CSIRO
Division of Groundwater Research

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Western Australian
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FINAL REPORT
FIRTA PROJECT 81/56

APPLICATION OF SATELLITE REAL-TIME SEA SURFACE TEMPERATURE DATA TO THE TUNA, SALMON, AND PILCHARDS FISHERIES

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D.G. Myers

P.T. Hick

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1.0 INTRODUCTION

1.1 INTRODUCTION

This is the final report for FIRTA project 81/56. The principal objective has been to study the application of real-time satellite-derived sea surface temperature measurements in assisting particular fisheries located in southern waters of Australia. Initially proposed for a three year period from 1981 to 1984, the project was granted an extension into a fourth year. It has been jointly conducted by the School of Electrical and Electronic Engineering of the Western Australian Institute of Technology, and the Remote Sensing Section of the CSIRO Division of Groundwater Research.

Satellites have much to offer the fishing industry. The polar orbiting NOAA satellites scan every part of the earths surface twice per day - once during sunlight hours and then exactly twelve hours later during the night - and there are usually two satellites in orbit at any one time. Sensors on these satellites provide image data from which the average surface temperature of the ocean over one kilometre square areas can be computed to within 0.5^{o}C. This temperature is strictly the ocean skin temperature, but given normal ocean conditions, such measurements reflect the upper 250 m of ocean water movements. Some commercial species of fish or the food sources of such fish are known to be temperature sensitive or prefer a habitat which is in some way influenced by ocean currents. For these species satellites offer a very fast, convenient, and inexpensive means of exploitation. Satellites scan a vast area of the ocean and do so at a far higher frequency than is practicable with aircraft. Moreover, a single satellite data set can be used for several different fisheries in numerous locations. Satellite-derived ocean current mapping can be used to determine optimal energy regimes for all classes of shipping, and so all sectors of the fishing industry.

The application of satellite imagery to the fishing industry was initiated in the United States in the late 1970's. Experimental programs verified its value on both the West and East coasts. Although this work continues, the most significant activity is now being undertaken by Japan. The fact that the Japanese will shortly launch a maritime research satellite with sensors remarkably well tuned to the needs of commercial fishing is significant.

This project was the first use of satellite near real-time imagery in the Australian fishing industry, and only became possible with the construction of a NOAA receiving station at WAIT. Overseas experience suggested satellite imagery could be of benefit to Australia, and in broad terms, the project set out to prove this. Three major steps were required in reaching that objective. First, to gather and process satellite data. Second, to obtain catch and related data from the fishermen concerned. Third, and most importantly, to compare the two and identify the correlations which would form the mechanisms for any long term operational service to the fishing industry.

This report is divided into sections that reflect these three divisions. In addition, there are some further divisions reflecting practical and philosophical issues which arose in the course of executing the project. In concluding, recommendations are given but these are divided into two parts. We make recommendations on practical steps to utilise the results of this work, and in addition, we outline future possible research activity in this field.

1.2 OBJECTIVES OF THE PROJECT

The initial objectives of this project were jointly formulated by Dr Frank Honey of CSIRO and Dr William Carroll of WAIT in 1981. At that time, the tuna fishery in Western Australia in particular was in decline while costs were rising steeply, and action was called for to assist the fishermen concerned. Overseas experience had established that satellite measurements could be of value to various fisheries, and provide a similar service to spotting aircraft. Since the industry in Western Australia was too small to sustain aircraft, it seemed worthwhile to formulate a project along these lines.

The project objectives put forward outlined three procedures each lasting one year. The first was devoted to examining existing fish catch data, and formulating procedures for gathering data from the industry in later years. The second was to be devoted to examining correlations between fish catches and satellite measurements. The third year would then see an experimental procedure whereby a control group of fishermen provided with satellite-derived data would be compared against the general industry.

Apart from the scientific objectives, there was one experimental objective worth noting. It was recognised the distribution of information would be a problem, and hence the intention was in the third year to derive contour maps which would be transmitted to the fishing ports using conventional facsimile methods. The approach was adopted as it had been, and largely still is, the method used in Japan and the United States.

It is important to note one of the main thrusts of these objectives. It was to aid the industry by finding a method to <u>increase</u> catches. The intention in short was to show satellites could be effective in increasing the productivity at sea.

1.3 CHANGES IN OBJECTIVES

In hindsight, some of the initial objectives were niave. Certainly, objections were raised at the time which should have been given greater attention. Nevertheless, the dramatic changes that have occurred within the fishing industry over the past four years could not have been foreseen, and these changes required quite substantial modifications in the objectives.

The continuing decline in tuna catches in Western Australia lead to the imposition of quotas. In the early years of the project, the catch decline had the effect of making fishermen very reluctant to supply catch data, or all the catch data requested. Then when quotas were established, it was an industry quota not one on individual fishermen, and this changed the fishermens attitude to one of extreme reluctance. They regarded these data as information of considerable commercial value, and they were concerned about confidentiality. In view of this, and the fact that the quota was most unlikely to increase in the near future, it was clearly pointless for the project to emphasise increasing catches. Rather, the emphasis should shift to the other major concern of the industry; reducing costs. Furthermore, it would obviously be inadvisable to have a priviliged group of fishermen regardless of the scientific need to establish any procedures developed.

The first year of the project encountered some significant difficulties. It was found existing catch, position, and temporal data were incomplete, and of negligable use. Liason was established with the fishermen to try and rectify this, but then it was found many boats did not have positioning equipment. Although the initial project was framed for the salmon, tuna and pilchard fisheries, it was also found in that year that the site-specific nature of the former two made satellite observations of limited use.

Another problem encountered in the first year was the extent of cloud contamination of the target region, viz. Cape Leeuwin to Esperance. Existing records did not suggest the degree of cloud cover encountered in the satellite data. As well, preliminary satellite data acquired prior to the project from the United States did not suggest a problem. In view of this, it was thought at the time it was simply an abnormality. However, in later years it was found this was indeed the normal situation. This fact had quite an influence on the execution of the project, and is discussed more fully later.

The second year of the project began with the expectation of forming correlations between the two sets of data. However, it soon become apparent that the anticipated cooperation with the fishermen was not generally forthcoming. Only very meagre catch data were obtained, and while that was enough to establish some preliminary conclusions and satisfy the team a successful end result would be achieved, it was far from sufficient to form a conclusive result.

The third year saw the abandonment of the idea of having a control group of fishermen, and a number of new initiatives were attempted to gain the necessary catch data. Cloud cover in that season was particularly bad, and the season itself was poor. Thus it proved very difficult to correlate the little catch data that was obtained with the few clear images of the ocean that were acquired.

In requesting an extension, the cumulative effect of these different problems was recognised, and a new set of objectives were proposed. They were as follows. First, only the tuna fishery would be considered. Second, the central theme of the project would be to seek methods by which satellite measurements could reduce the costs of this fishery. That is, to find methods by which fish could be located with precision and so minimise fuel costs of the fishermen. Third, in recognition of the practical difficulties facing the industry, there would be no attempt to favour one group of fishermen over another. Data would be supplied to all, and success or failure of the project would be judged by the value the industry placed on the services provided. A two year extension was requested, but only one year was granted. This necessitated some changes in the execution of the project, but not in the objectives. These changes mainly concerned the acquisition and distribution of data, and details will be given in later paragraphs.

1.4 SOUTH AUSTRALIAN ACTIVITIES

It is one of the regrets of the project team that this work was not extended into South Australia. This had been the intention because the South Australian fishery is accessing the same resource as the Western Australian, and it is a larger fishery. In the early part of the project, contact was made with South Australia, but only tentatively. Later, the personnel changes, pressure of the work, and other committments prevented the contact that had been planned. Nevertheless, satellite data were acquired, and it is possible to undertake some form an historical study.

1.5 PERSONNEL INVOLVED

The initial principal investigators were Dr Frank Honey of CSIRO an Dr William Carroll of WAIT. They were supported by a diverse group of specialists within both organisations. Once the initial grant was received, Mr Larry Podmore was appointed Experimental Officer, and much of the early preparation and fieldwork was performed by him.

As work proceeded, Mr Peter Hick of CSIRO became progressively more involved. It soon became apparent that the workload on both Mr Podmore and Mr Hick was too great, thus additional assistance was sought. This was initially provided by Mr Andrew Dobrowolski who accepted a short term appointment, and then by Mr Micheal Ivanac.

In January 1983, Dr Carroll left the project to take up a temporary position in Saudi Arabia. (He later resigned from WAIT to accept a position at RMIT.) Dr Douglas Myers then took control at WAIT, and has continued as principal investigator to the end of the project.

In May 1984, Dr Honey resigned from CSIRO to enter private industry. His position was not filled until after the project had been completed, thus Mr Hick assumed control at CSIRO.

In June 1984, Mr Ivanac left WAIT for a position at CSIRO. Mr Manh Vuong replaced him. Mr Ivanac continued to do work for the project until he left CSIRO in October of that year for a post with the South Pacific Commission. Dr John Wells replaced him, and has concentrated on the data transmission problem to the fishing ports. Also in that month, Mr Podmore left the project for another within WAIT. He was replaced by Mr Ian Rumble. Mr Rumble later resigned in March of 1985, and Mr Christopher Hickman was appointed for the remainder of the project.

For the 1984/85 season, funds were requested for liason officers in four ports. However, for a variety of reasons, it was impossible to do this. Mr Don Pearson, a former leading tuna skipper, was appointed as liason officer though, and he acted for the project along the entire south coast of Western Australia.

During the course of the project, short-term appointments were made at critical times. Those involved were Mr Andrew Dobrowolski as mentioned, Mr Ming Kwan and Mr Cornelius Neinaber. As well, a number of individuals made voluntary contributions to the project. Students at WAIT included Nickolas Andronis, Murray Thomas, Ian Halse, Liugi Iemi, Colin Bascombe, John Coffey, Roger Harrington, Steven Baines, Francis Baruch and Thomas Lam. Others at WAIT and CSIRO who assisted were Mr Steven Boak, Mr Noel Gardiner, Mr Kevin Gray, Mr Steven Llewellin, Dr Fred Prata, Mr Ian Tapley and Mr Alan Pearce. Mention must also be made of the many individuals in the canning industry, the DPI and the State Fisheries Department who provided advice and assistance.

2.0 DATA ACQUISITION

2.1 INTRODUCTION

Data acquisition covers two topics. First, the acquisition of satellite data, and second, the acquisition of fish catch data from fishermen or other sources.

