WELSH J G 1967. A new method of measuring coastal surface currents with markers and dyes dropped from aircraft. *J. Mar. Res.* 25(2):190-197.

APPENDIX III

MEMBERSHIP OF WORKING GROUP ON REMOTE SENSING IN OCEANOGRAPHY AND ITS *AD HOC* TASK GROUPS

Working Group

Dr L V Shannon (SFRI) (Chairman)

Mr J J Agenbag (SFRI)

Mr M L Gründlingh (DEMAST)

Dr M R Jury (UCT)

Dr C W Louw (FRD, NPRS)

Dr J R E Lutjeharms (DEMAST)

Dr O G Malan (DEMAST)

Mr I J Marais (SAC)

Mr M G Potgieter (Fishing Industry)

Mrs L Y Shackleton (FRD, SANCOR)

Mr N M Walters (DEMAST)

Ad hoc task groups

Shipping needs: Dr N M Walters, Dr M L Gründlingh

Fisheries needs: Mr M G Potgieter, Dr L V Shannon

Oil exploration: Mr C C Stavropoulos, Dr N M Walters

Sea diamonds: Dr J M Bremner, Mrs L Y Shackleton

Coastal zone management: Dr A Heydorn, Dr N M Walters

Coastal engineering: Dr D H Swart

Hardware needs: Dr N M Walters, Mr I J Marais, Mr J J Agenbag, Mr H Chamberlain

S A Geoid: Dr M L Gründlingh, Dr C Merry

Microwave data sources: Dr M R Jury, Mr J J Agenbag, Dr M Gerber

Aircraft packages: Dr M R Jury, Dr N M Walters

CODAR: Dr F A Shillington, Mr C C Stavropoulos

APPENDIX IV

ACRONYMS

APT	Automatic Picture Transmission
ART	Airborne Radiation Thermometer
AVHRR	Advanced Very High Resolution Radiometer
BEP	Benguela Ecology Programme
CNES	Centre National d'Etudes Spatiales
CODAR	Coastal Ocean Dynamics Applications Radar
CSIR	Council for Scientific and Industrial Research
CUEX	Cape Upwelling Experiment
CZCS	Coastal Zone Colour Scanner
DEMAST	Division of Earth, Marine and Atmospheric Science and Technology
EEZ	Exclusive Economic Zone
ERBE	Earth Radiation Budget Experiment
ERS	Earth Remote Sensing Satellite
ESA	European Space Agency
FRD	Foundation for Research Development
GRM	Geopotential Research Mission
ICSU	International Council of Scientific Unions
IGBP	International Geosphere/Biosphere Programme
JGOFS	Joint Global Ocean Flux Study
MODIS	Moderate Resolution Imaging Spectrometer
MOS	Marine Observation Satellite
MR	Microwave Radiometer
NCRS	National Committee for Remote Sensing
NOAA	National Oceanic and Atmospheric Administration
NPRS	National Programme for Remote Sensing
NRIO	National Research Institute for Oceanology
NROSS	Navy Remote Ocean Sensing System
SABC	South African Broadcasting Corporation
SAC	Satellite Applications Centre
SANCOR	South African National Committee for Oceanographic Research
SAR	Synthetic Aperture Radar
SFRI	Sea Fisheries Research Institute
SMMR	Scanning Multichannel Microwave Radiometer
SPOT	Systeme Probatoire d'Observation de la Terre
SRSC	Satellite Remote Sensing Centre
SST	Sea Surface Temperature
TIROS	Television and Infra Red Observation Satellite
TM	Thematic Mapper
TOGA	Tropical Ocean Global Atmosphere
UARS	Upper Atmosphere Research Satellite
UCT	University of Cape Town
VHRR	Very High Resolution Radiometer
WOCE	World Ocean Circulation Experiment

APPENDIX V

SOME USEFUL ADDRESSES AND TELEPHONE NUMBERS

Dr C W Louw (Deputy Manager) Tel: (012) 841-3895
National Programme for Remote Sensing
FRD, CSIR
P O Box 395
PRETORIA
0001

Mrs L Y Shackleton (Coordinator) Tel: (021) 6864663
Oceanographic Remote Sensing
FRD, CSIR
New Botany Building
University of Cape Town
RONDEBOSCH
7700

Dr L V Shannon (Chairman) Tel: (021) 253900
Working Group on Remote Sensing
Sea Fisheries Research Institute
Private Bag X2
ROGGEBAAI
8012

Dr N M Walters Tel: (02231) 75101
Environmental Information and Remote Sensing Programme
Division of Earth, Marine and Atmospheric Science and Technology
P O Box 320
STELLENBOSCH
7600

The Director Tel: (011) 6424693
Division of Microelectronics and Communications Technology
CSIR
P O BOX 395
PRETORIA
0001

For attention: Programme Manager, Satellite Applications Centre

RECENT TITLES IN THIS SERIES

48 A bibliography of seabirds in the waters of southern Africa, the Prince Edward and Tristan Groups. J Cooper and R K Brooke. December 1981. 297 pp.