2.2 THE NOAA SERIES OF SATELLITES

Satellite data used in this project emanated from the NOAA series of satellites. These are a polar orbiting, sun-synchronous series of satellites operating at a nominal altitude of 850 kms. Orbital inclination is 99°. At any time, there are usually two operating satellites in orbit, with one assuming an afternoon ascending node and the other the evening. That is to say, one satellite passes northwards in the afternoon and the other in the evening. As of the 1st of July 1985, the two satellites in operation are NOAA 8 in the evening orbit and NOAA 9 in the afternoon. NOAA 8 ascends between 6.00pm and 8.00pm each day, and NOAA 9 between 1.00pm and 3.00pm. Since the satellites are sun-synchronous, they pass over the same area in a descending node exactly 12 hours after ascending. Thus NOAA 8 gives data at about dawn, and NOAA 9 gives data in the early morning.

At the present time, there are in fact four NOAA satellites in orbit. NOAA 6 did provide some services, and suffers from several malfunctions, but is still on standby. NOAA 7 is also currently on standby, but did have a few minor problems when last operated. NOAA 8 had failed almost completely, but NASA has managed to restore its functions and it has just taken over from NOAA 6. NOAA 9 is functioning perfectly at this time. A new satellite to assume the evening orbit is due for launch in late 1985, and after trials, it will replace NOAA 8 which will then be placed on standby. These and all NOAA satellites until about 1992 are essentially the same. However, there are minor adjustments between the different units, and satellites intended for the evening orbit only carry a four band radiometer instead of a five.

NOAA satellites broadcast continuously, and these transmissions are accesible to anyone with the appropriate equipment. As a courtesy, the sponsoring agency - the National Oceanographic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce - should be informed of activities. Data products may be derived from the transmissions and sold to third parties without restriction. This series is guaranteed until 1992, at which time a new program will commence. It is highly probable the new series will be very similar to the existing, but carry more instruments, and more refined instruments. There is still discussion within the United States and between external users on the exact form of the service, but at this time it seems unlikely there will be any major changes.

Broadcasts by the NOAA satellites are on two frequencies. One is the VHF APT (Automatic Picture Transmission) and this is intended to provide information for weather forecasters that is similar and compatible with other satellite services. Thus the transmission is a facsimile transmission which combines and degrades some of the picture data. The U.S. has indicated it would like to phase this service out in spite of there being some 5000 receiving sites throughout the world. The other broadcast is the S-band HRPT (High Resolution Picture Transmission) on a frequency of about 1.7 GHz. HRPT includes all the data collected by the satellite, and is not just picture data. Indeed, it includes various measurements on the satellites internal systems.

There are six major instruments on NOAA satellites, of which four can be of use to a project like this. However, only one was actually used. The other three are :-

a) DCS/ARGOS

The Data Collection System or ARGOS is a simple data logging instrument on the satellite provided by the French. It was originally intended as an inexpensive means of gathering low data rate environmental information such as water temperature, wind speed, air pressure and so on from ocean buoys. Therefore, ARGOS is designed to be very simple to use and to be able to handle almost any data format. The ground station only requires a very basic transmitter which costs about $2,000, and the satellite can either act as a relay or it can store the data for later recovery in France. To use ARGOS requires negotiating with the French for a transmission time slot. The service is not free, but the charges are minimal. It is an ideal way of gathering sea truth data.

b) MSU

The Microwave Sounding Unit measures the microwave emissions from the earth's surface. The pixel dimension is 50 kms which limits its usefulness, but it has the advantage of not being affected by clouds. These data can be used as an independent calibration source for temperature measurements.

c) HIRS

The High Resolution Infrared Sounder is a true sounding instrument of particular interest to meteorologists. It measures surface emissions in the infrared band at 20 closely spaced frequencies located about an atmospheric window. These measurements enable a temperature profile of the atmosphere to be calculated for the column directly below the satellite. These calculations not only provide a useful calibration, but also can act as an alert for unusual conditions likely to cause artifacts in the picture data.

The major instrument on NOAA satellites and the one exclusively used in this project is the Advanced Very High Resolution Radiometer (AVHRR). This is a five channel (four on the evening ascending satellites) scanning radiometer measuring emitted and reflected radiation in the visible, near infrared, mid infrared, and far infrared bands. The instruments spectral characteristics are as follows :-

CHANNEL	SPECTRAL RANGE (microns)
1	0.550 - 0.600
2	0.755 - 1.100
3	3.550 - 3.930
4	10.500 - 11.500
5	11.500 - 12.500

Channel 2 responds purely to reflected energy, channel 3 to a mixture of reflected and emitted, and channels 4 and 5 purely to emitted radiation. All satellites use these bands but there are slight differences in the spectral window shapes, and the four band systems omit channel 5. The spatial resolution of the instrument is 1.1 kms at nadir, which is an IFOV of 1.3 mrads. The total angle scanned by the satellite is $+56^{o}$ to -56^{o} and 2048 samples are obtained per scanning line. The scan rate is six lines per second, and as the satellite is normally in view for about 15 minutes, the maximum acquisition is about 5500 lines. Since the radiometric resolution is 10 bits, an AVHRR image set is about 70 M bytes. The swath is approximately 3000 kms wide, hence this set shows an area approximately 6000 kilometres by 3000 kilometres.

The satellite is near sun - synchronous, and there is an eastward movement in the orbital path of about 300 kms per day, plus a shift in the pass time of about 11 minutes per day. Thus there is a 10 day periodicity in acquisition. The extreme swath of the satellite means that resolution falls to over 4 kms at the edges of the image, and considerable geometric distortion is evident. For a given area of interest then, this periodicity and the distortion means useful data can only be obtained about 7 or 8 days in every 10, and possibly less depending on the resolution requirements.

The extremely wide swath of NOAA means a single ground station at Alice Springs can gain coverage of the whole of Australia every day (with some slight problems due to the distortions). However, the existing facility at WAIT in Western Australia not only covers W.A., S.A. and the Northern Territory but also the ocean to some 3000 kms to the west. Thus for marine applications, what is needed is three stations located at Perth, Darwin and Sydney or Melbourne.

The five channels of AVHRR data can be used for many purposes. Channel 1 is about half the visible band and is useful for surface data. Channel 2 shows cloud formations particularly well. Channel 3 is ideal for monitoring gas flares, bushfires and the like, and as it monitors both emitted and reflected radiation, gives useful data at night. Channels 4 and 5 only measure emitted radiation, and so provide data at all times.

Individually, the channels provide much useful data, and certainly much more than is suggested here. Collectively they provide even more. Two combinations of bands are worth commenting upon. The first involves channels 1 and 2. The reflectance of green vegetation in the channel 1 band is fairly slight while in channel 2 it is high. The difference between the two is therefore an indicator of vegetative vigor. It is common practise to use the Normalised Vegetation Index (NVI), or Greenness Index as it is often called, which is a combination of channels 1 and 2 as follows :-

$$NVI = (2 - 1)/ (2 + 1)$$

This index is only a qualitative measure of chlorophyll content, but it still can be used to detect phytoplankton and algae in water. However, the relatively coarse resolution of NOAA satellites and other difficulties do not make them especially sensitive detectors of this material.

It can be shown that the radiation emitted by a heated uniform body is proportional to its temperature. A single measurement at one frequency then, is theoretically all that is needed to determine temperature, and with the radiometric resolution of NOAA satellites, they should be able to do this to within 0.12° C. In practise, the earth is not uniform, the surface has a variety of different materials upon it, the atmosphere is not uniform and absorbs radiation, and so temperature measurements using a single frequency suffer spatially-dependent errors. Moreover, these errors are very substantial. However, it can be shown that if <u>two</u> measurements are made, then the error in calculating temperature can be quite small. For NOAA satellites, it becomes of the order of 0.5° C. Further, the temperature is found by a linear weighted sum of the two measurements. If three measurements are available, then the error can be further reduced, but not as significantly. It is better in this case to use HIRS to estimate the atmospheric effects and correct for them. Claims of temperature estimates of within 0.2° C have been made in the literature for this approach.

Although this method of computing surface temperature seems relatively simple, there are some problems to note. First, it is necessary to calibrate the data due to drift in the instrument. To do this, the instrument is turned to view a precisely heated source within the satellite, and deep space, and these two measurements provide temperature extremes for calibration. Second, it is most important to note that if two images are added or subtracted, the noise in the result is always the RMS sum of the noise in each. Hence one reason for avoiding three measurement calculation of temperature is because it significantly increases the noise in the temperature image while increasing its accuracy only marginally. Third, the residual error in the temperature image can produce artifacts. Most can be attributed to atmospheric phenomena of one kind or another. A particular problem here is sub-pixel cloud. That is, cloud less than a kilometre square in size and so below the resolution of the satellite. This cloud affects the average value of measurements within the pixel, but is otherwise difficult to detect. Finally, it is important to note that with the four band satellites, temperature is usually impossible to calculate. The reason for this is that channel 3 is corrupted with reflected radiation, including in winter time when this comes from the cloud tops.

The difference between channels 4 and 5 gives some data of interest. Since the bands are spectrally so close together, there should be very little difference between them. This is largely true, but the variation that does exist can be quite interesting. Most of it is attributable to atmospheric variation, but the rest would seem to be a qualitative, and possible quantitative measurement of surface state. Foam and spray caused by rough conditions are known to give some variation in surface emissions.

2.3 THE WAIT FACILITY

Prior to the commencement of this project, the School of Electrical and Electronic Engineering at WAIT had built and installed a 5 metre parabolic antenna with the intention of receiving GMS transmissions. For this project, that antenna was mounted on an old Bofors gun mount in order to give it some tracking ability. Also, the School provided a receiver and monitoring facilities from its resources. However, several additional items were needed before this system could be used for NOAA acquisition.

The task of developing and installing that equipment fell to L Podmore. He assembled the first system and made it functional. In the light of experience gained, better equipment was later developed and installed by Mr N Gardiner, Supervising Technician with the School's communication section.

One of the key pieces of apparatus needed was an interface between the receiving system and WAIT's computer system. This interface had to detect a transmission and put it into an acceptable computer format. The first interface built was designed and constructed by N Andronis while he was a student at WAIT. He also developed the software needed by the unit. Subsequently, an improved interface was developed by L Podmore and A Dobrowolski, and the software was further refined by S Boak. Later still, an even more advanced interface was developed by C Neinaber which amongst other things, reduced the need for much of the software.

The prototype system was created quite quickly, and has worked very satifactorily for some time. It has one major flaw though, namely that it requires manual operation at all times. While this ensures great accuracy and good quality control, it also means two operators must be present which is most inconvenient for three of the four daily overhead passes. This labour problem had been recognised before the project began, and remedial steps had been taken. A 4.6 metre Cassegrain focus antenna had been obtained with a mount equipped with drive motors. As well, work had commenced on developing an antenna control system for automatic tracking. Manpower difficulties plus the non-availability of parts delayed this work for quite some time, and it was not operational for any of the seasons covered by this project.

2.4 SATELLITE DATA ACQUISITION

When the satellite will pass within range of the WAIT facility can be determined via orbital prediction software. Acquisition with the prototype system then involves two people actually tracking the satellite according to those predictions. That takes about 15 minutes. Immediately after acquisition, it is necessary to perform some basic processing and to archive the data. That takes one operator about 30 minutes. Subsequent correlations of SST images with catch data requires significant time and computation.

When the project began, it had been anticipated based on the best information available that three acquisitions per week were all that was needed. Indeed, for ocean observations that is quite sufficient, but they must be three clear observations per week. What had not been foreseen was the extent of cloud cover. This was so extensive that in practise, acquisitions were needed every day, and sometimes several times per day, in order to gain sufficient clear views. That is, a more than doubling of the anticipated requirement, and an increased demand on resources.

Since more effort had to be devoted to acquisition, there was a consequent reduction in effort elsewhere. As well, there was an added burden placed on the team. However, even with this increased effort, there were times when it wasn't sufficient, and no useful information could be gained. This had an important side effect. Since the continuity in data supply was lost, the fishermen gained an impression the team lacked interest in the project and was unreliable.

This problem arose because the project centred on the south west coast of W.A., and the prevailing weather conditions there make the ocean particularly cloudy. The west coast does not suffer this problem to the same degree, nor do the waters around Esperance or into the Bight. It was just unfortunate this project's area of interest happens to be one of the cloudiest stretches of ocean in Australia.

The problem was exacerbated to some extent by only taking the afternoon passes, as these tend to correspond to peak cloud cover. There is evidence to suggest the two descending passes may have been a better choice but possibly only marginally so. Nevertheless, any future work using a fully automated facility should be strongly encouraged to consider acquisition at these times.

2.5 FISH CATCH DATA

Satellite sensors scan the ocean, and the data they give can be used to derive an image where each point within that image represents the average temperature of the surface over a one kilometre square area at a given time on a given day. Comparing this against fish catch data requires at a minimum knowing the time, location and the size of the catch. It is also useful to know the water temperature as a check against the satellite estimate, but all other data are peripheral.

When this project began, there was no requirement in Western Australia for tuna fishermen to carry logbooks. The first steps taken then, were to supply the fishermen with these, where the books were obtained from the State Fisheries and Wildlife Department. However, at this early stage there was no real incentive for the fishermen to fill in the books, and few did. Those who were diligent frequently overlooked key information such as the time of the catch, and so at the end of the first year, there was little useful information. It had been hoped that data obtained by others prior to this project could also be used, but that was found to suffer the same problems.

In the second year, a revised logbook produced by DPI was distributed. The format of this log presented catch data in a form of some use to the fishermen themselves, and with encouragement from several sources to use the book, it was felt useful data would be obtained. This did not prove to be the case.

A major effort was mounted in the third year to acquire catch data, and to encourage the fishermen to supply it, satellite pictures were provided as often as possible. Fate intervened. The season was particularly cloudy, and sea conditions were reported to be quite abnormal.

In seeking an extension to the project, funds were requested for liason officers. It was clear that catch data would not be forthcoming unless there was direct and persistant contact with the fishermen. Attempts to simplify and improve the data collection in this year were based on the experiences gained in the earlier seasons. The problems likely to be encountered however, were greatly simplified by an unexpected turn of events. The imposition of individual quotas in the 84/85 season which were in total substantially below those of the prior industry quota, decimated the fleet. Although it had been the intention to have four liason officers, in this circumstance, only one was warrented.

Prior to the 84/85 season, the landed catch was of the order of 4500 tonnes, and of this, about 10% was reported to the project team in sufficient accuracy to be of use. The total catch in the 84/85 season was only 392.5 tonnes for the period covered by the team, but of that, some 43% was recorded. That still resulted in less data in total available for analysis.

The study period in this last year was from the 10th October 1984 until the 12th March 1985. During this period, imagery processed at either CSIRO or WAIT in the form of prints was rushed by courier to the ports arriving within 24 hours. Some 38 prints were supplied showing varying degrees of ocean structure.

3.0 INTERPRETATION OF THE EXPERIMENTAL DATA

3.1 INTRODUCTION

It was the expectation of this project that a correlation would be found between sea surface temperature and fish catches that could be used as a predictor of fish location. Early results encouraged this view, and so until quite recently, the teams attitude to data anomalies was that these could be interpreted as artifacts produced by insufficient data. However, following the 1984/85 season's results, a study was made of all the data collected, and the various apparent abnormalities were carefully noted. These were discussed with oceanographers and fishermen. From these discussions, it became increasingly clear they were far from abnormal. Rather, it was seen that the early correlations that seemed to be observed were artifacts of limited observations of a very complex situation.

We now conclude that there exists no significant correlation between the sea surface temperature and concentrations of Southern Bluefin Tuna along the southern coast of Western Australia. Our results show only a weak correlation between fish catches and either absolute temperature or temperature gradients. However, this is not to say that knowing the sea surface temperature is not important. We believe a quite complex interaction exists in southern waters, and temperature is an important parameter in this. We offer an explanation of this interaction within the chapter.

3.2 DATA PREPARATION

Preparing data for analysis was quite simple. The images produced were attached to a card like that included, and catch data was written in and marked on the photograph. Other comments could also be written on the cards covering sea state, weather, and any other information deemed relevant. By examining the cards collectively, further comments could be derived covering the movement of ocean features and similar events. Also on the card is a slide of the complete satellite pass, or a `quicklook'. If the satellite data required further examination, this slide was useful in retrieving the appropriate tape.

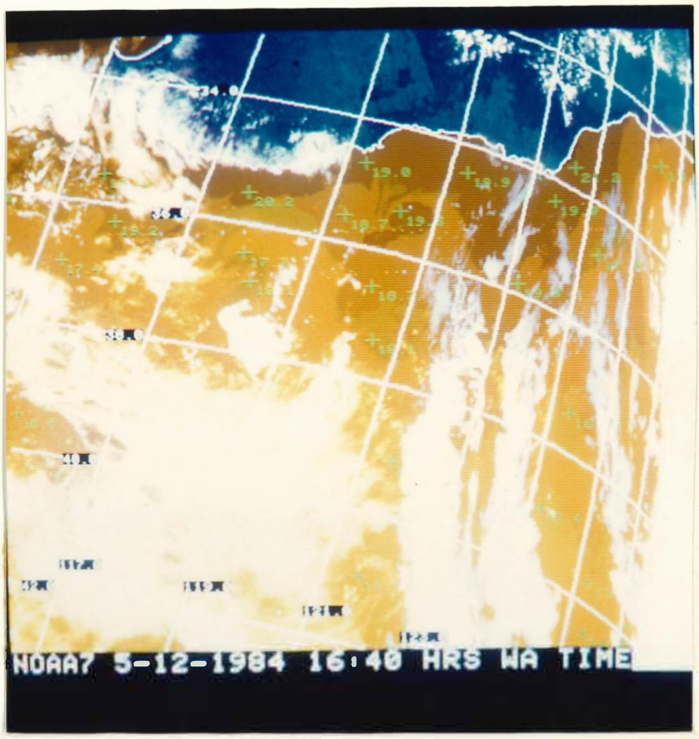
3.3 A STUDY OF THE DATA

Once a card set was completed for a season, then plots could be drawn. In the early part of the project, it was quickly found that plots of catches versus temperature differences across ocean thermal fronts seemed correlated. As well, there seemed to be a definite spatial correlation, but that could be explained by the practice of fishermen of only fishing at particular sites. A further observation was the presence of a periodicity in catches, but at the time, no explanation could be offered for this. These results greatly encouraged the team. As there was insufficient data for any statistically significant result, it was strongly felt that with more data, these results would be confirmed, and so a good correlation would be obtained.

Some of the data collected in the 1984/85 season is presented

N7-17803

5th DEC 84.



C.S.I.R.O. W.A.R.L.

Name ......

TOTAL CATCH THIS DAY ....

TOTAL CATCH FOR WEEK INCL. ....

FL, FP ALBANY:

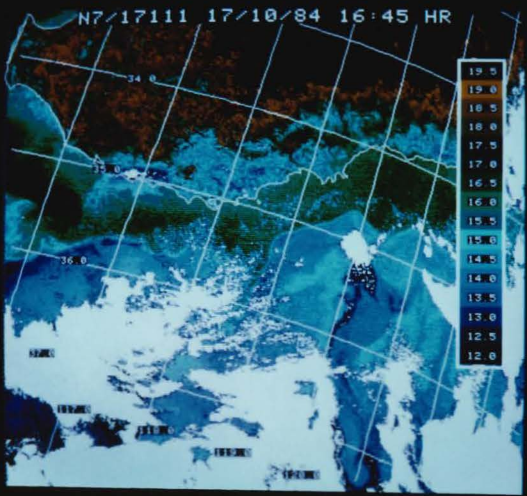
FL, FP ESPERANCE:

Det. ....

here in the two accompanying photographs and the plot of catches versus time. The plot shows two strong peaks, and the photographs show the sea surface temperature imagery produced for each of these periods. The presence of eddy-like structures in these images is very noticable. Although not shown here, imagery of the ocean during the slump periods observed on this plot was striking for the complete absence of these features. A similar result was found to apply to all the previous seasons.