49 *National Geoscience Programme. The evolution of earth resource systems. SACUGS. June 1981. 42 pp.

50 South African Antarctic Biological Research Programme. SASCAR. July 1981. 54 pp.

51 South African Marine Pollution Monitoring Programme 1979-1982. R J Watling and C E Cloete (editors). July 1981. 52 pp.

52 *Structural characterization of vegetation in the Fynbos Biome. B M Campbell, R M Cowling, W J Bond and F J Kruger in collaboration with D P Bands, C Boucher, E J Moll, H C Taylor and B W van Wilgen. August 1981. 19 pp.

53 *A bibliography of fynbos ecology. M L Jarman, R M Cowling, R Haynes, F J Kruger, S M Pierce and G Moll. August 1981. 73 pp.

54 *A description of the Benguela Ecology Programme 1982-1986. SANCOR: W R Siegfried and J G Field (editors). March 1982. 39 pp.

55 Trophic ecology of Lepidoptera larvae associated with woody vegetation in a savanna ecosystem. C H Scholtz. June 1982. 29 pp.

56 Man and the Pongola floodplain. J Heeg and C M Breen. June 1982. 117 pp.

57 *An inventory of plant communities recorded in the western, southern and eastern Cape Province, South Africa up to the end of 1980. C Boucher and A E McDonald. September 1982. 58 pp.

58 A bibliography of African inland water invertebrates (to 1980). B R Davies, T Davies, J Frazer and F M Chutter. September 1982. 418 pp.

59 An annotated checklist of dung-associated beetles of the Savanna Ecosystem Project study area, Nylsvley. S Endrödy-Younga. September 1982. 34 pp.

60 *The termites of the Savanna Ecosystem Project study area, Nylsvley. P Ferrar. September 1982. 41 pp.

61 *Conservation of Ecosystems: Theory and Practice. A report on a workshop meeting held at Tsitsikamma, South Africa, September 1980. W R Siegfried and B R Davies (editors). September 1982. 97 pp.

62 *A description of the Grassland Biome Project. M T Mentis and B J Huntley (editors). October 1982. 29 pp.

63 Description of a fire and its effects in the Nylsvlei Nature Reserve: A synthesis report. M V Gandar. October 1982. 39 pp.

64 Terrestrial ecology in South Africa - project abstracts for 1980-1981. December 1982. 148 pp.

65 *Alien invasive vascular plants in South African natural and semi-natural environments: bibliography from 1830. V C Moran and P M Moran. December 1982. 42 pp.

66 Environmental research perspectives in South Africa. December 1982. 39 pp.

67 The SANCOR Estuaries Programme 1982-1986. February 1983. 43 pp.

68 The SANCOR Programme on Coastal Processes April 1982 - March 1988. D H Swart (editor). February 1983. 30 pp.

69 Guidelines for the management of large mammals in African conservation areas. The proceedings of an international workshop held at Olifants Camp, Kruger National Park, South Africa. A A Ferrar (editor). May 1983. 95 pp.

70 *Marine linefish programme - priority species list. SANCOR. J H Wallace and R P van der Elst (editors). May 1983. 113 pp.

71 *Mineral nutrients in mediterranean ecosystems. J A Day (editor). June 1983. 165 pp.

72 South African programme for the SCOPE project on the ecology of biological invasions. A description and research framework produced by the Task Group for Invasive Biota of the National Programme for Environmental Sciences. July 1983. 25 pp.

73 *South African marine pollution survey report 1976-1979. B D Gardner, A D Connell, G A Eagle, A G S Moldan, W D Oliff, M J Orren and R J Watling. September 1983. 105 pp.

74 Ecological notes and annotated checklist of the grasshoppers (Orthoptera: Acridoidea) of the Savanna Ecosystem Project study area, Nylsvley. M V Gandar. November 1983. 42 pp.

75 *Fynbos palaeoecology: a preliminary synthesis. H J Deacon, Q B Hendey and J J N Lambrechts (editors). December 1983. 216 pp.

76 *A South African perspective on conservation behaviour - a programme description. A A Ferrar (compiler). December 1983. 34 pp.