While these eddy structures were found to have a major influence on catches, at no time did any correlation point to these features being the exclusive domain of fish concentrations. It is true significant catches were reported only when these structures were observed, and when they were not then catches were small, but significant concentrations of fish have been sited offshore by aircraft in locations which did not correspond to any of these features.

southern waters. Their catch data was not available to the team, and it is not known what fishing practises they follow. However, they have been reported in the presence of these features, and as well, they fish in the region beyond the range of the shore-based vessels supplying data to this project.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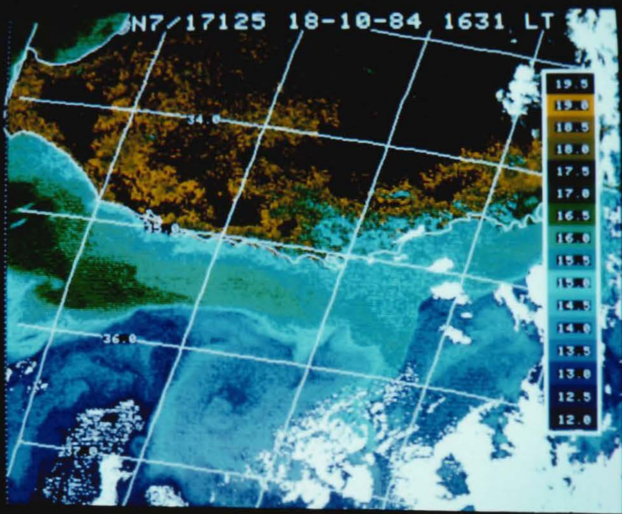
13.0
12.5
12.0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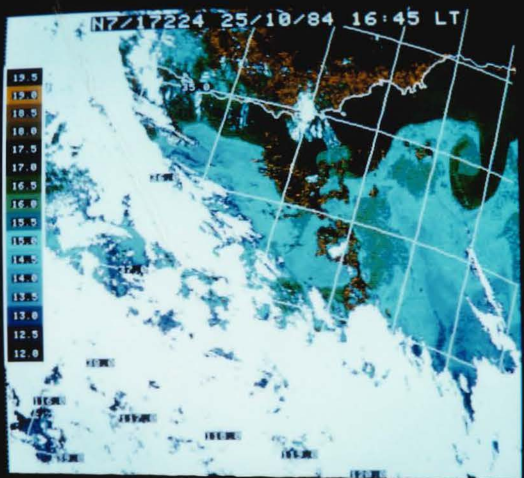
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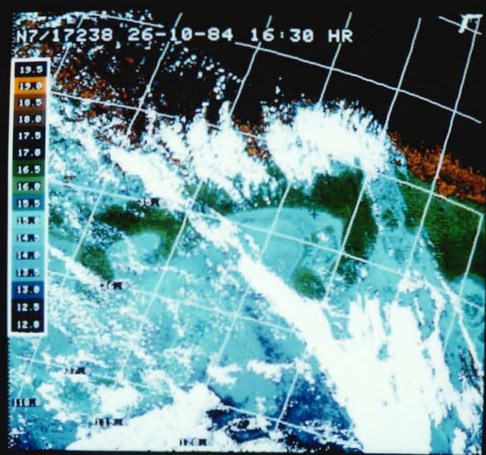
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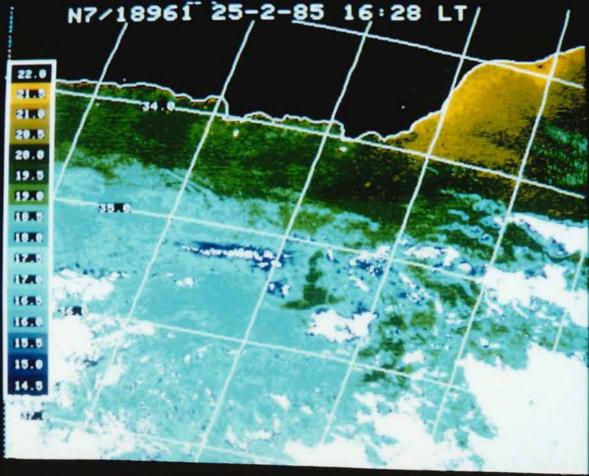
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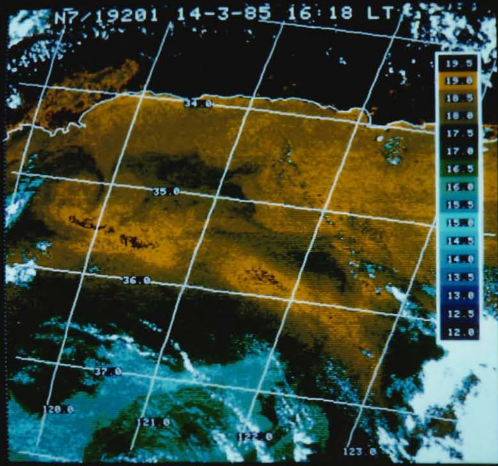
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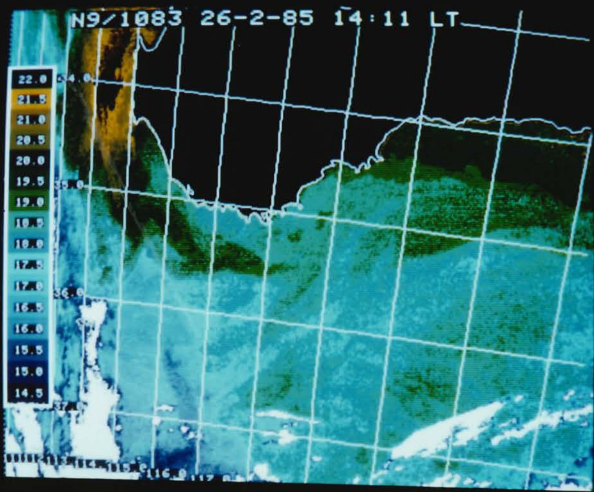
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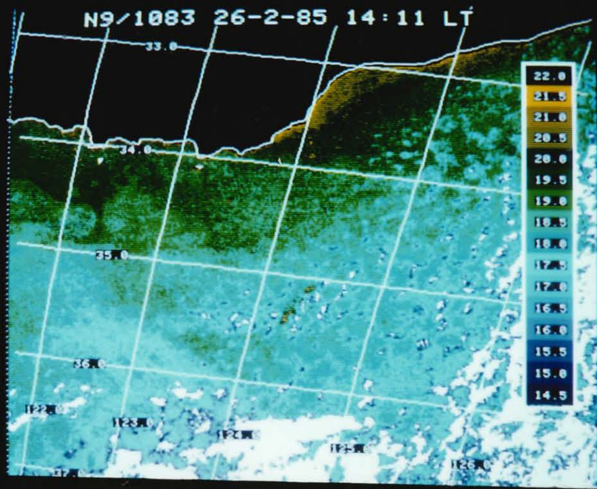
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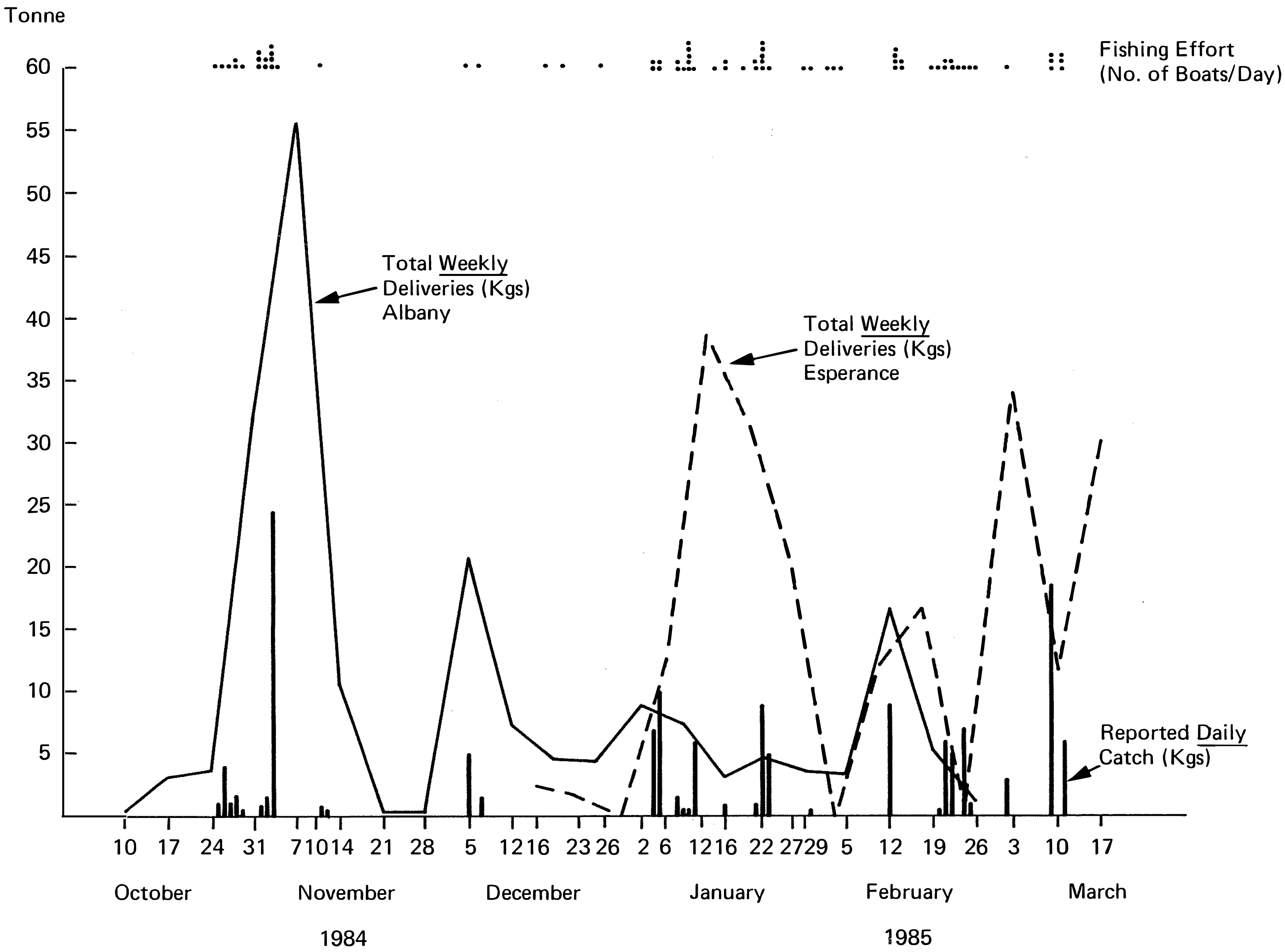
TOTAL TUNA CATCHES FOR ALBANY AND ESPERANCE
FOR OCTOBER 1984 – MARCH 1985



3.4 A MODEL OF THE TUNA FISHING ENVIRONMENT IN SOUTHERN WATERS OF WESTERN AUSTRALIA

Recent research has shown more clearly the mechanisms of ocean movements off Western Australia. The most important is the Leeuwin current. This is a band of warm, low salinity water of tropical origin about 50 kilometres wide and some 200 metres deep that flows southward. From Exmouth to Cape Leeuwin, it flows mainly above the continental slope. At Cape Leeuwin, it turns eastward and flows towards the Great Australian Bight, carrying with it a variety of tropical species of marine fauna.

The speed of the current varies from point to point. Around Cape Leeuwin, it accelerates, rides up onto the shelf, and flows toward the Bight as a shelf current. It remains in this state to at least 124^{o}E after which it may separate from the coastline. Evidence does show though, that in late winter it loses its identity before that by mixing with Bight waters.

The extension of the Leeuwin current eastwards into the bight is well-defined, largely as a shelf flow. Its outer or southern boundery is generally quite closely associated with the shelf break. Given the character of the current, this results in a surface temperature gradient of up to 5^{o}C occurring over a few kilometres in the Cape Leeuwin to Esperance region. The relatively high velocity of this water seems to create a sheer zone as associated with this current in this region is a succession of warm eddy-like features which spin off from the current and interact with the cool southern waters. The generating region for these features seems to be in the vicinity of Cape Leeuwin.

It is these eddy-like features which have largely captured the interest of the team since the project began. There is no question they have a strong influence on catches, but as mentioned, catches are far from dependent on these features alone.

It is important at this stage to make a comment on normal fishing practise in this region. Typically, fishermen based in Albany or Esperance would "troll" along the shelf break in preferred regions of known sub-surface abnormalities known as \`canyons´. These correspond to the seaward margin of the Leeuwin current, and when catches have been reported at these, they have invariably been made within a strong temperature gradient.

We now suggest the following as an explanation of the results obtained in this project. The concentration of tuna within the Leeuwin current is not uniform, but rather, most fish are congregated at the outer edge to take advantage of the better food supply. The eddy-like structures generated at this edge therefore have the effect of concentrating the fish within these structures. On their passage eastward, the major thermal and mixing activity which takes place at the \`canyons´ replenishes the local concentration of fish from the high concentration within the eddy. Hence the reason for significant catches when the eddies pass, and why after an eddy passes, there is a continuing but declining catch at these locations.

Discussions with fishermen and oceanographers give general support to these findings. They have a number of implications, but one relates to the future of the industry in this region. Fishermen are now moving toward larger, more sophisticated vessels in order to seek the larger, more premium-priced fish believed to exist offshore. If our model is correct, then these offshore features should be well-stocked and so the industry should revive. However, this industry will need to give strong consideration to curtailing costs, and that suggests a demand for frequent satellite-derived sea surface temperature information.

3.5 CONCLUSIONS

We conclude that local geographic conditions decide fish location in the southern waters off Western Australia. While we have not proved what we expected to do, we have nonetheless shown that satellite observations can achieve almost all the objectives originally set down. That is to say, as eddy-generation within the Leeuwin current concentrates the fish population, and as the simplest method by far of observing the eddy-generation is by satellite, then satellites offer a very simple and inexpensive means of identifying when to fish and where.

4.0 DATA DISTRIBUTION

4.1 INTRODUCTION

There were two areas where the degree of effort required was greatly underestimated. They were data acquisition, because the extent of cloud cover was not appreciated, and the distribution of data to fishermen. Problems in the latter area arose out of experience with the data, but changing technology now provides a very satisfactory solution to the problem.

4.2 INITIAL SUGGESTION FOR DATA DISTRIBUTION

When this project was first formulated, the stated objective was to derive temperature contour maps as the ultimate data product, and to relay these to the fishermen via a facsimile system. There were a number of sound reasons behind this decision. First, fishermen were familiar with such maps via the normal weather service. Second, it required only low cost equipment, but equipment which in many cases already existed on the fishing boats. Third, such maps have and still are used quite successfully overseas. Within the research team there was some discussion on exactly what form the contour maps should take, but it was generally agreed this was the approach to follow.

Problems were encountered shortly after the first maps were produced. These initial efforts were extremely cluttered, and it proved quite difficult gaining any useful information from them. Differentiating ocean features from cloud was extremely hard, and the ocean conditions produced very complex contours. A number of techniques were attempted to overcome this, including thinning and smoothing techniques, but none were particularly successful. It soon became appreciated that the only real advantage contour maps had was that they were better than no maps, but they were still a long way from being a useful product to the industry.

4.3 PHOTOGRAPHIC PRODUCTS AS A MEANS OF DATA DISTRIBUTION

One of the early misconceptions in the project was that fishermen would find it difficult to interpret satellite images. These images after all, are far from natural images, and after processing to highlight the different features, become a kaleidoscope of strongly saturated colours. The result looks quite bizarre. However, this was not the case at all. With minimal instruction, fishermen could easily interpret the images and compensate for the various distortions which existed. Further, it took them very little time to relate what they saw to sea conditions with which they were very familiar. That being the case, it seemed pointless to continue with contour maps, but to turn to photographs.

At first, monochrome photographs were supplied. The fishermen however, prefered the subtle changes in colour produced in normal image processing. Therefore, colour prints were introduced, and these became very popular. A problem though, was the time taken to produce the prints, and the cost involved. Neither CSIRO or WAIT had facilities for colour print production which meant film had to be delivered to an external processor.

While the photographic service was satisfactory in terms of delivering a good product to the end user, its high cost and the time required to produce prints made it very unappealling as a long term solution. There were also constraints in the service in that couriers and processors do not work at weekends, and so in effect, data could only be supplied around the three days in the middle of the week. By far the most unsatisfactory aspect of the service though, was the time it required. It was taking one person more than two hours per pass to see the production of prints through, and it was taking up to 36 hours for the images to reach the fishermen.

A simple varient was attempted. Polaroid instant slides were used. These can be developed within 5 minutes and so images can be posted within an hour of the pass. Via normal post, they could often reach the fishermen within 12 hours in some cases, but usually 24. While popular in some quarters, and a very useful approach indeed for archiving and related activities, these were not popular with the fishermen. Two reasons were commonly given. First, the small size of the slide. Second, the inability to write on the slide and draw in features.

4.4 FINAL ACTIVITIES WITH RESPECT TO DATA DISTRIBUTION

Although colour prints did prove very successful, their value can be questioned for reasons other than cost, time and inconvenience. A photograph is a fixed record of a scene. If such an image is to be used for quantitative purposes such as the identification of thermal fronts in the ocean, then certain assumptions need to be made concerning the processing of data to best highlight those features. In part, those assumptions assume the end product will be aimed at one purpose, and they must make some form of statement on what is a significant thermal feature and what is not. This is not a satisfactory situation. Expertise is not claimed by any of the team members in the fields of marine biology or oceanography. By nature, each fisherman has his own ideas on what forms optimal fishing conditions based on his own experience, preferred locations for fishing, and his resources. Photographs cannot be regarded as anything more than an intermediate solution to the data distribution problem.

It needs to be recognised that before satellite data can be used for any task, there are some common processing tasks to perform. These include the derivation of temperature images, the rectification or mapping of data to common grid coordinates to eliminate distortion, and the inclusion of coastal boundaries. Once these tasks are complete , the remaining processing is best done by the ultimate end-user of the data. Since each individual fisherman has his own perceived requirements, then each should be in a position of controlling the production of the information he requires. Our experience with an environment like this is that the most important factor in its success is a wide-ranging and intimate knowledge of the sea by the participants. With this foundation, it is very easy to train the fishermen in the techniques of image interpretation.

Personal Computers (PC's) provide a very simple solution to this problem of providing processing. Recent developments in microcomputer technology has produced machines which are more powerful in several respects than the machines used at both CSIRO and WAIT for much of this project. PC's are also relatively cheap at about $4500 for a useful configuration, and they are very easy to expand and upgrade.

The significant attraction of PC's is that many have exceptionally good graphics capabilities. The NEC APC 111 for example, offers a $600 display unit showing 640x400 points in any one of 8 colours. A satellite image of this dimension represents an area of about 700 kms by 450 kms, and that is significantly larger than most fishing grounds. If this image is a temperature image, then 8 particular temperatures could be shown, or 8 given temperature ranges. (Normally though, one colour would need to be used to identify land and another cloud, thus in practise only six temperatures or ranges could be shown.) Now while the difference between any two levels in a NOAA measurement theoretically represents 0.12° C, in practise the actual temperature discrimination is more like 0.5° C. Further, it is quite rare for the temperature difference in the ocean to be more than 4^{o} C in any area. Thus 8 colours are quite sufficient to show all the detail needed.

It is the graphics capabilities of PC's which makes them most appealing for a project like this as they are a very cheap and highly effective means of presenting image data. However, they have other features which add to their usefulness. Conventional secondary storage for such systems is floppy disks, and these are removable and easily stored. Each will hold about two images at very low cost. Thus a user can keep a complete record of satellite imagery for a season, which will give historical data to assist in planning for the next season. It can be quite simple to compare one days imagery against another and observe the changes which allows the user to surmise the strength of ocean currents, and the movement of features. The software needed to achieve this is relatively easy to develop.

The major attraction of PC's is that they largely solve the distribution problem as well as providing an important processing capability. A device called a modem converts any telephone line into a data channel that can be used for computer communication. Provided modems exist at both ends of a line, a user can dial up another computer, gain access to it with his PC acting as a terminal, and transfer data down the line. In this case then, a fisherman can gain access to satellite data within an hour or so of the overpass, and begin processing for the cost of a telephone call. It takes approximately 15 minutes to transmit a 640x400 point image. However, it may not be necessary to have an image this size, as in most cases a fisherman would only be interested in an area of about 300 square kilometres. Also, PC's can be operated at night during the off-peak period. Thus in practise, each transfer should only cost about the same as a colour print.