77 Limnology and fisheries potential of Lake Le Roux. B R Allanson and P B N Jackson (editors). December 1983. 182 pp.

78 Limnology of Lake Midmar. C M Breen (editor). December 1983. 140 pp.

79 The limnology of the Touw River floodplain. B R Allanson and A K Whitfield. December 1983. 35 pp.

80 *SANCOR: Summary report on marine research 1983. SANCOR. February 1984. 52 pp.

81 *South African Antarctic Earth Science Research Programme. SASCAR. February 1984. 53 pp.

82 *The SANCOR Marine Sedimentology Programme January 1984 - December 1988. I C Rust (editor). March 1984. 15 pp.

83 *A description of major vegetation categories in and adjacent to the fynbos biome. E J Moll, B M Campbell, R M Cowling, L Bossi, M L Jarman and C Boucher. March 1984. 29 pp.

84 Environmental research perspectives in South Africa. February 1984. 77 pp.

85 Invasive alien organisms in the terrestrial ecosystems of the fynbos biome, South Africa. I A W Macdonald and M L Jarman (editors). April 1984. 72 pp.

86 *Terrestrial ecology in South Africa - project abstracts for 1982-1983. May 1984. 198 pp.

87 Conservation priorities in lowland fynbos. M L Jarman. 1986. 55 pp.

88 A synthesis of plant phenology in the fynbos biome. Shirley M Pierce. July 1984. 57 pp.

89 *Aquaculture in South Africa: A cooperative research programme. O Safriel and M N Bruton. June 1984. 79 pp.

90 Pipeline discharges of effluents to sea. D A Lord, F P Anderson and J K Basson (editors). October 1984. 108 pp.

91 Monitoring in South African grasslands. M T Mentis. September 1984. 55 pp.

92 Conservation of threatened natural habitats. A V Hall (editor). November 1984. 185 pp.

93 Limnological criteria for management of water quality in the Southern Hemisphere. R C Hart and B R Allanson (editors). December 1984. 181 pp.

94 Water quality criteria for the South African coastal zone. J A Lusher (editor). December 1984. 42 pp.

95 National Programme for Weather, Climate and Atmosphere Research Annual Report 1984/85. C W Louw (compiler). December 1984. 28 pp.

96 A guide to the literature on research in the grassland biome of South Africa. N M Tainton. December 1984. 77 pp.

97 South African Red Data Book - Birds. R K Brooke. December 1984. 213 pp.

98 Directory of southern African conservation areas. T Greyling and B J Huntley (editors). December 1984. 311 pp.

99 *The effects of crude oil pollution on marine organisms. A C Brown. February 1985. 33 pp.

100 *"SANKON: Opsommingsverslag oor mariene navorsing 1984." SANCOR. February 1985. 51 pp.

101A *"Verslag van die Hoofprogram vir Navorsingsondersteuning." February 1985. 30 pp.

101E *Report of the Main Research Support Programme. February 1985. 30 pp.

102 National Programme for Remote Sensing. Report: 1984. P J van der Westhuizen. February 1985. 50 pp.

103 Bibliography of marine biology in South Africa. A supplement to the 1980 edition. A C Brown. March 1985. 83 pp.

104 The plant communities of Swartboschkloof, Jonkershoek. D J McDonald. March 1985. 54 pp.

105 Simulation modelling of fynbos ecosystems: systems analysis and conceptual models. F J Kruger, P M Miller, J Miller and W C Oechel (editors). March 1985. 101 pp.

106 The Kuiseb environment: the development of a monitoring baseline. B J Huntley (editor). March 1985. 138 pp.

107 Annotated bibliography of South African indigenous evergreen forest ecology. C J Geldenhuys. May 1984. 125 pp.

108 *Review of metal concentrations in southern African coastal waters, sediments and organisms. H F-K O Hennig. August 1985. 140 pp.

109 Coastal dunes of South Africa. K L Tinley. September 1985. 293 pp.

110 The limnology of Hartbeespoort Dam. NIWR. September 1985. 269 pp.

111 Management of invasive alien plants in the fynbos biome. I A W Macdonald, M L Jarman and P Beeston. (editors). October 1985. 140 pp.

112 *The SANCOR Marine Pollution Research Programme 1986-1990. October 1985. 16 pp.

113 Alien and translocated aquatic animals in southern Africa: a general introduction, checklist and bibliography. M N Bruton and S V Merron. October 1985. 59 pp.

114 A synthesis of field experiments concerning the grasslayer in the savanna regions of southern Africa. T G O'Connor. October 1985. 126 pp.

115 *South African marine pollution survey report 1979-1982. B D Gardner, A D Connell, G A Eagle, A G S Moldan and R J Watling. December 1985. 81 pp.

116 Basic needs in rural areas. A report on a seminar held in Cape Town on 19 February 1985. December 1985. 103 pp.

117 South African Red Data Book: Plants - fynbos and karoo biomes. A V Hall and H A Veldhuis. 1985. 144 pp.

118 Invasive alien plants in the terrestrial ecosystems of Natal, South Africa. I A W Macdonald and M L Jarman (editors). 1985. 88 pp.

119 Invasive alien organisms in South West Africa/Namibia. C J Brown, I A W Macdonald and S E Brown. 1985. 74 pp.

120 The impact of climate and weather on the activities of the building and construction industry in South Africa. G du Toit de Villiers (compiler). 1986. 40 pp.

121 Ecological research on South African rivers - a preliminary synthesis. J H O'Keeffe. 1986. 121 pp.

122 A description of the Karoo Biome Project. R M Cowling. 1986. 42 pp.

123 *SANCOR: Summary report on marine research 1985. SANCOR. 1986. 57 pp.

124 The karoo biome: a preliminary synthesis. Part I - Physical environment. R M Cowling, P W Roux and A J H Pieterse (editors). 1986. 114 pp.

125 South African Red Data Book - Terrestrial Mammals. R H N Smithers. 1986. 216 pp.

126 A bibliography of sandy beaches and sandy beach organisms on the African continent. R Bally. 1986. 179 pp.

127 Activities of the National Programmes for Ecosystems and Aquaculture Research, 1983-1985. E W Auret. 1986. 68 pp.

128 Historical sites at the Prince Edward Islands. J Cooper and G Avery. 1986. 80 pp.

129 Richards Bay effluent pipeline. D A Lord and N D Geldenhuys. 1986. 30 pp.

130 An assessment of the state of the estuaries of the Cape and Natal 1985/86. A E F Heydorn (editor). 1986. 39 pp.

131 The conservation of South African rivers. J H O'Keeffe (editor). 1986. 117 pp.

132 SIBEX - II: Report of the South African study in the sector (48-64°E) of the Southern Ocean. D G M Miller (editor). 1986. 47 pp.

133 The regional landscape: Nylsvley in perspective. P G H Frost. 1987. 26 pp.

134 South African Southern Ocean research programme. SASCAR. 1987. 58 pp.

135 Disturbance and the dynamics of fynbos communities. R M Cowling, C D le Maitre, B McKenzie, R P Prys-Jones and B W van Wilgen (editors). 1987. 70 pp.

136 "SANKON: Opsommingsverslag oor mariene navorsing 1986." SANCOR. 1987. 45 pp.

137 South African Red Data Book - Fishes. P H Skelton. 1987. 199 pp.

138A "Verslag van die Hoofprogram vir Navorsingsondersteuning - September 1984 - Junie 1987". 1987. 23 pp.

138E Report of the Main Research Support Programme - September 1984 - June 1987. 1987. 23 pp.

139 Marine Research in Natal. Proceedings of a symposium and workshop held at Durban, South Africa, 10 and 11 February 1986. A P Bowmaker, D van der Zee and J H Ridder (editors). 1987. 184 pp.

140 An environmental impact assessment of a proposed emergency landing facility on Marion Island - 1987. Report to the Minister of Environment Affairs. G Heymann, T Erasmus, B J Huntley, A C Liebenberg, G de F Retief, P R Condy and O A van der Westhuysen. 1987. 209 pp. (Available only from Department of Environment Affairs)

141 A preliminary synthesis of pollination biology in the Cape flora. A G Rebelo (editor). 1987. 254 pp.

142 The karoo biome: a preliminary systhesis. Part II - vegetation and history. R M Cowling and P W Roux (editors). 1987. 133 pp.

143 The Vaal River catchment: Problems and research needs. E Braune and K H Rogers. 1987. 36 pp.

144 A description of the Fynbos Biome Project intensive study site at Pella. M L Jarman (editor). 1988. 125 pp.

145 A description of the Research Programme for Wetlands. R D Walmsley. 1988. 26 pp.

146 The River Research Programme. A A Ferrar, J H O'Keeffe and B R Davies. 1988. 28 pp.

147 Dictionary of forest structural terminology. C J Geldenhuys, R S Knight, S Russell and M L Jarman (editors). 1988.

148 SANCOR: Summary report on marine research 1987. 1988. 60 pp.

149 Final Report of the Bagasse Programme. J C Patterson-JOnes (editor). 1988. 250 pp.

150 Atmospheric pollution and its implications in the Eastern Transvaal Highveld. P D Tyson, F J Kruger and C W Louw. 1988 150 pp.

151 South African Red Data Book - Reptiles and Amphibians. W R Branch (editor). 1988. 235 pp.

152 Remote sensing in the marine environment. L V Shannon and L Y Shackleton. 1988. 54 pp.

* Out of print.