With this arrangement, the central acquisition and processing site can be completely automated. The processing required is straightforward, and it is quite simple to arrange the software so that potential users know exactly what data are available. The project has been working to that end, and would strongly encourage future efforts along the same lines. Permission to proceed with this approach was not received until the middle of the 84/85 season, and for that reason it was not possible to use it during that season. However, some form of service should be initiated for the 85/86 season.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

The major conclusion of this report is simply expressed. Satellite imagery is a very cheap source of information that can be used with great effect by wide sectors of the fishing industry. It offers a simple yet powerful means of lowering costs. Given the large areas over which many Australian fisheries operate, and the lack of real-time data on ocean conditions, it would be tragic if this vital operational tool was overlooked by the industry.

Our research was confined to examining the application of satellite imagery to the tuna fishery located in southern waters. Although the work was conducted in Western Australia, there is no reason to suppose similar work could not be conducted elsewhere. Although confined to tuna, there is also no reason to suppose other pelagic fisheries could not be assisted in a similar way. Indeed, as will be discussed in more detail further on, there a good grounds for claiming satellite observations can assist every fishery in some way.

5.2 PRACTICAL EXPERIENCES OF THE PROJECT

In a practical sense, the key question in the project was whether the cost of obtaining and using satellite data is covered by the gain to the industry. What is to be discussed here is the factors which influence the cost of obtaining satellite data, which to a large extent means the operational cost of a satellite data acquisition and processing facility.

The experiences described here derive from an experimental facility attempting to verify a research procedure. An operational facility providing a reliable and regular service is operating at the other end of the spectrum, but both must include certain essential elements. The experimental system is attempting to provide the foundations of an operational service, and so it is an excellent guide to the latter.

The key question is the frequency of acquisition, and what that implies for any facility. Our experience is that an operational service must seek to gain every available pass. With NOAA satellites, that is approximately 12 per day divided into four groups of three passes where each of these is 101 minutes apart. Cloud cover can be regarded as random, and so if coverage is required for any given area, every available sample must be obtained. Even so, this may not be sufficient to ensure a regular supply of imagery, but it will ensure that in all situations other than extreme weather conditions.

The raw data must be processed. Early in the project, all that was done was to display the thermal bands (channels 4 and 5) on a monitor using red and green, together with channel 2 for blue. This gave an image where the ocean was yellow, and the tonal variations gave an indicator of temperature. In many respects, that is all that is necessary, as it clearly shows thermal fronts, eddies, tidal flow lines and other features. However, absolute temperature is important in fishing. For most pelagic species, there is a definite temperature range which they prefer, and this needs to be known. For this reason, it would be far better if an operational facility derived a temperature image, and presented that image conforming to a standardised temperature range. Any processed imagery produced must include a gray scale or colour scale showing that range.

Another aspect of processing raw data is rectification. This is the process of correcting distortions in satellite imagery due to the curvature of the earth, the motion of the satellite and the characteristics of the scanner. In an experimental environment, this distortion can be tolerated. In an operational one, it must be transformed into one of the common map projections. In this way, satellite imagery can be referred to entirely in terms of latitude and longitude, and that permits further standardisation.

This transformation is important for other reasons. AVHRR scans on NOAA satellites slightly overlap. Resolution in these overlapping zones is poor, and distortion is high. However, if each pass is rectified, and if the overlapping parts of adjacent passes are then averaged, a reasonable result can be obtained. Resolution is usually limited to about 4 kms, but that still permits useful measurements to be made of ocean parameters. Moreover, it means that a useful product can be derived virtually every day, all other circumstances permitting, rather than just 7 or 8 times in every 10 as is the case with unrectified data. A second reason for performing rectification is that every image shows a given area in exactly the same way. That permits a sequence of images to be displayed, making temporal changes obvious which is useful for observing ocean currents.

Acquisition, derivation of the temperature fields and rectification are tasks which require quite powerful and specialised computing equipment. It is therefore expensive. For that reason, it is best to think in terms of properly equipped regional acquisition sites rather than a series of sites. As mentioned earlier, only three sites are needed to gain coverage of the whole of Australia and the adjacent seas.

Beyond acquisition and this initial processing, the emphasis must be on display and interactive enhancement rather than processing. It needs to be recognised that this stage is concerned with information and its interpretation. Clearly, the user must have the requisite levels of interpretive skills, and without this, his ability or lack of it in manipulating the physical apparatus is of no real consequence. For the fishing industry, that user must be a competant fishermen with an appreciation of the sea and the fishery involved. This tool enhances human abilities; it does not supplant them. It cannot compensate for a lack of ability or experience. Satellite imagery will be a boon to the skilled and but will merely confuse the others.

The physical system must be a resource that is low cost and easy to use, and it must display satellite imagery well. That commends the transmission of data from a regional site, and processing by a Personal Computer. The fact such machines can be used in these circumstances is some cause for awe, but more realistically, is merely a confirmation that advances in technology are generally beneficial.

There are side benefits here. Since Personal Computers have become so popular, there are innumerable enthusiasts who can assist the apprehensive fisherman. As well, since these machines were primarily designed for other applications, business software and other available software opens an opportunity for fishermen to introduce further professionalism into their industry. A final benefit that is of some importance, is that each fisherman performing his own interpretation and processing ensures complete confidentiality.

Personal Computers are becoming faster and cheaper, but the power of a machine is still largely dependent on the software available for it. Software though, can be changed. As a better appreciation is gained of the application of satellite imagery to a given fishery, so better processing software can be developed.

5.3 THE EFFICACY OF SATELLITE OBSERVATIONS

While this project concentrated on finding relationships between satellite observations of ocean temperatures and fish catches, it should be noted they can provide much more than this. An image of the ocean temperature distribution is also to a large degree an image of ocean current distribution. Currents are a significant factor in marine biology, and that makes knowing them vitally important in research. However, it is also important to know them for framing a proper energy regime for shipping. Given the fact fuel costs are extremely high and certain to go higher, this is particularly true for all sectors of the fishing industry.

A question of some interest is how does the assistance provided by satellite observations compare against that provided by FAD's. FAD's in general terms have proved to be a useful means of augmenting catches for some species, but cannot be the sole basis for any but a very small fishery. While they have been quite succesful, FAD's do cost a considerable sum of money, and there is a high loss rate, particularly in active oceans such as those along the south coast. Satellite observations then, are of more general benefit to the fishing industry, but this does not deny a place for FAD's. Satellites can be used very successfully to determine where FAD's should be positioned for maximum effect, and if any should break loose and drift, then satellites can give clues on where they are most likely to be.

5.4 THE ECONOMICS OF SATELLITE OBSERVATIONS

The cost of providing a satellite service is not high in relation to general costs within the fishing industry. As mentioned earlier, three acquisition sites can cover the whole of Australia. Each of these sites requires :-

1. An antenna with amplifiers, receiving system and spare units.
2. A tracking controller for the antenna.
3. A computer with at least 1 G byte of disk storage and 2 M bytes of main memory together with magnetic tape drives and optical disks for archival storage.
4. An array processor.
5. A user console with graphics capability for basic monitoring of acquired data.

An Australian manufacturer fabricates much of this, and the other items are easily purchased. The total cost of the equipment is approximately $200,000. Buildings to accomodate it would cost about the same.

Such a facility can be automatically operated, but there would still need to be at least two people present to provide support. If the system was a completely independent facility - that is, not part of a tertiary institution or government authority - then this number would need to increase to five. Operating costs would therefore range from about $80,000 to $250,000.

While these costs are high, two points need to be kept in mind. First, the total cost is less than purchasing and operating an average fishing boat. Second, each such facility could provide data for about one third of Australia, and so when amortised across all fisheries in that zone, the cost is very low for the benefit obtained.

For the distribution of data, the recommendation of this report is to use the public telephone network and Personal Computers. Our experience of these systems would suggest a configuration comprising :-

a) a colour monitor of at least 200x200 points resolution displaying at least 8 colours simultaneously,

b) a machine with a coprocessor chip and at least 512 k bytes of memory,

c) one, but preferably two floppy disk drives,

d) a 1200 baud modem with auto dial-up facility.

In view of current trends, it would probably be best to standardise on IBM PC compatibility and the MS-DOS operating system. A typical system like this then, would cost of the order of $4,500, depending on the model selected. Other options that could prove of value would be a hard disk ($2,000) and a colour plotter/printer ($2,000).

6.0 FUTURE DIRECTIONS

6.1 INTRODUCTION

There are two sets of comments concerning future activities which are worthwhile making. First, how the work conducted in this project could be extended to other fisheries, and second, what further developments will take place in Western Australia as a result of this work.

6.2 APPLICATION OF SATELLITE OBSERVATIONS TO OTHER FISHERIES

This project generated some interest amongst fishermen in general in Western Australia, both professional and amateur. Some limited support was offered, particularly when it seemed this could give sea truth data of value to the project. However, this was very limited support, and so the comments here are more in the nature of identifying potential research problems areas.

There would seem to be some value in using satellite imagery in at least six other fisheries. They are, the scallop, prawn, abalone, shark, mackeral and rock lobster industries. How the data can be used varies according to the fishery, and that in turn illustrates how satellites can be used in other fisheries of consequence not mentioned here.

It would be natural to assume that if satellite observations are sucessful with one pelagic species then they should be successful with others. In broad terms, that does seem to be the case.

However, the only real experience gained so far is with the spanish mackeral fishery located around the Monte Bello islands in north-west Western Australia. This fish is especially temperature sensitive, and consequently, satellite observations seem an ideal tool for location. Success with other species will depend on just how important a parameter temperature is in their biology.

Predators of pelagic species can also be located if their food source can be located. That covers some species of shark, and also game fish such as swordfish and marlin. There is no real experience with the former, but some involvement with the latter in association with amateur groups. They gave encouraging results around Exmouth and off Perth.

For many crustaceans, the effect of temperature is indirect. The actual daily water temperature may by itself not be a parameter of some interest, but the integrated effect of temperature with time seems to be well-correlated with growth. As well, mesoscale circulation appears to affect settlement of larval stages.This appears to be particularly so for abalone off the west coast of Western Australia, and to a lesser extent scallops. It is very easy for a computer to keep a running sum of temperatures, and circulation can be directly observed, hence satellite data could find an important place in the efficient management of these fisheries.

At present, the value of satellite observations to the rock lobster industry seems to be in the determination of ocean circulation. Over the years of the project, some particularly interesting patterns have been observed about the Abrolhos islands, and along the west coast in general. These may be crudely related to known aspects of the life cycle of these animals in a way which strongly urges further research. In turn, these results may also suggest further and better ways of managing this key fishery.

A fishery of some interest to this team is the prawn industry. It is a particularly complex fishery, and it is not at all certain at this time whether a single parameter or a combination of parameters affecting this fishery can be derived by satellite observations. What a satellite can do is observe ocean circulation, circulation within sheltered bays, weather, water run-offs from the land, water temperatures, and to some degree algae, phytoplankton and similar marine organisms. Which of these is most important is not known. Preliminary work suggests any research for this fishery should be long-term, and it would need to involve a team of specialists including oceanographers, marine biologists and participating fishermen. The compact nature of prawning areas in Western Australia such as Shark Bay, Exmouth Gulf and Nichol Bay lend themselves to satellite studies. As well, given the general remoteness of these and other key prawning areas plus the economic importance of the industry, such a long term investigation is warrented.

6.3 GENERAL DETERMINATION OF OCEAN PARAMETERS

When this project began, there was limited experience anywhere in the world in the use of NOAA satellite data. That situation has changed dramatically, and there are now numerous groups within Australia using the data for different purposes. There are also three acquisition sites now, and another three are in the planning stage. Even with this effort though, there still remain significant gaps in our knowledge of what the satellite can do. Two research problems will be raised here which can be classed as fundamental rather than applied, and each shares some similar problems.

The detection of chlorophyll in the ocean shows the presence of marine life forms such as algae and phytoplankton. NOAA satellites can be crudely used for this via the normalised vegetative index. However, there appears to be a threshold problem. Also, the satellites resolution is one kilometre, and so significant concentrations are sub-pixel. Another problem is that the exact relationship between chlorophyll concentration and satellite measurements is not known, but must be assumed to be nonlinear.

Formulating a research program to determine how NOAA satellites can be used to quantitatively measure chlorophyll concentration is a formidable problem. The major task of simply gaining sea truth data is exceedingly difficult because it must involve making chemical measurements over a large expanse of ocean in a very short time. The best approach would appear to be an indirect one. First, to calibrate an aircraft or another satellites measurements against ocean measurements taken in a number of different waters. Then to calibrate NOAA against those data.

A second problem worth investigating but one without quite the same commercial significance, is measuring ocean roughness. Rough conditions produce foam and spray which then alters the emission spectrum of the sea. Taking the differences between the emission bands on NOAA could possibly detect this. However, there is a problem with atmospheric water vapour concentration, but the contamination due to this factor can be computed and so correction can be made. Again, the problem with such a research program is the difficulty in obtaining sea truth data, but again, this can possibly be overcome by the same indirect method previously mentioned.

The commercial significance of detecting chlorophyll is obvious. Determining surface roughness is also important though, but possibly not to the same extent. However, it is known that tuna congregate in disturbed water, and consequently, a measure based on roughness, chlorophyll, and temperature may give a much better predictor of fish location than that discussed here.

6.4 OTHER USES OF NOAA DATA

Although initially planned for oceanographic and atmospheric applications, recent work has shown significant benefits arise from using NOAA in terrestial applications. One key application for Australia is in the geological sphere where night thermal imagery, and comparisons between day/night pairs has proved of great value in locating particular minerals and hydrocarbons. Others of equal importance apply to the primary industries. Through vegetative indices, regular vigor maps can be produced which can be used for crop assessment and drought monitoring. NOAA also is of value in ground water monitoring.

6.5 FURTHER DEVELOPMENTS

The interest in NOAA satellite imagery is such that several research programs are now ready to enter an operational phase. That being the case, an assured supply of data is becoming essential. Thus several operational facilities are now installed or being installed.

In Western Australia, talks are well underway between CSIRO, WAIT and the State Government on jointly establishing an operational facility. It will have the options listed earlier, and so it will be possible to establish a service for fishermen in Western Australia, South Australia and the Northern Territory based on Personal Computers.

It is certain this facility will be used by the three groups for fisheries activities. In view of this development, and in the expectation that some form of PC-based service will eventually result, the team are continuing development in this area. Software for the PC's bought for the project will be further developed and refined so that a simple but effective package can be offered to fishermen. As well, trials will be conducted if possible to demonstrate the services utility. Equally, within the resources available, assistance will continue to be given where it can. In short, the team is continuing the project to within the limits of its available resources.

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APPENDIX II : THE PROBLEM OF GEOLOCATION

A problem in all satellite image processing is identifying the precise position of points in terms of latitude and longitude. This is the problem of geolocation. It is especially important in NOAA image processing due to the extreme distortion which exists in NOAA imagery. The inverse problem of marking a given latitude - longitude value on an image is also important.

Precise geolocation is a very difficult problem. The earth is broadly an oblate spheroid, but it has significant localised variations in shape. These give rise to gravitational anomalies, and so while a satellite orbit should be perfectly elliptical, in practise it is not. In fact, it suffers from short-term variations in position. Further, the orbit revolves within the orbital plane, and the orbital plane itself rotates about the earth. The latter is quite a useful effect, and is the means by which a satellite is sun - synchronous. The satellite itself can suffer pitch, roll and yaw, and that adds further complications. However, the spatial resolution of NOAA data is only one kilometre, and there are few circumstances that can be envisaged where better geolocation accuracy would be required. That allows some simplifying assumptions to be made. Specifically, that the earth is perfectly spherical, that orbits are perfectly circular, and that there is no pitch, roll or yaw. With these assumptions, the geolocation problem just becomes a problem of spherical geometry.

Consider a NOAA image. Let the lines be numbered from the start of scanning to the end. Also, let pixels be numbered from the left of the direction of motion of the satellite to the right. Then let a given point be described as pixel X and line Y.

There are two cases to consider in the geolocation problem. One is an ASCENDING orbit, and the other is a DESCENDING. An ascending orbit is one where the satellite is approaching the equator, and when it crosses, a new orbit begins. For Australia an ascending orbit is one where the satellite is coming from the south pole. These orbits have an effective inclination to due north of 9^{o}. A descending orbit is one where the satellite is approaching from the northern hemisphere, it has just passed over the equator on the half-way stage through an orbit, and it will complete that orbit once it passes over the south pole and reaches the equator again. The effective inclination of the orbit to due north is -9^{o}. A satellite's ascending orbit and descending orbit over a given point on the surface are exactly 12 hours apart.

Solving the geolocation problem requires executing the following steps :-

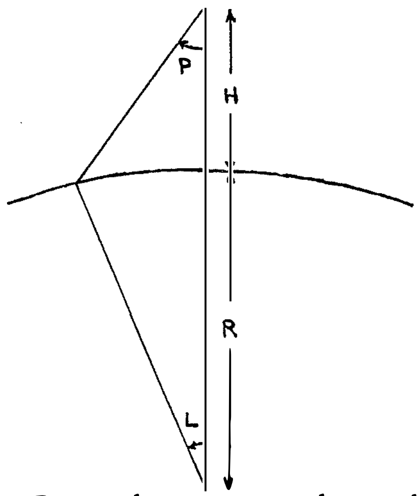
STEP 1 : DETERMINE THE SCANNER ANGLE

Each line has 2048 pixels, and pixels 1 and 2048 correspond to scanner angles of -56^{o} and $+56^{o}$. Hence an arbitary pixel X corresponds to a scanner angle P given by

$$P = (X - 1024.5) / 18.474729$$

STEP 2 : DETERMINE THE EARTH ANGLE

Consider



The scanner angle P can be converted to the earth angle L - the angle subtended from the centre of the earth to the point projected onto the surface - via

$$L = \sin^{-1}[\ (1.135 \cos P - \sqrt{1 - (1.135 \sin P)^2}\ ) \sin P\ )\ ]$$

Note that the sign is negative to accomodate ascending and descending passes in later calculations. Also, the factor 1.135 is in fact (1 + H/R) where H is the nominal altitude of the satellite, and R is the earth's radius. H can be taken as 860 kilometres, and R as 6365 kilometres.

STEP 3 : DETERMINE THE ANGLE SUBTENDED TO THE EQUATOR

The track angle will be defined as the angle swept out by the satellite from the start of the orbit to a given point in the orbit. Over a complete orbit then, the track angle is 360°. Let the elapsed time between the start of an orbit and the first line in the image being processed be t. Then

$$\text{track angle } \zeta = t/T \times 360^\circ$$

where T = the orbital period (about 101.96 minutes)

The AVHRR scanner in the NOAA satellite scans at a rate of six lines per second, or 360 per minute. Line Y therefore, is scanned Y/360 minutes after the first line of the image, and this is equivalent to an angle of Y/T degrees. The total angle swept out in the orbit so far then, is

$$TT = Y/T + \xi$$

Consider the angle subtended by the equator to the line Y along the orbital path. For an ascending pass, this angle is the angle to be swept, and is given by

$$\psi = 360^{o} - TT$$

but for a descending pass, it is referred back to the previous equator crossing, and so is

$$\psi = TT - 180^{o}$$

STEP 4 : COMPUTE LATITUDE

Through spherical geometry, it can be shown that

latitude = $\sin^{-1}(\sin \beta \sin z)$

where $\beta = 180^{o} - I + \sin^{-1}(\sin L / \sin z)$

I = orbital inclination of the satellite (99^{o})

$\cos z = \cos L \cos \psi$

STEP 5 : COMPUTE LONGITUDE

The first step here is to compute the longitude difference between the equator crossing longitude at the start of the orbit and the given point. It can be shown this is given by

$$\lambda = \tan^{-1}(\tan z \cos \beta)$$

where and z are as for latitude. This can now be converted to longitude. Let EQX be the equator crossing longitude. Now the NOAA satellite is sun - synchronous, thus the orbital plane is rotating, and this will change the longitude. The rotation is the rotational velocity of the earth (0.25^{o}/minute) multiplied by the elapsed time since the start of the orbit. That may be expressed as

$$\text{shift} = 0.25 \times 101.96 \times (360 - \text{latitude}) /360$$

The effective equator crossing longitude is therefore

$$EQE = EQX - \text{shift}$$

Then for an ascending pass

$$\text{longitude} = EQE + \lambda$$

and for a descending pass

$$\text{longitude} = EQE - \lambda - 180^{o}$$

Note that longitude here refers to longitude east.

The inverse problem follows from this. The steps involved are :-

STEP 1 : CALCULATE THE LONGITUDE DIFFERENCE

Let EQX be the actual equator crossing longitude. Then the effective longitude due to earth rotation is

$$EQE = EQX - 0.071(360 - \text{latitude})$$

The longitude difference if this is an ascending pass is then

$$\lambda = \text{longitude} - EQE$$

and for a descending pass

$$\lambda = EQE - \text{longitude} - 180$$

STEP 2 : CALCULATE THE EARTH ANGLE

From spherical geometry

$L = -\sin^{-1}(\sin \theta \cos I + \cos \theta \sin I \sin \lambda)$

where I = orbital inclination

θ = latitude

STEP 3 : CALCULATE THE SCANNER ANGLE

It can be shown

$$P = \tan^{-1}(\sin L / (1.135 - \cos L))$$

STEP 4 : CALCULATE THE EQUATOR SUBTENDED ANGLE

For a ascending pass

$\psi = 360 - \zeta - \cos^{-1}(\cos \theta \cos \lambda / \cos L)$

and for a descending

$\psi = 180 - \zeta + \cos^{-1}(\cos \theta \cos \lambda / \cos L)$

where ζ = the track angle to the beginning of the image

θ = latitude

STEP 5 : CALCULATE PIXEL POSITION

This is just given by

$$X = 18.474729 P + 1024.5$$

STEP 6 : CALCULATE LINE NUMBER

This is just given by

$$Y = 101.96 \psi$$

APPENDIX III : DERIVATION OF SEA SURFACE TEMPERATURE

Sea surface temperatures or SST's were computed by software developed by Dr F Prata, formally of WAIT, now Head, Remote Sensing Group, CSIRO Division of Groundwater Research. The software uses the split-window technique for the two thermal emission channels of AVHRR on NOAA satellites with coefficients derived by Dr I.J. Barton of the CSIRO Division of Atmospheric Research, viz.

$$T_s = a\,T_4 - (a - 1)\,T_5 + b$$

where T_s = sea surface temperature

T_4 = temperature estimate from AVHRR channel 4

T_5 = temperature estimate from AVHRR channel 5

$a = 3.76 + 1.10\,(\sec z - 1) - 0.32\,(\sec z - 1)^2$

$b = -0.42 - 1.20\,(\sec z - 1) + (\sec z - 1)^2$

z = scanner angle

The accuracy of the technique is to within 0.5° C of the true value.

The photographs included in chapter three illustrate this technique applied to NOAA data. These figures include a coastal overlay plus lines of latitude and longitude. The colour bar to the side of each image shows each temperature.

The basic theory of this technique is as follows. Upwelling radiance in the earths atmosphere from the surface is governed by the equation of radiative transfer :-

$$R(v_i,z) = e_s B[v_i,T_s]\tau(v_i,z,Ps) - \int_0^{Ps} B[v_i,T(p)] \frac{d\tau}{dp}(v_i,z,p)\, dp$$

where R = radiance measured by channel i

B = the Planck function

τ = the atmospheric transmission

v = the wavenumber

z = the zenith angle

T = the temperature

T_s = the surface temperature

p = the pressure

Ps = the surface pressure

e_s = the surface emissivity

In this case, the wavelength of interest lies near the so-called atmospheric window about 11 microns. The assumption here is that the response function is uniform over the relevant wavelength interval (which is not true in practise).

The surface temperature is embedded within the Planck function, and so the measurement R made by the satellite relates to it in a complex fashion. Further, in general the emmissivity of the sea surface varies with viewing angle and with sea state.

If the atmosphere was truly transparent at wavenumber v_i, then the integral term would vanish, and $\tau(v_i,Ps)$ would be equal to unity. Under these conditions, the radiative transfer equation reduces to

$$R(v_i,z) = e_s B[v_i,T_s]$$

The emmissivity of the ocean for relatively calm conditions and for small viewing angles is close to unity. Then if this is assumed, the equation can be inverted and T_s solved for explicitly using the Planck function. That function is

$$B[v,T] = c_1 v_3 \ / \ (\exp (c_2 v/T) - 1)$$

$$\text{where } c_1 = 1.1911 \times 10^{-5} \ \ mW/M^2 \ cm^{-1}$$

$$c_2 = 1.439 \ K \ cm^{-1}$$

The units of R and B are $mW/(M^2$ steradian cm^{-1}) and are commonly referred to as radiance units.

Unfortunately, the reduced approximation for the radiative transfer equation is poor because the atmosphere contains water vapour, and that absorbs radiation over a broad region of the infrared spectrum. This continuum absorption can be such as to reduce the inferred SST by 5^o C to 10^o C in the tropics, and by a few degrees in the mid latitudes. This water vapour absorption must be accounted for if accurate SST values are desired.

The AVHRR instrument on NOAA satellites takes two readings at two adjacent channels. Then

$$R_1 = B_1 \tau_1 - \int_0^{Ps} B_1 \frac{d\tau_1}{dp} \, dp$$

$$R_2 = B_2 \tau_2 - \int_0^{Ps} B_2 \frac{d\tau_2}{dp} \, dp$$

where the subscripts refer to each of the sounding channels and explicit reference to the other variables has been omitted for convenience. From the mean value theorem,

$$- \int_0^{Ps} B_1 \frac{d\tau_1}{dp} \, dp = \int_{\tau}^{1} B_1 \, d\tau_1$$

$$= (1 - \tau_1) \overline{B_1}$$

where B_1 = the average Planck radiance over the channel

Thus these equations may be expressed as

$$R_1 = B_1 \quad {}_1 + (1 - \tau_1) \overline{B_1}$$

$$R_2 = B_2 \quad {}_2 + (1 - \tau_2) \overline{B_2}$$

These can be expressed in terms of the Planck equivalent temperatures or brightness temperatures, viz.

$$T_1 = T_s \tau_1 + (1 - \tau_1) T_1$$

$$T_2 = T_s \tau_2 + (1 - \tau_2) T_2$$

Again, uniform response functions have been assumed for each channel. Now solving for T_s,

$$T_s = a \, T_1 - b \, T_2 + c$$

where $a = (1 - \tau_2) / (\tau_1 - \tau_2)$

$$b = (1 - \tau_1) / (\tau_1 - \tau_2)$$

$$c = (1 - \tau_1) (1 - \tau_2 (T_2 - T_1) / (\tau_1 - \tau_2)$$

This equation provides a means for deriving the brightness temperature of the sea surface from the two measurements of upwelling radiation. The coefficients may be calculated from a transmission model using standard profiles of temperature and water vapour or they can be derived by regression against an ensemble of simultaneous co-located independent measurements of the surface skin measurement. Both methods will still contain some uncertainty because of uncertainties in the transmission model and errors in the set of independent measurements. Note that because the transmission depends on the amount of the atmosphere through which the radiation has passed, and therefore the path length, the coefficients will depend on the angle of view.

The simple theory given above contains a number of assumptions and inaccuracies. However, once water vapour effects are largely eliminated, the remaining effects are only second order.

Calibration of radiance data is essential for accurate results. The spacecraft provides this by observing space and an internal black body every scan line. There are four platinum resistance thermometers sampling the internal warm resistance which is maintained at a temperature of approximately 285° K. The cold target - that is, space - and this measurement provide a two point linear calibration.

The conversion of radiance to temperature is accomplished by

$$T_i = \sum a_{ij} X_i$$

where X_i = the mean count for the thermometer i

a_{ij} = calibration coefficients which are supplied

and so the internal warm temperature is just

$$T = \sum_i 0.25 \ T_i$$

Space is assumed to give a zero temperature, thus this calibration point is used to provide a small correction to the counts to radiance conversion.

Clouds within the AVHRR instruments field of view will give an erroneous SST value unless they are taken into account. In general, AVHRR alone is insufficient to determine this. Nevertheless, there are two approaches to overcoming this cloud problem. One is to detect cloud contaminated pixels and reject them, and the other is to determine the degree of contamination and attempt to correct the cloudy radiance.

During the daytime, it is possible to use channels 1 and 2 on AVHRR to determine the albedo of each pixel. Since the albedo of the ocean is small ($< 10\%$) whereas the albedo of clouds is high, then albedo values can be used as a guide to cloud contamination. Threshholds can be defined, below which it is assumed there is no cloud contamination. Both the solar elevation angle and the viewing angle must be considered when determining the threshholds. One advantage of this method is that sub-pixel scale cloud will affect the albedo of the pixel and so can be detected.

The major problem with this method is that it can only be used during the day. In addition, some clouds are relatively transparent in the visible but can affect thermal radiation strongly. For example, cirrus. Finally, this technique works on single pixel data and so is of use in high resolution work.

Another approach is histogram techniques. These use an array of pixels of dimension NxN to determine the peak radiances corresponding to cloud free (warmest), cloudy (coldest) and partially cloudy conditions. Generally, the dimension N is of the order of 3 to 50 points, and the points are taken from the emission bands of the satellite data. If no significant warm peak is detected, then the array is assumed to be cloud contaminated. If two separated peaks are observed, then presumably the values have to be averaged to obtain the clear column temperature. Reducing the dimension of the histogramming array can alleviate this problem, but the statistical significance is also reduced.

Two separated peaks in the histogram can also indicate an area of one type of uniform cloud and no cloud, but in general, clear signatures may be discerned from uniformly cloudy signatures by the presence of a short, warm tail. That is, a Gaussian distribution. Cloudy signatures tend not to be Gaussian distributed. The Truncated Normal Distribution technique utilises a Gaussian curve which is fitted to the histogram warm tail. The peak of the Gaussian is then used as the cloud free brightness temperature or radiance.

A further method is the spatial coherence method which uses an NxN array of pixels divided into sub-arrays of dimension MxM with M << N. The mean and standard deviation of each sub-array is calculated and a scatter plot constructed. The plot typically gives an arch shape. The feet of the arch signify the two targets; each having low standard deviation and separated mean values. Intermediate points are expected because there will be sub-arrays consisting of mixed targets. The peak of the arch corresponds to mixed areas with high standard deviation. The mean temperature lies somewhere between the means of the two targets. This method is also capable of detecting more than two cloud layers.

All of these methods are local in the sense that data from nearby pixels is used to correct or detect cloudy radiances. A powerful method which essentially uses all data to estimate the clear column radiance at each pixel is to use a statistical estimator, namely the Kalman filter. This optimal filter takes proper account of the error fields associated with the radiances ans uses a priori information to constrain the estimates. There are several advantages in this. First, it can be used at night. Second, it provides an estimate of the clear radiance, and does not just detects it. Finally, it evaluates the errors.